

Pre-Christmas Warm-up 21-23 December 2013-Draft

By

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1. Overview

A large ridge over the west-central Atlantic ([Fig.1](#)) and trough moving into eastern North America (Fig. 1) produced a surge of subtropical moisture on 21-22 December 2013. This moisture plume resulted in a high impact weather event from the mid-Mississippi Valley into Quebec. A closed 5880 m ridge developed over the western Atlantic by 0000 UTC 21 peaking on 23 December when a closed 5940 m high developed ([Fig. 1e](#)). As the trough moved into the eastern United States the gradient between the trough and ridge increased producing a surge of deep moisture into the eastern United States ([Fig. 2](#)).

The plume of high precipitable water air ([Fig. 2](#)) was associated with heavy rainfall and a period of unseasonably warm weather over much of the eastern United States. On 22 & 23 December ([Fig 3](#)) over 150 high temperature records (Tables 1 & 2) were set or tied and on both days over 100 record high low-temperature records were set or tied. In the plume of high PW air heavy rain ([Fig. 4](#)) and flooding was observed in the Ohio Valley. The 2-day total QPE from northeastern Arkansas into western Ohio was over 128 mm (4 inches).

On the northern edges of the precipitation, snow was observed in the Great Lakes, a massive [ice storm](#) impacted northern New York, New England and southeastern Canada (AP 2013; CBC 2013). In the warm air ahead of the fast moving cold front there was an extensive late-season severe weather event which produced over 330 reports of severe weather to include 12 tornadoes on 21 December 2013.

The pattern which produced the warm-up, ice storm, heavy rains, and severe weather included a large ridge over the western Atlantic and as strong trough to the west that allowed deep sub-tropical moisture to move into eastern North America. This paper presents the pattern and some insights into the overall predictability of this high impact weather event.

2. Data and Methods

The large scale pattern was reconstructed using the 00-hour forecast of the NCEP Global Forecast System (GFS) as first guess at the verifying pattern. The standardized anomalies were computed in Hart and Grumm (2001). All data were displayed using GrADS (Doty and Kinter 1995). The standardized anomalies and the probability distribution functions are based on the re-analysis climate (**R-Climate**). Though not shown here, they could be produce from internal model system climatologies (**M-Climate**).

The traditional standardized anomalies were produced from the GFS 00-hour forecast using Climate Forecast System based means and standard deviations. The climatology spans a 30 year period. This 30-year period was used in the situational awareness (SA) tables to show the return period of the anomalies.

Temperature records were obtained from the National Climatic Data Center (NCDC). The estimated precipitation was derived from the Stage-IV 6-hour data and summed over intervals to highlight key times of heavy precipitation.

3. Pattern, anomalies and weather

The estimated precipitation ([Fig. 4](#)) showed that the heaviest precipitation, rain, fell in the Ohio Valley ([Fig 4d](#)). A secondary area of heavier rainfall, mainly in the form of freezing rain, fell over northern New York, New England and Quebec. The 24-hour precipitation images imply that there were two 24 hour periods of heavy rainfall over the Ohio Valley and the freezing rain in the northeastern area peaked from 1200 21-22 December ([Fig. 4d](#)).

The low-level PW plume ([Fig. 6](#)) and 850 hPa winds show that there was a surge of above normal moisture into the Ohio Valley by 21/0000 UTC ([Fig. 6a](#)) peaking around 22/0000 UTC as drier air moved into the region afterwards. During the time of the peak PW, the 850 hPa winds and v-wind anomalies peaked ([Fig. 7b-c](#)). The high PW air and the strong low-level winds likely contributed to the instability (not shown) and the severe weather ([Fig. 5](#)) observed in the Ohio Valley into western Pennsylvania.

The PW peaked in the Northeast and southern Quebec around 22/1200 UTC ([Fig. 6d](#)). The 850 hPa temperatures over the region were above normal over northern New England and southern Quebec ([Fig. 8](#)) though there was a strong temperature gradient with +12 to +16 air over southern New York and the Mid-Atlantic region and values near normal in central Quebec ([Fig. 8b-c](#)). Though not shown shallow cold air kept cold air in at the surface, reminiscent of the great Ice Storm of January 1998 (Gyakum and Roebber 1998).

The surface cyclone was relatively modest ([Fig. 9](#)). The key players were clearly the large anticyclone to the north and the anticyclone off shore.

4. Forecasts

The GEFS 500 hPa forecasts predicted the large scale ridge ([Fig. 10](#)) over the western Atlantic and the return flow plume of deep moisture over the Ohio Valley ([Fig. 11](#)). Due to uncertainty issues related to both the position and the intensity of the ridge, the moisture plume did not show the sharp gradient and the higher anomalies until forecasts produced after 1800 UTC 16

December 2013¹. The shorter range GEFS (Fig. 11d) showed PW anomalies over $+4\sigma$ indicative a good agreement with the position and the intensity of the PW plume.

The shift in the moisture plume, and the cyclone track, had a dramatic effect on the QPF (Fig. 12). The GEFS probability of 50mm or more QPF during the 48 hour period from 21/0000-23/0000 UTC shifted ***dramatically to the west*** and the solutions from all 21-members converged on a high probability of 50 mm or more of QPF in the Ohio Valley. Forecasts issued prior to 17/0000 UTC should lower probabilities and had the axis of the higher QPF farther east. One of the significant changes was related to a strong forecast in the anticyclone over the western Atlantic basin (Fig. 10b-c). Though not shown, as the plume of higher PW air became stronger and more focused, the GEFS began to show a higher probability of 100 mm or more of QPF in the Ohio Valley.

Once the more western position and strong anticyclone were consistently forecast, the forecasts converged with a stronger plume of high PW air over the Ohio Valley (Fig. 11) and placed the cyclone track (Fig 13) farther west. The forecasts produced from 1200 UTC data (Fig. 14) show the same shift in the cyclone track and intensity. Interestingly, in this time period from about 17/0000 through 18/1200 UTC the were uncertainty issues with considerable cycle-to-cycle changes (see Figs 13c-e verse Figs. 14c-e) in the ensemble mean cyclone intensity, which became hard discern from forecasts issued on and after 19/0000 UTC.

5. Summary

A large subtropical ridge over the western Atlantic (Fig. 1) and a strong short wave over central North America (Fig.1) produced strong southerly flow which flood much of southeastern North America with unseasonably warm moist air. This plume of deep moisture brought heavy rain, flooding, and a significant winter severe weather event to the Ohio Valley. To the north and east shallow cold air at low levels resulted in an significant ice storm across northern New York and New England and adjacent portions of southern Quebec. The pattern shared similar characteristics to the January 1998 ice storm in the same region (Gyakum and Roebber 2001). In addition to the precipitation event, the surge of warm air produced record warmth of portions of the eastern United States (Tables 1 & 2).

Clearly the strong southerly flow and intrusion of warm air played a critical role in the producing the heavy rainfall and the severe weather (Fig.5-7). The large anticyclone over the western Atlantic played a critical role in this surge of deep moisture. An examination of model and ensemble guidance implies that once this large anticyclone was predicted to be stronger and farther to the west, the numerical guidance was better able to predict the potential for the heavy rain, severe weather, and freezing rainfall.

¹ Only 0000 UTC Forecasts are shown here so 0000 UTC 17 December Figure 13 shows 12Z cycle cyclone tracks.

The GEFS showed a sharp shift in the cyclone track (Figs. 13&14) which was also associated with a shift in the axis of the plume of high PW ([Fig. 11](#)). This shift was associated with a convergence of forecasts and thus larger standardized anomalies and an increase in the probability of 50 mm or more of QPF ([Fig. 12](#)) and 100 mm (not shown). One critical aspect to this shift was the location and intensity of the large anticyclone over the western Atlantic. This large system played a critical role in the evolution of the transport of deep moisture and warm air into the eastern United States.

The resulting forecasts produced by the GEFS² showed a pattern conducive for heavy rain, severe weather in the plume of warm air, ice and snow along the northern and northwestern edges of the storm system, and the warm episode in the eastern United States. Due to uncertainty issues this evolution of the weather had about 5 days of predictability and the anticyclone was generally more predictable than the cyclone. This was especially true of the large 500 hPa anticyclone over the western Atlantic.

Prior to the convergence of forecasts around 17/0000 UTC, several single model forecasts produced potential winter storms and significant snow scenarios. A single EC model run initialized at 0000 UTC 15 December 2013 ([Fig. 15](#)) showed a colder solution and a heavy snow event due to a weak 500 hPa ridge over the western Atlantic.

The ability to predict both the upstream and downstream pattern is critical in predicting where the significant plumes of deep moisture will evolve. This case illustrates some of the limits of predictability and why it is a fool's errand to use single models in predictions of the meteorological conditions much beyond 3 days.

6. Acknowledgements

The Pennsylvania State University for gridded data access and the Mid-Atlantic River forecasts and Trevor Alcott for return period data and images. Elyse Colbert for NCDC data extraction and summations.

