P1.9 AN ANALYSIS OF SATELLITE-DERIVED GREAT LAKES SURFACE TEMPERATURES IN REGARDS TO MODEL SIMULATIONS OF LAKE EFFECT SNOW

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1. INTRODUCTION

The Great Lakes are the largest source of fresh water in the world with a surface area of roughly 245,000 km^2. Located in the middle of the North American continent, such a vast topographic feature has a major impact on the weather and climate of the region.

The Great Lakes cool (warm) more slowly than the air during the fall and early winter (spring and early summer). In the fall and early winter this source of heat and moisture causes local destabilization of the lower atmosphere resulting in enhanced clouds and precipitation downwind of the lakes (Niziol 1995).

On a local scale the Great Lakes spawn mesoscale lake effect snowstorms during the late fall and winter months. These severe winter storms have been well documented in the literature with the potential to produce several feet of snow over a period of a few days (Niziol 1982; Wagenmaker 1997). Great Lakes surface temperatures play a vital role in determining the potential for lake effect snow. Therefore, accurate observations of lake surface temperatures are necessary to accurately predict such mesoscale weather events. In addition, Petterson and Calabrese (1959) and more recently Sousounis and Mann (2000) have shown that the aggregate thermal effects of the Great Lakes can have a significant impact on synoptic scale weather patterns.

Over the past several years, the suite of Numerical Weather Prediction (NWP) models run at the National Oceanic Atmospheric Administration (NOAA) National Center for Environmental Prediction (NCEP) have continued to increase in spatial and termporal resolution so that many meteorological parameters associated with the Great Lakes are now able to be incorporated into these models, including Great Lakes surface temperatures. Currently, models such as the ETA-12 and RUC-10 are capable of explicitly predicting lake effect snows, at times with great accuracy. The models though, are only as good as the data sets that are used to initialize them. Extensive research has been referenced in the literature concerning the limitations of numerical models that operate at the meso-alpha and meso-beta scales including convective parameterization schemes and model physics (Baldwin et al., 2002). However, before one can address those limitations, it is imperative to identify the limitations in the data sets that are used to initialize boundary conditions, not only in the horizontal scale, but the vertical scale as well.

Great Lakes surface temperatures are remotely sampled by NOAA polar orbiter satellites. When the lakes are cloud covered, the data might not be updated for several days, resulting in a data set that may be in error by several degrees. During the fall, when lake temperatures are on average undergoing seasonal cooling on a daily basis, the satellite-derived data that is not updated due to cloud cover may develop a warm bias.

This paper will examine whether Great Lakes surface temperatures derived by satellite observations possess a warm bias in the fall and early winter when thick cloud cover is more common. Further, the implication of lake surface temperatures with a warm bias on the model simulation of a lake effect snow events will also be determined.

2. LAKE SURFACE TEMPERATURE DATA SAMPLING

Great Lakes surface temperatures are derived from the NOAA-12 and NOAA-14 polar orbiter satellite Advanced Very High Resolution Radiometer (AVHRR) instrument for the NOAA Coastwatch program (Li et al. 2001). The satellites are in a sun-synchronous orbit, scanning a swath of about 2700 km. Using two satellites, one with a morning/evening overpass and one with an afternoon/nighttime overpass, a satellite image is obtained approximately every six hours. Along with several other measurements, the AVHRR provides an estimate of lake surface temperatures from the radiometric data (Leshkevich et al. 1993).

The Great Lakes Surface Environmental Analysis (GLSEA) is a digital map of the lake surface temperatures and ice cover that is produced daily from the AVHRR data at NOAA's Great Lakes Environmental Research Laboratory (GLERL) through the NOAA Coastwatch program (Schwab 1999). Lake surface temperatures are updated daily with information from the cloud-free portions of the previous day's satellite imagery. If no imagery is available, a smoothing algorithm is applied, incorporating the previous day's map. It is very important to note that observed data

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measured at the Great Lakes data buoys *does not* go into the derivation of the GLSEA product.

