Event Review: Eastern United States Heavy Precipitation Event, March 4 - 7, 2011
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Overview: From March 4 through March 7, 2011, a large storm tracked across much of the eastern United States, producing heavy rain and snowfall. Upstate New York and New England were hit hardest by the storm. Heavy snowfall combined with occasional sleet or freezing rain caused significant travel difficulties over interior regions while heavy rainfall and melting snow closer to the coast led to flooding, ice jams, and mudslides. This caused numerous road closures, including the Bronx River Parkway in New York City, and forced many to be evacuated from their homes. In addition, over 50,000 power outages were reported across New York State and central Vermont. The heaviest snow fell across northern Vermont and the mountainous regions of Upstate New York, with many locations receiving over two feet of snow (Fig. 1). The highest total was 32 inches, which was observed at Bloomingdale, NY. Also of note was that Burlington, VT recorded its largest March snowfall event on record, measuring 25.8 inches.

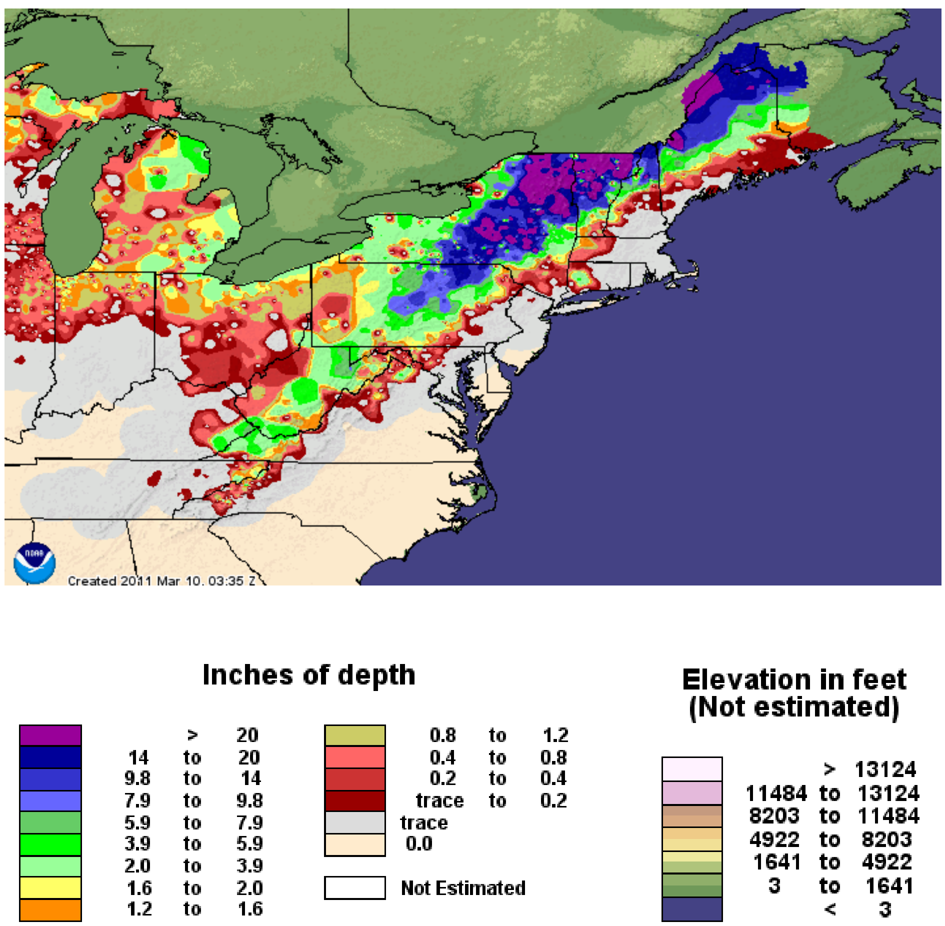

Figure 1: Total snowfall from 7 PM EST on March 4, 2011 to 7 PM EST on March 7, 2011. Source: National Operational Hydrologic Remote Sensing Center

Although the most significant damaging effects from this storm were felt in the Northeast, nearly all of the eastern United States was significantly affected. Louisiana in particular was hard-hit with 10 tornadoes reported across the state associated with a band of strong to severe thunderstorms. Elsewhere, widespread moderate to heavy rain (Fig. 2) led to flooding from the Ohio Valley to the Deep South. The following sections will examine the meteorology associated with this damaging storm system.

