The record eastern United States Severe Weather event of 3-4 April 2011-Draft

by
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with
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Abstract:

A strong upper-level wave and jet stream pulled shallow moist air northward into the plains States and an elevated mixed layer over this warm moist air mass. This early season elevated mixed layer combined with strong winds to produce what can only be described as a massive severe weather event. With over 1300 reports of severe weather, mainly from strong winds, this was likely the largest and most extensive severe weather event over observed over the United States.

With over 1300 reports of severe weather this event eclipsed the events of 2 April 2006 (872) and 7 April 2006 (871) which were the previous top 2 events since 2005. Only 12 events since 2005 have produced 500 or more severe weather reports. Whether this event was truly historic or represents a reporting bias is not clear.

The strong upper-level jet, strong low-level jet, and high values of precipitable water combined with an elevated mixed layer clearly combined to produce a meteorologically and climatologically significant severe weather event. Most fields associated with severe weather, such as low-level winds and precipitable water were 2 to 4σ above normal during the event. Other fields such as moisture flux were extremely anomalous on both 3 and 4 April 2011.

1. INTRODUCTION

A strong early spring frontal system brought widespread severe weather to the eastern United States on 3-5 April 2011 (Fig. 1). With 324 and 1347 reports on the 3 and 4 respectively (Table 1), this was one of the largest severe events in the Storm Prediction Center (SPC) storm reports database. With over 1153 reports on 4 April 2011, this was the largest single event report date. Single day events with 500 or more reports are listed in Table 2. Clearly, with so many reports of severe weather, this was an unusual event.

A transient frontal system with a strong 500 hPa trough (Fig. 2) which pulled a tongue of deep moisture (Fig. 3) into the central and eastern United States. The surge of warm air ahead of the upper-level wave showed extremely warm air over the central Plains with 850 hPa temperatures anomalies over 3σ above normal (Fig. 4). This surge of warm air was identified to be associated with an elevated mixed layer (EML:Carlson and Ludlum 1968;Carlson et. al. 1983;Banacos et al. 2010). Strong EML's are more typically observed in the late spring and summer when the elevated terrain of the southwestern United States readily heats up and this deep warm layer is advected eastward. The shallow moist air beneath the cap or "lid" can be released with the capping inversion is broken. The EML initially inhibits severe convection; it limits mixing, allowing the low-level moist air to penetrate poleward; convection often breaks out along the edges of the lid and can organize with a strong frontal system. Many historic and memorable severe weather events are associated with EML.

In addition to the strong EML, strong low-level winds and strong upper-level jet streaks (Uccellini and Johnson 1979) are important ingredients in larger and more widespread severe weather events. Shear and instability are key ingredients for widespread severe weather events.

This paper will document the widespread severe weather event of 3-4 April 2011 with a focus on the record day of 4 April 2011 when over 1000 severe reports were received by the National Weather Service Storm Prediction Center. The large scale pattern and anomalies are presented to show the conditions which may have favored such a widespread event.

2. Methods and Data

The overall pattern was reconstructed using the 00-hour forecasts from the operational GFS. The anomalies were derived using the GFS and comparing it to the 30-year mean and standard deviations computed from the NCEP/NCAR re-analysis data (Kalnay et. al 1996). All anomalies herein are shown as standardized anomalies (Hart and Grumm 2001).

The GFS is run on a 27 km grid. However the data shown here is on a 1x1 degree grid. This should mitigate some of the resolution issues between the coarser climatology and the model forecast grids. These effects are normally of minimal impact for parameters above the planetary boundary layer. Some variables such as PW are sensitive and will show higher values in higher resolution models than in the re-analysis dataset.

Forecasts from the NCEP Ensemble Forecast systems (EFSs) will be presented. Standardized anomalies will be presented as described above, computing anomalies from the ensemble mean and the NCEP/NCAR re-analysis data. Probabilities are derived using the ensemble output. These will be raw and uncalibrated probabilities unless specified otherwise.

For brevity, times will be denoted in the format 04/1800 UTC to signify 1800 UTC 4April 2011 and time such as 03/1200 would signify 1300 UTC 3 April 2011.

Comparable cases were reconstructed using the JRA25 data.

3. The Storm system and impacts

i. The pattern and key anomalies

The 250 hPa jet evolution (Fig. 5) showed the evolution of a jet entrance region over the central United States from 04/0000 UTC through 05/0000 UTC. The wind anomalies in this strengthening jet, east of the approaching 500 hPa short-wave (Fig. 2) reached 4σ above normal by 05/0000 UTC (Fig. 5e) with over 3σ wind anomalies in the jet on the western flank of the upper-level trough. On a synoptic scale, this event was associated with a strong mid- and upper-tropospheric trough and accompanying jet stream.

The surge of high PW air, focused mainly in the lower-levels of the atmosphere (Fig. 3) and the elevated warm air (Fig. 4) played a critical part in the evolution of this severe weather event. The 700 hPa temperatures reached 8-12C over the central United States (Fig. 6) with 2 to 3σ above normal anomalies observed in this temperature field. The 700 hPa temperatures were over 14C near the elevated heat source in northern Mexico.

The large scale pattern showed the thermal and moisture pattern often associated with elevated moist layers. The deep and anomalous 850 and 700 hPa temperatures (Figs. 4&6) fields and the above normal PW values implied a broad area covered by the EML with significant amounts of low-level moisture.

j. Regional pattern

The evolution of the surface cyclone (Fig. 7) shows a deep cyclone moving into the western Great Lakes with 3 to 4σ below normal pressure anomalies. The gradient implied a strong low-level southwesterly jet ahead of the cold front extending south of the cyclone. At 850 hPa the strong low-level jet (LLJ) with the anticipated southwesterly flow showed 3 to 4σ total wind anomalies. Though hard to see there were some small regions where the 850 hPa wind anomalies peaked near 5σ. The strong LLJ was well aligned with the upper-level jet entrance region (Fig. 4) and implied a strong jet circulation played a critical role in this event.

The strong LLJ and the high PW values contributed to high moisture flux (MFLUX:Fig. 9) at 850 hPa. The MFLUX anomalies were near and at times in excess of 6σ during this event. MFLUX is typically associated with heavy rainfall and flooding events. However, areas of high MFLUX often align well with severe convection in the presence of conditions favoring deep, upright convection. The GFS suggested over 5400 JKg-1 of convectively available potential energy (CAPE) over the Missouri Valley at 04/0000 UTC (Fig. 10). The CAPE remained unseasonably high ahead of the frontal system as it progressed to the east.

k. Observations

The sounding at Topeka, KS at 03/1200 UTC (Fig. 11) shows the elevated mixed layer. The boundary layer is relatively warm and moist while above the inversion, the EML is clearly defined from about 750 hPa to around 350 hPa where the steep lapse rate begins to relax, though the sounding is conditionally unstable to near 200 hPa. This elevated mixed layer was still present at 04/1200 as the shallow moist air mass and the EML moved eastward (Fig. 12). The EML and warm unstable air was present over Alabama at 1200 UTC 4 April. The airmass was not as unstable above the inversion in Alabama as it had been over Topeka one day earlier.

The first storms developed in Iowa and Kansas around 03/2300 UTC. Typical of EML events, the first storms were isolated. But a line of storms quickly developed as the Iowa storms and Kansas storm became more numerous and a line was evident by 04/0032 UTC (Fig. 13). The storms evolved and moved southeastward. Numerous lines were evident at 04/1232 UTC (Fig. 13). The convection became better organized during the daytime hours of 4 April and well defined line of storms marched across the southern United States on 4 April 2011 (Fig. 15). This line, combined with excellent spotters clearly contributed to the extreme number of severe reports on 4 April 2011.

l. Forecasts

Under contruction.

4. Conclusions

A strong upper-level wave and jet stream pulled shallow moist air northward into the plains States and an elevated mixed layer over this warm moist air mass. This early season elevated mixed layer combined with strong winds to produce what can only be described as a massive severe weather event. With over 1300 reports of severe weather, mainly from strong winds, this was likely the largest and most extensive severe weather event over observed over the United States. Despite the large number of severe reports, there were relatively few tornadoes. The strong forcing produced the tornado and was likely a contributing factor to the relatively predictable nature of the event.

A comparison of Figure 1 and Figure 10 implies that the lack of CAPE to the north limited the northern extent of the severe weather. The relatively high CAPE from Kansas to Wisconsin at 04/0000 UTC aligned well with the area of severe weather on 3 April 2011. The high CAPE was suppressed southward after 04/1200 UTC and may explain the focus of severe weather in the southern States and the lack of significant severe weather in the Mid-Atlantic and northeastern States. It should be noted that the GFS model CAPE may have under-played the CAPE in portions of the Ohio Valley relative to observed values.

