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A Multi-scale Analysis of the End of the Millennium Snowstorm

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1. Introduction

On 30-31 December 2000, a major snowstorm struck the Northeast, dropping copious amounts of snowfall over the region. This major nor'easter produced widespread snowfall accumulations of 25 cm (10 inches) and greater across eastern New York, New Jersey, the extreme eastern portion of Pennsylvania and adjacent New England in 10 to 15 hours. Portions of the eastern Catskill Mountains in New York, and northern New Jersey received 50 to 75 cm (20 to 30 inches) of snow from the storm with many daily snowfall records set across the Northeast.

Although, little or no snow fell across most of Pennsylvania, Delaware and Maryland (including Washington D.C.), major cities such as Trenton, Newark, New York City, Albany and Hartford were hit very hard. Snowfall rates of 5 cm to 7.5 cm (2 to 3 inches) per hour were common with the storm due to an intense mesoscale snow band located north and west of the area of low pressure. Near-blizzard conditions occurred at times with high winds in excess of 15 to 20 ms^{-1} (30 to 40 kt). The storm wreaked havoc on travelers on the last weekend before the dawn of a new millennium.

This poster will focus on an investigation of the evolution of the large-scale pattern associated with the snowstorm. The storm will be examined from a potential vorticity (PV) perspective, including a comprehensive analysis of dynamic tropopause (DT) maps. Additionally, the role of upper and lower level jet streaks will be investigated. The planetary scale teleconnection indices will be examined before, during and after the storm [e.g., North American Oscillation (NAO), Pacific North American (PNA) indices].

2. Data and Methodology

Data used in this analysis include 1° x 1° Aviation (AVN) model grids that were used to calculate potential temperature and winds on the DT. The DT maps will be utilized to diagnose the evolution of the disturbance/PV anomaly that caused the rapid surface cyclogenesis near the Delmarva Peninsula. The system evolution will also be examined from a quasi-geostrophic perspective via traditional synoptic maps. These two different ways of examining system evolution will be discussed.

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3. Teleconnection Indices

The predominant large-scale indices for the month of December were negative NAO and positive PNA (Table 1). The continental US was predominantly influenced by a 500 hPa ridge over the west coast and a trough over the east coast, including the Northeast during the month. The 500 hPa westerlies were weaker than normal over the Atlantic (less zonal flow) with negative NAO. The end of the millennium storm developed in an amplified positive PNA and marginally negative NAO large-scale environment. Daily values of these teleconnection indices indicated that the NAO was predominantly negative the week prior to the storm, and rapidly trended towards zero during the evolution of the event, while the PNA remained positive throughout.

Table 1: Monthly NAO and PNA values for September 2000 to January 2001 (http://www.cpc.noaa.gov)

Month	NAO	PNA
SEP	0.8	-0.2
OCT	1.1	-1.1
NOV	-0.7	0.6
DEC	-0.6	1.1
JAN	0.7	0.9

4. Synoptic Analysis

The synoptic situation at 0000Z/30 December 2000 (0000Z/30) featured an area of low pressure (1012 hPa) moving eastward through eastern Ohio

(Fig. 1), while a second weak surface low (1012 hPa) was situated 250-300 km (400-500 mi) southeast of North Carolina (visible in Fig. 2b, not indicated on Fig. 1). By 0600Z/30, a new coastal low (1004 hPa) had formed (much further north than anticipated by forecasters) near the Delmarva Peninsula. By 1200Z/30, the coastal low was about 200 km (325 mi) southeast of southern New Jersey, while the weakening primary low was situated south of Lake Erie. Heavy snow began falling across most of northern New Jersey and the New York City metropolitan area by 1200Z/30. By 1500Z/30, heavy snow was falling along the east facing slopes of the Catskills and was pushing rapidly north into east central New York and western New England. The coastal surface low (995 hPa) moved over New York City by 1800Z/30 and then progressed rapidly to the northeast to the Connecticut-Rhode Island border (992 hPa) at 0000Z/31.

