Weathering Change in WNY: WNY's Five Climate Zones

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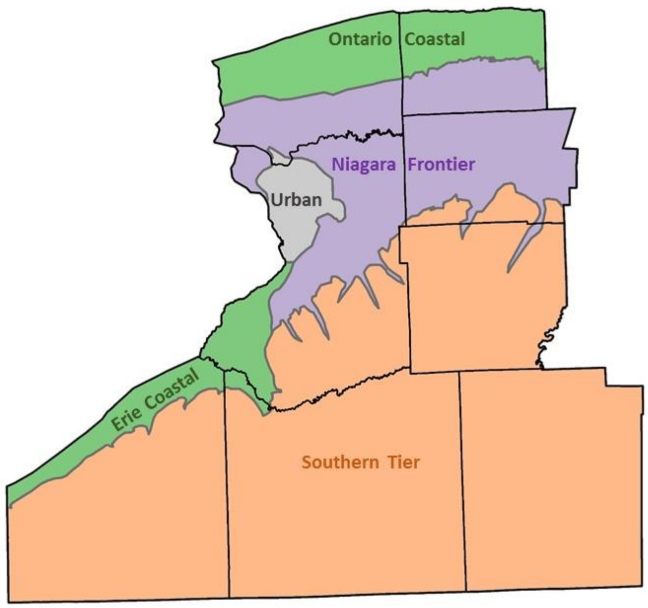

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Executive Summary

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Western New York (WNY) is defined here 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 often defined as the aggregate of long-term weather data (averages and extremes) collected by the National Weather Service (NWS) weather station located at the Buffalo-Niagara International Airport (KBUF). How representative is KBUF of the entire region? WNY is a political region defined by the boundaries of eight counties, while climate is defined by a number of interacting forces driven by atmospheric processes, defined as 'climate controls'. The goal of this report is to better characterize the climate of WNY by seeking a definition of unique climate zones, defined not by a single weather station nor by political boundaries, but by climate controls.

The classification of climates, like that of animals, plants, minerals, and clouds, was derived to better organize our understanding of nature's complexities. Based on the heterogeneous nature of WNY, the three 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) proximity to large bodies of water, as lakes moderate climates and promote clouds, rainfall, and LES; and 3) population density (urban area), where concentrated human activity creates an urban heat island effect.

The application of three simple climate controls appears to successfully identify climate variance in WNY at a spatial scale generally ranging from 10 to 100 miles, within the lower limits of what is spatially defined as 'mesoscale'. Five climate zones are identified in this report to describe climatic variance. These climate zones are labeled: Ontario Coastal, Niagara Frontier, Southern Tier, Erie Coastal and Urban. Each climate zone is demonstrably unique from one another.

Rather than applying artificial political boundaries, climatic studies, and the application of climate data, would be advanced by recognizing naturally occurring climate zones, much as land-based aquatic resources are often delineated and managed by watersheds. In addition, a companion study '*Weathering Change in WNY: Climate Trends (1965-2016)*' suggests that, in a warming world, climatic responses and non-responses within WNY may vary by climate zones.

While WNY temperature and precipitation variance is generally accounted for by the identified five climate zones, it is clear that the zones need to be more precisely defined and characterized – both spatially and temporally. The existence of a climate zone may be seasonal, or may vary in size by season, and it is possible that sub-zones may need to be established. Furthermore, the absence of a sufficient number of NWS COOP weather stations in certain climate zones (especially the coastal zones) will require a more thorough database search. With WNY climate zones efficacy now authenticated, future research needs to be supported so they may be more precisely defined and characterized.

This report was prepared for the Western New York nonprofit 'Designing to Live Sustainably' [d2ls] (http://d2ls.org/).

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INTRODUCTION

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 of time. 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".

Western New York (WNY) is defined here collectively as the eight westernmost counties of New York State (NYS): Niagara, Erie, Chautauqua, Cattaraugus, Allegany, Wyoming, Genesee, and Orleans (Figure 1).

Figure 1: The Eight Counties of Western New York (WNY).

The climate of WNY is characterized as a mid-latitude warm-summer, humid continental climate − Dfb, based on the Köppen climate classification criteria. 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 $\geq$ 10°C (50°F), but not greater than 22°C (72°F), winter temperatures of the coldest month as $\leq$ -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.

The Dfb definition of WNY's climate also does not take into account 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 ft 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 take into account 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, 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.

WNY is a political region defined by the boundaries of eight counties, and KBUF is often used as the station of record for this region. The collection and reporting of region-wide weather data (ie. thunderstorm, hail, or tornado occurrences) is reported by county. It is now widely recognized that natural characteristics, such as watersheds, are not confined by political boundaries and are not effectively defined by them. The same might be said for climate. The goal of this report is to better characterize the climate of WNY by seeking a definition of unique climate zones, defined not by a single weather station nor by political boundaries, but by climate controls.