With over 1300 reports of severe weather this event eclipsed the events of 2 April 2006 (872:Grumm 2006) and 7 April 2006 (871:Grumm 2006) which were the previous top 2 events since 2005. It should be noted that only 12 severe events since 2005 have produced 500 or more severe weather reports. The large number of reports with this event, with relatively few tornadoes and only 2 reported deaths to date raises some questions about severe weather reporting and reporting inflation (Fig. 1: Verbout et al 2006). Was this event truly a massively widespread and historic severe weather event or is there a reporting bias that contributed to the number of reports associated with this and more recent events. Are incrementally increased reports of severe weather, especially at the lower ends of severe reports an indication of a reporting bias. Verbout et al. (2006) showed this inflated report bias in relation to tornadoes in the United States. It is likely that such a bias is also in all severe reporting, but lacking a control, such as strong and violent tornadoes, relative to weaker tornadoes, this bias may be harder to define. There is no easy method to identify F1 or F2 or greater event days to distinguish between severe weather events when using hail and wind reports.

In addition to the reporting bias, the Storm Prediction Center (SPC) changed the filtering method of reports. Prior to March, 2011 all hail and wind reports within 10 to 15 miles of each other and tornado reports within 5 miles were filtered to show only one report. Despite this, a filtered list still had over 1000 total reports for the 24 hour period encompassing 4 April 2011. Some potential impacts which increased the number of reports may include[1]:

- *The long-lived nature of this fast moving event across a specific geographic domain with an expansive warm sector,*
- *sufficient population density in areas affected and the associated power grid,*
- *tree damage reports in the heavily forested areas of the southeast,*
- *Enhanced electronic communication including the web and social media to get reports in fast and easy,*
- *spotters and spotter networks leveraging aforementioned technologies,*
- *and over the years, increased vigilance of WFO's to build networks and seek reports.*

Thus, this event represented a significant event which occurred over the right area at the right time to leverage new technologies. There was clearly a convergence of technology and meteorology. It is interesting to note that despite all the reports of severe

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[1] Personal communication with Steve Weiss, Scientific Operations officer at the Storm Prediction Center.

weather and the impacts of the severe weather that so few METAR sites reported winds or wind gusts which reached or exceed severe thunderstorm levels. One can only speculate on the number of reports such a confluence of dynamics and technologies would have produced on 3 April 1974 and 25 November 1950.

This event shared many of the characteristics of the two recent large early April severe weather events. All three events contained some tornadoes but wind and hail reports dominated the events. A surge of high PW air along with above normal 850 and 700 hPa temperatures was a common theme in the 2 April 2006, 7 April 2006, and the 4 April 2011 events. A strong low-level jet and the implied strong shear were evident in all three events.

5. Acknowledgements

The Storm Prediction Center is acknowledge for their easy access to data and easily used website to examine current, recent, and past severe weather events. I would also like to thank the Storm Prediction Center, specifically a very old friend, Steve Weiss, for prompt and direct communications related to this event and reasons why this event had a record number of severe reports.

6. References

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Date	Tornado	Hail	Wind	Totals
3-Apr	0	255	69	324
4-Apr	38	89	1347	1347
5-Apr	9	1	32	42
Totals	47	345	1448	1713

Table 1. Severe weather by type 3-5 April 2011. Data form the Storm Prediction Website.
Return to text.

DATE	**# SVR**
4/4/2011	1347
4/2/2006	872
4/7/2006	871
3/12/2006	669
4/3/2007	594
5/25/2006	571
5/25/2008	560
6/10/2008	530
6/22/2006	528
7/22/2008	525
2/5/2008	524
6/19/2007	500

Table 2. List of severe events by date and the total number of severe reports. Return to text.

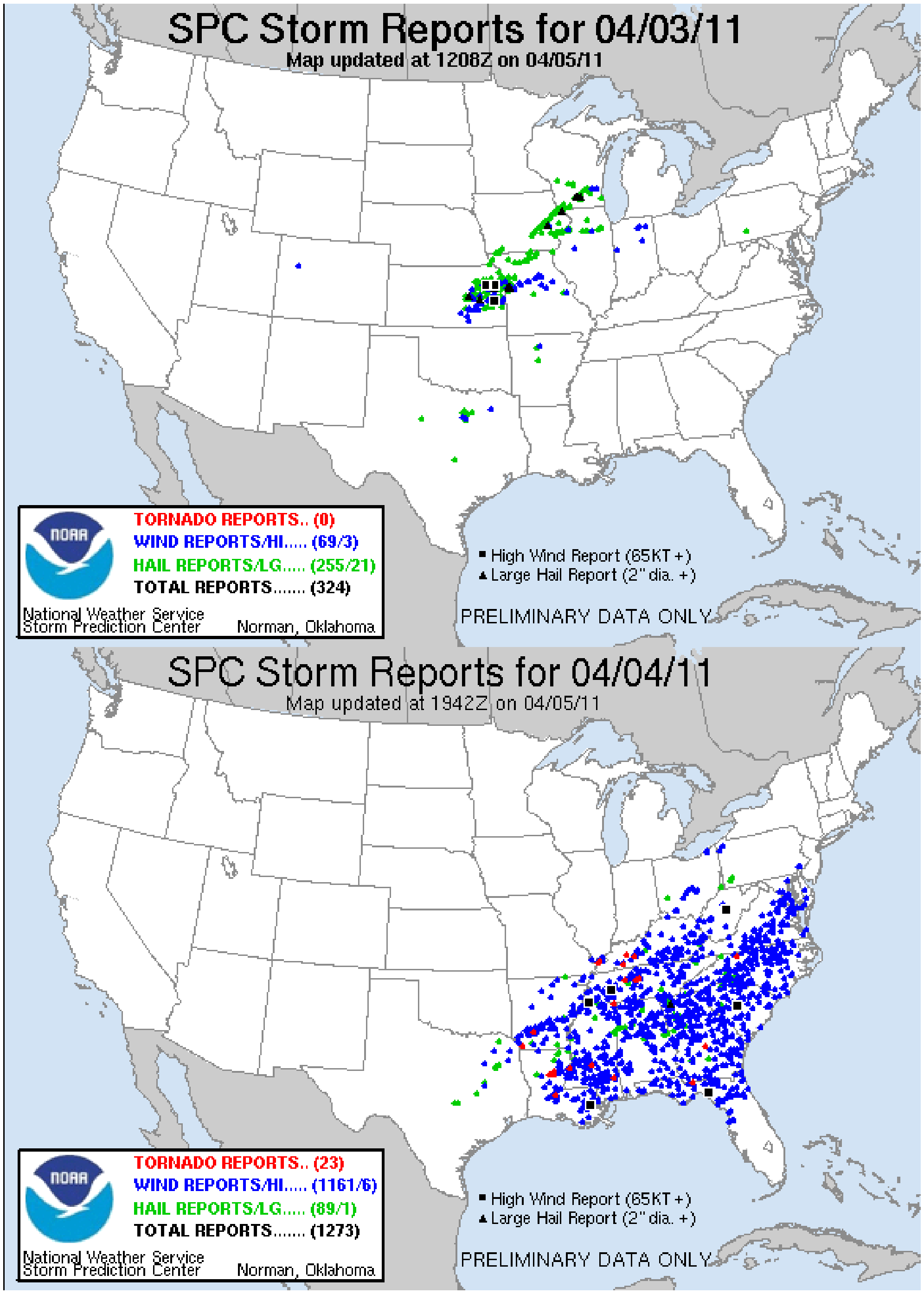

Figure 1. Storm Prediction Center (SPC) reports of severe weather by type for the periods ending at 1200 UTC 4 and 5 April 2011 making the report data for 3 and 4 April 2011. Return to text.

