10.2 Mesoscale Analysis of Nor'easter of December 9, 2005

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1. INTRODUCTION

Between December 9 and December 10 of 2005, a small, intense nor'easter developed off the coast of New Jersey, moved north as it strengthened, and reached Nova Scotia. During this period, the storm experienced rapid development, and produced heavy snow over coastal New England with the accompaniment of thunder and lightning. As can be seen in Fig. 1, there was a substantial snowfall, but the impact was all the greater since most of the snow fell within about a four hour time period. Snowfall rates of 3 – 4"/hour were not uncommon. The heavy snow fell on a Friday afternoon, causing massive traffic jams, as commuters tried in vain to "get home early". By early evening, the sky had cleared completely.

Because this storm was small and intense, much can be learned about the mesoscale influences contributing to the storm evolution. The sea level pressure in the center of the storm dropped a total of 26 hPa in less than 24 hours, with 17 hPa of this fall occurring in one six hour period. The convective precipitation appears to be due to an elevated region of instability. Unlike a typical nor'easter, most of the snow fell after the storm moved off the coast. Later in the storm evolution, it appears that a tropopause fold developed which allowed high velocity winds to be carried down to the surface, causing some structural damage.

High resolution modeling of this storm brings out the mesoscale variability in this storm, and provides some insight into the predictability of the mesoscale details, given the operational constraints on the resolution of the our forecast models.

2. Synoptic Evolution

The storm formed as a strong upper-level short wave approached the East Coast of the U. S. The vorticity maximum in the short wave had a value greater than $40 \times 10^{-5}\ s^{-1}$, and there was considerable cyclonic vorticity advection (see Fig. 2). However, the surface low pressure system formed from a pre-existing weak coastal trough stretching from the Delaware Peninsula to South Carolina. The surface low took shape near Delaware and slowly moved north and east along the coast, then turned more towards the east as it came under the influence of the upper level short wave (see Fig. 3). The surface low deepened slowly as it moved up the coast, then deepened very rapidly as it moved eastward along the shores of Connecticut, Rhode Island, and then over the Cape Cod peninsula of Massachusetts. It was offshore by 20 UTC. The deepening rate exceeded 1 hPa/hour for 24 hours, and was 3 hPa/hour for one 3 hour period.

Moderate precipitation fell ahead of a coastal front that formed as the storm moved along the southern coast of New England. The majority of the precipitation fell after the storm moved off the East Coast, as a mesoscale band formed west of the storm center. This band had three lines of maximum reflectivity for a portion of its lifetime, as can be seen in Fig. 4a, a plan position indicator plot (PPI) of the reflectivity on the 0.5^{o} elevation scan. Fig. 4b, which is a constant altitude PPI (CAPPI) at 1000 m elevation at the time of maximum delineation of the three lines. Fig. 4c shows a CAPPI at 2000 m for the same time; the lines lose some of their definition at this level.

3. Operational Model Forecast

The operational numerical model at the time was the Eta model, running at 12 km horizontal resolution with 60 vertical levels. The model run from 00 UTC on the 8^{th} of December produced an excellent forecast of this system. Fig. 5 shows the 42 hour forecast, valid 18 UTC on December 9^{th}, for the sea level pressure and precipitation, while Fig. 6 shows the same fields for the 45 hour forecast, valid at 21 UTC. The Eta forecast shows the surface slow slightly too far north, but has the sense of the band of precipitation. A cross section perpendicular to the band is shown in Fig. 7 for 18 UTC. No triple maximum in vertical motion is apparent – only a broad region of uplift. The separation between the lines was on the order of 20 – 30 km, which was apparently too close for the 12 km grid spacing of the Eta model to resolve.

4. Mesoscale Modeling

Two mesoscale models were run in research mode to try to simulate the mesoscale band of precipitation, both using the North American Mesoscale Model 6-hour Analysis grids for initial and boundary conditions. The Advanced Research WRF (Weather Research and Forecasting) (ARW) model was run at 4 km resolution with a single grid, while the Fifth Generation of the Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5) was run using three nested grids of 27 km, 9 km and 3 km horizontal spacing. The ARW model run was unable to produce most of the development of the storm, and will not be discussed here. The MM5 run was able to capture the

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sense of the rapid deepening, and the track of the surface low, but did not simulate the full depth of the surface low. Nevertheless, the MM5 was able to produce the mesoscale precipitation band, with the correct shape, size and location, and thus will be used to examine the details of the band.

