The Face of WNY's Weather

Stephen Vermette, PhD

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Cover Image: Icy coin operated viewfinder at Niagara Falls State Park. Image Source: NYS Office of Parks, Recreation and Historic Preservation (NYSOPRHP).

Author’s Preface

If you were born, or have lived for any length of time, in Western New York you recognize the letters W-N-Y as a well-known and cherished moniker for a region in Upstate New York. According to Google’s Ngram Viewer, WNY has been our moniker dating back to the 1840’s. It is not the “Upstate” that is a part of the Hudson Valley, Catskills, or Adirondacks. It is not the Finger Lakes in Central New York. Uniquely, it is the land between the lakes: Lakes Erie and Ontario. A land defined, in part, by the weather and climate influenced by these two lakes. Eight counties – Niagara, Erie, Chautauqua, Cattaraugus, Allegany, Wyoming, Genesee, and Orleans – lie within WNY.

There are places in the U.S. and around the world where the weather does not change from week-to-week, let alone day-to-day. In other places, where weather is more variable, a common expression is *“if you don’t like the weather, wait five minutes”*. In WNY, one can add to that expression: *“or travel five miles”*. These “five miles” could be the distance traveled inland from a shoreline, or “punching” through a lake-effect snow band.

Our weather even influences some of our food choices which take their place along with WNY’s other food icons, notable Buffalo Wings, Beef on Weck, and Friday fish fry’s. We enjoy Perry’s “Zero Visibility” ice cream named to celebrate of our most infamous winter storm (there is a sundae named after our October Surprise storm of 2006), we eat at establishments, and eat and drink food, with “Lake Effect” in the name, sip on ice wines, and even burn scented candles which smell of the outdoors after a heavy snow. Your mom may have even made you wear plastic Wonder Bread bags to waterproof your boots.

WNY enjoys four seasons. Yes, winter sometimes lasts extra-long and can be severe, but it also gives us our “grit”. Let’s call it “Buffalo Grit”. This toughness and pride echoes to this day from a Buffalo newspaper headline from over 100 years ago: *“Blizzard To Be Proud Of: Wind Blew Harder in Buffalo Yesterday Than Anywhere Else, Indeed.”* Spring doesn’t “hang around” very long, but our summers are seldom overly hot, and the autumn is often picture-perfect – two other seasonal points of pride in WNY.

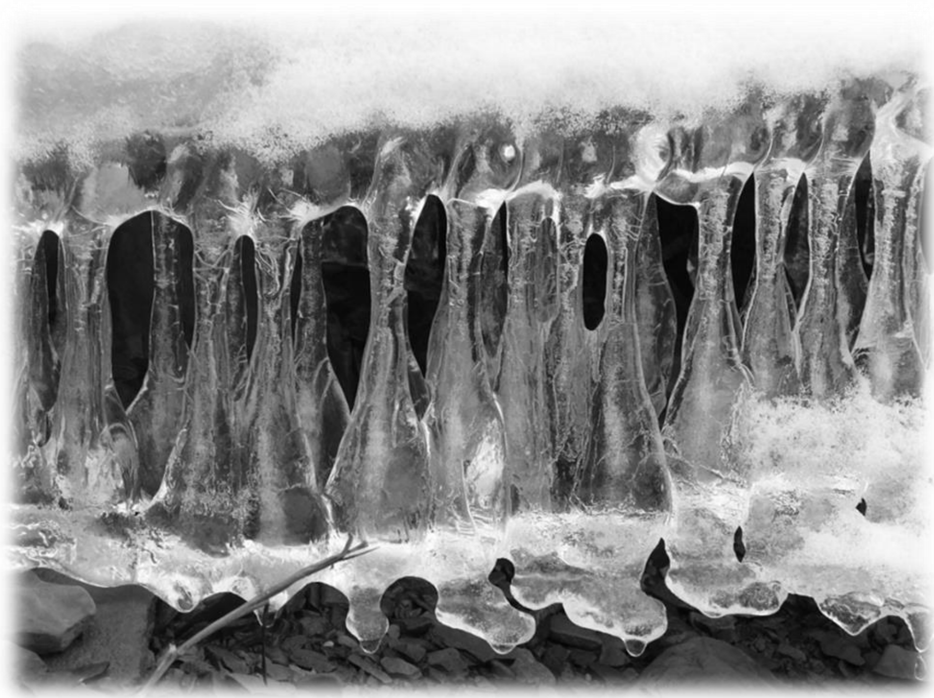
WNY is a region with unique lake-effect seasons, superimposed on the traditional ones, and where you travel south for the “snow”. And, as an aside, you travel west (not north) to cross into Canada. It is a region which has its share of severe weather, but that severity doesn’t match the weather-related destruction found in some regions of the U.S. and the world. Yes, we may have more “miles on our snow blowers than our cars”, but most WNY residents would not trade this for the weather disasters we hear about in other regions of the world.

This book strives to reveal the face of WNY’s weather and, throughout, examples are taken exclusively from WNY. In addition, numerous first-hand accounts are provided by WNYer’s having an interest in the weather. While the WNY region is stressed throughout the book, the basic meteorology presented here will be of interest to anyone with an interest in weather. To a reader from outside of WNY, the regional emphasis provides a useful and novel context.

The first pages in this book set the stage to understand the framework in which our weather occurs: describing the envelope of air above us, the reasons for the seasons, differentiating climate from weather, and redefining WNY into five climate zones, to name but a few sections. Subsequent pages describe and explain a host of weather-related phenomena experienced in WNY, such as growing a snowflake, the working of radar, thunderstorms, and locally sourced winds. Infamous weather events are recounted, and myths debunked. The focus of the book then shifts to the history of weather observation in WNY, focusing on our earliest weather observations and the history of the Buffalo Forecast Office of the National Weather Service (NWS). The final pages of the book examine how our weather has trended over the years, with an eye to our future weather and climate.

Over the years, I have learned that there is an ingrained interest in weather in WNY. After all, almost every planned undertaking requires us to check the weather forecast first and, with this repeated act, a general appreciation of and fascination with weather has entered our WNY DNA. I'll close with a "retweet" from BuffaloJoeSells.com@Joeya1 who summed it up best: *"Winter is at 6 am, Spring starts at 10 am. Summer is at 2 pm and Fall is around 4:30ish. Please dress accordingly."*

Western New York: "Land Between the Lakes"



Ice features along Cattaraugus Creek near Scoby Dam. Image Source: Stephen Vermette

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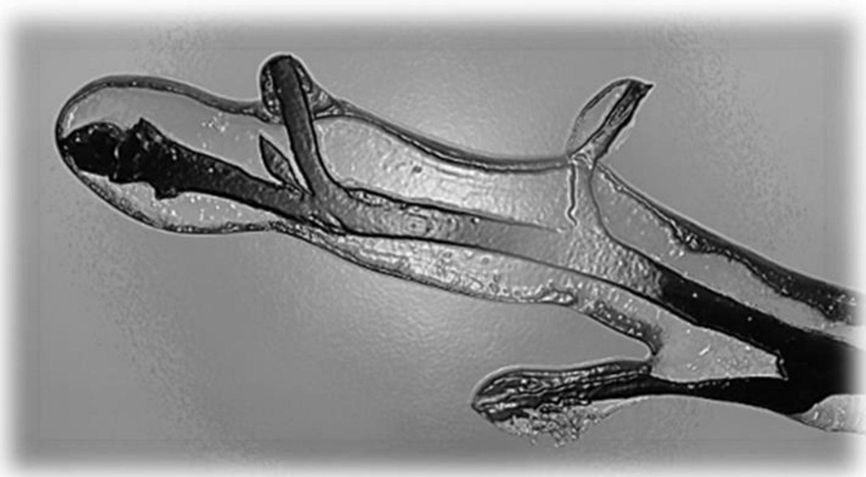
Beauty in an ice-covered puddle. Image Source: V. Vermette

Local Knowledge Contributors

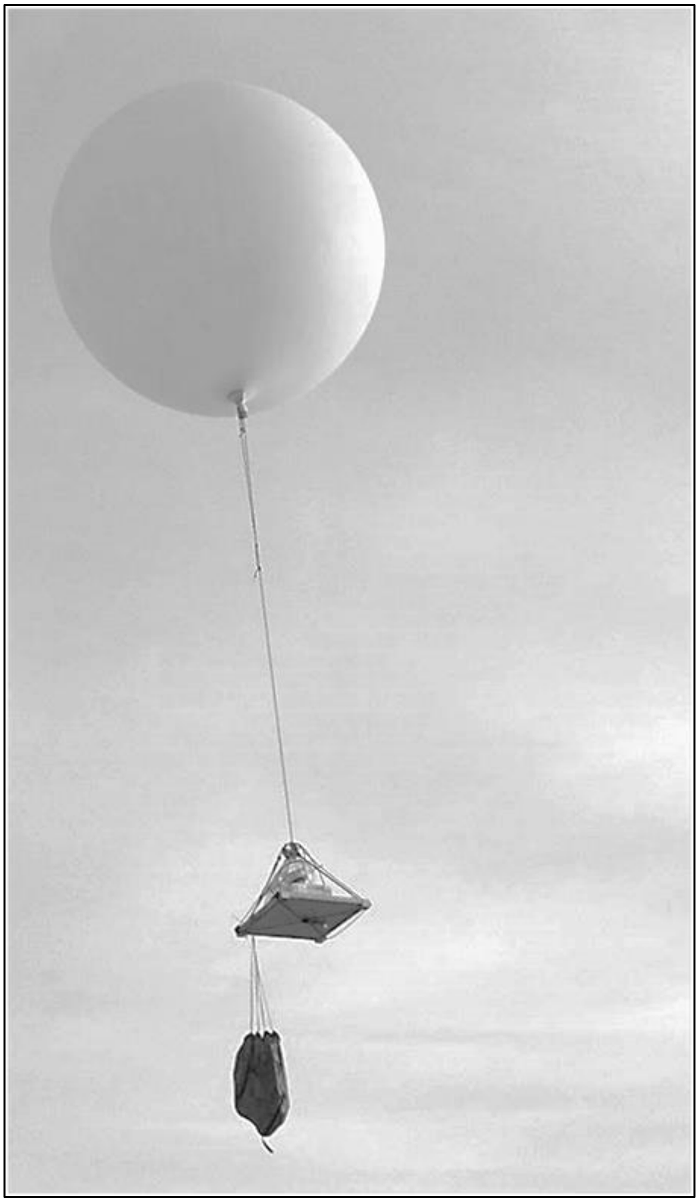


Branch entombed in ice. Image Source: Stephen Vermette.

Informational Boxes

Sidewalk leaf peels: rock salt, cement and mother nature. Image Source: Stephen Vermette

Chapter 1
Looking Up



The Bengal II balloon, with a payload of experiments, was launched on May 7, 2014 by Edward Bryant and Mike Zoubi, students in the Department of Physics, SUNY Buffalo State, as mentored by Dr. Dan MacIsaac. The balloon reached a height of 98,972 feet above WNY. Image Source: Stephen Vermette.

Above and Beyond

As a "place", the features of WNY are described in numerous ways, including geology, topography, soils, vegetation, borders, and towns, among others. Weather and climate, while linked to the atmosphere, are characterized by only their surface impacts. Seldom, except for clouds, does the sense of place include looking up into the atmosphere. WNY's envelope of air is just as much a part of this "place" as any other feature. Let us give the atmosphere its due by looking up (Figures 1 and 2).

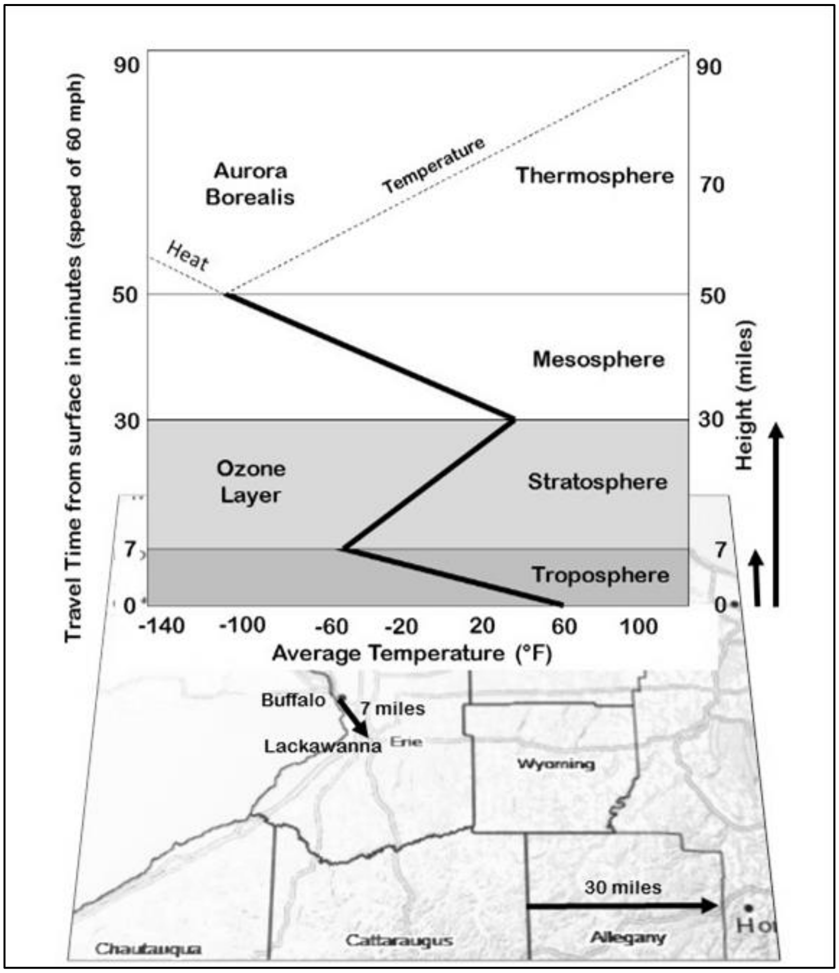


Figure 1. Structure of the atmosphere above WNY. See Box #1 for an explanation of temperature and heat in the thermosphere. Arrows show equivalent distance for height in the atmosphere and distance on land. Image Source: Stephen Vermette.

The lowest atmospheric layer, and the layer in which we live and take each breath, is called the troposphere. If one could drive directly upward, at a speed of 60 mph it would take about 7 minutes to travel 7 miles to the top of the troposphere (tropopause): a height above the clouds and weather. The height of the tropopause is about half at the poles, and a few miles thicker at the equator (due to the Earth's spin and centrifugal force shifting air to the equator and the equator's warmer temperatures). The troposphere is also referred to as the "weather sphere" because it is the only atmospheric layer in which weather occurs. On the way up you will encounter numerous seeds and migrating insects riding the winds. It is estimated that in the summer over a billion insects may pass through a column of air with a radius of about half a mile (the highest recorded insect was captured at a height of 19,000 feet). Arriving at the tropopause, atmospheric pressure would have dropped by about 75%, from 1000 mb to a little greater than 250 mb (see Box 2 for a discussion on pressure units), such that your blood would boil if you weren't wearing a space suit.

And temperatures would have dropped by about 120 degrees, from a surface average of 60°F to about minus 60°F at the tropopause. The proportion of gases (mostly nitrogen and oxygen) would remain the same as at the surface, but the number of air molecules available would be insufficient to fill your lungs and allow you to breathe. At this height, you would need to watch out of your car window to avoid the jet planes flying at their cruising altitude. In as little as 7 minutes, your drive upward has taken you to a region of WNY that is hostile to life!

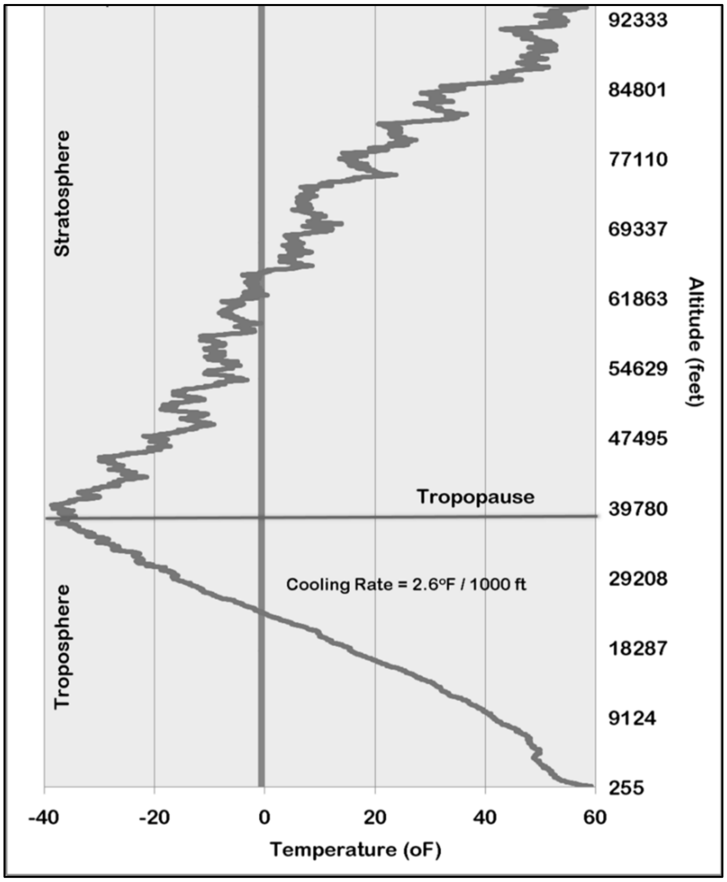


Figure 2. Temperature profile from the Bengal II balloon launch on May 7, 2014. On this day, temperatures dropped by about 100°F between the surface and the tropopause. The erratic temperature in the Stratosphere may be due to the rotation of the instrument package as it ascends. Image Source: Stephen Vermette. Original data from Edward Bryant and Mike Zoubi.

As you continued upward into our atmosphere, you would cross into the stratosphere. After another 7 minutes of driving you would have passed through 90% of the atmosphere's volume. At this point you should reflect on how thin the envelope of air is that covers WNY (Figure 3). By way of illustration, if you were to lay a piece of kitchen plastic wrap across a standard sized globe, the thickness of the plastic wrap would represent about 90% of the Earth's atmosphere. If you were to jump from this height, your fall would be silent, your clothing would not flap in the absent wind, and you would not feel air resistance against your body because there is essentially no air.

It would take another 13 minutes to reach the top of the stratosphere (stratopause), a total drive time within the stratosphere of 30 minutes (30 miles). Atmospheric pressure would drop to about 10 mb at the stratopause, which means that 99% of the atmosphere lies below you. Given the recent interest in colonizing Mars, it is worth noting that the surface pressure on Mars averages about 6 mb, somewhat like that at the top of Earth's stratosphere. Temperatures would increase as you drive up through the stratosphere to somewhere near the freezing point (32°F). This warming can be attributed to heat-releasing reactions between stratospheric ozone (O_3) and ultraviolet radiation (UV) which is streaming down from the sun. Stratospheric ozone acts as a protective layer that protects life on Earth from the detrimental effects of ultraviolet radiation.

We will end our upward drive here since we have passed through most of WNY's atmosphere. And, as noted previously, these heights are well above the weather focus of this book. Looking down from the stratosphere, you would see the familiar sight of blue skies and white clouds (Figure 4). Looking up, you would see the black of space through additional layers that do not resemble what we intuitively think of as the atmosphere.

Above the stratosphere is the mesosphere, the thermosphere, and the exosphere. In these layers, temperatures fall, eventually matching the cold of space. Within the thermosphere, and extending up into the exosphere, exists the borealis light displays (northern lights) which bring us a solar light show visible from the ground surface. At 60 miles above the surface (within the thermosphere) you would cross the "Kármán Line", an arbitrary line where the thin atmosphere gives way to space. Given that our atmosphere is a compressible gas held in place by gravity, decreasing in density with height above the surface, it is difficult to define its outer edge. The outer extent of the exosphere (about 6,200 miles above the surface) is usually used to define our atmosphere's extreme limit.

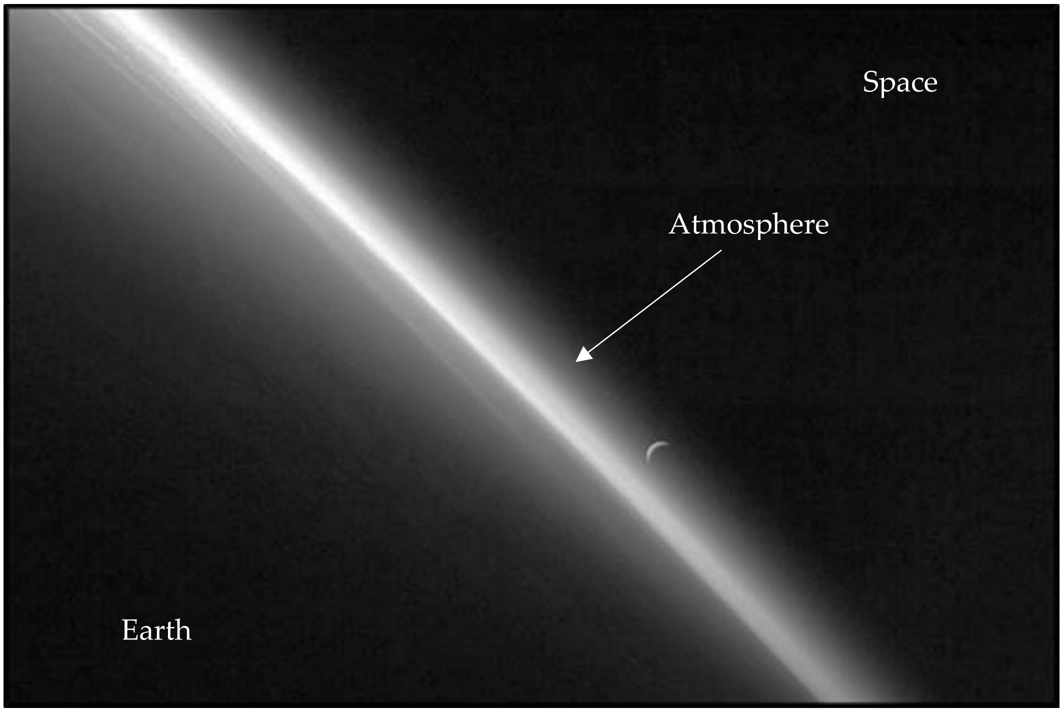


Figure 3. The thin line of Earth's atmosphere (troposphere, stratosphere, and lower level of the mesosphere). Image Source: Wikimedia Commons/NASA.

Figure 4. View of WNY at ~98,000 feet (within the stratosphere, as viewed from the Bengal II balloon). Image Source: Bengal II video/Edward Bryant and Mike Zoubi.

Box 1 **Temperature vs. Heat**

Temperature is a measure of molecular activity (kinetic energy). The faster molecules move, the higher the temperature. On the Kelvin temperature scale, absolute zero relates to the absence of molecular motion. There is no such temperature as negative Kelvin! The meniscus on a thread of liquid in a liquid-in-glass thermometer rises because increased molecular activity causes the liquid to expand – thus recording a higher temperature.

In describing the thermosphere, most books and web sites show temperatures increasing with height. This seems counter-intuitive to the perception of the "coldness of space". To make sense of this, we need to look at two definitions: temperature and heat. Temperature is defined as the average kinetic energy of a substance, whereas heat is defined as the total kinetic energy.

The temperature increase in the thermosphere is attributed to individual gas molecules absorbing the sun's energy and thus "heating the air". But there are so few air molecules, and they may be spaced miles apart, that the heat within the volume of the thermosphere is miniscule.

The difference between temperature and heat also comes in play when discussing lake effect snow in WNY, as the distinction between the two terms is used to explain why Lake Erie often freezes over, but Lake Ontario does not. The volume of Lake Erie is about 115 cubic miles (deepest point 210 feet), whereas the volume of Lake Ontario is about 390 cubic miles (deepest point 802 feet). Even if temperatures were the same, the volume of heat stored in Lake Ontario would be more than 3x that of Lake Erie. It is this added storage of heat that prevents Lake Ontario from freezing over in the winter.

Consider a cup of coffee and an unplugged hot tub, each with an initial temperature of 104°F. Which will cool fastest? The stored heat in the hot tube is far greater than the cup of coffee, thus the coffee would cool the fastest.

Origins of Our Atmosphere

The two most common elements in the universe are hydrogen and helium (numbers one and two on the periodic table of elements). These are origin elements, born with the birth of the universe, and on which other elements build. The Earth's atmosphere was originally made up of these origin elements, but they were lost to space during Earth's formation. An early molten planet − a hot mix of solids and gases − could not retain these gases due to: their high temperature and volatility that made it easy for them to escape; a weak planetary gravity that was unable to confine the atmosphere; and the lack of a magnetosphere to protect the Earth from a "gale" of solar winds which easily stripped away gases. As Earth cooled, the magnetosphere and gravity strengthened and evolved in ways allowing the retention of an atmosphere, yet the gases had already escaped! On to Plan 'B'.

Earth's secondary atmosphere formed from volcanic eruptions (outgassing) which spewed gases from the Earth's mantle, such as methane, nitrogen, carbon dioxide, and water vapor, among others. A methane haze hung over the planet. With the cooling of the earth, water vapor condensed to form clouds, rain, and oceans. Free atmospheric oxygen − the molecular oxygen we breathe − was not yet present. Its formation waited for release as a byproduct of plant photosynthesis (used to synthesize food from sunlight, carbon dioxide, and water). Plant life (early forms of bacteria) first appeared in oceans where they were sheltered from UV radiation. A growing abundance of oxygen released from ocean surfaces into the atmosphere reacted with methane and cleared the haze, giving WNY (and the planet) its signature blue sky ~2 billion years ago. Oxygen also reacted to form ozone in the stratosphere. The stratospheric ozone layer "blocked" much of the harmful UV radiation, allowing plants to gain a foothold on land. What followed was an oxygen boom. Sufficient breathable oxygen came to our atmosphere about 500 million years ago. Today, our atmosphere is made up mostly of nitrogen (78%) and oxygen (21%), leaving only 1% to account for all other gases.

Aurora Borealis

Within the thermosphere and extending into the exosphere, a solar light show known as the aurora borealis (northern lights) is sometimes visible from the ground. The show starts well beyond our atmosphere where solar winds (charged particles) emitted by the sun pass by Earth. If Earth were left unprotected, solar winds would rip away our atmosphere and destroy life on this planet, but the magnetosphere beyond our atmosphere acts as a shield deflecting these "winds" away from us.

Figure 5. Aurora Borealis (Northern Lights) as seen in West Seneca WNY. Image Source: Mike Shriver.

Much like a current eddy trapped on the backside of a boulder in a stream, some of the charged particles associated with the solar winds become trapped on the "backside" of the earth. From here, they travel down through our atmosphere along the Earth's magnetic field lines that are emitting from high latitudes surrounding the Earth's poles. It is these downward moving charged particles interacting with gas molecules in our atmosphere that generate the northern lights. To be more precise, the charged particles impart energy to gas molecules when colliding (moving them into an excited state), and the gas molecules returning to a grounded state releases the energy as light. The most prominent color of this released light is green, but red, yellow, blue, and violet colors are also associated with the northern lights. The color depends on the type of gas molecule and its altitude within the thermosphere. The height of the aurora borealis is generally confined to between 60 to 300 miles above the Earth's surface. Any higher and there is an insufficient number of gas molecules in the atmosphere to react with the charged particles, while below 60 miles the atmosphere is thick enough to block the downward progression of charged particles.

While the aurora is most often visible in the high latitudes of the Arctic and Antarctic, strong geo- magnetic storms from the sun can bring the aurora borealis down to WNY's latitudes (Figure 5). Aurora displays are visible in WNY a few times a year. If interested in a planned viewing, access space weather sites on the internet and watch for forecasted geomagnetic storms with a Kp-index >6 (Kp-index refers to the level of disturbance of the magnetic field) and clear skies.

The Missing Ozone

Stratospheric ozone (O_3) is a shield that protects us from the harmful effects of ultraviolet (UV) radiation from the sun (Figures 6 and 7), but there is not much of it in the stratosphere. Taken down to atmospheric pressures found at the Earth's surface, the ozone layer would be further compressed to a thickness of only about 1/8 inch thick. And there is far less of it than in years past. What is happening?

To understand how ozone is created and destroyed, consider three forms of oxygen: O (atomic oxygen); O_2 (molecular oxygen); and O_3 (ozone). The good news is that as ozone reacts with UV rays and is destroyed in the process, it can regenerate itself:

$$O_3 + UV \rightarrow O_2 + O$$

$$O + O_2 \rightarrow O_3$$

The bad news is that man-made chemicals such as chlorofluorocarbons (CFC's), known also as Freon, react with ozone in a way that the destruction is thousands of times more efficient than UV rays. CFCs were originally thought of as the perfect refrigerant (not toxic as were the early refrigerants) and were later used as aerosols because it was thought that they did not react with other chemicals. That assumption was shattered with the late 1970's discovery that CFC's rose up into the atmosphere and reacted with UV rays. The key to this elevated level of ozone destruction was the element chlorine (Cl), the "chloro" part of a CFC molecule.

Under normal conditions, chlorine released into the atmosphere reacts with other molecules and becomes bound. However, when trapped within a CFC molecule, the chlorine is carried up into the stratosphere, where it is released only after the CFC molecule reacts with UV radiation. Once released, the chlorine atom goes through a series of reactions where it is continually released and bound, such that one Cl atom can react with ("destroy") multiple O_3 molecules:

$$CFC + UV \rightarrow Cl + FC \text{ (left over radical)}$$

$$Cl + O_3 \rightarrow CLO + O_2$$

$$CLO + O \rightarrow Cl + O_2$$

Figure 6. On the Bengal II balloon, a water sample taken from the Scajaquada Creek was sent into the stratosphere. Bacteria was sanitized by UV radiation (labeled "space"), as compared to the bacteria in the petri dish control (the control sample was frozen to mimic freezing temperatures at high altitudes). Image Source: Stephen Vermette.

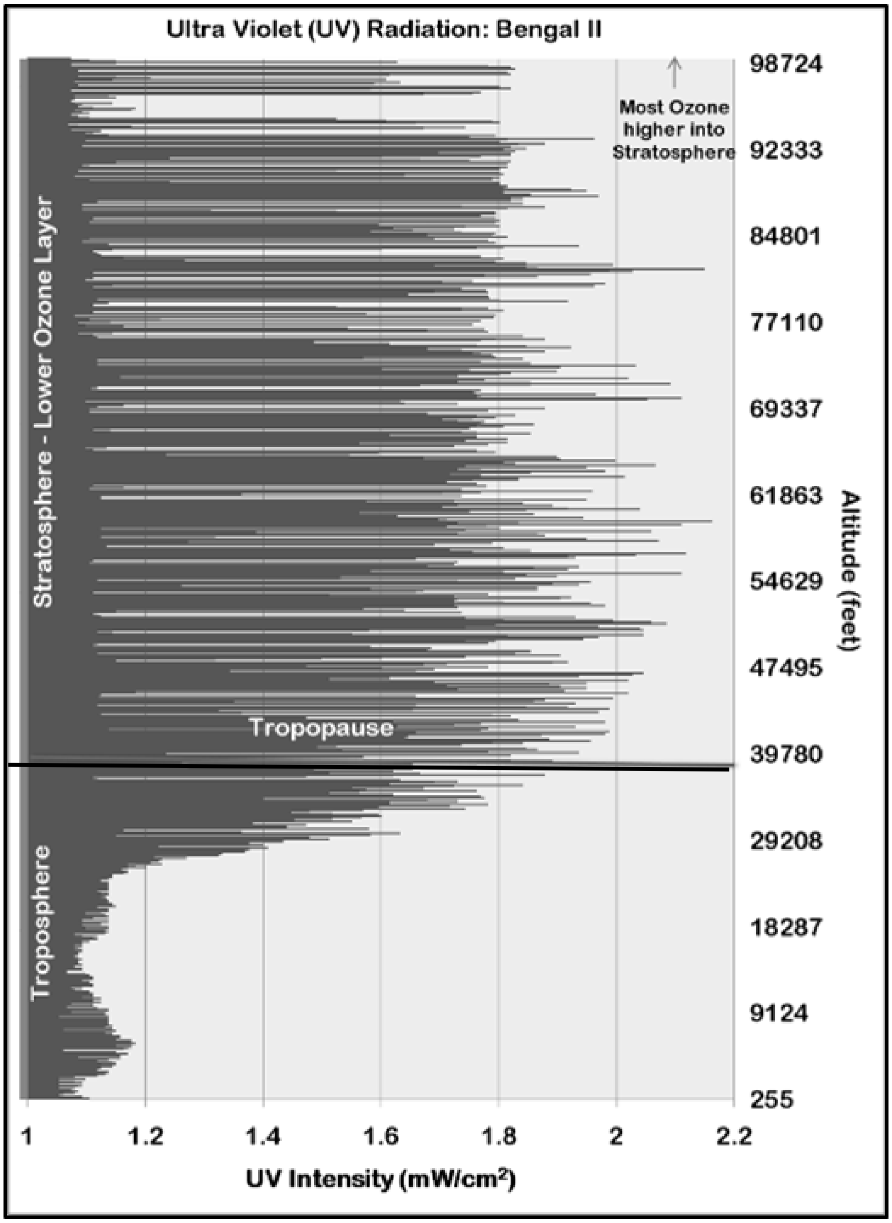


Figure 7. Ultraviolet radiation measured from Bengal II balloon. Note the UV decrease in the troposphere due to stratospheric ozone. Image Source: Stephen Vermette from Bengal II data.

The destruction of stratospheric ozone is more pronounced over Antarctica, giving reference to the "ozone hole" that occurs each spring. The reasons are complex but include the presence of stratospheric clouds (that occur only under the coldest conditions) and the polar vortex (upper air winds circling Antarctica) that tends to isolate the atmosphere over Antarctica from the rest of the planet.

While perhaps not as dramatic as the ozone hole, ozone destruction is also taking place in WNY's skies. On average, ozone levels at our latitude have dropped by about 4 to 5% since 1980, resulting in a comparable increase in UV radiation reaching the surface. In more recent times, after a global response which saw the banning of the most harmful CFC's, evidence suggests that the ozone level may be healing.

Stratospheric ozone is sometimes described as "good ozone", so what is "bad ozone"? It turns out that tropospheric ozone, generated by sunlight and reacting with air pollutants, is an airborne pollutant that makes breathing difficult. Of all the criteria pollutants (pollutants with an air quality standard) monitored by New York State's Department of Environmental Conservation, tropospheric ozone in WNY sometimes exceeds acceptable levels, and an air quality alert is issued. Tropospheric ozone is a secondary pollutant (not emitted from a source) that forms on hot days when sunlight and stagnant air reacts with other emitted pollutants (primarily nitrogen oxides (NOx) and volatile organic compounds (VOCs). There is no chemical difference between the two types of ozone. The only difference between the two is that we breathe the tropospheric ozone but not its stratospheric twin.

Colored Skies and Sunshine

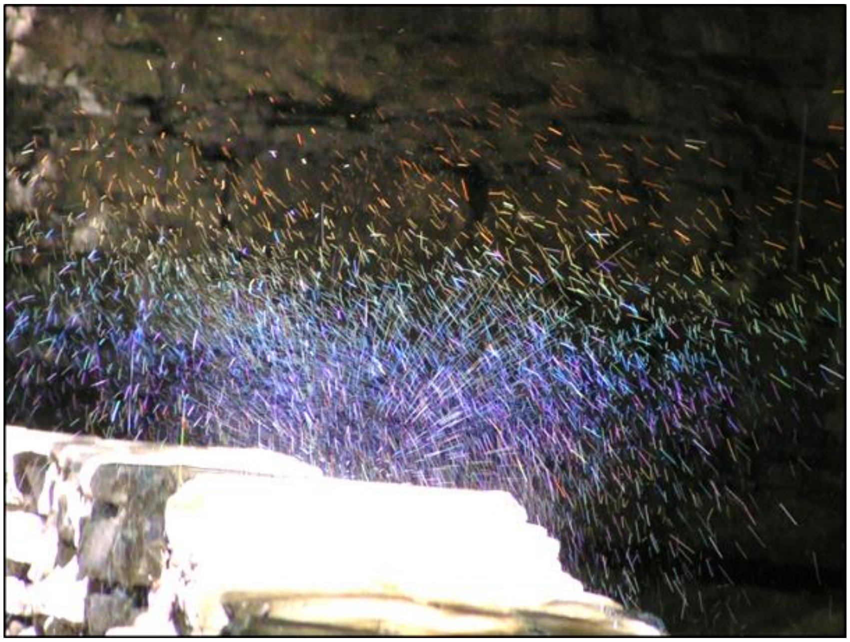


Figure 8. Splash of a falling drop acts like a prism revealing sunlight's visible spectrum. Image Source: Stephen Vermette.

Figure 9. Sunrise over SUNY Buffalo State. Image Source: Stephen Vermette.

The popular song "Blue Skies" by Irving Berlin, with the lyrics "*Smiling at me, nothing but blue skies, do I see…*", reflects how many of us feel on a sunny day in WNY. But why blue? The answer rests with the relationship between the wavelength and behavior of sunlight and the size of molecules that make up our atmosphere. The sunlight we see, or more precisely the visible wavelengths of the electro-magnetic spectrum, is made up of wavelengths of a very small size, measured in nanometers (nm), ranging from 400 nm (violet) to 700 nm (red). While visible light appears white, a prism can be used to separate these wave-lengths (colors) from one another. A rainbow, or even a water drop (Figure 8), is made up of the visible spectrum, where the water drops in a cloud serve as the prism.

Sunlight is scattered (dispersed in a range of directions) by gases, primarily the nitrogen and oxygen which make up 99% of our atmosphere. It is the closer size match between the gas molecules and the blue wavelength that allows the blue wavelength to be scattered most efficiently. This scattering is known as Rayleigh scattering and it gives the atmosphere its blue color. It is interesting to note that the wavelength of light was known before the size of gas molecules were. And it was the blue sky that led early scientists to determine the size of the sky's gas molecules.

The orange colors of sunlight at sunrise and sunset can also be attributed to Rayleigh scattering (Figure 9). At these times of the day, when the sun is low on the horizon, the path of sunlight through the atmosphere is longer (40x) than when the sun is overhead. Along this extended path, the blue wavelength is scattered away before reaching our eyes. This leaves only the larger wavelengths at the red end of the visible spectrum to scatter, coloring the sky and clouds with a reddish glow.

Scattering in the atmosphere plays another important role. When a sun beam enters a room, you are seeing the direct rays of the sun. But how is the rest of the room lighted beyond the sunbeam? The answer is "diffuse" light, resulting from the scattering of the light by the atmosphere in the room. Scattering of sunlight explains why there is light on a cloudy day and why there is a twilight period before sunrise and after sunset. And why the absence of scattering on the moon (no atmosphere) gives its daytime sky a black backdrop. An astronaut standing on the moon will either experience the sun's direct rays, or total darkness. The lack of an atmosphere, and thus scattering, means that the edge of the shadow between the night and day "terminator" is a clear, sharp line on the moon. There is no twilight period.

In years past, the Buffalo News published the "sunshine derby", an ongoing accounting of percent sunshine, which compared Buffalo with other cities, including Rochester, NY, Syracuse, NY, Orlando, FL and Phoenix, AZ. Based on the Derby, Buffalo did quite well, outshining Rochester and sunnier some years than Orlando. An investigation led by this author and Jack Kanack (Weather Medic), reported in the Buffalo News as "Professor rains on Buffalo's high ranking in Sunshine Derby", revealed that it was an "apples and oranges" comparison, actually comparing direct sunshine measurements (from Buffalo, NY) with cloud observations taken from the other cities – Buffalo was one of the few cities in the U.S. still measuring sunshine directly. The comparison was not equivalent, as the cloud observations were converted to sunshine values using a flawed algorithm. And the advantage went to Buffalo! It turns out that WNY is somewhat sunlight-challenged.

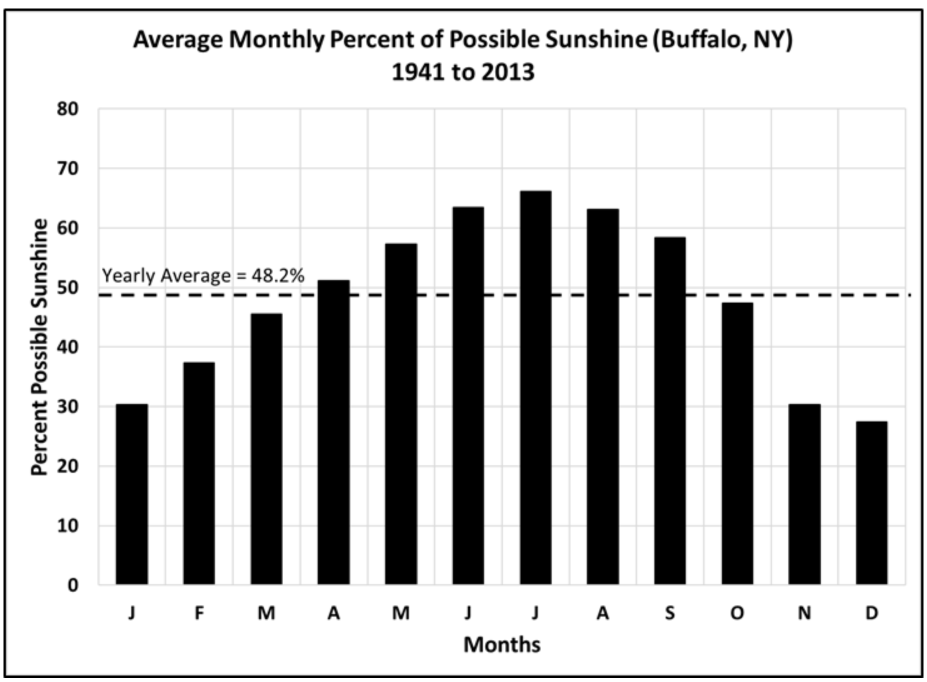


Figure 10. Average monthly sunshine data reported for the period 1941 to 2013. The NWS ended sunshine monitoring in 2014. Early sunshine data was also collected between 1890 and 1903 (not shown). The monthly pattern of the early data looks like the 1941-2013 data. Image Source: Stephen Vermette.

Direct sunlight, expressed as a percent of total possible sunshine, has been measured continually over WNY since 1941 (some earlier measurements are available), but ceased in 2013 (Figure 10). At that time, the antiquated sensor used (Foster-Foskett sunshine switch) could not be automated to match current collection protocols. Cloud cover and the measurement of radiation in the form of energy (watts) are used as measurements today. The solar energy market prefers watts. Based on the data collected from the Foster-Foskett sunshine sensor 1941-2013, on average WNY receives only about 48% of the available sunshine (as measured at the NWS airport station). There is a clear disparity by month, especially in the winter months when about 30% is received, compared to the summer months when about 60% is received. Notable is the sudden drop off in sunshine between the months of October and November. A bright spot, and a point of pride to some, is that WNY's summer sunshine is at the upper end of what is received by other upstate cities.

Stars in the Night Sky

With WNY's summer months experiencing the greatest number of hours of possible sunshine − the least amount of cloud cover − it is likely that summer offers the best advantage for star viewing at night. Aside from clouds, location is an important consideration as light pollution is a hindrance to viewing the stars in the night sky. Light pollution is caused by excessive or misdirected lights most often experienced in urban settings. According to the 2006 Light Pollution Atlas (Figure 11), the night sky, as viewed from cities of Buffalo and Niagara Falls and suburbs, appears a dull grey, and the Milky Way is, at best, very faint directly above (not visible elsewhere in the sky). The best viewing of stars occurs in the southern half of WNY. In areas of southern Erie and Wyoming counties, the Milky Way is brilliant overhead but cannot be seen near the horizon. Viewing in the Southern Tier (Chautauqua, Cattaraugus, and Allegany counties) away from urban areas presents a sky crowded with stars, and a brilliant Milky Way, but a glow of light pollution is often present near the horizon. The best place to star gaze in WNY is at Allegany State Park, and in the northeast corner of Allegany County. To see a sky crowded with stars from horizon to horizon, it is best to cross into northern Pennsylvania, to the Allegheny National Forest, or to take a boat out to the middle of Lakes Erie or Ontario.

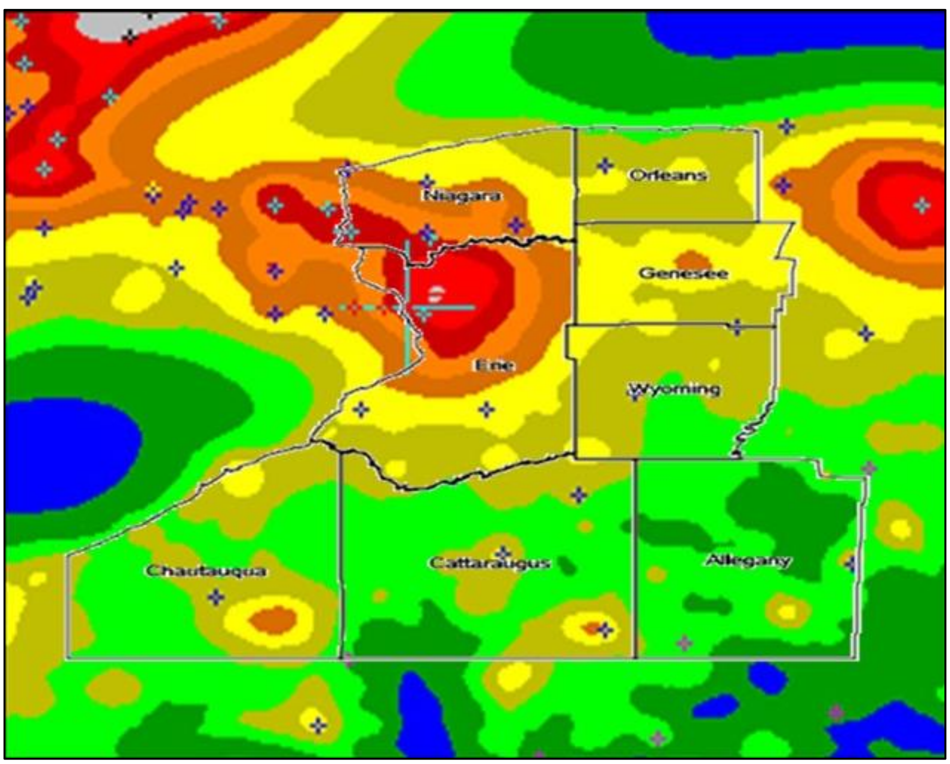


Figure 11. Light pollution map. Areas colored in red and orange experience the greatest light pollution in WNY, whereas as areas that are colored green to blue experience the least. Image Source: 2006 Light Pollution Atlas by David Lorenz, and the web site www.cleardarksky.com, as administered by Atilla Danko.

The Afternoon the Sun Disappeared over WNY

Perhaps the oddest chapter in WNY weather history occurred on Sunday, September 24, 1950. At approximately 1:00 p.m. the skies over WNY went black – day turned into night – but before the sun disappeared, the sky displayed a color palette never seen. The Courier-Express described a sky "*darkened with many hues… with the sun turning blue and displaying a yellow aurora*". Other sun colors included purple, pink, yellow and brown. According to the Buffalo News, *"Shortly after 2 o'clock, darkness began to fall. Between 3 and 4, it was complete"*. The Buffalo office of the U.S. Weather Bureau wrote that at 1:00 p.m. *"upper clouds yellowish – sun's disk visible with purple hue."* Charles Burchfield, WNY's famous water colorist, wrote in his diary: *"Dark and cold. It was not until noon that I first noticed the strange yellow light outside. It kept getting darker and darker. The strange hot tawny color at the zenith, had the quality of a yellow august afterglow, yet different. By 2:00 p.m. it was almost like night. In the west deep blue black clouds, then the sky went from mars violet up to a tawny orange – lower clouds white and cold. In the southeast brilliant light at the horizon."* His reference to actual paint colors allows for a re-creation of some of the color hues he witnessed (Figure 12).

Figure 12. From left to right: Yellow Afterglow (taken from sky color used in Burchfield's watercolor of the same name), Mars Violet, and Tawny Orange color swatches. Image Source: Stephen Vermette.

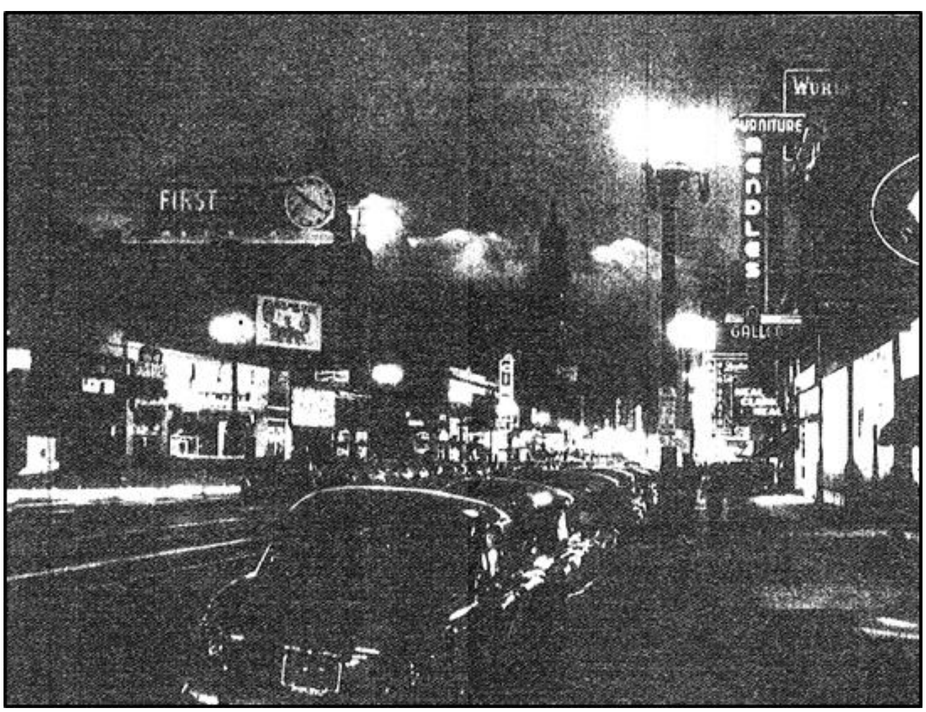


Figure 13. A photo of Main Street (looking south from Tupper Street) taken at 2:51 p.m. as it appeared on the front page of the September 25th Courier-Express. Image Source: A "Photo of Main Street", September 25, 1950. The Courier-Express microfilm. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

The U.S. Weather Bureau wrote that between 2:00 p.m. and 4:00 p.m. *"light from the sky was diminished to the dimness of late twilight (or pre-dawn)."* In both the newspaper and Weather Bureau accounts, it is noted that street lights came on and that *"Artificial lights were needed for all purposes"*. Runway lights came on at Buffalo Airport and planes used landing lights (Figure 13).

One can only imagine the sensation and confusion a person must have felt on the afternoon of September 24th, as one drove down a city street or walked out of a store or matinee that Sunday. I'm sure that all eyes were directed to the sky and that the darkness was the source of speculative conversation.

Some recalled end-of-the-world prophecies. Fresh into the Korean War and Cold War, others thought that *"an atomic bomb had been dropped somewhere nearby, possibly in Lake Erie"* – the beginning of a third World War. One woman stated *"I've just received a long-distance phone call from Cleveland. A radio station there has announced that Canada is on fire!"* The Buffalo News noted that the darkness *"aroused concern, wonder, fear, anxiety and an inordinate amount of speculation among the perturbed citizenry."* The Buffalo Office of the U.S. Weather Bureau noted in their monthly summary that the phenomenon was *"causing anxiety and incipient hysteria to a large segment of the population…due to the lack of information from any authoritative source and to some speculative remarks made by radio announcers."* According to the U.S. Weather Bureau's monthly summary, a reassurance statement was issued in "mid-afternoon" for broadcast by local radio stations.

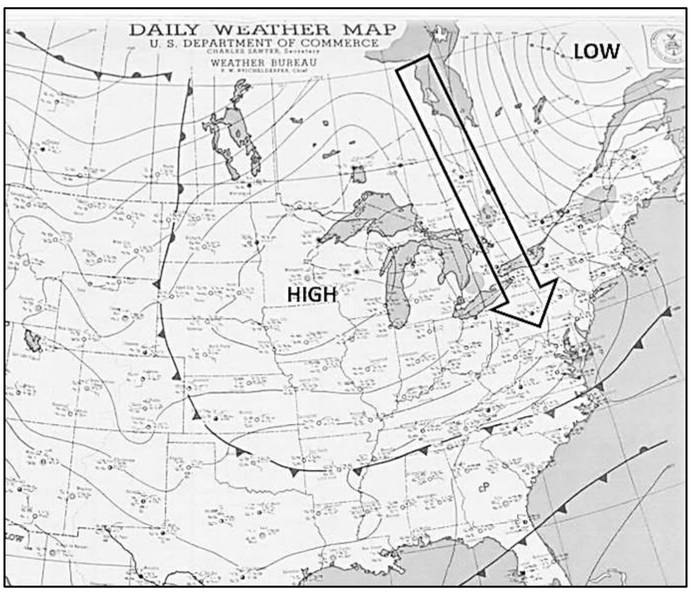


Figure 14. Smoke aloft drifted eastward across Northern Canada to Hudson Bay where, caught between a low- and high- pressure system, was directed over WNY (shown by arrow). Image Source: NWS/Daily Weather Map.

The woman's fear that "Canada was on fire!" was close to the truth. The "reassurance statement" given out by the Weather Bureau and local radios attributed the darkness to a smoke pall from forest fires in northern Alberta and British Columbia, where approximately 100 fires burned. The smoke produced by the fires, trapped in a layer of air between 12,000 to 17,000 feet above sea level (asl), first flowed eastward to the western coast of Hudson Bay in Canada, where the smoke aloft took a dramatic turn southward, caught as on a conveyer belt between the counterclockwise air around a deepening low pressure centered over Quebec and the clockwise air flow of high pressure over Manitoba. The smoke plume held together following a southeast course reaching WNY on September 24th (Figure 14).

The darkness can be easily attributed to the blocking of sunlight by the smoke aloft. The weird color hues noted by observers (e.g. a purple sun) can be attributed to the tiny smoke particles aloft scattering the sun's light in ways never seen. Additional to turning day into night, the smoke layer lowered the day's expected maximum temperature by about 10°F (46°F, as compared to 57°F the day before and 55°F the day after).

The stealing of an afternoon's daylight created a unique event in WNY's weather history. No one in WNY has experienced what those who looked to the sky on September 24, 1950 did on the afternoon the sun disappeared.

Living Under Pressure

Atmospheric pressure can be considered in two different ways: either as a measure of the atmosphere's weight; or as a force exerted by the atmosphere. When considered as a weight, we see that atmospheric pressure is greatest at lower altitudes – simply put, there is more atmosphere above you (thus a greater weight) at lower altitudes than would be if at higher altitudes.

As a force, the pressure exerted on your body is matched by an equal force that pushes back. The ear pain felt with rapidly increasing altitude is due to a growing pressure imbalance between your body and the outside air, and the relief from "ear popping" is a restoration of that balance. The same ear pain occurs when swimming underwater, except that the imbalance is opposite. Though an extreme example, if you travel unprotected too far up into the atmosphere, your body will explode (pressure greater inside than outside the body), whereas swimming too deep into an ocean may cause your body to implode (pressure greater outside than inside the body).

In the time of Galileo, it was believed that the Earth's atmosphere had no weight. The invention of the barometer by Evangelista Torricelli helped establish that the atmosphere did indeed have weight. In an experiment originally designed to create a vacuum, Torricelli filled a long tube with water and sealed it at both ends. He then submerged one end of the tube into a basin of water and opened it. Water spilled out, but a point was reached when it stopped. The water held in the tube remained at a height of about 35 feet. The water that did spill out created a space in the upper end of the tube that was a sustained vacuum. His experiment was successful! The notion of a vacuum (an empty space) was considered by some clerics of the time as heresy – God was everywhere…there could be no vacuum. To avoid heresy charges, or at the very least being accused of sorcery and witchcraft, Torricelli opted to use mercury. As mercury is 14x denser than water, replacing water with mercury only required a tube with a height of about 32 inches. His experiments would continue in secrecy.

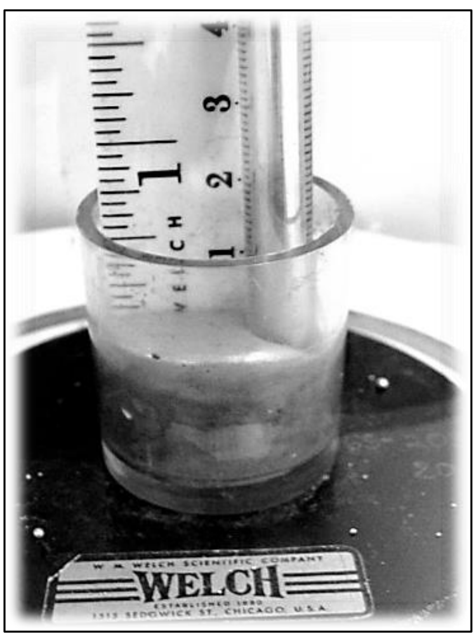


Figure 15. Liquid-in-glass mercury barometer. Image Source: Stephen Vermette.

What Torricelli discovered was that the column of water (later mercury) was a measure of the weight of the atmosphere, and thus became the workings of a liquid-in-glass barometer, as used today (Figure 15). By way of explanation, the weight of the atmosphere pushes down on the basin of mercury, forcing the mercury to rise up the column. The height of mercury in the column counterbalances the weight, or pressure, of the atmosphere. Thereby, a "rising barometer" is an indication of increasing atmospheric pressure, and a "falling barometer" is the column of mercury adjusting its weight to match a lowering atmospheric pressure. Inches of mercury, the unit of measure most commonly used to express atmospheric pressure, is simply an indication of the height of the mercury column.

While early observers linked the rise and fall of the mercury column to changing weather, it was left to Vice-Admiral Fitzroy, of the United Kingdom's Royal Navy, to be the first to provide weather forecasts (for the safety of shipping) based on the barometer. Numerous British harbors were outfitted with barometers embedded in stone cairns for all fisherman to read. In fact, Fitzroy coined the term "forecast" as it relates to weather. Even today, if you had to rely on only one weather instrument to derive a weather forecast, it should be the barometer.

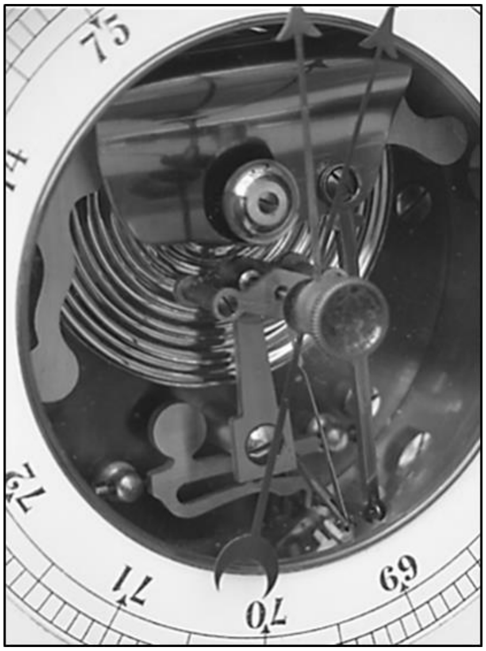


Figure 16. Aneroid barometer. Image Source: Wikimedia Commons.

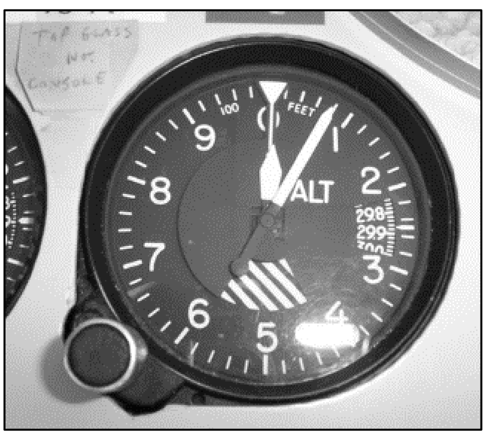


Figure 17. Barometric aircraft altimeter set at 75 ft showing a pressure of 29.87 in/Hg. Image Source: Wikimedia Commons/CambridgeBayWeather.

If you have a barometer in your home, it probably is not a liquid-in-glass barometer. Aside from being unwieldy due to its size and fragile nature, mercury is now recognized as a hazardous substance. Most likely you own an aneroid barometer (Figure 16). The critical component of an aneroid barometer is a sealed round metal box. The shape of the box changes in response to changes in atmospheric pressure, whereby an increase in pressure causes the box to contract and a decrease in pressure causes it to expand. A series of levers transfers the changing shape to a dial face calibrated to measure atmospheric pressure. The principle of an aneroid barometer is much as you might have experienced with a bag of chips when flying or when driving up a mountain. The bag expands in response to the decrease in pressure with altitude (we know the bag is mostly filled with air). Even canned foods act as barometers, as the lid of the can will bow in or out dependent on changing atmospheric pressure. To see the change, all that is needed is a horizontal lever to transfer the response of the lid and a ruler to measure it (the change is subtle, but it does occur).

Another application of a barometer is its use as an altimeter (to measure altitude or height). Understanding that atmospheric pressure decreases with altitude, a changing pressure corresponding to a climb or descent can be calibrated to measure height. Early mountain explorers, such as Alexander von Humboldt, carried these unwieldy liquid-in-glass barometers to great heights in order to record the elevation of mountain tops. Most likely (if not based on a global positioning system − GPS) the altimeter used in an airplane (Figure 17) or that you use when hiking relies on the relationship between barometric pressure and height. If you have an aneroid barometer you can test this. A change of about 0.114 inches of mercury is equivalent to about 100 feet change in elevation in WNY.

Units of Pressure

As previously noted, barometric pressure refers to the force or weight of the atmosphere, and the mercury barometer displays the weight of the atmosphere in "inches of Mercury (Hg)", the height of the mercury column at which its weight matches that of the atmosphere. The standard pressure, at sea level, is 29.92 inHg, and pressure, expressed as "inHg" is what is normally reported to the public in the United States. The unit of pressure used by the National Weather Service (NWS) in weather forecasting and on weather maps is the millibar (mb or mbar). The term "Bar" has its origin in the Greek word for weight, and 1.01325 bar, or 1013.25 mb is equivalent to 29.92 inHg. It turns out that neither "inHg" or "mb" are proper metric units. Our neighbors to the west and north (Canada) use the metric units Kilopascals (KPa) and Hectopascals (hPa) as their units of measure. A pascal is equivalent to one newton per square meter. Before throwing your arms up is despair and cursing metric units, be calmed by the fact that the "mb" and "hPa" are equivalent units, thus 1013.25 mb is also read as

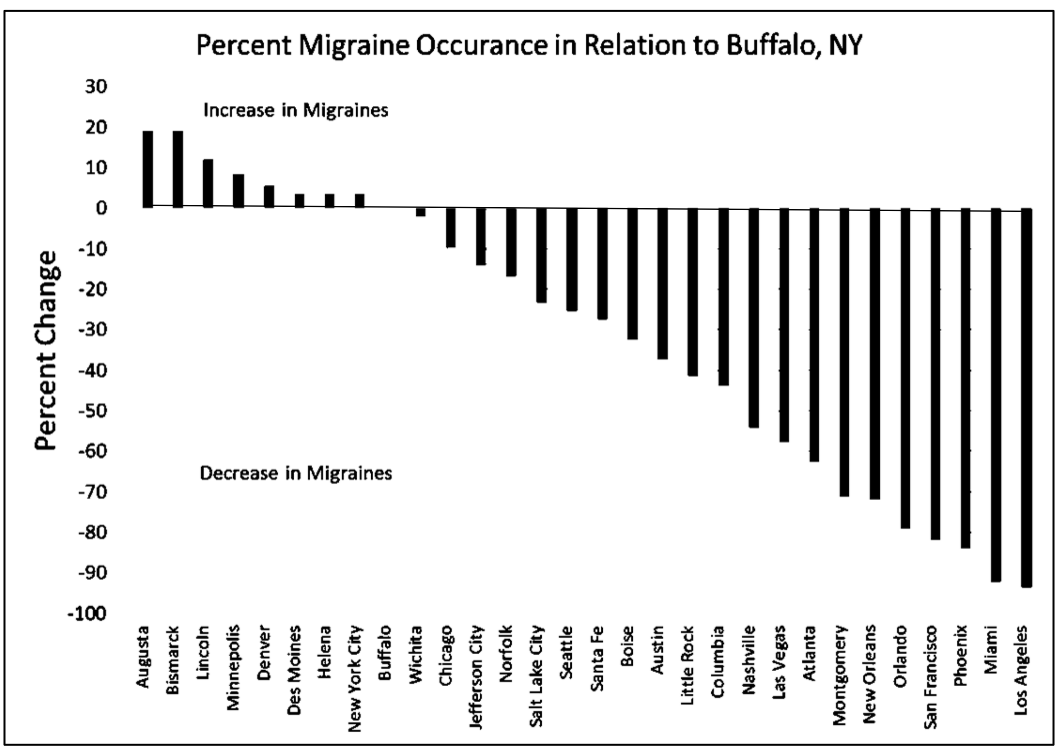
1013.25 hPa, while KPa is close, requiring moving a decimal place over one, to read 101.325 KPa. Most aneroid barometers in the U.S. report pressure as units of "inHg" and "kPa".

Box 2 Atmospheric Pressure is a Common Migraine Trigger

Migraines are excruciatingly painful headaches, complicated by nausea, vomiting, and sensitivity to light. The onset of a migraine may be triggered by several factors including marked changes in atmospheric pressure. A local migraine sufferer who identified pressure change as a substantial trigger, reached out to me to locate a place in the United States where he might find relief. Working with a student (Justin Blicharski), we looked at average daily barometric pressure data from 30 cities and compared them to Buffalo. Daily pressure differences were calculated by subtracting pressure values of sequential days for each of these cities.

For the case of this individual, the findings indicate that Buffalo does not fare well for migraine relief, as 21 of the 29 comparison cities experienced smaller changes in atmospheric pressure to that of Buffalo. Overall, data indicated that daily pressure changes decrease with decreasing latitude, and decreased along the coasts, as the country's mid-section exhibits a prominent increase in daily pressure changes attributed to cyclogeneses (development of storm systems) in the plain states.

Calculations based on daily pressure differences for these 30 cities became the basis of a hypothetical "percent increase or decrease in migraine occurrence" tailored to the local individual and compared to Buffalo. Based on our calculations, the cities of Los Angeles and Miami provided the possibility of a 90% reduction in headaches for the local migraine sufferer. The local individual moved to Los Angeles and in his last e-mail reported *"the change is remarkable not only for the decrease in frequency, but also the severity of the headaches… Unfortunately, the last few years have seen an increase in the frequency of pressure change, differing greatly from the historic average. I'm guessing this is part climate change.*



Chapter 2

Seasonal Rhythms

A multi-month exposure − June 21st (summer solstice) to December 21st (winter solstice) 2010 − showing the sun's daily path through the sky (sunrise to sunset), and the changing height of the noon day sun as the seasons progress (highest at the summer solstice, becoming progressively lower until the winter solstice. The image was taken in Toronto (camera pointed at the Prince Edward Viaduct Bridge) using a technique known as "solargraphy", in which a pinhole camera captures the movement of the Sun. In this case, the camera used was housed in a beer can. Check out the online site "The Global Project of Solargraphy", as administered by Tarja Trygg, to learn more about solargraphy and see additional images. Image Source: Ben Palich.

Reasons for the Seasons

In Western New York (WNY) we experience four well-defined seasons: winter, spring, summer, and autumn. What causes these seasons?

A first thought might be that the Earth's elliptical orbit (revolution) around the sun brings us closer to the sun in the summer and farther from it in the winter. This is not the case. Our distance from the sun is closer (Perihelion) during our winter, and farther (Aphelion) during our summer.

A more accurate thought is that our four seasons may have something to do with our position on Earth. WNY is located between 42°N and 43°N latitude, which is about halfway between the perceived "summer" conditions along the equator (0°) and the perceived "winter" conditions at the North Pole (90°N).

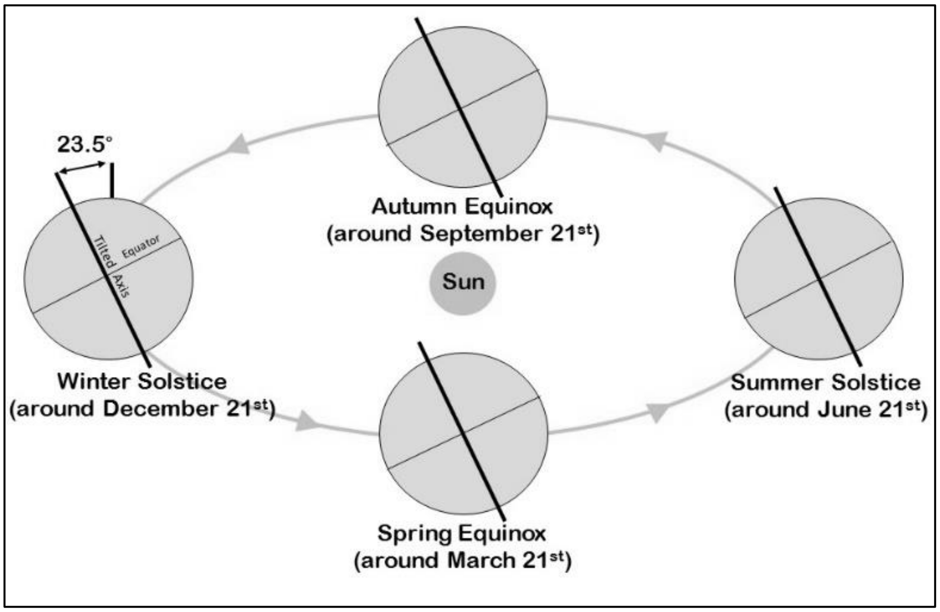


Figure 18. Earth's orbit and tilt in relation to the sun.
Image Source: Stephen Vermette.

A better answer is that our seasons have everything to do with the Earth's tilt and with its relationship to the sun. Our earth is tilted at 23.5° from the perpendicular of its orbital or elliptical plane about the sun (Figure 18). In other words, our planet has a slouch or lean. Along its revolutionary path around the sun, points on the earth sometimes lean (tilt) toward the sun and at other times tilt away. For example, during our summer, the Northern Hemisphere (latitudes north of the equator) tilts toward the sun, while during our winter the Northern Hemisphere tilts away from the sun. When tilting toward the sun, the sun's rays strike the earth's surface more directly (more energy received at a surface point) and the length of daylight is longer (more energy received because the sun is above the horizon for a longer time), than when tilting away. This pattern is intuitive to anyone living in WNY. We recognize that summer days are longer than winter days, and that the sun's rays feel more intense in summer than in winter. This difference in the sun's intensity and in the length of daylight defines our seasons. But more detail is needed.

March 20-21 (spring or vernal equinox) and September 22-23 (autumnal equinox) mark the dates (which vary slightly from year to year) when the sun's vertical rays strike directly on the earth's equator. All locations, from North Pole to equator to South Pole, receive 12 hours of daylight and 12 hours of darkness. The term "equinox" means "equal day and night", and both hemispheres receive the same quantity of energy. In WNY, these dates mark the beginning of spring and autumn, respectively. Between the first day of spring and the first day of autumn the Northern Hemisphere receives more of the sun's direct rays than does the Southern Hemisphere, and the daylight period is longer. Whereas between the first day of autumn and the first day of spring the Southern Hemisphere receives more of the sun's direct rays than does the Northern Hemisphere, and their daylight period is longer. On June 20-22 (WNY's summer solstice), the sun's vertical rays strike directly on the Tropic of Cancer (23.5°N). In WNY this date marks the first day of summer, the day with the longest period of daylight (about 15 hours). On December 21-22 (WNY's winter solstice) the sun's vertical rays land directly on the Tropic of Capricorn (23.5°S). In WNY, we experience the first day of winter, the day with the shortest period of daylight (about 9 hours).

When does Buffalo receive the sun's vertical rays? The answer is "never". The path of the sun's vertical ray's travels between the Tropics of Cancer (23°N) and Capricorn (23°S) (Figure 19). The highest we can achieve in WNY is a summer solstice noonday sun angle of about 70.5° from the horizon. In winter the noon sun angle is low, at only about 23.5° at winter solstice.

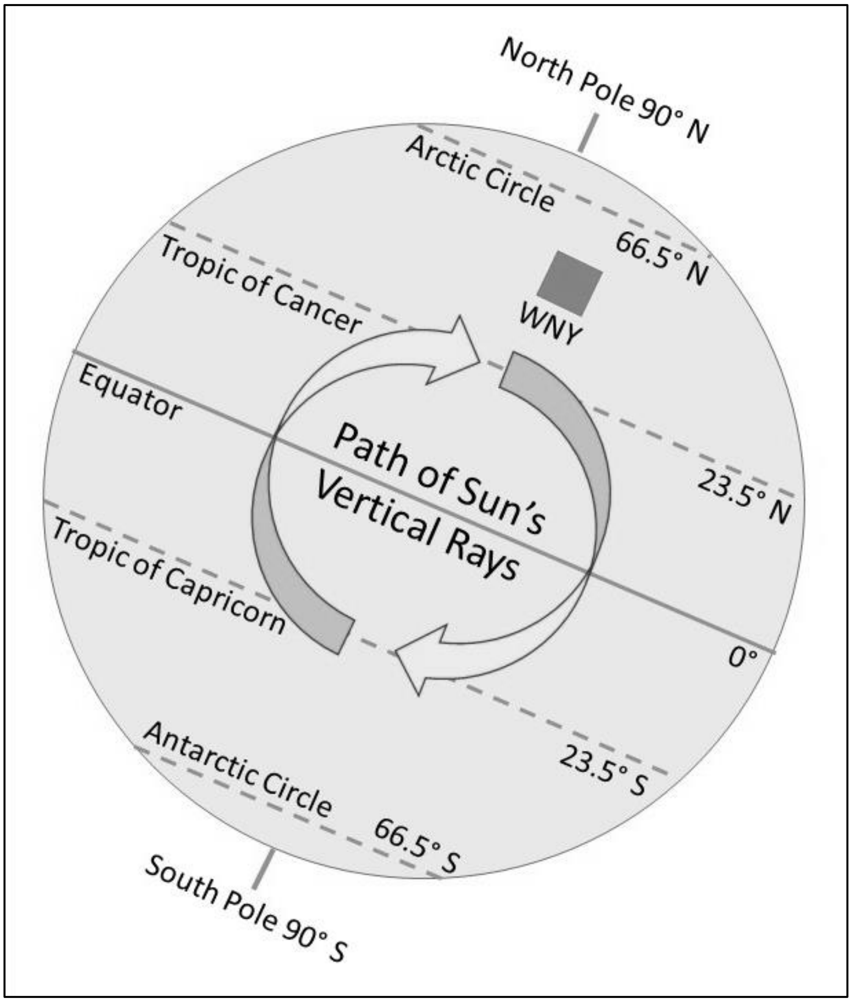


Figure 19. Path of the sun's vertical rays are restricted between the Tropics of Cancer and Capricorn. Image Source: Stephen Vermette.

Calculating the Angle of the Noon-day Sun

While the sun rises in the east and sets in the west, the noon sun angle occurs at that time each day when the sun is at its highest point in the sky (zenith). The calculation of the noon sun angle can be made for any location and for any day. To do so, you need to know the latitude of the location of interest and the latitude of the sun's vertical rays on a given date. By way of example, let us calculate the noon sun angle for Buffalo (43°N) on December 21st. December 21-22 marks the winter solstice, so we know that the sun's vertical rays are striking at the Tropic of Capricorn (23.5°S) on that date. To calculate Buffalo's noon sun angle, the first step is to determine the number of degrees of latitude separating Buffalo from the sun's vertical rays. In this case, the answer is 66.5 degrees of latitude (the difference in degrees of latitude between 43°N and 23.5°S). The second step is to subtract this number (66.5°) from 90° (zenith). The result is 23.5°. By way of calculation, we have determined that the noon sun angle on Buffalo's winter solstice is 23.5 degree above the horizon.

The latitude of the sun's vertical rays is easily known on four dates each year, those of the solstices and equinoxes. For other dates, the latitudes of the vertical noon sun location can be determined from an analemma graph which can easily be accessed on the internet.

When "East" Isn't East and "West" Isn't West

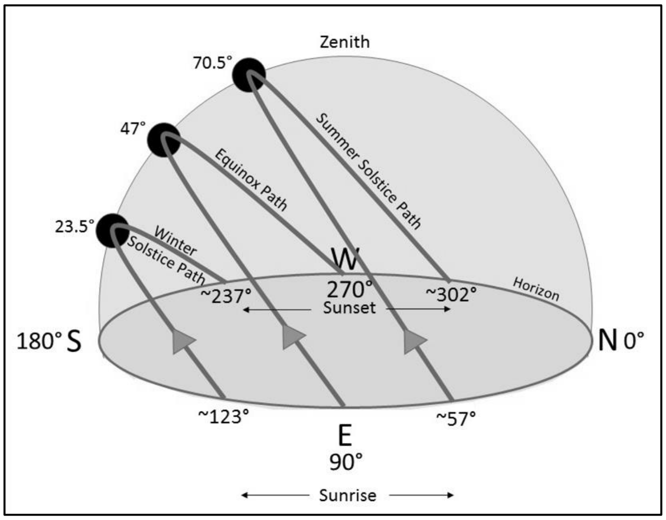


Figure 20. The changing seasonal sun height, sky arc, and sunrise/sunset compass orientations specific to Buffalo, NY (43°N). Image Source: Stephen Vermette.

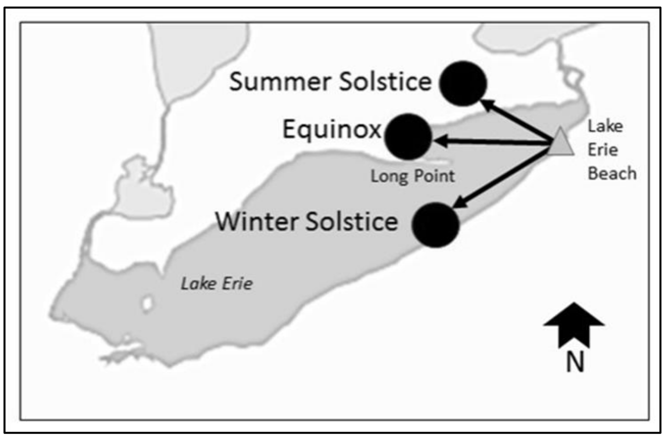


Figure 21. The changing sunset locations across Lake Erie, as seen from Lake Erie Beach, NY. Image Source: Stephen Vermette.

While we are always told that the sun rises in the east and sets in the west (due to earth's axial rotation), you may have noticed that the "east" and "west" do not always appear at the same location along the horizon (Figure 20). The location of sunrise and sunset varies with the seasons. By way of explanation, consider the winter solstice. At this time, the sun's vertical rays are focused on the southern hemisphere (the northern hemisphere facing away from the sun) and, subsequently, the sun is at its lowest zenith (height at solar noon) in the WNY sky. At WNY's latitude, we experience the upper arc of the sun's light as it passes across our sky (the sun is low and because the arc is short, so too is daylight). The sun rises above the horizon at a compass reading of about 123° (between SE and ESE) and sets below the horizon at about 237° (between SW and WSW). As an aside, Arctic regions (>66.5°N latitude) experience a day when the sun does not rise above the horizon, as the arc of sunlight does not extend that far north in the winter.

During the summer solstice, the northern hemisphere is facing the sun (the sun's vertical rays are striking the northern hemisphere and thus are closer to WNY) and subsequently the sun appears high in the WNY sky. WNY experiences more of the sun's arc of light, giving us a longer period of daylight, as well as an earlier sunrise and later sunset. The sun rises above the horizon at about 57° (between NE and ENE) and sets below the horizon at about 302° (between NW and WNW).

During the spring and fall equinox (when the sun's direct rays are striking at the equator, mid-point between the northern and southern hemispheres), in WNY the sun rises in the east (90°) and sets in the west (270°). So, sunrise in WNY varies along the horizon between ESE and ENE, and sunset varies along the horizon between WSW and WNW.

As a 'real world' example, if you were looking out across Lake Erie from Lake Erie Beach, you might notice that sunset locations appear to change with each seasonal visit (Figure 21). In the winter, the sun would set across the lake, while in the summer the sunset would appear somewhat parallel to the NY shoreline. In spring and fall (equinox), the sun would set due west, over Long Point, Ontario. Of course, this changing orientation does not apply only to Lake Erie Beach, but to anywhere you live in WNY.

The seasons described above, as defined by equinox and solstice, are referred to as the astronomical seasons. Meteorological seasons are often defined using groupings of three consecutive months: winter (December, January, and February), spring (March, April, and May), summer (June July, and August), and autumn (September, October, and November). This author has argued in publications that WNY's winters may better be defined as running from November through to March (five months).

Box 3 **Dunkirk Dave**

While Punxsutawney Phil at Gobbler's Knob (Punxsutawney, PA) is considered the bellwether of groundhog forecasting, WNY has its own weather prognosticator - Dunkirk Dave (Dunkirk, NY). In fact, Dunkirk Dave is the "world's second longest" prognosticating groundhog, and certainly WNY's regional expert on predicting early spring weather.

The U.S. groundhog tradition is rooted in German-speaking immigrants to Pennsylvania who brought with them the groundhog tradition. Groundhogs are "fossorial" animals, meaning they spend much of their life underground in dens − more so in the winter than at other times of the year − waiting to emerge with the arrival of warm weather. Groundhog lore states that if on February 2nd a groundhog emerges from its winter den, sees its shadow on a sunny day, and returns to its den, it is predicting six more weeks of winter. If the groundhog does not see its shadow because it is a cloudy day, the groundhog will remain outside, predicting an early spring.

WNY's Dunkirk Dave is cared for by Bob Will, a school teacher and state-licensed wildlife rehabilitator. Bob was introduced to groundhogs after rescuing and caring for a sick and injured groundhog that he later released back to nature. Since then, Bob has rehabilitated groundhogs (among other small animals). Consequently, there was always a groundhog around, and with press provided by editors for the Dunkirk Evening Observer, the "Dunkirk Dave" legend was born.

So, as Groundhog Day approaches, you can listen to what Punxsutawney Phil has to say but for a truer WNY forecast on spring's arrival, look no further than Dunkirk, NY to learn of Dunkirk Dave's prognostication. Image Source: Bob Will

WNY's Other Seasons

Lake Effect Seasons

The traditional four seasons of WNY can be augmented by yet another set of seasons. While the traditional seasons are defined by the tilt of the Earth and its relationship with the sun, the localized seasons discussed here are controlled by the influence of Lake Erie, and to a lesser degree by Lake Ontario (Figure 22). They are referred to as the "Lake Effect Seasons", but the effect goes beyond snowfall events. Some background information about specific heat is required before discussing these seasons.

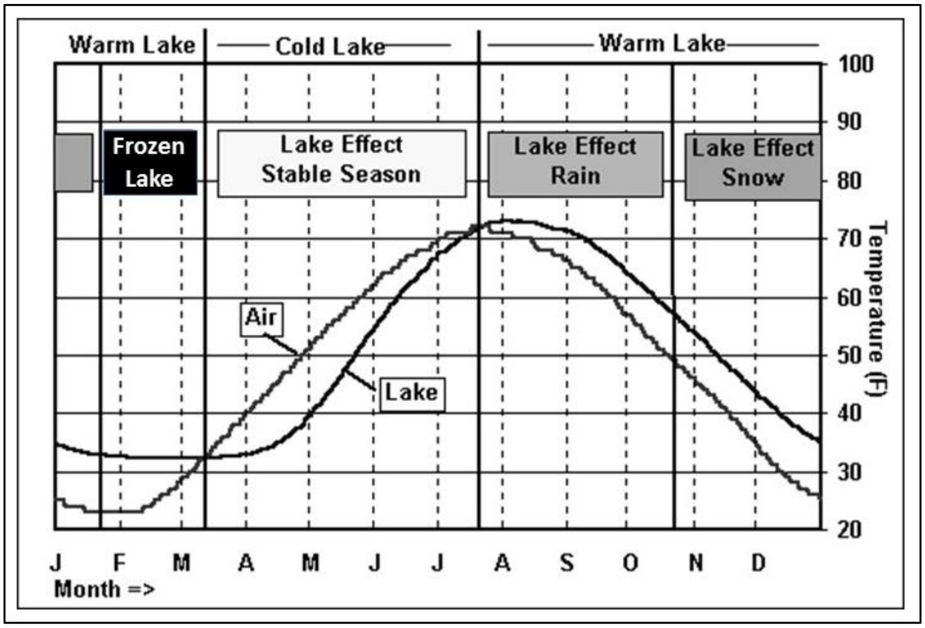


Figure 22. WNY's Lake Effect Seasons. Image Source: National Weather Service/Tom Niziol.

Specific heat refers to the quantity of energy required to raise the temperature of a unit mass of a substance by given temperature. Bodies of water have a greater specific heat than land surfaces, such that a greater quantity of the sun's energy is required to warm water bodies versus land surfaces.

And the reverse is also true: land surfaces tend to cool down faster than water bodies. As regional air tends to reach WNY from continental locations, there can be a temperature differential between air and water. This differential appears as a seasonal temperature lag, where regional air tends to warm faster than lake water in the spring/early summer, and regional air cools faster than lake water in the late-summer/autumn. Let us now look at WNY's localized seasons (refer to Figure 22).

From mid-March to mid-July, the regional air temperature tends to be warmer on average than that of the lake water. A layer of warm regional air passing over a cooler layer of air near the lake's surface (moderated by cool lake waters) sets up a vertical profile of stable air (an inversion), both over the lake and downwind. Under these conditions air tends not to rise, suppressing the formation of clouds and the production of rain. This season is referred to as the "Lake Effect Stable Season". During this season, areas over the lake and immediately downwind tend to experience a greater number of blue-sky days as compared to points farther inland.

From mid-July to late-October, the relationship reverses as the air near the lake surface is now warmer than regional air temperatures. A vertical profile of unstable air (rising air) promotes evaporation of lake water, and the formation of clouds, and rain. This season is referred to as the "Lake Effect Rain Season". During this season, areas over the lake and downwind experience a greater frequency of cloud cover and rainfall. Driving north from "ski-country" toward Buffalo, a demarcation line is often visible where cloud cover gives way to clear skies over the city. The clear skies over Buffalo sometimes occur when winds pass over the "protective" Canadian Niagara Peninsula landmass instead of the open waters of the lake. The "Lake Effect Rain Season" morphs into the "Lake Effect Snow Season" later in the year when regional air temperatures drop below freezing (late-October to mid-January). It is during this season that the lake's slow rate of cooling prevents it from freezing and regions downwind experience lake effect snow (LES).