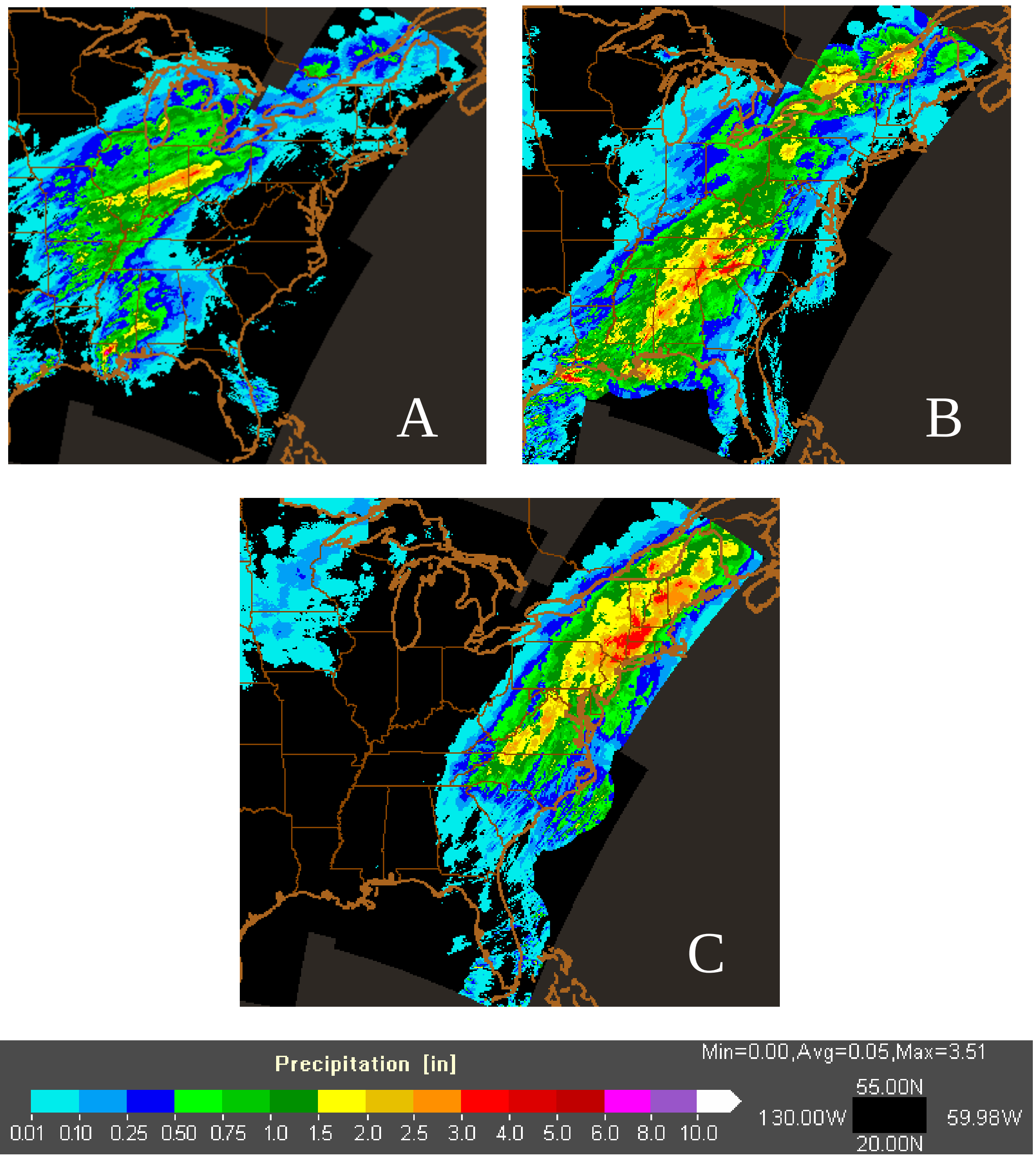

Figure 2: Total stage IV observed precipitation from 7 AM EST – 7 AM EST on A) March 4-5, B) March 5-6, and C) March 6-7, 2011. Source: National Mosaic and Multi-Sensor QPE

Synoptic Pattern:

Two upper-level troughs were in place over the eastern two-thirds of the country on March 5, 2011 (Fig. 3a). Although these troughs were slightly out of phase with each other, they combined to support a single yet extensive frontal system across the Central and Eastern United States (Fig. 3b). The large band of precipitation lines up very well with the surface front, but is located east of the regions of greatest differential positive vorticity advection (or DPVA) at 500 mb. This indicates that, during this stage of the storm, low-level frontal forcing likely played a greater role in the development of heavy precipitation than upper-level dynamics.

