A simulation of a lake effect snowstorm around the Great Lakes with a cloud resolving numerical model

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1. Introduction

Lake Effect Snowstorm (LES) is well known as a dominant disturbance which brings a heavy snowfall on the leeward of Great Lakes (e.g., Peach and Sykes 1966; Jiusto and Kaplan 1972; Niziol et al 1995). The LES is directly driven by the absolute instability due to cold air outbreaks over the relatively warmer lakes. Therefore LES is usually an aggregate of cellular or roll convections in shallow boundary layer.

The LES has various mesoscale morphologies, like as vortex, shoreline bands, and widespread rolls. Laird et al. (2003a, b) and Laird and Kristovich (2004) examined the factors which affect on the mesoscale morphology, and found that a ratio of wind speed and maximum fetch distance well predicts the morphology. Mann et al. (2002) examined an influence of multiple lake interactions on LES by numerical simulations including/excluding the individual lakes. This study found that the lake distribution affects the location and intensity of LES. Although the LES consists of shallow and small (~1 km) convections, these studies suggested that the Great Lakes scale phenomena (~1000 km) must be also considered to investigate the LES.

The above is way i) small grids width (< 500 m) which can resolve the dynamics of individual convective cells, and ii) a large domain (~1000 km) including whole Great Lakes, are needed to study the LES by using the numerical model. However it has been hard to execute such a heavy simulation because of the shortage of computational resource. In 2002, the Earth Simulator (ES) was developed and started the service by Japan Marine Science and Technology Center (JAMSTEC). The ES is a distributed memory parallel computing system and consists of 640 nodes. Each node has 8 vector processors with shared memory. This new computing system enabled the heavy simulation which resolves the individual convective cells over the Great Lakes.

In this paper, we simulated the LES on 13 January 2003 (Fig. 1) by using a cloud resolving numerical model with the large domain including almost all Great Lakes to examine the predictability of its cloud pattern and quantity of precipitation.

2. LES simulation on 13 January 2003

Figure 1 represents a MODIS true-color satellite image of a LES over the Great Lakes region at 1545 UTC 13 January 2003. The large-scale comma-shaped cloud feature along the southeastern corner of the image is associated with the synoptic-scale cyclone that established the northwesterly flow conducive to the initiation of the LES. At this time, cloud bands occur over and downstream of Lake Superior, Michigan and Huron as well as Georgian Bay. In addition to these bands that are oriented approximately perpendicular to the upwind shore of the lakes, there also exist cloud bands oriented parallel to the upwind shore of western Lake Superior. These bands are associated with gravity waves excited by the flow over topographic feature along this shore (Winstead et al., 2002).

Figure 2 represents the vertically integrated hydrometeor field from the model at 1700 UTC 13 January, the approximate time of the satellite image shown in Fig. 1. The model used in this study is the Cloud Resolving Storm Simulator (CReSS) version 2.1 developed at Nagoya University (Tsuboki and Sakakibara, 2002). This field was calculated by the vertical integration of all 5 hydrometeors contained in the model (cloud water, cloud ice, rain, snow and graupel). This field provides a succinct diagnostic of the characteristics of the clouds in the model. A comparison of Figs. 1 and 2 highlights the fidelity with which the model is able to reproduce the spatial characteristics of the cloud field associated with the LES. In particular, the model is able to simulate the development of the cloud field over and downstream of the Great lakes. For example, the transition from 2D roll to 3D cellular convection, which is often observed to occur in LES, was captured in the model. Distinct band clouds that extend downstream from Lake Huron and Georgian Bay were also simulated successfully. These bands are known as Type I or mid-lake snow bands (Niziol et al., 1995; Laird et al. 2003).

To examine the ability of the model to forecast the precipitation associated with this LES, simulated radar reflectivity fields were calculated from the model hydrometeor fields. Figure 3 shows the comparison of this simulated field with observations at 1309 UTC 13 January 2003 made

