P3.10

MULTI-DIMENSIONAL ANALYSIS OF AN EXTREME THUNDERSNOW EVENT DURING THE 30 DECEMBER 2000 SNOWSTORM

Neil A. Stuart*
NOAA/National Weather Service
Wakefield, VA

1. INTRODUCTION

Thundersnow is a relatively rare phenomenon that produces unusually heavy rates of snowfall. Forecasting thundersnow requires a significant increase in the amount of snow forecast and also requires crucial amendments to aviation forecasts. Lead times for forecasting thundersnow can vary greatly, but most often are twelve hours or less.

On 30 December 2000, a significant snowstorm formed off the mid-Atlantic Coast, and tracked into the northeastern U.S. Careful evaluation of satellite, radar, upper air and lightning data provided six to twelve hours of lead time for forecasting thundersnow in the northeastern U.S., where over two feet of snow fell locally. Some locations received two distinct periods of thundersnow.

2. EVOLUTION OF UPPER AIR AND LOW-LEVEL FEATURES

At 1200 UTC 28 December, water vapor imagery (6.7µm) depicted a strong upper low in the U.S. Northern Plains tracking southeast toward the Great Lakes and Ohio Valley. By 1200 UTC 29 December, an upper impulse was tracking south into North Dakota within the geostrophic flow around the upper low, which was centered along the Iowa/Illinois border (Fig. 1). This impulse played a critical role in the evolution of the storm that produced the thundersnow.

The upper impulse and 300-hPa jet streak tracked around the southern periphery of the upper low, into the Tennessee Valley through 29 December. Meanwhile, a strong southern stream upper level impulse tracked rapidly east along the northern Gulf of Mexico on 28-29 December. An 850-hPa low pressure center began to develop by 0000 UTC 30 December over the interior Carolinas (Fig. 2), in response to the low-level convergence associated with the thermally indirect circulation at the left exit region of the upper jet streak (Bluestein 1993).

The well-defined northern stream upper impulse tracked from the Tennessee Valley to the mid-Atlantic U.S. by 1200 UTC 30 December. The associated low-level thermal and moisture advection and convergence supported rapid surface cyclogenesis off the mid-Atlantic coast through 30 December.

By 0600 UTC 30 December, deep thermal and moisture advection was apparent in water vapor and infrared satellite imagery as an axis of enhanced cloudiness off the east coast, surging from south to north. At 0000 UTC 30 December, upper air analyses

***Corresponding Author Address:** Neil A. Stuart, NWS 10009 General Mahone Hwy, Wakefield, VA 23888
E-mail: Neil.Stuart@noaa.gov

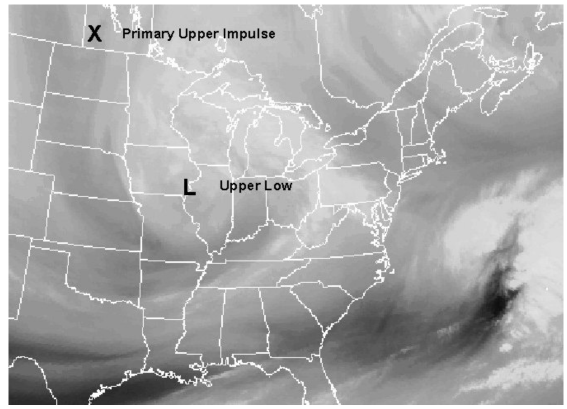

Figure 1. GOES-8 Water Vapor Channel (6.7µm) imagery for 1200 UTC 29 December 2000.

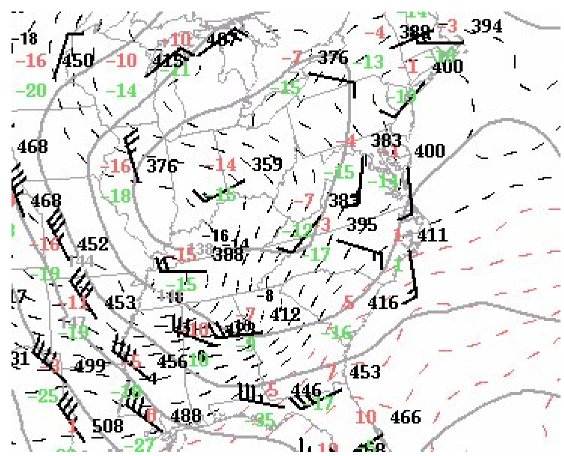

Figure 2. 0000 UTC 30 December 2000 850-hPa plot, with height contours (solid) and temperatures (dashed).

