Lake Effect Snowfall in a Changing Climate

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Introduction and Study Goals

There is strong scientific evidence that humans are influencing the climate system. Climate change has, and will continue to impact snowfall, particularly lake effect, within the Great Lakes region of North America. While numerous studies have examined trends in snowfall in this region, typically studies treat lake effect as the snow falling within the commonly defined 80-100km lake belt. This method does not necessarily separate snow due to non-lake effect sources. However, by examining snowfall that occurs only under lake effect synoptic conditions, actual lake effect snowfall can be investigated. Using a synoptic climatological technique, we gain a clearer understanding how lake effect snow is varying, why it is varying, and how it may change into the future. Knowing more about how the climate system is changing will aid in seasonal forecasting and resource allocation for those living within this region.

This study's goals are to:

- Isolate snowfall that is generated specifically under lake effect synoptic types.
- Investigate spatiotemporal trends in the isolated lake effect snowfall.
- Determine what is causing the trends in lake effect snowfall.

Methodology

Synoptic Classification:

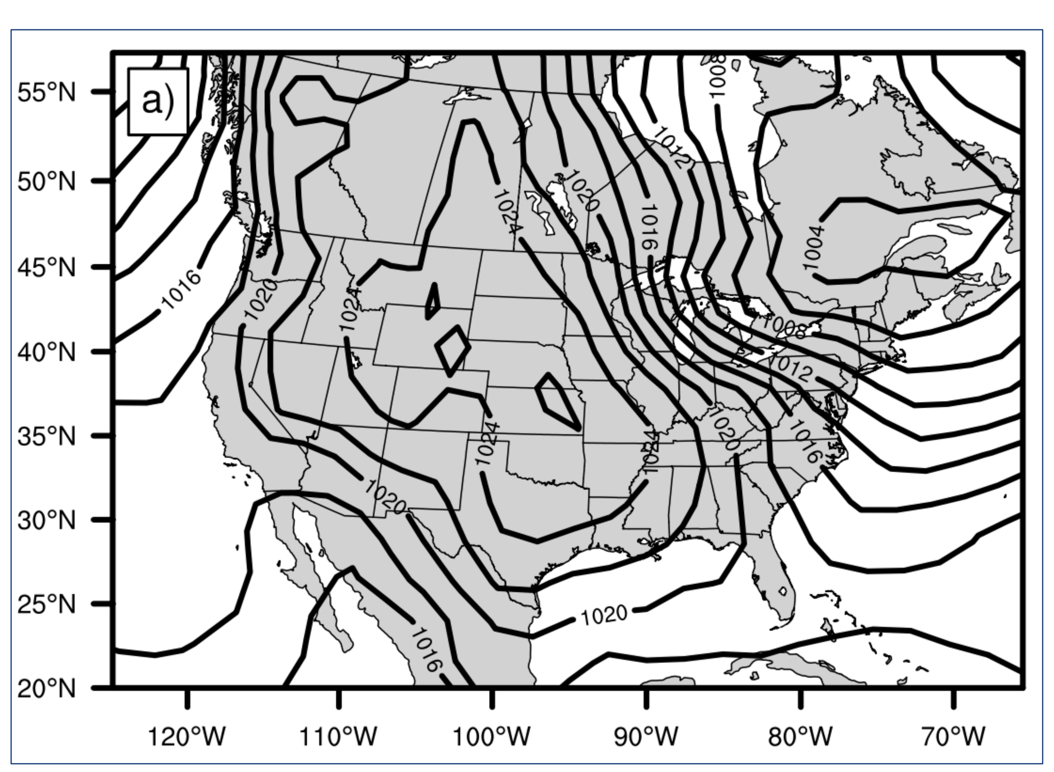
Using a Temporal Synoptic Index, daily synoptic weather classifications are developed for Buffalo, NY from 1950-2009. An unrotated principal components analysis (PCA) is run on daily meteorological variables from four daily observational periods for each season. PCA score time series with eigenvalues greater than 1.0 are clustered using within-group average linkage clustering to identify the various synoptic types. Composite maps are generated for each type depicting sea-level pressure, 500 hPa geopotential height, surface air temperature, and precipitation rate.

Lake Effect Type Determination:

Synoptic types are classified as "lake effect" if they meet all of the following criteria:

1) Atmospheric temperatures are conducive to frozen precipitation,
2) Wind flow at 850 hPa provides favorable fetch over the lakes and speeds are greater than 5 ms^{-1} while not exceeding 20 ms^{-1},
3) There is less than 30° of directional shear between the surface and 850 hPa winds, and
4) The lake surface to 850 hPa temperature difference is at least 13°C.