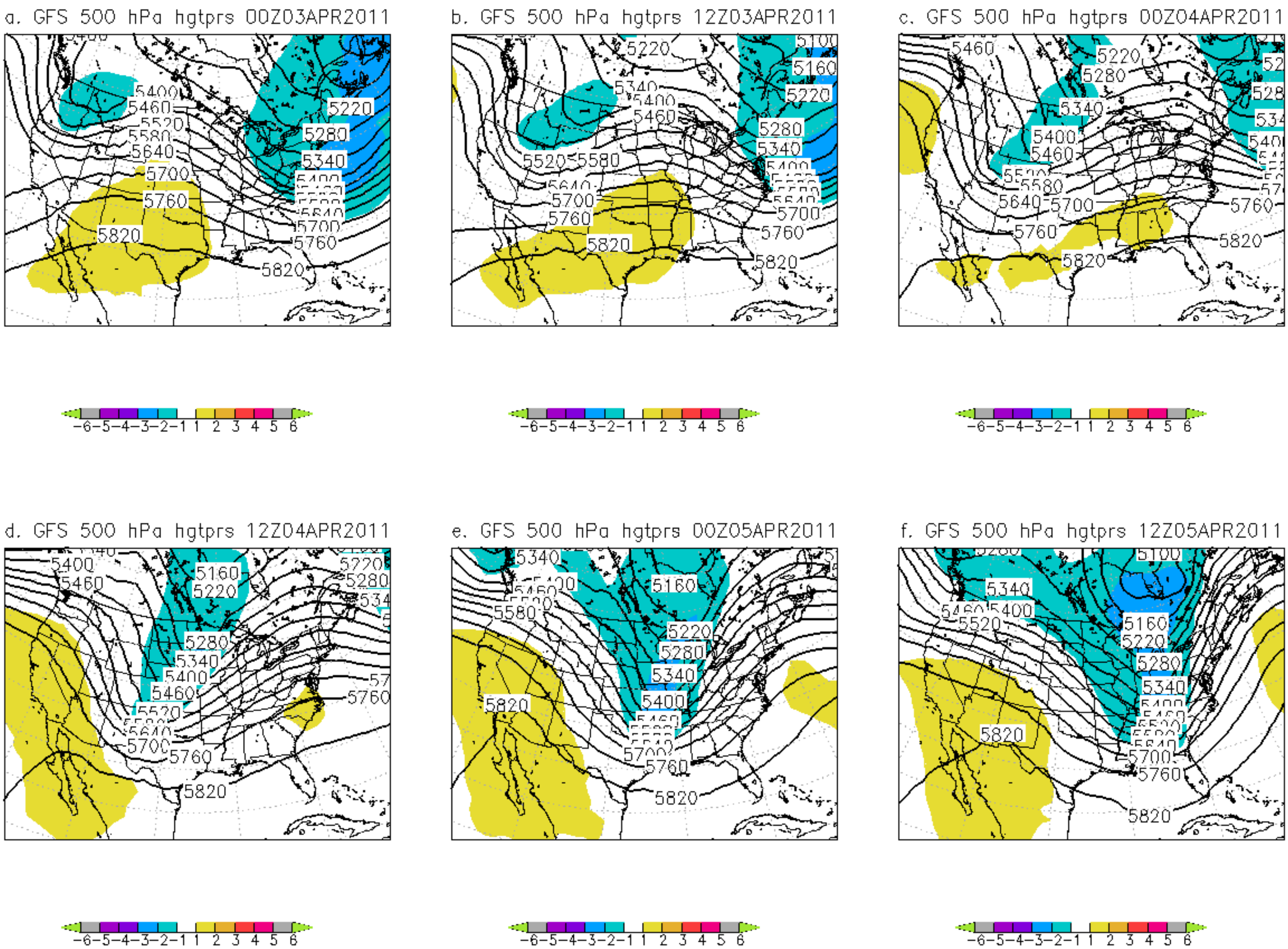

Figure 2. NCEP GFS 00-hour forecasts showing 500 hPa heights and height anomalies in 12-hourly increments from a) 0000 UTC 3 April 2011 through 120) UTC 5 April 2011. Heights every 60 m anomalies in standard deviations from normal. Return to text.

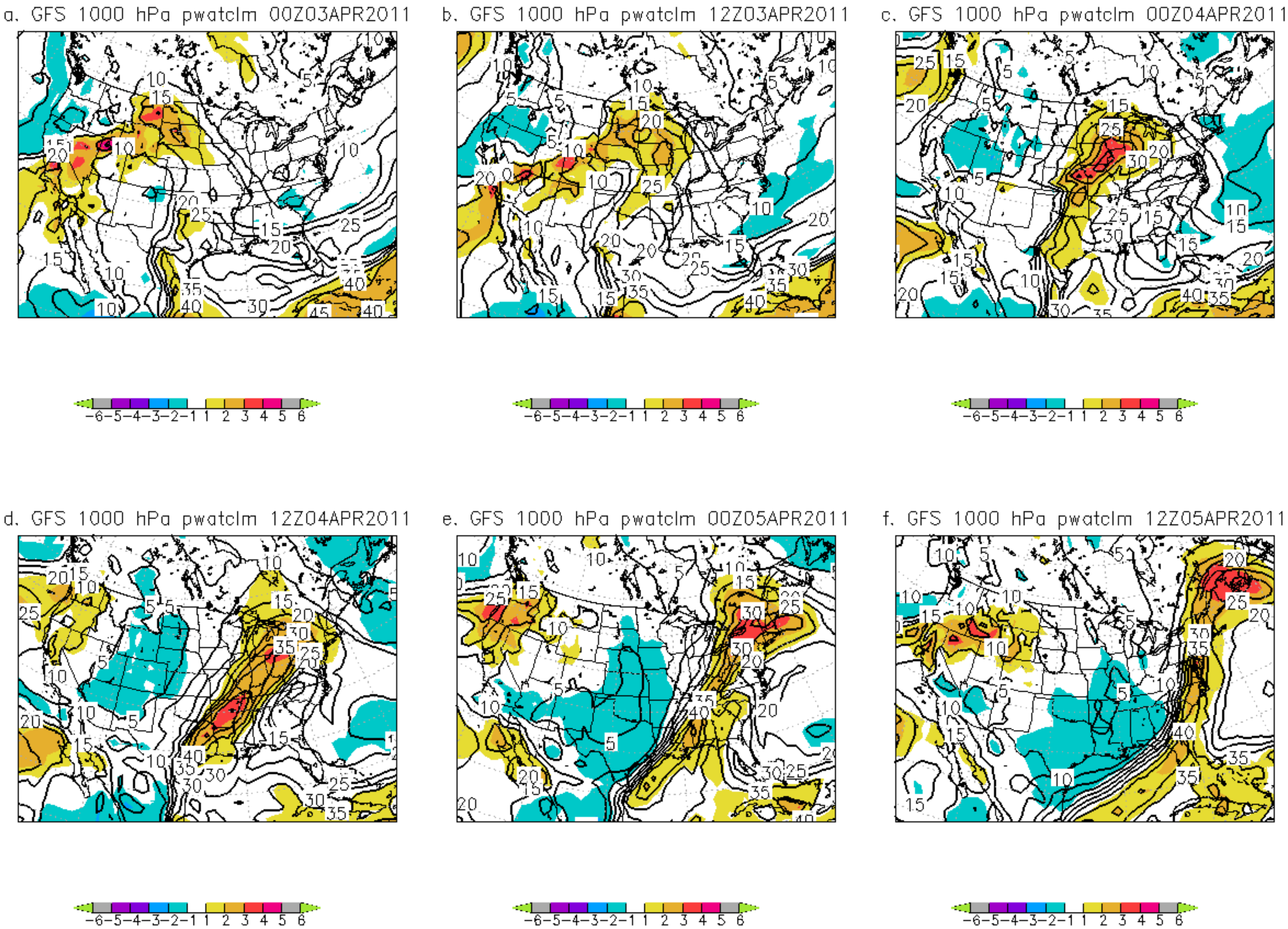

Figure 3. As in Figure 2 except for precipitable water and precipitable water anomalies. Return to text.

