R. Sykes – Panel Chairman

Panel Members: K. F. Dewey
R. E. Falconer (Not present)
B. Kolker
L. Lansing
R. Sykes

INTRODUCTION: R. Sykes

Panel format was rearranged due to:

a) A reduction in the allotted time for presentations by the panel. Such reduction was imposed at the Conference. Some time was allotted in the following Friday Morning Session during which some open discussion was possible.

b) The absence of Raymond E. Falconer, Research Associate, Atmospheric Sciences Research Center, State University of New York at Albany. Mr. Falconer was out of the country at the time of the Conference. Aspects of his talk according to the Thirty fifth Meeting announcement abstract, were covered by other Panel Members.

Certain aspects of the severe winter of 1976/77 sharpened interest in Lake Effect Snow Situations. Especially significant were the late January and early February 1977 conditions that involved major urban and suburban areas off the Eastern Lakes. Even as this Conference is in session, a following severe winter is in progress. Combinations of circumstances seem so far to have spared the larger urban areas some of the grief of the previous winter. Aims of the panel are:

a) To summarize some technical aspects relating to Lake Effect Snow situations;

b) To summarize factors directly influencing the lives of people in the affected areas;

c) To identify forecasting circumstances, problems and successes, peculiar to the Eastern Lake Region, and;

d) To emphasize aspects about these interesting and important conditions of particular concern in the near future.

Our panel brings together members with research backgrounds and, long experience with snow as it relates to people. They have faced directly into the problems of forecasting as well as personally and repeatedly, lived with the conditions in many challenging ways, year after year. We believe that here is a subject needing no justification to be in the forefront of this forum of the Eastern Snow Conference.

(At the Conference members presented their remarks alphabetically. For these Proceedings a slight rearrangement has been made. To conform to the rearranged time allotment the R. Sykes presentation was reduced mostly to a showing of a few sketches and, some color slides. To facilitate preparation of the Proceedings, the few comments of this member will follow soon after this introduction.)
SCALES AND PATTERNS RELATING TO LAKE EFFECT SNOW

SITUATIONS OFF EASTERN LAKE ONTARIO

Robert B. Sykes, Jr.
Meteorologist and Associate Professor
Department of Earth Sciences
State University College of New York at Oswego

ABSTRACT

In the Great Lakes area an interesting aspect of snow relates to the uniqueness of lake effect snowfall conditions – a part of the general lake effect phenomena. These snowfall conditions can be generally divided into those relating to one or more of:
  a. Lake-shore areas in particular;
  b. Large-scale cold air flows with local effects;
  c. Parts of major storms, for example – blizzards;
  d. Topographical conditions; and
  e. Miscellaneous factors.

Blizzard-like and snowburst situations are referenced, as well as similarities of these meso-micro scale phenomena to the larger macro scale pressure and frontal patterns. We seem to have 'marriage' of aspects of the energetic systems which sweep across our continent.

The heavier lake effect snowfalls divide into three categories: Blizzard-like situations with strong winds and a good deal of moving snow, some of which may be snowfall; b) Snowburst situations during which exceptionally heavy (e.g. 2 to 4 inches of snow fall per hour for several hours) snowfalls occur, frequently over limited areas
and/or in the famous 'bands'; and c) Blizzard-burst situations during which the 'worst' qualities of the preceding may occur.

Many lake effect snow situations seem to relate to rather local patterns as meso-micro scale phenomena. These appear to be manifestations of the larger and well-known macro scale pressure and frontal patterns. Patient study reveals 'inverted wave systems' along what appear to be land/lake 'breeze fronts'. These appear in both day and night sequences. Both such front-like and surface-pressure-pattern features seem to have wind, temperature, snowfall and many other weather changes accompanying their passages.

Certain mesosystems are particularly interesting. Mostly there seem to be limited in extent to shoreline and inland-for-a-mile-or-two, areas. These were reported upon with illustrations in the Thirty-third Proceedings (Richorn and Sykes) and especially in the 1972 Proceedings covering the meeting at Oswego, New York (Sykes).

(Sketches of the believed patterns for such meso-systems, snowburst situations, etc. and, a number of slides illustrated the remarks about these and associated weather conditions. The presentation closed with the showing during our discussion period of the following day, of several color slides. These detailed weather sequences accompanied some of the believed pattern occurrences.)
DEVELOPMENT OF A FORECAST GUIDANCE

PRODUCT FOR LAKE-EFFECT SNOWSTORMS

Kenneth F. Dewey

Climatology Program
Avery Lab 311
University of Nebraska

ABSTRACT

This paper examines the development of a National Weather Service guidance product for Lake-Effect snowstorms. Ten years of lake-effect snowfall data (1967-1976) were collected for both Lake Erie and Lake Ontario systems. Each 24-hour period of lake-effect snowfall was stratified into one of six snowfall intensity levels. Multiple discriminant analysis was employed to derive predictor coefficients. Utilizing these coefficients, the model was tested during the 1976-77 snowfall season. Evaluation of the forecast verifications is included within the description of the significance of this forecast product.

INTRODUCTION

One of the more dramatic features of the climatology of the Great Lakes region is the zone of heavy snowfall along the eastern and southern shores of the Great Lakes. These belts of heavy snowfall are the result of lake-effect snowstorms. During the winter months cold arctic air spreading over the Great Lakes picks up heat and moisture from the relatively warmer lake surface. The resulting vertical transport of heat and moisture renders these air streams unstable and consequently initiates the development of mesoscale precipitation cells. Ice cover is a limiting factor on the vertical exchange of heat and moisture, therefore as the winter progresses and the ice cover on the lakes increases, there is a decrease in the intensity of the lake-effect storms. It is significant to note that only Lake Erie normally totally freezes over, therefore even though lake-effect storms virtually disappear to the lee of Lake Erie, they continue throughout the winter to the lee of the other Great Lakes.

