The eastern United States Heat wave of 6-10 June 2008 -Draft

By
Richard H. Grumm
And
Marc Chenard
National Weather Service
State College, PA 16803

1. INTRODUCTION

A strong subtropical ridge dominated the weather over much of eastern North America from 5-10 June 2008. On the periphery of the ridge, warm moist tropical air collided with cooler air and produced a series of Mesocale Convective Systems (MCSs) and heavy rains (Fig 1). Some of these systems produced record flooding. Under the ridge, hot weather dominated and many locations in the Mid-Atlantic region experienced successive days of 100F+ temperatures. Richmond, Virginia and Raleigh-Durham had several days where the maximum temperatures exceed 100F. In Pennsylvania many locations experienced 3 to 4 consecutive days with temperatures at or above 90F qualifying this event as a heat wave.

There are varying definitions of a heat wave (Robinson, 2001). Several definitions require the duration of above normal conditions for 2-3 days. Others focus on high temperatures of approximately 2 standard deviations (SDs) above normal for about 2 days over a region rather than single stations. Robinson also describes a definition of a heat wave "as period of at least 48 h during which neither the overnight low nor the daytime high value of the heat index falls below 80F and 105F respectively". An early 20th century definition required 3 consecutive days of

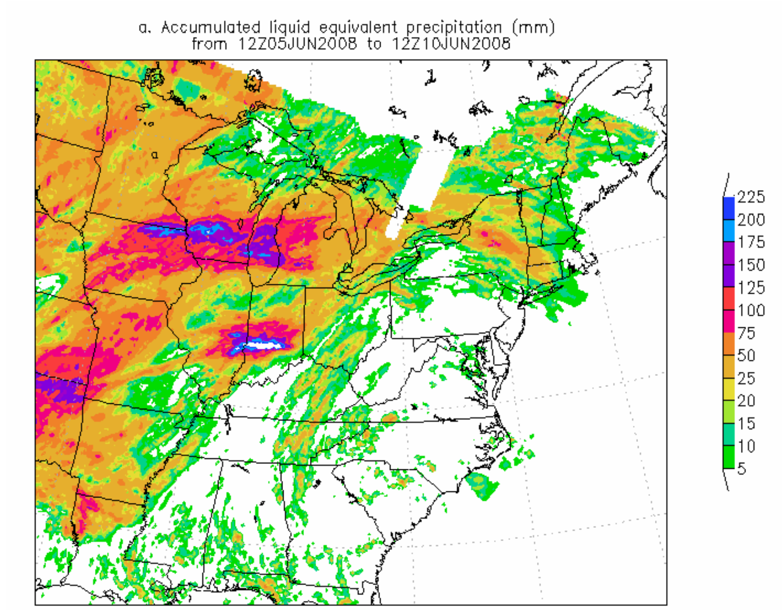

Figure 1 Total accumulated rainfall from 1200 UTC 5 June to 1200 UTC 10 June 2008. The impacts of the subtropical ridge are seen with dry weather beneath the ridge and heavy rainfall on the western flanks. The rain in the northeast was observed on the 5th as the ridge pushed northward into the region.

90F temperature observations. The generally accepted definition for a heat wave is

The sustained period of 100F high temperature readings over the Coastal regions of Virginia and the Carolinas suggest that the region met the traditional value associated with a heat wave. Richmond, VA hit 100F on 8 June 2008 breaking the hold record of 99 set back in 1899. With a high temperature of 100F in the 7, it was also the earliest recorded consecutive days with 100F readings at

Richmond[1] since record keeping began in 1877.

In North Carolina, Raleigh-Durham hit 100F 7 June 2008, this was the earliest occurrence of 100 at RDU in a calendar year since 1944. The previous earliest occurrence was 8 June 1999[2].

The high temperatures in Pennsylvania suggest that Pennsylvania also met traditional heat wave criteria. However, with overnight low temperatures in the 60s and 70s, the heat index values clearly fell well below the established criteria of a heat wave over Pennsylvania. Several locations in Pennsylvania tied record highs during this period of time.

Heat waves are one of the most significant causes of weather related fatalities. Changnon et al. (1996) documented the 1995 Midwestern United States heat wave, which caused 525 deaths in Chicago and 830 deaths nationwide. Contributing factors related to the deaths in Chicago included the high dew points, the urban heat island effects, the aging population, and the lack of ventilation. Kunkel et al. (1996) attributed two essential factors to the fatal affects of the heat wave including the high dew points and the urban heat island effects. The large number of deaths due to the 2003 European heat wave in France and Italy may have been related to population demographics and a lack of the wide use of air conditioning.

The heat wave of July 1999 caused an estimated 309 deaths in 21 States, with the majority (258) of the deaths occurring in the Midwestern United States in late July (Palecki et al. 2001). The July 1999 event was of longer duration than the July 1995 event but it did not achieve the intensity of the 1995 event. The apparent temperatures during the July 1999 event were lower than in the July 1995 event due to lower moisture values (Table 1).

Heat waves are not unique to the United States. Deadly heat waves struck Europe in the summers of 2003 and 2006[3]. The 2003 heat wave was responsible for around 35000 deaths (Schar and Jendritzky 2004). The conditions associated with the European heat waves of 1906, 1911, and 1990 that affected the United Kingdom were studied by Brugge (1991). The favored period for persistent heat waves appeared to be late July and early August. The synoptic scale pattern requires anticyclonic conditions and cloud free conditions. In the United Kingdom, low-level southeasterly flow off the continent is another important factor in achieving high temperatures. Antecedent drought conditions also appear important in the more intense heat waves. The United States heat wave of 1988 may have shared a similar antecedent drought scenario.

Namias (1982) showed that heat waves in the United States are characterized by strong subtropical ridges. Prolonged and damaging heat waves in the United States are also associated with ridges over the oceans. The association of anticyclones with United States and United Kingdom heat waves appears to be a common thread. The subsidence produces cloud free conditions and a subsidence inversion (Brugge 1991) which facilitate the development and maintenance of the low-level heat. The basic characteristics of mid-latitude heat waves in

[1] Wakefield, VA record event report 526PM 8 June 2008.
[2] Source Mike Brennan, NCEP/HPC

[3] NCDC climate hazards and extremes web page referenced the mid-late July 2006 European heat wave. New all-time high in UK on the afternoon of July 19th where temperature reached 36.3°C (97.3°F) at Charlwood.

the United States and Europe may contain several similar characteristics. Research on European heat waves show a similar dependence on a strong subtropical ridge in producing the long-lived events with record high temperatures. Livezey and Tinker (1996) documented the importance of the strong and persistent anticyclonic conditions which persisted over then Midwest during the fatal 1995 Chicago heat wave.

From a forecast perspective, the scenarios outlined by Namias (1982) and Brugge (1991) suggest a large subtropical ridge as a key ingredient in most heat waves. The intensity of these ridges can be identified using normalized climatic anomalies (Hart and Grumm 2001). Lipton et al. (2005) showed the anomalies of 500 hPa heights, 850 and 700 hPa temperatures , and 1000-500 hPa thickness for heat waves over the Mid-Atlantic region from 1948-1999. These data also showed the role of moisture, as shown by precipitable water anomalies in several heat waves.

Recent work on Mid-Atlantic heat waves identified a strong correlation with record high surface temperatures and 925 hPa anomalies. The National Centers for Environmental Predictions (NCEP) Global Reanalysis data re-analysis data (GR) correlated to high surface temperatures to large 925 hPa anomalies. In this paper, the NCEP forecasts of 925 hPa temperatures will be used to show the evolution of the heat wave.

This paper will examine the conditions associated the early season heat wave of 6-10 June 2008. The focus is on the value of climatic anomalies to predict and characterize the heat wave. Data from previous heat waves, as analyzed by the GR data, are also presented. The focus is on the traditional features used to identify heat waves including the traditional fields, such as 500 hPa heights, 925 and 850 hPa temperatures and their departures from normal (climatic anomalies). Precipitable water (PWAT) anomalies are shown as additional tools to characterize a heat wave.

2. Methods and Data

High temperature was extracted from the web[4] in near-real time to evaluate the event and track the observed high temperatures at synoptic sites. Pennsylvania data were retrieved from the local National Weather Service (NWS) Cooperative Observing Program (COOP) data base.