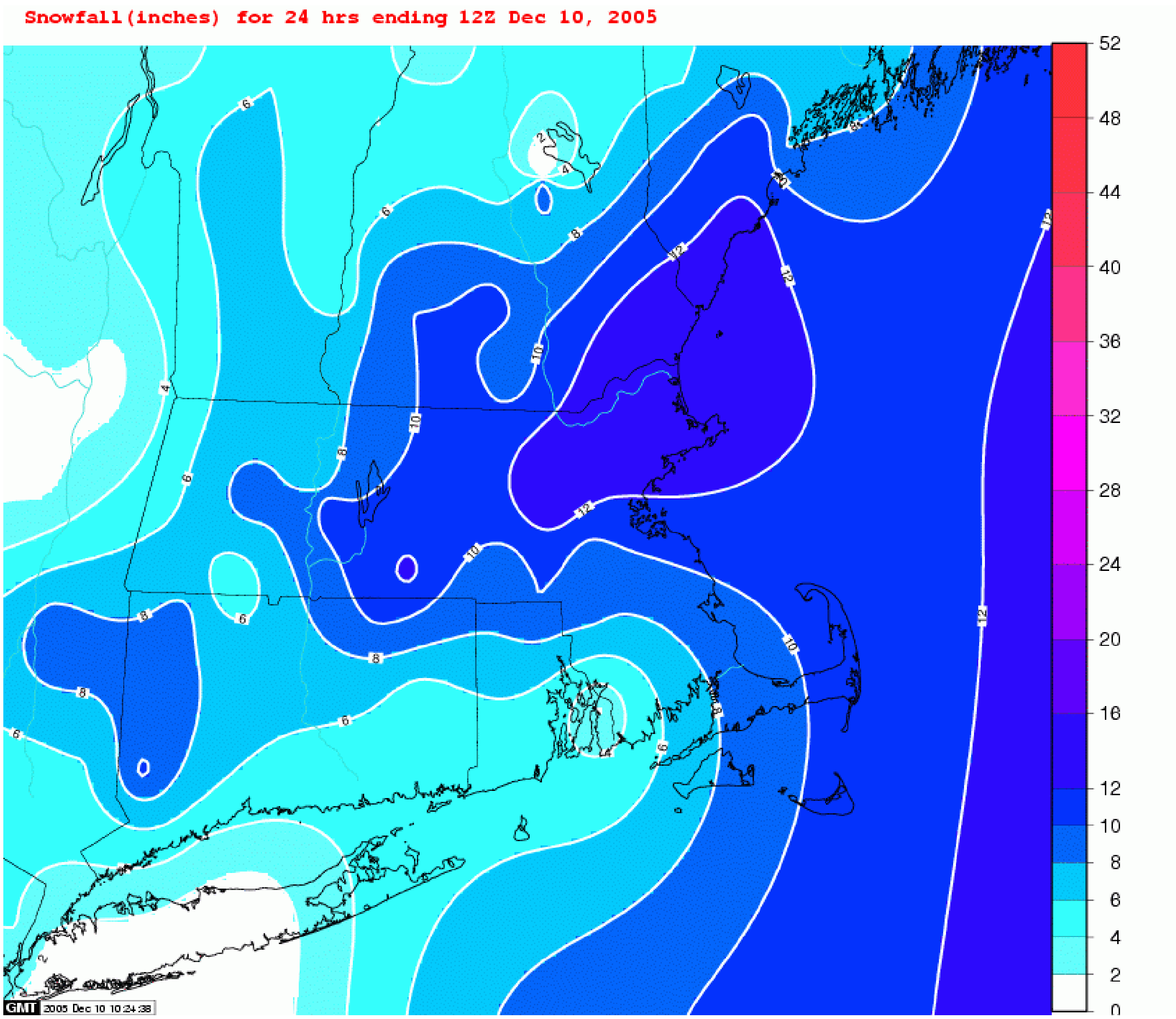


Figure 1. 24 hour snowfall between 12 UTC, 09 December 2005 and 12 UTC, 10 December 2005 in inches, from the National Weather Service office at Taunton, MA.

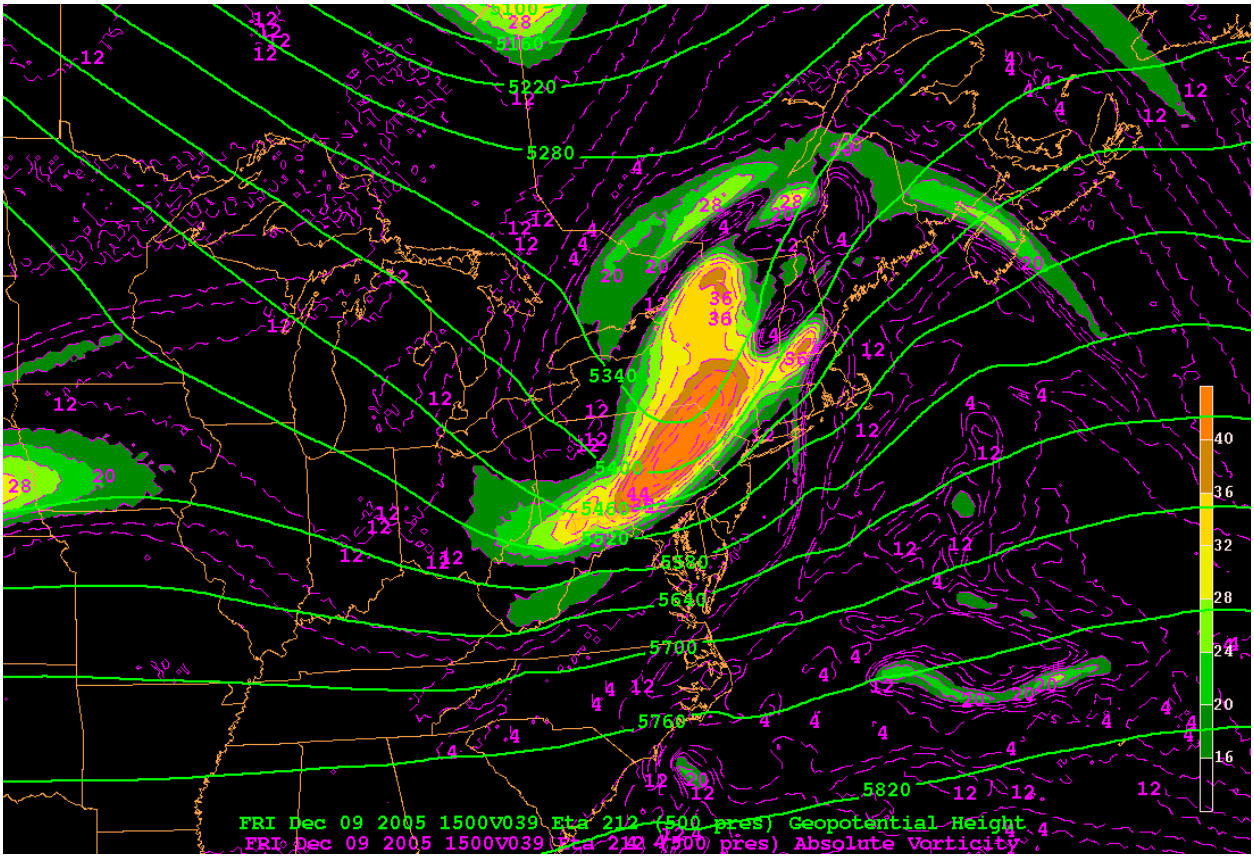


Figure 2. 500 hPa heights (green contours, m) and vorticity (purple contours, 10^{-5} s^{-1})

