The Use of High Resolution Data from the Nested Grid Model for the Prediction of Lake-Effect Snows

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ABSTRACT

High resolution model output from the National Meteorological Center's Nested Grid Model was made available on an experimental basis to the National Weather Service Office in Buffalo, NY during the winter of 1991 for research and evaluation. Increased vertical and temporal resolution of the model data, compared to the standard data available at NWS Buffalo allowed forecasters a more detailed look at parameters in the lowest layers of the atmosphere. This was especially important for the prediction of lake-effect snow, which is generally confined to the lowest 3km of the atmosphere.

Hourly wind direction forecasts were used to refine the timing on movement and location of lake-effect snowbands off Lakes Erie and Ontario. In addition, forecast hourly soundings were evaluated to determine the existence and height of the subsidence inversion that limits convective cloud growth in lake-effect snow. Case studies of single band storms that occurred during the winter of 1991-92 are presented here to show how the new model output can be used more efficiently as a forecast tool.

INTRODUCTION

Lake-effect snowstorms are notorious weather makers for the people that live downwind of Lakes Erie and Ontario during the late fall and winter months. This region is considered the snowiest populated area to the east of the Rocky Mountains, with annual snowfall amounts of greater than 500 cm (200 in) recorded at some locations (Fig 1).

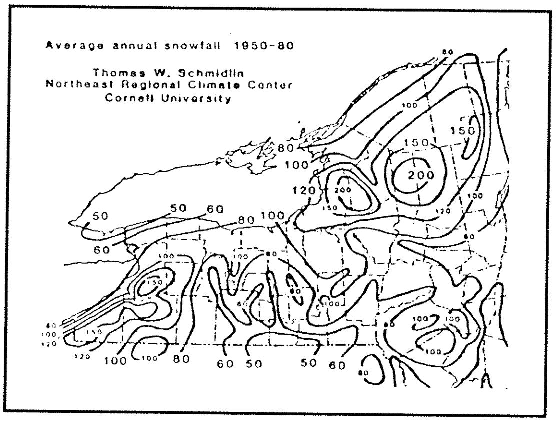


Fig 1. Average annual snowfall (inches) over New York State 1950-80. Note the snowfall maxima to the lee of Lakes Erie and Ontario. (Northeast Regional Climate Center)

These intense (yet very localized) snowstorms can severely impact an area, bringing a virtual halt to commerce and industry at times. For the forecast to be of more value to the public, the operational forecaster must be able to predict these events on very small scales in both time and space.

During the fall and winter of 1991-92, the forecast staff at the NWS office in Buffalo, NY evaluated experimental high resolution data from the National Meteorological Center's Nested Grid Model. Increased vertical and temporal resolution of the model data, compared to standard operationally available information, allowed forecasters a much more detailed look at parameters such as temperature, wind, and humidity, in the lowest layers of the atmosphere.

This paper will evaluate the high-resolution prognostic data for case studies that occurred during the winter of 1991-92, to determine whether improvements can be expected in short term forecasts for lake snows.

LAKE EFFECT SNOW ENVIRONMENT

Lake-effect snows are meso-alpha scale events as defined by Orlanski (1975). These storms are generally confined to the lowest 3 km of the atmosphere over a very localized area, with typical snowbands on the order of 5 to 20 km wide and less than 200 km in length (Hill 1971). Subtle changes in the large scale flow can cause snowbands to oscillate across a forecast region. These subtle changes may also occur over very short time scales, producing a wide range of weather conditions across the forecast area. Some of these storms have been known to produce extreme snowfalls with as much as 175 cm over a cross section less than 50 km wide (Sykes 1966, Niziol 1988).

Current numerical models, such as NMC's Nested Grid Model (NGM) are limited in their ability to simulate the mesoscale effects which the Great Lakes and local topography have on surrounding weather. In addition, prognostic model output made available to the forecaster usually is too limited in temporal and spatial resolution to accurately predict the evolution of lake-effect snow.

However, forecasters have developed a number of prediction schemes for lake-effect snow based on the synoptic scale data that is available from dynamic models (Niziol 1987). Using select forecast parameters, meteorologists are able to predict the general location and timing of these often intense snowstorms.

LAKE EFFECT FORECAST PARAMETERS

Forecasters generally follow the "Forecast Funnel" approach for the prediction of these mesoscale events (Snellman 1992). Synoptic scale pattern recognition categorizes the large scale weather features which will influence snowband development. Once a lake-effect favorable situation is recognized, select meteorological parameters are analyzed to determine how they might influence the mesoscale event. These include:

a. temperature difference between the lake and 850 mb level, as well as the 700 mb level.
b. height and strength of the capping (subsidence) inversion.
c. wind direction at the 850 mb level.
d. alignment of winds from the boundary layer through 700 mb.
e. synoptic scale vorticity advection

The temperature difference between the lake and the 850 mb level is used as an index of boundary layer stability. In general, a difference of 13 degrees Centigrade is considered necessary for lake snow to develop (Rothrock 1960, Hill 1971), though with synoptic scale enhancement, the temperature difference may be a bit less (Dockus 1985).

The temperature difference between 850 mb and 700 mb implies boundary layer depth, and the possible existence of the subsidence inversion that often accompanies the arctic airmass (Petterssen 1956). The capping inversion limits convective growth of snow producing clouds, and can be used as a predictor of snowband strength or termination.

In general, snow producing clouds align themselves with the average wind direction within the cloud layer. Over the Eastern Great Lakes, McVehil (1966) showed that snowbands aligned themselves best with winds at about the 850 mb level. Based on the research, forecasters developed a series of locator charts for Lakes Erie and Ontario to predict potential snowband location (Fig 2).

