P32 ANALYZING THE ROLE OF LOW-LEVEL FORCING IN SIGNIFICANT SEVERE WEATHER OUTBREAKS IN THE EASTERN U.S.

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1. Introduction

The operational implementation of convection allowing mesoscale models (CAMs) have been a major advancement in severe weather forecasting, however the primary strength of these models has been in forecasting convective mode (Kain et al. 2006), along with storm-scale quantities such as updraft helicity. While accurate forecasts of these factors can certainly improve forecasters situational awareness regarding the potential magnitude of severe weather events, additional, observation-based studies involving sources such as expanding meso-net networks and the GOES-16 satellite observations can still improve the quality of severe weather forecasts. This paper describes one such study.

The Storm Prediction Center and National Weather Service Forecast Offices are providing outlooks and forecasts with increasingly specific details on timing and mode of convection at lead times in some cases of a day or more. However, there are still some aspects of severe weather forecasting that are more difficult than others, including areal coverage and mode of convection in and downstream of complex terrain and proximate to large bodies of water such as the Great Lakes and Atlantic Ocean. These geographic features can significantly interrupt, disrupt and modify thermodynamic parameters and forcing mechanisms that affect the development and evolution of convection.

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Studies such as Banacos and Ekster (2010) have identified thermodynamic parameters that contribute to significant severe weather in the Northeastern U.S., namely Elevated Mixed Layers (EMLs). Stuart (2004 and 2012) analyzed instability, 850-hPa wind maxima and 850-hPa $\nabla\theta_e$ as forcing mechanisms that contribute to significant severe weather east of the Appalachian Mountains.

This study builds upon those previous studies and adds composites of 850-hPa θ_e in order to illustrate the life cycle of the low-level density discontinuity ($\nabla\theta_e$) and analyze its role in cases with significant severe weather. Composites for the Mid-Atlantic, Northeastern U.S. and derecho events will be presented. Characteristics of the baroclinic zone associated with significant severe weather events in these areas will be examined by evaluating 850-hPa $\nabla\theta_e$ over a fixed distance, in this study 400 km.

2. Data and Methods

The North American Regional Reanalysis dataset from 1979-present (Mesinger et al. 2006) was used to create composites of 850-hPa θ_e for significant severe weather events. The severe weather outbreaks of 9 June 1953 and 24 June 1960 could not be used for the composites because they predated the NARR dataset. Hence, for this study, composites were made from 9 events in the Northeastern U.S., 13 events in the Mid-Atlantic and 6 derecho events. Stuart (2004 and 2012) found that significant severe events in the Mid-Atlantic and Northeastern U.S. are typically associated with 850-hPa $\nabla\theta_e$ of equal to or greater than 25 K

(400 km)$^{-1}$; all of the events in this study equaled or exceeded this threshold.

Each significant severe weather event in the aforementioned categories was objectively analyzed and the time at which the magnitude of the 850-hPa $\nabla\theta_e$ was greatest across each respective domain was recorded. Composites of 850-hPa θ_e were then created at 3 hour intervals from 12 hours prior to greatest 850-hPa θ_e gradient to 12 hours after to illustrate the lifecycle of the 850-hPa θ_e gradients. The life cycles of the 850-hPa θ_e gradients were then analyzed to determine the role the low-level density discontinuities played in the low-level forcing component of significant severe weather outbreaks.

Mesoscale low-level density discontinuities often exhibit $\nabla\theta_e$ with large magnitudes over distances of 100 km or less that don't always initiate and sustain organized convection. The display of the magnitudes of $\nabla\theta_e$ is highly dependent on the resolution of the dataset or forecast model as different spatial resolutions can often result in considerable differences in magnitude. The focus of this study is the contribution of the larger synoptic scale $\nabla\theta_e$ to the low-level forcing in significant severe weather events. Hence, 850 hPa $\nabla\theta_e$ in units of K(400 km)$^{-1}$ were used to determine the threshold representing the low-level forcing in significant severe weather events.

3. Composites for Northeastern U.S. and Mid Atlantic severe weather events.

Composites of 850-hPa θ_e for both the Northeastern and Mid-Atlantic regions of the U.S. were created in 3-hour time steps from t-12 hours to t+12 hours of the greatest magnitude of $\nabla\theta_e$ in order to illustrate the eastward progression of the zones of $\nabla\theta_e$ in units of K(400 km)$^{-1}$. The composites did not resolve any mesoscale gradients or terrain effects on the $\nabla\theta_e$ as the $\nabla\theta_e$ crossed the mountains, likely due to the averaging and smoothing during the compositing process.