7. References

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² The NAEFS, CMC and EC all were rather similar.

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Date	Broken Records	Ties	Sum	Cumulative Sum	Total Possible	Locations
12/18/2013	18	14	32	32	5232	West
12/19/2013	64	30	94	126	5236	Central Plains
12/20/2013	6	7	13	139	5130	
						Southeast, Mid Atlantic, and Mississippi River Valley
12/21/2013	36	25	61	200	4804	
12/22/2013	250	38	288	488	5004	East
12/23/2013	161	46	207	695	5063	East

Table 1. List of NCDC reports of high temperature records broken, or tied and the cumulative number of the time of the warm episode. Data also include the total number of NCDC sites and the general location of where the warm temperatures were observed.

Date	Broken Records	Ties	Sum	Cumulative Sum	Total Possible	Locations
12/18/2013	17	10	27	27	5218	West
12/19/2013	21	6	27	54	5225	Central US
12/20/2013	34	17	51	105	5126	Mississippi River Valley; Texas
12/21/2013	72	17	89	194	4774	Mississippi River Valley; Mid Atlantic
12/22/2013	137	27	164	358	4993	East
12/23/2013	126	28	154	512	5030	East

Table 2. As in Table 1 except for the record high low-temperatures observed. Return to text.

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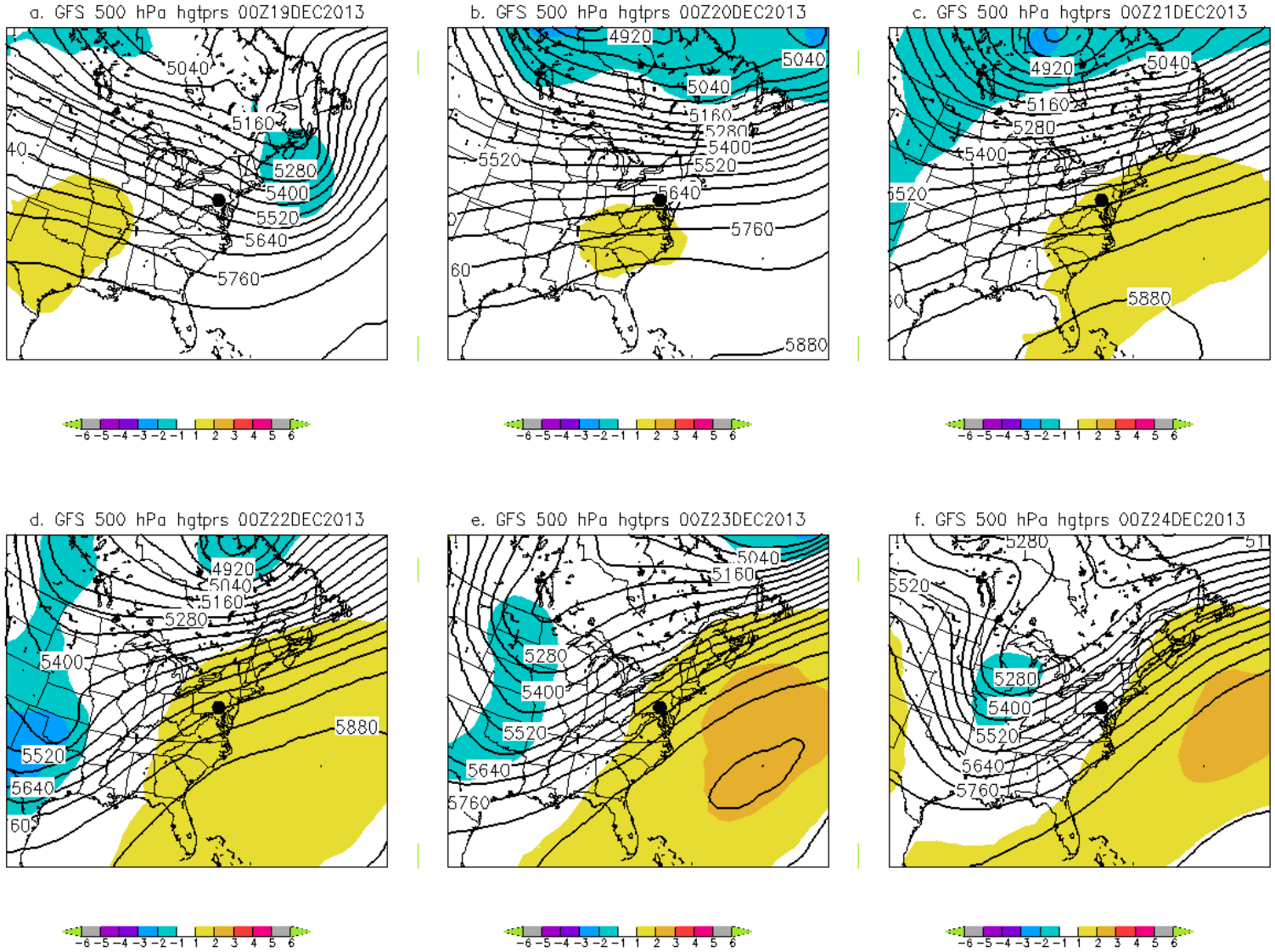
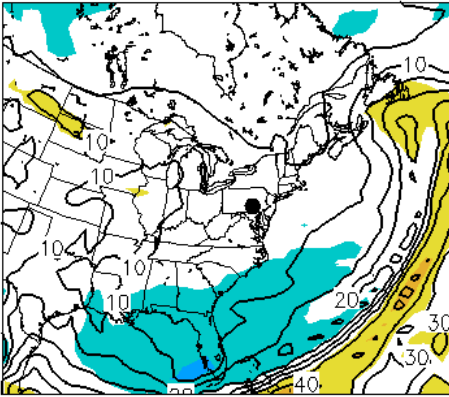


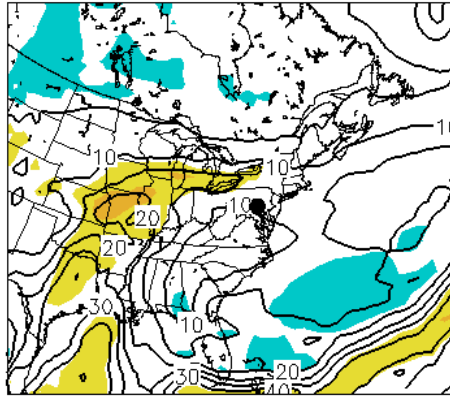
Figure 1. GFS 00-hour forecasts of 500 hPa heights and standardized anomalies in 24 hour increments from a) 0000 UTC 19 December 2013 through f) 0000 UTC 24 December 2013. Heights every 60 m and anomalies in standard deviations as in the color bar. [Return to text.](#)

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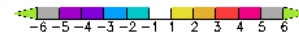
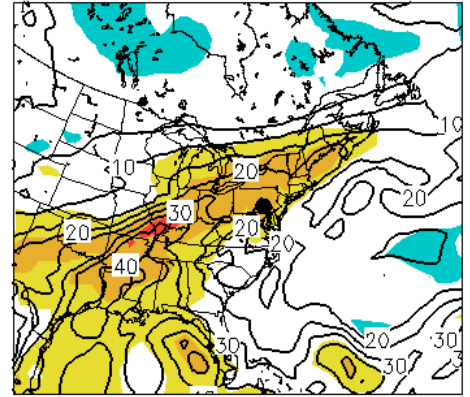
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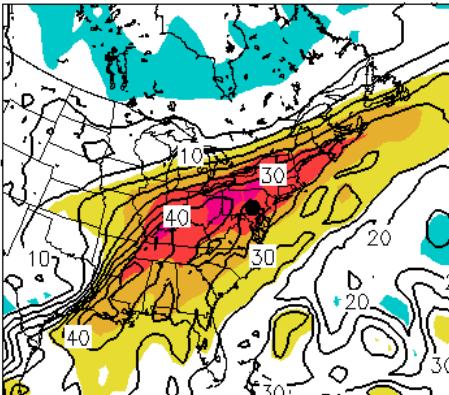
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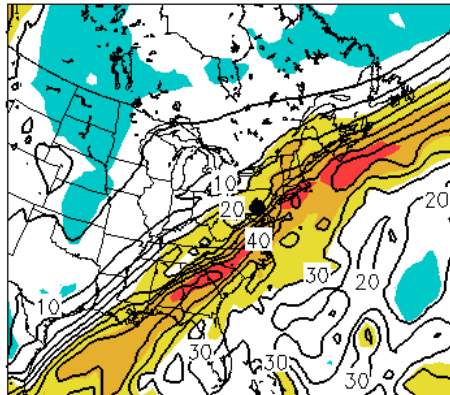
c. GFS 1000 hPa pwtclm 00Z21DEC2013



d. GFS 1000 hPa pwtclm 00Z22DEC2013



e. GFS 1000 hPa pwtclm 00Z23DEC2013



f. GFS 1000 hPa pwtclm 00Z24DEC2013

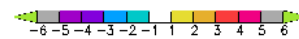
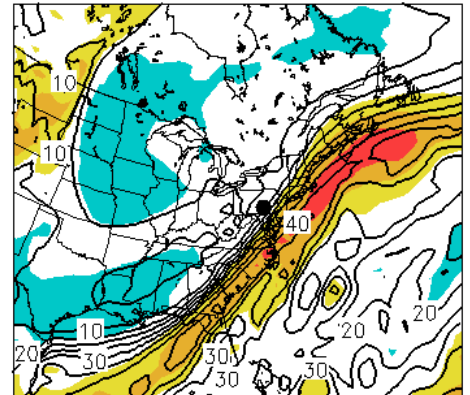