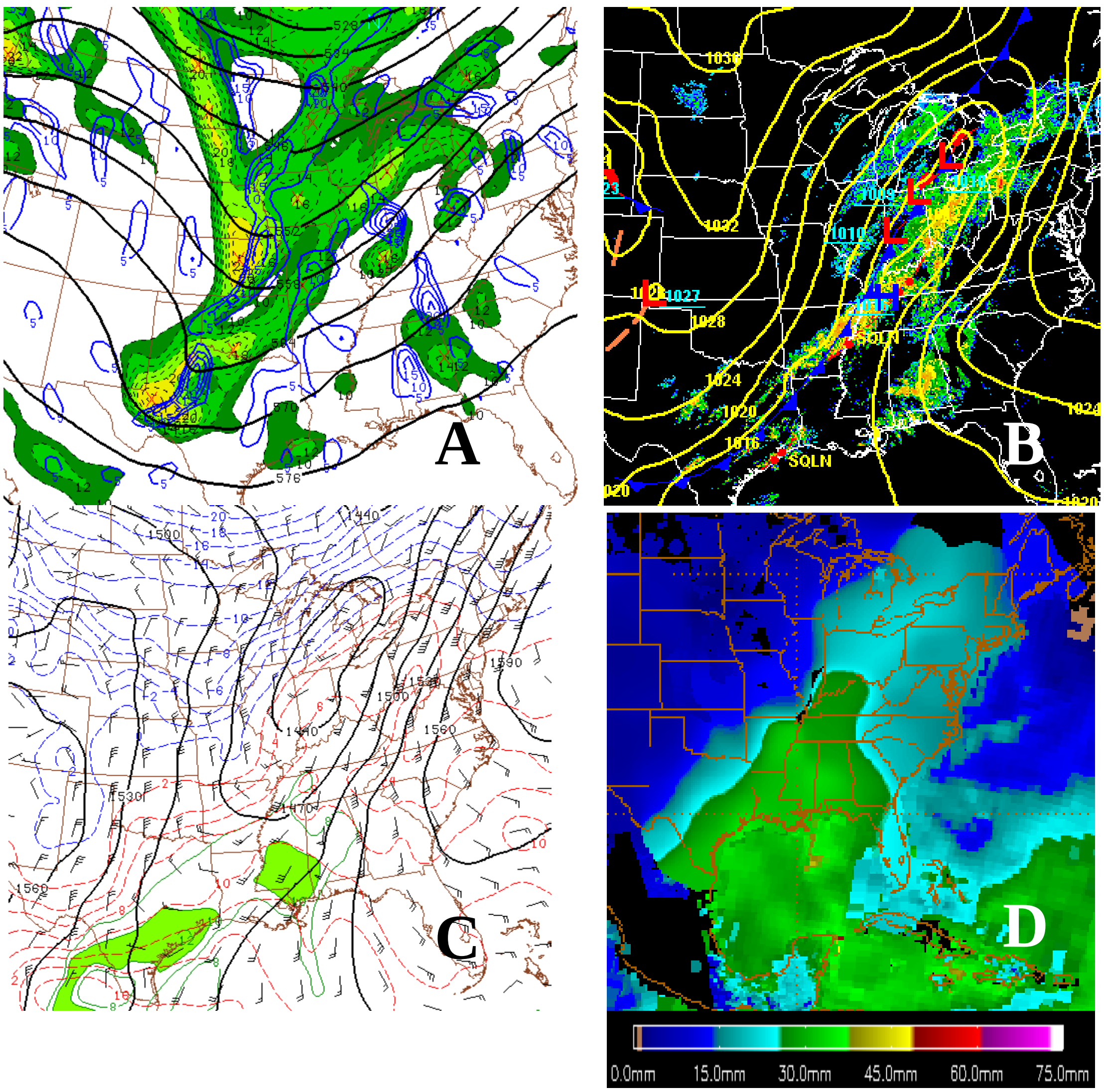

Figure 3: Various plots valid at 7 AM EST on March 5, 2011. A) 500mb height, vorticity (green/yellow fill) , and differential positive vorticity advection (blue contours). Source: SPC Mesoanalysis. B) Doppler radar and surface analysis. Source: HPC. C) 850mb height, winds, temperature (dashed contours), and dewpoint (green contours/fill). Source: SPC Mesoanalysis. D) Satellite-derived total precipitable water. Source: NESDIS.

