# Event Review: December 25-27, 2010 Winter Storm, Eastern United States

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**<u>Overview:</u>** From December 25, 2010 through December 27, a strong low pressure system produced significant snowfall across much of the Southeastern U.S. and the East Coast, along with very strong winds across the Northeast. Precipitation began in the Southeastern US during the early morning hours of December 25. Most of the precipitation was in the form of rain during this time, with snowfall first observed around 5 AM CST in northern Alabama and Mississippi. Snowfall would gradually spread north and east throughout the day, reaching as far north as the Delmarva Peninsula by late that night. As the storm began to move up the US East Coast on December 26, the snowfall began to intensify across the coastal regions of the Mid-Atlantic states. Heavy snow finally reached the Northeast on the evening of the 26th and persisted for several hours before precipitation finally came to an end a day later.

Figure 1 below shows a map of snowfall totals observed with this storm.

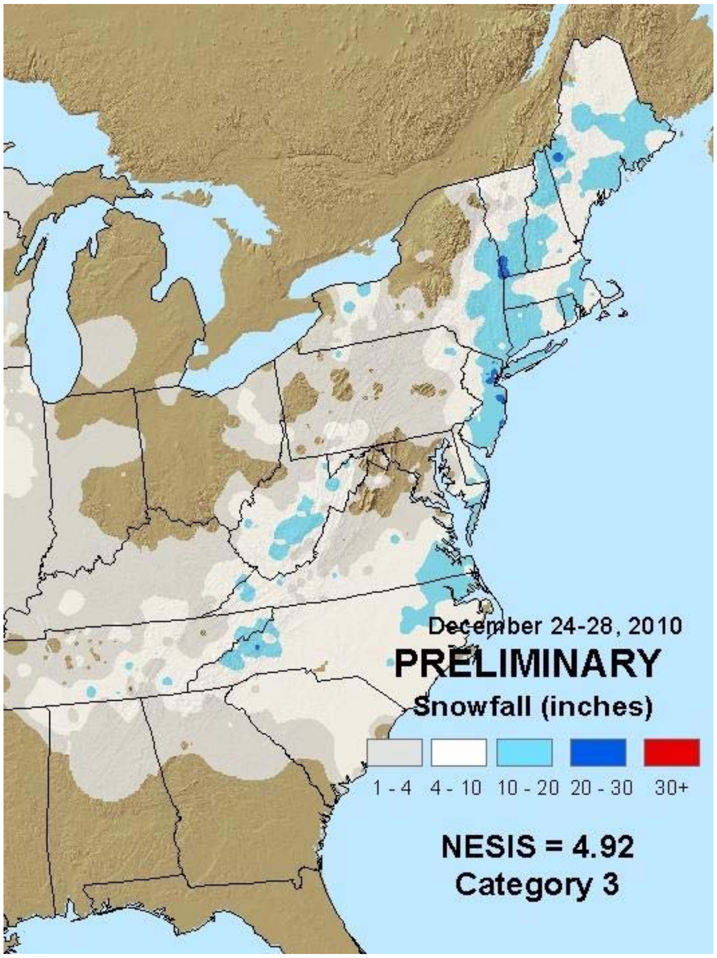

**Figure 1: Map of observed snowfall from this storm. Source: National Climatic Data Center**

Note the large swath of significant snowfall extending from North Carolina northeast through Maine. Major metropolitan regions affected by this storm include Raleigh, Norfolk, Philadelphia, New York City, and Boston. This storm was of historical proportions for several of these locations, and is now ranked as the third snowiest event of all time for both Norfolk, VA and Newark, NJ as well as the sixth snowiest event for New York City's Central Park. It was also rated as a Category 3 on the Northeast Snowfall Impact Scale. Northern New Jersey received the most snow, with 32 inches being observed at Rahway and many locations receiving over two feet. Of particular significance was the fact that this storm occurred during and immediately after the Christmas holiday, which is a time of increased travel across the U.S. Over 6,000 flights to and from East Coast cities were canceled and all three major airports in the New York metro area were closed simultaneously during the storm. In addition, after New York's JFK Airport reopened, twenty-eight flights arriving from international destinations were stranded on the tarmac for up to eleven hours due to the backlog of flights. The following sections will examine the meteorology behind this impressive storm.

**<u>Synoptic Setup:</u>** On December 24, 2010, a strong upper-level ridge of high pressure began to build over the western United States in response to an approaching trough from the Pacific. As this occurred, shortwave troughs embedded in the northern and southern streams began to dive down the backside of the strengthening ridge, moving into the plains by 18Z on the 24th (see Figure 2 below).

