12.8 The Anatomy of the Big Event That Never Happened – The Grand Finale of the May 2003 Tornado Outbreak

Neil A. Stuart*
NOAA/National Weather Service Wakefield VA

1. Introduction

During the week from 3-10 May 2003, over 400 tornadoes were reported across the central and eastern United States, more tornadoes than in any other week on record. Most of the tornadoes occurred west of the Appalachian Mountains, many were significant, rated F2 or greater on the Fujita scale (Fujita 1971). A series of strong 500 hPa level vorticity centers tracked out of the northern plains and into the Midwest and Great Lakes through the week, coupled with strong upper level jet stream dynamics, contributing to this historic tornado outbreak. The final in the series of strong upper level vorticity centers formed over southern Minnesota on 10 May, tracking into Wisconsin by early 11 May. This impulse was forecasted to affect the eastern U. S., triggering one last day of tornadoes, before exiting the northeast late on 11 May.

The National Oceanic and Atmospheric Administration (NOAA) Storm Prediction Center (SPC) and all local National Weather Service (NWS) Weather Forecast Offices (WFOs) serving the area from Maryland through the Carolinas, were predicting the formation of a severe squall line and a potentially significant wind damage and tornado outbreak. The threat for wind damage and tornadoes was emphasized on the SPC daily severe weather outlook, and local WFO statements and Hazardous Weather Outlooks. Despite the extreme instability present, no thunderstorms or severe weather were observed from Maryland through North Carolina. Considering the unanimous agreement within the meteorological community (NWS and media), that a significant severe weather outbreak was imminent, this can be viewed as a substantial forecast error, highly visible to the user community.

The 11 May non-event was compared with another recent non-event of 31 May 2004, which was similar to 11 May 2003, and 14 synoptic events that produced significant severe weather, including two recent events: 28 April 2002 (LaPlata, Maryland F4 tornado and other damaging severe weather in the Mid-Atlantic) and 2 May 2002 (widespread wind damage and hail in Virginia and North Carolina).

*****_Corresponding Author's Address: 10009 General Mahone Hwy, Wakefield, VA 23888_
E-mail address: Neil.Stuart@noaa.gov

Wind profile data from the NOAA profiler network, upper air plots from the SPC archive, and Numerical Weather Prediction (NWP) forecast model output will be presented, which will illustrate the forcing mechanisms at both the synoptic scale and mesoscale levels in the region from Maryland through the Carolinas.

Several important distinctions were identified between the 2 non-events, and the significant events. By comparing the evolution of the synoptic scale and mesoscale features associated with the non-events with the significant events, substantial differences can be seen in the evolution of synoptic features as well as differing forcing mechanisms. With this knowledge, forecasters will be able to identify significant events and non-events in real-time forecast operations.

2. Synoptic scale characteristics

In all the events, the primary upper-level vorticity center originates in the northern plains, and tracks toward the Great Lakes. The movement of the upper-level vorticity center after entering the Great Lakes is what distinguishes the events versus the non-events.

In the non-events, a nearly stationary upper-level vorticity center was moving from Wisconsin to Michigan in 12 hours (Fig. 1). In severe events where the primary upper-level vorticity center originated in the upper Mississippi River Valley, the upper-level energy tracked into New England and Southeast Canada in 12 to 18 hours (Fig. 2), similar to what LaCorte and Grumm (2003) concluded about Pennsylvania severe weather events. NWP forecast model output depicted the slow movement of the upper vorticity center very accurately for the 11-12 May 2003 event. The slow movement of the upper vorticity center over the western Great Lakes implied upper dynamics and forcing that were too far northwest of the Mid-Atlantic to increase low-level forcing and lift in the Mid-Atlantic.

