Applying GOES-12 Water Vapor and Total Column Ozone Observations to the 12-13 November 2003 Lake Erie Seiche

Sarah M. Dillingham, University of Georgia

June 2008

INTRODUCTION

On 12-13 November 2003, a non-convective wind event (NCWE) associated with a mid-latitude cyclone affected the Midwest and Great Lakes regions. The storm resulted in eight deaths, thousands of power outages, and total damages from the storm were estimated at over $36 million. Wind gusts as high as 39 ms^{-1} were reported at the height of the storm, and these intense winds were also responsible for a large seiche, of approximately seven feet, across Lake Erie on 13 November 2003 (Fig. 1). A previous study conducted by Lacke et al. (2007) on the climatology of cold season NCWE's found that 70-76% of associated wind directions were from the southwest quadrant. Thus it could be expected that Lake Erie would be highly susceptible to these winds due to its southwest to northeast orientation. This seiche was one of the most pronounced in the period of record for the Great Lakes, and the fact that the event was associated with an extratropical cyclone and upper level tropopause fold makes this particular case unique. Previous analysis performed on this event (Durkee et al., in preparation) found that an associated tropopause fold descended below 700 mb and was coupled with an upper-level dry slot over the areas of the strongest winds. The main focus of this study will be to apply the GOES-12 satellite imagery in conjunction with the GOES-12 (SFOV) TCO product to provide a better understanding of how the ozone concentrations might relate to near-surface winds and the resulting seiche.

DATA SOURCES

Several meteorological and climatological sources were used to evaluate the events that took place on 12-13 November 2003. The non-convective high wind reports that occurred throughout the period were obtained from the National Climatic Data Center. The North American Regional Analysis (NARR) data was utilized in order to examine and diagnose the surface and upper-air features across the Midwest and Great Lakes regions. This data was also referenced in creating the surface and upper-air maps, in addition to the vertical cross-sections used to analyze the dynamic features of the jet streak and planetary boundary layer. These graphics were created using the General Meteorological Package (GEMPAK) software.

The 6.5 µm water vapor channel of the GOES-12 satellite at 4km resolution was used to analyze the dry slot features associated with the cyclone. For the specific purpose of analyzing the ozone data, the GOES Single Field-of-View (SFOV) Total Column Ozone (TCO) product was used. The SFOV ozone product uses an algorithm that improves the hourly retrieval of the GOES-12 TCO and also has an increased resolution from 30 km x 30 km to 10 km x 10 km (Li et al. 2007). These images were obtained from the Space Science and Engineering Center at the University of Wisconsin-Madison.

RESULTS

On 12 November 2003, the low pressure area was located over northern Montana within a fast-moving, upper-level short wave trough (not pictured). By 1200 UTC, the system was centered over the western Great Lakes region as an area of high pressure formed over the Pacific Northwest, and the resulting pressure gradient between the two systems produced strong northerly winds across the Northern Plains. The wave further progressed through Iowa between 1600 and 1800 UTC on 12 November with wind speeds of 25 -29 ms^{-1}, before moving into southern Wisconsin.

Perhaps the most interesting events occurred between 1800 UTC 12 November and 0600 UTC 13 November as the system continued to intensify, affecting Lower Michigan and Lake Erie, with wind gusts reaching as high as 33 ms^{-1} along the shores of Lake Erie. The surface observations at 1800 UTC 12 November indicated that the low was located over the Upper Peninsula (UP) of Michigan (Fig. 2a), and the core of the jet streak was located over Iowa, just to the southeast of the low (Fig. 2b,). The correlative SFOV TCO imagery depicts the ozone concentrations over Lake Erie at 1746 UTC 12 November (Fig. 2c), the time of the onset of the seiche. As the storm progressed across Lake Erie and Lower Michigan between 0000 UTC and 0300 UTC 13 November, the central pressure dipped to 990 mb over the UP of Michigan. At 0045 UTC 13 November, water vapor imagery depicts a dry slot moving across northern Indiana and Ohio, as well as southeast Lower Michigan (Fig. 3). The ozone imagery at this time is also pictured (Fig. 4). Between 0146 UTC and 0246 UTC 13 November, an ozone concentration gradient pushes across Lake Erie during the period of the strongest winds (Fig. 5). Cross-sectional analyses from Marquette, MI to Youngstown, OH show a tropopause fold, delineated by lines of potential vorticity, reaching down to approximately 700 mb (Fig. 6). In this same figure, the dotted lines represent Bulk Richardson number values less than 1 ($Ri \leq 1$), indicating dynamic instability over Lake Erie at the time of the seiche. Further discussion will explain the connections between these upper-level features and their role in the downward transport of high-momentum air to the surface. With the upper-level conditions in place, the surface conditions at Lake Erie deteriorated, leading to the seiche.