The change in wind direction with height within the cloud layer not only signals warm or cold air advection within the airmass (synoptic scale), but can indicate the mesoscale organization of the band. Less than 30 degree change in wind direction with height contributes to well organized snowbands, whereas greater than 60 degree directional shear may spread the snowbands out or break them up altogether (Niziol 1987).

Synoptic scale forcing, analyzed operationally through positive vorticity advection, has been shown to elevate the capping inversion in the lake-effect snow environment (Jiusto et al 1970). As a result, the 500mb vorticity pattern is considered as a prime forcing function in lake-effect snow.

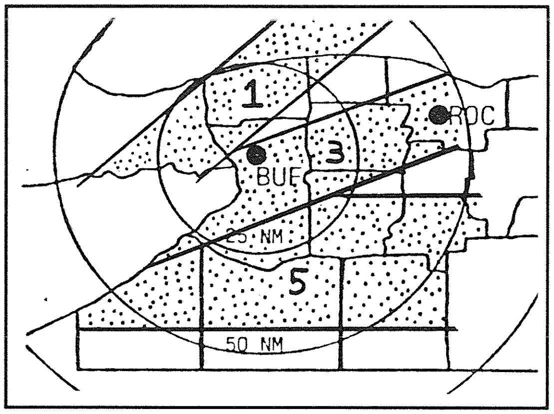


Fig 2. Lake-effect snow locator chart for Lake Erie depicts 3 of 6 Areas including: (1) 230-239° (3) 250-259° and (5) 270-289°.

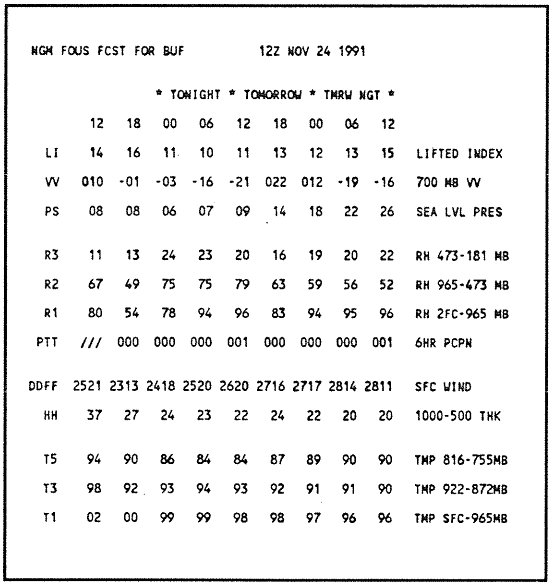
Current and past forecast procedures most often use information from the surface, 850 mb, 700 mb, and 500 mb levels to predict lake-effect snows. These levels were chosen because this was the only information available to operational forecasters on a daily basis. Even though higher resolution data is computed by the NGM model, prognostic information is only available to forecasters at a minimum of 6 to 12 hour intervals. This information does not adequately account for the types of changes that occur within the space and time scale of lake-effect snows. Consequently, the forecast can only generalize the potential scenario of a lake-effect snow event.

COMPARISON OF AVAILABLE MODEL DATA

The standard model output available in forecast offices includes both synoptic scale graphics, and alphanumeric listings of various forecast parameters for specific points (NGM FOUS Fig 3).

When the NGM FOUS data became available to forecast offices in the mid 1980's, it provided additional model output which was not previously available from the Limited-AREA Fine Mesh (LFM) model. The NGM FOUS includes temperature forecasts for 3 sigma levels below 700 mb, which allows forecasters to estimate the potential height and strength of the subsidence inversion (Reinking 1991). However, a major deficiency in the NGM FOUS data continues even today; that is the lack of wind forecasts below 700 mb, where most of the lake-effect snow events are confined.

The introduction of NGM high resolution prognostic data into the operational forecast setting fills many of the voids left by the original NGM FOUS, as shown in Fig 4.



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NGM FOUS FCST FOR BUF            12Z NOV 24 1991

                    * TONIGHT * TOMORROW * THRW NGT *

        12   18   00   06   12   18   00   06   12
  LI    14   16   11   10   11   13   12   13   15   LIFTED INDEX
  VV   010  -01  -03  -16  -21  022  012  -19  -16   700 MB VV
  PS    08   08   06   07   09   14   18   22   26   SEA LVL PRES

  R3    11   13   24   23   20   16   19   20   22   RH 473-181 MB
  R2    67   49   75   75   79   63   59   56   52   RH 965-473 MB
  R1    80   54   78   94   96   83   94   95   96   RH 2FC-965 MB
 PTT   ///  000  000  000  001  000  000  000  001   6HR PCPN

DDFF  2521 2313 2418 2520 2620 2716 2717 2814 2811   SFC WIND
  HH    37   27   24   23   22   24   22   20   20   1000-500 THK