At 850 mb a very sharp trough was in place, which produced a stream of southerly to southwesterly winds over the region (Fig. 3c). These winds allowed moisture from the Gulf of Mexico to be transported northward towards the Great Lakes. Note the large area of elevated precipitable water across the Eastern United States in Fig. 3d, indicating that there was ample moisture available for heavy precipitation across this region.

By the morning of March 6, the southern stream trough had caught up with the surface frontal system (Fig. 4). Notice how the region of DPVA was much better aligned with the southern surface low. This alignment likely aided in the strengthening of this low pressure system, since DPVA induces lift. The DPVA associated with the southern stream trough was also well-aligned with the precipitation over the Southern Appalachians, indicating that upper-level forcing for ascent was contributing to the heavy precipitation over this region.

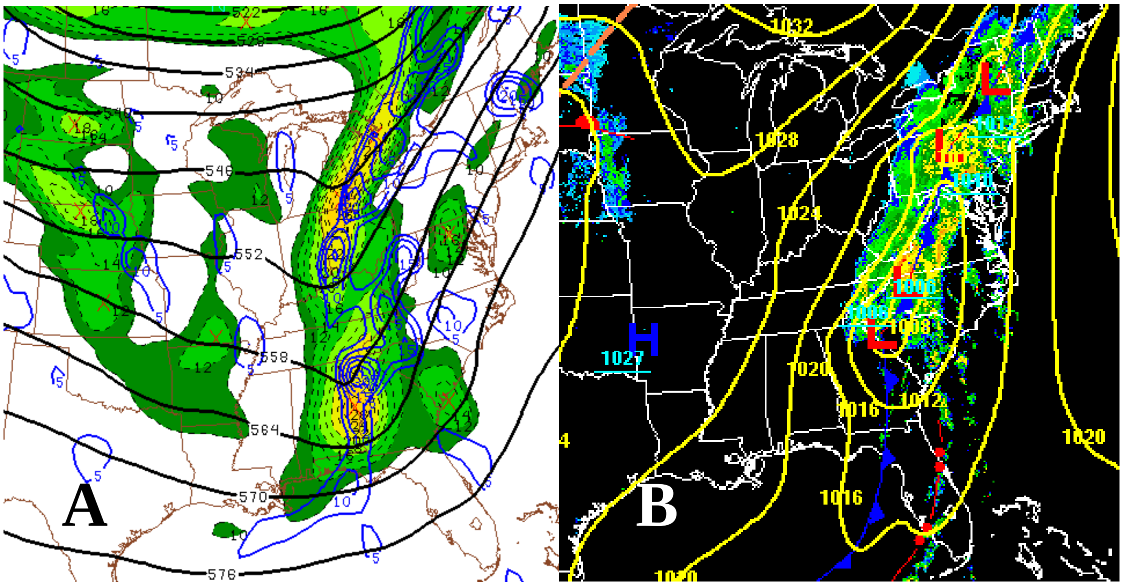

Figure 4: A) 500mb heights, vorticity (shaded) and 700-400mb DPVA (blue contours at 10 AM EST on March 6, 2011. Source: SPC Mesoanalysis. B) Surface analysis and radar imagery valid at the same date and time. Source: HPC

By the evening of March 6, the southern stream upper level trough had moved northeast, along with the associated surface low and heavy precipitation (Fig. 5a).

