*EASTERN REGION TECHNICAL ATTACHMENT*
*NO. 92-4A*
*APRIL, 1992*

# WATERSPOUTS ON LAKE ERIE - ANOTHER TWIST

*Michael T. Eckert*
*Anton F. Kapela*
*National Weather Service Forecast Office*
*Cleveland, Ohio*

## 1. INTRODUCTION

Waterspouts are common on the Great Lakes during the late summer and fall months. They are usually short lived, but are still a hazard to marine interests, and draw considerable attention due to the high population density along the shores of the Great Lakes. This paper will describe the atmospheric conditions present July 25-28, 1991, when numerous waterspouts formed on Lake Erie (Figure 1).

It was thought that waterspout generation was similar to the development of a funnel cloud into a tornado, whereby the circulation developed aloft, and spun down from the cloud-base to the ground or water surface (Golden 1974a,b). This is probably true for mesocyclone induced vortices that move offshore, subsequently generating waterspouts. While waterspouts associated with supercells have been observed over the Great Lakes, particularly during the spring and early summer months, these waterspouts evolve differently from the more frequent, late summer and fall events discussed by Kieltyka (1987). The Florida Keys' waterspouts studied by Golden (1974a,b) also do not (except for the largest 10%) appear to be mesocyclone induced. These waterspouts typically formed within towering cumulus whose tops average approximately 10,000-20,000 feet. Rather, there are indications that many of these waterspouts develop from the water surface up to the cloud base, not from the clouds down to the water. This formation theory has also been applied to vortices over land, termed landspouts (Bluestein 1985; Brady and Szoke 1989). This paper will describe how the July 25-28, 1991, waterspouts appeared to "spin-up," in the manner described by Wakimoto and Wilson (1989).

## 2. PRECURSOR ENVIRONMENTAL CONDITIONS

### 2.1 Synoptic Scale

During the last week of July 1991, an upper level low pressure system became well established over James Bay, Canada, with the associated cyclonic flow dominating the Great Lakes region (Figures 2a-d). Weak short waves tracked through the cyclonic flow during this period, periodically enhancing the synoptic scale vertical motion fields.

The surface pressure pattern during this four day period consisted of a cold front crossing the area on July 25th, with high pressure centered northwest of Lake Erie during July 26-28 (Figures 3a-d). Note, the synoptic scale conditions were very similar to those mentioned by Kieltyka (1987) as being favorable for Lake Erie waterspout formation.

The overall weather conditions during this period consisted of normal, to slightly below normal temperatures, and surface wind speeds generally less than 15 kt. The wind direction during this period was mostly from the northwest to northeast, except immediately prior to the passage of a cool front during the late afternoon of the 25th. Precipitation was not reported during the period, nor was it indicated by Cleveland's WSR-74C radar during any of the waterspout occurrences.

### 2.2 Mesoscale

The Lake Erie water temperature near Cleveland during this period was around 25°C. The overnight low temperatures over land were 13-17°C. The Detroit, MI, to Pittsburgh, PA, surface pressure difference at 1200 UTC on three of the four mornings was less than 2.5 mb. The gradient on July 26 was 2.8 mb. The weak pressure pattern, along with the substantial land-lake temperature gradient, was instrumental in the development of a land breeze. These conditions are almost identical to those outlined by Naglic (1991) in his study of lake breezes during the spring and early summer. It will be shown in subsequent sections that this land breeze front was instrumental in the development of the waterspouts on Lake Erie.

Composite soundings for northern Ohio at 1200 UTC were generated based on the observed soundings from: Dayton, OH; Flint, MI; Pittsburgh, PA; and Buffalo, NY. These composite northern Ohio 1200 UTC soundings (Figures 4a-d) were very stable with respect to the temperature/moisture profile over land. However, if the composite soundings are further modified using the surface temperature and dew point over Lake Erie, the atmosphere becomes conditionally unstable.

## 3. MECHANISMS FOR WATERSPOUT DEVELOPMENT

Late summer and fall waterspouts on Lake Erie have long been assumed to be a direct result of instability generated by cold air aloft and a warm surface water temperature (Kieltyka 1987). In these cases, clouds form as a result of the unstable lapse rates over the lake. A circulation develops in the clouds, and spins down as a "cold air funnel" and/or waterspout.

This theory evolved, at least in part, as an outgrowth of the theories associated with supercell/mesocyclone related vortices that occur more commonly in the spring and early summer months. Tornadoes (or intense convection in general), according to classical theory, require, in addition to a convectively unstable airmass, most (if not all) of the following pre-cursor atmospheric conditions (summarized from Fawbush et al. 1951; and Kessler 1985):

1) A synoptic scale disturbance (e.g., a strong upper-level short wave);
2) Increasing speed and veering of the wind with height;
3) A low level jet. This can serve to advect low level moisture into the area, enhance warm advection at low levels (both decreasing atmospheric stability), and provide a more favorable wind profile (item 2);
4) A mid-level dry intrusion;
5) A surface boundary, or other source of lift.

The atmospheric conditions over Lake Erie during the series of waterspouts in the period of July 25-28 consisted of:

1) A broad upper-level cyclonic flow over the Great Lakes region with only weak short waves;
2) Weak and disorganized speed and directional wind shear;
3) No low level jet;
4) No mid-level dry intrusion;
5) A significant surface boundary;

In addition to conditional instability, only one of the pre-storm conditions existed. A surface boundary was evident over northern Ohio and Lake Erie during the waterspout events. Consequently, it appears quite evident that these waterspouts did not form in an environment conducive to mesocyclone development.

The one pre-storm condition that was met, a surface boundary, was a direct result of the diurnally induced temperature and weak pressure gradients that occurred during this period. The resultant land breeze created a mesoscale convergence boundary each of the four mornings along the south shore of Lake Erie (Figures 5a-d). The strongest land breeze boundaries developed on July 25$^{th}$ and 28$^{th}$. Note, all but one of the waterspouts occurred on these two mornings. The boundary was much weaker and not as extensive on July 26$^{th}$ and 27$^{th}$. The lake breeze boundary provided mechanical lift, which, in conjunction with the conditionally unstable atmosphere, spawned lines of cumulus clouds (Figures 6a-d).

Along any type of convergent boundary (synoptic, mesoscale, or microscale) there exists an unknown number of vortices. These vortices are typically a result of horizontal wind shears across the boundary, although they can also be enhanced by buildings, variable terrain, or other surface features (e.g., a land/sea interface) whose varying frictional properties can disturb the boundary layer flow. As described in Wakimoto and Wilson (1989), the life cycle of the non-supercell tornado is proposed to develop from surface vortices that become superimposed underneath an updraft. The updraft acts on the vortex, stretching it vertically (Figure 7). This is similar to the spin-up that occurs when a spinning ice skater pulls in his/her arms.