Model data, focused on the NCEP Global Ensemble Forecast system (GEFS) was used to show the evolution of the case. In this paper, the focus is on 00-hour forecasts showing the general evolution of the event. The 00-hour forecast fields were displayed showing departures from normal relative the 30-year mean and standard deviations derived from the NCEP GR data as presented in Hart and Grumm (2001) and Lipton et al. (2005). All images are from 0000 UTC as this is closest to the time of maximum heating. Though not shown, 0600 and 1800 UTC were also examined. All times are in the format 09/0000 UTC implying 0000 UTC 9 June 2008.

The GR means and standard deviations span the 30-year period of 1970-2000. Archives of all GR data spans 1948-2006, allowing the extraction of the conditions associated with previously documented heat waves. For illustrative purposes, previous heat wave cases are displayed using these data.

3. Results

[4] The Pennsylvania State University site at: http://www.meteo.psu.edu/~gadomski/MAXMIN_NA/naloop8.html

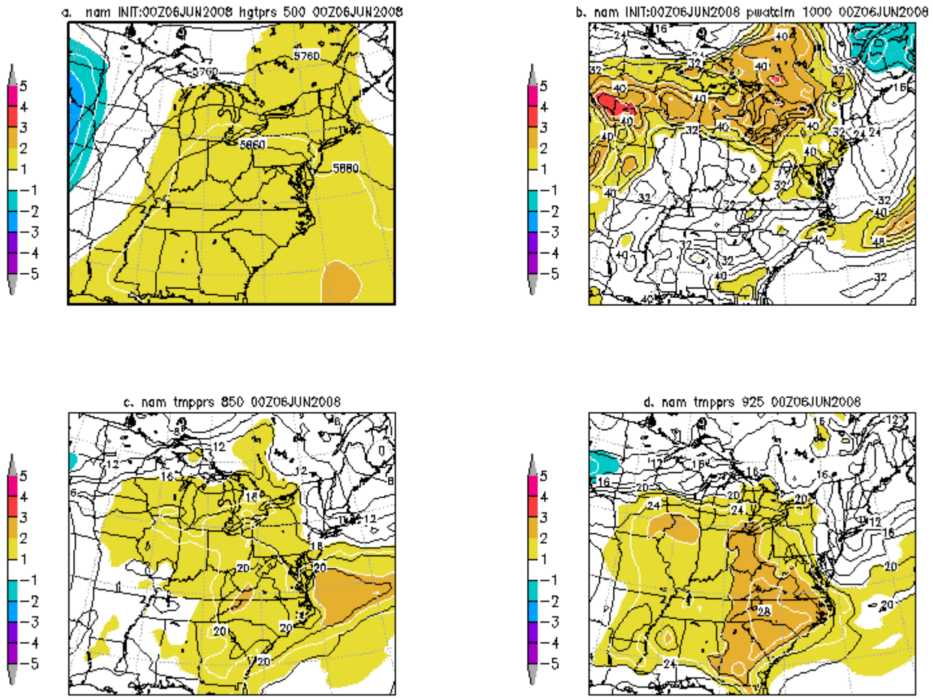

Figure 2. NAM 00-hour analysis valid at 0000 UTC 6 June 2008 showing a) 500 hPa heights (m) and anomalies, b) precipitable water (mm) and anomalies, c) 850 hPa temperatures (C) and anomalies, and d) 925 hPa temperatures and anomalies.

i) Overview of the pattern

Figures 2-6 show the large scale pattern over the eastern United States from 06/0000 through 10/0000 UTC in 24 hour increments. The subtropical ridge is captured in the 500 hPa height and height anomaly fields (Figs 2a-6a). The first closed 594dm contours appears at 07/0000 UTC over the Carolinas and persists until 08/0000 UTC. By 09/0000 UTC the 500 hPa heights begin to fall and by 10/0000 UTC the subtropical ridge has moved offshore. The 500 hPa height anomalies peaked at around +2 to +2.5SDs above normal over this 5-day period.

Another established heat wave feature is the surge of high PW air north and west of the affected region. The high PW air, marked by the +1 to +3SD above normal plumes of high PW values were present along the western and northwestern edges of the strong subtropical ridge. During most of the event, PW anomalies were normal to slightly above normal where the highest temperatures were observed with the notabl exception of 08/0000 UTC where above normal PW values were present over the much of the northeastern United States. High PW air contributes to keeping overnight lows high and likely can be related to higher values of surface dewpoints and thus higher heat index values.

The plumes of high PW air on the western flank of the subtropical ridge often contribute to convection and rainfall in these areas. Not surprisingly, heavy rains and flooding impacted Indiana on 7 June and portions of Iowa, Wisconsin, Minnesota, and Michigan from 7-9 June 2008.

The 850 and 925 hPa temperatures and temperatures anomalies are also shown in Figures 2c-6c and Figures 2d-6d respectively. These data show that both 850 and 925 hPa temperatures were above normal for the entire period. At 09/0000 UTC large areas of the eastern United States had 925 hPa anomalies of +2SD or greater above normal with an area of +3SD above normal anomalies over the southeastern United States. These large anomalies persisted into 9th of June as shown in the temperature anomalies valid at 10/0000 UTC. These magnitude of the temperature anomalies appeared to peak after the ridge began to weaken. However, they also appeared to be related to a sharpening of the ridge suggesting some increased subsidence may have been present.

By 11/0000 UTC (Fig. 7) the GFS clearly showed that the subtropical ridge and the low-level thermal anomalies were weakening and moving to the east. In addition to the height and thermal pattern, the PW fields clearly showed below normal PW the north and east indicating that the poleward flow of tropical air into eastern North America had ended.

j) Observations

Figure 8 shows the daily high temperatures from ASOS sites from 6 to 10 June 2008. The primary definition of a heat wave being 3 or more consecutive days over 90F, the first large 90F day was 6 June 2008 (Fig. 8a). On 7 June the 90F temperatures moved into Pennsylvania and New England with a few 100F readings in Virginia (Fig. 8b). On the 8th most of Virginia had its third consecutive 90F day (Fig. 8c) and on the 9th (Fig. 8d) many Pennsylvania locations reached the third consecutive 90F day. The 10th of June marked the 5th day for many locations in Virginia and the 4th day in eastern Pennsylvania where daytime highs exceeded 90F.

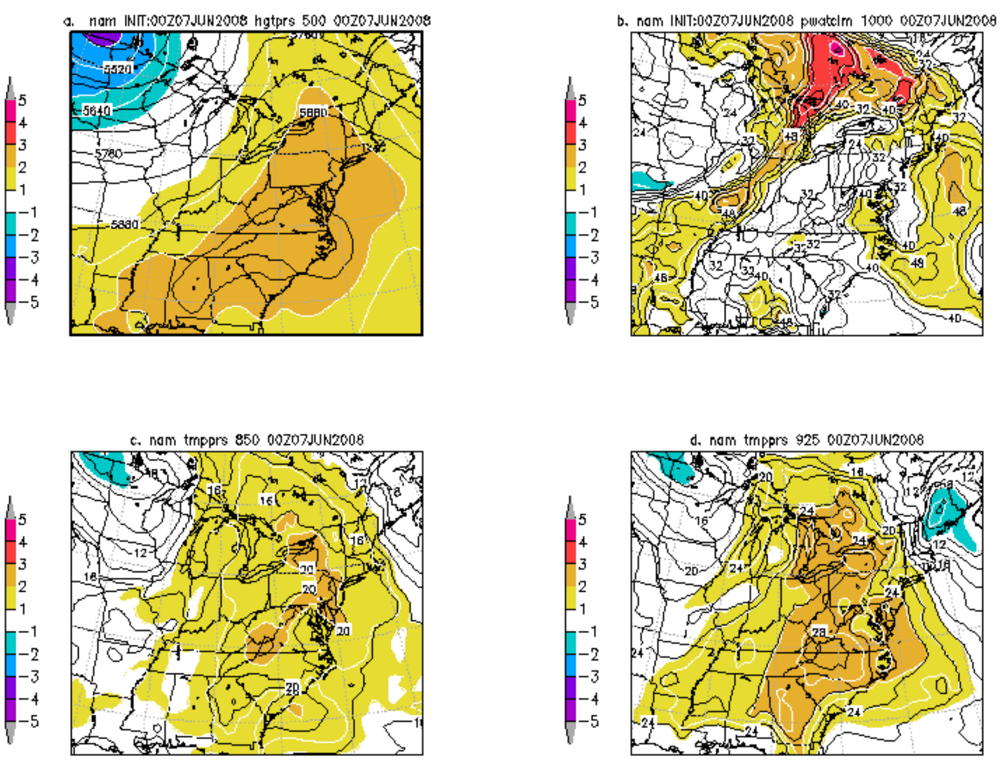

Figure 3. As in Figure 2 except valid at 0000 UTC 7 June 2008.