This report was prepared for the Western New York nonprofit 'Designing to Live Sustainably' [d2ls] (http://d2ls.org/).

METHODOLOGY

The classification of climates, like that of animals, plants, minerals, and clouds, was derived to better organize our understanding of nature's complexities. 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). Another approach to climate classification examines the effect of air masses on a region. A region influenced solely by a maritime tropical (mT) air mass (wet and hot) will experience a very different climate than a region affected by a continental polar (cP) air mass (dry and cold). Standard climate classification systems are usually defined simply by temperature and precipitation parameters. For the purposes of this study, we considered the influence of 'climate controls' in defining WNY's climate zones.

The climate of a place is influenced by a number of factors, defined as 'climate controls'. Based on the heterogeneous nature of WNY, the three 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) proximity to large bodies of water, as lakes moderate climates and promote clouds, rainfall, and LES; and 3) population density (urban area), where concentrated human activity creates an urban heat island effect.

Constructing the climate zones first involved mapping the shoreline boundaries of Lakes Erie and Ontario. WNY's terrain ranges in elevation from 237 ft asl along the Lake Ontario shoreline to 2,500 ft asl in the Allegany Plateau. Elevational boundaries were defined by the 500 ft contour, delineating the Niagara Escarpment, and the 1000 ft contour delineating the Chautauqua Ridge in Chautauqua County. The 1,000 ft contour was extended as a boundary further east into Erie and Genesee Counties where the contour and ridge is less prominent. A boundary for the urban zone was defined from an image acquired using enhanced thematic mapping on NASA's Landsat 7 Satellite (Figure 2) https://earthobservatory.nasa.gov/IOTD/view.php?id=47704. Modeled climate data and USDA plant hardiness zones (PRISM data), using the 1981-2010 Normal, were superimposed over the controls to validate these boundaries and to characterize the climate within each zone http://prism.oregonstate.edu/. These long-term average datasets are modeled using a digital elevation model (DEM) as the predictor grid. Individual weather station data, obtained through the National Weather Service (NWS) Cooperative Observer Program (COOP) at http://xmacis.rcc-acis.org/, were used to further validate the modeled data and climate zones. The maps used in this report are map overlays created by this author, based on originals created by Mary Perrelli (Department of Geography & Planning at SUNY Buffalo State) for a GIS course module "Climate Classification Based on Climate Controls" (http://arcg.is/2tSIvoJ).

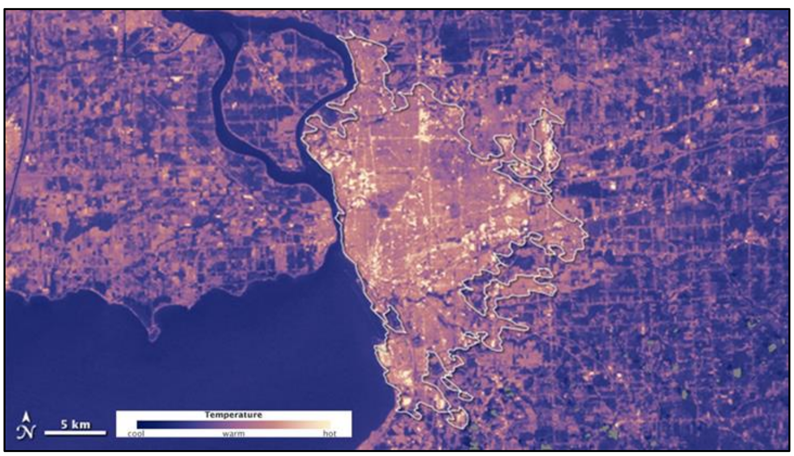

Figure 2: Buffalo's urban heat island. Image acquired on August 3, 2002 from enhanced thematic mapping on NASA's Landsat 7 satellite

RESULTS

Constructing Climate Zones

The contour boundaries (Niagara Escarpment and Chautauqua Ridge, 500 and 1,000 ft asl, respectively) are shown in Figure 3. Also shown are the shorelines of Lakes Erie and Ontario, and the City of Buffalo. The resulting map (Figure 4) delineates five climate zones: Ontario Coastal, Erie Coastal, Niagara Frontier, Urban, and Southern Tier (Figure 4).

Figure 3. Climate zone boundaries, including the Lakes Erie and Ontario shorelines, Niagara Escarpment and Chautauqua Ridge, and the City of Buffalo.