Snowfall amounts can be quite heavy during these lake-effect storms. A five-day lake-effect storm in January 1966 deposited a total of 102 inches (259 cm) of snow at Oswego, New York. The lake-effect snowstorm of 9 January 1976 buried Adams, NY under 68 inches (178 cm) of snow in a period of less than 24 hours (Dewey, 1977). As significant as these systems are, they are generally spatially limited in their impact on the communities bordering the Great Lakes. Numerous studies (for example, Eichenlaub, 1970; Muller, 1966; Strommen 1978; and, Wiggins 1950) have illustrated that although clouds have been observed several hundred miles inland, the heavier snowfalls are generally limited to an area within 100 miles (161 km) of the shoreline of the lake.

Because of the limited spatial extent, the National Weather Service has given these storms only slight attention during the development of their forecast guidance products. Buffalo WSFO, for example, has developed their own forecast guidance product for Lake Erie systems based upon several years of empirical evidence. During 1976-77 a research effort was initiated within the Techniques Development Laboratory of the National Weather Service to develop an automated lake-effect forecast guidance product. This report will summarize the development of the forecast product and illustrate how well it performed during the 1976-77 snowfall season.
RESEARCH METHODOLOGY

The first step in this research effort was the isolation of all Lake Ontario and Lake Erie lake-effect snowfall events which occurred during the 10-year period November 1967 to March 1976. All days which had air temperatures in excess of the lake surface temperatures, wind directions between 100° and 200° azimuth (these winds would put the study region upwind of the lake), and, frontal systems passing over the lake or within 250 miles (402 km) of the lake were eliminated from the study. In this manner, all non-lake-effect days as well as lake-effect days which occurred concurrently with synoptic scale precipitation events were excluded. Due to the inability of determining the magnitude of the lake-effect component during synoptic events, this latter exclusion was necessary. The remaining days were then classified as lake-effect days.

The precipitation records were examined for each lake-effect period which occurred during the 10-year data sample. Each 24-hour period was then classified into one of seven observed snowfall intensities. Figure 1 illustrates the distribution of observed lake-effect snowfall intensities for both Lakes Erie and Ontario. The intensity names were chosen based upon examples of intensity levels described in the literature and the six letter format was chosen for uniform computer display purposes.

DEVELOPMENT OF A STATISTICAL FRAMEWORK

At this point a search was initiated to determine which predictors were responsible for the observed variation in intensity of these snowfall systems. Based upon previous lake-effect investigations (Dewey, 1975; McVehil et al., 1968; Juusto et al., 1970; and Paine and Kaplan, 1971), 21 predictors were chosen for the initial statistical analysis. Most of the predictors already existed within the National Meteorological Center (NMC) computer system, however, several predictors were generated specifically for the Lake Erie and Lake Ontario region. The total list of predictors included several measures of the mesoscale moisture gradient over the lake, the mesoscale surface wind field over the lake, the mesoscale thermal gradient over the lake, the amount of fetch over water for the advecting air mass, several synoptic scale stability indices, the moisture content of the advecting air mass, the synoptic scale vertical velocity field, the wind velocity over the lake at several upper levels, the ice cover on the lake, and the orographic rise for the area downwind of the lake.

With the 24-hour storm periods stratified on the basis of seven intensity levels, predictor values were collected for each of the 21 predictors. These data were then subjected to statistical analysis utilizing multiple discriminant analysis. The intensity of the snowfall system was known beforehand, so it was not the object at this point to predict intensity levels. Instead, the discriminant analysis program examined the predictor values of each observed 24-hour period of snowfall and indicated whether the combination of predictor values was statistically similar to the other days in its group or perhaps more indicative of the predictor values in one of the other groups.

If the values for a specific predictor did not naturally group together according to the various intensity levels, there would obviously be no ability for this predictor to discriminate between snowfall intensities. It should be noted that the multiple discriminant analysis program incorporated a "Stepwise" procedure in its predictor selection procedure. The predictor which offered the most ability to discriminate between groups was selected first. The procedure was replicated until the last predictor (the one with the least ability to discriminate) was chosen. As each predictor was added to the model its ability to discriminate in conjunction with the previously chosen predictors was evaluated. It was possible to set a statistical limit beyond which a predictor would be discarded due to its lack of offering additional discriminating ability. A level of significance of f0 = .10 for the standard "F" test was chosen and
Figure 1. Observed snowfall intensities during lake-effect period (1967-1976).

