A Look at Lake Effect Snow Cloudbands With Satellite Imagery

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1. INTRODUCTION

Satellite imagery is an important source for the observation and short term forecasting of mesoscale lake-effect snow events. GOES (Geostationary Operational Environmental Satellite) imagery, available to NWS forecast offices, provides both visible and infra-red images over the Great Lakes throughout the day and night. This paper will discuss the advantages and limits of satellite imagery as a forecast tool. Examples of visible and IR images will show various types of lake-effect cloudbands common to the Great Lakes. These include wind parallel single and multiple bands, "enhanced" bands that develop on upwind lakes, and thermally induced cloudbands.

2. OBSERVATION AND SHORT TERM FORECAST TOOL

The scale of lake-effect snowstorms makes their detection very difficult at times. This is especially true over the Great Lakes, where there are far too few automated observing platforms to supplement standard observing sites. National Weather Service radars in general provide adequate coverage of precipitation echoes associated with synoptic scale weather systems, but are located too far apart to detect many mesoscale lake-effect snow events because the precipitation tops associated with these storms rarely exceed 3km (Hill 1971). Forecasters at NWS Buffalo, NY estimate that in many cases, weather radar is often of limited use in the detection of lake-effect precipitation beyond about a 120 km radius of the site, except for strong, synoptically enhanced systems that occur in a deep layer of arctic air (Niziol 1987). Because of these limitations, satellite imagery is an important remote sensing tool that is often used exclusively by operational forecasters to follow the evolution of these mesoscale events.

Figure 1. Map of the Great Lakes area.

Visible images from GOES (Geostationary Operational Environmental Satellite) have a 1 km resolution and are available to the forecast office on an hourly basis throughout the daylight hours on a sector located over the Great Lakes (Clark 1983). The fine resolution of the visible image allows the forecaster to monitor very detailed cloud structures over the Great Lakes and adjacent shores as discussed in the following examples.

Single band snows occur most often when winds through the first 2 to 3 km of the atmosphere are aligned along the long axis of the elliptically shaped eastern Great Lakes (see Fig. 1). The roughly parallel shorelines produce a strong mesoscale convergence zone under the cloudband (Peace 1966). This convergence, in combination with the long fetch over the lake, can produce very intense snowfall at times.

The visible satellite image shown in Fig. 2 was taken at 2001 UTC 05 NOV 1982. The cloudband is stretched along the long axis of Lake Erie, with a similar band extending along Lake Ontario. The corrugated texture of the clouds over Lake Erie indicates convective development. The arctic airmass that produced this storm extended higher than 3km, and there were numerous episodes of lightning and thunder within the storm. Nearly 40 cm (15 inches) of snow fell at Buffalo, NY during approximately a 12 hour period. The mesoscale organization of the storm is shown in Fig. 3, taken at 1631 UTC 07 NOV 1982. The pattern of snow cover at the eastern end of Lake Erie from the previous day's storm is clearly evident.