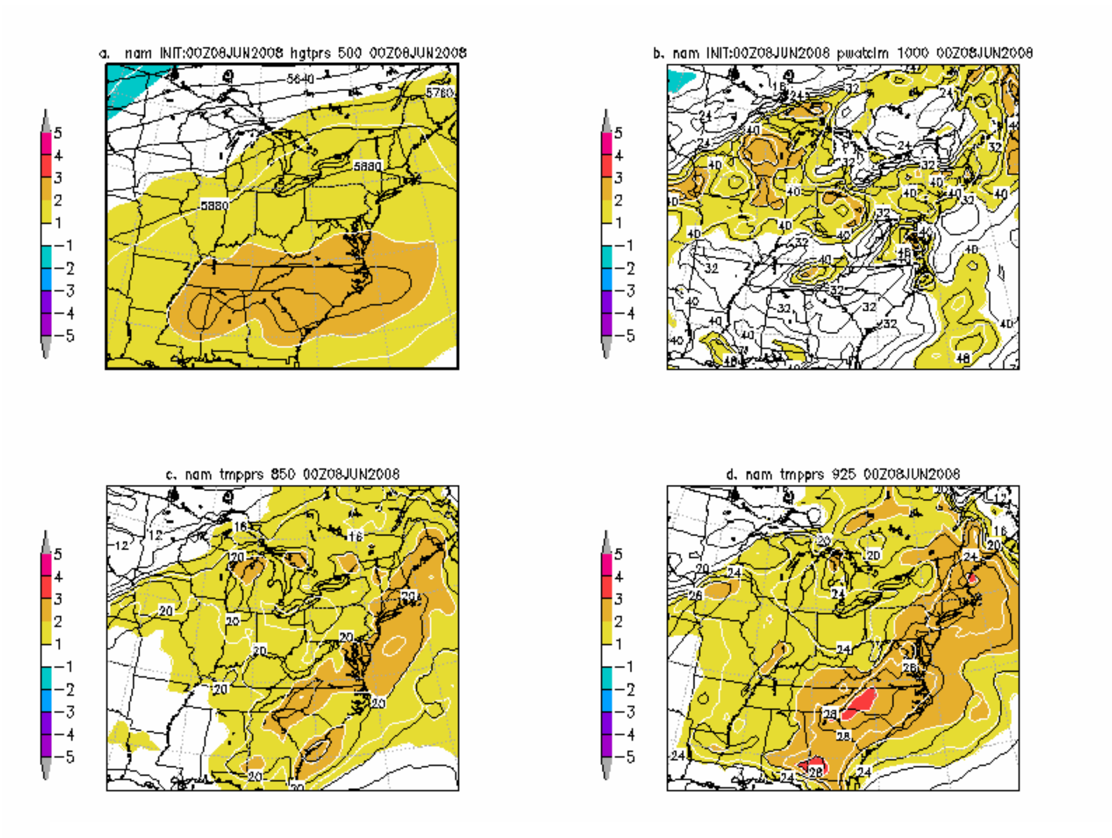

Figure 4. As in Figure 2 except valid at 0000 UTC 08 June 2008.

Based on the data in Figure 8, many locations in the Mid-Atlantic and southern New England had 3 consecutive days of 90F or greater day time temperatures. This satisfied the requirement for a heat wave on the simplistic definition.

The more rigorous definition (Robinson 2001) with daytime heat indices (HI) over 105 or greater and maintaining HI values of 80 or greater was met in far fewer locations.

Figure 9 shows the HI values on 8 June 2008. The 1000 UTC HI values of 80 or greater are displayed as shaded. The area of 80 or greater extended from Ohio into the New York State and across Pennsylvania. Much of the coastal plain had HI values greater than 80. During the daytime maximum HI values of 105 or greater were confined to portions of Virginia and Maryland with a few isolated hot spots in the Philadelphia area. No data was available south of the Virginia-North Carolina border.

HI values tended to peak each day between 2000-2200 UTC time and reached minimum values between 1000 and 1100 UTC. The highest observed value in these data was 112 on the Delmarva Penninsula. Only a small region of coastal Virginia and North Carolina were able to maintain HI values above 80F and attain afternoon HI values of 105F. This strict definition would limit the heat wave to a very localized region of the Mid-Atlantic region.

k) forecasts

The options of forecast systems and fields to choice from is prohibitive. The focus here is on GEFS forecasts of select fields and times. To varying degrees, the NCEP GEFS forecast the heat event with at least 7 days lead time. The duration of the event varied but the overall concept of anomalous subtropical ridge and anomalous low-level temperatures was forecast with some degree of success with considerable lead time. Only the 1200 UTC cycle is presented here though all 4 cycles were available.

The 02/1200 UTC GEFS 500 hPa heights valid at 07/0000 UTC are shown in Figure 10. These data show the high degree of agreement amongst members and the potential for 1.5SD above normal 500 hPa heights over the eastern United States. The 850 hPa temperatures were also forecast to be 1 to 2 SDs above normal over the eastern United States. These forecasts however indicated that the event would end late on the 8th as cooler air moved into the region.

GEFS forecasts initialized on 03/1200 UTC was able to predict the 1 to 2SD above normal 850 hPa temperatures from 5-10 June 2008. Figure 11 shows the forecasts valid at 07-09/0000 UTC from the 03/1200 UTC cycle. The core days of the heat wave were forecast by the GEFS. These warmer and more persistent temperatures were in line with a strong and more persistent 500 hPa ridge (not shown) over the region. The GEFS mean did not show a closed 594 dm contour. Why the ridge no longer was forecast to retrograde in an interesting question.

Forecasts initialized 04/1200 UTC of 500 hPa heights are shown in Figure 12. These data show the first closed 594 dm contour valid at 07/0000 UTC and the persistent and strong 500 hPa height anomalies over the eastern United States. Though not shown, these forecasts implied the heat event could persist through 11-12 June, longer than observed. The 850 hPa temperatures (not

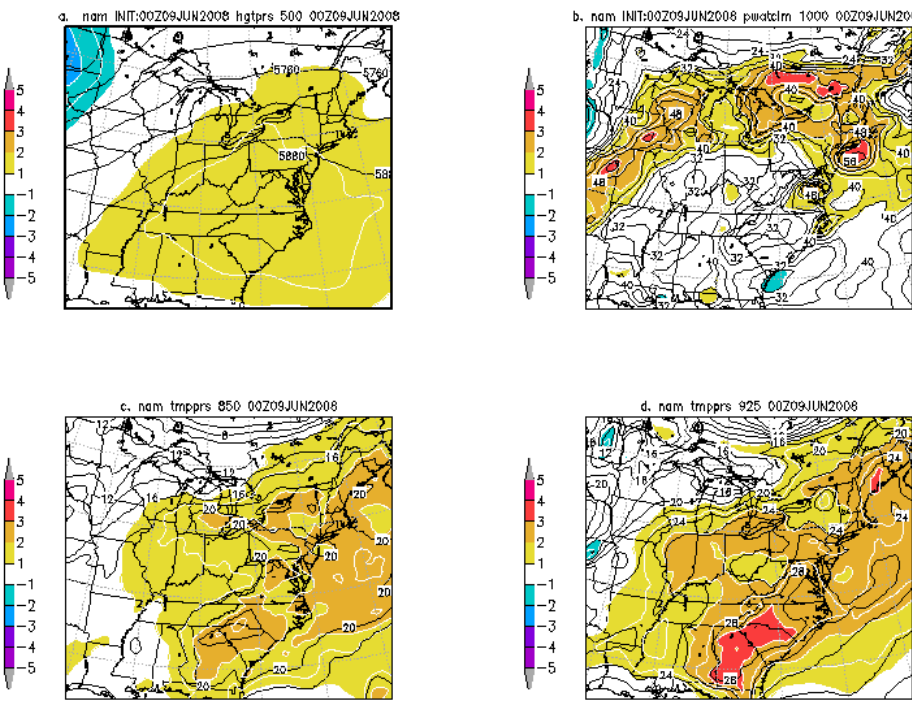

Figure 5. As in Figure 2 except valid at 0000 UTC 9 June 2008.