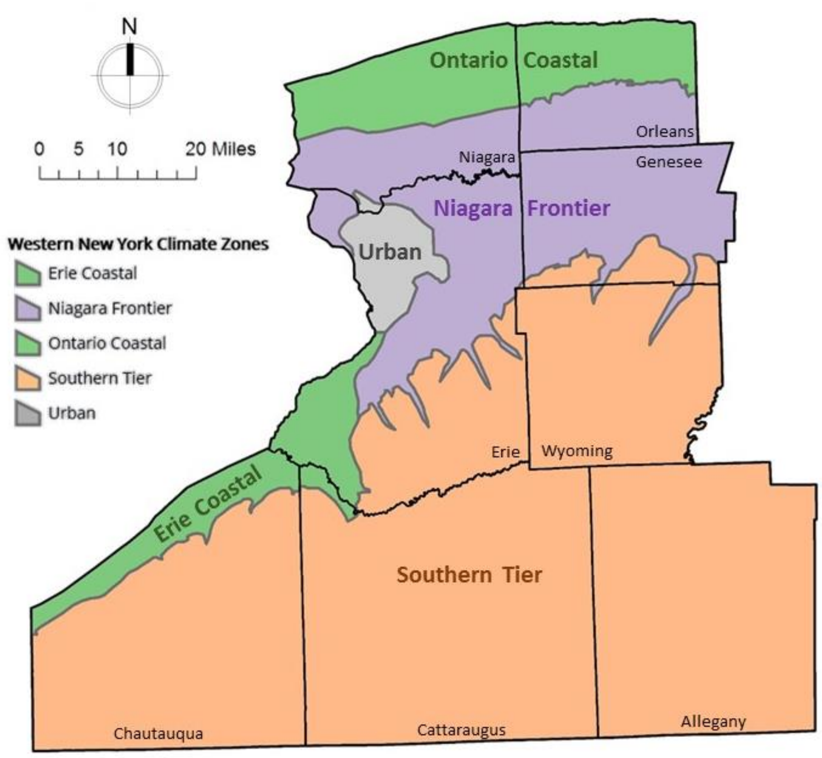

Figure 4. WNY's five climate zones. The Urban Zone boundary was obtained from Landsat 7 imagery. County boundaries are shown for reference.

Temperature Validation

Annual and seasonal temperature data, using 1981-2010 Normals obtained from PRISM, were superimposed on the proposed climate zones (Figures 5 and 6). The temperature data show a good fit, with some exceptions.

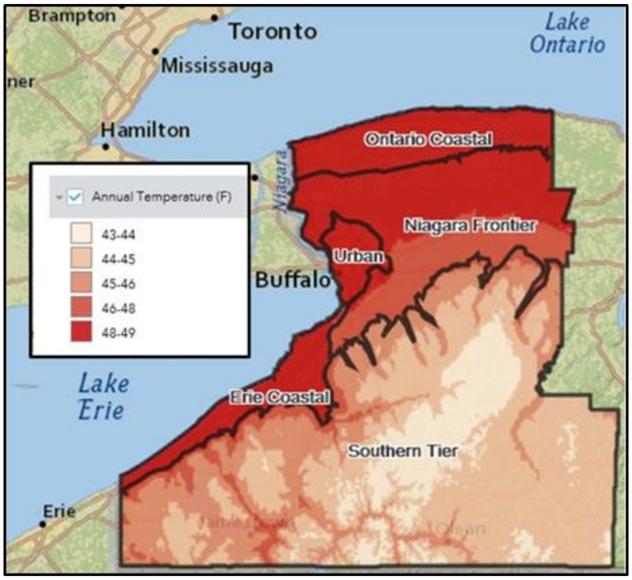

Figure 5. Annual temperature data (PRISM data) superimposed on WNY's five climate zones.

The 1,000 ft contour appears to be a good boundary, separating the Southern Tier climate zone from the Niagara Frontier and Erie Coastal zones. The 500 ft contour boundary (Niagara Escarpment) separates the Ontario Coastal and Niagara Frontier climate zones during the winter and fall seasons, but does not appear to be a boundary for annual temperatures, nor for the spring and summer seasons. In spring, the influence of Lake Ontario appears to be confined to a narrower near-shore zone, while this zone disappears altogether during the summer months. This narrow spring cold zone is also apparent along the nearshore of the Lake Erie Coastal zone, with a graduated warming occurring further inland, until reaching the Chautauqua Ridge. It is expected that a more detailed study of the two coastal zones would reveal sub-zones during the spring season. In both spring and summer, as well as with the annual data, the Niagara Frontier zone appears to be bifurcated − the northern section exhibiting warmer temperatures than that of the southern. This temperature boundary appears to align with the Onondaga Escarpment, which is less prominent than the Niagara Escarpment. This 'hard' boundary may be a relic of PRISM modeling. It is more likely that a broader north-south temperature gradient exists, reflecting a down-sloping terrain.