Over the Northeastern U.S., the zone of $\nabla\theta_e \geq$ 20K(400 km)$^{-1}$ starts in the Great Lakes at t-12 hours and is centered over the Northeastern U.S. at t=0 hours (Fig. 1), then south of Long Island New York at t+12 hours. The Mid-Atlantic composites are similar, showing the zone of $\nabla\theta e \geq$ 20K(400 km)$^{-1}$ centered north and west of the Appalachian Mountains at t-12 hours, centered over the Carolinas, Virginia and Maryland at t=0 hours (Fig. 2) and just off the East Coast at t+12 hours. However, some minor "composite smearing" is likely masking the greater magnitude $\nabla\theta_e$ in most of the individual events that contributed to the composites, which depicted $\nabla\theta_e \geq$ 25K(400 km)$^{-1}$.

The composites of θ_e are quite representative of individual events within the 9 member Northeastern U.S. and 13 member Mid-Atlantic composites. Figure 3 shows the 850-hPa θ_e for the 1 June 2011 event in the Northeastern U.S. Note the similarity in $\nabla\theta_e$ between the composite shown in Fig. 1 and the single case shown in figure 3. Also note the changes in θ_e within the 400 km distance, further illustrating that there are $\nabla\theta_e$ of higher magnitude over the 400 km distance.

4. Derechos

Serial derechos are considered a subset of the significant severe weather events associated with the progressive θ_e boundaries along the leading edge of low-level cold advection. Widespread damaging wind reports are often among the significant hail and tornado events in severe weather events associated with cold advection and eastward and southward movement of low-level density discontinuities. Hence, composites of $\nabla\theta_e$ for the progressive θ_e boundaries are valid for the serial derechos as well.

However, the low-level forcing and convective processes associated with progressive derechos is different due to the relatively stationary nature of the low-level density discontinuity that is the source of initiation and maintenance of the convection.

The composite for progressive derechos shows west to east-oriented $\nabla\theta_e$ across the Great Lakes but a $\Delta\theta_e$ of only 15-20K (Fig. 4). This composite suffers from "composite smearing" due to the different positions of the θ_e boundaries for the different events. A look at the maximum $\nabla\theta_e$ in two events will show the more representative higher magnitude $\nabla\theta_e$ in actual derecho events. Figure 5 shows the $\Delta\theta_e$ and $\nabla\theta_e$ during the 29 June 2012 derecho that affected the Ohio Valley to the Mid-Atlantic U.S. Figure 6 shows the $\Delta\theta_e$ and $\nabla\theta_e$ for the 15 July 1995 derecho that affected the Adirondacks in New York. Note that in both events, the $\nabla\theta_e$ exceed 25K(400 km)$^{-1}$.

5. Discussion and Conclusions

Low-level forcing is just one contributor to the occurrence of significant severe weather, but when lacking, often results in little-to-no severe weather, sometimes even minimal convection (Jurewicz (2004), Stuart (2004 and 2012)). Analysis of individual significant severe weather events in the Northeastern U.S. and Mid Atlantic U.S. revealed that 850-hPa $\nabla\theta_e \geq$ 25K(400 km)$^{-1}$ represented the low-level density discontinuity and forcing component of significant severe weather events.

In this study, composites of 850-hPa θ_e were produced for Northeastern and Mid-Atlantic U.S. significant severe weather events and progressive derechos. The Northeastern and Mid-Atlantic U.S. composites of 850-hPa $\nabla\theta_e$ revealed a threshold of 20K(400 km)$^{-1}$ for significant severe weather, while individual events exhibited 850-hPa $\nabla\theta_e \geq$ 25K(400 km)$^{-1}$. The progressive derecho composites exhibited 850-hPa $\nabla\theta_e$ of 15K-20K(400 km)$^{-1}$. Individual progressive derecho events showed 850-hPa $\nabla\theta_e \geq$ 25K(400 km)$^{-1}$.

Since all of the composites suffered from some degree of "composite smearing" due to the different locations of the gradients for each individual event it is recommended that the $\nabla\theta_e \geq$ 25K(400 km)$^{-1}$ better defines the $\nabla\theta_e$ associated with significant severe weather. It should be noted that until an NWP model product displaying $\nabla\theta_e$ objectively in units of K(400 km$)^{-1}$ is available, there will be some subjectivity in analyzing $\nabla\theta_e$ of 25K over a distance of 400 km.