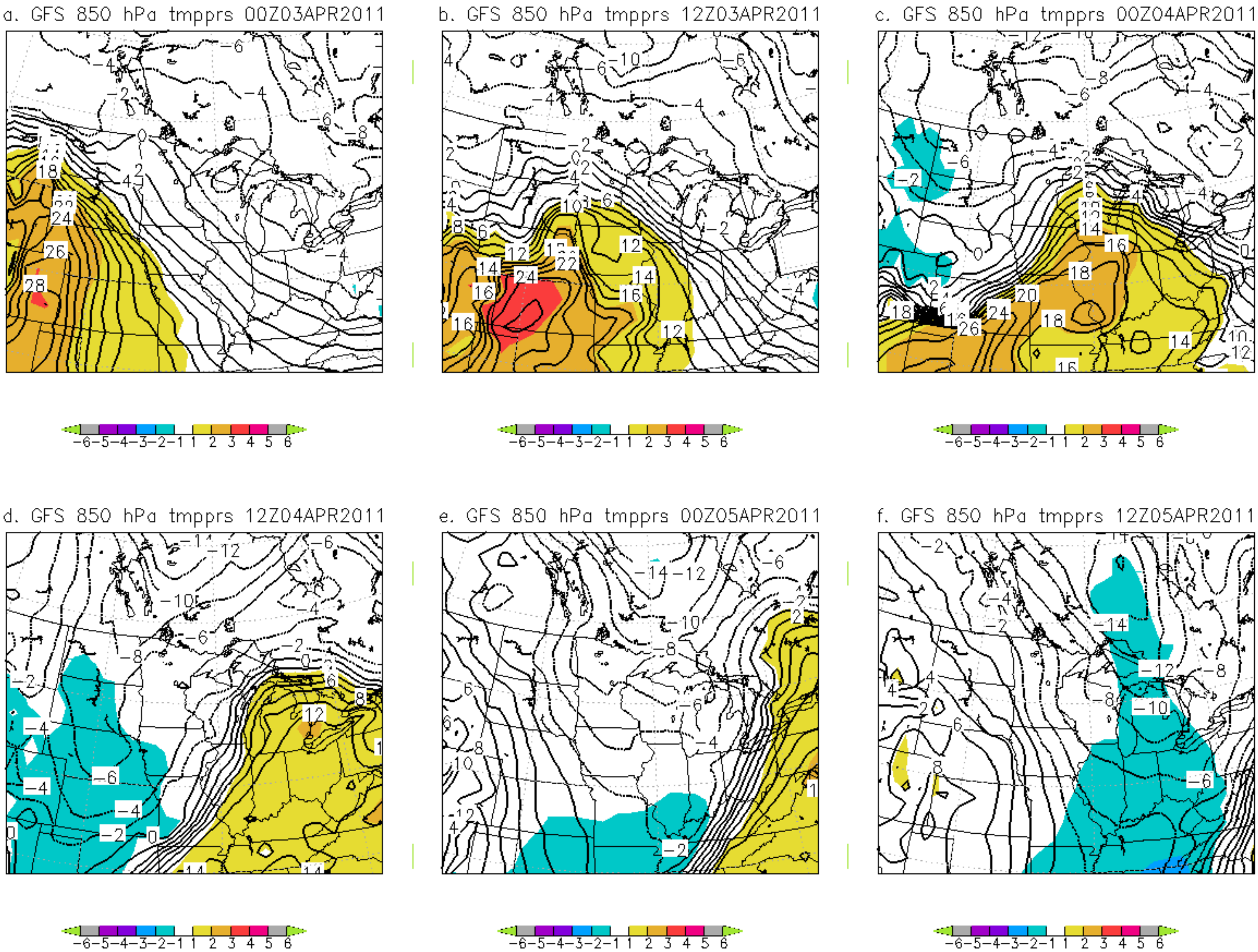

Figure 4. As in Figure 2 except for 850 hPa temperatures and temperature anomalies zoomed over the central United States. Return to text.

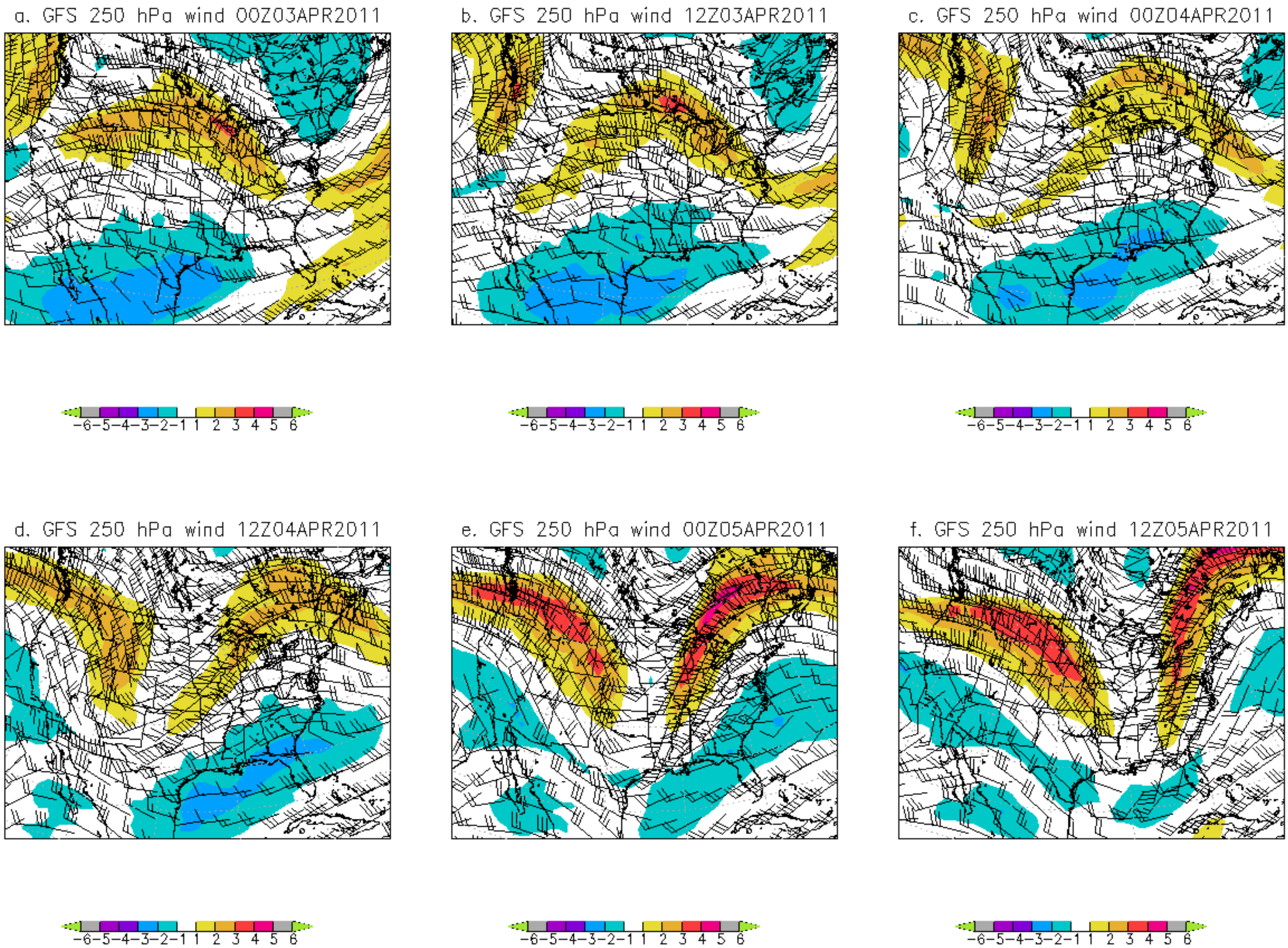

Figure 5. As in Figure 2 except for 250 hPa winds (ms-1) and total wind anomalies. Return to text.