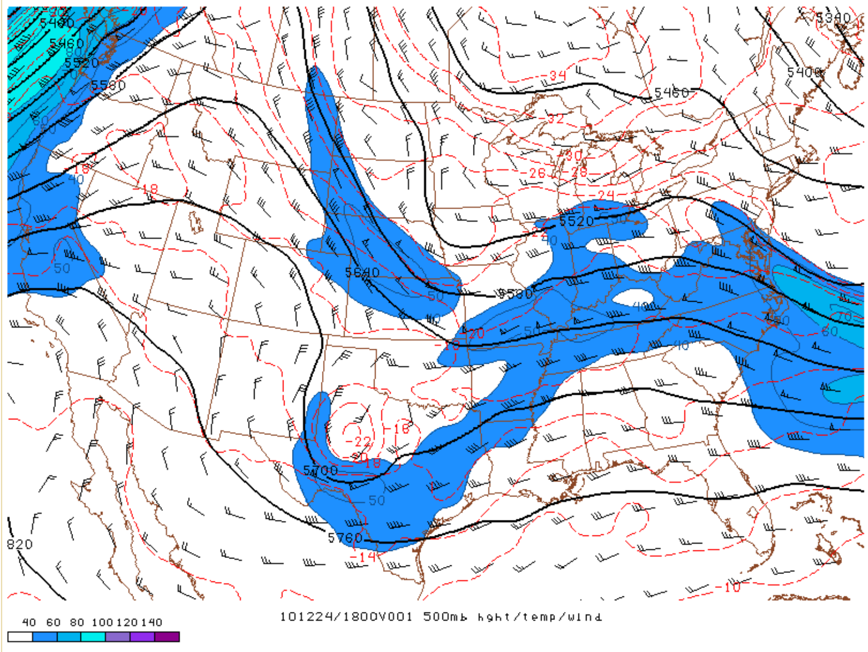

**Figure 2: 500mb winds, isotachs, and geopotential height at 18Z (12 PM CST) on December 24, 2010. Source: SPC Mesoanalysis**

The southern stream shortwave proceeded to move eastward while the northern stream trough amplified and began to dive southward towards the southern stream. At the surface, low pressure associated with the southern stream shortwave was also moving eastward (see Figure 3).

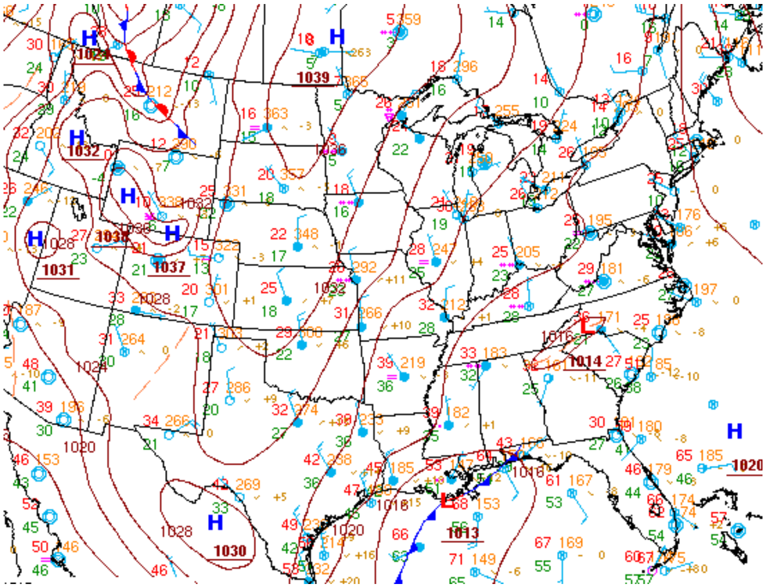

**Figure 3: HPC surface analysis from 12Z (6 AM CST) on December 25, 2010.**

Cold high pressure then settled in to the north of this system as the northern stream trough moved southward. By 12Z on the 25th, the anomalously deep northern stream trough had allowed freezing temperatures at 850 mb to reach as far south as northern Louisiana and central Mississippi. The cold air would penetrate even farther south as the northern trough continued to amplify, setting the stage for snow across the southeast.

The southward movement of cold air coincided with the formation of a band of precipitation across the southeast, which was associated with warm air advection and frontogenesis in a deformation zone north of the developing surface cyclone (see Figure 4).