<table>
<thead>
<tr>
<th>24-Hour Snowfall</th>
<th>Intensity Definition</th>
<th>Lake Erie Days Analyzed</th>
<th>Lake Ontario Days Analyzed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 inches</td>
<td>NOSNOW</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>≤ 1 inch (2.5 cm)</td>
<td>FLURRY</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>1-4 inches (2.5-10 cm)</td>
<td>LTSNOW</td>
<td>61</td>
<td>47</td>
</tr>
<tr>
<td>4-8 inches (10-20 cm)</td>
<td>MDSNOW</td>
<td>74</td>
<td>58</td>
</tr>
<tr>
<td>8-12 inches (20-30 cm)</td>
<td>HVSNOW</td>
<td>21</td>
<td>49</td>
</tr>
<tr>
<td>12-24 inches (30-60 cm)</td>
<td>SQUALL</td>
<td>31</td>
<td>54</td>
</tr>
<tr>
<td>24 inches + (60 cm)</td>
<td>BURSTS</td>
<td>9</td>
<td>24</td>
</tr>
</tbody>
</table>
seven of the predictors were removed from the forecast model, for they statistically
offered no explanation of the dispersion between the groups of snowfall intensity. It is
interesting to note that ice cover was the last statistically significant parameter to be
chosen for the Lake Ontario model while it was the fifth chosen in the Lake Erie model.
This reflects upon the fact that ice cover on Lake Ontario is normally not as significant
a factor as for Lake Erie. Pondy (1971) in his Great Lakes Ice Atlas, indicated that the
normal maximum extent of ice on Lake Erie is 95% yet for Lake Ontario it is only 15%.

The combination of 14 predictors which were found to be statistically grouped into
snowfall intensity levels are listed in figure 2. Utilizing several standard statistical
measures, it was concluded that it should be possible to predict intensity levels of the
lake-effect system using this set of predictors and the attendant discriminant equations
and coefficients.

AN INDEPENDENT TEST OF THE FORECAST MODEL

The next and final step in this study was an independent test of these equations
and coefficients which had been developed from a 10-year data base. The 1976-77 winter
season was an ideal period for testing the lake-effect model as there were numerous lake-

effect occurrences throughout the snowfall season. Using predicted values for those
parameters which are automatically produced by the National Weather Service, NMC and
using the latest available values for those predictors not automatically predicted (such as ice cover), forecasts of lake-effect snowfall intensity were made during the past
winter.

The statistical relationship

\[ P(k) = \frac{e^{f_k}}{\sum_{i=1}^{k} e^{f_i}} \]

was utilized where \( P(k) \) is the probability of membership in group \( k \), \( f_k \) is the discrim-
inant index value for group \( k \), and \( \sum_{i=1}^{k} e^{f_i} \) is the sum of the discriminant index values
for all groups \( i \) through \( k \). This equation produced a discrete probability for each group
and a forecast was made based upon the group with the highest probability. For example,
the following probabilities were generated for January 16, 1977, and the Lake Erie snow-

belt:

<table>
<thead>
<tr>
<th>NOSNOW</th>
<th>FLURRY</th>
<th>LTSNOW</th>
<th>MDSNOW</th>
<th>HYSNOW</th>
<th>SQUALL</th>
<th>BURSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>00.1%</td>
<td>01.8%</td>
<td>23.5%</td>
<td>67.9%</td>
<td>6.5%</td>
<td>0.2%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

A forecast of moderate snow (4-8 inches, 10-20 cm) was selected due to the highest fore-

cast probability occurring within that snowfall intensity level. On this specific day a
maximum of 5 inches (13 cm) was observed to the lee of Lake Erie.

It should be noted that this is a conditionally operative model which was employed
only when the previously listed two criteria were satisfied. When the observed snowfall
amounts were made available from the National Climatic Center, the forecasts were then
verified for the entire snow season.

Overall, the results were quite satisfying for both the Lake Erie and Lake Ontario
forecast model. It is difficult to measure the relative success of this forecast product.
There are no other operational lake-effect snowfall models which predict lake-effect
intensity, therefore this model cannot be evaluated in a comparative sense with any
existing forecast product. A measure of the model's success can be illustrated however,
through a subjective evaluation of the forecast verifications.
Figure 2

Summary Table of Predictors Which Were Utilized in the Lake-Effect Forecast Model

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Temperature of the water – Temperature at 850mb</td>
</tr>
<tr>
<td>2</td>
<td>Temperature of the water – Temperature upwind</td>
</tr>
<tr>
<td>3</td>
<td>Temperature of the water – Temperature of the air 2km over the lake</td>
</tr>
<tr>
<td>4</td>
<td>Vapor pressure gradient at 2km over the lake</td>
</tr>
<tr>
<td>5</td>
<td>850mb relative humidity</td>
</tr>
<tr>
<td>6</td>
<td>Average relative humidity, Surface to 500mb</td>
</tr>
<tr>
<td>7</td>
<td>Precipitable water of the air mass</td>
</tr>
<tr>
<td>8</td>
<td>Surface wind speed over the lake</td>
</tr>
<tr>
<td>9</td>
<td>850mb wind speed</td>
</tr>
<tr>
<td>10</td>
<td>Surface wind fetch over the lake</td>
</tr>
<tr>
<td>11</td>
<td>850mb wind fetch over the lake</td>
</tr>
<tr>
<td>12</td>
<td>Stability index (Lifted Index)</td>
</tr>
<tr>
<td>13</td>
<td>Orographic rise</td>
</tr>
<tr>
<td>14</td>
<td>Ice Cover</td>
</tr>
</tbody>
</table>
Figures 3 and 4 illustrate the predictions and verifications for each lake during the past snowfall season. Less than 17% of the verifications were more than one classification category from the predicted intensity of snowfall for each lake. Examining the distribution of forecast verifications, it is interesting to note that the model had a tendency to over forecast snowfall intensity for the Lake Ontario systems and under forecast snowfall intensity for the Lake Erie systems.