At 0000Z/30 December, a strong 500 hPa short wave moved southeastward from the Midwest into the Carolinas (Fig. 2a), while a shortwave ridge was located over southern New York and New England. The amplification of the massive mid-level ridge over the Rockies (consistent with positive PNA) helped cause this trough to dig further equatorward and develop a pronounced negative tilt. This feature is also visible on the DT as a cold PV anomaly (Fig. 3a) which is being advected towards the mid-Atlantic states by strong winds of over 50 m s^{-1} (100 kt).

The Northeast was located on the cyclonic shear side of a strong 250 hPa jet (Fig. 2b). A jet streak of greater than 70 m s^{-1} was moving northeast through North Carolina and Virginia (Uccellini and Kocin 1987; Kocin and Uccellini 1990). A tropopause fold was evident over the Tennessee Valley and the Southeast, where 300 and 305 K potential temperature (θ) values overlay 325 K θ values on the DT (Fig. 3a). Steep gradients of potential temperature indicate a sharply sloped tropopause and regions where jet streaks are located (Hoskins et al. 1985). Pronounced diffluence was present over New York, Pennsylvania and New England at 0000Z/30, as evidenced by 22.5 m s^{-1} (45 kt) southerlies over central Pennsylvania and over 50 m s^{-1} (100 kt) southwesterlies over Maryland and the Delmarva peninsula on the DT (Fig. 3a). Additionally, a nose of high equivalent potential temperature (θ_e) air at 850 hPa was nosing northward towards the Delmarva peninsula in the southwesterly flow ahead of the 850 hPa low at 0000Z/30 (Fig. 3b).

At 1200Z/30, the 500 hPa trough continued to exhibit a negative tilt as the shortwave ridge over the Gulf of Maine continued to amplify (Fig. 4a). This resulted in a tightening of the absolute vorticity gradient and an increase in cyclonic vorticity advection at 500 hPa over the Delmarva peninsula. Rapid surface cyclogenesis occurred at this time off the Delaware coast underneath this region of strong cyclonic vorticity advection aloft. Cyclogenesis was also aided by enhanced ascent under the cyclonic exit region of the 70 m s^{-1} upper-level jet streak (Fig. 4b). The jet exit region is visible as an area of weakening θ gradient and strongly diffluent winds on the DT (Fig. 5a). θ_e values of over 300 K at 850 hPa were being advected towards the mid-Atlantic coast and southern New England at 1200Z/30 (Fig. 5b). Potential temperatures on the DT were near 310K over New Jersey and off the mid-Atlantic coast. Thus, the cyclogenesis occurred in a region where the difference between the 850 hPa θ_e and the DT θ values was less than 10 K, indicative of weak static stability (Figs. 5 a, b; Bosart and Lackmann 1995). At this time, heavy snow was occurring over extreme northern New Jersey and the New York City metropolitan area.

5. Summary

A favorable large-scale pattern of negative NAO and positive PNA set the stage for the coastal cyclogenesis event on 30 December 2000. A potent mid- and upper-level jet streak (as seen on the DT) enhanced the explosive surface development and contributed to the heavy snowfall over the Northeast. Coastal cyclogenesis occurred in a region of weak static stability from 850 hPa to the DT, underneath a region of strong cyclonic vorticity advection aloft. Examination of this event via a combination of traditional synoptic and DT maps aided in the diagnosis of the important features involved in the evolution of the storm.