The temperature data does not appear to identify an Urban zone, with the possible exception of summer where warm temperatures dip further south within the Urban zone. This 'dip' south also appears with the annual temperature data. PRISM data likely does not include a sufficient number of weather stations to differentiate the urban heat island from its surrounding rural area. A 'quick comparison' was done of 2017 weather data from Weather Underground stations located north of Buffalo's downtown and the rural locations of Alden, Elma, and Lancaster east of the city. This comparison reveals heightened annual urban temperature differences in the city of +2°F, as well as heightened seasonal averages (winter: +1.7°F, spring: 1.7°F, summer: +2.5°F, fall: +2.6°F). A more detailed study of Buffalo's urban heat island boundary and intensity is needed.

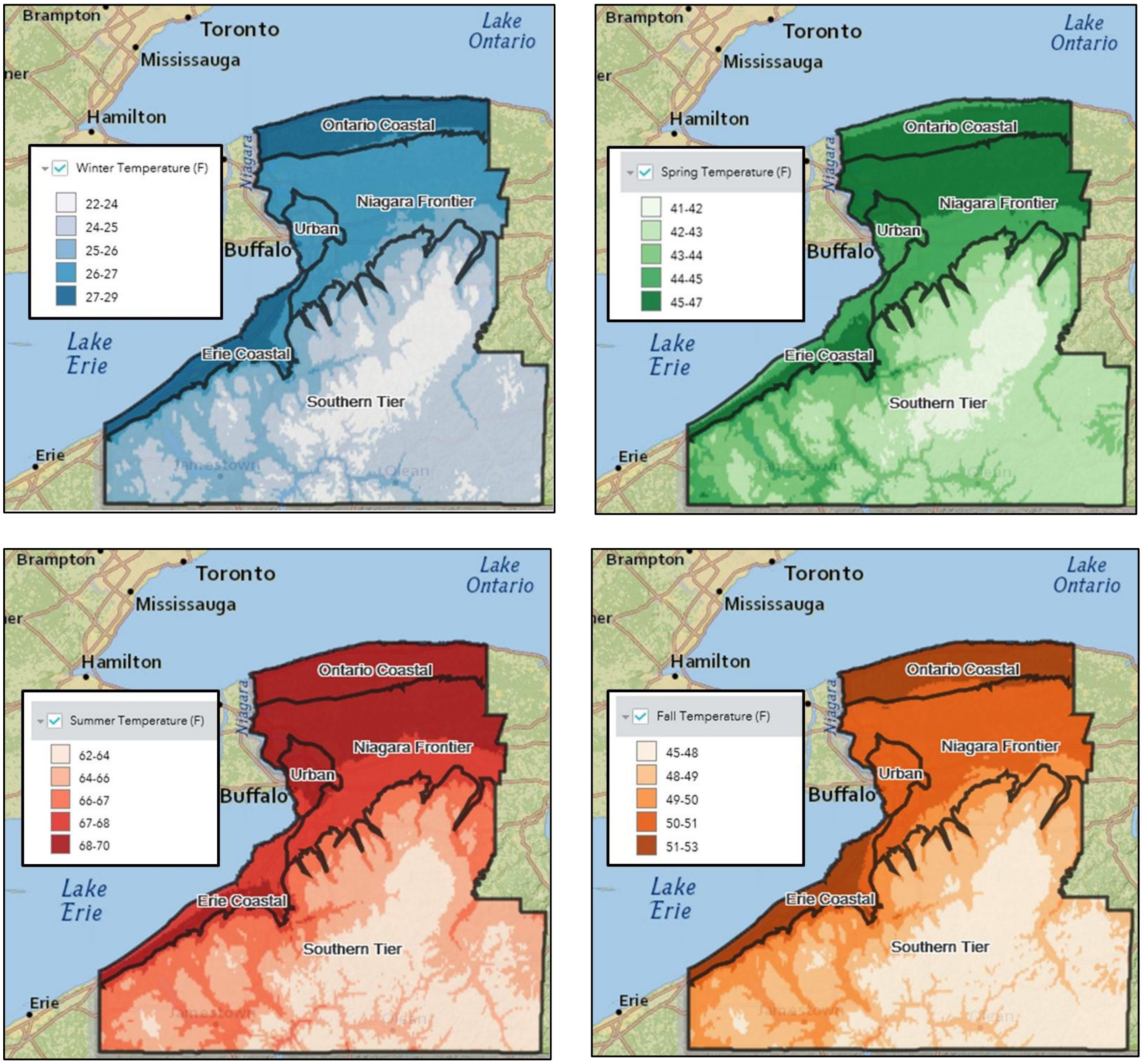

Figure 6. Seasonal temperature data (PRISM data) superimposed on WNY's five climate zones.