depicted the exit region of a strong 300-hPa jet segment in the Carolinas, associated with an area of increasing upper-level divergence (Fig. 3). This upper jet segment and increasing upper level divergence was likely increasing the low-level thermal and moisture advection associated with the thermally indirect circulation (Uccellini and Kocin 1987). By 0600 UTC, mesoscale waves were present within the axis of deep cloudiness offshore, suggesting significant turbulence and a strengthening upper jet (Bader et al. 1995).These mesoscale wave disturbances were also consistent with research by Uccellini and Koch (1987)

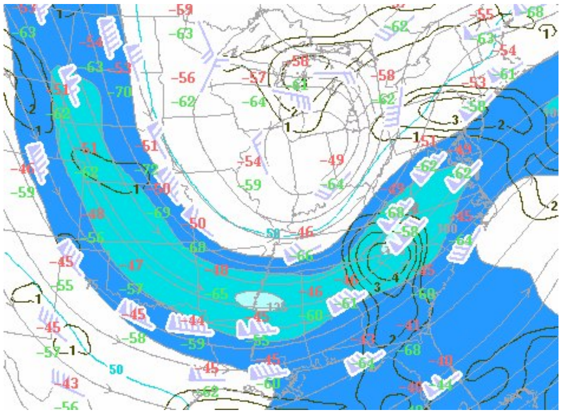

Figure 3. 0000 UTC 30 December 2000 300-hPa plot with height contours (solid gray), wind barbs (Knots), and divergence (black contours).

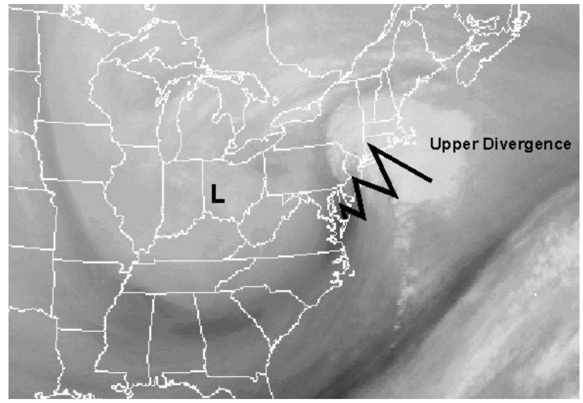

Figure 4. GOES-8 Water Vapor (6.7μm) imagery from 1200 UTC 30 December 2000.

occurring in the left exit region of the upper jet, just upstream of the upper ridge axis, and bounded by the jet axis to the northwest. Since the jet was evolving and expanding between 0000 UTC and 1200 UTC 30 December, there may have been considerable geostrophic adjustment occurring, which Uccellini and Koch (1987) suggest may be a mechanism for production and maintenance of mesoscale wave disturbances. Mesoscale disturbances enhance upward vertical motions, leading to better potential for convection (Uccellini and Koch 1987).

The enhanced cloudiness expanded significantly into New England by 1200 UTC 30 December (Fig. 4), in response to increased upper divergence. The mesoscale waves and turbulence were still apparent, and extended south, to the ocean off the Carolinas. A well defined upper deformation zone was forming over New Jersey, as an enhanced region of subsidence associated with the upper jet streak was depicted in water vapor imagery. The 850-hPa low pressure center was rapidly developing over the northern Chesapeake Bay, and the surface low pressure center strengthened as it tracked east of Delaware between 0000 UTC and 1200 UTC 30 December.

By 1600-1800 UTC 30 December, water vapor imagery depicted a very strong upper jet and center of upper level subsidence over Long Island, New York. Infrared and visible imagery showed a classic comma feature with the upper deformation zone in southeastern New York and northern New Jersey (Fig. 5). Visible imagery also depicted mesoscale waves and turbulence wrapping into the storm through southeastern New York and northern New Jersey.

3. RADAR AND LIGHTNING ANALYSES

Precipitation developed around Hampton Roads, Virginia and into the DELMARVA shortly after 0000 UTC December 30. Light freezing rain was reported from Norfolk to Wallops Island and Ocean City.

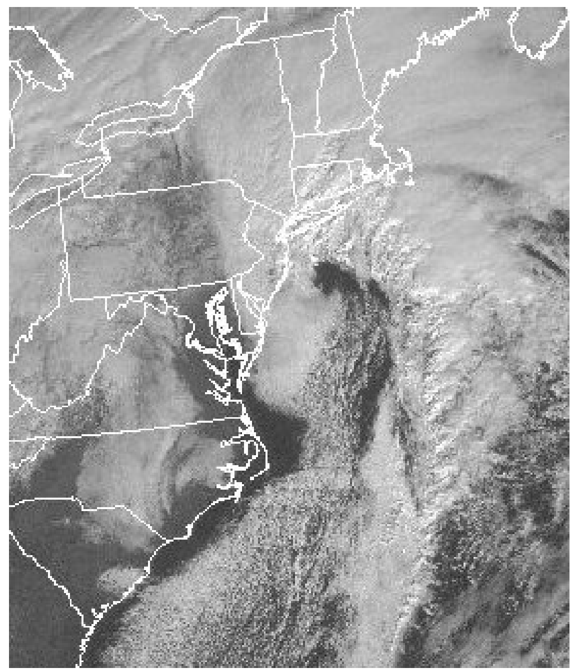

Figure 5. GOES-8 Visible imagery from 1545 UTC 30 December 2000.