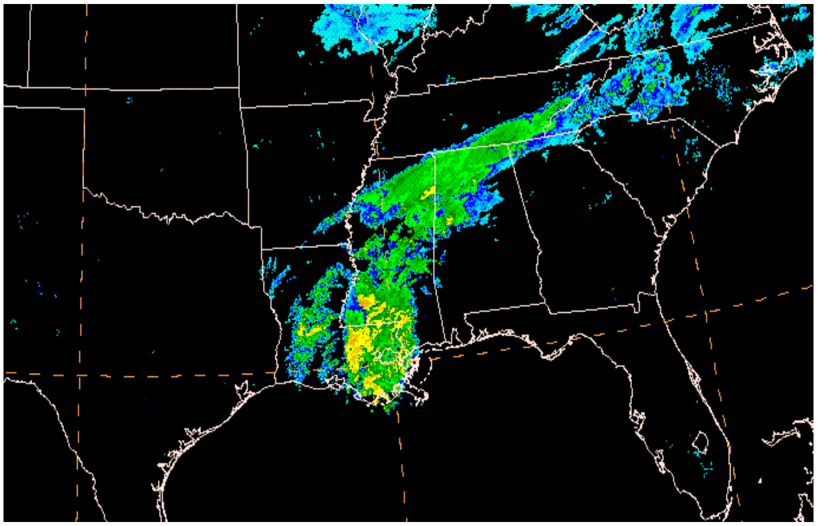

**Figure 4: Radar image from 12Z (6 AM CST) on December 25, 2010. The band across northern Mississippi and Alabama is mostly snow. Mostly rain is falling across Louisiana and southern Mississippi.**

Aiding in the development of this feature was an upper level jet-streak associated with the northern stream trough (see Figure 5).

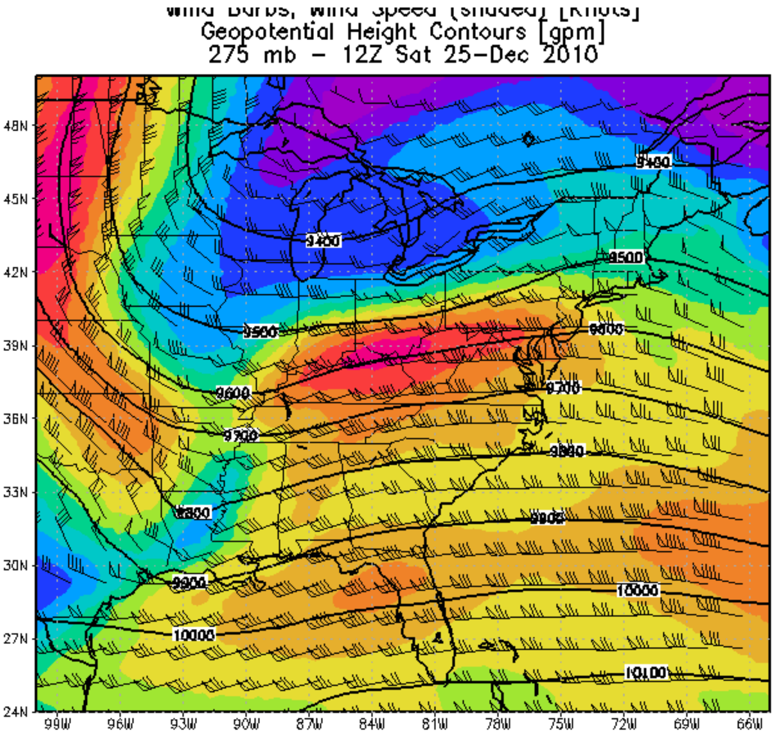

**Figure 5: 275mb winds, isotachs, and geopotential height at 12Z (6 AM CST) on December 25, 2010. Source: North American Regional Reanalysis**

The right entrance region of a jet streak is usually associated with enhanced vertical motion (Moore & Vanknowe 2429). This vertical motion was able to aid in the development of this band of snow, which produced significant amounts of snow over portions of northern Alabama, Mississippi, and Georgia as well as portions of Tennessee and North Carolina.

By 00Z on the 26th, the two shortwaves had merged, forming one amplified trough over the eastern United States. As this occurred, the associated surface low pressure system began to deepen significantly and move northeast up the Atlantic coastline (see Figure 6). Both the advection of lower thicknesses behind the strengthening cyclone and the strengthening Western U.S. ridge helped the upper trough intensify into a large upper low by 12Z, which began to slowly move eastward over the Appalachians (see Figure 7).