6. Acknowledgements

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7. References

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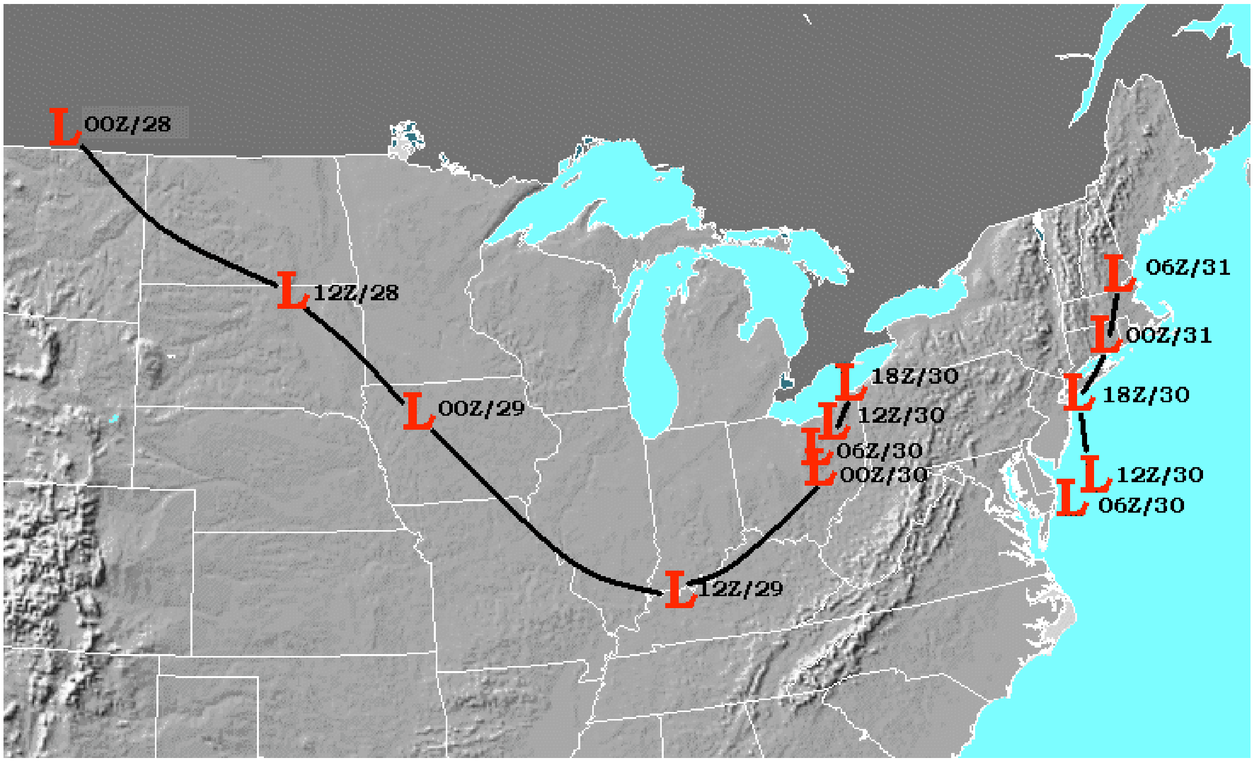

Fig. 1: Track of surface primary and secondary cyclones from 0000Z/28 to 0600Z/31.