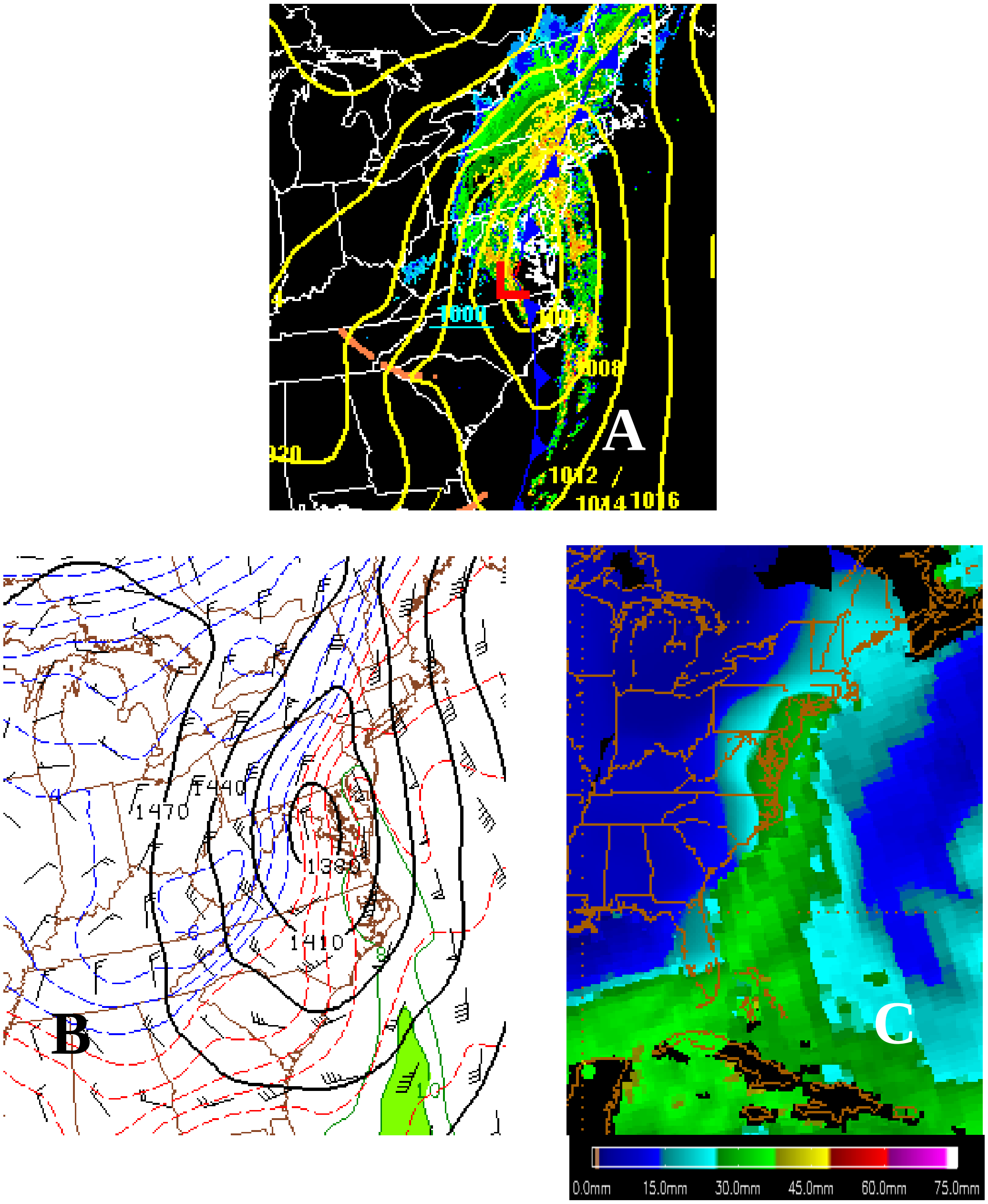

Figure 5: All images valid at 7 PM EST on March 6, 2011. A) Surface analysis and radar imagery. Source: HPC. B) 850mb height, temperature (red/blue contours), dewpoint (green contours/fill), and winds. Source: SPC Mesoanalysis. C) Satellite-derived total precipitable water. Source: NESDIS.

At 850 mb, a strong closed low had developed that was generating strong counterclockwise flow. The southerly flow to the east of the low was carrying a warm and very moist air mass into the Northeast, while the northerly flow farther west was bringing a cold air mass southward (Fig 5b-c).

Also, note the warm air advection over New York City, as indicated by the wind barbs crossing over isotherms in Fig. 5b. This thermal advection generated lift which, in combination with the copious amounts of moisture being transported over the area, allowed for the development of heavy precipitation over the city (Fig. 5a). In addition, the transport of moisture northward into a frontal boundary, indicated by the temperature gradient in Fig. 5b, led to the development of overrunning precipitation in the cold air mass north of the boundary, as well as the associated heavy snow.