During the time in which the vertical structure of the atmosphere was well aligned for the transport of air downward, Lake Erie was being affected. The water plots for Lake Erie show a significant change in water levels between 1800 UTC 12 November and 0600 UTC 13 November (Fig. 1). Fermi Power Plant, MI on the eastern banks of Lake Erie, experienced a drop of ~2.3 m over the course of 12 hours, beginning at 1800 UTC 12 November and reaching its peak at 0600 UTC 13 November (Fig. 1a). Three hours later, Buffalo, NY, on the eastern banks of Lake Erie, recorded a water surge of ~2.2 m over the course of 6 hours, initiating at 2100 UTC 12 November and reaching its peak 0400 UTC 13 November (Fig. 1b).

DISCUSSION

Further analysis of the ozone imagery between 0000 UTC and 0300 UTC 13 November will provide a more detailed picture of the vertical structure of the atmosphere. Comparisons of the water vapor imagery at 0045 UTC 13 November with the ozone imagery at 0046 UTC 13 November show a direct correlation between the ozone concentration gradient (Wimmers and Moody, 2004) and the most intense area within the nose of the dry slot. In addition to this feature, the imagery in Figure 5 shows concentrations are near 300 Dobson Units at 0146 UTC 13 November (Fig. 5a), and by 0246 UTC, the concentrations have increased to almost 350 Dobson Units (Fig. 5b). Notice that a large area to the west of Lake Erie has missing ozone data. This is hypothesized to be a possible result of thick cloud cover, in which the SFOV TCO algorithm is not capable of resolving ozone amounts.

In order to get this high-wind-speed air to the surface, there must be sufficient evidence to support the downward mixing of high-momentum air from the upper troposphere. In relation to the tropopause folds and stratospheric intrusions, there have been cases of this ozone-rich air being detected at the surface under favorable boundary layer conditions (Lamb, 1977). In this case, the area below the nose of the tropopause fold in Figure 6, shows Ri values that are ≤ 1, signifying an atmosphere that is susceptible to Kelvin-Helmholtz instability (Stull, 1988). These values, combined with weak static stability, seen in the large spacing of the moist isentropes (thin solid lines), lead to an environment that has low resistance to vertical motion. Furthermore, Lake Erie is located under this region of dynamic instability, providing conditions that could have allowed the high-momentum air aloft within the tropopause to reach the surface.

In addition to the instability profiles, transverse jet streak circulations were also hypothesized as having a role in the vertical mix down of the ozone-rich air. However, further analysis of the 300 mb jet streak at 0000 UTC and 0300 UTC 13 November, in combination with the vertical cross-sections, revealed that areas of convergence (negative divergence) which had begun to move into the eastern end of Lake Erie did not show a close enough correlation to be considered as a mechanism of momentum transport.

CONCLUSION

After careful analysis of several upper-air features, it was discovered that the tropopause fold, coupled with weak boundary layer static stability, and low Bulk Richardson values signifying dynamic instability, could have led to a downward transport of high-momentum air to the surface across Lake Erie. It is important to note that at the onset of the seiche, 1800 UTC 12 November, the greatest ozone concentrations were not located over Lake Erie. The focus, rather, was the collocation of the ozone gradient and the observations at the surface between 0000 UTC and 0300 UTC 13 November. The progression of this gradient feature, in conjunction with the aforementioned dynamic conditions and observed surface conditions, suggests that other processes may be at work along this gradient that are assisting in this downward transport. The atmospheric conditions needed to produce a non-convective wind event remain undetermined. The ability to forecast these non-convective wind events still needs further examination in order to develop a possible methodology for understanding exactly how and why these high-wind-speed, ozone-rich winds reach the surface. The GOES-12 (SFOV) Total Column Ozone could prove to be a great tool in weather analysis and forecasting. If favorable atmospheric conditions, such as those leading up to the seiche event, could be earlier identified, forecasters could include the use of this product in combination with water vapor imagery and stability profiles to better estimate if, when, and to what intensity high-momentum air will impact the surface.