If cold air persists through the winter, Lake Erie will freeze over. Ice cover prevents the transfer of energy and moisture from the lake to the atmosphere. LES ceases (for the most part) and we enter the fourth season: the “Frozen Lake Season” (mid-January to mid-March). Lake Ontario does not freeze over because of its depth and large reserve of stored heat; thus, the lake effect machine does not shut down the way it does for Lake Erie. It is for this reason, and no surprise, that the City of Syracuse (positioned downwind/leeward of Lake Ontario) has won the “Golden Snowball Award” many more times than that of the City of Buffalo (see Box 4).

The lake effect season can also be described as it relates to lake shore surface air temperatures. Due to specific heat capacity differences, large bodies of water such as Lakes Erie and Ontario take longer to warm or cool in relation to neighboring land, thus moderating surface air temperatures near the lake shore by cooling air temperatures in spring and early summer and warming temperatures in the late summer through the winter. The inland penetration of lake moderated air temperatures is attributed to lake breezes, which are localized onshore winds generated by lake/land temperature differences, and by regional winds blowing off the lakes. While moderating surface air temperatures inland, the lake modified surface air rapidly reaches inland values after traveling only a few miles. Thus, a WNY spring weather forecast may read “a high of 75°F, but cooler near the lake.”

The high temperature in the hypothetical weather forecast above refers to the official reading at the Buffalo-Niagara International Airport (located inland about 9 miles east of Buffalo, NY), the official monitoring site of the National Weather Service (NWS). This was not always the case as prior to 1943 the NWS site was in downtown Buffalo, and thus the temperatures reported were influenced by proximity to the lake. A 1982 study by Quinn compared NWS climate data for Buffalo prior to 1943 (1914 to 1942) with those of Lockport, New York, the closest inland station with an uninterrupted record. The comparison revealed that Buffalo experienced a typical lake effect control, being cooler than Lockport during the spring and early summer and warmer than Lockport during fall and winter. After the weather station’s 1943 move to its current inland location, Quinn reported that the difference in temperature between Buffalo and Lockport all but disappeared. Prior to the weather station’s move to the airport, two years of NWS data (1941 and 1942) were simultaneously collected at both the downtown (former) and inland (current) sites. As with the Buffalo-Lockport pre-1943 comparison, the simultaneous collections revealed, as reported by Quinn, that the lake effect was absent from the inland site.

In a re-examination of the “lost lake effect”, this author compared air temperature data (1943 to 1987) recently obtained from a waterfront location found in the log books of the Colonel Ward Pumping Station, located at the confluence of Lake Erie and the Niagara River. The Colonel Ward Pumping station air temperature data were not available to Quinn in his assessment. The availability of the post-1942 pumping station temperature data serves as a proxy for the original NWS downtown location, allowing for a lengthier comparison of waterfront (downtown) and inland (airport) station temperatures.

Differences in average monthly temperatures between the waterfront Colonel Ward Pumping Station and the inland NWS location at the Buffalo Niagara International Airport support the earlier claim by Quinn. The character and magnitude of the lost lake effect can be described as one with winter months that would have averaged 0.80°F to 0.93°F warmer than the current Buffalo record. Spring and early summer temperatures would have averaged 0.75°F to 0.89°F cooler than the current Buffalo record, with the month of April experiencing the greatest cooling (1.15°F to 1.33°F). The autumn months would have averaged 0.52°F to 0.77°F warmer than the current Buffalo record, peaking in the early winter month of December (0.88°F and 0.98°F). March and July (and August and September to a lesser degree) appear as transition months showing the least impact in the post-1942 climate record.

Within the 1943 to 1987 study period, the impact of the lost lake effect on the annual mean temperature record appears minimal (-0.04°F) as temperature gains in one season are lost in another. Overall, the inland move of the NWS weather station impacted seasonal mean temperature records, but essentially had no impact an annual mean temperatures.

Buffalo's Persistent Myth

Figure 23. Ice boom preventing ice from Lake Erie Entering the Niagara River – 1966 aerial view. Image Source: Niagara Falls (Ontario) Public Library.

The myth goes something like this: "The extended lake ice in Lake Erie's eastern basin and the cool spring air temperatures are attributed to the presence of the ice boom".

A seasonal ice boom was first installed across the eastern end of Lake Erie in 1964-65. The ice boom is seasonal, installed in the early winter and removed in the early spring. The ice boom is made up of 22 spans, each with a series of steel pontoons (originally floating timbers), anchored to the river bed and stretched across just less than 2 miles at the confluence of Lake Erie and the Niagara River (Figure 23). The ice boom was designed to reduce disruptions of hydroelectric power generation caused by ice flow down the Niagara River that jammed the water intakes of hydroelectric plants. A subsequent benefit was a reduction in ice damage and flooding to shoreline properties along the Niagara River.

The heart of the myth is that the ice boom acts as an ice dam creating a backlog of ice in the lake's eastern basin. The public perception is that the ice boom caused ice to form earlier than normal, that ice volume was increased, and that the ice persisted longer. The reality is that this buildup of ice at the eastern end of Lake Erie occurs independent of the ice boom. The ice buildup is due to a combination of cold temperatures, the easterly migration of ice by southwest prevailing winds, the narrowing and concave shape of the eastern basin, and the narrowness of the Niagara River outlet. Without the ice boom, ice would certainly float down the Niagara River, but the volume of ice that would float down the river is negligible when compared to what builds up in the eastern basin.

Air passing over the accumulated ice in the eastern basin most certainly cools the nearshore environments of Erie County, including the City of Buffalo but, given the earlier point that the ice buildup occurs independent of the ice boom, means that the ice boom cannot be blamed. An examination of the airport weather office records revealed a form on which instrumental equipment and exposures are noted. On that form, a description of station exposure is entered and includes a list of pronounced lake effects. Listed is *"Heavy ice localized to east end of Lake Erie reduce spring temperature."* This statement was entered on the form decades before the installation of the ice boom.

To burst this myth, research by this author and others examined spring air temperatures for the years preceding and following the installation of the ice boom. Temperature data were examined from the National Weather Service (NWS) weather station at the airport site, and from temperature records obtained from the Colonel Ward Pumping Station located at the head of the Niagara River. Water temperatures and "ice-out" dates were also examined. The conclusion was that the ice boom had no measurable influence on air and water temperatures. The nearshore environments in the City of Buffalo and south are certainly cooler in the spring than if the ice was not present, but this cooling cannot be blamed on the ice boom.

Season of Lake Disaster

There is one other season to consider. At the turn of the 20th Century, when Buffalo was one of the most important Great Lakes ports, the early winter season was sometimes referred to as the "Season of Lake Disaster". The gales of November (sometimes referred to as "Freshwater Furies") were famous here, and across the Great Lakes, for causing shipping disasters and the loss of life. Deep low-pressure systems tracking over the Great Lakes were intensified by the lakes' relative warm waters which made it easier for the air to lift and intensify the storms. By December, the cooling of the waters no longer provided this additional lift. A reminder of this "Lake Disaster Season" was the sinking of the Edmund Fitzgerald during a Lake Superior storm on November 10, 1975. This disaster represents the largest ship (half the size of the Empire State Building) ever to have sunk in the Great Lakes, a disaster immortalized by the ballad "The Wreck of the Edmund Fitzgerald", by Gordon Lightfoot. The ballad makes numerous references to November, such as *"When the gales of November gave early"; "T'was the witch of November come stealing"; and "With the gales of November remembered"*. Over time, improvements in navigation, ships, and weather forecasting, reduced the threat. Buffalo's diminished importance as a port means few of us think of the threat to ships, as was the case in the past. The November gales still blow, but the threat today is perceived from the land.

Box 4 The Golden Snowball Award

The Golden Snowball is given out to the one of upstate cities − Albany, Buffalo, Binghamton, Rochester, and Syracuse – that receives the most snow in a given year. The contest began in the 1970's with efforts by Peter Chaston at the Rochester Office of the NWS. The contest ended with the closure of the Rochester Office in the 1990's but was revived in 2002 by Steve McLaughlin and Tom Niziol from the Buffalo Office. The award has always been about fun, bragging rights, and a way to celebrate the end of a long winter. An internet search will bring you to a website dedicated to telling the story of the award and archiving its statistics.

Looking back as far as the winter of 1952-53 (earliest winter when all 5 cities collected snowfall data), Steve Madsen has assembled the statistics on which city would have, or did, win the award. Based on these statistics, Buffalo has won the award 7 times (winters of 1956-57, 1961-62, 1976-77, 1983-84, 1985-86, 1994-95, and 2001-2002). Rochester has won as many, but the favorite, by far, is Syracuse.

The Golden Snowglobe Award is a national snow contest, pitting cities with a population of 100,000 or more for the title of snowiest city.

At the time of writing Buffalo was winning both contests, on its way to being declared the snowiest city for 2018-19.

Weather vs. Climate

Weather can be defined as short-term variations (minutes to days) in atmospheric conditions (temperature, rain, wind, etc.) at a given location, whereas climate can be defined as the aggregate of weather (averages and extremes), for a given location, over an extended period. The weather forecast extends only a few days, while climate provides a longer view. The standard period for climate description is 30 years, referred to as a "Normal". A simple way to separate weather and climate is to consider the aphorism *"climate is what* *you expect, and weather is what you get"* (attributed to Robert Anson Heinlein, an American novelist and science fiction writer), or as one of Mark Twain's students remarked, *"Climate lasts all the time and weather only a few days"*. Politics aside, an illustration of the confusion over these two terms is illustrated in a tweet sent by President Trump during an intense cold snap: *"Perhaps we could use a little bit of that good old Global Warming that our Country, not other countries, was going to pay TRILLIONS OF DOLLARS to protect against. Bundle up!"* This obfuscation of terms is something we are all guilty of at times.

A WNY example distinguishing weather versus climate can be found in the watercolors of Charles E. Burchfield (1893-1967), whose bulk of work was confined to an area south of Lake Erie, including WNY. "Weather Event", a curated exhibition (this author and Tullis Johnson of the Burchfield Penney Art Center) provides a meteorologist's interpretation of many of his watercolors, interpreted individual watercolors, such as "Hot September Wind", "Sunshine During a Blizzard", "Summer Solstice", and "Clearing Skies", as weather, whereas the aggregate of more than 50 years of his writings, drawings, and paintings, characterized our region's climate. More about "Weather Event" and Charles E. Burchfield can be found at The Burchfield Penney Art Center, located on the campus of SUNY Buffalo State (Buffalo, NY).

Why Do We Have Weather?

We know from looking at the seasons that the Earth is heated at different rates based on latitude and time of year. It is this differential heating that drives our weather. The purpose of weather is to redistribute heat from one place to another via the atmosphere (ocean currents also contribute to this distribution). An examination of the latitudinal heat balance shows that along about 37°N and 37°S the Earth releases the same quantity of energy as it receives from the sun. These latitudes are called the 'lines of radiative balance'. Locations north of 37°N (which includes WNY) and south of 37°S receive less energy from the sun than is released (direct net loss). Areas between these latitudes receive more energy from the sun than is released (direct net gain). If this remained as described, areas between these two latitudes would be getting progressively hotter, and areas on either side toward the Poles would be getting progressively cooler. To prevent this progressive buildup and loss, the Earth must redistribute the imbalance of energy by way of wind, hurricanes, cyclones, phase changes of water, etc. This need to transfer energy is the reason we have weather, and by aggregation, climate. If a heat differential between latitudes did not exist, weather would not exist. So, let us give thanks to weather, especially the next time that southerly flow of warm air passes over WNY.

What is Normal?

When considering a weather forecast, the current weather conditions (eg. temperature and precipitation) are sometimes compared to what is normal. When thinking of "normal", the words "typical", "expected", "frequent", or "common" come to mind.

In weather, a normal, or more specifically a "climate normal", has a more precise meaning. It is a statistical average that covers a prescribed period of 30 years. Daily and monthly temperature departures from normal are routinely reported in the NWS monthly summaries of local climatological data (Figure 24).

Mandated by international agreement, nations have routinely calculated a 30-year climate normal since 1901. The choice of 30 years is a period of time deemed sufficiently long to provide a stable average (filtering out short-term variability) and assuring comparability between data collected at different stations. The normal is sufficiently short so that successive normal can be used to reveal longer trends (Figure 25). The current climate normal (at the time of writing) is 1981-2010. The time period of the climatic normal updated every 10 years, so a "climate normal' value can change too. Every 10 years, the normal is recalculated by including the most recent 10 years and removing the earliest 10 years. So, in 2021 the new normal will include the years 1991-2020. Previous normals were (going back in time): 1971-2000, 1961-1990, 1951-1980, 1941-1970, 1931-1960, 1921-1950, 1911-1940, and 1901-1930.

STATION: BUFFALO NY
MONTH: SEPTEMBER
YEAR: 2018
LATITUDE: 42 55 N
LONGITUDE: 78 44 W

TEMPERATURE IN F: :PCPN: SNOW: WIND :SUNSHINE: SKY :PK WND

1	2	3	4	5	6A	6B	7	8	9	10	11	12	13	14	15	16	17	18
									12Z	AVG	MX	2MIN						
DY	MAX	MIN	AVG	DEP	HDD	CDD	WTR	SNW	DPTH	SPD	SPD	DIR	MIN	PSBL	S-S	WX	SPD	DR
1	86	65	76	9	0	11	0.06	0.0	0	8.6	17	250	M	M	6	1	22	210
2	83	72	78	11	0	13	0.02	0.0	0	11.3	21	240	M	M	5		30	240
3	85	72	79	12	0	14	0.07	0.0	0	10.2	23	290	M	M	4		32	290
4	89	69	79	13	0	14	0.00	0.0	0	4.1	13	240	M	M	4	1	17	250
5	90	72	81	15	0	16	T	0.0	0	10.5	21	250	M	M	1	3	27	250
6	79	68	74	8	0	9	0.04	0.0	0	6.7	17	330	M	M	7	1	20	330
7	78	63	71	6	0	6	0.00	0.0	0	5.2	14	40	M	M	8		17	40
8	64	51	58	-7	7	0	0.00	0.0	0	10.6	20	60	M	M	9	8	26	60
9	60	50	55	-10	10	0	T	0.0	0	11.8	21	70	M	M	10		24	70
10	65	52	59	-5	6	0	1.40	0.0	0	9.8	21	70	M	M	10	1	26	70
SM	779	634			23	83	1.59		0.0	88.8			M		64			
AV	77.9	63.4								8.9	FASTST		M	M	6		MAX (MPH)	
								MISC	---->	#	23	290					# 32	290

Figure 24. Portion of Buffalo, NY Climatological Summary for September 2017. Shown are temperatures (columns 2, 3 and 4) and temperature departures from normal (column 5). Temperatures in the first 10 days of September show a striking swing from above to below normal.
Image Source: NWS.

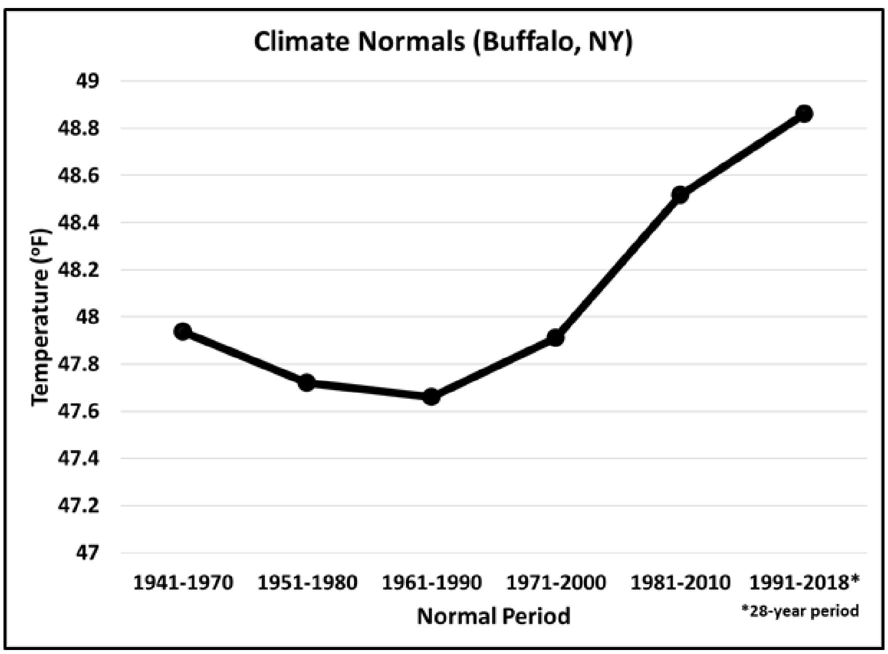


Figure 25. Buffalo, NY average temperature normals. A warming trend is apparent since the 1960's. Calculated from data obtained from the Buffalo NWS Airport Forecast Office. Image Source: Stephen Vermette.

The Year Without a Summer (1816)

The Buffalo Gazette newspaper ran a strange story under the heading *"Teramo, Italy – December 21, 1815": "There has fallen, during six hours, in our city, and its environs, a greater quantity of snow then has been known in memory of man. To this phenomenon there is added another, even more astonishing, which is that this snow is red and yellow. Religious processions have been made to appease the Heavens. People believe that something extraordinary has taken place in the air."*

While winter oddities were reported in many areas across the planet, it was the spring and summer months of 1816, most notably in Eastern North America, Europe and parts of Asia, that challenged our definition of these seasons – this period became known as "The Year Without a Summer". In Eastern North America fitful frosts occurred throughout the growing season, killing crops, requiring replanting, only to kill the crops anew. Snow, as well as river and lake ice, appeared during the summer months. The cold wasn't consistent as there were bouts of 'normal' weather, but it kept returning as unseasonable cold snaps resulting in hardships and food scarcity.

The clue to the cause was a persistent reddish haze in the sky and, as in the case for Teramo, Italy, a red and yellow snowfall. While unknown at the time, it was the massive eruption of Mount Tambora (Indonesia) that had released fine ash and sulfate into the stratosphere. Once in the stratosphere, it circled the planet, blocked sunlight, and lowered global temperatures. Eventually the sulfate dissipated, but for a period of a year the planet was in its grip.

The absence of summer did not escape notice in WNY. The "coldness" was first mentioned in the April 30, 1816 issue of the Buffalo Gazette: *"Our present spring thus far, is something backwards in the vicinity of this (village). This is perhaps, in a great (way) occasioned by the unusual (amount) of ice, which yet remains in the (eastern) part of Lake Erie."* Reports of abnormally dry and cold conditions were continually reported from across the northeast U.S. The cold snaps persisted. The Buffalo Gazette reported on June 11, 1816: *"We have had a very uncommon spring in this part of the country. The weather through April and May was unusually cold and dry. On the 16th of May there fell snow in the village. The frost on Sunday night last, and several nights previous in succession, very much injured the gardens and corn where it has come up. The forest trees and vegetation generally assume a sickly hue, and should a change of weather not take place shortly the hopes of the husbandman will be entirely cut off."* And again, on June 18, 1816: *"The late extraordinary weather it appears by accounts, was even more severe than here – and extended almost universally as far as we have heard. The fact of the fall of snow in June we believe is unparalleled in this climate."* The June 18th edition included reprints from newspapers for towns located to the east of WNY: Canandaigua, Onondaga, and Geneva, NY which offer a glimpse of the effects, and supposed causes considered at the time.

Canandaigua, June 11, 1816

> *"The cold weather for a week past, has thrown a deep gloom over the prospect of the season. Since the beginning of the present month, we have experienced the chilling winds of autumn, and the withering effects of foliage, has given to the fields a dreary aspect. Some of our farmers are planting their corn a second time; and our gardens, especially in fruit and vines, have suffered much from frost and drought. To make us comfortable, fires have been necessary in our houses, and great coats when we go out. The cause of this extraordinary weather, is left for our weatherwise to divine; the most common and rational opinion seems to be, that the Spot on the Sun, or rather the supposed planet which has for some time been observed between the Earth and the Sun, has obstructed much of the heat usually imparted to the Earth."* Repos

Onondaga, June 12, 1816

"The most aged people in this part of the country say, with astonishment, that they have never witnessed such extreme cold weather, in the month of June, as we have experienced during the week past. On Thursday morning, it snowed plentifully, for an hour or two, but melted chiefly as it touched the ground; and on Friday morning, 7th of June, ice was to be found one fourth of an inch thick! – We leave it to greater philosophers than we are, to develop the causes of such phenomena as have appeared in the course of the present season; for natural causes these undoubtedly are; although Providence might justly send them, as a chastisement, for the coldness of our ingratitude to the Supreme Author of all the we possess, and all the bountiful seasons we have enjoyed." Gazette

Geneva, June 12, 1816

"Winter in June! – During the past week the weather has been extremely cold for the season, and we have experienced several severe frosts, which have nearly destroyed the gardens and done much injury to the crops of grain. On Thursday morning a considerable quantity of SNOW fell. Such unseasonable weather has never been known in this country by the oldest inhabitants. The prevalent winds during this period of cold, have been from north to west, and have at times been violent."

Gazette

Jason Sample, a trustee with the Chautauqua County Historical Society, has researched the local impacts of that summer's weather. Sample, interviewed by WGRZ reporter Danny Spewak, and in my conversation with him, noted that *"In Chautauqua County, farmers could only produce and sell about a quarter of their normal food quantities"*. He went on to say that *"The weather that year forced many settlers to leave the area, including the Frank family, who owned the county's largest farm."* The weather during the Independence Day celebration in the town of Ellicott was described: *"Before morning the weather was uncomfortably cold and those who returned home the latter part of the night, especially the ladies in white dresses, complained much of the severity of the cold. The grass was frozen stiff, and the ground quite hard. All the more tender vegetation was badly injured. The corn was all destroyed…"* (Young's History of Chautauqua County, 1875). Sample did note that the *"famine wasn't as serious in WNY* (as compared to points east), *since the area was mostly unsettled and people were able to fish and hunt for their food."* Based on the journal writings of Abner Dingley of Gerry, NY, the weather took its toll on the residents. According to Sample, the diary entries talked about how difficult it was, and how trying it was on his psyche. And he was depressed throughout the entire summer.

The weather improved over the latter half of the summer and there were hopes that the harvest would be considerable, but late September saw a return to the killing frosts, cutting off any hope. Most Western New Yorker's, at that time, would have agreed with the assessment of the Italians, that "something extraordinary has taken place in the air."

WNY's Past Climates

The climate of WNY has not always been as it is today. Our climate has changed dramatically over geologic time. In addition, how you might have gotten around in WNY has changed over time, too. By way of example, WNY was part of a shallow subtropical sea located south of the equator about 380 million years ago. The aquatic fossils (sea lilies, clams, snails, and trilobites) locked in the rock of the Penn Dixie Quarry Fossil Park & Nature Reserve (Hamburg, NY) attest to this, as do the evaporated sea salts buried in Livingston County, mined by the American Rock Salt Company LLC. The forces that changed our climate are many, including continental drift, mountain building, volcanic emissions, solar output (sun spots), and changing orbital characteristics, to name but a few. The latter – changing orbital characteristics – explains the most recent ice age (Pliocene-Quaternary glaciation), with its alternating glacial and interglacial periods, experienced by WNY over the past few million years.

During the latest glacial period (Wisconsin: beginning about 110,000 years ago and ending about 15,000 years ago), WNY was covered by the continental – Laurentide Ice Sheet – extending south from northeastern Canada. Northern WNY was covered by up to 3,000 feet of ice. To visualize the thickness of this ice, consider the height of Buffalo's City Hall, then stack another six city halls on top. The thickness of the ice decreased southward, with the terminus of the ice sheet located in northern Pennsylvania. In WNY, only a small portion of Cattaraugus County, within Allegany State Park, was untouched by glaciers. It was during the Wisconsin glaciation that the Great Lakes and Finger Lakes (Central NY) were carved out or damned, as was Zoar Valley (created by melt waters) in Cattaraugus County. In fact, the gravels in our soils and the many boulders strewn across the landscape (referred to as glacial erratic's) did not form here but were carried south to us by the glaciers.

While buried under the ice sheet, WNY would have experienced a climate somewhat like that over today's Greenland ice sheet (the ice sheet is a remnant from the last glacial period), with average monthly temperatures consistently below freezing. As the air warmed and the glacier retreated, the ice gave way to a treeless tundra environment about 13,000 years ago. The climate then was like that which is found today in the Canadian Arctic (north of the Arctic Circle at 66.5°N) to our north, where average temperatures of the warmest month would not have exceeded 50°F. The ice sheet edge would have been affected by cool katabatic winds (down sloping winds) blowing off the glacier. Between 12,000 to 10,000 years ago, the treeless tundra gave way to a boreal forest (mostly coniferous trees), with a climate like what is found today in northern Ontario (north of Lake Superior, or north of 50°N). The summers would have been short, and winters long and severe. About 9,000 years ago the boreal forest gave way to the mixed forest of hemlock, oak, elm, birch, ash, beech, and maple trees that we experience today in WNY. Essentially, the evolving climate of WNY from the end of the last glaciation to the present day can be mimicked today by traveling the about 2,000 miles from WNY to Greenland. But, there is one additional consideration.

Additional to local effects on weather and climate, researchers question the extent to which the Laurentide ice sheet (formed in the northeast corner of the North American continent) influenced global atmospheric circulation and weather systems. The dome of cold air created over the glacier would have caused air to descend, establishing a high-pressure cell and a clockwise flow around the high – the creation of an atmospheric "glacial anticyclone". The impact is mostly conjecture, but WNY's prevailing winds were likely from the northeast (as compared to being from the southwest today) resulting in cooler temperatures. Continental storm-tracks possibly shifted to the north, and cyclogenesis (the formation of low-pressure cells and associated storms) likely decreased over WNY. With the melting of much of the ice sheet by about 7,000 years ago, the glacial anticyclone would have disappeared, and WNY's weather and climate stabilized to what we generally experience today. Having said this, a new climate change force – anthropogenic greenhouse gases and the enhanced greenhouse effect – are currently at work changing our climate.

WNY's 5 Climate Zones

Western New York (WNY) is defined collectively as the eight westernmost counties of New York State (NYS): Niagara, Erie, Chautauqua, Cattaraugus, Allegany, Wyoming, Genesee, and Orleans.

The climate of WNY is characterized as a mid-latitude warm-summer, humid continental climate − Dfb, based on the Köppen climate classification criteria. The Köppen climate classification (as developed by Wladimir Köppen) relied on the vegetation boundaries to which Köppen ascribed climatic parameters. For example, the tree line, whether north in the Arctic, or at high elevations in mountainous terrain, occurs at locations where the mean temperature of the warmest month does not exceed 50°F (10°C).

Dfb is a type of climate typically found in the interior of a continent, north of latitude 40°N. Another term is "hemiboreal" which refers to an ecosystem and climate occurring halfway between the temperate and subarctic zones. The Dfb criteria further defines the temperature of each of the four warmest months as > 10°C (50°F), but not greater than 22°C (72°F), winter temperatures of the coldest month as < -3°C (26.6°F), and precipitation generally evenly distributed throughout the year. This definition of the WNY climate is based on aggregate weather data collected at the National Weather Service weather station located on the grounds of the Buffalo-Niagara International Airport (KBUF). How representative is this station?

WNY's Dfb designation does not take into consideration the heterogeneous nature of the region. WNY is bounded by two Great Lakes (Erie and Ontario) which moderate near-shore temperatures. Contrasting lake/land temperatures, prevailing southwest winds, and lake-land breezes mute the frequency and intensity of extreme heat and generally keep temperatures cooler in the spring/early summer and warmer in late summer/autumn than inland locations. Lake-induced atmospheric stability in the spring brings more sunshine and fewer thunderstorms to near-shore and downwind locations, while lake-induced instability brings more cloud cover and precipitation in the late summer/autumn. Over half of WNY's annual snowfall comes from the "lake effect" process − Lake Effect Snow (LES) – with locations in the region's southern areas receiving much more lake effect snow than locations to the north.

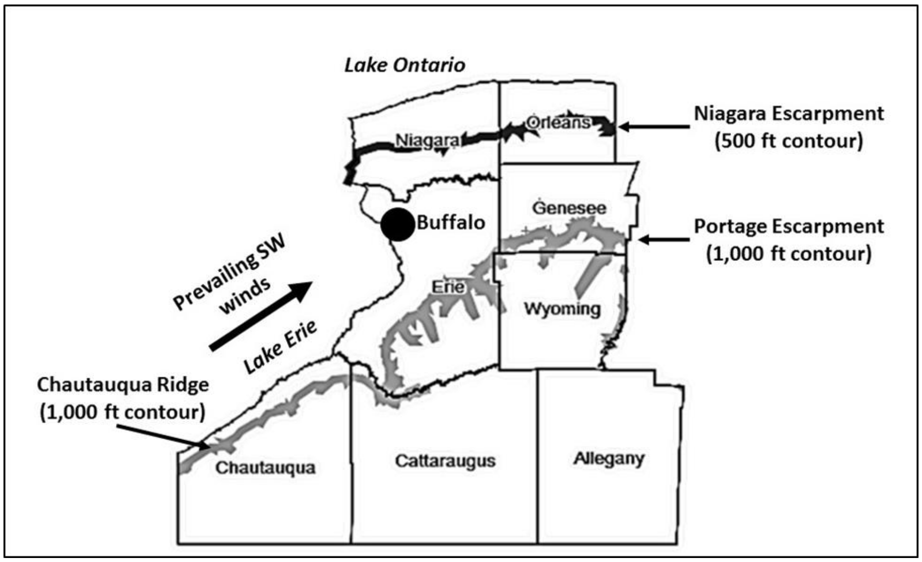


Figure 26. Climate zone boundaries as defined by Lakes Erie and Ontario shorelines, Niagara Escarpment and Chautauqua Ride/Portage Escarpment, and the City of Buffalo Metropolitan area. Image Source: Stephen Vermette

The Dfb definition of WNY's climate also does not consider the rolling higher elevations in the southern counties of WNY where the terrain is an extension of the Allegany Plateau. The Allegany Plateau is dissected by numerous valley and hills, with maximum elevations of 2,400 to 2,500 feet above sea level (asl). These higher elevations bring cooler temperatures and additional LES to the region, as compared to other WNY locations. In addition, down-sloping southerly winds moving across the Allegany Plateau bring enhanced warming to the lower elevations north of it, attributed to adiabatic warming (decreasing altitude increases pressure, and heats air).

The Dfb definition of WNY's climate also does not consider the impact of large urban areas on climate (i.e. the City of Buffalo). The 'Urban Heat Island' describes an urban area that is consistently warmer than surrounding rural areas, the urban warming enhanced by the concentration of waste heat, building materials (eg. asphalt, brick, and cement) that effectively absorb and later release heat, and the lack of evaporation (a cooling process) attributed to the redirecting of rainwater by storm sewers.

The climate of a place is influenced by several factors, defined as "climate controls" (Figure 26). Based on the heterogeneous nature of WNY, the four climate controls considered here are: 1) elevation, where places at higher elevations would be expected to be cooler than places located at lower elevations, and winds passing over elevated terrain will cool as they rise, and warm as they descend; 2) prevailing southwest winds; 3) proximity to large bodies of water, as lakes moderate climates and promote clouds, rainfall, and

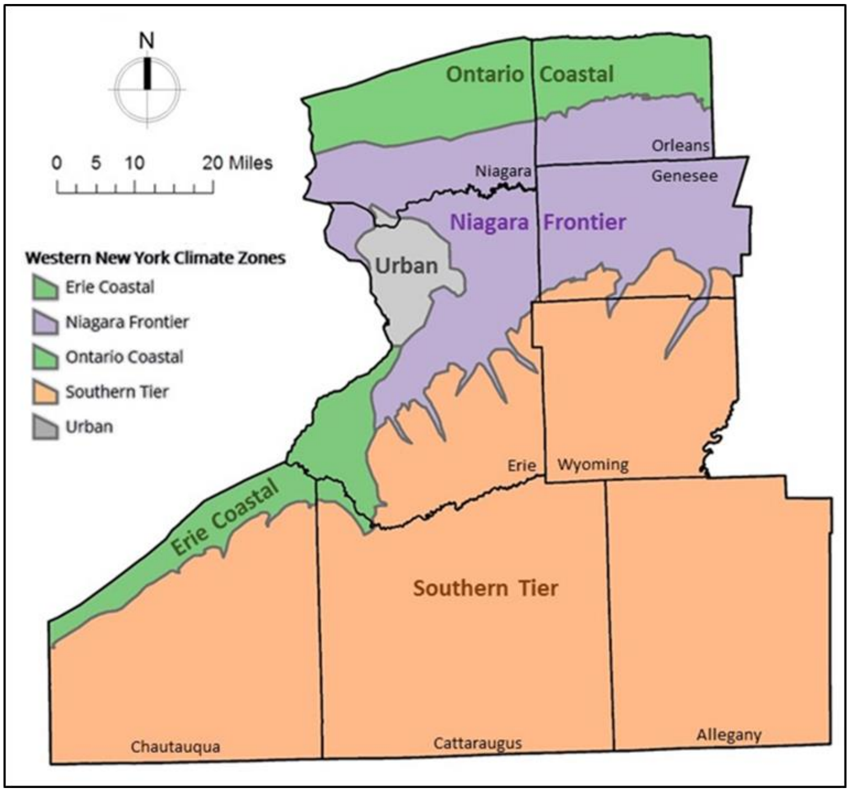


Figure 27. WNY's five climate zones. The Urban Zone boundary was obtained from Landsat 7 imagery. County boundaries are shown for reference. Image Source: Mary Perrelli and Stephen Vermette.

LES; and 4) population density (urban area), where concentrated human activity creates an urban heat island effect. The contour boundaries used (Niagara Escarpment and Chautauqua Ridge/Portage Escarpment, 500 and 1,000 feet asl, respectively), as well as the shorelines of Lakes Erie and Ontario, and the City of Buffalo.

The final map delineates WNY's five climate zones: Ontario Coastal, Erie Coastal, Niagara Frontier, Urban, and Southern Tier (Figure 27). The climate zone boundaries encompass forecast wording couched as "warmer or cooler near the lake" (dependent on season) or use of the well-established WNY geographic monikers "south-towns", "northtowns", and "ski-country".

Figure 28. A spring walk along a trail in Niagara County reveals how slope orientation impacts air/surface temperatures. Image Source: Stephen Vermette.

Microclimates

Walking around your house you may have noticed that temperatures appear to vary across the yard. The side of the house with a southern exposure is usually sunnier and warmer than the side with a northern exposure; standing on the cement patio feels warmer than standing on the grass; or an area protected from the wind may feel warmer than one that is more exposed. These are all examples of microclimates, or "small-scale climates". As a gardener, I might plant a cold-sensitive plant (one that the USDA Plant Hardiness map suggests might not survive

WNY's climate) on the south side of the house, near the foundation – an area warmed by its sunny orientation, protected from the wind, and heated by the warmed brick of the house. Another example of microclimates might be illustrated by taking a walk through an east-to-west running gorge (eg. Zoar Valley) and looking up along the valley sides. Given that the sun is in the southern half of the sky, trees on the north facing slope are often in shade and are likely dominated by a cool-tolerant and shade-loving tree species such as Eastern Hemlock, whereas the south facing slope may be dominated by broad-leafed deciduous trees that thrive on the more available sunshine. In short, microclimates result from a combination of elements that create a complex variability of climates within a broader geographic area: orientation to the sun, shading, surface wetness (evapotranspiration cools the air), humidity, topography (cold air drainage), wind, and the influence of surface materials (darker surfaces better absorb the sun's energy and emit more heat into the air than lighter ones) (Figures 28, 29 and 30). Even within WNY's five climate zones there is no such thing as meteorological symmetry.

Figure 29. A line of trees in front of Water Front Elementary School in Buffalo, NY. The side of the tree facing the lake (right side) has not yet leafed and bloomed, while the side facing away from the lake (left side) has leafed and bloomed. One possible explanation is that direct exposure to the cold spring air blowing off the lake has delayed sprouting on the tree's right side. Image Source: Stephen Vermette.

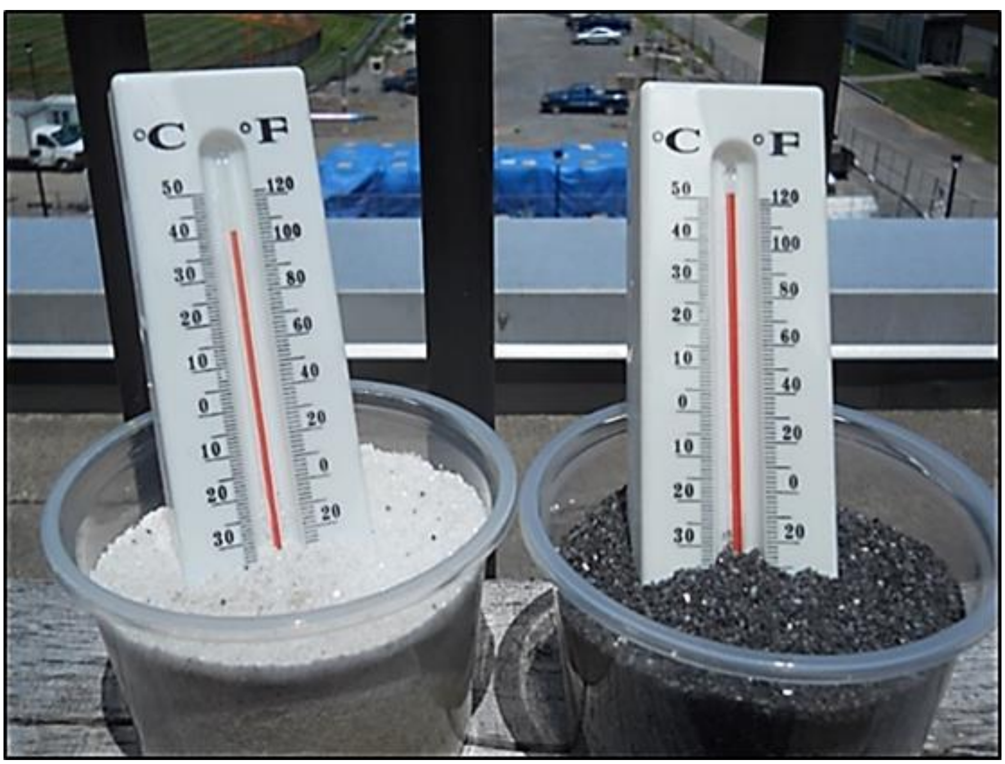


Figure 30. Thermometers placed in two pots – one in white sand and another in black sand. Under similar exposure to the sun, the white sand (reflects more energy) reached a temperature of about 105°F, whereas the black sand (absorbs more energy) reached a temperature of 125°F, a 20-degree difference. Image Source: Stephen Vermette.

BOX 5 Lake Mirages

You may have looked out across either Lakes Erie or Ontario and noticed that objects (buildings, trees, and even boats) sometimes appear vertically stretched along the horizon. Or objects normally below the horizon appear to be "floating" on the water or appear to be "looming" in the air.

As a child you learned that what appeared as pool of water on an otherwise dry road was simply a mirage – a reflection of the sky off the road – that disappeared upon approach. This is referred to as an "inferior mirage" because the mirage is seen below its actual position.

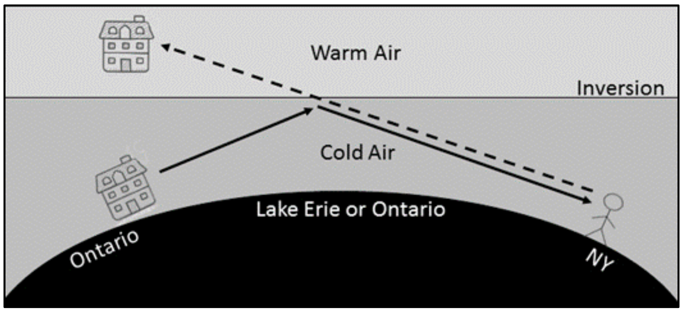


Image Source: Stephen Vermette

The "lake mirage" is also a reflection, but in this case the reflection occurs higher in the atmosphere. Because the object is seen above its actual position, it is referred to as a "superior mirage" or "Fata Morgana". It occurs in the spring and early summer when the cool lake water's chill the air immediately above it. This sets up a temperature inversion, where warm regional air is layered above the lake-cooled air. Light rays traveling from an object are refracted downward in the colder air below the inversion boundary but our "lyin' eyes" are tricked because they assume the rays traveled a straight line of sight from the object to our eyes. This mirage sets up several weird visions on the horizon, where objects appear vertically stretched or appear above their original position or even flipped upside-down. The detail of any image is best seen with binoculars.

There are some historical accounts of note. On April 16, 1871 there is an account of seeing the Canadian shoreline clearly from Mount Hope Cemetery in Rochester, NY. And on August 16, 1894 "a remarkable image", as seen in Buffalo, was later reported in Scientific America and in newspapers across the country (see below). Oddly, the Weather Bureau ledgers only report *"Generally fair, cool and pleasant, with northerly winds"*. There is no mention of the mirage!

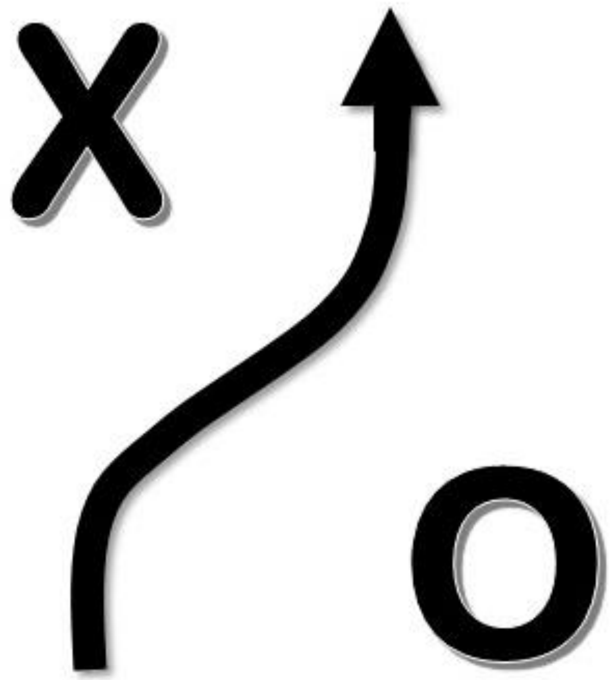
"The people of Buffalo, N.Y., were treated to a remarkable mirage, between ten and eleven o'clock, on the morning of August 16, [1894]. It was the city of Toronto with its harbor and small island to the south of the city. Toronto is fifty–six miles from Buffalo, but the church spires could be counted with the greatest ease. The mirage took in the whole breadth of Lake Ontario, Charlotte, the suburbs of Rochester, being recognized as a projection east of Toronto. A side–wheel steamer could be seen traveling in a line from Charlotte to Toronto Bay. Two dark objects were at last found to be the steamers of the New York Central plying between Lewiston and Toronto. A sailboat was also visible and disappeared suddenly. Slowly the mirage began to fade away, to the disappointment of thousands who crowded the roofs of houses and office buildings… A close examination of the map showed the mirage did not cause the slightest distortion, the gradual rise of the city from the water being rendered perfectly. It is estimated that at least 20,000 spectators saw the novel spectacle. This mirage is what is known as that of the third order; that is, the object looms up far above the level and not inverted, as with mirages of the first and second orders, but appearing like a perfect landscape far away in the sky."

Scientific America: August 25, 1894

Box 6 Weather-related Days to Place on Your Calendar

Date	National Day
January 8	Winter Skin Relief Day
February 2	Groundhog Day
February 5	Weather Person Day (honoring Wx professionals)
February 10	National Umbrella Day
2nd Sunday in March	Daylight Savings Time Begins
March 20-21 (varies)	Spring Equinox (first day of spring)
March 23	World Meteorological Day
April 3	Find a Rainbow Day
April (date varies)	Ice Boom Out
April 12	Big Wind Day (commemorates windiest day ever)
Easter Monday	Dyngus Day, Celebrating Polish heritage and Spring
April 22	Earth Day
May 1	May Day (a traditional springtime festival)
May 4	Weather Observer Day (for those who like watching)
Last Friday in May	Heat Awareness Day
June 12	Hooray for Climate Scientist Day
June 20-22 (varies)	Summer Solstice (first day of summer)
June 23	Hydration Day
June 27	Sunglasses Day
August 1	Lammas Day (marks the annual wheat harvest)
August 23	Ride the Wind Day (celebrating hang gliding)
September 22-23 (varies)	Autumn Equinox (first day of autumn)
1st Sunday in November	Daylight Savings Time Ends
December (date Varies)	Ice Boom In
1st Saturday in December	Skywarn Recognition Day
December 21-22 (varies)	Winter Solstice (first day of winter)

Chapter 3
Basic Concepts



Five Guiding Principles of Meteorology

The study of "meteorology" requires an understanding of several principles to explain any number of meteorological processes. While some principles are specific to a particular process, many are repeated over and over again. A quote from Ralph Waldo Emerson (an American essayist) captures this reiteration: *"Nature is an endless combination and repetition of a very few laws. She hums the old-well-known air through innumerable variations."* Understanding these foundational principles early on will help you better understand meteorological concepts and even deduce the forces at play. Described here are five deceptively simple guiding principles that, as in meteorology, will repeat themselves in this book. The five guiding principles are:

1. Hot air rises
2. Rising air expands and cools
3. Cold air holds less water than warm air
4. Rising air lowers surface air pressure
5. Air moves from high to low pressure

"Hot air rises" is easily demonstrated by holding a hand above a burning candle or watching a hot air balloon. The balloon rises only when the air contained within it is warmer than the surrounding air. By way of explanation, the air in the balloon is heated by a flame (as is the candle). Once heated, the confined air expands. As a result of its expansion, the air becomes less dense and the hot air balloon floats (becomes buoyant), much like a piece of less dense wood easily floats on denser water.

Understanding the principle that "rising air expands and cools" requires an understanding of temperature and adiabatic cooling. Temperature is a measure of molecular activity; the agitation and vibration of air molecules. The greater the agitation and vibration, the warmer the air. As unconfined air rises, its volume expands. This expansion is due to an altitudinal decrease in the air pressure that normally pushes against (squeezes) the air. The expanding air cools "adiabatically" as air molecules within an expanding parcel of air spread apart and undergo less agitation and vibration. In other words, the air does not cool through the loss of heat via conduction, convection, or radiation loss, but by the simple act of expansion.

An example of expansion is provided by the helium-filled balloons that are released twice daily at the Buffalo-Niagara International Airport weather station. The balloons carry a package (radiosonde) to measure elements of weather at increasing height in the atmosphere. These balloons are released at an initial diameter of about 6 feet. As the balloon rises and outside pressure decreases with height, the balloon expands to a diameter of about 30 feet before eventually bursting, and the radiosonde returns to the surface by a parachute. An easy demonstration of the adiabatic cooling-due-to-expansion process is to consider an aerosol can. By releasing some of the compressed contents, the remaining content is allowed to expand and the can feels cooler to the touch.

The principle that "cold air holds less moisture than warm air" can be demonstrated by taking a glass containing a cold drink into a warm humid room. Drops of water form on the outside of the glass because the room's air is cooled when contacting the cold glass, such that the air immediately surrounding the glass cannot hold the same amount of moisture as it could when at room temperature. The term "hold" is actually a simplification, as air does not hold moisture like a sponge holds water. Rather, in cooled air, condensation (a change of state from vapor to liquid) takes place at a greater rate than evaporation (a change of state from liquid to vapor). The term "hold", as it refers to atmosphere moisture, will be used for the purpose of simplicity (the reader can apply a silent edit when they come across this word later in the text).

The fourth principle, “rising air lowers surface pressure”, is more difficult to visualize. Given that atmospheric pressure is sometimes defined as the weight of the atmosphere, a scale can be used as an analogy. By placing several heavy objects on a scale, the subsequent lifting away of the objects (as with rising air) reduces the weight or pressure on the scale.

The fifth, and final, principle is that “air moves from high to low pressure”. A balloon can once again be used to illustrate this principle. The inflation of a balloon increases the pressure within the balloon as compared to the surrounding air (I’m purposely ignoring the added pressure attributed the elasticity of the balloon). Once released, the balloon will be propelled across the room as air is expelled. Another easy illustration is the consideration of a flat tire. A car’s tire pressure is usually somewhere about 35 pounds per square inch (psi), while atmospheric pressure is about 14 psi. Thus, a tire puncture will result in the loss of air from the tire.

An experiment that combines a number of these principles is the “egg in the bottle”, where a hard-boiled egg placed on the opening of a bottle will “magically” enter the bottle. The set up for this experiment is to first light a flame in the bottle. The heated air will rise (principle #1) and lower the air pressure in the bottle (principle #4). Placing a shelled hard-boiled egg on the opening will result in the egg being pushed into the bottle (principle #5).

One last point. Only four of the five guiding principles are reversible. Which of the five is not? Consider: if hot air rises then cool air descends; if rising air expands and cools then descending air compresses and warms; if cold air holds less moisture than warm air then warm air holds more moisture than cold air; if rising air lowers surface air pressure then descending air increases surface air pressure; if air travels from high to low pressure then…? In nature, air will not travel from low to high pressure.

Please keep these principles in mind as you read through this book. If certain ideas are confusing as presented here, they will become clearer as context is added in the pages ahead.

The Greenhouse Effect

While the sun provides the necessary energy, the heating of the air has more to do with the surface of the Earth than with the sun itself! The incoming energy from the sun, or insolation (incoming solar radiation), represents a wide electromagnetic spectrum of energy, with wavelengths ranging from the very small (gamma rays at 10^{-5} nanometers) to the very large (radio waves at 1,000 meters). The vast majority of insolation falls within the visible light range, peaking at 0.5 microns. The sun’s energy is referred to as solar or shortwave radiation. Insolation passes through the atmosphere with the limited interruptions of reflection from cloud tops, blocking of ultraviolet radiation by stratospheric ozone, and Rayleigh scattering. On average, 50% of the sun’s insolation is absorbed by the earth’s surface. It is this touchdown of energy that works to heat the surface.

There are two laws of radiation that need to be addressed here: 1) all objects with a temperature above absolute zero emit radiation; and 2) the hotter the object is, the shorter the wavelength of its maximum radiation (Wien’s Law).

Applying these two laws, the heated surface of the Earth emits radiation and the emitted radiation is at a longer wavelength than that from the sun. This radiation is referred to as terrestrial or longwave radiation. Unlike solar radiation (Insolation), the emitted longwave terrestrial radiation more readily reacts with gases in the atmosphere. While some terrestrial radiation escapes directly to space, its path outward is more torturous than that faced by incoming insolation (Figure 31).

These reactive atmospheric gases (carbon dioxide, methane, and water vapor, among others) are referred to as greenhouse gases, and are part of what is being described here as the greenhouse effect. The intercepted terrestrial radiation heats these gases, and they in turn emit longwave radiation in all directions, including downward toward the surface. It is the greenhouse effect that keeps our atmosphere at a livable temperature. The average global surface temperature is about 59°F. Without the greenhouse gases, the average surface temperature would be about 0°F. This explains why temperatures in the troposphere decrease with height from the Earth's surface, and why you might experience cooler temperatures when hiking in the hills of the Allegany Plateau, or might hear a weather forecast stating that snow will be confined to hill tops in the Southern Tier.

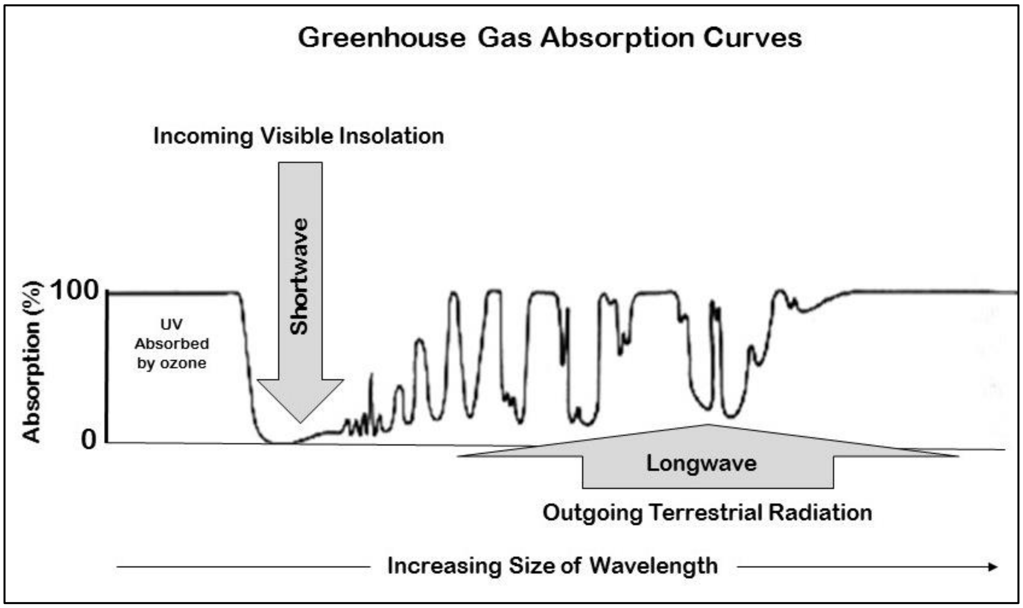


Figure 31. The electromagnetic spectrum (wavelengths) is represented on the x-axis, and the absorption efficiency of greenhouse gases in Earth's atmosphere is represented on the y-axis. The peak emission range of incoming solar radiation is visible radiation, whereas the peak emission range of outgoing terrestrial radiation is made up of longer wavelengths more easily absorbed by the greenhouse gases. Image Source: Stephen Vermette.

A simplified analogy of the greenhouse effect is to consider lying in bed without a blanket over you. Like any object, your body emits radiation and you will eventually start to feel cool. Feeling cool, you place a blanket over yourself. The blanket traps your outgoing radiation, much like the greenhouse gases around the Earth "trap" the heat. Another example occurs with the threat of an early frost during a WNY autumn. Early frosts usually occur on clear nights when terrestrial radiation is easily lost into the atmosphere, whereas a cloudy night (remember that water vapor is a greenhouse gas) restricts this energy loss. On a clear night, you might place a cover over your plants to limit the loss of terrestrial radiation.

While the greenhouse effect explains the heating of the troposphere, the addition of greenhouse gases by human activity has resulted in what has been termed as the "enhanced greenhouse effect", where increasing tropospheric temperatures are driven by the increasing emissions of greenhouse gases attributed primarily to human activity. Current CO_2 concentrations in the atmosphere are just over 400 ppm (from about 280 ppm in the late 1800's), higher than anytime in human history!

I'm Walkin' in the Hot Sand

While lying on one of the many beaches of WNY listening to "Hot Sand" sung by Marika Veres, you may have pondered why dry sand feels so hot on a sunny summer's day. We have all danced the "sand dance", prompted by the soles of our feet first touching and then recoiling from the hot sand, while at the same time cursing gravity.

By way of explanation, the energy from the sun produces two types of heat, "sensible" and "latent" (Figure 32). It is the sensible heat that we feel as a rise in temperature. Latent heat is another matter. Latent heat is used to change the state of matter, such as to evaporate water. The term latent refers to "hidden heat" that does not affect temperature. A damp or wet surface that partitions heat into the two forms does not heat up to the same degree as a dry surface where the energy is converted to sensible heat only. It is for this reason that wet sand is cooler than dry sand. And why the air over a cement or stone plaza with water treatments (water fountains and pools) feels cooler than one without. And why the evaporation of our perspiration cools our body; evaporation being a cooling process.

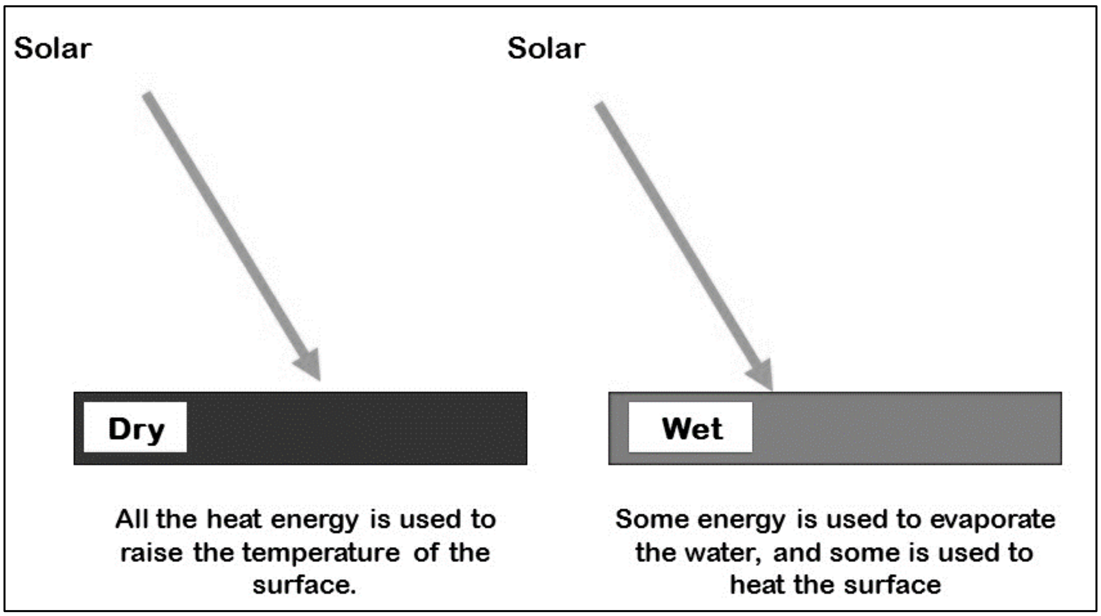


Figure 32. Sensible versus latent heat. Image Source: Stephen Vermette.

Something About April

Operational meteorologists in WNY have observed that modeled daily maximum temperatures for the month of April often under-predict reported maximum temperatures on dry sunny days, more so than in other months. In April, trees have not yet leafed and crops have not been planted. The heating could be attributed to a greater penetration of the sun's energy (insolation) through a leafless canopy striking the exposed leaf-littered forest floor and agricultural soils. The dark color and dryness of the surface would allow for greater absorption and heating (sensible heat) than would likely occur later in the summer after the 'green-up' (vegetation) has occurred. In addition, April budding would draw up moisture from plant roots, further drying the soil.

To test whether there is "something about April", a study was conducted by this author. Thirty years of temperature, sunshine, and precipitation data (1966 to 1996), taken from Local Climatological Data Monthly Summaries, were used to differentiate sunny "dry ground days" (DGD) from sunny "wet ground days" (WGD), and to determine maximum daily temperatures. A DGD was defined as a day when no measurable precipitation was recorded on that day and the two previous days, and the day experienced greater than 50% of maximum possible direct insolation (sunshine). A WGD was defined as a day when no measurable precipitation was recorded on that day, but measurable precipitation was recorded on the previous two days, and the day experienced greater than 50% sunshine.

Focusing here on the months of April and July, differences in maximum temperatures between DGD's and WGD's (DGD-WGD) were found in both April (8.3°F) and July (4.1°F), as might be expected (more energy portioned to sensible vs. latent heat). But the difference in temperature between dry and wet ground days was far greater for April (4.2°F higher than that of July). While the study also considered other months and found the relationship to be similar between spring and summer, the month of April stood out from all other months. There is indeed "something about April".

Thermometers 101

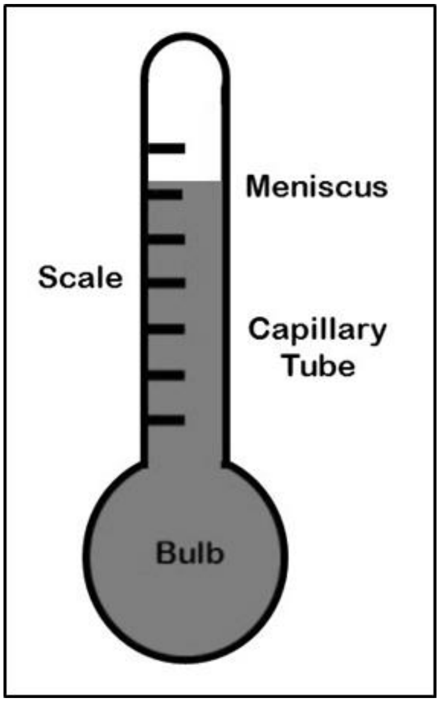


Figure 33. Elements of a basic thermometer. Image Source: Stephen Vermette.

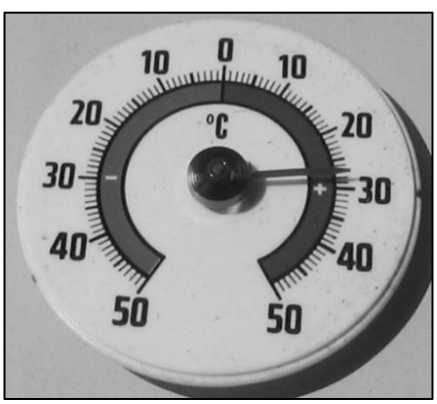


Figure 34. Dial-type thermometer with a bi-metal coil (temperature shown in Celsius). Image Source: Wikimedia Commons.

As previously noted, temperature is a measure of molecular activity (kinetic energy) that is felt as sensible heat. It is this kinetic energy – the movement of molecules when heated – which explains the workings of a liquid-in-glass thermometer. Let us first dissect a typical thermometer into its basic parts (Figure 33). The bulb holds the liquid (usually alcohol (ethanol) because it remains unfrozen at 32°F); the capillary tube provides a path for the expanding liquid; the scale provides a means to read the thermometer; and the meniscus is the point on the thermometer at which the temperature is read.

When heated, the molecules in the liquid enclosed in the thermometer's bulb expand, and subsequently the liquid rides up the capillary tube. The hotter the surrounding air, the greater the molecular activity, the more the liquid expands, and the farther it rises up the capillary tube. Of course, when the air cools, molecular activity decreases in the bulb, the liquid contracts, and retreats toward the bulb. As an aside, satellites monitor the kinetic energy (vibration) of gases in the atmosphere to determine air temperatures at various heights. In addition to the ground-based thermometer measurements, satellites are now used to monitor global warming.

Other types of thermometers exist. The workings of a dial-type thermometer are usually a bi-metal strip of two different metals fused together which expand differently when heated, causing the metal to bend and the attached dial to move (Figure 34). An electronic thermometer responds to changing resistance in the wires (Figure 35); and a decorative Galileo-type thermometer responds to the changing density of floating liquid-filled spheres (Figure 36).

To emphasize a hot day, a person might say: "It was 95 degrees in the shade". Actually, the most accurate air temperatures are taken in the shade so that the thermometer measures the temperature of the air without the added effect of direct sunshine (insolation). Thermometers are usually sheltered or placed away from the sun (the north side of a house works well) (Figure 37). A thermometer exposed to the direct rays of the sun gives erroneous readings since it is not recording the temperature of the air but rather the temperature of the sun-heated liquid in the bulb!

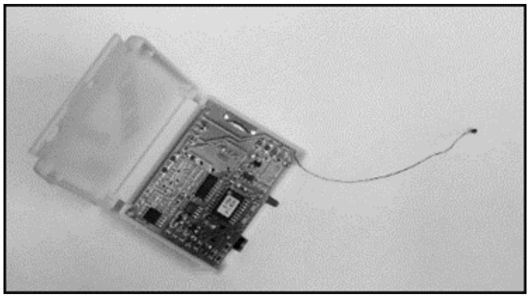


Figure 35. An electronic thermometer. Image Source: Stephen Vermette.

Figure 36. Spheres of varying density floating in a Galileo Thermometer. Image Source: Wikimedia Commons/Fenner.

The factor that makes the height of the liquid column, or the bend of the bi-metal strip, usable and comparable is the scale on the thermometer. The two scales most commonly used are "Fahrenheit" (°F) and "Celsius" (°C), each named after the individual who came up with them. Each scale has different reference points and scale increments.

The Fahrenheit scale was set with 0°F as the lowest temperature obtained with an ice, water, and salt mixture, and was probably set at 100°F for the highest point (some debate about the setting) based on the temperature of the human body (this upper point has been adjusted a few times, and currently reads 98.6°F). Today, the fixed points used on the Fahrenheit scale are 32°F (the freezing point of water) and 212°F (the boiling point of water), with 180 equal parts (degrees) separating the two fixed points.

The Celsius scale uses 0°C as the freezing point of water and 100°C as the boiling point of water, with 100 equal parts (degrees) separating the two fixed points. One last scale in common use (mostly in science) is the Kelvin scale which, unlike the other two scales, has as its lowest fixed point "absolute zero" (0 K) – the temperature at which all molecular activity ceases (no temperature). Subsequently, there are no negative values on the Kelvin scale. As the size of each "unit" of the °C and K are the same, the freezing point of ice is 273.15 K, and the boiling point of water is 373.15 K. Note that Kevin is not expressed as a degree, rather just as a Kelvin.

The conversion between the Fahrenheit and Celsius scales is dependent on using the number 32 (which relates to the difference in degrees between the two scales as related to the freezing point of water), and 1.8 (which is the difference in size of the "degree" between the two scales). Celsius is converted to Kelvin by simply adding 273.15, and Kelvin is converted to Celsius by subtracting 273.15.

Celsius to Fahrenheit: °F = (1.8 x °C) + 32
Fahrenheit to Celsius: °C = (°F - 32) / 1.8
Celsius to Kelvin: K = °C + 273.15
Kelvin to Celsius: °C = K - 273.15

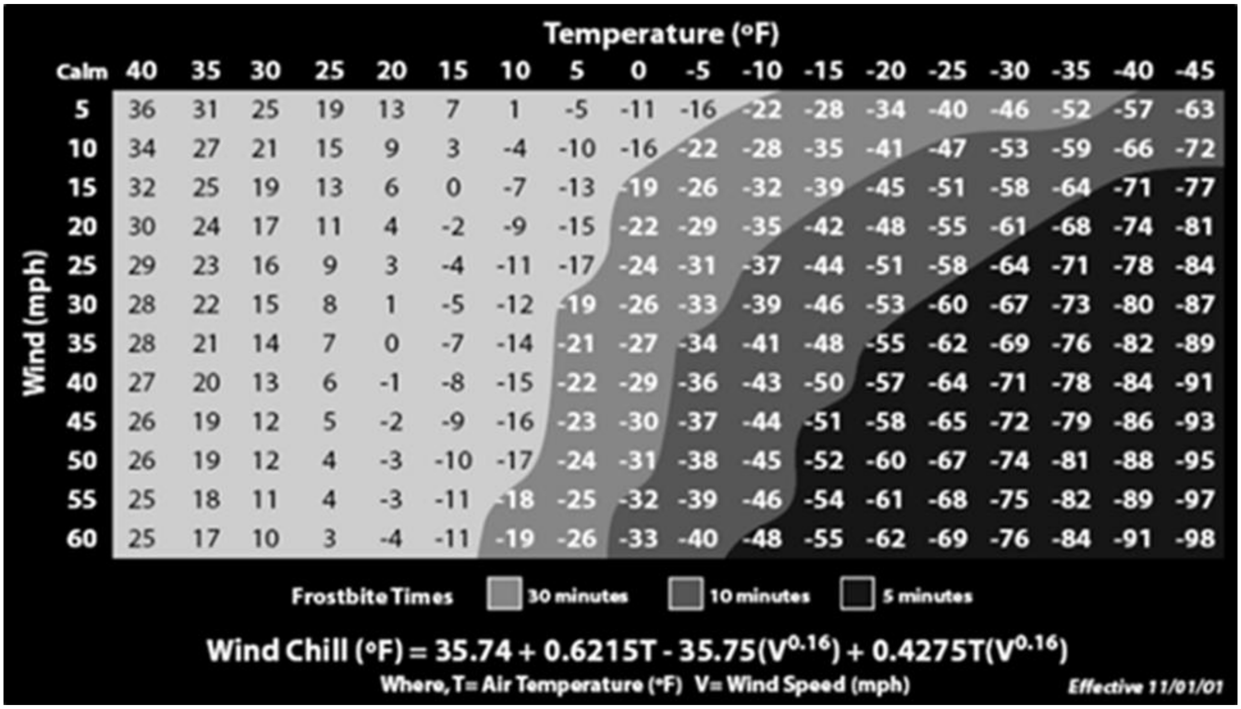
Figure 37. Thermometer shelter for electronic sensor (left) and analog thermometer (right). Usually louvered and colored white. Some shelters are aspirated (air blown across the thermometer). Image Source: Stephen Vermette.

A quick "mental method" to make sense of the Celsius temperatures reported by our Canadian neighbors (converting Celsius to Fahrenheit) is to double the Celsius reading, add 32, and take off a few degrees equal to double that of the first digit of the Celsius value. For example: 10°C is equivalent to (10 + 10 + 32 = 52, minus two degrees = 50°F; and 20°C is equivalent to (20 + 20 + 32 = 72, minus four degrees = 68°F; or 30°C is equivalent to (30+30+32 = 92, minus six degrees = 86°F. Or, simply accept that 0°C feels cold, 10°C feels cool, 20°C feels warm, and 30°C feels hot.

One additional thought may be offered regarding thermometers, specifically temperature scales. While Fahrenheit and Celsius are the two most common temperature scales, there is nothing "special" about them, other than their universal acceptance (Celsius more so than Fahrenheit). In the past, I've challenged my students to invent their own temperature scale. I can recall one student who used the temperature of the water in a toilet bowl as the lower fixed point and the temperature of a car's engine block (after idling for 10 minutes) as the upper fixed point. Dividing the difference into equal parts, they came up with their own unique scale. Still others used color or insect names as a temperature scale. It is perfectly fine to come up with something of your own. The challenge is to get others to accept it!

Wind Chill

When listening to a weather forecast you will hear the forecaster report the air temperature but, under particularly cold conditions, a "wind chill" might be reported. The wind chill temperature is not real – it cannot be measured with a thermometer – but it is what your body perceives or feels and, because of this, should not be ignored Figure 38).



Temperature (°F)

Wind (mph)	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Figure 38. Modern wind chill chart prepared by the National Weather Service.
Image Source: Wikimedia Commons/NOAA.

The heat generated by a body forms a layer or envelope of warm air around the body which keeps a person warm. The cooling power of wind occurs because wind blows that heat away. In response, the body must work harder to replace the lost heat. The faster the wind blows, the harder the body needs to work, and thus the harder the body works, the colder the air "feels". By way of example, an air temperature of 20°F with a 10 mph wind "feels" like 9°F. A simple nylon windbreaker, worn in the spring and autumn, keeps a person warm by retaining the heat generated by the body. An insulated coat is needed in the winter.

The wind chill calculation was developed by the U.S. military to better protect WWII soldiers. A recalculation was released on November 1, 2001, to more accurately account for wind – the old calculation apparently exaggerated the "cold feel". Readers born after 2001 can use this information to counter statements such as *"it was colder when I was a child"*. It should be noted that only warm-blooded animals (organisms that generate internal heat) can perceive wind chill – a tree does not feel wind chill, nor does a car battery (meaning we can't use wind chill as an excuse for a car that won't start). Joking aside, exposure to cold temperatures and wind chill without enough protection can leave a person at risk of cold (hypothermic) related illnesses: excessive shivering, frost nip, frostbite, loss of consciousness, and even death.

A person's desire to urinate in cold weather (cold-induced diuresis) is an early stage of hypothermia. The cold-induced blood flow to the body's core (working to maintain the body's core temperature) increases the core's blood pressure and, in response, the kidney releases urine to reduce that pressure.

In context of weather, "Code Blue" refers to an emergency service which provides the homeless shelter on bitterly cold nights. At some locations, individuals and families who do not have electricity, water, gas, etc. are also invited to seek shelter. The temperature/wind chill criteria vary from location to location.

Box 7 **Summer's Cricket Thermometer**

With windows open on a summer's night, the chirping of crickets often fills the air. Rather than counting sheep, you may want to count chirps. Actually, there is a practical purpose here. Crickets are cold-blooded creatures (ectotherms) whose metabolism is dependent on temperature. A reflection of this metabolism is the frequency of times they rub their wings together to create the chirp sound – an attempt to attract a mate. The warmer the air temperature is, the greater the frequency of chirps. To obtain a temperature in Fahrenheit, count the number of chirps over a 14-second period and add 40. By way of example, a count of 25 chirps reveals an outside temperature of about 65°F. It turns out that at a temperature below 40°F the crickets remain quiet – likely no longer interested in attracting a mate. Besides, at 40°F the summer is pretty much over!

Box 8 **Rhododendron Thermometer**

When temperatures are above freezing, the leaves of the rhododendron extend out at approximate right angles from their stems. However, during the cold days of winter, the leaves appear curled and hang down on the stem. Known as a thermotropic response, the leaves of the rhododendron curl and droop in response to freezing temperatures in order to protect themselves. The colder the temperature, the tighter they curl and the more they droop. You can use the degree of leaf curl and angle to estimate the outside air temperature. Test it against your outdoor thermometer!

Image Source: Stephen Vermette

Our Invisible Ocean of Water

Clouds are analogous to icebergs floating in a sea of water but, in the case of the atmosphere, much of this "sea" is composed of water vapor that is too small to see. There are about 37,000,000,000,000,000 gallons of water in the atmosphere at any point in time. Water is present in the atmosphere even on a sunny cloudless day. Our atmosphere doesn't store water; rather, water is moved through it as part of the hydrologic cycle or water cycle. Water enters the atmosphere via evaporation and transpiration (from plant leaves) and exits mainly via precipitation.

While on its journey, water undergoes phase changes (solid, liquid, and vapor). Water is the only chemical that undergoes all three phase changes at naturally occurring temperatures. These phase changes are important as they move energy around in our atmosphere and give us different types of weather (Figure 39).

With "phase change", there are two directions to consider: phase changes that require the addition of heat energy, and phase changes that release heat energy. A simple way to think of which applies when is to think of the three phases of water as a hierarchy based on kinetic energy, increasing as one moves from solid (ice) to liquid (rain) to vapor (mist). Heat energy is required to move up the hierarchy, and heat energy needs to be released to move down the hierarchy. With this in mind, added heat is required to melt ice and to evaporate water. In this book, evaporation will be repeatedly described as a "cooling process" because it requires heat energy. By way of example, the evaporation of perspiration takes heat away from your skin, and thus cools your body. Heat is lost (released) when water vapor condenses and when liquids freeze. Consider the expelled heat on the back of an air conditioner or freezer. The source of heat is what is being released by condensation of water vapor (as in the case of an air conditioner) or freezing of water (as in the case of a freezer).

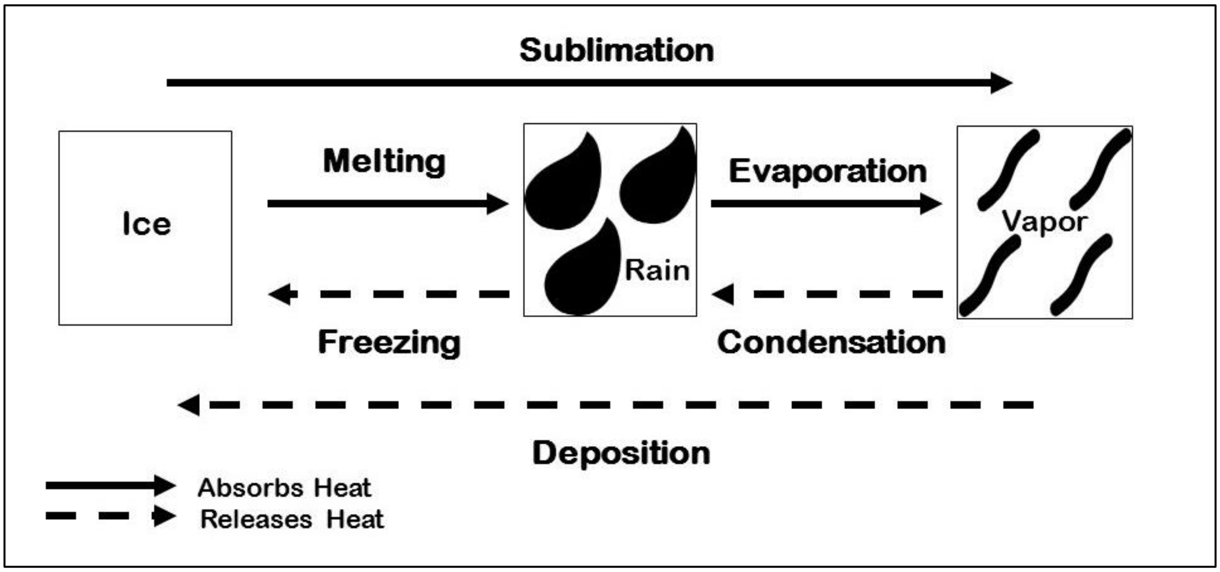


Figure 39. Changes of state involve the exchange of heat energy (absorbed or released).
Image Source: Stephen Vermette.

There are two "short cut" phase changes. Sublimation describes how ice can directly become water vapor if enough heat is added quickly. A weather-related example occurs when unusually warm air passes over a snowpack, or when bright sun shines on it (added heat energy in both instances). The snowpack sublimates into a vapor (you can see steam − "snow haze" − rising above the snow), bypassing the melting process. The other short cut, deposition, follows the opposite path (rapid release of energy), where cooling deposits the vapor as a solid known as frost. The added or released heat energy that causes these phase changes is referred to as latent (hidden) heat.

Assorted Humidities

As previously noted, water exists in the atmosphere even though it is invisible to the eye. Its presence is measured and described as "humidity". The actual amount of water in air is referred to as the "absolute humidity", "specific humidity", or "mixing ratio". The different terminology depends on whether you are measuring the mass of water in a mass of air or in a volume of air. This distinction does not matter for our purposes.

A measure of humidity reported on weather forecasts is "relative humidity". This measure of humidity is expressed as a percent and describes how "full of water" the air is. To understand relative humidity, one must be aware of the "saturation mixing ratio" which describes the maximum amount of water vapor air can "hold" (its saturation level) for a given temperature. Relative humidity is determined by considering the ratio of the "absolute humidity" to that of the "saturation mixing ratio". By way of example, if a given volume of air contains 20 oz of water (absolute humidity), and the air can hold 40 oz maximum at a given temperature (saturation mixing ratio), then the relative humidity is said to be 50% ((20/40) x 100). As the actual amount of water increases in air held at a constant temperature, its relative humidity also increases. When the air is full or saturated, the relative humidity is said to be 100%, and the air is said to have reached its "dew point temperature", the temperature at which air is saturated, or at 100% relative humidity.

To understand how relative humidity changes, let us first consider a conceptual model (Figure 40). Consider three cup sizes: the largest cup 24 oz is, for the purpose of this demonstration, the amount of water air can hold at 80°F; the 12 oz cup is the amount of water air can hold at 60°F; and the 6 oz cup is the amount of water air can hold at 40°F. All three cup sizes refer to the air's saturation mixing ratio (the amount of water air can hold for a given temperature). The amount of water added to each cup represents its specific humidity (the actual amount of water in the air). Let us add 3 oz of water to each. What is the relative humidity in the smaller cup? As 3 oz were added to a 6 oz cup, the relative humidity would be 50% (3/6). Assume the air warms up to 60°F, the air can now hold 12 oz of water. Given that the specific humidity (3 oz) has not changed, the relative humidity would be 25% (3/12). If the air finally heats up to 80°F, it can now hold 24 oz. Given the same amount of actual water in the air (3 oz), the relative humidity would drop to 12.5% (3/24).

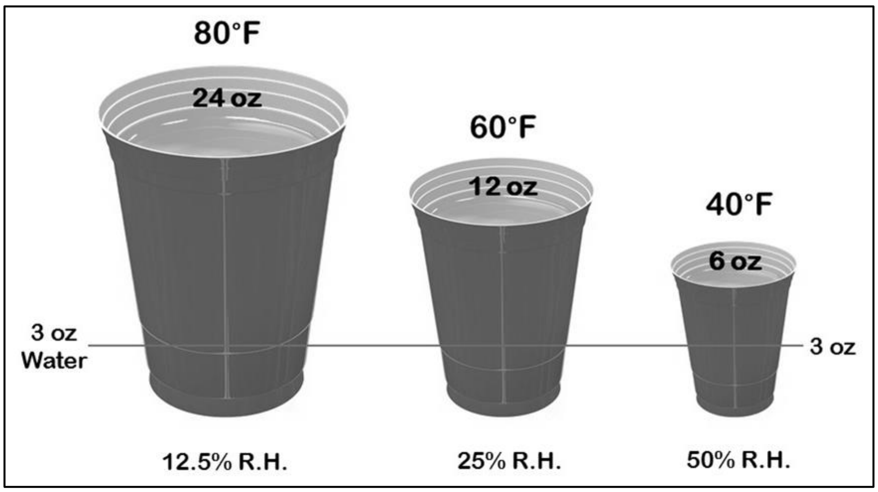


Figure 40. The actual amount of water in each cup (absolute humidity) is 3 ounces. While the absolute humidity is unchanged, the relative humidity changes based on the size of the cup (changing saturation mixing ratio). Source of Image: Stephen Vermette.

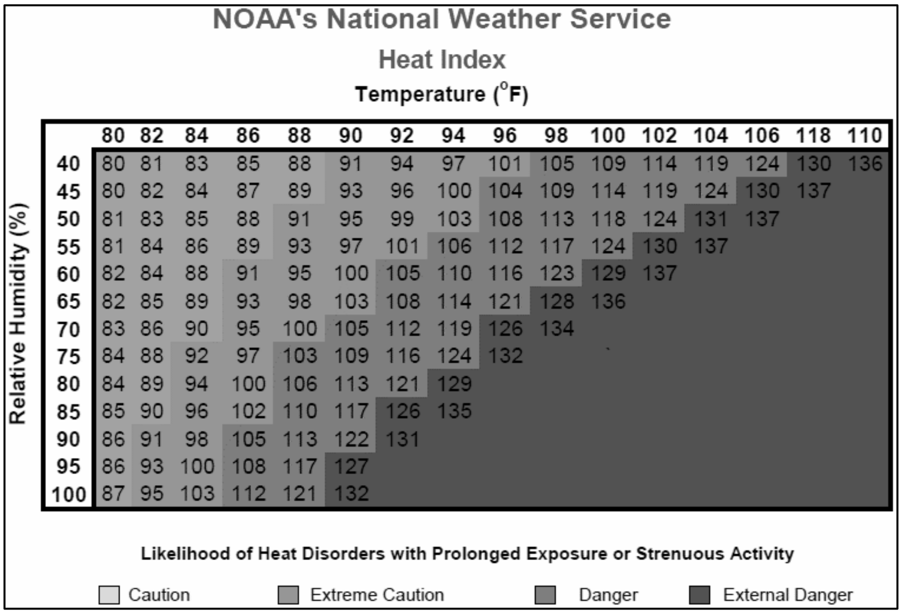
A few immediate applications come to mind. Consider how indoor air feels so dry in the winter (your skin dries out and lips chap). What you are experiencing is the low relative humidity of that air. The outside air may have a high relative humidity, but when you warm it up indoors, its ability to hold water increases (larger cup), and its humidity decreases. There are two ways to increase winter's indoor relative humidity: either add water to the air (perhaps through use of a humidifier) or cool down the room temperature.

You may have noticed how the air seems to become more humid in the evening hours. As the evening air cools, its ability to hold water decreases (smaller cup) and, as a result, its humidity increases. A summer nighttime relative humidity >60% is generally considered uncomfortable for sleeping.

Previously, it was mentioned how evaporation of perspiration takes heat away from your skin and cools your body. On hot humid days, when the air is at or near saturation, the evaporation of perspiration is restricted or halted as the air has little "space" for added moisture. As a result, your body is not cooled through evaporation and you feel discomfort. The NWS heat index is a measure of discomfort felt as a result of the combined effects of the temperature and humidity of the air. Relative humidity is the humidity measure of choice on weather reports because it affects your body – it is what you feel.

Heat Index

In the summer, the cooling power of wind is often welcome. Another factor affecting how we might perceive temperature is "humidity". Right or wrong, the expression "It's a dry heat" is used to dismiss the perceived impact of air temperatures, as compared to similar air temperatures at humid locations (the U.S. southwest as compared to WNY, for example). The effect of heat and humidity is accounted for with the "Heat Index" (Figure 41).



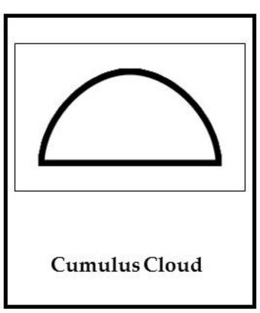
RH (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	118	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Figure 41. Heat index chart prepared by the National Weather Service.
Image Source: Wikimedia Commons/NOAA.

Our bodies cool through perspiration. Evaporation is a cooling process so the removal of perspiration from a body by evaporation makes it feel cooler. However, at times of high relative humidity, evaporation is restricted as the air surrounding us is at or near its moisture capacity. As a result, the body feels hot and muggy. By way of example, a 90°F temperature feels like 109°F when the air's relative humidity is at 75%. Consider a swim in a pool. On days with a low relative humidity, stepping out of a pool might result in goose bumps, as rapid evaporation quickly cools off your body. Alternatively, on a very humid day there is little or no evaporation such that the water sticks to you and you feel muggy (you want to jump back into the pool).

A word of caution is due. The heat index values were devised for shady conditions. Exposure to full sunshine can increase heat index values by up to 15°F. Exposure to hot temperatures and a high heat index, without sufficient hydration and other precautionary steps, can leave a person at risk of heat (hyperthermic) related illnesses: heat exhaustion, heat cramps, heat (sun) stroke, and even death.

How to Build a Cloud



A view of planet Earth from space reveals not only the oceans and continents, but also the enveloping atmosphere, visible in the form of clouds. Moisture in the form of invisible water vapor exists in our atmosphere (mixing with other gases), but it is only when it is collected as tiny droplets or ice crystals that it becomes visible as a cloud. So, how does a cloud form?

A series of steps are involved that always begin with the presence of water vapor and rising air. This series of steps can be collectively visualized as a rising "condensation staircase", where each step is necessary, and each step brings one closer to the formation of clouds.

To best understand the next few steps, visualize a parcel of air as might be held within a balloon. As the air rises, its volume expands. This expansion is due to an altitudinal decrease in the air pressure that normally pushes in (squeezes) the parcel of air. As the air parcel rises, the "squeeze" of atmospheric pressure becomes less. The expanding air cools. This process is known as adiabatic cooling, where air molecules within an expanding parcel of air undergo less agitation and vibration. Recall that temperature refers to kinetic energy, or the vibration of molecules (less agitation and vibration equates to a lower temperature). And recall the cooling-due-to-expansion process when using an aerosol can. In the atmosphere, as the air temperature cools, its ability to hold water decreases and its humidity increases. The air becomes saturated when it can no longer contain the water vapor within it. The final step to cloud formation is condensation, but this final step requires further explanation.

Condensation, to produce cloud droplets, requires the presence within clouds of tiny particles referred to as "cloud condensation nuclei" (CCN)/Ice Nuclei (IN) or simply "seeds". The CCN/IN are made up of microscopic water absorbent (hygroscopic) dust particles, sea salt, soot, spores, pollen, and bacteria, among other particles. The phrase *"April showers bring May flowers"* could correctly be reversed to read *"April flowers bring May showers"*, given that fragmented (not intact) pollen may be CCN and contribute to the formation of clouds! Most recently, airborne microplastics (degradation of larger plastic products) are showing up everywhere, including the water you drink, the fish you eat, and in the air you breathe. They are showing up in rainwater too. While not currently considered CCN (too large), it would be no surprise to find them to be so in future studies.