Most recently, the 850-hPa $\Delta\theta_e$ met the threshold of 25K(400 km)$^{-1}$ on 15 May 2018 when a significant severe weather outbreak occurred over Pennsylvania, southern New York and southwestern New England (not shown). Future work will include increasing the database of events to further verify the 850-hPa $\nabla\theta_e$ threshold. Additionally, $\nabla\theta_e$ will also be analyzed for severe weather events with numerous reports of hail and damage that do not meet the definition of significant weather but still produce a significant societal impact. Cool season cases will also be analyzed, especially in the Mid-Atlantic region where severe weather can occur during the transition to the cool season.

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References

Banacos, P., and M. Ekster, 2010: The association of the elevated mixed layer with significant severe weather events in the Northeastern United States. *Wea. Forecasting*, **25,** 1082–1102

Jurewicz, M. L. 2004: The May 11, 2003 severe weather null case across the Northeastern and Mid-Atlantic states. *Preprints* 22nd Conference on Severe Local Storms. Hyannis, MA, 10.6.

Kain, J.S., and Coauthors, 2006: Examination of Convection-Allowing Configurations of the WRF Model for the Prediction of

Severe Convective Weather: The SPC/NSSL Spring Program 2004. *Wea. Forecasting,* **21**, 167–181, https://doi.org/10.1175/WAF906.1

Lacorte, J. J. and R. H. Grumm 2002: The climatology and character of Pennsylvania severe weather. *Preprints* 21st Conference on Severe Local Storms. San Antonio, TX, P8.3.

Mesinger, F., and Coauthors, 2006: North American Regional Reanalysis. *Bull. Amer. Meteor. Soc.*, **87**, 343–360.

Stuart N. A. 2004: The anatomy of the big event that never happened – The Grand Finale of the May 2003 Tornado Outbreak. *Preprints* 22nd Conference on Severe Local Storms. Hyannis, MA, 12.8.

Stuart N. A. 2012: Identifying Key Features to Predict Significant Severe Weather Outbreaks in the Northeastern United States. *Preprints* 26th Conference on Severe Local Storms. Nashville, TN, P9.140.