Another important difference was the 300 hPa jet structure. In the severe event cases, the Mid-Atlantic region was situated in the left-exit or right-entrance regions of the upper jet (Fig. 3). These regions of the upper jet have been shown in previous research to increase upper divergence (Uccellini and Kocin 1987), which can enhance thunderstorm updrafts, and increase the potential for significant severe weather. During the non-events, the Mid-Atlantic region was not situated in these favorable regions of the upper jet (Figure 4).

3. Mesoscale Features

The difference in the evolution of synoptic-scale features has a profound effect on the evolution of mesoscale features. Mesoscale features are the key to sustaining convection as it crosses the mountains, and when an upper-level vorticity center is not progressive, mesoscale features are not maintained as they move east of the mountains.

An important factor during the 2 non-events was the lack of low level forcing or a convective trigger. Low-level forcing from the surface through 850 hPa (as the upper limit of the friction zone, and vertical extent of the Appalachian Mountains) was analyzed. For this study, the surface and 850 hPa fronts will be defined as the region where the tightest gradient of equivalent potential temperature (θ_e) exists. In the severe weather events, the 850 hPa cold front was characterized as a θ_e gradient of 25ºC or more in the region of the tightest gradient, typically in a distance ≤400 km (not shown). Regions east of the Appalachian Mountains that do not experience the passage of this 850 hPa θ_e gradient, but sufficient instability and shear are present for severe weather, have greatly reduced chances of observing severe weather, even thunderstorms.

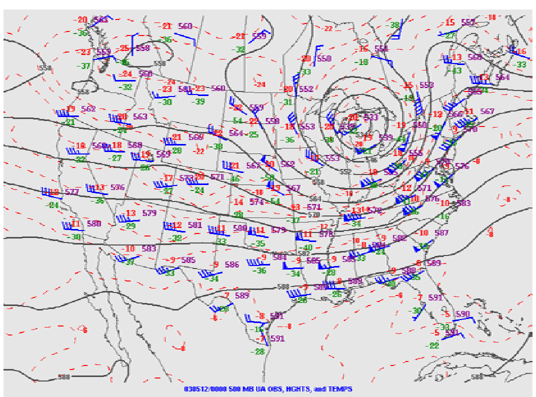

Figure 1. 0000 UTC 12 May 2003 observed 500-hPa plot, with height contours (dm; solid), wind barbs (kt) and temperatures (C; dashed). Note the upper low over Michigan.

During the non-events, the θ_e gradients of the surface and 850 hPa cold fronts either loosened to <25ºC in a distance ≤400 km, or did not track east of the Appalachian Mountains until the surface based instability had exited (Fig. 5). In fact, this was the case during both non-events. The low-level forcing must be sustained as it crosses the Appalachian Mountains for significant severe weather, even thunderstorms to occur in the Mid-Atlantic U.S.

The presence of a low-level jet, wind shear and the associated low-level forcing were evaluated through analysis of wind profiles from the events between 2001 and 2004. This is especially important when determining the presence of down slope wind flow in lee of the mountains. The Appalachian Mountains are oriented southwest to northeast, roughly 230° from due north, which is an important factor when considering down slope flow on the lee side of the mountains. Sinking motion on the lee side of the mountains can disrupt the low-level forcing mechanisms that initiate or sustain convection. Hence, if the mean 0-6 km wind flow over the Mid-Atlantic is nearly orthogonal to the mountains, then either strong low-level forcing or strong upper dynamics must overcome lee side down slope processes. Otherwise, the convection will weaken or dissipate in the process of crossing the mountains.

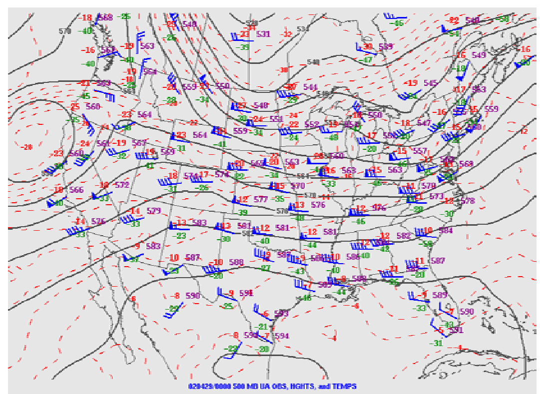

Figure 2. 0000 UTC 29 April 2002 observed 500-hPa heights (dm; solid), wind barbs (kt) and temperatures (C; dashed). Note the 500 hPa trough that was exiting the Great Lakes.