Figure 2. Visible GOES Imagery from 1830 UTC 05 NOV 1982

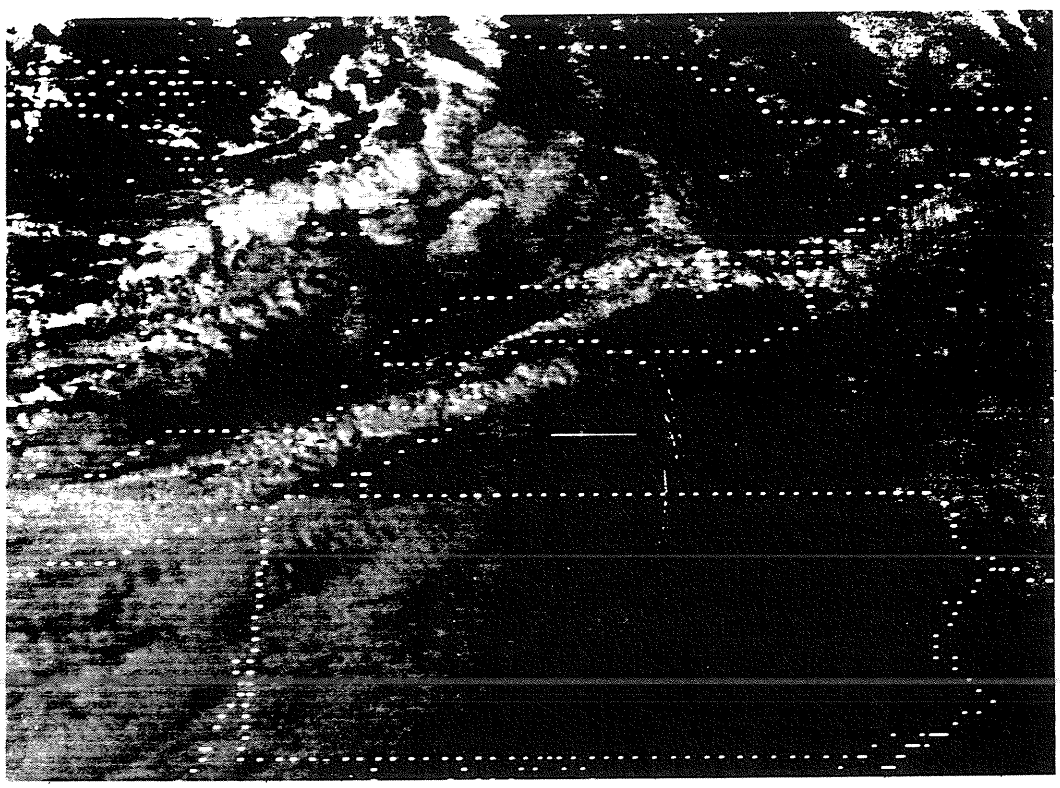
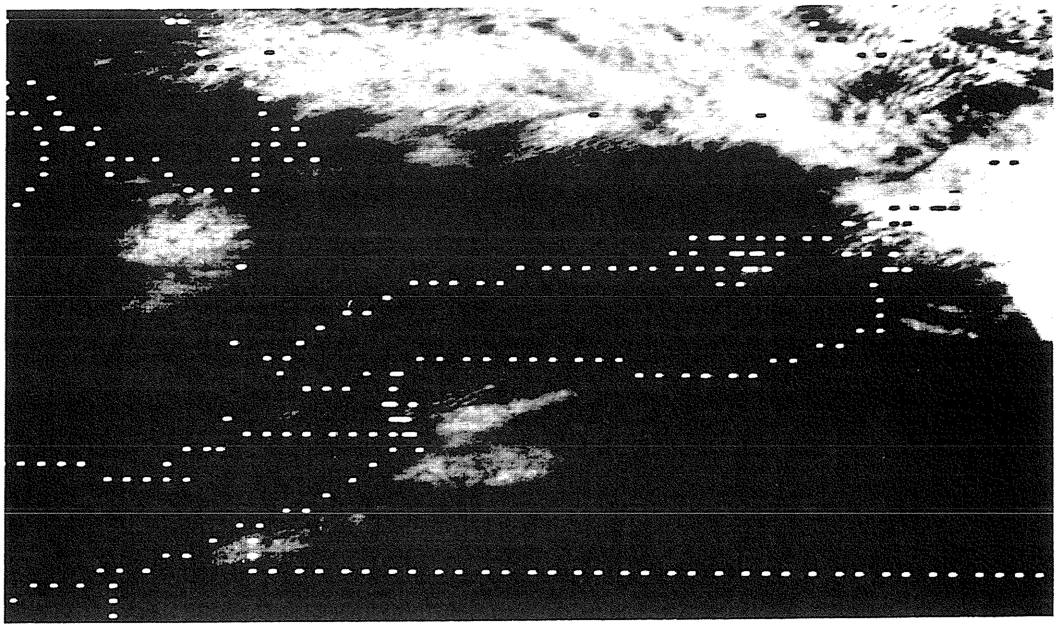