Figure 2. As in Figure 1 except for precipitable water (mm). [Return to text.](#)

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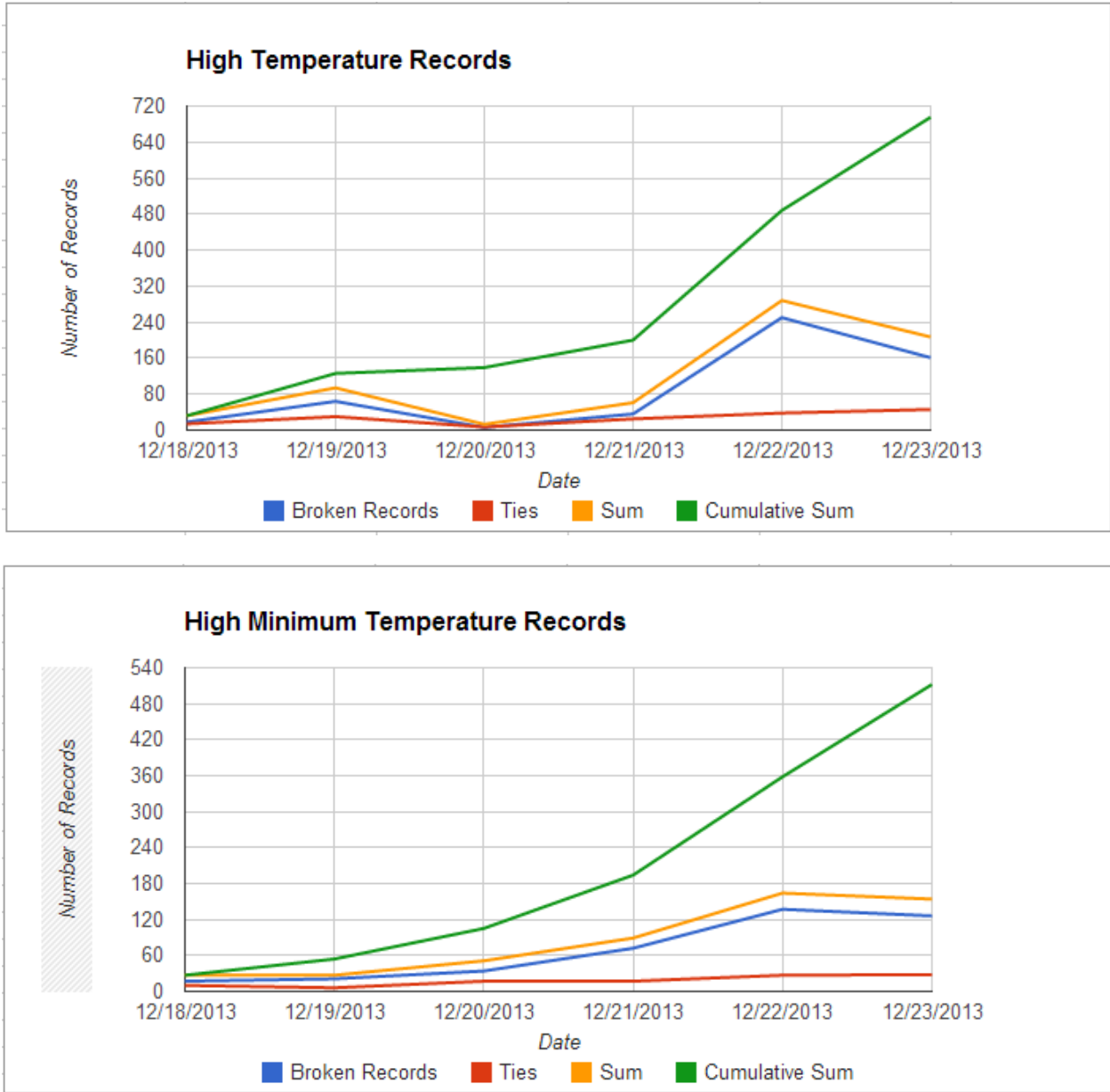


Figure 3. [Return to text.](#)

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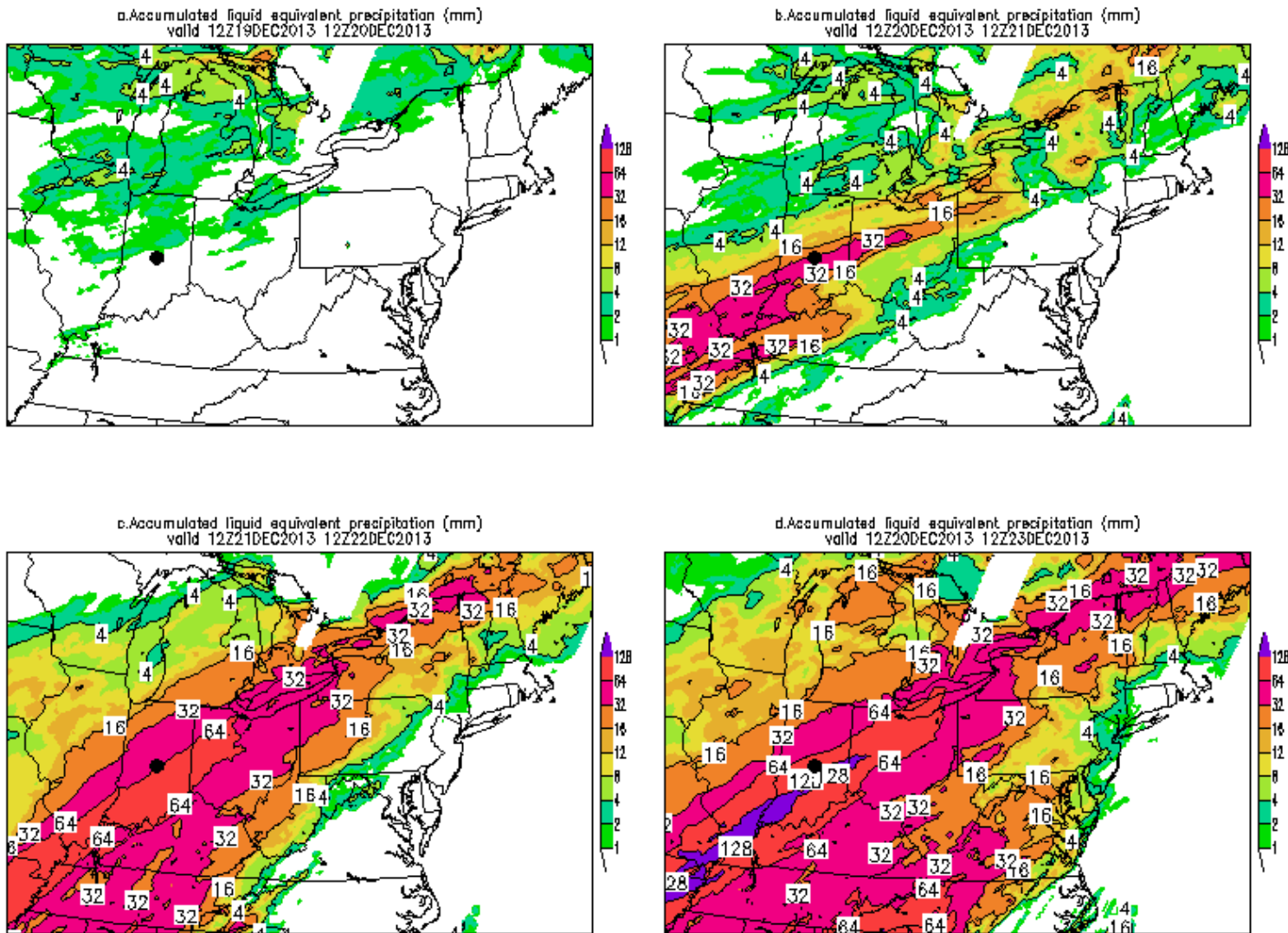


Figure 4. Total estimated precipitation (mm) from stage-IV data for the a) 1200 UTC 19-20 December, b) 1200 UTC 20-21 December, c) 1200 UTC 21-22 December, and d) the total precipitation for 1200 UTC 21-23 December 2013. [Return to text.](#)