  T5    94   90   86   84   84   87   89   90   90   TMP 816-755MB
  T3    98   92   93   94   93   92   91   91   90   TMP 922-872MB
  T1    02   00   99   99   98   98   97   96   96   TMP SFC-965MB
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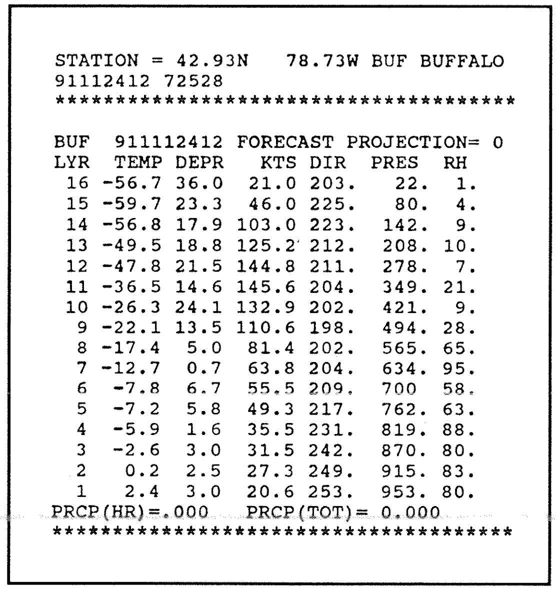
Fig 3. NGM FOUS forecast for Buffalo, NY at 1200 UTC November 24, 1992 (Hauser 1986). The file provides a 48 hour forecast in 6 hour increments.



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STATION = 42.93N   78.73W BUF BUFFALO
91112412 72528
*************************************

BUF  911112412 FORECAST PROJECTION= 0
LYR  TEMP DEPR   KTS DIR   PRES  RH
 16 -56.7 36.0  21.0 203.   22.  1.
 15 -59.7 23.3  46.0 225.   80.  4.
 14 -56.8 17.9 103.0 223.  142.  9.
 13 -49.5 18.8 125.2 212.  208. 10.
 12 -47.8 21.5 144.8 211.  278.  7.
 11 -36.5 14.6 145.6 204.  349. 21.
 10 -26.3 24.1 132.9 202.  421.  9.
  9 -22.1 13.5 110.6 198.  494. 28.
  8 -17.4  5.0  81.4 202.  565. 65.
  7 -12.7  0.7  63.8 204.  634. 95.
  6  -7.8  6.7  55.5 209.  700  58.
  5  -7.2  5.8  49.3 217.  762. 63.
  4  -5.9  1.6  35.5 231.  819. 88.
  3  -2.6  3.0  31.5 242.  870. 80.
  2   0.2  2.5  27.3 249.  915. 83.
  1   2.4  3.0  20.6 253.  953. 80.
PRCP(HR)=.000   PRCP(TOT)= 0.000
*************************************
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Fig 4. NGM high resolution model output at t=0 hrs. for Buffalo, NY at 1200 UTC November 24, 1992. Forty eight hourly "soundings" are available to the forecaster for all 16 levels of the model.

The data is sometimes referred to as a forecast sounding and includes hourly forecasts of specific parameters for all 16 levels of the model, including 5 levels below 700 mb out to 48 hours. The forecast data includes temperature, dewpoint depression, wind speed and direction, relative humidity and precipitation for select locations, interpolated from the NGM grid. The NGM high-resolution prognostic data provides a much more complete set of guidance for the forecast process.

MODEL SENSITIVITY

In order to evaluate the high-resolution model data as a forecast tool, a preliminary step was taken to compare the interpolated data to actual observations. Initialized model data was compared to observed upper air data taken twice a day at Buffalo, NY for the period January-March 1992. In addition, 12-48 hour NGM forecasts were compared to initialized NGM model data to determine the consistency of model runs. Parameters included wind direction and temperature observed at the 850 mb with model forecast data for sigma layer three (roughly 878 mb). Keeping in mind that only a limited data set was analyzed, a few observations can be made about the correlation of observed and forecast data.

Wind direction forecasts were filtered to remove data when wind speed was less than 10 mph, due to the wide variability of wind direction with weak winds. A comparison of NGM high resolution data and corresponding 0-24 hour forecast runs generally showed a standard deviation of less than 10 degrees difference. Thus, as a forecast tool, model wind direction may be a good indicator of snowband location orientation; however, as little as a 10 degree wind shift can relocate a snowband to a different part of the forecast area (Niziol 1987).

Similarly, a comparison of sigma level 3 data and observed temperature at 850 mb indicated that a standard deviation difference of approximately 1.5 degrees Centigrade can be expected for 0-24 hour forecast runs. This would suggest that the model, in most cases, realistically forecasts temperatures in the lower layers of the atmosphere.

VERIFICATION

The major forecast parameter verified during the case studies was wind direction vs. snowband location. In addition the existence of the subsidence inversion was also evaluated for a specific event.

The wind direction forecasts were verified by comparing the location of precipitation echoes off the WSR-57 radar with model forecast wind direction. A line was drawn through the axis of the strongest radar echoes within the snowband to determine in which forecast area the heaviest snowfall was occurring. For the same time period, forecast wind directions for the bottom three sigma layers were analyzed to predict where the heaviest snow should be occurring. Sigma levels one and two were tested in addition to sigma level three to determine whether they would correlate better with snowband location. The observed forecast areas were compared to the predicted areas with contingency tables (Fig 5).

OBSRVD	FCST 1	2	3	4	5	6	TOT
1	1	1					2
2	1	1	1				3
3			3				3
4				1	2		3
5				1	6		7
6					1	3	4
TOT	2	2	4	2	9	3	22

(a)

OBSRVD	FCST 1	2	3	4	5	6	TOT
1	1	1					2
2	1	2					3
3		3					3
4		1			2		3
5			1	1	5		7
6					3	1	4
TOT	2	7	1	1	10	1	22

(b)

OBSRVD	FCST 1	2	3	4	5	6	TOT
1	1	1					2
2	2	1					3
3	1	2					3
4		1			2		3
5			1	1	5		7
6					3	1	4
TOT	4	5	1	1	10	1	22

(c)

Fig 5. Contingency tables for predicted vs. observed snowband location off Lake Erie for the first three sigma levels from the NGM forecast valid 1200 UTC 24 Nov 1991. (a) sigma 3 (878 mb) (b) sigma level 2 (925 mb) (c) sigma 1 (965 mb).