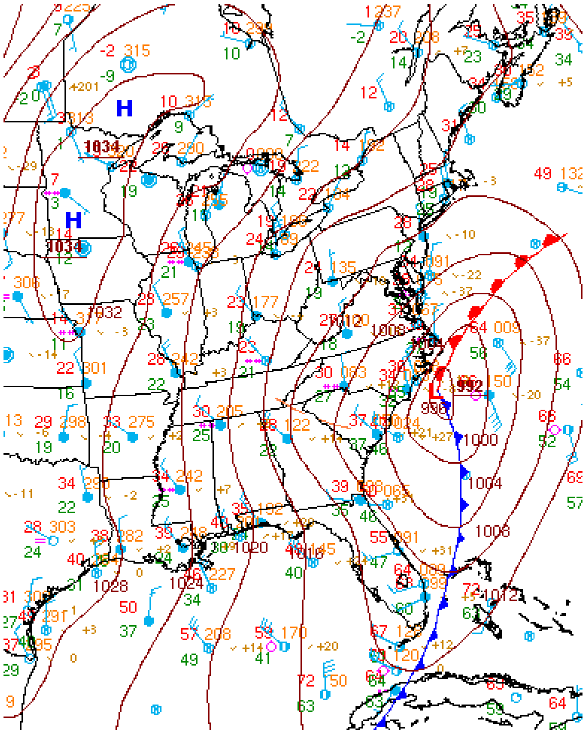

**Figure 6: HPC surface analysis valid at 12Z (7 AM EST) on December 26, 2010**

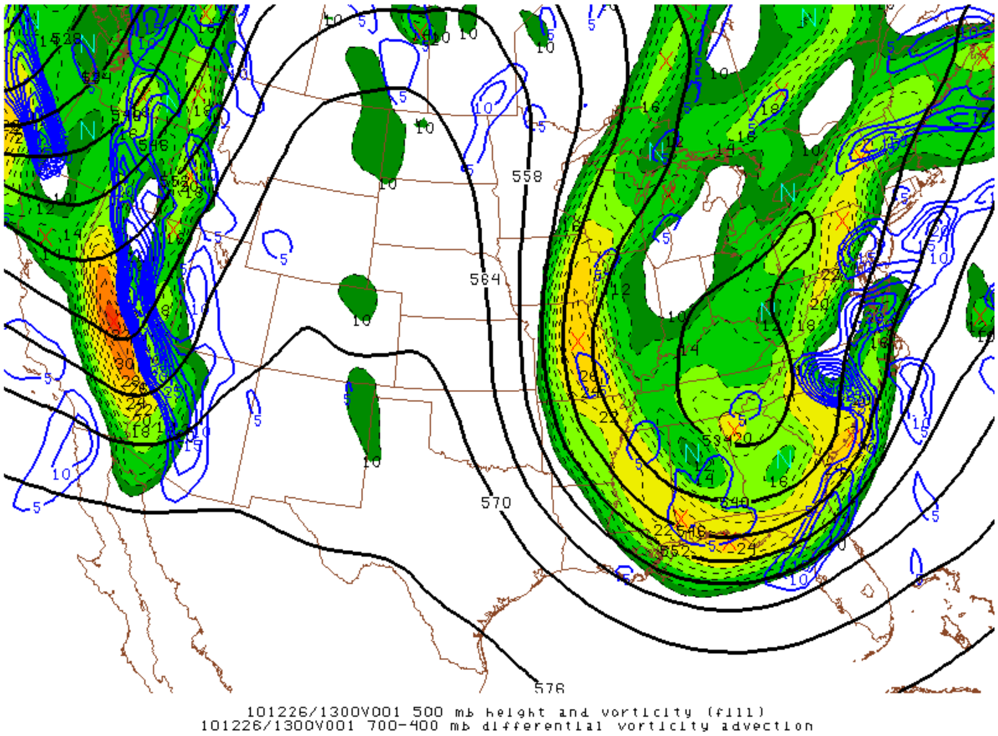

**Figure 7: 500mb geopotential height (black countours) and absolute vorticity (color fill) and 700mb – 400mb differential vorticity advection (blue countours) at 12Z (7 AM EST) on December 26, 2010.**

As this occurred, areas of differential positive vorticity advection (DPVA) and warm air advection overspread the southern Mid-Atlantic states, creating large scale lift over the area.  In addition, two strong jet streaks had set up over the eastern seaboard by 12Z.  At this time, the entrance region of the northern jet streak and the exit region of the southern jet streak were located over northeastern North Carolina and southeastern Virginia(see Figure 8).  These two regions are favorable for synoptic scale lift (Moore and Vanknowe 2432), and their presence over this region aided in the development of heavy snow over locations such as Norfolk, VA(see Figure 9).