ACKNOWLEDGEMENTS

Special thanks to Phil Kurimski of the National Weather Service's Green Bay office for first alerting us to this cyclone windstorm as it was developing on 12 November 2003. Scott Bachmeier and Chris Schmidt of CIMSS/SSEC at the University of Wisconsin-Madison provided satellite and SFOV data, and Tom Mote at UGA provided assistance with GEMPAK. Thanks to Joshua D. Durkee, Christopher M. Fuhrmann, and Dr. John A. Knox for their work with this cyclone case study and for providing GEMPAK images. Also, thanks to Great Lakes Environmental Research Laboratory (GLERL) for providing the water level data.

REFERENCES

J. Li, J. Li, C. C. Schmidt, J. P. Nelson, III, and T. J. Schmit, “High temporal resolution GOES sounder single field of view ozone improvements,” *Geophys. Res. Lett.*, vol. 34, L01804, 2007. doi:10.1029/2006GL028172.

Lacke, M. C., J. A. Knox, J. D. Frye, A. E. Stewart, J. D. Durkee, C. M. Fuhrmann, and S. M. Dillingham, 2007: A climatology of cold-season non-convective wind events in the Great Lakes region. *Journal of Climate*, 20, 6012-6022.

Lamb, R.G., 1977: A case study of stratospheric ozone affecting ground-level oxidant concentrations. *J. Appl. Met.*, 16, 780-794.

Stull, R. B., 1988: An *Introduction to Boundary Layer Meteorology*. Springer-Verlag, 684 pp.

Wimmers, A. J., and J. L. Moody (2004), Tropopause folding at satellite-observed spatial gradients: 1. Verification of an empirical relationship, J. *Geophys. Res.*, *109*, D19306, doi:10.1029/2003JD004145.