The exceptional ice cover on Lake Ontario during the winter of 1976-77 (estimated to exceed 42% on February 15, 1977) can perhaps be linked to the over forecasting bias in the Lake Ontario model. The average maximum ice cover in the 10-year data sample which was utilized to create the predictor coefficients was 16% with the greatest extent of 25% ice cover observed during the winter of 1973-74. Although the extensive ice cover on Lake Ontario did limit the intensity of lake-effect snowfall systems during the past winter, the relatively low coefficient weighting for ice cover in the Lake Ontario model did not allow the model to adequately assess the significance of ice cover in the intensity of these snowfall systems. Unfortunately, there appears to be no simple explanation for the under forecasting of intensity of the Lake Erie snowfall systems.

SUMMARY

In summary, a lake-effect snowfall intensity forecast guidance product was developed for both Lake Erie and Lake Ontario. A 10-year data sample was collected and was analyzed utilizing multiple discriminant analysis. This statistical test illustrated that it should be possible to discriminate between the occurrence and non-occurrence of lake-effect snowfall systems as well as six intensities of lake-effect snowfall utilizing a combination of 14 predictors. An independent test of the Lake Erie and the Lake Ontario model was run during the 1976-77 winter season. The forecast verifications were evaluated and the forecast model for each lake had a similar highly acceptable level of success. The lake-effect model will be further evaluated during the present (1977-78) snowfall season and it is hoped that the success ratio will continue to improve. After two years of testing, it is hoped that the model will be implemented as an operational product by the National Weather Service.
Figure 3. 1976-77 snowfall season forecast verifications -- Lake Erie model

<table>
<thead>
<tr>
<th>Observed Group</th>
<th>NOSNOW</th>
<th>FLURRY</th>
<th>LITSNOW</th>
<th>MDSNOW</th>
<th>HVSNOW</th>
<th>SQUALL</th>
<th>BURSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOSNOW</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FLURRY</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LITSNOW</td>
<td>2</td>
<td>2</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MDSNOW</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>13</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HVSNOW</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SQUALL</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>BURSTS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Number of days (P-O) > 1 classification category = 8 days (16% of the forecasts)
Number of days (P-O) > 2 classification categories = 2 days (4% of the forecasts)

Figure 4. 1976-77 snowfall season forecast verifications -- Lake Ontario model

<table>
<thead>
<tr>
<th>Observed Group</th>
<th>NOSNOW</th>
<th>FLURRY</th>
<th>LITSNOW</th>
<th>MDSNOW</th>
<th>HVSNOW</th>
<th>SQUALL</th>
<th>BURSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOSNOW</td>
<td>1</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>FLURRY</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LITSNOW</td>
<td>1</td>
<td>-</td>
<td>6</td>
<td>2</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>MDSNOW</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>10</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>HVSNOW</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>SQUALL</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>BURSTS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
</tr>
</tbody>
</table>

Number of days (P-O) > 1 classification category = 9 days (17% of the forecasts)
Number of days (P-O) > 2 classification categories = 2 days (4% of the forecasts)
REFERENCES


LAKE EFFECT SNOWS OFF THE EAST END OF LAKE ONTARIO.

Livingston Lansing
Research Associate
State University of New York
Boonville, New York, Field Station


For maximum lake effect conditions, we need the correct lapse rate through the atmosphere (a steep one), with the advection of very cold air aloft, freedom from temperature inversions aloft, the warmer the lake water the better, and a marked zone of convergence.

For instance, if the wind is W.N.W. at Watertown Airport, and W.S.W. at Syracuse Airport, more than likely, there is a zone of convergence between these two places. One can almost automatically say, there is a lake-effect condition existing between these cities in the winter season.

Helpful to L.E.S. conditions, but not a necessity, is a rising shore line on the downwind shore of the lake. This, at times, acts as an orographic trigger to get the storm conditions underway over the land area, when the lake itself is not sufficient to trigger the L.E.S. The vast majority of L.E.S. conditions get underway after the passage of the cold front and with westerly winds.

Keeping all this in mind, let us take a look at the east and southeast end of Lake Ontario, the recipient of the bulk of these storms that can and do occasionally extend back 75 miles inland from the lake shore. It should be noted, however, that the great bulk of L.E.S. conditions occur within 40 miles of the lake with a zone of maximum L.E.S. conditions between 10 and 25 miles inland from the lake shore.

The immediate lake shore is often a zone of minimum snowfall. Most of these L.E.S. storms, running west to east, are between 15 and 25 miles wide north and south. The controlling factors of where the maximum snow falls is elevation. (How rapidly the land rises on the lee shore of the lake,) and the strength of the wind (High winds tend to blow the storm well back from the lake.). Towards the end of a given storm, as the wind dies down, the snow will slowly retreat back towards the lake.

If a storm has mostly light winds, under 15-17 miles per hour, most of the snow will not get as far east as the Black River Valley, but will stay considerably closer to the lake shore, especially if the wind is very light. Of course, most important for distribution and location of the storm is the gradient wind direction prevailing after passage of the cold front. Often a well exposed anemometer will approximate the gradient wind close enough for record purposes, because gradient wind data is not always available locally.
Taking a map of the east end of Lake Ontario, we have shown the zone of maximum occurrence, and another zone of secondary occurrence. There is still a third zone outside the secondary zone that is plagued on infrequent occasions by these storms, but is not important enough here, except to make mention of this zone in passing.

Within the maximum area zone, there are two zones that appear to get more of these lake-effect storms than anywhere else. The first zone is approximately 10 miles either side of a line drawn from Ellisburg, through Adamo, Barne Corners, and Copenhagen, petering out near Deer River in the Black River Basin. This zone is the zone of the W.S.W. winds which some years (for instance 1976-77) predominated.