In previous studies, Schwab et al. (1999) found that the mean temperature difference between buoys and the GLSEA analysis averaged over a 5-year period was on the order of 0.5°C or less. Li et al. (2001) found similar results for a comparison of AVHRR-buoy data on the Great Lakes during a 3-month period in 1997. Biases for each satellite ranged from 0.3°C to 1.5°C. Although the averaged temperature differences are small, there is an important point to consider here. The comparisons were done only for data points that were cloud-free. During extended periods of cloud cover over the lakes, those data points will not be updated in the GLSEA analysis and larger temperature differences may result. It is not uncommon for the Great Lakes Region to remain cloud covered for several days during the late fall and winter when cold air crosses the relatively warm lakes, which also corresponds to the period for the development of lake effect snow. In fact, Schwab (1999) noted that during the winter and early spring season there are some areas where new temperature data is not available for as long as 30 to 40 days due to cloud cover.

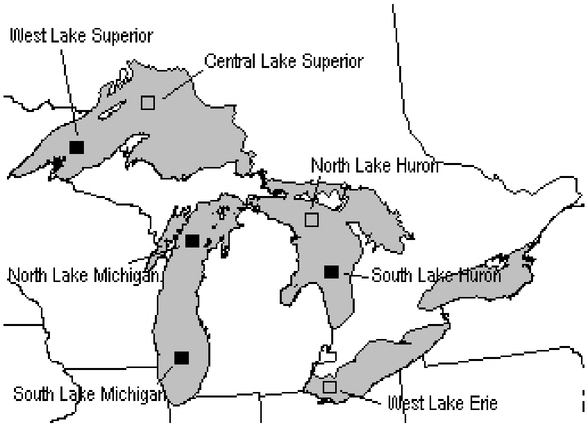

Figure 1: Location of moored data buoys on the Great Lakes that were used in the comparison with GLSEA analyses. The open squares represent location of buoys shown in Figure 2.

In order to assess the accuracy of the GLSEA analysis, select data points were compared to observations located at seven of the eight NOAA data buoys deployed on the Great Lakes (Figure 1). Although the data set is small, these are some of the only direct measurements of lake surface temperatures available for the Great Lakes. The data buoys are equipped with a water temperature sensor on the bottom of their hull approximately 1 m below the surface. Although the buoy lake surface temperatures sensor is not exactly comparable to the satellite derived temperatures, the differences are considered to be generally less then 1°C for typical lake conditions, which are acceptable (Wesley 1979).

3. METHODOLOGY

A five-year data set from 1996-2000 during the late fall and winter was compiled for the GLSEA analysis at locations corresponding to Great Lakes data buoys. The GLSEA analysis at each grid location was then compared to observations taken at each data buoy from the NOAA National Data Buoy Center (NDBC) database.

Unfortunately, the NDBC data buoys are removed from the Great Lakes before the winter season each year because of the potential for instrument damage due to ice cover. In addition, deployment and removal dates for each buoy differs. As a result, it was very difficult to assess the combined effects of temperature biases from all buoys in the entire Great Lakes Region. Despite these limitations, temperature data was compiled for individual buoys, yearly and over a 5-year period while buoys were deployed. The data was compared to GLSEA analyses, then graphs were produced to highlight certain anomalies and patterns from year to year.

4. RESULTS

During periods when thick cloud cover masks the lakes for an extended period of time, new information is unavailable for those grid points and significant differences may develop between the GLSEA analysis and the buoy observations over time. During the October-December (April-June) time frame when seasonal cooling (warming) of the lakes occur, one might be able to detect a consistent warm or cool bias to the GLSEA analysis during periods of extended cloud cover. As an example, during the fall when lake surface temperatures are generally cooling each day, persistent cloud cover will result in cloud covered grid points not being updated by the satellite derived method. Instead of that grid point cooling each day, the temperature will be held constant. As a result cloud covered grid points will become warmer or develop a warm bias compared to buoy observations. This warm bias will not be corrected until a clear day occurs to allow the satellite to take a direct measurement.