As the surface based circulation rises, the vortex air cools adiabatically. However, if there is a large surface dew point depression, the condensation funnel might not be seen until the rotation nears, or reaches the cloud base. In addition, over water, there is a lack of loose debris, which usually would enable a person to view the circulation at low levels. This might give an observer the impression that a funnel cloud has formed and extended down from the base of a cumulus cloud. However, one current theory suggests that one type of vortex actually spins-up from the boundary layer to the cloud base, as presented in the conceptual models in Wakimoto and Wilson (1989), and Brady and Szoke (1989). Additional evidence that most waterspouts evolve in this manner is the observation by Golden (1974a) of a "dark spot" on the ocean surface before the appearance of a visible funnel.

Hence, it appears the surface boundary provided the focus for the development of the waterspouts on July 25-28, 1991. However, the modification of the boundary layer from Lake Erie's heat and moisture was another key ingredient. For example, if the mechanical lift supplied by the boundary was applied to the atmosphere over land, the large dew point depression and cold surface temperatures would inhibit the development of a sustained updraft. Therefore, the addition of the heat and moisture from Lake Erie was necessary to create a conditionally unstable low level sounding that allowed the mechanical forcing to initiate a sustained updraft. Figure 8 depicts the modified temperature and moisture profile over Lake Erie on July 28. This modified sounding indicated that cloud bases would be around 3500 feet, with tops around 10,000 feet. These values were close to the observed conditions.

## 4. SUMMARY

From July 25-28, 1991, 15 waterspouts were reported on Lake Erie, primarily occurring during the morning hours. All of the waterspouts formed along a surface boundary along the south shore of Lake Erie. This boundary developed in response to a large lake-land temperature, and weak pressure gradients that maximized around sunrise. Apparently, surface-based vortices developed along the boundary, some of which became collocated with an updraft. The updraft likely vertically stretched the vortices, intensifying the circulation as it spun up to the cloud base. As this ascending circulation approached the lifted condensation level, the associated adiabatic cooling resulted in a visible condensation funnel just below cloud base. Occasionally, this visible funnel is reported as a cold air funnel, when it is actually a waterspout that originated at the water surface. A remaining question is: What mesoscale processes caused these surface-based vortices to form at particular locations along the boundary? Hopefully, Doppler radar observations, as well as additional modeling experiments, will yield further understanding of Great Lakes waterspout formation in the near future.

## 5. REFERENCES


Bluestein, H. B., 1985: The formation of a "landspout" in a "broken-line" squall line in Oklahoma. Preprints, 14th Conference on Severe Local Storms, Amer. Meteor. Soc., Indianapolis, 267-270.

Brady, R. H., and E. J. Szoke, 1989: A case study of non-mesocyclone tornado development in Northeast Colorado: Similarities to waterspout formation. Mon. Wea. Rev., 117, 843-856.

Fawbush, E. J., R. C. Miller, and L. G. Starrett, 1951: An empirical method of forecasting tornado development. Bull. Amer. Meteor. Soc., 32, 1-9.

Golden, J. H., 1974a: The life cycle of Florida Keys' waterspouts. I. J. Appl. Meteor., 13, 676-692.

Golden, J. H., 1974b: Scale-interactions implications for the waterspout life cycle. II. J. Appl. Meteor, 13, 693-709.

Kessler, E., 1985: Severe weather. Handbook of Applied Meteorology, D.D. Houghton Ed., John Wiley & Sons, New York, 133-204.

Kieltyka, F., 1987: Cold air waterspouts over Lake Erie. Eastern Region Technical Attachment 87-9, NOAA/NWS, Bohemia, NY, 3 pp.

Naglic, S. J., 1991: Forecasting the lake breeze at Cleveland Hopkins International Airport. Eastern Region Technical Attachment 91-10B, NOAA/NWS, Bohemia, NY, 7 pp.

Wakimoto, R.M., and J. W. Wilson, 1989: Non-supercell tornadoes. Mon. Wea. Rev., 117, 1113-1140.