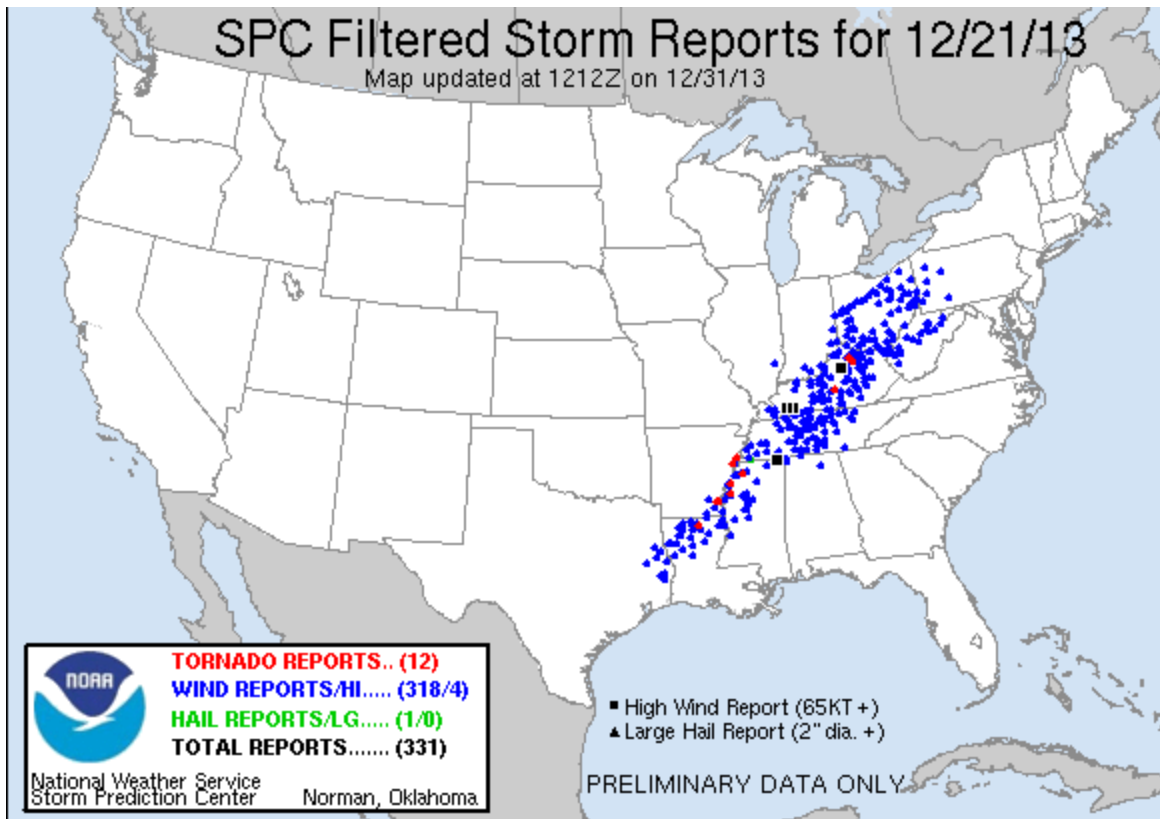
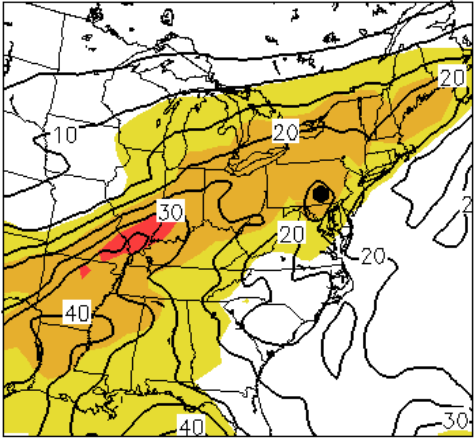


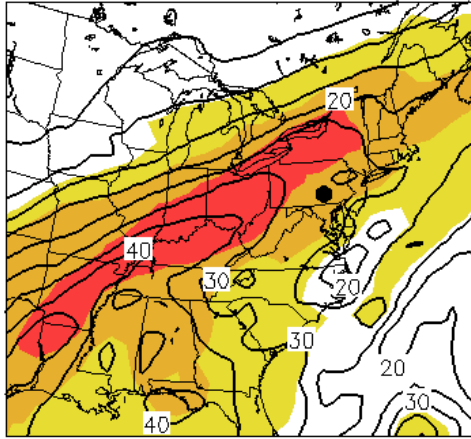
Figure 5. Storm reports from the storm prediction center (SPC) for all severe weather reported on 21 December 2013. [Return to text.](#)

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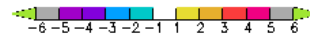
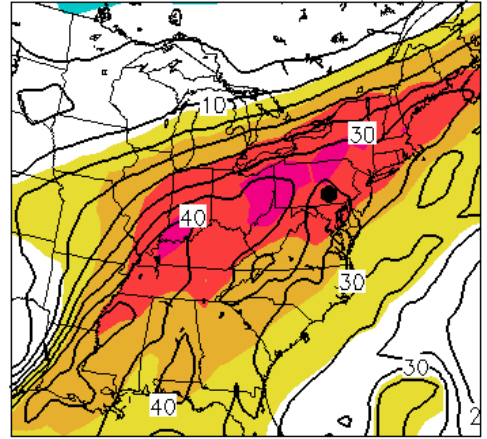
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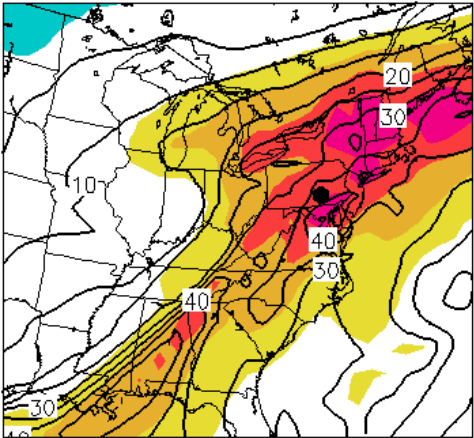
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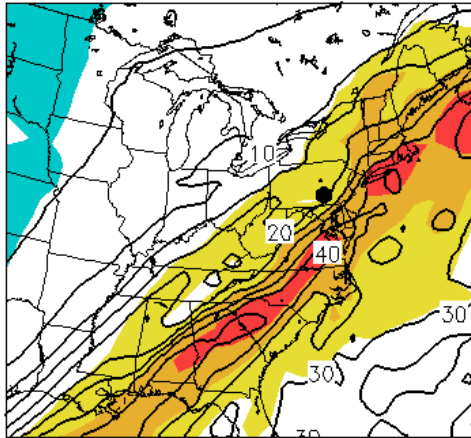
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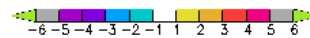
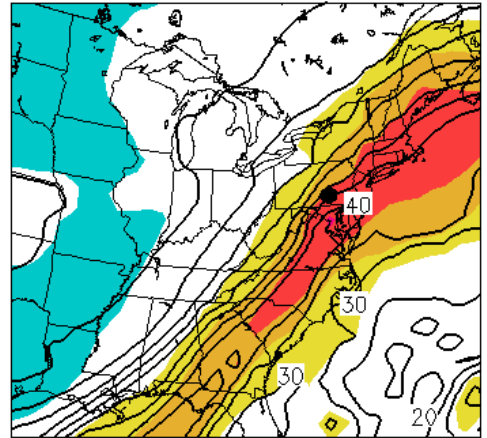


Figure 6. As in Figure 1 except for precipitable water in 12-hour increments from a) 0000 UTC 21 December through f) 1200 UTC 23 December 2013. [Return to text.](#)

