

## **Spatiotemporal Snowfall Trends in Central New York**

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### **ABSTRACT**

Central New York State, located at the intersection of the Northeastern United States and the Great Lakes basin, is impacted by snowfall produced by lake-effect and non-lake-effect snowstorms. The purpose of this study is to determine the spatiotemporal patterns of snowfall in Central New York, and their possible underlying causes. 93 Cooperative Observer Program stations are used in this study. Spatiotemporal patterns are analyzed using simple linear regressions, Pearson correlations, principal component analysis to identify regional clustering, and spatial snowfall distribution maps in ArcGIS. There are three key findings. First, when the long-term snowfall trend (1931/32-2011/12) is divided into two halves, a strong increase is present during the first half (1931/32-1971/72), followed by a lesser decrease in the second half (1972-2012). This suggests that snowfall trends behave non-linearly over the period of record. Second, Central New York spatial snowfall patterns are similar to those for the whole Great Lakes basin. For example, for five distinct regions identified within Central New York, regions closer to and leeward of Lake Ontario experience higher snowfall trends than regions farther away and not leeward of the lake. Finally, compared with multiple climate indices, only the Atlantic Multidecadal Oscillation, with no lag, had the greatest significant ( $p < 0.05$ ) correlation (-0.41) with seasonal snowfall totals in Central New York. Findings from this study are valuable as they provide a basis for understanding snowfall patterns in a region affected by both non-lake-effect and lake-effect snowstorms.

Keywords: lake-effect snow, Lake Ontario, snowfall, COOP

### **1.0 INTRODUCTION**

Natural forces have always shaped the earth's climate, but recently the IPCC (2013) has noted a positive correlation between global air temperatures and carbon dioxide from anthropogenic sources. This finding has considerable implications on the regional climate of an area, especially in the snow-dominated latitudes of the United States. Most of the observed warming in the last century has been in the high latitudes, increasing the potential for precipitation to fall as rain rather than snow (Knowles et al. 2006).

Central New York has grown accustomed to seasonal snowfall totals regularly exceeding 250 cm, which has created a societal dependency on snowfall for winter recreation, spring snowmelt, and insolation of plant biomass from freezing temperatures (Kunkel et al. 2002). Central New York is unique compared to other regions in the Great Lakes basin because it is located at the intersection of the Northeastern United States and the Great Lakes basin. As a result, snowfall in Central New York regularly occurs from both lake-effect and non-lake-effect snowstorms. Lake-effect snowstorms are those that result from the advection of a cold air mass (generally a polar or Arctic air mass) over a relatively warm lake (Peace and Sykes 1966). The moisture, lift, and

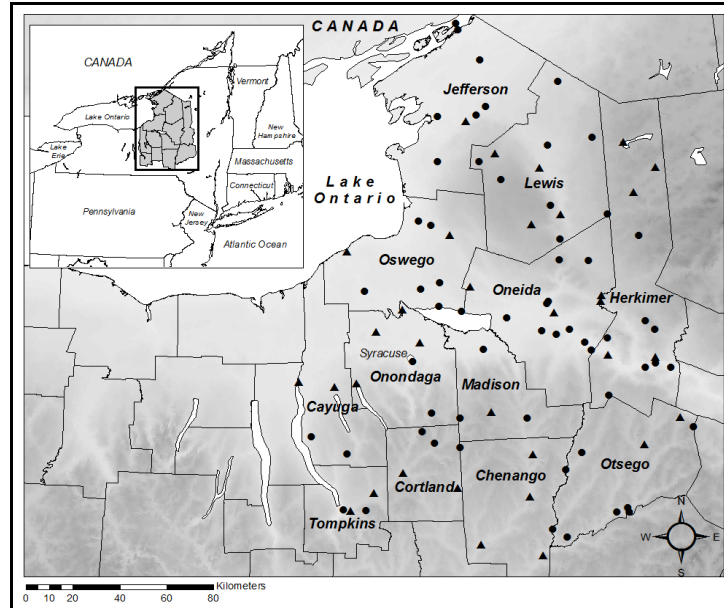
instability that generate the snowfall are thus produced solely by the advection of cold air over warmer water. Non-lake effect snowstorms are those that result from all other mechanisms responsible for organizing moisture, lift, and instability into snowfall. These storms are generally associated with a transient low pressure system (i.e. mid-latitude cyclone or Nor'easter). Yet, several studies have found a large contrast between non-lake effect snowfall trends and lake-effect snowfall trends, as follows.

