Severe Lake-effect Snowstorms over the Great Lakes

- A Climatological, Numerical, and Forecasting Approach

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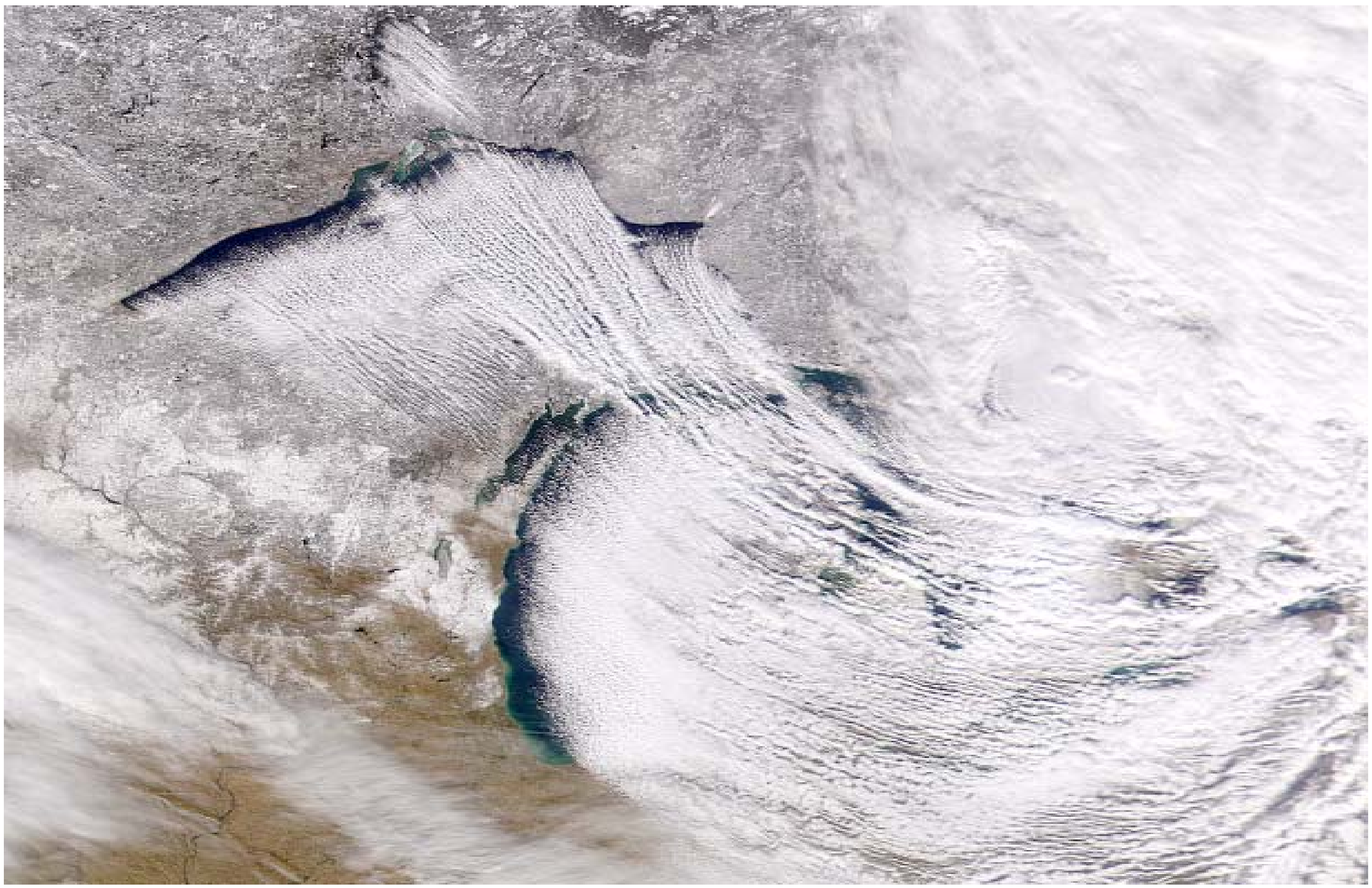
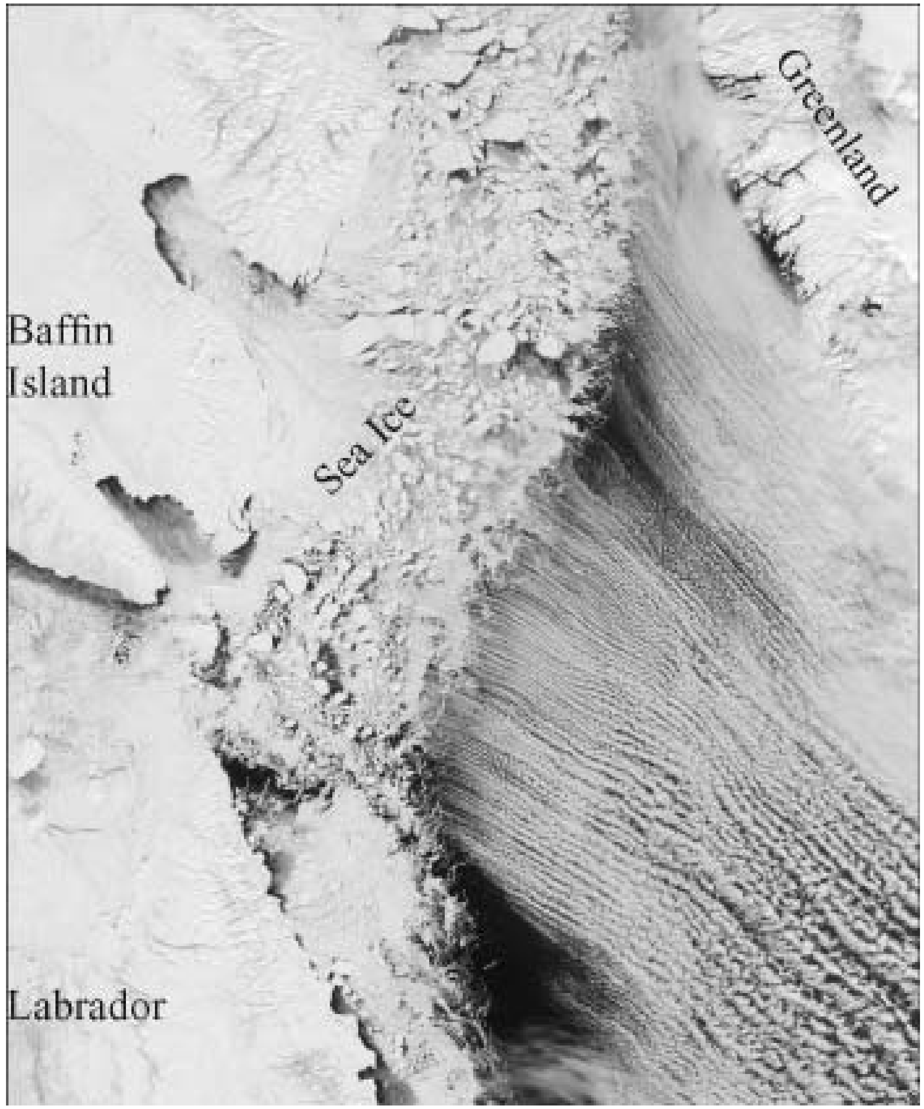
for departmental oral examination (June 30, 2005)