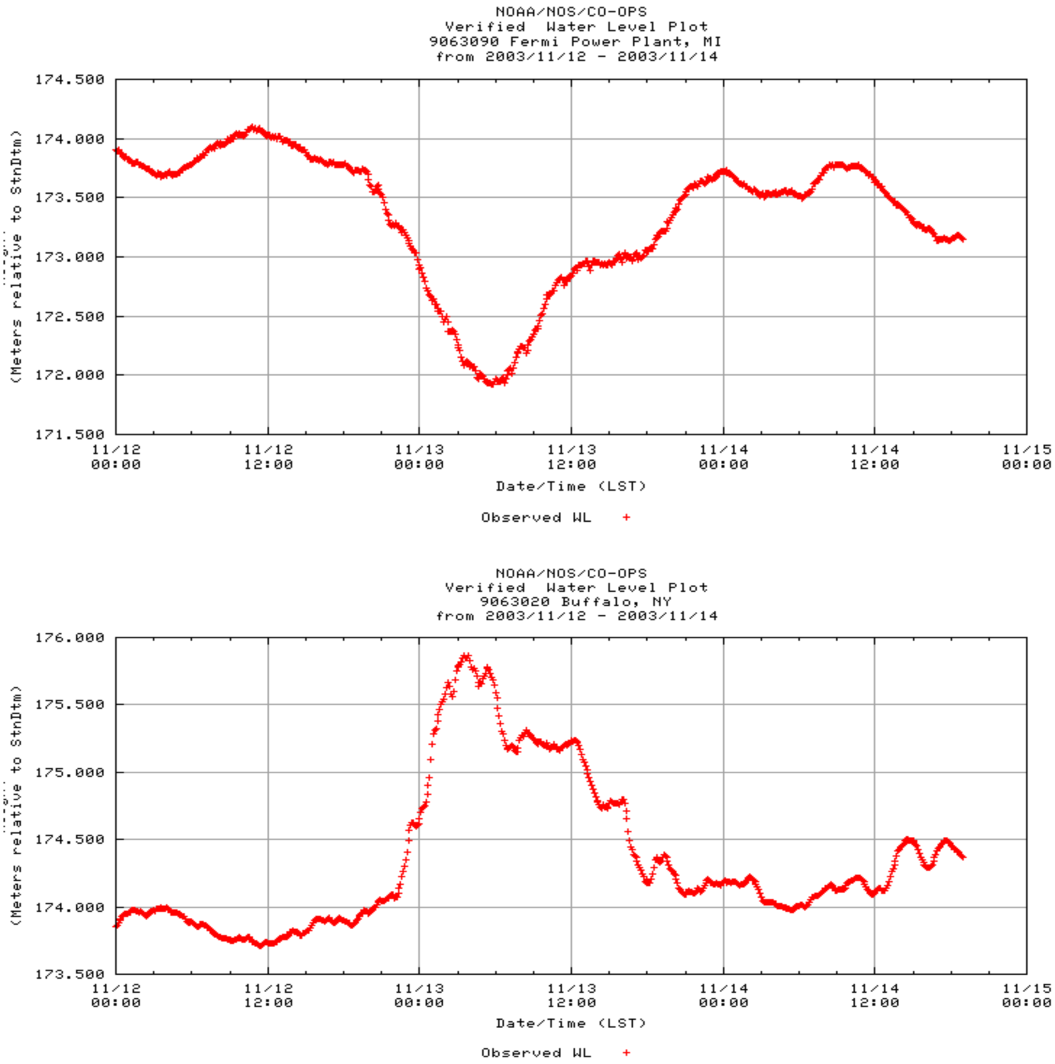

Figure 1. Observed Water Levels between 0000 UTC 12 November 2003 and 0000 UTC 15 November 2003: (a) Fermi Power Plant, MI – eastern Lake Erie (b) Buffalo, NY – western Lake Erie