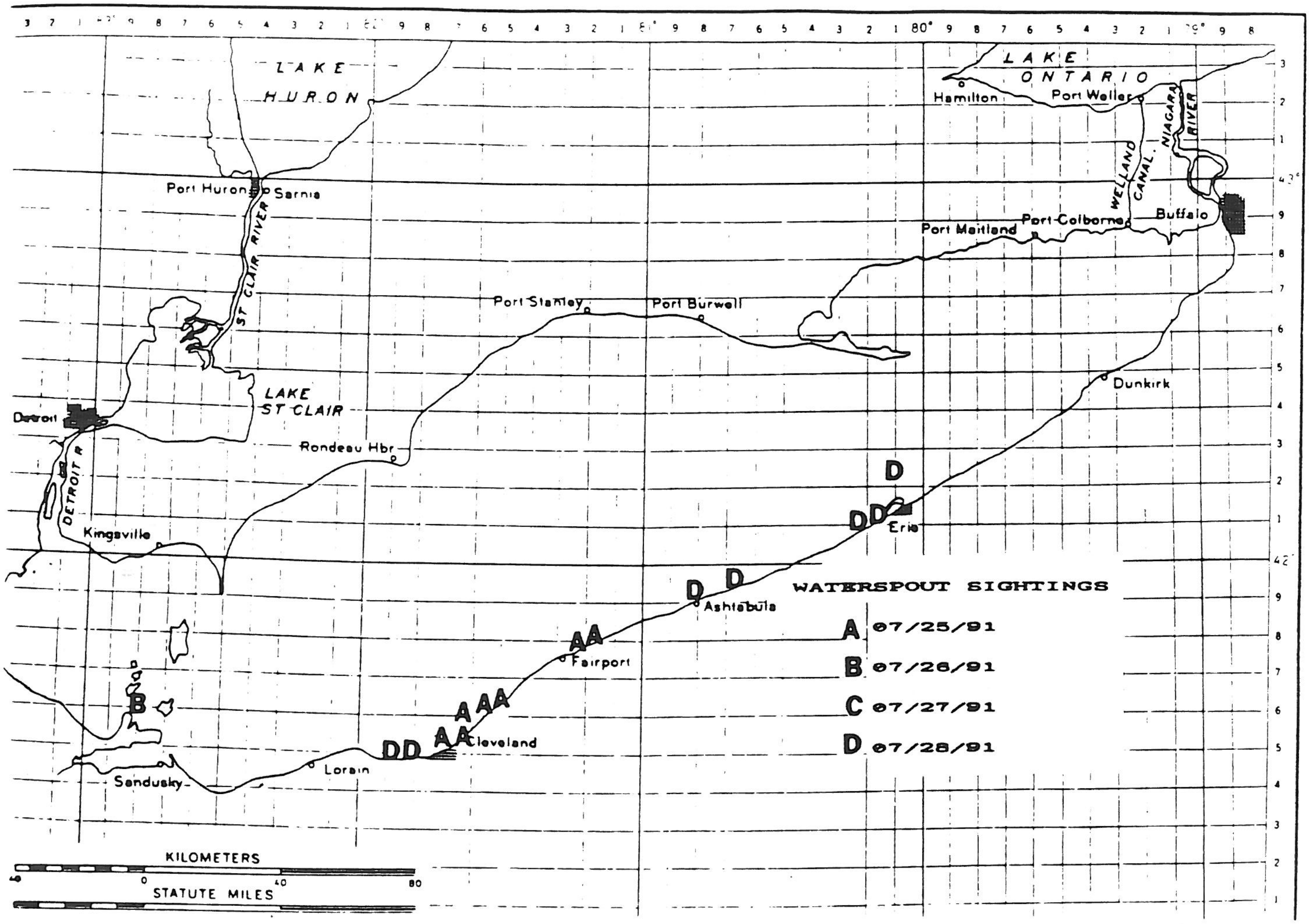



**Figure 1.** Waterspout sightings in Lake Erie July 25-28, 1991.

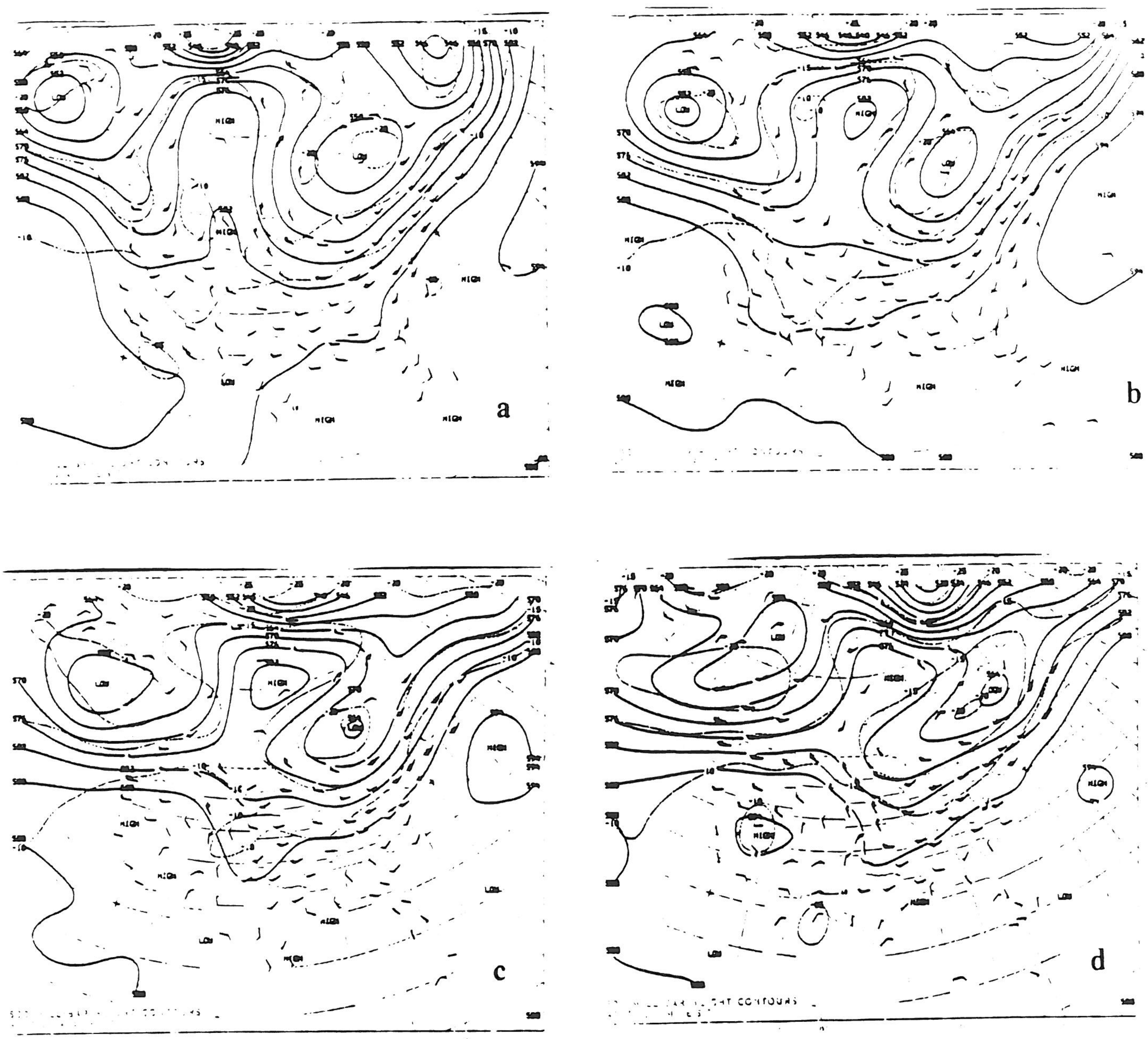



**Figure 2.** 500 mb analysis for: a) 1200 UTC July 25, 1991; b) 1200 UTC July 26, 1991; c) 1200 UTC July 27, 1991; and d) 1200 UTC July 28, 1991.