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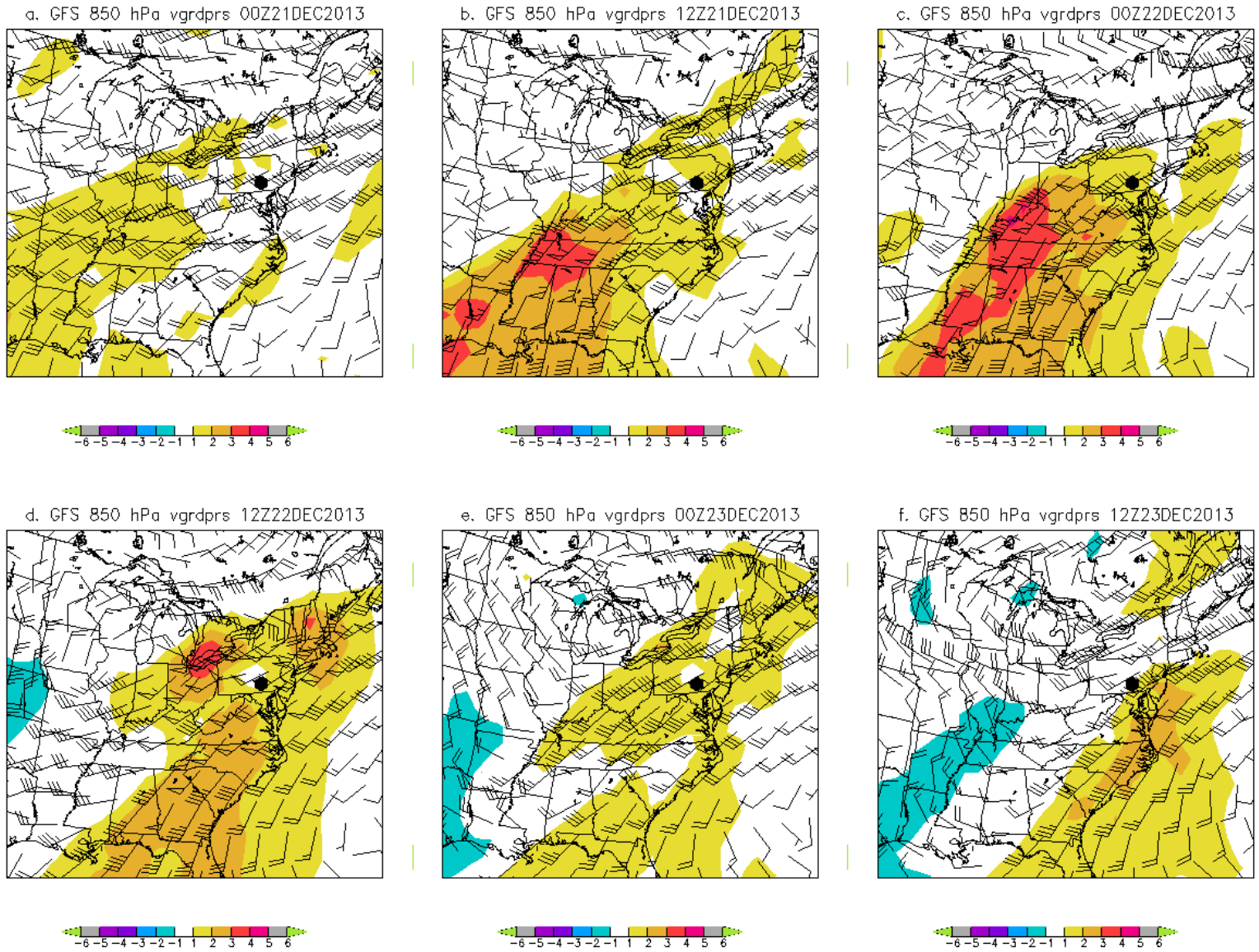


Figure 7. As in Figure 6 except for 850 hPa winds and u-wind anomalies. [Return to text.](#)

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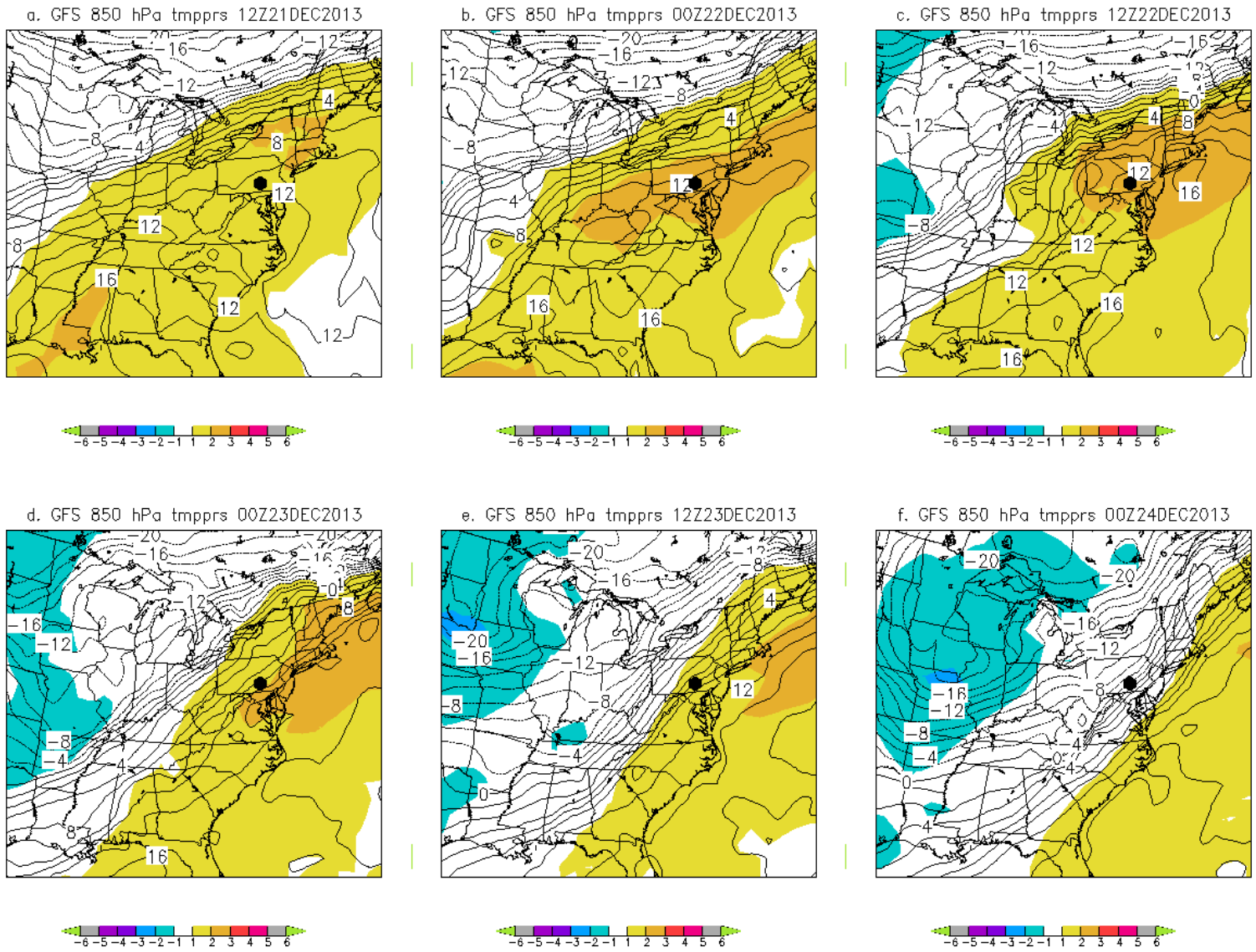
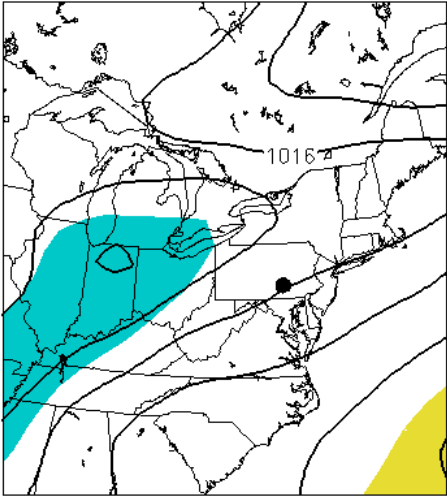


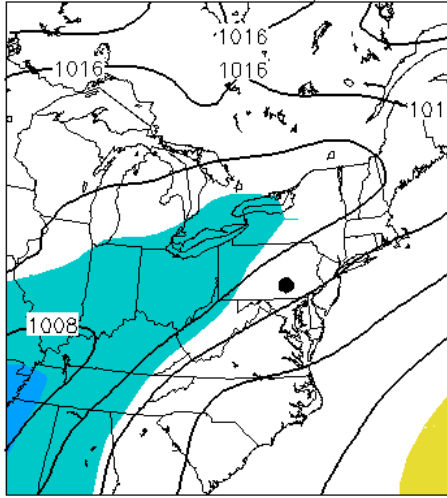
Figure 8. As in Figure 6 except for 850 hPa temperatures and temperature anomalies. [Return to text.](#)