Roll Clouds over the High Lattitude Ocean during Cold Air Outbreaks



Cloud Streets over the Labrador Sea on 12 April 2002

Severe Weather Associated with Lake-Effect Snowstorms (LES)

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thestar.com

Mar. 2, 12:59 EDT

Multi-car pileup on 401 leaves five injured

Snowfall creates hazardous driving conditions around the GTA

NEWTONVILLE, Ont. (CP) - As many as 100 cars were involved in a pileup on an icy stretch of the 401 east of Toronto today, sending at least five people to hospital.

The accident occurred in the westbound lanes of Highway 401 near this town about 100 kilometres east of Toronto during a snowy morning rush hour.

''There are no fatalities; there are five injured persons,'' said Sgt. Joseph Alexander of Whitby provincial police.

''The roads were very slippery, snow-covered, and it was snowing, which didn't help matters at all.''

A number of tractor-trailers were involved, with many of them jack-knifing across the ice-slicked roadway, police said. A firefighter said some cars had rolled over into the ditch and two people were in serious condition.

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Stewart Richardson, a firefighter at the nearby Bowmanville fire department, said the Jaws of Life had to be used to get two people out of one vehicle. They suffered serious injuries.

''They had to be extricated,'' Richardson said. ''The whole scene was pretty chaotic.''

...ter the 8:30 a.m. pileup, most cars were still on the highway, he added.

...'s westbound lanes were to be closed until about 2 p.m., with traffic being rerouted ...y 2.

...as just the worst of many accidents that snarled traffic across the GTA this morning.

...lowdowns were caused by the snow, especially to the north and east of the city, where ... the heaviest. The Ministry of Transportation reported most major highways in the ...nto Area were snow-covered with bare, slushy and icy patches.

... Grimley of the Durham Regional police said roads were still very treacherous despite ...sh hour. Grimley said there had been numerous calls about minor accidents during the ...

...as expected reopen at noon today, following a fatal accident on Island Rd. shortly after

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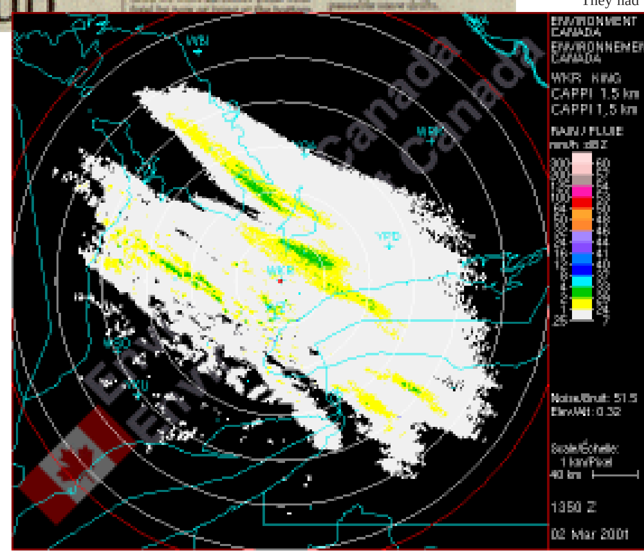


Controlling Factors of LES Development

1) Lake surface conditions

An ice free, warm lake surface can increase the vertical fluxes of heat and moisture and intensify lake-effect activity, while a cold lake surface and ice cover can result in a reduction in lake-effect snowfall

2) Synoptic-scale atmospheric conditions

Upwind atmospheric temperature, stability, humidity, inversion height, and wind speed can impact the intensity of lake-effect snowbands.

3) Topography

More intense lake-effect snowbands will develop over the higher elevation. A 330 m increase in elevation to the lee of lakes will result in a 12-20 cm increase in annual snowfall amount (Muller,1996).

Numerical Simulations of Roll Clouds

1) Two-dimensional simulations based on the observed homogeneity in the cross-roll direction;

2) Three-dimensional simulations in a large domain but with a coarse resolution;

3) Three-dimensional simulations with a high spatial resolution but in a small domain;

"Three-dimensional models with domains large enough to capture the mesoscale structure in their large contexts and with spatial resolutions fine enough to capture the internal behavior of the rolls and cells, probably offer the beat opportunity for elucidating the mechanisms" (Atkinson and Zhang,1996)

CReSS, Cloud Resolving Storm Simulator, a high resolution cloud resolving model, is employed to simulate roll clouds in a realtive large domain.

1) Non-hydrostatic and compressible; terrain-following;
2) Cloud physics using a bulk method for cloud rain;
3) Subgrid eddy motion are parameterised using a TKE closure scheme;
4) Parallel computation.