In addition, a standard forecast technique was evaluated with the new data set. Hourly wind forecasts from sigma level three were plotted against time. In this way the forecaster gets an overall picture of the trend in wind direction throughout the forecast period. Then along with the locator charts in Fig 2, a general forecast of snowband movement and location with time can be provided to the public. This "real world" forecast approach provided the public with an expected scenario of the lake-effect storm (i.e. whether or not the storm would move into the northern suburbs that evening, or will it come back this way once it passes through...)

Soundings taken at Buffalo, NY were compared to forecast model data to determine if the NGM model could accurately predict the subsidence (or capping) inversion that often develops over the Great Lakes in association with the arctic or polar-continental airmass (Petterssen 1956). During intense lake-effect snow episodes however, the temperature inversion may be eroded away altogether, and the dry layer elevated somewhat due to convection within, and close to a snowband. In the case studies that were analyzed it was observed that when no subsidence temperature inversion existed, precipitation echo tops from the Buffalo radar were limited to within a few hundred meters of the base of the dry subsidence layer on the sounding. So, it was decided to compare the height of the base of the deep, dry subsidence layer between the forecast model data and the actual Buffalo sounding.

CASE STUDIES

The main case study was a single band snowstorm that occurred off Lake Erie over metropolitan Buffalo during 24-25 November 1991. About 37 cm (15 in) of snow was recorded around Buffalo during the event. In addition to the main case study, two other events are reviewed briefly to demonstrate the potential benefits of the hourly forecast wind direction plot as a forecast tool. The second event occurred during 18-19 January 1992 and produced two brief bouts of heavy snow over metropolitan Buffalo. The third event was a prolonged stationary single band storm off Lake Ontario that dumped about 225 cm (90 in) of heavy snow over portions of southern Oswego county in central New York State!

November 24-25 1991

The event of 24-25 November 1991 was a single band snowstorm that occurred at the east end of Lake Erie. This storm was significant, because it affected a population of over a million people in the Buffalo area. Storm totals of 37 cm (15 in) of snow fell over the suburbs just south of the Buffalo airport, with another maximum of 30 cm (12 in) over the southern tier of New York (Fig 6). During 26 November additional snowfall occurred over western new York from lake-effect streamers off Lake Huron.

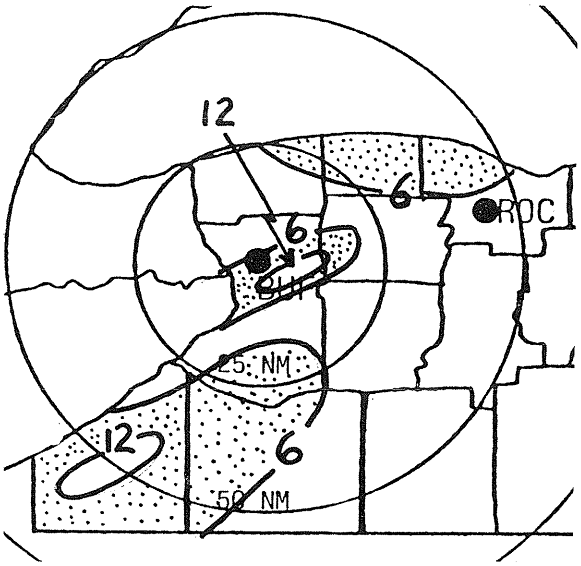
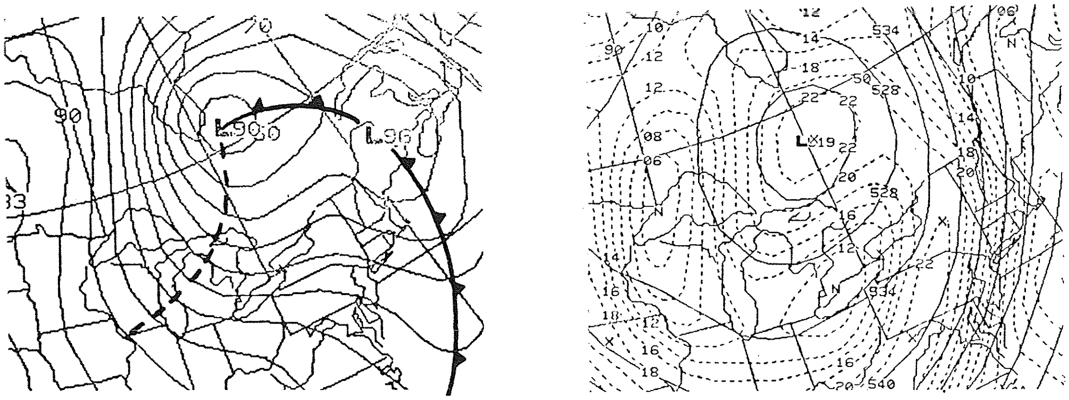


Fig 6. Total snowfall (inches) from the Lake Erie snowstorm during 24-25 Nov 1991. Note two snowfall maxima over a localized stretch.

Synoptic scale pattern recognition flagged this event to begin as an intense single band storm, which would eventually evolve into a multiple band event. A 500 mb closed low was forecast to move east from the upper Great Lakes to just south of James Bay Canada during the period (Fig 7a). At the surface, the nearly vertically stacked Low was forecast to push a strong cold front through western New York on the morning of the 24th, followed by a secondary cold front associated with the upper trough, early on the 25th (Fig 7b).