After the passage of the cold front, often these storms, with this type of W.S.W. winds, will continue 36 or more hours, averaging 2-3 inches per hour of low density snow. As the W.S.W. winds are often high winds, these storms may, at times, extend well back from the lake. For example, as far inland as Gouverneur.

The second zone within the maximum zone area occurs with west winds, and starts in Oswego County, 10 or 12 miles or so on either side of a line passing in the vicinity of Hannibal, Fulton, the southern part of Oswego, Mexico, and between Maple View and Central Square on Interstate 81, eastward tapering off in the vicinity of Camden. This line can vary, of course, often to the north, so that Oswego, Richland, Redfield, Oaunola, West Leyden, are in the line of fire, with the storm tapering off to the east in the Boonville area. The secondary snow belt starts near Red Creek in eastern Wayne County, extends into the Adirondacks near North Lake - Old Forge - Lake Bonapart, and extends north of Watertown to the Chaumont vicinity. Finally, occasional heavy storms hit Gouverneur in St. Lawrence County, Cape Vincent, and the southwest side of the Prince Edward County Peninsula of Ontario, which extends well out into Lake Ontario.

It must be noted, however, the East end of Lake Ontario from Port Ontario through the Sandy Pond section to Henderson and Sackettes Harbor, and to Cape Vincent -- all on the immediate lake shore -- that this section is one that most often has a very little snow from the lake-effect storms. These figures are based on many years of surveying the snow at Sandy Pond, which almost always registers the lowest figure in snow and water content for any of the stations at the east end of the lake, including the inland stations.

In fact, the Watertown Airport, within a mile or so of the lake, registers less than half the snow of the city of Watertown does, 10 miles from the lake, showing the importance of rising topography and orographic lifting of the air, plus the cold air bank that warmer air would have to rise over as it comes off the east end of the lake.

As a second part of this discussion, the question has been posed: why the sudden shift of the L.E.S. storms with a wind shift of 10 to 15 degrees? Such a shift will blow the storm out of one area and start it in an adjacent area. As the wind shifts from the S.W. to the N.W., after the passage of the cold front, these storms tend to migrate southward. Further, as the wind shifts, we have observed the barograph very closely on numerous storms through the years, and the barograph trace often will look like the drawing illustrated, with the pressure rising in steps. At the end of each step, with a sudden rise of the barograph, the wind will shift 10 to 15 degrees, taking the storm with it and, most often, moving it south. It also should be noted, the L.E.S. can move from south to north, if the wind, after the cold front passage, starts as N.W. and slowly backs to S.W. But this is no where as near likely as the reverse.
NEW YORK STATE

Key to Illustration Map No. 1
This map shows the three most common paths of "LES" off the E & SE corner of Lake Ontario with their gradient wind directions.

I - WSW wind snows as Watertown (SE side), Adams and Copenhagen to Deer River
II - West wind snows as Oswego-Boonville
III - Northwest wind snows as Syracuse, Oneida, & Cazenovia

Communities in these snow belt areas are numbered on the map as follows:
1 - Adams
2 - Copenhagen
3 - Watertown
4 - Barnes Corners
5 - Deer River
6 - Oswego
7 - Parish
8 - Oseola
9 - Boonville
10 - Fair Haven
11 - Syracuse
12 - Cazenovia
Map No. 2 shows zone of convergence with a typical WSW "LES" storm. Also illustrated are zone I, the real snow belt area and zone II, the secondary snow belt area.

Numbers on the map represent the following communities:

1  - Red Creek
2  - Oswego
2A - Hannibal
3  - Syracuse
4  - Central Square
5  - Mexico
6  - Canastota
7  - Boonville
8  - Lowville
9  - Copenhagen
10 - Barnes Corners
11 - Adams
12 - Watertown
13 - Sackets Harbor
14 - Gouverneur
15 - Rensselaer
16 - Pulaski & Sandy Pond
17 - Chaumont Bay
18 - Cape Vincent
19 - Prince Edward Peninsula, Ontario
Following, is an example of this step like structure with a rising barometer and a shift wind from W.S.W. through west to N.W.

FIGURE NO. 1: BAROGRAPH CHART

Baragraph chart with L.E.S. and various wind directions with these L.E.S. snows.

Forecasters should note, for instance, a lake-effect condition can not be going on at Boonville and Syracuse at the same time, because these communities have L.E.S. conditions with different wind directions. Thus, to forecast the position of the lake-effect storm, the forecaster is up against predicting a 10-15 degree wind shift, what time this wind shift will occur, and this is most difficult to do. We believe the answer is to be found somewhere in the upper air charts. The warning, of course, is after a sudden increase in pressure, as the storm starts to move to a new location.

Unfortunately, the sudden rise in pressure coincides almost immediately with the storm movement, so there is little or no warning. What must be worked out is a way to forecast these sudden rises in pressure. If this can be done, the shifts of the storm from one area to an adjacent area can be predicted.