Mesoscale Pattern: In addition to the synoptic pattern, support for heavy precipitation was also present at the mesoscale. Most of this support was in the form of strong frontogenesis present in areas of instability.

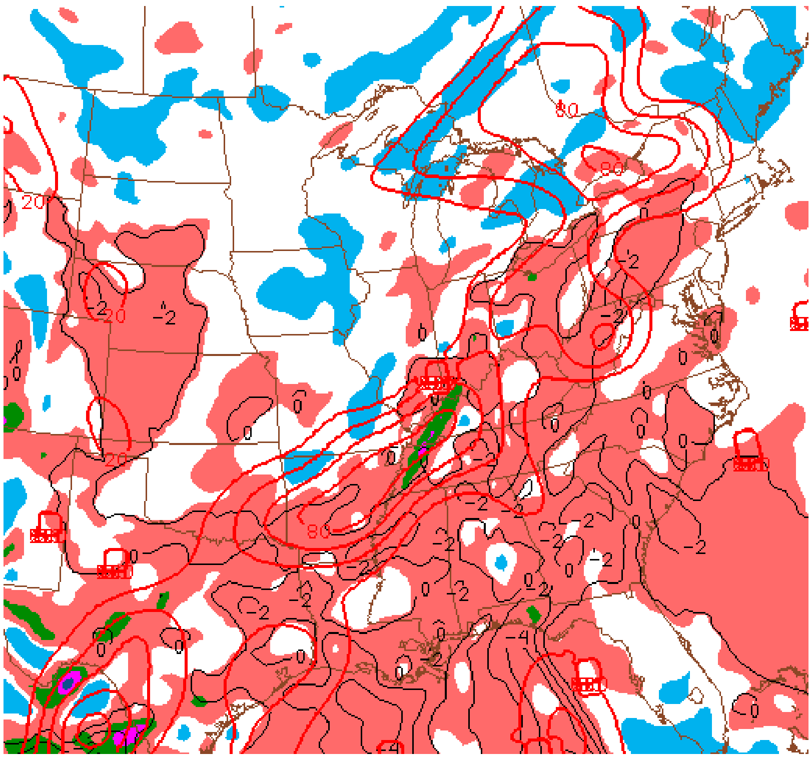

Figure 6: 850mb frontogenesis (red contours) and 800-750mb saturated equivalent potential vorticity (shaded), which corresponds to areas of instability, at 7 AM EST on March 5, 2011. Source: SPC Mesoanalysis.

At 7 AM March 5 an area of strong instability was located on the warm side of the frontogenesis maximum over Tennessee and Kentucky (Fig. 6). Frontogenesis induces a circulation where air rises in the warm sector. The fact that this region was very unstable meant that this circulation was likely quite strong, leading to significant upward motion. This strong vertical motion combined with the high levels of moisture discussed in the previous section to generate the heavy rainfall rates seen in Fig. 3b.

Precipitation was even more impressive across Louisiana later in the day. Areas of intense convection are apparent over this region, indicating the presence of strong instability. A 12 PM CST sounding taken at New Orleans (Fig. 7) shows that to be the case, with CAPE values approaching 1800 J/kg during the midday hours. Also note the modest 0-1 km shear of approximately 15-20 knots along with the extremely low LCL. Both of these parameters are favorable for tornado development, and indeed ten tornadoes were reported across Louisiana on March 5.