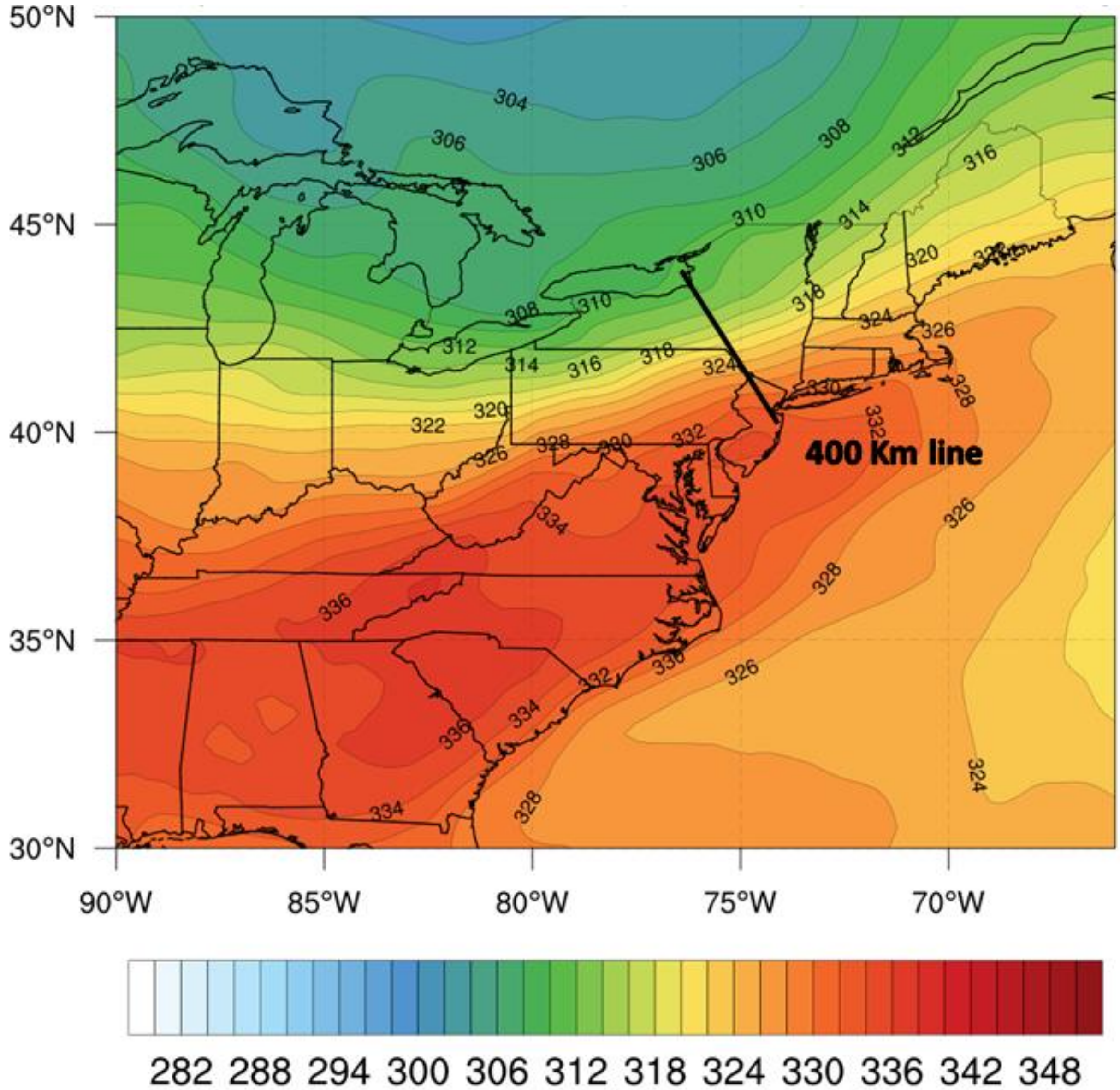

Figure 1. Composite (N=9) of 850-hPa θ_e for severe weather events in the Northeastern U.S. at the time of maximum magnitude with a line 400 km in length overlaid.