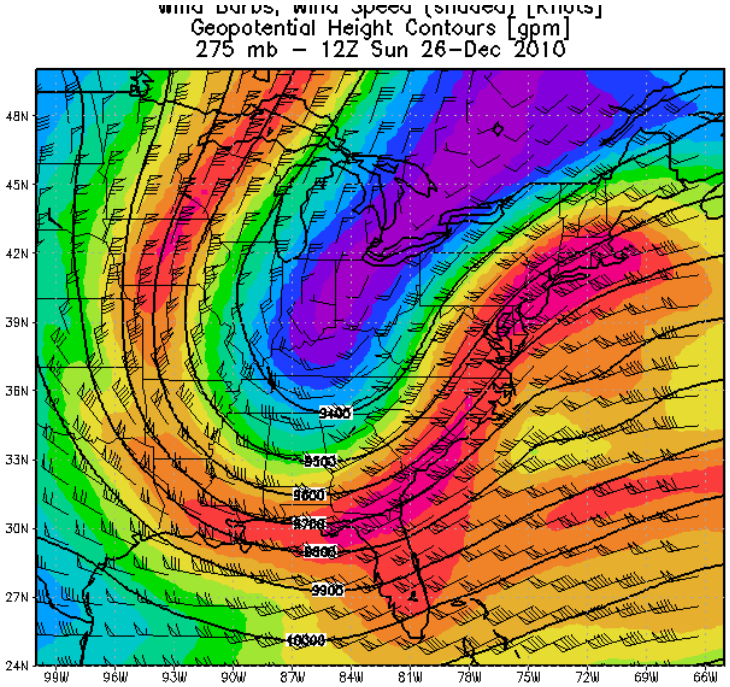

**Figure 8: 275mb wind, isotachs, and geopotential height at 12Z (7 AM EST) on December 26, 2010. Source: North American Regional Reanalysis**

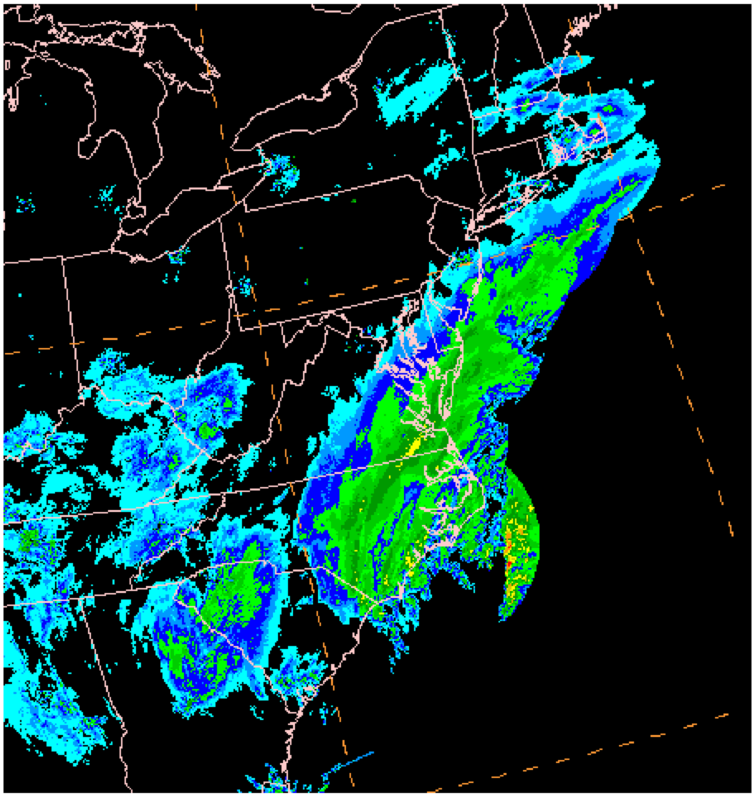

**Figure 9: Radar image from 13Z (8 AM EST) on December 26, 2010. Note the enhanced precipitation across southeastern Virginia and northeastern North Carolina.**

The surface low pressure system then continued to move northeast, intensifying along with the associated upper level low. As this occurred, the two aforementioned jet streaks also moved northeast so that their entrance and exit regions, some of which are favorable for large-scale lift, moved offshore. However, the upper low was still located near the US East Coast, and was creating large areas of DPVA over the Northeast (see Figure 10). This setup ensured that enough synoptic-scale lift was present over the area to allow for a persistent large swath of heavy snow (see Figure 11).

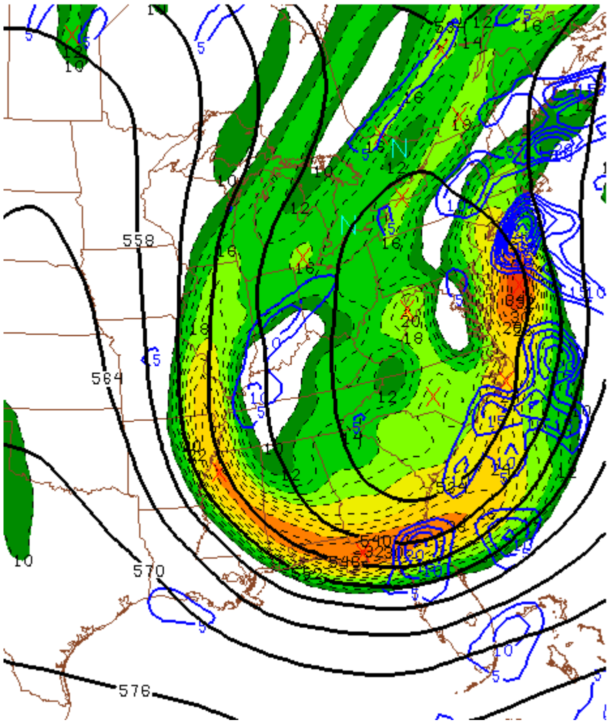

**Figure 10: 500mb geopotential height (black countours) and absolute vorticity (color fill) and 700mb – 400mb differential vorticity advection (blue countours) at 23Z (6 PM EST) on December 26, 2010.**