Water vapor is attracted to CCN particles whereupon it condenses and forms cloud droplets – at the center of every cloud droplet is a CCN or IN. These cloud droplets, or ice crystals if the cloud is at a sub-freezing temperature, are so light that they float in the air and give a cloud its form.

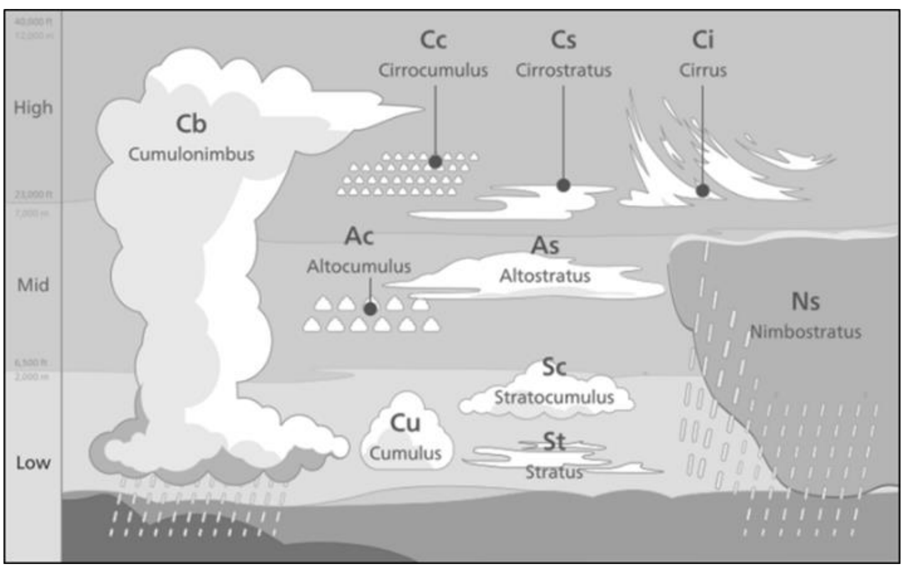


Figure 42. The 10 basic cloud types (genera).
Image Source: Wikimedia Commons.

The identification of clouds is based on altitude (high > 23,000 feet, labeled "cirrus" or "cirro"), middle (6,500 to 23,000 feet, labeled "alto"), and low (<6,500 feet), as well as by form: layered, labeled "stratus", and globular, labeled "cumulus". By combining height and form, 10 basic cloud types can be identified (Figure 42). For example, cirrostratus refers to a high altitude layered cloud, and altocumulus refers to a middle altitude globular cloud. When absent an altitude prefix, the cloud is assumed to occur at low altitudes, as is the case for a stratus cloud. Another prefix sometimes used in cloud identification is "nimbo", which refers to a cloud that releases precipitation. A separate cloud category is reserved for the cumulonimbus cloud which is a cloud of vertical development – growing vertically up from low altitudes and possibly reaching heights that extend up to the tropopause. These are the clouds that produce thunderstorms.

There are many more clouds types than described here, as clouds are classified according to a more detailed Latin system like the one used for plants and animals (genus, species, and variations). These numerous cloud types are meticulously identified and described in the International Cloud Atlas, first published in 1896.

As an aside, you may have used or heard the phrase "on cloud nine" which refers to being very happy. A musical reference to "cloud nine" is a 1969 hit single of the same name recorded by The Temptations for the Motown label. "Cloud nine" refers to the cloud type (cumulonimbus) shown on plate #9 of an early version of the "International Cloud Atlas". The International Cloud Atlas added new cloud names in 2017 (the first time in 30 years). These include the category "homogenitus" which refers to clouds that form associated with human activity, including the contrail behind a jet aircraft (cirrus homogenitus) and clouds over industrial smokestacks (cumulus homogenitus). While at Niagara Falls, you are likely to see "cumulus cataractagenitus" rising above the cataracts Figure 43).

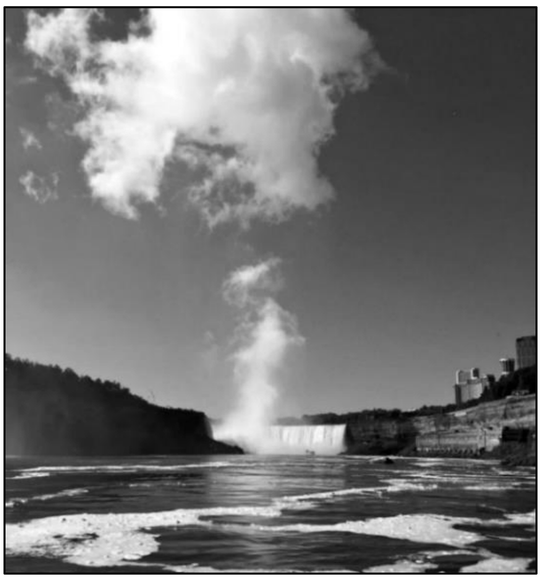


Figure 43. Cumulus Cataractagenitus forming over Niagara Falls. Image Source: Amanda Robson.

Further attention must be given to cirrus homogenitus, more familiarly known as condensation trails or "contrails", which appear as long cloud streaks behind a jet aircraft. At altitudes of about 30,000 ft asl the air is extremely cold and dry. Given the correct atmospheric conditions, the added moisture and particles exhausted from jet engines quickly form into cloud ice crystals − the contrail. Jet aircraft with two jets produce two contrails, while jets with four engines produce four contrails. Climate change modeling indicates that contrails have a significant impact on atmospheric temperatures. "Chemtrail" is a fallacious term used by some to describe these streaks. The explanation for the use of this terminology rests on a conspiratorial belief that the government, or some secret society, is adding toxic chemicals or biological agents for undisclosed purposes. The only "chemtrail" is what comes out of a crop dusters airplane.

Box 9 Cloud Viewing

While looking up at clouds it is in our nature to "see" all types of identifiable shapes in the sky – bunny's, horses, butterflies, etc. While looking up you may have found it difficult to estimate the height of clouds. A simple approach is to use your hand as a scale. When observing a cumulus cloud, hold your hand up to the cloud. If the cloud can be covered by your small finger then it is a high cloud (cirrocumulus), if covered by your thumb it is a middle cloud (altocumulus), and if it takes your fist, then it is a low cumulus cloud. The age of a cumulus cloud (or parts of a cloud) can be observed by observing its edges. A growing cumulus cloud has sharp well-defined edges, whereas a dissipating cloud has fuzzy poorly defined edges. A source of cloud information, as well as an opportunity to join with others in admiring clouds, can be found with the "Cloud Appreciation Society", which describes their mission as *"fighting the banality of blue-sky thinking"*.

Fog Bound

Simply put, fog is a type of cloud that touches the ground. It builds from the condensation process, including CCN, in a way similar to the development of clouds. When composed of ice crystals, it is termed ice fog. The National Weather Service operationally describes fog based on visibility distance (usually in increments starting at less than 1 km or 5/8 mile). Fog notifications are usually reported to the public when visibilities are ≤ 1/4 mile. If the fog does not obstruct visibility at 6 feet above ground level, it is referred to as a shallow fog. This definition of fog distinguishes it from mist which has visibility greater than 5/8 mile with a relative humidity of 95% to 100%.

There are two ways that fog forms: either by cooling of the air, or by the addition of moisture. As the temperature of air cools, its ability to "hold" moisture decreases. If air continues to cool, it reaches its dew point (the temperature of saturation or 100% relative humidity), with condensation following. Associated types of fog include: radiation fog, where lower layers of air cool due to the loss of terrestrial radiation at night; advection fog, where warm moist air blows over and is chilled by a cool surface; and upslope (orographic) fog, where humid air cools as it moves up a slope.

Radiation fog most often appears and persists in the early morning and late evening hours. This type of fog can be thick. It dissipates once the sun rises. Soon after sunrise, the sun's energy heats the ground and appears to "lift" the fog, as the ground and the air immediately above is heated first. The arrival of warm air over frozen or snow-covered ground in winter often brings a radiation fog. Advection fog affects the shoreline areas of Lakes Erie and Ontario when it blows in off the lakes (Figure 44). A variation of radiation fog is valley fog. Here the cooled dense air on hilltops sinks and pools in valleys and low areas in general (Figure 45). Along with valley fog, upslope fog is most common in areas of the Allegany Plateau, where "low clouds" appear to cling to hill sides.

Figure 44. Foggy Buffalo, NY. Advection fog blowing in off Lake Erie.
Taken from the 28th floor of city hall.
Image Source: PublicDomainPictures.net.

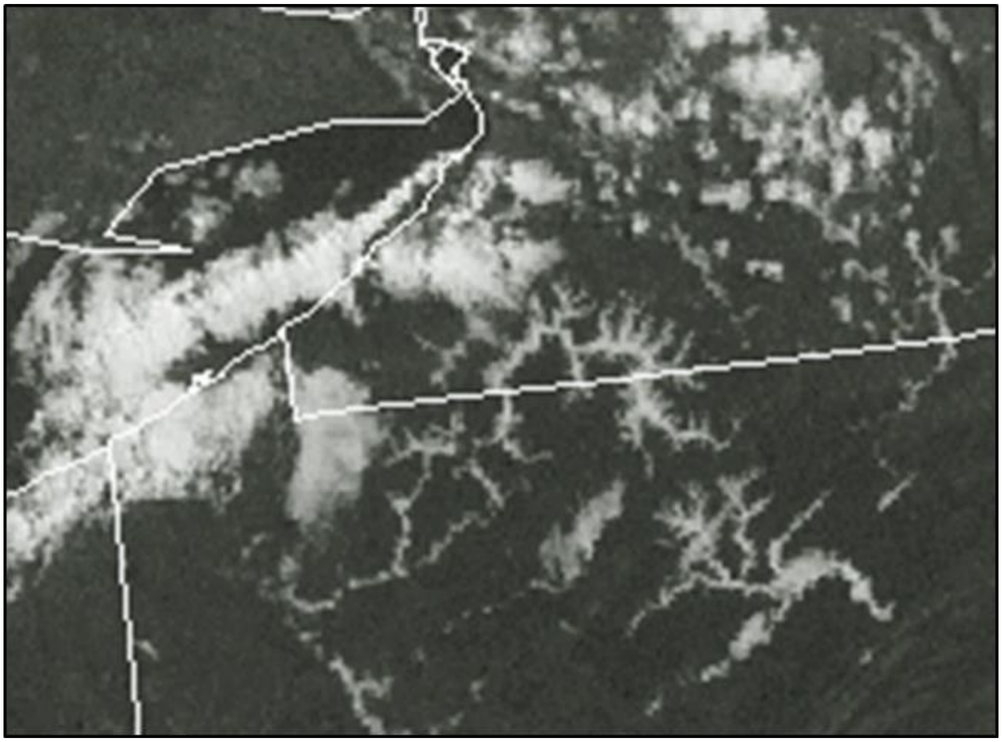
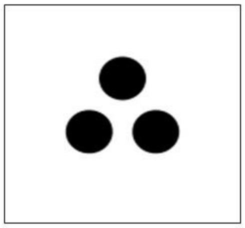


Figure 45. In this satellite image taken on August 15, 2013 (7:31 a.m.) valley fog is seen as "white vein" features located in WNY southern tier and in northern Pennsylvania valleys. Clouds are shown to the north and northwest.
Image Source: Binghamton, NY Weather Forecast Office/NWS.

The second way in which fog forms is through the addition of moisture by evaporation. Associated types of fog include steam or evaporation fog, where cool air moves over a warm body of water; and precipitation fog, formed due to the evaporation of rain drops below the cloud base. Steam fog, seen as rising from lakes and ponds, is prevalent in WNY during the late summer and autumn. Here, evaporation from the warm water quickly saturates the air and condenses in the cool air immediately above. This type of fog is usually seen as wisps of condensation over a lake or pond. You experience this same type of fog when soaking in a hot tub. In the winter a snow fog forms when unusually warm air passes over a snowpack. Rather than evaporation, the snow sublimates (a phase change bypassing evaporation whereby snow changes directly into a vapor form) and condenses when the air above becomes saturated. A winter cold snap will often produce steam fog over the Niagara River.

Understanding precipitation fog requires a little more context. I remember driving along the I-190 during a period of heavy rain and listening to a weather forecast that reported a relative humidity of 80%. Yet, it was raining – a condition needing a humidity of 100%! The humidity measurement likely was not taken within the rainstorm but, even if it was, it is possible for the air below a rain cloud to not be saturated with moisture. The saturation required for rain must be found within the cloud itself, not below the cloud. A classic example of this is "virga", streaks of precipitation descending from the base of the cloud that evaporate before reaching the surface. Precipitation fog occurs when raindrops falling through the unsaturated air below the cloud undergo evaporation. But unlike virga, the evaporated moisture is enough to raise the humidity such that the dew point is surpassed, forming fog. The combination of rain and fog leads to poorer visibility, than rain alone.

Let it Rain


Rain (continuous)

As previously discussed, rising (unstable) air and cloud condensation nuclei (CCN) are required to produce cloud droplets, and thus clouds. But how is rain and snow created within the cloud? The key to understanding the process of rain formation, at a basic level, is no more complicated than what a rain-covered window pane might reveal to a keen eye. Gravity draws the clinging drops downward along the glass. When the descending drops collide with one another, they coalesce and form an even larger drop that continues to move downward, but faster. This process repeats itself as the drops slide down the window pane. Similarly, cloud droplets falling under the force of gravity collide and coalesce with one another. When the drops become large enough that the updrafts in the clouds can no longer support them, they fall out as rain. This mechanism is referred to as "collision-coalescence".

This mechanism explains, at least in part, why raindrops come in many sizes. Large drops are often associated with tall clouds, where the path of collision and coalescence is longer than clouds with less vertical development. There is another process at play here. As drops fall, the pressure exerted on them by the atmosphere causes the drops to break apart into smaller drops. If this occurs within the cloud, these smaller drops will individually grow as they fall, creating even more drops that grow through collision and coalescence.

Falling rain drops do not look like the classic tear drop that you see in drawings and even on forecaster's weather maps. The initial raindrop has a spherical shape (due to water surface tension), but as the drop falls pressure differences around the drop tend to reshape it. The greater pressure at the bottom of the spherical drop moves the water molecules within the drop to its side and top (areas of less pressure), thus flattening the bottom of the rain drop.

Rain formation gets an additional boost from ice crystals found in clouds at sub-freezing altitudes which, like CCN, attract water vapor and grow. Within this "frozen" cloud, moisture can be present in three forms: liquid drops, water vapor, and ice crystals. The liquid drops exist here as supercooled drops: clean water can remain as a liquid in temperatures well below freezing! The vapor pressure over a supercooled water drop is greater than that over an ice crystal. Just as air molecules travel from high to low pressure (creating wind), water vapor is transferred from a water droplet, an area of high vapor pressure, to the ice crystal, an area of lower vapor pressure. As a result, ice crystals grow at the expense of the water drops. The altitude in a cloud where temperature and humidity align to produce snowflakes is known as the dendritic growth zone. Airplanes are sprayed with deicer prior to take-off because they act as super-sized ice crystals when passing through this growth zone. Once an ice crystal grows large enough, it falls through the cloud as a snowflake. A snowflake is made up of many ice crystal combinations, such that no two snowflakes are alike. If the air within the lower section of the cloud is above freezing, the snowflake melts and falls as rain. This process of rain and snow formation is referred as the "cold-rain process".

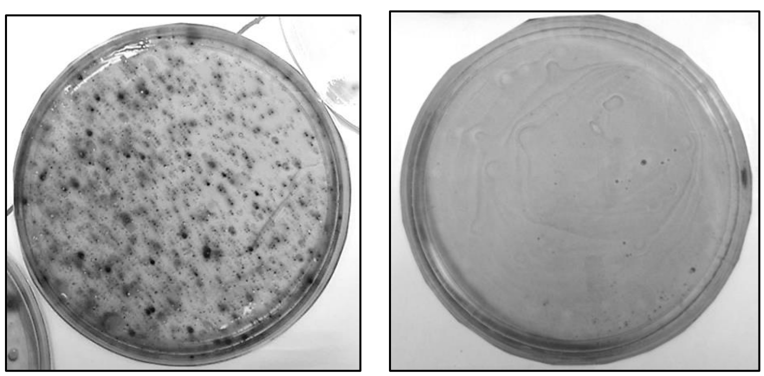
It is fascinating to think that rain falling from a summer thunderstorm may have its origins as snow. And even more fascinating to think that when you catch a raindrop or snowflake on your tongue, it is made up of not only water, but also includes condensation nuclei comprising dust particles, soot, sea salt, or even bacteria.

Where droughts are severe, efforts are made to coax rain out of clouds, a technique generally referred to as "cloud seeding" (artificially adding CCN to a cloud). The 'seeds' added to the clouds are usually crystals (often in the form of silver iodide), meant to enhance the rain process. While quantifying the impacts of cloud seeding has been elusive, research continues to understand the physical chain of events of seeding within a cloud.

Such rain augmentation was short-lived in New York State. The earliest accomplishment was the pioneering work in cloud seeding which occurred at a General Electric Corporation (GE) lab in Schenectady, NY. In 1946, the addition of dry ice in a deep freezer, mixed with the researcher's breath, produced the first augmented atmospheric ice crystals. The second rain augmentation in New York State was a field-based (real world) attempt to alleviate a New York City drought in the early 1950's. It is difficult to say what happened with this attempt. No sooner had a contract been signed to augment rainfall when the skies opened and released copious amounts of rain which soon filled the city's Catskill's reservoirs. The seeding attempt went on as planned and it rained even more. So much rain fell that farmlands flooded, and bridges were washed out. Was the rain all natural or was some augmented? The question was never answered but suffice it to say that cloud seeding was never again attempted by the City.

Box 10 Beach Closures and Rainfall

Are Lakes Erie and Ontario clean enough to swim in? The answer is yes, if you stay well away from the shoreline. Beaches along the shorelines are often impaired by fecal matter and associated pathogens found in nearshore waters. The source of this fecal matter is not rainwater nor in situ lake water, but rather storm water runoff contaminated by sewer overflows, partially treated discharges, septic system failures, and agricultural runoff, to name a few. After a substantial rain, the storm water runoff pours into creeks, flows along its watershed, eventually discharging into our lakes. And due to nearshore lake currents the polluted water hugs the shore. You may have noticed the number of beach closures increases during a wet spring and summer period.



Petri dishes showing incubated colonies of coliform bacteria from water samples collected at the mouth of the Cattaraugus Creek (left) and the absence of coliform bacteria at mid-lake (eastern basin of Lake Erie).
Image Source: Stephen Vermette.

Beach forecast models have been developed to forecast pre-emptive beach closures, and rainfall is an important factor, among others, within these models (often a 0.5 inch threshold within a 24 hour period).

In a 2008 study of Erie County Lake Erie beaches, this author recommended that the rainfall rule be tightened to ¼ inch but offered the caveat that the location of the rainfall within a watershed be considered. By way of example, ¼ inch of rain measured upstream from a beach will have a far greater impact on water quality, than ¼ inch of rain falling only at the beach.

Freezing Rain

Freezing Rain

The state of a liquid as being "supercooled" was introduced with the formation of rain (see above). The term appears again when explaining freezing rain. Freezing rain is defined by the NWS as *"Rain that falls as a liquid but freezes into glaze upon contact with the ground".* And glaze is defined as *"Ice formed by freezing precipitation covering the ground or exposed objects."*

As previously noted, most precipitation, especially in the winter, forms as ice crystals (snow) within clouds. The form of precipitation that reaches the ground depends on the temperature of the air below the height of its initial formation within a cloud (Figure 46). Cloud-formed ice crystals fall as rain if the air layer below formation is above freezing, but as snow if the freezing air extends down to the surface. Freezing rain occurs when a layer of warm air is sandwiched between two layers of cold (freezing) air. In the case of freezing rain, the frozen precipitation first falls through a layer of warm air that is deep enough to melt the snow, then through a thin layer of freezing air near the ground that cools the liquid water below its freezing point. This water is cooled to a temperature that is below freezing but remains as a liquid (supercooled) as ice crystals have not had enough time to form. Upon contact with the cold ground, it freezes as a film of ice coating tree limbs, power lines, and roadways (Figures 47 and 48). If accumulation becomes significant, it is referred to as an ice storm. A thicker layer of freezing air near the surface will result in sleet.

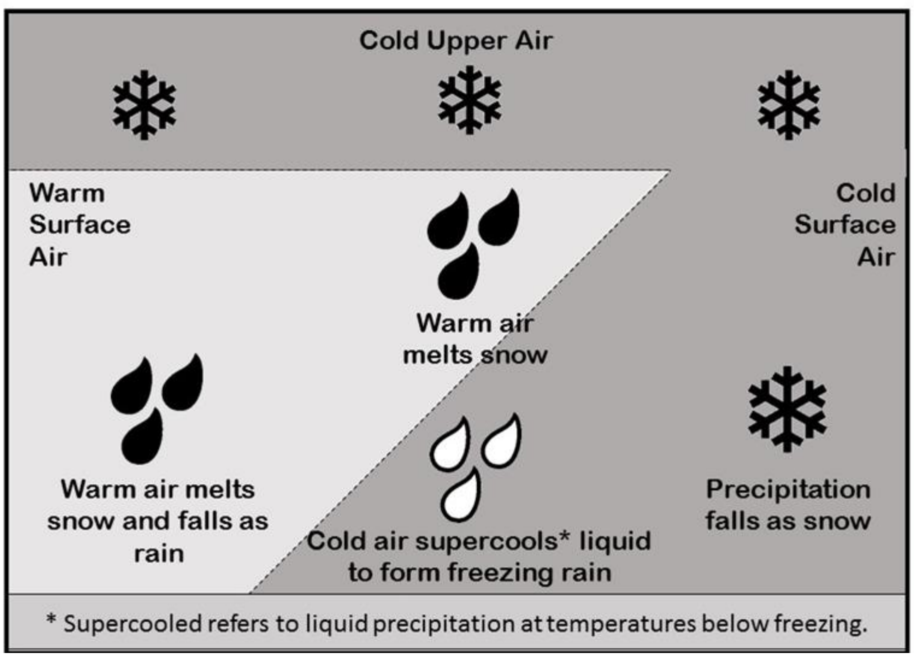


Figure 46. The precipitation that reaches the ground depends on the temperature of the air below the height of its initial formation within a cloud. Freezing rain occurs when a layer of warm air is sandwiched between two layers of cold (freezing) air. Image Source: Stephen Vermette.

I recall a time, as an elementary student, when I was able to skate to school after an ice storm but didn't have the presence of mind to bring shoes for my time at school and for the return trip home after the road ice had melted.

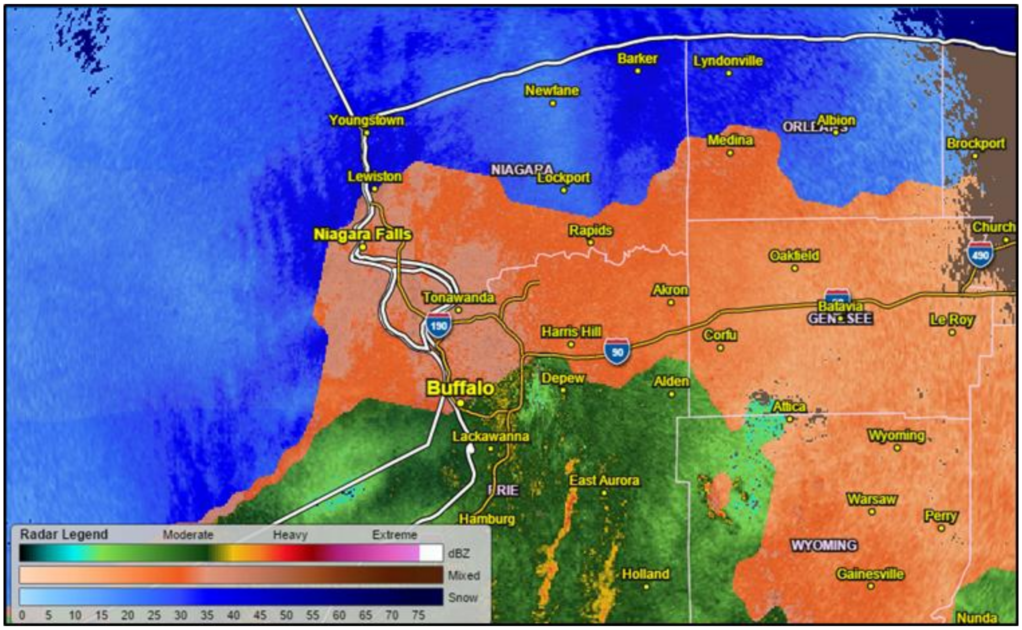
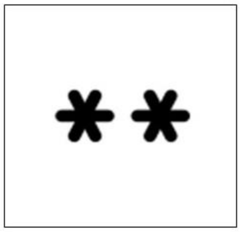


Figure 47. Weather radar echo showing rain (green and yellow), freezing rain (salmon) and snow (blue) during a March 2, 2016 WNY precipitation event. Image Source: WeatherTap/Stephen Vermette.

Figure 48. Crab apple encased in ice. Icing event of February 6, 2019 on campus of Buffalo State College. Image Source: Stephen Vermette.

Growing a Snowflake



Snow (slight, continuous)

The origin of every snowflake is a single cloud-bound ice crystal – a single crystal with a hexagonal (6-sided) form (Figures 49 and 50). On this core hexagonal crystal, additional water vapor condenses and freezes, building out the snowflake following the hexagonal blueprint of the core crystal. Therefore, when you draw an iconic snowflake it will be made up of six arms branching out from its core crystal. Some of the variety in the shape of snowflakes comes from the fact that the buildout, while first branching from the core ice crystal, can also build out from subsequent crystal faces. By way of an analogy, consider the game of dominos. The use of spinners allows for the branching out of the original line of dominoes. While varying forms of snowflakes exist, the hexagonal crystal remains the building block of each one.

Figure 49. Snowfall beauty captured in upstate New York.
Image Source: NOAA's National Weather Service (NWS) Collection/ Terry DeCorah.

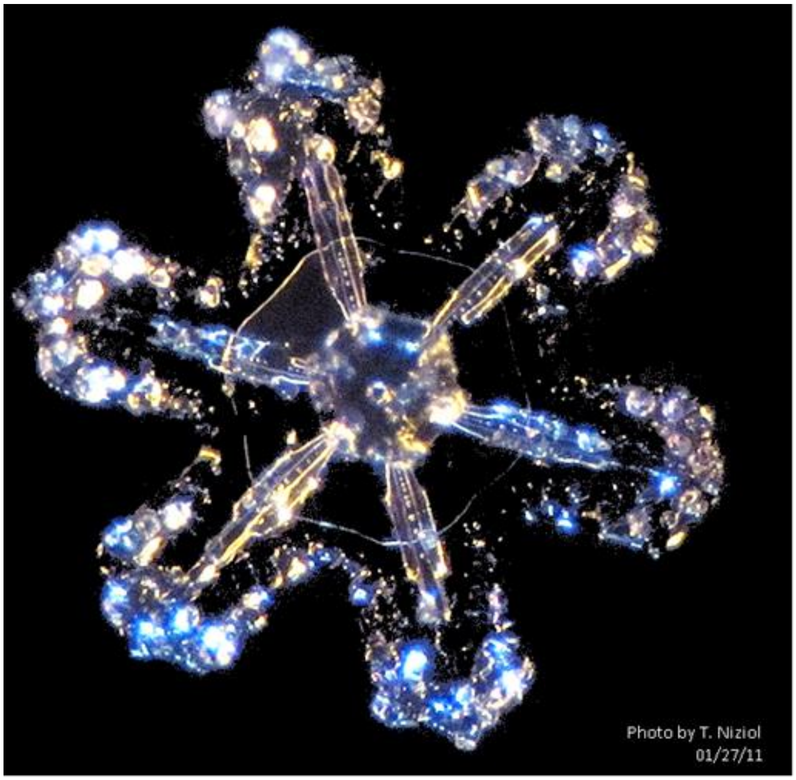


Figure 50. Classic dendritic snowflake photographed in WNY. Image Source: Tom Niziol.

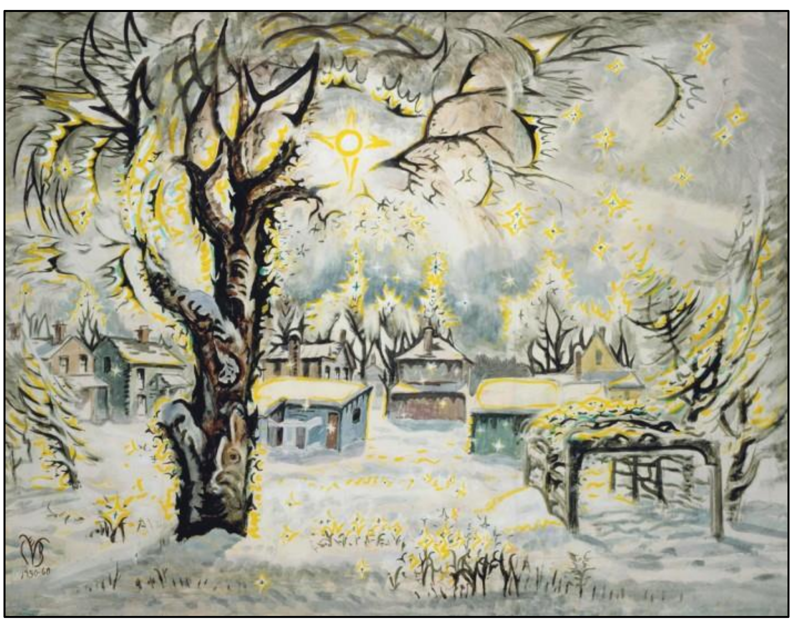


Figure 51. Charles E. Burchfield (1893-1967), *Winter Diamonds*, 1950-1960; watercolor on paper, 36 x 46 inches; Image from the Archives at the Burchfield Penney Art Center.

The shaping of the varying forms of snowflakes (dendrites, plates, needles and columns) is influenced by varying temperature and relative humidity within a cloud. For example, the classic dendritic (branching) pattern grows best in cloud temperatures between 15°F and -5°F, under high humidity conditions. The location within a cloud where this occurs is known as the "dendritic growth zone" and is referred to by meteorologists when forecasting snowfall amounts. The phrase *"no two snowflakes are alike"* stems from the near-infinite variety of temperature and humidity conditions within a cloud, and cloud conditions that vary over time.

To the keen eye, the form of snow crystals in new fallen snow says a lot about atmospheric conditions in the originating cloud. While the symmetrical dendritic form is what usually is photographed and described, it is somewhat rare to see as snow usually falls as agglomerations of crystal fragments buffeted by their decent through the cloud. Henry David Thoreau (a 19th Century naturalist) said it best: *"Commonly the flakes reach us travel-worn and agglomerated, comparatively without order or beauty. Far down in their fall. Like men in their advanced age."*

On a cold winter's day, the new-fallen snow sometimes sparkles as millions of crystal faces appear animated by reflected sunlight. Charles Burchfield's watercolor "Winter Diamonds" captures such a spectacular winter scene in WNY (Figure 51).

While on the topic of snow, you may have noticed that snow sometimes squeaks underfoot. This "squeak" is dependent on the temperature of the snow itself. When the snow is very cold (below 14°F), the pressure from your step crushes the snow crystals such that they rub and break – producing a squeaking sound. When temperatures are greater than 14°F, the pressure from your step melts the snow ever so slightly to allow the crystals to pass over each other without a noticeable sound.

Box 11

Instant Snow

Image Source: Wikimedia Commons

Application of phase change knowledge can be used to understand how ski resorts augment nature's shortcomings by making instant snow. The key components of a snow cannon are a powerful fan, aerosol nozzles, compressed air, and liquid water.

Water is aerosolized (made into very tiny water droplets) by passing it through fine nozzles while it is sprayed into the air by compressed air. The compressed air and aerosol mixture rapidly cool with expansion and, if released into dry air, evaporation further cools this mixture. Under cold air conditions, this flash freezing quickly transforms fine water droplets into ice crystals − instant snow. It turns out that the added cooling of compressed air and evaporation can produce snow in air that is a few degrees above freezing. The key here is to operate the snow cannon when the relative humidity is low, to enhance the evaporation and cooling.

How to Measure Precipitation

What may appear as a simple task – measuring precipitation – is far more complex than one might first believe. Consider that rain gauges come in numerous sizes and shapes, each with varying collection efficiencies; that turbulence around a gauge can lead to a wind-induced under catch of the collected precipitation; that precipitation can splash into and out of a gauge; and that evaporation can cause a loss of collected precipitation. Also, consider that what is measured represents only what fell into the gauge.

We know that precipitation quantity and intensity can be highly variable from place-to-place, begging the question: how many gauges are needed to represent an area the size of WNY? A quick calculation for WNY reveals that there are about 75 official rain gauges covering a collective surface area of approximately 16 square feet. Add to this list a "garden variety" of available online personal weather stations (PWS) in people's back yards and the coverage area increases by many fold but this still represents a very small percentage of WNY's surface area. As an effective spatial tool, it must be assumed that each gauge represents a spatial area much larger than its collection orifice. To better characterize spatial representativeness, weather radar, with proper calibration, can estimate rainfall, and augment a rain gauge network. To better understand global hydrologic cycle, NASA and the National Space Development Agency of Japan launched a satellite designed to estimate precipitation in tropical and subtropical regions of the world.

Figure 52. An eight-inch standard rain gauge, as used by the National Weather Service. The 4-inch versions are easily purchased for other networks and home use. Image Source: National Weather Service.

Most official gauges have a wide orifice (a diameter of 4 to 8 inches) that directs rainfall into a funnel designed to minimize out splash (Figure 52). The collected rainfall passes through a small opening (which minimizes evaporative loss) into a graduated cylinder. The diameter of the cylinder is 1/10 the size of the orifice such that rainfall amounts are magnified in the cylinder (0.01 inches appears as 0.1 inches in the cylinder). If rainfall is below 0.01 inch, it is measured as "T" for trace. A modified approach to rainfall collection is the tipping bucket rain gauge (Figure 53). The rain that passes through the funnel initially fills a "bucket" with a set volume of water. Once full, the bucket tips, positioning a second bucket to collect the rain water. Each tip simultaneously records a volume of rainfall. This gauge has several advantages over that of the standard gauge because it can easily be connected to a computer (which counts the tips) and, in addition to measuring volume, it can also measure the intensity of rainfall (inches/hour), and it is self-emptying. A further variation on the standard rain gauge is a weighing-type rain gauge that uses the collected water weight to measure both the volume and intensity of rainfalls.

The accuracy of the rain gauge in collecting precipitation is dependent on the siting, or location, of the gauge itself. Exposure of gauges in wide-open spaces or elevated sites should be avoided to minimize wind-induced under catch. In open areas, gauges are surrounded by a wind shield to minimize the effect of a wind-induced under catch (Figure 54).

The best location is one that is protected on all sides – such as by trees or buildings, albeit away from immediate obstructions. A general rule is to maintain an open cone above the gauge extending out to at least 30 degrees above the horizon (Figure 55). I recall a volunteer who remedied the "inconvenient" location of their rain gauge by moving it to the side of their home – an obvious obstruction violation.

Figure 53. The inner workings of a tipping-bucket rain gauge. The left bucket is positioned to receive rain water and will tip when full, exposing the second bucket to rainfall.
Image Source: Wikimedia Commons.

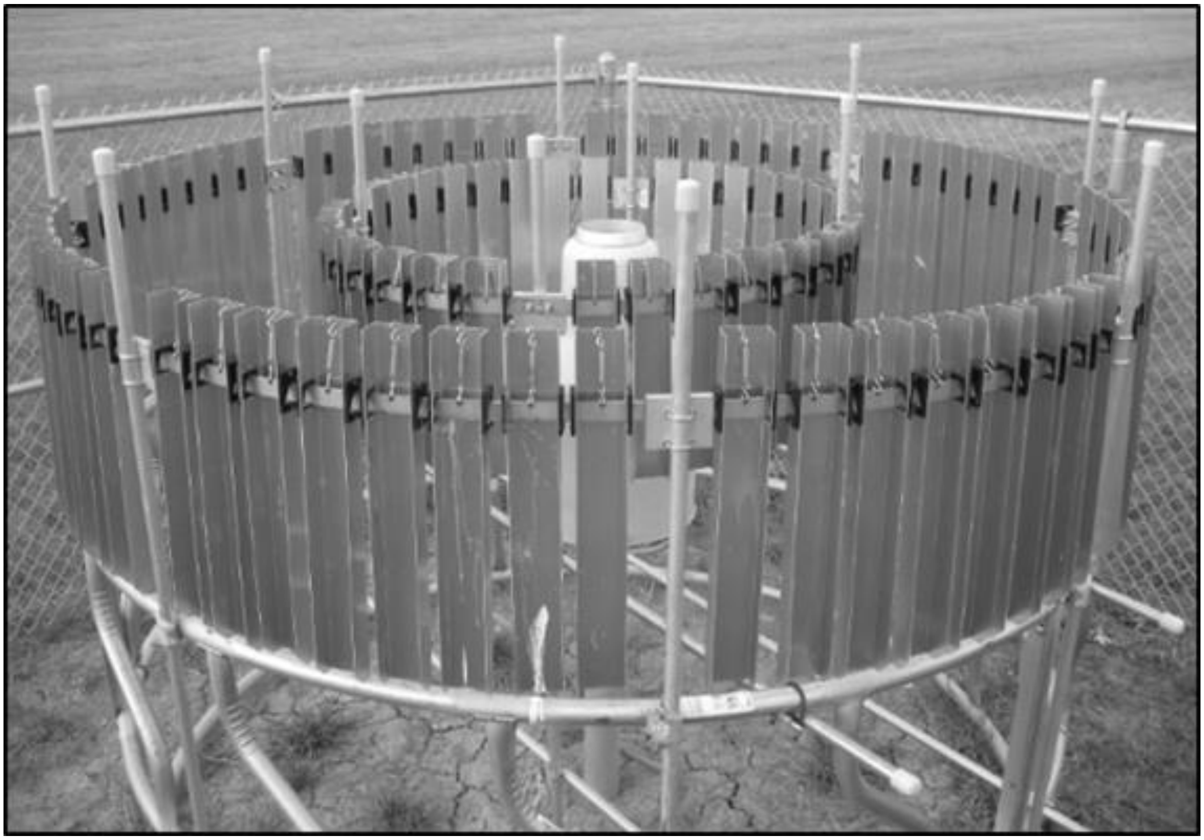


Figure 54. Alter wind shield (double) surrounding a weighting-type rain gauge rain gauge at the SUNY Buffalo NY-Mesonet site. The hanging metal strips swing with the wind creating a calm space over the gauge. Image Source: Stephen Vermette.

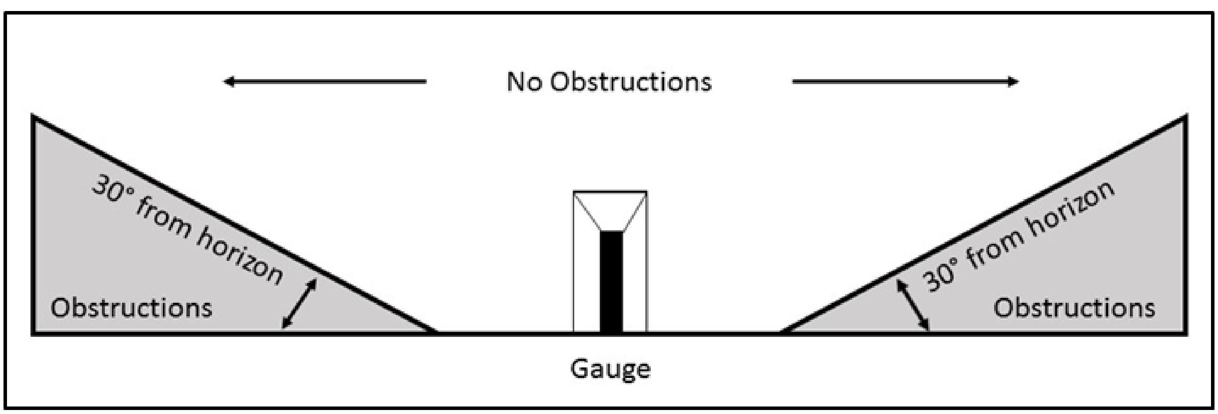


Figure 55. Proper siting of a rain gauge to avoid obstructions. Image Source: Stephen Vermette.

Box 12 — Showers of Fish

One of my favorite reads was a book titled "It's Raining Frogs and Fishes", by Jerry Dennis, who wrote about natural phenomena and oddities of the sky. Under the descriptor "truly peculiar weather" he recounted events of fish and other organisms that "rained" down from the sky. Most of the accounts were attributed to thunderstorms or waterspouts, accompanied by strong winds.

I was delighted to learn that Buffalo and vicinity has had their own accounts of this type of peculiar weather. The following was obtained from records at our Buffalo weather office:

May 13, 1899: *"A shower of fish fell in the northern part of the city this morning. About 7:15 a.m. when rain was falling, Patrolman Collins stationed at the City Zoo Park, reports that quite a large number of fish fell on Jewitt Avenue near the park at the time. They were quite numerous and were of the species usually found in the smaller streams and creeks of the vicinity."* He goes on to attribute the cause as to a thunderstorm which passed through the area.

September 29, 1939: Embedded within a description of a severe thunderstorm that flooded streets there was the following mention: *"there were also a report that small fish were deposited on the street in front of the Lehigh Valley Terminal in Lower Main Street during this storm."*

June 12, 1978: *"Thunderstorms struck Niagara Falls uprooting trees and knocking down power lines. A funnel cloud had been reported with storms. In the aftermath of the storms, little fish were found strewn on the lawns of Van Rensselaer Avenue."*

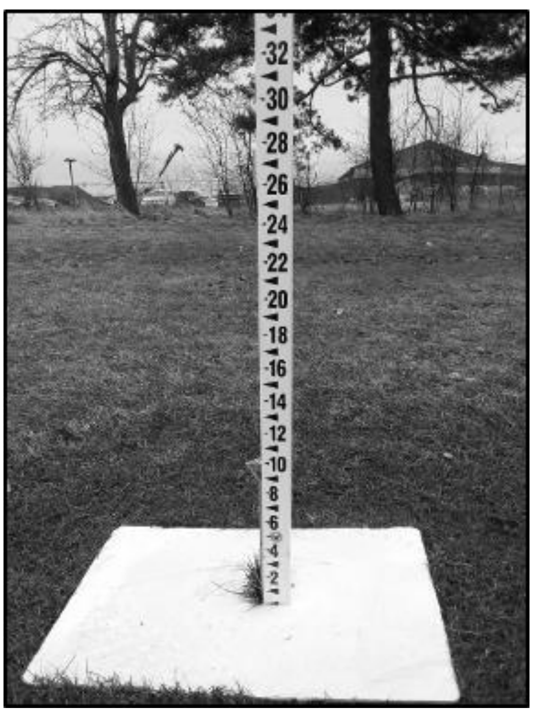


Figure 56. Snow ruler and snow board.
Image Source: Stephen Vermette

Collection of precipitation is further confounded with the measurement of snowfall. While snowfall can be collected in a gauge, it is recorded as the "water equivalent" of the melted snow. The "snow gauge" must be winterized such that collected snow is melted in a heated funnel, or the gauge must be funnel-less with a layer of antifreeze in the collection container. Non-winterized rain gauges should not be used for snow collection as the snow simply mounds up in the funnel, and the re-freezing of any melted snow or collected rainwater will cause the gauge to crack and leak due to the expansion of freezing water.

Snow depth is typically measured, as it has been through the ages, with the use of a ruler (Figure 56). The best measurement site is one that is removed from snow drifts and open wind-scoured areas. The usual practice is to take ruler measurements at a few locations a few feet apart, and to record the average depth (rounded to the nearest 1/10 of an inch). Snowfall should not be measured more than four times in 24 hours as more often will exaggerate the measured depth. Official measurements are taken on a snowboard (a 2-foot by 2-foot snow board placed on the ground) which is cleared off and raised onto the snowpack between measurements. For a primer on the proper placement of snowboards one needs not look further than Erie, PA. Back in 2017-18 Erie, PA was chasing Buffalo's annual snowfall record of 199.4 inches (1976-77) – Buffalo holds the record for cities with a population of at least 100,000 people). While their snowfall measurement came up short by less than an inch, some of their measurements were deemed to be invalid. One reason given was that the observers did not always place the snowboard on top of the snowpack after each measurement (drifting snow likely became trapped by the inset snowboard). As a result, there snowfall total was downgraded to 166 inches (a record for Erie, PA).

Unstable Air – Again, but with More Detail

In explaining weather forecasting, Tom Jolls (retired WKBW weathercaster) once stated that *"Weather is so easy, high pressure is nice weather, low pressure is bad weather."* There is a basic truth to this statement as high pressure, characterized by falling (descending) air, prevents the formation of clouds, and low pressure, characterized by rising (ascending) air, triggers cloud formation. In the "Five Guiding Principles of Meteorology", we conceptualized the condensation staircase: rising air follows a sequence of expansion, cooling, and humidification, which may lead to cloud formation and possibly precipitation. Of course, descending air follows an opposite sequence (compression, warming and drying), limiting the formation and growth of clouds.

A basic concept to grasp in meteorology is "atmospheric stability" – a measure of the air's tendency to remain in its original position or rise/fall. The stability of air comes up several times in meteorology to explain the growth of clouds, the formation of thunderstorms, how the warm water of a lake triggers lake effect snow, and how pollution becomes trapped in urban areas. What we need to know is: when will a discrete parcel of air rise or fall within the surrounding atmosphere and when will it remain stationary? There are a few definitions we need to know before answering that question.

The "environmental lapse rate" (ELR) refers to the way in which the temperature of the atmosphere changes with altitude. Recall that temperature, on average, decreases with height as one rises into the troposphere. Another term, "adiabatic temperature", refers to changes in the temperature of a discrete parcel of air within the atmosphere solely due to its expansion or contraction - rising air expands and cools as it rises, while an air parcel compresses and warms as it descends. This rate of temperature change depends on whether the air is saturated. In general, the "dry adiabatic lapse rate" (DALR) (relative humidity is <100%) is a constant change of 5.5°F/1000 feet (10°C/1,000 meters). The "wet adiabatic lapse rate" (WALR) (air is at 100% relative humidity) is typically 2.75°F/1,000 feet (5°C/1,000 meters). The value of the lapse rates varies somewhat with moisture but will be considered constant for purposes of explanation.

To understand atmospheric stability conditions, the temperature of a discrete parcel of rising or sinking air is compared to the temperature of its surrounding air. If warmer than the surrounding air, the air parcel will rise (warm air is less dense) but, if cooler, it will descend (cool air is denser).

Unstable Air

By way of demonstration, consider a conceptual model where a parcel of air floats in a larger atmosphere of air (much like a floating balloon), as shown in Figure 57. Air temperature is shown on the x-axis and altitude (height) on the y-axis. Drawn is the rate of cooling of the ELR (solid thick line) which represents the sur-rounding air, and the DALR (dashed line) which represents the rate of cooling of the air parcel (assuming air at <100% relative humidity).

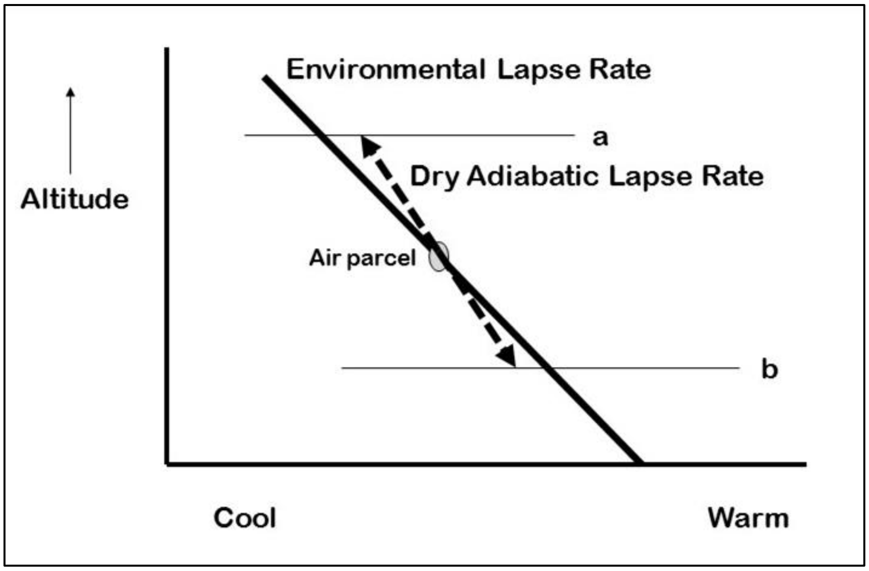


Figure 57. Condition of unstable air. Image Source: Stephen Vermette.

Beginning at the air parcel (the circle where the two rates intersect), imagine that it is lifted to a higher altitude (up to the horizontal black line 'a'). As it rises, it cools following the DALR. Ask yourself: at the height of the upper horizontal line 'a', is the parcel of air warmer or cooler than the surrounding air (ELR)? It is "warmer". Because the air parcel is warmer, and therefore less dense than the surrounding air (ELR), it will continue to rise. The parcel of air is thus considered "unstable". Similarly, if the air parcel were to descend, it would cool at the DALR. At the lower horizontal line 'b', it would be cooler, and denser, than the surrounding air (ELR). The cooler air parcel will continue to descend and is considered "unstable". In both cases, the air parcel does not return to its original stationary position. It is the air parcel's "unwillingness" to return to its original position that identifies it as "unstable".

Stable Air

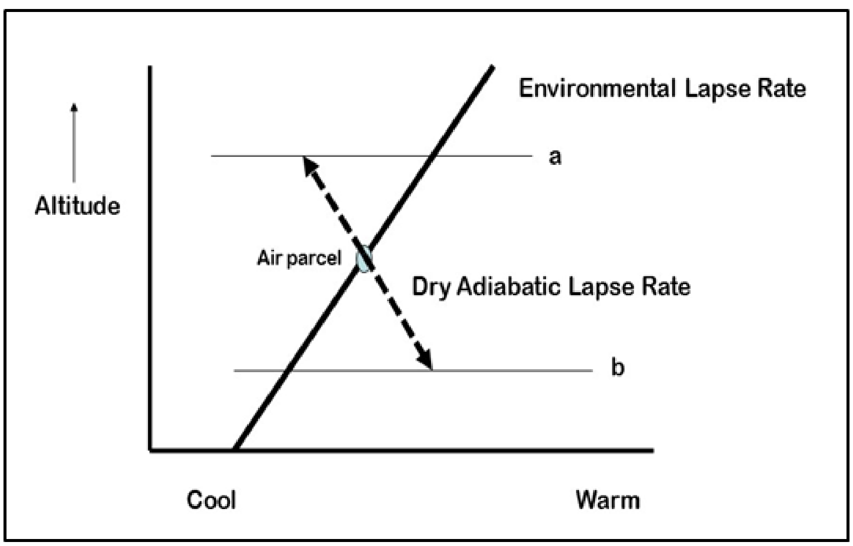


Figure 58: Condition of stable air. Image Source: Stephen Vermette.

While the dry (DALR) and wet (WALR) adiabatic lapse rates are considered constant, the environmental lapse rate (ELR) changes from time-to-time and from place-to-place. At a time and place within the atmosphere, the air may warm with height above the surface, rather than cool, as is typical. This condition is referred to as an "inversion" and the upward movement of an air parcel is prevented. Figure 58 demonstrates the condition of stable air and inversions. Recall that the rate of cooling of the ELR (solid thick line) represents the surrounding air, and the DALR (dashed line) represents the rate of cooling of the air parcel.

Beginning at the air parcel (the circle where the two rates intersect), imagine that it is lifted to a higher altitude (up to the horizontal black line 'a'). As it rises, it cools following the DALR. Ask yourself: at the height of the upper horizontal line 'a', is the air parcel warmer or cooler than the ELR? It is "cooler" and therefore denser than the surrounding air, so it will sink. As the cool air parcel descends, it returns to its original position, and thus is considered “stable”. Similarly, if you were to lower the parcel of air to the horizontal line ‘b’, it would become warmer than the surrounding air. The warmer air parcel will rise it to its original position and, again, is considered “stable”. In both cases, the air parcel returns to its original stationary position. It is the air parcel’s “desire” to return to its original position that identifies it as “stable”.

Mixed Layers of Stable and Unstable Air

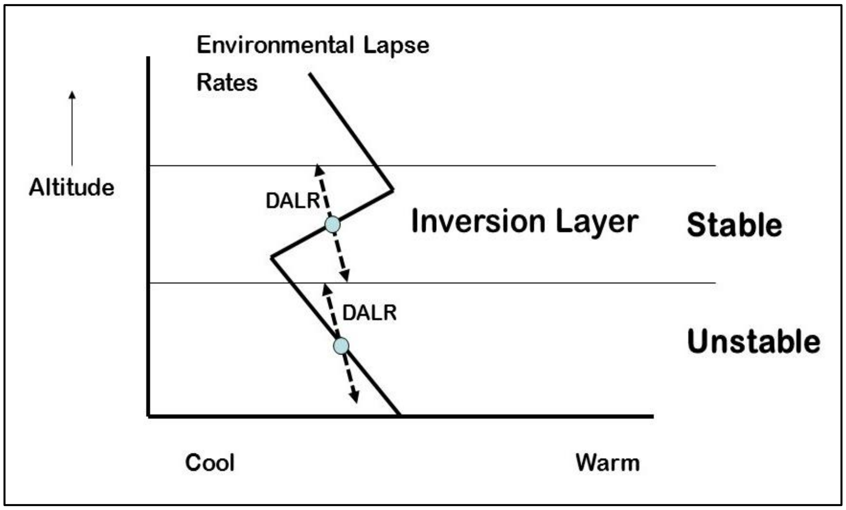


Figure 59. An atmosphere with changing unstable and stable layers. The stable layer acts as a lid, preventing the greater dispersion of the lower layer of air. Image Source: Stephen Vermette.

Figure 59 depicts an atmosphere with mixed layers. In the case shown, the inversion (very stable air) acts as a lid, preventing further upward motion of the unstable air below.

A ground level inversion is shown for Hamilton, Ontario on April 6, 1986 Figure 60). Cold surface air blowing off Lake Ontario wedged cold air under an otherwise warm layer of air (blue skies) over the city. The pollution “brown haze” below the blue sky is attributed to an inversion trapping pollution from the shoreline steel mills and city automobile traffic.

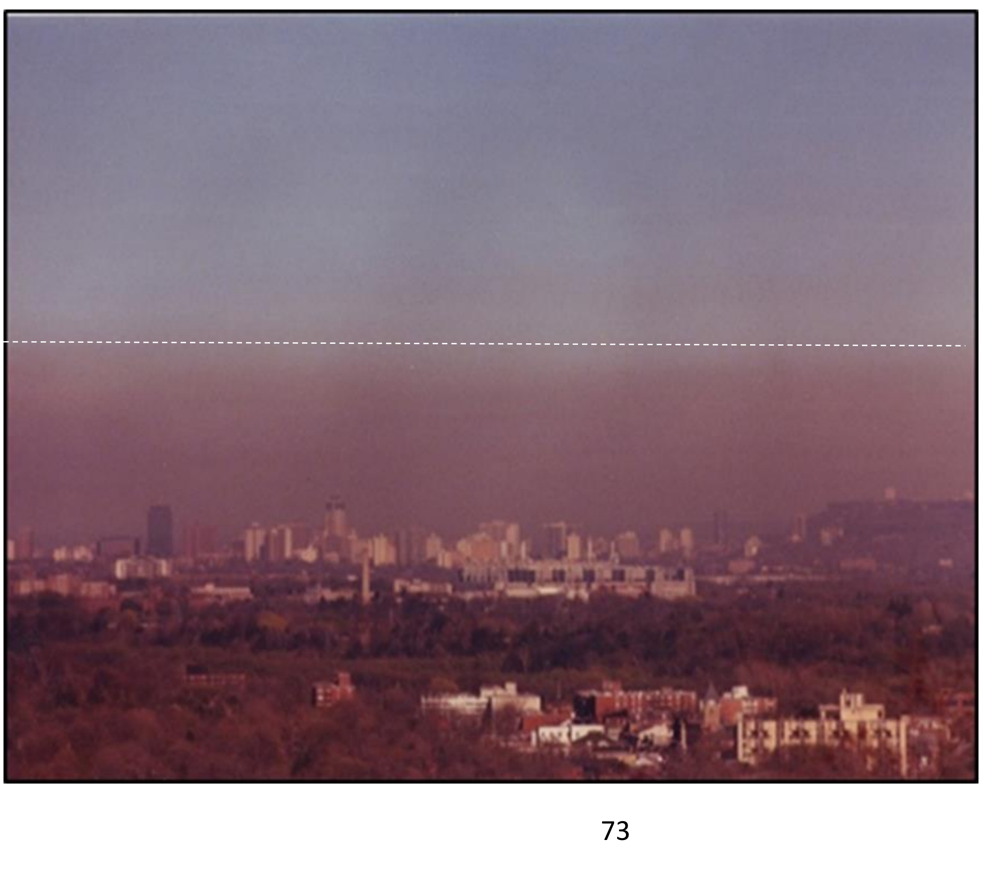


Figure 60. A ground level inversion is shown in Hamilton, Ontario on April 6, 1986. Cold surface air blowing off Lake Ontario (left to right in the photo) wedged cold air under an otherwise warm layer of air (blue skies) over the city. Image Source: Stephen Vermette.

Conditional Stability

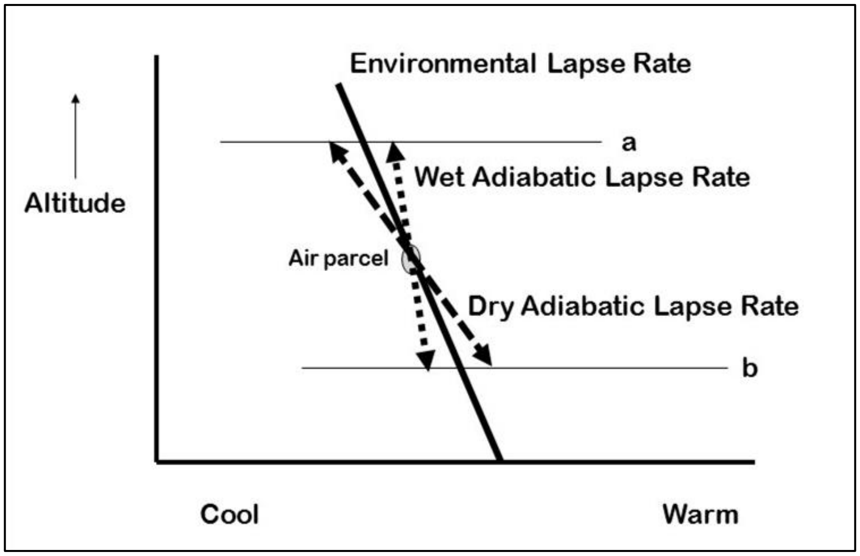


Figure 61. Conditional instability. Image Source: Stephen Vermette

There remains yet one more stability condition to consider, which is "conditional" (Figure 61). The "condition" here refers to the humidity of the air parcel. Air that is at <100% relative humidity cools and warms at the DALR (dashed line). In this example, it would be considered stable relative to the surrounding air (ELR). However, if the relative humidity were to increase to 100%, the air parcel would cool and warm following the WALR (dotted line). In the case of humid air (100% relative humidity), the rising air following the WALR would be warmer than the surrounding air at the upper horizontal line 'a' and would continue to rise (unstable). The descending air following the WALR would be cooler than the surrounding air at the lower horizontal line 'b' and would continue to descend (unstable). Thus, the stability class is considered "conditional" because the stability of the air parcel depends on its relative humidity.

Another Way to Look at Atmospheric Stability/Instability

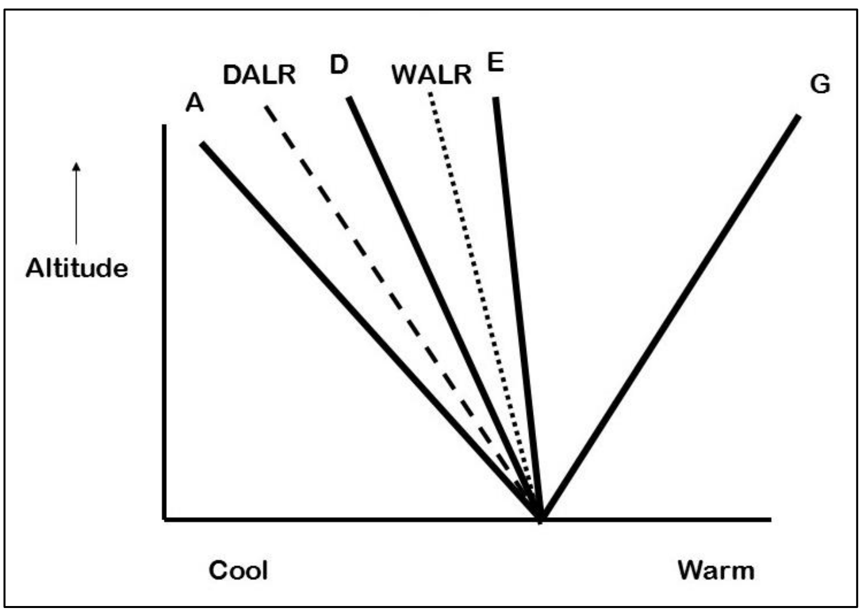
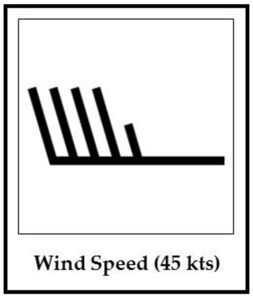


Figure 62. Various environmental lapse rates (ELRs) and stability classes: A = unstable; D= conditional; E = stable, and G = stable/inversion), along with the dry adiabatic lapse rate (DALR) and the wet adiabatic lapse rate (WALR). Image Source: Stephen Vermette.

To make things simpler, you need only remember that an atmosphere with an ELR between the DALR and the WALR (eg. a temperature change of 2.75°F - 5.5°F/1,000 feet) is "conditional"; an atmosphere with an ELR that is greater than the DALR (>5.5°F/1000 feet) is considered "unstable"; and an atmosphere with an ELR less than the WALR (<2.75°F/1,000 feet) is "stable". Figure 62 provides a visual of the stability classes of four ELR's (A, D, E, and G, are actual letter stability designations used in the literature) as related to the dry and wet adiabatic lapse rates.

Go Like the Wind



To begin, we must clarify a point of confusion for some. Wind direction refers to the direction that the wind is coming from. A wind vane points into the oncoming wind. The reason meteorologists are interested in where the wind comes from is that it delivers weather with it. By way of example, a north wind usually brings cooler air to WNY, while a south wind brings warmer air. Typical wind instruments are depicted in Figure 63. The ultrasonic sensor eliminates ice-related problems and is the most accurate of the wind instruments at measuring wind gusts. A makeshift wind vane. Hanging near a door sill at Fort Niagara, is shown in Figure 64.

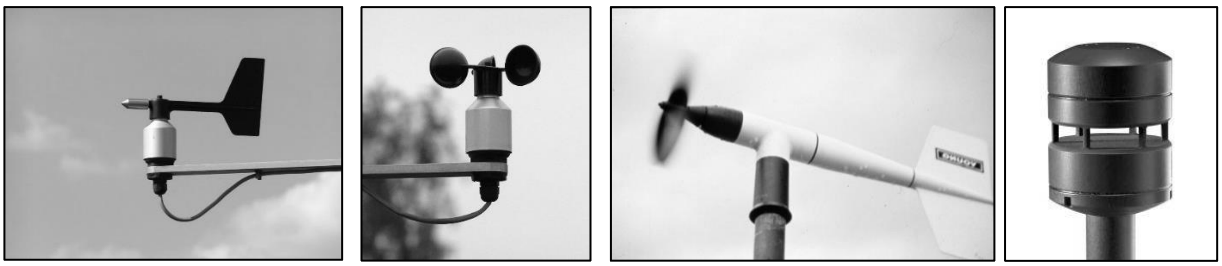


Figure 63. From left to right: wind vane (wind direction); 3-cup anemometer (wind speed); aerovane (wind direction and speed), and an ultrasonic sensor (wind speed and direction). Images source: Wikimedia Commons.

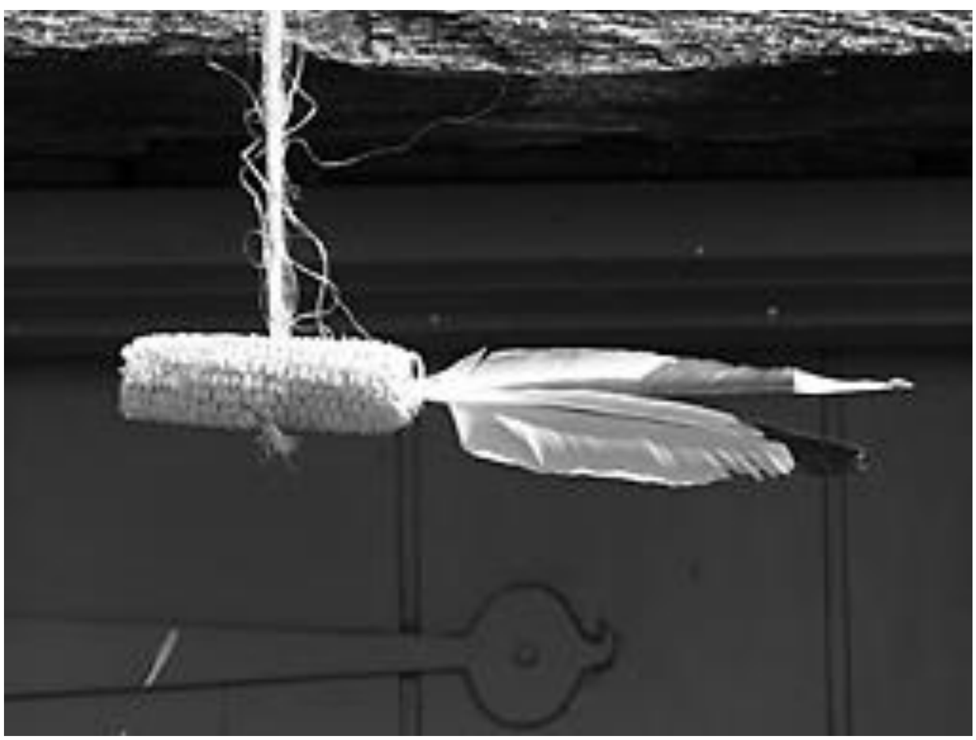


Figure 64. Creative (corn cob and feather) wind vane hanging from a door sill at Fort Niagara. Image Source: Stephen Vermette.

What causes wind? Earlier we described how the atmosphere works to maintain an equilibrium. Wind is an agent for this equilibrium. Unequal heating produces pressure differences and it is these differences in pressure that push air from areas of high pressure to areas of low pressure (pressure gradient force). Wind is defined as the natural movement of air. The pressure gradient is the force that causes wind and is one of three forces that influence its direction and speed.

In addition to initiating wind, the pressure gradient force influences both its direction and speed. Wind initially follows a path from high to low pressure, and the differences in pressure between the two points influence its speed. The difference between high and low pressure is much like a toboggan run, the greater the height difference (slope), the faster the toboggan will run. Similarly, as in the case of wind, the greater the pressure difference the faster it blows. Strong winds are often used as a harbinger of changing weather.

The other two forces affecting wind are Coriolis and friction. The Coriolis force is not a real force but, rather, compensates for something that is difficult to envision. We know that the earth rotates (spins) on its axis in a counterclockwise direction (from the perspective of the Northern Hemisphere). We see this in the sun's path across the sky and in the movement of stars. We have long given up the notion that the earth is the center of the universe. But, because we cannot feel this movement, we think that we are standing still. At 43°N in WNY we are traveling with the earth at a speed of about 770 mph. The Coriolis force was invented to include the effect of this "spin" (rotation) on the movement of wind – we pretend that the wind turns, and the earth is stationary.

The Coriolis force describes how wind deflects to the right of its path of motion in the northern hemisphere, and to its left in the southern hemisphere, compensating for the earth's rotation. This effect was first recognized when cannon fire extended to greater and greater distances. The projectiles would miss their intended target, as if the intended target had moved out of the way. A football analogy applies here. A quarterback never throws the football to a receiver, but rather to where the receiver will be on the field. The upshot of this is that rather than winds blowing directly from high to low pressure, they are apparently "deflected" from their path.

The best illustration of the interaction of the pressure gradient and Coriolis forces is to consider Earth's global winds (Figure 65). The example described below is a basic conceptual model that assumes a uniform surface (mixed surfaces of land and water complicate things) when the sun's rays are perpendicular over the equator (spring and fall equinox). Pressure and wind belts move slightly northward in the summer, and southward in the winter, following the path of the sun's direct rays.

Recalling the guiding principle "rising air lowers surface pressure", a series of pressure belts can be defined on the earth. Focusing on the northern hemisphere, heating at the equator causes air to rise. This rising air descends at about 30°N, establishing a high-pressure belt located at that latitude (attributed to descending air due to upper air cooling). Surface winds flow from the high to low pressure (pressure gradient force) but are deflected to the right of their path of motion (Coriolis force), creating the northeast trade winds. This cycle is referred to as the "Hadley cell". Surface air travelling from 30°N to 60°N flow from high pressure (30°N) to low pressure (60°N - a low-pressure belt attributed to warm air meeting cold air from the polar region), causing the surface warm air to rise along the polar front), but is deflected to the right of its path of motion creating the westerlies. For WNY, the prevailing winds are the westerlies (blowing most often from the southwest). The polar easterlies are attributed to air moving from the poles (high pressure) to the polar front (low pressure) and deflected to the right of their path by the with Coriolis force.

The pattern of winds are duplicated in the southern hemisphere, where the Coriolis deflection is to the left. The "Intertropical Convergence Zone" at the equator is where the southeast trade winds of the southern hemisphere converge at the equator, providing yet another lifting mechanism.

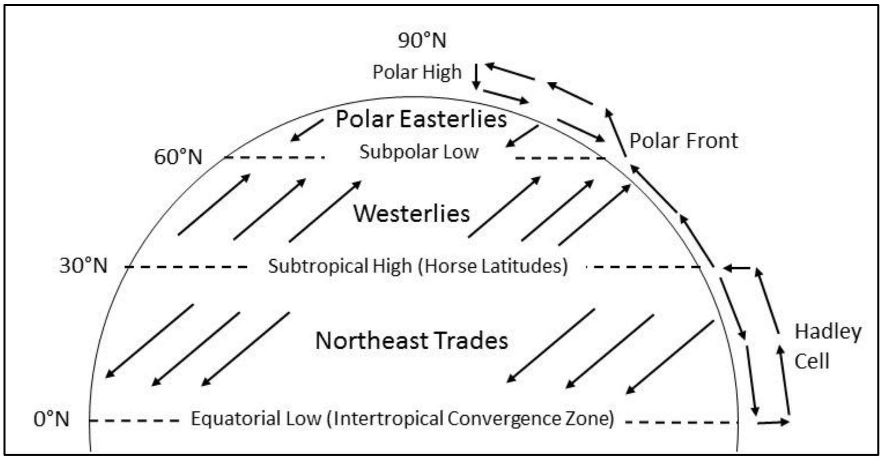


Figure 65. Northern Hemisphere pressure belts and winds. Image Source: Stephen Vermette.

Consider Columbus' discovery of the New World. Columbus had learned that the prevailing winds off the bulge of Africa were from the northeast. He used this knowledge to sail westward from Africa where he made first landfall in the New World on the island of San Salvador, Bahamas in October of 1492. In the "Rime of the Ancient Mariner", the lines *"Day after day, day after day, We stuck, nor breath nor motion; As idle as a painted ship Upon a painted ocean."* describe the absence of wind around 30°N where global winds diverge (separate). This area is sometimes referred to as the "Horse Latitudes" purportedly because horses were thrown overboard to lighten the load, hopefully allowing sails to catch enough wind to move the ship along.

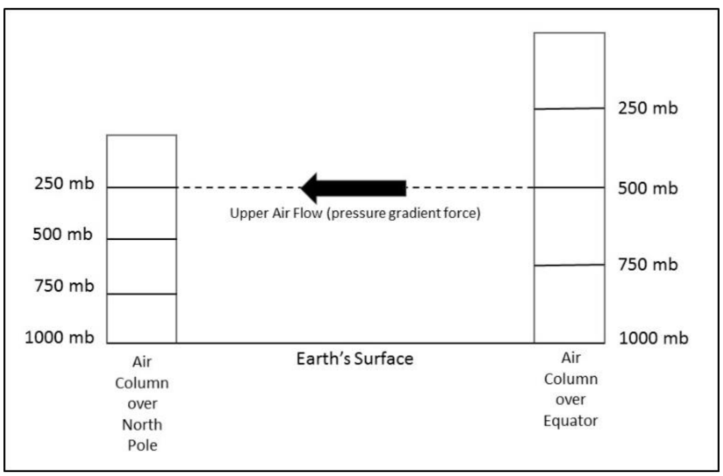


Figure 66. The atmosphere is thickest over the equator, such that upper air at a given altitude in the northern hemisphere flows north from higher to lower pressure and is subsequently deflected to the right of its path of motion by the Coriolis Force, resulting in upper air winds that flow from west to east. Image Source: Stephen Vermette.

The interaction of pressure gradient and Coriolis also influences the direction and speed of upper air winds, but the controlling mechanism is a little different than that for surface winds (Figure 66). Based on the principle that "hot air rises" (buoyant), the warmer troposphere over the equator is thicker (taller) than the colder air over the poles. For any given air pressure (mb), the altitude is higher over the equator than over the poles. The horizontal movement of upper air at a particular altitude is directed by the pressure gradient force. In the case of the northern hemisphere, air flows from the higher pressure over the equator to lower pressure at the same altitude over the north pole but is deflected to the right of its path of motion by the Coriolis force. Thus, the prevailing direction is from west to east across the entire northern hemisphere. In fact, the left deflection in the southern hemisphere also results in upper air winds traveling from west to east.

The balance between pressure gradient forces and Coriolis causes these upper air winds to blow parallel to lines of equal pressure (isobars). This flow is referred to as "geostrophic" flow. This means, for example, that a jet plane flying east will always have a tail wind, while one flying west will always have a headwind.

“Rossby waves” are the undulations in upper air winds, and “jet streams” are the fastest flowing areas of the upper air winds. More about this later.

Given that pressure decreases with height, one question to ask is why there are not strong vertical winds powered by the strong vertical pressure gradient? The answer is that there is a counter force; gravity. The balance between these two forces is referred to as “hydrostatic equilibrium”.

Back to surface winds, it is here that the third force, friction, has its greatest influence. Wind passing over the surface creates a frictional drag that slows it down. This layer of drag is referred to as the “boundary layer”. The frictional drag not only reduces the speed of the wind but also affects its direction. The Coriolis force is impacted by wind speed in that faster winds create a stronger Coriolis force. So, as wind speed weakens from frictional drag, so too does the Coriolis force and the degree of the wind’s deflection.

These three forces, pressure gradient, Coriolis, and friction, can be harnessed to explain the inward counterclockwise flow around a low-pressure system (also referred to as “cyclonic” flow), and the outward clockwise flow around a high-pressure system (also referred to as “anticyclonic flow”). Let us first consider a northern hemisphere low pressure system. While all three forces work simultaneously, when broken down into steps: air first flows inward toward the low’s center due to the pressure gradient force, then is deflected to its right due to the Coriolis force, then finally inward to the left due to the weakening Coriolis force (less deflection) where the weakening is caused by surface friction. In the case of a northern hemisphere high pressure system, the flow is outward away from the high’s center, then deflected to the right, and outward to the left due to friction. These wind directions are opposite in the southern hemisphere, due to the “left” deflection attributed to the Coriolis force.

A modification of “Buys Ballot’s Law” can help apply this knowledge. The law, as it applies to WNY, states that when outside stand with your back to the wind, turning slightly to the left to account for friction. By extending your left arm out you are pointing in the general direction of a low-pressure system, the extension of your right arm points in the general direction of a high-pressure system. As weather usually travels from west to east (remember that WNY is in the westerlies) whatever is to your west is approaching your location, and to your east, leaving your location. A low-pressure system is likely to bring cloudy wet weather, while a high-pressure system is likely to bring clear dry weather. Yes, back to Tom Jolls and “weather is easy”.

Box 13 **Gull Wind Vanes**

Image Source: Stephen Vermette

The lakeshores along Lakes Erie and Ontario are a year-round home to gulls (Ring-billed gull). You may have noticed that groups of perched gulls tend to face in the same direction, into the wind. This behavior is likely related to comfort, as facing away (in the downwind direction) would ruffle feathers and allows for ease of takeoff for flight. By consistently facing into the wind, gulls provide a reliable indicator of wind direction.

WNY's Locally Sourced Winds

Local Lake-Land Breeze

The local lake-land breeze that occurs on WNY's Lakes Erie and Ontario shorelines is distinct from regional winds that blow on or off of the lakes. This local breeze creates a distinctive wind pattern, which is an expression of the different heating properties of land and water (Figure 67). Land heats up faster and loses heat at a faster rate than does water. During relatively calm sunny days, the land warms up faster than the lake. The warm air over the land rises, creating a localized area of low pressure, whereas the colder air over the lake subsides, creating a localized area of high pressure. In the absence of a larger scale regional wind, the pressure difference is enough for air along the water-land interface to flow landward (from high to low pressure). This flow is referred to as a "lake breeze". A return air flow at a higher altitude completes the circuit.

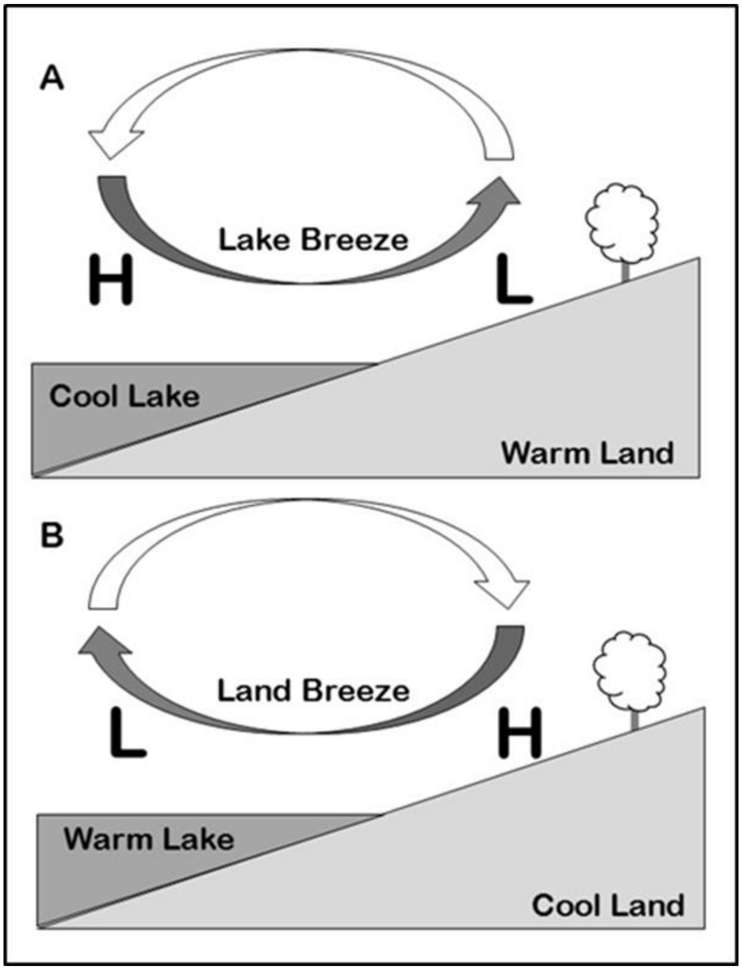


Figure 67. Lake Breeze (A) showing surface winds blowing onshore. Land Breeze (B) showing surface winds blowing offshore. Image Source: Stephen Vermette.

The opposite "land breeze" usually occurs at night when the areas of high and low pressure, as described for the lake breeze, are reversed. During calm clear nights, the land cools down faster than does the lake. The warmer air over the lake rises, creating a localized area of low pressure, whereas the cooler air over the land subsides, creating a localized area of high pressure. Under these conditions, the surface wind travels lakeward. As with the lake breeze, a return air flow at a higher altitude completes the circuit.

On a hot, calm summer days, the beach is a destination partly due to the cooling breeze coming off the lake. Europeans in Africa would refer to a sea breeze as "the doctor" because of the relief it provided in those tropical regions. The penetration of the lake breeze in WNY varies with atmospheric conditions, but usually extends only a few miles inland, although it can extend farther (about 20 miles) at times. It is usually at its strongest during late spring hot spells. The local lake-land breeze plays an important role in moderating spring temperatures near the shorelines of Lakes Erie and Ontario, preventing early budding during periods of unseasonably warm temperatures inland. For this reason, vineyards and tender fruits are grown along the lake's shorelines. In the past, the plumes from the now-defunct shoreline steel mills and power plants would first drift one way, and then another, in concert with the diurnal cycle of the lake-land breeze. Today, you can monitor the lake breeze by watching waving flags and soaring kites along the shorelines of Lakes Erie and Ontario.

Country Breeze

Under low wind velocities, cool air is sometimes pushed into urban areas from the countryside. These winds are induced by the "urban heat island", where excess heat generated by activities within the city establishes a surface low pressure. Given that air travels from high to low pressure, a local country breeze is generated. A well-designed city takes the country breeze into consideration due to its beneficial summer cooling effects.

Mountain-Valley Breeze

In the higher elevations of southern WNY (the Southern Tier), within the Allegany Plateau, the land is dissected by numerous valleys and hills. These abrupt differences in elevation can set up a very localized breeze under otherwise calm conditions. During the day, the hill slopes receive more sun than does the valley, thus warming the air relative to the valley. The rising air along the hill slope sets up a pressure gradient where air travels upslope from the higher pressure on the valley floor. At night, the air cools along the slopes and, due to its density, descends into the valley. While the breeze is not often measured, the cool air pooling in a valley (under saturated conditions) is sometimes evident as valley fog.

Down-Sloping Winds

The terrain within WNY varies in elevation between about 2,500 feet asl within the Allegany Plateau to the south, and about 243 feet asl along the Lake Ontario shoreline to the north. A cross-section of WNY's terrain reveals a persistent south-to-north downward gradient – sloping from the Allegany Plateau, through the Niagara Frontier, including the Onondaga and Niagara escarpments, to the shore of Lake Ontario. On days with southerly winds, forecasted temperatures are often raised a few degrees beyond those which are anticipated by model outputs for places in the Niagara Frontier, north of the Allegany Plateau. The raised temperatures are attributed to the adiabatic warming of down-sloping southerly winds. This means that the air moving down slope warms as it undergoes compression due to increased atmospheric pressure.

A NWS forecast discussion on such a day read: *"Given the south to southeast flow in the lower part of the boundary layer...the risk for any lake cooling will be negated. There will also be some down sloping. This will particularly be the case across the Niagara Frontier and Rochester Area, where compressional downslope warming will be most effective."*

Local Knowledge

Making Sense of the Winds on Lakes Erie and Ontario

Contributed by J.J. Ptak and Dean Aschenbrenner

"Local Knowledge" is an actual sailing term that refers to how conditions in a specific geographical area affect boating in that region. People who frequent local waters are familiar with the variables in currents, the safest way to get around, and the vagaries of wind and weather. That is local knowledge and it can be crucial. J.J. Ptak and Dean

Aschenbrenner are sailors and WNY weather enthusiasts. They provide their own accounts of sailing and dealing with the vagaries of wind and weather off the WNY shores of Lakes Erie and Ontario, respectively.

"Sailing on Lake Erie" by J.J. Ptak: Lake Erie is long and narrow and is also the shallowest of the Great Lakes, so winds can whip it up into a churning mess in no time. Joshua Slocum, who famously was the first to single-handedly circumnavigate the globe, was said to have tried sailing on the Great Lakes. He is reputed to have said that *"no one should ever sail on Lake Erie."*

In the Buffalo area, winds blowing from the northern directions blow over higher land and then over the lake, resulting in flatter water but good winds. It makes for a fast but smooth sail. There is a funneling effect as you cross the Niagara River, but the Black Rock Channel, which runs alongside it, can catch you off-guard. Its higher sides and narrow channel form a wind tunnel that can raise wind speeds, sometimes almost exponentially. If you're not aware of that, it's a surprise, to say the least.

Easterly winds, coming across the land, are different. The city is right there with all its buildings and other features and as the air bounces through all this, you end up with fluky winds and some funny oscillations. South winds along the city and southern suburbs are less fluky than east winds, but as you get away from buildings and more toward open country, they settle out and winds become steadier.

Lake Erie has a southwest to northeast orientation, so the prevailing southwesterly winds follow the full length of the lake producing big lumpy water and swells. Sailing toward Erie, Pennsylvania in heavier air, as you take it on the nose, makes that a challenge, while coming back to Buffalo in those winds gives you following seas that can make for some real adventure.

From the west, the word is "choppy". Waves seem to be on top of each other, which in lower winds are manageable, but make for a smashing experience in strong breezes. Toss in the expected oscillations and gusts and you can have an exciting day on the water.

This is Buffalo. Things change as you head over to Dunkirk, Erie, Port Colbourne, and Long Point, or anywhere else on any body of water. They have their own "local knowledge".

"Sailing Through a Thunderstorm on Lake Ontario" by Dean Aschenbrenner: Born and raised in WNY, I have been a sailor on Lake Ontario out of Wilson, New York since 1971 so I have a deep respect for the weather and its vagaries. On most days, a planned sail begins by checking on the daily forecast, wind direction, wind speed, and wave heights as well as the predictions for the time I expect to be out.

Sailing at the western end of Lake Ontario, westerly winds have a relatively short fetch so they don't build much. Easterly winds, on the other hand, have 400 miles of fetch and usually build some serious chop that may last for a day or so.

Sailing on a beautiful summer day is a great sport. Sun, fair winds, and light waves make for a most relaxing time. I average 40 – 45 sails per summer over a 5-month period.

Last summer (6 August 2017) I was out sailing with a friend on his boat and expecting a fine summer day. After a couple hours of great sailing and being about 5 miles from shore, we began to see building clouds to the west that would pass between us and the shore. Heading back in, we saw the clouds darken and a check of the weather radar indicated that a thunderstorm had developed most unexpectedly and that we would be caught by it.