During the severe weather events of 2001-2004, the area wind profilers at Fort Meade, Maryland, Richmond, Virginia and Raleigh, North Carolina, showed surface winds backing to a more southerly direction an hour or less prior to the severe weather, increasing the directional shear within the 0-3 km layer. This evolution of low-level winds was apparent at Richmond, Virginia, just prior to the passage of a severe line of convection that produced widespread damaging winds, on 2 May 2002 (Fig. 6).

One of the forcing mechanisms that can sustain convection across the mountains is the 850 hPa jet. Speed convergence at the nose of the wind speed maximum was shown to contribute to the forcing that initiated and sustained the convection during the severe weather events (not shown).

Anomalously high wind speeds at 850 hPa peaked at 40-60 kt in all the events, but the timing and movement of the nose of the jet is one key to initiating and sustaining the convection. This is similar to what LaCorte and Grumm (2003) concluded in their study of the climatology of Pennsylvania severe weather. Broad, widespread 40-60 kt of wind at 850 hPa may not contain a definitive jet core with enhanced

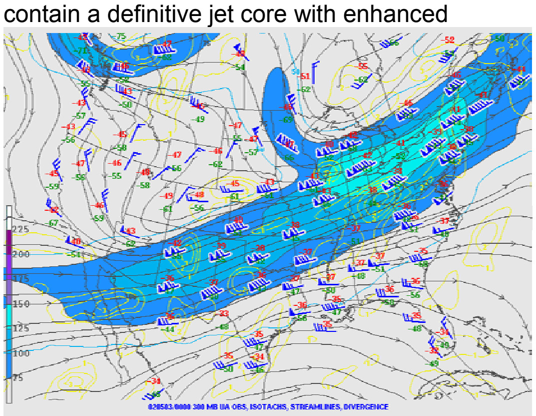

Figure 3. 0000 UTC 03 May 2002 300-hPa plot with streamlines (solid gray), wind barb (kt), and wind speed (above ___ shaded). Note the upper jet segment tracking out of Illinois and Indiana, putting the Mid-Atlantic in the right-entrance region of the upper jet.

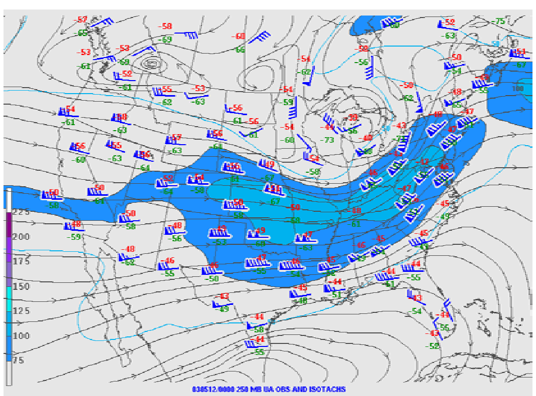

Figure 4. 0000 UTC 12 May 2003 250-hPa plot with height contours (dm; solid), wind barbs (kt), and wind speed (above __ shaded). Note that the Mid-Atlantic is not in a favorable region of the broad upper jet extending from the central plains through the Mid-Atlantic.

convergence. However, horizontal roll processes (Schultz et al. 2004) can contribute to initiation and sustaining of convection, in the presence of sufficient low-level θ_e gradient forcing.

Similar to 850 hPa features, the evolution of surface features directly impacts the initiation and maintenance of convection as it crosses the mountains. Surface convergence due to a wind shift or θ_e gradient can sustain convection as it crosses the mountains. Similar to features at 850 hPa, the surface low pressure center, wind shift and θ_e gradient must be progressive and not weakening.