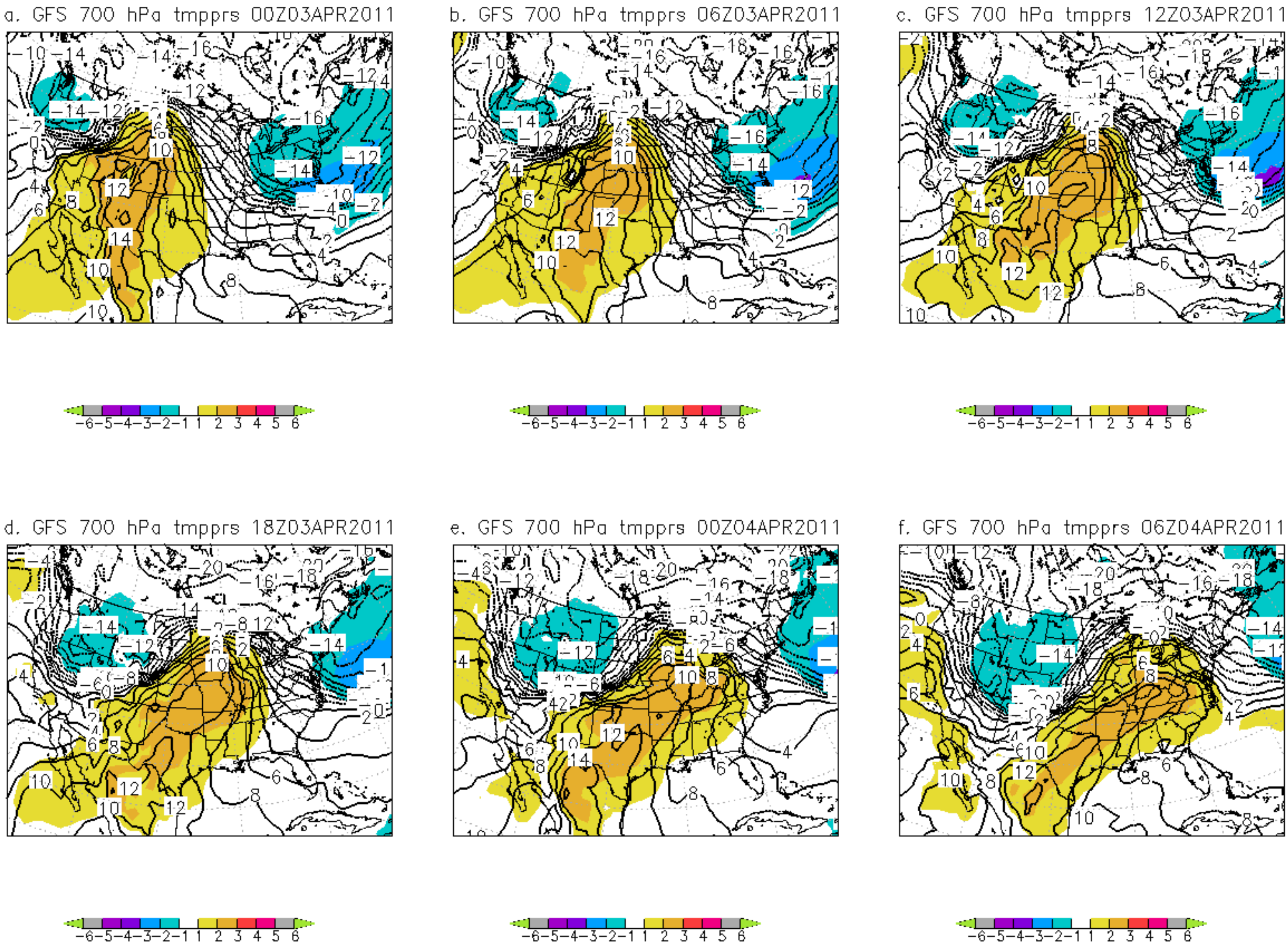

Figure 6. As in Figure 2 except for 700 hPa temperatures and temperature anomalies. Return to text.

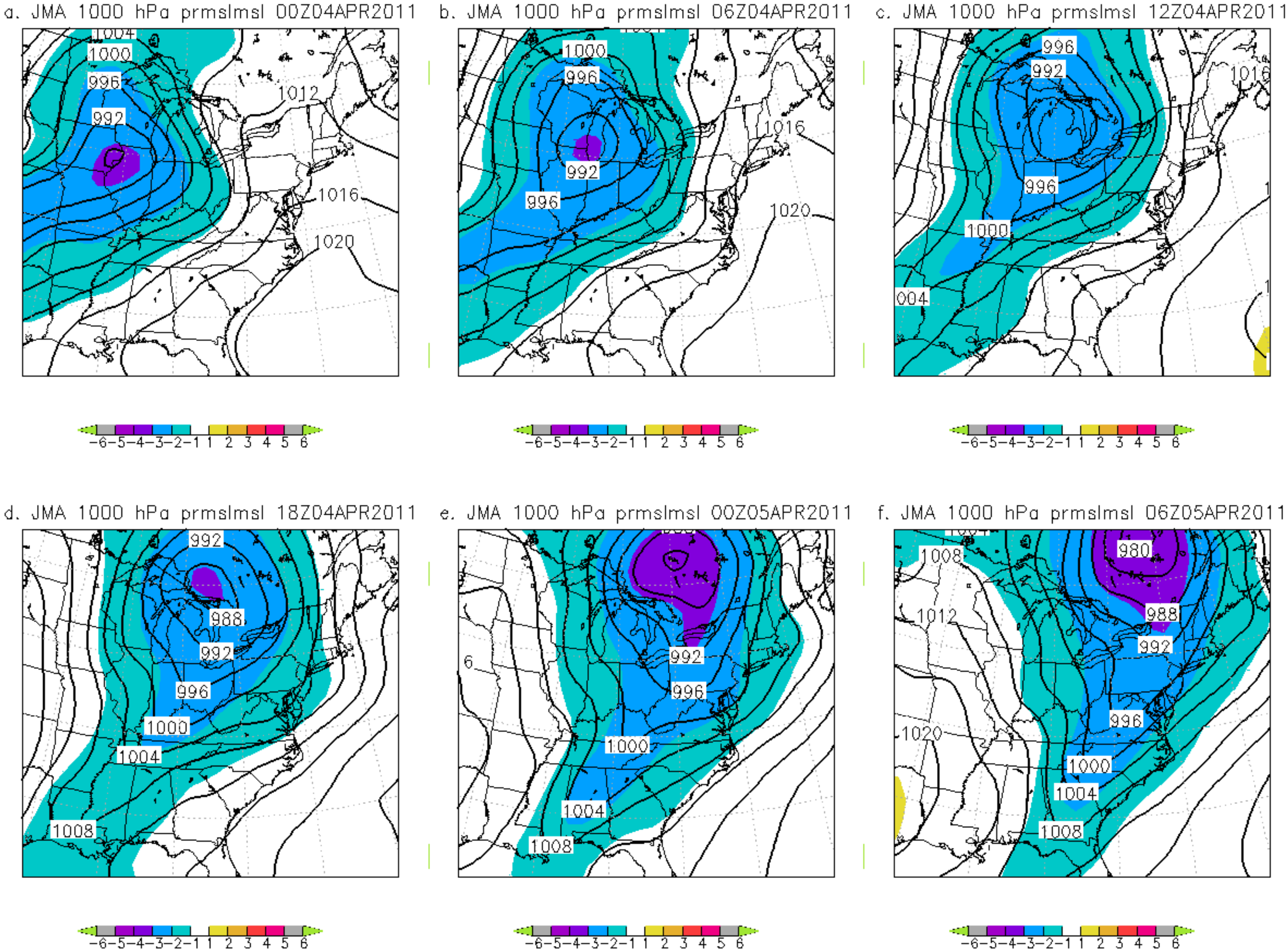

Figure 7. As in Figure 2 except for GFS mean sea-level pressure (hPa) and pressure anomalies in 6-hour increments from a) 0000 UTC 4 April 2011 through f) 0600 UTC 05 April 2011. [Return to text.]