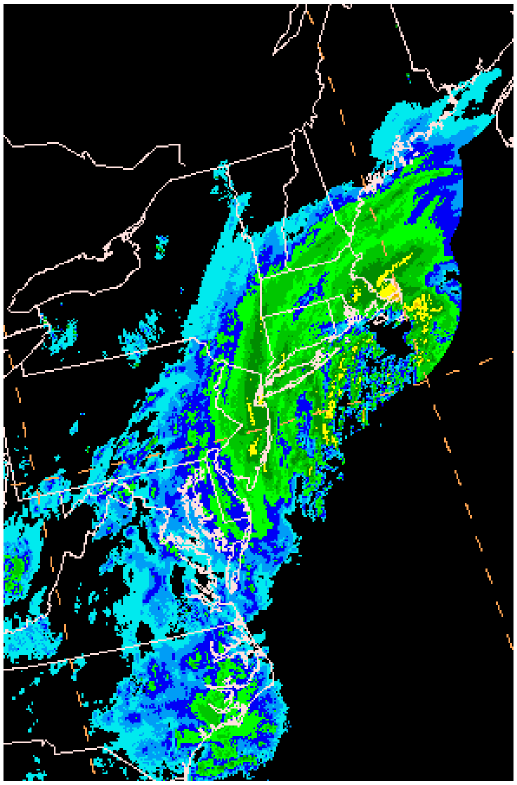

**Figure 11: Radar image from 23Z (6 PM EST) on December 26, 2010**

In addition to the heavy snow, very strong winds were present across the Northeast at this time, leading to near whiteout conditions as well as blowing and drifting snow. Gusts over 60 mph were observed across the New York City metro area and New England, and winds reached as high as 80 mph along Cape Cod. These winds resulted from the strong pressure gradient forces created by the nearby passage of the rapidly intensifying surface low. The HPC surface analysis valid at 09Z on December 27 is shown in Figure 12 below to illustrate just how strong this pressure gradient was. Note the incredible packing of the isobars across the Northeast. These were the areas that saw the strongest winds.

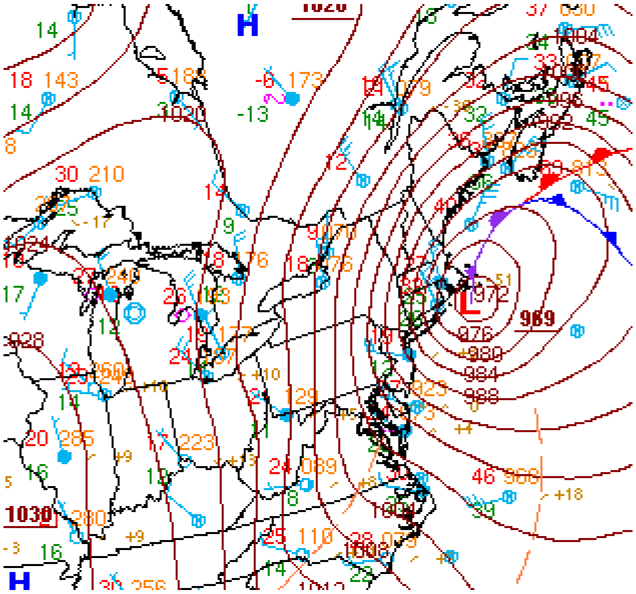

**Figure 12: HPC surface analysis valid at 09Z (4 AM EST) on December 27, 2010.**

**Mesoscale Pattern:** While the synoptic forcing played a large role in producing significant snowfall with this system, mesoscale forcing also provided a significant contribution.

As the storm moved up the Atlantic Coast, a strong shear axis developed north of the low center in the low to mid levels of the atmosphere. Strong easterly winds carried warm air inland from the Atlantic. These winds met strong northerly winds, which were advecting cold air southward. The result was strong convergence across a large temperature gradient, which resulted in significant frontogenesis. Frontogenesis creates a circulation in the atmosphere where air rises on the warm side of the front and sinks on the cold side (Sanders & Bosart). The lift induced by this circulation was a significant factor in the creation of heavy snow bands across the East Coast.

Southeastern Virginia and northeastern North Carolina were the first regions to benefit from this added forcing (see Figure 13).