As with the seasonal temperature data, USDA Plant Hardiness Zone data superimposed onto the climate zones appear to show a good fit (Figure 7). Minor varients to this fit include an extrusion of the 6a hardiness zone into the 6b hardiness zone (prominent in the Ontario Coastal Zone) which may be associated with bench lands along the Niagara Escarpment – a narrow strip of gently inclined land that is bounded by a distinctly steeper slope to the south. A similar, though less extensive, example of this 'extrusion' can be seen on the fall season temperature map in Figure 5. In addition, the 1,000 ft contour appears slightly out-of-line in seperating the 5b from the 6a hardiness zones between the Southern Tier and Niagara Frontier, and between the Southern Tier and Erie Castal Zones. Lastly, the boundary between the Niagara Frontier and Erie Coastal zones does not appear to reflect plant hardiness zones.

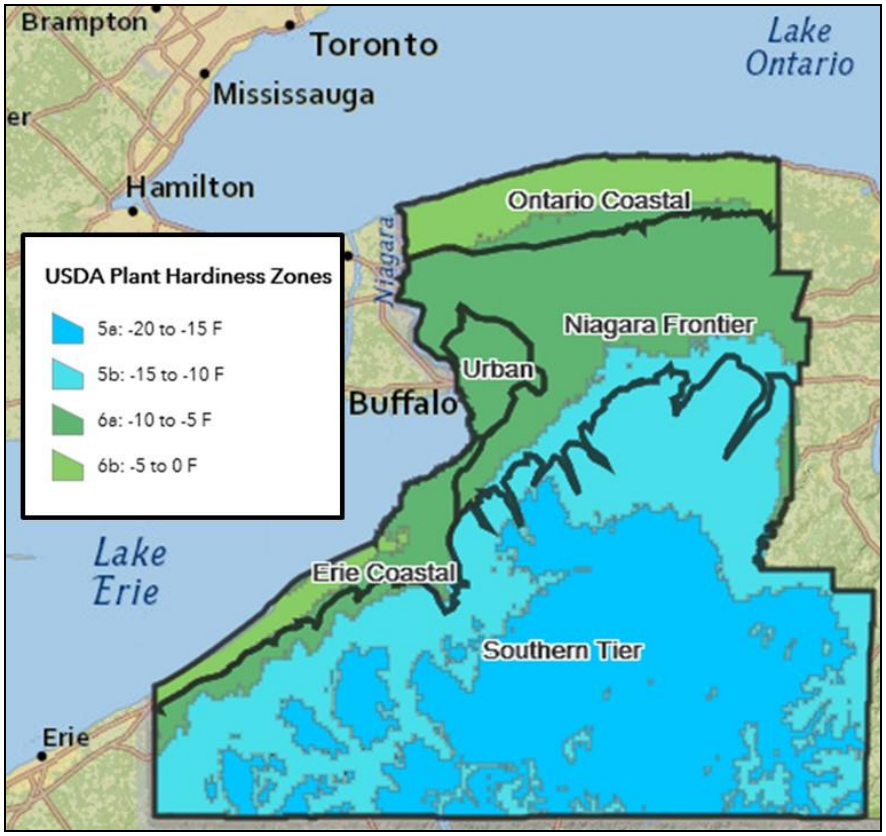

Figure 7. USDA Plant Hardiness Zones (PRISM data) superimposed on WNY's five climate zones.

Precipitation Validation

Annual and seasonal temperature data, using 1981-2010 Normals obtained from PRISM, were superimposed on the proposed climate zones (Figures 8 and 9). The precipitation data shows a reasonable fit with the climate zones.

A north-south precipitation gradient clearly exists in WNY, where rain and snow increases as one travels south. The 1,000 ft contour appears to be the boundary confining the higher precipitation (annual and seasonal) to the Southern Tier climate zone. The precipitation contrast at the Southern Tier and Erie Coastal boundary is most striking at the 1,000 ft contour along the Chautauqua Ridge. The 500 ft contour (Niagara Escarpment) also appears to be a boundary, delineating the lesser precipitation, especially snowfall, that occurs north of the Escarpment.

The Urban Zone does not show an urban-influenced precipitation pattern. In addition, a general decrease in precipitation appears on the eastern edge of the Ontario Coastal, Niagara Frontier, and Southern Tier climate zones. This decrease may be explained, at least in part, by distance from Lake Erie. Moisture obtained from Lake Erie instability, falling as rain or snow downwind, appears to dissipate with distance from the lake.