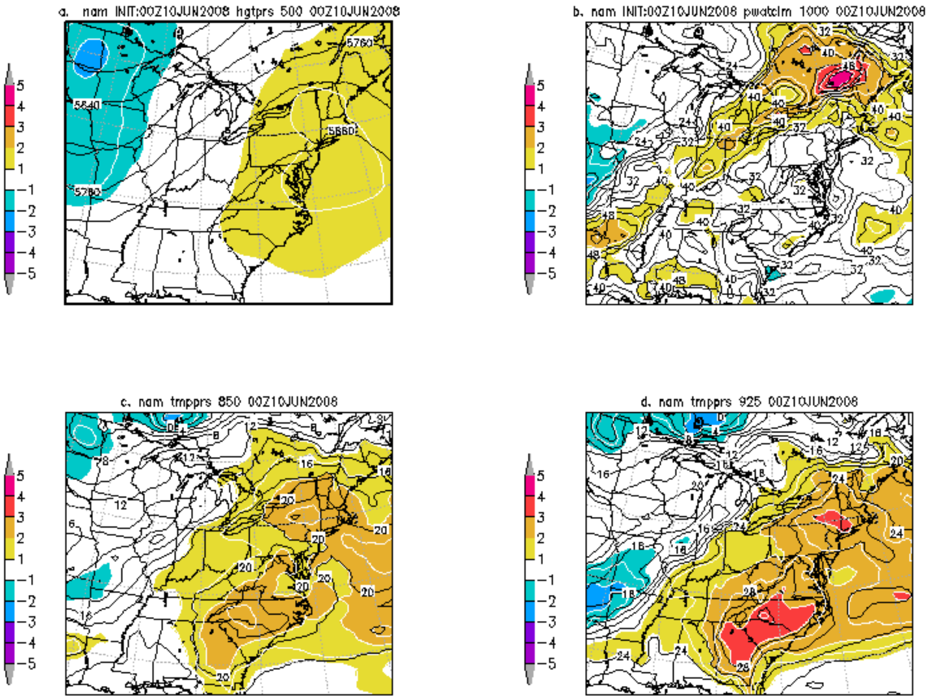

Figure 6. As in Figure 2 except valid at 0000 UTC 10 June 2008.

shown) revealed some +1.5 to +2SD thermal anomalies during this period.

Forecasts initialized 06/1200 UTC of 500 hPa heights are shown in Figure 13. It should be noted that forecasts initialized on both the 5th and 6th began to correctly predict the end of the heat wave on or about 10-11 June 2008. The 850 hPa temperatures shown reveal the last 3 afternoons of the event including the onset of lowered 850 hPa temperatures at 11/0000 UTC.

Shorter range forecasts were more accurate and tended to show some of the key anomalies. Though not shown here, the 925 hPa temperatures and PW forecasts showed all the signals associated with heat waves including the surge of above normal PW air west and north of the subtropical ridge.

4. Conclusion

A heat wave affected the United States from around 6-10 June 2008 based on the definition of daily maximum temperatures reaching or exceeding 90F on at least 3 consecutive days. Few locations were able to meet the more rigorous HI criteria of a heat wave.

The large-scale conditions associated with this heat wave were similar to those associated with previous heat events, including a large subtropical ridge with anomalous 500 hPa heights. At lower levels, 850, and 925 hPa temperature anomalies were associated with regions of extreme heat where surface temperatures approached and exceeded 90 to100F.

In addition to the above normal ridge, 850 hPa 700, and 925 hPa temperatures, a surge of above normal PW north of the ridge is an indicator of a heat wave. This event had the classic signature with *the surge of anomalous PWAT north of the subtropical* *ridge and area of highest surface temperatures.* This likely contributed to the heavy rains observed in upper Mid-west during the heat wave.

This case demonstrated some of the key fields often used to identify and track heat waves. The emphasis here was on the 500 hPa heights associated with the ridge and the anomalous temperatures at 850 and 925 hPa. Though not shown, the strong ridge produced a deep warm air mass and 700 hPa temperatures were also 1-2SDs above normal.

The characteristics of heat waves over North America are relatively well known. These characteristics can be used to identify key predictors. These predictors include 850 hPa temperature, 700 hPa temperature, 925h Pa temperatures, 500 hPa height and precipitable water anomalies.

The GEFS was able to forecast this heat wave with some degree of accuracy several days in advance. They key to the forecast was correctly forecasting the intense subtropical ridge. Early forecasts, from 2-3 June suggested the event would be short-lived. Forecasts on 4 June implied it would be a longer lived system as the westward moving subtropical ridge in earlier forecasts

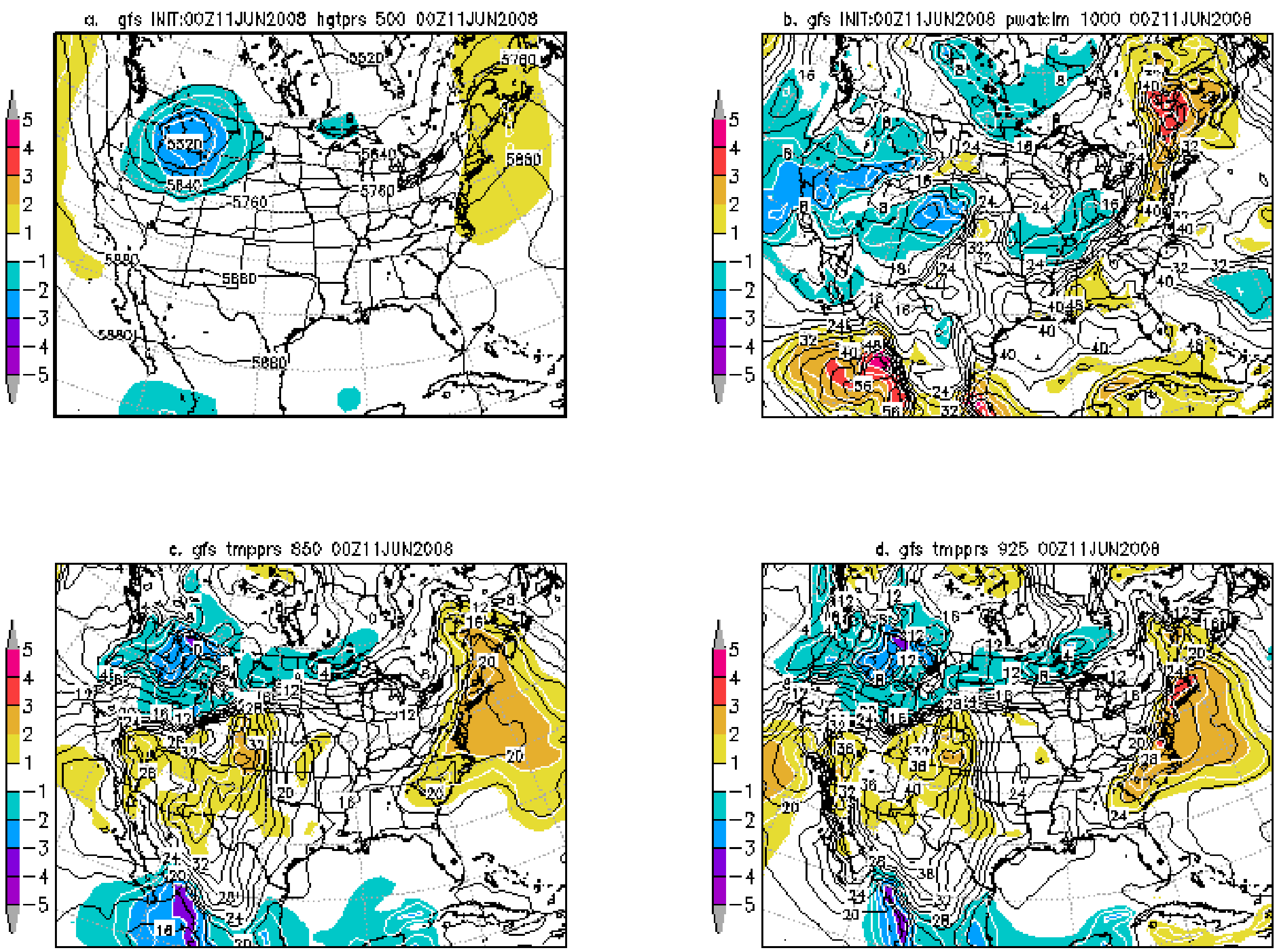

Figure 7. As in Figure 2 except GFS 00-hour forecast valid at 0000 UTC 11 June 2008 showing the pattern over the entire United States.

remained in place over the eastern United States. No attempt to explain this is offered suffice to say it was evident in the forecasts.