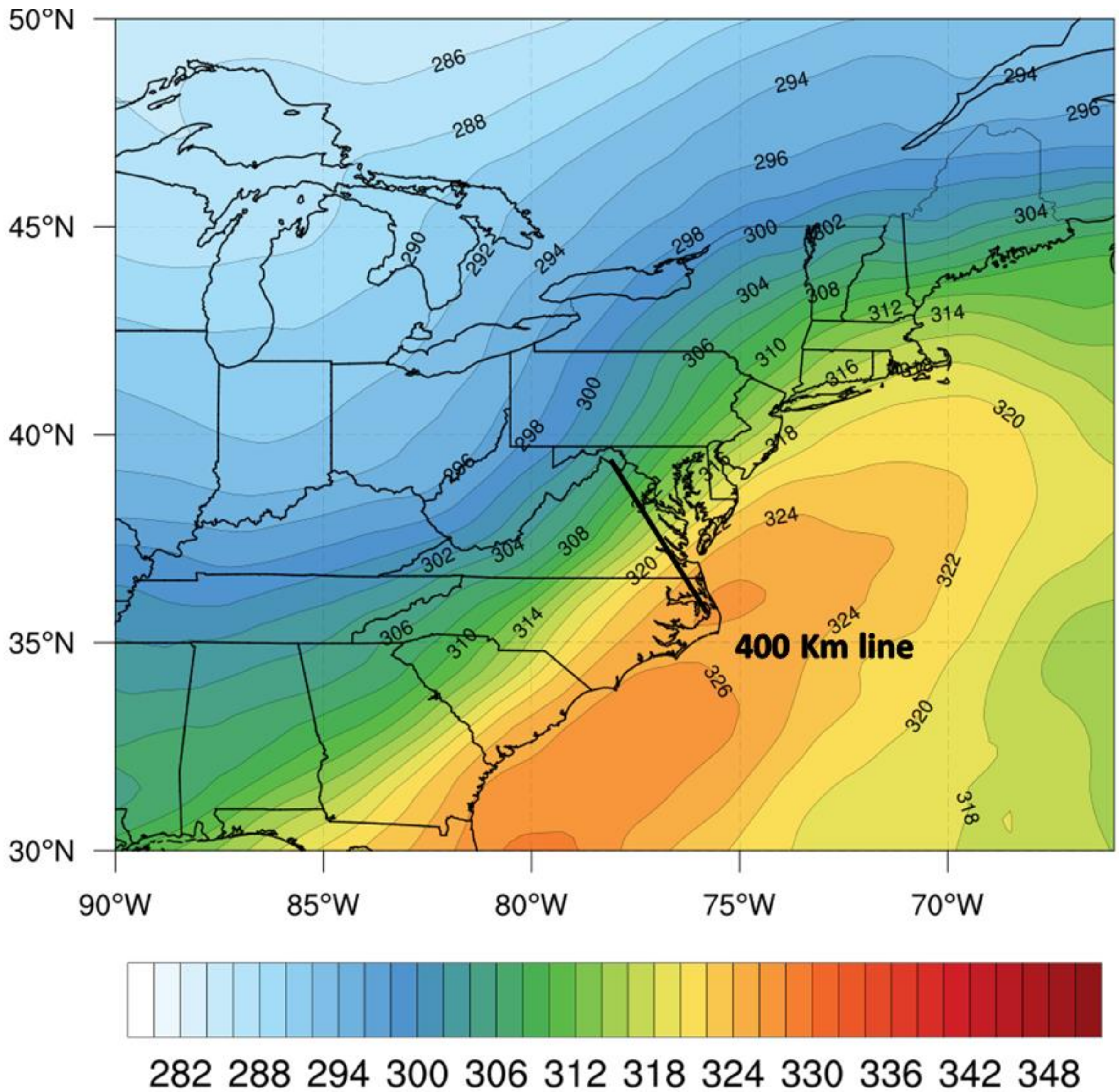

Figure 2. Same as in Fig. 2 except for 13 cases in the Mid Atlantic U.S.