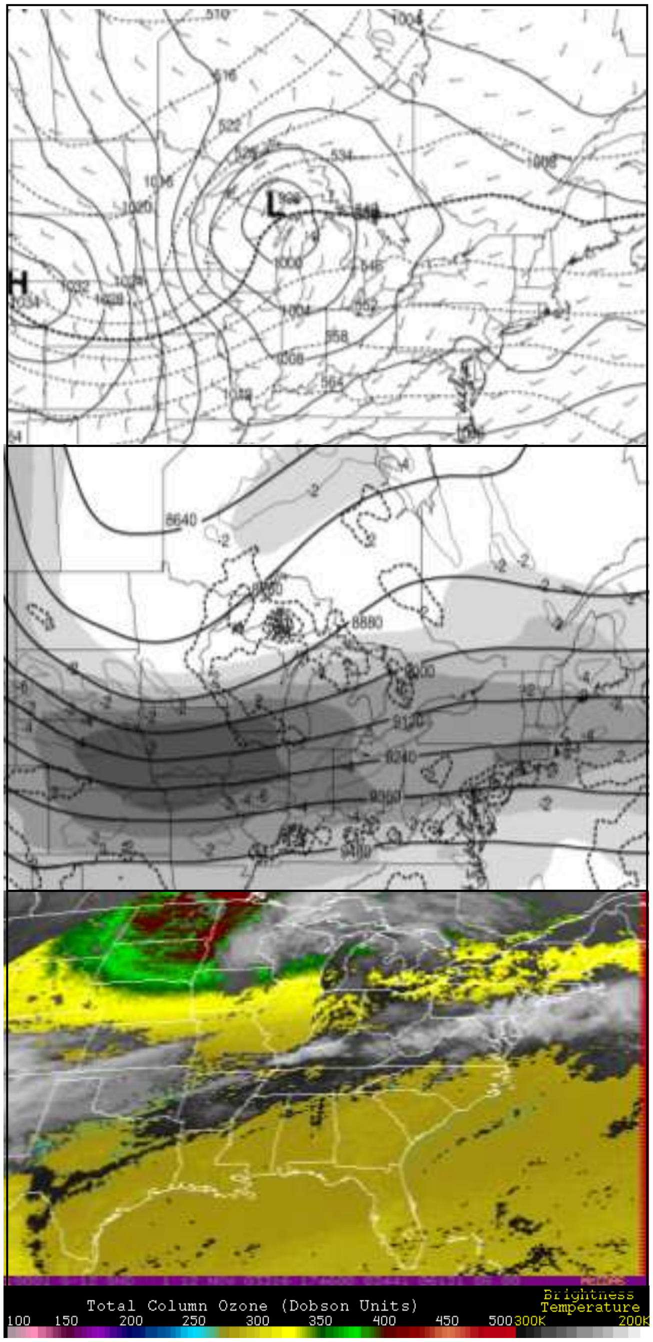

Figure 2: Synoptic conditions at 1800 UTC 12 November 2003: (a) sea level pressure (solid line, mb), 1000-500 mb thickness (dashed line, m), and surface wind vectors (standard barbs); (b) 300 mb heights (thick solid line, m), divergence (thin solid line, s^{-1}), and wind speed (shading, m s^{-1}); and (c) 1746 UTC 12 November 2003: GOES-SFO TCO ozone concentrations (Dobson Units) and Brightness Temperature (degrees Kelvin)