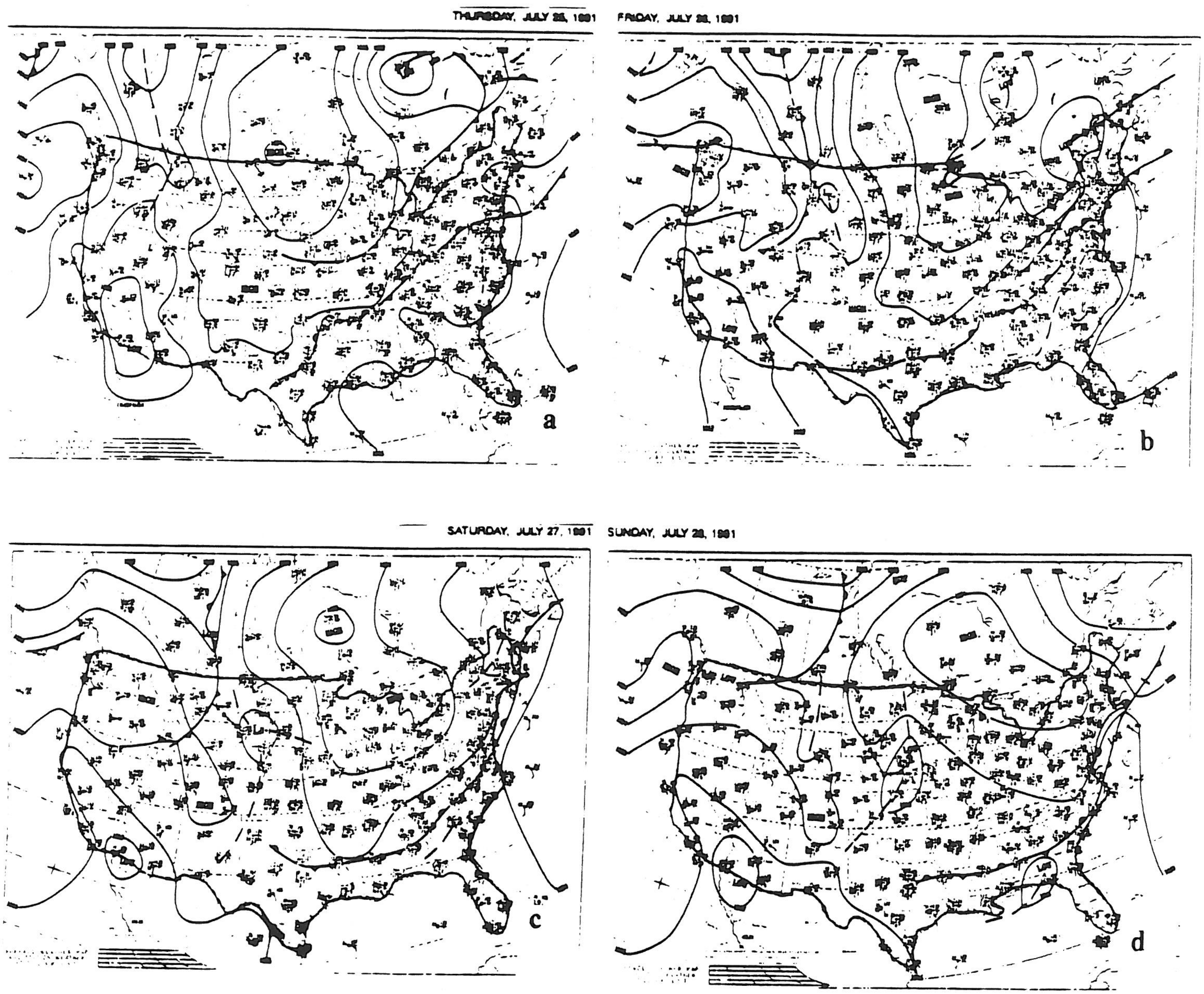
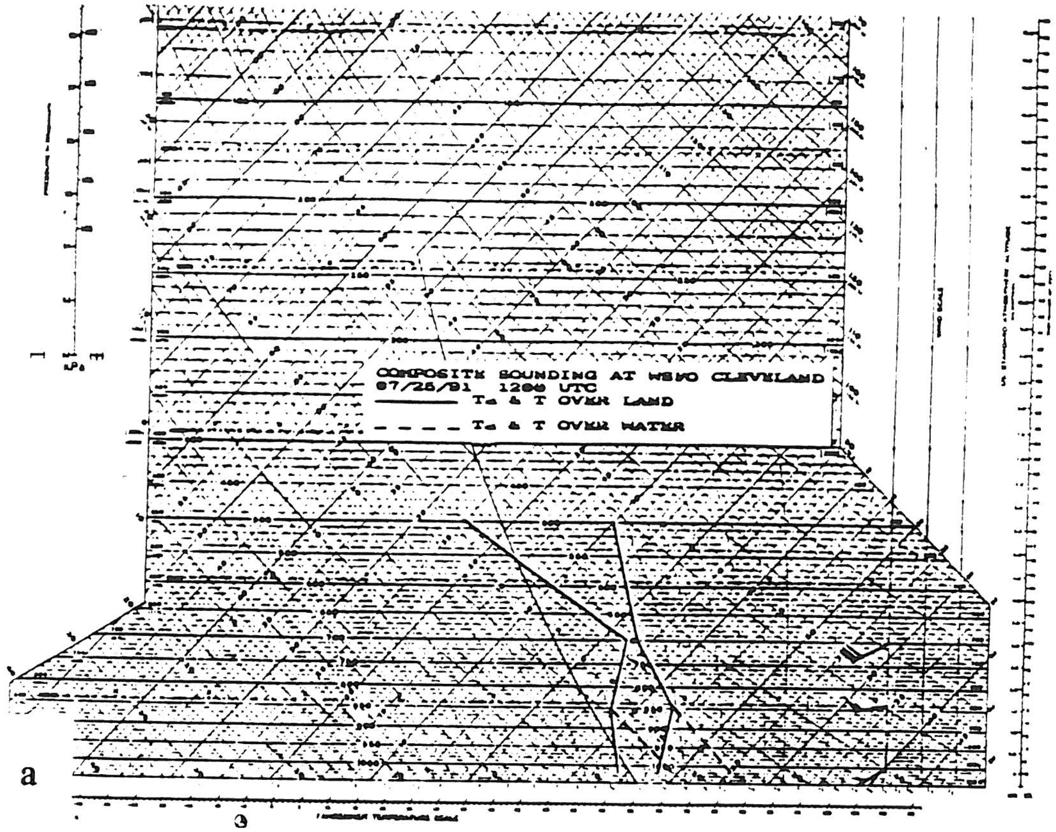
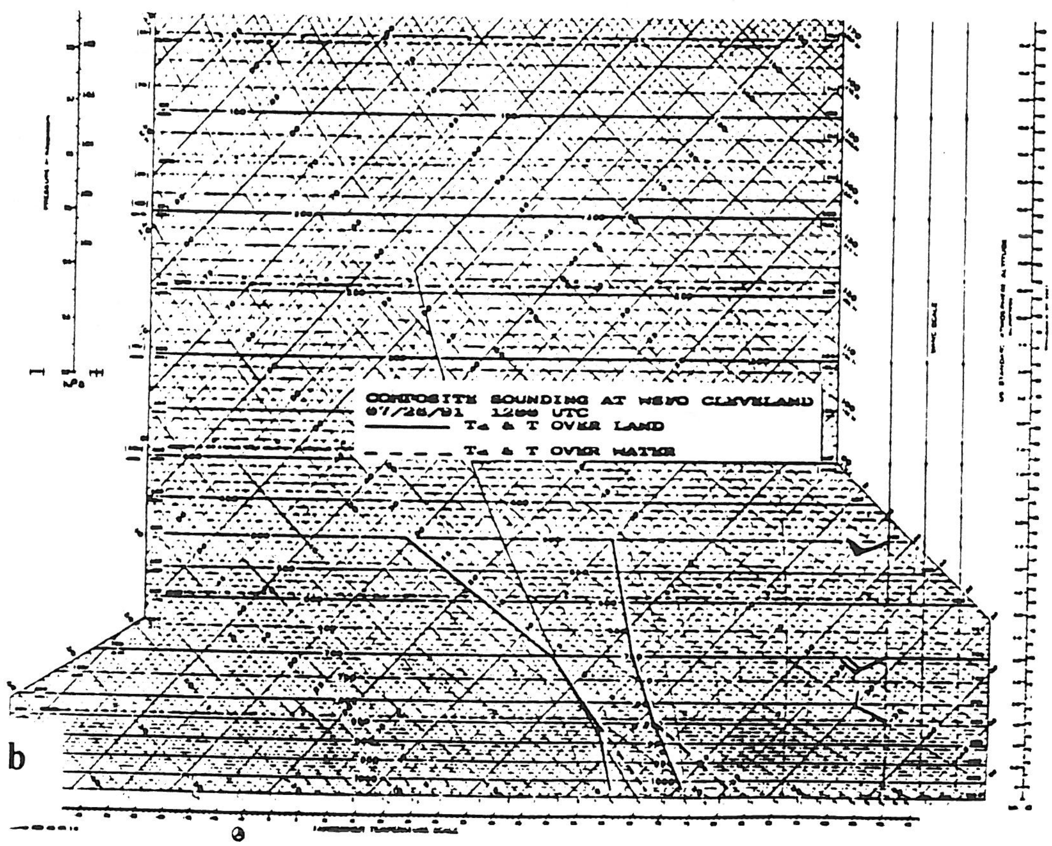



**Figure 3.** Surface analysis for: a) 1200 UTC July 25, 1991; b) 1200 UTC July 26, 1991; c) 1200 UTC July 27, 1991; and d) 1200 UTC July 28, 1991.

