Forecasting Heat Waves using Climatic Anomalies

By

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1. INTRODUCTION

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. The several contributing factors to the deaths in Chicago were attributed to the high dew points, urban heat island effects, 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. The differences in the moisture with these two events will be examined to explore whether climatic anomalies can help distinguish between heat wave types.

Heat waves are not unique to the United States. A deadly heat wave struck Europe in the summer of 2003. This 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 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 the United States and Europe may contain

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several similar characteristics. Research on European heat waves shows 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.

This paper will examine the conditions associated with mid-latitude heat waves. Climatic anomalies will be used to characterize the heat waves presented. Specific attention is provided to previously documented heat waves over the United States with a focus of conditions over the eastern United States. A forecast example is presented using the heat wave event over Western Europe during August 2003. This paper will serve to document some of the conditions associated with this deadly mid-latitude heat wave.

The departures of specific fields, such as 500 hPa heights and 850 hPa temperatures, from normal (climatic anomalies) will be presented for specific cases. All anomalies were obtained from National Centers for Environmental Predictions (NCEP) Global Reanalysis data.

2. Methods and Data

NCEP reanalysis data were used to show the patterns associated with the heat waves. The departures of the reanalysis data and NCEP model data were computed using the 30-year climatology of means and standard deviations as discussed in Hart and Grumm (2001). The archive spans 1948-2005, allowing the extraction of the conditions associated with previously documented heat waves. Several example heat waves were taken from the published literature.

A regionalized approach was undertaken to find heat waves in the eastern United States focused over Pennsylvania. Available observational data were used to determine periods where the daily maximum high temperature remained 2 standard deviations (SDs) above normal for at least 2 consecutive days at any site over the region. The sample was limited to the June-September time frame. Thus, no attempt was made to characterize ***warm episodes*** which occur through out the year, but to focus on warm season warm episodes, referred to as **heat waves,** which can have devastating impacts.

The European heat wave of August 2003 was analyzed using the reanalysis data. Forecast aspects of this event were evaluated with NCEP MREF data. This case was selected for several reasons including data availability, and also since one of the authors was forecasting in Europe during the time of this event. Forecast data will be shown at the meeting in August.

3. Results

i) Documented mid-latitude heat waves

Several documented heat waves include the heat waves and droughts of the summer of 1980 (Namias 1982 and Lyon and Dole 1995) and 1988 (Lyon and Dole 1995) and the deadly heat waves of 1995 and 1999. These four events affected large areas of the United States.

The July 1980 event was associated with a prolonged drought and heat wave that spanned the months of May, June, and July. During the month of July, the high temperature at Dallas, Texas exceeded 100F on each day of the month (Wagner 1981). This heat wave was characterized by an anomalous 500 hPa ridge (Fig. 1), anomalous 850 and 700 hPa temperatures and below normal precipitiable water (PW) over the southern United States. The data in Figure 1 are valid at 0000 UTC 14 July 1980. Though not shown, the anomalous ridge over the region persisted from late June well into July. The 14th of July image was chosen as a representative time and it characterized the key variables associated with many heat waves. This included the anomalous 500 hPa ridge and the above normal 850 and 700 hPa temperatures. Unlike some of the deadly heat waves, this event was associated with below normal precipitiable water anomalies.

The 1988 heat wave affected the eastern United States from 6-15 July 1988. Drought conditions and above normal warmth affected the central and southern United States through most of the summer. The conditions around the peak of the heat over the Mid-Atlantic region are shown in Figure 2. These data show similar features, though shifted northeastward to those associated with the heat wave of July 1980. One significant difference was that northern areas had above normal precipitiable water anomalies and near normal precipitable water anomalies over most of the Mid-Atlantic region. In this example, the value of using anomalies is evident in the 700 and 850 hPa temperature fields. Note the 32C and 22C 850 hPa temperatures over the southwestern and eastern United States respectively. The 32C values are *near normal* while the 22C values are considerably *above normal* over the eastern United States.

An intense heat wave struck the Midwest and eastern United States in July 1995. Daytime high temperatures in Chicago were 32.2C (90F) to 41.1C (106F) or greater from 10 July through 16 July 1995 (Changnon et al. 1996) and the temperature exceeded 40C in Philadelphia. The conditions associated with this heat wave near its peak are shown in Figure 3. The key features include the closed 594 dm contour at 500 hPa associated with the upper level ridge. This corresponded to the 1000-500 hPa thickness values that were +2 to +3SDs (not shown) and +3 to +4SD values for the 850 hPa temperatures and +2 to +3SD above normal 700 hPa temperatures the western Great Lakes. The 25C 850 hPa temperatures over northern Illinois and southern Wisconsin represented temperature departures approaching 4SDs above normal which was anomalously warm. A contributing factor to the severity of this heat wave may have been the abnormally high precipitable water (Figure 4d) that moved across the region on the 12th, 13th and 14th of July. The high precipitable water values from northeastern Illinois and eastward suggested humid air was in place over the region. This may have limited overnight cooling which contributed to higher temperatures on the following day.