We lowered sails and prepared the boat for the oncoming storm. A last check of the radar showed that it was a small, circular storm of minimum density but it was still going to be upon us. When it did hit, it brought rain and winds in the 30 mph range but thankfully, because of the rain, the waves did not rise too much - the rain was so hard that it basically knocked the waves down into the 3 to 5 foot range. After losing sight of the shore for about 20 minutes, the storm passed, the sun came back out, and we finished a lovely sail – although a bit wet.

Western New York Weather – they say *"If you don't like it, wait five minutes and it will change."* They were surely correct on that day.   Sail safe.

Box 14 Salt – The Cost of Living in WNY

Brine solution surrounding a piece of salt. Image Source: Stephen Vermette

In WNY, road salt (rock salt) is a necessary ingredient keeping our roads and walkways clear of ice in winter − reducing accidents and injuries and keeping our economy humming. Slick surfaces are a winter hazard. As a forensic meteorologist, I've been involved in many winter slip-and-fall court cases associated with slick surfaces. To lessen risk, the city of Buffalo spreads about 30,000 tons of rock salt per year, whereas smaller communities use less (eg. Town of Amherst about 15,000 tons, and Town of Concord about 1,000 tons). Equal to each community, however, is the 'pain' associated with the budget hit for road salt – one of the wintertime costs of living in WNY.

When temperatures drop below 32°F, surface ice forms − often as a transparent coating of ice known as 'black ice'. While there are varying techniques for de-icing, the application of salt on snow or ice (or on surfaces before a freezing event) is generally used. This application creates a brine solution which lowers the freezing/melting point of water, preventing the liquid water from freezing at temperatures below 32°F. Generally, salt is not effective at temperatures lower than 15°F. Under these conditions it is best to use sand or other gritty substance for traction. The appearance of a white coating on roads in the winter is simply residual salt that will linger until a good rain. One downside of road salt is that it rusts the underside of our vehicles − rusting from the bottom up. A vehicle with a rusted roof, however, has likely spent time along a seashore, as the salt spray settling on the surface tends to rust a vehicle from the top down. In addition to rusting vehicles, excess salt application can damage concrete, vegetation, and contaminate our local creeks. The practice of dumping plowed snow into waterbodies has long been discouraged because of the residual salt embedded within the snow.

Chapter 4
WNY's Weather

Roller coaster at Darian Lake Theme Park Resort. Image Source: Wikimedia Commons/Michael Greiner

WNY's Rollercoaster Weather

For anyone who lives in WNY, the "ups and downs" of our weather are well known. A warm sunny weekday in July can easily be followed by a cold rainy weekend at the beach. Winter weather forecasts alternate between snow warnings and flooding. And the freezes and thaws of winter wreak havoc with our snow cover. I recall one cold August day sitting in the bleachers of Pilot Field (recently named Sahlen Field) to watch the Buffalo Bisons play ball while "freezing" due to the wind coming off the lake. This level of variability is not found everywhere in the world. For example, while working in Cambodia (about 12°N) I didn't even bother checking day-to-day weather, as it was essentially unchanging during my stay (Figure 68).

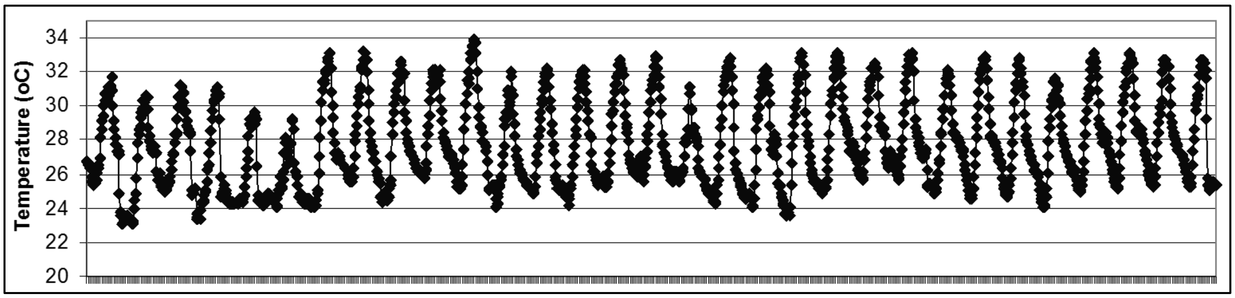


Figure 68. October temperature measurements (30-minute increments) taken near Phnom Penh, Cambodia. The diurnal pattern of daily maximum and minimum temperatures change little over a month. The number of days can easily be counted for the month of October based on their diurnal highs and lows. Image Source: Stephen Vermette.

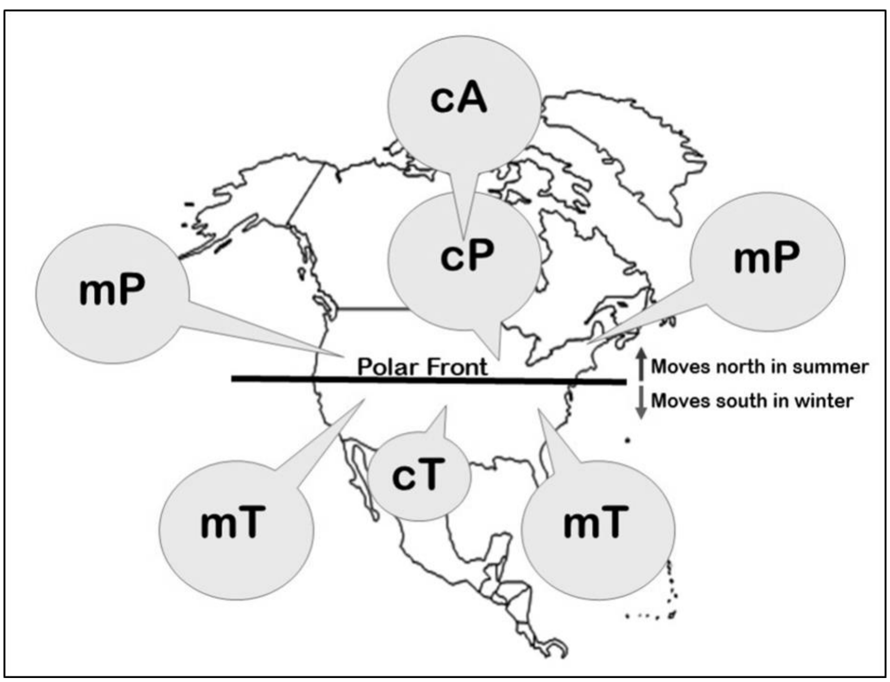


Figure 69. Types and source regions of air masses. Image Source: Stephen Vermette.

To make sense of our weather rollercoaster ride, let us first consider WNY's position in relation to the source regions of North America's air masses (Figure 69). Air masses are large bodies of air which take on the characteristics of the homogenous surface that underlay them. By way of example, an air mass that forms over a desert is hot and dry, whereas an air mass that forms over an ocean is humid in contrast to one that forms over land. The nomenclature used to describe air masses is based on humidity and temperature, such that mT and cT refer to maritime and continental tropical air masses, respectively; and mP and cP refer to maritime and continental polar air masses, respectively. Even colder than these classifications is the cA air mass located in the Canadian high Arctic.

Geographically, air mass source regions are positioned either north or south of WNY. Air masses migrate, and when doing so, they are modified by the surface over which they are moving while maintaining their basis characteristics − a polar air mass transports cold air south, while a tropical air mass transports warm air north. The same situation occurs with contrasting humid and dry aspects of air masses. WNY is often caught in the middle, the battleground between contrasting air masses and their boundaries (fronts). As a greater proportion of the sun's energy moves away from the northern hemisphere and into the southern one, the approach of winter across North America sees polar air masses penetrate farther and farther south along a leading boundary known as the "polar front". In winter, WNY is usually north of this front, meaning generally cold conditions. In summer, WNY is usually south of this front, meaning warmer conditions. While the migration of the polar front is persistent on a seasonal scale, it does get pushed north and south from time-to-time, leading to short-term incursions of warmer and colder spells of weather. It is along air mass boundaries, or fronts, that weather is most variable. This is the first turn on our weather "rollercoaster ride".

Early weather maps displayed air masses but the use of a boundary or front to conceptualize weather first came about after WWI (it was adopted by the U.S. Weather Bureau much later, around WWII). This conceptual model is known as the "Norwegian Model" as it was developed by Norwegian scientists. The frontal terminology used in the model relied on WWI references to battle fronts and trench warfare occurring during its development. Today, a weather forecast map, especially one presented to the public, is reliant on the use of these fronts.

The two basic categories of fronts are the "warm" and the "cold" front (Figure 70). The warm front is depicted as a line with rounded half-circles, where the half-circles mimic the helmets worn by the WWI allied forces.

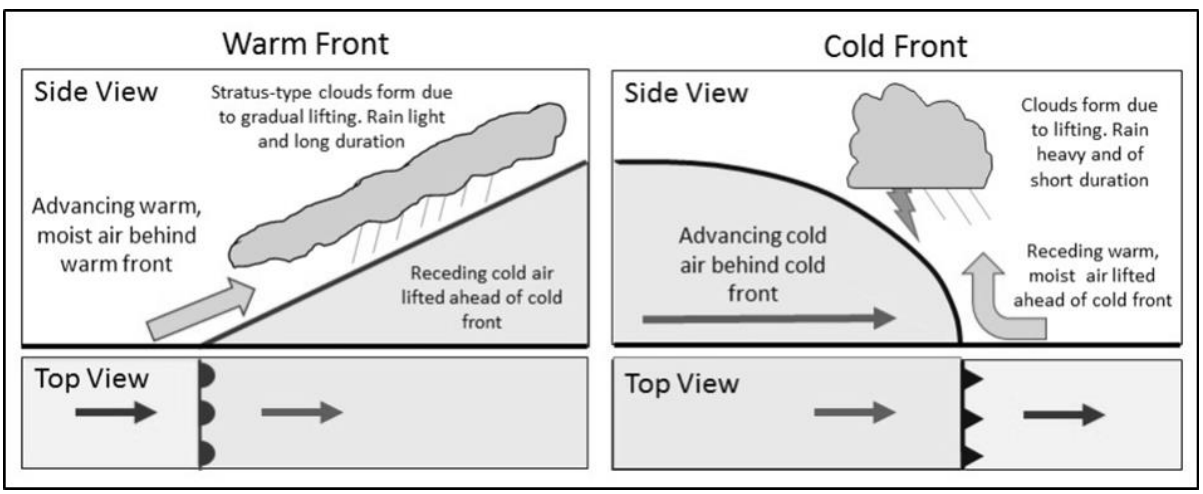


Figure 70. Warm and cold front depictions. Image Source: Stephen Vermette

The warm front describes a boundary where advancing warm air ascends (rises) over retreating cold air. The approach of a warm front is often indicated by the progressive lowering of cloud heights as the front approaches (cirrus, altostratus, and stratus-type clouds). As the angle of the front is slight, precipitation is often long-lasting but light in intensity.

The cold front is depicted as a line with spikes, where the spikes mimic the spike atop a Pickelhaube (pointed) helmet worn by the German forces. The cold front describes a boundary where advancing cold air bulldozes warm air ahead of it and replaces that warm air in the region previously occupied by it. As the slope of the front is steep, the rapidly rising air may generate thunderstorms and related severe weather

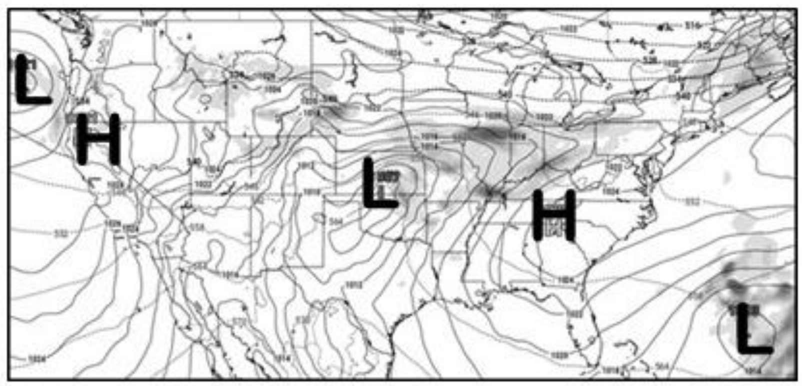


Figure 71. A "train" of high- and low-pressure systems moving across the country. Image Source: PivitolWeather.com.

(cumulonimbus clouds), but the severe weather is often of a short duration (as compared with a warm front).

These fronts are components of larger systems known as extratropical or midlatitude cyclones (low pressure cells) sandwiched between anti-cyclones (high pressure cells) that migrate from west to east across the U.S., much like box cars on a traveling train (Figure 71).

The formation of the two pressure cell types is attributed to the changing speed of upper air winds. In areas where upper air winds speed up, air is drawn up from the surface creating a surface low, whereas in areas where upper air winds slow down, the air is forced downward creating a surface high (Figure 72).

Because the surface pressure cells are intricately tied to the upper air, the path and speed of the upper air can be used to predict the direction and speed of these surface pressure systems − generally traveling at speeds half those of upper air winds. If the ebb and flow of seasonal air masses is the first turn on our roller coaster ride, this moving "train" of high- and low-pressure cells is our second. High pressure is associated with descending air which generally bring clearing skies, followed low pressure and rising air which generally brings cloud and precipitation, followed again by high pressure, and so on.

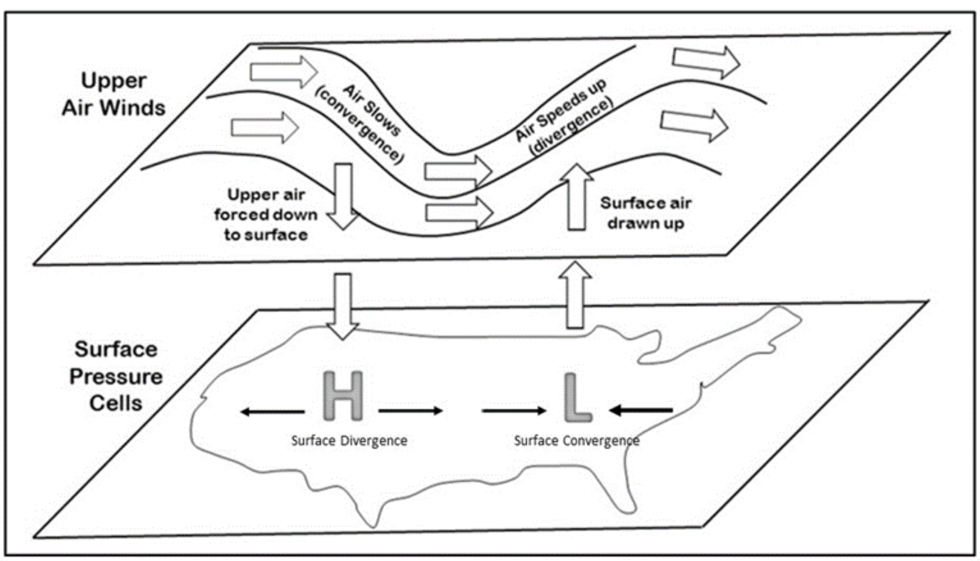


Figure 72. Upper air winds generate surface high- and low-pressure cells. These surface cells migrate across the country following the upper air winds.
Image Source: Stephen Vermette.

Midlatitude cyclones move across the country following preferential paths known as "storm tracks" (Figure 73). "Alberta Clippers" form in southern Alberta, Canada. They tend to contain low moisture, but develop and move quickly eastward, usually passing north of WNY. "Colorado Lows" form just east of the Rocky Mountains. These lows contain intermediate amounts of precipitation, moving east at a slower pace than the "Alberta Clipper. The Colorado Low can bring severe weather to the Plain and Midwest states (thunderstorms and tornadoes in the warm months and blizzards in the cold months). The "East Coast Low" forms along the coast of the Gulf of Mexico (sometimes in Texas) and tends to migrate northeast along the Atlantic seaboard. These storms contain large amounts of moisture, developing and moving slowly. The moisture initially comes from the Gulf of Mexico, but additional moisture is provided by the Atlantic Ocean. These storms are referred to as "Nor'easters" in New England, as counterclockwise winds north of the low deposit copious amounts of rain or snow in the region. The expression "Winds from the east are good for neither man nor beast" describe the winds of the Nor'easter. WNY may be impacted by strong Nor'easters, but eastern and central New York are impacted more because precipitation diminishes westward from the storm's center.

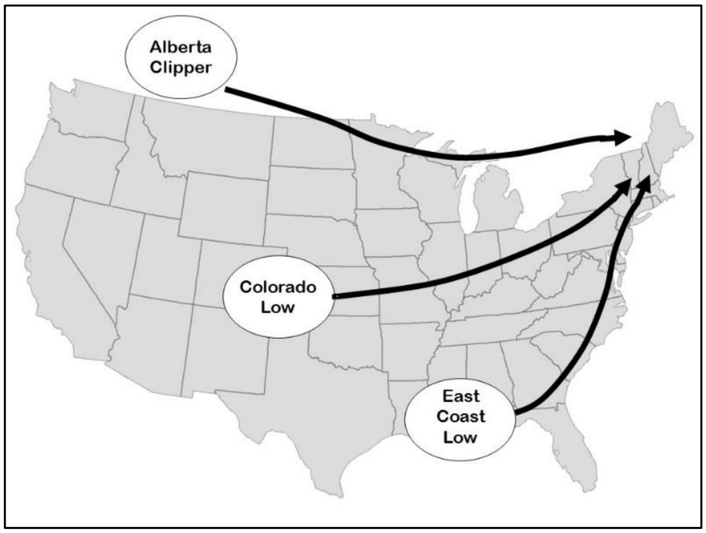


Figure 73. Formation areas and tracks of principal storms across the country. Image Source: Stephen Vermette.

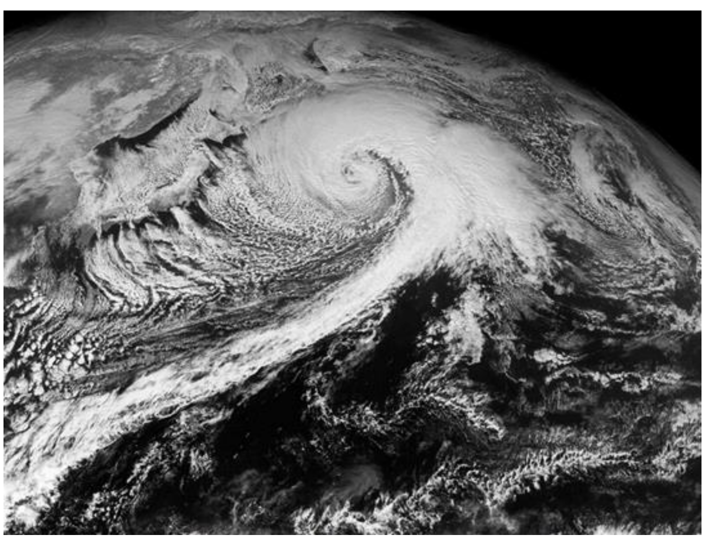


Figure 74. Satellite image of an extratropical cyclone showing the cloud shield around the center "Low" and the cold front extension giving the "comma" shape. Image Source: Wikimedia Commons.

Yet another turn may be added to our weather rollercoaster ride. Within the counterclockwise flow of a mid-latitude cyclone, warm surface air is drawn north by a warm front, and cold surface air is drawn south by a cold front. The shape of the cyclone is distinctive on a satellite image, where the cloud shield and cold front extension look like a large comma (Figure 74).

While an extratropical cyclone generally brings clouds and unsettled weather, it is along the frontal boundaries within a midlatitude cyclone that the greatest weather variability occurs (Figure 75). Along the warm front, the advancing warm air rises gradually over the retreating cold air. The rising air creates cloud cover and the gentleness of the rise brings light but long-lasting rains or snow – wind directions shift, and warm conditions follow. Along the steeper cold front, the warm air rises quickly, often producing a line of thunderstorms and associated severe weather – wind directions shift, the precipitation usually passes quickly, and cold conditions follow. In the warm sector, behind the warm front and before the passage of the cold front, the weather is warm and often clear or partly cloudy. Areas in the northern half of the cyclone experience extended periods of cloud cover and light rain. So, even within a midlatitude cyclone there is a great deal of weather variability. The weather depends on your position within, and the passage of, the cyclone. This represents the last turn on our weather rollercoaster.

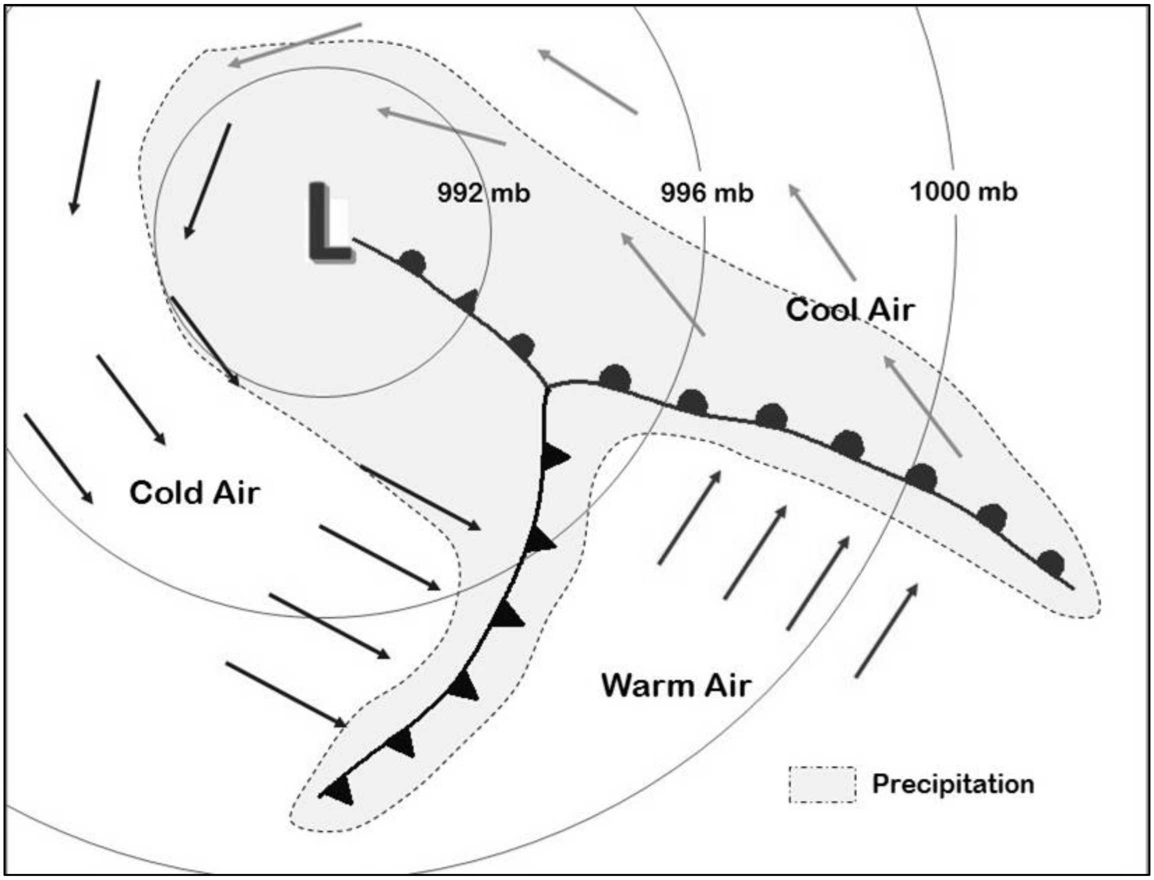


Figure 75. Typical extratropical cyclone, showing warm, cold, and occluded fronts. Area shaded is precipitation. Image Source: Stephen Vermette

“Cyclogenesis” describes the birth and death of the midlatitude cyclone. Initially, the frontal boundary is stationary (surface air flow is parallel to the front). A distortion along this front (see upper air winds) causes a wavelike pattern where warm and cold fronts form and advance perpendicular to the original front – warm air advancing on cold, and cold air advancing on warm. Focusing on the cyclone’s demise, the cold front advances at a faster rate than the warm front and the two eventually meet, creating what is known as an occluded front – forces air up cutting it off from the cyclone. This front first forms near the center of the cyclone, where the cold front first overtakes the warm front and over time extends away from the center, much like a closing zipper. Once “zipped”, cyclogenesis is in its final stage as warm mass is cut-off from the cyclone. While further storm intensification and precipitation may still occur over the short term, the cyclone eventually dissipates, along with its associated weather.

As part of cyclogenesis, a rapid drop in atmospheric pressure can intensify the midlatitude low-pressure system in a process known as “bombogenesis”, referred to recently as a “bomb cyclone” – typically defined as an atmospheric pressure drop of at least 24 mb in 24 hours (in reality the drop in pressure is dependent on latitude, so at our latitude it would be defined as 18 mb in 24 hours). The rapid deepening of the low-pressure system increases wind speeds creating dangerous and long-lasting gusts along with weather typically associated with a midlatitude cyclone. Bombogenesis is most common in the autumn, winter, and spring months when the clash between cold and warm air masses are most pronounced, and along the eastern seaboard (the big nor’easters are usually bomb cyclones).

To recount the ride, our "turns" on the weather rollercoaster include: 1) the migration of air masses; 2) the traveling "train" of high (anticyclones) and low (cyclones) pressure cells that move across the country; and 3) the dramatic weather variability within a midlatitude cyclone. These conditions are unique to the midlatitudes, which include WNY. And why our weather is so intriguing.

Flapping Butterfly Wings or Teleconnections

The butterfly effect describes how a small disturbance at one location – a butterfly flapping its wings, for example – can theoretically create a storm some distance apart, at another location. Similarly, teleconnections explain how recurring and persistent large-scale patterns of atmospheric pressure and circulation anomalies in one part of the globe may impact the weather/climate in another. The two teleconnections of interest to WNY's weather/climate − the North Atlantic Oscillation (NAO) and the El Nino Southern Oscillation (ENSO) − are located outside of the continental United States and have been shown to impact our winter weather. The influence of each teleconnection is on the flow of upper air winds (jet stream). A west-to-east flow (zonal flow) brings WNY warmer-than-normal temperatures, while a flow with a northerly and southerly amplitude (meridional flow) brings a greater frequency and intensity of cold air outbreaks to WNY.

The NAO is measured at two pressure centers located over the North Atlantic Ocean: a semi-permanent low-pressure system typically located over Iceland, and a semi-permanent high-pressure system typically located over the Azores in the eastern Atlantic. Periodically, the Icelandic Low and the Azores High will strengthen (positive phase NAO), resulting in an increased pressure difference between the two centers. This enhanced difference in pressure strengthens the jet stream, reinforcing zonal flow across eastern North America, such that WNY experiences warmer-than-normal temperatures during the winter months. A negative phase NAO indicates a weakening of both the low-pressure center over Iceland and the high pressure over the Azores, resulting in a decreased pressure difference between these two centers. The lower pressure gradient weakens the jet stream, promoting a meridional flow, which in turn allows cold air to build up over Canada and to migrate south into WNY, bringing below normal temperatures during the winter months.

The second teleconnection considered here is the El Nino/Southern Oscillation (ENSO). The ENSO pattern involves a fluctuation in sea surface temperatures (SSTs) and atmospheric pressures in the equatorial Pacific Ocean. These fluctuations have been shown to cause variations in regional climate patterns beyond the Pacific. The two extreme phases of ENSO are termed 'El Nino' and 'La Nina'. A third state exists that may be considered a neutral state, which exhibits SST's between that of the El Nino and La Nina phases.

The El Nino (warm) phase occurs with the warming of the SST's of the central and eastern equatorial Pacific coupled with an oscillation in surface pressure across the Pacific (increasing in the west Pacific and decreasing in the east Pacific). The El Nino phase typically creates an upper air zonal flow, resulting in a milder-than-normal winter across the northern states. The La Nina (cool) phase is essentially the opposite of El Nino. The SST's of the central and eastern equatorial Pacific are cooler than normal. The La Nina phase changes the amplification of the jet stream, increasing meridional flow across the United States, resulting in cold air outbreaks in the northern states.

As for WNY, the expected swings in milder and colder temperatures associated with ENSO do exist but occur at a much lesser intensity than found in states further to our west (especially the northern plain states). However, the slight warming attributed to El Nino and slight cooling attributed to La Nina are amplified in WNY when synchronized with the NAO (eg. a positive NAO paired with El Nino amplifies the warming of each, while a negative NAO paired with La Nina amplifies the cooling of each). Something to think about the next time you see a butterfly flap its wings.

How Weather Radar Works

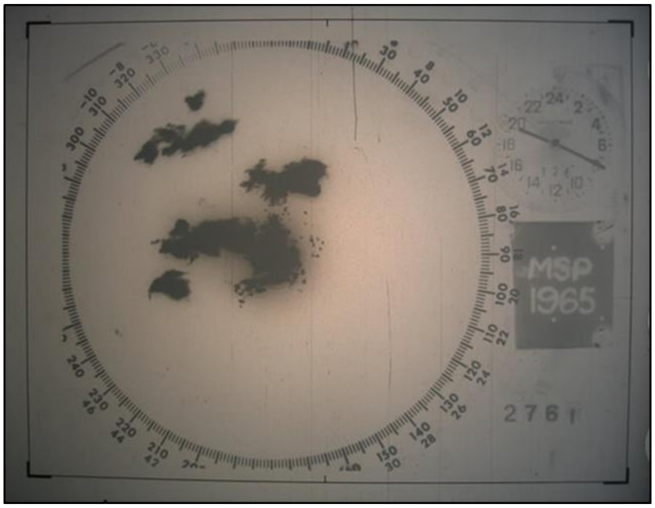


Figure 76. Early weather radar image showing thunderstorms from 1965. Inage Source: Wikimedia Commons/NOAA.

A map showing high- and low-pressure systems and associated fronts provides a "snapshot" of current weather and what might happen in the future (referred to as "synoptic meteorology"). Weather radar imagery reinforces our understanding of a weather event by providing tangible evidence of precipitation related events. While research into weather radar began just prior to WWII, it was the release of surplus aircraft radars at the end of the war, and their subsequent modification for weather use, that saw them first deployed as part of a major research initiative on the development and structure of individual thunderstorm cells ("The Thunderstorm Project"). The country also saw its first network of "Weather Surveillance Radars" (WSR). The first radar images were no more than "blobs" on a screen (Figure 76), but technical improvements and research over time allowed the evolution in resolution and understanding that we see today Figure 77).

A WSR was first operational at the Buffalo-Niagara International Airport in October 1961 (WSR-57). Across the country, a few progressive television stations purchased their own weather radars, with WNY's WIVB-TV an example of this. Later, "Next Generation Radar" (NEXRAD) or Doppler radar was installed at the airport in December of 1995 (WSR-88D). The latest upgrade, at the time of this writing, is "Dual Polarization Doppler Radar", operational since April 12, 2012. Weather radar revolutionized short-term weather forecasting, as well as the issuance of weather-related warnings.

The general workings of basic weather radar are relatively simple. Radar operates in two consecutive and repeating phases: the emission of microwave energy pulses over a series of sweeps of increasing heights, followed by a "listening" phase. If the pulsed energy strikes an object (e.g. a raindrop), the energy is scattered, and a fraction is returned to the radar as an echo. This energy is measured as decibels of Z (dBZ), where Z refers to energy.

The higher the dBZ, the greater the intensity of the precipitation (usually sequencing in increasing intensity from the colors blue, green, yellow, red, purple, and white respectively).

20 dBZ light rain or snow
30 dBZ moderate rain or snow
40 dBZ light thunderstorm or heavy rain
45 dBZ moderate thunderstorms
50 dBZ strong thunderstorms and potential flooding
60 dBZ severe thunderstorms and potential flooding

The location of precipitation, as determined by radar, is defined by the length of time between the outgoing pulse and the returning signal, while precipitation intensity is based on the strength of the energy received.

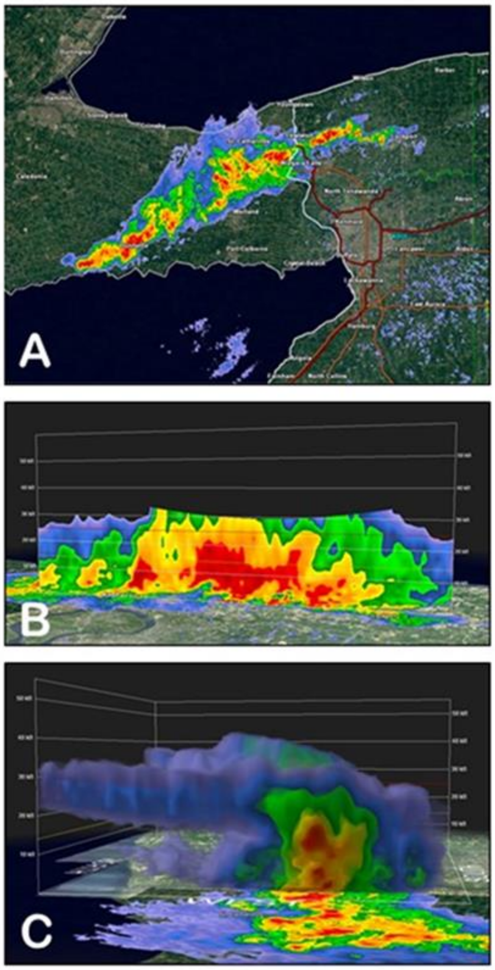


Figure 77. Radar image of a line of thunderstorms approaching WNY from across the Niagara Peninsula (A). Cross-sections of the thunderstorm (A and B). Image Source: R2Analyst.

Doppler radar is an improvement over basic weather radar in that it can additionally determine the movement of precipitation within a cloud (and thus the movement of updrafts and downdrafts within the cloud). It does this by further analyzing the returning energy in context of the "Doppler Effect". The Doppler Effect is often described as the changing pitch (changing frequency of sound waves) heard when race cars race toward you (higher pitch), and then away (lower pitch). About Doppler radar, a shift in the frequency of energy is detected, indicating whether the energy is striking precipitation within a cloud that is moving toward or away from the radar. Energy moving toward the radar is compressed (squeezed) in what is referred to as being "blue shifted" (some-times appears as a green color on a radar screen), whereas energy moving away from the radar is stretched in what is referred to as being "red shifted" (Figure 78). It cannot be understated that Doppler radar, with its ability to "see" the dynamics within a cloud, has greatly improved the ability of meteorologists to understand the development of severe weather, and to issue severe weather warnings, including tornado warnings. This ability is enhanced by placing Doppler radar on trucks – Doppler-On-Wheels (DOW) – which allows researchers to bring radar (sometimes multiple DOW's) to the storm.

The latest form of Doppler radar is called "Dual Polarization Doppler Radar". The dual polarization describes the pulsing and return of a 3D energy wave (taking in both side-to-side and up-down dimensions) that can measure the shape of the target. In other words, it can distinguish rain, hail, and snow based on their different shapes, and thus provide information on the type of precipitation within the cloud.

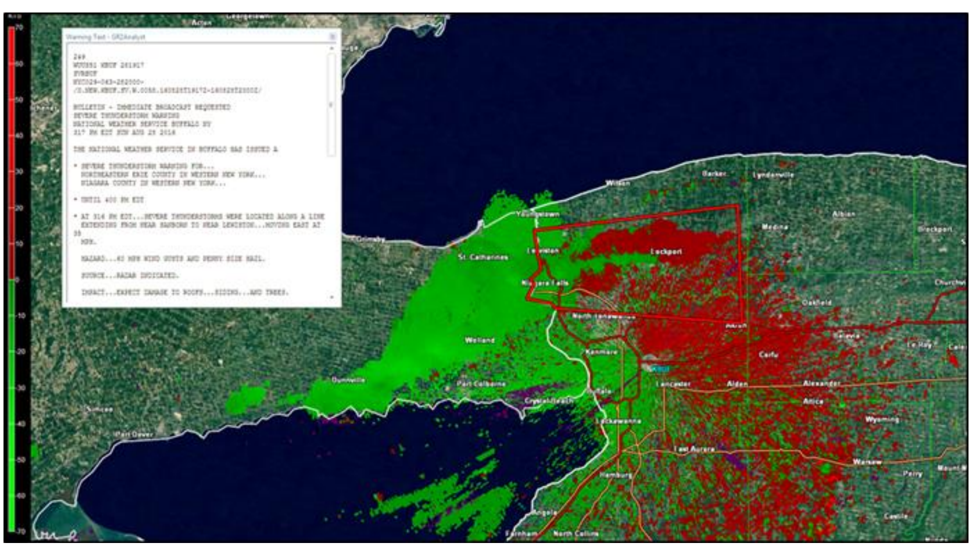


Figure 78. Velocity image of thunderstorms (8/28/2016). Green indicates precipitation moving toward the KBUF radar, whereas red indicates precipitation moving away from the radar. The red polygon indicates area under a "thunderstorm warning". Image Source: R2Analyst.

Radar's Basic Limitations

Weather-related limitations of radar are linked to the angle of the emitted pulse, the distance it travels, and interferences. Near the radar source, the angle of the beam intercepts ground-based objects (eg. buildings and elevated terrain) giving a "cluttered" display on radar screens. At the source, the radar's maximum upward tilt of 19.5 degrees creates an empty space over and immediately around the radar where data (an echo) is not available – referred to as radar's "cone of silence". Farther away, the elevation of the radar beam increases with distance due to the tilt of the radar and may overshoot precipitation (the elevation above the surface also increases due to the curvature of the Earth). Furthermore, the beam widens with distance, loses strength, and provides fuzzy, less detailed imagery. A good analogy is a flashlight beam that weakens with distance, such that objects farther away are more difficult to identify than those closer in.

A more recent limitation with radar is associated with the proliferation of wind turbines. If at enough height, the spinning blades of wind turbines interfere with weather radar beams in a way that gives a false echo of precipitation. Current interference algorithms can remove clutter caused by stationary objects (eg. building and hills), but it is not possible to filter out the spinning blades (Figure 79).

The "Steel Wind" wind farm located along the Lake Erie shoreline (Lackawanna, NY) do not impact radar beams as they are not of sufficient height. However, wind farms east of Buffalo, first appearing on ridge tops in Wyoming County in 2008 and 2009, are of sufficient height to intercept KBUF's radar pulse. Likewise, a wind farm in Chautauqua County interferes with the radar pulse. The returned energy is interpreted as an area of heavy precipitation. The result is several persistent false echoes located in Wyoming and Chautauqua counties that appear as a permanent storm on radar images.

After the tragic February 12, 2009 downing of Continental Flight 3407 on its approach to the Buffalo International Airport, the search for causes of the crash led investigators momentarily to the radar echoes over Wyoming County. While these echoes were dismissed as not related to weather, the distraction they cause must be kept in mind when interpreting weather radar imagery in this region. Furthermore, the false echoes mask any actual precipitation that might be occurring within the false echoes.

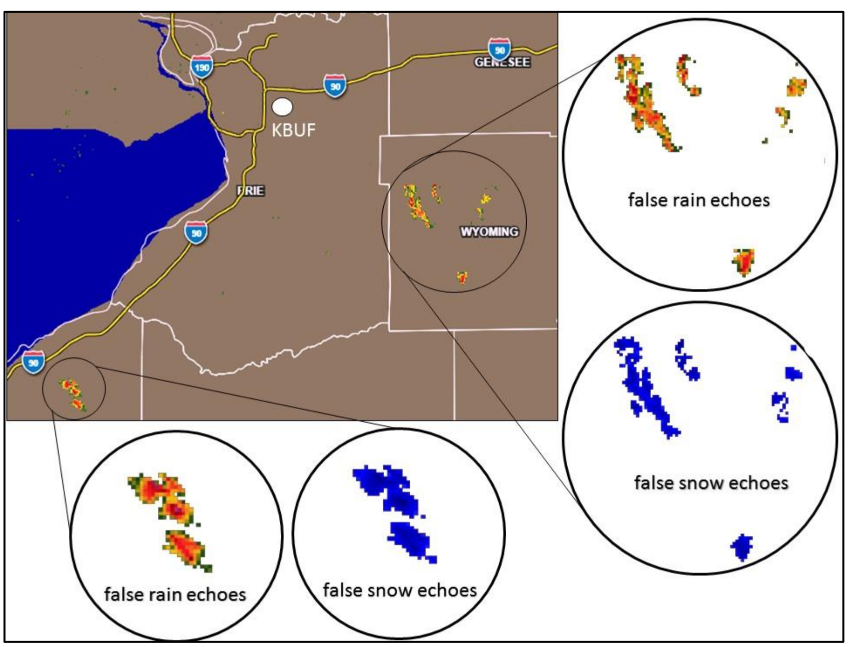


Figure 79. False echoes (rain and snow) attributed to wind turbines on ridge tops in WNY. Image Source: Stephen Vermette/Weathertap.com.

Former Bethlehem Steel Site Fire

Weather radar can detect objects in the sky, other than precipitation, such as the migration of insects and birds. In a review of relevant weather conditions during the November 9-11, 2016 former Bethlehem Steel site fire (Lackawanna, NY), the detection of the smoke plume on radar provided yet another example of weather radar's versatility. The radar images allowed for the determination of the plume's migration, height, and relative particle concentrations ranging from red (most concentrated) to blue (least concentrated) (Figure 80).

Weather radar detects precipitation (rain, snow, etc.), however, very small targets such as cloud droplets (averaging about 10 microns) are not detected. Raindrops are typically 10 to 1,000 times larger than cloud droplets, so the plume that was detected on November 9th by weather radar was defined by the presence of large sized particles, well above PM-10 (<10 microns) sized inhalable particles that are linked to health standards. The smallest size particle detected was about 500 microns (the length of dust mite). The plume certainly included smaller inhalable particles and gaseous pollutants, but the plume, as shown on weather radar, was not defined by these smaller particles and gases.

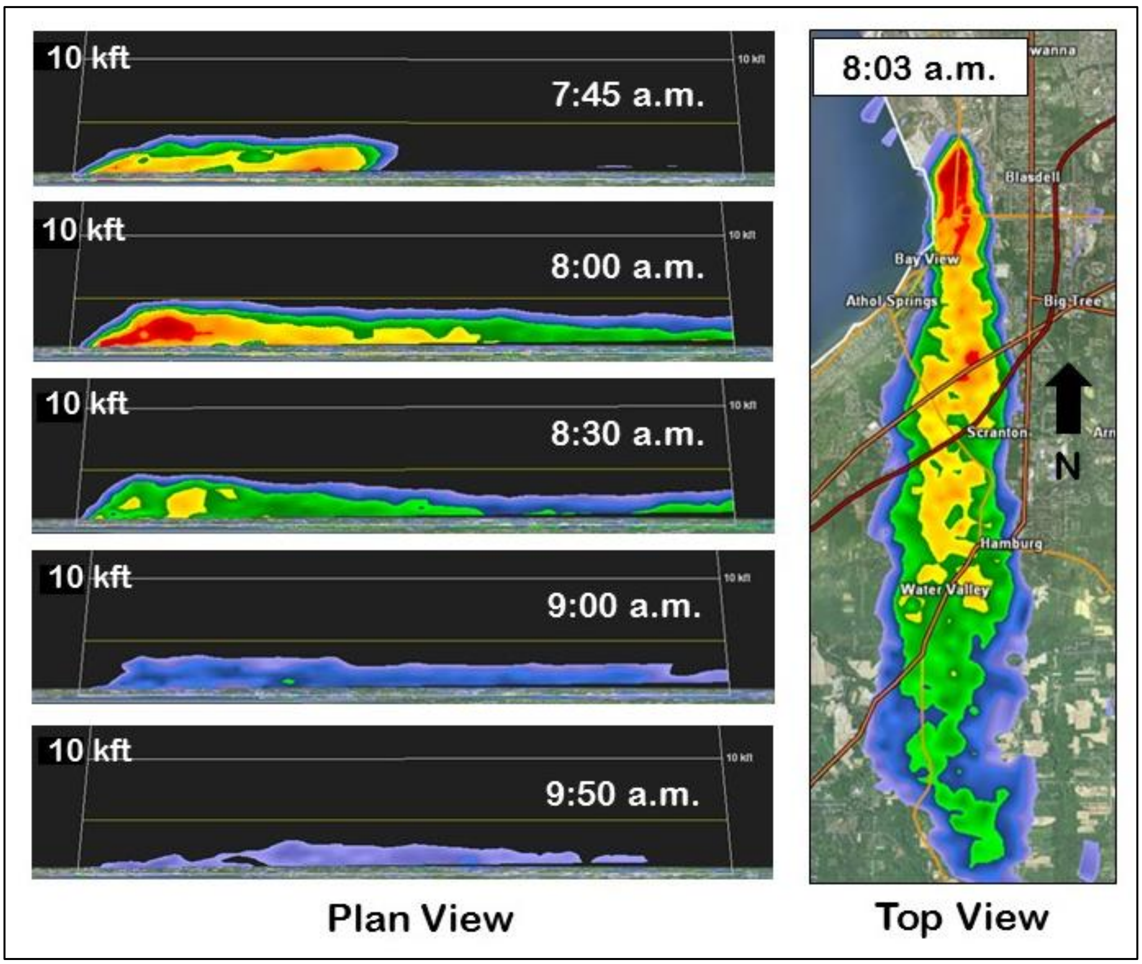


Figure 80. Weather radar detected smoke plume associated with the former Bethlehem Steel fire on November 9, 2016. Image Source: GR2Analyst/Stephen Vermette.

Weather Satellites

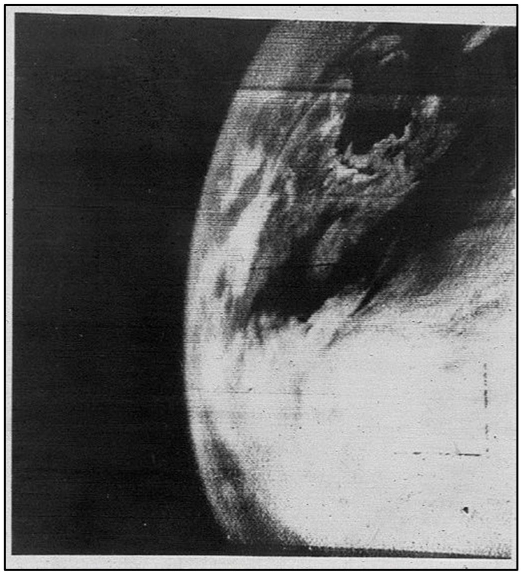


Figure 81. First television image of Earth from space. Taken from TIROS-1 Weather Satellite (April 1, 1960). Image Source: Wikimedia Commons/NASA.

A "big picture" of weather, as interpreted by cloud cover, has been available from satellite imagery since 1960, albeit rudimentary in its early years (Figure 81). Weather satellites follow geostationary orbits (a synchronized orbit with the earth to remain over the same surface). In the U.S. the two weather satellites (Geostationary Operational Environmental Satellites "GOES") are GOES East (positioned over the eastern U.S. at 75° W and provides a view of most of the U.S.) and GOES West (positioned at 137°W over the Pacific Ocean and provides coverage of the western U.S. and eastern Pacific Ocean). These satellites provide continuous imagery of cloud cover in both the visible spectrum (only usable during daylight hours) and the infrared spectrum (which detects heat-based radiation and thus measures clouds day or night) (Figure 82). The shape and brightness of clouds reveals a great deal of weather-related information to the trained and knowledgeable eye. By way of example, cooler surfaces (occurring at higher altitudes) appear bright on an infrared image and thus can be used to measure cloud height. Enhanced infrared imagery color codes the various "whites" to better interpret cloud heights. The newest satellites provide faster processing and clearer imagery and offer much more than just cloud cover and water vapor products, including lightning detection, detection of thunderstorm energy (whether they are stalled or if they are gathering strength), land and sea surface temperatures, ocean dynamics, flow of water, vegetative health, atmospheric chemistry, and more.

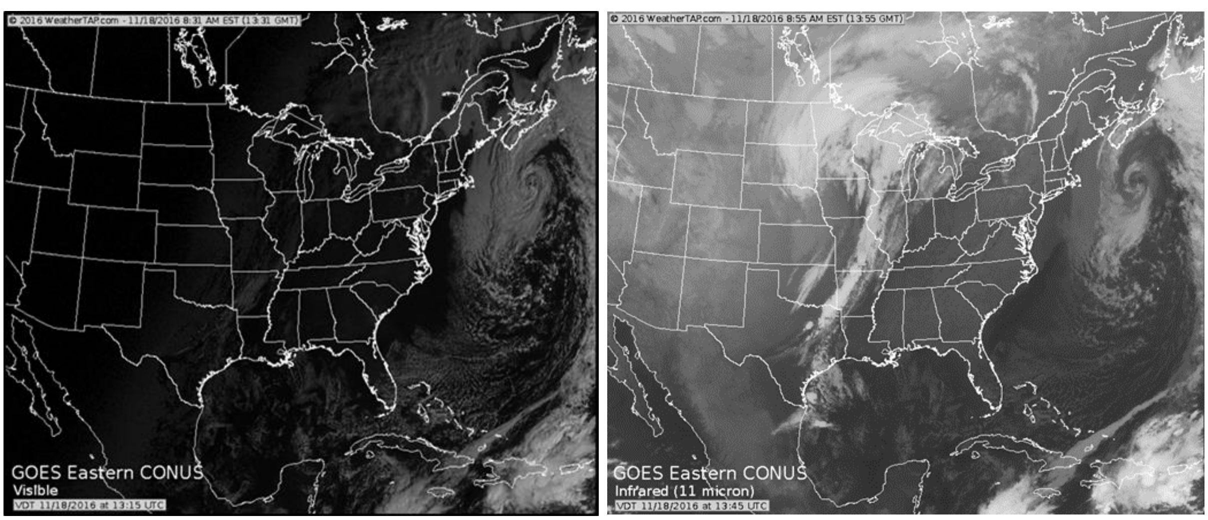


Figure 82. Two winter satellite images taken at approximately the same time of day (between 7:30 and 7:55 a.m. CST, prior to sunrise). The left image is a "visible" satellite image, while the right image is an "infrared image". Note how the midlatitude cyclone, with its extending cold front, that is approaching WNY is only visible on the infrared image. Image Source: Weathertap.com.

Box 15 Western New York Weather Society

WNY's interest in weather knows no bounds. Back in 1949 yearly dues of $1 would have allowed you to become a member of the newly formed Western New York Weather Society. The Society was affiliated with the American Meteorological Society (AMS). The society was organized *"to promote intelligent interest in the understanding of weather phenomena"* and invited individuals with an interest in meteorology to attend *"programs designed to present some interesting development or application of a meteorological nature using a minimum of technical language."* Fast forward 70 years to 2019 and you can join the same organization, the Western New York Chapter of the AMS.

Early activities included monthly presentations, tours of nearby facilities, an annual picnic, and Ladies Night. Not much has changed in 2019, save the "Ladies Night".

Box 16 Radon's Weather Connection

Radon is a naturally occurring, odorless, colorless, radioactive gas produced by the radioactive decay of Uranium-238 found with varying concentrations in WNY's bedrock. As a gas it is mobile, and escapes into the atmosphere. Outdoor (ambient) atmospheric concentrations are too little to be of concern, but radon can seep into basements or crawl spaces through cracks, fittings, windows, and sump pumps, where it accumulates. The concern with radon is that life-time exposures to high concentrations exposes residents to cancer risks. Radon is the second leading cause of lung cancer, after cigarettes.

Weather conditions can affect how much radon may seep into a home. On days of low atmospheric pressure, radon easily travels up from the ground into the ambient atmosphere (moving from high to low pressure). Again, levels in the ambient atmosphere are not usually a concern. However, when soils are water saturated or frozen and covered by snow and ice, radon migration paths through rock and soils are usually made more difficult. That is, unless an easy escape route presents itself − seepage into a comparatively low-pressure environment within a house. Compounding this ease of movement, winter heating draws air up into the house to be replaced, in part, by radon seeping in through the basement or crawl space (stack effect). Winter usually yields the highest levels of radon. It is also a time when a house is closed (to retain heat) and more time is spent indoors. The weather links described above are more complex than this, but it is in consideration of weather variability that short-term radon testing requires multiple tests over time.

Chapter 5

Extreme Weather

A shelf cloud, forming along the leading edge or "gust front" of a thunderstorm's outflow, approaching off Lake Ontario (July 12, 2007). The shot was taken at the end of Route 425 looking north - at the north edge of Wilson, NY with Route 18, about 500 feet behind the photographer. About 1/8 mile east of the Boat House Restaurant. Image Source: Jack Kertzie.

WNY's Severe/Noteworthy and Extreme Weather

Most days in WNY are somewhat benign, but there are days that are a challenge weather-wise. While extreme weather does occur in WNY, the severity doesn't match the blanket destruction found in some regions of the U.S.: the hurricane-related wind and flooding along the east coast; droughts, wildfires, and mud slides out west; supercell thunderstorms and tornado outbreaks in our country's midsection; and flooding along the Mississippi River.

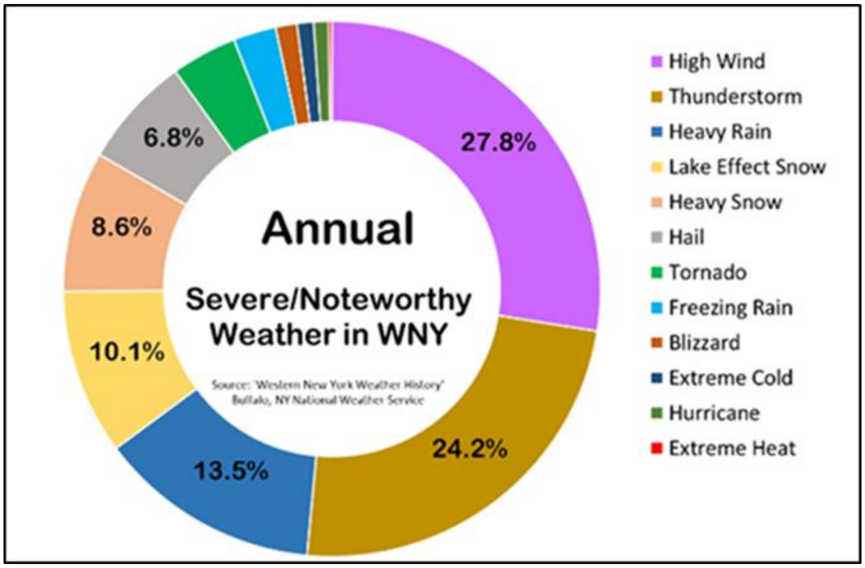


Figure 83. Severe/Noteworthy weather events. Data Source: Buffalo Office of NWS/Stephen Vermette.

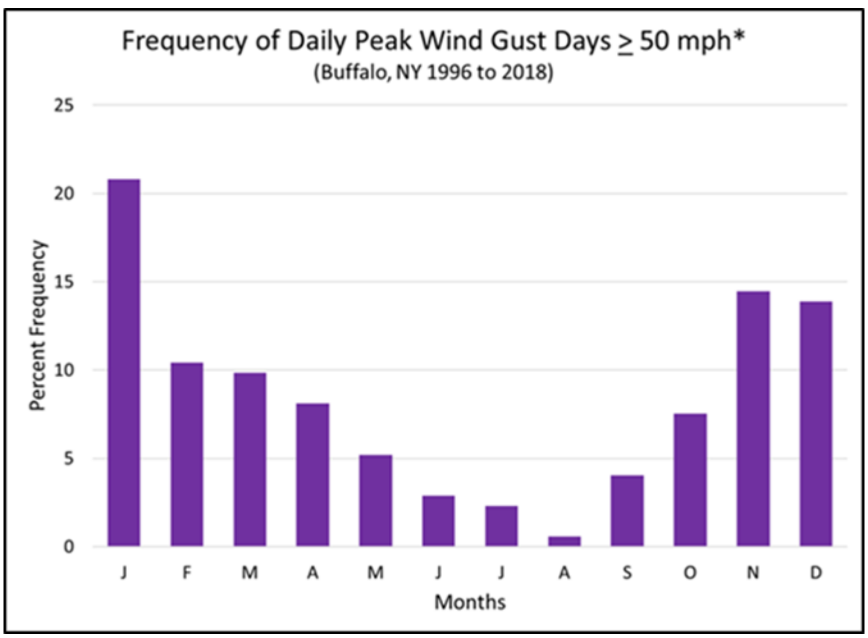


Figure 84. Frequency of peak wind gust days (> 50 mph) taken from NOAA monthly weather summaries between 1996 and 2018.
Image Source: Stephen Vermette

A survey by an online residential real estate site listed WNY as a region where one can escape Mother Nature's wrath – low risk for floods, tornadoes, wildfires, hurricanes and earthquakes. The site, however, did caution readers about our copious amounts of snow. There is some truth to characterizing WNY as a safe harbor from extreme weather, but the damage, injury, and death associated with bouts of extreme weather is very real in WNY. To obtain an overall picture of severe/notable weather, descriptive words were "mined" from the daily weather listings of a database maintained by the Buffalo Forecast Office of the NWS ("History of WNY Weather"). The criteria for the listing of weather events is undefined, as is a strict definition of some of the terms. However, it represents a period of well over 30 years and provides a general description of what may be defined as the climatology of severe / noteworthy weather events in WNY.

The mined words were grouped into each of 12 weather categories: high wind, blizzard, heavy snow, lake effect snow, extreme cold, freezing rain, heavy rain, thunderstorm hail, tornado, hurricane, and extreme heat. One event may count in more than one weather category. For example, a thunderstorm may include high winds and hail, and thus would be included in three categories. The one exception was "heavy snow" and "lake effect snow" which were considered separately. In addition, words indicating weather-related impacts were also mined. They were grouped into 11 impact categories: power outage, trees down, property damage, flooding/erosion, closings, traffic accidents, lightning damage, emergency, evacuated/stranded, deaths, and crop damage.

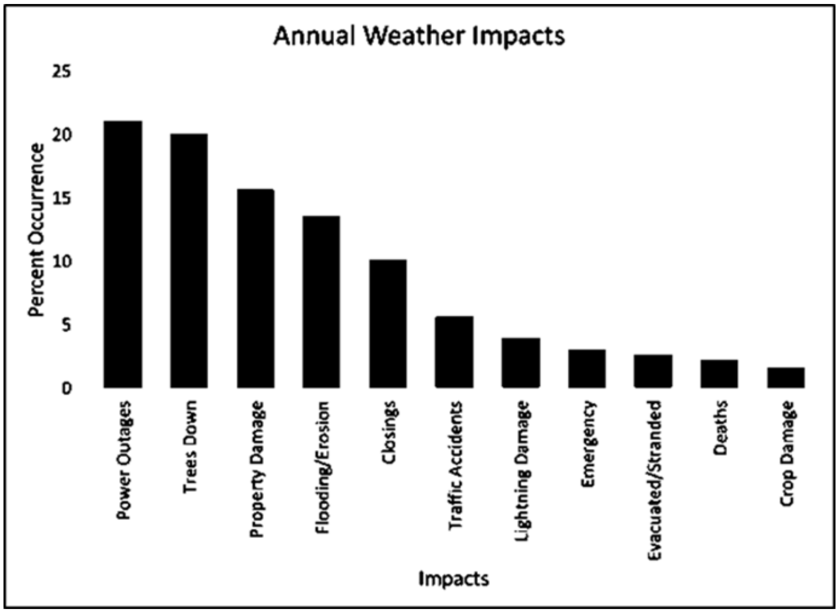


Figure 85. Severe/Noteworthy weather impacts in WNY.
Image Source: Stephen Vermette.

Based on this database, the most common categories of severe/noteworthy weather in WNY are periods of high winds, followed by thunderstorms, and heavy rain (Figure 83). High winds and heavy rain are often associated with thunderstorms. High winds are also associated with strong low-pressure systems that cross our region, especially during the cold months (Figure 84). Taken together, high winds and thunderstorms account for 65.5% of our severe/noteworthy weather and explain the higher percentage of impacts of power outages and trees down. Toppled trees and broken branches are a major weather-related hazard, as they often bring down power lines and cause property damage (Figure 85).

A tree uprooted by wind is referred to as being "windthrow" or "blowdown". It has been pointed out to me that WNY's trees are more prone to uprooting with a strong east to northeast wind, as opposed to a prevailing southwest wind. The reason for this is that tree roots have grown in such a way as to better anchor them from the prevailing winds.

Temperatures – extreme heat and cold – fall short on the list of severe weather frequency. Buffalo averages less than a handful of fingers with ≥ 90-degree days each summer. Buffalo's highest official temperature was recorded at 99°F on August 27, 1948 (that month recorded four days with temperatures > 90°F), and the city's lowest temperature recorded at -20°F on February 2, 1961. There was an earlier lowest temperature record of -21°F or -20°F (depending on where you read the official recorded) on February 9, 1934, but it was downgraded as is was recorded at a downtown site with a higher official thermometer elevation.

There is a seasonality to our severe/noteworthy weather. In winter, lake effect snow (LES) and heavy snow dominate, accounting for 53.4% of WNY's weather events, but high winds remain a major weather-related hazard at 21.9%. In winter, the greatest weather-related impacts are closings and traffic accidents. The remaining seasons are much the same as the annual values, with the exception that thunderstorms dominate the severe/noteworthy weather in the summer, effectively increasing the number of tornadoes, as well as the percentage of fallen trees and lightning damage. High winds account for a greater percentage of severe/noteworthy weather events in the autumn (Figure 86).

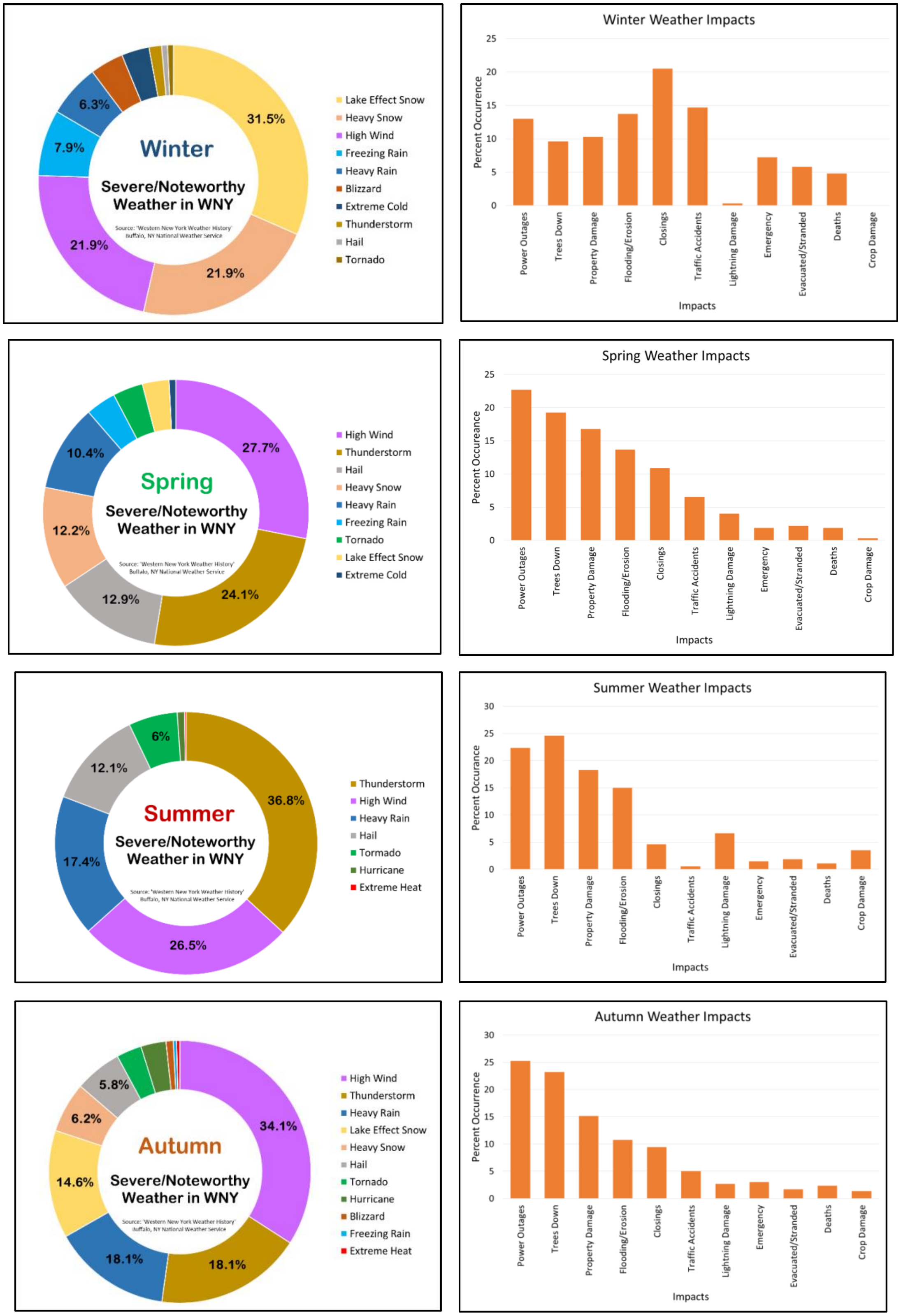


Figure 86. Seasonal Severe/Noteworthy weather events (values of less than 5% are not enumerated) and impacts in WNY. Source: Buffalo Office of NWS/Stephen Vermette.

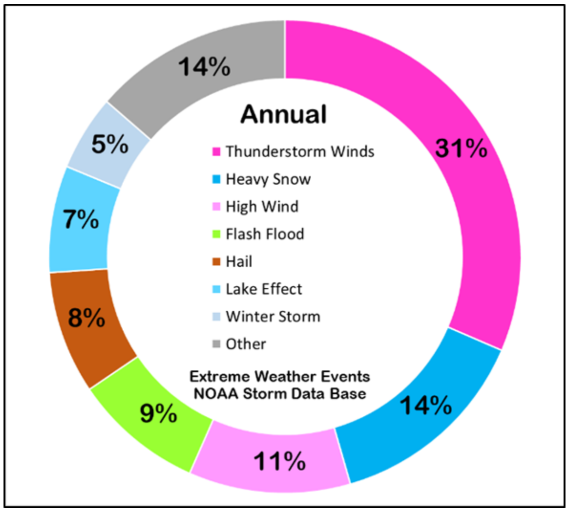
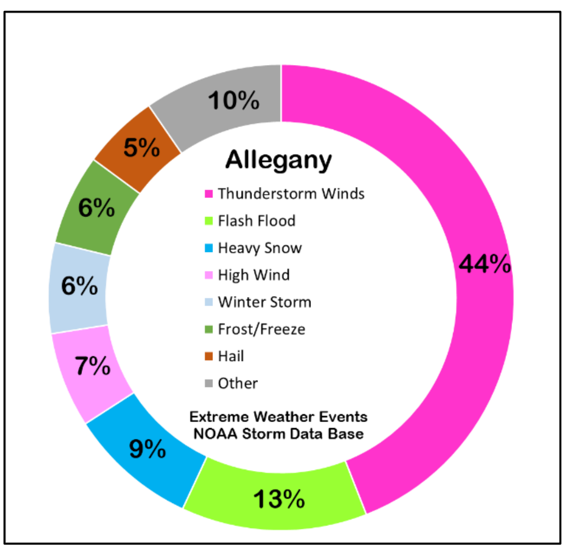


Figure 87. WNY wide extreme weather events (1997-2016). Source: NOAA's Storm Events Database/Stephen Vermette.

A search of NOAA's National Centers for Environmental Information (NCEI) Storm Events Database (1997-2016) provides a window into the most extreme weather events in WNY (Figure 87). The definitions applied here are exclusively "extreme". By way of example, "thunderstorm winds" are defined as winds arising from convection, occurring within 30 minutes of observed or detected lightning, with speeds of at least 58 mph, or as winds of any speed producing a fatality, injury, or damage "Hail" is defined as ¾ inch or larger in diameter, or smaller sizes which result in fatalities, injuries, or significant damage. The "Other" category includes individual extreme weather events that account for less than 14% of the total number of events.

Based on this database, "thunderstorm winds", expressed as a percent of all severe weather events, account for the single largest source (31%) of extreme weather in WNY. Taken together, combined winds (thunderstorm and regional) account for 42% of the region's extreme weather, while thunderstorm activity (thunderstorm winds, hail, and flash flooding) acount for 48%. Snow-related severe weather (heavy snow, lake effect snow, and winter storm) accounts for 26% of our extreme weather events. Extreme heat and cold events, combined, account for ≤0.2% of extreme weather events.

Expressed as a percent of a county's total number of extreme weather events, severe thunderstorm winds are most prevalent in Allegany (44%), Cattaraugus (39%), Niagara (38%), and Chautauqua (34%), while thunderstorm and synoptic wind events are more equally divided in the other counties. Snow and winter-related extreme events are most prevalent in Wyoming County (36%), closely followed by Cattaraugus (30%), Chautauqua (27%), and Erie (27%) counties. With regard to Allegany, Niagara, and Orleans counties, lake effect snow (LES) events account for ≤3% of each counties extreme weather events as these counties are located outside the LES belt. Flooding (flash floods and flood) appear most prevalent in Allegany County (17%) and least prevalent in Niagara (6%) and Orleans counties (5%). Tornado events account for ≤2% of extreme events aross all counties of WNY (Figures 88).



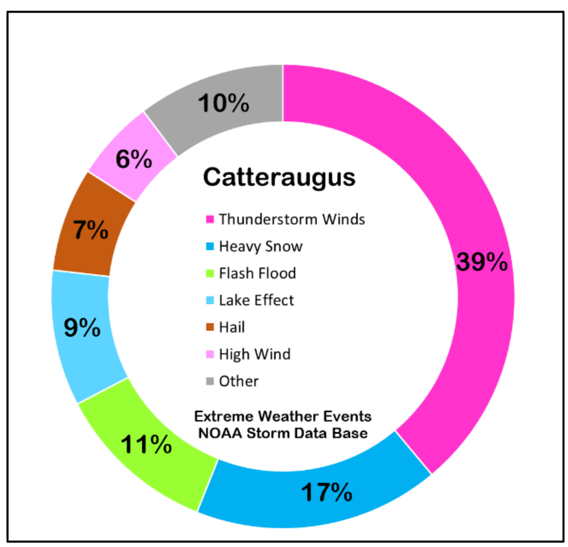


Figure 88. Extreme weather events (1997-2016) by county. Image Source: Stephen Vermette.

Box 17 Heat Advisories and Excessive Heat Warnings

A heat advisory is issued by the National Weather Service when there is a threat of heat-related illness if precautions are not taken. The criteria vary between regions across the country. In New York (including WNY), a "heat advisory" is issued when a heat index of 95-104°F is forecasted for a period of no less than two hours (the minimum criteria was revised in June 2018 from 100°F to 95°F). Heat advisories are issued by county (Erie County is separated by its northern and southern halves) when a location within the county is expected to reach criteria. The new lower criteria limit was chosen because the NYS Department of Health showed that emergency room visits increased when the heat index surpassed 95°F. By comparison, Pennsylvania's criteria still begin at 100°F. The average high July temperature for Phoenix Arizona is about 106°F (104°F in June and 105°F in July), so much of that state would experience a heat advisory all summer long.

The next level up for New York is an "Excessive Heat Warning", requiring a heat index of 105°F or greater for a period of no less than two hours. Numerous studies have indicated that mortality begins to increase exponentially as the heat index rises above 104°F.

Heat is the number one weather-related killer in the United States. WNY fares well. Excessive heat warnings have rarely been issued for WNY. According to the NWS "Storm Events Database" (1995-2017), there was only one reported death (Erie County, July 23, 2005) associated with excessive heat – a 25-year-old construction worker collapsed from heat stroke as he was walking home from his construction job.

Figure 89. Tree damage. Image Source: "Gowanda Street Cleanup", September 20, 1977. The Courier-Express Photograph Collection, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

While pouring over numerous storm images from the Courier-Express photograph collection as part of my research on this book, it quickly became apparent that the storms and the damage they cause are ageless – dated only by vintage automobiles and fashions. Each generation and community remember "their storm", but they often look similar. In other words, if you measure time by storm events, tomorrow will look much like yesterday. The following images (Figures 89 through 94) reveal the ageless nature of our severe weather.

I was once told by a local meteorologist that WNY greatest weather hazard are trees!

Figure 90. This photo, taken on January 28, 1978, marks the anniversary of arguably WNY's largest storm, the Blizzard of '77. Image Source: "Happy Anniversary", January 28, 1978. The Courier-Express Photograph Collection, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

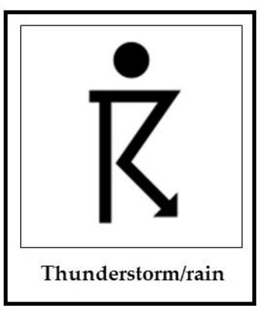
Figure 91. Blizzard scene in WNY. Image Source: "Storms", February 1958. The Courier-Express Photograph Collection, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Figure 92. Tornado rips roof in WNY. Image Source: "Home", May 9, 1968. The Courier-Express Photograph Collection/Ed Zagorski, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Figure 93. National Guard armored personnel carrier makes its way in Town of North Collins, NY. Image Source: "Rescue", February 20, 1958. The Courier-Express Photograph Collection/Ed Zagorski, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Figure 94. The monumental task of digging out. Image Source: “Stuck”, February 19, 1958. The Courier-Express Photograph Collection/Ron Muscati, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Thunderstorms



Thunderstorms, by definition, are rainmakers that include lightning and thunder. While varying in size, these storms can grow to sizes that shadow an entire city and reach heights beyond that of any mountain. Most thunderstorms are not severe. Having said this, much of WNY’s severe weather − lightning, high winds, heavy rains, hail, and tornadoes − are associated with thunderstorms. And while they mostly occur in the warm season, they do occur in the winter, too – thundersnow, most often associated with lake effect snow.

The genesis of a thunderstorm is divided into three basic stages (Figure 95). The first stage is the “towering cumulus stage”, where a cumulus cloud builds in size due to updrafts or thermals (rising moist air). These updrafts are invisible, becoming apparent only when condensing water vapor visualizes as a cumulus cloud. Glider pilots take advantage of these “hidden” updrafts in order to gain altitude during flight. The cloud will grow if it is “fueled” by an updraft. The “fuel” for a thunderstorm is latent heat, energy that is brought up from the surface by evaporation and released into the cloud by condensation. The term CAPE (Convective Available Potential Energy) is a measure of this instability (rising air) and energy.

The second stage of a thunderstorm is the “mature stage”. It is during this stage that the cumulus cloud has built to a sufficient size to produce precipitation (cumulonimbus cloud) and lightning. The falling precipitation creates a downdraft within the cloud. This is the stage where precipitation is most intense, as it is the stage associated with severe weather.

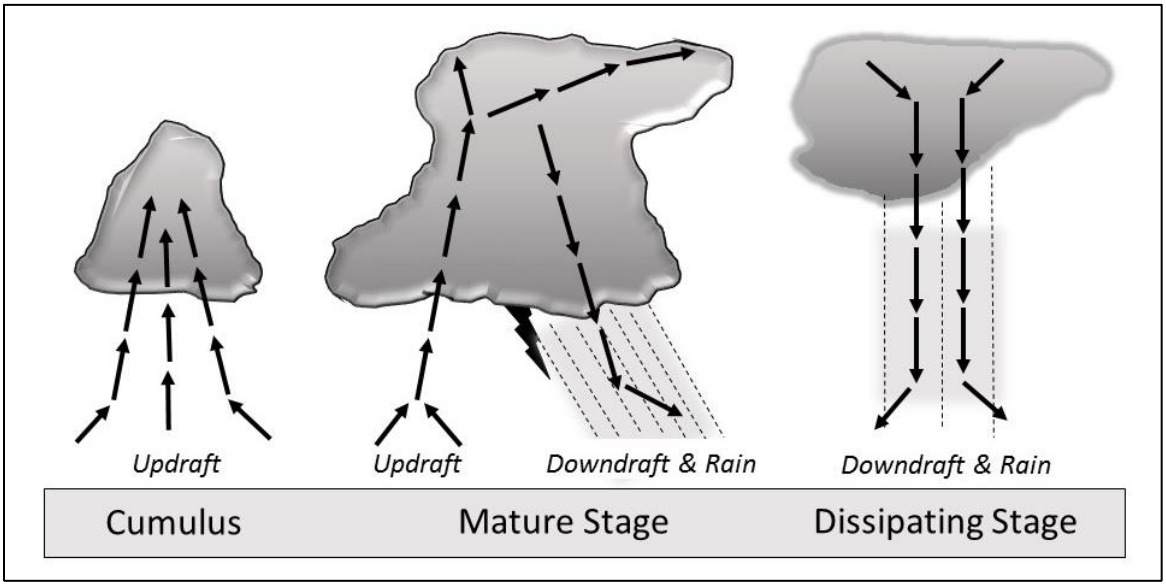


Figure 95. Three stages of thunderstorm development. Image Source: Stephen Vermette.

The final stage is the "dissipating stage" when the updraft dissipates (dissolves) and the precipitation-driven downdraft dominates. Precipitation will continue to fall (associated with the downdraft) until its existing precipitation supply is exhausted. The initial weakening and subsequent loss of the updraft is attributed to the storm's cloud cover and to the entrainment (carrying) of cold air by the downdraft. Both cool the surface below and eliminate the rising air. With an approaching thunderstorm you may have felt a sudden gust of cool air just prior to precipitation. This is referred to as the gust front and is the leading edge of a thunderstorm's downdraft.

There are two basic types of thunderstorms. One type is the air mass or pop-up thunderstorm which occurs on hot humid days (within hot humid air masses). A common summer weather forecast may read something like: *"Today will be hot and humid with a chance of thunderstorms in the afternoon"*. These thunderstorms form due to convective lifting (updrafts) associated with surface heating (Figure 96).

While one or more thunderstorms may occur in any given area, it is tricky to predict when and where that will be. A simple forecast analogy is to guess which of several popcorn seeds on a hot plate will be the first to pop. Pop-up thunderstorms may washout a backyard barbeque in Kenmore, while at the same time skies remain sunny over Cheektowaga. These storms are usually short-lived (less than an hour), and partly sunny to sunny skies often occur before and after the storm.

A second type of thunderstorm is associated with frontal movement (often a cold front) and is referred to as a "frontal thunderstorm" (Figure 97). The passage of a cold front (cold air advancing toward warm air) lifts the warm air up along the cold front. This lifted air can result in thunderstorm development organized along a front, referred to as a squall line. A squall line is a line of adjacent thunderstorms with the occurrence of continuous heavy precipitation along the line. While any given thunderstorm may only last an hour or so, the continuous lifting environment along a front can create new storms and carry the forecast area for thunderstorms over a greater distance, and with more certainty than for pop-up thunderstorms.

The reality is that there are numerous boundaries along which thunderstorms can develop. One boundary is the leading edge of a downdraft's gust front where cool air rushing down and out of a thunderstorm can

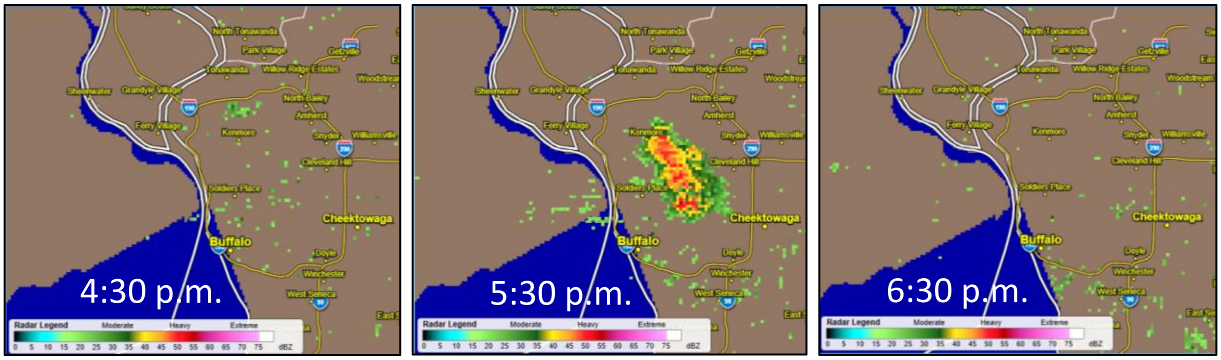


Figure 96. The afternoon temperatures reached the mid 90's. Skies were clear. Air mass thunderstorms developed by mid-afternoon in Erie, Chautauqua, and Cattaraugus Counties. Shown is a short-lived thunderstorm that formed over the Buffalo area. Image Source: Weathertap.com/Stephen Vermette.

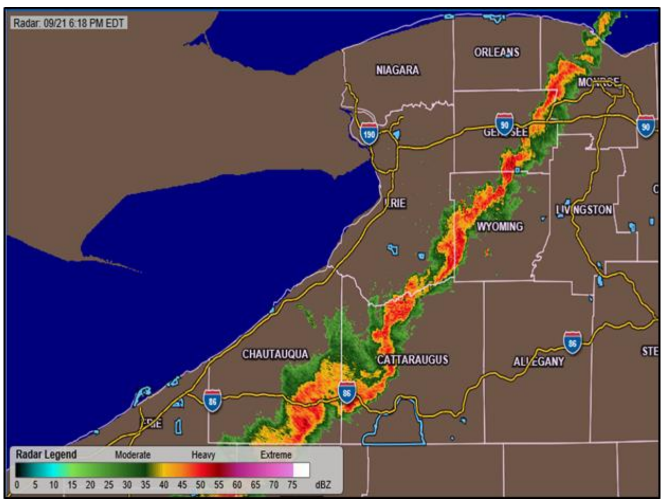


Figure 97. A frontal thunderstorm moving across WNY. Image Source: Weathertap.com/Stephen Vermette.

trigger warm air to rise and develop thunderstorms anew. In WNY, thunderstorm triggers also include lake breeze boundaries in proximity to Lakes Erie and Ontario. Thunderstorms with a straight vertical updraft quickly dissipate – they are "choked out" by a competing downdraft. What allows a thunderstorm to persist, grow in height, and strengthen, are updrafts within a thunderstorm that take on a tilt or rotation that allows them to exist alongside downdrafts. The tilt or rotation is caused by wind shear (varying wind speeds with height in a storm). This separation between updrafts and downdrafts helps to maintain the lifetime of the storm. The rotating updraft is referred to as a "mesocyclone" that can, under certain conditions, spin off a tornado.

Based on data obtained from the NWS Buffalo airport site, the region experiences an average of about 30 thunderstorm days per year. There are some notable differences within the region, specifically differences related to the timing of storms over and along the shorelines of Lakes Erie and Ontario. The spring/early summer lake effect season, where lake water temperatures are cooler than the air that passes over it, creates a stable air layer which dampens the formation of thunderstorms, both over the lake and along shorelines. Many weather watchers, anticipating an approaching thunderstorm traversing the lake, are vexed by radar echoes that repeatedly dissipate with the storm's passage over the lake. There are times when this is not the case. Thunderstorms triggered by strong frontal activity obtain their instability (growth) independent of, and above, the stable air layer over the lake. While spring/early summer thunderstorms are more common inland than along shorelines, the warmer land surface combined with a lake breeze "trigger" may initiate thunderstorm activity which further enhances the number of inland thunderstorms. Conversely, as the lake warms and loses its stable air layer, the lake-induced dampening effect lessens. In fact, lake-induced evening thunderstorms become a feature of the late summer and early autumn in areas near the lakes – developing in the evening hours when nighttime lake water temperatures are warmer than land-based temperatures.

Lightning and Sprites

A thunderstorm is produced by a cumulonimbus cloud and is always accompanied by lightning and thunder. However, any discussion of lightning must first step back to view the wider picture of where a thunderstorm is positioned as part of a larger electrical cycle or circuit (Figure 98).

The ionosphere (sometimes referred to as the electrosphere) occurs within the thermosphere. It is here that the auroras occur. The ionosphere carries a net positive charge and the Earth's surface a net negative charge. The atmosphere acts as an insulator, such that an electric potential (difference in charge) exists between the two altitudes. However, a weak but continuous fair-weather current (sometimes referred to as an air leakage current) draws positive charges down to the earth's surface. Within this overall budget, thunderstorms act as generators that discharge electrical current to the surface, as well as back up to the ionosphere, closing the electrical circuit.

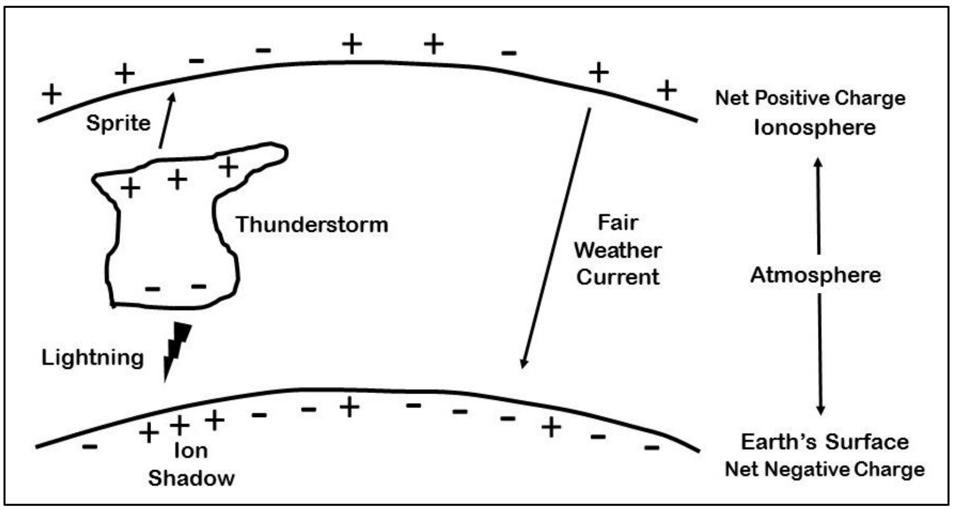


Figure 98. Earth's electrical circuit. Image Source: Stephen Vermette.

Within a cumulonimbus cloud, the jostling and bumping of precipitation particles generates electrical charges, which separate from one another by following updrafts and downdrafts within the cloud. Preferential areas of negative charge tend to accumulate in the lower section of the cloud, while positive charges accumulate in the upper sections. The separation of charges creates an electrical field within the cloud. A second electrical field sets up between the base of the cloud and the ground below. In the latter case, the negative charge at the base of the cloud attracts a positively charged shadow on the ground beneath. This shadow of positive ions follows the storm's movement. Within the shadow, the positive ions climb tall objects (trees and buildings) to minimize the distance between the electrical fields. Saint Elmo's fire (or light) describes the blue-violet glow sometimes seen extending from elevated objects when a strong electrical differential is present. St. Elmo's fire was often seen reaching upwards from a ship's mast and was named after the patron saint of sailors. Photos of individual's "hair-raising" experiences are the sign of a strong electrical potential, where the hair is lifted by positive ions reaching up for the cloud. Clearly, this is a warning sign that lightning is about to strike.