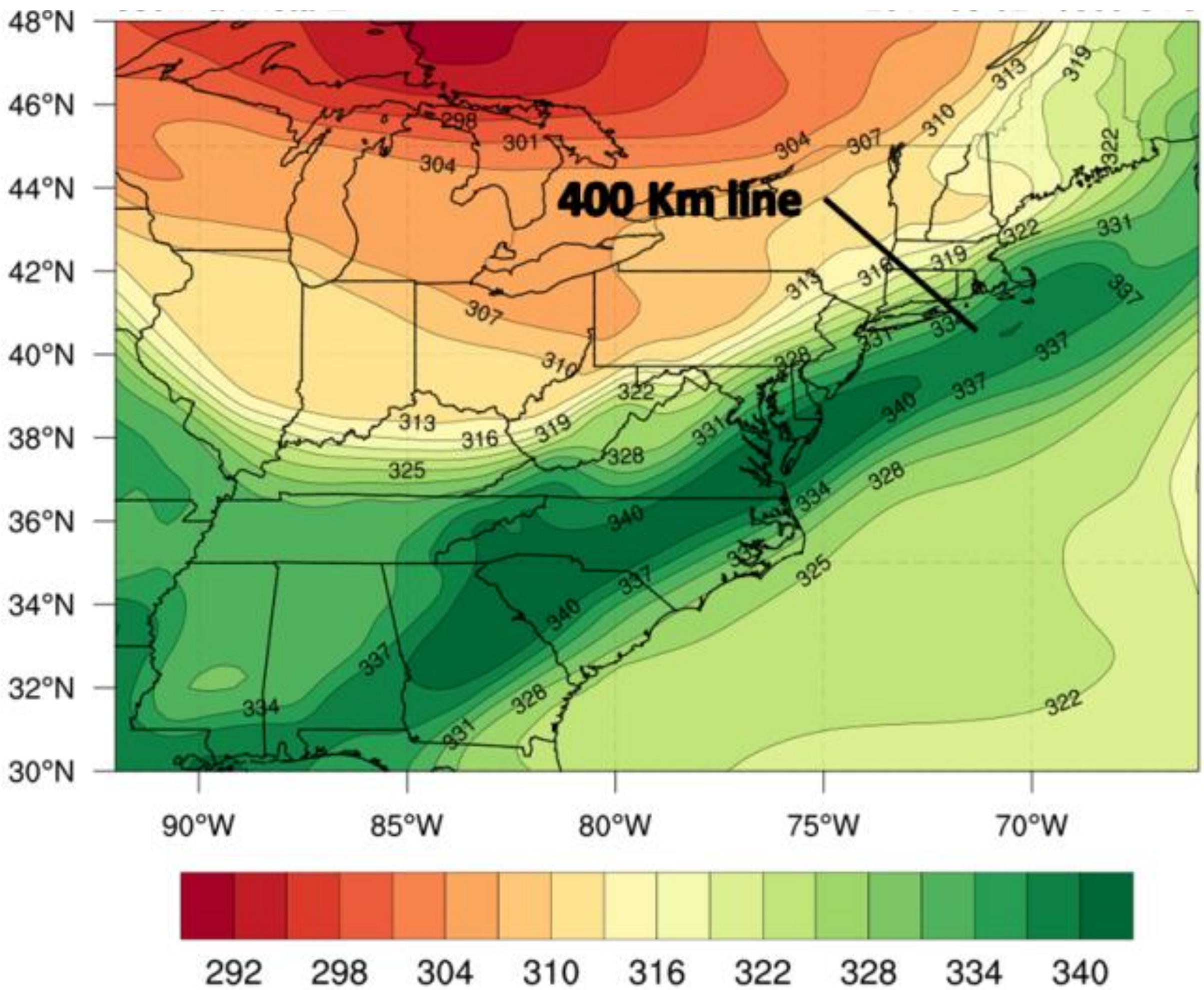

Figure 3. NARR analysis of 850-hPa θ_e valid 0300 UTC 2 June 2011 with a line of 400 km length overlaid.