Using the sigma level three wind output the operational forecaster predicted snowband location bordering across Areas 1-2 from 1200-2000 UTC on the 24th (Fig 8). A snowband did develop over Areas 1-2 during that morning (Fig. 9a). Wind direction was forecast to veer slightly during late



(a)

(b)

Fig 7. (a) NMC surface analysis (4mb contour) at 0300 UTC 25 Nov 1991. (b) NMC 500 mb analysis of height (dam) and vorticity (10^{-6}) at 0000 UTC 25 Nov 1991.

afternoon and become steady again by evening. As predicted, by that evening the snowband had intensified and drifted south over the City of Buffalo and the airport (Fig 9b), where it remained for about a 4-5 hour period. By 0600 UTC the band moved south to the southern suburbs, and was producing snowfall at a rate greater than 1 inch per hour (Fig 9c). At this time, the wind direction plot indicated that the band would remain over that area for about a four to five hour period. About 33 cm (13 in) of snow was recorded in that Area. After 0700 UTC the band widened, weakened, and drifted well south of Buffalo over Area 5, where it remained for the better part of the day and night (Fig 9d). The wind plot predicted the band to move to Area 5 and remain there for about an eighteen hour period. Although the fetch was reduced somewhat over Lake Erie, the snowband produced as much as 30 cm (12 in) of snow over the higher elevations of Area 5. Toward the end of the forecast period multiple snowbands were observed on radar off Lake Ontario and Lake Erie. Satellite imagery confirmed that these snowbands originated well upstream of western New York, off Lake Huron. The wind plot and locator tables also predicted this scenario.

A special weather statement issued early on the morning of the 24th posted snow squall warnings for portions of western New York off Lake Erie. The statement notified the public that "...squalls would most likely begin later in the morning off Lake Erie over parts of Niagara, Orleans, and extreme northern Erie counties, then shift southward into the Buffalo area later in the day". That night the squalls were forecast to "...most likely remain over parts of Erie and Genesee counties for several hours before gradually moving toward northern Chautauqua and Cattaraugus counties...".

The comparison of wind direction forecasts for the first three sigma levels showed that sigma level 3 (878 mb) correlated best with observed snowband location (Fig 5a). In fact, all time periods were within one forecast sector of observed location. The predicted wind directions in both lower sigma levels were generally too far south of west, with forecast areas one or two sectors away from observed snowband location. This reinforces the earlier research on the eastern Great Lakes in which McVehil (1966) found that snowbands generally align themselves with the winds near the 850 mb level.

For this case study the plot of forecast wind direction provided a fairly accurate depiction of the evolution of the storm, including the location, amount of time spent over each forecast area, and approximate timing of the movement of the snowband.

The forecast height of the dry layer associated with subsidence compared well to the observed height. Although lake snow did not cease altogether, most of the lake snow activity decreased to only a few flurries during the late afternoon of the 26th, when the predicted base of the dry layer dropped below the 800 mb level (Fig 10).

January 18-19 1992

This event was also a single band storm that

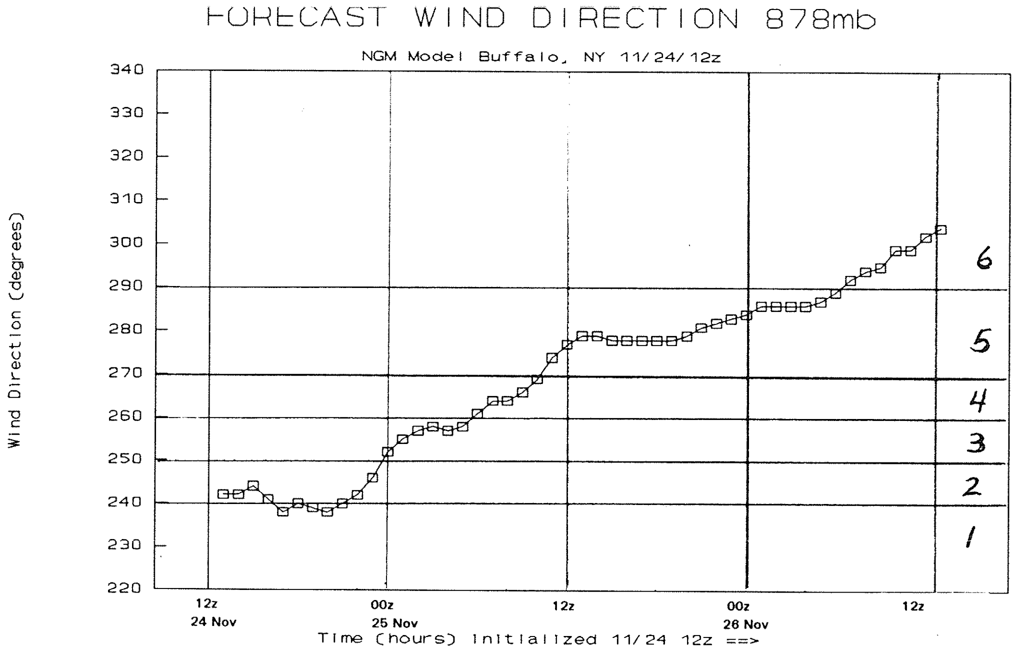


Fig 8. NGM sigma level 3 (870mb) wind direction forecast vs. time for Buffalo, NY at 1200 UTC Nov 24, 1991. Corresponding forecast areas are numbered 1-6 at the right of the graph.