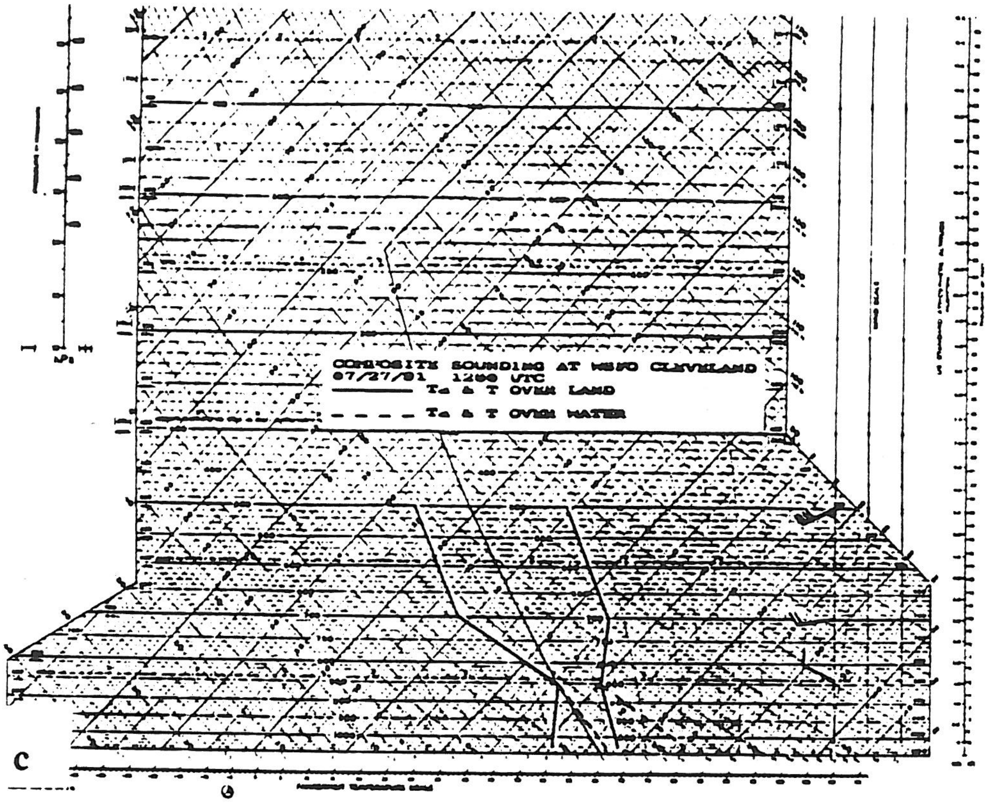



a



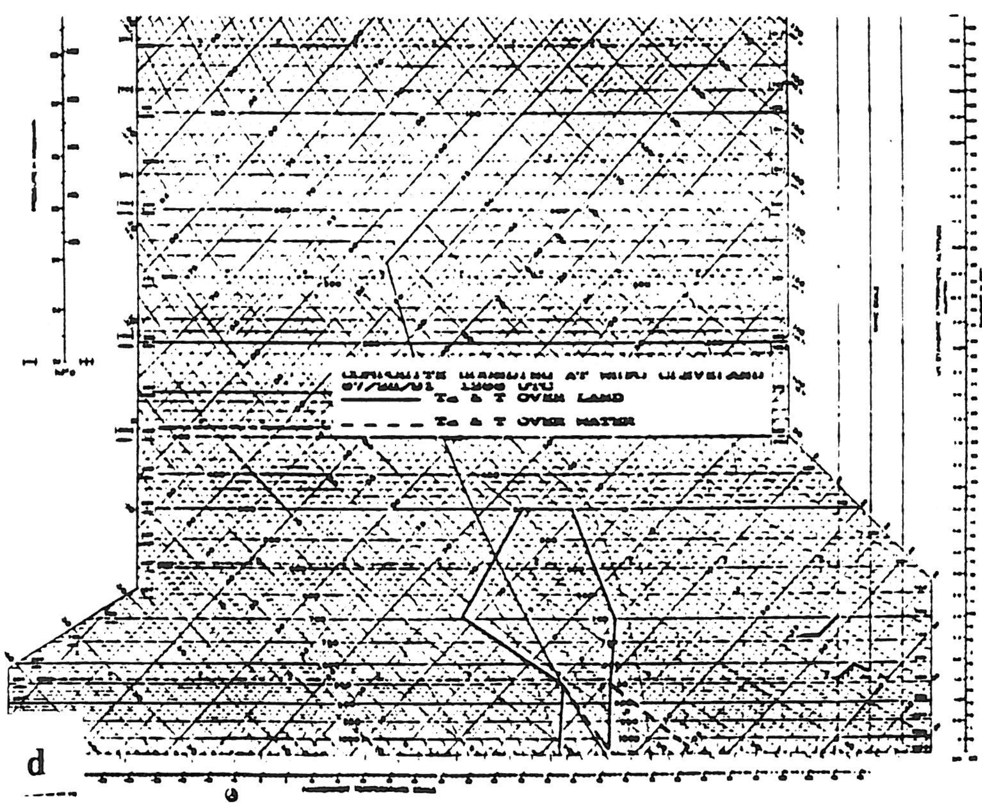

b

**Figure 4.** Composite sounding at Cleveland for: a) 1200 UTC July 25, 1991; b) 1200 UTC July 26, 1991; c) 1200 UTC July 27, 1991; and d) 1200 UTC July 28, 1991.