Once an electric field is established, lightning may occur (Figure 99). Lightning starts with multiple negatively charged "step leaders" descending from the thundercloud. The "steps" refer to a series of random leaps made by the step leader in its search for positive ions. When the downward-moving "step leader" gets close enough, several positively charged "streamers" (sometimes referred to as "sparks") leap upward from the ground or from the top of any close object. It is this propensity for positive ions to search out tall objects that explains why individuals caught outside during a thunderstorm are advised to avoid them (eg. searching for shelter under a lone tree is not a safe choice). A conductive channel (lightning) is created by the union of a downward-moving step leader and a streamer. Within the conductive channel, positive charges (referred to as the "return stroke") surge upward from the ground to the cloud (therefore lightning is said to move up from the ground). Negative charges surge downward from the cloud base to the ground as "dart leaders" (no longer "stepping" as they are now following an established conductive channel). All of this occurs in a fraction of a second!

Figure 99. Lightning as seen from a backyard in Rochester, NY. Image Source: NOAA's National Weather Service (NWS) Collection/ Patty Singer.

Described here is a cloud-to-ground strike, but lightning can occur within and between clouds too. Multiple return strokes in quick succession give some lightning strokes the appearance of flickering. The branching appearance of lightning is due to the dimmer illumination of the original branching steps (outside of the brightly illuminated conductive channel) that failed to connect to a streamer.

Another form of lightning is often referred to as the "bolt from the blue". In this case, the lightning strike originates from higher in the cloud where positive charges dominate, and it strikes away from the cloud toward where negative ions dominate (away from the positive ion shadow which follows below the cloud). These lightning strikes are particularly dangerous as they hold a larger charge and strike away from the cloud in a direction where they are not anticipated.

The thunder associated with lightning is the sound produced by the shock wave caused by the rapid heating of the lightning channel to a temperature reaching 50,000°F (5x that of the surface of the sun). Whether thunder is heard as a loud single "clap" or "peal" or as a rumbling sound depends on an individual's distance from the lightning channel. If close, the sound is loud and singular. If distant, sound from different segments of the channel will be fainter and get to you at different times, heard as a rolling rumble.

The distance of a lightning strike away from your location can be determined by the gap in time between the stroke and the sound of thunder. The flash is seen before the thunder because light travels at a faster speed than sound. To calculate the distance, count the seconds between the time the flash was seen and the time the thunder was heard, then divide the time by 5. By way of example, a time difference of 15 seconds calculates as a lightning strike 3 miles away.

Reference is sometimes given to "heat lightning". The name conjures up a hot humid summer evening where lightning flashes occur far off in the distance and thunder is not heard. The idea that heat lightning is the product of heat and humidity is a fallacy, as heat lightning is not caused by a warm humid night but is rather nothing more than a distant thunderstorm occurring too far away for the thunder to be heard.

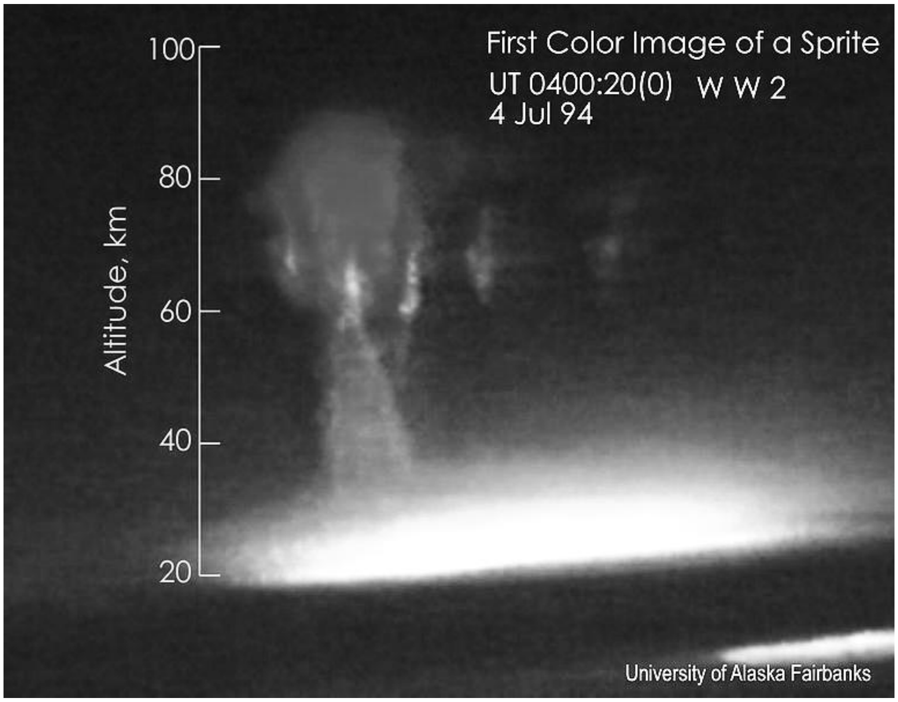
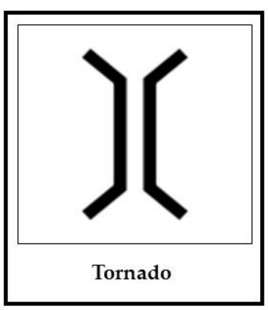


Figure 100. Sprite appearing above a thunderstorm cloud.
Image Source: Wikimedia Commons/Eastview NASA.

The final step in the overall electrical cycle can be explained by a relatively new discovery: "sprites" (Figure 100). Sprites are faint flashes of light seen above thunder-storms, appearing as a direct electrical connection between thunder-clouds and the upper ionosphere. The light seen may be due to the collision of ions with gas molecules occurring in a rarified atmosphere (few gas molecules) which allows ions to transfer energy to the gas molecules that they collide with. This process is much like that described for the aurora borealis, with the exception that the source of charged particles is from below, as opposed to above in the case of the aurora. While our understanding of sprites is in its early stages, the existence of sprites does complete the global electrical circuit.

Tornadoes



Few weather words strike more terror than "tornado". Tornadoes can destroy in seconds, ripping apart homes, tossing cars, splintering trees, and even peeling back pavement. And while warnings have improved over time, tornadoes often strike with little or no warning. Tornadoes are a point of inexhaustible fascination, witnessed by the numerous storm chasers that launch themselves each spring into the American heartland known as "tornado alley".

Definitions do not do justice to a tornado. Simply put, a tornado is a column of rapidly rotating air that extends downward from the base of a cumulonimbus cloud and touches the ground or water surface. If the column of air does not touch the ground, it is referred to as a funnel cloud. It is important to recognize that a tornado may not always be visible as a cloud, so that the only sign of a "touch down" may be the debris cloud kicked up at the point of contact with the ground. The condensation that produces a tornado is white, and it is the debris picked up by a tornado that provides the typical darker color. Another characteristic feature of a tornado or funnel cloud is that it is always attached to the cloud base., Sometimes confused for funnels or tornadoes, scud clouds are actually just fragments of low clouds present below, and detached from, the cloud base. In addition, scud clouds do not exhibit rotation.

Tornadoes are associated with thunderstorms, the largest of which (supercells) produce some of the most intense tornadoes. A precursor to tornado formation is the presence of a mesocyclone (rotating updraft) within a cumulonimbus (thunderstorm) cloud. This vertical rotation is caused by rising air and varying wind speeds with height. The base of the mesocyclone is sometimes seen as a rotating "wall cloud" which extends below the storm's cloud base. It is below the wall cloud that a tornado will develop. The mesocyclone and wall cloud often form at the rear flank of a thunderstorm. A tornado chaser does not usually travel through a storm, but rather "flanks" the storm, coming to it from behind, where the tornado will most likely form. You may have noticed how tornadoes are often photographed with a backdrop of clearing skies. Having said this, tornadoes are not always generated so precisely, nor made so clearly visible (often shrouded in rain and darkness).

The actual formation of the tornado (tornadogenesis) remains an active field of investigation. Tornadoes can form where wind shear exists (winds traveling at different speeds and directions around, and within, a thunderstorm) to produce rotation. An early clue to tornado formation was the radar hook echo (a hooked-shaped radar reflection) that appeared on early radar screens. The "hook" was used for decades to help identify a tornado within large storms. The hook echo captures the storm's rear flank downdraft as it reaches the surface and is drawn into and wrapped around the rising mesocyclone, building a tornado from the ground up. A more detailed explanation is referred to as the "dynamic pipe effect". Under certain conditions, the mesocyclone is stretched vertically (the pipe), narrowing the path and increasing the rotation of rising air within the cloud. This "narrowing" forces air from below (near the ground) to constrict as it positions itself to rise up into the "pipe" – and a tornado is born! A conceptual analogy is to consider heavy traffic along a multi-lane highway. Barricaded lane restrictions ahead force traffic to merge into one lane, with the merging usually starting well before the barriers are reached (much like rising air is forced to constrict below the cloud to form a tornado). While the air rises from the ground into the cloud, the tornado appears to descend from the cloud because the cooling of the rising air and the subsequent condensation (what makes the tornado visible) progresses downward from the cloud.

The strength of a tornado (based on wind speed) is difficult to measure directly. In 1971, a tornado scientist by the name of Theodore "Ted" Fujita, developed the "Fujita Tornado Scale" to estimate wind speed based on the damage caused by tornadoes. Fujita (referred to as "Mr. Tornado") pioneered much of the terminology and our understanding of tornado theory. The Fujita scale was modified in 2007 to reflect different types of building structures and changes in building practices. This newly-named "Enhanced Fujita Tornado Scale" ranges from EF0 (weakest) to EF5 (strongest). Always intriguing is the peculiar expression of tornadic winds, including this photo of a vinyl record penetrating a telephone pole (Figure 101).

Enhanced Fujita Tornado Scale		
EF Rating	Wind Speed (mph)	Sample Damage (as related to houses)
0	65-85	Peels surface off roofs
1	86-110	Roof torn off house
2	111-135	Roofs torn off well-constructed houses
3	136-165	Some walls torn off well-constructed houses
4	166-200	Well-constructed houses leveled
5	>200	Strong framed houses leveled and swept away

The National Weather Service (NWS) now issues tornado watches and warnings but this has not always been the case. Prior to the early 1940's, public tornado awareness was non-existent. The use of the word "tornado" and the issuance of tornado warnings were banned until 1938. Back then it was believed that a

Figure 101. The awesome power of a tornado demonstrated by a vinyl record penetrating a telephone pole, while the record itself is not damaged. Image Source: NOAA's National Weather Service (NWS) Collection.

tornado warning would do more harm than good – causing a panic in a community and hurting long-term economic development (especially in the U.S. Midwest and Great Plain states). Furthermore, the science of tornado forecasting was in its infancy. This all changed with the first successful tornado warning in 1948, and organized tornado warning which followed soon after.

Early tornado "warnings" were local, disseminated by church bells (a dinner bell, in the case of a 1924 tornado that struck a farm in Boston, NY), telegraph and later by rural telephone operators calling each other. And involved the use of emergency vehicles to warn the public – putting emergency responders at risk (Figure 102). Later, in tornado prone areas of the U.S., civil defense warning sirens were used and are still in use today. In WNY, as in other parts of the country, tornado warnings are disseminated by commercial radio and television stations, weather radio, and numerous wireless applications.

Figure 102. A public affairs picture (not from WNY) illustrating tornado dangers (1960's). The policeman appears superimposed over violent weather imagery. Image Source: NOAA's National Weather Service (NWS)

Today, tornado awareness is proactive. A "watch" is issued when conditions are favorable for the development of tornadoes. The watch area can cover multiple counties for an extended period (usually 4 to 8 hours). A watch provides time to reflect on your surrounding and prepare to move to safety if conditions worsen. A tornado "warning" is issued for an area when a tornado has been sighted by spotters or has been indicated by Doppler radar. The warning is for a short period of time (usually 30 minutes) and is restricted to a smaller geographic area (a warning polygon). A tornado warning can be issued without a watch in affect. This is often the case in WNY, where weaker tornadoes generate from thunderstorms without regional preconditions. A warning requires that you take immediate shelter. The safest locations are usually in basements and small rooms without windows. The warning is not a license to peer out a window or step outside to look for a tornado, but rather to take immediate shelter. The NWS reports that the average lead-time for a tornado warning is 13 minutes, but this warning time can be much less if you are in the immediate path of a tornado that has just touched down!

The U.S. experiences more tornadoes than any other country, and while tornadoes can occur in any state and any month, they are most common and intense in the U.S. Great Plains, Midwest, and southeastern states region where thunderstorms are most frequent; the area known as "Tornado Alley".

Though not common in our area, tornadoes do occur in WNY (Figure 103). Most tornadoes in WNY are at the lower end of the Fujita Scale (EF0 and EF1), and no EF5 tornado is on record. WNY averages 1.4

tornadoes per year, most (about 90%) occurring in Chautauqua, Erie, Cattaraugus, and Allegany counties, with far fewer (about 10%) occurring in Niagara, Wyoming, Genesee, and Orleans counties. Many weather enthusiasts consider Chautauqua County, with WNY's largest tornado count, to be positioned on the northeast edge of "Tornado Alley". Across WNY there have been years when no tornadoes have touched down, but also years with multiple touchdowns (the record being 1994 with 6 tornadoes). While mainly structural damage and personal injuries are associated with tornadoes, there have been four fatalities since 1950 (two each in Chautauqua and Genesee counties). A July 23, 1920 tornado in West Seneca (Erie County) may have also caused two fatalities.

Figure 103. Tornado west of Olean shot through car windshield in rain (June 27, 2006). Image Source: Jack Kertzie.

Tornadoes have left lasting impressions in towns across WNY and are too numerous to mention here. Three notable WNY tornado outbreaks include:

On July 20, 2017 four tornadoes (ranging from EF0 to EF2) tore a path across Erie and Allegany Counties leaving structural damage and a path of shredded and downed trees in the towns of Holland, Rushford, Allen, and Angelica. The largest tornado touched down in Hamburg and followed a path to Chestnut Ridge Park in Orchard Park, NY causing damage at the Erie County Fairgrounds and nearby buildings. Notable were the hundreds of cars windows that were blown out at the fairgrounds.

On July 30, 1987 (Holiday Showcase Tornado) a tornado touched down in Cheektowaga, damaging over 40 homes, severely damaging three, and ripping the roof off the Holiday Showcase restaurant. A truck carrying hazardous material was overturned on the thruway. This tornado dispelled the myth that tornadoes occur only in the countryside.

The tornado outbreak of May 31, 1985 included 21 tornadoes that tore across Northeast Ohio and Northwest Pennsylvania. One tornado (F4) crossed into Chautauqua County, and another (F3) touched down in Clymer, NY (Chautauqua County). Dozens of homes were destroyed (many more were damaged), and 20 people were injured.

Downbursts, Bow Echoes and Derechos

When a thunderstorm-related wind event causes severe damage, the first thought is often that the damage was caused by a tornado. There is another culprit: the "downburst" or the more compact "microburst" (≤ 2.5 mile radius) – strong downward winds that may be embedded within the cold air downdraft associated with mature thunderstorms. What sets the downburst apart from a typical downdraft is inordinate evaporation. The entrainment of cold dry upper air from the back edge of a mature thunderstorm (referred to as a rear-inflow jet), along with the passage of this jet through a layer of dry air below a thunderstorm, in both cases initiates rapid evaporation. The evaporative cooling increasing the density of the falling air, the added weight further increasing the speed of its descent. Upon impact with the surface, the rapidly falling air produces straight-line surface winds with speeds that can reach 130 mph. Damage associated with a downburst or microburst can be as devastating as that caused by an EF0, EF1, or even an EF2 tornado. One evident difference is that tornadoes produce a rotational damage pattern, whereas downbursts produce a linear damage pattern aligned in the same direction (e.g. wind-felled trees oriented in the same direction).

Downbursts and microbursts are dangerous for aviation, especially during takeoffs and landings. In fact, it was the wind-related crash landings of numerous airplanes that led to downburst and microburst research – a sudden downburst can cause a plane to be slammed into the runway upon landing or prevent it from gaining altitude at take-off. Today Doppler radar can detect the development of downbursts within a thunderstorm, and airplane takeoffs and landings can be delayed based on Doppler guidance.

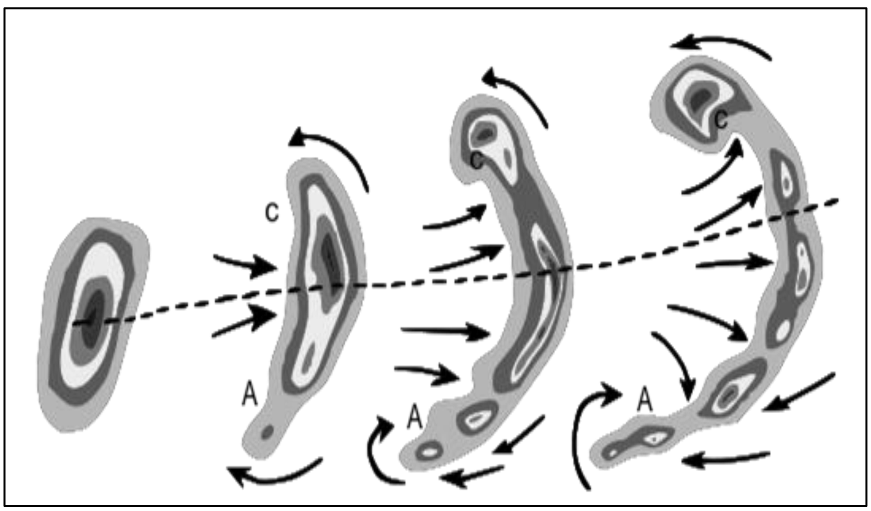


Figure 104. Evolution of a thunderstorm into a bow echo. Tornadoes may form at the book ends of the echo. Image Source: Wikimedia Commons/National Weather Service.

A fast-moving thunderstorm, or a squall line of fast-moving thunderstorms, may evolve to form a bow shape (backward "C"), referred to on Doppler radar as a "bow echo" (multiple bow echoes may form along a long squall line) (Figure 104). The center of the bow echo is pushed outward by fast moving surface winds, associated with strong downbursts and potentially damaging straight line winds. Cyclonic and anticyclonic rotation exists at the book ends of the echo, and this is where weak tornadoes may form.

If the bow echo persists (continues to regenerate at it travels), it is then referred to as a "derecho", defined by the NWS as a *"widespread and usually fast-moving windstorm associated with convection (thunderstorms) that in addition to heavy rains and flash flooding can produce damaging straight-line winds over areas hundreds of miles long and more than 100 miles across."* An operational description is a long lived (at least 6 hours), fast moving wind storm, progressing along a path for at least 250 miles, while maintaining wind severe gusts of at least 58 mph. In the case of WNY, many derechos are associated with heat waves occurring in the central/eastern U.S., strong low-level instability, and are primarily late evening or overnight events during the warm season.

Three noteworthy WNY derechos are described below. The diagrams show the progression of the derecho with the curved lines indicating the progression of the bow echo in time-steps – essentially a fast-moving wall of wind and rain. The "+" symbols (or values) indicate the locations of wind damage or wind gusts (measured or estimated) above 58 mph. The descriptive text (see below) was taken from the NWS "Western New York Weather History", as obtained from the NWS Buffalo web site (edited to focus on WNY).

"The Southern Great Lakes Derecho of 1991"

The derecho developed in South Dakota and dissipated in central New York (Figure 105). Impact on WNY, as taken from the "WNY Weather History" link to NWS–Buffalo web site: *"Nocturnal thunderstorms…produced damaging winds. The strong winds downed trees and power lines causing scattered power outages in parts of Erie, Cattaraugus, Chautauqua, and Wyoming counties. Some homes and property were damaged by downed tree limbs. Unusually vivid and continuous lightning with the storms reportedly sparked six house fires. The thunderstorms dropped from an inch and a quarter to two and a quarter inches of much needed rain resulting in some reports of localized flooding."*

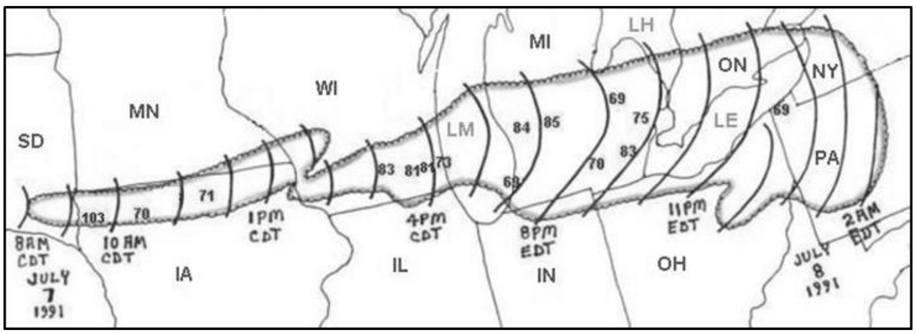


Figure 105. Progression of "The Southern Great Lakes Derecho of 1991" on July 7-8, 1991. Wind speeds (MPH) indicated. Image Source: NOAA-NWS-NCEP Storm Prediction Center web site.

"The Southern Great Lakes Derecho of 1998"

The derecho developed in Minnesota and dissipated just east of Watertown, NY (Figure 106). Impact on WNY, as taken from the "WNY Weather History" link to NWS–Buffalo web site: *"An outbreak of severe storms began across the region during the early morning hours. The storms were particularly dangerous because of the speed that they were moving across the region--sometimes in excess of 60 mph. Most of the damage associated with these storms occurred from a combination of high winds and hail. There were reports of numerous trees and wires down as well as power outages. Tens of thousands were without power. In Niagara and Orleans counties, about 50% of the apple crop was damaged by the pelting hail stones. Several flights were delayed or cancelled at the Buffalo and Rochester airports due to the storms. Three-quarter inch hail was reported in Lockport, Ripley and East Otto."*

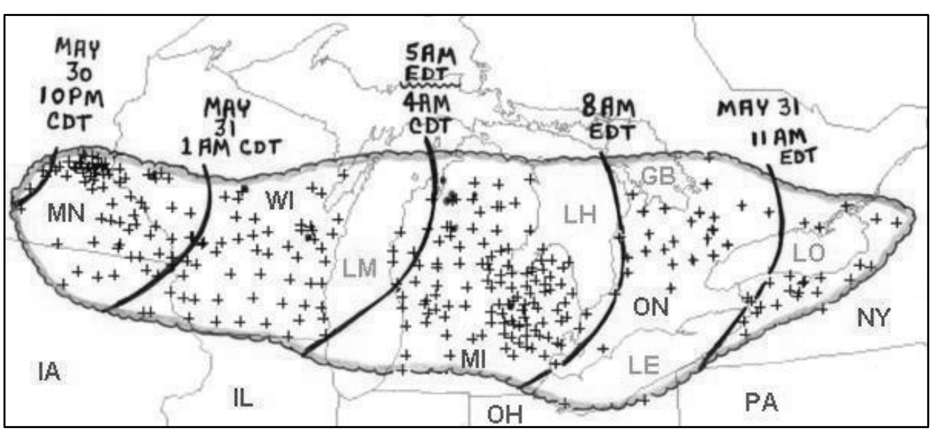


Figure 106. Progression of "The Southern Great Lakes Derecho of 1998" on May 30-31, 1998. Crosses show high wind speed measurements. Image Source: NOAA-NWS-NCEP Storm Prediction Center web site.

Syracuse Derecho of Labor Day 1998

The derecho developed in northwest WNY and dissipated in eastern Massachusetts (Figure 107). Impact on WNY, as taken from the "WNY Weather History" link to NWS–Buffalo web site: *"Severe thunderstorms moved onshore over northeast Niagara County shortly before midnight near Olcott and Golden Hill State Park in Barker. The line of storms quickly moved across Orleans, Monroe, Wayne, Ontario, and northern Cayuga counties. Across the area the damage path was nearly one hundred miles long and five to ten miles wide. Winds were estimated between 80 and 100 mph throughout the two hour event. Along the entire path, damage and debris all laid in an easterly direction consistent with the damage from straight-line winds. Most of the damage consisted of downed trees and limbs. The falling trees and limbs in turn downed power and telephone lines and resulted in damage to buildings and automobiles. Power outages, some lasting nearly a week, were widespread across parts of Orleans, Monroe and Wayne counties. Hundreds of thousands of customers were without power. The strong winds themselves also resulted in structural damage to homes, barns and buildings along the path. States of Emergency were declared throughout Monroe and Wayne counties and sections of Orleans County. The strong winds severely damaged apple crops and trees from Niagara across Orleans and Monroe through Wayne counties."*

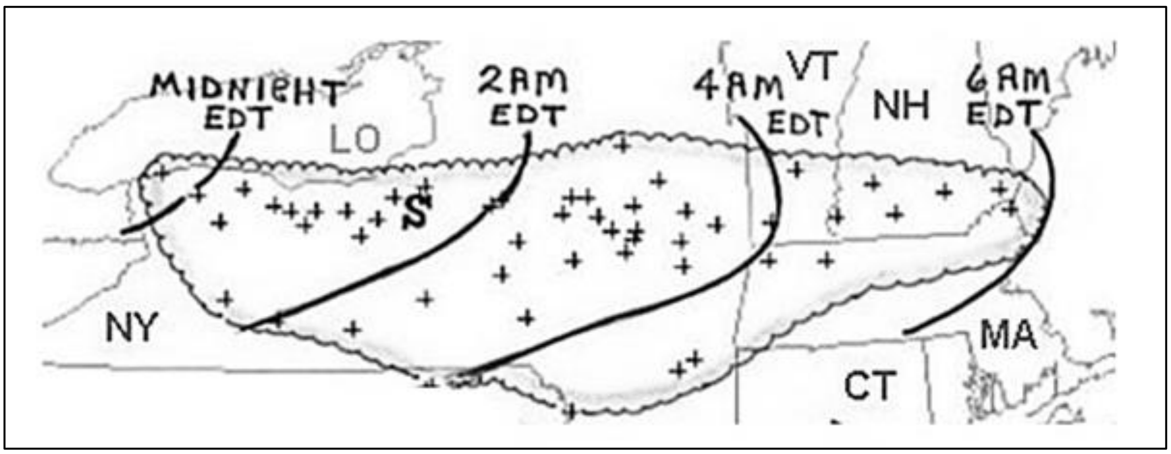


Figure 107. Progression of "Syracuse Derecho of Labor Day 1998" on September 7, 1998. Crosses show high wind speed measurements. Image Source: NOAA-NWS-NCEP Storm Prediction Center web site.

Hurricanes

Hurricanes are massive tropical cyclones of swirling winds and rain that form over oceans and sometimes make landfall. There is no shortage of adjectives to describe these storms. Choosing one letter of the alphabet, hurricanes can be described as dangerous, deadly, destructive, devastating, and dreadful. The monster hurricanes Harvey, Irma, and Maria helped make 2017 the costliest year ever for natural disasters. Residents of WNY do not encounter hurricanes, but we sometimes do experience what is left over (post-tropical cyclones or remnants) as they pass by prior to their dissipation over the North Atlantic. Because it is the Atlantic-formed hurricanes that impact the U.S. east and gulf coasts, our discussion will focus on these storms.

Hurricanes occur in the tropical and subtropical waters of the Atlantic Ocean, often forming off the bulge of Africa (referred to as Cape Verde-type Hurricanes), but they also can form in the Gulf of Mexico, and anywhere in between. There are two "birthing" restrictions that limit their geography: surface water temperatures $\geq$80°F (providing the needed energy and moisture), and the presence of the Coriolis force which gives the hurricane its signature rotation. For these reasons, hurricanes usually form between 5°N and 25°N latitudes (no Coriolis force near the equator). Whether or not a hurricane forms between these latitudes depends on the persistence of other factors − a lifting trigger, unstable air, and weak upper air winds (low wind shear) − that promote thunderstorm development.

A grouping of thunderstorms can form in tropical and subtropical areas where strong lifting triggers occur, the most prominent of these being the Intertropical Convergence Zone (ITCZ) where trade winds converge (collide), and convergence zones within the easterly trade winds. These grouping of thunderstorms, referred to as a "wave pouch", can organize and intensify if the speed of movement of the pouch matches that of the wave's advancement – in a sense, riding the easterly wave much like a surfer rides an ocean wave. While "riding the wave", the wave pouch develops a counterclockwise rotation caused by the Coriolis force. Within the wave pouch, smaller areas of updrafts (the growing thunderstorms) rotate counterclockwise and areas of downdrafts (between the growing thunderstorms) rotate clockwise. Influenced by the counterclockwise rotation of the wave pouch, the similarly rotating smaller updrafts will tend to aggregate (combine), whereas downdrafts will migrate outward and weaken. The clouds and thunderstorms thus organize to form a hurricane. These developing conditions must persist so that the group of thunderstorms, referred to as a "Tropical Disturbance", first organizes into a "Tropical Depression" (winds below 39 mph), and then evolve into a "Tropical Storm" (winds within 39 to 73 mph), and finally into a hurricane (winds above 73 mph).

Often, conditions necessary for development change and tropical storms and hurricanes do not form. For those storms that do reach hurricane status, further intensification can take place. Following the Saffir-Simpson Hurricane Scale, hurricanes can intensify from a Category 1 (74 to 95 mph) up to a Category 5 (>156 mph) status. A name is assigned when the tropical depression becomes a tropical storm. The naming of Atlantic hurricanes follows a yearly alphabetized list of male and female names (between 1953 and 1979 only female names were used, prior to 1953 hurricanes were unnamed). The order of hurricanes for any particular year can be determined by their order in the alphabet. Hurricane season runs from June 1st through November 30th, peaking around September 10th. The timing of hurricanes is certainly something to think about when planning a Caribbean get away.

Tropical storm and hurricane tracks generally follow the easterly trade winds (moving from east to west), but eventually shift northward then eastward as the storm is guided over the North Atlantic. Sometimes the "turn" follows a wide arc and sometimes it is abrupt. Sometimes the turn takes place halfway across the Atlantic Ocean and at other times well into the Gulf of Mexico. Though unpredictable, hurricanes do turn. Contributing to this turn is the Coriolis force. The strength of the Coriolis force varies with latitude, increasing northward. For a hurricane that stretches hundreds of miles across, the Coriolis force is strongest on the northern flank and weakest to the south. It is this disparity in the strength of the Coriolis force that draws the storm ever northward while it is traveling along the easterlies. In addition, the west side of the semi-permanent Bermuda High, located off the east coast of the U.S., adds yet another northward pull on hurricanes (recall that winds flow clockwise around a high-pressure cell). At some point, the northward-moving tropical storm, hurricane, or remnant becomes caught up in the prevailing westerly winds where it is carried eastward across the North Atlantic Ocean to eventually dissipate.

The death (or beginning of the end) of a hurricane can be initiated by landfall and/or passage over cold ocean waters where the storm's source of moisture and energy is cut off. Having said this, these storms may persist for days beyond their energy and moisture sources.

The damage inflicted by a hurricane includes wind damage, storm surge, and inland flooding. The wind damage is obvious, but it needs to be placed in perspective. In WNY, damaging wind storms are usually forecasted by citing wind gusts. By definition, a wind gust is a wind speed of short duration, measured in seconds or minutes. A WNY wind storm with 60 mph gusts can cause "warning status" damage. In the case of a hurricane, the reported winds are not gusting but sustained winds. The damage caused by WNY wind gusts cannot be compared to the tremendous wind damage associated with a hurricane. Wind speeds within a hurricane vary by location within the storm. Winds on the right side of a storm (as it relates to the storm's path) are strongest, as the net wind is a combination of the circulating winds and the storm's movement forward (eg. 100 mph (circulating wind) + 30 mph (movement forward) = 130 mph). The wind on the left side is weakest as the net wind is the difference between the circulating winds and the movement of the storm (eg. 100 mph – 30 mph = 70 mph). This difference has consequences for landfall. Given a choice, it is best to weather a hurricane on its left side.

Storm surge refers to the rising level of seawater and its subsequent push forward onto land. The impact of a storm surge is dependent on the shoreline topography but is usually confined to an area less than a few miles from the shoreline where it can wash out everything in its path. This rise in seawater level can be attributed to a draw-up of water under the intense low pressure of the hurricane that's pushed forward onto the land. Compounding the storm surge are occurrences of strong onshore winds, wave action, and the timing of high tide. Storm surge from Sandy (2012) flooded the New York City subway system, many road tunnels, and underground garages.

Inland flooding easily causes the most widespread damage from a hurricane. It may affect places far inland and for many days after a hurricane has been downgraded. A classic New York illustration of inland flooding can be found with Irene (2011) where areas of Long Island, Hudson Valley, the Catskill Mountains, and the Adirondack Mountains were devastated by flooding. An extreme example of flooding was from Harvey (2017), where Houston, TX and its immediate suburbs received over a year's supply of rain (about 50 inches) in only a few days.

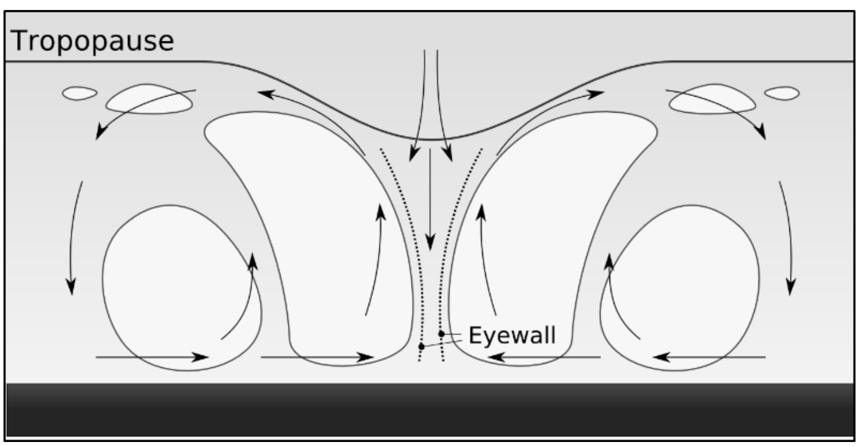


Figure 108. Hurricane Structure. Image Source Wikimedia Commons/Jannev (based on NASA graphic).

A hurricane is made up of spiraling rain bands, an eyewall, and its most identifiable feature, the "eye" (Figure 108). The spiraling rain bands bring intermittent periods of heavy and lighter rainfall with the storm's passage. Due to increasing centrifugal force associated with the hurricane's rotation, the eye wall (which surrounds the eye) contains the storm's strongest winds and precipitation. The most curious part of a hurricane is its eye. The eye is characterized by light winds and clear skies. The passage of a hurricane's eye gives a false indication that the storm has passed, when in actuality the approaching eye wall quickly returns the earlier ferocity of the hurricane. The strength of a hurricane can be identified by the definition of its eye, as the eye is the first to break down as a hurricane dissipates. How does a hurricane's "eye" form?

As air ascends within a hurricane, it rises to the tropopause where a further rise is inhibited (stopped) by a stratospheric inversion (a layer of warm air over cold which prevents the air from rising further). As a result, the air exhausts outward away from the center, creating a huge cirrus cloud shield. But some air exhausts inward, meeting at the storm's center. This inward moving air converges and, because it cannot move upward, is forced downward, forming the hurricane's eye. As you recall, descending air compresses

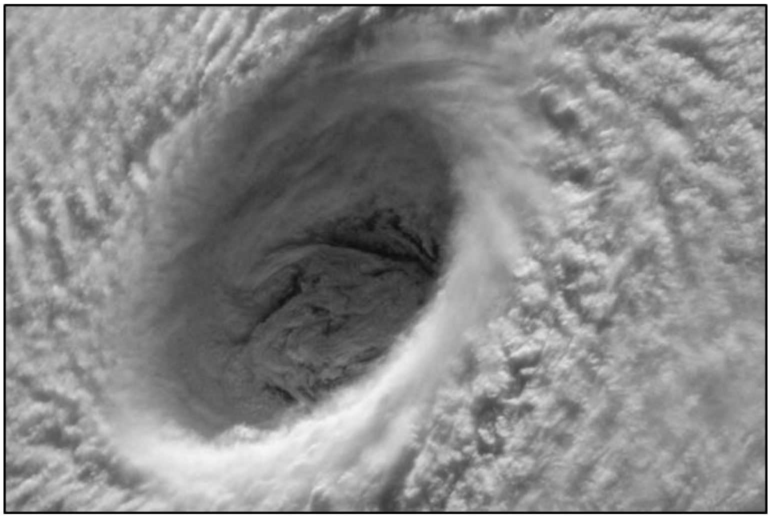


Figure 109. Looking into an eye of a hurricane captured by astronauts aboard the International Space Station. Source: Wikimedia Commons/ NASA.

and warms, causing it to dry, and clouds do not form in descending air. In addition, the forced downward descent of the drying air mixes with moist air along the eye wall boundary, leading to evaporative cooling, which increases the descending air's density and further reinforces the sinking (Figure 109).

While hurricanes have crossed into eastern New York, especially over Long Island, since 1851 only 8 hurricane remnants have tracked across WNY (Figure 110). Most are early unnamed storms, but the list includes hurricanes Hazel (1954), Connie (1955), Hugo (1989), and Opal (1999). Katrina (2005) brought rainfall to WNY but was not tracked as a hurricane remnant beyond Ohio. An unnamed hurricane (H1) in 1893 apparently passed just west of Allegany County, weakening to a hurricane remnant over Hemlock Lake, NY. Both Agnes (1972) and Frederick (1979) passed east of WNY, though contributing much rain to WNY.

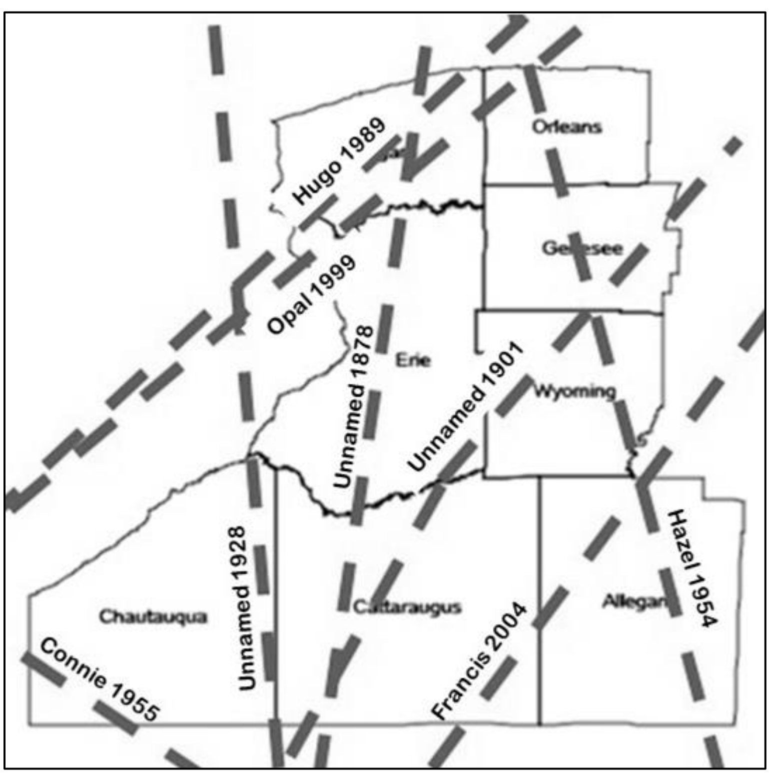


Figure 110. Remnant hurricane tracks passing over WNY. Image Source: Stephen Vermette.

Though not passing over WNY, the remnants of hurricane Hermine (September 2016) had a WNY connection. The Niagara Falls Air Base hosted the 53rd Weather Reconnaissance Squadron which flew numerous flights into the storm to take measurements while it lay off the U.S. Northeast coast.

On August 21st, 2005, the remnant of Katrina delivered over 2 inches of precipitation to WNY. The impacts of Agnus (1972), Frederick (1979), and Opal (1995) are noted in "Western New York Weather History" (maintained by the Buffalo Forecast of the National Weather Service).

Hurricane Agnes (June 1972)

"Remnants of hurricane Agnes dropped 3.97 inches of rain from the 21st through the 24th with up to a foot or more over portions of the southern tier. Disastrous flooding reached record levels in Allegany, and Cattaraugus counties. The dike system was exceeded in Salamanca. The water level behind the Mt. Morris dam reached within three feet of the top (Figure 111). Property damage was in the hundreds of millions of dollars with 24 deaths in New York State."

Figure 111. Mount Morris Dam on the Genesee River. During Tropical Storm Agnes in 1972, $210 million in flood damages were prevented down river. Image Source: U.S. Army Corp of Engineers.

Hurricane Frederick (September 1979)

"The remnants of Tropical Storm Frederic brought record amounts of rainfall to western New York. Buffalo International Airport received 4.94 inches in a 24-hour period. The maximum recorded in the area was 7.10 inches at Holley in Orleans county. Frederic's heavy rains caused extensive flooding over much of western New York and the Buffalo metropolitan area. Most streams rose to above their flood stages. There were countless cases of basement flooding. Power was disrupted in some areas. Many roads were inundated. Schools and offices had to close. Damage to crops was very high, especially in Genesee county. Many property owners who live near streams were evacuated."

Hurricane Opal (October 1995)

As recorded in Western New York Weather History (Buffalo NWS): *"The remnants of Hurricane Opal passed just to the west of Buffalo on the 5th and 6th. Two to three inches of rain fell over much of the area with isolated amounts of near four inches over parts of the Western Southern Tier. Sustained winds were estimated between 35 and 40 mph, but the easterly winds (in contrast to the prevailing southwest direction) did down some trees and power line*

Local Knowledge

Storm Chasing Across WNY

Contributed by Jack Kertzie, a local storm chaser based in Wilson, NY

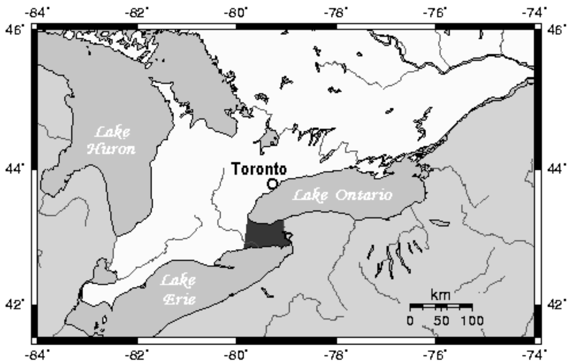
I have been a storm chaser and spotter since 1996. I was born in Buffalo and raised in Amherst, NY. Ever since seeing the Wizard of Oz on black & white TV when I was very young, I have wanted to see a tornado. Finally, as an adult, I decided to make that dream a reality. This would require a reasonable amount of education about severe weather forecasting as well as knowing the dangers of storm chasing. Few would think that WNY would be a good area for this. When I started, most people here did not even know that we actually had a tornado history and I knew that my chances were limited of seeing any myself. I was surprised at how many we have actually had and I knew that if I could recognize the correct weather patterns I might be successful. Lake breezes interacting with fronts and upsloping in the southern tier along with the right winds, air pressure, and moisture can produce tornadoes in our area.

I saw my first tornado near Rushford in August of '96 and two more along I-86 a few years later. I also caught the Corfu tornado in 2009. In addition, I have seen countless funnel clouds, a few waterspouts on the Great Lakes, large hail at times, flooding, and several other interesting events. I even found myself outside, unprotected, in a strong microburst in Lewiston. At that point I had realized why some people report them as tornadoes. The dust and flying debris is incredible, and small stones hitting your skin hurt!

Something that I really find interesting is what you see if you spend enough time under and near thunderstorms. It is funny but you start to get the impression that it is always raining! Not all tornadoes are reported or expected here either. I have seen several small tornadoes locally and what are called "landspouts" all over the Southtowns and even where I live in Niagara County. Interestingly, I have come home after seeing a tornado or been in a hailstorm and my wife will say *"It was sunny here the whole time you were gone"*. Experiencing the winds and changes in temperatures near the storms can be very interesting, as well as the always changing cloud formations. Low hanging 'rotating wall clouds' are more common than you would think in WNY and they are very imposing structures and can happen with any thunderstorm if the wind shear is directional. I have come across several of these and the lightning near them can be intense. Some of the storms in the Southtowns hang so low to the ground that they get pushed uphill by the steering winds, which makes for an amazing sight.

All in all, storm chasing has been a great experience for me and I have learned a healthy respect for what the weather can do, but once it gets into your blood you have it for life!

BOX 18 In the Shadow of the Niagara Peninsula



Throughout this book, mention is made of the moderating effects of Lakes Erie and Ontario on the weather of WNY: cited to define the region's climate zones, to explain weather forecasts which include the caveat "cooler (or warmer) by the lake", to explain the dampening of thunderstorms passing over Lakes Erie and Ontario, as well as attributing winter cloud cover, precipitation, and snow to the lee of the lakes.

Sandwiched between Lakes Erie and Ontario is the Niagara Peninsula (N.P.) of Ontario, Canada (see area darkly shaded on map) which, while not a part of WNY, offers its own influence on our weather. For the most part, the influence is a reversal of the lake effect. This influence extends north of Buffalo along the Niagara River shoreline to a few miles south of the Lake Ontario shoreline, and east a few miles inland to the point where conditions blend to inland sites normally removed from the modification of shoreline locations.

A case in point is the influence of the peninsula on the intensity of heat waves. The higher elevations of WNY's southern tier and the modifying effects of the lakes generally buffer WNY from the worst of extreme heat. However, areas in the shadow (to the immediate east) of the Niagara Peninsula are repeatedly hotter than other "shoreline" locations in WNY due to the absence of lake moderation. By way of example, consider a comparison of 2:00 p.m. temperatures taken at the NWS site located at The Buffalo International Airport (located just south of the N.P. shadow) with that of the NWS site at the Niagara Falls Airport (located within the shadow) during the first week of the July 2018 "heat wave". Over the seven days of the heat wave, the 2:00 p.m. temperatures at the Niagara Falls site were consistently higher than at the Buffalo airport (averaging 5.5 degrees higher) – experiencing ≥90°F on all seven days, compared to the one 90°F day at the Buffalo Airport.

Furthermore, spring and early summer thunderstorms, which often shrink and dissipate with passage over Lakes Erie and Ontario to the New York shoreline, are not similarly dampened with passage over the Niagara Peninsula. While in the winter, the sun shines immediately east of the peninsula while lake effect related snow clouds are visible to its north and south.

Image Source: Wikimedia Commons

The Lake Effect Snow Machine

Lake effect snow is distinctive from broad synoptic-type snowstorms associated with the passage of a midlatitude cyclone moving across the country. As used here, the lake effect snow "machine" refers to Lakes Erie and Ontario and the air above them under specific atmospheric conditions. During the lake effect snow (LES) season, conditions are prime for these lakes to generate snow over and downwind (leeward) of them. WNY's lake effect snow belt extends about 50 miles inland from Lake Erie (less so from Lake Ontario) (Figure 112) and is but one of several snow belts across the Great Lakes Region, all leeward of their respective lakes.

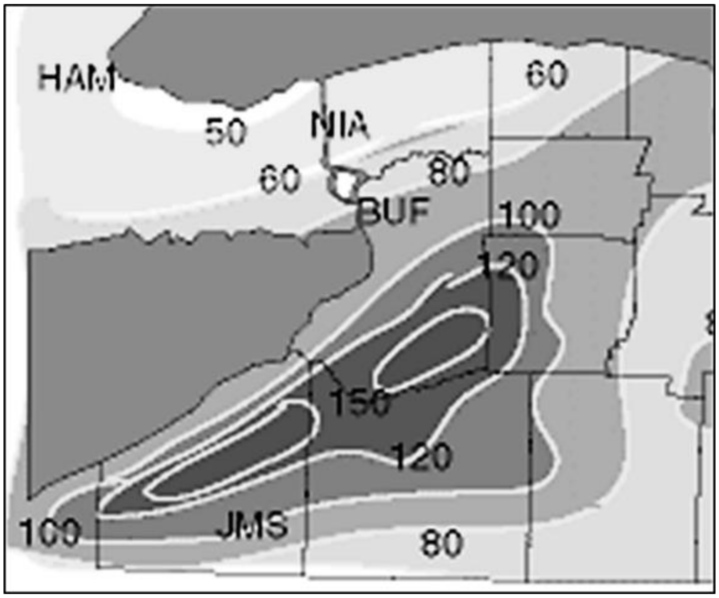


Figure 112. WNY snow map showing regional snow belt. Image Source: Buffalo NWS Forecast Office.

The early set-up for LES is passage of a strong low-pressure cell migrating west-to-east across northern Ontario and Quebec (north of WNY). The counterclockwise flow of surface air around the low-pressure cell draws polar air south (behind a cold front) around the west side of the low and across the lake's surface. If the lake waters are warm relative to the polar air, and several other conditions are met, LES may result. One of these other conditions is an air-lake temperature difference of at least 23°F (the warmer the waters in relation to the air, the greater the lake effect potential). The air temperature is measured at about 5,000 ft asl (850 mb), as this is the height in the cloud at which snow begins to form. The extent of lake ice is another condition affecting LES formation. A frozen lake does not produce snow since the ice prevents evaporation, effectively shutting down the lake effect machine. As Lake Erie is often covered in ice by late January, the threat of LES diminishes in late winter. This is not the case for Lake Ontario as it does not freeze over because its greater depth permits a larger volume of stored heat. Having said this, even small openings (leads) in the ice may release enough moisture and energy to fuel LES.

Surface wind direction is an important factor in the formation of LES. The longer the path (fetch) over the lake, the greater the transfer of energy and moisture from the lake to the air, increasing the potential of increased LES amounts. Buffalo and WNY are positioned at the eastern end of Lake Erie, such that a southwest wind provides a 240-mile fetch across the lake, building the potential for substantial LES. In general, winds between SSW to WSW (200 to 250 degrees on the compass) impact the city of Buffalo and the North Towns, whereas winds between WSW to WNW (250 to 300 degrees) impact areas to the south. For Niagara and Orleans counties, west and northwest winds (270 to 315 degrees) generate snow off Lake Ontario but, as the fetch is limited across Lake Ontario, the LES in these counties is usually less than what comes off Lake Erie. Similarly, a northwest flow across Lake Erie can generate weak LES downwind into Erie and Chautauqua counties. While LES events are usually discrete events related to a single lake, favorable atmospheric conditions can extend (merge) snow bands off Lakes Superior and Huron and Georgian Bay, across Lake Erie, and into WNY.

There are two remaining LES conditions to be aware of. The build-up of clouds to produce LES is dependent, in part, on the direction of upper air winds. If their direction matches that of surface winds (the difference between the upper air winds and surface winds is within 60 compass degrees), then the clouds can grow in height to produce LES, whereas dissimilar winds (directional wind shear) will prevent their build up. Lastly, topography plays a role as higher elevations force air to rise, leading to adiabatic cooling and greater amounts of snow. This partly explains why LES amounts in WNY are greatest in Chautauqua County, located just east of the Chautauqua Ridge.

The weather on different sides (windward and leeward) of a lake can be dramatically different. Consider a hypothetical cross-section of a lake. Polar winds on the windward (upwind) side are accelerated over the lake due to reduced friction, creating a divergent (separating) air flow. To compensate, air on the windward side is drawn down from above, creating a local high-pressure area which keeps skies clear. As the cold air moves across the open waters of a lake, the lower layers of the air are heated (latent heat) by the warmer water, and moisture is evaporated into the air. At the same time, the air is destabilized by a temperature gradient where the warmed, unstable air rises, cools (increasingly cooler temperatures with height), and builds up cumulus clouds through condensation. The greater the temperature difference, the taller the clouds, and the greater the amounts of snow produced. "Thundersnow" (thunder during a snowfall) is an indication that the clouds have built-up to the size of a thunderstorm (cumulonimbus cloud). Finally, air reaching the leeward (downwind) shore is slowed by friction. The resulting pile-up of air (convergence) along the shore causes it to build upward, further enhancing cloud development and LES amounts. So, while the windward shore may be enjoying a sunny day, the cloud-covered leeward shore may be buried in snow! Crossing the Skyway outbound from the city of Buffalo provides a wonderful view of the build-up of LES clouds as they cross Lake Erie from Canada.

Lake effect snow bands come in two basic forms. The form associated with winds that blow along the long-axis (long fetch) of a lake is referred to as a "Single or Shore-Parallel Band". These bands tend to form in the center of the lake, controlled by land breezes along the shores. With a WSW to WNW air flow, the band is pushed southeast to straddle the Erie and Chautauqua county shoreline. This type of snow band is the most intense and is commonly associated with LES off Lake Erie (Figure 113). When winds blow along the short-axis of a lake (short fetch) "Multiple or Wind Parallel Bands" form. The reduced fetch associated with these bands limits the latent heat and moisture acquired from the lake, and thus they tend to be multiple and weaker with lower snowfall rates than are typical of "single" bands. Multiple bands are most common when winds are from the northwest across Lake Ontario, where they impact Niagara and Orleans counties, and across Lake Erie with northerly winds.

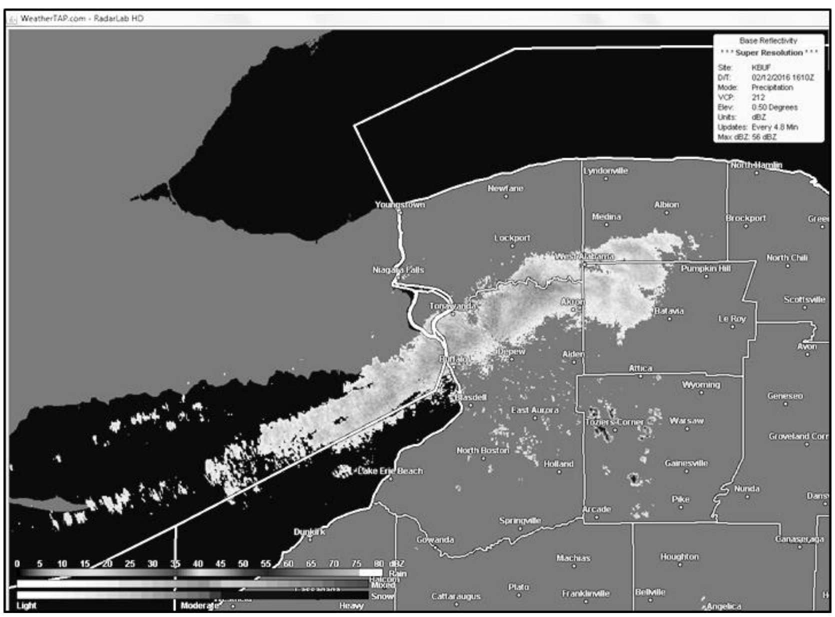


Figure 113. Long-axis lake effect band forming off Lake Erie, impacting Buffalo, NY. Image Source: Weathertap.com/Stephen Vermette.

Lake effect snow bands have a dynamic nature that makes them fascinating to observe and difficult to predict, as they may be narrow in width and migrate with changing wind direction. Given a similar rate of snowfall, a band that is stationary, or moves little, will "dump" far more snow in a concentrated area than one that migrates. Numerous times in my commute I have "punched" through lake effect snow bands, traveling from sunny skies, into blizzard-like conditions, and out into sunny skies again, or have found myself needing to consider "exit strategies". Upon hearing that there is a lake effect band in Tonawanda which will move south through Buffalo on its way to the Southern Tier, I might exit the city early, ahead of the snow band, if anticipating traveling south, or let it pass before traveling north. A common weather phrase is *"wait five minutes and the weather will change"*. In WNY, you could add *"travel five minutes and the weather will change"*.

Box 19 **"Snow Day" Rituals**

As a child, you likely hoped for snow days. That is, days when school was canceled because it was too cold or too snowy – just plain too dangerous to be waiting for a bus, driving, or walking to school. The decision to call a snow day usually rests with a school district's superintendent. While student safety is imperative, there is no exact weather criteria on which a decision is made, and this leads to a student's uncertainty and anguish (parents, too) on the eve of a potential snow day. Students aren't helpless in forcing a snow day. There are the time-tested rituals. The ritual seemingly most common in WNY is to wear your pajamas inside out. Other snow day rituals include placing a spoon under a pillow, placing white crayons (pennies or a fork for some) in the freezer, flushing ice down the toilet, and just not talking about it in fear of jinxing yourself. While there are no statistics to assess the success of these rituals, be reminded that there are forces at work other than that of Mother Nature.

Thundersnow

Thunderstorms in WNY are usually a warm season phenomena, but they do occur from time-to-time in the winter too. A winter thunderstorm can come to WNY associated either with warm or cold air.

The warm-type thunderstorm usually follows the arrival of a substantial winter thaw (temperatures rising into the 50's or 60's F) associated with the passage of a synoptic low-pressure system. The warming is part of the cyclone's "warm sector" which is sandwiched between the counter-clockwise spiraling arms of its warm and cold fronts. It is between these two fronts that warm air is drawn up to WNY from the Gulf of Mexico. The thunderstorms follow with the passage of the warm air in advance of the approaching cold front. It is along this frontal boundary that warm moist air is rapidly lifted to create thunderstorms. These thunderstorms are usually weak with a few thunderclaps heard and temperatures then drop rapidly following the passage of the cold front.

The cold-type thunderstorm is linked to lake effect snow (LES) events. The passage of cold air over the warm waters of Lakes Erie or Ontario provides the energy and moisture needed for LES. Unlike typical LES events, the disparity between the air and lake temperature is so great that the lake-induced CAPE (Convective Available Potential Energy) creates a cumulonimbus (thunderstorm) cloud. The claps of thunder heard during falling snow are what give this type of storm the name "thundersnow". These LES thunderstorms are dependent on the lake for their energy and moisture and thus do not extend very far inland. Thundersnow is rare outside of "lake effect" as winter snow events lack the necessary energy to power a thunderstorm. Who can forget the excitement of Weather Channel meteorologist Jim Cantore upon hearing thundersnow – "Yes! We got it baby!!" – along the Northeast sea coast.

This author's most vivid memory of thundersnow was the early-season lake effect snowstorm – "October Surprise" – that hit Buffalo and its eastern suburbs the evening of October 12, 2006. This storm was one of Buffalo's most destructive weather events.

On October 12th the lake temperature was 62°F and, with the passage of a cold front and the polar air that followed, an air (measured at 850 mb) to water temperature difference of about 43°F developed. The difference was more than enough to build a lake effect (cold-type) thunderstorm. The resulting thunderstorm had a lake-induced CAPE described as "unprecedented for a lake effect event" and cloud heights of 25,000 to 30,000 feet. It was a monster poised over the city of Buffalo and its immediate suburbs, dumping unprecedented amounts of snow for so early a date in the autumn.

This storm was notable for the damage caused by up to 2 feet of heavy snow that fell on fully-leafed trees. It is estimated that 90% of Buffalo's trees were damaged, and many thousands were lost. The loss of trees, property damage from falling limbs unable to support the heavy snow, downed power lines (over 400,000 people without power for up to five days), and stranded motorists led to the declaration of a state disaster emergency.

Memories of those people caught in the storm include the snowfall, but most often center on the cracking sounds made by limbs falling around and on homes, and the rapid-fire lightning flashes and rumbling thunder throughout the night. Though not in Buffalo, I watched the lightning show from the Southtowns and can best describe it as analogous to a continuous series of flash bulbs going off over the city. Upon arriving in Buffalo as the sun rose on October 13, I was shocked to see the degree of damage, but it was the unceasing lightning and accompanying thunder that I remember most vividly.

Box 20 **Another "Face" of WNY's Weather**

Article/Image Source: "Snow Pattern", December 8, 1959. The Courier-Express Photograph Collection, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Miss Barbara Weber, 23, was doing the dishes in the kitchen of her home…yesterday afternoon when she glanced out of the window and gasped *"It's Fantastic!"* Without taking her eyes off what she saw in the snow-covered backyard, she called to her family to come and confirm it. Barbara's grandmother, Mrs. Annavieve Gersting came and looked. *"It's like he's come back to me."* Mrs. Gersting whispered, and there were tears in her eyes.

Wet snow clinging to the side of a barrel covering a fig tree in the backyard had formed the unmistakable figure of a man. But it was more than that the five persons in the home agreed. It was as if some unseen hand had sculpted the facial and body features of Fred Gersting, husband of Annavieve, even to his hair line.

Gersting died in Sisters Hospital last December... A native of Buffalo, he was a retired millwright and prohibition era agent for the Justice Department. Mrs. Gladys Weber, step-daughter of Gersting, said the resemblance was phenomenal. *"Notice how the figure seems to be stooping."* Mrs. Gersting said. *"Fred was like that. It was the result of an illness he suffered."*

WNY's Notable Lake Effect Snow Storms

Figure 114. A wall of intense snowfall descending on the Buffalo Southtowns during the first of two historic back-to-back lake-effect snow events in November 2014. Image Source: Shawn Smith (2014), retrieved from

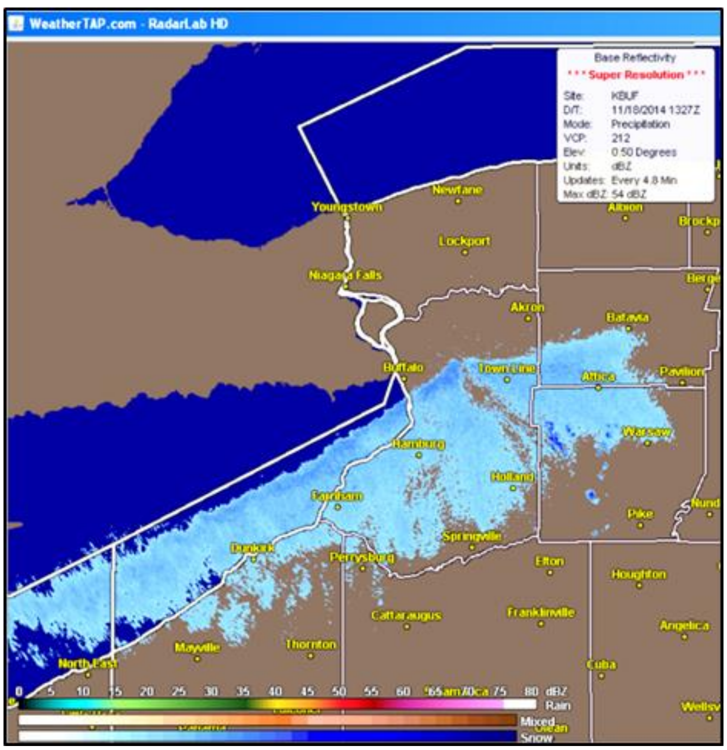


Figure 115. Radar image of Snowvember lake effect band, as recorded on November 18, 2014 (first day of the storm). Image Source: Weathertap.com/Stephen Vermette.

It is not uncommon for WNY to experience a foot or more of snow as cold air passes over Lakes Erie and Ontario and stirs up the "lake effect machine". These events are many, but most are forgotten due to a blurring of events with the passage of time. Some are just too big, too disruptive, or too recent to forget. Based on local experiences, residents of each town and village in WNY can come up with their own list. The list below is admittedly biased toward Buffalo and its suburbs.

November 18-21, 2014 (The Knife or Snowvember)

Areas in and south of Buffalo, New York, were smothered by back-to-back lake effect snow events—events that "kept on giving" to the tune of up to seven feet of snow. The accumulated snow led to travel bans, thruway closures, abandoned vehicles, heroic survival stories, "Good Samaritan" acts, numerous roof collapses, a call-out to the National Guard, and, sadly, 14 deaths. The first lake effect event in this one-two punch is remembered for its visible "wall of snow" − a Mason-Dixon Line of sorts − that sharply defined the northern boundary of the lake effect (Figure 114). The dual lake effect events may also be described as a "tale of two cities": the areas of South Buffalo and south of the city (the "Southtowns") experienced "snow-maggedon," while the areas of North Buffalo and north of the city (the "Northtowns") received little snow, and residents went about their business under sunny skies. The areas most impacted ran from South Buffalo, into central Erie County, and into Wyoming County (Figures 115 and 116). Who can forget the repository of snow that appeared as a mountain of snow at Buffalo's Central Terminal, remnants of which existed well into the summer of 2015?

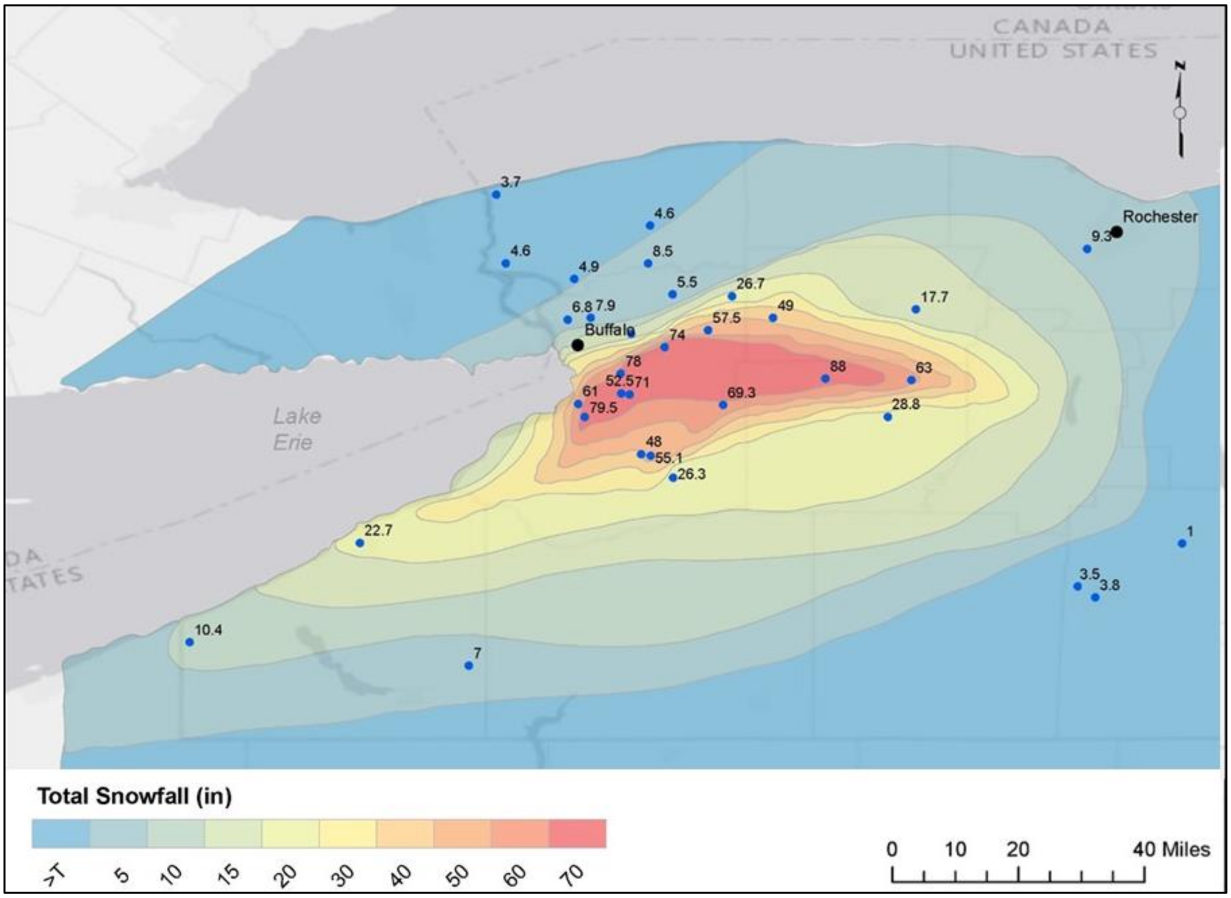


Figure 116. Snowvember's snowfall distribution across WNY. Image Source: Mary Perrelli (SUNY Buffalo State).

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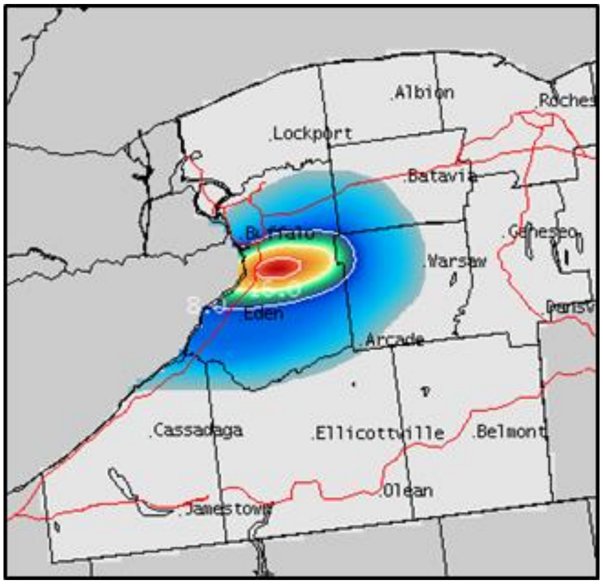
Box 21 2307: Winter's Dream

The 2017 film: "2307: Winter's Dream" (written and directed by Joey Curtis) takes place in a futuristic dystopian world (2307 A.D.) where the Earth has been locked in a perpetual cold for 300 years. A "cold" that is so brutal that Earth's few survivors live underground, as they cannot live on the planet's frigid surface. Humans can tolerate only short times on the surface when injected with a form of a "biological" induced insulation. The story goes on…

While watching the movie, you may notice that many of the exterior shots look familiar. Indeed, the lifeless tundra known as the "Dead Zone" was filmed in WNY, taking advantage of the heavy snowfall of 2014 and Lake Erie's ice cover. Scenes included the Lake Erie ice pack off Hamburg, NY, Silo City, 18-Mile Creek and Zoar Valley. Climate-wise there is much that is not right with the exterior shots – given 300 years of "winter" it is difficult to reconcile the trees, wet snow, and melting icicles – but it is best to suspend disbelief and enjoy the movie's uninhabitable world, a winter world that we call WNY!

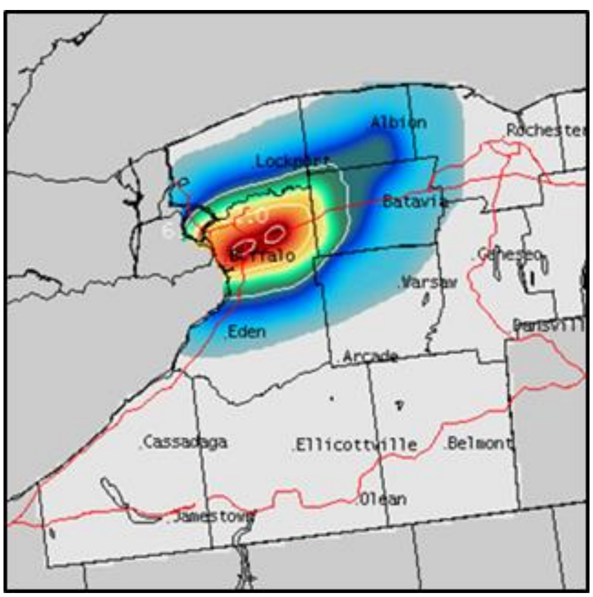
December 1-3, 2010



At the time, the Buffalo Office of the NWS described this storm as *"one of the most intense and disruptive storms on record for the Buffalo area."* It was striking in that the lake effect band remained stationary over a 30-hour period, depositing most of the snowfall into a 12-mile wide band over south Buffalo (Figure 117). Buffalo's snow measurements ranged from trace to 39 inches. A storm maximum of 42 inches was measured at Depew, NY. The closure of the Thruway being necessary only between exits 52 and 54 is testament to the storm's intensity and limited footprint.

Figure 117. December 1-3, 2010 lake effect event snowfall distributions. Heaviest concentration in WNY over south Buffalo, NY. Original Image Source: National Weather Service, Buffalo, NY.

October 12-13, 2006 (October Surprise)



The 2006 "October Surprise," dumped up to two feet of wet snow on Buffalo while trees were in full foliage (Figure 118). The weight of the accumulated snow caused widespread tree damage and prolonged power outages to a large percentage of the city and its surroundings. The cracking and falling of tree branches and the relentless lightning, or thundersnow, which persisted through the night will forever haunt the memories of those who experienced it.

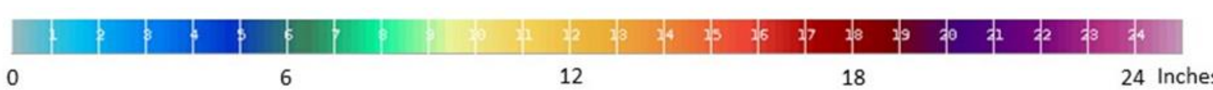
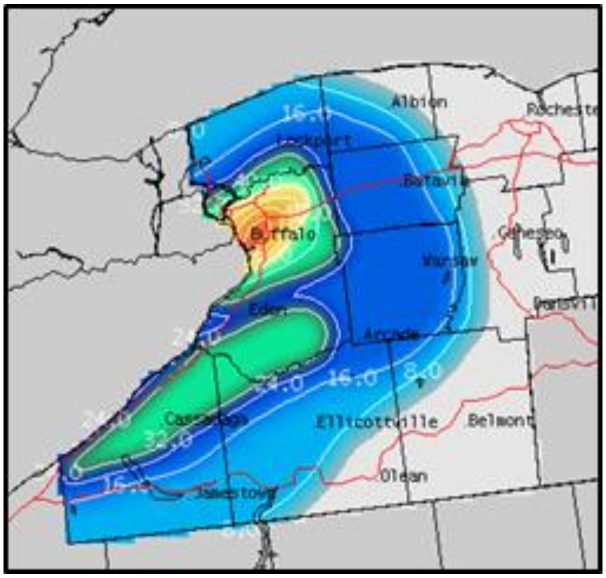


Figure 118. "October Surprise" snowfall distribution. Original map and WNY focused map. Original Image Source: National Weather Service, Buffalo, NY.

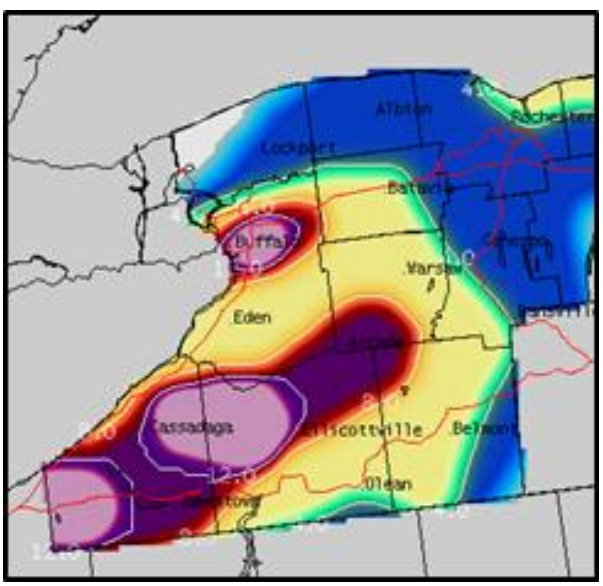
December 24, 2001 – January 1, 2002



WNY was jolted from an early winter complacency of little snow with the arrival of slightly under 7 feet of snow in a period of about five days. The heaviest areas hit were South Buffalo and West Seneca (Figure 119). The lake effect oscillated across Northern Erie and Niagara counties no less than six times, before settling into Erie, Chautauqua, and Cattaraugus counties where it dumped a few feet of snow. In areas hit hardest, snow removal was an issue as traditional plows were useless – snow had to be lifted by front end loaders and carried away by truck. This storm was forecasted well in advance and because it occurred over the Christmas/New Year holiday, storm-related disruptions for the average citizen were less than would otherwise be expected.

Figure 119. December 24, 2001 – January 1, 2002 lake effect event snowfall distributions. Highest totals in Buffalo area. Original Image Source: National Weather Service, Buffalo, NY.

November 20-23, 2000



With snow, timing is everything. This record-breaking early season storm struck midday on the 20th, burying the city of Buffalo in snow during the afternoon rush hour. With snowfall rates of 4 inches/hour roads quickly became impassible, traffic came to a standstill, and cars were abandoned (Figure 120). Thousands of school children were caught on buses. I recall that my wife was able to safely exit the city around 2:00 p.m., while I stayed another few hours at work, and was not able to leave the parking lot. Many people spent the night of the 20th at work, school, or in shelters. The storm drifted south and delivered a second punch on the 21st-22nd to the western southern tier, where about 2 feet of snow fell (about 30 inches fell in Stockton and Albion). The counties of Erie, Chautauqua, and Cattaraugus were declared Federal Disaster areas.

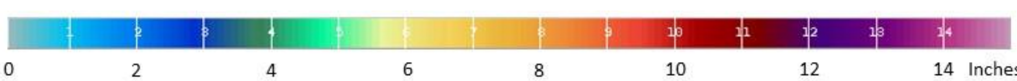
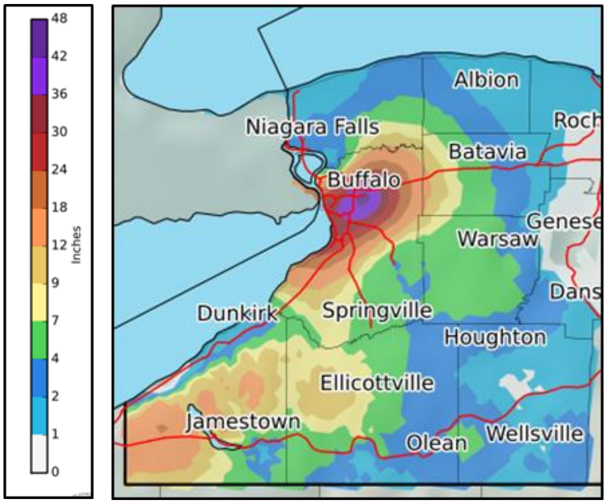


Figure 120. November 20-23, 2000 Lake Effect event snowfall distribution. Heaviest in Buffalo area and parts of the Southern Tier. Original map Image Source: National Weather Service, Buffalo, NY.

December 9-12, 1995



This storm set its sights on the city of Buffalo and its immediate northern and eastern suburbs, establishing new daily and 24-hour snowfall records (33.9 and 38 inches, respectively) for the city of Buffalo (Figure 121). Two feet of snow fell in only 8 hours. The area was paralyzed for days with numerous States of Emergency declared. Striking was the narrow band and sharp gradient in snowfall from the storm. Snow amounts varied by as much as 30 inches over just a few miles!

Figure 121. December 9-12, 1995 Lake Effect event snowfall distribution. Heaviest snowfall concentrated in the Buffalo Area. Image Source: National Weather Service, Buffalo, NY.

January 19-22, 1985 (Six-Pack-Blizzard)

This event was a true blizzard. The four-day storm snow total was 34.4 inches accompanied by frequent whiteouts, winds gusting over 50 mph, wind chills as low as −60°F, and snow drifts up to 8-feet deep. Cars were abandoned on roadways, driving bans declared, and emergency shelters set up for those who were stranded. The governor declared a State of Disaster for Erie, Niagara, Orleans, Genesee, and Wyoming counties. This storm was further made memorable by Mayor Jimmy Griffin's advice to Buffalonians *"Stay inside, grab a six-pack and watch a good football game"*.

January 10-11, 1982

This storm possessed the hallmarks of a notable lake effect storm. Along with 2 feet of snow, 50 mph winds whipped up wind chills dropping to −30°F (based on new wind chill chart). The Thruway was closed from Rochester to the Pennsylvania border. Many people were stranded; from thousands of hockey fans trapped in Buffalo's Memorial Auditorium, to hundreds of skiers at Kissing Bridge in the Southtowns.

In 1982, Nuray Aykin arrived from Turkey to begin her semester at SUNY Buffalo. In her book "Pomegranates and Grapes: Landscape from my Childhood" she reminisces about that January in Buffalo: *"I understood what lake-effect snow was about. It really snowed in blankets. There were days I had to lift my leg up high as my belly in order to walk. You could easily get stuck in the hip-high snow. And, believe me it was very tiring."*

November 29-30, 1975

A rush hour nightmare, the lake band first formed just south of the city of Buffalo and moved north across the city snarling the morning rush hour traffic with 1 to 2 feet of snow and near-blizzard conditions. Reaching as far north as Grand Island and Niagara Falls, the snow band turned back on itself. It drifted south through the afternoon, paralyzing the afternoon rush hour traffic. The band continued to drift south, settling into southern Erie County where it unloaded 4 feet of snow before dissipating. States of Emergency were declared in the towns of Evans and Angola.

Local Knowledge

On-Air Meteorological Experience: Lake Effect Storms

Contributed by Don Paul, WNY Broadcast Meteorologist for over 30 years

Prior to my arrival at WIVB in August of 1984, I had been working close to the other end of Lake Erie in Detroit, Michigan. To those not familiar with Great Lakes climatology, cities on the western side of the lakes generally don't get much lake snow. More commonly, prevailing winds from the NW, W, or SW deliver the snow to the leeward side of the lakes. Nearly all of Detroit's snow came from large-scale low-pressure systems. I hadn't experienced much lake snow in SE Michigan. I had lots to learn.

When I got here, then-NWS Meteorologist in Charge, Don Wuerch, was kind enough to invite me to the Buffalo NWS Office, gently instructing me how I'd have to "live it" here to understand lake snow development and placement. He gave me an office "decision tree" paper dealing with lake snow off both Lakes Ontario and Erie. That paper was of enormous value in dealing with my first big lake effect storm during January 19-21 in 1985. That storm resulted in the first Blizzard Warning since the infamous 1977 event. For placement of lake snow alone, the paper was golden. I could sit and try to calculate with a compass and protractor which towns get targeted by lake snow bands with which precise wind directions/vectors. But that would have left me with slim hopes for success for a novice. The decision tree was built on a firm basis of climatology and experience of countless past lake effect events.

One of the primary problems in forecasting low level wind direction much in advance with the more primitive models of that era was their inherent unreliability due to starkly limited physics. That included the role of thermodynamics associated with the lakes. The dominant NWS model at that time was called the limited-area fine-mesh (LFM). The LFM had to represent the Great Lakes as flat plains. That wasn't out of ignorance, of course. We simply lacked the computer crunching power to resolve smaller geographic features such as the Great Lakes as being moisture and heat sources.

The overall call on the Blizzard of '85 was very good, with plenty of lead time warning. Even so, my recollection is the morning of the 21st, when the Blizzard Warning was issued, the low-level wind direction forecast was off by 30-40 degrees on the compass. Had the band been typically narrow with no synoptic, or large scale, snow occurring, an enormous forecast bust would have resulted for those meteorologists who decided to rely completely on model output.

Today, much higher resolution models have become commonplace. We almost never see wind direction output off by so wide a margin. Instead, we often find ourselves in the conundrum between overreliance on these far better models, or occasional overreliance on "gut instinct." What is needed is a careful blending of model output and our own pattern recognition.

Even with these powerful model tools, there are still issues of timing, intensity and movement of shifting bands, and how much instability is likely to develop to fuel the development of strong bands. The magnitude of the uncertainties has been reduced…but not eliminated.

What sorts of uncertainties? If winds shift direction too much with increasing altitude, that kind of directional wind shear can tear bands apart. It's not enough to know winds will be "from the southwest." We need to know the precise direction up to about 5000 feet for the winds which steer the bands. A wind from 240 degrees on the compass tends to steer the band north of Buffalo into Amherst, Clarence, Akron and the NE 'burbs; 245 degrees can shift the band to the southern part of Amherst and northern Cheektowaga; 250 degrees takes the band straight into Buffalo and out to Batavia; 255 degrees hits South Buffalo and Lancaster. If your wind forecast is off by 3-5 degrees on the compass in densely populated northern Erie County, you can warn—or not warn—the wrong 100,000+ people. If the air above the lake has lower humidity than forecast, the band can be weaker than expected, and vice versa. If low level winds are too strong, that kind of speed shear can also tear bands apart.

As for "gut instinct," the October 2006 Surprise Storm was a case in which I leaned too much on past climatology. One NWS model was forecasting temperatures at 5000 feet to be cold enough to produce very heavy, water-laden snow. I relied heavily on the climatology and thought only a few inches could accumulate at lower elevations that early in the season. Past events in the first half of October at lower elevations in northern Erie County had no real analog for big amounts. So, I assumed that model was an "outlier" and after forecasting some limited lake snow a week in advance, (and feeling smug about that lead time) I decided climatology should take accumulations down to perhaps 2-4" or 3-5". But, 22 inches later, I realized gut instinct had gotten the best of me. Maybe now we'd overcompensate in the other direction given similar conditions.

High resolution models with better physics have been one great technological breakthrough. Another has been the deployment of advanced Doppler radar, by which wind direction, speed and shear at many different altitudes can be detected. We can see whether and where moisture convergence is most likely to develop even before the flakes fly. Busted lake effect forecasts still occur, but they occur with much less frequency and, when they do occur, with much less severity.

In sum, the improvements in lake snow forecasting during my time here in Western New York have been substantial. Continuing education online enabling adaptation to these great new technologies has been an awesome boon to local meteorologists, young and old. At least I know I can speak for the latter group.

Blizzard of '77

The "Big One" most often refers to an inevitable major earthquake in California, but in WNY it refers to the Blizzard of '77, the blizzard by which every subsequent winter storm has been compared. This storm has infused itself into the region's DNA. Perry's (Akron, NY) ice cream flavor "Zero Visibility" was created in recognition of the blizzard and Perry's connection to WNY (zero visibility was reported for 13 hours at the Buffalo Airport). Regardless of whether you lived through the blizzard or were born or moved into the region after the storm, it is part of your psyche. The storm certainly cemented Buffalo's reputation as a city of snow. I recall talking to a couple while traveling outside of WNY. Upon hearing that I am from the Buffalo area, they mentioned that the one time they passed through Buffalo, they could not believe the amount of snow. I asked them when they passed through Buffalo. They responded: the winter of 1977!

Blizzards are defined by the NWS as sustained winds or frequent gusts to 35 miles an hour or greater, and considerable falling and/or blowing snow that frequently reduces visibility to ¼ of a mile or less that prevail for a minimum of 3 hours. Most common in the northern Plain states, true blizzards are rarer in WNY.