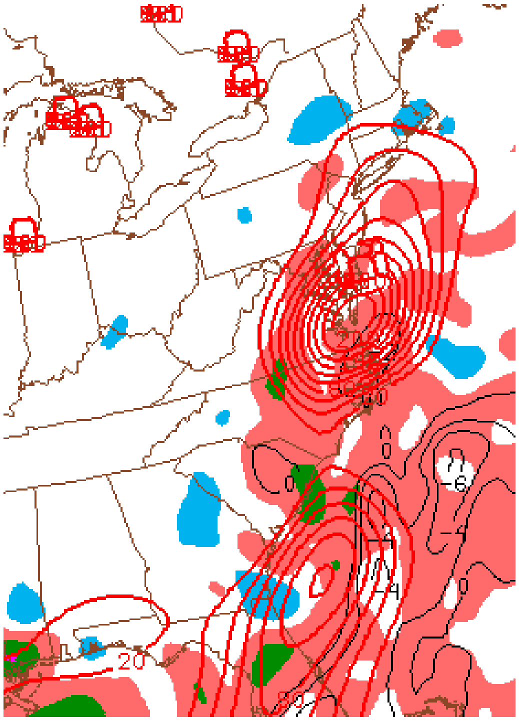

**Figure 13: 700mb frontogenesis (red countours) and 650-500mb saturated equivalent potential vorticity (shaded) at 13Z (8 AM EST) on December 26, 2010. Source: SPC Mesoanalysis**

Note the strong area of mid-level frontogenesis over this region, as well as the shading on the warm (eastern) side of the front. This shading represents areas of instability, which acts to enhance the vertical motion generated by the mid-level frontogenesis. As Figure 13 shows, instability is present with mid-level frontogenesis over this region, allowing significant lift to occur. As noted earlier, synoptic-scale forcing was also present over this region, which enhanced the upward motion even further. The result was the formation of a band of heavy snow (see Figure 9). Although mesoscale bands of snow are often narrow, as in this radar image, they often produce very high snowfall rates. Over a foot of snow fell in Norfolk, VA, most of which was a result of this banded snowfall.

Southeastern Virginia and northeastern North Carolina were not the only regions to benefit from frontogenetical forcing. As mentioned previously, mesoscale forcing likely played a major role in generating the incredible snowfall totals seen across portions of the Northeast. Note the band of heavy precipitation across New Jersey and southern New York at 23Z on December 26 (see Figure 11). In particular, notice how this band is embedded in the larger swath of precipitation created by the synoptic-scale forcing discussed in the previous section. Seven hours later, much of this precipitation had moved north into Maine and New Hampshire (see Figure 14). However, the band of heavy snow was still present over northern New Jersey and portions of Upstate New York, even though the main region of precipitation had moved northward.

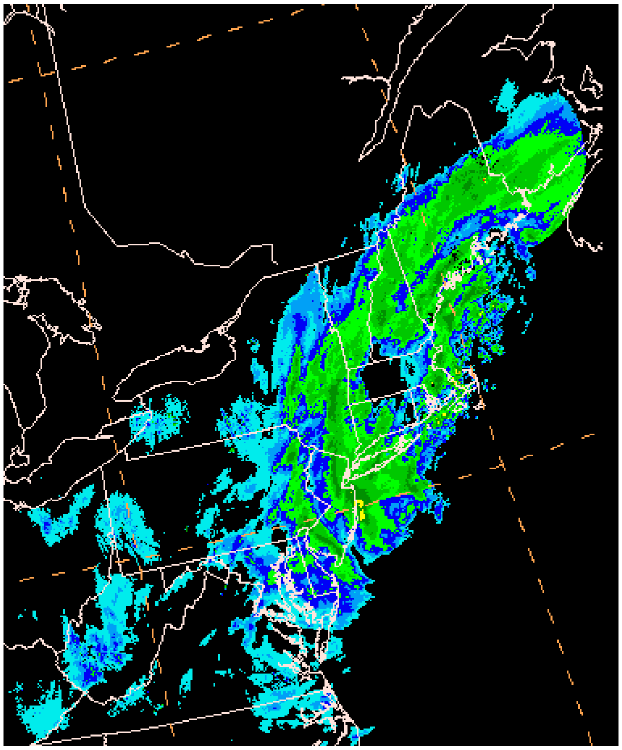

**Figure 14: Radar image valid at 06Z (1 AM EST) on December 27, 2010.**

To understand why this occurred, the mesoscale pattern must be examined. Figure 15 shows regions of 850mb frontogenesis and instability at 23Z on December 26. Notice the area of extremely strong frontogenesis over the Northeast, as well as the CSI present over the northern Mid-Atlantic Coast and southern New York State. This coincides very well with the band of heavy snow seen in Figure 11 over this region, indicating that frontogenetical forcing played a major role in the development of this band. It was during this period that New York City observed thundersnow, which is indicative of the intense convection resulting from this combination of strong forcing and instability.