COMPOSITE SOUNDING AT WSFO CLEVELAND
07/27/81 1200 UTC
Td & T OVER LAND
Td & T OVER WATER


c



AT
Td & T OVER LAND
Td & T OVER WATER


d

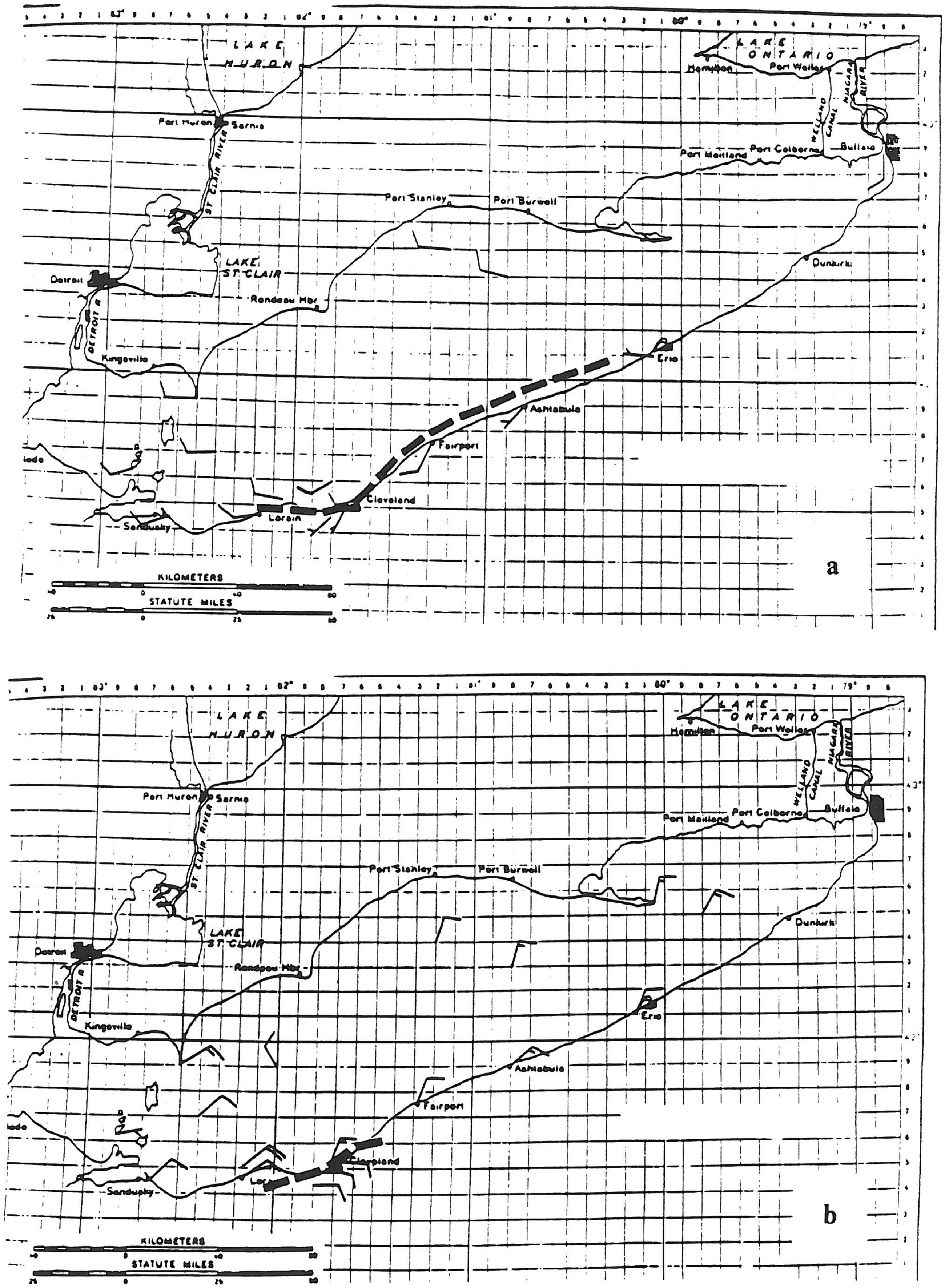



**Figure 5.** Surface wind plot for: a) 1200 UTC July 25, 1991; b) 1200 UTC July 26, 1991; c) 1200 UTC July 27, 1991; and d) 1200 UTC July 28, 1991.