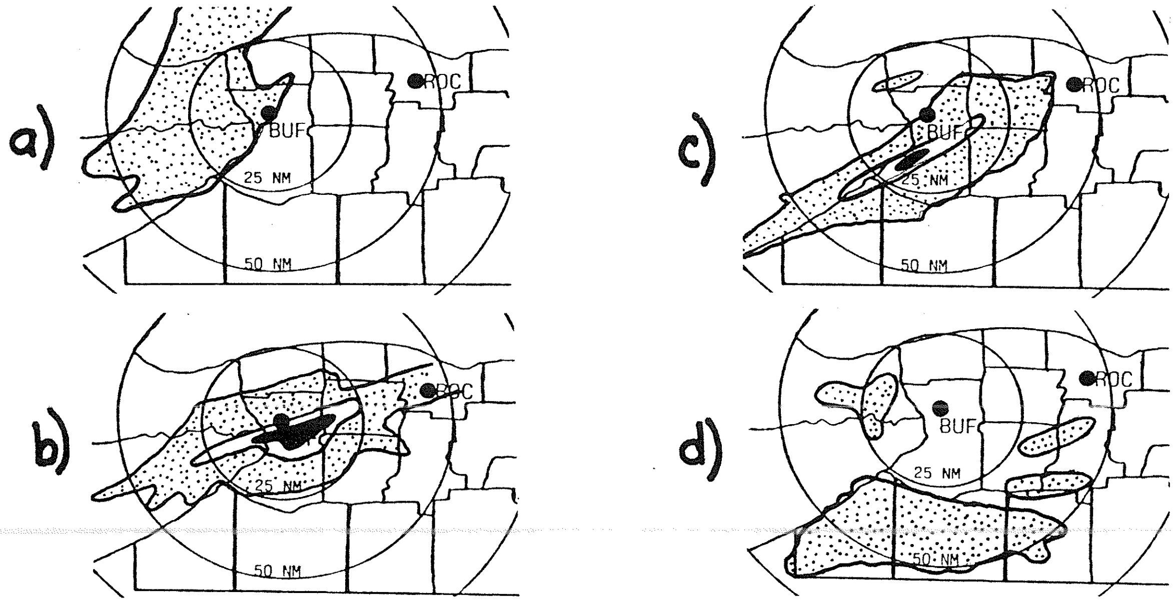


Fig 9. Radar overlays off the WSR-57 DVIP radar at Buffalo, NY. To highlight the intensity of low density lake-effect snow, the linear signal is outlined. level 1 = full gain, level 2 = 12dBz attenuation, level 3 = 21 dBz attenuation. (a) 1400 UTC 24 Nov 1991 (b) 0200 UTC 25 Nov 1991 (c) 0600 UTC 25 Nov 1991 (d) 1800 UTC 25 Nov 1991.

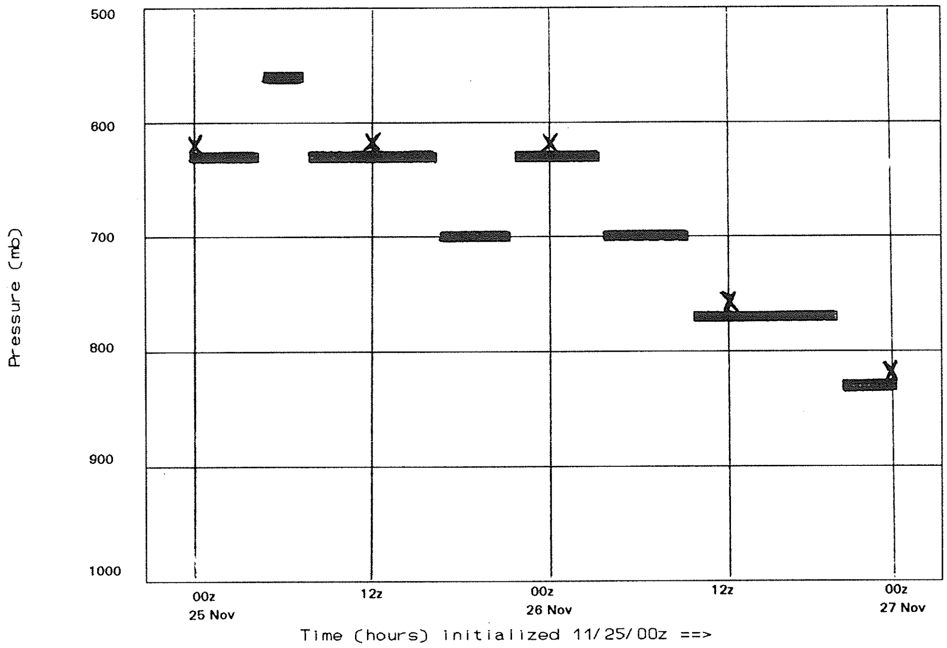


Fig 10. Approximate height of the subsidence level observed at Buffalo, NY (X), and the corresponding NGM forecast subsidence level (solid bar) for the NGM model run at 0000 UTC Nov 25 1991. The subsidence level is defined here as the base of a deep layer of dry air that exceeds a dewpoint depression of 5°C.

affected parts of western New York just east of Lake Erie including Buffalo. Total snowfall from this storm did not exceed 22 cm (9 in), however the event could have been quite a headache for forecasters because the migratory snowband produced two separate bouts of heavy snow over the metropolitan area around Buffalo.

The snowband developed during the morning of the 19th and continued through the morning of the 20th, before significant warm air advection stabilized the airmass across Lake Erie, ending the snow event.