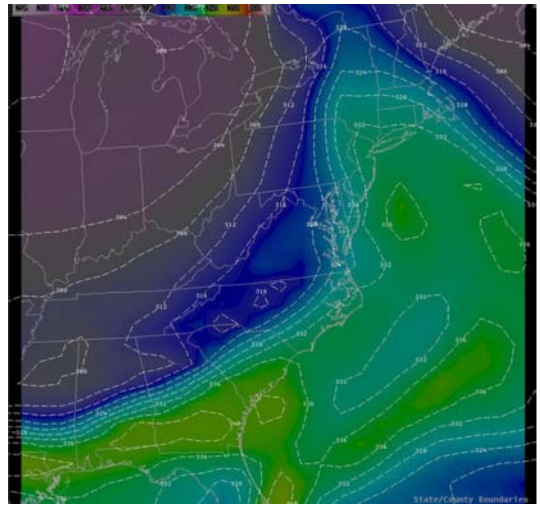

Figure 5. 6 hour forecast of 0000 UTC 12 May 2003 Global Forecast System (GFS) 850-hPa plot of θ_e (K). Note the tightest 850 hPa θ_e gradient in eastern Virginia is <16ºC.

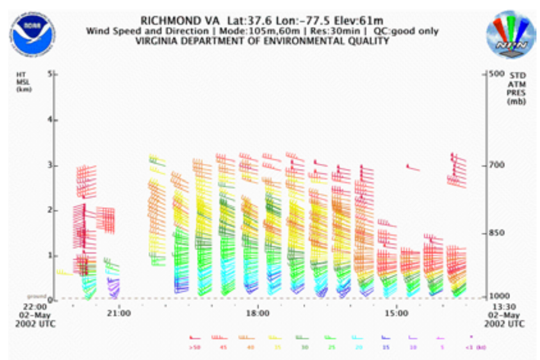

Figure 6. Richmond, VA wind profile at 2200 UTC 2 May 2002. Wind barbs are in knots. Note the surface winds backed between 2000 UTC and 2100 UTC.

4. Conclusion

Analysis of 14 other significant severe weather events, where either widespread wind damage or multiple F2+ tornadoes were observed (Table 1), showed that an 850 hPa θ_e gradient of at least 25ºC was present in the region of the tightest gradient in all the events, and progressively moved east, across the Appalachian Mountains and through the Mid-Atlantic U.S. The primary upper vorticity centers in all the events were progressive, tracking into the northeast U.S. or southeast Canada in 12 to 24 hours, and the Mid-Atlantic region was also situated in a region of the upper jet, favorable for enhanced vertical motion.

Evidence in the data for the 11 May case showed that the potential for severe thunderstorms was much less than was forecasted. By comparing expected events that do not occur, to events with similar synoptic and mesoscale characteristics that did produce severe weather, forecasters can improve their forecasting skills. Additionally, potential events and non-events can be identified in NWP model output in real-time forecast operations.

Table 1. Selected significant severe weather events that affected the Carolinas through Maryland during the past 20 years.

Event	Observed Severe WX
28 March 1984	Multiple F2+ tornadoes
08 May 1984	Multiple F2+ tornadoes
14 October 1986	Multiple F2+ tornadoes
28 November 1988	Multiple F2+ tornadoes
04 May 1990	Multiple F2+ tornadoes
04 November 1992	Multiple F0/F1tornadoes
23 November 1992	Multiple F2+ tornadoes
06 August 1993	Multiple F2+ tornadoes
07 January 1995	Widespread wind and F1/F0 tornadoes
11 November 1995	Widespread wind and F1/F0 tornadoes
01 April 1998	F3 tornado
24 September 2001	Multiple F2+ tornadoes
28 April 2002	Multiple F2+ tornadoes
02 May 2002	Widespread wind and hail

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