Norton and Bolsenga (1993), Burnett et al. (2003), Ellis and Johnson (2004), and Kunkel et al. (2009a) found a significant increase in snowfall for stations that experience lake-effect snowfall (those within the extent of the Great Lakes basin) since the early-20<sup>th</sup> century. For Lake Ontario basin, Burnett et al. (2003) noted an approximate  $1.5 \text{ cm yr}^{-1}$  increase from 1931-2001. However, Kunkel et al. (2009a) noted that due to inhomogeneities within the dataset of Burnett et al. (2003), the snowfall increase was overestimated by approximately  $0.9 \text{ cm yr}^{-1}$ . Kunkel et al. (2009a) suggests that this difference is attributed to the use of filtered Cooperative Observer Program (COOP) data, which removes biases in the data and reduces an overestimation of snowfall trends by Burnett et al. (2003).

The previously discussed studies all framed snowfall trends as a long-term increase. In contrast, a subsequent study by Bard and Kristovich (2012) proposed the presence of a trend reversal. The authors noted that the long-term snowfall trend actually experienced a reversal in the late-1970s, suggesting that since the 1970s, snowfall has decreased for the Lake Michigan basin. However, notable differences exist between Lake Michigan and Lake Ontario, such as the orientation of the two lakes, the influence of coastal low pressure systems (i.e. Nor'Easters), and the water properties (i.e. depth, temperature, surface area, ice onset and breakup) of the two lakes (Wang et al. 2012). Therefore, it is important to expand upon the findings of Bard and Kristovich (2012) to determine if a trend reversal is also present for the snowfall in a second Great Lakes basin, and more importantly, quantify how significant it may be.

The presence of a trend reversal may suggest a cyclical pattern in snowfall trends, which could be driven by teleconnection patterns. Studies have found a climatic influence on weather patterns in the Northeast and Great Lakes basin from three particular oscillations: the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Atlantic Multidecadal Oscillation (AMO). Grimaldi (2008) discovered that during the El Niño (warm) phase of ENSO, early winter months in Syracuse, New York are generally warmer with anomalously low snowfall totals. This pattern then reverses during later winter months. Along with ENSO, Kocin and Uccellini (2004) found that the NAO is negatively correlated (-0.64) with seasonal snowfall in the eastern United States. The AMO, a 65-70 year variation in Atlantic sea surface temperatures (SSTs), has not been as widely studied as ENSO or the NAO, although studies have begun to focus on the AMO's impacts on the North American climate. For example, Zhao et al. (2010) suggested that changes in the AMO result in shifts in the magnitude and location of the jet stream. Also, Fortin and Lamoureux (2009) linked changes in the AMO with northeastern United States' snowfall, as warmer than average North Atlantic sea surface temperatures favor moister conditions and increased snowfall in boreal and arctic regions.

Previous studies have observed snowfall trends for the entire Great Lakes basin. However, it is also important to understand the spatial and interseasonal snowfall changes at a local level. Therefore, an objective of this study is to determine if snowfall trends in Central New York, located in the Lake Ontario basin, behave in a similar manner to trends outlined by Norton and Bolsenga (1993), Burnett et al. (2003), Kunkel et al. (2009a) and Bard and Kristovich (2012). A major finding of previous studies was that snowfall significantly increased throughout the 20<sup>th</sup> century for lake-effect stations in contrast with stations distant from the lakes. However, the spatial variability of snowfall trends for the Great Lakes basin has not been examined. Thus, this study also determines if changes in seasonal snowfall totals are spatially homogenous throughout Central New York. Finally, the influence of teleconnection patterns on seasonal snowfall totals within Central New York is examined.



**Figure 1.** Study area. The labeled counties are the twelve counties that make up Central New York. Points symbolized with circles and triangles represent the 93 COOP stations in the study area. The 33 stations represented by a triangle report snowfall for the duration of the study period (1931/32 – 2011/12), while the 60 stations represented by a circle are not included in long-term (1931/32 – 2011/12) snowfall calculations.

## 2.0 METHODS

### 2.1 Study area

With a population of over 1 million people, Central New York is defined by twelve counties (Figure 1). Due to its location, snow associated with transient low pressure systems and lake-effect snow regularly impact the region, making the city of Syracuse the snowiest metropolitan area in the United States (NOAA 2011). Lake Ontario is the primary source of moisture and warmth for lake-effect precipitation development. Even though it is the smallest of the Great Lakes in surface area, it rarely freezes over during the winter (Niziol 1987; Wang et al. 2012). Due to its east-west orientation and leeward position relative to Lake Ontario, macro-scale wind patterns favor the development of lake-effect precipitation over Central New York (Niziol et al. 1995).

### 2.2 Data

Seasonal snowfall totals, defined here as the total snowfall from 1 July to 30 June, were examined from 1931-2012 for 93 National Weather Service COOP stations located in the twelve Central New York counties. Monthly snowfall data were accessed through the National Climate Data Center's (NCDC) online Monthly Summary Observations (digital database TD3220).