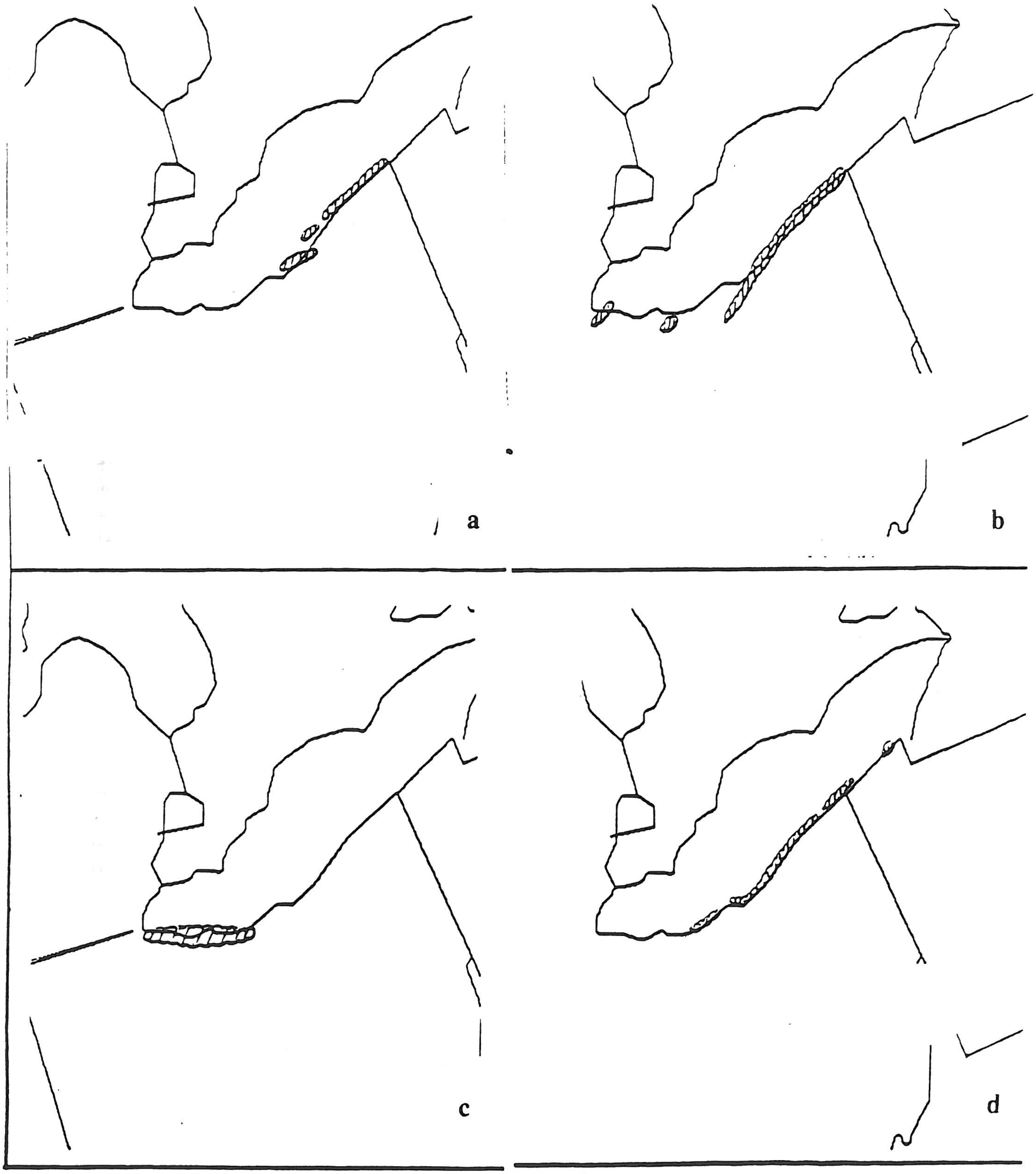
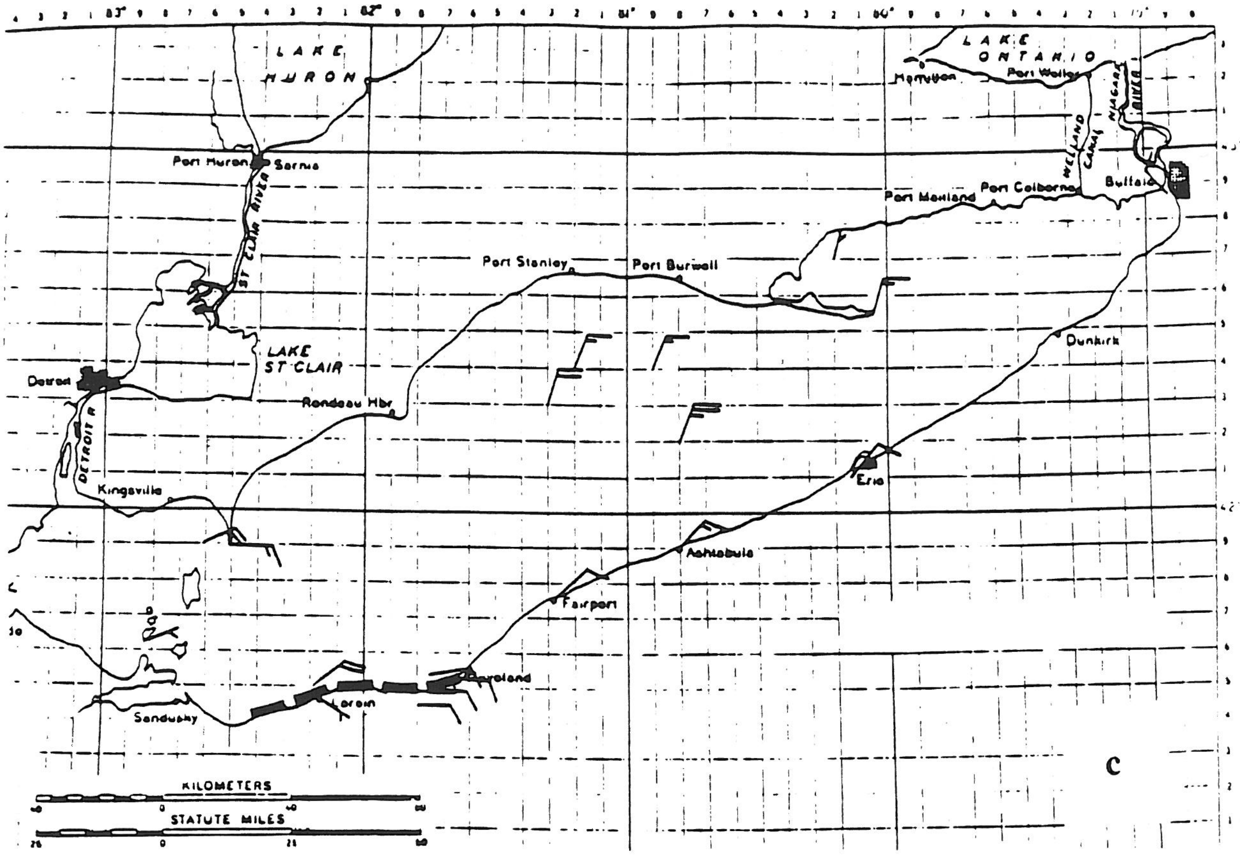
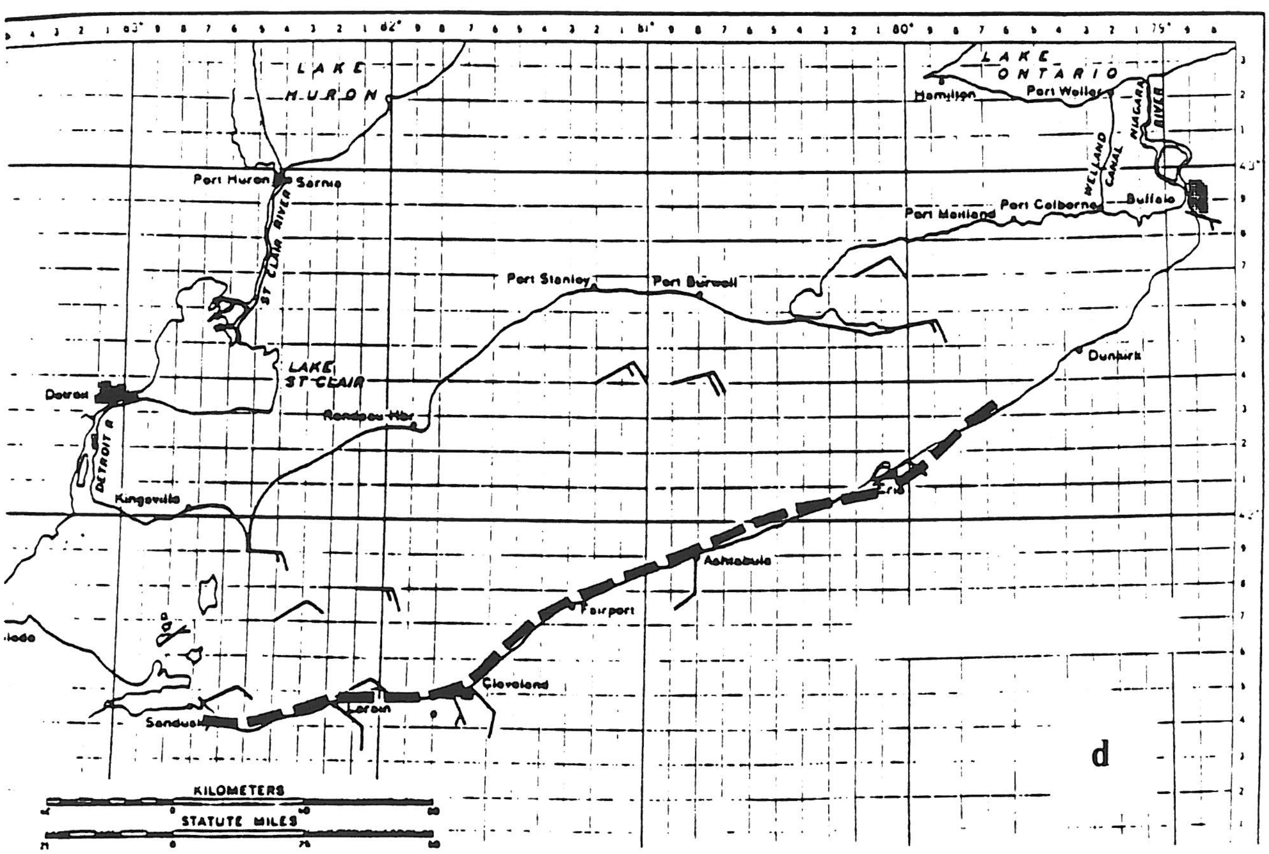



**Figure 6.** Cumulus bands apparent from satellite imagery for: a) 1200 UTC July 25, 1991; b) 1200 UTC July 26, 1991; c) 1200 UTC July 27, 1991; and d) 1200 UTC July 28, 1991.