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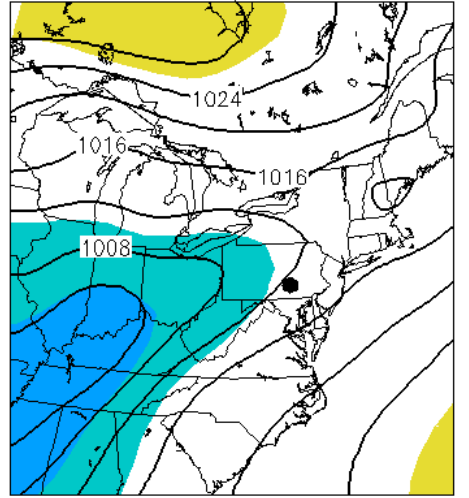
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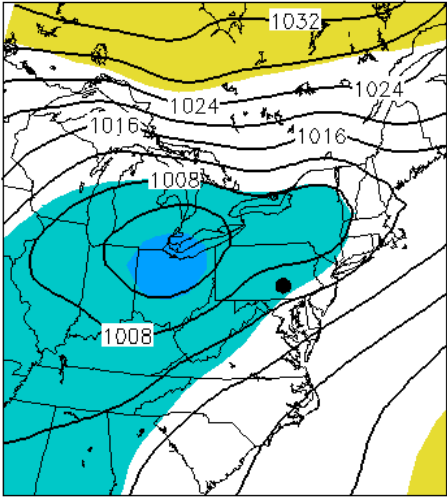
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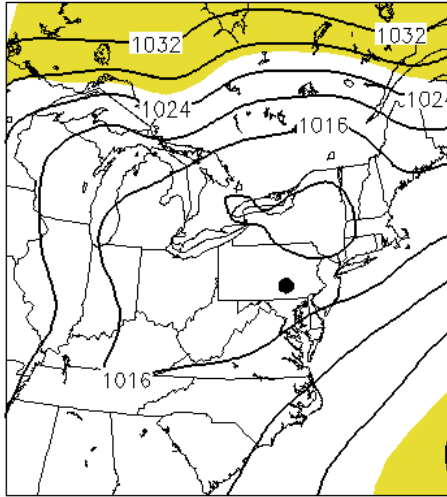
c. GFS 1000 hPa prmslmsl 00Z22DEC2013



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e. GFS 1000 hPa prmslmsl 00Z23DEC2013



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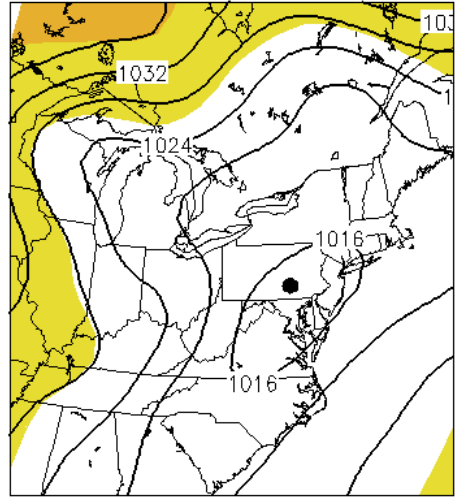


Figure 9. As in Figure 6 except for MSLP and anomalies. [Return to text.](#)

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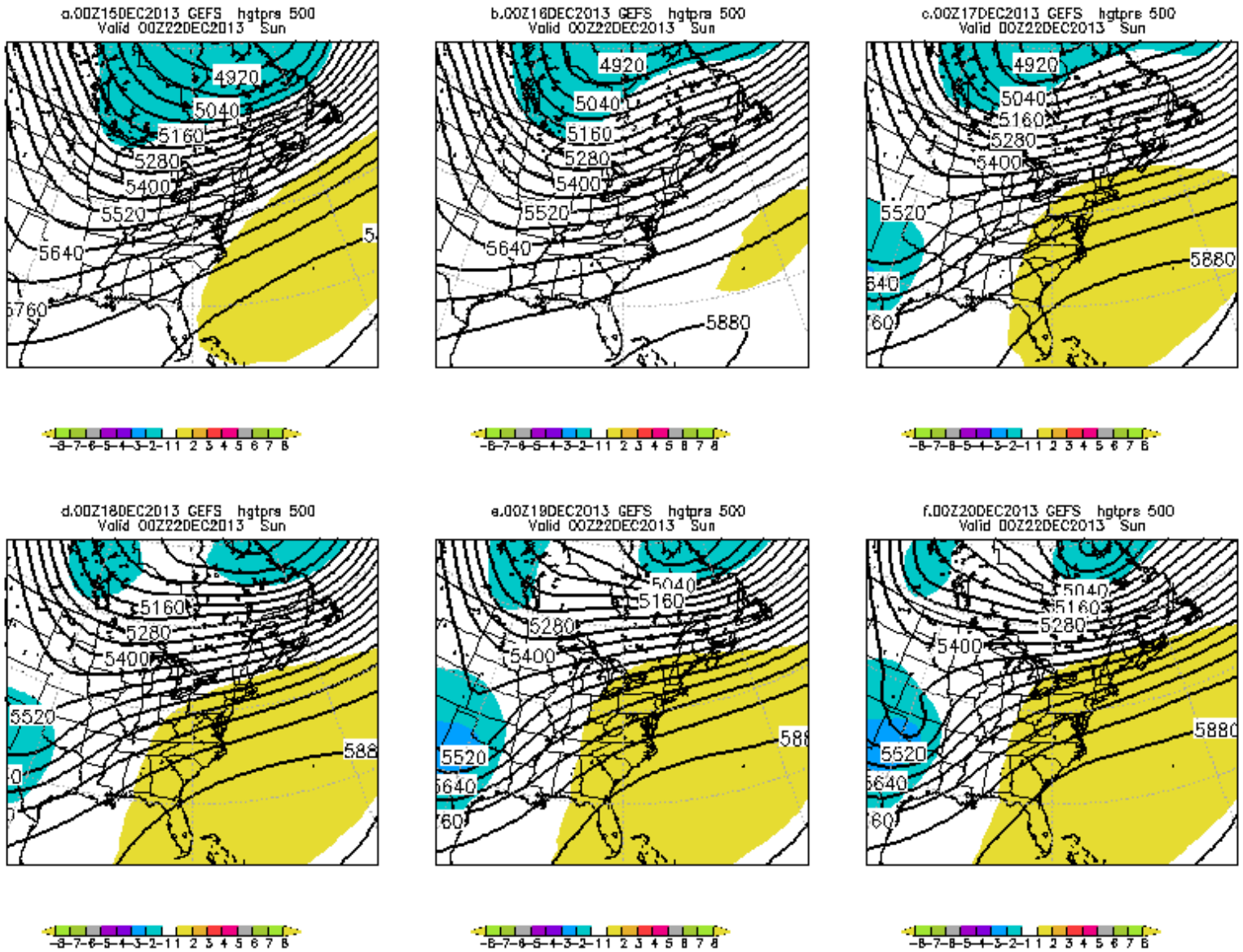


Figure 10 GEFS forecasts of 500 hPa heights and 500 hPa height anomalies valid at 0000 UTC 22 December 2013 from GEFS forecast initialized at a) 0000 UTC 15 December, b) 16 December, c) 17 December, d) 18 December, e) 19 December and f) 20 December 2013. Return to text.

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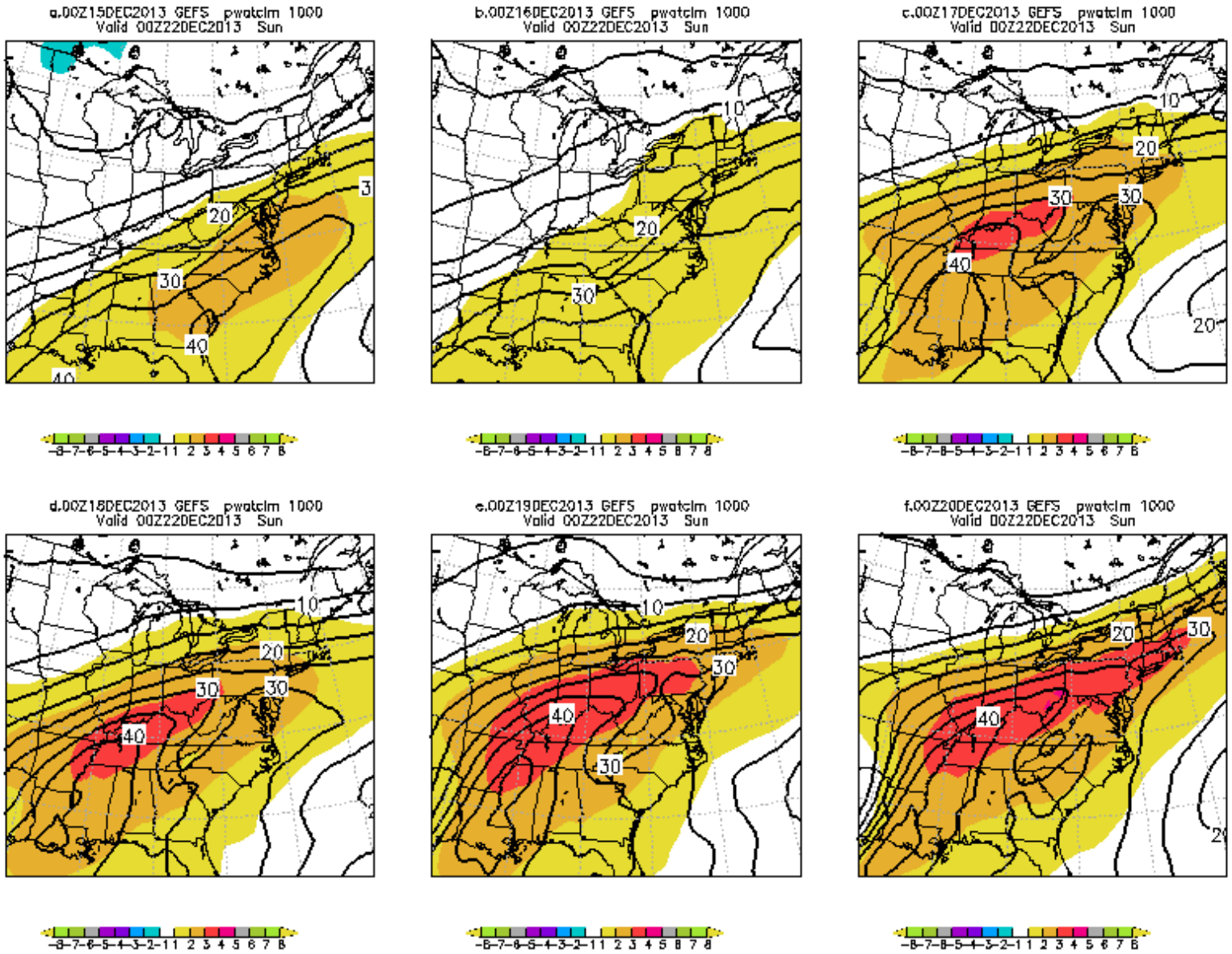