Often in the popular mind, if the storm stops in a given area, everyone says, "Isn't it great, the storm has finally ended." The storm has not ended, however, it has simply moved down the road or slightly south, and is plaguing a new area. This may go on for days as the storm oscillates back and forth along the east and SE end of the lake with winds ranging from NW to SW.
CURRENT FORECAST PROCEDURES FOR LAKE EFFECT SNOWS IN WESTERN NEW YORK ESPECIALLY RELATED TO 1976-1977 AND 1977-1978 WINTERS

Benjamin Kolker
Weather Service Forecast Office, Buffalo, New York

ABSTRACT

Weatherservice meteorologists at Buffalo, N.Y., have become skilled in forecasting lake-effect snows off the Great Lakes into Western New York. They base their skills on empirical relationships and experience derived from using new observational tools developed during the past 40 years...rawinsonde, weather radar, and satellite photography.

Discussion of record snowfall during the 1976-77 winter and an example in the 1977-78 winter illustrates applications of these procedures. In 1976-77 a persistent synoptic pattern kept unseasonably cold air circulating across the Great Lakes under conditions favorable for frequent lake effect snowstorms. Heavy accumulations of loose unpacked snow from these snowstorms on frozen Lake Erie and over Western New York, without a thaw to lock up the snowpack, helped create the January 28, 1977 severe blizzard which caused a major weather disaster in Western New York.

1. INTRODUCTION

Major forecast problems near the Great Lakes are unexpected local snowstorms and even rainstorms which do not fit the usual precipitation patterns related to low pressure or frontal systems. Weather publications of the early 1900's indicated forecasters around the Great Lakes were aware of these phenomena and related them to the influence of the lakes. Little research was done until after 1940 to get a more detailed idea of the lake influence. I suspect the old-time weathermen, as with other local forecast problems, avoided specific reference to lake snows in forecasts because of limited observational data.

Since 1940 improved observational equipment such as the rawinsonde and weather radar enabled meteorologists to get a useful picture of the life history of lake effect snows. As a result forecast offices involved with lake snows developed empirical relationships to use in their forecasting. B. L. Wiggan, former meteorologist-in-charge at Buffalo, was a leader in this work. He summarized his ideas in a brief article published in the December, 1950, "Weatherwise". Forecasters at Buffalo keep a copy of this summary available for reference and training. Using Wiggan's ideas plus upper air and radar data, Great Lakes forecast centers have built up a background of experience enabling them to issue more definitive forecasts of lake snows including geographic location in their areas of responsibility.

To improve lake effect forecasting, limited basic research was sponsored by the Weather Service in the sixties and seventies. The results of these studies improved the understanding of the lake snow problems and enabled meteorologists to issue more useful forecasts, statements, and warnings.

Experience and research indicate that basically lake snow effects relate to the following factors: a trajectory of cold air crossing warm lakes; heat and moisture absorbed from the lakes producing an unstable temperature lapse rate; release of the moisture as precipitation being triggered by fronts, vorticity, convergence, convection, or orographic
uplift...individually or in a combination. Assessment of the role of these factors is an important phase of forecasting offices like Buffalo, N.Y. Later in this paper such action will be illustrated in relation to the record 1976-77 winter and a lake effect snowstorm in December 1977.

2. RECORD SNOWFALL OF THE 1976-77 WINTER IN WESTERN NEW YORK

Millions of residents of Western New York will never forget the winter of 1976-77. Buffalo from October 1976 to May 1977 piled up a total of 199.4 inches of snowfall, far exceeding the old record of 126.4 inches set in 1909-10.

Figure 1 illustrates the 1976-77 seasonal snowfall for the Western New York area mainly subject to snows off Lake Erie. Kenneth Dewey in the December 1977 "Weatherwise" has a similar chart for a larger area of Western New York including the snows off Lake Ontario. Both charts show snowfall distribution similar to the averages in Figure 2. The prevailing northwest winds during the winter months put the centers of heaviest accumulations downwind of the lakes. The record snows of 1976-77 exceeded the mean snowfall by amounts of up to 100 inches off Lake Erie and up to 270 inches off Lake Ontario.

The map patterns in Figure 3 had a great deal to do with the record snowfalls of the 76-77 winter. They look like the synoptic descriptions described in Hill's (1971) paper conducive to snow squall development: upper air pattern causing a strong flow of arctic air across the open Great Lakes after a low has moved into eastern Canada; a southward extension of the parent low in the form of a trough over the Great Lakes; a trough aloft over the eastern United States and Canada which frequently stagnates or broadens to the west. The January 1977 700 mb. contour chart bears out the persistent daily pattern which prevailed most of the winter. This daily pattern caused frequent lake effect snowstorms in Western New York leading to the abnormal record total accumulations reported. The smaller 700 mb. chart for January 25-29, 1977 reflects several periods of heavy lake snows especially south of Buffalo and off the east end of Lake Ontario. It relates to the Jan. 28, 1977 blizzard discussed later in this paper. Daily current and prognostic guidance charts were checked by Buffalo forecasters for the patterns just described and used as a basis for issuing forecasts, warnings, and statements. The success of their efforts in Western New York was rewarded by National Weather Service Unit Citations.

3. NOTEABLE FACETS OF THE JANUARY 28, 1977 SEVERE BLIZZARD IN WESTERN NEW YORK

Figure 4 weather charts show the synoptic conditions over North America which caused the January 28, 1977 blizzard. Note that these map patterns are comparable to the basic ones of section 2 of this paper. A pronounced occluded front crossed Western New York during the late morning and afternoon of the 28th. Blizzard conditions developed quickly after the frontal passage because of the high winds from the strong pressure gradient behind the front, very cold arctic air following the front, some falling snow from the front itself, and the major source of blowing snow—the widespread blanket of deep loose snow which had accumulated on frozen Lake Erie and in Western New York.