Contributions from my thesis study

1. Development of a climatology of LES over southern Ontario for the period 1992-99 (MWR, 2004).

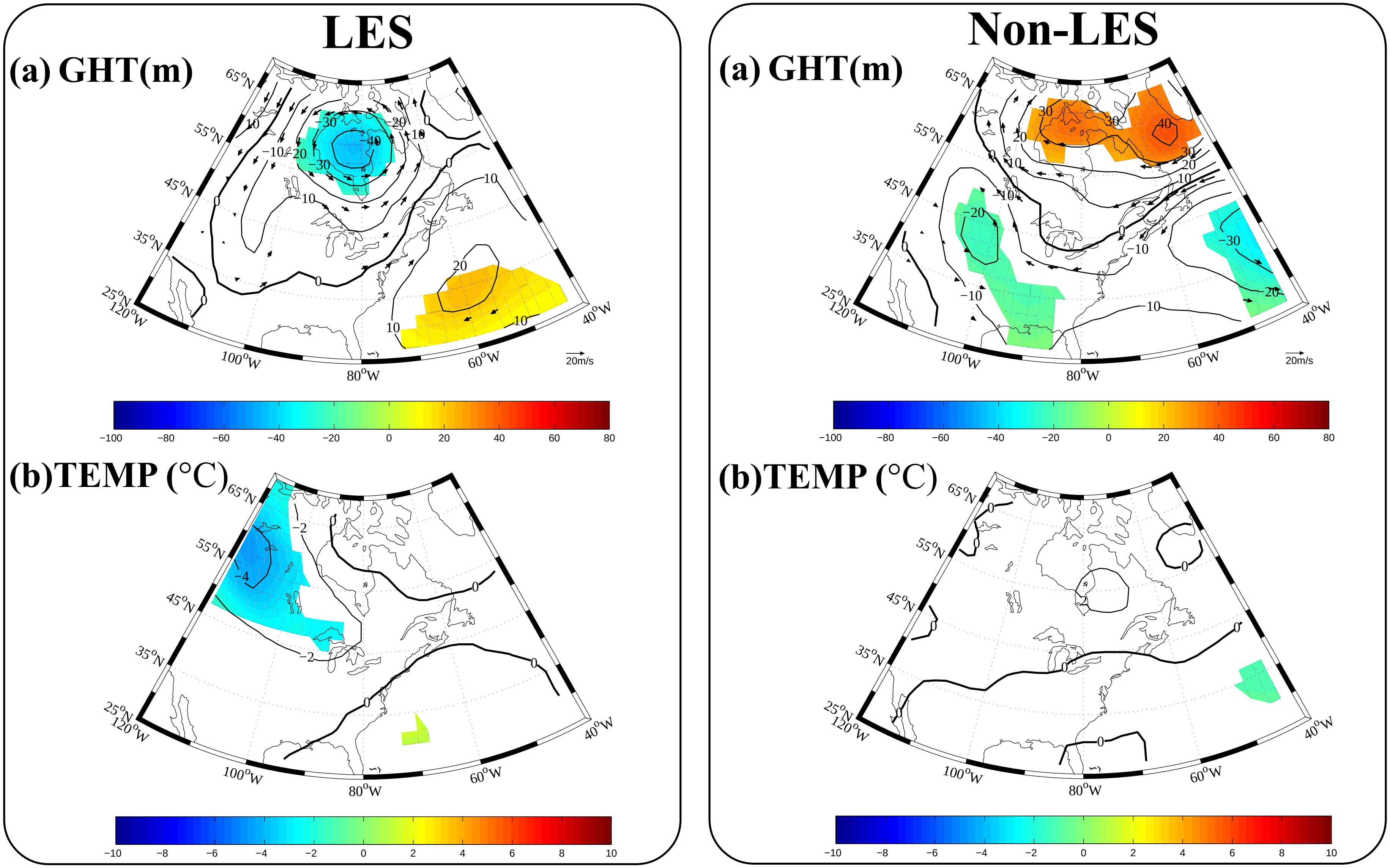
2. Application of a high-resolution cloud resolving atmosphere model (CReSS) to simulate roll cloud development over the Labrador Sea (GRL, 2004).