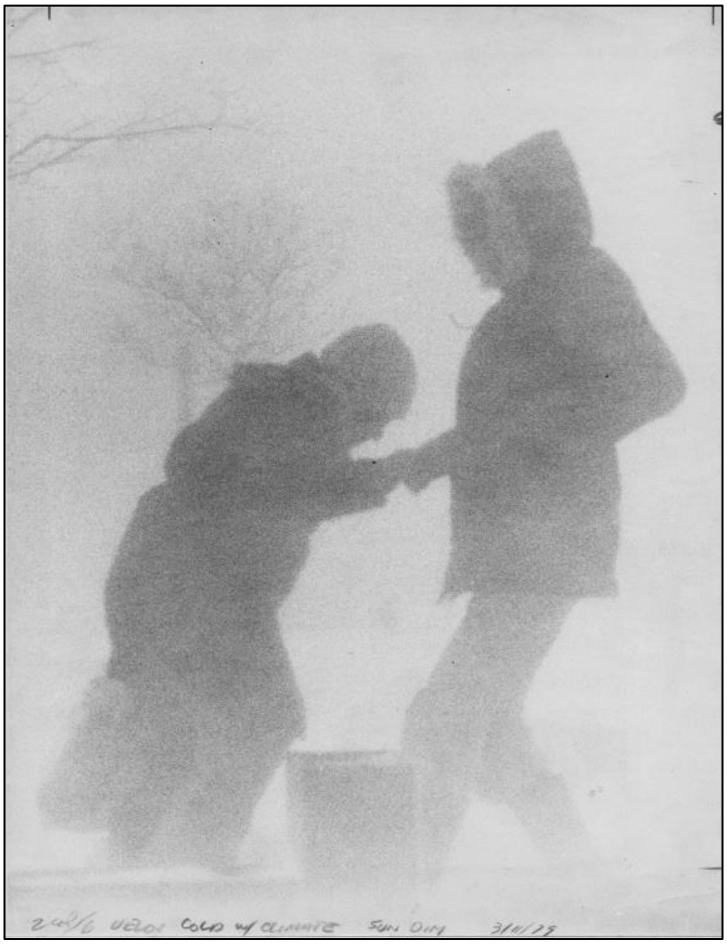


Figure 122. Six weeks before the Blizzard of '77 pedestrians helping each other are all but obliterated in whiteout. Image Source: "White Out", December 10, 1976. The Courier-Express Photograph Collection/Ron Moscati. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Many are surprised that the Blizzard of '77 was not a lake effect snow storm, at least as these storms are defined, and thus was not included on the previous list of notable lake effect snow storms. The blizzard had its roots going back months before the storm hit. November and December 1976 were extremely cold. Average temperatures were −5.7°F and −5.9°F, respectively, below the 1941-1970 Normal used at the time, or −6.6°F and −8.1°F, respectively, below today's 1981-2010 Normal. Lake Erie froze over by mid-December, an early record (Figure 122). Abnormally cold conditions persisted through January 1977. Snowfall was unrelenting through the months of December (60.7 inches) and January (59.1 inches before the blizzard). It snowed almost every day (51 out of 58 days) in December and January prior to the storm. Street plowing was falling behind, and snow was creating havoc in the city and surrounding areas. Plans were made to mobilize the National Guard, even before the blizzard hit. Buffalo was on its way to a seasonal record-breaking snowfall of 199.4 inches. By late January there were 33 inches of snow on the ground, and on the ice on Lake Erie.

An extremely cold Arctic front passed over the region at about 11:30 a.m. on Friday, January 28th, bringing with it extremely cold temperatures (0°F) and strong winds (46 mph, with gusts up to 69 mph), which, when combined, created wind chills of about −35°F (based on new wind chill chart). The snow and wind mix reduced visibility at times to make travel impossible. These were blizzard conditions. Interestingly, radar showed very little snow falling from the sky. The snow associated with the blizzard was supplied by the approximate 33 inch snowpack which, over the previous weeks, had accumulated on Lake Erie's ice (officially, only about 12 inches of new snow fell on the days of the blizzard). The snow drifts in Buffalo and area were legendary, reaching heights of 30 feet in many places.

The initial blizzard blast, seen as a "wall of snow", caught residents off guard and many were stranded, either where they were when the blizzard struck or trying to get home. The cold front was tracked, and the Buffalo NWS indicated that *"very strong winds will once again produce near blizzard conditions beginning late this afternoon and continuing tonight"*, but the "once again" in the forecast did not convey the uniqueness of this storm. At 11:00 a.m., minutes before the storm hit Buffalo, the NWS issued it's first-ever Buffalo blizzard warning. The Blizzard of '77 board game (designed by C.P. Marino) reflects how this sudden change in weather caught people unprepared. Initially, the players use a game piece and dice to easily travel across the game board from home to five locations (work, bank, hardware store, grocery store, and drug store). The first player to accomplish all five and return home is the winner. But, once the "blizzard card" is drawn, the board is flipped over and travel is subsequently made almost impossible by travel squares that include zero visibility, stalled cars, high drifts, driving bans, etc. I have played this game numerous times and, most of those times, players quit before a winner is declared – relenting to the blizzard.

The Blizzard of '77 persisted for about four days (January 28th to February 1st), with recovery times extending well beyond that (most schools were reopened by February 14th). The city of Buffalo and surrounding area was paralyzed. Travel in some areas was limited to snowmobiles (mostly providing aid). Countless numbers of people and cars were stranded, numerous States of Emergency and travel bans were declared, extreme hardships were experienced by many, and unfortunately 29 individuals died in the blizzard (9 were found frozen in cars buried by snow). While the Blizzard of '77 is a story about a city and the region, there are countless first-person experiences that better describe the blizzard and its impact. Figures 123 to 128 provide a visual image of the blizzard. One of the best chronicles of individual stories is the book "White Death: The Blizzard of '77", written by Erno Rossi. The individual experiences, as told in this book, reinforce why the Blizzard of '77 is part of WNY's psyche.

Figure 123. Snowy intersection at Sheridan and Niagara Falls Blvd at 12:20 p.m. Image Source: The Courier-Express Photograph Collection. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Figure 124. Buried cars near the 198. The Courier-Express Photograph Collection. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

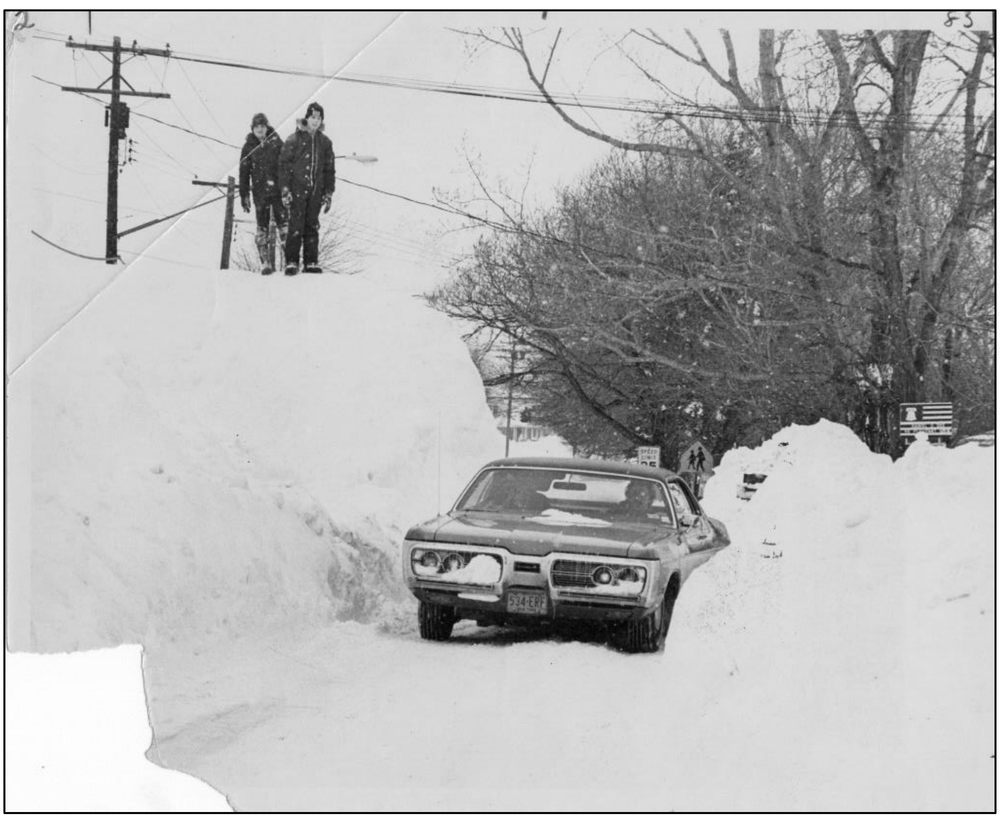


Figure 125. Two boys watch as a motorist edges past a snow drift (Harris Hill Road in Lancaster, NY). Image Source: "Harris Hill Road, February 3, 1977. The Courier-Express Photograph Collection/Ron Schifferle. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

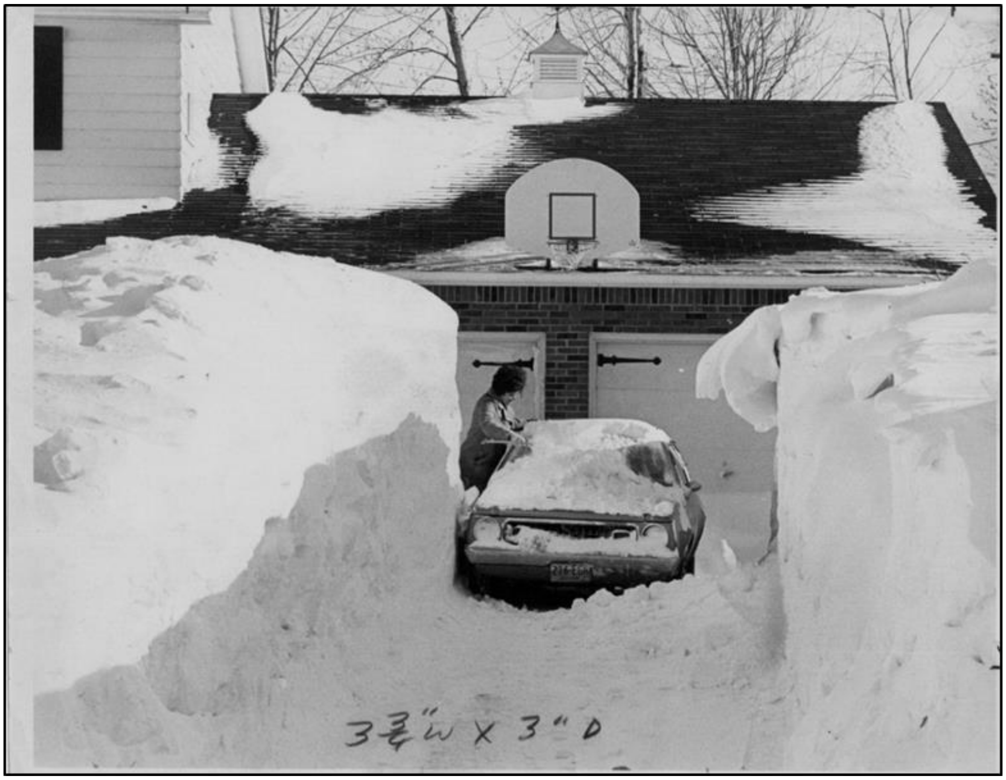


Figure 126. Snow Tunnel in Town of Tonawanda, NY Driveway. Image Source: Snow Tunnel, February 8, 1977, The Courier-Express Photograph Collection/Ron Schiffera, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Figure 127. Car Buried in Snow Drift. Image Source: The Courier-Express Photograph Collection, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

Figure 128. White-washed building facades on Chippewa Street near Main Street. Image Source: "Winter Storms, February 1, 1977. The Courier-Express Photograph Collection/Cliff Preisigke, Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

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Box 22 **"Buffalo Grit"**

"Buffalo Strong" defines the hardiness and the devil-may-care attitude of WNY citizens to the harshness of a winter storm. While researching this book I came across a newspaper headline from the Courier (February 23, 1912) that defines "Buffalo Grit": "BLIZZARD TO BE PROUD OF: WIND BLEW HARDER IN BUFFALO YESTERDAY THAN ANYWHERE ELSE, INDEED." The definition of "Buffalo Strong" can be captured in a mental image of a Buffalonian (and here I include all WNY) shoveling or blowing snow while wearing shorts. Add a Buffalo Bill's jacket and the image is complete. Another "Buffalo Grit" example came to light during a blizzard in Boston, MA. An individual was spotted working his way along a blizzard-shrouded street wearing only a business suit. He caught the interest of a News reporter covering the storm. When asked where he was headed, the individual responded that he was going to the office. And where was he from? Well, using a line many of us have used, his response was *"I'm from Buffalo. I'm used to this."* He added *"It's like Spring Break"*. A final example were the spectators at a Buffalo Bills winter football game (December 10, 2017) that appeared to be taking place within a snow globe, at New Era Field, Orchard Park, NY. While a dense band of lake-effect snow may have made it difficult to follow the plays, it did not deter the fans at the stadium because they were "Buffalo Grit"; as were the Bills players themselves as they prevailed over the Indianapolis Colts. Image Source: WIVB-TV

A First-Hand Recollection of the Blizzard of '77

Warren Glover's recollection, as told to Stephen Vermette, on March 21, 2018.

Warren F. Glover has lived his entire life in WNY. At the time of the Blizzard, he was an employee of the city's Parking Enforcement Bureau, working out of the old City Court building. Warren has always been a "weather person", and he is currently President of the WNY Chapter of the American Meteorological Society. What follows is a recollection of his blizzard experience:

In early January, I went out to Lake Erie because everyone was saying to go look at the lake. It looked like a white desert. The snow was piled up between ice ridges that were aligned like "zippers" along the ice. The drifts were moving all the time. I stood there for no more than about five minutes because it was so cold. With the wind, I could see the snow coming off the drifts toward the shore. It was like a tsunami – a snow tsunami – that hit me in the face and I could see the drifts piling up and reforming. Winds everyday were at least 20 mph.

Before going to work (Friday, January 28th), I looked at the Courier Express newspaper weather report – it was the morning paper. The forecast in the upper right-hand corner of the newspaper called for snow and frigid conditions. Gee, that was nothing to worry about, as the forecast had been the same as I'd been seeing for weeks.

While working in the old City Court building, I noticed that around 11:00 o'clock (a.m.) it started to get dark. I said, *"Gee, it's getting dark. I better turn on the office light"*. In those days I oversaw a crew that handled the public response to the tickets, and around 11:15 the number of people coming in dropped dramatically. And I said, *"What's going on?"*. I was told that there was a big change in the weather announced on the radio. We got orders to remain – you are to stay on your post until you are dismissed at the end of your work day. The few people that did come in were plastered with snow. It looked like they were whitewashed. And they told stories that you would never believe. We had a revolving door at the entrance of the building and the wind was revolving the door. And the doors were whitewashed with the snow. I packed up to leave around 4 o'clock, as no one was coming in. The few that did straggle in were seeking shelter. I wanted to get home.

I went out the front door and the wind blew me back against the building. The winds were hurricane force! I held my arms out and I felt my way along the wall, because I thought that if I get out to the middle of the sidewalk, I would get blown down the street. Everything was obscured. All I could see was a white fog. I couldn't make out objects, it was so intense. I didn't know where I was. I couldn't tell the curb. I couldn't tell the street. Everything was just a blur. My whole face was caked in snow and ice. It took all my strength to make it across the street. I felt my way along the walls of the parking garage, and then crossed the final road to City Hall, where I followed the wall to an entrance door. I couldn't pull open the door. It took three guys to open the door. The tip of my nose was grey and white – it was just starting to get a little frost bite.

City Hall was still serving food and employees remained in the building through the night. I spent the night, as did others, trapped and wandering in between offices and floors. For a short time I sat in the cafeteria, then later joined about 100 people watching the serial "Roots" on television. Toward morning the following day, Mayor Stanley Makowski announced to people assembled in the lobby: *"My orders to all of you still here is not to try to* *go home because it is hazardous. Stay here for at least two to three days until we get some relief and the roads are more passable."* I wanted to get home.

Despite what the Mayor said, I put myself together and left the building for home. The wind was still very strong and very cold. I found my car in the parking garage completely buried in snow. I looked around and found a coal scoop and a bucket of salt. I took the scoop and dug out my car. I looked under my hood and saw that it was snow packed – I couldn't see the engine. I scooped the snow out of the engine compartment. The car started up.

I drove down the ramp, and into Niagara Square where the buildings appeared to be whitewashed from the force of the horizontally blowing winds. I was able to make it halfway around Niagara Square and up Delaware Avenue along two tracks in the snow. It looked like a truck had been through earlier. I was in the two tracks all the way up Delaware. There was no traffic. I wasn't going to stop. I went through red lights. I thought that if one car comes in the opposite direction, we were both done. You couldn't go off the tracks, as the snow was just too deep. Drifts were as high as three to four feet. Fortunately, whatever made the tracks also pushed snow away and to the side – creating a trough. I was dumbfounded that I was able to make it up Delaware Avenue all the way to Kenmore Avenue. At Kenmore Avenue it had been plowed curb-to-curb by the village! I made it home to my Kenmore apartment. It took about four weeks before Buffalo returned to normal.

Overall, it was an experience I've remembered all my life, and can describe with clarity even today, so many years after the blizzard.

The Great March Ice Storms

Figure 129. Fallen branches and wires – "hot" wires send steam up from melting ice. Image Source: "Hot Wires, March 3, 1976. The Courier-Express Photograph Collection. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

The WNY region has been impacted by two "disastrous" March ice storms; one in 1976 and the other in 1991. At the time, the March 1976 ice storm that stuck the Buffalo area was the worst in memory and perhaps among the worst, according to the then-meteorologist-in-charge, James E. Smith, at the Buffalo Office of the NWS. However, events in January 1977 (Blizzard of '77) soon eclipsed the ice storm from our collective memory.

Despite its removal from our memories, the 1976 ice storm caused the March 3rd closure of virtually all schools, businesses, and factories in portions of surrounding counties. The heaviest hit Erie County, and many in nearby areas were the towns of Hamburg, Orchard Park, East Aurora

Figure 130. March 1976 Ice Storm. Image Source: Ice Storm", March 3, 1976. The Courier-Express Photograph Collection/Ron Moscati. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

and West Seneca. Ice accretion (glaze) an inch thick was observed in the Village of Hamburg and, according to James Smith, that thickness may have been exceeded in nearby places (Figures 129 and 130). The affected areas were declared major disaster areas by President Ford. The ice storm similarly impacted areas of Wisconsin and Michigan on route to WNY.

The freezing rain began on March 1st, with most damage occurring on the night of March 2nd and the morning of March 3rd. In his report, James Smith described broken tree limbs and *"entire trees three-to-four feet in diameter toppled, taking electric and telephone wires down."* The town of Hamburg was impassable due to tree debris, and hundreds of roads were blocked by fallen trees and limbs. Snow plows were used to remove the debris from streets. Power outages were widespread and lasted for four days. Freezing temperatures were a concern as residents attempted to heat their homes to prevent their pipes from freezing. James Smith noted *"a number of house fires resulting from the use of candles and fireplaces, as residents attempted to heat and light their homes with alternative methods."*

James Smith recalled that the first forecast to mention freezing rain was issued at 5 a.m. on March 1st, but he did allude to a difficult forecast call, noting that the National Meteorological Center (NMC) guidance was poor because forecasted temperatures provided by the NMC were "too warm".

Fifteen years later, almost to the day, the March 3-4, 1991 ice storm paralyzed Allegany and Genesee counties. The storm was part of a larger ice storm that traveled up the Genesee Valley and coated Rochester, NY and area east with ice. The bold headlines of the Rochester Democrat Chronicle newspaper simply read "ICED OVER". The damage narrative played out much as it did for the Buffalo area in 1976, with widespread tree damage, downed power lines, and associated hardships – a federal disaster was declared by President Bush.

Ice storms, like other forms of severe weather, can offer a paradox of beauty that should not be overlooked. Life switched to survival mode in the aftermath of a February ice storm that left me and my family without power for a week. But there were moments when the scene that caused the disaster and hardship was breathtaking to observe. This paradox explains why we can marvel at the glittering coat on an ice-stressed tree, at a sky filled with lightning accompanying the approach of a potentially damaging thunderstorm, and at the thick blanket of white that covers the ground even as we struggle to get out of our driveway.

Rising Waters

While flooding is not a weather element in itself, the potential for flooding exists in response to a number of weather-related factors: heavy rains in the order of > 1 inch over a short period of time, rapid melting of a snowpack (the Snovember lake effect snow event was followed days of warm temperatures and flood watches), frozen ground (prevents soil absorption of rainwater or snowmelt), and ice-choked creeks that hold rain or meltwater back (Figure 131). Non-weather-related factors include surface impermeability (paved surfaces), the morphology of a watershed (high-relief and small watersheds are most prone to flooding), and soil moisture levels (already saturated soils flood with less rainfall).

Figure 131. Ice Filled Cazenovia Creek. Image Source: "Ice Filled Cazenovia Creek", January 8, 1962. The Courier-Express Photograph Collection. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

In discussing potential flooding, "return periods" are often noted. A return period is a statistical measure of the probability of a rain or flooding event of a prescribed intensity. For example, the probability of a 100-year-rain event has a 1% chance of occurrence in any given year. Structures are often designed, and zoning designated, to withstand a 100-year return period. A cautionary note is that the 100-year event is statistical. There is always the chance that multiple "100-year events" could occur within a hundred-year period.

For Buffalo, NY (airport weather station) the 1-hour 100-year return period is about 2.3 inches/hour, while the 1,000-year return period is about 3.5 inches/hour. The 6-hour 100-year return period is about 4 inches/hour, while the 1,000-year return period is about 6 inches/hour. The intensity of WNY precipitation return periods varies with location (Figures 132 and 133).

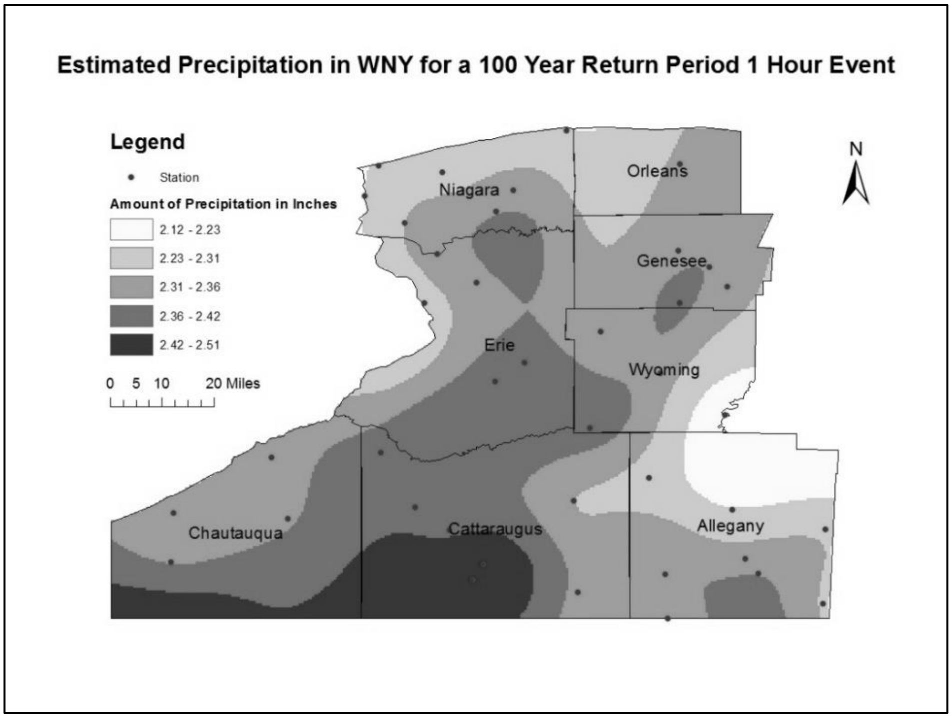


Figure 132. Estimated precipitation in WNY for a 100-year return period one-hour event. Image Source: Zachary Nuedeck and Stephen Vermette.

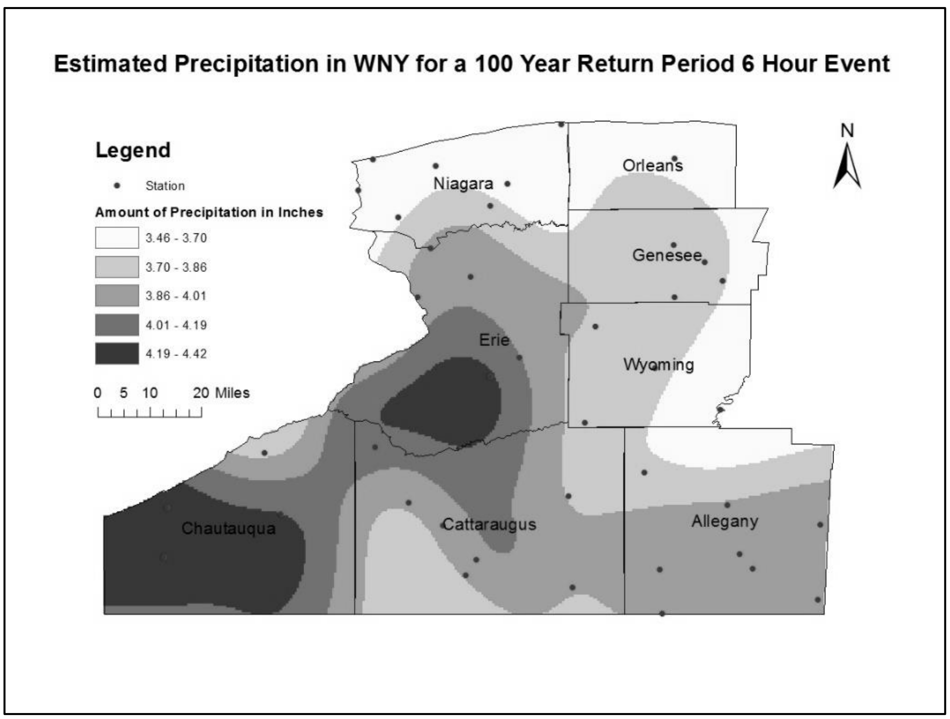


Figure 133. Estimated precipitation in WNY for a 100-year return period six-hour event. Image Source: Zachary Nuedeck and Stephen Vermette.

The 2009 Flooding of Gowanda and Silver Creek, New York

On August 9, 2009, a squall line of severe thunderstorms formed over Lake Erie and moved eastward across Chautauqua and Cattaraugus counties. This line of storms merged with another line of storms that originated over Lake Ontario. Together they stalled over Cattaraugus Creek, an east to west oriented creek that serves as a boundary between Erie County to the north, and Chautauqua and Cattaraugus counties to the south. The rainfall was intense, and the villages of Gowanda and Silver Creek were downstream in the path of the flood waters. Radar-derived estimates of rainfall were over 4 inches in a 3-hour period. One rain gauge measurement recorded nearly 6 inches of rain in a period of about 1.5 hours. The recurrence interval of this storm was in excess of 500 years, and possibly over 1,000 years. The short-term intensity of this rainfall is likely the highest ever recorded in WNY.

The flood damage was extensive, destroying culverts, damaging roads, compromising drinking water supplies, and generating evacuations. Hundreds of homes and businesses were flooded. The hospital in Gowanda was evacuated. Campers in nearby Zoar Valley were hanging on to cars and trailers before being rescued by helicopter. The flooded region was declared a Federal disaster area.

The 2009 flood waters, and subsequent stream erosion, brought about more long-term concerns. The West Valley Nuclear Demonstration Project (a former nuclear waste remediation site) is in Cattaraugus County and is hydraulically connected to the Cattaraugus River, Lake Erie, and the downstream drinking water supply of Buffalo, NY and other WNY communities. The intense rainfall associated with the August 2009 flooding caused extensive stream bank erosion near the Demonstration Project. Would future, and potentially more frequent, intense rain storms compromise the buried radioactive material? Is 6 inches the high-water mark of WNY short-term rainfall? I cannot help but consider Smethport, PA (just across the border from WNY and about 50 miles from the Demonstration Project) which holds the United States record for the most intense rainfall over 12 hours (34.3 inches) and 3 hours (28.5 inches). Both records were set on July 18, 1942.

Lake Ontario Shoreline Flooding

Beginning in April 2017, high lake levels eroded the Lake Ontario shoreline (including Niagara and Orleans counties), pummeled break walls, inundated docks, flooded properties, and closed roads. Lake levels have risen and fallen over the years and flooding has occurred in the past but, in the spring and summer of 2017, Lake Ontario was at its highest level in 100 years – the "bowl" was full. Coastal communities were most at risk from wind-driven waves and storm surges.

The cause of the high-water levels was unbelievable precipitation amounts – almost double the average in April and May – in the Lake Ontario watershed. In addition, inflow from the upper Great Lakes was high (Lake Erie was the highest it has been in 20 years). Much like a bath tub, the lake filled as drainage through the Saint Lawrence River was limited. There was another issue. Some people, including Governor Cuomo, blamed "Plan 2014". Plan 2014 was a management plan with specific "triggers" for lowering or increasing water output during periods of extreme highs or lows by controlling the outflow of the Moses-Saunders Dam along the Saint Lawrence River. It was not the new plan that created an issue (the triggers, for the most part, remained unchanged from previous criteria), but that the watershed of the Ottawa River experienced a similar "unbelievable" rainfall. Residents of Montreal and areas along the shoreline of the St. Lawrence River were fighting back flood waters also. Opening the Moses-Saunders Dam further might have reduced the flooding along the shores of Lake Ontario, only to exacerbate the flooding in Montreal and downstream shorelines. Furthermore, increasing flow in the St. Lawrence River placed commercial navigation at risk. Much like the ice boom myth discussed earlier, the Plan 2014 myth will likely persist for years. The point to stress here is that natural factors, not regulatory ones, were to blame for the flooding.

Communities responded to the flooding with their own emergency plans (including the building of berms and pumping water out of sewers), and Governor Cuomo declared a State of Emergency for affected counties, empowering the Department of Environmental Conservation (DEC), the New York Army National Guard, and other state agencies to respond. A Lake Ontario Rapid Response Team was organized, and a multimillion-dollar relief package was signed into legislation for communities, businesses, and home owners. Eventually, affected areas were declared a Federal Disaster Area.

Box 23 **Flooding of Love Canal**

Love Canal, or the "Love Canal Disaster", refers to a neighborhood in Niagara Falls, NY "discovered" to be built upon buried hazardous waste. Toxic waste was discovered flowing into household and school yards and playgrounds. In 1978, the area was the first-ever human-caused disaster declaration.

While many people in WNY are familiar with the Love Canal story, and there is considerably more to consider about Love Canal, there is a weather angle to contemplate that played an important role in the spread of the buried toxins. The toxic waste was dumped into an old canal, prepared by lining it with impermeable clay. After about 10 years, the canal was closed and covered with clay to prevent surface water leakage into it.

Within a few years, new suburbs of Niagara Falls found their way to the open lands adjacent to the canal dump site. Construction of sewer and water lines breached the dump's protective clay cap, and some of the clay was removed and used as construction fill. The clay seal was breached, such that heavy rains, snowmelt, and a rising water table penetrated the dump site. This is the weather angle previously alluded to. Over time, the canal filled with water, and toxins essentially floated out of the canal traveling along sewer and water lines, contaminating the adjacent community, pooling in basements and yards, and putting resident's health in danger.

Offshore Extreme Weather

Standing on the shore, or in the case of Lake Erie from a favorite vantage point in a Buffalo high rise, looking out across Lakes Erie and Ontario offers an unobstructed view of sunsets and weather, but also of severe weather types uniquely restricted to our lakes and shorelines.

Waterspouts

There are two types of water spouts to watch out for. One is a "tornadic waterspout" which is simply a tornado associated with a thunderstorm that forms over water and may move onshore. The type of waterspout most commonly observed over Lakes Erie and Ontario is what is referred to as "fair weather" waterspouts. These waterspouts develop from the water surface upward and are associated with the influx of warm air into a cloud. The key to their formation is a strong temperature gradient between the warm water and colder cloud and a horizontal wind shear that gets caught up in the cloud's updraft. The whirling column that forms is made visible due to condensation and rising lake mist. Fair weather waterspouts are best viewed in late summer and autumn when the air is unstable (easily rises) and air-lake temperature differences are at their greatest.

Fair weather waterspouts usually don't move around much, so they put on a good show (especially when occurring in clusters) when viewed from shore. While weak in comparison to their tornadic cousins, they do pose a risk to boaters, and while they dissipate rapidly when making landfall, they can put onshore viewers at risk and cause minor property damage.

A rare version of a fair-weather waterspout is termed a "winter snowspout". These occur with the passage of a very cold air mass over water that is rapidly losing its heat and producing steam. As with the waterspout, rising air and wind shear combine to produce the spin. The shape of the spout is often a mix of steam and falling snow. Apparently only six photos of winter snowpouts exist at the time of writing, and four of these were taken over Lake Ontario. The term “snowspout” also refers to snow versions of land-based “dust devils” (best termed a “snow devil”). Here, the heating of a snow or ice cover by the sun can produce rising steam (sublimation), that along with rising air and wind shear give the spout its shape (loose snow may mix in as well).

Seiche

The word “seiche” translates as “to sway back and forth”. It describes what can happen in an enclosed body of water. Rapid pressure changes and strong winds blowing across a lake can push water from one end of the lake basin to the other – the water pile-up at one end of the lake is matched by a drop in water level at the other end. When the winds weaken or reverse, the pile-up of water rushes back to its original side of the lake raising water levels there. The water may slosh back and forth before the normal horizontal surface returns. And with each pile-up of water, first at one end then the other, flooding may occur. Individuals are cautioned to avoid walking or wading out into areas made shallow with the retreating water as the surge of returning water often takes place quickly and without warning: and returning water may surpass typical levels. The seiche isn’t a wave with vertical motion: it is best thought of as a relentless surge of water. The southwest-northeast orientation of Lake Erie aligns it with the region’s prevailing winds, which makes it, and the city of Buffalo located at its east end, susceptible to seiches. Similarly, a Nor’easter, with its strong northeast winds pushes lakes waters toward the lake’s western basin, only to have it return when these winds weaken.

This is what happened on October 18, 1844 when, after strong northeast winds pushed water up Lake Erie into its western basin, a sudden wind shift pushed surging water back into the eastern basin where it quickly breached a sea wall and flooded the city of Buffalo without warning. It was as if a dam had burst! The surge of water quickly raised water levels 22 feet, flooding the harbor, destroying hundreds of buildings, swamping and tossing boats, and dragging people into the lake. While the worst damage occurred in Buffalo, harbors and ships all along the Lake Erie shoreline sustained damage.

The Seiche of 1844 was one of Buffalo’s most devastating weather disasters. And like many disasters of note, it has been immortalized as a song in the folk tradition by “Rush the Growler”, a folk band based in Buffalo, NY.

Title: The Lake Erie Seiche Disaster

Words and music by Matt Englert of “Rush the Growler” (used with permission)

On the 18th of October in the year of ‘44
Jim awoke to a big loud crash there was water at the door
Get up, get up his father cried, the lake has overflowed
And if you want to see tomorrow, upstairs you must go

Chorus: *Oh the wind was blowing from the east and pushed the water down*
When it blew back from the west it washed away the town
So many people died that night when the mighty wind did blow
So many people died that night when the wave hit Buffalo

They huddled together in the attic, frightened as could be
Mom and Dad, baby brother, sister, and he
Lake Erie rushed right up their street, it got to six feet high
Jim prayed the water to recede then heard his mama cry

Chorus: *Oh the wind was blowing from the east and pushed the water down*
When it blew back from the west it washed away the town
So many people died that night when the mighty wind did blow
So many people died that night when the wave hit Buffalo

Some days and weeks later, oh it all came to light
How many ships and buildings were damaged on that night
The Robert Fulton and St. Louis lost people over side
GW Bailey and Columbus washed ashore on the south side

Chorus: *Oh the wind was blowing from the east and pushed the water down*
When it blew back from the west it washed away the town
So many people died that night when the mighty wind did blow
So many people died that night when the wave hit Buffalo

Meteotsunami

Not to be confused with a seiche or an ocean tsunami associated with seismic activity, a meteotsunami is a meteorologically induced water wave caused by thunderstorm activity over a body of water. They occur in the Great Lakes with some regularity. In fact, Buffalo, positioned on the eastern end of Lake Erie, experiences more meteotsunamis (17 per year) than any other Great Lake location, save the southern basin of Lake Michigan (29 per year). Simply put, a large local change in atmospheric pressure caused by the passage of an over-the-lake thunderstorm "punches" down onto the surface of the water, displacing the water and creating a surface wave. The pressure differential caused by the "punch" transfers energy to the water and creates a wave. This wave, referred to as a long-wave, amplifies only when the forward speed of the pressure disturbance (thunderstorm) and surface waves are synchronized – this resonance amplifies and perpetuates the long-wave. Well way from the initiating thunderstorm, the long-wave will further grow in height as it travels over shallow water (it slows down, and energy is transferred to build up the wave) and crashes onto shore. While most meteotsunamis reach shore unnoticed (under 1 foot in height), waves of up to 10 feet have occurred. These large waves, and associated currents, have swept individuals of off break walls and piers into the water and swamped moored boats. As these waves can travel great distances, and reflect off shorelines, they can "arrive" on locally clear days and catch people unaware, well removed in space and time from the original thunderstorm that generated them. Thus, they appear to a person onshore as a "rogue wave".

Ice Caves, Ice Volcanoes, and Ice Balls

Ice caves and ice volcanoes are associated with very cold atmospheric conditions that lead to the formation of lake ice, and both are associated with shifting ice (shove ice). Ice caves form when lake ice is broken up and shifted by winds and currents to pile up on top of itself. This pile-up of shove ice can form hollow areas within the piles – ice caves. In 2014, one ice cave on Lake Erie was measured at about 15 feet wide and about 6 feet high. Under periods of sustained onshore winds, shove ice also explains the relentless surge of lake ice that sometimes pushes onshore. This is sometimes referred to as an "ice tsunami."

The ice volcano forms near the shore, where nearshore ice breaks up due to the forces of winds and currents and piles up on itself. With onshore wave action, sometimes the shallow water underneath the ice has no place to go but up through a crack (hole) in the ice and then out as a blast of water (much like a blowhole associated with a sea cave). The falling spray freezes, building a mound around the hole. The whole thing – the shape and eruption – resembles an erupting volcano (Figure 134).

Ice balls (or ice boulders) are rounded chunks of ice that resemble water-smoothed boulders. They start out as layers of ice (called pancake ice if circular) that form on the water just off shore. They may form a continuous layer (in calm waters) or are broken up into pieces against the shore by wind and waves where they fuse with shoreline ice. However, some of these pieces float out into deeper water, where they are repeatedly rolled by waves and become rounded. Blown back to shore, they reappear along shorelines as clusters of rounded ice balls.

Figure 134. Ice volcanoes formed along the Lake Erie shoreline at Evangola State Park. Image Source: J.J. Ptak.

Chapter 6

The Business of Weather

The operations floor (2019) at the NWS Buffalo Weather Office. Image Source: Stephen Vermette.

Basic Forecasting Methods

Any observer of the sky makes a weather forecast – some are more conscious of the making of a forecast than others. For the most part, it requires a sense of your surroundings, skills of observation, and basic weather knowledge. A personal weather forecast can be taken a step forward by use of the internet − never has there been so much information, so easily available, on which to make a weather forecast. It's easier than you might think!

The act of simply casting one's eyes to an unchanging sky allows for a basic forecast of the weather – referred to as a "persistence forecast". If the weather is sunny and cloudless then there is a very good chance that this good weather will continue one or two hours into the future; or, if cloudy and raining, that weather will continue the same. The persistence forecast might be stretched out for a longer period until you see something that might suggest a change in the weather. In fact, in parts of the country that experience persistent weather, this form of forecasting might gain you a good track record.

Assuming that observed weather occurring upstream will persist and move along to affect your area, you may utilize a "nowcasting" forecast approach. Examples of upwind changes include changes in atmospheric pressure as read from a barometer, changes in observed cloud cover, a change in wind direction, a windy day (strong winds often herald a weather change), or simply watching the weather radar. A typical "nowcast" might call for clear weather for the next few hours with rain moving into the region afterwards, as indicated by weather radar.

The synoptic map, with its depiction of high- and low-pressure cells (low pressure troughs and high-pressure ridges) and associated fronts, is a conceptual model of weather that had been the workhorse for weather forecasting in decades past (Figure 135). Though seldom used in forecasting today, its use still provides a visual and rationale to understand forecasted weather (a basic synoptic map is often part of a television weather forecast). "Synoptic forecasting" requires a forecaster to extrapolate future conditions from a "snap shot" of current conditions. The key to synoptic forecasting is in understanding the weather associated with pressure cells and fronts and considering the upstream weather data. By following the movement of weather systems and evolving station weather data over time, the speed, path, and intensity of incoming weather can be determined. By way of example, if a cold front travels 500 miles in 24 hours, the forecaster could predict where the cold front might be in 12 hours.

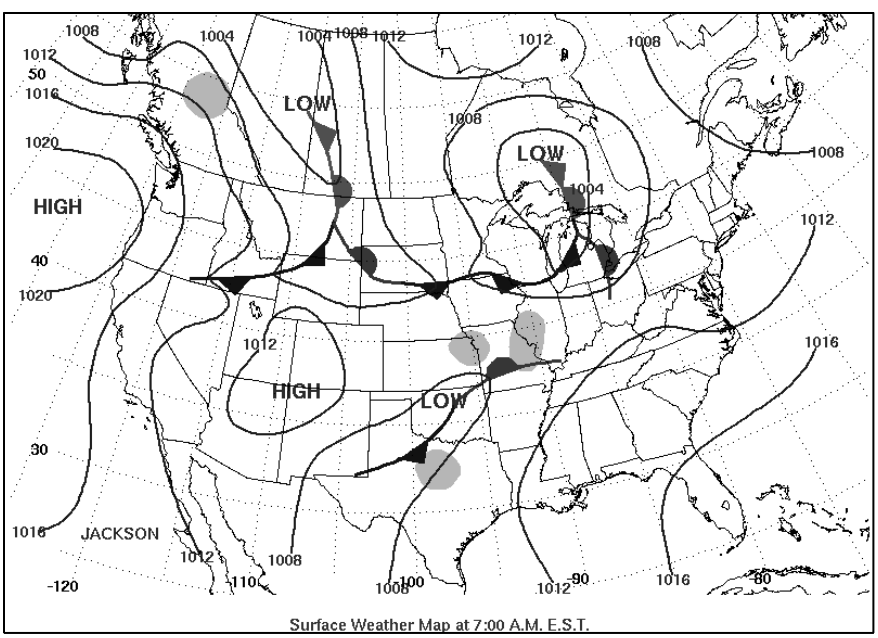


Figure 135. Surface weather map (July 30, 2008) showing a low-pressure cyclonic cell and associated fronts over the Great Lakes approaching WNY.A second cyclonic cell appears to be following it. Image Source: Daily Weather Map Archive/NOAA.

A professional weather forecast approach might include statistics – "statistical forecasting" – where past weather patterns are used as predictors of future weather. This approach uses computer programs to match a current weather pattern to similar patterns of past weather that have been archived going back decades. A simple example is a precipitation forecast which states that there is an 80% chance of rain. The 80% does not refer to the percent of the forecast area to receive precipitation but, rather, refers to the statistical chance of rain in the forecast area. In other words, 8 out of 10 times in the past, the current weather pattern has resulted in the occurrence of precipitation. Furthermore, the "chance of precipitation" does not forecast the amount but, rather, the chance of measurable precipitation – meaning at least 1/100th of an inch of rain or 1/10th of an inch of snow.

Today, a weather forecast relies on numerical model outputs based on a series of mathematical equations, referred to as Numerical Weather Prediction (NWP). These calculations are no small feat, requiring complex model algorithms and the world's fastest computers. Let the reader be reminded that Chaos theory – a branch of mathematics which studies how small changes in initial conditions can make large differences over time – comes from meteorology.

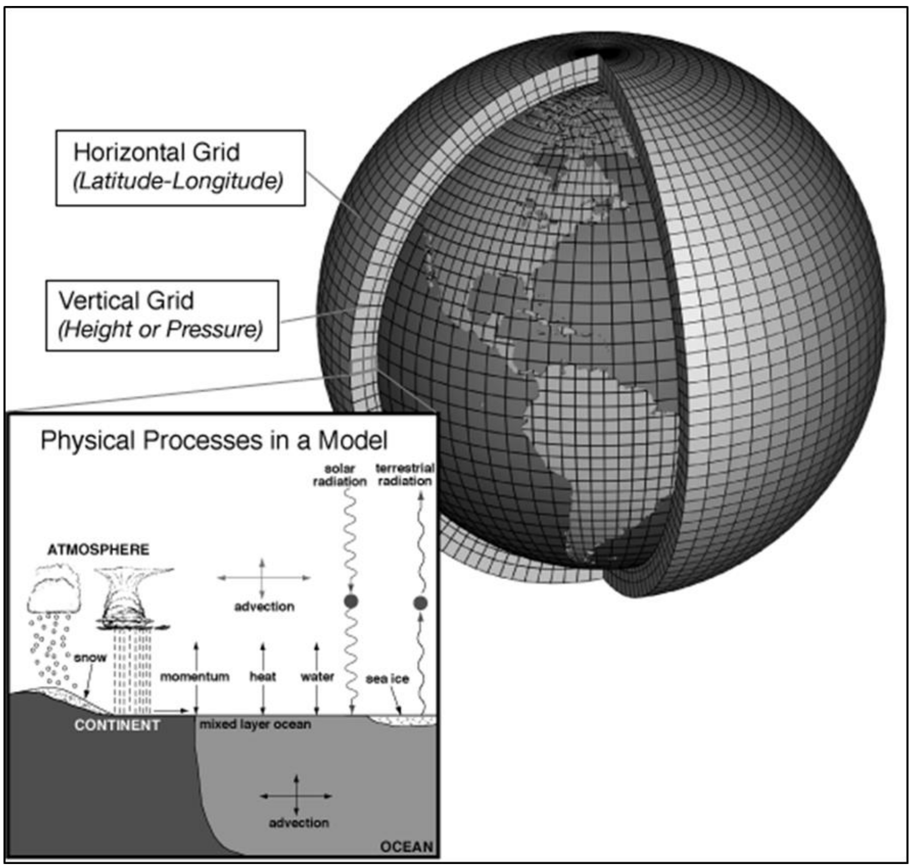


Figure 136. The planet is divided into 3-dimensinal grid, in which a system of equations calculates the state of the atmosphere in a series of time steps within each grid and interactions with neighboring grids. Image Source: Wikimedia Commons/NOAA.

A numeric model follows a processed-based approach. It divides our planet into several 3-dimensional grids (Figure 136). As models have evolved, the size of the grids and, thus the weather forecasts, cover a smaller area. The smaller the grid, the more accurate and detailed its forecast. Current atmospheric conditions are the starting point for each grid. The state of the atmosphere evolves (considering land and ocean interactions with the atmosphere) over time within each grid using the model's equations of physics and fluid dynamics. These equations include Newton's Second Law of Motion, the Ideal Gas Law, the First law of Thermodynamics, the Law of the Conservation of Mass, etc. In a series of time-steps, the calculated state of the atmosphere is transferred to adjacent grids, and so on, over time and space. The output from the numerical model is the basis for a modern weather forecast. NWP came to its own in the 1980's where operational forecast skills have continued to improve with increased computer power and the influx of new weather data sources, including satellite data.

There are numerous numerical models and outputs available to the weather forecaster. Each model is constructed a little differently and each has inherent bias (under-predicting or over-predicting under varying conditions). The reader may recall that the tracking of Hurricane Sandy brought about a debate on whether the European numerical models out-performed the North American models. The growing challenge of the weather forecaster is to choose between model outputs when developing a weather forecast. As an aside, many of these numerical model outputs (map and chart form) are available on the internet for use by amateur forecasters.

Buffalo's National Weather Service (NWS) Forecast

By one accounting, it is estimated that one third of the U.S. economy ($5 trillion) is weather sensitive, and that over 90 percent of all federally declared disasters in this country are weather related. These two points offer a good jumping off place to discuss the role of the National Weather Service (NWS) and its mission: *"… provide weather, hydrologic, and climate forecasts and warnings for the U.S., its territories, adjacent waters, and ocean areas for the protection of life and property and the enhancement of the national economy."* To do this the NWS has developed and maintains a data collecting infrastructure and provides a national information database which can be used by itself, other government agencies, the private sector, the public, and the global community. The NWS is evolving its vision to prepare a "Weather-Ready Nation", one that is better prepared for and responds to weather-dependent events. While anyone can create forecasts (including private forecasting companies such as Accuweather or The Weather Channel), it is the NWS that provides the necessary infrastructure, and is the only agency that can issue watches and warnings in the U.S. and its territories

The story of weather forecasts does not begin here in the U.S. but is a part of a global effort organized by the "World Meteorological Organization" (WMO). It is stunning to think that 24 hours a day in real-time tens-of millions of data characters are collected from satellites, buoys, aircraft, ships, balloon launches (radiosondes), and some 10,000 land-based observation stations, thousands of weather charts are created to display the collected data, and powerful computers – numerical weather prediction models – churn out forecasts that pass through three world, 35 regional and 183 national meteorological centers cooperating with each other in preparing weather analyses and forecasts. And, it is all repeated the following day.

In the U.S. the NWS is divided up into 122 local weather forecast offices (five of which cover New York State). About New York State, I think it can be argued that we are well served. By way of comparison, the Province of Ontario, Canada has only one forecast office, with a territory 7x larger than that of New York State! The U.S. local weather offices are supported by numerous National Weather Centers with specific missions, some that readers might recognize, including the "Storm Prediction Center" in Norman, Oklahoma, the "National Hurricane Center" in Miami, Florida, and the "Climate Prediction Center" in College Park, Maryland.

The Buffalo weather forecast office covers all eight counties of WNY, and eight eastern counties that share a coast with Lake Ontario – a total of 16 counties (Figure 137). The coverage area (adjacent to Lakes Erie and Ontario) has provided local NWS forecasters with a great deal of expertise in forecasting lake effect snow events. By way of example, Bufkit – a weather forecasting visualization and analysis tool – was developed by the NWS Buffalo Office to assist forecasting lake effect snow events. It has since evolved to include non-winter related weather and is used nationwide as a local forecasting tool. As an aside, you may have noticed that "Buffalo" is sometimes tagged in the national press with significant lake effect events that occur elsewhere in WNY or in counties to our east (eg. Syracuse or Watertown). This is, at least in part, because these regions are linked to the Buffalo weather office.

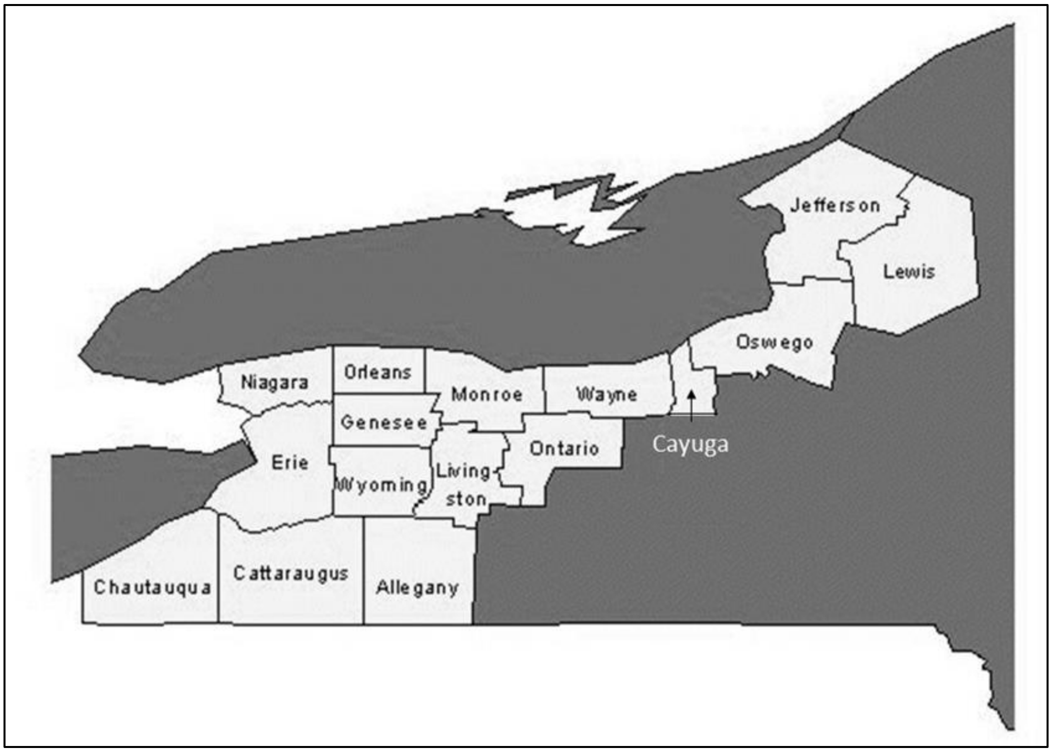


Figure 137. New York counties included in the forecast area of the Buffalo local weather office. Only the northern half of Cayuga County is included in the Buffalo Office forecast area. Image Source: National Weather Service. Modifications made by Stephen Vermette.

WNY contributes to the collection of weather data for use by local forecasters, and to feed weather prediction models. Included is the Automated Surface Observing System (ASOS) located on the grounds of the Buffalo-Niagara International Airport, as well as in Niagara Falls, Dunkirk, and Wellsville (Figure 138). Automated Weather Observing System (AWOS) stations, operated and controlled by the Federal Aviation Administration (FAA), are located at area airports (Jamestown, Batavia, and Olean). ASOS/AWOS stations are completely automated, representing a continuing effort by the NWS/FAA to automate its collection of weather data. As an aside, one reason that the decades old sunshine record was discontinued by the NWS (discontinued in 2014 at the Buffalo Office of the NWS) was that the measurement was not easily automated. An important weather element – snowfall – remains problematic, as it is traditionally measured with a ruler (the NWS is experimenting with automated sensors for snow measurement). In addition to ASOS data collected on the airport grounds, Doppler radar continuously monitors for approaching precipitation and severe weather, and balloon (radiosonde) launches, made twice daily (morning and evening), collect weather-related upper air data.

In addition to on-site monitoring, the Buffalo Office of the NWS relies on an army of trained weather observers, as part of the age-old Cooperative Observer Network (COOP) to take and observe daily measurements of temperature and precipitation across their forecast area (some sites go back to the late 1800's). Many of these observers, and other volunteers, are part of the CoCoRaHS (Community Collaborative Rain, Hail & Snow) network that take daily readings of precipitation. In addition, the weather service trains informal severe weather observers through its Skywarn® outreach.

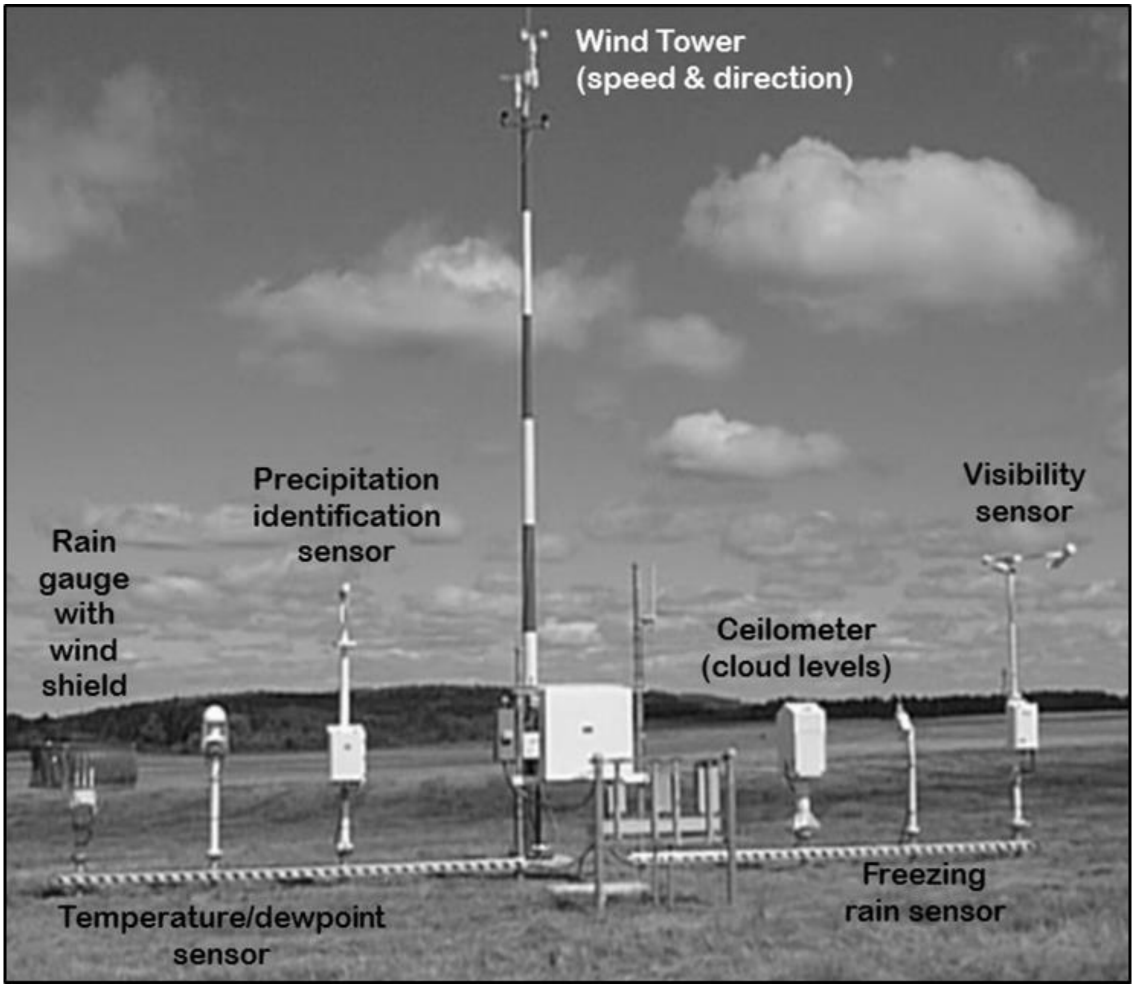


Figure 138. Typical Automated Surface Observing System (ASOS). Image Source: National Weather Service. Labels were added to the image by Stephen Vermette.

Recently, New York State has installed 126 NYS-MESONET environmental monitoring stations across the state (13 in WNY), as part of the New York State Early Warning Weather Detection System – their slogan: *"More Stations. More Data. Better Decisions"*. NY-MESONET stations measure temperature, relative humidity, wind speed & direction, atmospheric pressure, solar radiation, soil moisture and temperature (various depths), precipitation, dew point, and snow depth (measured by observing a camera image of a ruler) (Figure 139). A few select stations (UB SUNY and Clymer, NY) uses lidar to estimate wind velocities in the vertical, a microwave radiometer to obtain vertical profiles of temperature and liquid up to 10 km above ground level, and a photometer which provides and image of sky cover and the sun's direct radiation. In addition, nine Thruway Micronet stations (stretched along the Thruway from Buffalo, to Ripley, PA), provide readings of temperature, relative humidity, dew point, wind and snow depths (camera focused on a ruler in the ground).

Never, has WNY been better monitored for weather-related parameters which, fed into weather models, will result in better and more site-specific weather forecasts. Today, Apps can track weather conditions and forecasts – cell phones can receive emergency texts of weather-related emergencies – as you travel the roads of WNY and beyond (The history of, and more details about, Buffalo's NWS can be found in Chapter 7).

Figure 139. A NYS-Mesonet site located at SUNY Buffalo. Image Source: Stephen Vermette.

Local Knowledge

Reflections by a NWS Cooperative Observer

Contributed by Jack Kanack, a longtime observer from North Tonawanda

Known as 30-6047-9 in the National Weather Service (NWS) Cooperative Observer Program (COOP), Jack Kanack has observed and recorded weather in North Tonawanda, NY since September 1981 − not missing a day other than when asked to shelter in place during a department store fire, during a train derailment, and to avoid being shot at by a police officer chasing a "pistol packing punk". Not bad for 37 years! For this, and for going above and beyond what is expected, he has received the NWS two highest awards: the John Campanius Holm Award, for outstanding accomplishments in the field of meteorological observations; and the Thomas Jefferson Award, the highest award the NWS presents to volunteer observers. We are fortunate in WNY to have such a dedicated volunteer observer. This piece was written by Jack upon his retirement from the COOP after 37 years of service.

I've been a cooperative observer since September 1981, reporting temperature and precipitation data to the National Weather Service Forecast Office in Buffalo, NY from my home in North Tonawanda, NY. My interest in observing began as a college student when I looked after weather instruments at SUNY Buffalo State. This in turn led to an opportunity to serve as a cooperative observer for the NWS, because my home – eight miles from the Buffalo-Niagara International Airport and eight miles from the Niagara Falls Airport Base – filled a geographic gap in weather observations and would be the first station to observe weather coming in from Ontario, Canada (I would receive telephone calls from the Weather Service inquiring about weather conditions at my home). At that time, we were paid $22/month, with an additional $1 for each requested weather report (over time these payments ceased). Those were good times, as we were part of a "weather family" invited to outings and assisting at weather-service-run events, including picnics and going to Sabres and Bills games. Much has changed with computerization (a little more impersonal), but cooperative observers remain the 'eyes and ears' of the Weather Service, a proud tradition that goes back to the inception of the weather service.

Our observing instruments have not changed over time, consisting of a minimum and maximum thermometer protected within a weather instrument shelter (Cotton Region Shelter), a standard rain gauge, and a snowboard to aid in measuring snow depth. I kept the weather station in working order and maintained high standards, making sure equipment was clean and in working order so weather measurements were as accurate as possible (I battled the birds daily in summer from making unwanted 'deposits' in the rain gauge and battled deer in winter from defecating on my snowboards). I was also fully responsible for quality control of observational data, both past and present and made certain all forms were completed accurately. I practiced current, sound methodology in weather observation techniques. So yes, that meant I had to be home to take measurements at midnight every night without fail since 1981, and I tried to be home anytime the weather was about to turn 'ugly' when my services might be needed. The Weather Service would like to know, to the nearest 15 minutes, when precipitation begins, and when it ends. This can be challenging if it precipitates for several days in a row, especially overnight, or if it showers on and off – especially with lake effect. I remember having 68 starts and stops of precipitation in a 24-hour period – it can drive one crazy at times!

I have been trained to correctly report observations of severe or hazardous weather in my area including shelf clouds, tornadoes, funnel clouds or confirmed rotation, and hail (I have money handy as hail size is reported as bb shot, pea, dime, penny, nickel, quarter, golf ball, etc.). Severe weather observation included damaging winds (the extent of damage to trees, powerlines, power outages etc.), flooding (field flooding, basement flooding, closed roads, streams that are close to, or at, bankfull) and heavy rains – rain amounts of 0.5 inch or more in three hours or less.

In the winter, I reported heavy snowfall totals greater than 3 inches in 24 hours, snowfall rates greater than 1 inch per hour, sudden starts or stops of snow, persistent whiteout conditions, freezing rain or freezing drizzle of any amount or any ice accumulation. I also did daily snow-water equivalents of snow for hydrological purposes.

I was involved with many projects – most notably giving ground truth data with respect to determining precipitation by radar estimate (Z function), and shoveling a different part of the driveway every hour, every three hours, every six hours, every 12 hours, and every 24 hours during a snow event and adding up the individual totals to determine how the snow settles and how often to report newly-fallen snow. I had a few projects of my own, including determining frost depth of shoveled vs unshoveled ground using frost tubes.

All weather observers serve as the National Weather Service's ambassadors. They must be courteous and comfortable speaking with the general public as occasionally I received calls for my weather observations from the media and from attorneys working on weather-related cases. I served as a contact between what was happening in North Tonawanda and the National Weather Service and provided researchers and other staff with up-to-date weather and climate information for my area.

So, when you use COOP data, consider the dedication and sacrifice of the many cooperative observers (the numbers are around 30 to 35 throughout WNY) who provide the National Weather Service and WNY with high quality weather data with a human touch (something rare in today's world).

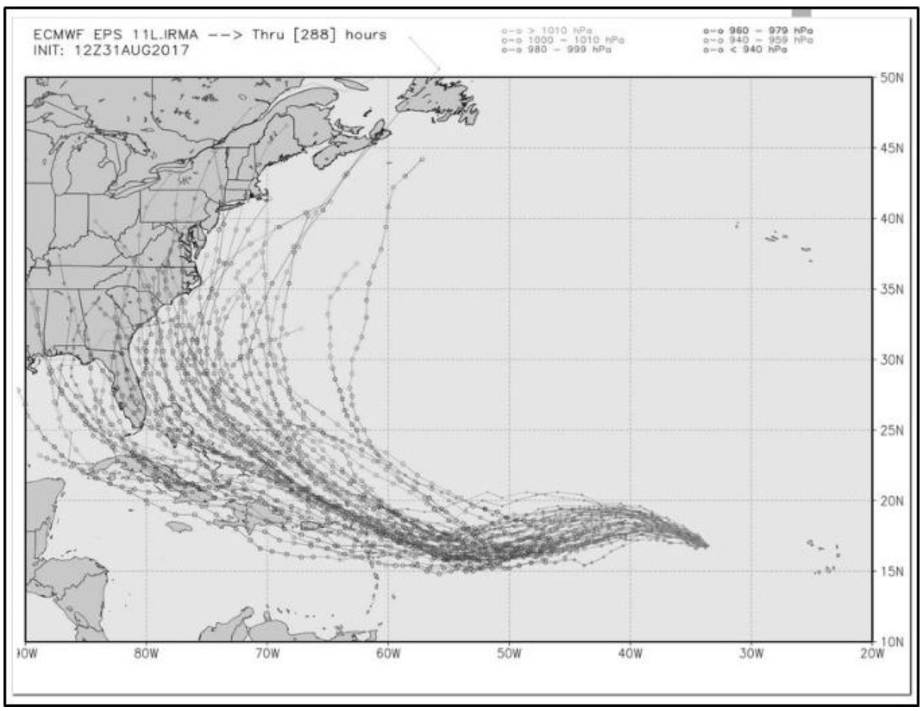


Figure 140. Modeled path of Hurricane Irma 10 days before making landfall in the lower Florida Keys. Image Source: European Centre for Medium-Range Weather Forecasts.

As with the other local weather offices across the U.S., forecasters in the NWS Buffalo office most apply weather-related outputs and modeled forecasts that come down from the U.S. National Meteorological Center to the local situation and augment the modeled forecasts with local data (including Doppler radar) and knowledge. The challenge for the weather forecaster is to choose from numerous numeric models and apply their forecast to a much smaller area – spatial grids of 3 to 5 km, as compared to countywide forecasts of old. The task is easiest when model outputs agree, and a challenge when they do not. By way of illustration consider the modeled path of Hurricane Irma, as taken from an August 31, 2017 model run (51 separate sub-models – referred to as spaghetti models) 10 days before making landfall in the lower Florida Keys (Figure 140).

Long gone are the days when NWS meteorologists relied on interpreting synoptic maps to create a forecast. I can recall being at the Buffalo Weather Office in the 1990's and seeing printouts of maps filled with data (station models) on which the forecaster identified high and low pressure systems, drew in the fronts and shaded in areas indicating rain (they used to save these maps for me so that I could use them in my meteorology classes). From these maps, and other sources, the forecaster prepared the wording for the weather forecast. Here too, the crafted wording of a weather forecast, is long gone. Today, the forecast you read or hear is generated by a computer algorithm dictated by the data from the numeric model output. The forecast can only be altered, by adjusting the output data.

Complementary to the forecasts, are required interactions by forecasters with local and state emergency managers, a task assigned to the Warning Coordination Meteorologist (WCM) at the Buffalo Office. In the last couple of years, the use of social media has dramatically increased in the issuance of forecast products and communication with the public and emergency managers.

Box 24 Weather Alerts

The National Weather Service has long implemented a Watch, Warning, Advisory (WWA) system to alert and protect the public from severe weather. The NWS is the only entity (government or private) that can issue these alerts. They are usually issued by county or, in the case of isolated storms (thunderstorms, tornadoes, flash floods), as warning polygons where the shape is defined by the area under threat. Examples of these alert products include severe thunderstorms, tornadoes, flash floods, heat, frost, wind chill, blizzards, winter storms, freezing rain, ice storms, and high winds, to name a few. In general, a watch is issued when there is a potential for hazardous weather, while a warning is issued when hazardous conditions are occurring or expected to occur. Advisories are for conditions less serious than warnings.

While the WWA system provides for public safety, there are times when too many overlapping alerts may confuse the public. A recent effort, referred to as the "Hazard Simplification (Haz Simp) Project", is working to consolidate some of these alerts, and to clarify them by using a consistent message format which includes "What", "Where", and "When", along with additional details and precautionary/preparedness actions.

One causality of Haz Simp is the elimination of the "Lake Effect" watch, warning, and advisory common to a WNY winter and easily understood by the public. Lake effect and freezing rain will be consolidated as a "Winter Storm" alert, which includes heavy snow, sleet, ice, or blowing snow. But all is not lost: while the title of the alert has been consolidated as a "Winter Storm", the text of the alert will identify the reason By way of example, a warning text may read "winter storm warning for lake effect snow…".

At the time of writing, the eastern Great Lakes forecast offices resisted the elimination of the "Lake Effect Warning" for the winter of 2017-18 but did change to the HazSimp format for lake effect watches and advisories. It is uncertain whether the "warning" will be retained or changed in future.

Local Knowledge

Forecasting Reflections by a Senior Forecast Meteorologist

Contributed by Steve McLaughlin, retired with 21 years of service at the Buffalo Weather Office.

My name is Steve McLaughlin and I'm a retired Meteorologist with the National Weather Service in Buffalo. My 21-year career was varied, starting as a hydrologist (influenced by my previous career as a civil engineer) and working my way up through junior to eventually senior forecaster for the last seven years. It was a most rewarding career since, unlike most federal jobs, this one allowed us to make decisions which affected the community and provided needed information for everyday life – as weather affects us all!

My job included issuance of typical routine products such as daily public forecasts for 16 counties, marine forecasts for two Great Lakes, and more specific aviation forecasts for several airports, and, most importantly, timely issuances of advisories and warnings for our area of responsibility across western and central New York State.

For routine typical operations, we worked in three shifts – 8-4, 4-12, and midnight to 8. All shifts had a minimum of three people, two forecasters (senior and junior "journeyman") and a met. technician. The day (8-4) shift had several more, including the three-person management staff (meteorologist-in-charge, science operations officer, and warning coordination manager). The science officer was responsible for ongoing staff training and the warning coordination person was responsible for coordination with outside organizations such as county and local officials.

There were deadlines for product issuances with the two major ones being 4 am and 4 pm, when all products were completely revised and issued. General updates to the first 24 hours of the forecasts, based on actual conditions, were made at 10 am and 10 pm. In recent years, the forecasts are updated hourly for the following 6-12 hours to reflect ongoing current conditions.

The routine forecast process has changed dramatically during my career due to rapid technological advances as well as the dramatic increase in reliable guidance and models. We have gone from worded forecasts for larger countywide areas to specific gridded forecasts down to a few miles. As you can imagine, this has entailed a rapidly changing forecast process and it has not been without its difficulties. Twenty years ago, one would spend an hour or two analyzing perhaps two or three models and develop worded forecasts for a group of counties – perhaps four or five general forecasts for our 16 counties – say, Buffalo-Niagara, southern tier, greater Rochester, and north country. Beginning shortly after 2000, we began to use gridded forecasts – contouring different probabilities, temperatures and winds on a gridded map – allowing for much more precise forecasts for specific areas, at least digitally. We were able to utilize more mesoscale models for this task, and our job increasingly became blending various models with the human input being based on previous experience with which model was best under certain conditions. We still had to get the final product out to the public in words and, initially, that was a major problem as the first word formatters were very rough and choppy.

For example, in the "old days", with an approaching synoptic system spreading rain in from west to east, the forecast may have read *"Rain developing later this afternoon"*, but the word formatter forecast would read "*Chance of rain between 1 and 2 pm, rain likely between 2 and 3 pm, then rain after 3 pm.*" This is because the word formatters take the increasing rain chances on the grids and interpret them that way. Even worse is a winter situation with snow changing to rain with a mix of conditions in between. We might have said in the "old days": *"Snow mixing with sleet and freezing rain before changing to rain this afternoon"*. Word formatters would have given a choppy mess like *"Snow likely, chance of sleet, freezing rain likely, sleet likely, chance of rain, rain likely, rain"*. So, for a few years, we had to spend a good deal of time adjusting the words which came out of the grids! This situation has improved in the last few years with better word formatters and since most people now get their forecasts hourly on smartphones for a precise location and not in worded county forecasts. But it sure has been a fast and complicated evolution in the forecast process!

As for determination of the forecasts, there has been a revolution in forecast guidance in the past 20 years. We have gone from two or three basic models to 20 or more various types of models, many of them very mesoscale down to 3-5 km spacing. This has greatly improved the accuracy on mesoscale features and has especially aided us here in our region as our most difficult and impactful events have always been the "lake effect snows". But a big problem now is the overabundance of data and guidance and our talents are needed in determining which model to use and which to ignore!

All of the above discourse has involved our routine operations but, of course, our most important job is to warn our over-three-million people about upcoming weather conditions which can be a threat to life and property, and, to a lesser degree, just those that may be inconveniences and annoyances. We cover these potential impacts with watches, warnings and advisories. There are many of these "flags" and all have minimum criteria (like >6 inches snow in 12 hours, etc.), but we have the option and flexibility to issue these with conditions which may not technically meet the guidelines, due to unusual situations such as unseasonably early snows or dramatic changes which can affect commerce.

Operationally, our staffing will increase during potential or actual severe weather conditions, and all regular staff hours are suspended. Even management is trained to help in these situations too.

"Warnings" are our most important product and we issue these for a variety of situations. In our area, most of these involve wintry situations such as winter storm warnings, while summer focuses on severe thunderstorm warnings, with high wind warnings and various types of flood warnings year-round. We also issue marine lakeshore flood warnings, and more specific but rare types such as blizzard, freezing rain and even wind chill, heat, and fire weather warnings. Most of these warnings had previously been issued on a county-wide basis, but in recent years they are becoming more mesoscale as well, which is a great improvement, especially for mesoscale events such as lake effect and severe thunderstorms.

There is an underlying issue here, though. As our warnings have become more precise and specific, there tends to be more of them, and this can be confusing to our users, our emergency managers, and our public. We need to use common sense in issuance of warnings, and I feel this can be a problem and that we are on a learning curve. I've seen cases this past winter when we literally had five warnings, watches, and advisories issued at the same time for nuisance events such as a few inches of snow, perhaps a bit of ice, and maybe a strong wind two days hence.

One thing that has changed immensely during my career has been the actions taken by local authorities based on our warnings. This is a good sign and shows how accurate our forecasts have become. Schools close before the first flake flies and outdoor games are cancelled ahead of the storm, minimizing the potential impacts. But sometimes I think we are still a bit overly-enthusiastic in issuing too many products at once: we don't want to create the "crying wolf" syndrome. A three inch snowfall in early November after 60 degree weather has much greater impact than a three inch snowfall in early February after two weeks of daily snow and cold. We shouldn't be using the same product for both. This was always a source of conflict in our determination of which "flag" to use!

During my 21-year career, I forecasted and warned for many events, but one certainly stands out as the most memorable; the freak lake effect snow of October 12-13, 2006. This was arguably the most widespread, destructive, and damaging storm of any kind ever to hit the greater Buffalo area. It delivered one to two feet of wet snow on fully-leafed trees, causing massive tree devastation and loss of power to over 80% of the area for a week or more. And, just 24 hours prior to the event we had no "flag" up at all! Why was that? Probably because of the conflicting model data and also the historical feature in our minds. Buffalo had never recorded a snow over two inches before late October in the 130 years of history so the meteorological conditions would have to be unprecedented. We do follow the model data of course but, as experienced forecasters in our area, we also need to know a bit of the usual climate. This usually is a plus as it allows us to be more skeptical of unusual guidance and data, but it can also be a detriment in extreme cases as we, being human, have never experienced this so we tend to use perhaps too much skepticism in a potentially record-breaking event. In any case, here is a brief scenario of our forecast of this potential event during the several days prior to its occurrence...

On Sunday, October 8, as we basked in typical early October weather – pleasant 60s, dry, with our green foliage just showing the beginning stages of turning color – models were all showing an unusually strong shot of cold air sweeping southward into the Plains by later in the week and eventually across the lower Great Lakes by the weekend. Now, early season cold shots always get our attention here as our most significant weather threats are early season lake effect snows. This infamous mesoscale process is caused by extreme instability over the lakes as cold air interacts with the still warmer lake waters to create instability. In forecasting, we usually use the magic difference 23.4°F (13°C) between the lake water temperature and the air temperature at cloud level (close to 850mb/5000ft). This creates enough instability to get the lake effect process going, and the wind direction aims it downwind. Of course, this number is not etched in stone as we can get lake effect going with as little as a 18-19.8°F (10-11°C) difference in a very moist environment while you may need 27°F (15°C) in a dry sheared (changing wind direction with height) environment. In any case, early season events are usually the most intense as the lake waters are often over 50°F (10°C) well into November and the 850mb-to-lake difference can exceed 36°F (20°C) in cold surges. In fact, the majority of Buffalo's largest lake effect snowstorms have occurred during the period of mid-November to mid-December and are often accompanied by thunder and lightning.

But, here we were in early October and, yes, we could expect a significant lake effect event within a few days though it was difficult to imagine that it would be snow rather than rain.

There was no doubt we would meet the lake temp/850mb difference criteria as the lake temperature was still a balmy 61°F (16°C) but the big question was whether the resulting precipitation would be rain or snow.

We usually use about a 21 or 19°F (-6 or -7°C) 850 mb temp as a rough guide in rain vs snow in early season lake events, and models were showing about 21°F (-6°C) for Friday, October 13th. So, our initial forecasts on Monday the 9th for the upcoming Thursday into Friday period mentioned that some wet snow may mix in with lake effect rain but with little or no accumulation. Models continued to show about the same situation as we got closer but, on Wednesday the 11th, they ticked down to about 19°F (-7°C) for the 850 mb temperature. We became a bit more concerned, especially when one of the models showed several inches of snow for Buffalo, but this model was notorious for "overdoing" precipitation and snow, so was generally discounted. We continued with the "rain mixed at times with snow" forecast with perhaps an inch or two inland.

I came into work for the day shift on Thursday, October 12th a bit concerned. The cold front had passed in the predawn hours, sending temps from the 60s to the mid-40s by mid-morning. The strong southwest flow of cold advection over the warm lake was already setting up bands of lake effect rain by late morning but, looking upstream at Detroit and Cleveland, temperatures and dew points were a few degrees colder than models had projected. Also, graupel had already begun to mix with the rain bands by noon at our office and some wet snowflakes were already observed by around 1 pm. I began to get a terrible feeling as I knew that the wind direction and cold advection would not change for at least another 12-18 hours and we were already starting to change to snow. As senior forecaster on shift, I called in the meteorologist-in-charge and we agreed to go all the way and issue a lake effect snow warning, our strongest warning, for the evening and overnight period. This was to be based on impact as we expected only a 2-6" accumulation thereby not meeting the official criteria, but we did it knowing that all trees were in full leaf and there would be major consequences with even a few inches of this pasty wet snow on trees and power lines. This warning was issued around 2:30 pm but there was little anyone could really do except to warn the public that power would probably be lost in many areas and utility companies could be put on alert.

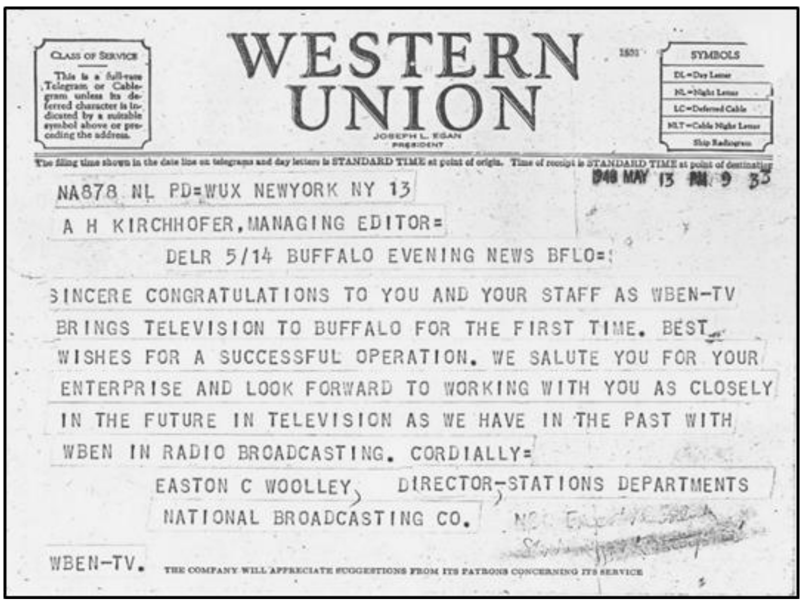
Of course, the rest is history. By 8 pm, power was going out for thousands, after just 2-3" of wet snow but the fully-leafed green trees just couldn't take the load. None of us in Buffalo metro will ever forget that sleepless night of thunder and lightning, crashing trees and limbs on roofs, and a week without power. We awoke to 10-20" of wet snow on the ground and a scene of massive tree devastation.

In retrospect, although we did get the warning out a few hours ahead of the main event, I think we were a bit too influenced by history and climate: the fact that it had never happened this early (although, upon further research, we did find a similar event 100 years prior – almost to the day – in 1906). Also, we thought that the areas near the lake would be warmed a bit by the 61°F lake water and tend toward rain rather than snow but, conversely, what probably happened is that the warm lake created even more extreme instability, which forced the air to rise even more turbulently, therefore cooling it further! I suggest now that a 21°F (-6°C) 850mb temperature over a 59°F (15°C) lake temperature) in October would be more likely to result in snow than a 21°F (-6°C) 850 mb temp over a 44.6°F (7°C) lake temp in mid-December (which would result in rain as the instability/rising air would be less).

In any case, this was one of many memories in my most rewarding 21-year career as a meteorologist with the National Weather Service in Buffalo. I was proud to serve the people of western New York!!!

On-Air Meteorology

Arguably, weather is the linchpin of local news, made more so when severe weather is forecasted or occurring. While local weather was, and is, reported in newspapers, on the radio, and more recently viewed in apps, it is the TV weathercaster who is invited into your home daily to put a "face to the weather". We have our favorites, and as such, the local weathercaster is often recognized as a celebrity in our community. I recall inviting local weathercasters to give lectures at Buffalo State, and of all the weather experts invited over the years, it was only with weathercasters that an autograph/photo line formed. Even I once queued up at a weather conference for an autograph from Jim Cantore of the Weather Channel on behalf of one of my students who could not attend the conference.


WESTERN UNION

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A H KIRCHHOFER, MANAGING EDITOR=

DELR 5/14 BUFFALO EVENING NEWS BFLO=

SINCERE CONGRATULATIONS TO YOU AND YOUR STAFF AS WBEN-TV BRINGS TELEVISION TO BUFFALO FOR THE FIRST TIME. BEST WISHES FOR A SUCCESSFUL OPERATION. WE SALUTE YOU FOR YOUR ENTERPRISE AND LOOK FORWARD TO WORKING WITH YOU AS CLOSELY IN THE FUTURE IN TELEVISION AS WE HAVE IN THE PAST WITH WBEN IN RADIO BROADCASTING. CORDIALLY=

EASTON C WOOLLEY, DIRECTOR-STATIONS DEPARTMENTS
NATIONAL BROADCASTING CO.

WBEN-TV.

THE COMPANY WILL APPRECIATE SUGGESTIONS FROM ITS PATRONS CONCERNING ITS SERVICE

Figure 141. Western Union telegram sent to WBEN-TV (now WIVB-TV) congratulating the station for bring television to Buffalo for the first time. Image Source: WIVB-TV.

WNY has enjoyed a rich tradition of local television weather since 1948, with the sign-on of WBEN-TV, known today as WIVB-TV (Figure 141). At the time WBEN-TV was the 25th television broadcasting station in the U.S. and WNY counted only 1,000 television sets (most of the 7 x 10 inch screen variety). By 1949 there were 10,000 television sets, and a few years later the count soared to 200,000. WGRZ-TV (signing on as WGR) joined the airwaves in 1954, followed shortly thereafter by WKBW-TV in 1958. These three stations rounded out the "Big 3" network affiliates that dominated television for many decades.

Prior to the internet, television was the undisputed source of weather information to the public (Figures 142 and 143). More recently, there are a growing number of eyes seeking out online and app sources for weather information. Television stations are responding – following the "eyes" of viewers - by putting the forecast and the weathercaster's face on the internet and social media. I recall shadowing Aaron Mentkowski (WKBW-TV), noting that while he did a lot of on-air work, his time was equally dedicated to online efforts. But still, it is television that many of us reach out to for local weather. Asked the question "How do you check the weather?", most respondents in a recent online survey conducted by "538" (a

Figure 142. Early WBEN-TV (now WIVB-TV) television news set, showing the weather map with graphics. Ken Phillips is shown in front of the map. Image Source: WIVB-TV.

Figure 143. Early WBEN-TV (now WIVB-TV) weathercaster Ward Fenton "old school" presentation. Image Source: WIVB-TV.

website focusing on opinion poll analysis) listed television (35.8%) as their #1 source. The number of people watching weather on television is likely even greater since the "538" survey was conducted online.

With regard to the "face of weather", there are 210 U.S. television Designated Market Areas (DMA's) as determined by Nielson. New York City is ranked #1, while Buffalo, NY is ranked #53 (some argue that it would be ranked higher if Canadian audiences were considered). Throughout these DMA's, there are about 1,000 television weather forecasters. They are of different pedigrees, some with degrees in meteorology, others with a degree in communications, still others with a television entertainment background, and some with a combination of all three. Whatever the pedigree, the primary role of the weather forecaster is to provide the public with accurate weather information.

For some forecasters, a good weather forecast is tailored from a commercial forecasting service, while others take on the task of creating their own. In most cases, the on-air weather forecaster works closely with the National Weather Service. Don Paul, in a parting comment from WIVB-TV, expressed three things that he would like to be remembered for while on-air: *"Someone with passion for his work, someone who did good work, and someone who was a reasonably nice person and was funny at times, when appropriate."* I believe this statement is the creed of all weather forecasters. Television and weather is a tough job market, where many weather forecasters bounce around between stations before landing at one where they "stick" for some time. Many weather forecasters have passed through the Buffalo market over the years, while a few have "stuck".

WIVB on-air personalities that come to mind as having "stuck" are Don Paul (recently retired from WIVB-TV) and Mike Cejka, both long-term weathercasters, with 60 years of experience between them. Previous WIVB-TV weather forecasters the reader may remember include: Ken Phillips, Ward Fenton, Lou McNally, Ted Textor, Chuck Gurney, Chris Daniels, Lindsay Schwarzwalder, Amelia Segal, Mary Beth Wrobel, and Bryan Shaw, to name but a few.

Another on-air personality that "stuck" in the WNY market is "native son" Kevin O'Connell, WGRZ's long-term chief weather anchor who came to the station in 1993 (he was a main weathercaster at WBEN-TV (WIVB-TV) in the 1970's, and remembered, in part, for "Weather with a Beat"). Kevin is a prime example of an on-air personality involved with numerous and long-term community and fund-raising activities. Past weathercasters on WGRZ-TV include Barry Lillis, Geoff Fox, Stan Roberts (Figure 144), Frank Benny, and Eric Warren. June Bacon-Bercey aired as a weathercaster for WGRZ in the 1970's. To her credit belongs several notable firsts: first African American woman to earn a degree in meteorology; first female television meteorologist in the country; and the first African American and the first woman to earn the American Meteorological Society's Seal of Approval for excellence in television weathercasting.

Figure 144. Stan Roberts, WGR-TV (now WGRZ-TV) Weather. Image Source: Buffalo Stories Archives/Steve Cichon Collection.