Figure 3. Visible GOES Imagery from 1631 UTC 07 NOV 1982



When wind direction is perpendicular to the long axis of the lake, less intense multiple bands develop, often as a result of parallel roll convection (Kelly 1982). An example of this type of band is shown in Fig. 4. These bands usually produce much less snowfall than single band storms due to shorter over-water fetch and a shallower mixed layer, which limits convective cloud growth (Hill 1971). In addition, lower precipitation tops associated with this type of cloudband result in limited radar detection range, so forecasters track such features almost exclusively with satellite imagery.

Figure 4. Visible GOES Imagery from 1700 UTC 03 MAR 1984

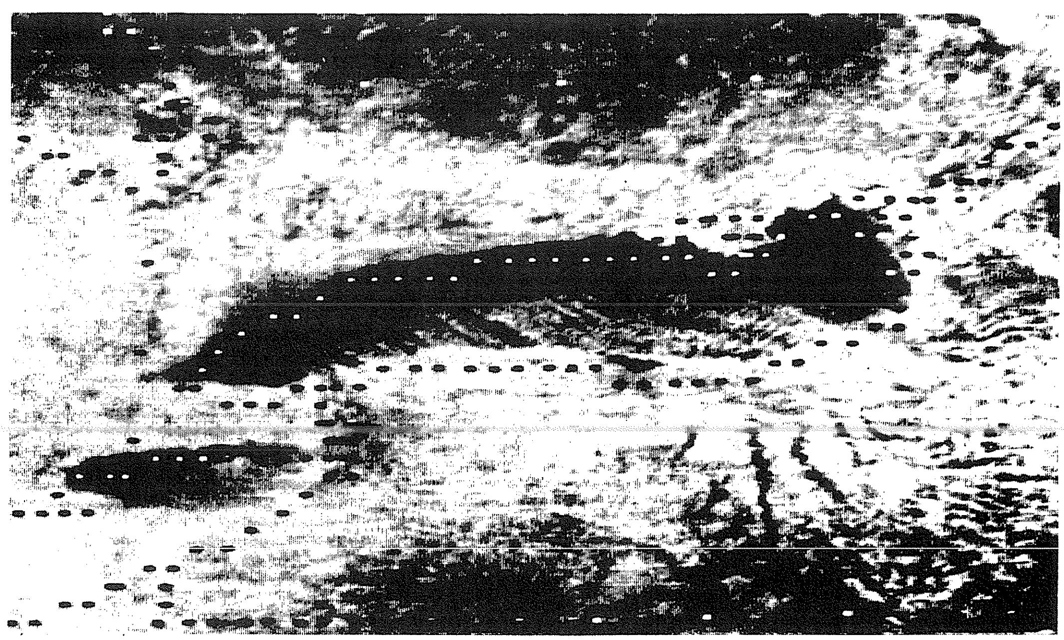
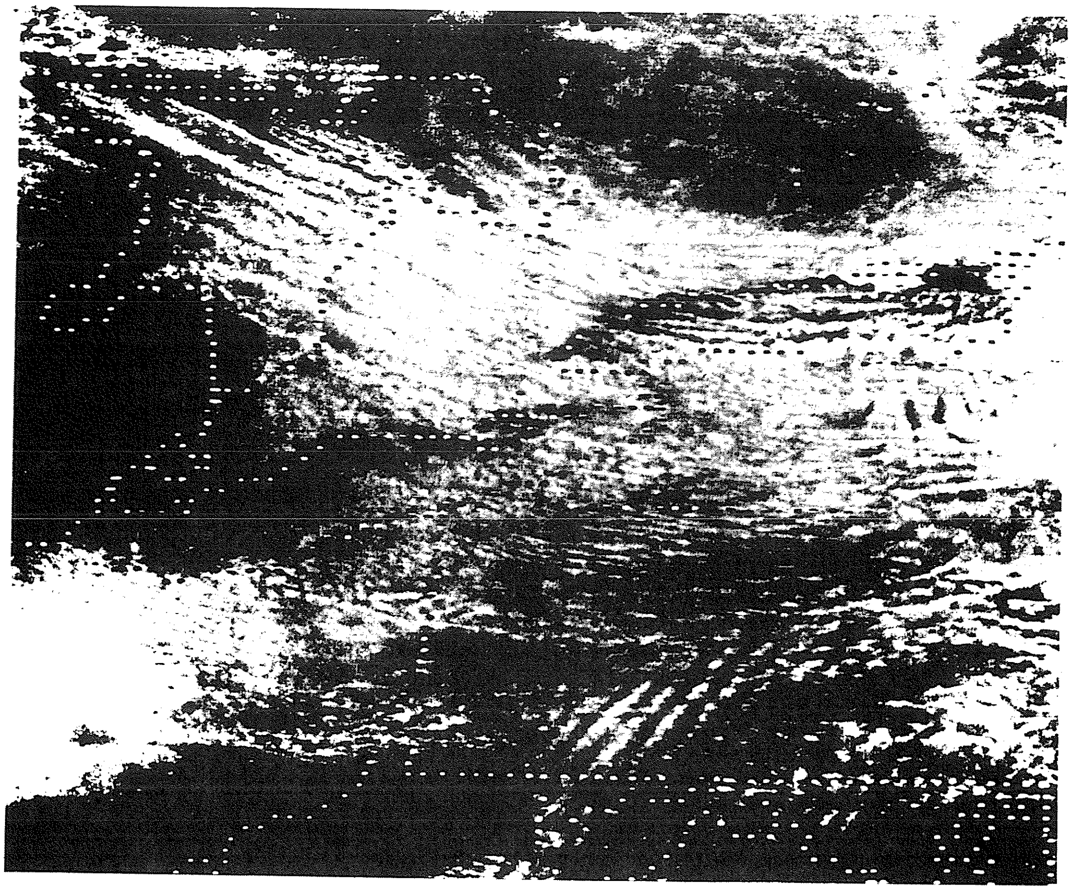