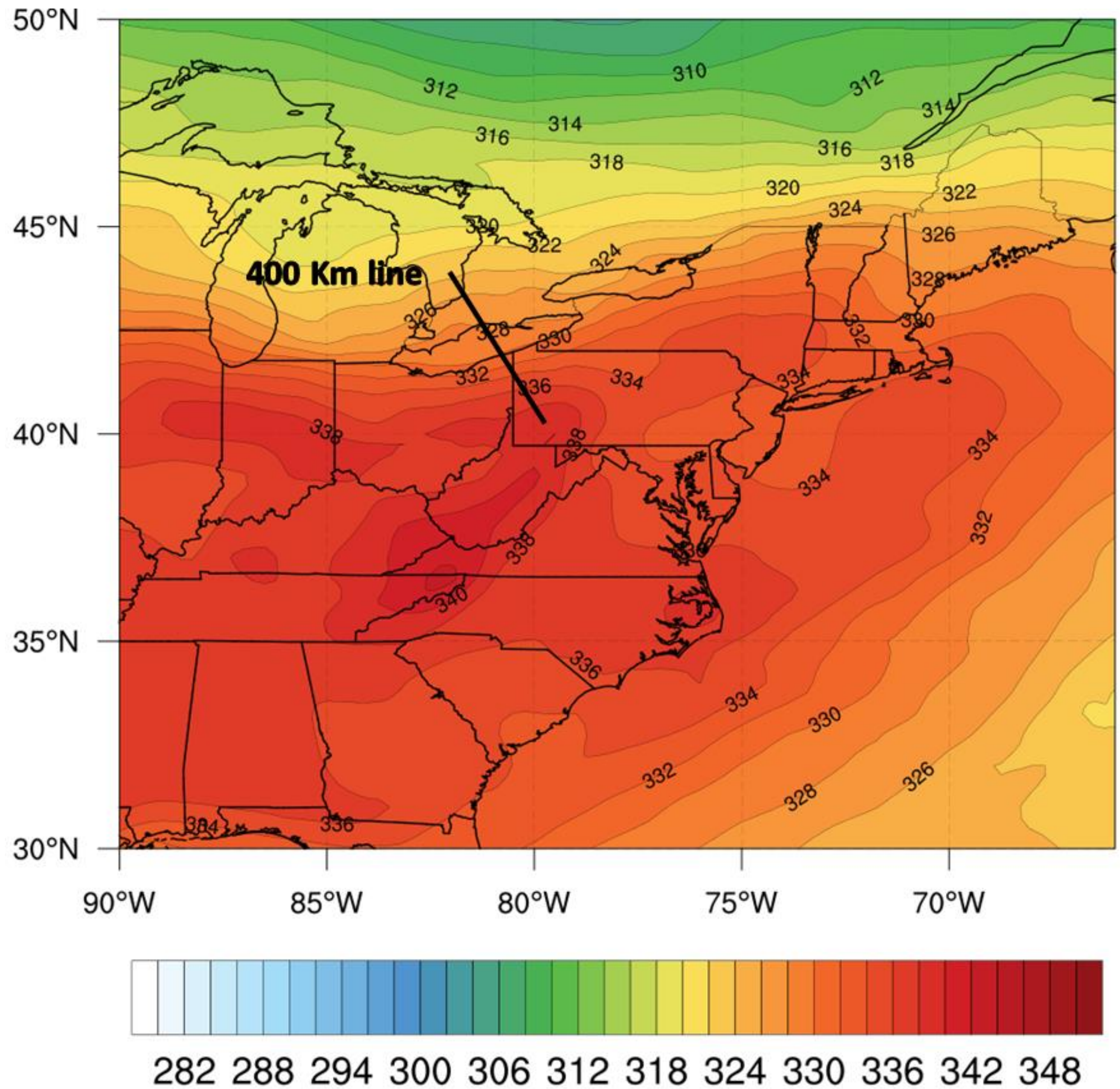

Figure 4. Same as in Fig. 1 except for 6 progressive derecho cases.

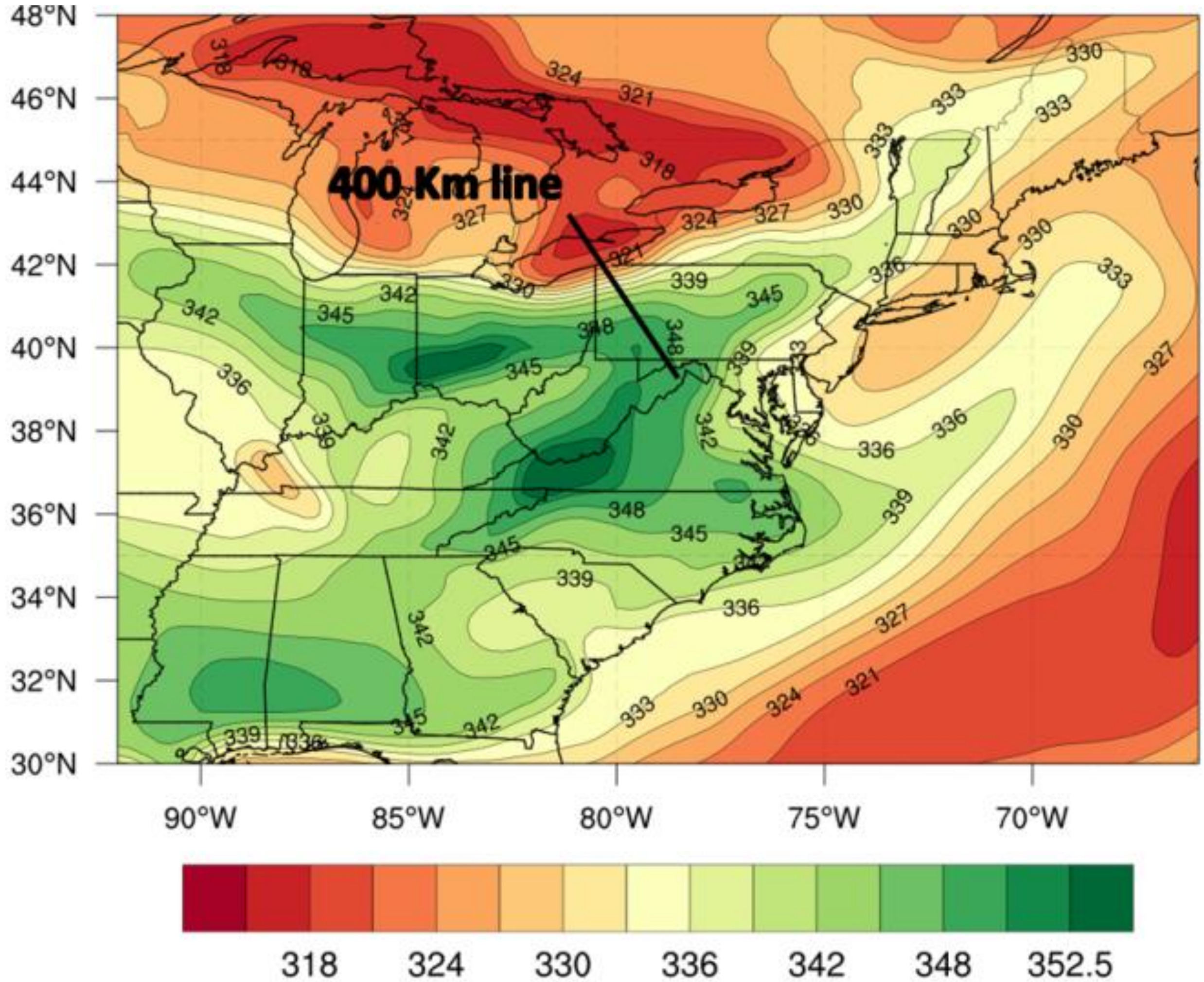

Figure 5. NARR analysis of 850-hPa θ_e valid 2100 UTC 29 June 2012 with a line of 400 km length overlaid.