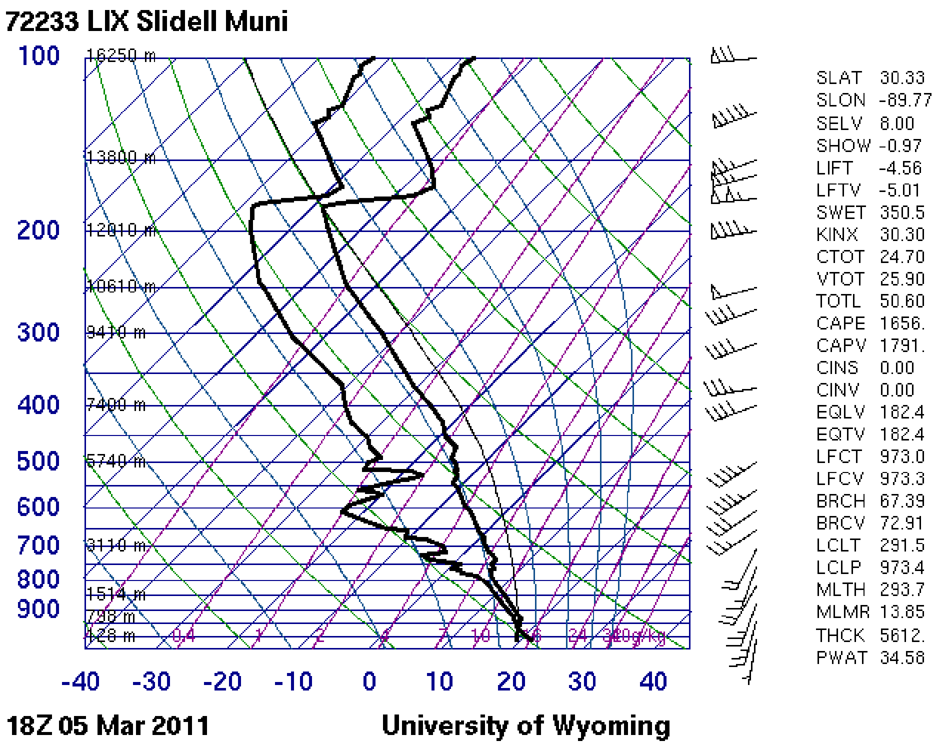

Figure 7: Atmospheric sounding taken at Slidell, LA at 12 PM CST on March 5, 2011. Source: University of Wyoming

Frontogenesis was also an important factor in the heavy precipitation that fell over the western slopes of the Southern Appalachians. The sharpness of the trough at 850 mb caused incredible convergence in the mid-level winds. Southerly to southeasterly winds east of the Appalachians were carrying warm, moist air off the Gulf of Mexico and the Atlantic Ocean, while northerly to northwesterly winds west of the Appalachians were advecting cold continental air into the region. This convergence in the presence of the temperature gradient resulted in strong frontogenesis, which induced strong lift west of the Appalachians. However, the speed of the frontogenesis was just as important as the strength. The slow movement of the 850 mb trough during this time allowed the frontogenesis to be nearly stationary for a period of time, leading to high precipitation totals (Fig. 8).

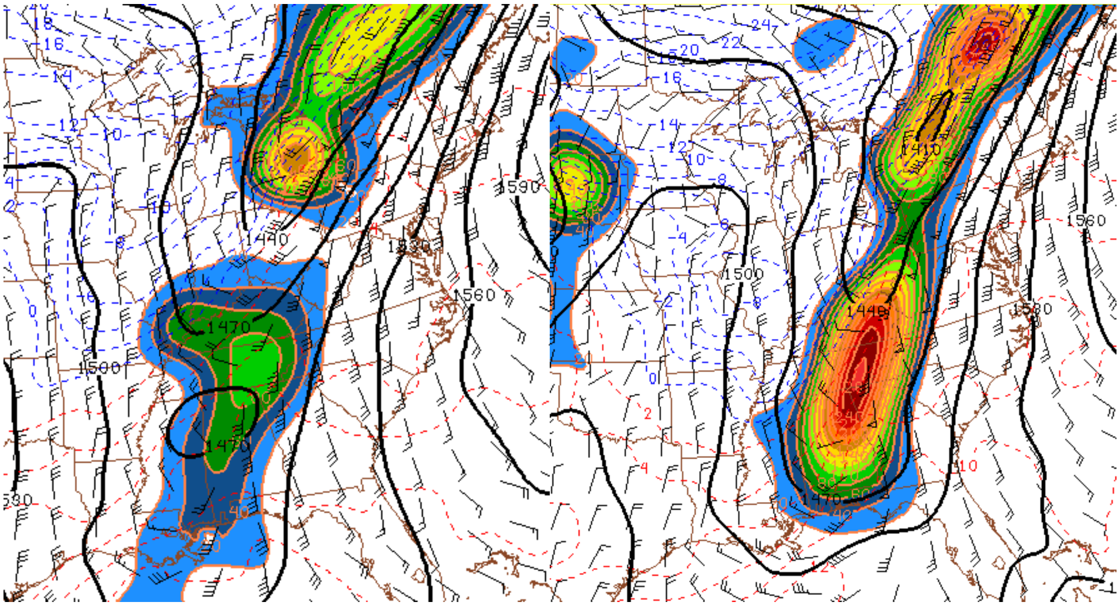

Figure 8: 850mb height, winds, and frontogenesis (shaded) at 7 PM EST on March 5, 2011(left image) and 1 AM EST on March 6 (right image). Source: SPC Mesoanalysis.