Forecasts initialized on 6 June 2008 clearly showed that the event would end, as it did, on or about on 10 June 2008 as the forecasts valid at 11/0000 UTC showed the cooling of the 850 hPa temperatures.

The impacts on heat waves can be considerable. Heat waves have been attributed with causing many deaths over the years. As of 12 June, 30 deaths have been attributed to the heat and humidity. As with most heat deaths, the majority of the victims were elderly. Deaths by State include 7 in Virginia, 15 in Philadelphia, 6 in New York City and 2 in Maryland. These numbers will likely rise over the coming weeks.

In addition to human impacts, heat waves can have significant meteorological impacts including setting and establishing new temperature records. Table 2 summarizes the high temperatures across the eastern US during the June 6-10 heat wave at select sites. The numerous records set are an indication of how extreme this event was for so early in the summer. For many locations this event was in the top 2 for earliest consecutive days of extreme heat. Raleigh and Richmond saw records set on 4 successive days. Many other locations saw 2-3 records broken over a 5 day span.

The heat was most anomalous over Virginia and North Carolina where Richmond reached 100 the earliest ever on record and Raleigh had 4 straight 100 degree days for the 2nd time on record. Further north across the Mid-Atlantic the duration of the heat was the most impressive factor with widespread 4 consecutive 90 degree days. The intensity of the heat was not quite as extreme over these areas though, as shown by the fewer records broken.

New England did not escape the heat, although they did manage to stay cool until the 6th. The warm air moved into the region on the 7th. Despite the delayed onset, the duration and intensity were both impressive for so early in the year over New England with most places seeing 3-4 90 degree days and numerous high temperature records broken (Table 2).

5. Acknowledgements

Ron Holmes, ITO State College of heat index charts and ASOS data.

6. References

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	State	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	
Harrisburg	PA	83	93	93	94	93	
		99(1925)	96(1999)	96(1999)	97(1933)	96(1984)	
Williamsport	PA	85	**96**	95	97	**95**	
		100(1925)	96(1925)	98(1933)	99(1933)	93(1991)	
State College	PA	**91**	92	90	**93**	90	2nd earliest 5 consecitive 90 degree days. 6 consecitive ending 6/4/1895.
		90(1968)	94(1933)	95(1933)	90(1984)	94(1911)	
Raleigh	NC	**99**	**100**	**101**	**100**	**101**	2nd earliest 100 day. June 5 1943 is earliest. Only 2nd time ever with 4 straight days over 100. 4 straight ending 8/23/1983 was the other time.
		98(2002)	97(1947)	100(1999)	98(1999)	97(1947)	
Richmond	VA	91	**100**	**100**	**98**	**101**	Earliest 2 straight days of over 100.
		96(1952)	99(1984)	99(1899)	98(1999)	98(1964)	Earliest ever 100 degree reading.
Philadelphia	PA	80	94	**95**	97	**98**	
		100(1925)	98(1925)	95(1999)	98(1933)	97(1964)	
New York	NY	74	94	93	96	**96**	
		98(1925)	96(1925)	95(1933)	97(1933)	95(1984)	
Providence	RI	60	85	**94**	**97**	**96**	2nd earliest 3 consecitive 94 or above days. 5 consecitive ending on 6/7/1925 is earliest.
		96(1925)	96(1999)	94(1984)	95(1984)	94(1974)	
Boston	MA	61	92	93	95	95	
		100(1925)	97(1999)	97(1984)	96(1984)	96(1959)	
Concord	NH	58	94	**94**	94	**98**	Earliest ever 4 consecitive days 94 or above.
		96(1925)	96(1999)	93(1984)	98(1933)	95(1959)	
Baltimore	MD	84	95	93	94	96	
		99(1925)	96(1999)	97(1999)	98(1933)	97(1964)	
Washington	DC	84	**98**	96	96	96	
		97(1925)	98(1999)	98(1999)	102(1874)	100(1964)	

Table 2. Summary of temperature records for select sites. For each site the daily high temperature is provided. Bold numbers indicate a new record. The old records and the year of occurrence are provided beneath each high temperature. Remarks about records are indicated to the far right. Most sites are ASOS sites. State College is a COOP site dating back to the 1890s. Return to text.

Mid-Atlantic Heat Waves 1948-2003

Year	Dates	Comments
1948	Aug 26-30	594dm ridge over Mid-Atlantic. Area +2 to +3SD 850 and 700 hPa temperatures under the ridge.
1949	Jul 04-06	594dm over Ohio Valley
1949	Aug 10-12	Weak signal
1952	June 25-27	Expansive area +2SD temps 850 hPa and 700 hPa eastern US.
1953	Aug 26-04 Sep	Large 588dm ridge to 594dm in September. Above normal PW.
1954	Jul 14-15	594dm ridge over Midwest a cold front dragged in +3SD 850 hPa anomalies ahead of the frontal boundary.
1955	Jul 21-23	Warm air over Canada. Low PW with heat.
1955	Aug 02-07	
1957	Jun 16-17	Rare early heat wave.
1957	Jul 21-22	Large subtropical ridge expansive 588 dm contour.
1966	Jul 2-5	Well aligned 700 and 850 hPa thermal anomalies. 500 hPa ridge to west.
1973	Aug 28-03 Sep	+2 SD 850 and 700 hPa anomalies with 594 contour Ohio valley.
1975	Aug 01-02	
1977	Jul 15-21	594dm ridge persistent heat with above normal PW
1980	Jul 20-22	Figure 1 was an antecedent condition to this event. Heat and moisture peaked on the 21st with 594dm contour.
1983	Aug 20-23	594dm ridge large area +3SD 850 hPa temperature anomalies.
1987	Jul 21-24	594dm ridge over region. Temp anomalies only 1-2SD above normal.
1988	Jun 22-25	Hot pocket of +2SD 850 hPa temperatures came from Canadian plains as upper ridge squeezed east ahead of cold front.
1988	Jul 20-22	Several sporadic days earlier in month.
1988	Aug 13-18	Prolonged period with 594 dm 500 hPa high over Midwest and eastern US. Peak 500 hPa anomaly +2SD over Pennsylvania on the 14th. The 850 hPa temperature anomalies peaked on the 17th over 3SD's above normal.
1990	Jul 04-05	Transient event short-lived 594dm ridge.
1991	Jul 18-24	594dm ridge over southeast. 1-2SD thermal anomalies.
1991	Aug 02-03	Weak signal
1993	Jul 8-10	Strong 500 hPa ridge. Modest temperature anomalies.
1995	Jul 15-17	594dm ridge 2-3SD above normal 850 and 700 hPa temps with above normal PW. Figure 3 is the onset time.
1999	Jul 05-07	Large 594dm contour. 4 July peak in 700 hPa anomalies in 3-4 SD range. 500 heights 2-3SD above normal eastern US.
1999	Jul 18-19	Small 594dm contour. More fleeting than early July event.
1999	Jul 24-01 Aug	Anomalies peak 31 Jul-01 August. Thermal anomalies dominated. See Figure 4.