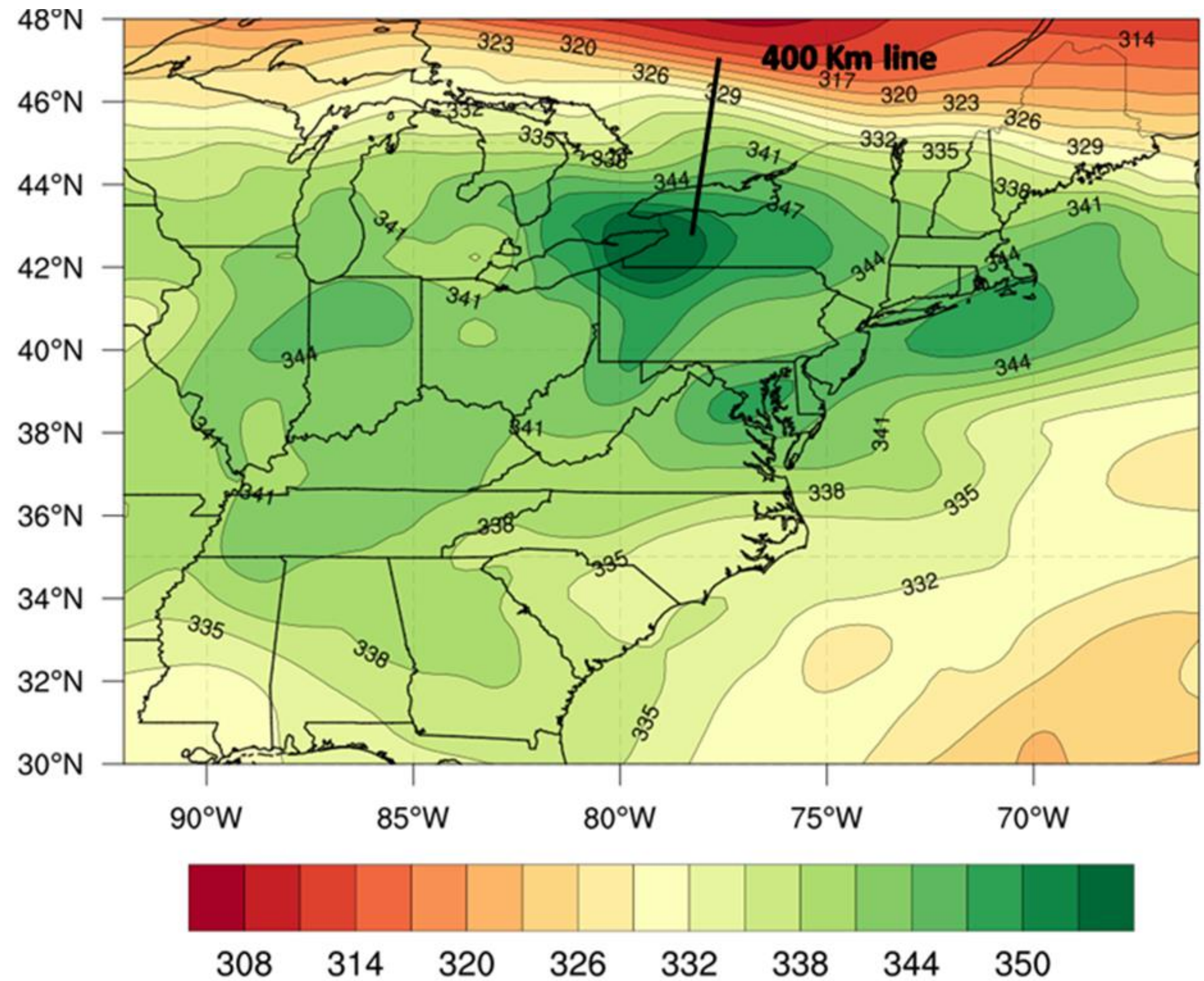

Figure 6. NARR analysis of 850-hPa θ_e valid 0900 UTC 15 July 1995 with a line of 400 km length overlaid.