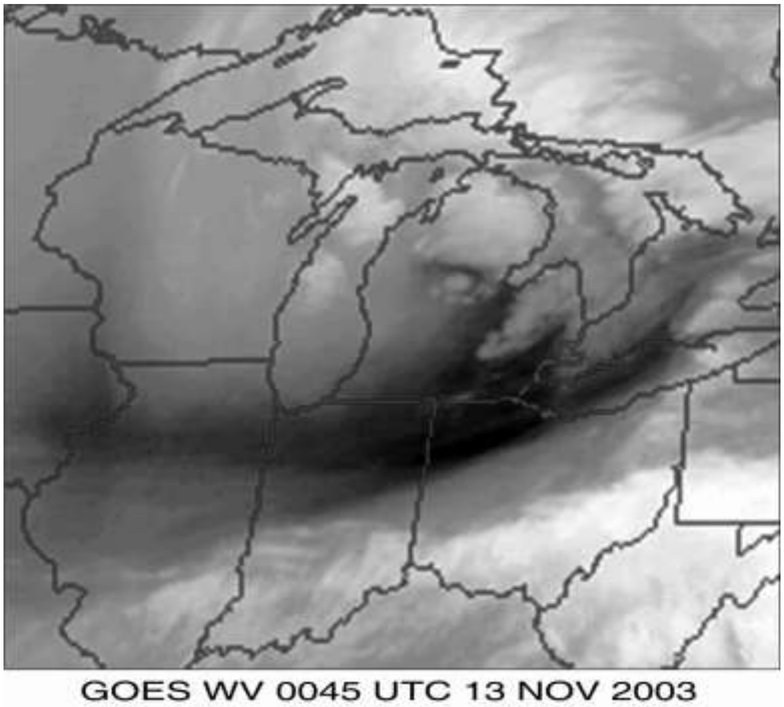

Figure 3. GOES Water Vapor Imagery at 0045 UTC 13 November 2003

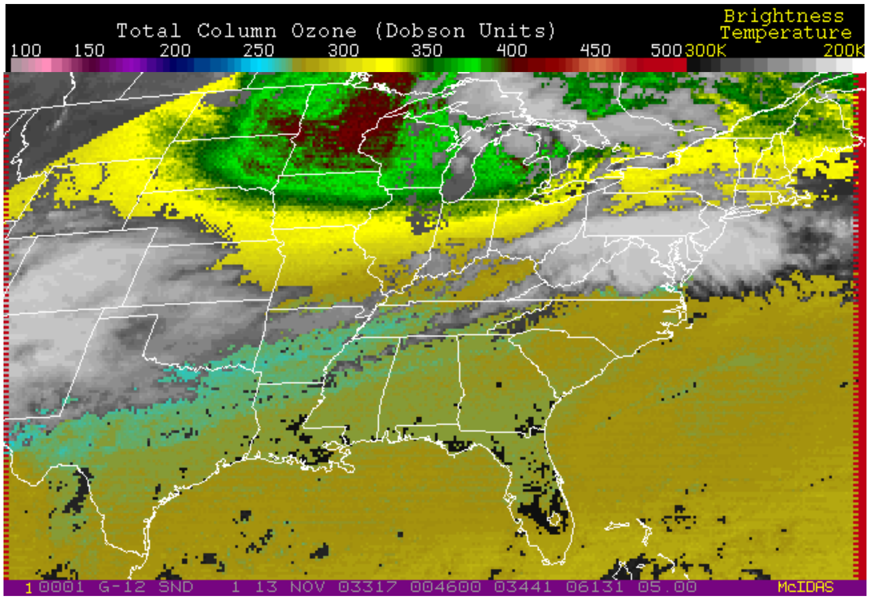

Figure 4. GOES-SFOV TCO at 0046 UTC 13 November 2003: ozone concentrations (Dobson Units) and cloud brightness temperatures (degrees Kelvin).

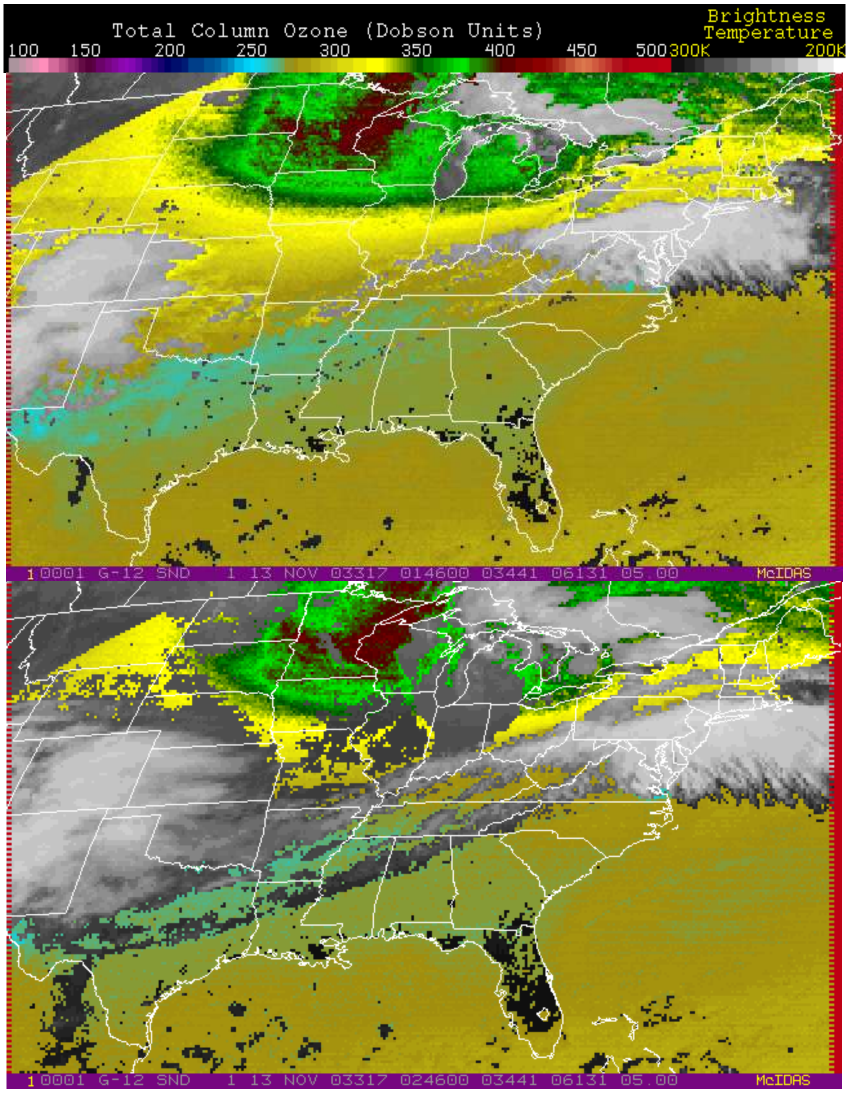

Figure 5. GOES-SFO TCO ozone concentrations (Dobson Units) and Brightness Temperature (degrees Kelvin): (a) 0146 UTC 13 November 2003 and (b) 0246 UTC 13 November 2003