Figure 5. Visible GOES Imagery from 2000 UTC 03 NOV 1984

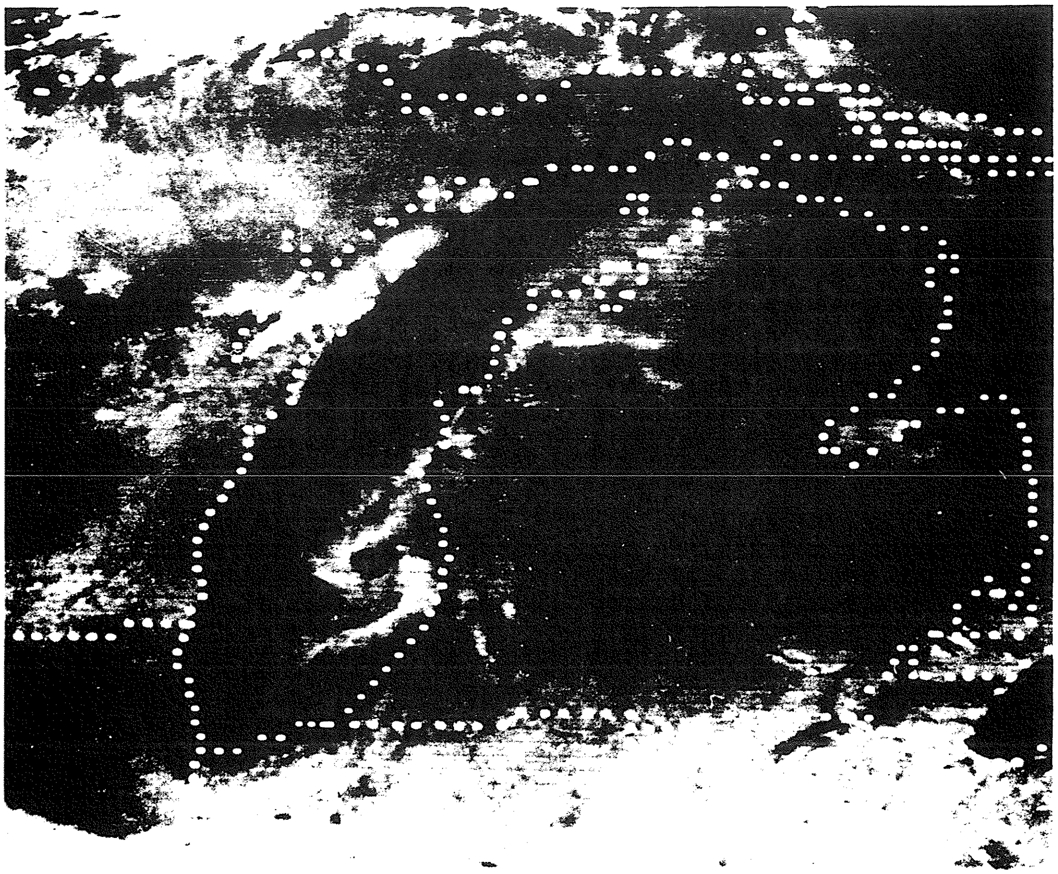


Parmenter (1976) noted that wind parallel cloudbands can be used to help analyze the general wind field over the lakes. It's easy to tell the wind direction within the cloud layer from the satellite image in Fig 5. Strong, well aligned northwest winds that occur in a cyclonically curved synoptic scale pattern often produce wind parallel streamers on the Upper Great Lakes which travel hundreds of kilometers downwind. As these streamers cross the Lower Great Lakes, they pick up additional heat and moisture, and deposit snow on their lee shores. This type of band often migrates across an area in response to minor changes in wind direction. These bands do not generally produce as much snow as single bands, but their location is more difficult to pinpoint. This is because very small changes in the cloud layer wind direction tend to move the bands about considerably.

Forecasters on the eastern Great Lakes monitor images of lake-induced cloudbands from upwind lakes (such as Lake Huron and Georgian Bay) to gain information about the upstream wind field. The information provides the forecaster with a short term forecast tool to predict small scale changes in the cloud layer wind direction, and potential cloudband movement over the eastern Great Lakes.

Holroyd (1971) added to the understanding of physical processes involved in lake-effect snow formation. From a study of numerous satellite images he noted that many of these mesoscale storms had preferred origins on the Great Lakes. Under weak synoptic scale winds and very cold air, cloudbands often develop in response to local wind field created by the temperature contrast between the warm waters of the lakes and the