3. Investigation of the influence of upstream atmospheric conditions on lake-effect snowstorm development (submitted)

4. Examination of the effect of sea-ice on the development of high latitude boundary layer roll clouds (BLM, in press)

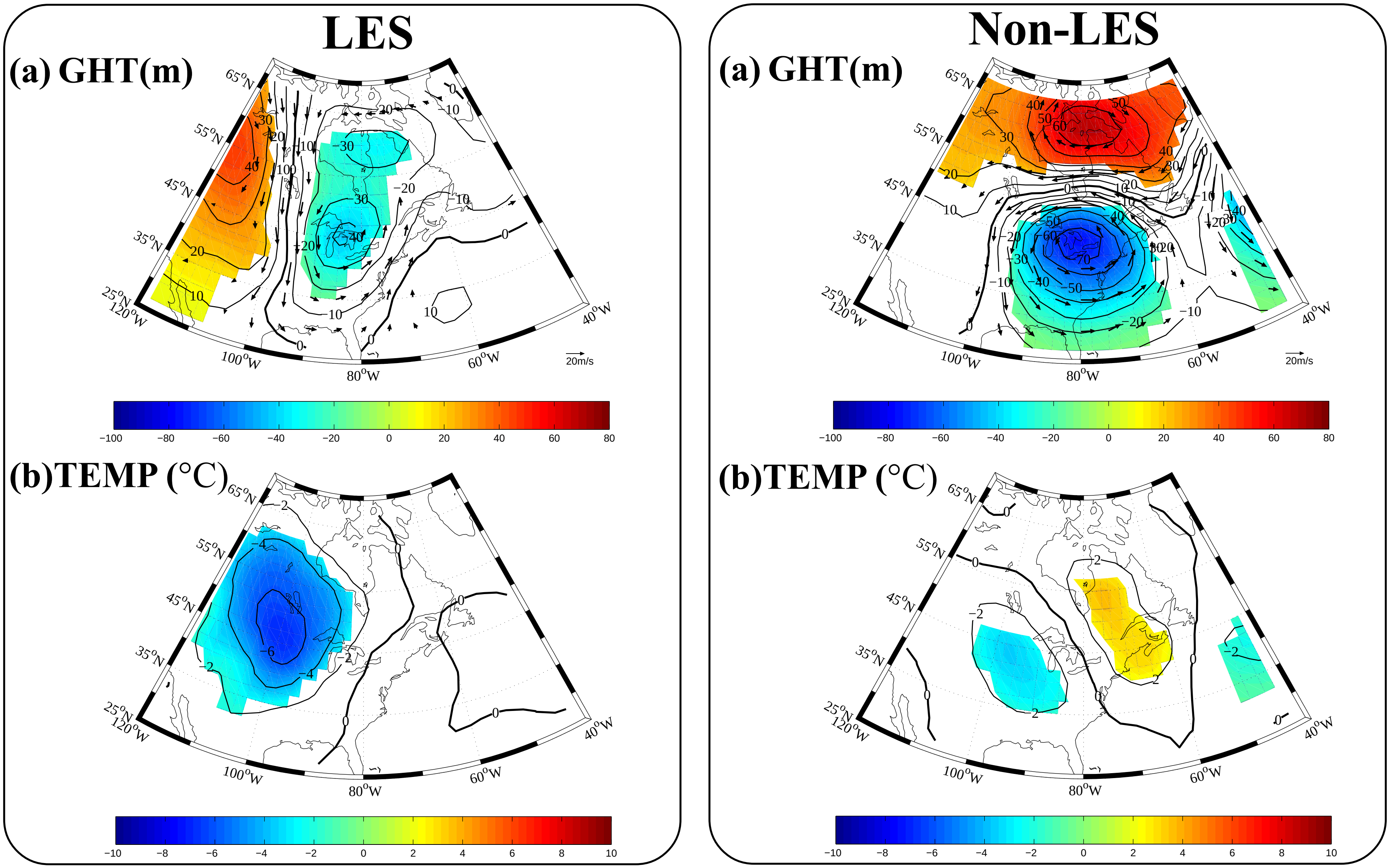
5. Forecast the evolution of the cloud and severe weather elements associated with an observed LES event (submitted)

Composites of the: (a) 850-mb Geopotential Height and Horizontal Wind and (b) 850-mb Temperature at day -2.



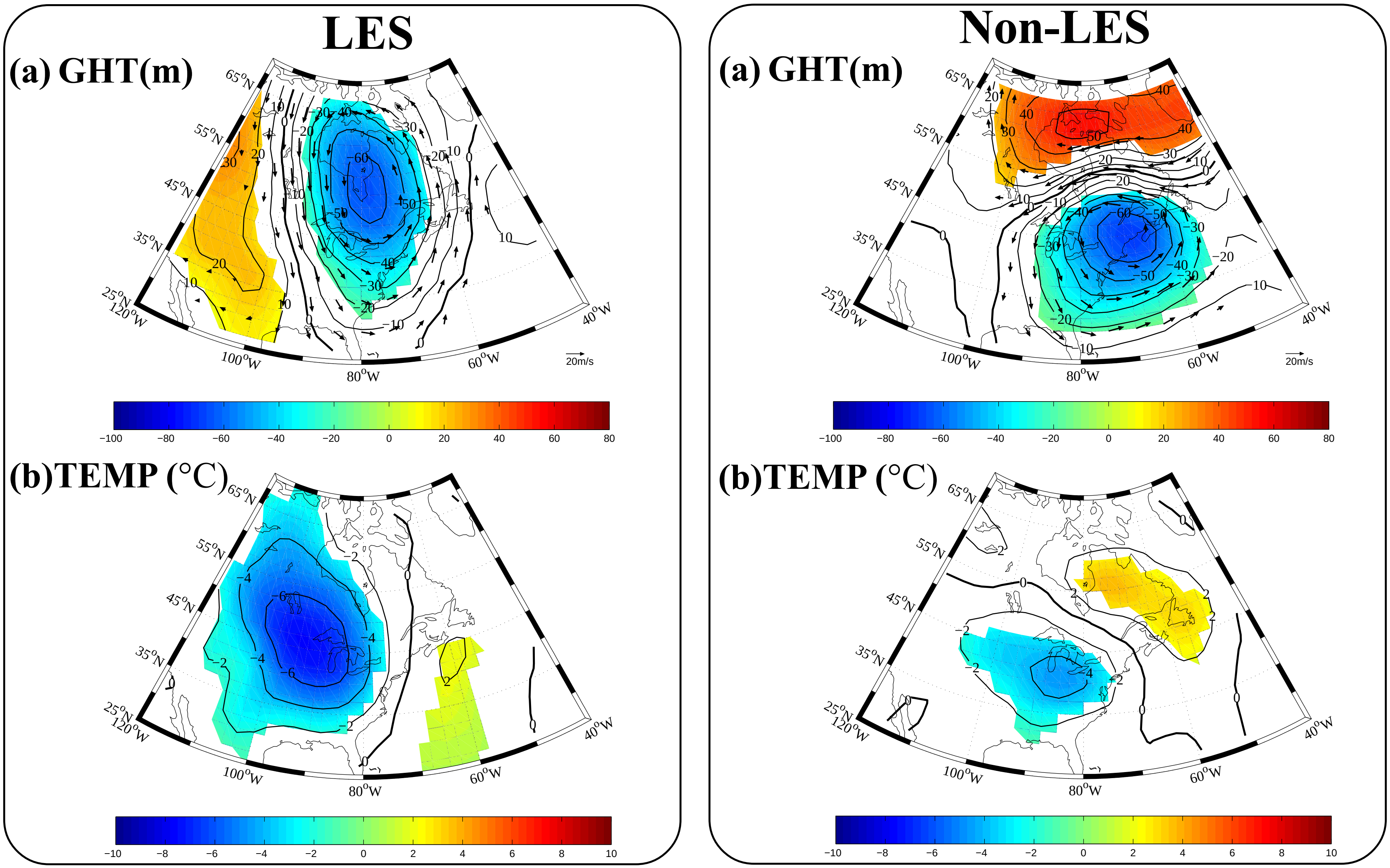
The shaded regions are those where the anomaly is statistically significant at the 95% level. For horizontal wind, vectors are shown at those grid points where at least one component is statistically significant at the 95% level. All fields are from the NCEP reanalysis.