The reporting consistency for each COOP site varied, therefore stations were only used if observations were recorded for at least 5 consecutive years from 1931-2012, with at least 85% of the winter (November-April) monthly snowfall record reported during that time. A slightly lower threshold was used in this study compared to that of Kunkel et al. (2009a), who used 90% reporting frequency, in order to increase usable snowfall observations. If monthly snowfall data were missing for a station, daily COOP snowfall records were acquired for the missing month(s) from NCDC's Global Historical Climatology Network. If at least 85% of the days within an unreported month were observed, then the monthly snowfall total was used. However, after examining daily snowfall totals, if observations were missing for two or more snowfall months (November-April), then the annual snowfall total was not reported. If only one winter month was

not reported, a 4-point weighted bilinear interpolation was used to estimate the missing monthly snowfall total (Accadia et al. 2003). Once interpolated, monthly snowfall totals were summed from November-April and reported as a seasonal snowfall total.

Since lake-effect snowfall is positively correlated with elevation (Clowes 1919), each station was scrutinized for inhomogeneities outlined in Kunkel et al. (2007), with a particular emphasis on elevation changes greater than 10 meters, and changes in latitude/longitude greater than 0.15°. Many reported relocation changes were actually updated geographic coordinates. Therefore, beyond these thresholds, it was judged that a change was likely due to a relocation instead of updated coordinates. A station was also deemed inhomogeneous if the time series for the station was less than 5 years.

Data for the Southern Oscillation Index (SOI), NAO, and AMO indices were obtained from National Center for Atmospheric Research's climate data guide server (NCAR 2012). Monthly values were obtained for each teleconnection, and seasonal values were calculated from 1931-2012 by averaging data from November-April. Oscillation data was based on the standardized Tahiti/Darwin dataset for the SOI, Hurrell (1995) for the NAO, and unsmoothed Kaplan SST V2 data calculated by NOAA/ESRL/PSD1 for the AMO.

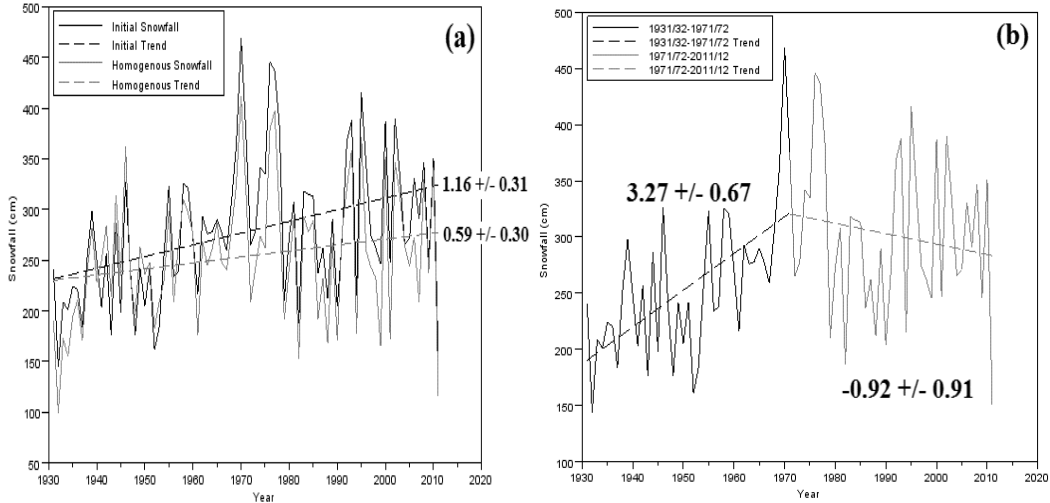
## RESULTS

### Temporal Snowfall Patterns

Temporal snowfall trends at a 5% significance were calculated using simple linear regressions (Figure 2). Autocorrelation tests were performed on each time series to investigate periodicities in the dataset, but no significant ( $> 0.3$ ) correlations existed within the dataset. Snowfall trends were calculated for the entire region by averaging snowfall totals for all available stations for each snowfall season. To detect non-linearity in the trendline, trends were calculated for the entire time series (1931-2012), at two 41-year increments (1931-1972 and 1971-2012), and by computing a 21-year trend with a 1-year moving window.