Conditions associated with the 29-30 July heat wave valid at 0000 UTC 31 July 1999 are shown in Figure 4. At 500 hPa, a ridge was present but the height fields did not represent a significant departure from normal. The low level thermal anomalies were well above normal. In the southeastern United States, 850 hPa temperatures were +4 to +5SDs above normal and there was a region where 700 hPa temperatures were on the order of +3 to +4SDs above normal. Positive thermal anomalies dominated most of the eastern half of the United States with the largest anomalies over the southeastern United States. Unlike the July 1995 event, the precipitable water anomalies were near or slightly below normal during the 1999 event in and around the location of the warmest thermal anomalies.

ii) Historic European heat waves from previous research

There have been many heat waves in Western Europe and over the United Kingdom, a few of which have been well documented. Three heat waves of note include July 1976, August 1990, and August 2003. Each, in its day, set record high temperatures over the United Kingdom and other parts of Western Europe. The August 2003 heat wave will be addressed in a following section.

Conditions with the 26 June-3 July 1976 "British Heat" and the 3-4 August 1990 heat wave are shown in Figure 5 and Figure 6, respectively. The hottest temperatures were 35.9 on 3 July 1976 and 37.1C on 3 August 1990. Both readings were recorded at Cheltenham. Both heat waves were characterized by anomalous 500 mb heights, high thickness values, and above normal 850 and 700 hPa temperatures. Though not shown, the precipitiable water anomalies were 1-2 standard deviations above normal over southwestern England and western France on the 3rd of July 1976. Overall, the thermal anomalies were large in 1990, but a distinguishing characteristic of the hotter 3 August 1990 reading was the warmer 700 hPa temperatures (8C) relative to the 1976 event (4C) over southwestern England. Though not shown, the 1000-850 hPa thickness anomalies were very high in the 1976 event.

The summer of 2003 produced several protracted heat waves in Europe. The first heat wave struck southern Europe in June producing a period of hot weather in the Mediterranean region. Rome, Italy broke its all-time high temperature for the month of June. A second heat wave struck the same general region in the middle of July with daily temperatures between 30-37°C (86-98°F) across many areas from France, Switzerland, Italy, and across the Mediterranean. According to the National Climatic Data Center, temperatures across Italy reached 36°C (96°F) on the 15th. The hottest weather then shifted eastward across the Balkan Peninsula on the 17th, when one of the hottest days of the summer of 2003 occurred in Kosovo (R. H. Grumm, personal observation).

iii. *European heat wave of August 2003*

In August, the subtropical ridge built into Western Europe. This ridge brought record high surface temperatures to France, Germany, and the United Kingdom. This heat wave was long-lived with abnormally high temperatures beginning in France on 3 August and ending on the 13th. Heat wave related problems included buckling railroad tracks and approximately 35000 heat stress related fatalities (Schar and Jendritzky 2004). The majority of the deaths were reported in France. In addition to the deaths, persistent drought conditions affected crops and river transportation networks.

Maximum hourly observed temperatures for select sites in Europe are shown in Table 1. The data span 1-14 August 2003 capturing the onset of heat wave, which dissipated after the 14th in Germany. Frankfort, Paris, and Roth Germany all had 30C or greater maximum temperatures everyday for the first two weeks of August 2003. Paris hit 40C on the 6th, 11th, and 12th and set daily high temperatures record from the 4th through the 12th.

Historical and newsworthy records are shown in Table 2. These data show that several of countries set all-time high temperature records, many of which had stood for over 100 years. The data suggest that England, Switzerland, and Italy set all-time records that had stood for over century. The German record was simply stated as the all-time record high ever reported in Germany with no indication as to how long the previous record had stood. The heat wave of August 2003 was an enduring and historical event.

Climatic Anomalies of 500 hPa heights, 1000-500 hPa thickness, 850 hPa, and 700 hPa temperatures are shown in Figures 7 through 9 to capture the onset and some of the record breaking days during the event. Figure 7 shows the conditions on 4 August with the heat wave well established over France and the southwestern United Kingdom. Key features included the anomalous 500 hPa ridge over France, accompanied by anomalous thickness values over the same region. The largest anomalies were in the 850 hPa temperature fields where anomalies were +3 to +4SDs above normal over France and the southwestern United Kingdom.

Paris broke 40C on the 6th and the conditions associated with this record hot day are shown in Figure 8. The striking feature is the area of +4 to +5SD above normal 850 hPa temperatures over the English Channel and northwestern France at 1200 UTC on 06 August. This coincided with the upper-level ridge and anomalously warm temperatures at 700 hPa. Though not shown, precipitable water values were near normal over Western Europe, though above normal precipitable water values dominated northern Scotland and Scandinavia on the 6th. Several heat waves in the United States were also shown to have similar plumes of anomalously high precipitable water values extending poleward on the far northwest side of the upper level ridges, possibly indicative of the strength of southerly winds and moisture transport associated with anomalously strong and deep layered mid latitude anticyclones.