Graphs of temperature differences between buoy observations and the GLSEA analyses averaged over a 5-year period of time are shown for three buoys on the Great Lakes including Central Lake Superior, Northern Lake Huron and Western Lake Erie (Figure 2). The data includes all days, including those that were cloud covered. The graphs show a distinct cool bias to GLSEA analysis in the April-June time frame and a warm bias in the September-December time frame. Other buoy locations (not shown here) indicated similar results. The differences between buoy observations and the GLSEA analysis are greatest for the western Lake Erie buoy. This is likely due to the fact that Lake Erie is the shallowest of all of the Great Lakes and the western end of Lake Erie, where the buoy is located, is quite shallow. Shallower lakes respond more quickly to temperature changes, therefore during the Fall, Lake Erie shows the quickest response to the seasonal cooling of all of the Great Lakes. In contrast, on Lake Superior, where the seasonal change in temperature is much less, the corresponding warm bias due to periods of extended cloud cover would be less as well.

The Lake Superior buoy is often the first to be removed from the Great Lakes each season, so that any comparison to other buoys after early November is not possible. This is unfortunate because November and December often produce the greatest overall precipitation from lake effect snow storms (Jiusto 1970). So, even though Lake Superior does not exhibit a large warm bias through early November, it is impossible to determine whether or not the warm bias will increase as it does at other buoy locations that are removed later in the season.

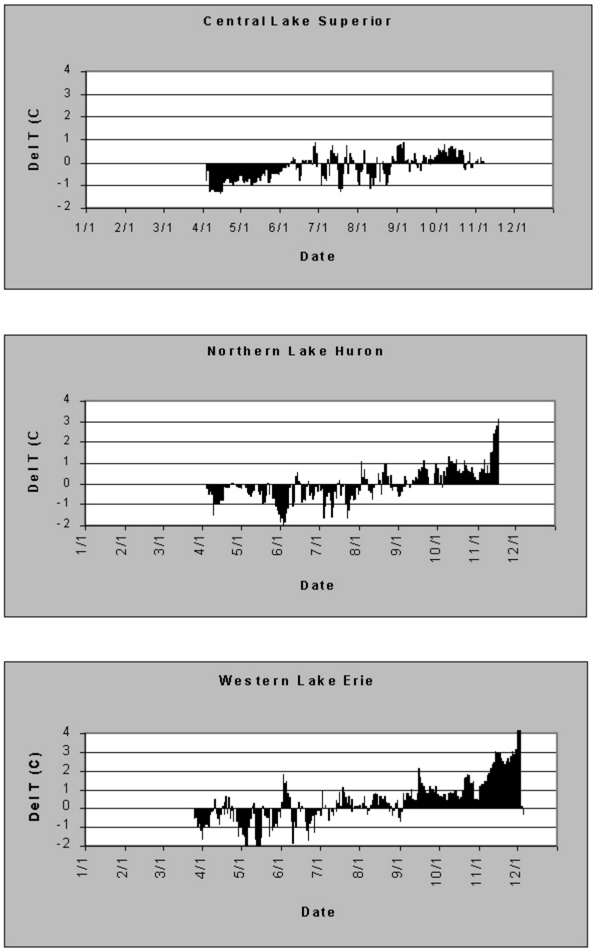

Figure 2: Averaged temperature difference from 1996-2000 between the GLSEA analyses and observed buoy lake surface temperatures at three data buoys on the Great Lakes. Positive readings indicate the GLSEA analyses temperatures were warmer than observed lake surface temperatures. Note that not all data points were averaged over the full 5 years due to different deployment and retrieval dates each year.