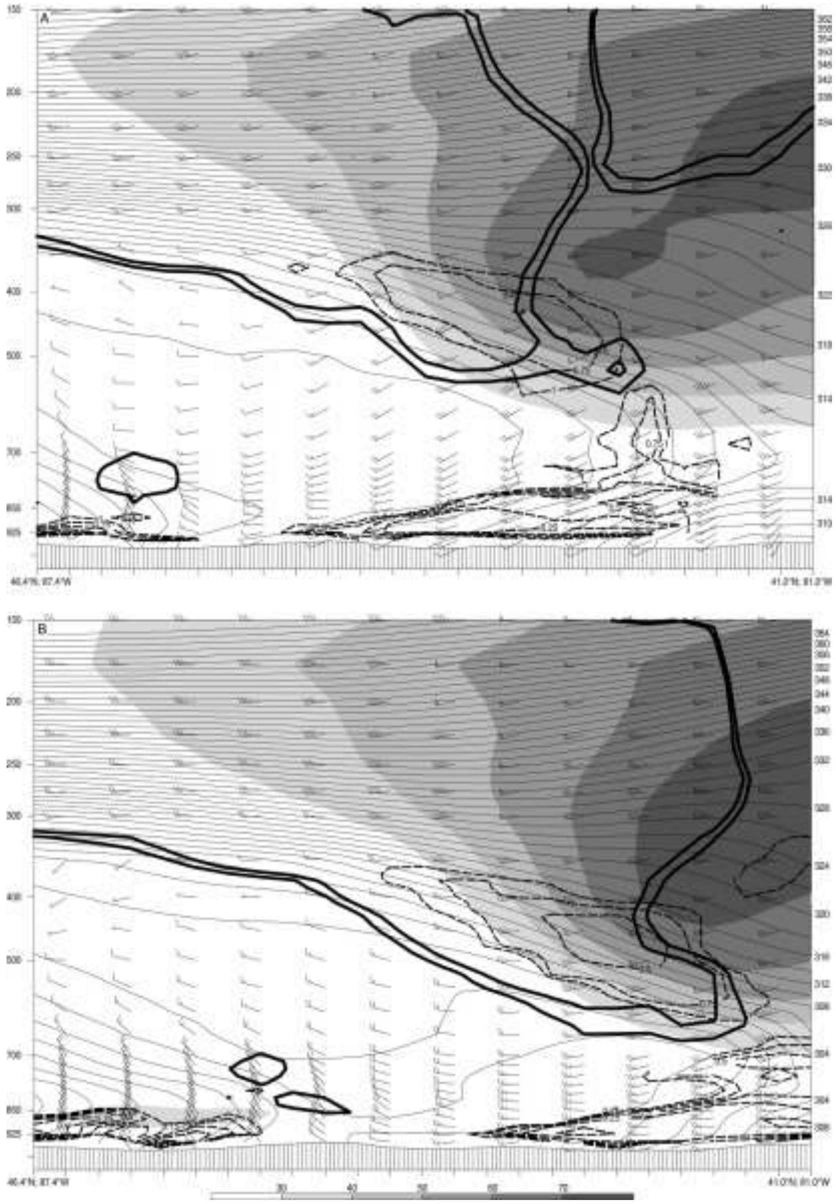

Figure 6. Vertical cross-section from Marquette, MI to Youngstown, OH at (a) 0000 UTC 13 November 2003 and (b) 0300 UTC 13 November 2003 showing moist isentropes (i.e. θ_e, thin solid line, K), wind vectors (standard barbs), wind speed (shaded, m s^{-1}), potential vorticity values of 1.5 and 2.0 (thick solid lines, 1 PVU = 10^{-6} K m^2 kg^{-1} s^{-1}), and bulk Richardson values ≤ 1.0 (dashed line, dimensionless).