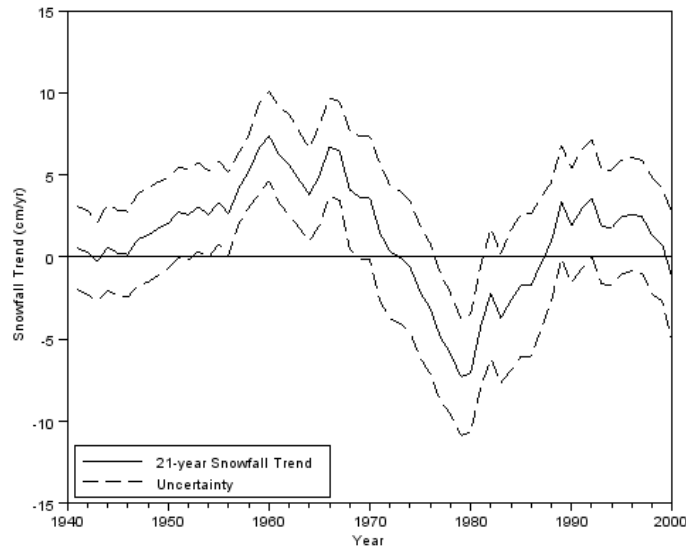
The long-term (1931/32-2011/12) seasonal snowfall trend (Figure 2a) for Central New York was  $1.16 \pm 0.31 \text{ cm yr}^{-1}$  ( $p = 0.05$ ), comparable to the  $1.5 \text{ cm yr}^{-1}$  snowfall increase reported by Burnett et al. (2003). After filtering for inhomogeneities within the dataset, the recalculated long-term snowfall trend reduced to approximately  $0.59 \pm 0.30 \text{ cm yr}^{-1}$  ( $p = 0.05$ ). This supports Kunkel et al. (2009a) who noted the snowfall increase found by Burnett et al. (2003) reduced from approximately  $1.5$  to  $0.6 \text{ cm yr}^{-1}$  after filtering for inhomogeneities. However, it should be noted that for the long-term record, only nine stations were deemed homogenous in Central New York, with nearly half (four stations) located in Onondaga County. Therefore, the decrease from  $1.16$  to  $0.59 \text{ cm yr}^{-1}$  may be a result of regional clustering instead of inaccuracies in nonhomogeneous data.

If the trend is considered as two distinct time periods (Figure 2b), the first half of the record exhibits a strong increase in snowfall,  $3.27 \pm 0.67 \text{ cm yr}^{-1}$  ( $p = 0.05$ ), while the second half demonstrates a non-significant ( $p = 0.05$ ) change in snowfall. Long-term snowfall trends calculated by previous studies (Norton and Bolsenga 1993; Burnett et al. 2003; Kunkel et al. 2009a) may not best represent changes in the data up to the present time, as also suggested by Bard and Kristovich (2012) for the Lake Michigan Basin. This may particularly hold true for the trends in the later studies done by Burnett et al. (2003) and Kunkel et al. (2009a), as both studies' time series included the lower snowfall totals in the early-21<sup>st</sup> century, in contrast to the higher snowfall totals in the latter 20<sup>th</sup> century (1970s and 1990s). Thus, similar to the findings of Bard and Kristovich (2012), snowfall patterns in the Great Lakes may not be best portrayed using a long-term trend, as there is a noticeable trend reversal within the data. This trend reversal is possibly driven by teleconnection patterns, as described later in this study.



**Figure 2.** Initial and homogenous snowfall trends for multiple time intervals. Trends are significant at the 5% level. Figure 3a represents the long-term trends, while Figure 3b represents two 41-year trends using initial COOP stations.

Variations in snowfall trends are best demonstrated by the 21-year snowfall trends calculated each winter from 1942/43 to 2000/01 (Figure 3). Twenty-one year snowfall trends during this time period were highly variable, ranging from approximately  $-7.6$  to  $7.6$   $\text{cm yr}^{-1}$ . The greatest change in snowfall trends occurred from 1966-1980, in which snowfall trends rapidly decreased ( $\bar{X} = -1.04$   $\text{cm yr}^{-1}$ ,  $\sigma = 4.35$   $\text{cm yr}^{-1}$ ). Snowfall trends during the earlier (1940-1959), and later (1990-2000) part of the record were less variable ( $\bar{X} = 2.41$   $\text{cm yr}^{-1}$ ,  $\sigma = 2.13$   $\text{cm yr}^{-1}$  and  $\bar{X} = 1.85$   $\text{cm yr}^{-1}$ ,  $\sigma = 1.37$   $\text{cm yr}^{-1}$  respectively). From the mid-1970s through the late-1980s, 21-year snowfall trends were less than zero. This supports the finding that longer-term snowfall trends experienced a reversal after the 1970s, which may be influenced by cyclical oscillation patterns. Caution should be taken when inferring the presence of a cyclical oscillation in the data, but if this signal is real, then the slight decrease starting in the late 1990s may be signs of another reversal.