News accounts of buckled train tracks and record high temperatures were reported on the 8th. The conditions over Europe on the 8th are shown in Figure 9. The 500 hPa ridge had retrogressed over the United Kingdom. The largest 850 hPa temperature anomalies, +3 to +4 SDs above normal, were focused over the United Kingdom. The large +2 to +3 SD 700 hPa thermal anomalies over the same region show that this was a deep warm air mass. The striking feature remained the anomalous 850 hPa temperatures with above normal 700 hPa temperatures suggesting a deep warm boundary layer.

The conditions over Europe and the eastern Atlantic on the 9th are shown in Figure 10. Record high temperatures were observed over much of France and western Germany. The largest 850 hPa thermal anomalies were west of the areas of highest surface temperatures. The highest surface temperatures were observed to the east of the large subtropical ridge which extended from Spain into the North Sea. The largest 500 hPa height anomalies were located over England and the North Sea while the largest thermal anomalies were located close to the ridge. The 700 hPa temperatures were generally in the 7-8C range over most of France and Germany. The surge of above normal moisture was displaced poleward, well north of the area affected by the heat wave, which is a characteristic of heat waves in eastern North America too. Despite the large +4 to +5SD 850 hPa thermal anomalies, the 9th was not exceptionally hot in London. Similar conditions persisted on the 10th (not shown) when Gravesend, in southeast England, set a new record for the hottest temperature in the United Kingdom of 38.1C (100.6F).

iv. Mid-Atlantic heat waves

Mid-Atlantic heat waves are a subset of the wider heat waves that affect the United States. These events were identified using a temperature database to determine when the daily high temperature exceed the 10-day running mean high temperature by more than 2SDs above normal for at least 2 consecutive days. The tests were limited to June through September when high temperatures can produce heat stress. The results of this test revealed the existence of unseasonably warm episodes which often occurred during the above noted events. Table 3 lists known Mid-Atlantic heat waves observed between 1948 and 2004. The majority of prolonged heat waves occur between late June and early September with July being the peak month of heat wave activity. This section will show examples of the large scale patterns associated with several of these events.

Figure 11 shows the conditions near the peak of the August 1948 heat wave. This heat wave had a classic pattern with the strong 500 hPa ridge and closed anticyclone with the 594dm contour. The 594dm contour was associated with many Mid-Atlantic heat waves. Heights were on the order of +2 to +3SDs above normal. Beneath this massive ridge, 850 and 700 hPa temperatures were +2 to +3SDs above normal. Though not shown, 850 hPa temperatures peaked near 25C, nearly +4SDs above normal on 29 August 1948. As with many intense heat waves, the juxtaposition of the 850 and 700 hPa anomalies was in the same area. This implies a deep, warm boundary layer. The poleward surge of the anomalous PW anomalies was present in this case.

The late season heat wave of August-September 1953 built slowly and peaked in intensity in early September 1953. The conditions valid at 0000 UTC 2 September 1953 are shown in Figure 12. A large area of above normal 500 hPa heights dominated the eastern United States with a small enclosed 594 dm anticyclone off the southeastern coast of the United States. The 850 hPa temperature anomalies were +2 to +3SDs above normal with +1 to +2SD above normal 700 hPa temperature anomalies. The PW anomalies were on the order of +1 to +2SDs above normal creating the combination of heat and humidity which can make for a deadly heat wave.

4. Conclusion

The large-scale conditions associated with Mid-latitude heat waves were presented. The emphasis was on heat waves in the United States, Western Europe, and a unique subset of heat waves over the Mid-Atlantic region of the United States. These heat waves all shared similar characteristics outlined by previous research (Namias 1982).

All the Mid-latitude heat waves presented were associated with a mid-tropospheric anticyclone. In most instances, this anticyclone was associated with at least +1 to +2SD above normal 500 hPa heights. In the eastern United States, the 594dm contour appeared to be a tell-tale signal for an unusually strong 500 hPa ridge and attendant heat wave. Namias (1982) and Brugge (1995) pointed out the importance of the upper-level ridges and heat waves over the United States and Europe respectively. In this study, the height anomalies were presented in standard deviations above normal to show how significant the height anomalies can be in these strong ridges associated with mid-latitude heat waves. It is believed that the anomalies and not the absolute height values are more indicative of heat episodes.

In addition to the strong ridge, above normal lower tropospheric temperatures are often associated with heat waves. In this study all the heat waves were associated with 850 hPa temperature anomalies between +1 and +4 SDs above normal. Some of the record events had areas where the 850 hPa thermal anomalies were slightly over +4SDs above normal. Furthermore, in many of the record events, such as the European heat wave of August 2003, above normal 700 hPa temperatures were in the same general region as the anomalous 850 hPa temperatures. This implies the existence of a deep warm boundary layer pointed out by previous research (Brugge 1995; Namias 1981; Chang and Wallace 1987). Thus, the juxtaposition of the 850 hPa and 700 hPa height anomalies appear to be good indicators of significant heat waves.