LAKE HURON
LAKE ONTARIO
Hamilton
Port Weller
WELLAND CANAL
NIAGARA RIVER
Port Huron
Sarnia
ST CLAIR RIVER
Buffalo
Port Colborne
Port Maitland
Port Stanley
Port Burwell
LAKE ST CLAIR
Dunkirk
Detroit
Rondeau Hbr
DETROIT R
Erie
Kingsville
Ashtabula
Fairport
Cleveland
Sandusky
Lorain
KILOMETERS
STATUTE MILES

c


LAKE HURON
LAKE ONTARIO
Hamilton
Port Weller
WELLAND CANAL
NIAGARA RIVER
Port Huron
Sarnia
ST CLAIR RIVER
Buffalo
Port Colborne
Port Maitland
Port Stanley
Port Burwell
LAKE ST CLAIR
Dunkirk
Detroit
Rondeau Hbr
DETROIT R
Erie
Kingsville
Ashtabula
Fairport
Cleveland
Sandusky
Lorain
KILOMETERS
STATUTE MILES

d

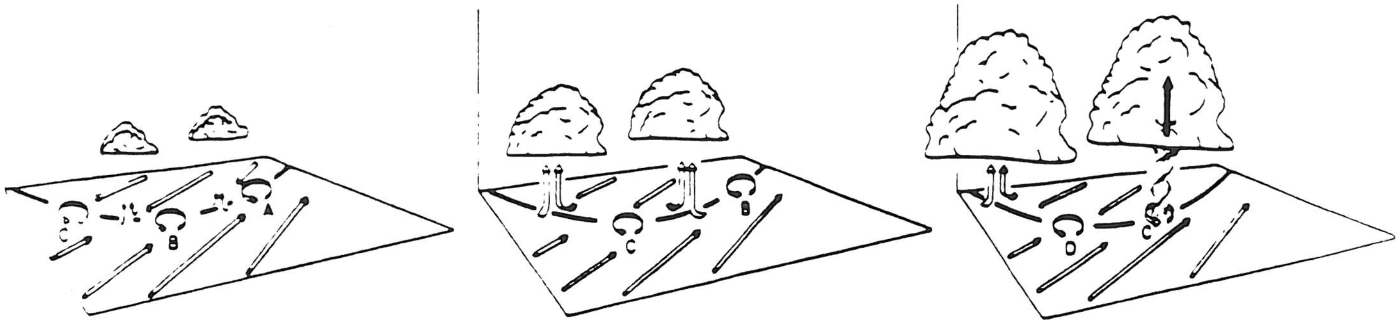


Figure 7. Development of waterspout from surface boundary (from Wakimoto and Wilson 1989).

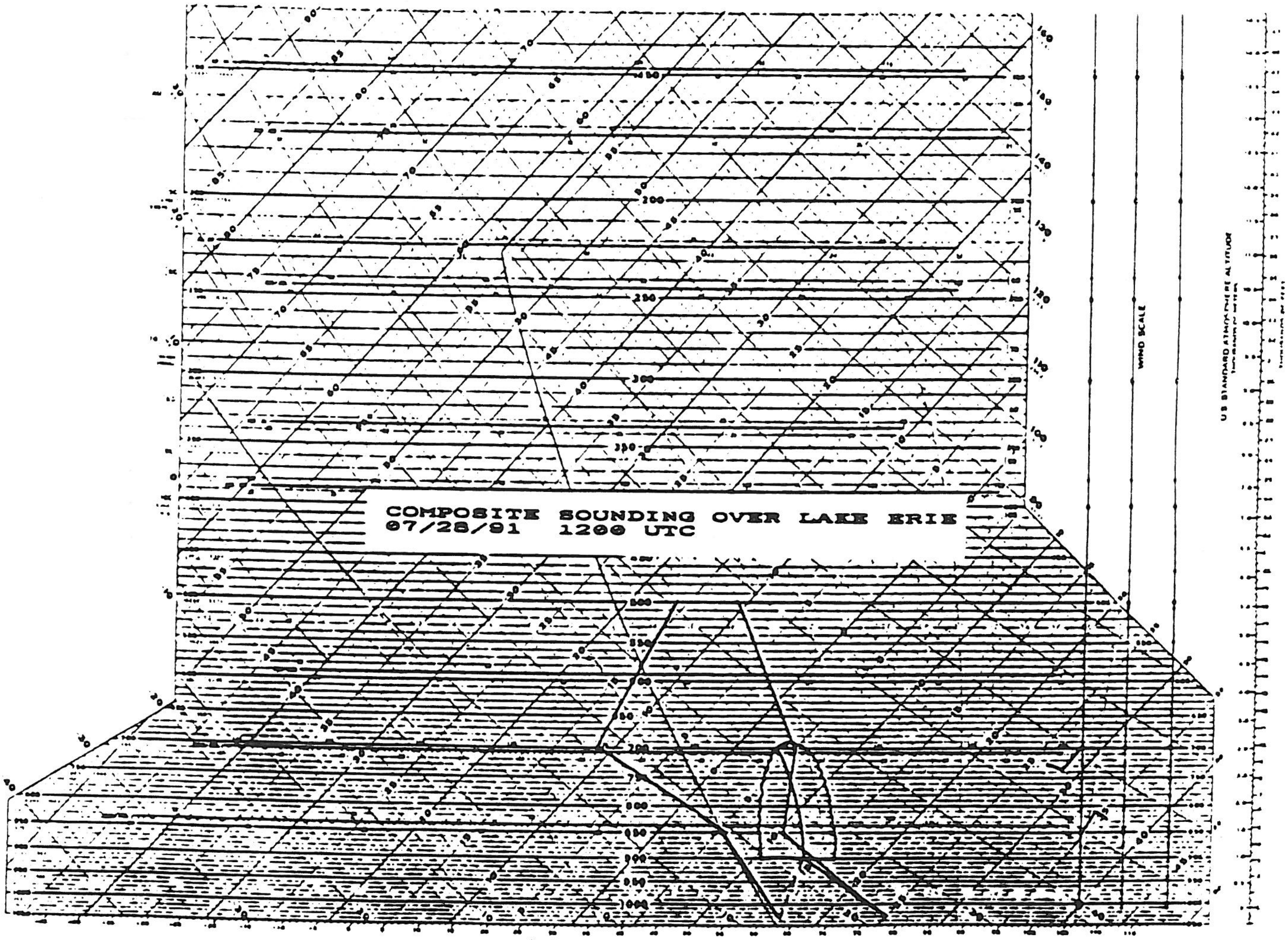



**Figure 8.** Composite sounding over Lake Erie for 1200 UTC July 28, 1991 indicating lifted condensation level and cloud depth.