Figure 6. Visible GOES Imagery from 1930 UTC 08 JAN 1981

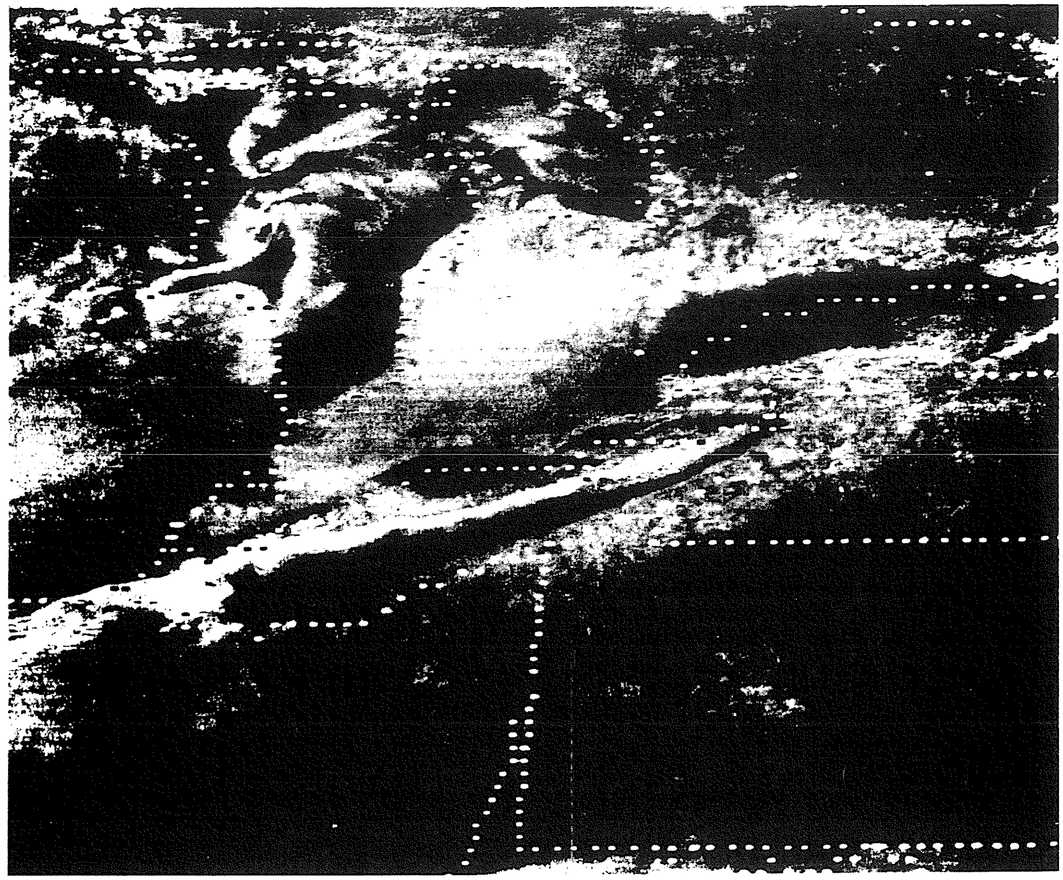


surrounding cold airmass. Instead of aligning themselves with the prevailing wind, the shape and orientation of these cloudbands are more closely associated with the adjacent topography. Very unique cloud structures may result. This is strikingly apparent in Fig. 6, where a mesovortex has developed over the "bowl" shaped southern part of Lake Michigan. This type of shoreline is conducive to mesovortex development (Niziol 1984, Forbes 1984). The visible image in Fig. 7 shows that each type of shoreline configuration is capable of producing interesting thermally induced cloudbands. These types of cloudbands generally occur under relatively shallow layers of arctic air, and in most cases, produce much less snow than single band storms.

At night only IR images are available to the forecast office, making lake induced cloudbands more difficult to locate[1]. IR images only have a resolution of 7km which is much coarser than visible imagery. Therefore it is often difficult to identify or separate the smaller scale cloudband. In addition, low cloud tops once again limit the forecasters ability to detect the cloudband. The low cloud tops are often not much colder than the surrounding landmass (which is

[1] Visible nighttime images of cloud structures are possible with low light sensors on the Defense Meteorological Satellite Program (DMSP) series of satellites (Foster 1991). However, that information is not available on an operational basis to a standard forecast office.