Figure 11. As in Figure 10 except for precipitable water and precipitable water anomalies. [Return to text.](#)

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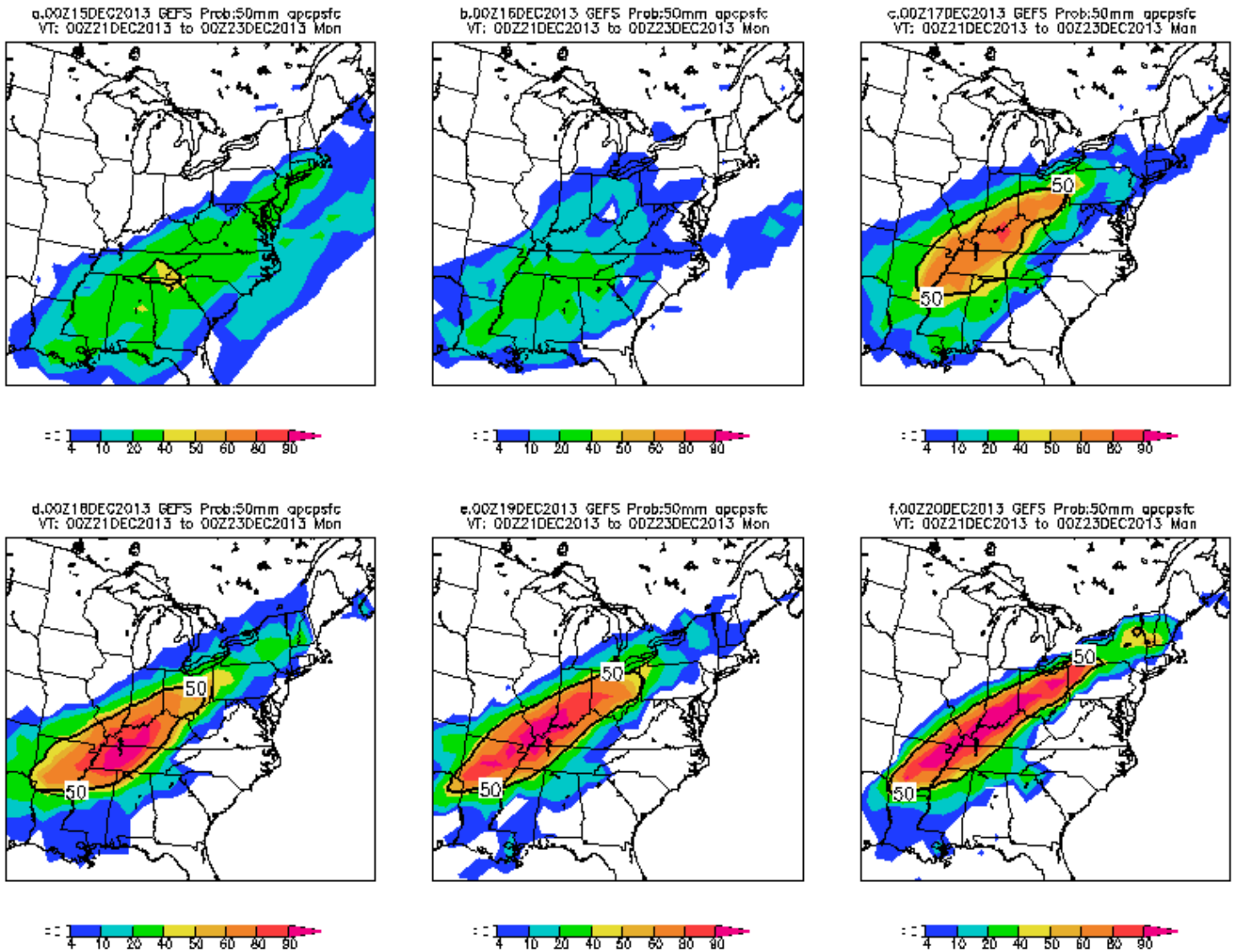


Figure 12. As in Figure 10 except for the probability of 50 mm or more QPF. [Return to text.](#)

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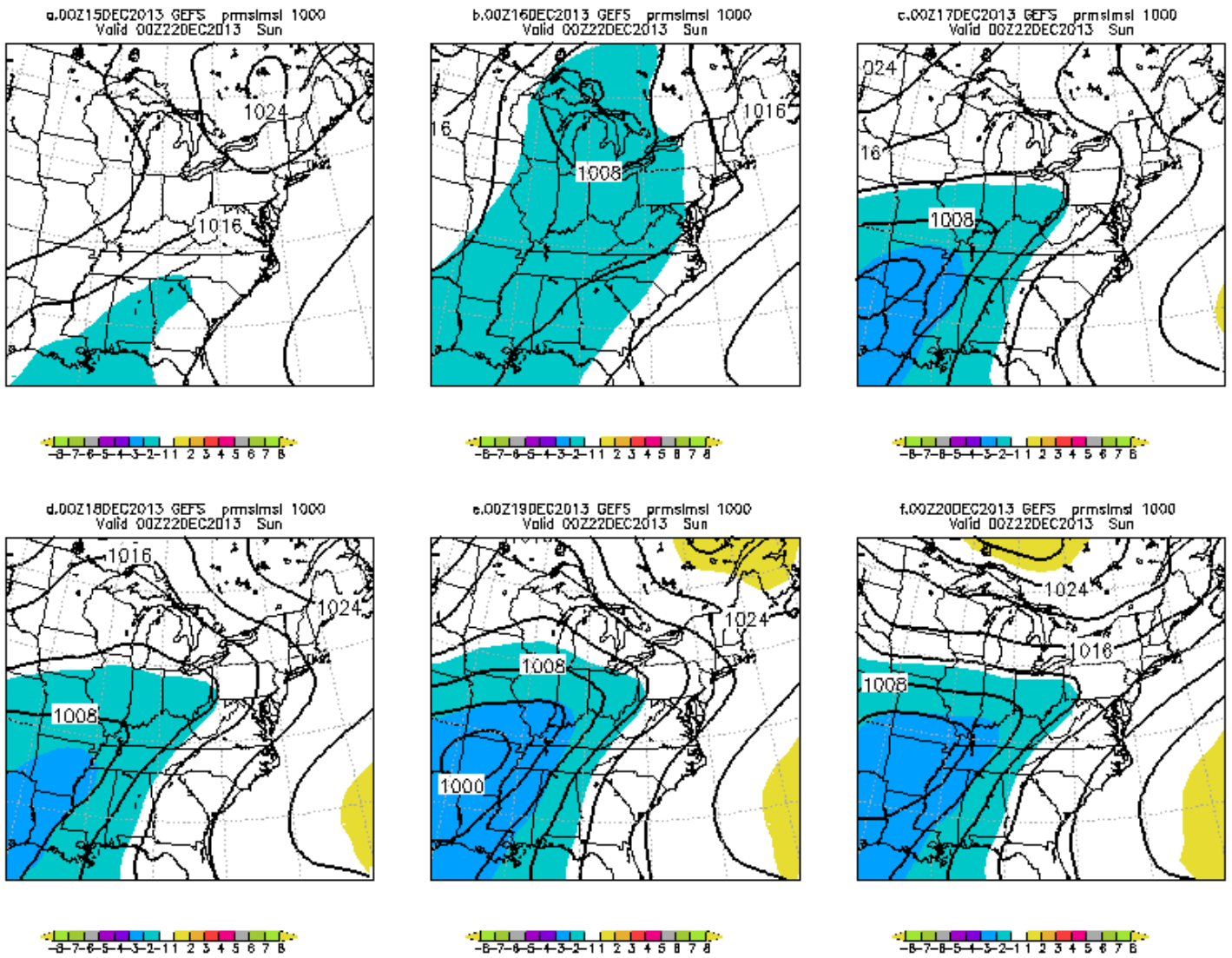