The surface observation form (Figure 5) at Buffalo, N.Y., for January 28, 1977 shows the guillotine effect of the blizzard striking Buffalo. In less than an hour from 1050 EST to 1138 EST ceilings and visibility dropped from 800 feet and 3/4 of a mile to zero height and zero miles. From personal observation the change at Buffalo Airport occurred in a few minutes—a white cloud rapidly enveloped the airport terminal in the teeth of a howling gale. In a short time you couldn’t see out the windows—they appeared to be white frosted glass. The observation form shows the zero/zero ceiling/visibility conditions lasted without abatement till midnight. In this 12 hour period the worst effects of the blizzard occurred. The 2 to 3 feet of snow loosely distributed on ice-covered Lake Erie and on the ground elsewhere was blasted into tremendous hardpacked snow drifts up to 10 to 20 feet or more deep which locked up cities, towns, villages, homes, and highways so it took special heavy-duty earth-moving equipment to open them up to normal winter activity.

The operational radar overlays used at Buffalo (Figures 6 to 8) show the snowfall activity before and after the passage of the occluded front. Contour lines represent intensity levels of snowfall...light snow for the outer contour, moderate snow for the second contour,
Figure 1.
WINTER 1976-1977 SEASONAL SNOWFALL...WESTERN NEW YORK
(Totals in inches..few stations with January 1977 totals)
Figure 2

MEAN SEASONAL SNOWFALL, INCHES

Data are based on the period 1931-60. Isolines are drawn through points of approximately equal value. Caution should be used in interpolating on these maps, particularly in mountainous areas.

Source: Climates of the United States, Water Information Center Inc. p. 274
Figure 3  MEAN MAP PATTERNS JANUARY 1977

Mean 700 mb height contours (dekameters) for January 1977

Mean 700 mb contours

Source: Monthly Weather Review, April, 1977, p. 553-559
Figure 4. SYNOPTIC CHARTS 1/28-29/77 BLIZZARD

Source: Weatherwise, Vol. 30, p. 89
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<th>WEATHER AND OBSTRUCTIONS TO VISION</th>
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Figure 6. RADAR OVERLAYS 1/28–29/77 BLIZZARD...BUFFALO NY
Figure 7. RADAR OVERLAYS 1/28-29/77 BLIZZARD...BUFFALO NY
Figure 8. RADAR OVERLAYS 1/28-29/77 BLIZZARD...BUFFALO NY
heavy and very heavy snow for the interior two contours. Approximate visibilities related to the intensity contours would be 3/4+, ½, and zero miles.

At 1632Z the innermost contour in a north-south position is the leading edge of the front ready to hit Buffalo. At 1732Z the front is between Buffalo and Rochester. At 1932Z the western edge of snowfall from the front is just over Buffalo Airport. From 2032Z the western edge of the frontal snowfall is 20 miles east of the airport. From 2032Z to 0432Z the frontal band of snow moved to the east and out of view of the overlays. Scattered areas of snowfall developed mainly over Lake Ontario. At 0132Z and 0432Z the snow areas over Lake Ontario are really westward extensions of the lake effect snowband which dumped up to 6 feet or more of snow east of Lake Ontario on January 28-29, 1977.

Radar overlays show that for much of the afternoon of the 28th the radar did not pick up any snow over and within an appreciable range of Metropolitan Buffalo. The observation sheet for the 28th shows zero visibilities and ceilings with light snow and blowing snow. The explanation seems to be that for much of the time the blizzard was a blowing snow condition to a depth that prevented observation of the sky, and the top of the blowing snow was too low to be picked up by the radar. Bearing this out is a comparison of the 2350 EST surface observation and the 290432Z radar observation. The observer noted he was only getting blowing snow and the radar indicates no snow about the airport.

Figure 9 shows plotted curves of upper air soundings for January 28-29. On the 28th the 07 EST and 19 EST curves show the radical change in temperatures and winds aloft before and after the frontal passage. On the 29th the curves show soundings typical of Arctic air masses crossing the Great Lakes to produce lake effect snows. These soundings tie in with the heavy lake effect snows reported east of Lake Ontario. Lake Ontario was mostly open water at 32 degrees Fahrenheit (0 degrees Celsius). The empirical forecast graph in section 5 of this paper indicated heavy snow bands likely off Lake Ontario like those that occurred.

4. DECEMBER 9, 1977 LAKE EFFECT SNOWSTORM

December 1977 Weather Notes for Buffalo, N.Y., included the following paragraph:

"The first major snowstorm of the month began on the 5th. Cold air, following a low center, produced heavy lake effect squalls from the 6th through the 8th, mainly south of Buffalo, Jamestown being hardest hit. On the 9th, the squalls swept into the city, producing blizzard conditions for several hours. Winds gusted as high as 55 mph. Six people died as a result of the storm."

Radar overlays in Figures 10 to 11 illustrate heavy snow bands shifting into and then back out of Metropolitan Buffalo in a typical situation as the wind circulation controlling them shifted from west to southwest and then back to west again. The heaviest snow contour moves in over Metropolitan Buffalo causing the blizzard conditions mentioned in the weather notes. At 1531Z the heaviest contour is just south of the Weather Office. By 1732Z it covers most of Metropolitan Buffalo and shows up with a little southward shift at 1932Z. By 2229Z the two heaviest contours are south of Metropolitan Buffalo and the northern edge of the whole snowband is moving southward out of the city area.

The weather map for December 9, 1977 had a basic pattern for wind shifts moving the snowbands. A deep low passed north of Western New York producing first southwest and then west winds in the controlling low level circulation.