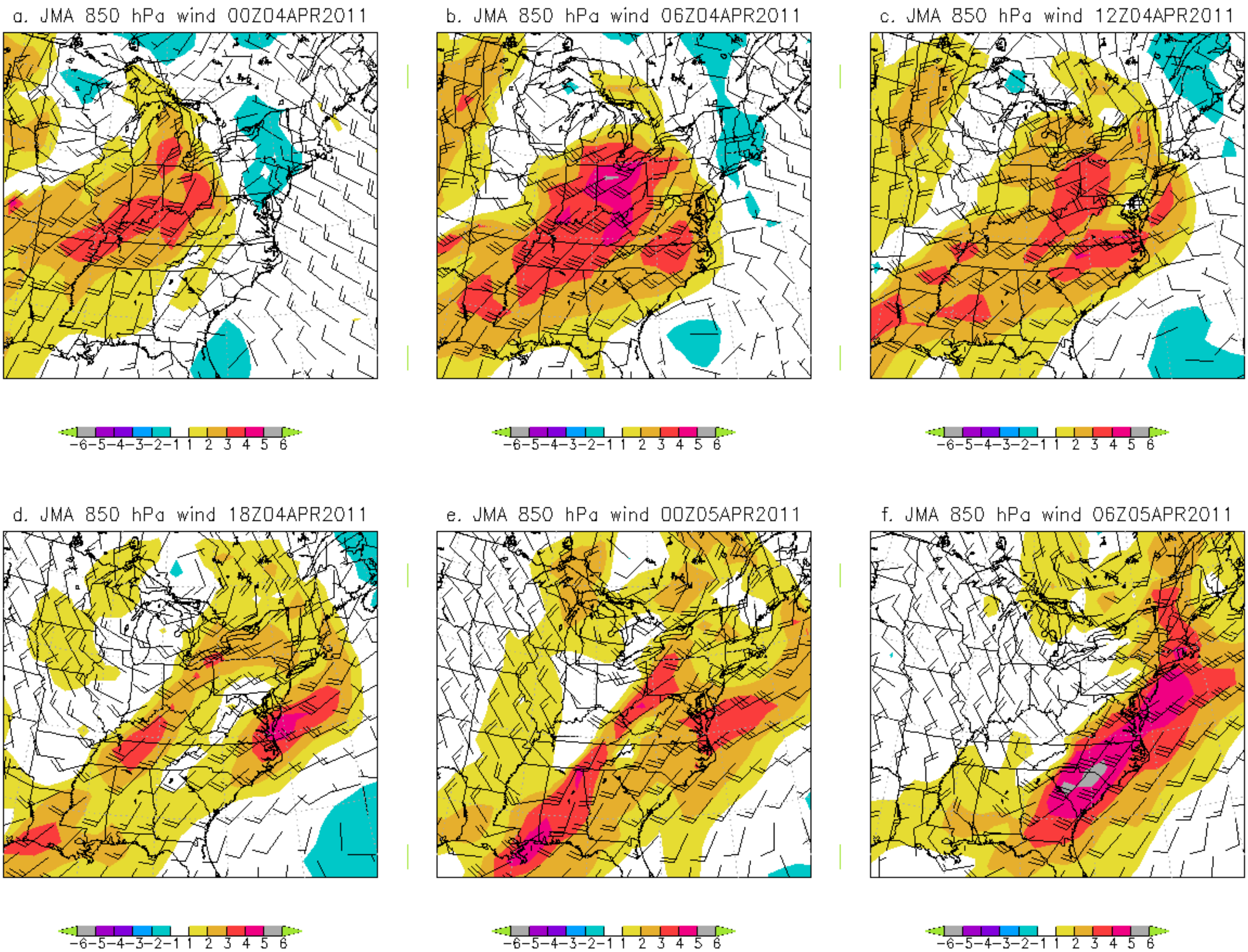

Figure 8. As in Figure 7 except for GFS 850 hPa winds and total wind anomalies. [Return to text.]

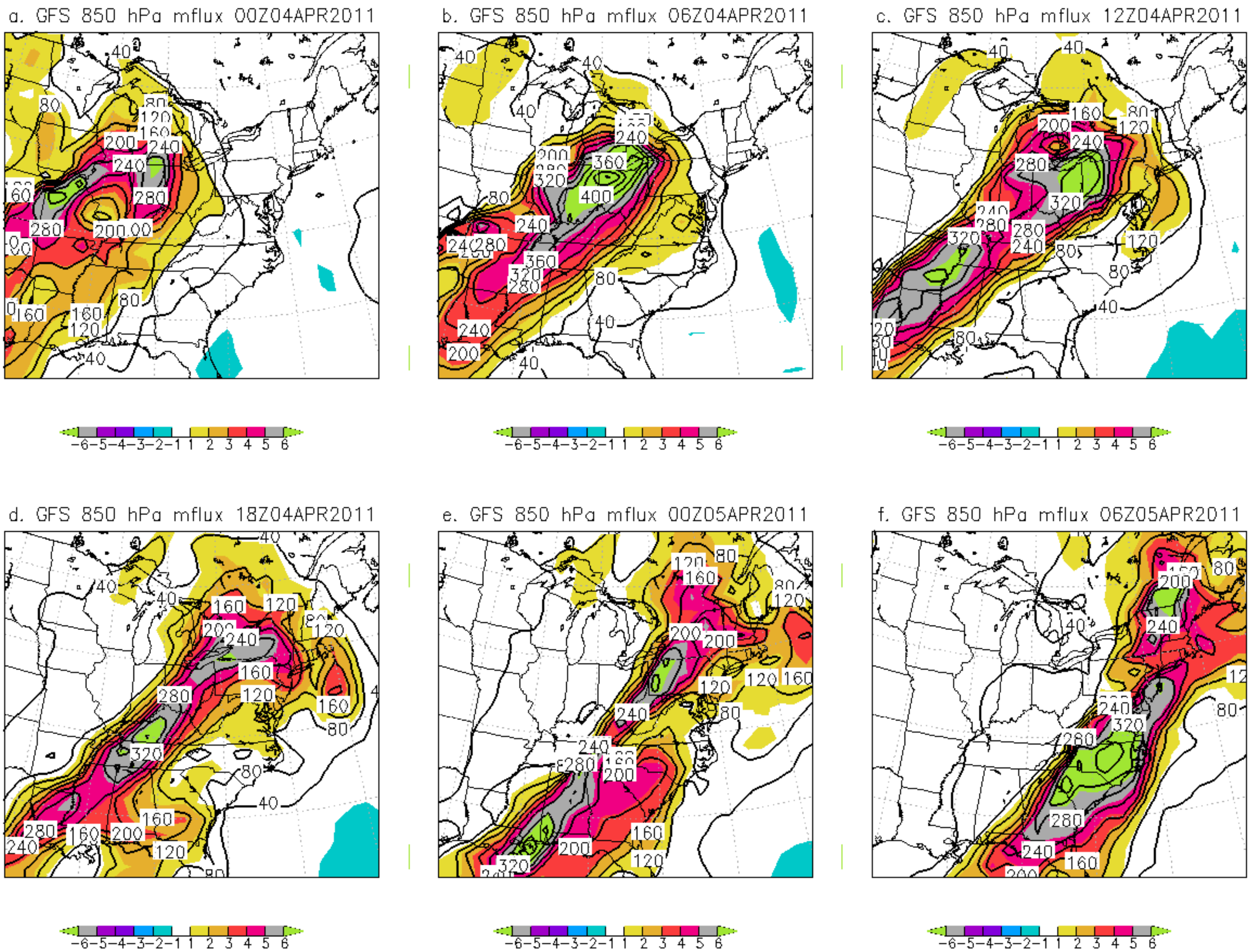

Figure 9. As in Figure 7 except for GFS 850 hPa moisture flux and moisture flux anomalies. Return to text.

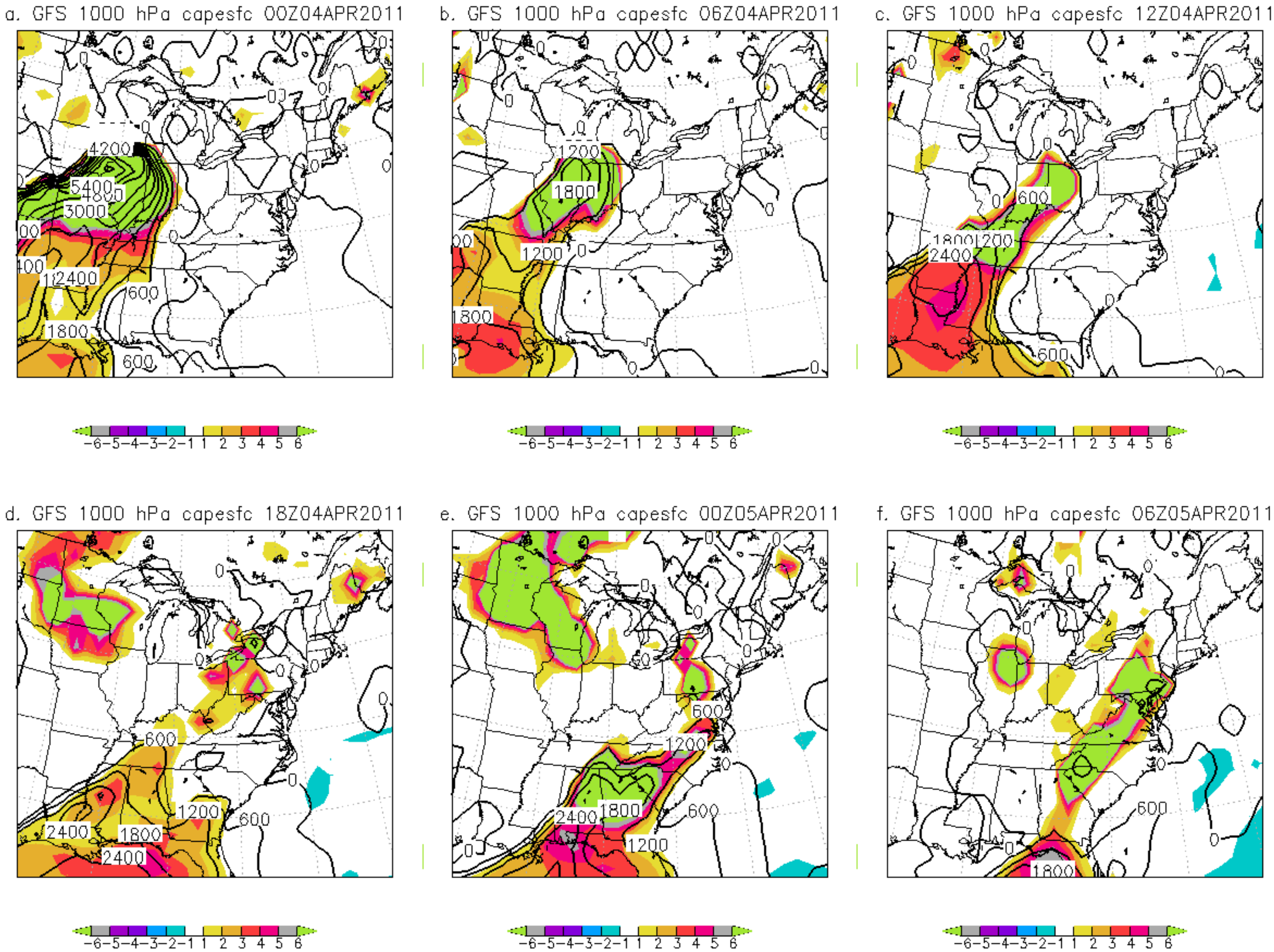

Figure 10. As in Figure 7 except for CAPE and CAPE anomalies. [Return to text.](#)