Seven different synoptic types across the Nov-Mar season meet this criteria. The sea-level pressure composite map (left) represents one of the lake effect synoptic types. For this type, a broad 1004 hPa Low pressure center is located over the Gulf of St. Lawrence that results in strong westerly flow over Lakes Ontario and Erie. This synoptic type generates a large amount of lake effect snow each winter in central New York with over 9 cm per event (on average) over the Tug Hill Plateau.



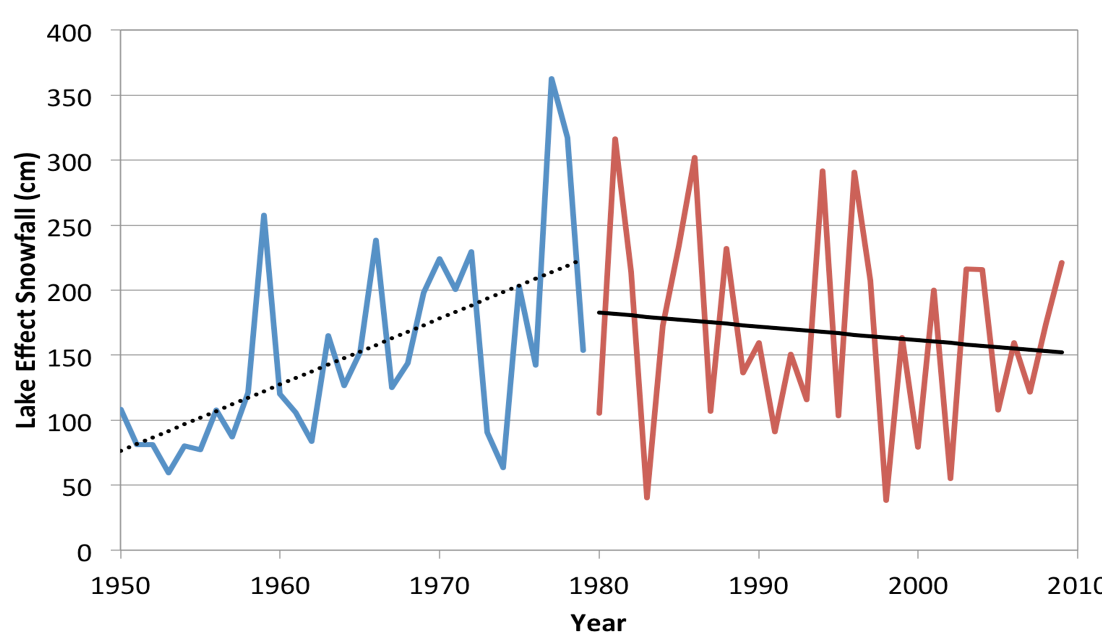
Snowfall Dataset:

Observed snowfall data is from a 1 x 1 degree daily gridded North American dataset interpolated from COOP stations from NCEI data via Spheremap spatial interpolation. Daily snowfall events from lake effect synoptic types are summed monthly and seasonally (Nov-Mar) for trend analysis.

Results and Discussion

Lake Effect Snow Increases before 1980, Then Begins to Decline After

Lake effect snow accounts for roughly 45-50% of seasonal snowfall within the lake belts of the eastern Great Lakes. During the period of record (1950-2009) lake effect snow significantly increases, however there is a more interesting history within the data. Isolating the region directly to the east of Lake Ontario (including Syracuse & Oswego), trends in snowfall are broken down into two 30-year periods (left). Lake effect snowfall significantly increased roughly 5.1 cm $year^{-1}$ from 1950-1979 (blue) then from 1980-2009, snowfall declines by over 1.0 cm $year^{-1}$ (red).