The hourly wind direction forecast is plotted in Fig 11. As correctly predicted by the model winds, the snowband moved across metro Buffalo (Area 3) during the evening of the 19th, then crossed back south through the same area before sunrise on the 20th. The zone forecast correctly predicted this scenario; however the snowband crossed through Buffalo about 2 hours earlier than expected, and retraced its path through Buffalo a couple of hours later than the model winds predicted.

March 12-13 1992

This storm produced one of the most significant snowfalls in recent history off Lake Ontario. The combination of synoptic scale snowfall, and heavy lake effect snow produced about 225 cm (90 in) of total snowfall, in the town of Palermo, about 20 miles northwest of Syracuse, NY.

The NGM wind direction forecast, issued at 1200 UTC 12 Mar 1992 for Syracuse is shown in Fig 12. After a major synoptic scale snowfall covered the region, heavy localized lake effect snow squalls developed during the night of March 12th. The wind direction plot clearly shows a nearly constant wind direction for close to a 20 hour period, when Palermo was receiving snowfall rates of 8 to 10 cm (3 to 4 in) per hour. In addition, the model winds suggest a slight veering of the wind between 0000-0400 UTC on March 13th. During this time the snowband actually drifted south across metro Syracuse and reduced visibilities to less than 1/2 mile in moderate snow and blowing snow.

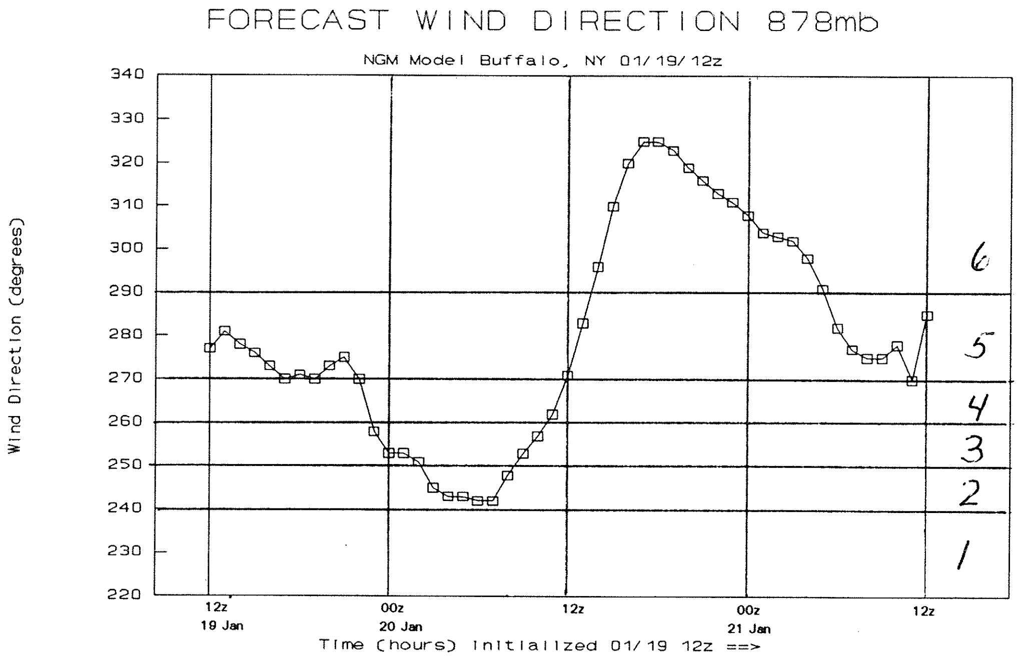


Fig 11. NGM sigma level 3 (870mb) wind direction forecast vs. time at Buffalo, NY for 1200 UTC Jan 19, 1992. Corresponding forecast areas for Lake Erie induced snowbands are numbered 1-6 at the right of the graph.

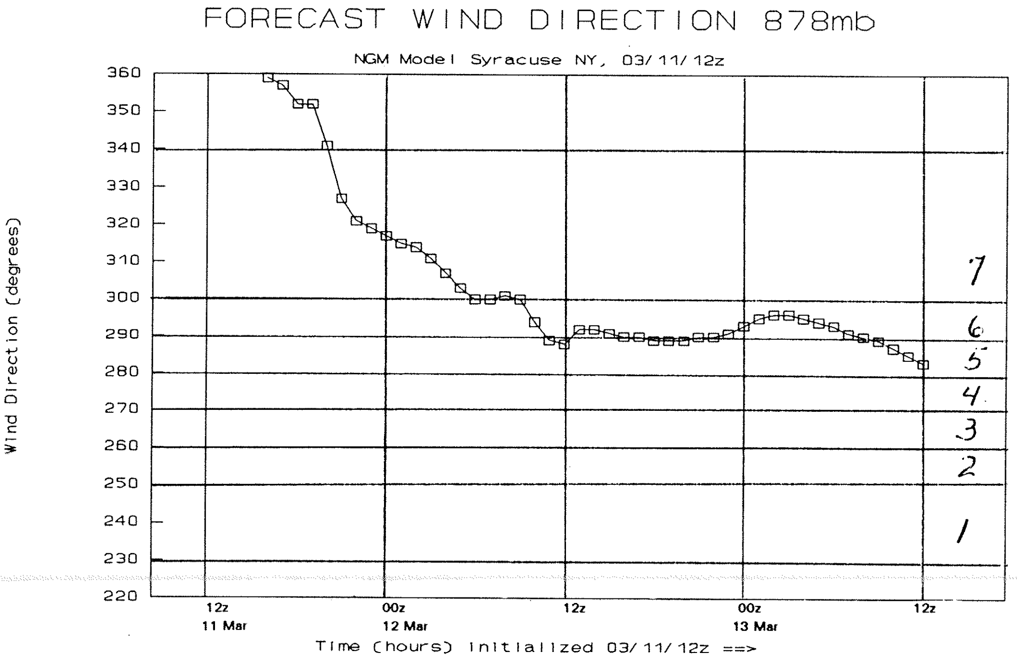


Fig 12. NGM sigma level 3 (870mb) wind direction forecast vs. time at Syracuse, NY for 1200 UTC Mar 11, 1992. Corresponding forecast areas for Lake Ontario induced snowbands are numbered 1-7 at the right of the graph.