At WKBW, long-timers included WNY's popular native Tom Jolls (part of the longest-running anchor team in television history − 1965 to 1989) who retired in 1999. An earlier weather forecaster was Dave Thomas, who is also remembered as host of the children's show "Rocketship 7", and "Dialing for Dollars". Like Dave, Tom Jolls took on other television-related duties such as host of the long-running "Commander Tom Show". Mike Randall arrived at the station in 1983 (first assigned weather duties in 1989) and is still on the air at the time of writing. He is sometimes described as an American actor, playwright, meteorologist, and reporter. Tom, Dave, and Mike represent a generation of early weather forecasters with roots in entertainment. Former weather forecasters include Tracy Humphrey, Danny Neaverth, and Warren "Clip" Smith, Bill Sweet, and Bob Koshinski to name but a few.

Over the years, the look and feel of the weather forecast has evolved, with stations changing formats, sets, and adding new elements (often driven by changes in technology) to improve their conveyance of weather information, and to obtain a rating edge over competing stations. Early on-air visuals usually included a static display which comprised a base map and moveable pieces (arrows and weather icons).

In 1982, Time Magazine altered its iconic "Man of the Year" by instead naming the personal computer "Machine of the Year". That same year, WGRZ meteorologist Eric Warren was promoted as being "wired for weather", highlighting his use of state-of-the-art computer technology (Figure 145). The promo included an onscreen individual who said: "I do enjoy the computer, I do enjoy him (Eric)", followed by

Figure 145. WGRZ-TV weathercaster Eric Warren in a 1982 promo titled "wired for weather". Image Source: Retrontario.com.

Figure 146. The weather bug is all over WNY and meteorologist Don Paul having a little fun, as shown in a WIVB-TV "Weatherbug" promo. Image Source: WIVB-TV.

another onscreen individual who added "Once Eric gets the information from the computer, he breaks it into common terms." There was no turning back, as WNY stations adopted digital technology.

There were other innovations too. For WIVB, this included the station's collaboration with "WeatherBug", which promoted a network of WNY backyard weather stations under the moniker "Neighborhood Weather-Net" (Figure 146). Also popular was WIVB's Weatherline (844-4444) which, prior to the internet, was the quickest and easiest way to get a weather update. In addition, WIVB operated a local Doppler radar (4x4 Warn Doppler) in the 1990's and early 2000's, before switching over to the NWS Doppler radar.

Like WIVB, WGRZ operated an in-house weather radar – today branded as "Live Precision Doppler 2". As radar evolved so too did its on-air presence. WGRZ attempted several forays into 24-hour weather channels: the "Weather Plus" channel (since shutdown) and, later, "Weather-Nation TV" which airs 24-hour weather by combining local forecasts from in-house meteorologists with national forecasts. Most recently (2016), the station debuted "Rooftop Weather", an outdoor weather set that takes advantage of the station's downtown location, and views of city landmarks.

WKBW is fondly remembered for its "Weather Outside" segments, and for Tom Jolls' "Weather Word" – a one-word summation of the day's weather (Figure 147). WKBW was the first station in the Buffalo market to introduce a morning show and, in 2014, were chosen by their corporate owners to pilot a short-lived morning news format with a strong emphasis on weather. And one cannot forget Andy Parker's "weather machine", which brings weather to local schools in a spectacular fashion. Most recently, WKBW debuted its own storm chaser vehicle – the "7 First Alert Mobile Weather Lab" complete with a dash cam, multiple radar sources, and a built-in weather station.

On-air or online, whether "watched" on a television, computer, tablet, or smart phone, accessed through streaming, a webpage, facebook, blog, youtube, twitter or app, the local weather forecaster will likely continue to provide WNY with timely and relatable weather information – putting a "face to the weather."

Figure 147. Tom Jolls "weather outside" segment from January 18, 1987.
Image Source: Retrontario.com.

Local Knowledge

Reflecting On-Air Weather Experiences

Contributed by Mike Cejka, a local broadcast meteorologist with over 30 years in the WNY Market

Experiencing the brute force of Nor'easters, the wind, rain, sometimes snow, it was easy to catch the weather bug. Little did I know that my path would eventually lead me to a city where some of the greatest snowfall rates in the country have been observed.

After a year and a half stint at Bangor, Maine, I relocated to Buffalo to begin my tenure at WIVB during January 1983. During the early years at the station, we would air brush clouds onto a sheet of acetate which was later shot by the studio cameras to produce on-air weather maps. Our satellite pictures were archaic gray scale national NOAA satellite loops that came down on the CBS network news feed several times a day. Gosh, how things have changed.

Eventually, I experienced the advent of superior graphics computers, to the advancement and proliferation of computer forecast guidance. I recall some of the rudimentary modeling available to forecasters while attending college; the Primitive Equation Model, Barotropic, Baroclinic, none which remain in their original form today. Since, operational, and ensemble modelling has grown exponentially, and is now being generated by many industrialized nations.

Being the weather geek that I am, I have been lucky to have experienced and covered some of the harshest winter conditions; thundersnow, outrageous snowfall rates of 3-5 inches per hour, and the intricate localized weather patterns that come with our proximity to the Great Lakes. The lake convergence boundaries, and the huge minimum temperature ranges between the lakeshores, and inland valleys that are so commonplace during autumn.

I may have missed the Blizzard of ’77 by a few years, but I did experience the New England Blizzard of ’78. Though it received a lot less press, in many ways it was very similar to what the people of western New York experienced just a year prior. Car clogged highways became buried by feet of snow, and there were causalities.

A few years after arriving at WIVB, came the Blizzard of ’85. Due to impassable city streets, I recall parking three blocks away from the WIVB studios in the Village of Kenmore, and then walking to the station amidst horrific sub-zero wind chills. While preparing for a live report on Elmwood Avenue, I’ll never forget standing outdoors without gloves as wind chills plummeted into the -30s. I had misplaced my gloves in the weather office.

Before a time when almost everyone had 4 wheel or all-wheel drive, I remember the days when station management would hire drivers with Jeeps to transport staff to work. Our broadcast infrastructure obviously provided one of highest lightning rods around Buffalo. While sleeping over at the station during several severe snowstorms, the building would rock as lightning struck the tall relay tower behind the station. It frequently takes lightning hits during thunderstorms.

There has never been a dull moment observing and forecasting western New York weather, and after these 35 years, it never ceases to amaze me.

Chapter 7

History: Yesteryear to Present

THE SUNDAY NEWS.

BUFFALO, NOV. 27, 1898.

GREAT WEATHER MAN

All Things Revealed to the Penetrating Gaze of Forecaster Cuthbertson.

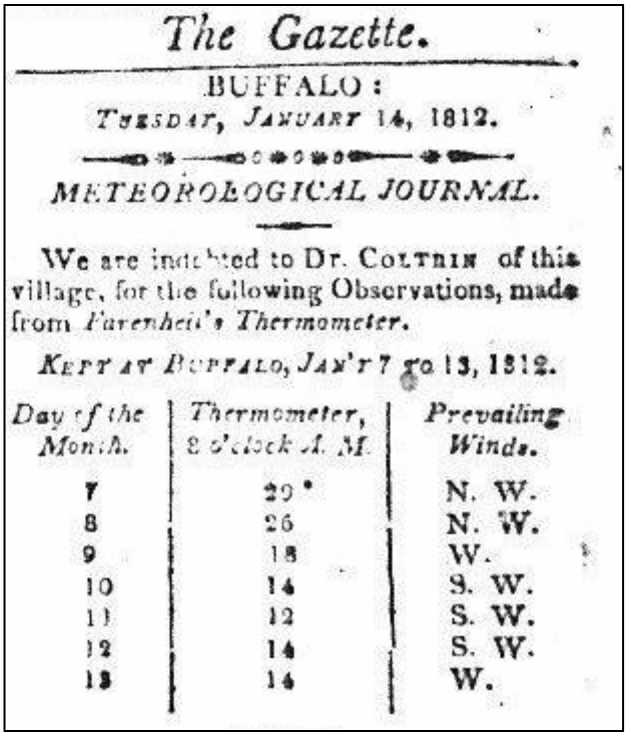
HE SWEEPS THE HORIZON.

Reads the Thermometers in Iowa and Describes the Appearance of Gotham--Young Blizzard in Buffalo.

Image Source: Clipping Book. Manuscript on file at Buffalo Museum of Science.

The Earliest Years of Record

Prior to the 1870 establishment of the U.S. Army Signal Service's "Division of Telegrams and Reports for the Benefit of Commerce" − the initial name of what is today the National Weather Service (NWS) − the recording of weather data was limited to private journals and later to fledgling weather networks. The description of pre-NWS weather-related events in WNY can be gleaned also from newspaper accounts and historic retelling of events that include a weather-element to the story.



The Gazette.

BUFFALO:

TUESDAY, JANUARY 14, 1812.

METEOROLOGICAL JOURNAL.

We are indebted to Dr. COLTRIN of this village, for the following Observations, made from Farenheit's Thermometer.

KEPT AT BUFFALO, JAN'Y 7 TO 13, 1812.

Day of the Month.	Thermometer, 8 o'clock A. M.	Prevailing Winds.
7	29	N. W.
8	26	N. W.
9	18	W.
10	14	S. W.
11	12	S. W.
12	14	S. W.
13	14	W.

Figure 148. Early presentation of weather data as it appeared in the Buffalo Gazette on Thursday, January 14, 1812. Image Source: "Meteorological Journal", January 14, 1812. The Buffalo Gazette microfilm. Archives & Special Collections Department, E. H. Butler Library, SUNY Buffalo State.

The Buffalo Gazette was published between 1811 and 1818, about a decade after a survey by the Holland Land Company of WNY and the arrival of the first wave of settlers. In the late 18th Century there were about 20 to 25 pioneers in the Buffalo area. The earliest, if not the first, public listing of weather data in WNY appeared in the Gazette's January 14, 1812 edition (Figure 148). It was listed as the "Meteorological Journal", reporting temperature and prevailing wind data from an 8:00 am observation in the village of Buffalo, as maintained by Dr. Coltrin (likely Dr. Asa Coltrin, a resident of Buffalo, NY in 1810 and for several years after, with an office on Main Street).

On Saturday, January 18, 1812, Buffalo's 8:00 am temperature reading was reported in the Buffalo Gazette as -10°F. A note of explanation followed: *"That our readers may judge the extreme cold felt at this place, we have published the above statement. There are but few instances in our latitude that the mercury falls as low as it did on Saturday last."* The explanation goes on to explain how to interpret the thermometer's reading: 32°F (freezing point); 55°F (temperate); 76°F (summer heat); 98°F (blood heat); and 112°F (fever heat). Reference to "Blood Heat" is the temperature of human blood, while "fever heat" referred to an abnormally high body temperature. These reference points cited in the Buffalo Gazette were likely printed on the thermometer used, as was often the case with early 19th Century thermometers. These reference points were noted, from time to time in the newspaper, with subsequent observations. For example, on May 19, 1812 it was reported *"between 2 and 3 o'clock P.M. the ther. (thermometer) stood at 80 – 4 above summer heat."*

The winter of 1812 appears to have been a cold one. The February 19, 1812 edition of the Buffalo Gazette included the following commentary which followed the daily listings in the Meteorology Journal: *"It has been observed by gentleman of intelligence who have kept journals of the weather, that the winter thus far has been more severe than any since that of 1804. In that winter, it will be recollected, that many were frozen to death. In the present we have heard of but few instances; but still there have been a pretty good crop of damaged ears, noses, feet, etc."* Later, on March 2, 1812, the Buffalo Gazette listed a morning temperature of -12°F, noting *"This was probably the coldest morning ever experienced in this place."* And again, on April 28th, 1812 it was noted that the temperature on April 11, 1812 *"stood at only 16 degrees"*.

An example of measurement error is noted in the April 8, 1812 issue: *"At 1 o'clock P.M. the thermometer around at 70 degrees in shade − on being suspended near a window facing the sun it rose to 102 degrees, being 4 degrees above blood heat."* Clearly, this was recognized as not a proper exposure for a thermometer.

Over time, one-word descriptions of the weather were included in the Meteorology Journal of the Buffalo Gazette − clear, cloudy, windy, rain, and snowy − along with the daily temperature and wind direction. And for a short time, daily measurements, having been taken at 6:00 am, 12 noon, and 6:00 pm, were published in the paper.

The credit for the weather observations changed hands from Dr. Coltrin to that of the publisher of the Buffalo Gazette, H.A. Salisbury, and later to an unknown individual. The Meteorological Journal was printed only for the first few months of 1812 and reappeared again in 1813 for an even shorter period before once again disappearing from the paper's pages. Though not routinely reported, it does not mean that weather observations were not maintained in WNY. In the January 19, 2013 issue of the Buffalo Gazette, a Mr. Henry Johnson, Jr. of Clarence, NY provided a table summarizing 1812 weather conditions based on his weather journal. And it reveals what would be expected for WNY: a greater frequency of cloudy and stormy days in the winter.

Month	Stormy Day	Cloudy Day	Clear Day
January	11	15	5
February	9	11	9
March	5	16	10
April	3	11	16
May	5	6	20
June	3	11	16
July	6	8	17
August	6	6	19
September	5	8	17
October	6	14	11
November	9	16	5
December	7	20	4
Year	75	142	149

Mostly absent from the Buffalo Gazette was the reporting of specific weather events which occurred in WNY. There are exceptions – *"There was a thunderstorm in the evening at a great distance in the direction of Lake Erie"* and *"A violent squall of thunder, rain and hail, was experienced in this city on Saturday morning; during which a brick house at the corner of Broadway and Spring Street, occupied by Mr. Peck, grocer, was struck by lightning and very much shattered"* −, but these reports were few. To put this into perspective, the reported number of duels between offended gentlemen outnumbered those of local weather stories.

Mention was often made of weather events occurring outside of WNY, for comparative purposes, or to note extreme weather in other parts of the country (eg. a hurricane in New Orleans, a northeaster in New England, and a tornado in Charleston, South Carolina). The rationale for the lack of local weather stories, in comparison to reports of weather events afar, may have been the readerships' awareness of their local weather, and their need to learn about events happening elsewhere. By way of example, the New Orleans hurricane was relevant to the WNY readership because it related to the War of 1812. The U.S. Naval Station in New Orleans had just received word that, three weeks earlier, the U.S. Congress had declared war on Great Britain. As preparations were being made for war, a hurricane slammed into New Orleans on August 19, 1812. Ships were completely unrigged by the storm, others sank, and still others were driven ashore or stranded on mud banks. The city and naval station were left defenseless. It appeared that the British would have the advantage. The fear was unwarranted as nature was an equal opportunity player. The very storm that leveled New Orleans also scattered the British fleet across the Gulf of Mexico.

The pages of the Buffalo Gazette gave way to war news. WNY shared a border with Canada and thus found itself on the front lines. This became painfully evident with the burning of the villages of Buffalo and Black Rock by the British on December 30, 1813. There are several references to weather that relate to local conflicts. Surprisingly, three of the most notable local events occurred in the month of September 1813.

One of these notable events was the battle off the Genesee River in Lake Ontario (September 11, 1813), where the American squadron had the wind, but the British were becalmed and got badly shot as they attempted to row themselves out of American gun range. An evening land breeze then filled their sails, enough to allow the British to withdraw.

A stalemate was not the order of the day on September 13, 1813 when nine U.S. vessels commanded by Commodore Perry took on a squadron of six British ships off the coast of Ohio. This naval engagement was suitably named the "Battle of Lake Erie", and it turned out to be one of the most decisive battles of the war. The British had the weather gage and for two hours pounded the U.S. fleet. Sailing vessels sought the "weather gage" in battle - a position upwind of the enemy ship. The upwind position allowed a vessel greater maneuverability and the ability to bring guns to bear. Much of a naval battle was a series of maneuvers to gain the weather gage, and the maneuvering of several ships was termed the "weather line". Those ships downwind (or leeward) of the weather line often ran off to re-maneuver. Frustrated with his efforts, Commander Perry issued orders to turn away. Before his orders were conveyed, the winds suddenly shifted. The wind shift gave Perry the weather gage, and thus the important naval advantage. The rest is history: Perry captured all six ships of the British squadron and gave the U.S. control of Lake Erie throughout the remainder of the war. From this battle came one of the most famous literary lines of the war: *"We have met the enemy, and they are ours."*

Yet a third weather event affected the outcome of the war. The date was September 28, 1813. Six British warships originally stationed in York Harbor sailed to meet a larger force of 10 American ships. A battle ensued in Lake Ontario, approximately 12 miles south of York (Toronto). Broadsides were exchanged between the British flagship, HMS Wolfe, and the American flagship, the USS General Pike. The Wolfe, under Commodore Yeo, was seriously damaged, having lost her main sails and, with the British fleet, raced for protection under the Burlington Bluffs (western end of Lake Ontario). From this escape, a War of 1812 legend was born. According to legend, the Wolfe raced to Burlington Bay, with not only the General Pike in pursuit but a strong nor'easter as well. The strength of this easterly gale increased over the three-hour chase and piled water into the western end of Lake Ontario (what today would be described as a "storm surge"). The Wolfe, as well as the other British ships, took advantage of this high water as they approached a sandbar separating Lake Ontario from Burlington Bay, and were lifted to safety by the rising waters. While the encounter and chase did take place, there is plenty of evidence to effectively debunk the legend of the "lifting" of the British ships into Burlington Bay.

The newspapers of the day had much to say about the summer of 1816, referred to as the "Year Without a Summer" (see page 36 to learn more).

An early description of the climate of Buffalo, NY, which at the time had a population of just over 2,000 people, can be found in an 1825 pamphlet authored by Mr. S. Ball, In the pamphlet, he included a description of the climate of the village that today's readers might recognize: *"The climate is more pleasant than any situation in an equally northern latitude in our country and equally healthy. The summers and autumns are peculiarly fine; the lake affords a gentle breeze during those seasons, much resembling a sea breeze, but of more elasticity and sweetness. The winters are less uniform than in most other parts of the country; the snow rarely falls to a greater depth than six inches; the cold is not so severe as in other places in the same latitude situated remote from* *the lake, yet in winter, when the waters are covered with ice the winds are often cold and piercing...The spring season is variable. The changes of weather are often sudden, especially during the continuance of ice in the Lake, which probably has a tendency, in some instances, to produce chronic and inflammatory complaints."*

An early account of severe weather in the Southern Tier can be found in the book "Prairie Fires: The American Dreams of Laura Ingalls Wilder" (of Little House on the Prairie TV fame), where author Caroline Fraser notes that Laura's great-grandfather, Samuel Ingalls, moved to Cuba, NY in 1833. While there, he wrote a poem describing a great hail and wind storm that passed through Cattaraugus and Allegany counties in the spring of 1834. In his poem he purportedly describes 8-inch hail and a tornado that carried away houses. This poem represents one of the earliest written accounts of severe weather in WNY.

In what may be the earliest U.S. weather map, James P. Espy, working with the Committee on Meteorology of The Franklin Institute in Philadelphia Pennsylvania, plotted weather data for a March 16-19, 1838 storm (barometer and sky conditions) (Figure 149). The map was based on 50 responses from 250 circulars that were sent out to observers. Station #28 (a response) recorded observations at a location south of Rochester, NY and just west of the Genesee River.

For the article "On Two Storms Which Were Experienced throughout the United States, in the Month of February 1842" (Transactions of the American Philosophical Society, 1845), Elias Loomis included a map with three arrows indicating three observations from WNY (the points of the arrow are the points of observation). These may be the first observations from WNY depicting weather on a map. In addition to wind direction, temperature, pressure, and weather type are included on the map (map not shown).

A map dated April 1, 1843 (3 p.m.) is one of a pair of maps created by James P. Espy, drawn to track the progress of a storm (thought to be the first U.S. set of weather maps) (Figure 150). Arrows depict the direction and force of the wind and, as in the previous map, the points of the arrows are the points of observation. There appear to be four WNY points of observation, one likely located at Fort Niagara, two near Buffalo, NY, and one in the Southern Tier. These pioneering maps reveal the early struggle with the visualization of weather data on maps.

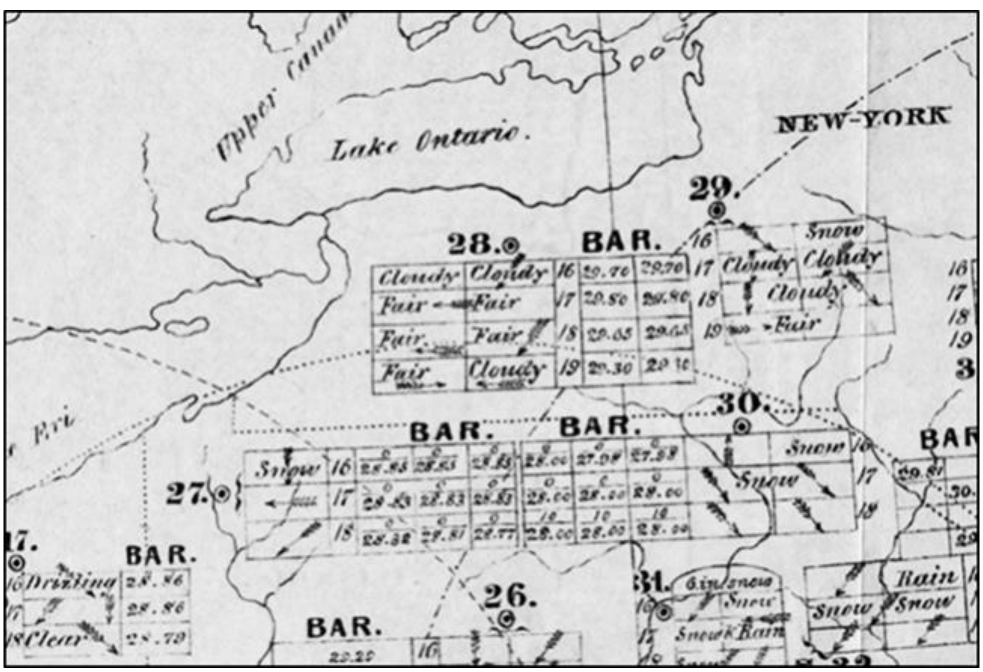


Figure 149. A portion of an early James Pollard Espy weather map (March 16-19, 1838) showing barometer and sky conditions for station #28 located near Rochester, NY. Image Source: Historic Maps Collection, Dept. of Rare Books and Special Collections, Princeton University Library.

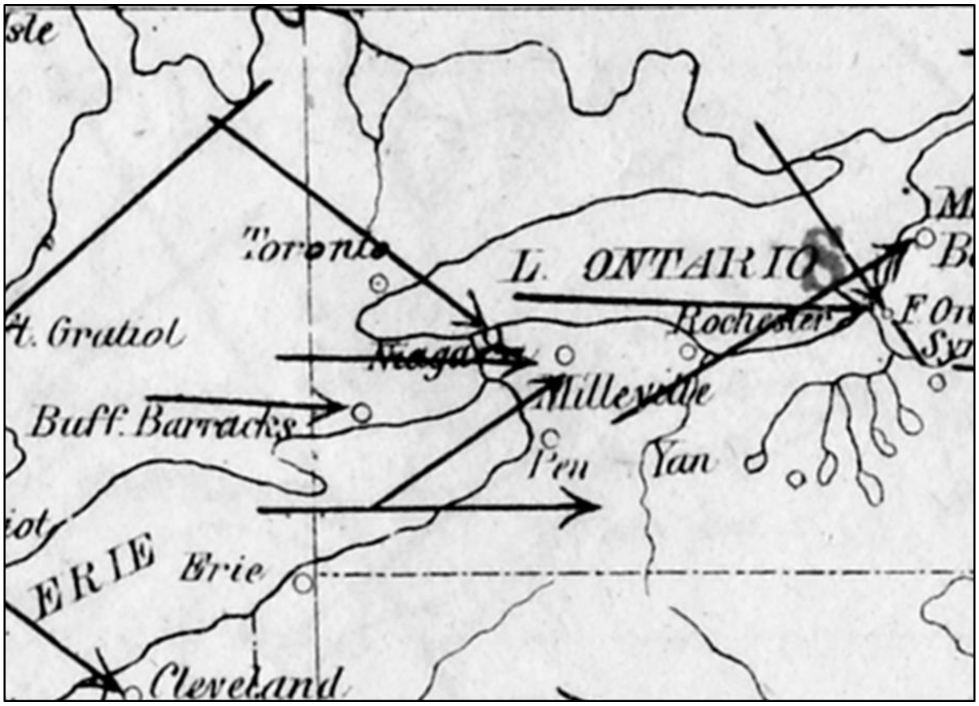


Figure 150. A portion of an early James Pollard Espy weather map (April 1, 1843 at 3 p.m.) showing four observation sites in WNY. The points of the arrow are the points of observation. Image Source: Image Source: Historic Maps Collection, Dept. of Rare Books and Special Collections, Princeton University Library.

Early Weather Networks

Early weather observations were few and usually made by individual citizens. It was after the War of 1812 that this all began to change. Dr. James Tilton was appointed the very first Surgeon-General of the American Army in 1813. He issued an order to army hospital, post, and regimental surgeons that read in part *"He shall keep a diary of the weather…"* This order, by Dr. Tilton, is recognized as the first organized effort by the United States Government to create a meteorological network. Its advantage over personal diaries is that weather observations were available at fixed locations, something early researchers used to advantage in publishing some of the country's first climate summaries. Records show that surgeons at Fort Niagara and Fort Porter (Buffalo) maintained the ordered weather observations.

Some of the earliest weather records in WNY were made by observers associated with academic institutions in New York State. Simon DeWitt, Vice Chancellor of the University of the State of New York, procured a grant from the state legislature to maintain weather observations. Observers in Buffalo, Cuba, Fredonia, Gaines, Jamestown, and Lewiston, Springville, and Wyoming, New York were a part of this state-wide network.

Along the side of Route 436, just east of the village of Nunda, NY (Livingston County) and south of Letchworth State Park, there exists a roadside placard titled "Telegraph Road" which commemorates the route of the New York and Erie telegraph line constructed in 1848 (a line from Buffalo, NY to Lockport, NY was constructed in 1845). The 1848 telegraph line then connected Buffalo, and thus WNY, to cities across the eastern U.S. as never before. Communication became instantaneous, rather than requiring the sending or receiving of dispatches that would take several weeks passing to and from New York City. As new telegraph lines were established and integrated, Buffalo's connection to the country and world grew.

Joseph Henry, the first Secretary of the newly established Smithsonian Institution in Washington D.C., recognized the natural pairing between the telegraph and weather. Recognizing that weather travels generally from west to east, he realized that the telegraph could quickly convey weather observations − telegraphing weather observations ahead − to provide warnings of approaching storms (unlike the previous weather maps that required years to assemble and publish). By 1849, Joseph Henry established a network of 150 volunteers (growing to 600 within a decade) to provide weather observations to the Smithsonian Institution via telegraph. The Smithsonian Institute provided weather instrumentation to many telegraph offices and he arranged for free transmission of weather data – "Weather Telegraphy" was born. The received data was processed by about a dozen individuals, referred to as "computers". By the mid-1850's many communities participated in the Smithsonian's weather service. In WNY, Alfred, Angelica, Eden, Falconer, Little Genesee, Niagara Falls, and Wellsville were Smithsonian stations. William Ives, former Librarian of the Young Men's Association (parent organization of the Buffalo Museum of Science) was a Smithsonian meteorological observer. He recorded daily weather in Buffalo, NY from 1864 until 1876 (Mr. Ives ledgers are archived by the Buffalo Museum of Science). The outbreak of the Civil War put an end to this early effort of the Smithsonian Institute (loss of southern stations and the need for more urgent business along telegraph lines). At the war's conclusion, Joseph Henry pushed for a renewed weather network, one to be administered by the federal government.

Earliest Networked Weather Stations

Station	County	Earliest Year	Affiliation	Instruments
Alfred	Allegany	1852	Smithsonian	DT, SRG
Angelica	Allegany	1854	Smithsonian	DT, SRG
Buffalo	Erie	1831	NYSBR	DT, SRG
Fort Porter	Erie	1849	Surgeon General	SRG
Cuba	Allegany	1840	NYSBR	DT, SRG
Eden	Erie	1856	Smithsonian	DT
Falconer	Chautauqua	1853	Smithsonian	N.R.
Fort Niagara	Niagara	1820	Surgeon General	DT, SRG
Fredonia	Chautauqua	1830	NYSBR	DT, SRG
Gaines	Orleans	1839	NYSBR	DT, SRG
Jamestown	Chautauqua	1850	NYSBR	DT, SRG
Lewiston	Niagara	1831	NYSBR	DT, SRG
Little Genesee	Allegany	1866	Smithsonian	DT, SRG
Niagara Falls	Niagara	1867	Smithsonian	SRG
Springville	Erie	1834	NYSBR	DT
Wellsville	Allegany	1857	Smithsonian	DT, SRG
Wyoming	Wyoming	1826	NYSBR	DT, SRG

NYSBR = New York State Board of Regents

DT= dry bulb thermometer SRG = standard rain gage N.R. = no record

Buffalo's National Weather Service (1870 to Present)

WNY's official weather/climate record is based on observations made by the Buffalo Office of the National Weather Service (NWS). This office has been the region's official record for almost 150 years, but this record is bimodal – divided between the "historic" record and the "modern" record. The historic record includes the initial 74 years when the observing station was in downtown Buffalo, and the modern record includes observations taken at the Buffalo Airport (74 years to-date). The divide between the two periods is July 1, 1943, when the official observation site was moved from downtown to the airport. Synchronized temperature and precipitation measurements ended at the downtown site on July 1, 1994.

Using the full period of weather observation can sometimes be problematic, as the downtown site and protocol differed from that at the airport site. The downtown site was strongly influenced by Lake Erie (lake effect). Its location required observations made from progressively higher buildings over time in the heart of the city, and observation protocol and siting of observation equipment was in its infancy. The observation site at the airport was (and still is) located 9 miles inland from downtown Buffalo, and thus experienced less lake effect, represented a rural/suburban setting removed from the heart of the city, and observation protocol and siting criteria were closer to modern criteria. In general, the full observation record is used when comparing weather-related records, but the modern record is most often used to characterize Buffalo's climate and climate trends.

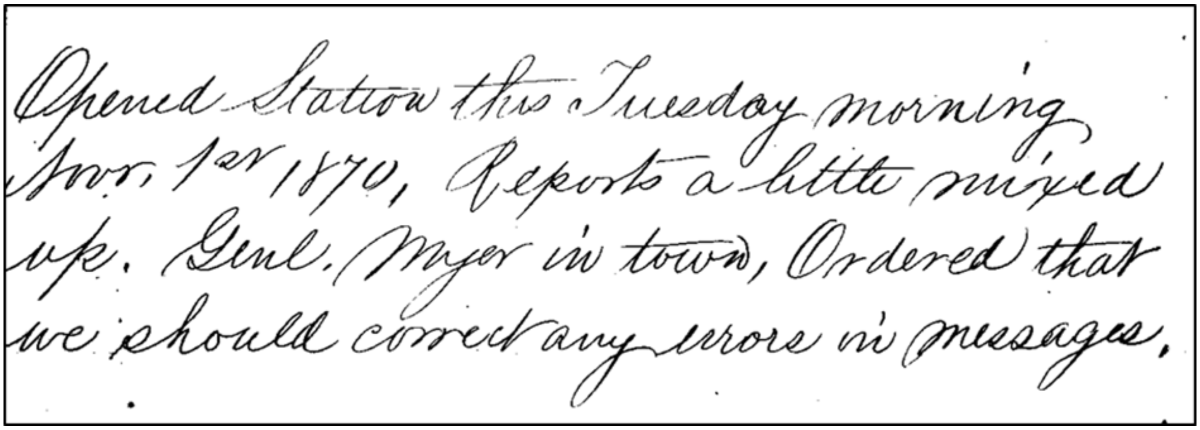
The Historic (Downtown) Record (1870 to 1943)

Figure 151. General Albert J. Myer (1829-1880). Image Source: Wikimedia Commons.

Recognizing that *"military discipline would probably secure the greatest promptness, regularity, and accuracy in the required observations"* of weather, the dream of Joseph Henry of the Smithsonian Institution was realized on February 9, 1870 with the passage in Congress (signed into law by President Ulysses S. Grant) of a resolution calling on the Secretary of War *"to provide for taking meteorological observations at the military stations in the interior of the continent, and at other points in the States and Territories...and for giving notice on the northern lakes (Great Lakes) and on the seacoast, by magnetic telegraph and marine signals, of the approach and force of storms"*. Implementation of the newly passed resolution fell to the U.S. Army Signal Service's new "Division of Telegrams and Reports for the Benefit of Commerce" − the initial name of what was later referred to as the Weather Bureau and today is referred to as the National Weather Service. Brevet Brigadier General Albert J. Myer, an early supporter of weather observation and forecasting, served as the chief signal officer for the new division (Figure 151). General Myers graduated from the University at Buffalo Medical School. When he passed away in 1880, his remains were interred in a mausoleum at Forest Lawn Cemetery, Buffalo, NY.

The first entry logged (October 12, 1870) was by Observer-Sergeant William Slater reporting to General Myer on his arrival in Buffalo. The U.S. Army Signal Services Buffalo station first opened its door on November 1, 1870 in downtown Buffalo (Hollister Building, located at Main and Seneca) with General Myers in attendance (Figure 152). It was one of 24 stations in the new Division. The stations were manned with a Private and Observer-Sergeant, the latter receiving considerable training. The first official act was a

7:00 a.m. weather observation made on opening day. From that day on, measurements were routinely taken at 7:00 am, 2:00 pm, and 9:00 pm. In addition, synchronized measurements with Washington DC, were taken at 7:28 am, 4:28 pm, and 11:28 pm each day. The early records also show routine measurements taken at 11:52 am each day. These were to be reported to Washington DC only if they differed substantially from the earlier measurements. A review of reported data also showed "fair" and "foul" sunset measurements, which were used as an indication of the following day's weather - the adage "Red sky at night, sailors' delight. Red sky at morning, sailors take warning" comes to mind. Over time, the frequency of measurements would increase to hourly measurements.


Opened Station this Tuesday morning
Nov. 1st 1870, Reports a little mixed
up. Genl. Myer in town, Ordered that
we should correct any errors in messages.

Height of Barometer	Reduced Barometer	Dry Bulb	Wet Bulb	Direction of Wind	Velocity of Wind	Amount of Cloud
29.41 in/Hg	29.38 in/Hg	40°F	38°F	West	15 mph	none

Figure 152. November 1, 1870 entry in the Buffalo Weather Office Daily Journal, and the first official measurement at Buffalo, NY taken at 7:00 am on November 1, 1870. Image Source: manuscripts on file at Buffalo Museum of Science.

The initial weather office was located on the fourth floor of the Hollister Building, located at the corner of Main and Seneca Streets in downtown Buffalo. Based on station notes and correspondence, the thermometer and hydrograph were in an "ordinary" window shelter – a common practice in the late 1800's – at a height of 52.7 feet above the sidewalk. A barometer was in the fourth-floor office at 57.0 feet above the sidewalk, and a rain gage was located on the building's roof, with the gage top being 66.0 feet above the sidewalk.

Two early orders from General Myers are of interest. The first provides an example of international cooperation about the sharing of weather data *"Gen, Myers, Chief Signal Officer, U.S. Army is here and says that he is of the impression, the War Department would authorize copies of the U.S. Weather Reports to be taken for Canada Ports as an act of courtesy, if properly requested."* The second order allows for the dissemination of weather data in the morning newspapers with the clear order *"But not to make any predictions of the weather, let the people do that for themselves."* This request comes across as odd given General Myer's interest in serving the civilian community.

The value of the new weather service was immediate, as capsulized in the following call received at the Buffalo office recorded by the observer on duty: *"…expressed himself highly pleased with the service and informed me that it was exciting publics outreach all over the country. What seemed to be a foolish undertaking…by* *the general public was now considered the greatest science of the age. Did not think that sufficient publicity had been given the service in this city."*

Between 1870 and 1943, the Buffalo weather office had moved between seven different buildings in downtown Buffalo before its final move to the Buffalo Airport. Though it shuffled around downtown Buffalo, each move took it no more than a couple blocks away, such that *"it has remained within a circle one-fourth of a mile in diameter"*, as described in weather station correspondence. The correspondence went on to say that at the time *"Open exposure to the prevailing winds, which here are from the west-southwest, and unobstructed view of the lake (Lake Erie) have been of primary consideration in its location."* An unobstructed view was critical for the visibility of weather-related signal flags (and lanterns at night) across the city, but especially the harbor area (Figure 153). The storm flags were of obvious value, but other flags such as the "cold wave" flag was important too. Office correspondence noted that *"Great dependence is placed upon the cold wave warning, as perishable articles are carefully watched, shippers of such goods always take the warning and save"*.

Figure 153. Signal flags (center of image) as seen from New York Harbor (1883). A similar scenario could be envisioned in Buffalo's harbor. Image Source: NOAA's National Weather Service (NWS) Collection.

Each downtown relocation was to a taller building, reflecting a growing city (Figure 154), but also a growing monitoring problem. By way of example, the height of the stations' rain gage ranged from 62 feet above the sidewalk in 1871 to 258 feet in 1896. And there were complaints from time-to-time that weather-related signals could not be seen, necessitating a higher flag staff or a move to a taller building.

Period	Building Occupied
Nov. 1, 1870 to Mar. 24, 1871	Hollister Bldg., Main and Seneca
Mar. 25, 1871 to Aug. 30, 1871	Brown Bldg., Main and Seneca
Aug. 31, 1871 to Nov.1, 1881	Weed Bldg., Main and Swan
Nov. 1, 1881 to November 1, 1883	White Bldg., 292 Main St.
Nov. 1, 1883 to Feb. 28, 1896	Board of Trade Bldg., Seneca and Pearl
Mar. 1, 1896 to Feb. 13, 1913	Prudential Bldg., Church and Pearl
Feb. 13, 1913 to Jun. 30,1943	New York Telephone Bldg., Church and Franklin

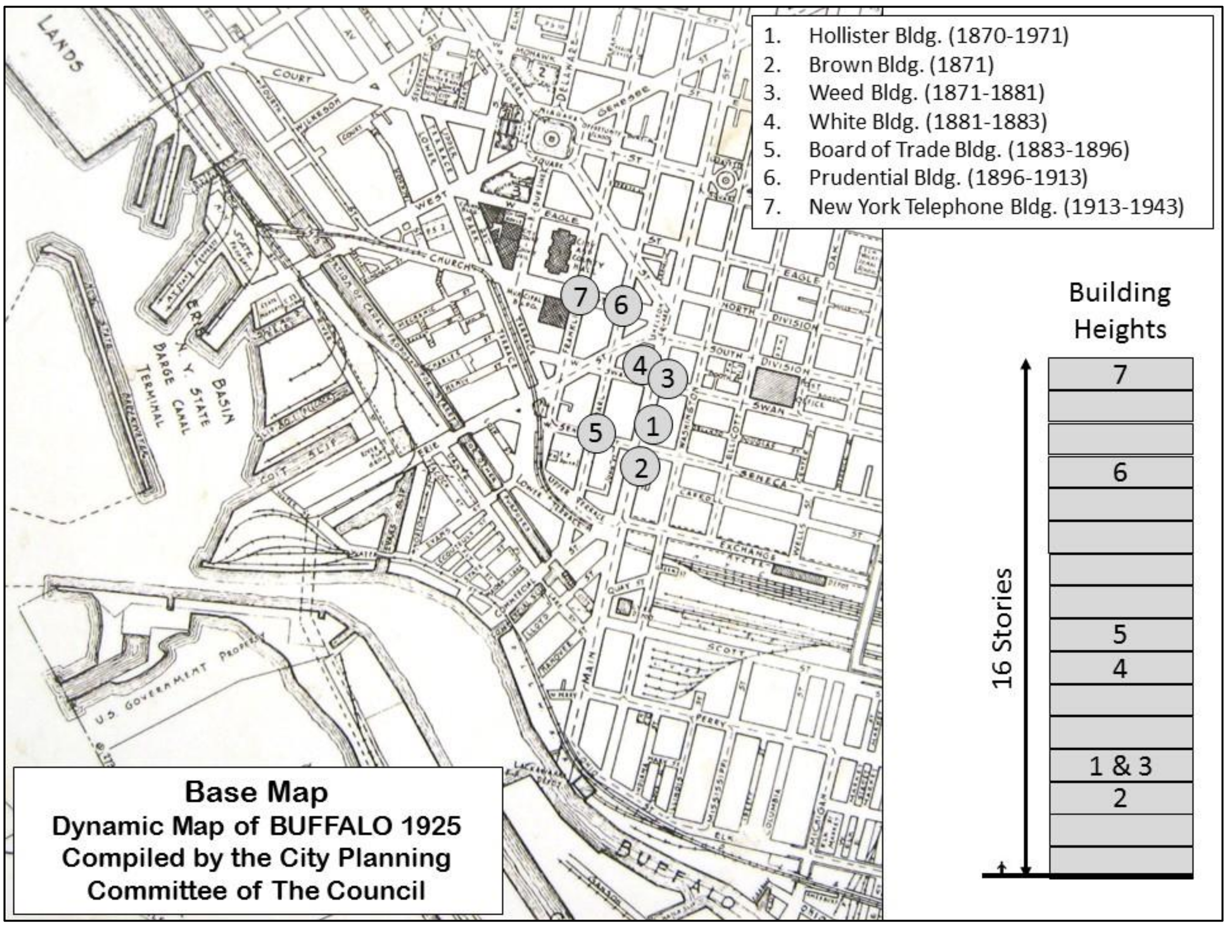


Figure 154 Location of Buffalo's downtown weather stations and station heights. Instruments were placed on the building rooftops. Image Source: Stephen Vermette. Base map from Department of Geography & Planning, SUNY Buffalo State, collection.

Brown Building: March 25, 1871 to August 30, 1871

According to correspondence, the weather office and equipment was briefly moved from the Hollister Block to the three-story Brown Building on March 24, 1871, before a subsequent move to the Weed Block

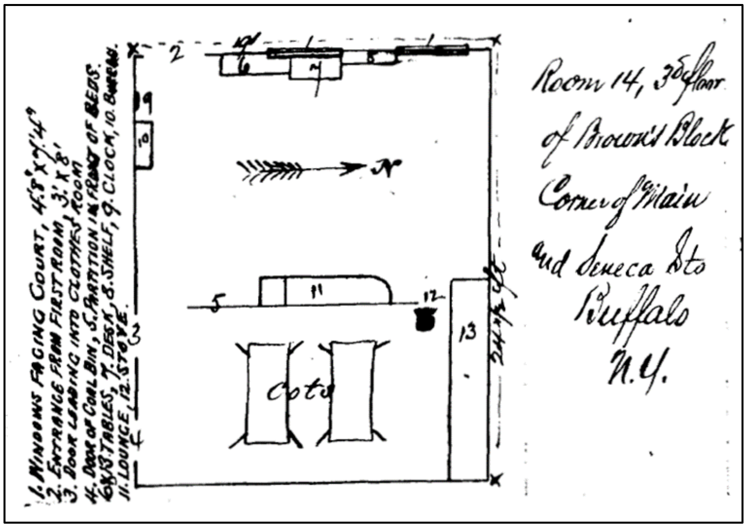


Figure 155. A schematic of the Buffalo station layout in the Brown Building. Image Source: Signal Service Inspector's Report, manuscript on file at Buffalo Museum of Science.

on August 31, 1871. An inspection report described the Brown Block station as being in the business center of the city, in proximity to the post office, Western Union telegraph office, and principal newspapers. The station comprised two rooms on the third floor in the east wing of the building (Figure 155). One room served as an office and a second room (divided from the first by a partition) served as a bedroom with two cots. The inspector noted that a barometer hung near one window, and from the other window projected an instrument shelter for the thermometer and hygrograph (humidity measure). The instrument shelter was referred to as an imitation of the Smithsonian plan (made of lattice blinds) that protected the thermometer from the sun but allowed outside air to pass over it. The backside (facing into the room) of the shelter was sealed off by a sash and board casing. The instrument shelter measured 3 feet wide by 5 feet high and extended 2 feet out from the window. It faced west (based on the station schematic), but was later referred to as facing north, into what the inspector referred to as a "court". The inspector did comment that the station had the "poorest located thermometer and hygrometer". Other instruments included a roof top rain gage (62.4 feet 4 in above the sidewalk), as well as a wind vane (on a 15-foot pole, 77 feet above the sidewalk) and anemometer (5.7 feet on a pole positioned 67.9 feet above the sidewalk).

The reason for the station's brief occupancy of the Brown Building can be found in the scathing remarks in the inspector's report. He found the office was used as a storage room and referred to the rooms as being "defaced and soiled". He noted that *"newspaper pictures (some of them of an improper character, tho' not recognized as such by the Sergeant – having been put up by his assistant), were pasted on the walls."* He went on to describe the rooms as *"not fit for occupancy – needing scrubbing, painting and paper or whitewashing – besides not possessing the facilities for the exposure of instruments."* Criticism was also leveled at the observers, noting *"The sergeant in charge at this station is very well versed in his duties, but seems afflicted with chronic laziness, which has caused him to do as little work as he could get along with, hence the shiftless, unclean appearance of everything around him."* Based on the inspector's report, the office was relocated to the Weed Block.

Weed Building: August 31, 1871 to November 1, 1881

An office (room #22) on the fourth (top) floor of the Weed Building was procured and the relocated station was operational on August 31, 1871. As with the previous station, the location was considered beneficial as it was only one block from the telegraph office, two blocks from the post office, and eight blocks from the docks (Figure 156). The Sergeant was instructed to clean-up his act, and equipment transferred to the new station was polished, painted, and repaired. The new office consisted of two rooms that received a favorable review from inspectors. A detailed schematic shows the position of furniture, including a waste paper basket (#12) and a spittoon (#13) (Figure 157). Everything was counted and inspected by the inspector, down to the office's one eraser and spittoon which, on July 23-26, 1872, were reported as being in "good" condition, while the waste basket was in "poor" condition. The inspectors offered a much more

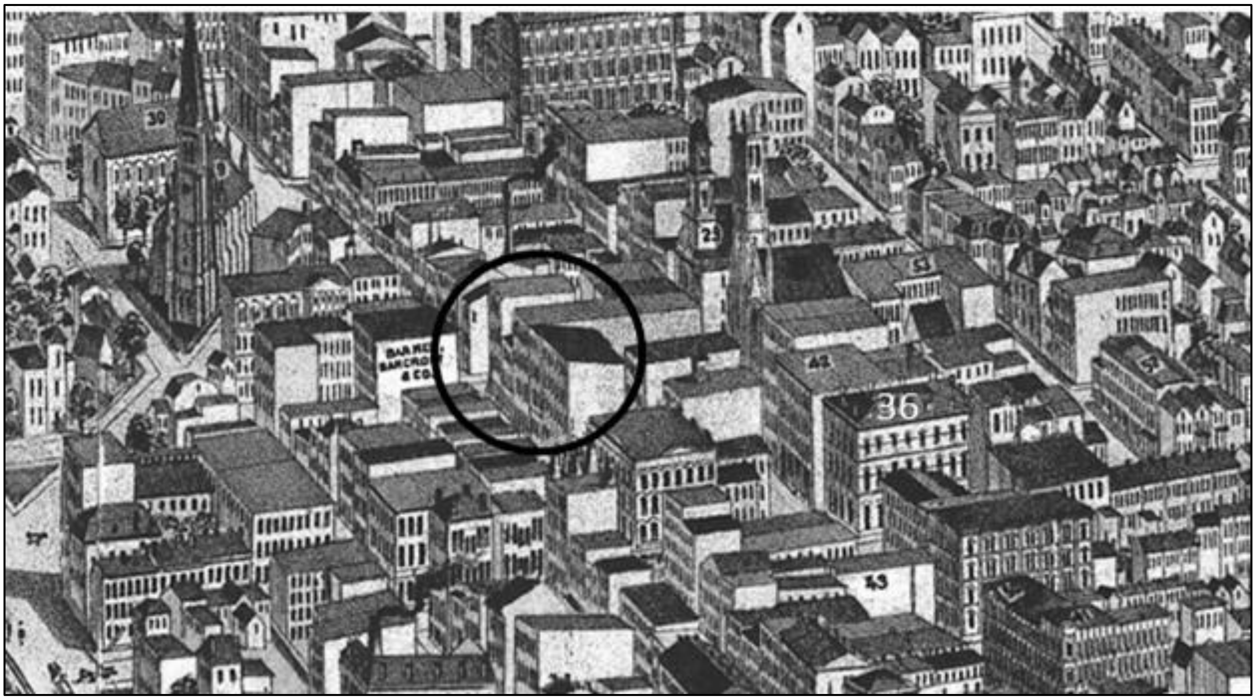


Figure 156. Approximate location of the Weed Building on the corner of Main and Swan Streets (circled) shown on an 1880 Lithograph of the City of Buffalo. Number 36 marks the post office.
Image Source: Wikimedia Commons.

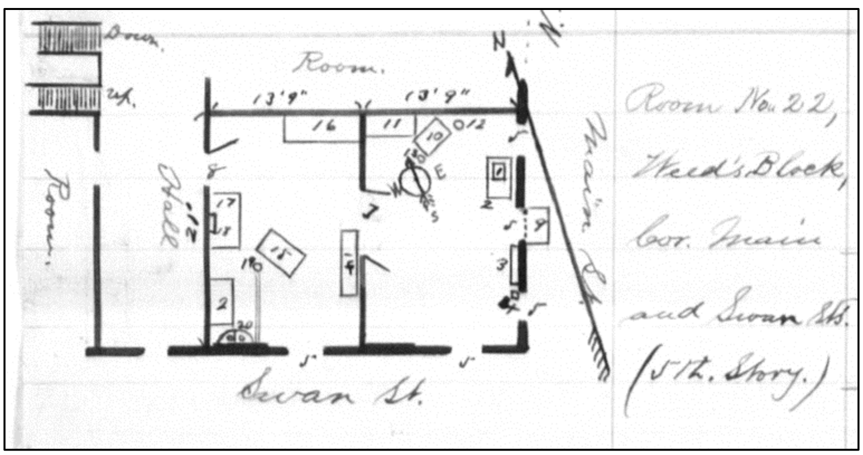


Figure 157. Station office schematic. Image Source: July 23-26, 1872 Inspection Report. Manuscript on file at Buffalo Museum of Science.

favorable assessment of the office: "The office is found in excellent condition – the instruments well cared for – the books, circulars, general orders, and records generally showing care." In a subsequent inspection it was noted that *"not a single error has been found in any branch of the public business at this site."*

About equipment positioning, the barometer was hung on the east wall, and the window shelter was rebuilt from the old one and installed on an east-facing window. The window shelter housed a thermometer and hygrograph and was used until June 21, *1873 (Figure 158). Inspector reports had noted that due to its exposure to morning sun "the shelter being on the east side of the building cannot give the true temperature". Repeated inspections called for a new instrument shelter to be built on the building's roof. The new shelter was described as a double shelter consisting of lattice work with inside dimensions 7 feet square and a height of 8 feet. It is further described as being* constructed with *"double walls, double floor, and flat double roof, with a 1-foot space in walls, floor and roof." The outside shelter was 3 feet larger than the inside one, with a height of 9 feet. Housed within the shelter (facing north) was a thermometer, maximum and minimum thermometers (new to the station), and a hygrograph (Figure 159). A Smith-*

sonian standard rain gage was positioned on the roof of the building. A self-registering anemometer and wind vane (newly purchased) was positioned on a pole above the roof (see Figure 158). The self-register read-out was in the weather office.

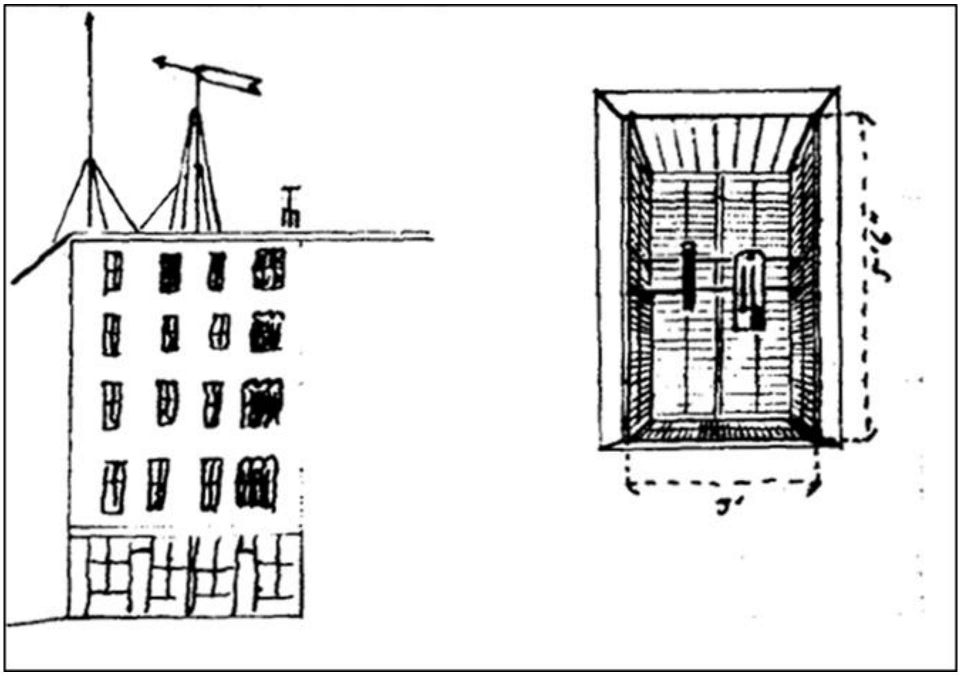


Figure 158. Shown is the roof configuration and window instrument shelter (used until June 21, 1873) as of July 23-26, 1872 at the Weed Block station. Image Source: July 23-26, 1872 Inspection Report. Manuscript on file at Buffalo Museum of Science.

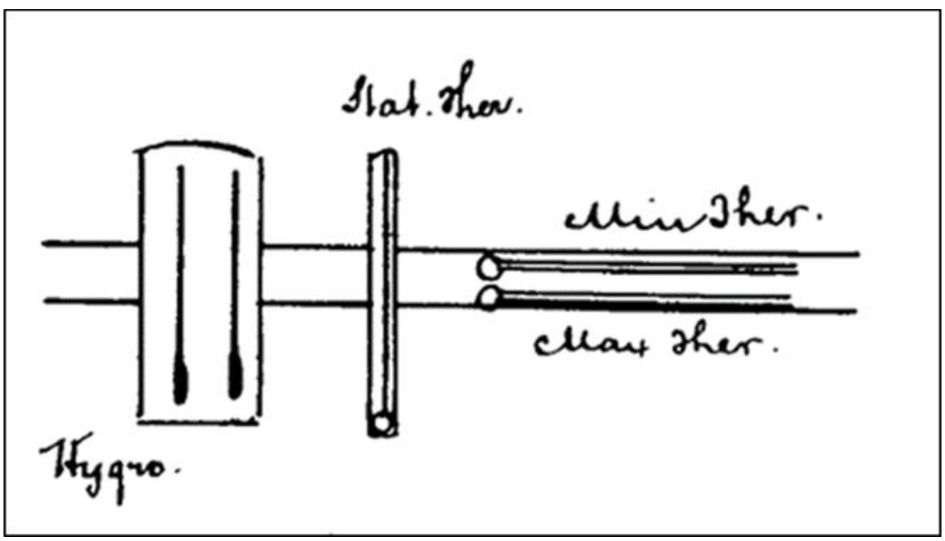


Figure 159. Instrument configuration in roof-top instrument shelter. Showing hygrometer, thermometer, and minimum and maximum thermometers. Image Source: Inspector report March 12-16, 1875. Manuscript on file at Buffalo Museum of Science.

White Building: November 1, 1881 to November 1, 1883

On November 1, 1881, the station was relocated from the Weed Block to the adjacent newly-constructed seven-story White Building. Being the tallest building in Buffalo at the time, the additional three stories affected wind speed and direction measurements at the previous Weed Block station. The new station office consisted of three rooms on the top floor (Figure 160).

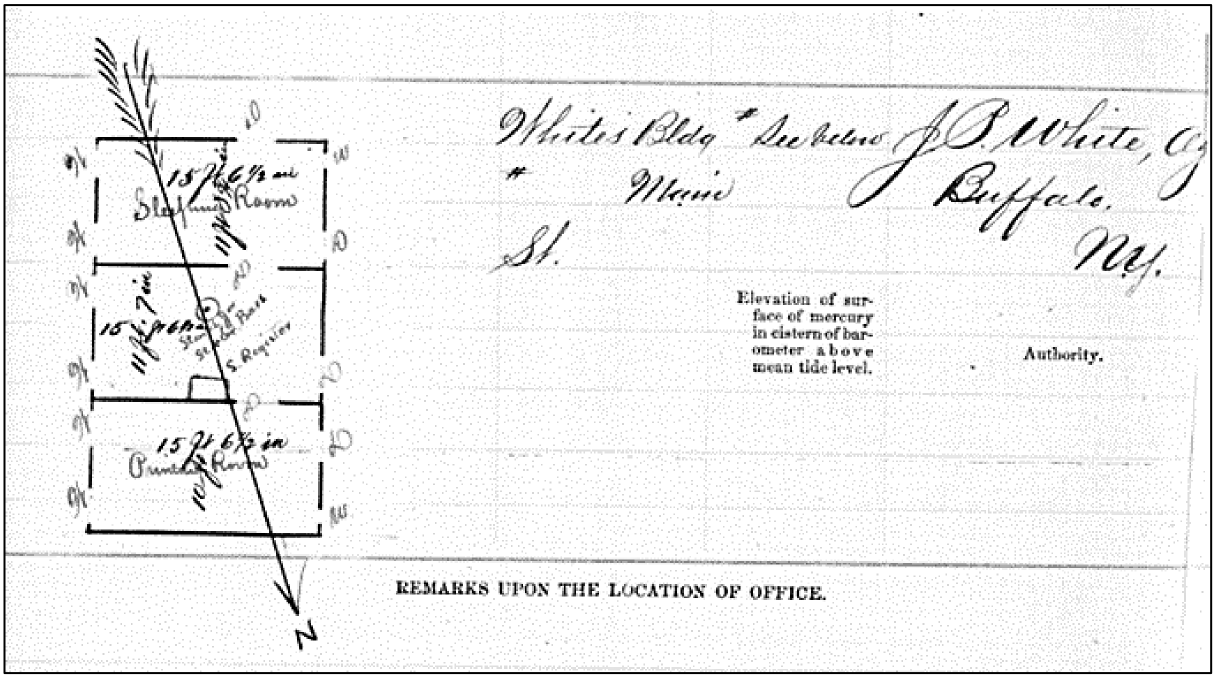


Figure 160. White Building office schematic. Image Source: December 13 to 15, 1881 Inspector Report. Manuscript on file at Buffalo Museum of Science

The weather instruments were transferred (some replaced) from the old to the new station (including the instrument shelter). The height above the sidewalk changed, as the office location and roof top of the new station were higher than at the previous site. This height was described as having excellent exposure *"as there are no higher buildings in the immediate vicinity to break the force of the wind or deflect it."*

The inspector reports are always interesting to read, as they go over the minutia of running the station including correspondence, postings, expenditures, condition of equipment, operator telegraph speed (words per minute), knowledge of station textbooks (including "Instructions to Observers", "Loomis Meteorology", and "Manual of Signals"), as well as personnel issues. Inspectors gave praise when deserved, but also criticism – in reference to one observer an inspector wrote: *"He makes numerous errors and seems either devoid of energy or is worthless."*

Board of Trade Building: November 1, 1883 to February 28, 1896

The station was moved to the Board of Trade Building on November 1, 1883. The station consisted of three rooms, including an office, printing room, and store room (sometimes described as a bedroom or observer room) (Figure 161). The new station received high praise: *"The office is now located in an excellent building and the location is the best possible to be obtained for giving the people and shipping the full benefits to be received from the service. It is in full view from the lake and vessels have no difficulty in seeing signals when displayed. The instruments are all well exposed."*

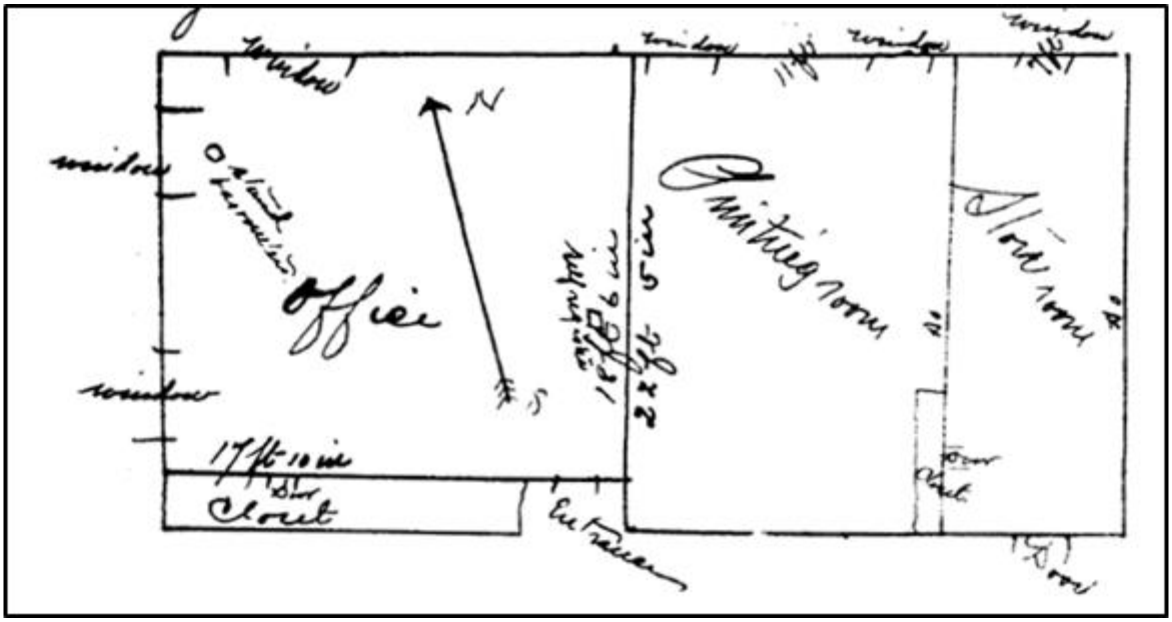


Figure 161. Office schematic at Board of Trade Building. Image Source: Signal Service Inspector's Report. Manuscript on file at Buffalo Museum of Science.

A printing room is shown in the office schematic. Weather conditions were observed, and reported by telegraph to Washington, DC, and returning telegraphs brought weather forecasts. An important role of the Buffalo weather office was to disseminate this information locally to newspapers, and to print weather bulletins which were distributed and posted across the city and region. The Buffalo Office was doing a good job, as noted in an inspector's report: *"The public is greatly interested in the service generally, and in the Buffalo station in particular; the public is well served here."*

Two equipment concerns were noted by inspectors (aside from the usual calibration and cleaning issues). First was that the roof top flag shaft was too short, not allowing the signal flag to be seen from points nearby, and from the harbor. In response, the signals were temporarily moved to Fulton Market for better viewing, before returning to the Board of Trade Building on a taller 50-foot shaft. Second, it was determined that the bottom of the instrument shelter was too near the asphalt roof (5 feet, 4 inches) and, as the shelter was too bulky to be raised, it was condemned and replaced with a standard "Hazen" shelter on May 1, 1887. The Hazen shelter was 3 feet wide and high, and 2 feet 6.5 inches deep, with the bottom of the shelter raised 11 feet above the roof. A thermograph was added to the equipment in the shelter about a year later. The rain gage was positioned directly on the roof of the building.

Mention was made in a June 28, 1888 inspection that in addition to the Board of Trade Building, storm signals were displayed at Life Saving Station #5 on the lake front, and cold wave signals were displayed on 8 or 10 prominent private flag staffs.

In addition, the following comment was made about the effect of air pollution: *"The action of the smoke of the soft coal so generally burned in Buffalo very quickly destroys all metal surfaces on instruments in the open air and quickly corrodes bright surfaces indoors."*

On October 1, 1890, the meteorological responsibilities of the Signal Service passed into the civilian control of the newly created U.S. Weather Bureau in the Department of Agriculture.

Guaranty (Prudential) Building: March 1, 1896 to February 13, 1913

On March 1, 1896, the station was relocated to the 13th floor of the Guaranty (renamed Prudential) Building (Figure 162).

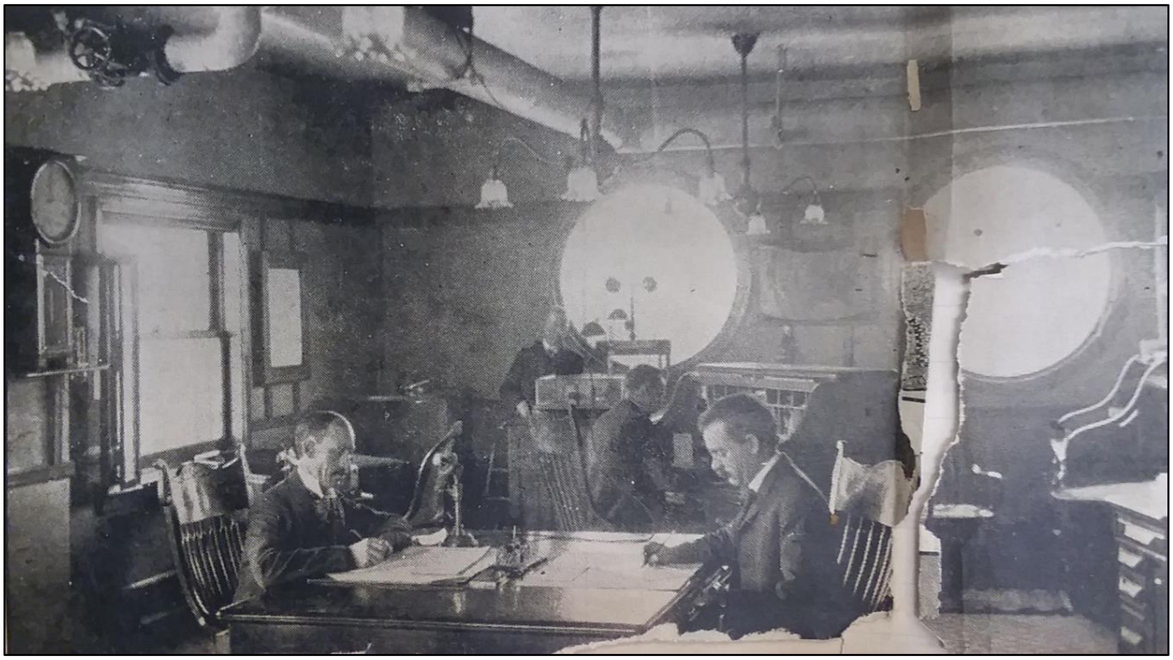


Figure 162. Inside the Prudential building weather office. Image Source: Buffalo Illustrated Times, January 1903, Clippings Book. Manuscript on file at Buffalo Museum of Science.

A newspaper reporter provided a description of the weather office for the Buffalo Illustrated Times (January 1903): *"Up high above the trees; up where the winds howls and the clouds roll; up so high that it seems one has reached the spot where the snow is really made is located one of the most important United States offices in Buffalo…up above the surrounding buildings, so high that the town appears as if viewed from a balloon… up so high that the noise of the street does not reach, the weatherman has his nest."* (Figures 163 through 165).

Figure 163. An artist view of the top of the Prudential Building. Image Source: Buffalo Illustrated Times, January 1903, Clippings Book. Manuscript on file at Buffalo Museum of Science.

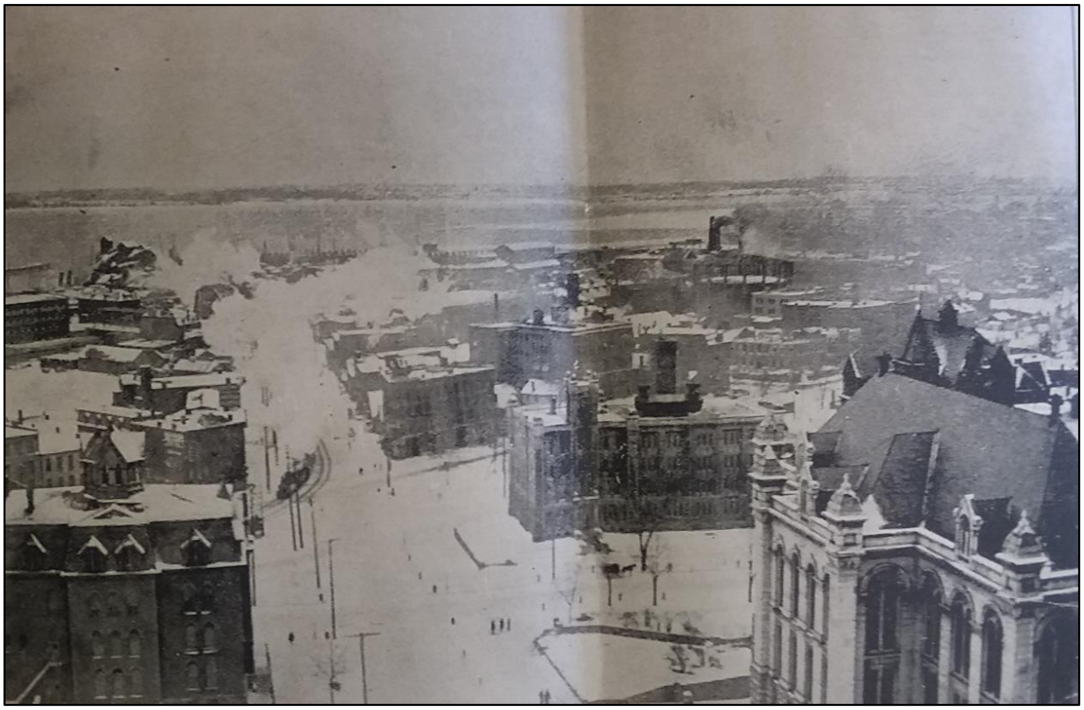


Figure 164. Bird's-eye view of Buffalo, looking Southwest from the Prudential building weather office. Note the clear view of Lake Erie (upper left side). Image Source: Buffalo Illustrated Times, January 1903, Clippings Book. Manuscript on file at Buffalo Museum of Science.

Figure 165. Birds-eye view of Buffalo, looking Northwest from the Prudential building weather office. Image Source: Buffalo Illustrated Times, January 1903, Clippings Book. Manuscript on file at Buffalo Museum of Science.

The printing of weather reports transferred from Cornell University to Buffalo, NY in 1899 (Figure 166). The anemometer and wind vane were located on an iron tower 43 feet above the building's roof (Figure 167). The Hazen instrument shelter was built into the iron tower, and its bottom was 13 feet above the roof of the building. The rain gauge was replaced with a Marvin weighing rain gauge on January 1, 1898. Mention was also made of a sunshine recorder. Based on a drawing that appeared in a newspaper article, the recorder appeared to be a Maring-Marvin thermoelectric sunshine duration recorder. The instrument recorded hours of sunshine received within a day. The use of the sunshine recorder was confirmed with the discovery of sunshine data observed between February 1890 and December 1903.

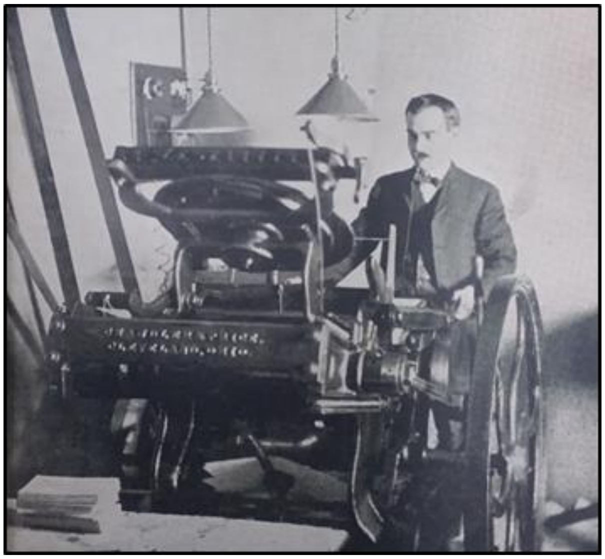


Figure 166. J.F. Hurley printing weather bulletins in local weather office. Image Source: Buffalo Illustrated Times, Clippings Book. Manuscript on file at Buffalo Museum of Science.

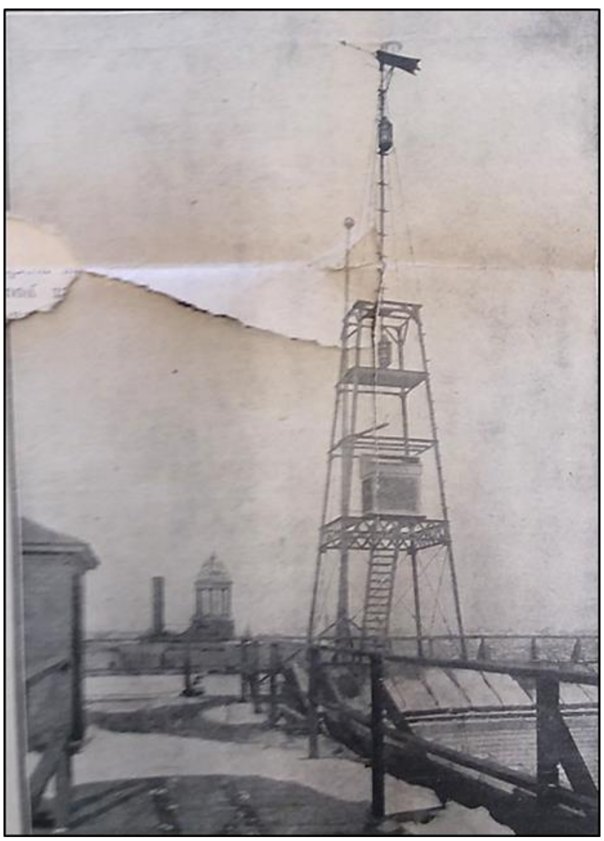


Figure 167. Iron tower on roof of Prudential Building showing wind vane and the instrument shelter (top of stairs) built into the tower. Image Source: Buffalo Illustrated Times, Clippings Book. Manuscript on file at Buffalo Museum of Science.

In reading newspaper clippings from this period, one cannot help but notice the admiration of the press for the Chief weather forecaster in the Buffalo Office, David Cuthbertson (Figure 168). Mr. Cuthberston joined the Signal Service in 1872, serving in New York and Cleveland, before landing in Buffalo in 1884 as the person in charge. He served in the Signal Service/Weather Bureau in Buffalo for just under 42 years. Clearly, Forecaster Cuthbertson made an impression in the community. In the press, the Weather Bureau is often personalized by referring to it as "the office of Forecaster Cuthbertson". Their esteem for him is also evident in statements such as this made during a Christmas holiday season: *"Buffalonians are exceedingly grateful to Forecaster Cuthbertson for the excellent weather he is furnishing during the shopping season…Mr. Cuthbertson's generosity is greatly appreciated by the children, who are pleased that there is no storm to keep them from visiting Santa Claus…"* He was referred to in the press as the "Great Weather Man", "Uncle David", "Prof. Cuthy", and the "Sage of the Prudential Building". And his forecasting skills were legendary: *"All things revealed to the penetrating gaze of Forecaster Cuthbertson"*, and with regard to storms: *"He can smell 'em a darn side farther than he can see 'em."*

Figure 168. Courier Newspaper cartoon. Image Source: Weather Bureau Clipping Book obtained from the NWS Buffalo Weather Office.

During this period, a street-level weather kiosk was erected in downtown Buffalo as a public service but was later removed as a liability for the city (both on the recommendation of Forecaster Cuthbertson). The kiosk, comparable to installations in other large cities across the country, was to be in full view of the interested public and was installed with great fanfare. On one side were displayed weather instruments: a large mercurial thermometer, a thermograph, maximum and minimum thermometers, an aneroid barometer, a hair hygrometer (the stretching or shrinking of hair responded to changing humidity levels), and a tipping-bucket rain gage. On the other three sides were posted weather maps, daily forecasts, and warnings for the general public (Figure 169).

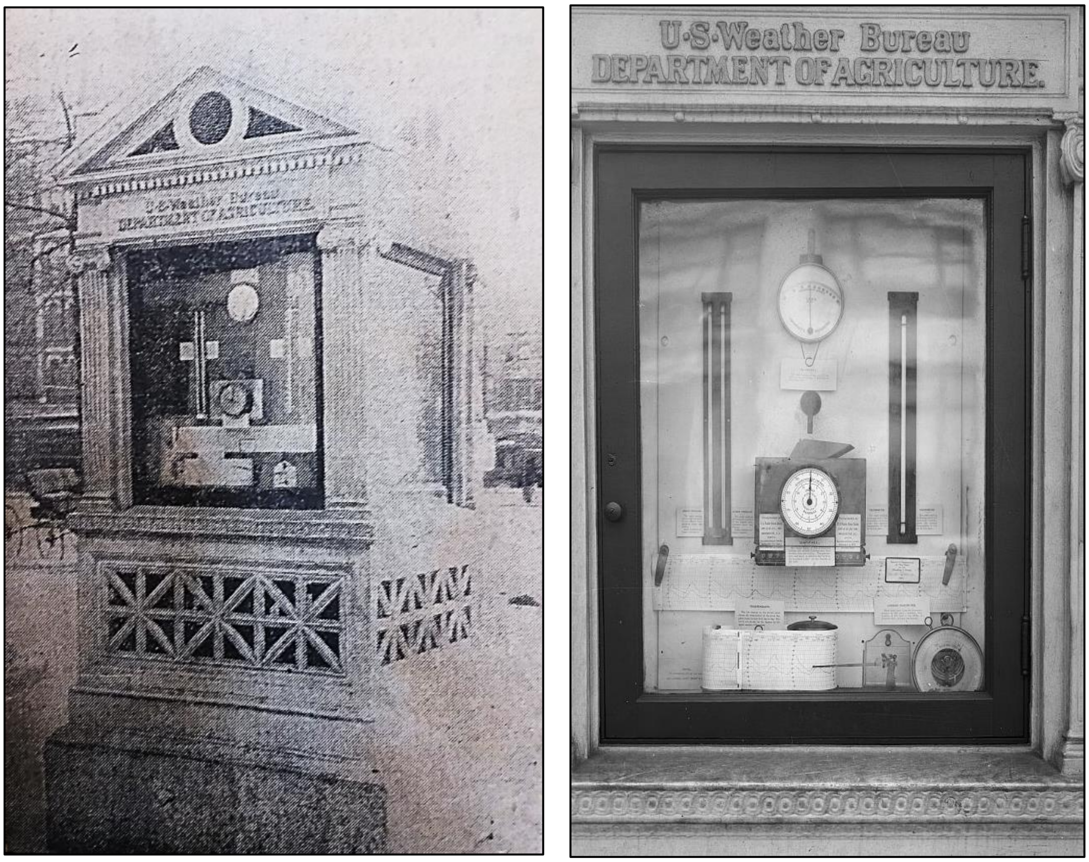


Figure 169. Weather kiosk at street-level in downtown Buffalo (left), and closeup of instruments from a typical weather located in another city (right). Image Sources: Clipping Book. Manuscript on file at Buffalo Museum of Science (left), and Wikimedia Commons/Library of Congress/Harris & Ewing, photographer (right).

In what was initially seen as a public service soon turned into a liability for the city. As it turned out, the temperature measurements at ground level differed from the official record taken on the roof of the Prudential Building. Not only did they differ, but they differed in a way - warmer in the summer and cooler in the winter – that ran counter to the city's narrative of a comfortable city. Newspaper headlines such as *"Buffalo Comfortable While Other Cities of the Country Swelter"* and *"Weather Record Gives Reason Why People Come Here: Statistics Show that Buffalo is Without Peer as Summer City"* supported this narrative. These concerns were brought to light in an article published in the Enquirer newspaper stating that *"Evidence from the Chamber of Commerce and from citizens is that the kiosk temperature records are inaccurate, that they are quoted in such fashion as to indicate Buffalo weather in summer as much warmer than it actually is and this form of detrimental advertising works to the city's disadvantage in reference to tourist business and the securing of conventions."* I cannot help but think that this narrative exists in Buffalo even today.

New York Telephone Building: February 13, 1913 to July 1, 1943

Figure 170. The Guaranty (Prudential) Building showing the iron tower on the roof. The New York Telephone Building (to the right) was the next station site. Image Source: Patrick J. Mahoney.

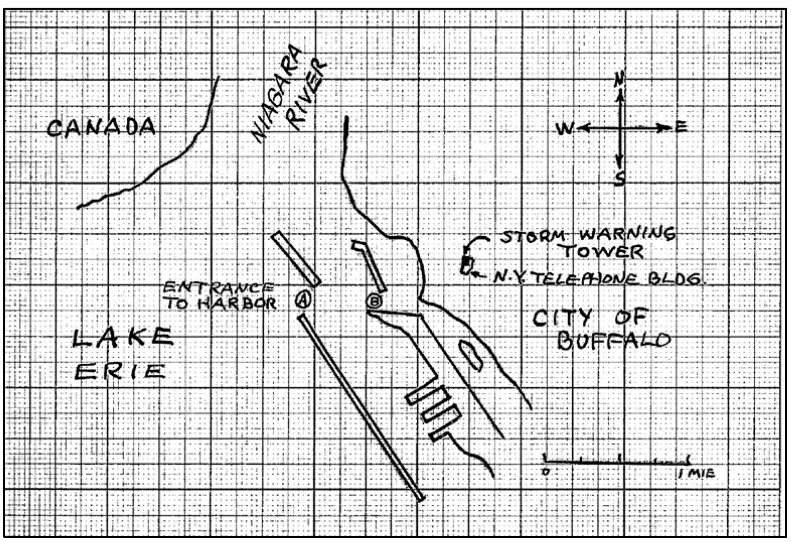


Figure 171. Diagram accompanying a report on the excellent visibility of the storm warning tower atop the New York Telephone Building. Image Source: NWS scanned archives 1937-08-26 WB-4065E.

The final downtown move was to the 16-story New York Telephone Building on February 13, 1913 (Figure 170). The move, as with earlier moves, was required because the newly constructed New York Telephone Building was 63 feet higher than the Prudential Building, rendering the roof-based weather instruments useless at their previous location. Critical, as with previous locations, was the visibility of the storm warning tower. About the tower it was written *"The displays are excellent and can be easily seen from the lake and entrance to the harbor…"* (Figure 171). In addition, the new building provided more office space and had a (pneumatic) tube system that allowed messages to travel up and down the building rapidly, replacing the need for messenger boys.

Near the roof's center, a 40-foot "storm warning" tower (Figure 172) supported the wind instruments (placing the anemometer 280 feet above the sidewalk), as well as the instrument shelter (containing thermometers) with its base 9 feet above the roof (instruments within shelter were 246 feet above the sidewalk). The tipping bucket rain gage was located on a wooden platform on the roof, 238 feet above the sidewalk. It was noted in 1940 correspondence that the exposure for these gages was not satisfactory. About snow: *"This location on the Telegraph* (telephone) *Building is not much used in obtaining precipitation from snow during the long winters. We weigh the snow and use this factor in connection with the average depth obtained by careful measurements in several parts of the city. We go to no end of trouble to get it right."* The note goes on to say *"Exactly what methods were used prior to 15 years ago we are not certain."* Sunshine recordings appear to have continued from the previous two stations. Here, the sunshine recorder was said to be attached to the top of a stone pillar at a height of 7.5 feet above the roof, always exposed to the sun.

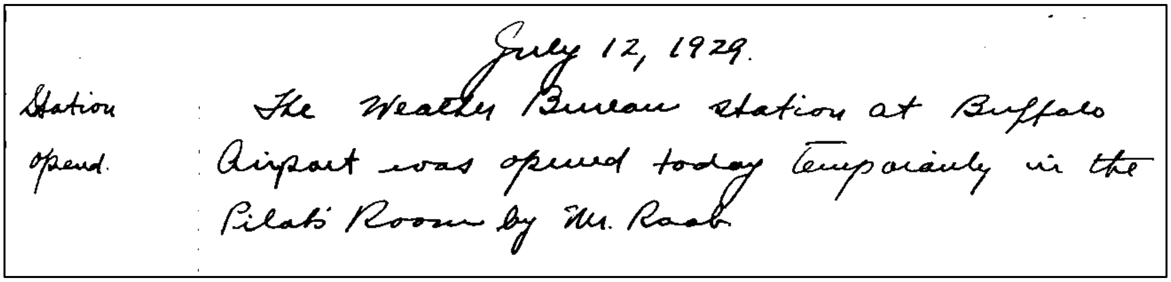
It should be noted that, in addition to Buffalo Harbor, the Buffalo Weather Office maintained several warning signal towers in WNY, including one at Dunkirk, Fort Niagara, and Tonawanda. On November 24, 1916 a wind storm saw hurricane warning flags raised. According to a newspaper account *"only extreme severe and dangerous storms bring the rare warning."*

Figure 172. Forecaster Cuthbertson standing on the tower atop The New York Telephone Building. Image Source: Weather Bureau Clipping Book obtained from the NWS Buffalo Weather Office.

Forecaster Cuthbertson reflected on the changing weather service from his days in the Signal Service when *"In the early days the determination of weather-to-come was for the purposes of the army and navy* (one might add shipping on the Great Lakes here) *informed, while today there is hardly an event pre-arranged by anyone, but that the weather to exist during that period of the event is not considered and reported."*

Canisius College was the location chosen for the first branch office weather station in Buffalo, and one of the first in the U.S. The site was established on September 1, 1913 and closed on June 30, 1919. The site was located at the College's new building at Main and Jefferson Streets, and was inspected by Professor Willis L. Moore, Chief of the U.S. Weather Bureau. According to Buffalo Forecaster Cuthbertson: *"The purpose of such a station is that we will be able to secure observations where the climate conditions are more in harmony with the residential section of the city. The surroundings of Canisius College appealed more strongly to Prof. Moore than any of the other places reviewed."* The station was well-instrumented and was placed in charge of the Jesuit Fathers.

In response to the Air Commerce Act of 1926 (directs Weather Bureau to provide weather services to civilian aviation), a subsequent branch weather office was established on July 12, 1929 at the recently built administrative building on the grounds of the Buffalo Municipal Airport (Cheektowaga, NY) (Figures 173 and 174). The branch station served the newly-open airfield (passenger and airmail service began in 1927) and allowed for upper air balloon observations for the Airway Division, of the Department of Commerce (with the "balloon house" constructed in the fall of 1929, and the first observation taken on December 16, 1929).


July 12, 1929.

Station opened. The Weather Bureau station at Buffalo Airport was opened today temporarily in the Pilots' Room by Mr. Raab.

Figure 173. July 12, 1929 entry in the Buffalo Weather Office Daily Journal.
Image Source: manuscripts on file at Buffalo Museum of Science.