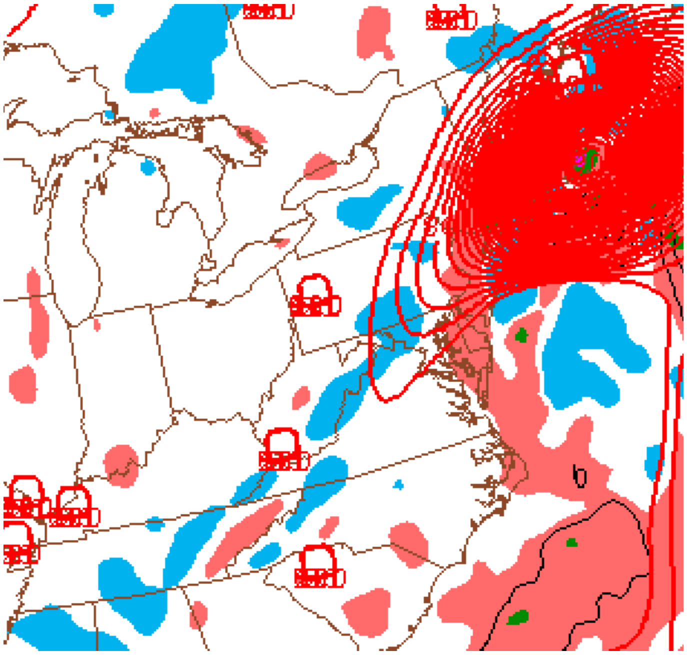

**Figure 15: 850mb frontogenesis (red countours) and 800-750mb saturated equivalent potential vorticity (shaded) at 23 Z (6 PM EST) on December 26, 2010. Source: SPC Mesoanalysis**

Figure 16 shows the same parameters seven hours later. Notice how frontogenesis and instability have lingered over the northern Mid-Atlantic states even though the main area of frontogenesis has moved further north. This lingering area of mesoscale forcing explains the persistence of this band over northern New Jersey, which allowed it to produce snow totals as high as 32 inches.

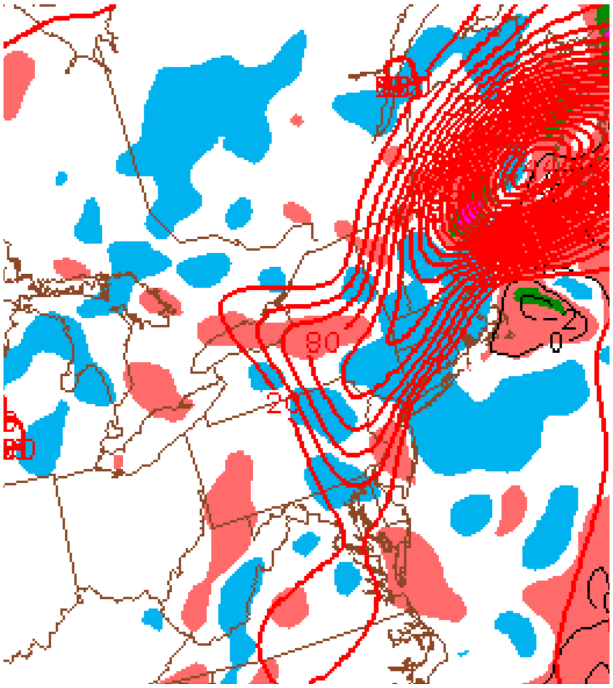

**Figure 16: 850mb frontogenesis (red countours) and 800-750mb saturated equivalent potential vorticity (shaded) at 06 Z (1 AM EST) on December 27, 2010. Source: SPC Mesoanalysis**

Frontogenesis was also present at the 700mb level (not shown), and this allowed for a band of heavy snow to set up across northern New England as well. While this band was not quite as intense as the band across northern New Jersey, snow totals of 20 inches or greater were not uncommon across Vermont and New Hampshire.

**Conclusion:** A strong low pressure system tracked up the US East Coast from December 25-27, 2010, producing snowfall across a large area from the Deep South to New England, which included some of the country's most densely populated regions. Very strong synoptic forcing induced by jet dynamics and an unusually deep upper low allowed for the development of a large swath of snowfall across this region. This synoptic-scale lift would combine with vigorous frontogenetical forcing to produce persistent bands of heavy snowfall over certain regions, leading to localized snowfall totals of up to two and a half feet. The impacts of this storm were both substantial and far-reaching, making this storm one of the most significant of the season.

## References:

Moore, James T., Glenn E. Vanknowe, 1992: The Effect of Jet-Streak Curvature on Kinematic Fields. *Mon. Wea. Rev.*, **120**, 2429, 2432.

Sanders, Frederick, Lance F. Bosart, 1985: Mesoscale Structure in the Megalopolitan Snowstorm of 11–12 February 1983. Part I: Frontogenetical Forcing and Symmetric Instability. *J. Atmos. Sci.*, **42**, 1050–1061.