Table 1. Mid-Atlantic heat waves identified from observational data 1948-2003. Data include the year, time span of the period of highest temperatures, and comments related to observations of re-analysis data during the event. Return to text.

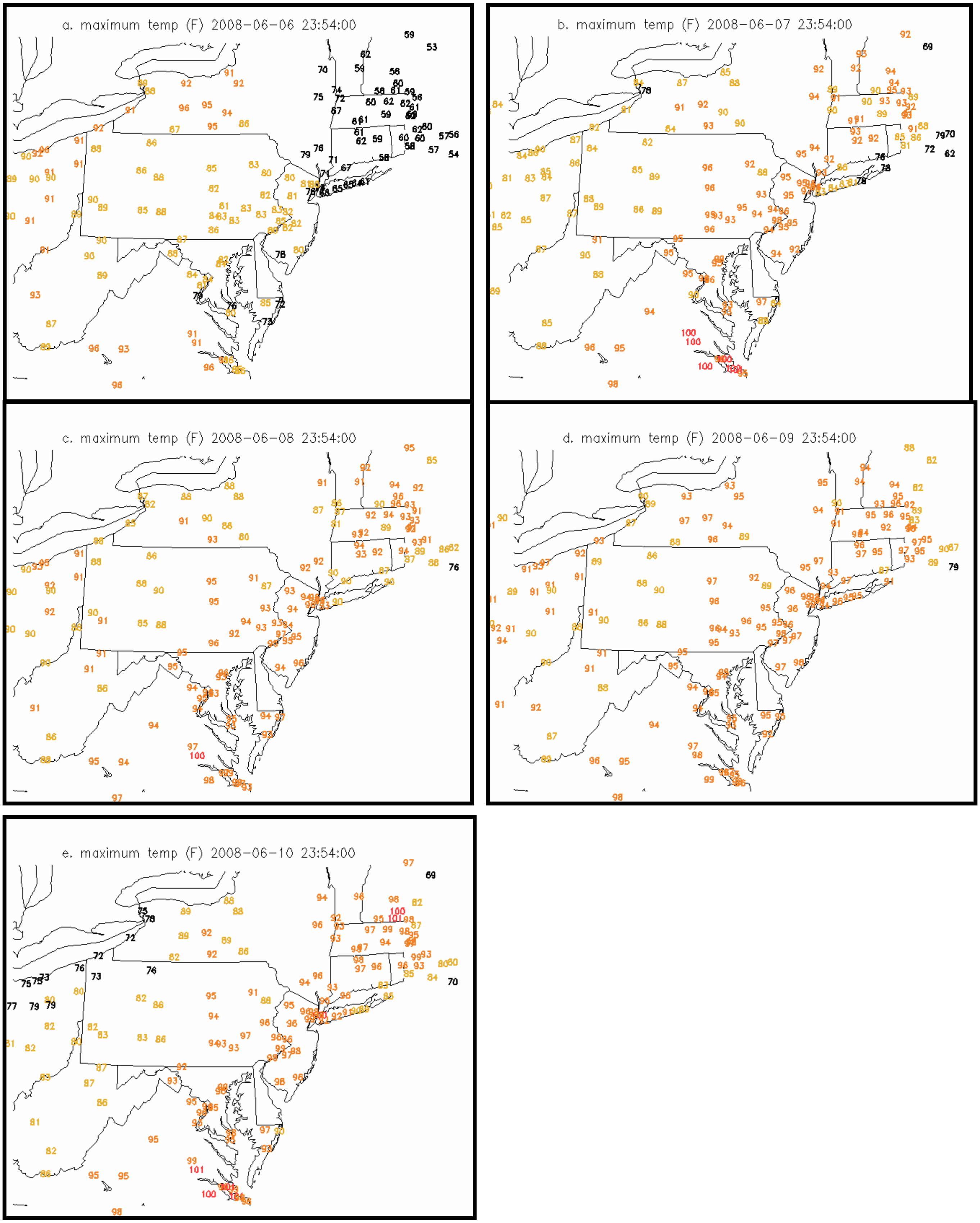
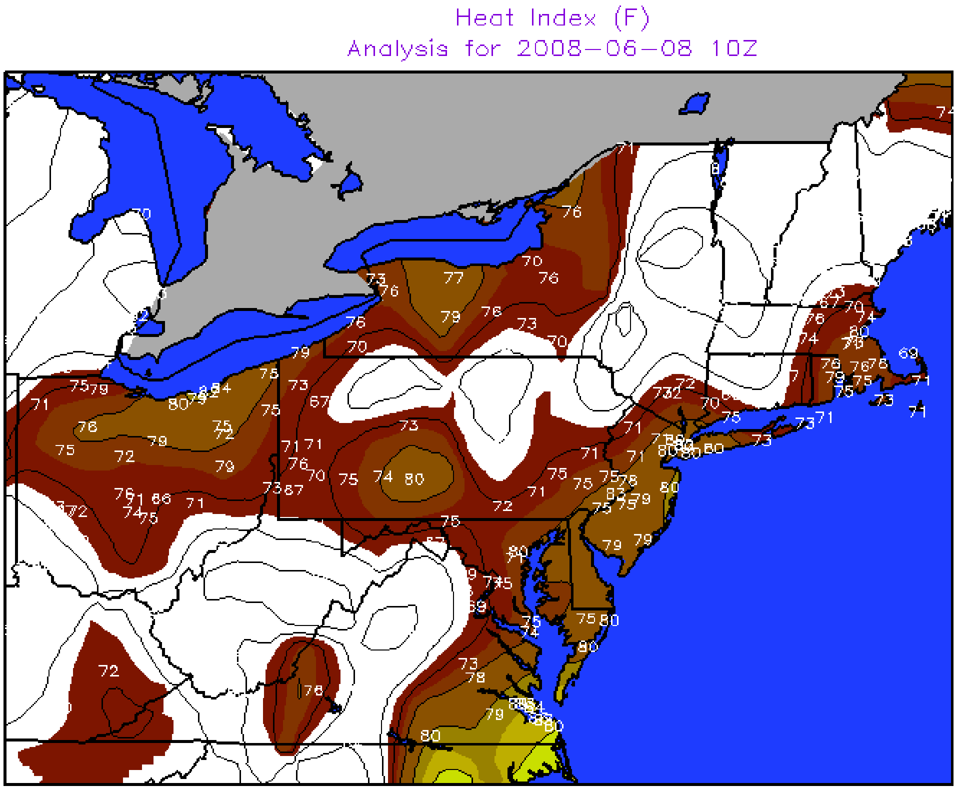


Figure 8. Maximum temperatures (F) from ASOS sites valid for a) 6 June, b) 7 June , c) 8 June, d) 9 June, and e) 10 June 2008. Values are color coded by temperatures red is over 100F, orange is 90F, and yellow is over 80F values lower than 80 are black.