Figure 13. As in Figure 12 except for GEF5 ensemble mean sea-level pressure (hPa) and pressure anomalies. [Return to text.](#)

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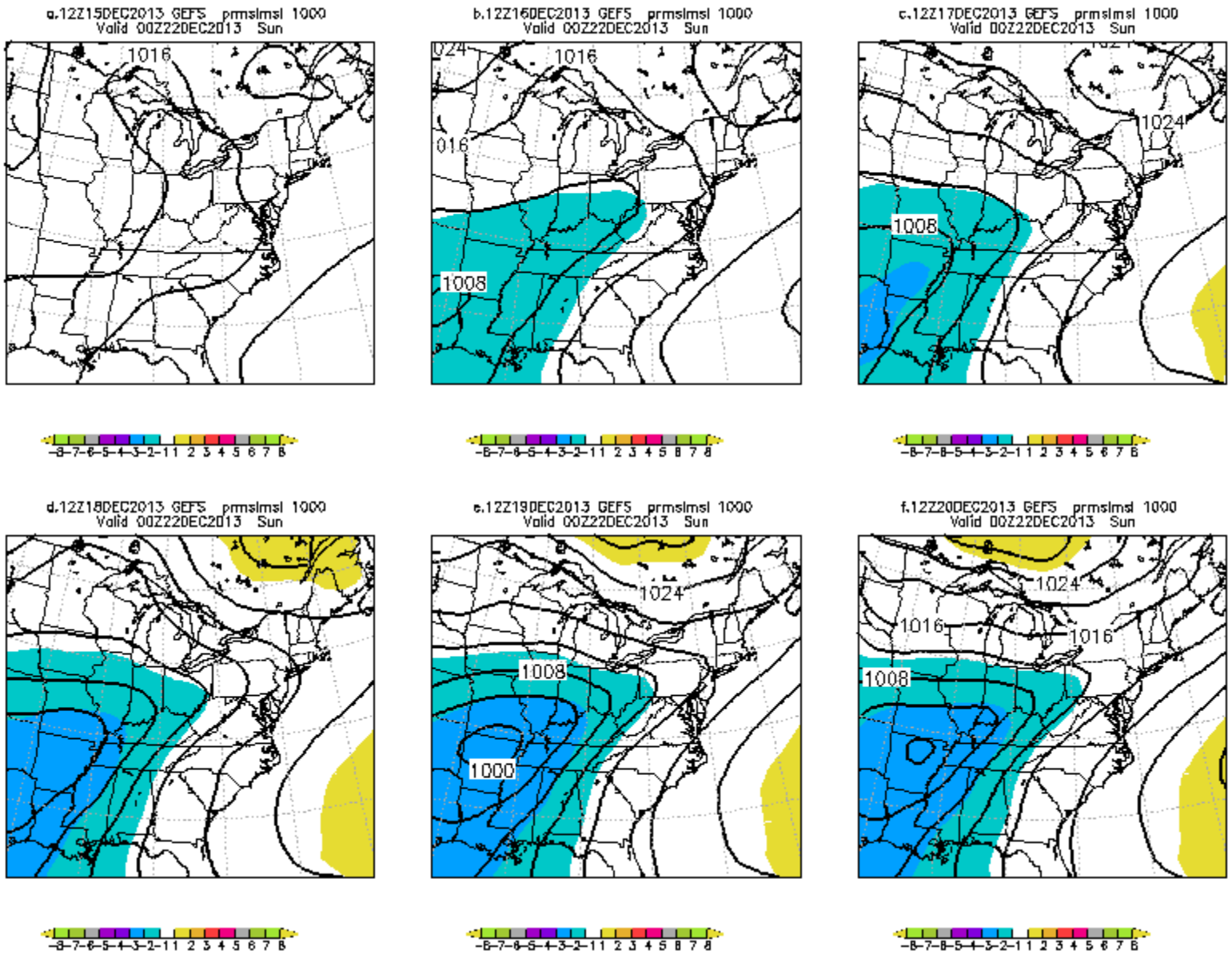


Figure 14. As in Figure 13 except for GEFS ensemble mean sea-level pressure (hPa) and pressure anomalies from GEFS forecasts from the 1200 UTC data cycle. [Return to text.](#)

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ECMWF Total Snowfall [inches] INIT: 12Z15DEC2013 fx: [186] hr --> Mon 06Z23DEC2013
Liquid Equivalent Snowfall [10:1 ratio] between 12Z15DEC2013 -- 06Z23DEC2013

Max: 23.3 inches

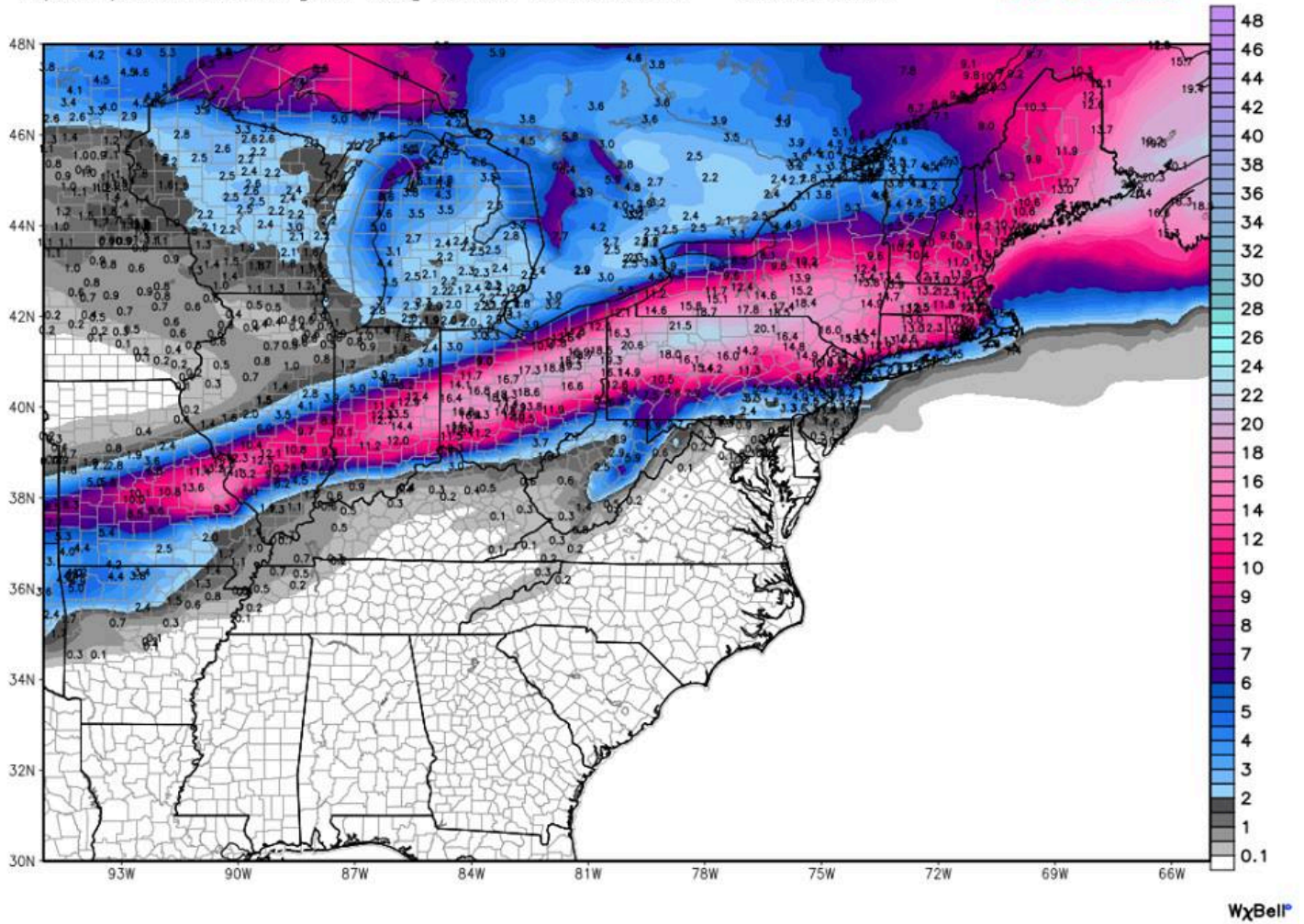


Figure 15. Total estimated snowfall for the period of 1200 UTC 15 through 0600 UTC 23 December from the 1200 UTC 15 December European Center model. Snow fall in inches. [Return to text.](#)

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