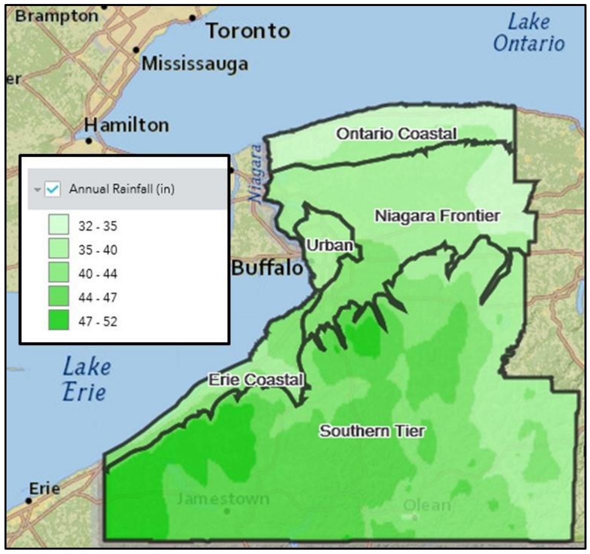

Figure 8. Annual precipitation data (PRISM data) superimposed on WNY's five climate zones

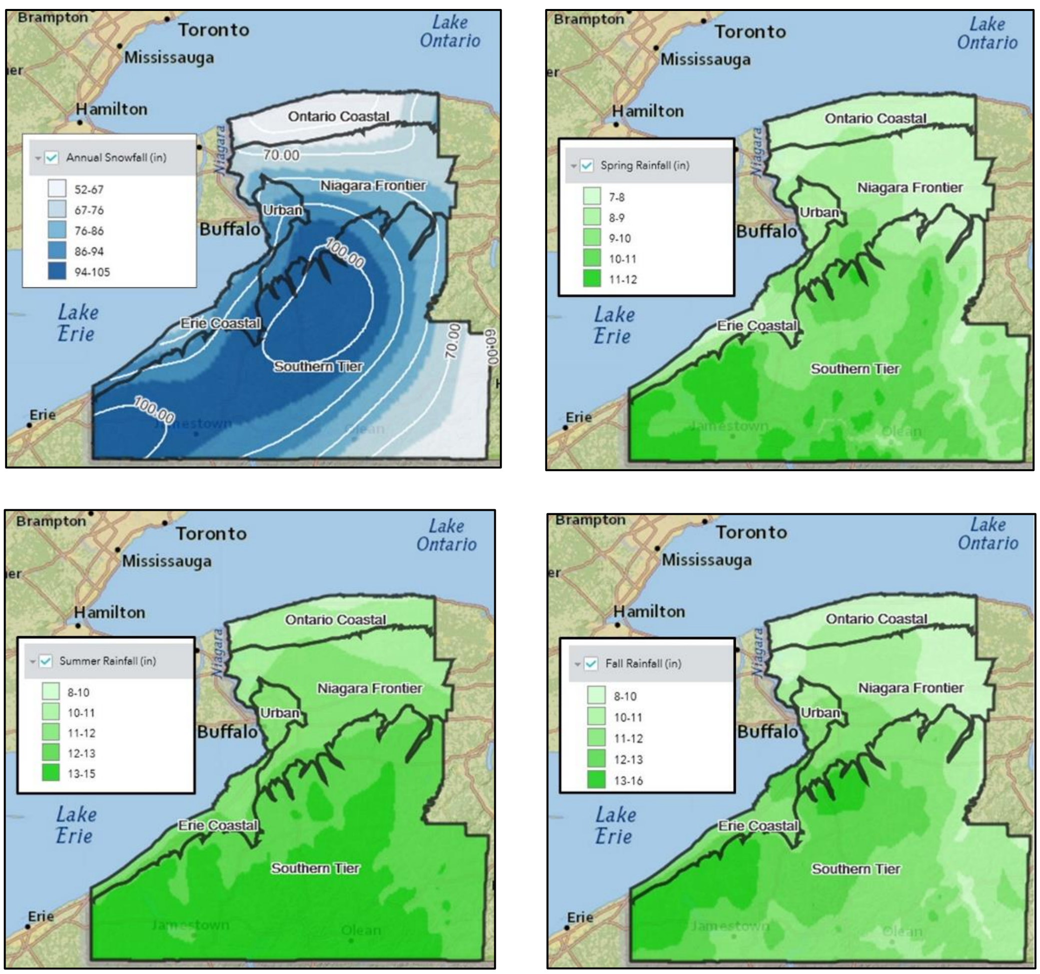

Figure 9. Seasonal Precipitation data (PRISM data) superimposed on WNY's five climate zones.