**Figure 3.** 21-year Central New York snowfall trends at 1-year time-step intervals. The solid line represents the 21-year snowfall trend for each year from 1942-2000, while the dashed lines are the associated uncertainty of the trends and are significant at the 5% level.

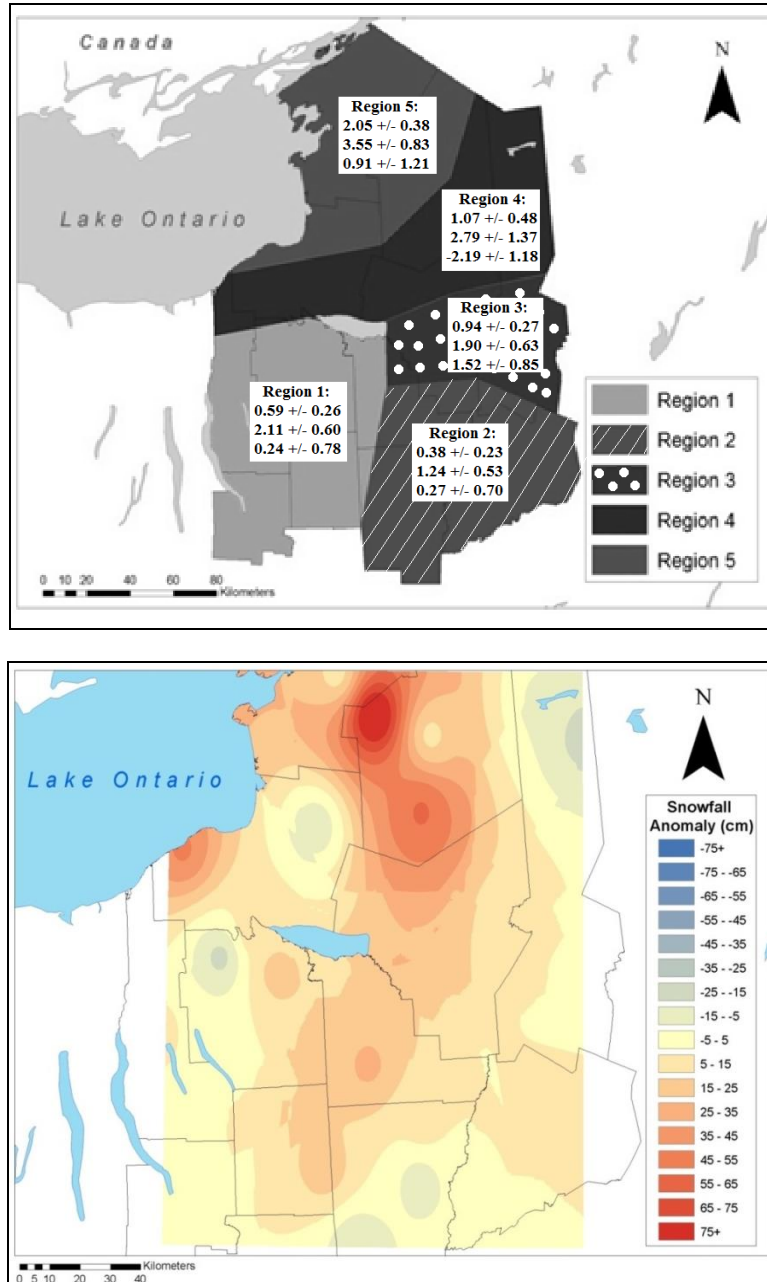
### **Intraregional Snowfall Variability**

In order to group stations by region within Central New York, principal component analyses (PCA) were used to extract hidden temporal and spatial correlations in seasonal snowfall totals. Two PCAs were conducted, first when missing seasonal snowfall values were excluded (PCA-a) and a second when missing values were replaced with the mean (PCA-b). Using the two PCAs, five distinct modes, further referred to as regions, were identified within Central New York (Figure 4). Each station was grouped into a single region based on the absolute value correlation ( $\geq 0.30$ ) with each of the five modes, and mapped using the ArcGIS polygon feature. It is important to note that the borders between the five regions are loose, and crossing regions does not suggest a vast difference between seasonal snowfall totals. Instead snowfall patterns for stations within the same region behave more similar than stations between regions. It should also be noted that all of the regions are generally concentrated to a subsection of Central New York, except for Region 4 which extends over a narrow and elongated area.