Box and whiskers plots were also constructed for the three buoys for a 5-year time frame (Fig. 3). The data included a time period that extended from October 1st to the annual removal date for each buoy. The removal dates ranged from as early as October 17th to as late as November 28th. This time frame was chosen to reflect the period during which lake effect snows are most likely. The boxes denote the 25th and 75th percentiles and the thin vertical lines (whiskers) show the maximum and minimum temperature difference between the GLSEA analyses and the buoy observations. Although the data set is limited, they do show an overall warm bias to the GLSEA analyses during the fall time frame.

In addition, a separate analysis (not shown) that compared temperature differences at all seven data buoys on each day indicated that there were a few times each fall season in which at least three of the seven buoys exhibited a warm bias of 2°C or more on the same day. Based on the trends exhibited in the graphs in Figure 2, the author feels that the GLSEA warm bias would exceed 2°C at several buoys more often if the buoys remained deployed in the lakes through the latter part of the fall and early winter. Therefore, the 2°C value was chosen for the model simulation.

5. MODEL SIMULATION

To investigate the effect that a GLSEA analysis with a warm bias would have on a simulation of a lake effect snow event, a very simple approach was taken using an operational mesoscale model that is readily available to NOAA National Weather Service (NWS) forecast offices and universities. The workstation Eta model was configured to allow a simple adjustment of the water temperatures of all of the Great Lakes grid points. As indicated above, a GLSEA warm bias of 2°C was used at each grid point.

A non-hydrostatic model was run on a 55 x 91 grid with a spacing of 8km using a Kain-Fritsch convective parameterization scheme (K-F CP scheme) covering the entire Great Lakes Region. The time step was 30 seconds and the model was run out to 30 hours. A control run was done first, then the model was re-run with all of the lake grid points increased by 2°C.

The model was run using the case study of 20 November 2000 that resulted in a major lake effect snow storm. This storm produced nearly 40 cm (24 in) of snow in about an 8-hour period over Buffalo, New York. At the same time, a portion of western lower Michigan received nearly a foot of lake effect snow downwind of Lake Michigan.