In addition to the above normal ridge, 850 hPa and 700 hPa temperatures, a surge of above normal PW north of the ridge is an indicator of a heat wave. In nearly all the events examined, a plume of above normal PW extended over the top of the ridge. This suggests that the surge of moisture may indicate the strength and persistence of the larger scale pattern. The PW is often north of the region with highest temperatures. In some of the more deadly heat waves in the United States, the above normal PW was in the same general region as the above normal thermal anomalies. The juxtaposition of the PW and thermal anomalies is potentially deadly combination suggesting the combination of high heat and humidity. This combination of heat and humidity during the Midwestern heat wave of August 2001 was considered significant in the heat death of a Minnesota Viking line backer in Mankato, Minnesota on 2 August 2001.

The unusually strong and persistent heat wave that struck Western Europe during the first 14 days of August 2003 had all the ingredients associated with eastern United States heat waves. An anomalously strong and persistent subtropical ridge developed over the region and produced the record event. The re-analysis data showed that the heat wave was accompanied by large positive 500 hPa height, 850 hPa temperature, and 700 hPa temperature anomalies. The anomalous PW anomalies remained just north of the affected region.

The above normal PW over Chicago during the 1995 event likely contributed to high overnight low temperatures, allowing the heat to build. Additionally, the high PW values implied a high apparent temperature, a critical value in determining heat stress. The two United States heat waves showed the contrast between a heat wave associated with normal to above normal precipitable water at the onset of the event (1995) and one with normal to below normal precipitable water values during the event (1999). High precipitable water during the 1995 event likely contributed to the unusually high nighttime low temperatures (Changnon et al.1996), which in turn may have contributed to a deeper boundary layer, and record high daytime temperatures. The combination of this heat and the humidity associated with the 1995 event likely contributed to the higher death rate than associated with the July 1999 event.

The ability of forecasters to anticipate large heat waves could help mitigate the devastating impacts of these events. Using fields such as 850 and 700 hPa temperatures, 1000-500 and 1000-850 hPa thickness, and precipitable water forecasts combined the climatic anomalies from model output should help identify potentially significant heat wave events. Longer range outlooks may require examining these fields from ensemble prediction systems (EPS's). Future research should examine the effectiveness of ensembles in forecasting heat wave events.

Future research, using the new regional analysis data may be of value to refine the overall climatology of all standard forecast parameters. These data, with higher temporal and spatial resolutions may help better define the characteristics of heat waves over North America. Key predictors of these events might include 850 hPa temperature, 700 hPa temperature, 500 hPa height and precipitable water anomalies. When this new climatology is achieved, it can be compared to mesoscale model output to define areas of potential record high surface temperatures.

As shown earlier for the August 2003 European heat wave, despite the large 4-5SD 850 hPa thermal anomalies, the 9th of August was not exceptionally hot in London. This implies that other factors can impact heat waves. Mixing, subsidence, and cloudiness may also be important indicators for days when record and near record temperatures are possible. Additional data would be required to determine why the 9th of August was a relatively cooler day.

5. Acknowledgements

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EUROPEAN HEAT WAVE DATA AUGUST 2003

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bonn	29	30	31	32	33	35	37	38	34	33		39		
Frankfort	31	35	36	37	36	36	38	38	39	36	36	38	35	30
London	20	20	28	28	29	35	29	30	29	37	34	30	29	25
Paris	30	32	35	37	38	40	38	37	37	39	40	40	34	
Roth	30	33	36	36	37	34	35	36	39	37	35	37	40	33

Table 1. Select hourly maximum observed temperatures (^{O}C) during from 1 to 14 August 2003. These data may not reflect the actual observed daily maximum temperatures.

2003 European Records Heat Wave Records

Location	Temperature	Comments
Roth, Germany	40.4C (104.7F)	All time German record high on the 13th
Neutstat, Germany	27.6C (81.7F)	All time overnight high low for Germany
Paris, France	25.5C (77.9F)	All time overnight high low 11th
Turin, Italy	41.7C(107F)	All time record high in 250 years of records on the 11th
Bern, Switzerland	37C(98.6F)	Hottest day since 1865 on the 13th
London (Heathrow), England	37.9C(100.2F)	Hottest observed temperature since records began 130 years ago, on the 11th
Gravesend, England	38.1C(100.6F)	All time England high temperature on the 10th In southeast England.
Badajoz, Spain	44.7C (112.6F)	Highest temperature in 50 years on the 7th

Table 2. High temperature records set during the August 2003 European wave. Data include the city and country, the record temperature (C and F) and pertinent additional data about the temperature recorded. Data courtesy of the United States Air Force Combat Climatology Center, Ashville, North Carolina.

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 3. 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.