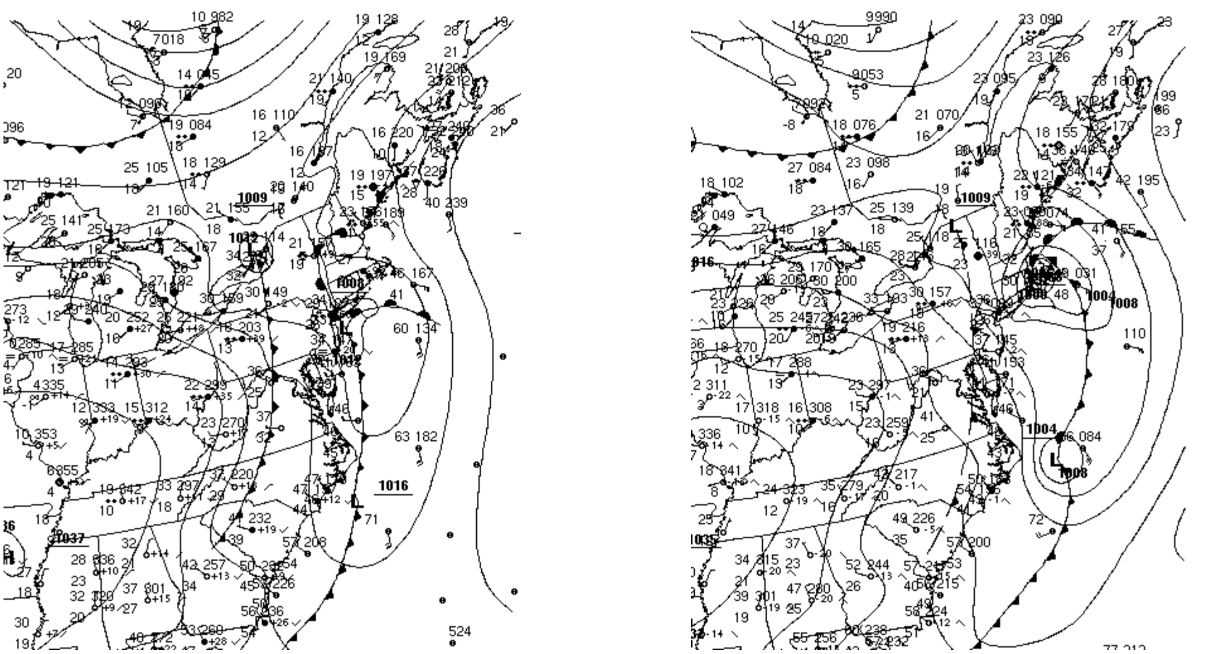


Figure 3. Surface Difax analysis from NWS for December 09, 2005. Left side valid 15 UTC, right side valid 18 UTC.

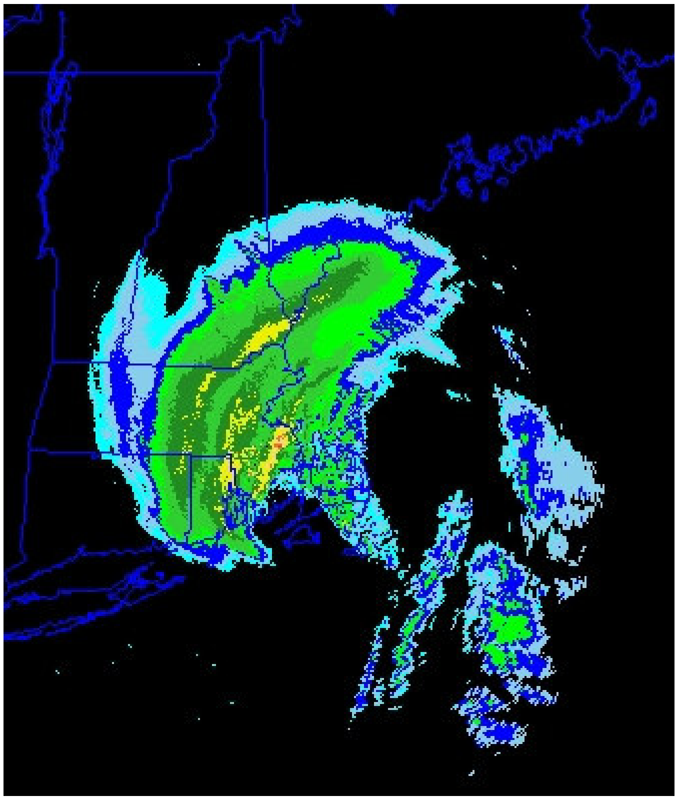
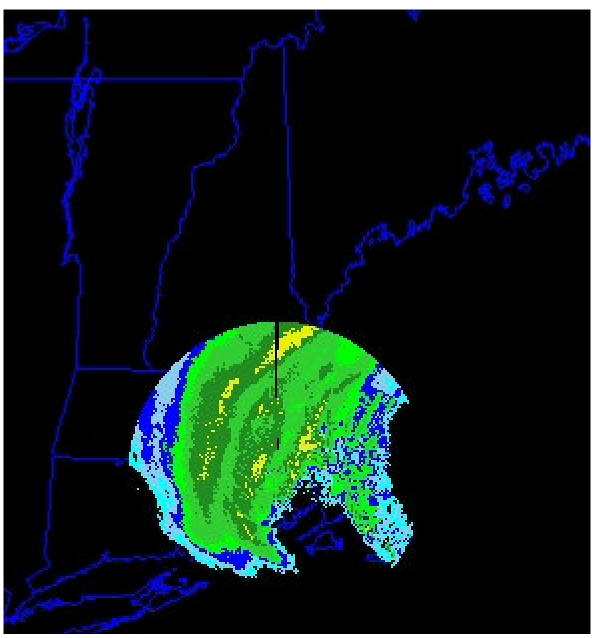


Figure 4a. Reflectivity from Taunton NWS radar, for 1856 UTC, 09 December 2005, 0.5^{o} elevation scan.



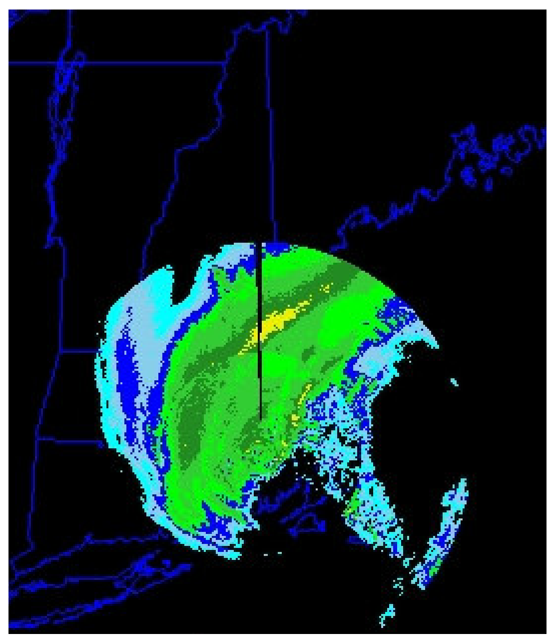


Figure 4b. CAPPI for 1856 UTC at 1 km.

Figure 4c. CAPPI for 1856 UTC at 2 km.