Forecasting Validation

When providing weather forecasts and weather-related watches, warnings, and advisories, the NWS delineates along county boundaries. One exception is Erie County, which is often subdivided into a northern and southern section. This division, it can be assumed, is based on accumulated weather-related observational experience. This division generally reflects the separation of Erie County in this study, placing northern Erie County in the Niagara Frontier zone, and southern Erie County in the Southern Tier zone, bisected by the 1,000 ft contour. In addition, forecast wording couched as "warmer or cooler near the lake" (dependent on season) or use of the well-established geographic monikers "southtowns", "northtowns", and "ski-country", reflect the climate zone boundaries established in this study.

Climate Zone Descriptions

Ontario Coastal (502 sq. miles)

The boundary of the Ontario Coastal zone is defined by Lake Ontario to the north and the Niagara Escarpment (500 ft asl) to the south.

Temperatures in this zone are moderated by its proximity to Lake Ontario. The Ontario Coastal zone is seasonal. It is best manifested in the autumn and winter months, with average temperatures of 51°F to 53°F, and 27°F to 29°F, respectively. These values match Erie Coastal temperatures (located in proximity to Lake Erie), and are the warmest average temperatures in WNY. The USDA Plant Hardiness zones reflect this as well, designating most of the Ontario Coastal zone as 6b, with minimum severe temperatures ranging between -5°F to 0°F. In the spring, the Ontario Coastal zone departs from the boundaries described above as it is confined to a narrow strip of land along the Lake Ontario shoreline. Temperatures within this narrow strip average 44°F to 45°F. In the summer and on an annual basis, the Ontario Coastal zone does not exist as temperatures cannot be differentiated from the Niagara Frontier located to its south.

The Ontario Coastal zone best conforms to its prescribed boundaries in relation to annual precipitation and snowfall, 32-35 inches and 52-67 inches, respectively. In both cases, this region experiences some of the lowest values in WNY, although the boundaries vary − hugging the Ontario shoreline in summer, while in spring and fall extending south into northern areas of the prescribed Niagara Frontier zone. Lake effect snow occurs off of Lake Ontario, but the Ontario Coastal zone experiences the least LES of all five zones. As a zone, it is least prone to tornadic activity.

Niagara Frontier (1,247 sq. miles)

The Niagara Frontier zone encompasses a northward-sloping terrain which includes a series of escarpments (steps). The Niagara Escarpment (500 ft asl) defines the northern boundary, while the southern boundary is defined by the Chautauqua Ridge (1,000 ft asl) where it extends eastward across WNY. The western boundary abuts the Urban zone and the northern edge of the Erie Costal zone.

The average temperature of this zone conforms to the prescribed boundaries in the fall and winter months, 50°F to 51°F and 26°F to 27°F, respectively. The USDA Plant Hardiness zones reflect this as well, designating most of the Niagara Frontier zone as 6a, with minimum severe temperatures ranging between -10°F to -5°F. The spring and summer temperatures show an increasing south-to-north temperature gradient within the Niagara Frontier zone that could be divided into two north-south subzones, with spring temperatures averaging 44°F to 45°F in the north and 45°F to 47°F to the south, and summer temperatures averaging 67°F to 68°F in the north and 68°F to 70°F in the south.

The precipitation pattern is not homogenous within the prescribed boundaries of the Niagara Frontier zone; instead it reflects a transition between the Ontario Coastal and the Southern Tier zones. Annual precipitation ranges from 32 to 44 inches, with lower values (32 to 35 inches) found in the east and higher values (40 to 44 inches) in the southwest. Additionally, this pattern of increasing precipitation from northeast to southwest is found in the spring, summer, and fall seasons. Snowfall increases in a series of steps from north to south, from 67 to 76 inches to 94 to 105 inches, respectively. This difference can be attributed to lake effect snow coming off of Lake Erie.

Southern Tier (4,324 sq. miles)

The Southern Tier zone is defined by its elevation – the highest in WNY. The western boundary is defined by the Chautauqua Ridge (1,000 ft asl), as is the northern boundary where the ridge extends eastward across WNY.

Temperatures in this zone are controlled by elevation, with cooler temperatures found at the higher elevations (coolest in WNY) and warmer temperatures confined to valleys within the zone (notably Catteraugus River, Allegany River, Geneese River, and Chautauqua Lake). The annual and seasonal temperatures conform well to the prescribed boundaries of the Southern Tier zone: annual (43ºF to 45°F); winter (22°F to 25°F); spring (41°F to 43°F); summer (62°F to 66°F); and fall (46ºF to 49ºF). The USDA Plant Hardiness zones reflect the influence of elevation, designating areas of higher elevation in the Southern Tier zone as 5a, with minimum severe temperatures ranging between -20ºF to -15ºF in areas of higher elevation, and as 5b in areas of lower elevation, with minimum severe temperatures ranging between -15°F to -10°F.