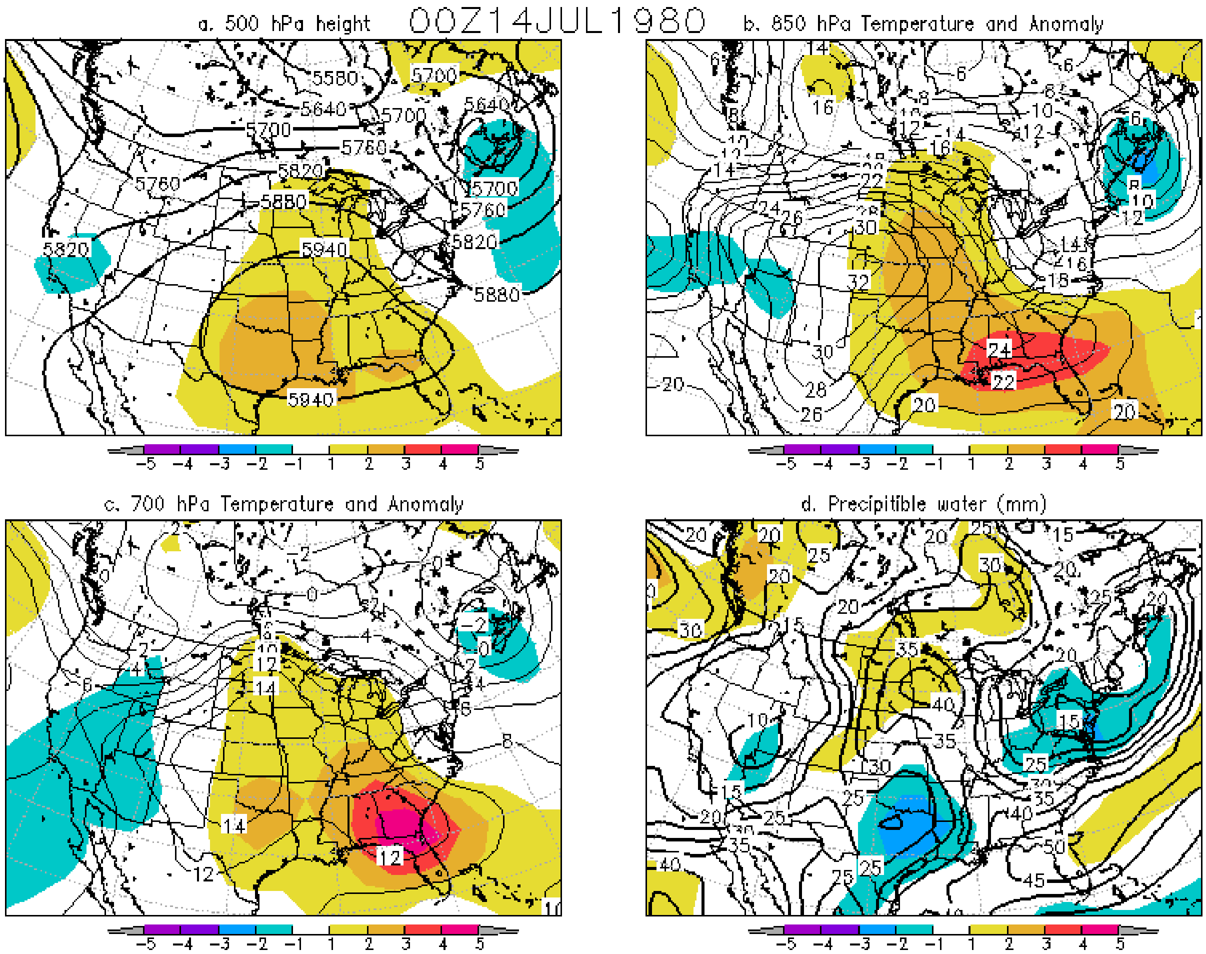

Figure 1. Reanalysis data over the United States valid at 0000 UTC 14 July 1980. Return to text.