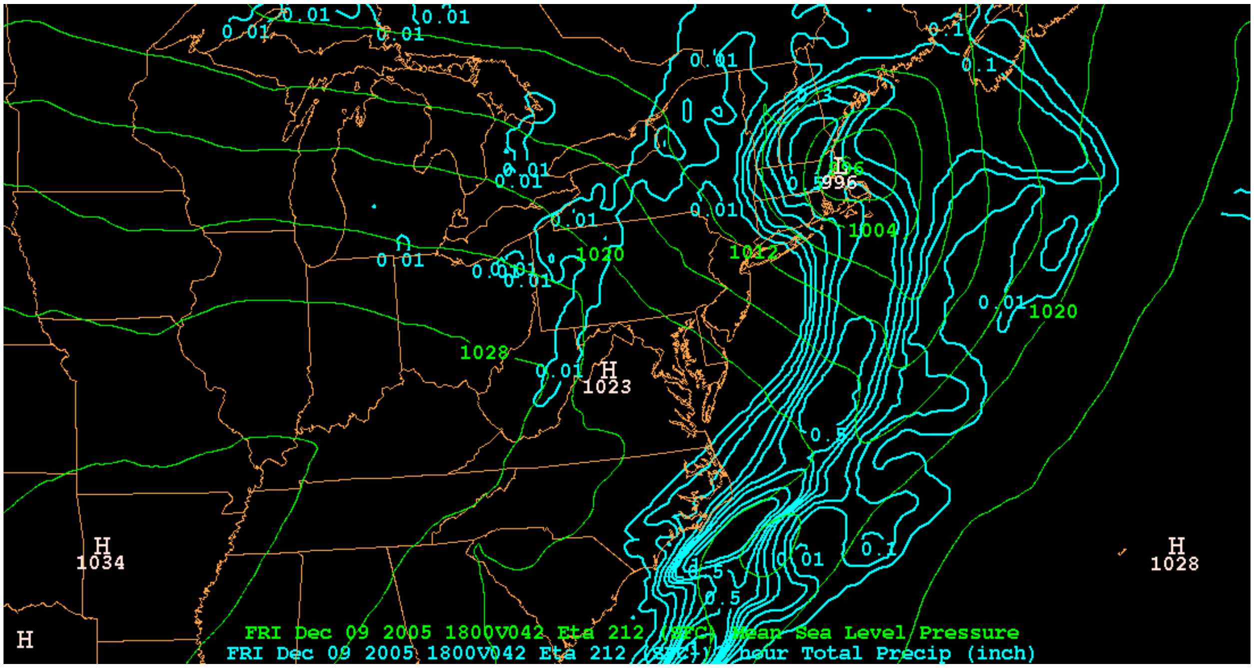


Figure 5. 42 hour forecast valid 18 UTC, 09 December 2005. Green contours are sea level pressure (hPa) and blue contours show accumulated liquid precipitation from 15 UTC to 18 UTC, as labeled in inches.

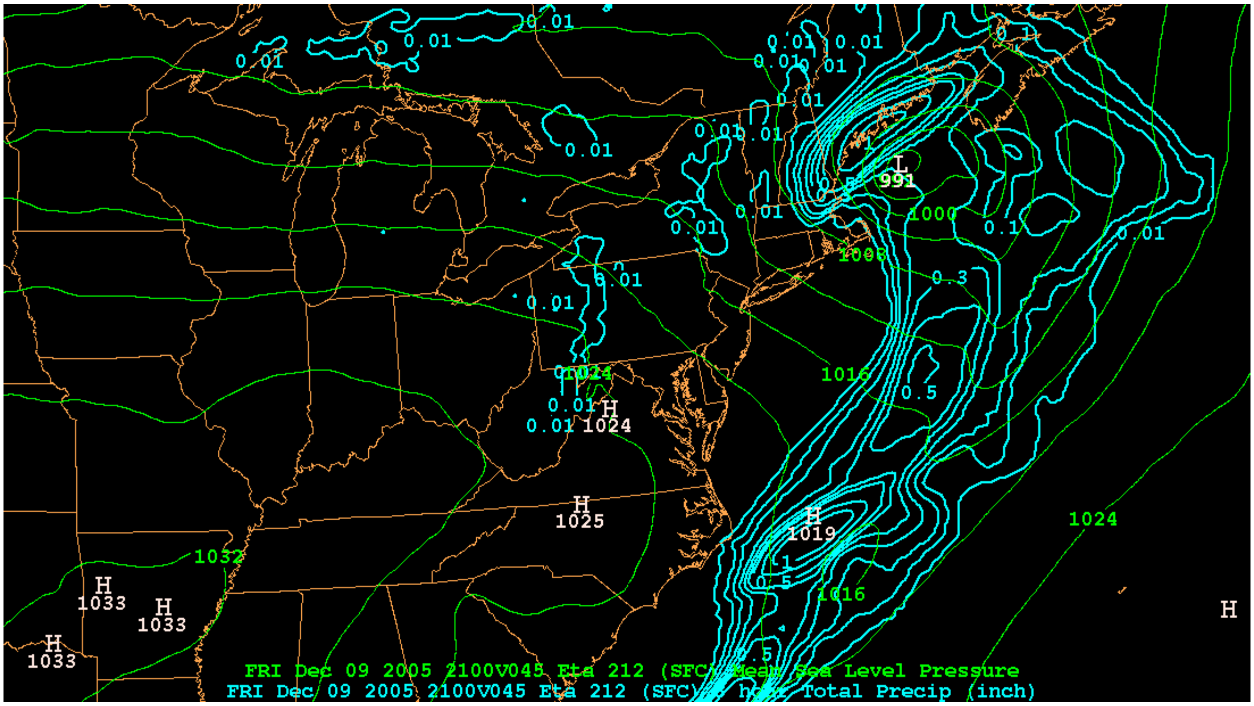


Figure 6. As in Fig. 5 but showing 45 hour forecast valid at 21 UTC.