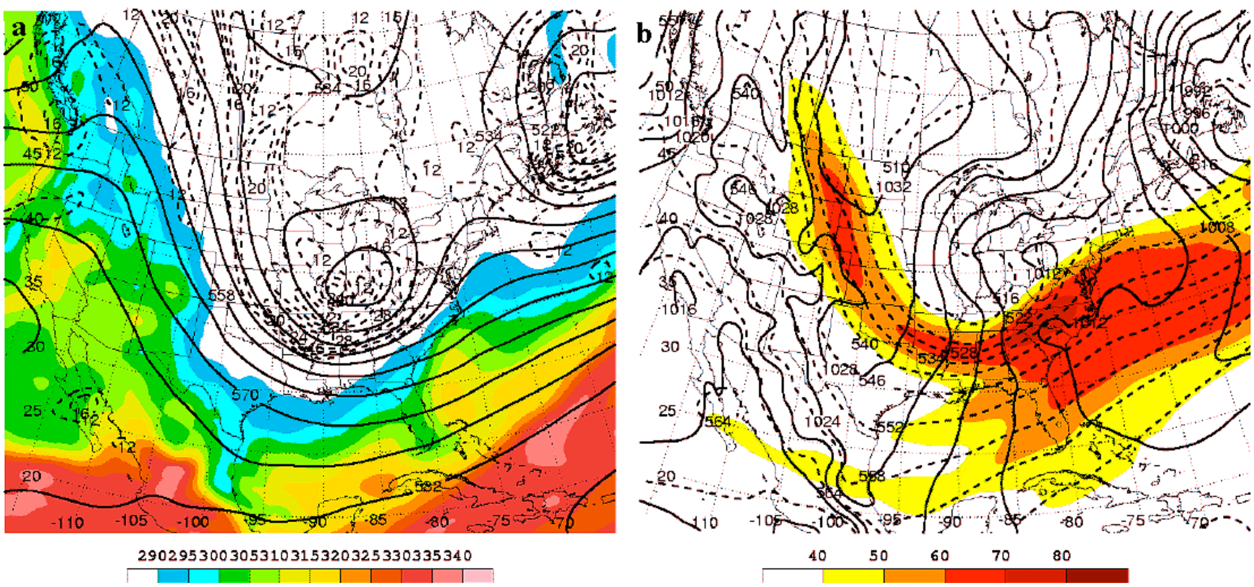

Fig. 2: a) 500 hPa height (dam, solid), absolute vorticity (x 10^{-5} s^{-1}, dashed), and 850 hPa equivalent potential temperature (K, shaded), and b) mean sea level pressure (hPa, solid), 1000-500 hPa thickness (dam, dashed), and 250 hPa isotachs (m s^{-1}, shaded) for 0000Z/30.

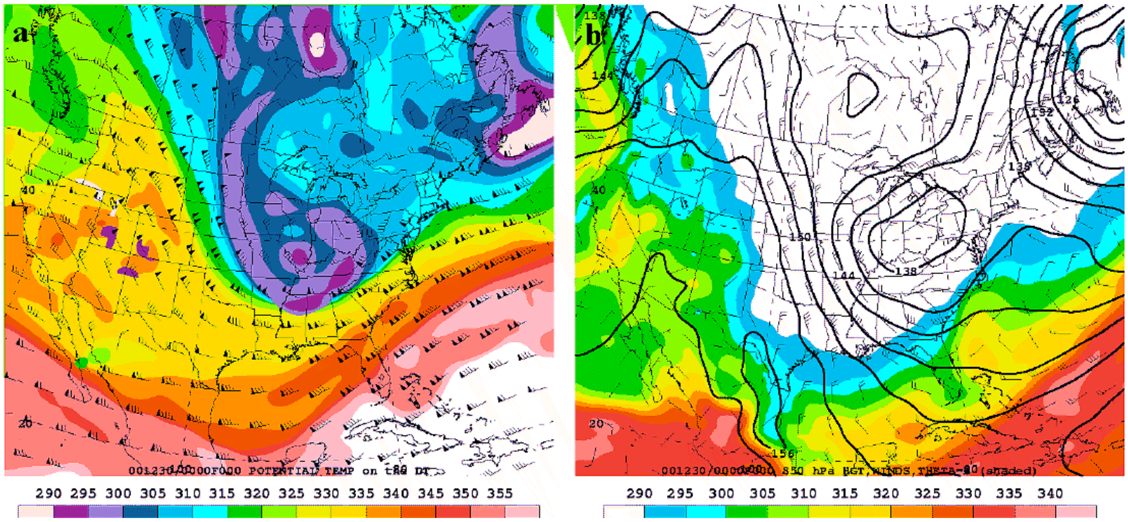

Fig. 3: a) potential temperature (K, shaded) and winds (kt) on the 1.5 PVU surface, and b) 850 hPa height (dam), equivalent potential temperature (K) and winds (kt) for 0000Z/30.