Composites of the: (a) 850-mb Geopotential Height and Horizontal Wind and (b) 850-mb Temperature at day 0.



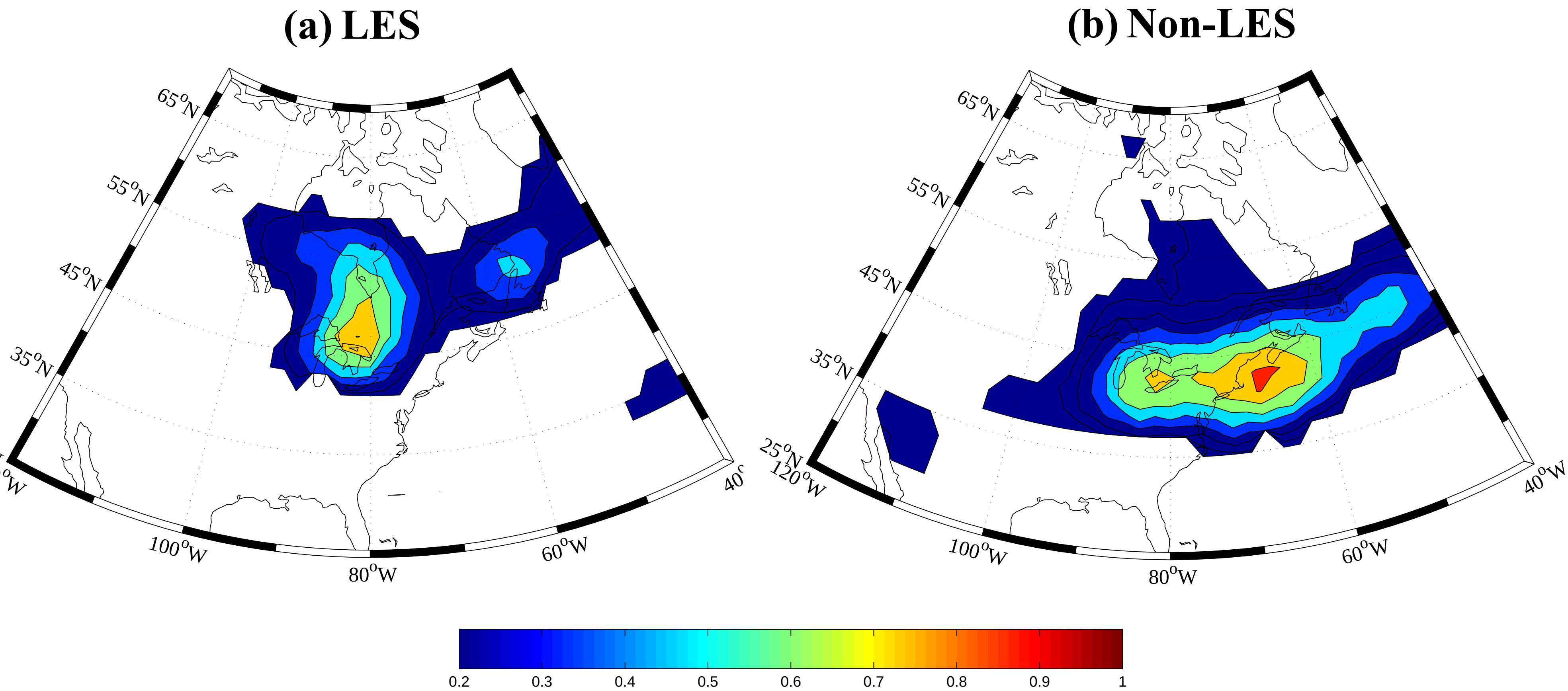
The shaded regions are those where the anomaly is statistically significant at the 95% level. For horizontal wind, vectors are shown at those grid points where at least one component is statistically significant at the 95% level. All fields are from the NCEP reanalysis.

Composites of the: (a) 850-mb Geopotential Height and Horizontal Wind and (b) 850-mb Temperature at day +1.



The shaded regions are those where the anomaly is statistically significant at the 95% level. For horizontal wind, vectors are shown at those grid points where at least one component is statistically significant at the 95% level. All fields are from the NCEP reanalysis.

Track Density in the 850-mb Geopotential Height



Improving the Forecasting of Regional High Impact Weather Events with a Cloud-resolving Numerical Model