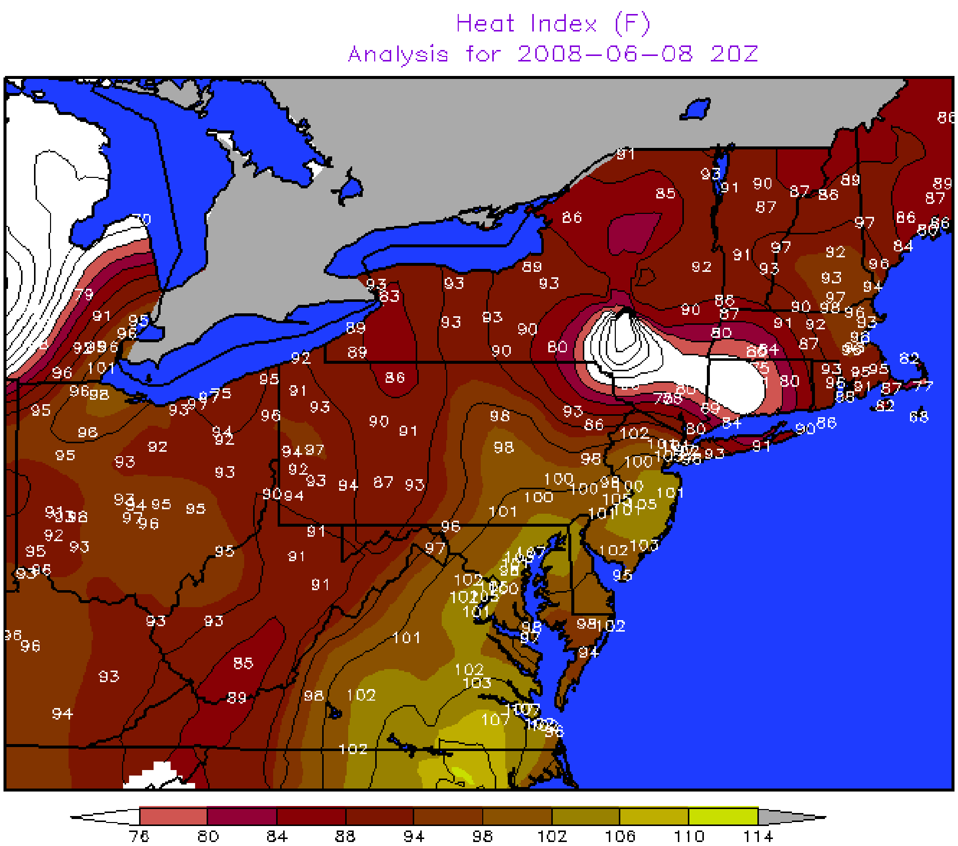


Figure 9. Heat index values derived from ASOS sites showing heat index values at (top) 1000 UTC and (bottom) 2000 UTC 8 June 2008.

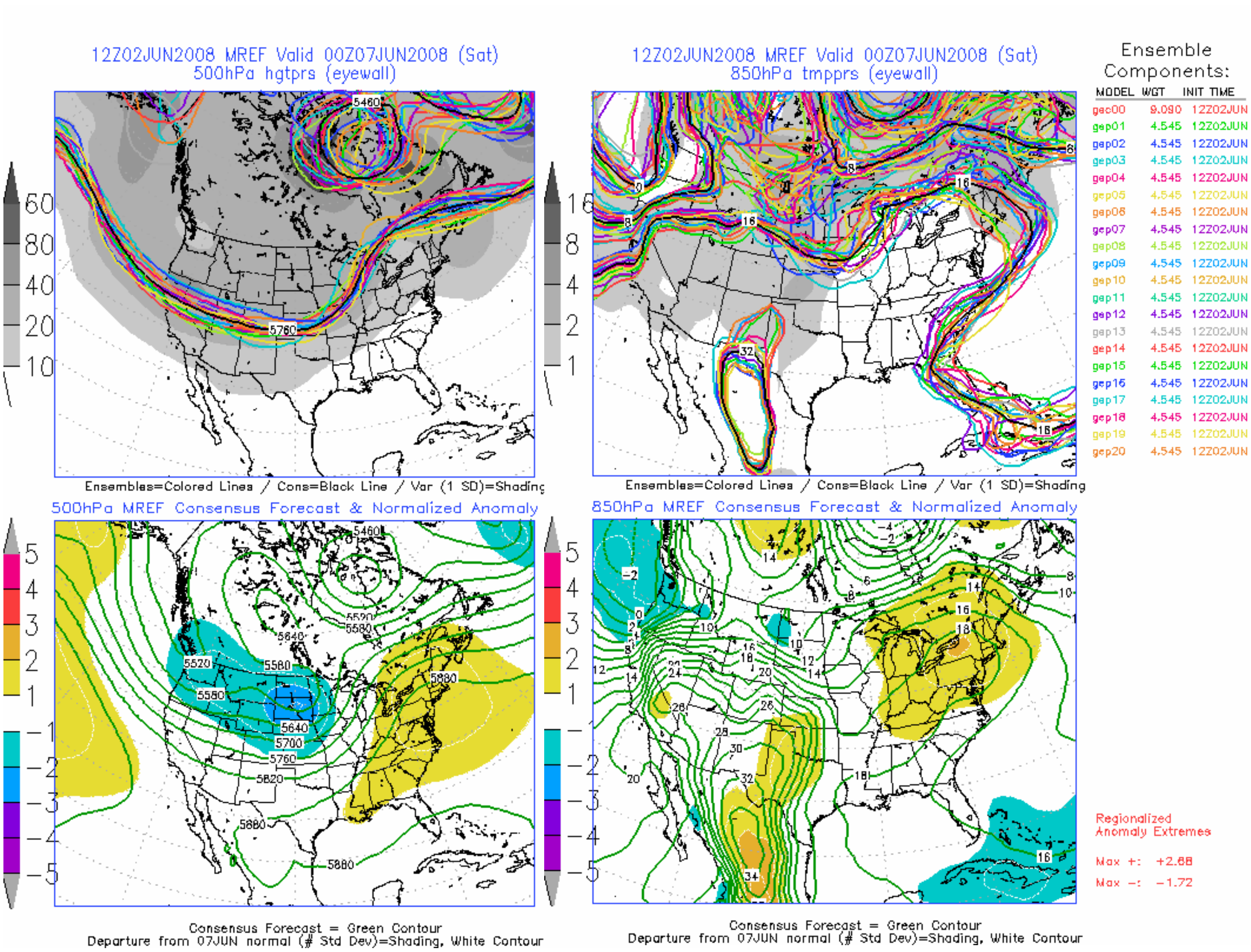


Figure 10. GEFS forecasts initialized at 1200 UTC 2 June 2008 showing 850 hPa temperature (C) and 500 hPa heights (m) forecasts valid at 0000 UTC 7 June. On the left, upper panel shows each members 5760 and 5520m contour and the ensemble mean of that contour and the variance about the mean. Lower panel show the ensemble mean and the standardized anomalies of this field. On the right upper panel shows each member 32,16, and 8 C contour and the lower panel shows the ensemble mean and the standardized anomalies of this field.