Seasonal snowfall totals for stations in each region were averaged together, and autocorrelation tests ( $\geq 0.30$ ) were used to test for nonlinearity in the dataset. Snowfall trends for the entire record and two 41-year records were then calculated at the 5% significance level using simple linear regressions for each individual region (Figure 4). Similar to the findings for the entire Central New York basin, snowfall trends exhibited a strong trend reversal, as snowfall trends for all regions were considerably higher for the first half of the record (1931/32-1971/72) than the latter half (1971/72-2011/12). There were also strong regional variations in the snowfall trends. During the long-term and first half of the record, Regions 4 and 5 experienced the largest positive snowfall trends. Both regions are in areas conducive for lake-effect snow development due to their position to the east of Lake Ontario, and due to their inclusion of the Tug Hill Plateau and Adirondack Mountains. Therefore, a larger increase in snowfall totals in these regions suggests an increase in lake-effect snow rather than non-lake-effect snow. A diminished snowfall increase for locations further from the lake is supported by snowfall changes in Region 2. Compared to the other five regions, Region 2 experienced the smallest snowfall increase, likely because Region 2 is farthest from Lake Ontario and is southwest of the lake. Thus, it is assumed that lake-effect snowfall is less common for this region, with the majority of the region's snowfall coming from non-lake-effect snowstorms. A lower snowfall increase over the period of record for non-typical lake-effect regions in Central New York is consistent with previous studies (Norton and Bolsenga 1993; Burnett et al. 2003; Kunkel et al. 2009a) which noted that stations distant from the lake experienced little to no appreciable increase in snowfall throughout the 20<sup>th</sup> and early part of the 21<sup>st</sup> century.

Spatial representations of snowfall changes were constructed using ArcGIS 10.1 and consisted of a 41-year snowfall difference map. The 41-year snowfall difference map was calculated by subtracting average snowfall totals for available stations during the latter period (1971/1972-2011/12) by average snowfall totals of the earlier period (1931/32-1971/72). Recall that 1971/1972 represents the break point of the trend reversal. In order to represent snowfall totals throughout Central New York, 10-point interpolations were performed using the inverse distance weighting function (Chen and Liu 2012).

The snowfall difference map (Figure 4) supports the idea of an overall increase in snowfall for Central New York, but the increase is not spatially homogenous. The northern reaches of Central New York, within the Tug Hill Plateau (See Figures 1 and 2), experienced the greatest increase (over 75 cm) in average seasonal snowfall totals. An appreciable increase in snowfall totals was also noticed for eastern Oswego County (45-55 cm increase) and for a north-south transect in central Central New York, extending from northern Lewis County to southern Cortland County ( $\geq 15$  cm increase). A few areas experienced a decrease in annual snowfall, most notably northwestern Onondaga, southern Chenango, western Oswego, and northern Herkimer counties. All of these regions, except for northwestern Onondaga and western Oswego Counties, are not commonly associated with lake-effect snow due to their orientation to, and distance from, Lake Ontario. This further supports the notion that snowfall increases in Central New York are not evenly distributed and instead are highest in typical lake-effect snow locations and lowest near the edges, or in non-typical lake-effect locations of the Lake Ontario snow basin.



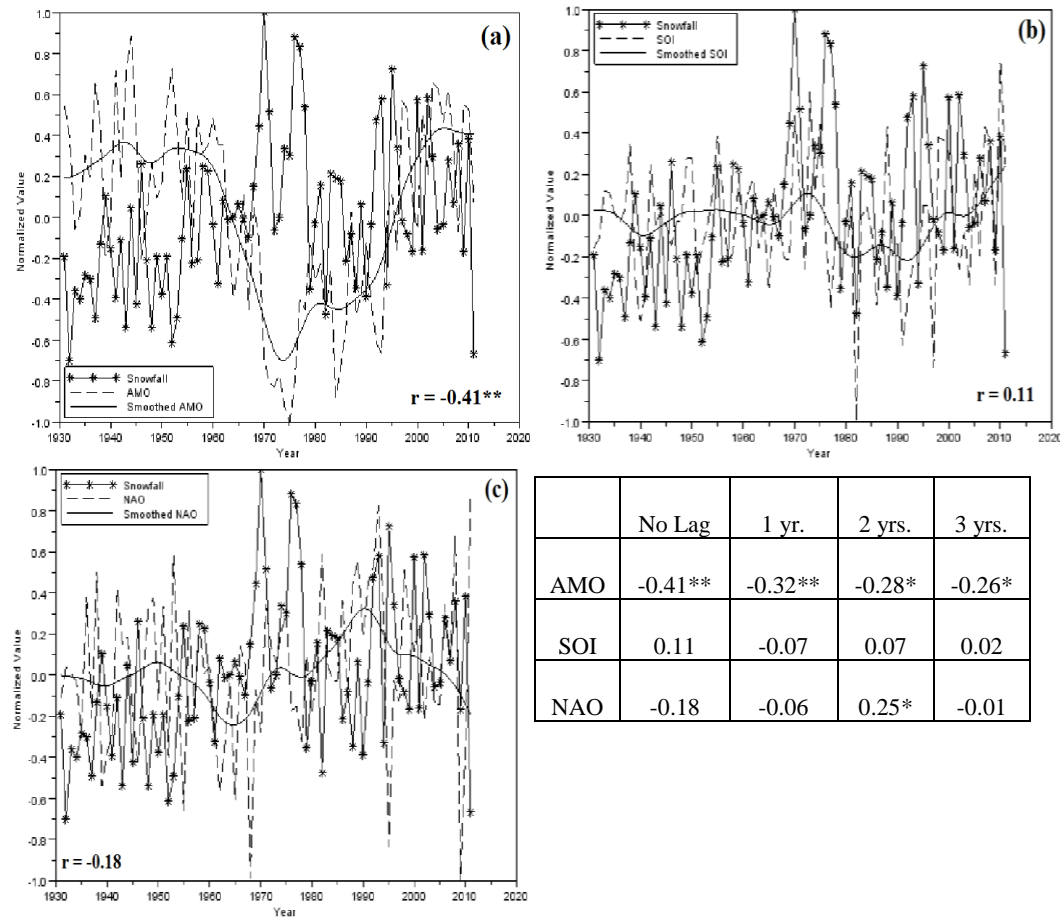
**Figure 4. (top)** Regional snowfall trends classified by PCA-a and PCA-b. Trends and uncertainties are reported in  $\text{cm yr}^{-1}$  and are significant at the 5% level. The trends are ordered from top to bottom: first trend is the long-term trend (1931/32–2011/12), the second trend is from 1931/32–1971/72, and the third trend is from 1971/72–2011/12. **(bottom)** Difference in mean annual snowfall totals between 1971/72 – 2011/12 and 1931/32 – 1971/72.