Frontogenesis higher in the atmosphere also played an important role in this storm, especially as it began producing heavy snow over portions of the Northeastern United States. Many near the border between Pennsylvania and Upstate New York saw over a foot of snow with this storm system. One of the main reasons for this was the long duration of the snowfall. For example, Williamsport, PA saw just over thirteen hours of snowfall while Binghamton, NY saw nearly seventeen hours. Part of the reason the snowfall persisted for such a long period of time was the amount of time mid-level frontogenesis was in place over the region (Fig. 9). During this time, an upper low developed over the Central Appalachians and moved slowly northeastward over Pennsylvania and New York State. Strong convergence across a temperature gradient was present both north and south of this low, which created a band of frontogenesis. Because of the slow movement of the upper low, convergence and its associated frontogenesis remained present over this region for an extended period of time, as shown in Figure 9, which led to persistent vertical motion and precipitation.

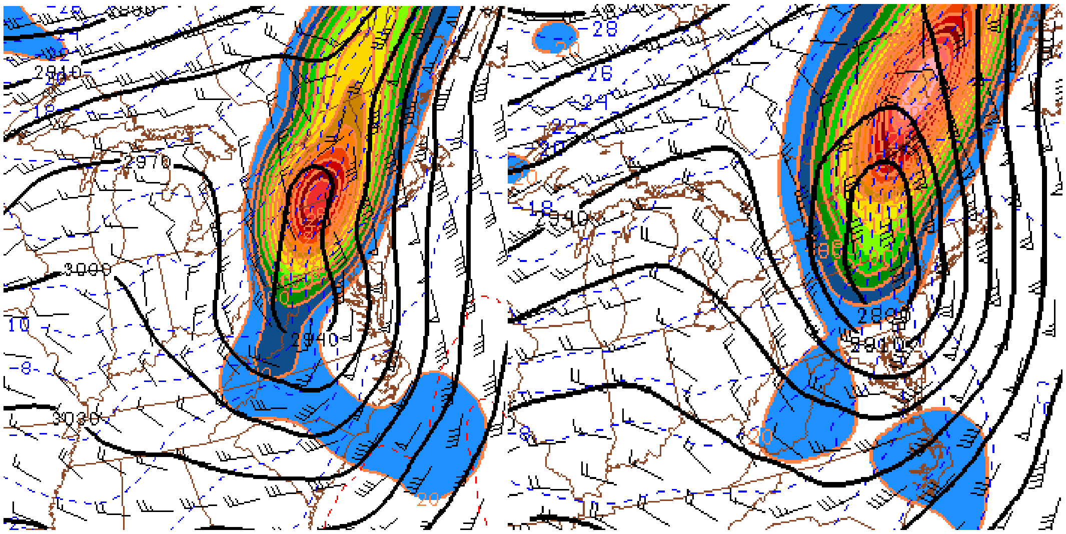

Figure 9: 700mb height, winds, temperature (dashed contours), and frontogenesis (filled contours) valid at 7 PM EST on March 6, 2011 (left image) and 5 AM EST on March 7 (right image). Source: SPC Mesoanalysis

The frontogenesis was even stronger further northeast over the Adirondack Mountains and Northern New England and also persisted for an extended period of time. This led to even higher totals across this region.

<u>Conclusion:</u> This storm produced a wide variety of disruptive weather, including heavy snowfall, flooding, and tornadoes. Strong synoptic-scale forcing both aloft and near the surface combined with vigorous mid-level frontogenesis to induce strong vertical motion in a very moist air mass, leading to heavy precipitation. This air mass was in place over much of the eastern United States because of strong southerly flow originating in the Gulf of Mexico and the warmer waters of the Atlantic Ocean. The interaction of this air mass with arctic air over Canada allowed heavy snowfall to develop across interior regions of the Northeast. Such a heavy snowfall late in the season led to many travel difficulties, while warmer temperatures closer to the coast led to melting snow and heavy rain, which caused flooding in many areas.