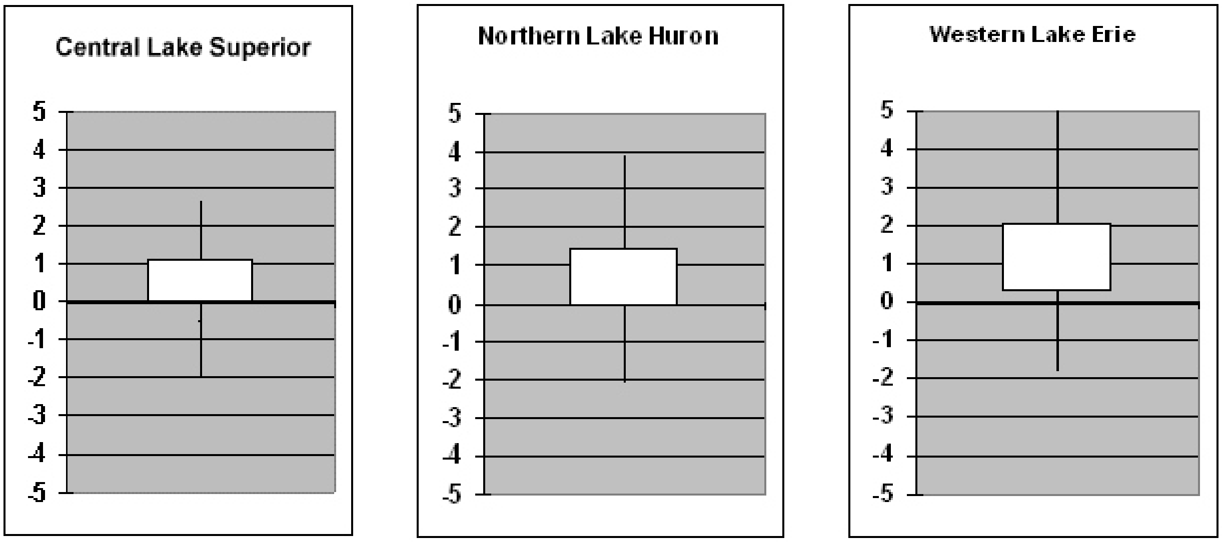

Figure 3: Boxes indicate the 25th and 75th percentiles and the thin vertical lines (whiskers) show maximum and minimum temperature differences between GLSEA analyses and observed lake surface temperatures during the time frame from October 1st through removal of data buoys each season between 1996-2000. Positive values indicate warmer GLSEA temperatures. Note that even when averaged over a 5-year time frame, the satellite-derived GLSEA temperatures show a warm bias.

6. MODEL RESULTS

For this study, the model forecast 24-hour snowfall was compared. The control run produced significant snow bands downwind of both Lakes Erie and Michigan. The 24-hour snowfall totals for the control and warm run off Lake Erie are shown in Figure 4a, b. Both runs show a narrow plume of heavy snowfall that extended inland across metropolitan Buffalo, New York. The general location and shape of the snowfall plume are very similar between the two simulations. However, the warm lake run shows snowfall maxima that are roughly 15 to 20% greater than the control run. Similarly, off Lake Michigan similar results were obtained as shown in Figure 4c,d, with the warm simulation producing roughly 33% more for maximum 24-hour snowfall than the control run.

In both locations on the Great Lakes, the warm lake runs produced more snow than actually was recorded in each event. Warmer boundary conditions however are only one potential source of error in numerical models. Other factors such as different convective parameterization (CP) schemes introduce errors that are at least as great as the data initialization, so that direct comparison of storm total snowfall to the observed values are not valid. As an example, when the model was run with the warmer boundary layer conditions and the CP scheme was replaced with explicit precipitation (not shown), then storm total snowfall was as much as 67% greater than the control run!

7. SUMMARY

Satellite derived lake temperatures show a warm bias for select data buoys on the Great Lakes during the fall and early winter. The warm bias may introduce significant errors into mesoscale numerical models, especially in regards to snowfall from lake effect snow storms. In this study the warm bias that was introduce into the mesoscale model resulted in simulations that predicted more snowfall for lake effect snow events than a control run. In general, a simple model simulation with all of the Great Lakes surface temperatures warmed by 2°C produced significant snowfall differences for a lake effect snow event on both the eastern and western Great Lakes.

With the proliferation of NWP models that can be set up and run locally, it is even more important that forecasters be aware of the impact that incorrect boundary layer data can have on model solutions. Before other modeling assumptions are even considered, poorly initialized boundary layer data can introduce significant errors into the model solutions that may negatively impact the operational forecast. That is why a thorough understanding of the operational aspects of numerical modeling is becoming an even greater part of every forecasters knowledge to accurately predict the weather.

In January 2001, the Real Time Global SST Analysis (RTG_SST) was developed specifically for use by the NCEP weather forecasting models (Thiebaux 2001). Each daily product uses the most recent 24-hours of *in situ* and satellite-derived surface temperature data. However, this new and improved analysis is