#### Potential Factors of Snowfall Variability

The IPCC (2013) suggests that anthropogenic forcing is the underlying cause of air temperature change; however, teleconnections have significant impact as well (Serreze et al. 1998; Livezey and Smith 1999; Kocin and Uccellini 2004; and Kunkel et al. 2009b). The correlations of the SOL, NAO, and AMO with seasonal snowfall totals in Central New York were calculated. Each

teleconnections' time series was normalized between -1 and 1 and plotted at 0-3 year lags, along with the average seasonal snowfall totals for Central New York. Pearson correlations were then performed between snowfall and each teleconnection lag to determine if annual snowfall totals in Central New York are correlated with the teleconnection indices.

Contrary to previous studies (Grimaldi 2008; Kocin and Uccellini 2004), no significant correlations were apparent between snowfall totals and the SOI, possibly because Grimaldi (2008) observed a shorter time period and Kocin and Uccellini (2004) focused on the Northeast United States. There is a slight significant ( $p = 0.05$ ) correlation with the NAO at a 2-year lag. However, of the three observed teleconnections (SOI, NAO, and AMO), the AMO demonstrated the largest significant ( $p = 0.01$ ) correlation with snowfall (Figure 5). The greatest correlation with the AMO was negative and at no lag. This anti-correlation is most noticeable during the 1970s and 1990s, when the AMO is below normal and snowfall totals are well above normal.



**Figure 5.** Normalized climate indices plotted with normalized Central New York snowfall. Figure 5a represents the time-series for the AMO, 9b is the SOI, and 9c is the NAO. Each time series was smoothed using a 3-year Gaussian filter. The values within the table represent correlations between average CNY snowfall and the teleconnection at various time lags up to 3 years. Value significant at the 1% are denoted with a (\*\*) and at the 5% level an (\*).

The AMO is a long-term oscillation in sea surface temperatures in the North Atlantic (0-87.5°N). Compared to the SOI ( $\bar{x} = 2.274$ ,  $\sigma = 1.508$ ) and NAO ( $\bar{x} = 0.556$ ,  $\sigma = 0.746$ ), from 1931/32-2011/12 the AMO experienced a smaller variance ( $\bar{x} = 0.008$ ,  $\sigma = 0.178$ ). From 1931-2012, the AMO experienced a warm phase from 1930-1960 peaking in 1944, a strong cool phase from 1970-1990 peaking in 1975, and transitioned back into a warm phase during the mid-1990s



peaking in 1993 (Gray et al. 2004). This 20-30 year variation in the AMO coincides with changes in snowfall, as well as air temperatures, due to the negative correlation between air temperatures and snowfall (Figure 7). For example, during the 1970s snowfall is at a maximum, while air temperatures and the AMO index are below normal. Similarly, the AMO is higher during the early decades (1930s and 1940s), while air temperatures are slightly above normal, and snowfall totals are diminished. The inverse relationship between snowfall and the AMO is inconsistent with the finding of Fortin and Lamoureux (2009) who noted a snowfall increase in northeast North America during the positive AMO phase, which may be due to the restriction to a predominately lake-effect snowfall area.