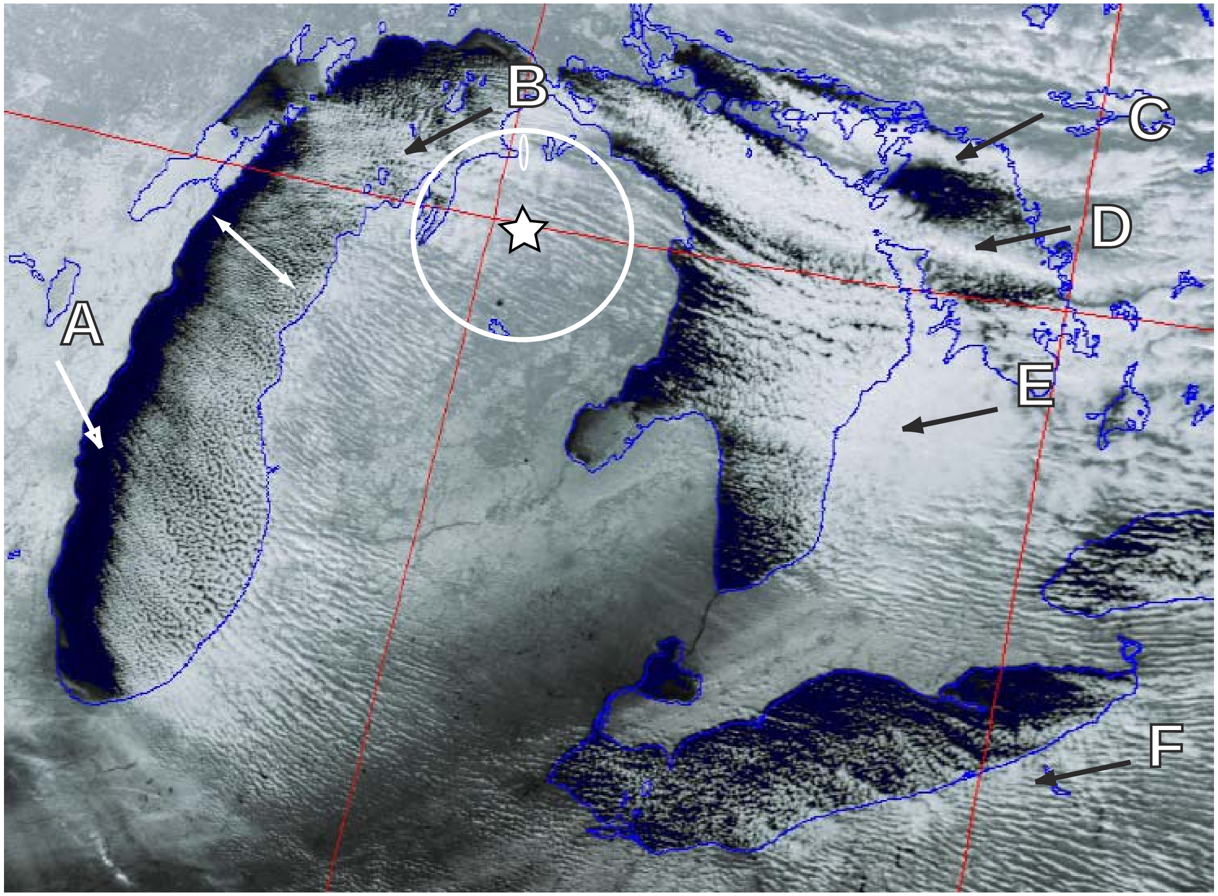
Challenges in Forecasting Severe Weather:

1. small-scale convective motion
2. complicated cloud physics and
3. need to capture regional scale atmospheric flow or surface variability.

Improvements:

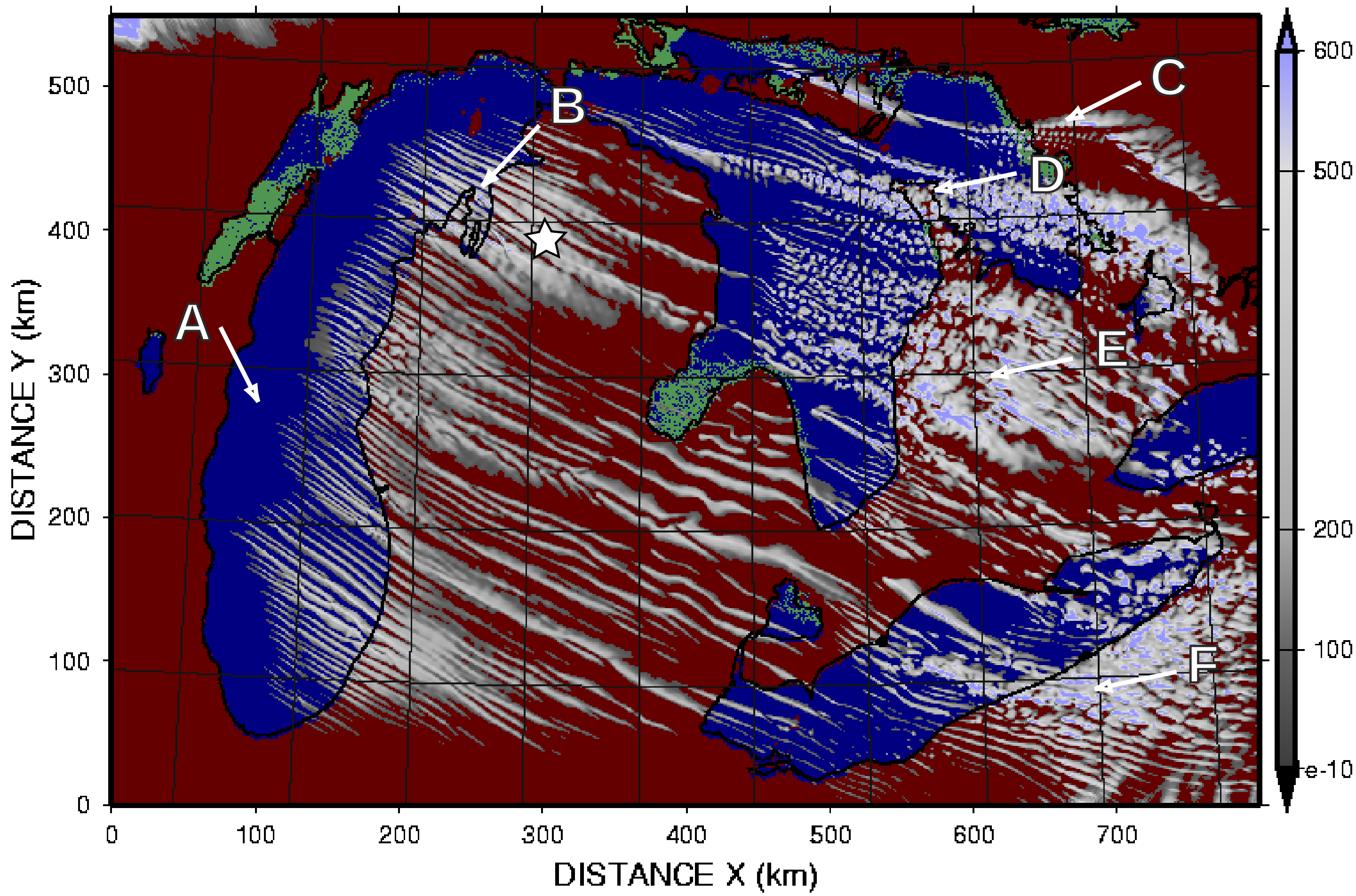
1. high resolution cloud-resolving model
2. improved initial and boundary conditions (3DVAR)
3. improved representation of terrestrial conditions (lake ice)
4. high performance computer system, Japan's Earth Simulator.