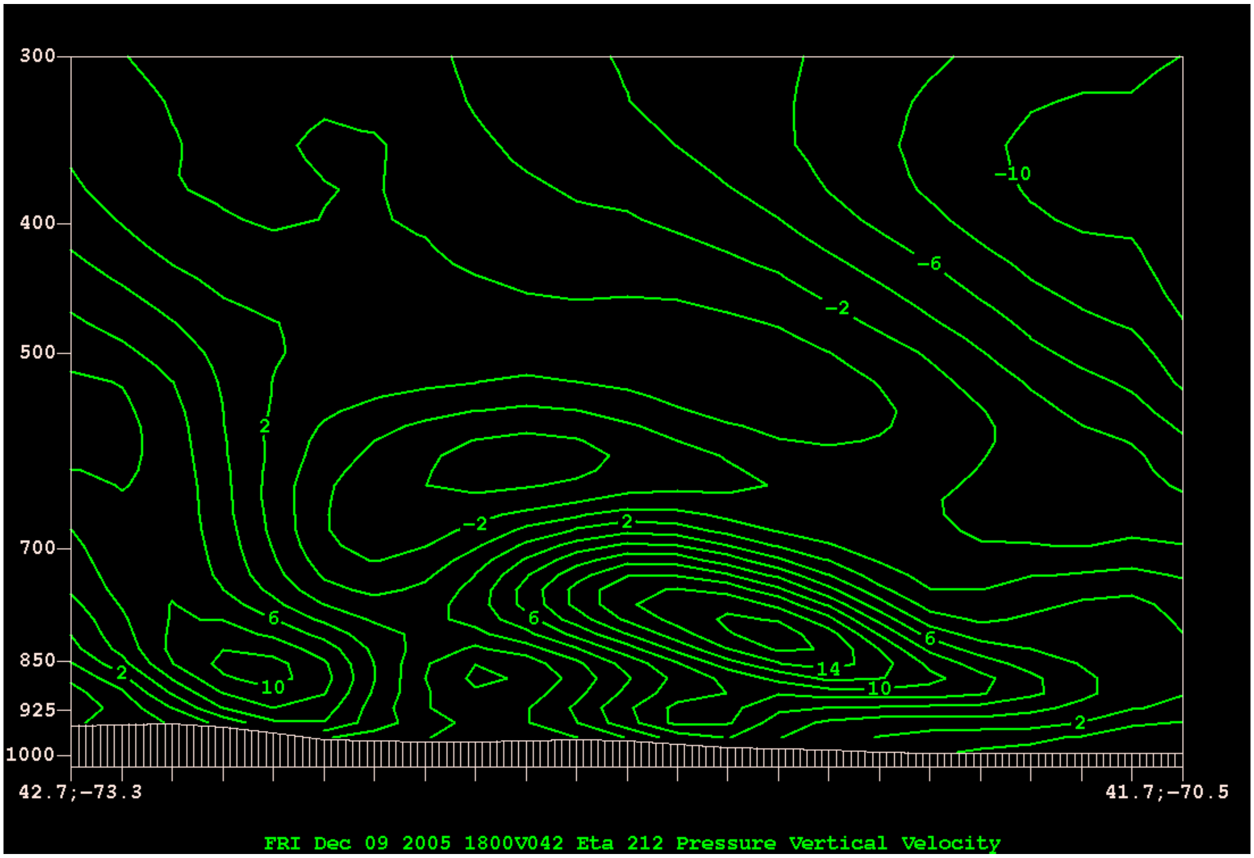


Figure 7. Cross section perpendicular to precipitation band at 18 UTC, 09 December 2005, from Eta 42 hour forecast.

4a. *MM5 Simulation*

Figure 8 shows the sea level pressure analysis at 18 and 21 UTC from the MM5 simulation. Notice that the surface low was actually composed of two lows, one further south along the cold frontal trough, and the main low hugging the New England coast. To the north of the low, a coastal front extends along the coastal plane, as can be seen in the temperature analyses in Fig. 9. As the surface low continued out to sea to the east, the low level circulation advected cold air from the north, dropping the air temperatures from near or slightly above freezing, to well below freezing, thus insuring that any precipitation that might fall would be snow.

Fig. 10 shows the precipitation from the MM5 simulation at 21 UTC, showing how precipitation did not end as the storm moved off the coast. A cross section from the 3 km domain of the MM5 simulation, drawn perpendicular to the band at 18 UTC, appears in Fig. 11. A careful examination of this figure shows that the triple line structure seen in the radar images is also present in the cross section, as shown by the computed reflectivity and the vertical motion near sigma = 0.9.

The forcing for the band appears to be a blend of convective instability (CI) and symmetric instability. Figure 12 is a cross section of geostrophic momentum and equivalent potential temperature. Where equivalent potential temperature decreases with height (assuming a saturated atmosphere), we have upright convective instability. Where the slope of the equivalent potential temperature lines are more vertical (but not showing CI), than the geostrophic momentum lines, we have CSI. There are regions of both in this cross section, with the CI in a layer above the CSI. Hence, both types of instability were present.

There is evidence of a tropopause fold that shows up on cross sections of potential vorticity. Figure 13 shows potential vorticity at 19 UTC from the 3 km domain of the MM5 model run, and there are regions of stratospheric potential vorticity (values greater than 2) which extend down into the troposphere.

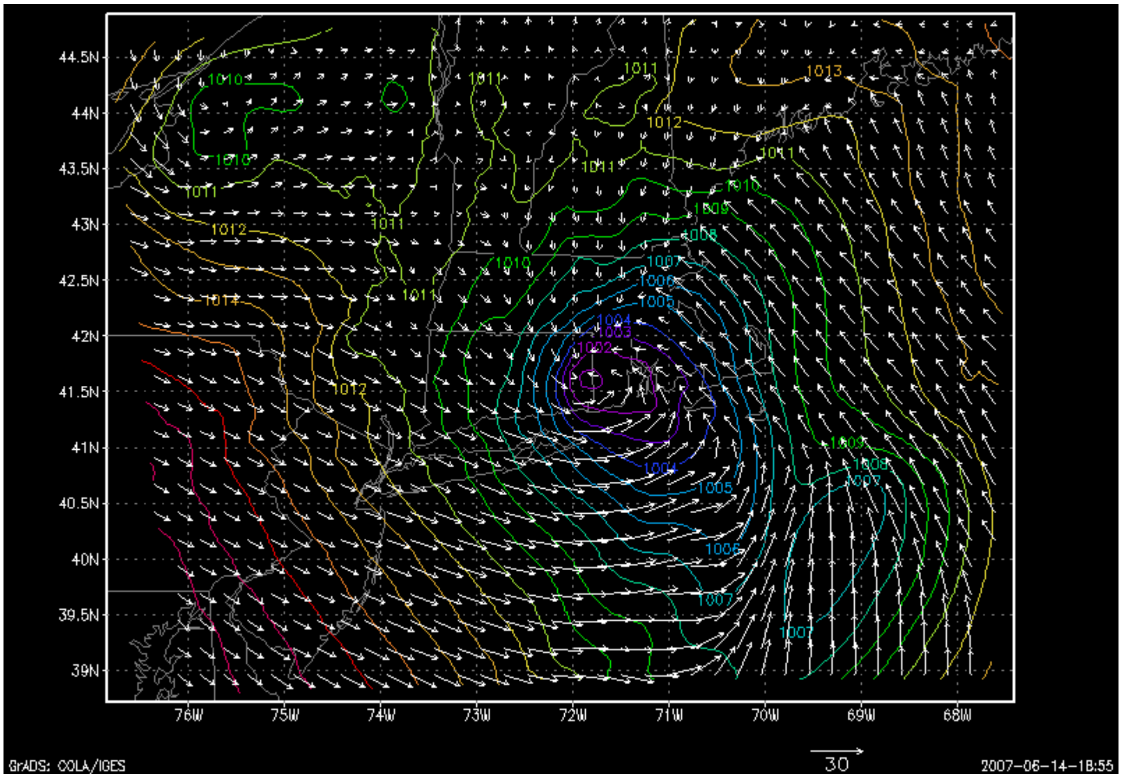


Figure 8a. Sea level pressure (hPa) and near-surface winds from MM5 simulation, 9 km domain, valid 18 UTC, 09 December 2005.