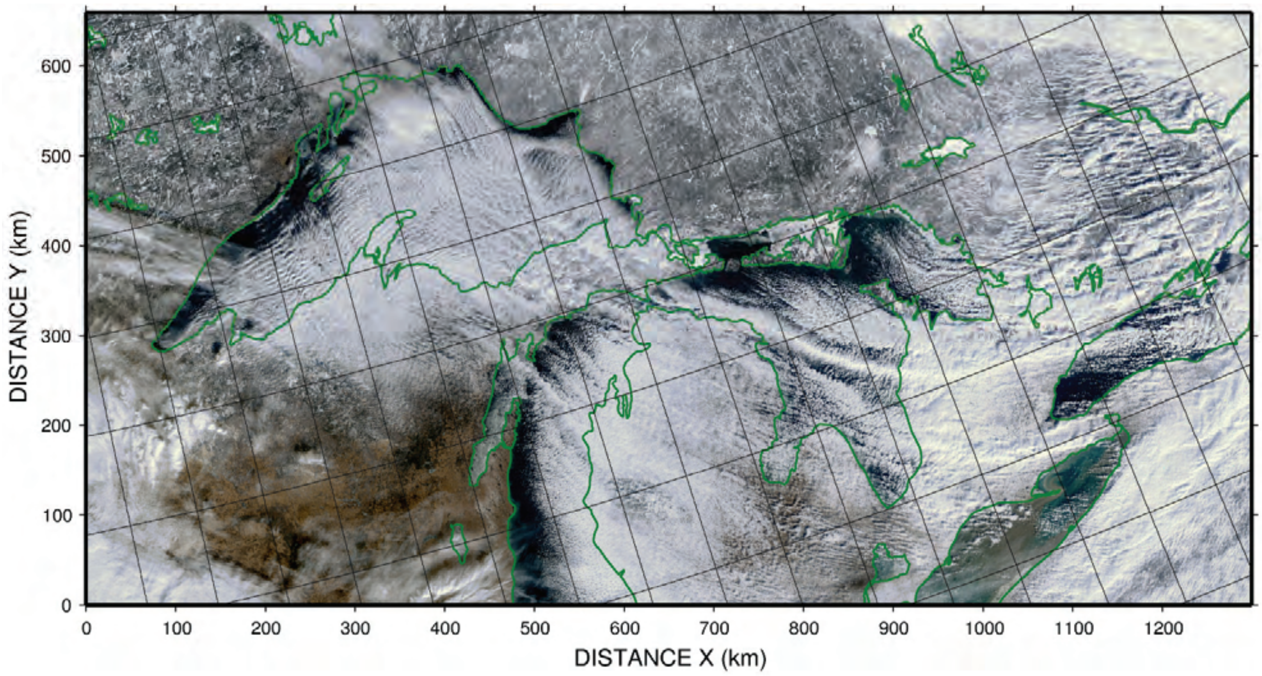

Fig. 1. MODIS true-color satellite image of the Great Lakes region of North America at 1645 UTC 13.

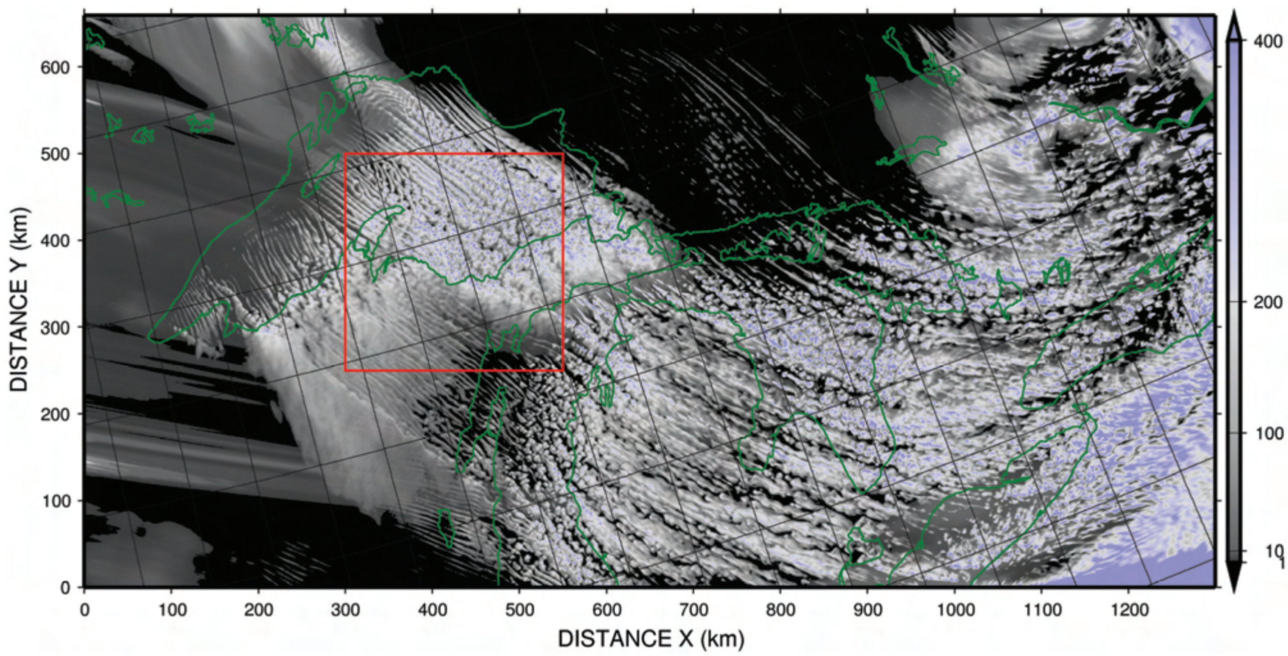

Fig. 2. Vertically integrated hydrometeors (cloud water, cloud ice, rain, snow and graupel) (g m^{-2}) simulated by the numerical model (CReSS). The domain is the same as that shown in Fig. 1. The red rectangle indicates the domain of Fig. 3.