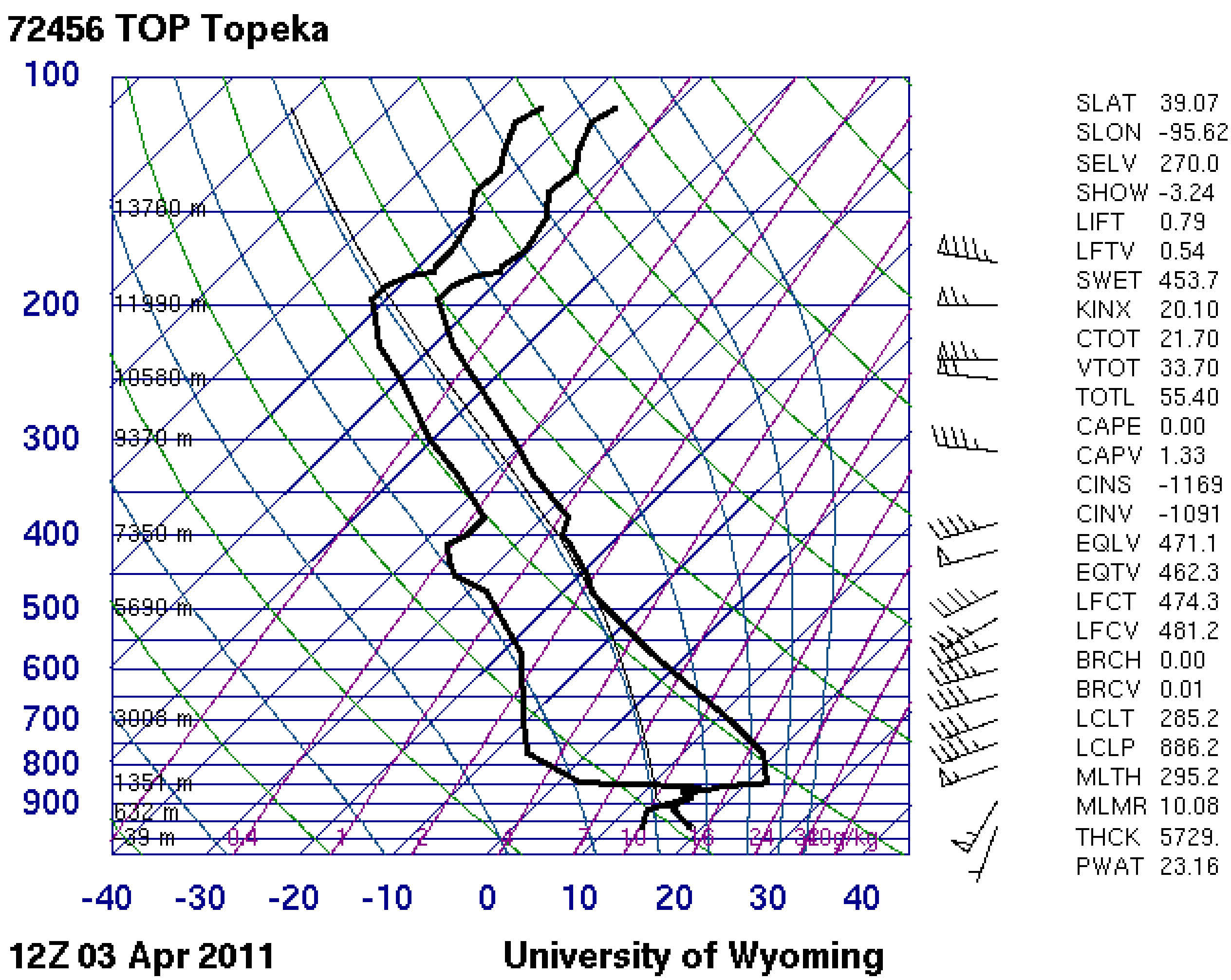

Figure 11. Sounding at 1200 UTC 3 April 2011 taken at Topeka, Kansas. Data from the University of Wyoming sounding retrieval site. Return to text.