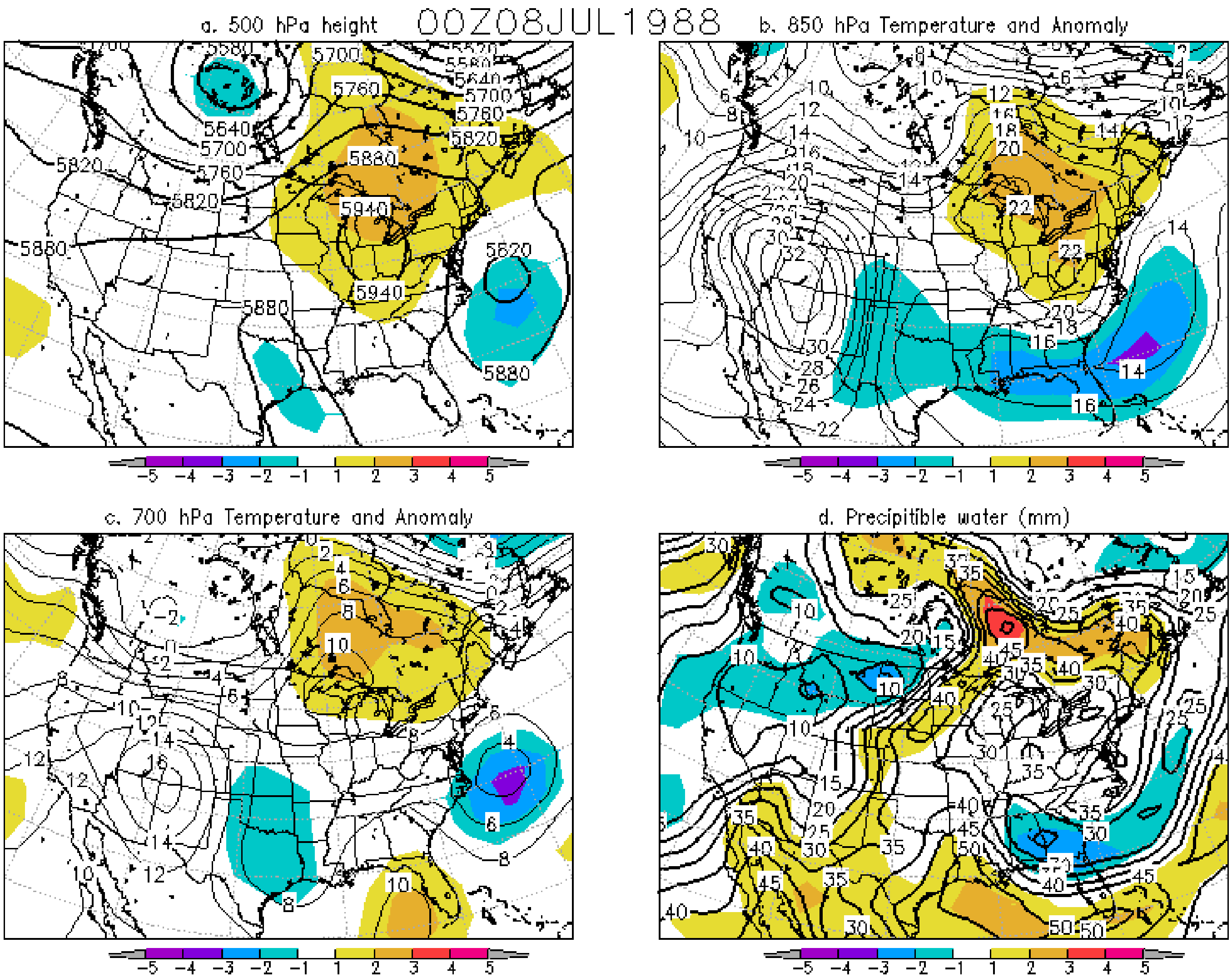

Figure 2. As in Figure 1 except valid 0000 UTC 08 July 1988. Return to text.