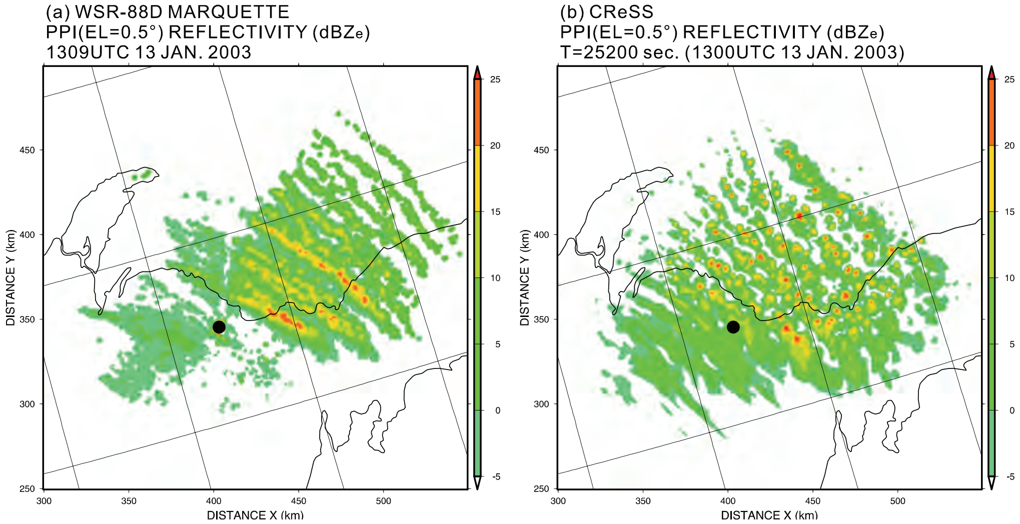

Fig. 3. Radar reflectivity PPI (Plan Position Indicator) image with an elevation of 0.5°. The domain is indicated by the rectangle in Fig. 2. a) Observed by WSR-88D at Marquette, Michigan at 1309 UTC 13 January 2003. b) Simulated by the model at 7 hours after initialization (corresponding to 1300 UTC 13 January 2003).

with the WSR-88D radar at Marquette, Michigan. The maximum observation range of WSR-88D radar is 450 km; however the observation range for the LES are typically only 100-150 km as a result of the shallow nature of clouds and the earth's curvature. As was the case with Figs. 1 and 2, the similarity between the observed and simulated reflectivity fields is striking. In both instances, the bands are aligned with the mean wind, which was from the northwest. Both the observed and simulated reflectivity fields indicate that the bands were well developed over Lake Superior and at this time, tended to become less organized upon landfall. There is also good agreement in the magnitude of the observed and simulated reflectivity. The observed bands tend to narrower and more linear in character as compared to the model bands.

3. Conclusion

In this study, we used a cloud resolving numerical weather model in a large domain to simulate the evolution of a LES that developed over the North American Great Lakes region on January 13th, 2003. The simulation succeeded to reproduce the important natures of LES, such as the transition from 2D roll to 3D cellular convections and the mid-lake snow band. The simulated snowfall intensity in the model coincided with that of radar observation. The results of this study suggest that it is possible to such models to produce realistic simulations of mesoscale weather systems such as LES that develop as the result of the interaction of synoptic-scale and cloud-scale circulations in the presence of varying surface conditions.

References

Jiusto, J. E., and M. L. Kaplan. 1971: Snowfall from lake-effect storm. Mon. Wea. Rev., 100, 62-66.

Laird, N. F., D. A. R. Kristovich and J. E. Walsh, 2003a: Idealized model simulations examining the mesoscale structure of winter lake-effect circulations. Mon. Wea. Rev., 131, 206-221.

Laird, N. F., J. E. Walsh and D. A. R. Kristovich, 2003b: Model simulations examining the relationship of lake-effect morphology to lake shape, wind direction, and wind speed. Mon. Wea. Rev., 131, 2102-2111.

Laird, N. F. and D. A. R. Kristovich, 2004: Comparison of observations with idealized model results for a method to resolve winter lake-effect mesoscale morphology. Mon. Wea. Rev., 132, 1093-1103.

Mann, G. E., R. B. Wagenmaker and P. J. Sousounis, 2002: The infuluence of maultiple lake interaction upon lake-effect storms. Mon. Wea. Rev., 130, 1510-1530.

Niziol, T. A., W. R. Snyder and J. S. Waldstreicher, 1995: Winter weather forecasting throughout the Eastern United Status. Part IV: Lake effect snow. Wea. Forecasting, 10, 61-77.

Peach, Jr., R. L. and R. B. Sykes, Jr., 1966: Mesoscale study of a lake effect snow storm. Mon. Wea. Rev., 94, 495-507.

Tsuboki, K and A. Sakakibara, 2002: Large-scale parallel computing of Cloud Resolving Storm Simulator. High Performance Computing, Springer, H. P. Zima et al. Eds, 243-259.

Winstead, N. S., T. D. Shikora, D. R. Thompson and P. D. Mourad, 2002: Direct influence of gravity waves on surface-layer stress during a cold air outbreak, as shown by synthetic aperture radar. Mon. Wea. Rev., 130, 2764-2776.