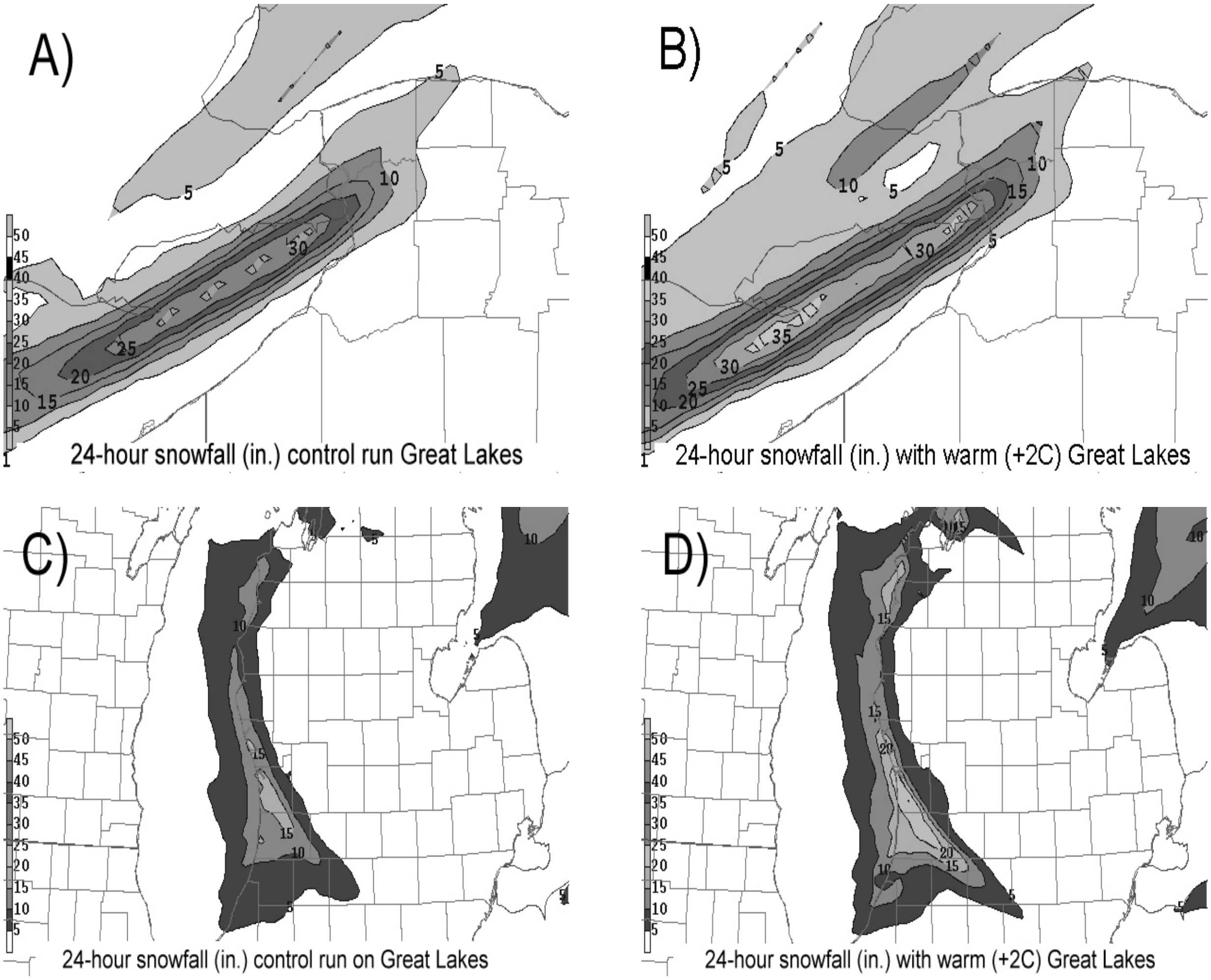

Figure 4. November 20, 2000 24-hour snowfall: A).Lake Erie control run, B). Lake Erie warm run, C) Lake Michigan control run, and D). Lake Michigan warm run. Snowfall was calculated on a 25:1 snow to water ratio.

currently not used over the Great Lakes (Katz, personal communication, 2003). Future enhancements to the GLSEA analysis will hopefully incorporate similar techniques including *in situ* buoy observations, climatological and realtime statistics to land based temperature fields, as well as newer remote-sensing technology to improve the analysis of Great Lakes surface temperatures. The result of the improved data sets will be directly realized in NWP output and lead to improved forecast products.

In addition to developing new and improved methods of initializing boundary layer conditions in mesoscale numerical models, continued research is necessary to examine the roles that convective parameterization and model microphysics play in the simulation of lake effect snows. It will also be imperative to continue the education and training of operational forecast staff to improve their knowledge of NWP models.

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