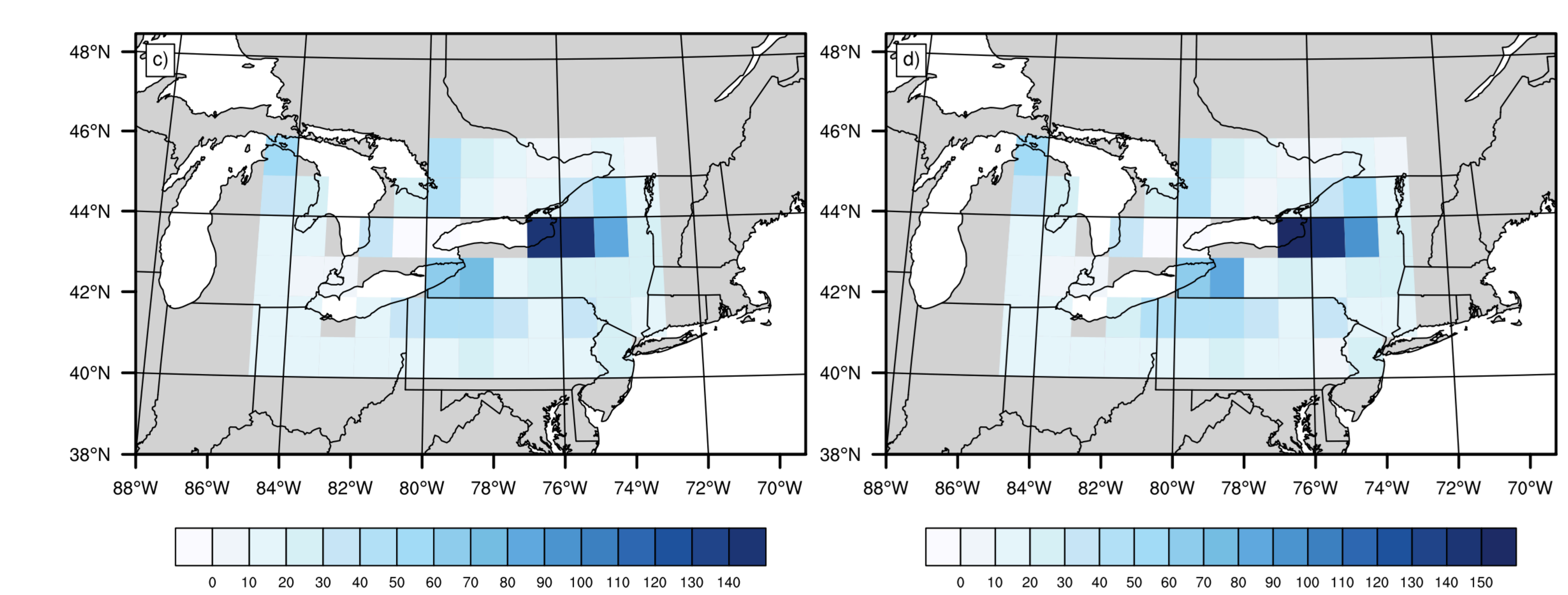
Frequency and Intensity of Synoptic Types Explain Trends in Lake Effect

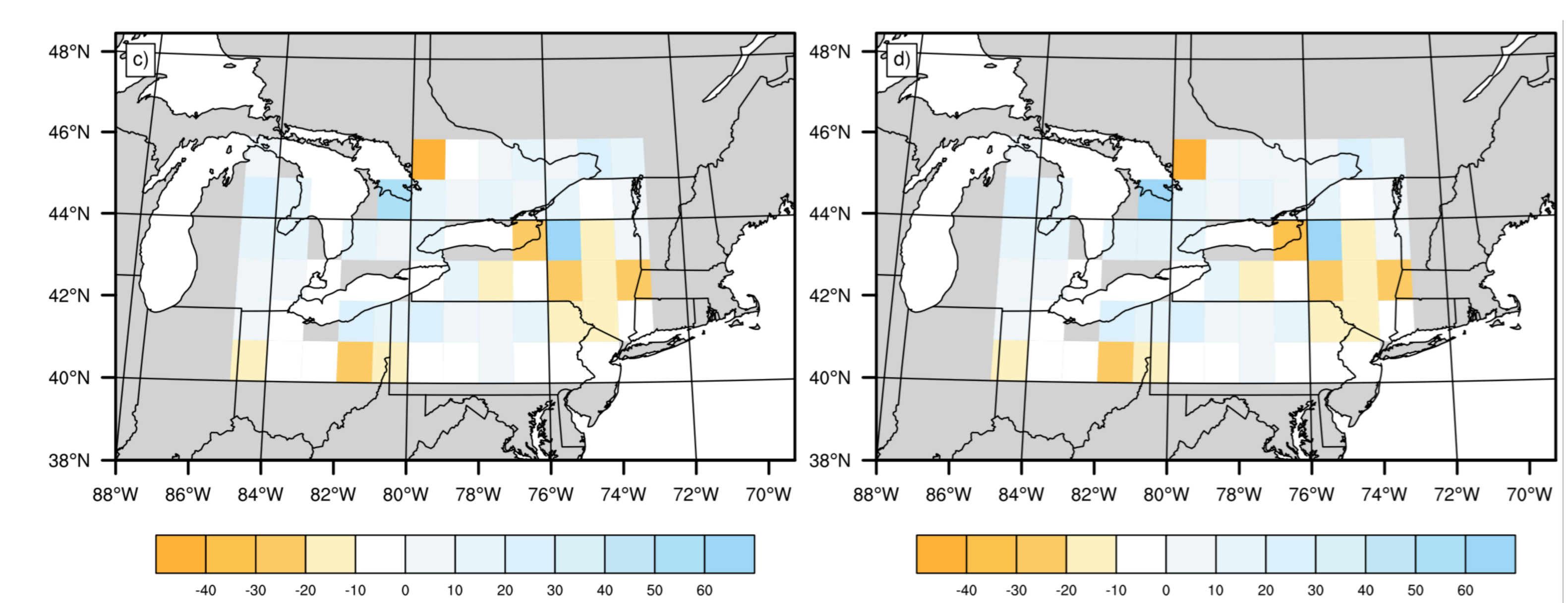
To understand the relationship between lake effect synoptic type frequency/intensity, and snowfall, the frequency and intensity time series are combined with seasonal lake effect snowfall data to calculate a modeled snowfall change due to frequency and intensity variations. Modeled snowfall changes from synoptic type frequency and associated snowfall intensity (C) account for almost the entirety of the observed snowfall changes (D) throughout the study region during both the 1950-79 (Left) and 1980-2009 (Right) periods.