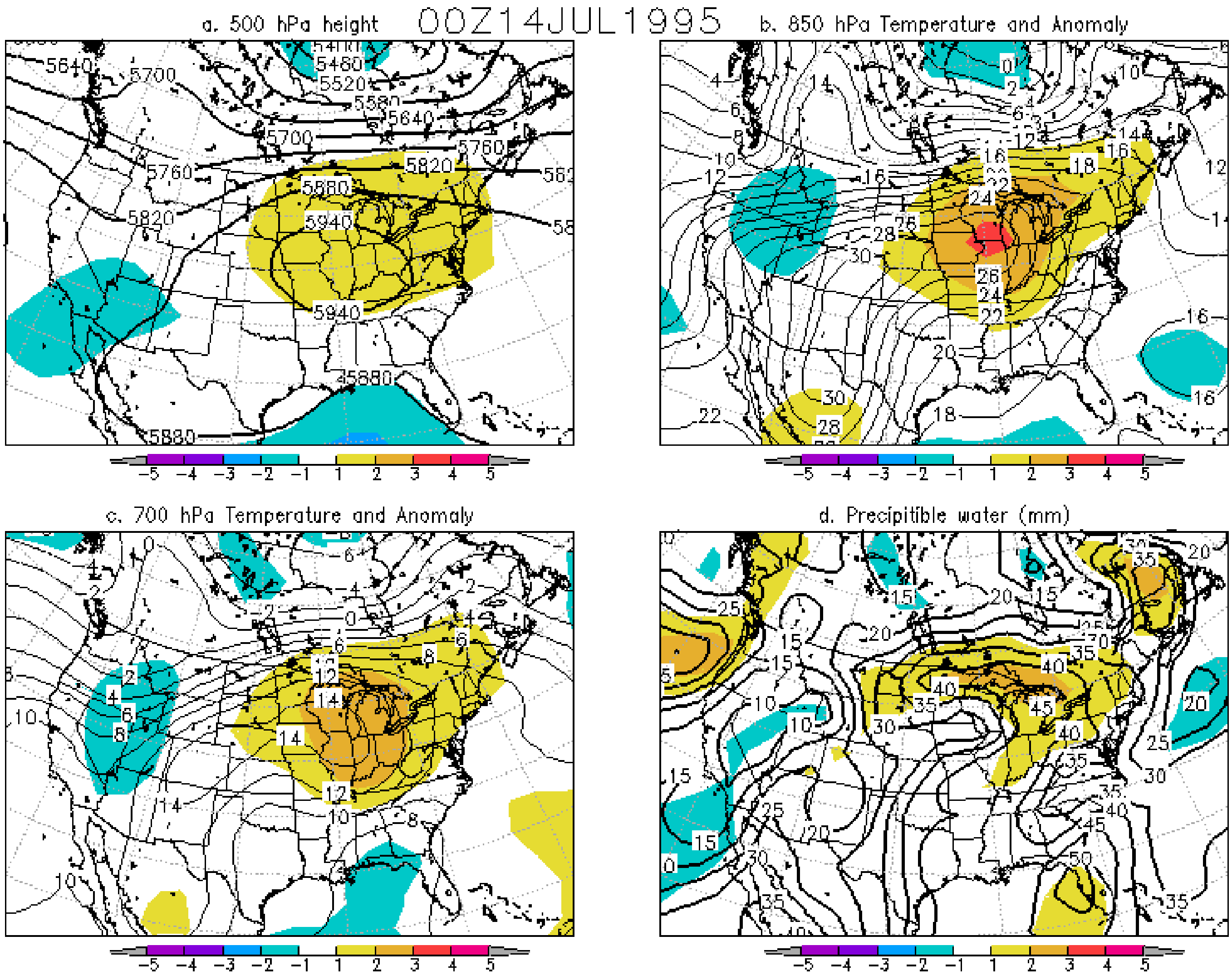

Figure 3. As in Figure 1 except valid at 0000 UTC 14 July 1995. Return to text.

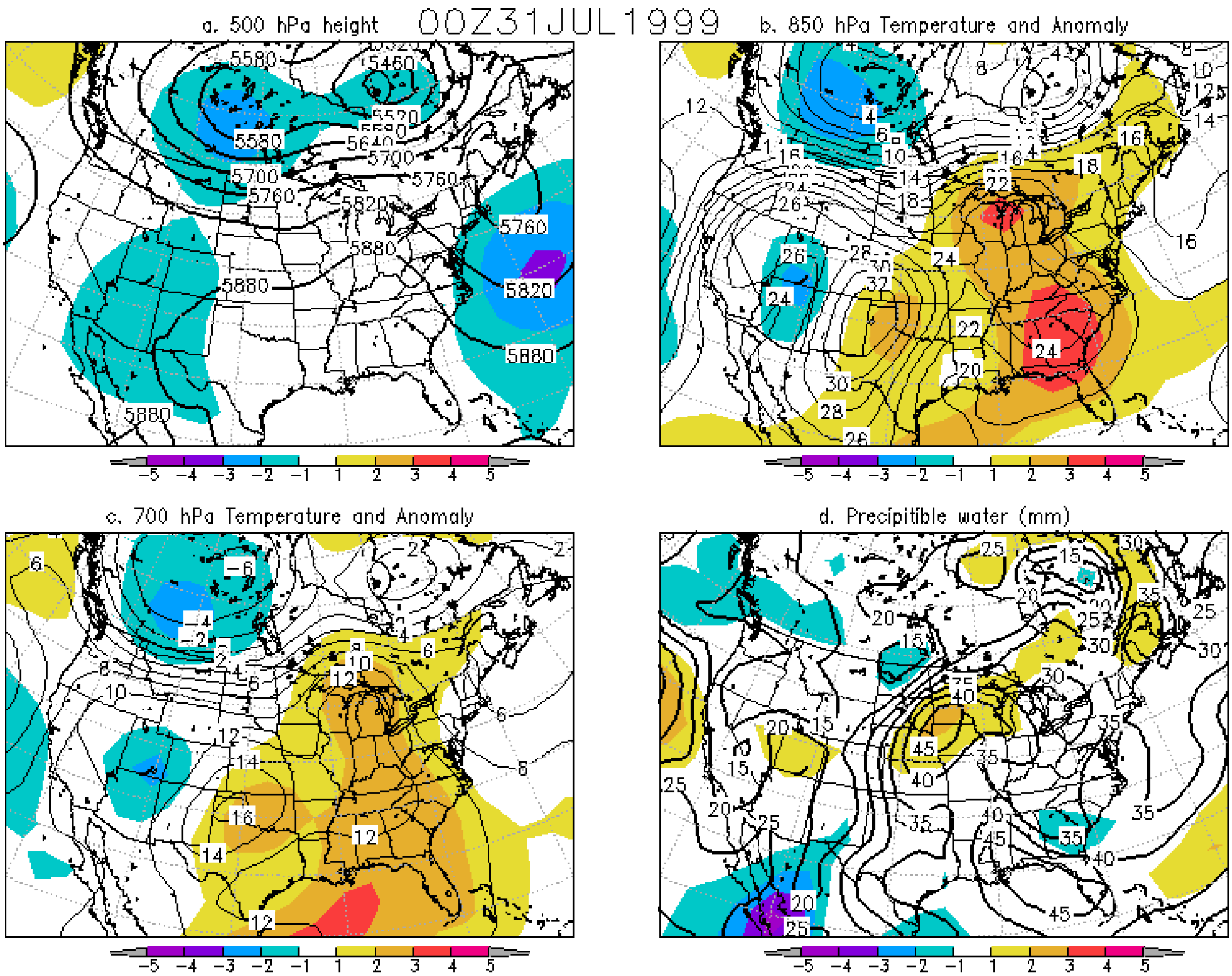

Figure 4. As in Figure 1 except valid at 0000 UTC 31 July 1998. Return to text.