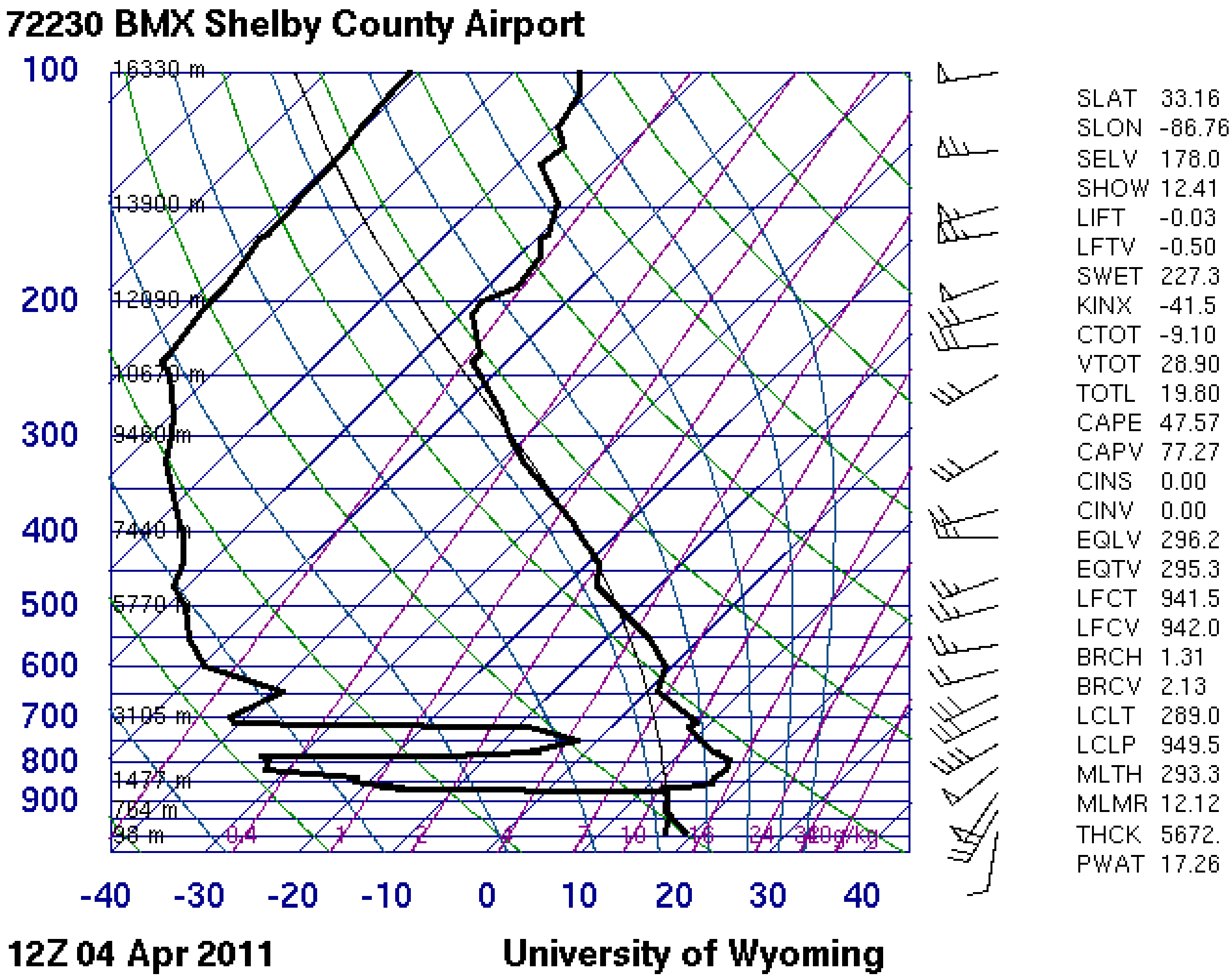

Figure 12. As in Figure 11 except for Shelby County airport near Birmingham, Alabama at 1200 UTC 4 April 2011.
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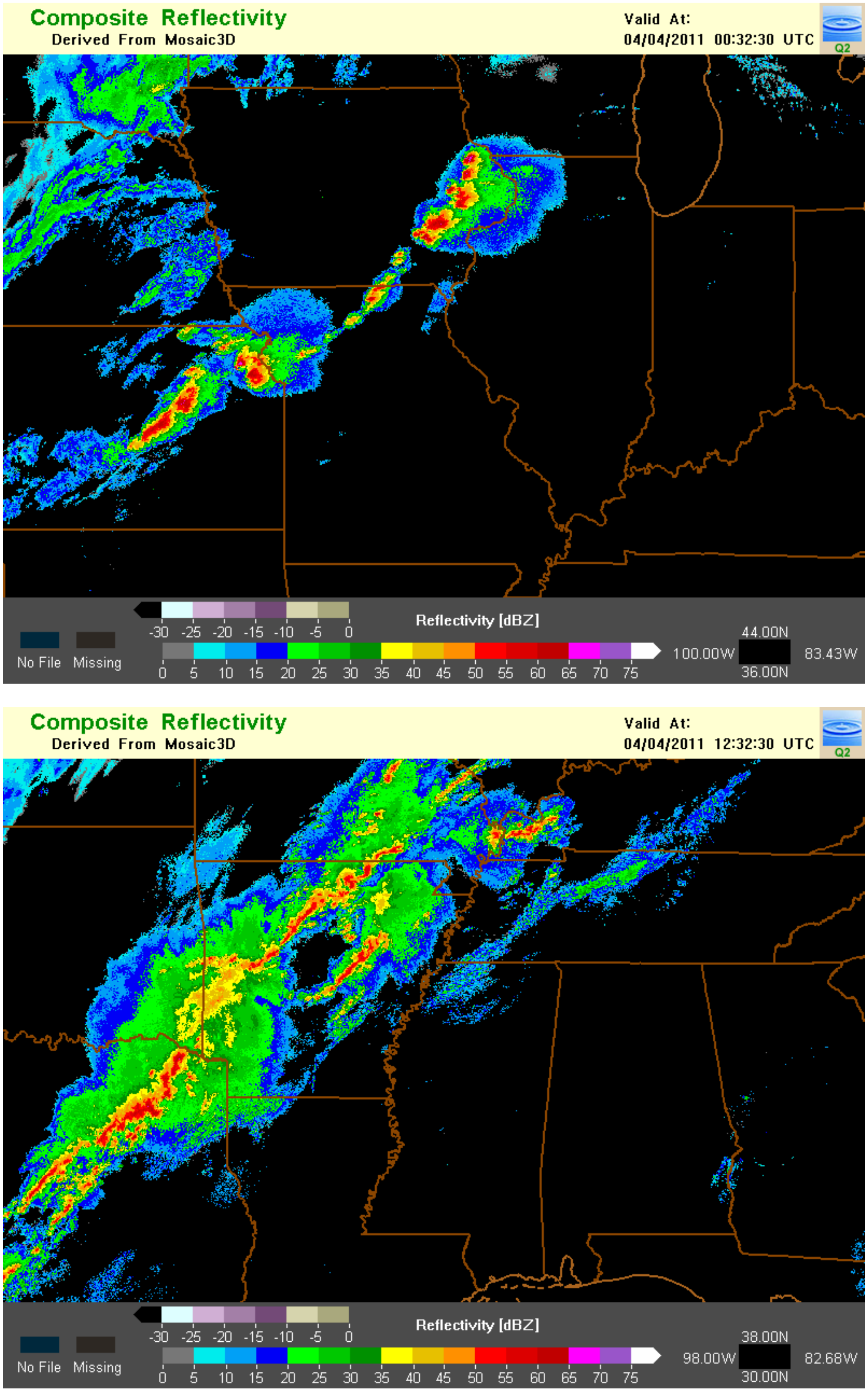

Figure 13. Composite radar from the NMQ site. Upper panel shows the developing line within a few hours of the first cells developing on Sunday afternoon at 00:32 UTC 4 April 2011. The bottom panels show the southern line of sotrm at 1232 UTC on 4 April. Return to text.

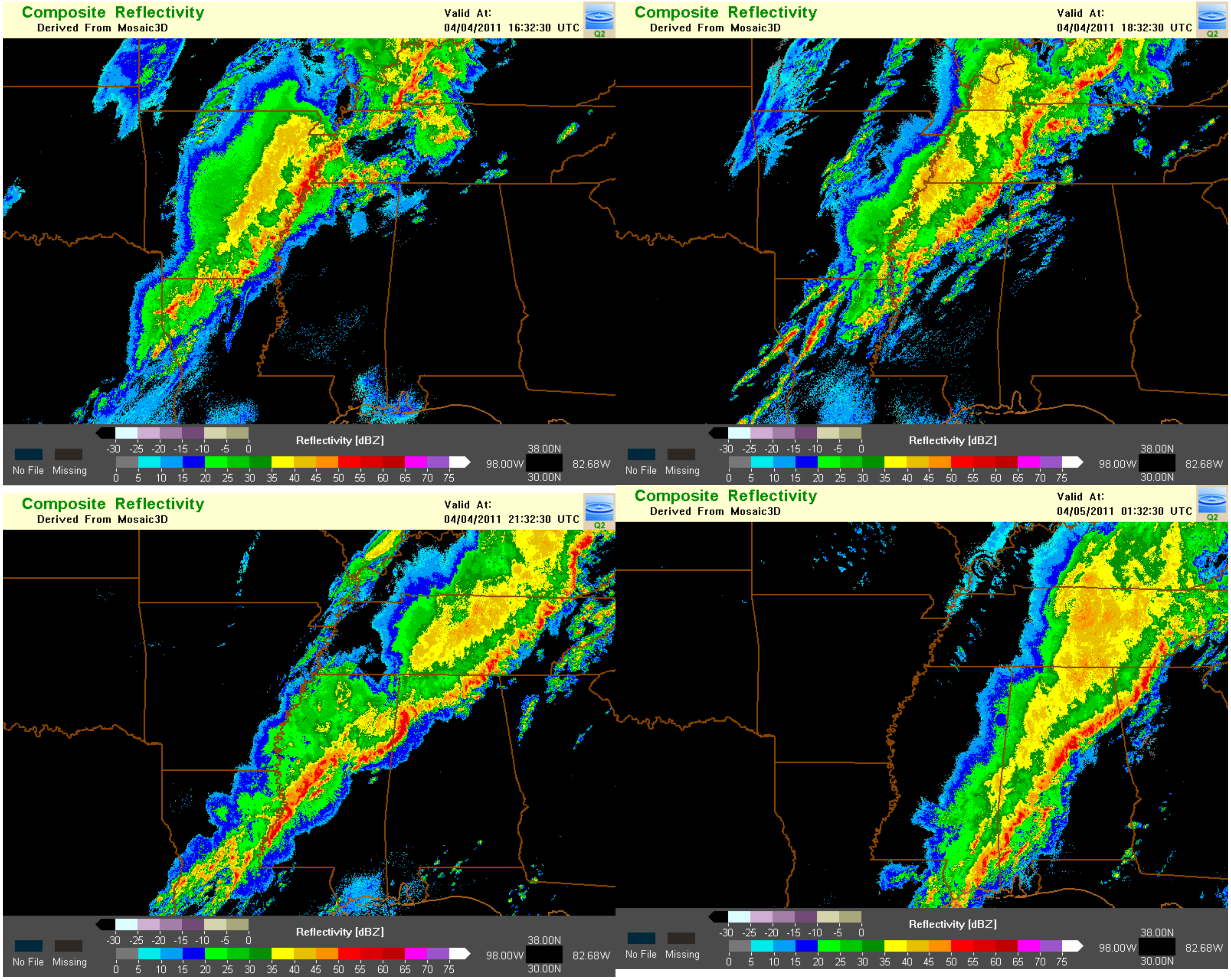

Figure 14. As in Figure 13 except for the line moving across the southern United States at 1632, 1832, 2132 on 4 April and 01:32 UTC on 5 April 2011. Return to text.