As the three cases show, the plot of hourly forecast winds from sigma level 3 produces a reasonable scenario of the expected location and movement of the snowband. Of course the model is not able to fully simulate the mesoscale affects of the lakes. In fact, in the 18-19 January 1992 case, there was a couple hour lag in the movement of the snowband as suggested by the wind forecast, at a time when the snowband was aligned along the longest axis of the lake. The lag time is important to note, because forecasters have seen this happen before. There is some suggestion that there is a persistence of the snowband and its mesoscale convergence zone to maintain its orientation along the long axis of the lake, until the synoptic scale weather pattern overpowers the mesoscale forcing. At the present time this cannot be predicted by such a large scale model as the NGM.

OPERATIONAL FORECAST LIMITS

Forecasts of snowfall amounts were not studied in this paper. Total snowfall is still a very difficult problem for the operational forecaster. Typically, total storm accumulations for any given area are a combination of snowfall rate, and the amount of time the snowband remains over an area. In addition, snow to water ratios vary greatly depending on the airmass temperature, and such local effects as orographic enhancement (Hjelmfelt 1992). However, the wind direction forecasts at least suggest the amount of time that the snowband might remain over a given area, and general categorical snowfall forecasts are possible in these cases.

Operational forecasters regard this information subjectively and issue snowfall forecasts that provide the most important information, without causing undue panic for the public. Currently, snowfall amounts are included in the first 12 to 24 hours of the forecast, and are categorized.

CONCLUSIONS

The availability of high resolution NGM data in the forecasting office has been received with great enthusiasm by forecasters. The high resolution model data was used to predict snowband evolution during the winter of 1991-92 at Buffalo, NY, based on past research at NWS Buffalo, relating low level wind forecast to snowband location. To simplify the time-consuming task of analyzing huge data files, a computer generated forecast aid that plotted wind direction vs. time was developed. Although this was a very limited data set, the one case study suggested that sigma level three (878 mb) was found to correlate well with snowband location and movement, a statement that confirms previous research results. In general, the hourly wind forecasts could predict the location and movement of single banded storms with much better temporal and spatial resolution than previously available model data. Wind direction forecasts were not perfect, but they were shown to have provided valuable additional information to the forecaster for the prediction of the lake-effect snow event.

FUTURE WORK

The availability of high resolution data from dynamic models at the forecast office has opened up the possibility of mesoscale modelling for local forecast problems right in the operational forecast setting. Currently, the forecast office at Buffalo,NY is participating with the State University of New York (SUNY) Colleges at Brockport and Oswego in a COMET (Cooperative Program for Operational Meteorology, Education and Training) Partners Project which will evaluate the use of such new data sets with various mesoscale models. The ability to tap such a valuable information resource and use the data in the operational setting, should heed in the understanding of these events, and bring a great benefit in the form of better local forecasts to the end users.

REFERENCES

Dockus, Dale 1985: Lake effect snow forecasting in the computer age. Nat. Wea. Dig. , Vol 10, No. 4, pp. 5-19.

Hill, J. D., 1971: Snow Squalls in the lee of Lake Erie and Ontario. NOAA Tech. Memo. NWS ER-43.

Hjelmfelt, M. R., 1992: Orographic effects in simulated lake effect snowstorms over Lake Michigan. Mon. Wea. Rev., 120, 373-377.

Jiusto, J.E., Paine, D.A., Kaplan, M.L.,1970: Great Lakes snowstorms Part 2: Synoptic and Climatological Aspects. ESSA Grant

E22-13-060 (G) ASRC, SUNY Albany.

McVehil, G.E., and Peace, R. L., Jr., 1966: Project lake effect. A study of lake effect snowstorms. Final contract report. CWB 1231, 52pp. available from CALSPAN, Buffalo, NY.

Niziol, T. A., 1987: Operational forecasting of lake effect snowfall in western and central New York. Wea. Forecasting, 2, 310-321.

Niziol, T. A., 1988: Some synoptic and mesoscale interactions in a lake effect snowstorm. Postprints, Winter Weather Workshop, Raleigh NC, NOAA Tech. Memo. NWS ER-82.

Orlanski, I., 1975: A Rational Subdivision of Scales for Atmospheric Processes. Bull, AMS, 56, 527-530.

Petterssen, S., 1956: Weather Analysis and Forecasting, Volume II. Weather and Weather Systems. McGraw-Hill. 266pp.

Reinking, R.F., 1991: Lake Ontario Winter Storms Project Final technical report. 213 pp., Niagara Mohawk Power Corp, Syracuse NY.

Rothrock, H.J., 1960: An aid in forecasting significant lake snows, NOAA Tech. Memo. WBTM CR-30, Dept. of Commerce.

Snellman, L.W., 1992: An old forecaster looks at modernization - pros and cons. Nat Wea. Dig., Vol 16, No. 4, pp 2-5.

Sykes, R.J. Jr. 1966: The Blizzard of '66 in central New York: Legend in its time. Weatherwise 19, 241-247.