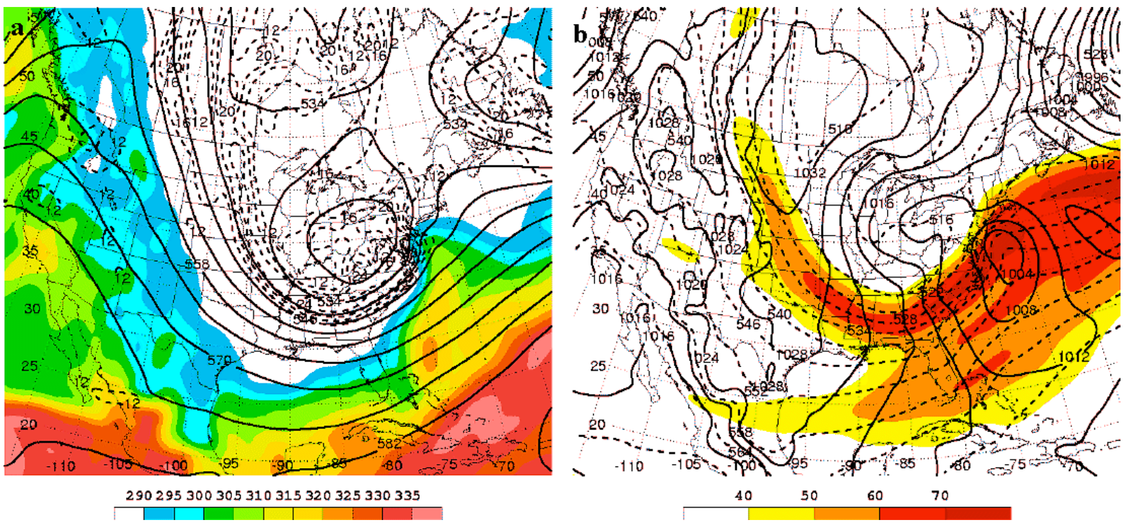

Fig. 4: As in Fig. 2 except for 1200Z/30.

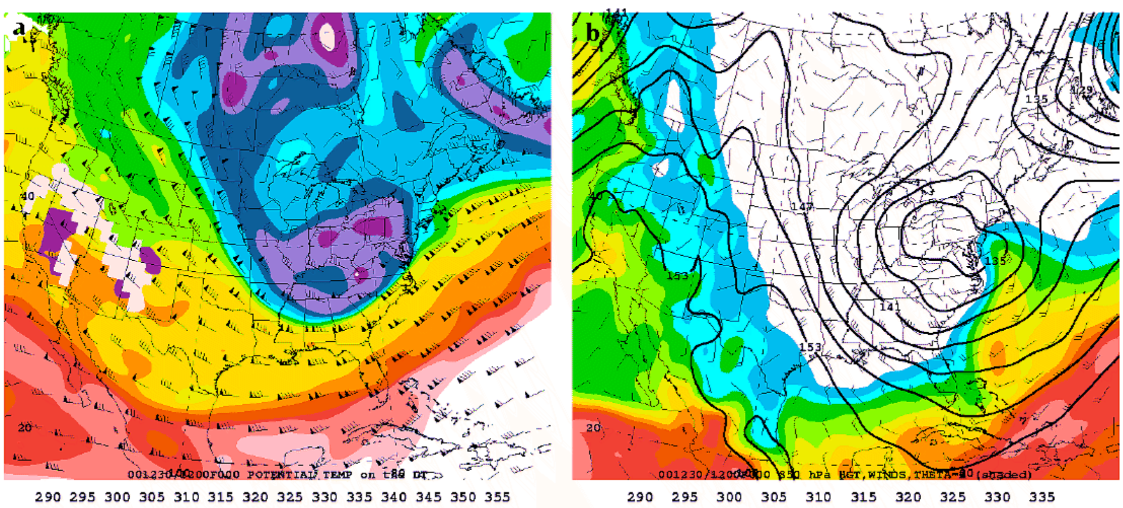

Fig. 5: As in Fig. 3 except for 1200Z/30.