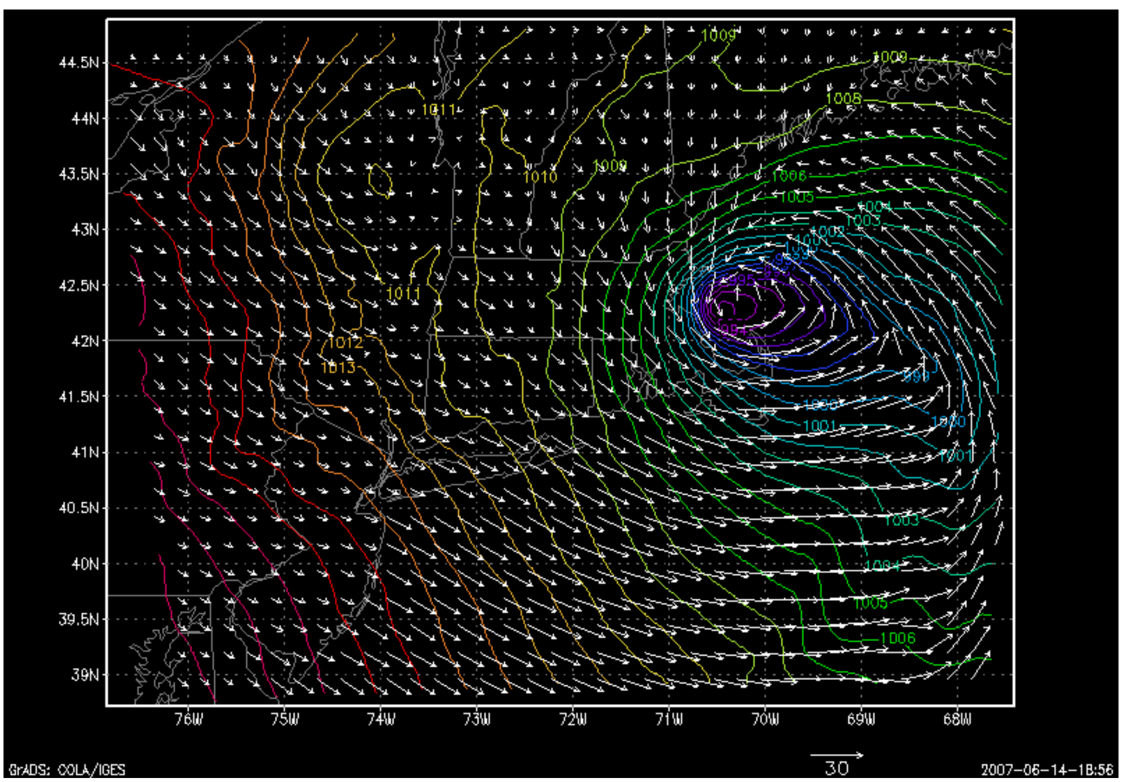


Figure 8b. As in Fig. 8, except for 21 UTC.

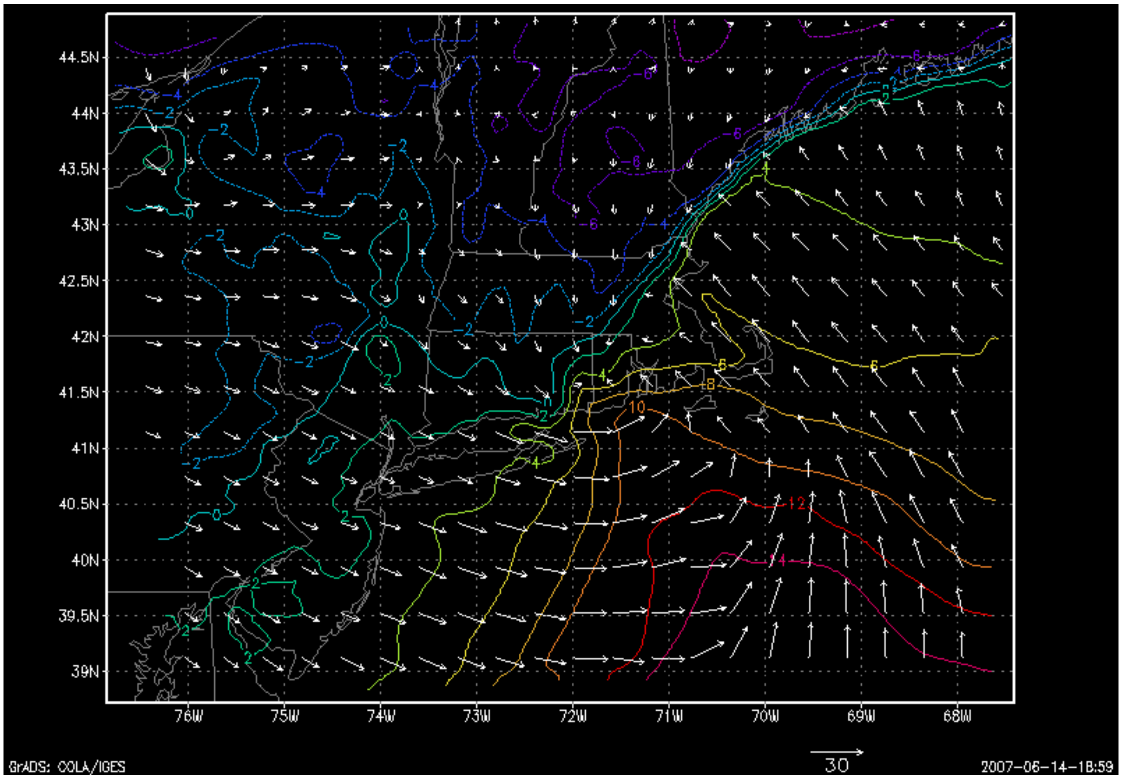


Figure 9a. As in Fig. 8a, except for near-surface temperatures in ^{o}C.