Convection developed over the offshore waters off the Carolinas before 0500 UTC 30 December, as cloud-to-ground lightning strikes were being detected on the National Lightning Detection Network (Fig. 6). However, the thunderstorms were out of range of east coast radars. The convection was associated with the mesoscale waves seen in satellite pictures.

Between 1200 and 1600 UTC 30 December, heavy snow spread into New Jersey, New York and New England. Base reflectivities peaked as high as 45 dBZ and the mesoscale waves were being entrained into the system, tracking northwest, into northern New Jersey and southeastern New York (Fig. 7). At 1700 UTC 30 December, the Upton, New York radar (OKX) base velocity depicted an inbound southeasterly low level jet around 50 knots, and an outbound maximum near 50 knots from the northeast, illustrating the strong cyclonic curvature of the low-level flow around the low pressure center.

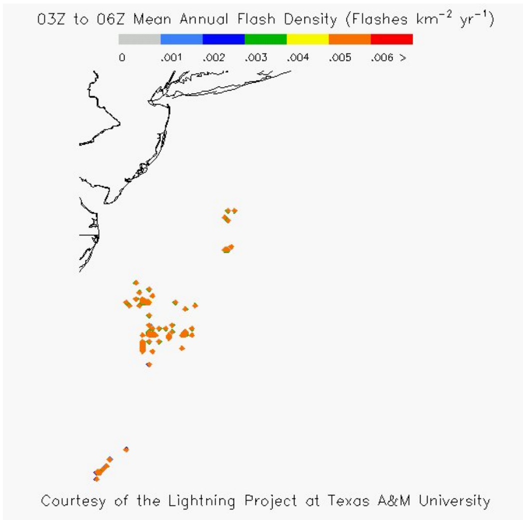

Figure 6. Cloud-to-ground lightning flash density (km^{-2}yr^{-1}) 0300 UTC through 0600 UTC 30 December.

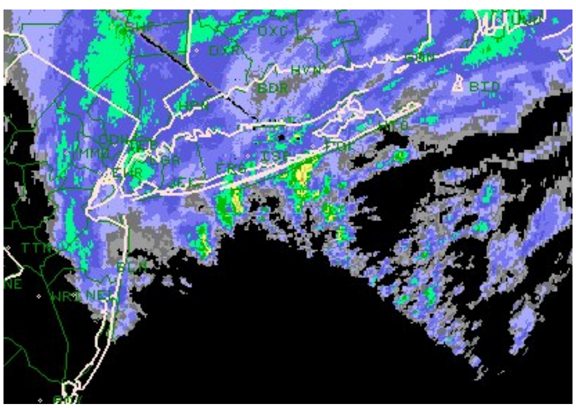

Figure 7. 1700 UTC 30 December Upton, New York WSR-88D (OKX) 0.5° base reflectivity. Peak reflectivity 50-55 dBZ just south of Long Island, New York.

4. VERTICAL THERMODYNAMIC PROFILES OF THE ATMOSPHERE

When convection formed offshore North Carolina and Virginia after 0000 UTC 30 December, the instability and moisture was not resolved within the upper air network. However, low-level winds turned to the south and southwest by 0000 UTC 30 December at WAL, MHX and GSO, but there was very little moisture available to advect north along the coast. Most of the deep moisture was being directed offshore, as seen in satellite and radar imagery. By 1200 UTC 30 December, the thermodynamic profile from OKX showed the entire depth of the atmosphere was below freezing, directional warm advection was occurring, and the atmosphere was nearly saturated through a deep layer.

Between 1700 and 1800 UTC 30 December, the OKX upper air site was in the region of the mesoscale waves (based on radar and satellite imagery), and produced the thermodynamic profile seen in Figure 8. At this time, the OKX upper air site was just northeast of the cloud-free low-level center of the storm, and proximate (Brooks et al. 1994) to ongoing thunder and cloud-to-ground lightning (Fig. 9).

One notable aspect of this sounding is the vertical wind profile. Northeast surface winds veer sharply through 850-hPa, and increase to over 50 knots. The sounding was also nearly saturated below 800-hPa. This confirms the strong low level thermal and moisture advection associated with the thermally indirect circulation of the upper jet, that previously was occurring over the ocean, outside of the upper air network. The south winds at 50 knots extended up to around 600-hPa, then increased and trended southwest through 200-hPa.