5. SUMMARY OF FORECAST PROCEDURES AT BUFFALO

Previous sections of this paper illustrate ways for forecasters at Buffalo to check the life history of the heavy snow bands which are a major forecasting problem in Western New York.

Another tool is the satellite picture receiver located in the forecast office. Pictures every half hour give a view from outer space of the cloud patterns affecting the area. Lake effect snowbands are frequently visible to the visual and the infra-red cameras. Figure 12 is a sample of such a use. Snowband streamers stretch in north to south lines
Figure 10. SHIFTING LAKE-EFFECT SNOWBANDS 12/9/77...BUFFALO NY
Figure 11. SHIFTING LAKE-EFFECT SNOWBANDS 12/9/77...BUFFALO NY
Figure 12. NOAA-2 VISIBLE IMAGE, January 29, 1973. Pass 1326, 1539 GMT
over eastern Lake Ontario, from Lake Huron across western Lake Erie and from eastern Lake Superior down Lake Michigan. Access to these pictures allow forecasters to keep a watch on the development, persistence, and final dissipation of the snowbands.

From radar overlays and satellite pictures the forecaster may get a good idea of lake effect snows and can act accordingly in issuing forecasts, statements, and warnings to the various public interests.

The daily routine of a Western New York forecaster includes:

a. Interpretation of the twice-daily synoptic and forecast guidance package supplied by the National Meteorological Center via facsimile or computer terminal. He gets the overall expected picture of weather events for Western New York. The minimum of guidance supplied by the Center is usually a note of lake snows on a precipitation forecast chart.

b. During the lake effect season the forecaster checks the guidance package for the factors mentioned in the last paragraph of section 1 of this paper.

c. Selected data from the package may be referred to local empirical aids developed in the past 10 years. Figure 13...dashed line section...was developed by James E. Smith, former Meteorologist in Charge at Buffalo, based on a limited number of pure lake effect incidents. Figure 13...solid line section...was developed by Stephan J. Broumas, one of Buffalo's Intern Graduates. His chart is based on lake effect snow incidents not adequately covered by Smith's work and considering other elements apparently related to the occurrence of heavy lake effect snowbands. Figure 14 illustrates special charts available to Buffalo forecasters prepared by Smith. Geographic location of snowbands is related to low-level wind flow. For an expected wind direction the forecaster checks the appropriate chart to determine the area most likely to feel the effects of the snowbands. Buffalo's charts relate to Western New York. Other locations around the Great Lakes can make up similar charts for their areas.

d. Since lake effect snows have major economic effects in Western New York, Buffalo forecasters keep a continuous watch throughout a lake snow situation. Timing is an important part of the forecast problem. When will the squalls start? How long will they last? How much snow will drop during the period? When will wind shifts occur that relocate the snowbands? What kind of oscillation pattern can cause the bands to shift back and forth across the area? Using the procedures already described the Buffalo meteorologist is under a constant strain to adequately keep the public fully aware of what is going on.

6. SUGGESTED FUTURE DIRECTIONS FOR LAKE FORECAST PROCEDURES

Newspaper publicity on lake effect snows indicate these snows are a major forecast problem around the Great Lakes. Consequently special efforts should be made in the future to develop improved forecast procedures along the following lines:

a. Training for and research done by forecasters involved with lake effect snows.

b. As part of AFOS develop lake snow models for the local computers at the forecast centers.

c. Store lake snow forecast rules in local AFOS computers to be applied in some routine to each potential situation.

d. Develop on-going local forecast research based on available observational data and forecast products.

e. From AFOS guidance materials extract hourly wind, temperature, and other surface and upper air data which could be used to derive more timely forecast issuances.

f. Reassimilate current literature and research reports to expand available forecasting rules. These rules should relate to the factors producing lake effect snows such as
Figure 13  EMPIRICAL AIDS FOR ESTIMATING LAKE-EFFECT SNOWFALL
(Composite of Graphical Aids by Smith and Broumas)
Figure 14. WIND FLOW RELATION TO GEOGRAPHIC LOCATION OF LAKE-EFFECT SNOWBANDS
wind velocity and direction, lake temperature, air temperature, trajectories, upper air soundings, identity details from satellite pictures and also from radar overlays and pictures.

7. CONCLUSION

Establishment of forecaster centers near the Great Lakes since World War II has developed meteorologists with great skill in forecasting lake effect snows especially in Western New York. The skills are based on experience and empirical relationships derived from the use of equipment such as rawinsondes, weather radar, and weather satellites.

An unusual number of familiar synoptic patterns for lake effect snows are considered to have produced Buffalo's record snowfall during the 1976-77 winter.

The severe blizzard of January 28, 1977 was apparently caused by the coincidence of a rare set of circumstances—a deep pile-up of loose unpacked snow from frequent snowstorms on frozen Lake Erie and Western New York ground areas, lack of a thaw prior to the blizzard which could have locked up the snowpack against movement, arrival of a major windstorm and arctic cold wave. During the blizzard the zero conditions of visibility were shown by radar to be mostly the result of only blowing snow with a minimum of falling snow.

Despite progress in forecasting lake effect snows by dedicated meteorologists, there is a need for further research. An important step in this direction will be the installation of Automatic Forecast and Observation Systems (AFOS) at forecast offices. Research efforts by Weather Service personnel and other interests should be encouraged to increase the effectiveness of weather service to the public.

8. BIBLIOGRAPHY