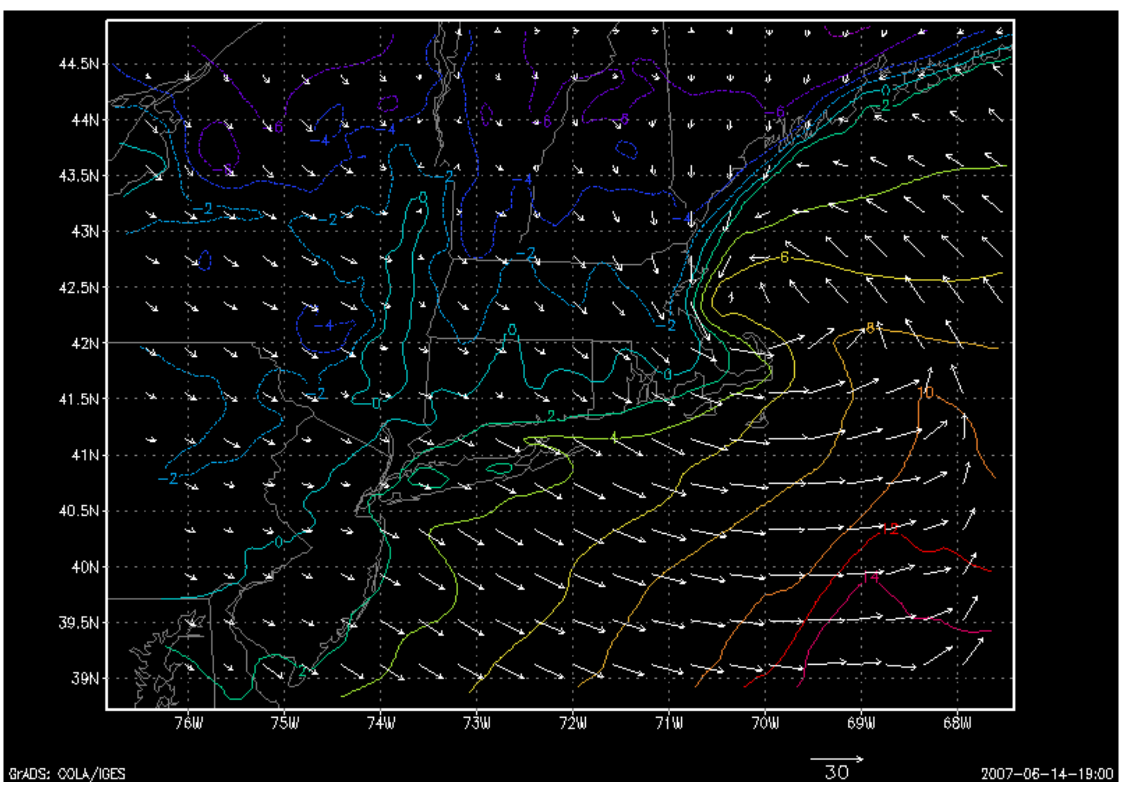


Figure 9b. As in Fig. 8b, except for near-surface temperatures in ^{o}C.

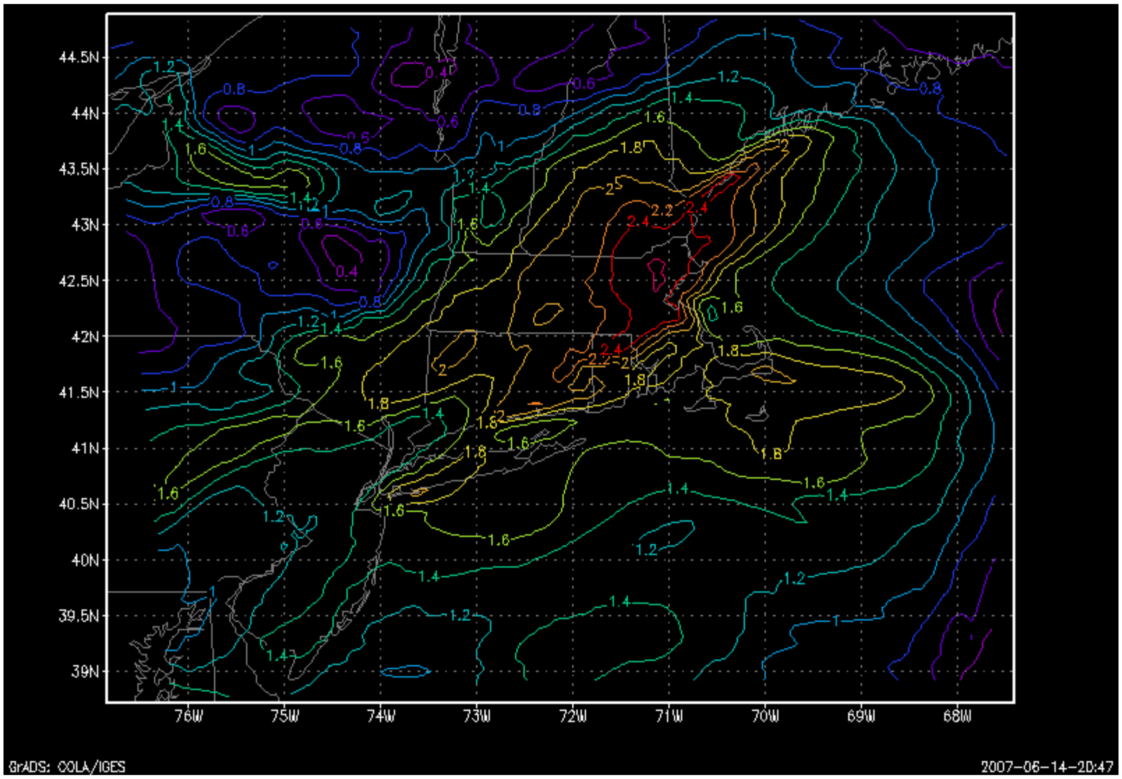


Figure 10. Accumulated liquid precipitation between 20 and 21 UTC on 09 December 2005, from MM5 model simulation, 9 km domain.

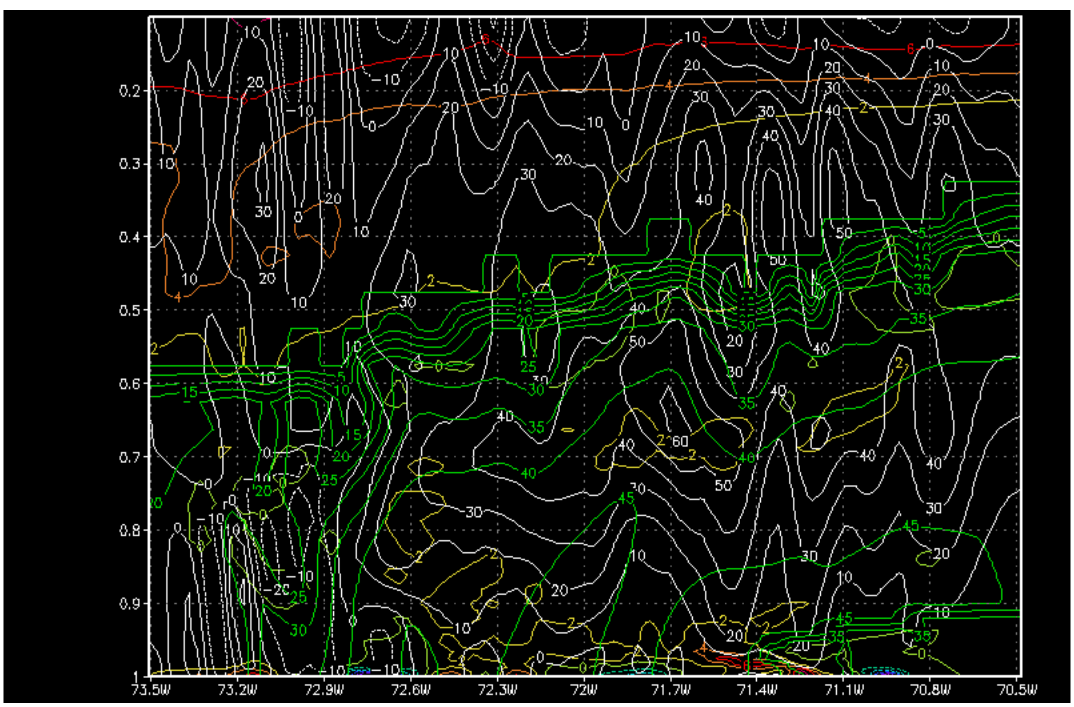


Figure 11. Cross section at 18 UTC from 3 km domain of MM5 model run perpendicular to the main precipitation band. Colored contours are potential vorticity in pvu units, white contours are vertical motion (cm/s) and green contours are computed radar reflectivity in dBz.