Another notable aspect of the sounding is the low-level inversion that was present. The inversion was shallow, and not very strong, but is consistent with research by Uccellini and Koch (1987), supportive of mesoscale wave disturbances.

The most notable aspect of this sounding is the convective instability above 830-hPa. After the virtual temperature correction (Doswell and Rasmussen 1994), 51 J/Kg of positive Convective Available Potential Energy (CAPE) was calculated between 830 and 610-hPa. The entire temperature profile between the surface and 610 hPa was below freezing and nearly saturated, hence, elevated upright convective snow was possible over southern New York, confirmed by the radar data (not shown).

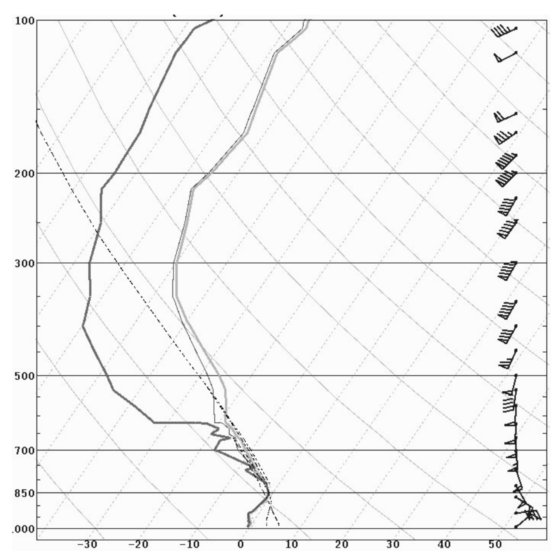

Figure 8. 1800 UTC 30 December Upton, New York upper air sounding (OKX), analyzed in N-SHARP.

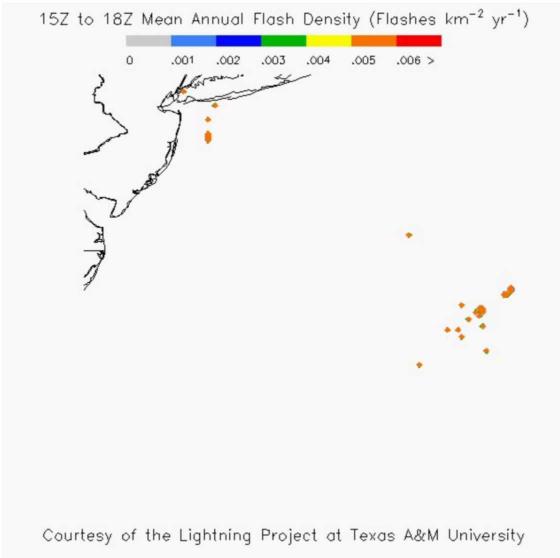

Figure 9. Cloud-to-ground lightning flash density (km^{-2}yr^{-1}) 1500 UTC through 1800 UTC 30 December.

5. SUMMARY

The thundersnow event of 30 December 2000 was very noteworthy, as many atmospheric processes worked together to support upright convective snow. However, the atmospheric conditions favoring convective snow were not resolved in the upper air network, so analysis of other data sources was necessary for anticipating the development of thundersnow.

A strong upper level jet streak tracked along the southern periphery of an upper low, and offshore the mid-Atlantic U.S. The thermally indirect circulation associated with the left exit region of the upper jet streak, aided in the development and strengthening of the low-level (850-hPa) jet off the east coast of the U.S. The relatively warm ocean temperatures (around 7°C near shore to >15°C offshore) aided in destabilizing the lower atmosphere, and mesoscale waves within the region of turbulence associated with the strengthening upper and low level jets, resulted in enhanced vertical motions over the ocean.

Convection developed over the ocean, further enhancing the upward vertical motion off the east coast, and aiding in surface cyclogenesis (Bluestein 1993). The surface low pressure center, in association with the strong southerly low-level jet, enhanced the low-level thermal and moisture advection into southeastern New York and northern New Jersey. The mesoscale waves and convection were also advected into the region. An observed radiosonde thermodynamic profile from the Upton, NY upper air station at 1800 UTC 30 December, was completely below freezing, and showed positive Convective Available Potential Energy between 830-hPa and 610-hPa.

Since the surface low pressure and convection developed over the ocean, atmospheric conditions supportive for thundersnow were not apparent in upper air or surface data until the thundersnow was occurring. Satellite, radar and lightning data provided important information that showed the development of convection up to twelve hours before thundersnow was observed.

Please refer to the following website for more images and analysis: http://www.nws.noaa.gov/er/akq/tsnowcase.html

ACKNOWLEDGMENTS

Thanks go to Roger Edwards of the Storm Prediction Center for the OKX N-SHARP sounding and analysis. Thanks also go to Dr. Richard Orville and Brandon Ely of Texas A and M University for the lightning plots.

REFERENCES

References are available upon request.