Convective Roll Clouds over the Great Lakes Region



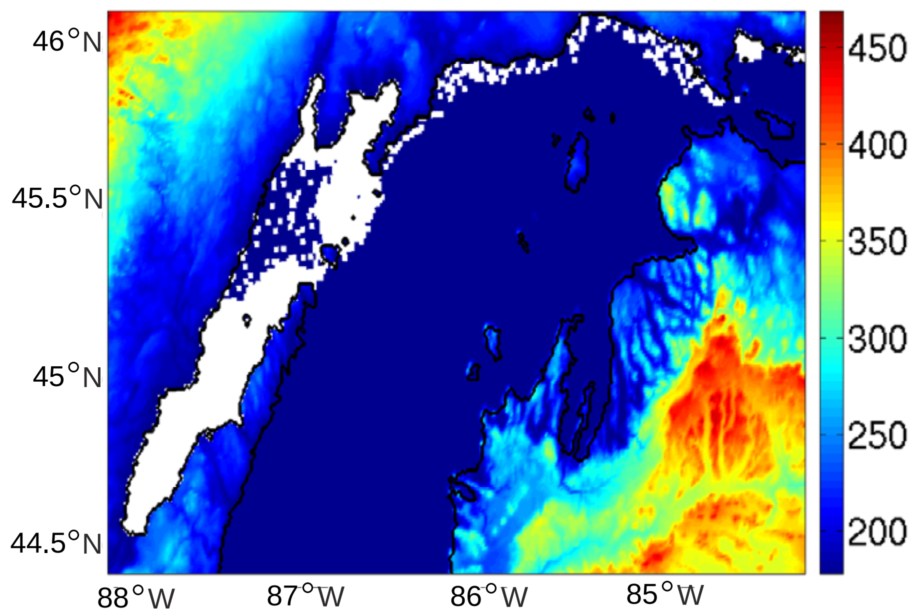
National Oceanic and Atmospheric Administration (NOAA) Satellite *NOAA-14* false color image between 1936-1950UTC 13 Jan 1998.The arrow indicates a re-search aircraft flight track along which the vertical structure of the LES was sampled. The white circle indicates the region observed by the weather surveillance radar located at Gaylord, Michigan whose location is indicated by the star.

The Model Forecast Field of Roll Clouds

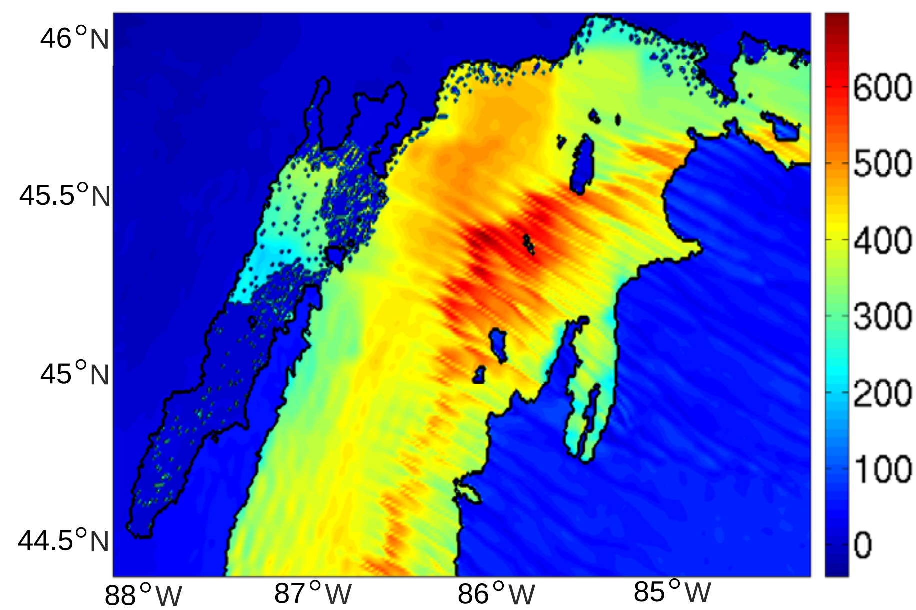


The model forecast field of the vertically integrated hydrometers, including cloud water, cloud ice, rain, snow and graupel, at 1600 UTC 13 January 1998. The star indicates the location of weather surveillance radar at Gaylord, Michigan. With regard to surface type, red indicates land, blue lake and green lake-ice.

Topography with Distribution of Lake Ice



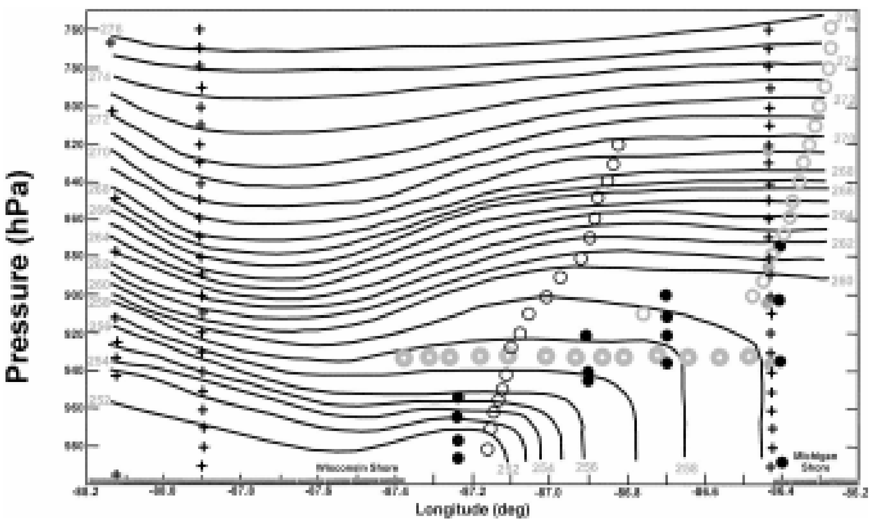
Model Forecast Field of Total Surface Heat Flux