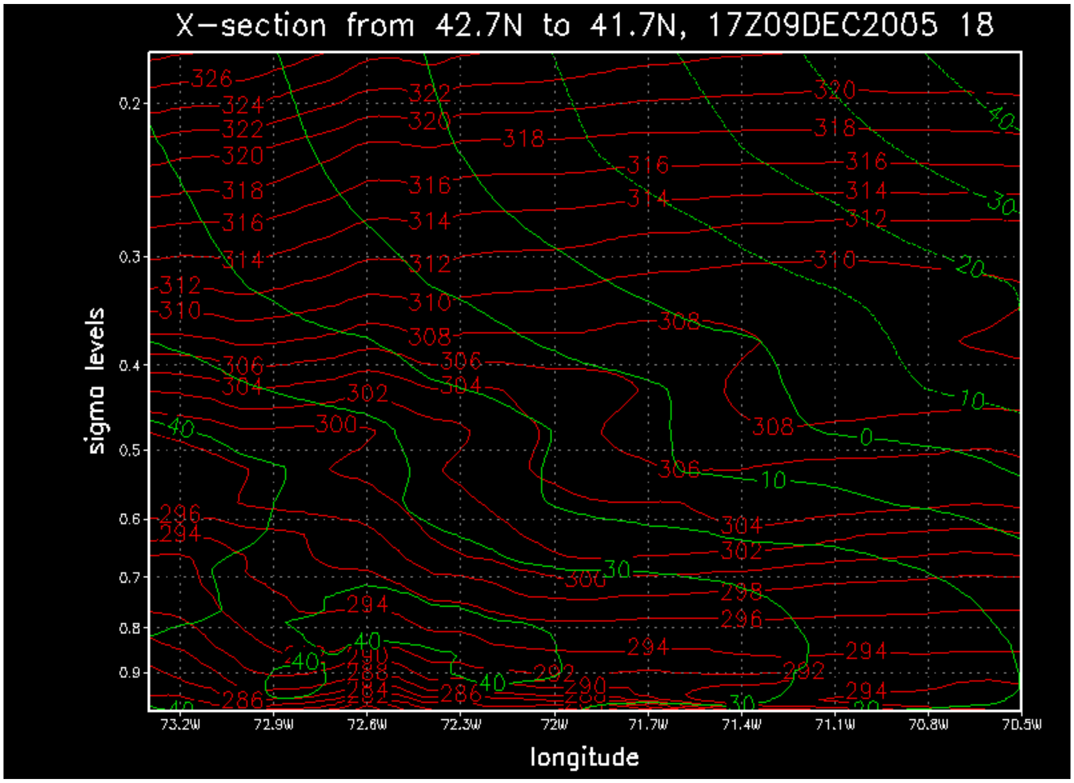


Figure 12. As in Fig. 11 except green contours show geostrophic momentum (m/s) and red contours show equivalent potential temperature (K).

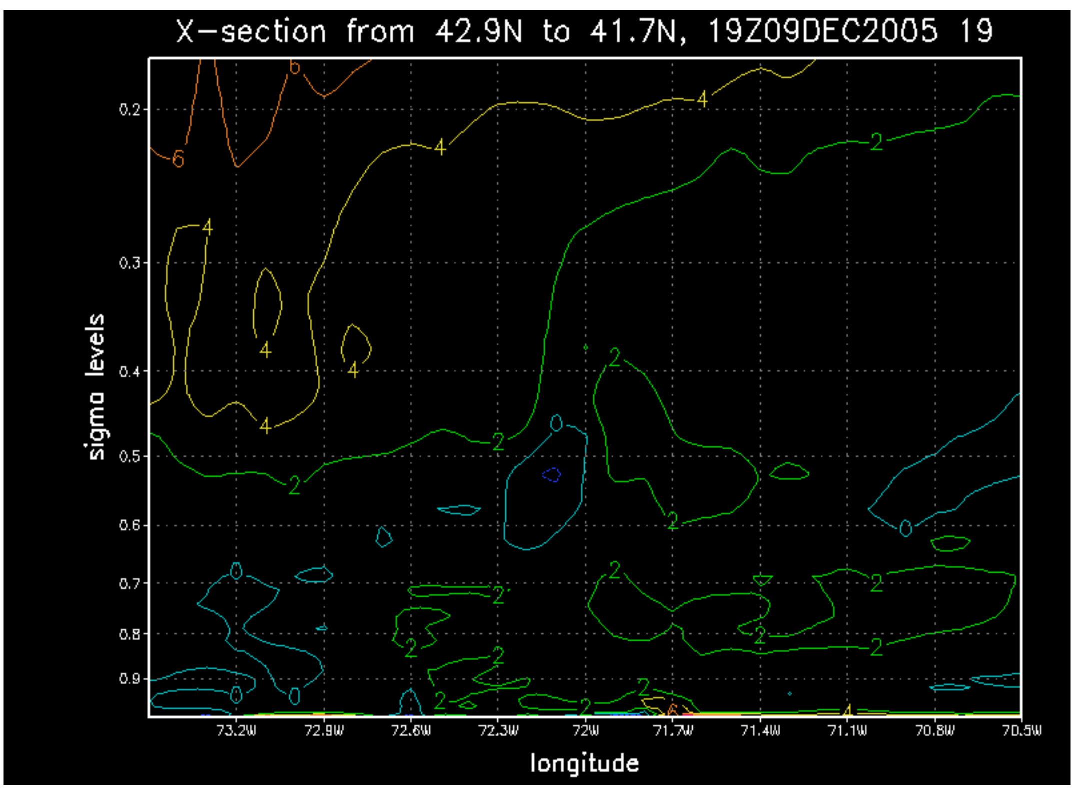


Figure 13. As in Fig. 11, except only showing potential vorticity.

5. Conclusions

The 9 km domain of the nested MM5 simulation was able to produce many of the observed mesoscale details, some of which were not forecast by the operational Eta model, despite the fact that the Eta was running at 12 km spacing, very close to that of the MM5. But the multiple lines within the main rain band were separated by only about 20 – 30 km, which would only be 2 – 3 grid boxes in the Eta, but 3 – 4 grid boxes in the MM5. Thus, the quality of the simulation of the mesoscale details on this scale were very sensitive to the grid size

Further research will focus on the development of the layer of instability, the role of surface fluxes over the ocean in the early lifetime of the system, and the impact of the quality of the boundary conditions. The Eta model run relied on the Global Forecast System output for boundary conditions, while the MM5 run used only analyses, not forecast fields for its boundary condition. Finally, the failure of the WRF model to simulate this nor'easter will also be investigated.