Teleconnections and Intra-Synoptic Type Characteristic Changes Explain Variability in Lake Effect Synoptic Types

For each of the 7 synoptic types, snowfall changes are majoritively influenced by different combinations of frequency and intensity changes. In the synoptic types with snowfall that is strongly influenced by frequency changes, the frequency changes can be partially explained by relationships to large-scale modes of variability. Specifically, these types' frequencies are highly correlated to the phases of the Arctic Oscillation (AO), North Atlantic Oscillation (NAO), and/or Pacific/North American pattern (PNA). When the AO/NAO phases are negative and/or the PNA is positive, there is the tendency for enhanced troughing over the eastern US typically resulting in cyclonic storm development along the eastern coast of North America due to upper-level divergence. The synoptic types in question are all associated with cyclonic systems in eastern/coastal Canada and have a strong upper-level trough over the eastern US.

For the synoptic types with snowfall that is strongly influenced by intensity changes, a majority of the intensity changes can be partially explained by intra-synoptic type variability, specifically significant changes to the nature or character of the synoptic types over time. Increases in snowfall are associated with low pressure centers becoming stronger favoring stronger winds that could enhance convection, decreasing surface temperatures enhancing the instability over the lakes, and more prominent westerly flow (either U or V component changes) resulting in a longer fetch over the lakes and enhanced convection/snowfall rates. In cases where snowfall decreases, there are significant increases in surface temperatures which would lessen the potential for snow, and decreasing U wind component that could result in shorter fetches and/or less intense lake bands and streamers.





Conclusions

1) Snowfall from the 7 lake effect synoptic types accounts for 45-50% of the seasonal snowfall in regions downwind of Lakes Erie and Ontario.
2) Directly east of Lake Ontario, there has been a distinct trend change in lake effect snow between 1950-1979 and 1980-2009 where snowfall increased by over a 5 cm per year in the initial period, then decreased by greater than a 1 cm per year during the later period.
3) Trends in lake effect across the entire region can be mostly explained by changes in the frequency of lake effect synoptic types, and by changes in associated snowfall intensity.
4) The relative phases of the AO, NAO, and PNA are highly correlated to certain synoptic types' frequency and partially explain the frequency changes that cause snowfall changes.
5) Changes in snowfall intensity associated with a synoptic type can be partially explained by significant changes to the nature or character of the individual synoptic type. Specifically, changes in surface temperature, wind direction and speed, and surface pressure of a synoptic type all fundamentally alter the development of lake effect snow.

Acknowledgements and References

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Suriano ZJ, Leathers DJ. *Under Review*. Synoptically Driven Lake Effect Snowfall Changes to the Lee of Lakes Erie and Ontario. *Climatic Change.*
Suriano ZJ, Leathers DJ. *Under Review*. Synoptic Climatology of Lake Effect Snowfall Conditions in the Eastern Great Lakes Region. *International J. Climatology.*
Suriano ZJ. *In Preparation.* Forcing Mechanisms Behind Lake Effect Synoptic Type Frequency and Associated Snowfall Intensity Variability. *Expected Submission to Journal of Applied Meteorology and Climatology*.