WNY annual and season precipitation is generally highest in the Southern Tier zone where it follows a gradient of decreasing precipitation from west (47 to 52 inches) to east (32 to 35 inches). Similarly, snowfall is greatest in the west and central area of the zone (94 to 105 inches), and least in the east (52 to 67 inches). The Southern Tier is the zone most prone to lake effect snow off of Lake Erie, and to tornadic activity.

Erie Coastal (329 sq. miles)

The boundary of the Erie Coastal zone is defined by Lake Erie to the west, the Chautauqua Ridge (1,000 ft asl) to the east, and the Urban zone to the north.

Temperatures in this zone are moderated by proximity to Lake Erie, showing a sharply increasing temperature gradient along the Chautauqua Ridge. The annual, winter, and fall temperatures conform well to the prescribed boundary, with annual temperatures 48°F to 49°F, winter temperatures 27°F to 29°F, and fall temperatures 51°F to 53°F. A temperature gradient is apparent in spring and summer, where temperatures are cooler near the lake and warmer inland. In spring, temperatures range between 42°F to 43°F near the shoreline and 45°F to 47°F inland, while in summer they range between 67ºF to 68ºF near the shoreline and 68°F to 70°F inland. The USDA Plant Hardiness zones designate much of the Erie Coastal zone as 6b, with minimum severe temperatures ranging from -5°F to 0°F. Where the Erie Coastal zone widens in its northern reaches, it is designated 6a, with severe minimum temperatures ranging from -10°F to -5°F.

The Erie Coastal zone is drier than the Southern Tier zone, exhibiting both less rain and less snow. A gradient of increasing precipitation occurs with distance from the shoreline. The Erie Coastal zone is prone to lake effect snow off of Lake Erie, and to tornadic activity.

Urban Zone (147 sq. miles)

The Urban zone is defined as the City of Buffalo and its first ring suburbs, bordering the Niagara Frontier and Erie Coastal zones. Average annual temperatures are about 2°F warmer than temperatures in the adjacent Niagara Frontier zone, being slightly greater in the summer and slightly less in the winter and spring. These warmer temperatures result from the urban heat island effect. The exception is the area immediately adjacent to Lake Erie which experiences cooler temperatures in spring and summer when winds are off of the lake. The Urban Zone is prone to lake effect snow off of Lake Erie.

CONCLUSION

The climate across WNY is often treated as homogenous, although it is recognized by those living there as being varied, with variance existing at many different scales. The application of three simple climate controls appears to successfully identify climate variance at a spatial scale generally ranging from 10 to 100 miles, within the lower limits of what is spatially defined as 'mesoscale'. Five climate zones are identified in this report to describe the variance. These climate zones are demonstrably unique from one another.

The advantage of climate zones is that their existence (boundaries and characteristics) constitutes a controlling affect not based on arbitrary political boundaries. It is the practice of the National Weather Service (NWS) to report severe weather events by county, but climatic studies and the application of climate data might be further advanced by recognizing climate zones, much as land-based aquatic resources are often delineated and managed by watersheds. In addition, a companion study *'Weathering Change in WNY: Climate Trends (1965-2016)'* suggests that in a warming world climatic responses and non-responses within WNY may vary by climate zones.

While temperature and precipitation variance is generally accounted for by the identified climate zones, it is clear that the five WNY climate zones need to be more precisely defined and characterized – both spatially and temporally. The existence of a climate zone may be seasonal, or may vary in size by season, and it is possible that sub-zones may need to be established. Furthermore, the absence of a sufficient number of NWS COOP weather stations in certain climate zones (especially the coastal zones) will require a more thorough database search. With the efficacy of WNY climate zones now authenticated, future research needs to be supported so they may be more precisely defined and characterized.

ACKNOWLEDGEMENTS

My appreciation to Mary Perrelli who created the original maps which were used to create the map overlays used in this report. The original maps were prepared for use in a WNY GIS course module "Climate Classification Based on Climate Controls". Funding for the GIS module was provided by a 2016 SUNY IITG (Innovative Instruction Technology Grant) awarded to Mary Perrelli and Wende Mix (Department of Geography & Planning at SUNY Buffalo State). The module serves as a companion piece to this report.

http://gistechhub.buffalostate.edu/sites/gistechhub.buffalostate.edu/files/uploads/Documents/Climate%20Classification_9_25_17.pdf. Additional research was provided by Zachary Neudeck, a Buffalo State geography major. Additional guidance was provided by George Besch, Michael Shelly, and Allison Leet of d2ls. I am also appreciative of the insight provided by numerous individuals present at early presentations of this research − thank you. Funding for this report was provided by the Buffalo State SUNY Research Foundation.