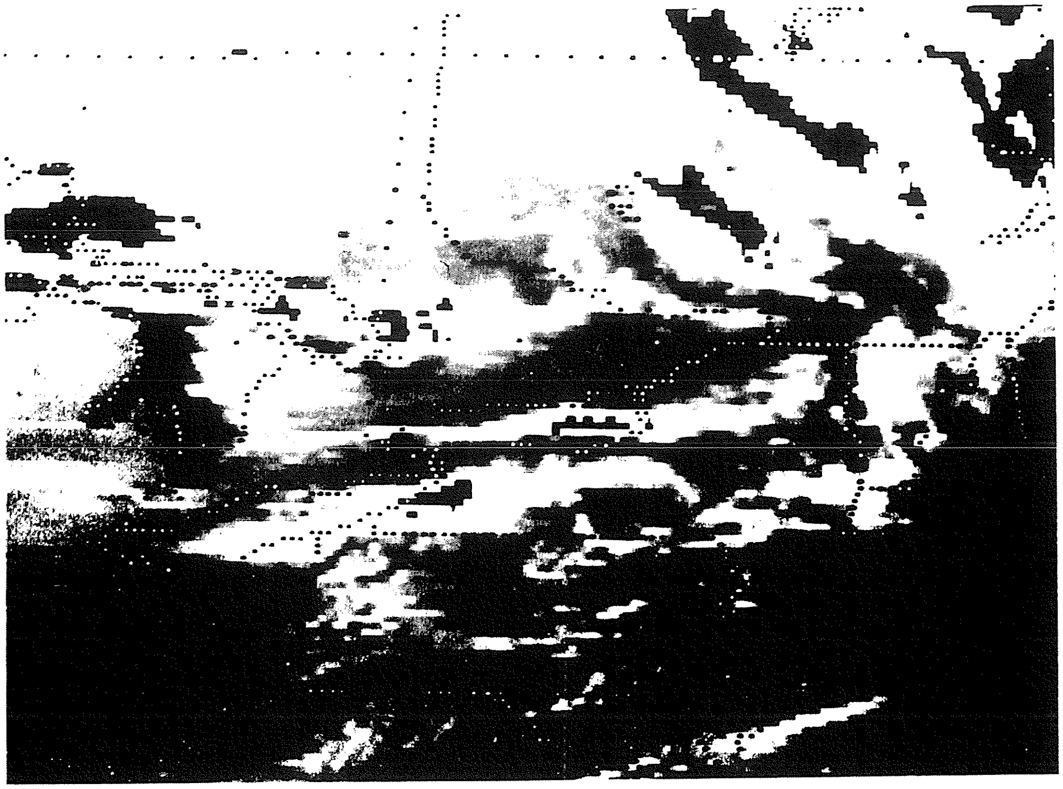
Figure 7. Visible GOES Imagery from 1730 20 DEC 1983



often snow covered) during the winter. The small temperature contrast causes lake-effect clouds to blend in with the background temperatures and be more difficult to track over land. Over the lakes however, the IR cloud images have a good contrast against the background of warm water.

Recently, satellite forecasters at the National Environmental Satellite and Data Information Service (NESDIS) have experimented with a series of algorithms that estimate snowfall rates based on cloud top temperatures from IR imagery of lake-effect cloudbands (Kusselson 1992). The events examined have been limited to the more intense single band storms that develop in a deep layer of arctic air. These storms often gain enough vertical development and therefore the cloud top temperatures are much colder than surrounding land temperatures and are depicted as enhanced grey scales on IR imagery (Fig 8). Satellite precipitation estimates are made available to the forecast office, and are considered and important aid in the short term forecast of such events.

Figure 8. Infra-red GOES Imagery from 0101 UTC 05 JAN 1988



3. SUMMARY

Satellite imagery is an an important observational and short term forecast tool for lake-effect snow because the current observing network is often too coarse to detect such small scale events. Visible images with a 1 km resolution are capable of detecting many of mesoscale features associated with lake-effect cloudbands. The orientation of cloudbands provides the forecaster with some indication of wind direction within the cloud layer, which can be used in short term forecasts of possible relocation and movement of lake-effect snow activity.

Although there are limits in the detection of cloudbands at night, IR-imagery often provides some indication of lake-induced cloudbands. This is especially true of single banded storms that develop in a deep layer of arctic air and produce relatively cold cloud tops. Operational researchers are currently evaluating algorithms that incorporate cloud top temperatures into the prediction of snowfall rates under these bands. The use of satellite imagery to detect and monitor the evolution of lake-effect cloudiness is an integral part of forecasting these events.

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