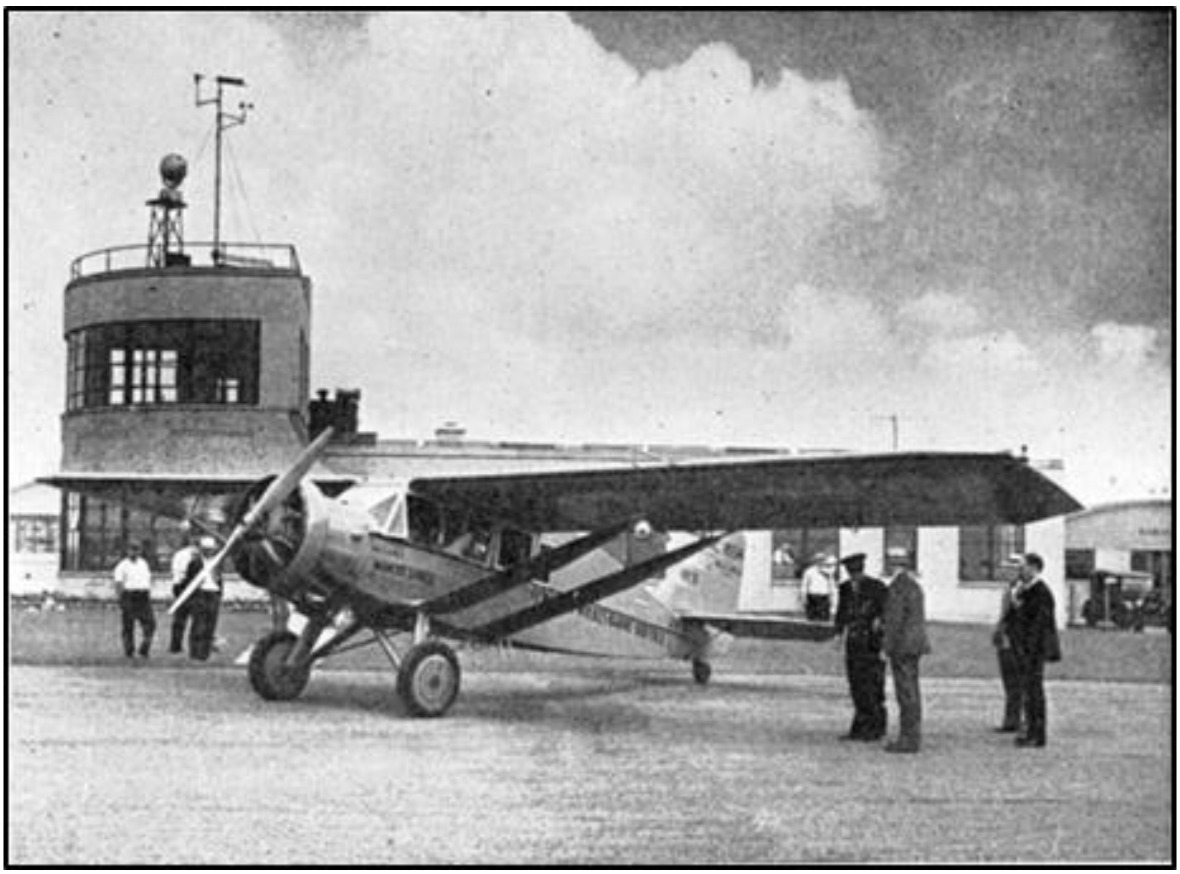


Figure 174. Original administration building (circa 1937) at Buffalo Airport. Wind instruments shown on roof. Image Source: Wikimedia Commons.

A November 8, 1932 inventory of equipment at the substation included basic weather instrumentation: a thermometer, instrument shelter, wind vane and anemometer, both a mercurial and aneroid barometer, a barograph, and equipment needed for balloon launches (regulator for hydrogen, clinometer (theodolite), and a ceiling light projector for night measurements). Subsequent equipment included a maximum and minimum thermometer and a hygrograph.

The airport branch station was moved to the west wing of a new V-shaped terminal building on November 18, 1939. The weather office was located on the building's second floor west wing (room 201) (Figures 175).

The wind instruments were installed on a 12-foot pole mounted on the control tower's roof (the anemometer was 95.6 feet above the ground, and the wind vane was 98.1 feet above the ground). The instrument shelter was located on the terminal's second floor roof (the base of the shelter was 5.6 feet above the roof, so instruments were about 34 feet above the ground), as was a standard (8 inch) rain gage (with its top 3.2 feet above the roof). A balloon-inflation house and launch platforms (on either side of the tower) were also located on the second-floor roof.

Figure 175. Postcard showing airport terminal building erected in 1939. Image Source: Buffalo Stories Archives/Steve Cichon Collection.

The original balloon launches were of Pilot Balloons (referred to as "pibal") that were tracked by a theodolite instrument (a telescopic device that measures angles to determine the balloons position) to measure wind heights and speed aloft, and to determine cloud base heights (a battery-operated lighting unit was attached to the balloon for night measurements). Starting on September 1, 1939, radiosonde balloon launches (raobs) at the Buffalo Airport provided the transmission of weather data to a ground station (antenna with receivers installed on the east wing of the terminal roof) while ascending the atmosphere. Both pilot balloon and radiosonde launches continued through the 1940's, but it is the radiosonde launches that continue to the present day.

The downtown weather station was partially consolidated with the Buffalo Airport branch station on July 1, 1943, and completely consolidated on June 30, 1944 with the termination of temperature and precipitation records at the downtown site. Buffalo's downtown station was closed. Its closure ended what today can be considered the "historic" period of weather observation in Buffalo. All official Buffalo records, beginning with July 1, 1943, are from the Buffalo Airport station.

This final move was considered one of economy, as well as reflecting the shift from the Signal Service's original nautical mandate (Buffalo being a major harbor) to a new emphasis on providing service for expanding civil and military aviation. From this point on, Buffalo's official weather station was located at the Buffalo Municipal Airport, to be later renamed the Buffalo-Niagara International Airport.

1943 to Present (the Modern Record)

Since June 30, 1944, official weather observations in WNY have been confined to the property of the Buffalo-Niagara International Airport, albeit instruments have been moved to accommodate an evolving airport. One major difference between the two periods is that, for the most part, the modern period instrumentation has been located at or near ground level, as opposed to multi-story roof tops during the historic period.

A 1948 inspection report noted that the balloon house was enlarged to accommodate larger radiosonde balloons. Aside from minor location adjustments, the principle weather instruments and the weather office remained housed at the airport administrative building until August 1960.

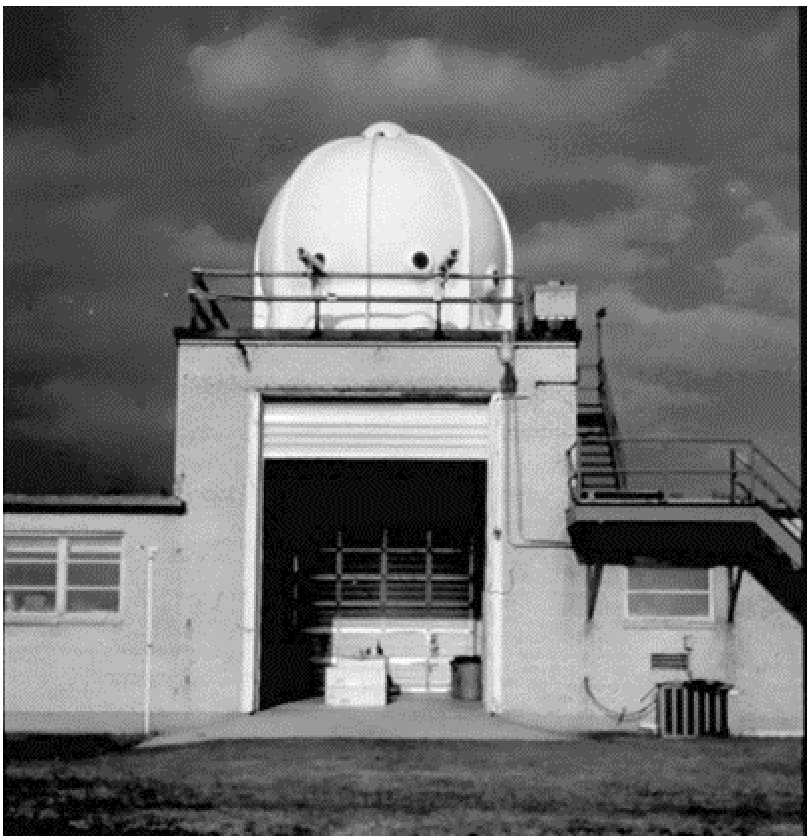


Figure 176. Upper Air Observatory as pictured in 1997. Image Source: Buffalo Weather Office.

A series of inspection reports through the 1950's noted growing office space limitations and unsatisfactory roof release conditions for upper air balloon launches. On August 22, 1960, the surface and upper air observation program were consolidated at a new observatory located off Amherst-Villa Road on the east side of the airport, located 2,200 feet northeast from the administrative building (balloon launches to this day are launched from that observatory) (Figures 176 and 177). A separate forecast office remained in the terminal building.

Wind instruments were located on the field. The first U.S. Weather Bureau surveillance radar was installed at the Buffalo Airport on October 29, 1961 (radar type WSR-57) and located approximately 1,000 feet WSW of the weather observatory (if you're familiar with Genesee St, it would have been across the street from where the McDonald's is now). In October 1963, wind and hygrothermometer (temperature and humidity) equipment were transferred to a grass plot west of the observatory, about 2,000 feet west-northwest from its original location on the administration building. The changing of the field site was necessitated by the lengthening of runways for jet operation.

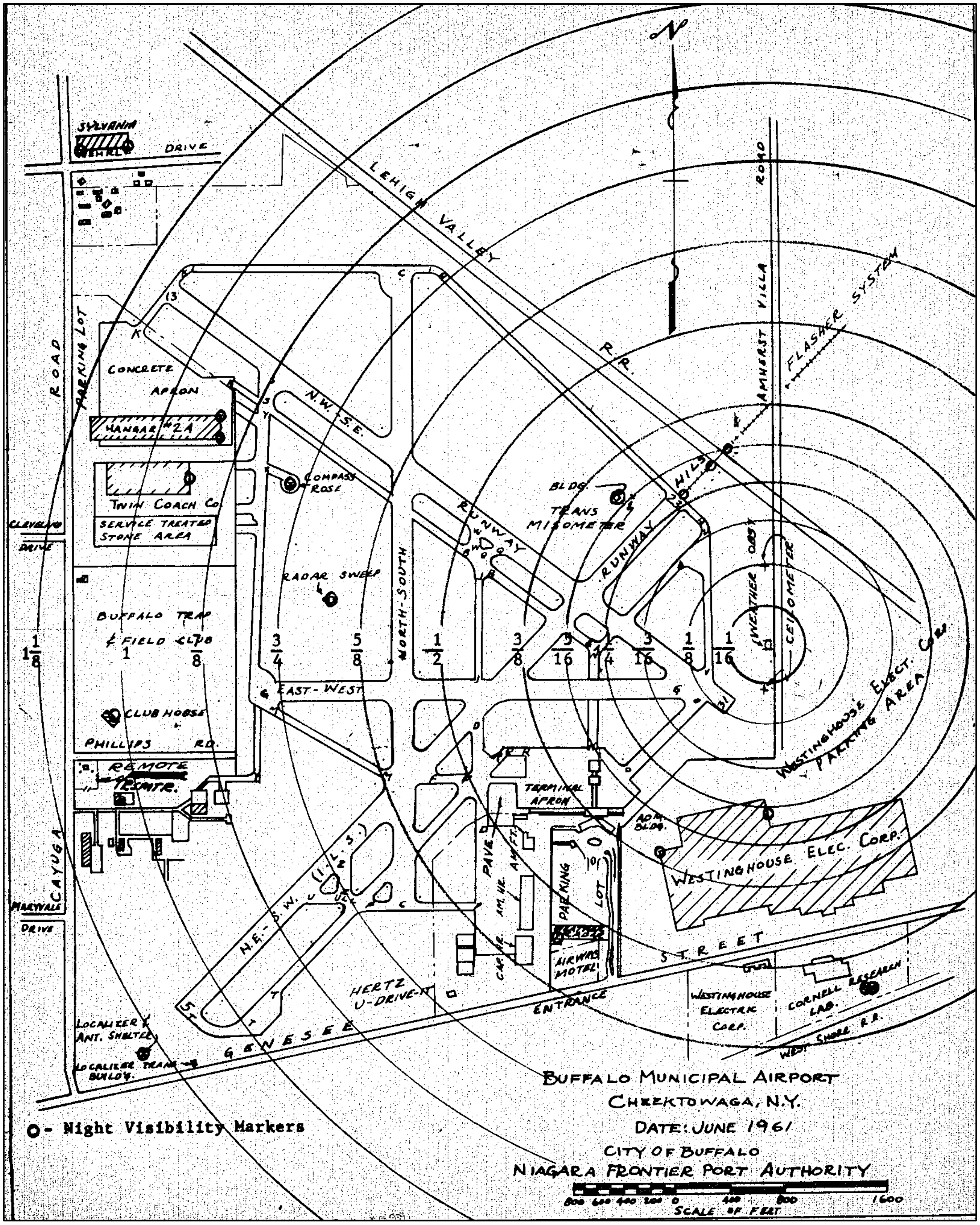


Figure 177. Greater Buffalo International Airport visibility chart (April 1962). New weather observatory located at center of bullseye, off Amherst-Ville Road. Image Source: Buffalo NWS Weather Office (scanned 1962-04-26_vis_chart).

Figure 178. Teletype at the Buffalo Weather Office. Image Source: Buffalo Weather Office.

Figure 179. Facsimile printers at the Buffalo Weather Office. Image Source: Buffalo Weather Office.

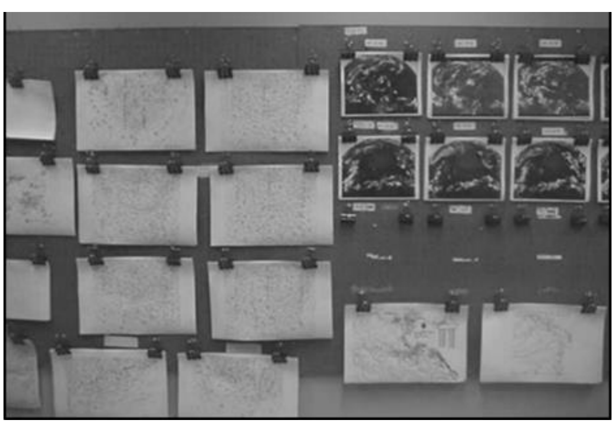


Figure 180. Bulletin Board with satellite imagery and weather charts. Image Source: Stephen Vermette

The early 1980's saw a mix of old and new technologies within the Buffalo Weather Office, many of which had been in service since the 1950's and 60's. It was past time for upgrades, but on the national stage the Weather Service was caught up in budgetary and political squabbles, not least of which was consideration to privatize parts of the Service.

In Buffalo, the WSR-57 radar installed in 1961 was still in operation, communication was still by teletype, and facsimile was used to transmit black & white satellite images and weather charts (Figures 178 and 179). Walking into the weather office, visitors would see several bulletin boards filled with maps and charts (positioned so that they could easily be flipped through to view changes over time), and large drafting tables where meteorologists would layout the facsimile charts to draw in isobars and outline or color in areas of observed weather based on the printed station codes (Figure 180). During one holiday season I can recall seeing a precipitation pattern drawn in the shape of a Christmas tree on one chart – obviously the staff having some fun in the office. A stepping stone into the future was the installation of the Automation of Field Operations and Services (AFOS) computer, which linked NWS offices for the transmission of weather data and offered one of the first opportunities to work with digital products (Figure 181).

It was in the 1990's that the Buffalo Office saw major changes, in step with a country-wide NWS modernization and restructuring that had been delayed and, in the view of many, was desperately needed in a period of technological advancement. More than the individual changes made, it was the needed modernization and restructuring that took the NWS into the 21st century and positioned it to continue to adapt and thrive with the changing times.

The Buffalo weather office modernization, part of a larger network overhaul, included: the construction of a new stand-alone forecast office (which began operating on April 17, 1995) (Figure 182); installation of Automated Surface Observing System, or ASOS, which replaced manual weather observations; the installation of an advanced Doppler Radar Next Generation Weather Radar (NEXRAD) Doppler

Figure 181. Early computerization showing the 1980's era Automation of Field Operations and Services (AFOS) computer terminals with the standing mainframes to their right. Image Source: NWS Buffalo Weather Office.

Radar (WSR-88D) which became operational in Buffalo in December 1995 (Figure 183); satellite upgrades with advanced observation capabilities; higher resolution and more sophisticated numerical weather prediction models; and the replacement of the 1980's era AFOS computer with a near-complete digitization of the NWS using powerful computers which are a part of the Advanced Weather Interactive Processing System (AWIPS). AWIPS, and later AWIPS-II, ingests, integrates, and disseminates weather-related data from numerous sources, accessed by the forecaster at a single desk station (Figure 184). The lay-out of the various components of Buffalo's official weather station at the Buffalo-Niagara International Airport is shown in Figure 185.

Figure 182. Buffalo's current forecast weather office. Image Source: Stephen Vermette.

Figure 183. Buffalo’s Doppler radar.
Image Source: Stephen Vermette.

Figure 184. Advanced Weather Interactive Processing System (AWIPS II) work stations.
Image Source: Stephen Vermette.

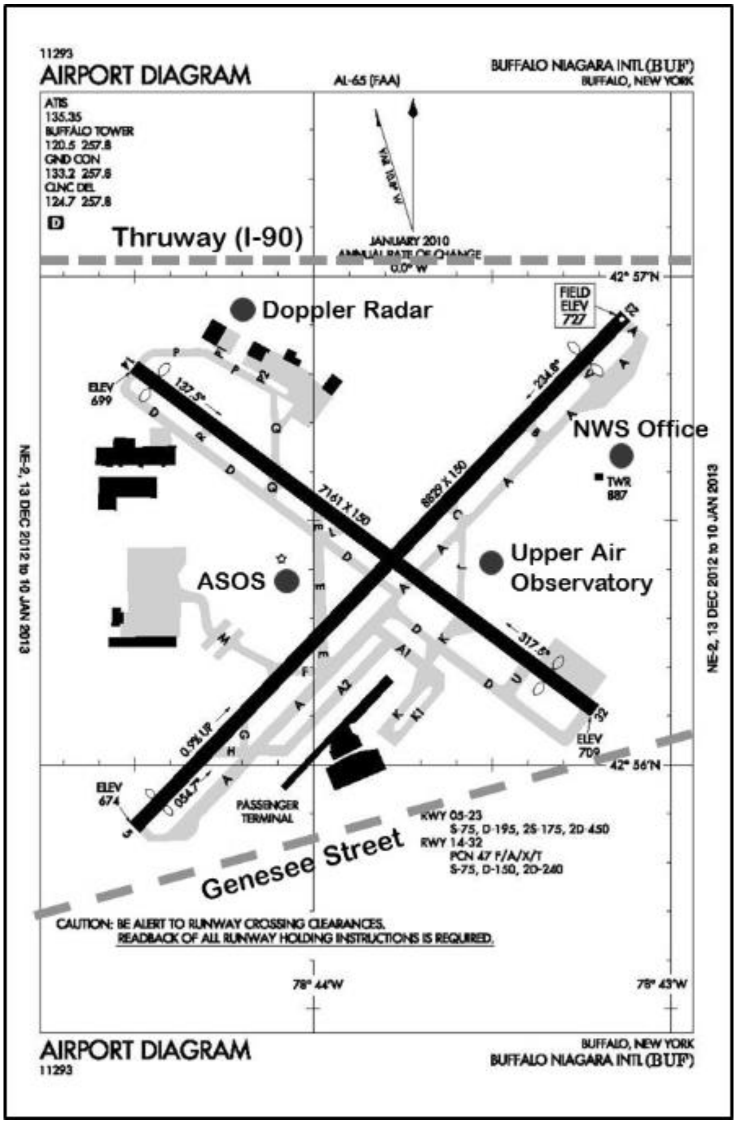


Figure 185. Position of Buffalo weather office structures at the Buffalo-Niagara International Airport. Image Source: Wikimedia Commons/modified by Stephen Vermette.

An important "modernization" often overlooked is the establishment of the Warning Coordination Meteorologist (WCM) position at the local weather office. In the past, community outreach was often ad hoc, as staff were focused on analyzing data and issuing forecasts and warnings. The communication was often one-way, responding to media requests. The WCM position created a two-way communication, working with the local communities to better prepare, respond, and mitigate weather-related hazards. The WCM position has grown to include such outreach efforts as SkyWarn®, Storm-Ready® and Weather-Ready Nation.

The network modernization came at a cost – 256 field offices (52 WSFOs and 204 Weather Service Offices (WSOs)) were reorganized as 122 Weather Forecast Offices (WFOs) organized within six regions. The Buffalo weather forecast office was retained as one of the 122 and moved into new facilities in April 1995. The Buffalo weather office is part of the Eastern Region with a geographic area of responsibility of 16 counties stretching along the Great Lakes from Chautauqua County in the west to Jefferson County in the east. Many of the closed field offices, and the work previously done by human weather observers, were replaced by automated weather stations. The Rochester weather office, part of the original network of Signal Service weather stations, was closed with the modernization and replaced with an automated weather station. A similar fate befell the Niagara Falls weather office, initially established on January 1, 1943 at the city's municipal airport.

While the "modernization" ended in 2000, the NWS continues to adopt new methods and technologies, including new satellites and numerical weather models. Doppler radar was upgraded to Dual Polar radar in April 2016, and the Buffalo Office is currently operating under AWIPS II.

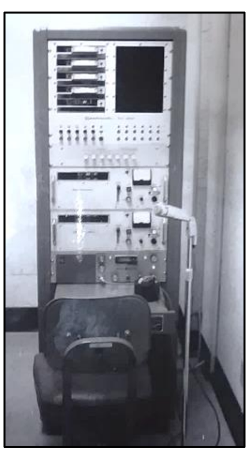
Buffalo's weather office – from Signal Service, to Weather Bureau, to today's National Weather Service - is approaching its 150th year of operation. Listed below are the men and woman who served as the "Meteorologist in Charge" at the Buffalo Weather Office. Over these many years this office has served Buffalo and WNY well. In my research, I've read numerous testimonials of the important forecasting work and community engagement of the Buffalo Office, beginning with its inception in 1870, to today. I recall attending a weather office open house in 2009 and being amazed at the number of people who attended, and of their eagerness to see the operations. While post 9/11 has restricted access to the facilities for most people (in the past you were permitted to walk into the office unannounced or "hang around" to watch the launch of a radiosonde), the importance of the weather forecast, and outreach efforts continue. The public's interest and appetite for weather and climate information has only grown over the years.

Observer Sergeant's and Meteorologist-in-Charge Positions at the Buffalo Weather Office

Dates	Meteorologist-in-Charge (MIC)
Oct 12, 1870 to Oct 23, 1871	William F. Slater
Oct 24, 1871 to March 11, 1876*	J. Mitchel*
March 12, 1876 to Dec 1878*	B.M. Purssell*
Jan 1879 to July 1880*	O. Parker*
Aug 1880 to Dec 31, 1884*	William Finn*
Feb 1, 1884 to Dec 31, 1925	David Cuthbertson
Jan 1, 1926 to Jul 31, 1940	James H. Spencer
Aug 1, 1940 to Mar 31, 1942	Ralph C. Mize
Apr 1, 1942 to November 19, 1942	Andrew P. Keller
Nov 20, 1942 to June 7, 1945	William Tracey
Jun 8, 1945 to Dec 30, 1965	Bernard Wiggin
Dec 31, 1965 to Apr 5, 1966	Benjamin Kolker (Acting)
Apr 6, 1966 to Feb 25, 1977	James E. Smith
Feb 26, 1977 to Jul 3, 1977	Benjamin Kolker (Acting)
Jul 4, 1977 to Sep 3, 1993	Donald E. Wuerch
Sep 4, 1993 to Aug 3, 2001	Guy Tucker
Aug 4, 2001 to October 6, 2001	Stanley Levine (Acting)
Oct 7, 2001 to Sep 3, 2004	Darin Figurskey
Sep 4, 2004 to Dec 31, 2011	Thomas Niziol
Jan 1, 2012 to Dec 15, 2012	Judith Levan (Acting)
Dec 16, 2012 to Jul 9, 2016	Jason Franklin
Jul 10, 2016 to Present	Judith Levan
*Exact dates and name spelling are uncertain.	

Box 25

NOAA Weather Radio



NOAA weather radio came to WNY in the early 1970's. It provided continuous weather information and weather alerts directly from the Buffalo weather office 24/7. Originally, Buffalo NWS staff recorded messages to be broadcasted locally. In the late 1990's a text-to-speech system was employed – the first computer voice known as "Paul". Continual improvements have been made over the years, with the newest computer voice coming on line in 2016. It is always interesting to hear how local place names are pronounced by these computer-generated voices. Shown is the early 1970's NOAA radio console at the Buffalo weather office. Not the chair and microphone to record taped messages.

Image Source: Buffalo Weather Office.

Local Knowledge

The Role of the NWS Warning Coordination Meteorologist

Contributed by Stan Levine, retired from the Buffalo Office of the National Weather Service.

I have been looking up towards the sky since childhood. Originally, it was the sun, moon, planets, and stars which caught my attention. My parents, always encouraging me, bought a Gilbert telescope, and I thought I would grow up to be an astronomer. However, a little later on, it was the clouds, wind, rain, and snow which became my passion. So after receiving a Lionel Scientific Weather Station from my parents (Yes! Lionel did sell science kits for a while), I came down to Earth, so to speak, and I dreamed of becoming a meteorologist.

I attended the City College of New York (CCNY) and, while I was a student, I was fortunate to be able to work at the Weather Bureau as a summer Student Trainee. Upon graduation, I became a Meteorological Intern in the New York City area. I was then transferred to the Weather Service Forecast Office in Albany where I served as a forecaster and Warning Preparedness Meteorologist for almost 20 years. I was then selected as the first Warning Coordination Meteorologist (WCM) at the Buffalo NWS office in 1994. I served as the WCM for WNY until my retirement in 2006.

As a WCM, it was my responsibility to work directly with emergency managers representing villages, cities, counties, and multi-county regions. Other emergency managers represented electric utilities and schools. With the help of the Weather Service staff, I would organize seminars and workshops to help the risk managers identify the impacts of extreme weather and flooding in their areas of responsibility. I would recommend steps that could be taken to lessen those impacts that could potentially threaten lives and property.

Direct communications links, including dedicated telephone, radio (including NOAA Weather Radio), and secure Internet networks were established and tested. Rapid communications are important so weather forecasters can disseminate timely briefings and warnings, and also can receive real time ground truth reports of severe weather and/or flooding occurring.

I would also work directly with the general public to help people recognize the risk of severe storms and flooding and suggest ways they could protect themselves, their families and their property. I would organize public awareness campaigns with the help of the broadcast and print media. With the help of emergency management officials and NWS staff, I would present SKYWARN training seminars where people could learn to identify severe weather clues, rapidly report severe storms, flooding and damage to their local authorities, and learn how to be prepared in case a storm strikes or flooding occurs.

In recent years, people of WNY have been exposed to a variety of dangerous weather conditions, including tornadoes, thunderstorms, flash flooding, and synoptic windstorms. However, the most frequent severe weather events to occur are lake effect snowstorms and blizzards. These storms can pile up several inches of snow every hour and paralyze a community. The Blizzard of '77 is perhaps the most well-known and most deadly event to occur, but it was by no means the only one.

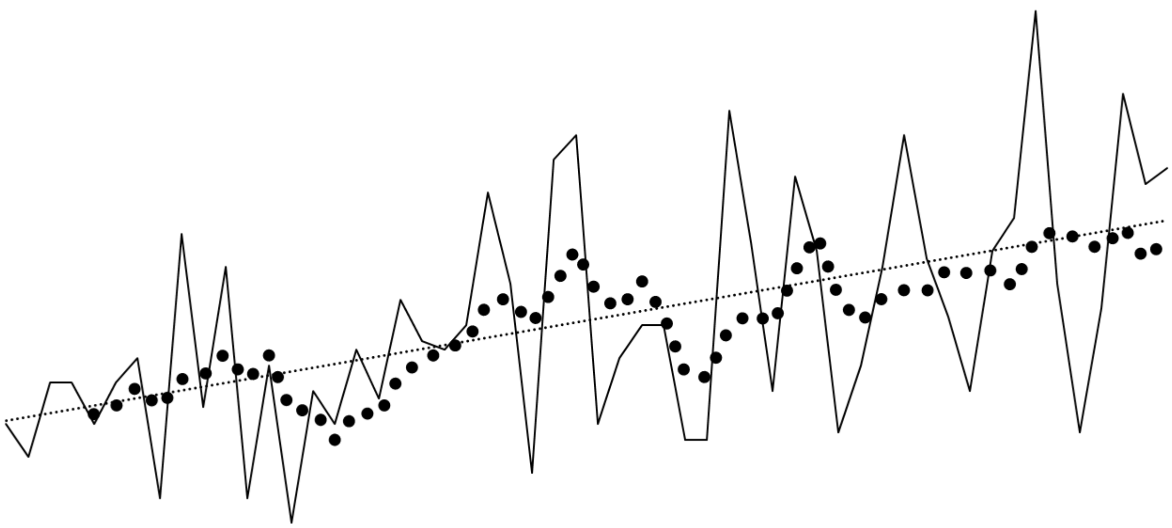
During my time living in WNY, there have been several events. There was the lake effect storm of November 2000 when snowfall rates of up to 4 inches per hour crippled several communities, leaving motorists stranded in their cars, in some cases overnight. I was at the weather office during that event. It was snowing so heavily that forecasters had to frequently brush off our antenna dish to prevent our communications from being cut off.

About 6 months after I retired, the October Surprise of 2006 left many people (including myself) without power for over a week. The heavy wet snow brought down trees and much of the above-ground electrical infrastructure. While it was a severe inconvenience, I consider myself very lucky when compared to those that had to endure the deadly lake effect storm of November 2014 which dumped over 5 feet of snow in a relatively narrow band from West Seneca and Hamburg to Orchard Park, Lancaster, and southern Cheektowaga. The image of a wall of snow stretching inland from Lake Erie will forever remain etched in my memory.

Buffalo's Signal Service ledgers from the 19th Century. Housed at the Buffalo Museum of Science.

Chapter 8

Living in a Warming World



Buffalo's warming temperatures. Image Source: Stephen Vermette.

Enhanced Greenhouse Effect

When discussing the past climate of WNY, I described the forces that changed our climate, siting changing orbital characteristics as a means of explaining the most recent ice age (Pliocene-Quaternary glaciation), with its alternating glacial and interglacial periods, experienced by WNY over the past few million years. Past climates have also been driven by other forces, including changes in solar output, volcanic activity, and continental drift. The changes in climate that we are experiencing today and have been experiencing over the last 100+ years, are explained by another forcing – the anthropogenic (human caused) buildup of greenhouse gases - carbon dioxide (CO_2) and methane CH_4), among others) in our atmosphere, referred to as the "Enhanced Greenhouse Effect".

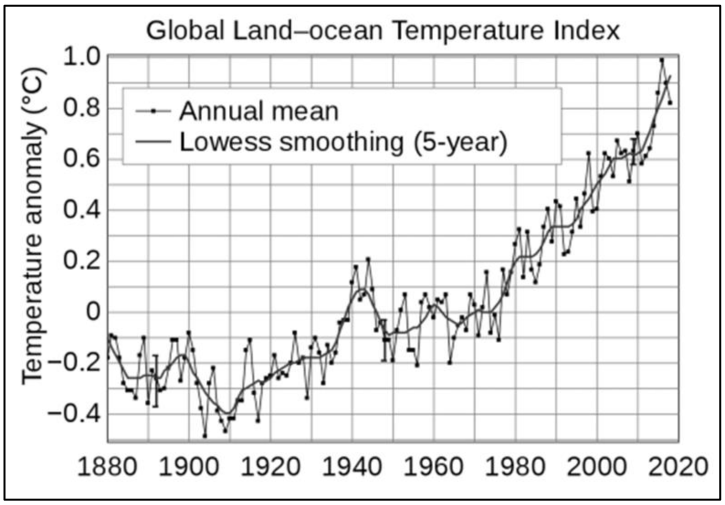


Figure 186. Global surface temperature (1880 to 2018) anomaly relative to the 1951-1980 average. The graph shows an overall long-term warming trend. Image Source: NASA/GISS.

There is no question that anthropogenic activity is adding greenhouse gases into our atmosphere at an unprecedented rate, and that increases in human CO_2 emissions and atmospheric concentrations are closely linked. Current atmospheric concentrations of CO_2 are in excess of 400 parts per million (ppm) – off the chart when compared with background levels of the past 800,000 years, and higher than anytime in human history. In response, global atmospheric temperatures have increased by about 2.2°F from the late 1800's (Figure 186), and it is expected that temperatures will increase by 6°F by the year 2100). No other attribution, other than the "enhanced greenhouse effect", can explain this temperature increase.

There is a canon of science supporting both global climate change and the environmental responses to these changes. Scientific consensus takes time to form. Climate change, like any other scientific understanding, at first is met with conflicting studies (the world is cooling…the world is warming), but over time these studies coalesce into a common consensus – consider the spherical shape of the Earth, the drifting of continents, evolution, and even the harmful effects of smoking), all of which were hotly debated in their time. In the case of climate change there is a scientific consensus: the earth is warming, and the warming is caused by human activity.

Rising global temperatures, melting ice, and rising sea levels are the most obvious manifestations of the warming, but a greater frequency of heavy rain events, periods of drought, and other forms of severe weather, varying by geography, have been attributed to a changing climate, as well. The earth and its atmosphere are a complex system, with complex feedback mechanisms that scientists continue to study. By way of example, the accelerated heating of the Arctic has reduced the temperature gradient between the equator and pole, which in turn has reduced the pressure gradient, resulting in a weakened jet stream (upper air winds). You may recall that the jet stream is important to our weather, as it separates cold and warm air masses, and influences the strength and movement of midlatitude low-pressure storm systems. Periods of extreme cold and heat, and systems stalling over a region (persistent flooding rains or excessive heat) can be explained by the impact of a warming world on the changing speed and path of the jet stream.

WNY’s Observed Climate Trends

The climate trends, as described here, were obtained from weather data obtained at the NWS site at the Buffalo-Niagara International Airport. The primary purpose of the data trends, as presented here, is to show how are climate has, or has not, changed over the past 50+ years. The statistical significance of the trend was determined, at the 95% confidence level, based on the Mann-Kendall test. While extrapolation of the trends into the future is not processed-based, they do provide a data-driven method that can be compared with climate model results.

The period 1965 to 2018 (54 years) was chosen based on two primary considerations. First, while the Buffalo, NY record includes weather data going back to the late 1800’s, prior to 1944 it was monitored at multiple high-rise sites in downtown Buffalo, as compared to ground-level measurements at the current airport site. The urban setting prior to 1944, and the questionable citing of monitoring equipment, renders weather data prior to 1944 unusable for purposes of understanding trends. In addition, these downtown sites were located along the Lake Erie shoreline and thus subjected to the greater influence of seasonal lake effect influences on temperature and other weather elements, as compared to the present location. Second, it is during the years 1965 to present that the Northern Hemisphere and the U.S. have clearly shown a continuing rise in temperatures consistent with climate forcing associated with the rapid atmospheric buildup of greenhouse gases.

Responses to a Warming World (Significant Trends)

Temperatures in WNY are increasing at a rate (0.43°F to 0.46°F per decade) that is slightly less than the U.S. average. This warming can be seen in both the annual mean, maximum and minimum temperatures (Figures 187 to 189), although the rate of increase for year-on-year minimum temperatures (warmer nights) appears to exceed that of maximum temperatures.

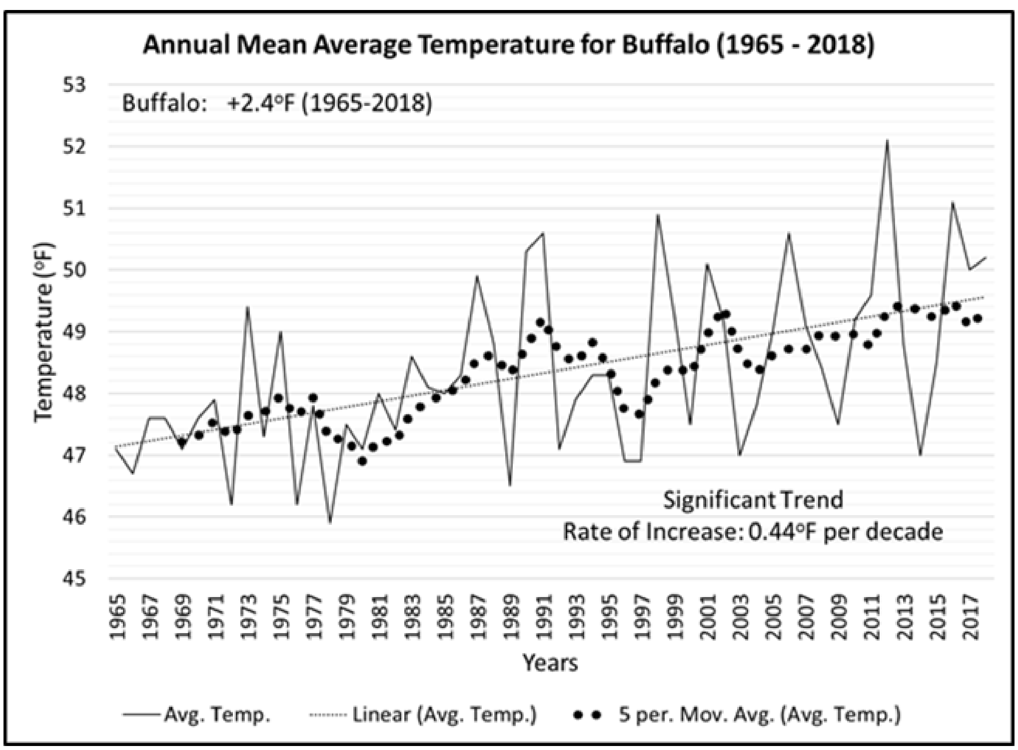


Figure 187. Annual mean average temperature trend for Buffalo, NY (1965-2018). Image Source: Stephen Vermette.

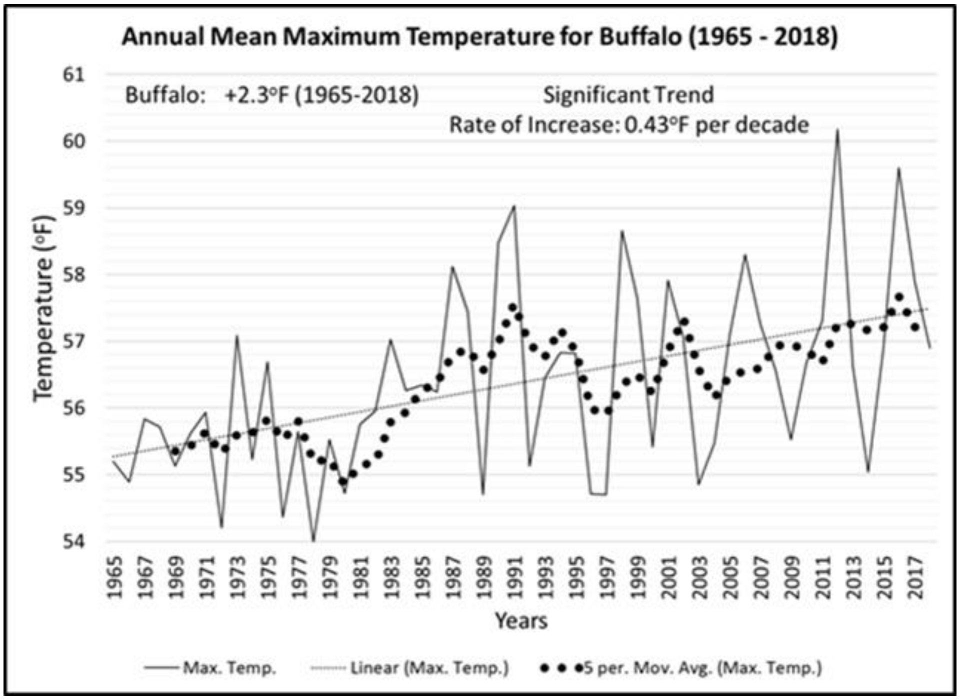


Figure 188. Annual mean maximum temperature trend for Buffalo, NY (1965-2018).
Image Source: Stephen Vermette.

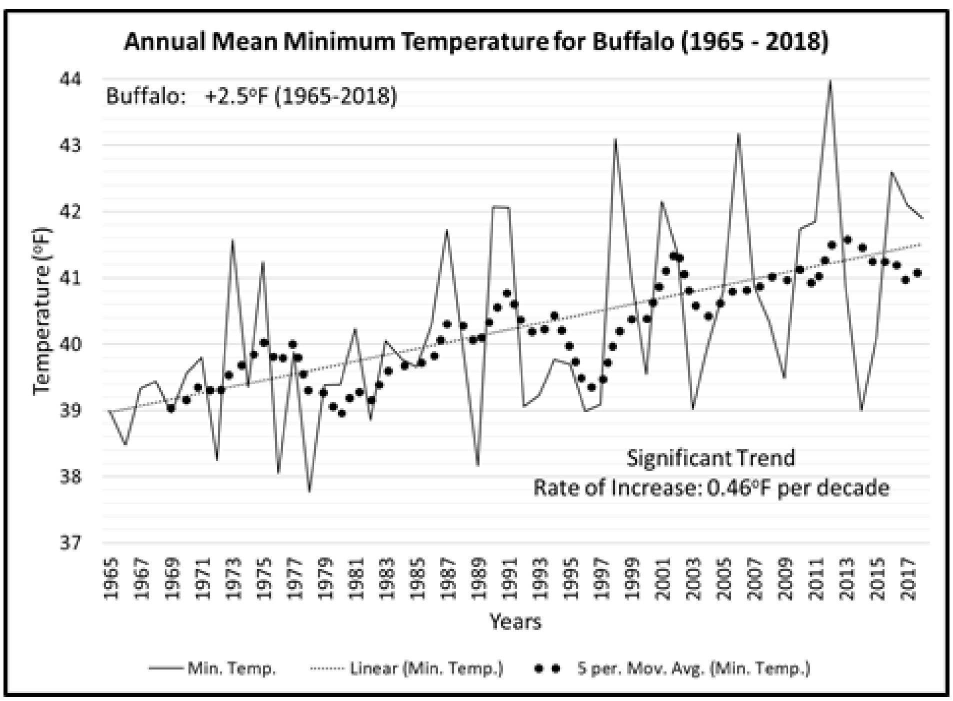


Figure 189. Annual mean minimum temperature trend for Buffalo, NY (1965-2018).
Image Source: Stephen Vermette.

In line with the rise in temperatures, daily temperature records show a significant decrease in the percentage of 'low temperature' records and an increase in in the percentage of "high temperature" records over time (Figure 190), a significant lengthening of the growing season (by about 18 days over the past 54 years) (Figure 191), a need for less heating and greater cooling of buildings, a significant warming of Lake Erie's waters (Figure 192), less lake ice coverage, and significantly earlier ice-out dates on the lake (Figure 193). Average daily wind speeds appear to be decreasing over time (Figure 194).

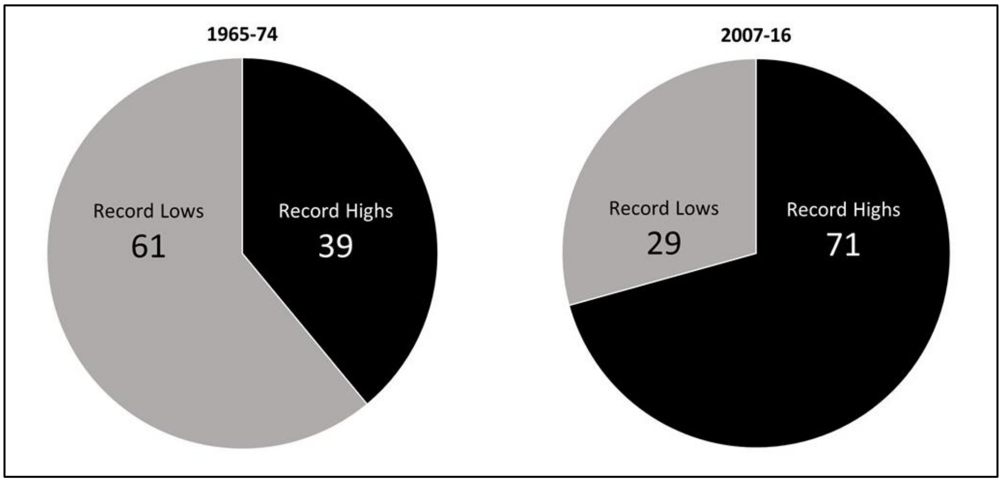


Figure 190. Percentage of temperature records of both the first and the most recent decade (1965-2016) for Buffalo, NY. Image Source: Stephen Vermette.

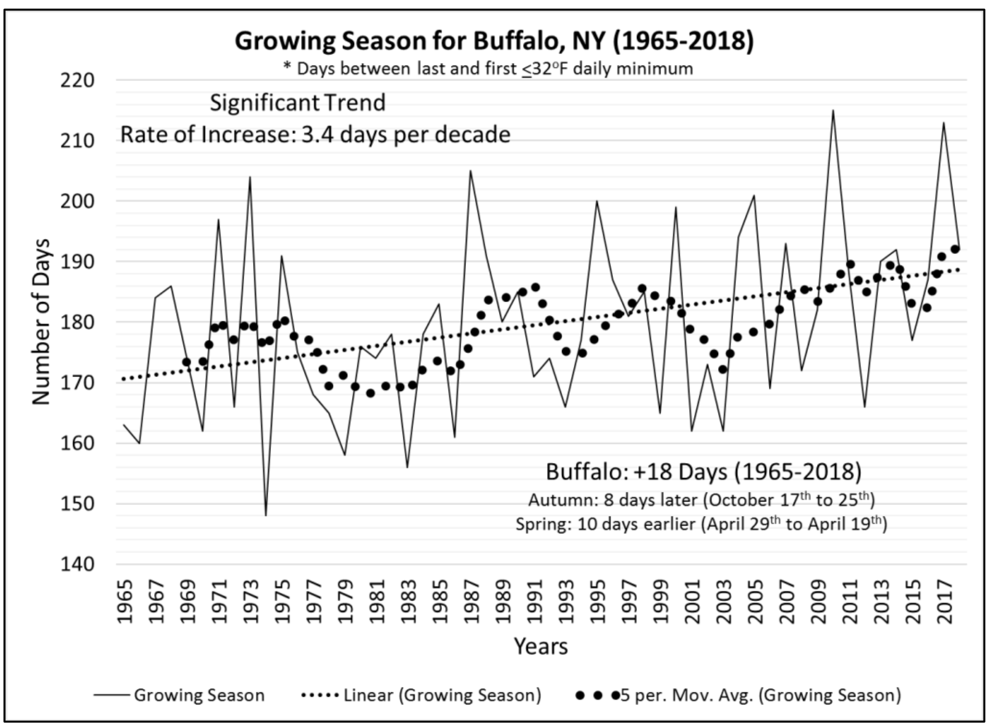


Figure 191. Trending length of the growing season for Buffalo, NY (1965-2018). Image Source: Stephen Vermette.

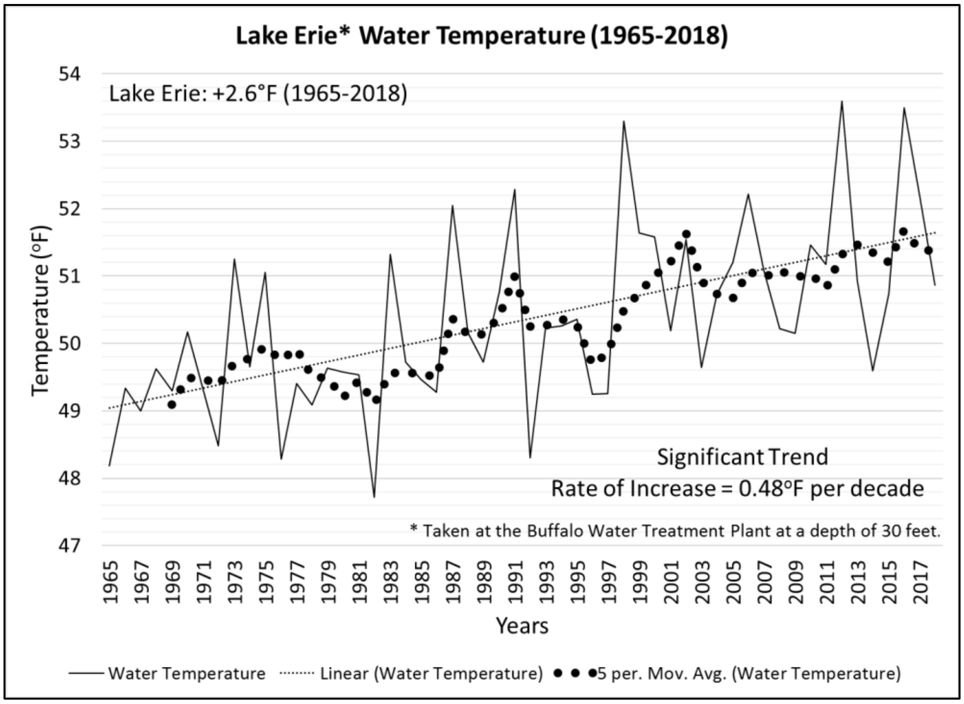


Figure 192. Lake Erie water temperatures as measured at the Buffalo Water Treatment Plant at a depth of 30 feet (1965-2016). Image Source: Stephen Vermette.

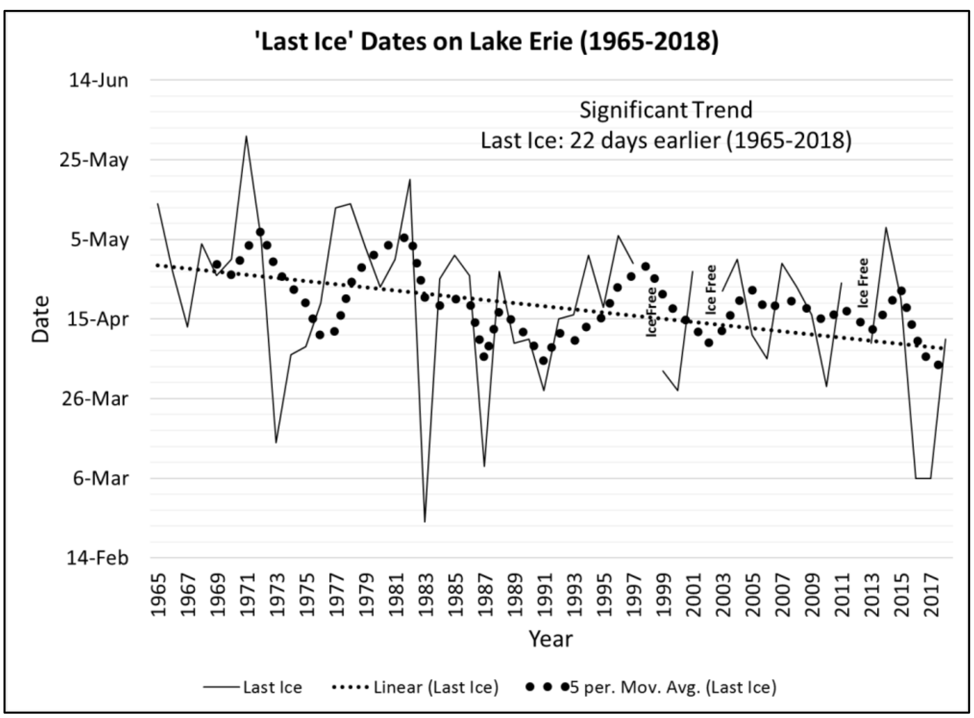


Figure 193. Lake Erie 'Last Ice' dates (1965-2016). Operationally defined as less than 250 square miles of ice remaining in the eastern basin of Lake Erie.
Image Source: Stephen Vermette.

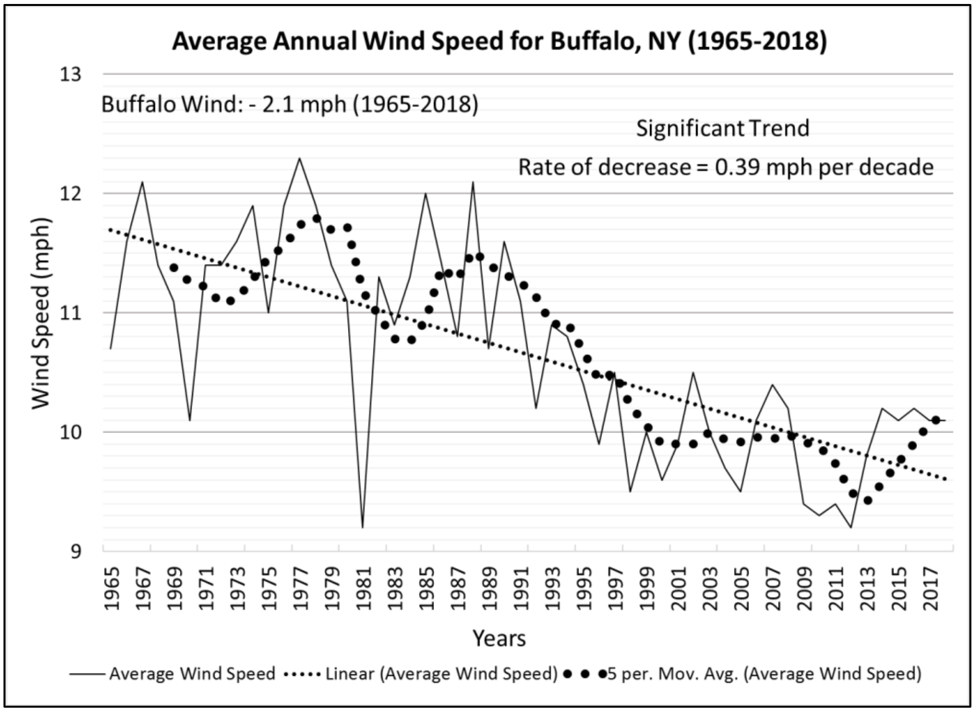


Figure 194. Average annual wind speed for Buffalo, NY (1965-2017).
Image Source: Stephen Vermette.

Non-responses to a Warming World (Absence of a Significant Trend)

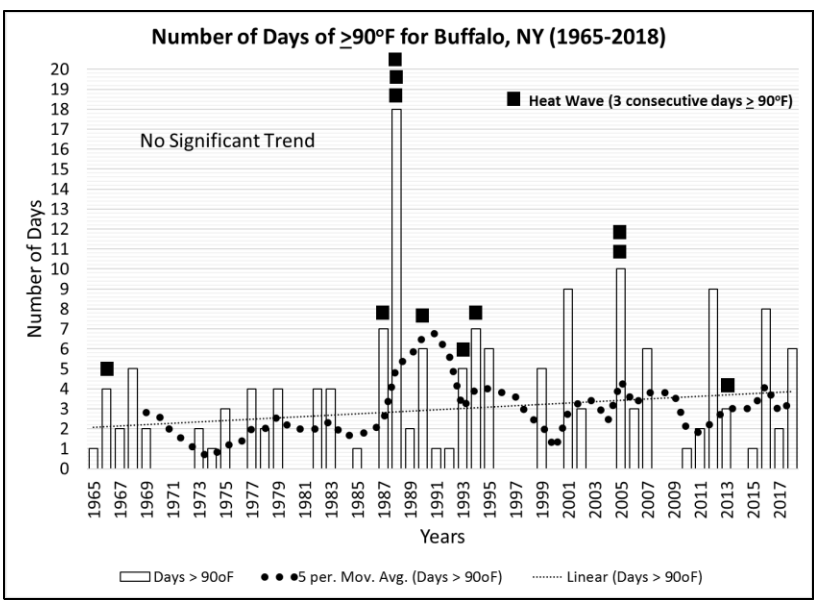


Figure 195. Number of days with maximum temperatures ≥ 90°F and frequency of heat waves (squares) for Buffalo, NY (1965-2018).
Image Source: Stephen Vermette.

Parameters showing no significant trend (even if there is a slight increase or decrease shown over time) are indicated as non-responding climatic parameters in a warming world. Examples of non-responses are the number of days ≥ 90°F and heat waves (Figure 195), and drought conditions (Figure 196) for WNY. Buffalo and WNY has long been touted as a region resistant to scorching temperatures and heat waves.

Other non-responses include precipitation amount (shows a slight increase but is not significant), precipitation intensity, and thunder-storm days (Figures 197 through 199). While the Northeast U.S. has shown an increase in intense rain events (some-times referred to as "rain bombs"), this trend is currently not apparent in WNY. Furthermore, snowfall amounts and Lake Effect Snow frequency (shows a slight increase but not significant) appear unchanged over the years (Figures 200 and 201). Severe weather in WNY does not appear trending in any direction, including tornadoes and high wind gust days (Figures 202 and 203) and hail (not shown).

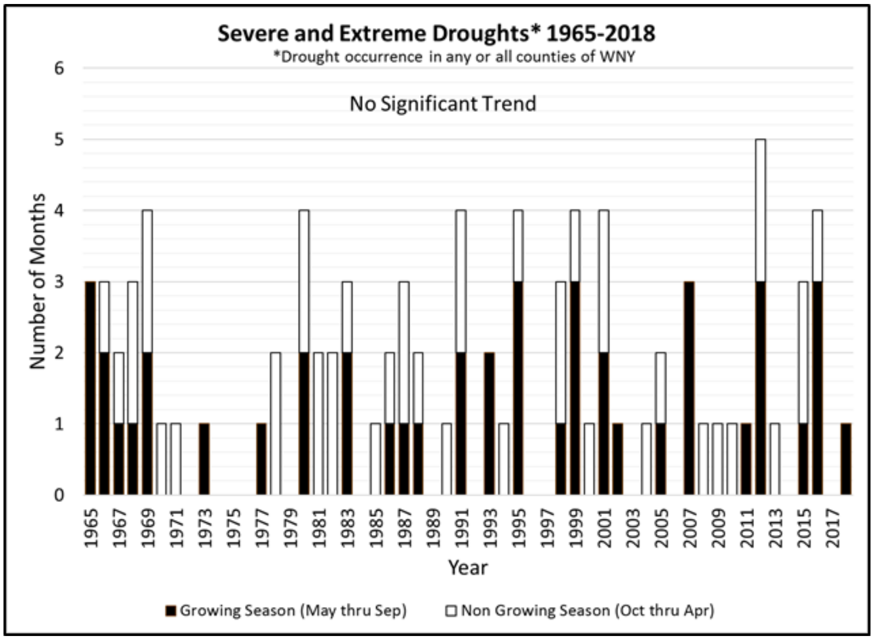


Figure 196. Drought occurrence in any or all counties of WNY. Palmer Z-Index. Measures drought on a monthly timescale, with no memory of conditions in previous months. Image Source: Stephen Vermette.

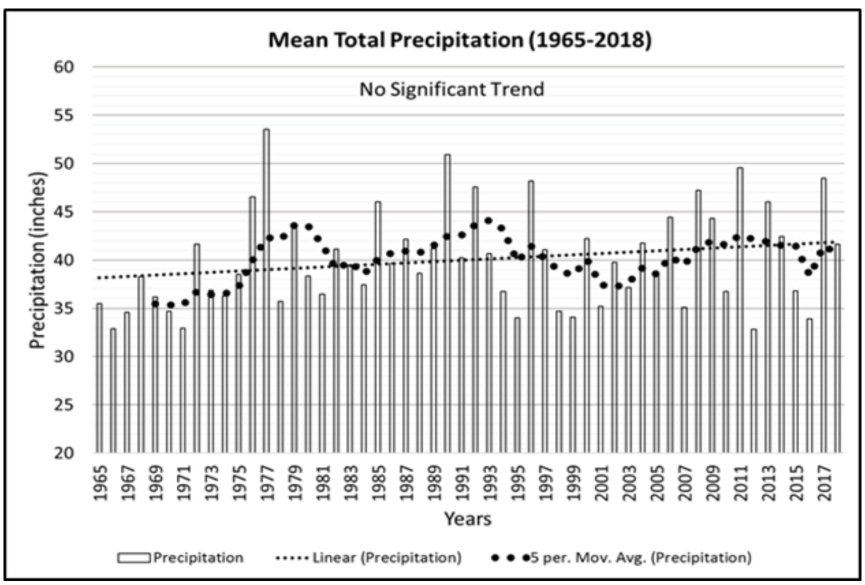


Figure 197. Mean total precipitation for Buffalo, NY (1965-2017). Image Source: Stephen Vermette.

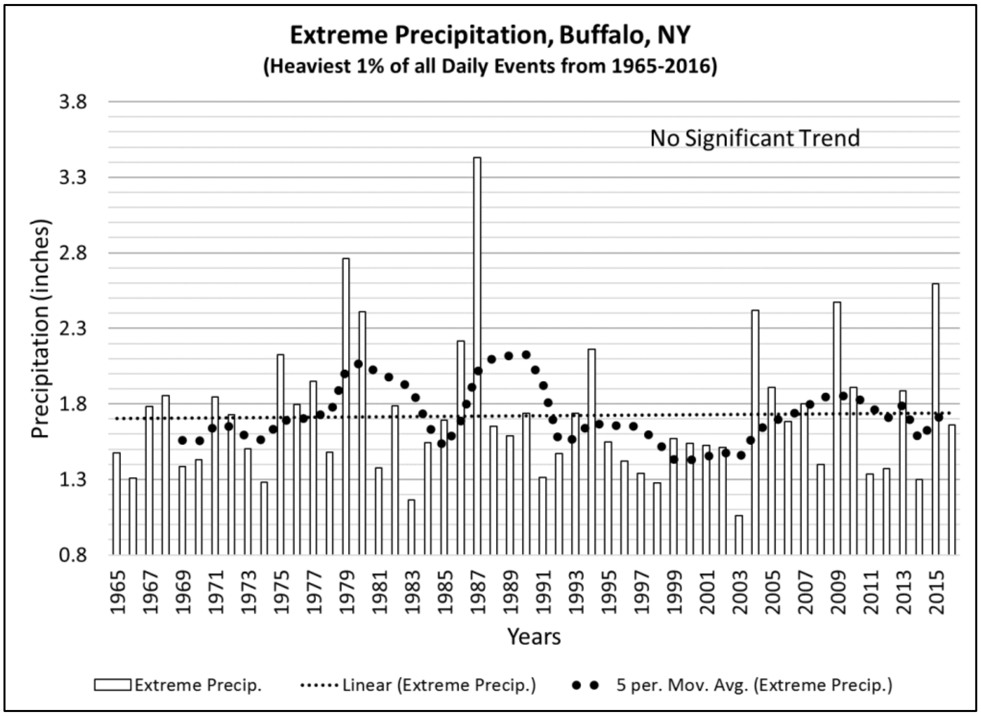


Figure 198. Extreme precipitation events (heaviest 1% of all daily events) for Buffalo, NY (1965-2016). Image Source: Stephen Vermette.

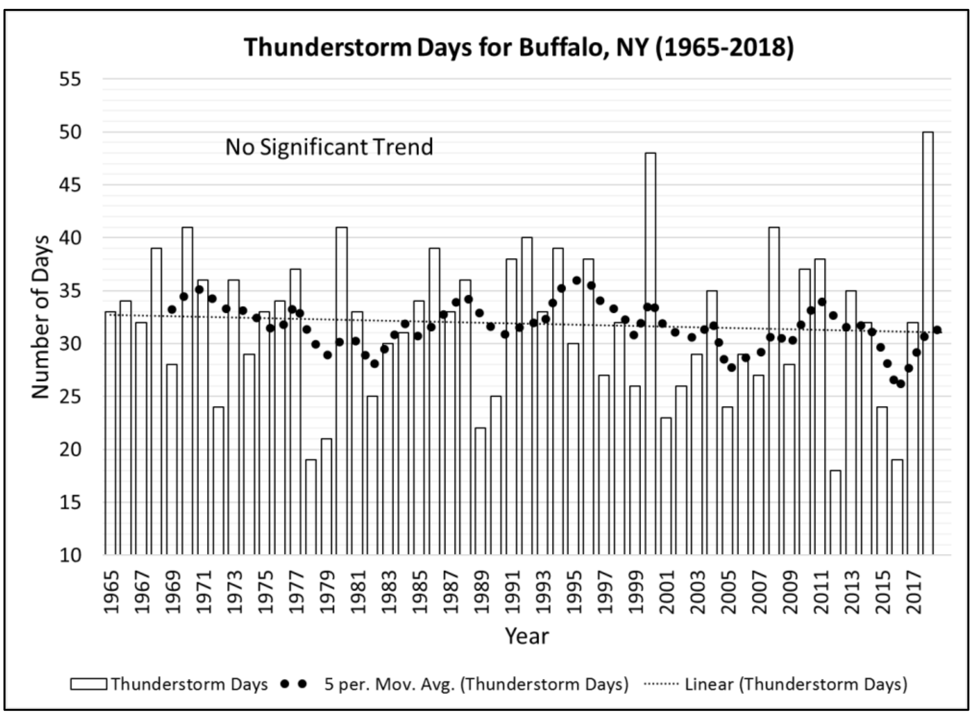


Figure 199. Frequency of thunderstorm days reported for Buffalo, NY (1965-2017). Image Source: Stephen Vermette.

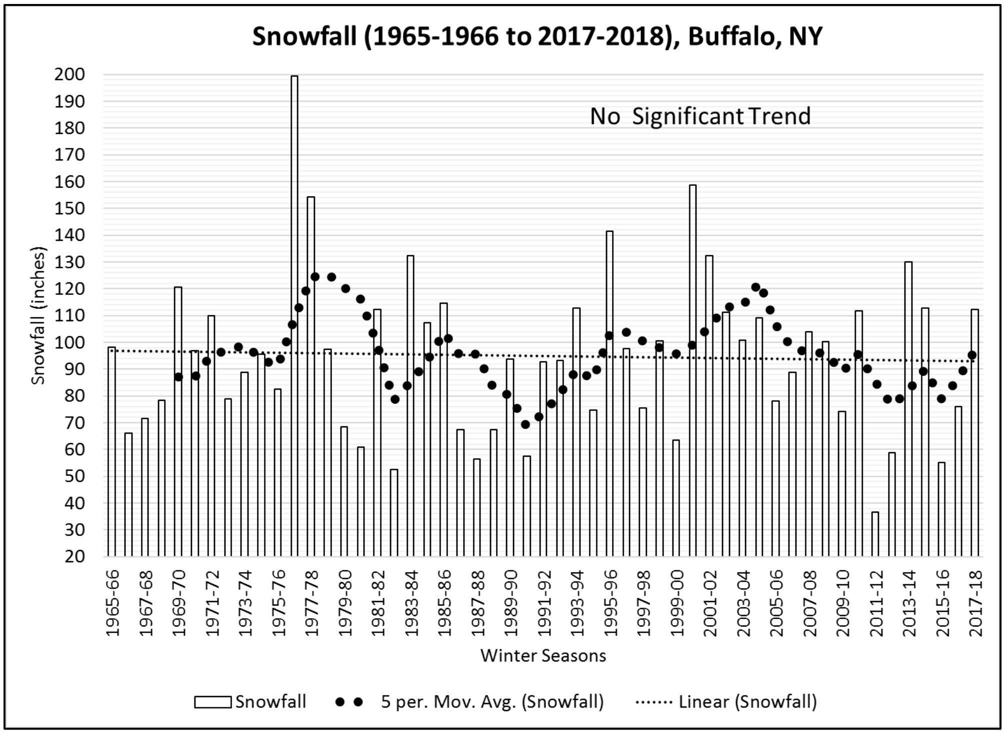


Figure 200. Total snowfall for Buffalo, NY (1965-66 to 2017-18).
Image Source: Stephen Vermette.

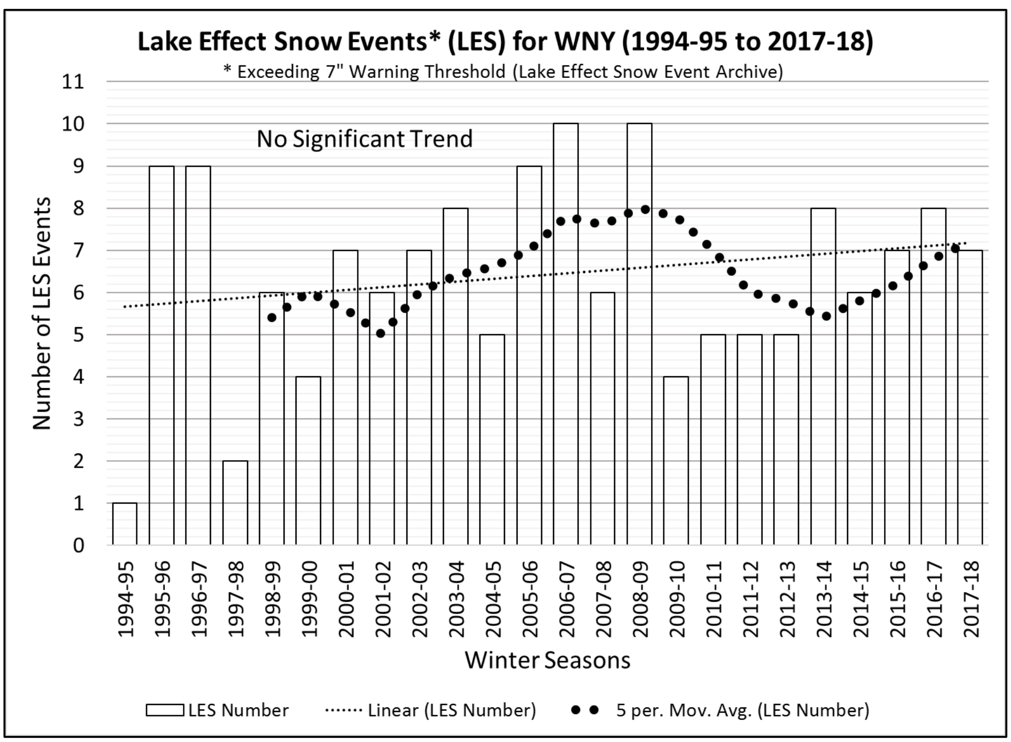


Figure 201. Frequency of lake effect snow events (LES) across WNY (1994-95 to 2017-18). Image Source: Stephen Vermette.

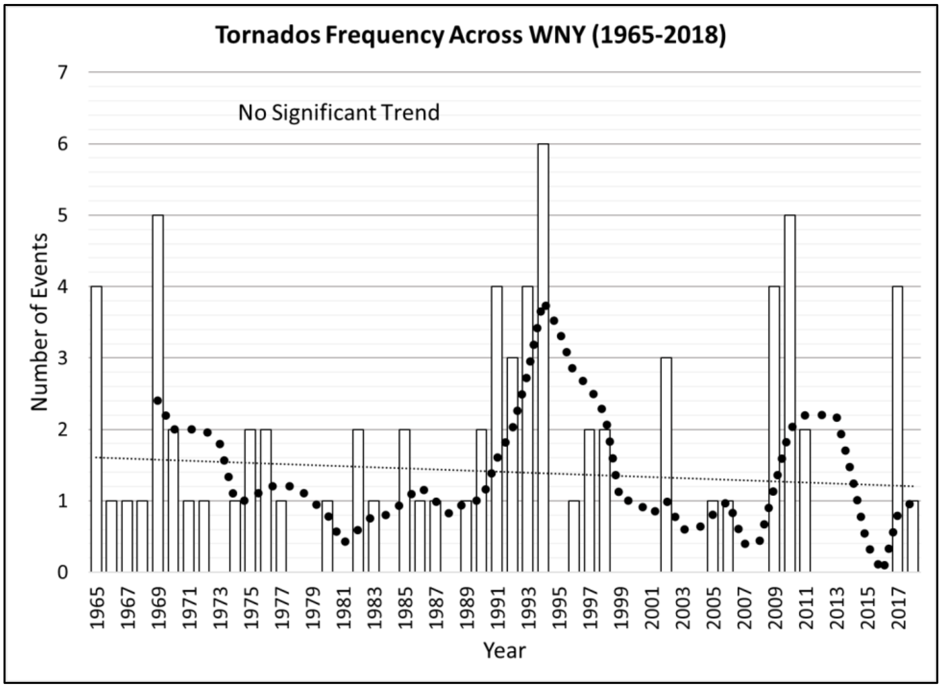


Figure 202. Frequency of tornadoes across WNY (1965-2018).
Image Source: Stephen Vermette.

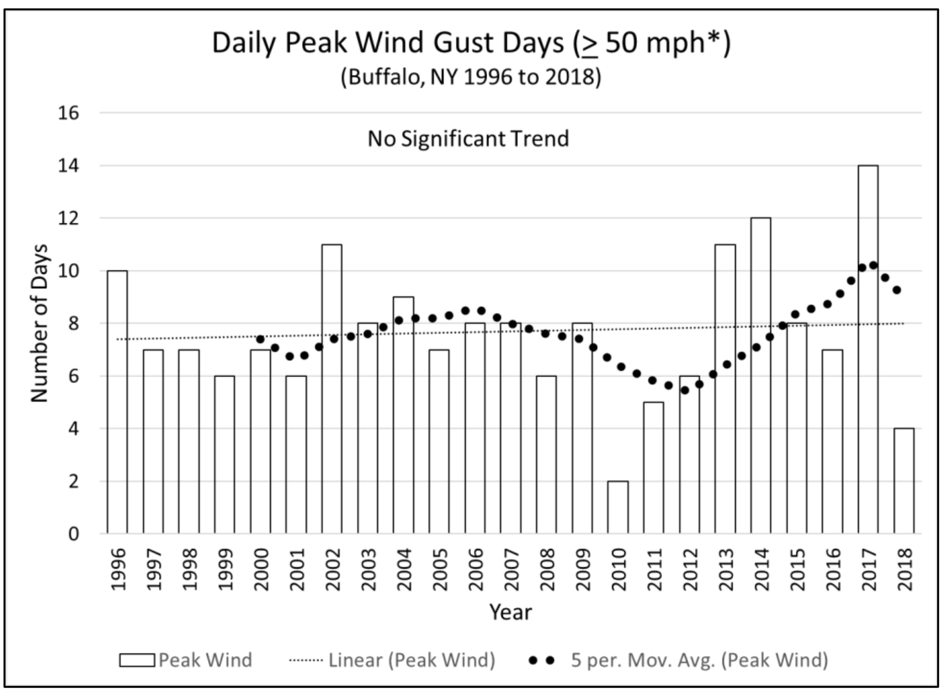


Figure 203. Frequency of wind gust days (≥ 50 mph*) across WNY (1965-2018). Peak wind measured as a 3-second gust between 2008 and 2018, and as a 5-second gust between 1996 to 2007. The 5-second gust was adjusted to an equivalent 3-second gust. It is difficult to reconcile earlier measurements of gusts.
Image Source: Stephen Vermette.

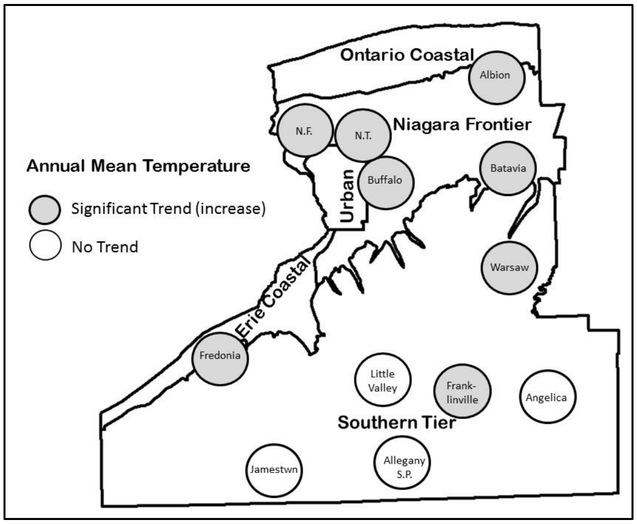


Figure 204. Temperature trends, shown on a WNY climate zone map. Image Source: Stephen Vermette

Readers of this climate trend section might recognize it as being somewhat Buffalo-centric. To correct for this, it must be noted that a preliminary examination of NWS cooperative observing stations across WNY show, like Buffalo, the absence of overall precipitation and snowfall trends. Similarly, most stations, show significant temperature increases across the region, with one regional exception (Figure 204). Stations in the Southern Tier − Jamestown, Little Valley, Allegany State Park, and Angelica – do not show similar warming. And, if snowfall data is restricted to the period 1980 to 2018, there appears to be a significant increase only in the Southern Tier – Jamestown, Little Valley, Allegany State Park, Franklinville, Warsaw, and Angelica.

It is interesting to see how WNY's climate has, and has not, changed over the past 50+ years. It cannot be ignored that the trends seen here have occurred within a warming period globally, to which our region's current response to climate change corresponds. An examination of WNY's climate data (1965-2018) clearly indicates that the region is impacted by climate change. WNY's response to a warming world appears to be predominantly a rise in air temperatures and related indices. Precipitation and severe weather indices, for the most part, show no significant response with the noted exceptions in the Southern Tier.

Buffalo's and WNY's climate responses appear somewhat muted as compared to other regions of the country, and we may find ourselves better suited to survive climate change than those other regions. A September 2018 article published in The Guardian (a U.K.-based newspaper), and then echoed in the Buffalo News, described the impact of climate change on several U.S. cities over the next 100 years. In the article, titled "Where should you move to save yourself from climate change?", climate change adaptation expert Jesse Keenan (Harvard University) highlighted Buffalo (WNY region) as an ideal climate refuge. Buffalo's mayor, Byron Brown declared Buffalo to be a climate change refuge city. Whether it is true or not, this view plays into WNY's historic narrative of being a comfortable city free from weather extremes − except for our abundant snow, of course. To borrow from Buffalo Bills coach Marv Levy "*Where else would you rather be than right here, right now?*"

Local Knowledge

Adapt & Thrive—Where Better to Confront the Effects of Climate Change than WNY

Contributed by George Besch, an environmentalist with the nonprofit Designing to Live Sustainably

Global warming is controversial, yet its undeniable effects make for a modern conundrum. Reversal is impossible and mitigation alone will not prevent the effects that will be impacting us with greater frequency and magnitude for the foreseeable future. Smart, sustainable adaptation is necessary no matter how successful we are at reducing greenhouse gas emissions.

While we focus, quite importantly, on changing the culture of denial about global warming and human activity's role in it, we are in de facto denial of its effects and thus are not adequately preparing for them. It is predicted that by 2050 there will be 5 billion people suffering from lack of water, with its associated food issues, and 1 billion climate refugees, some of whom will be refugees due to too much water—sea level rise and floods; some due to too little water and drought. That 1 billion does not include those who will chose to re-locate as un-forced climate migrants. The Pentagon names climate change as the #1 national security threat.

The effects of global warming are all about water. Too much, too little, coming with too little warning and no way to save it for when it is needed. Floods, sea level rise, droughts, desertification. Which brings us to why WNY is so well-sited and well-resourced to adapt and thrive in these challenging times. We are likely to fare well as water issues impact more-and-more of the country and the world. We see 20% of the world's fresh water flow past us, and along with most of the NE USA and SE Canada, we will be receiving increased precipitation. Indications are WNY will experience less drought than other areas in the NE region.

While the expectations are for WNY to receive more precipitation, that is not true of the Lake Erie and Lake Ontario headwaters. So, we may see a lowering of those lake levels. Affecting how much water we do get, its quality, and both commercial and recreational use. One aspect of the water quality – the eutrophication of Western Lake Erie waters-- is a Federal issue but one that demands our attention. We also need to do better with the water we get from Lake Erie, inadequately treated and distributed via aging infrastructure.

Sea level rise and other catastrophic events will affect us indirectly, but significantly, because from those, WNY will see increasing numbers of people, and businesses, relocating here due to our favorable climate and resources. We will be a refuge, a relative oasis from the worst of the effects impacting elsewhere. The NYS Department of State said we can expect not only refugees and migrants from around the world and the country but relocating here from New York City and Long Island due to sea level rises.

We have water—not too much and not too little, and farmland. While WNY has squandered much of its wealth of farmland to sprawl, we still have a great deal of it available. Studies show the country lost 31 million acres of farmland, just between 1992-2012. While maps indicate a lot of arable land in the Midwest, if those maps were overlain with predicted droughts and other severe weather events, and its diminishing supply for water from depleted aquifers, WNY's advantageous position becomes easy to see. Even without lack of water, the Mid-West's industrial farms are not sustainable, too dependent on fossil fuel-based fertilizers and equipment.

While some of our challenges with water are persuading the Federal Government to do better upstream of us, saving what farmland can still be saved rests with local governments, and due to NYS being a home-rule state, persuading those local governments to save farmland is essential to our adapting and thriving.

Yes, there are some direct effects of climate change that we need to consider—but the larger issues that we can prepare for will be occurring outside of WNY. Those effects mean we need to prepare for an increase in population that needs to be accommodated on other than arable land; and a great deal of decentralization of energy services, food production and water conservation is in order.

Our reliance on large scale energy produced at a distance from our consuming it is vulnerable to both weather and intentional interruption and is inefficient in its transmission. Industrial wind and solar farms have all those issues, plus taking up our valuable arable land. On-site wind and solar is more efficient, less vulnerable, and saves farmland. Geo-thermal energy can be added to that mix. All are suitable for homes, multiple-occupancy housing, and businesses.

As food production around the world, including our Mid-West, becomes less-and-less reliable, downscaling to local farming, Community Supported Agriculture (CSAs), urban agriculture, cooperative gardens, home gardens, backyard orchards, and adaptive permaculture will be important. All these alternatives to large scale industrial agriculture are less vulnerable to severe weather, erosion, disease, more likely to produce healthful food not impacted by pesticides and herbicides, be more effective with water usage, and not contribute to the greenhouse gases that industrial agriculture does via its massive machinery and tilling.

Since we will experience some warming and want to retain the water we do receive in manageable and useful ways, trees, trees, trees should be high on our list of priorities, from the countryside and watersheds to urban areas. Currently, Buffalo is less of a heat island than overbuilt cities. If we don't plan on keeping areas green with flora instead of just adding built environment to accommodate our growth, we will lose that advantage.

The physical effects of global warming will impact everyone, from the most prominently successful businesses to those needing the most help to emerge from inequality. We can adapt and thrive only if we respect that and apply judicious planning that includes everyone. If we don't include that in our work, taking our responsibility to future generations to heart, the now disadvantaged will become even more disadvantaged, and if we do plan judiciously and prepare accordingly, we will help end the inequality. Our region's advantages not only allow for producing the food to feed our local population, but—especially with greenhouse and vertical gardening—develop export food-based businesses.

Fortunately, the physical adaptations described above lend themselves to developing a more just and sustainable social infrastructure. The downscaling/decentralizing of energy production will lead to sharing via neighborhood micro-grids and cooperatives. The downscaling of food production will lead to more affordable, healthful food via CSAs, community gardens and orchards (also contributing to reducing greenhouse gases and retaining precipitation).

Bringing preparedness to the Buffalo-Niagara Region presents an opportunity to thrive, not just survive if we prepare both our physical and societal infrastructure and continue to build on the revitalization it is already experiencing. A once Queen City could be so again in a region that will be one of the most livable in the country.

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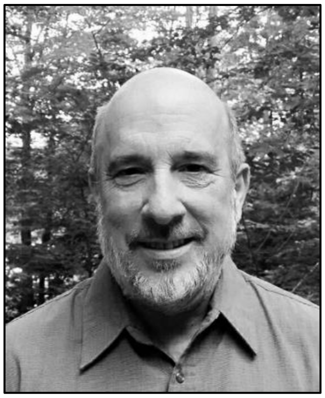
A radiance of ice beams. Image Source: V. Vermette

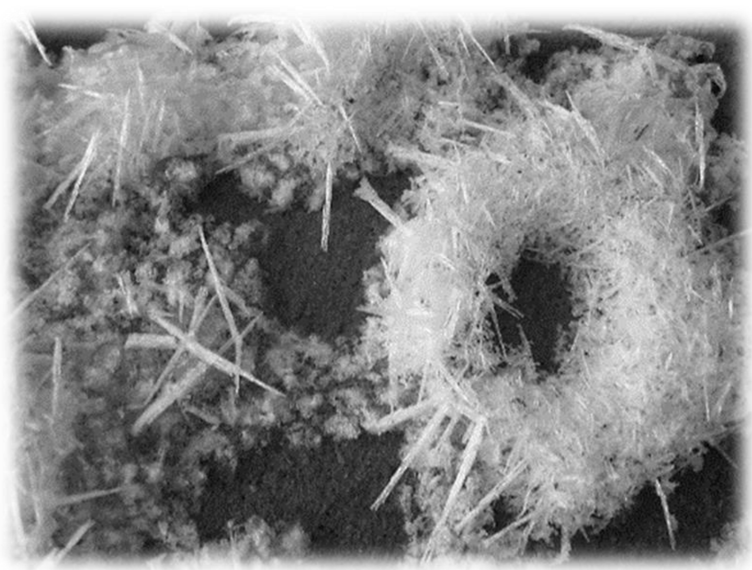
About the Author



Dr. Stephen Vermette is a professor of geography in the Department of Geography and Planning, SUNY Buffalo State where he has taught meteorology and climatology courses, and mentored students, for over 25 years. He is an elected member of the American Meteorological Society (AMS), involved with the local AMS Western New York Chapter. Dr. Vermette received a commendation from the National Geographic Society for his dedicated leadership rendered to the State of New York to ensure the geographic literacy of the next generation, as well as receiving the Virginia Figura Award in recognition of distinguished service to Geographic Education in New York State. Dr. Vermette was also awarded the National Council for Geographic Education Distinguished Teaching Award, and Buffalo State's President's Award for Excellence in Teaching. In addition, he was honored with an Espirit de Corps Award from the Burchfield Penney Art Center.

Dr. Vermette's research in meteorology/climatology began with an analysis of intense storms in the Detroit-Windsor area, as part of his undergraduate and Master's Theses while at the University of Windsor (Windsor, Ontario). His research interests migrated to atmospheric chemistry, researching the atmospheric deposition of pollutants while completing his doctorate at McMaster University (Hamilton, Ontario). Working with the Atmospheric Chemistry Section of the Illinois State Water Survey, Dr. Vermette focused on the modeling of urban air pollutants and is a co-founder of the bi-national Mercury Deposition Network. In addition, served as Assistant Director of the Illinois Climate Change Program.

While in WNY, Dr. Vermette returned to his roots in meteorology/climatology where, additional to teaching, he has published numerous articles on local weather, provided local weather expertise for media outlets, and served the community with his expertise, including as a forensic meteorologist. The Wall Street Journal referred to Dr. Vermette as a "rare climatologist", noting that he co-curated (with Tullis Johnson) a traveling art exhibition "Charles E. Burchfield: Weather Event", which received an Award of Commendation from Museumwise. Dr. Vermette has an eclectic interest in all things related to weather and climate, especially as it relates to Western New York (WNY).



Ice needles forming around rock salt on a sidewalk. Image Source: Stephen Vermette