Findings from the present study suggest that the AMO possibly influences snowfall changes in Central New York. Since the AMO varies at such a low frequency and snowfall measurements only date back to the 1930s, caution should be taken when analyzing the data and making predictions. However, if the signal is real and periodic and dominates over other influences, snowfall might peak again around 2030 in Central New York. Unfortunately, due to little information on past phases of the AMO, prediction capabilities are sub-par (Gray et al. 2004). It should also be noted that even though there is a significant correlation with the AMO, the correlation value is not large, and further study would need to be undertaken to evaluate how the AMO phase physically relates to lake-effect snowfall changes.

## CONCLUSION

Several studies (Norton and Bolsenga 1993; Burnett et al. 2003; Kunkel et al. 2009a) have noted an increase in snowfall for lake-effect stations in the Laurentian Great Lakes since the early 20<sup>th</sup> century. Bard and Kristovich (2012) were the first to recognize a trend reversal within the time series for snowfall in the Laurentian Great Lakes, focusing on Lake Michigan. Due to numerous physical and climatic differences between Lake Michigan and Lake Ontario, this study examined snowfall trends for Central New York – located in the heart of the Lake Ontario snow basin.

There are three key findings of this study. The first finding was the recognition that Central New York snowfall trends are not linear, and instead experienced a trend reversal during the 1960s-1970s. Norton and Bolsenga (1993), Burnett et al. (2003) and Kunkel et al. (2009a) all noted a long-term increase in snowfall for lake-effect stations compared to non-lake-effect stations. This finding was corroborated by the long-term snowfall trend ( $1.16 \pm 0.31 \text{ cm/yr}^{-1}$ ) for Central New York, but further analysis demonstrated a reversal in the trend. It was found, similar to Bard and Kristovich (2012), that above average snowfall during the 1970s and 1990s likely increased long-term snowfall trends, especially during the latter half of the time series (1971-2012). Annual 21-year snowfall trends continually decreased from the mid-1970s through the mid-1980s, further suggesting that Central New York snowfall trends behave non-linearly over the period of record.

Second, snowfall patterns in Central New York are not spatially homogenous. It is common for a study to overgeneralize a region, for example the Lake Erie basin, the Lake Ontario basin, or even the Great Lakes basin. However, there are important microclimatic variations that should be accounted for. Therefore, one goal of this study was to spatially represent snowfall trends in Central New York. It was found that Central New York can be divided into five distinct regions, with the regions closer to and leeward of Lake Ontario experiencing higher snowfall trends than regions farther away and not leeward of the lake. Since 1931, the Tug Hill experienced the largest increase in snowfall for Central New York. The Tug Hill is commonly known for the vast amounts of lake-effect snow that it receives over a snowfall season. Therefore, it is suggested that even though Central New York is a lake-effect snow dominated region, there are spatial differences in which areas typically associated with lake-effect snow (the Tug Hill, the Southern Hills, and Oswego County) experienced a higher snowfall trend than areas not characteristically associated with lake-effect snow (northeastern and southern Central New York).

Finally, the AMO has the greatest correlation with seasonal snowfall totals in Central New York. It was found that for the teleconnection patterns observed, the AMO, with no lag, had the greatest significant ( $p < 0.01$ ) correlation (-0.41) with seasonal snowfall totals in Central New

York. The driving forces of the AMO's influences are not determined in this study, but it is recognized that there is a 30-year snowfall pattern in seasonal snowfall totals, likely connected to the AMO.

Due to the relative abundance of snowfall throughout the winter season, snowfall is an important resource in Central New York. Stable seasonal snowfall totals are vital for the region's habitats and economy, as agriculture, water resources, winter recreation, wildlife, and the Department of Transportation depend on stable snowfall totals. Therefore, the results from this study will help understand Central New York snowfall trends and aid in forecasting seasonal snowfall totals. Enhanced forecast predictions will allow better preparation for and adaption to future seasonal snowfall totals.

Future work should expand the analysis of driving factors of snowfall patterns in Central New York. For example, lake-effect snow is largely dependent on the air-lake temperature contrast; therefore, it would be beneficial to examine yearly air and lake surface temperatures to determine their influence on seasonal lake-effect snow totals. Further analysis should also be done to explore the influence of the AMO on seasonal snowfall totals in Central New York, specifically examining the AMO's influence on other factors such as changes to lake ice (Wang et al. 2012), the lake-air temperature difference (Peace and Sykes 1966), and the tracks of low pressure systems.

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