Topography (m) with distribution of lake ice indicated in white; Total surface heat flux ($W\ m^{-2}$)

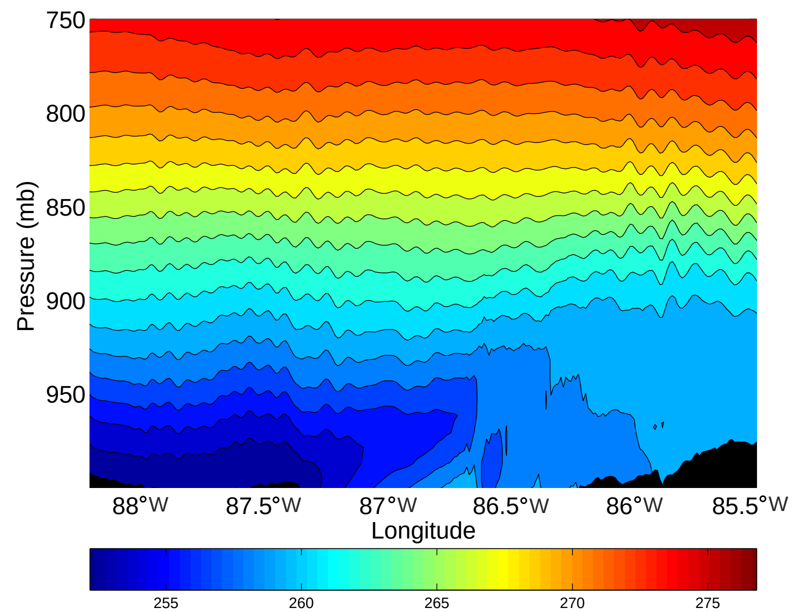
The Evolution of Potential Temperature Cross Upper Lake Michigan

Observation



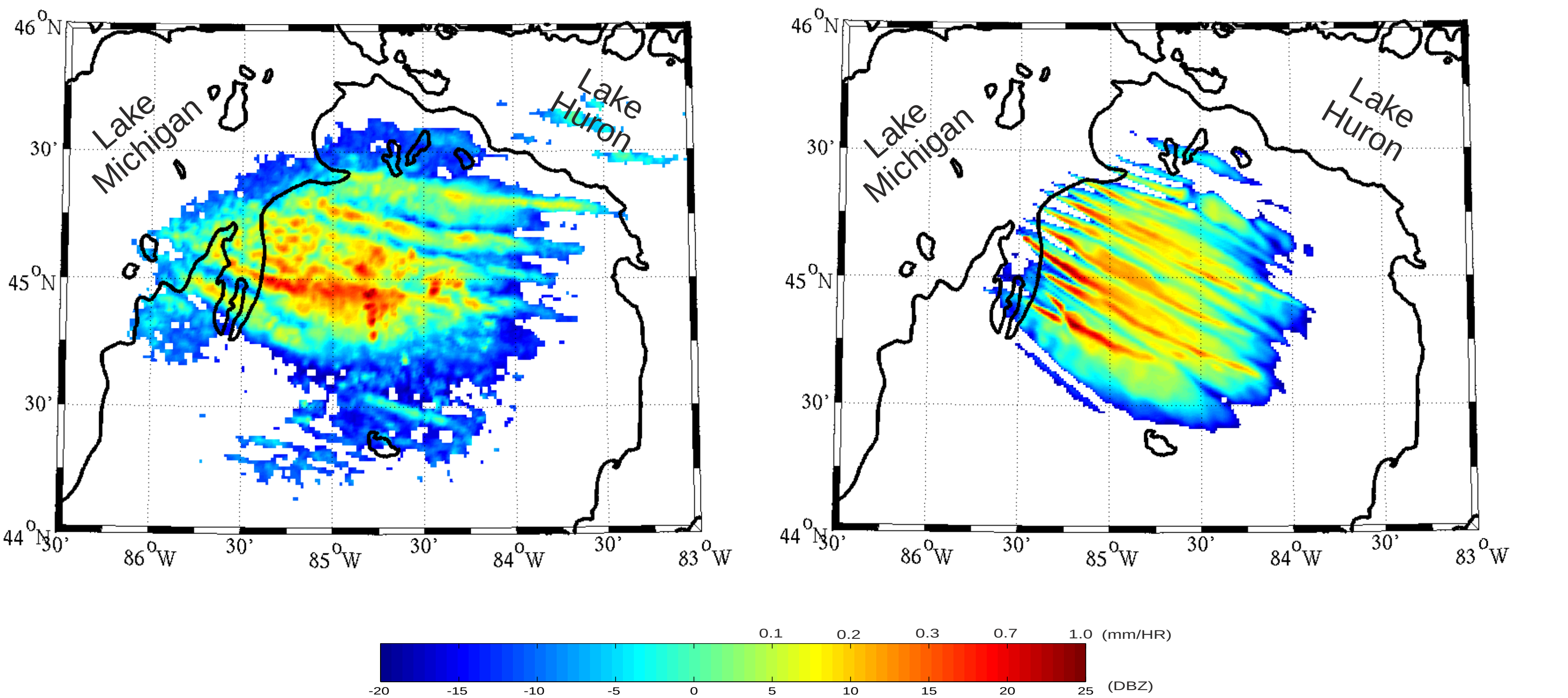
Kristovich, D.A.R. et al., 2003 , MWR

Model Forecast



The model forecast field of potential temperature(K) at 1600 UTC 13 January 1998.

A comparison of observed (left) and (b) model derived (right) reflectivity and precipitation from the weather surveillance radar at Gaylord, Michigan



Summary

Through the development of a climatology of LES over Southern Ontario for the period 1992-99, I identified the favorable synoptic conditions for their development;

I used a high-resolution cloud resolving atmosphere model (CReSS) to simulate roll cloud development and validated the results using previous observational data; then numerically investigated the influence of upstream atmospheric conditions and ice concentration on roll cloud development;

Finally through forecasting the evolution of the cloud and severe weather elements associated with an observed lake-effect snowstorm event , we show that in the near future routine forecasts of such high impact weather systems will be a reality.