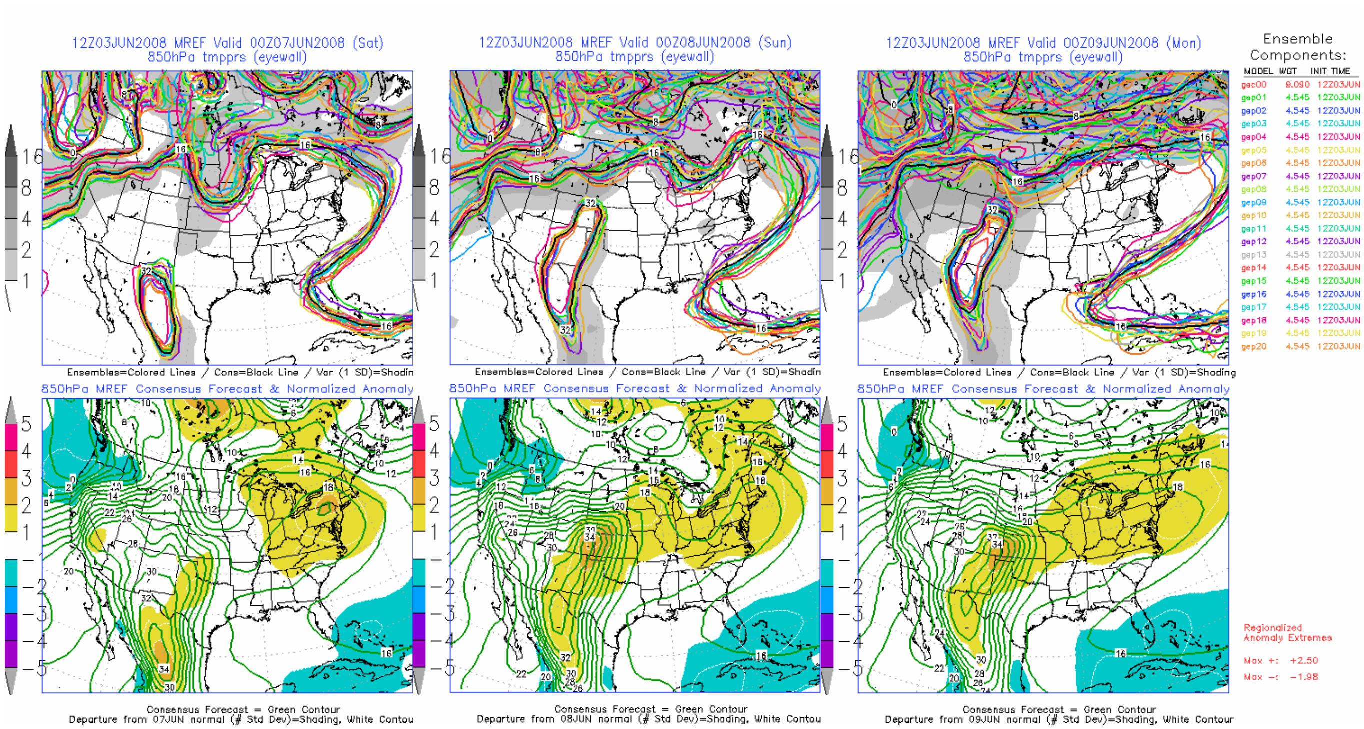


Figure 11. GEFS forecasts initialized at 0000 UTC 3 June 2008 showing 850 hPa temperature (C) forecasts valid at 0000 UTC a) 7 June, b) 8 June, and c) 9 June 2008. Upper panels show each members 32, 16 and 8C contour and the ensemble mean of that contour and the variance about the mean. Lower panels show the ensemble mean and the standardized anomalies

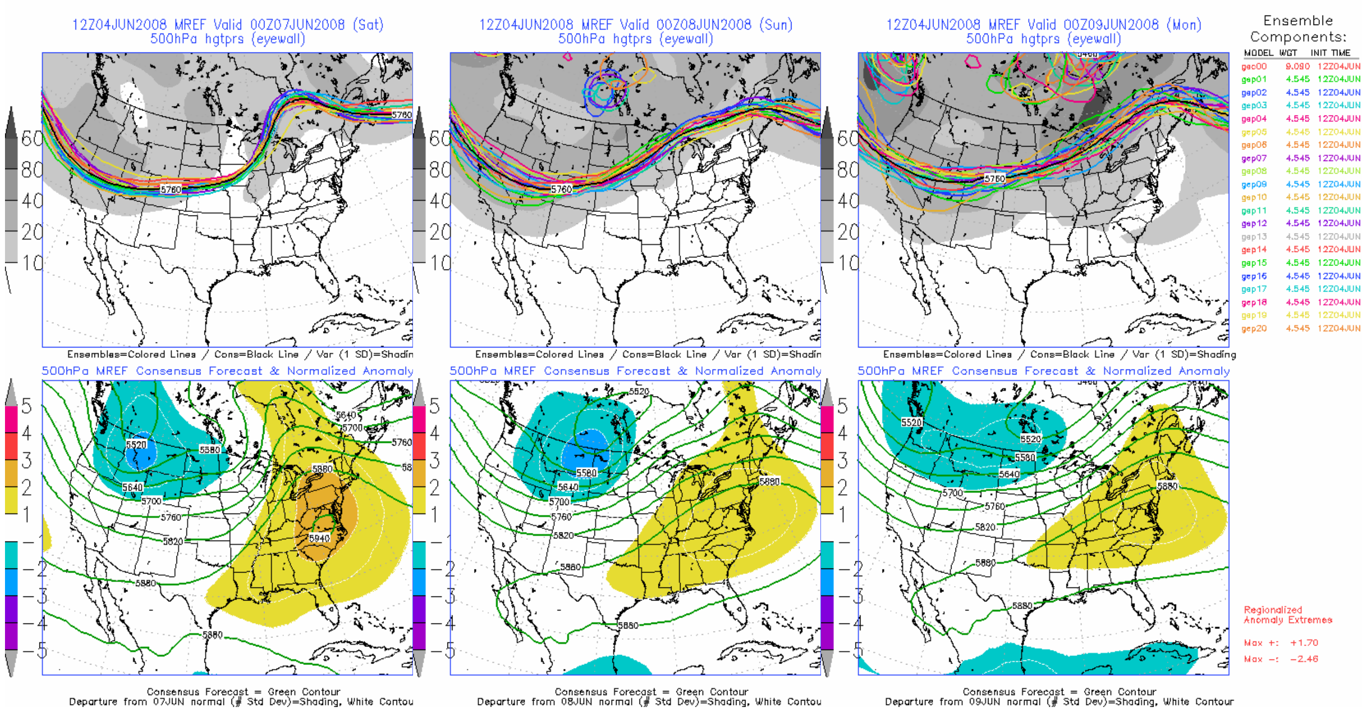


Figure 12. GEFS forecasts initialized at 1200 UTC 4 June 2008 showing 500 hPa heights (m) forecasts valid at 0000 UTC a) 7 June, b) 8 June, and c) 9 June 2008. Upper panels show each members 5760, 5520 m, contour and the ensemble mean of that contour and the variance about the mean. Lower panels show the ensemble mean and the standardized anomalies of this field.

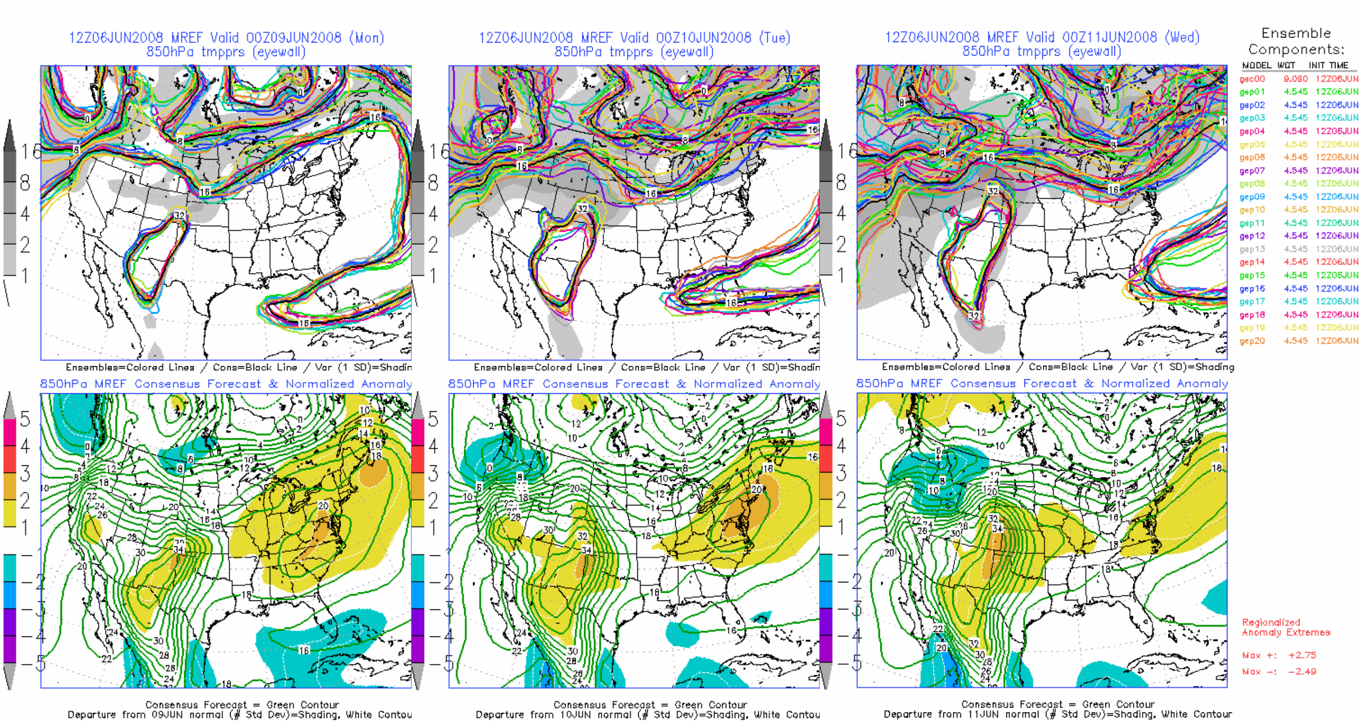


Figure 13 As in Figure 12 except GEFS initialized at 1200 UTC 6 June 2008 valid at 0000 UTC a) 9 June, b) 10 June and c) 11 June 2008.