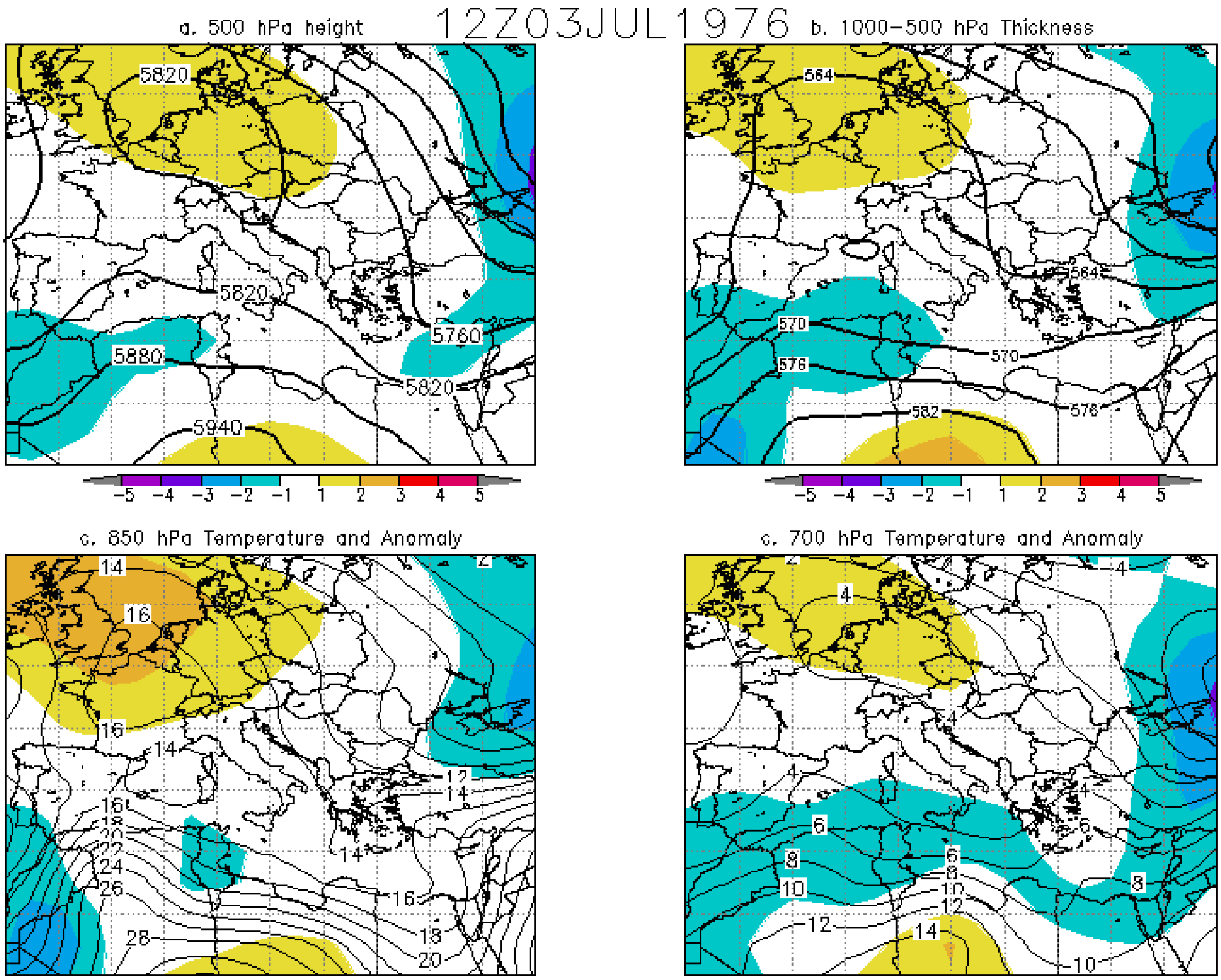

Figure 5. NCEP reanalysis data valid at 1200 UTC 3 July 1976 showing a) 500 hPa heights and anomalies, b) 1000-500 hPa thickness and anomalies, c) 850 hPa temperatures and anomalies, and d) 700 hPa heights and anomalies. Isotherms in degrees C every 2C. Thickness contours in dm with a 6dm contour interval. Anomalies are shaded in 1 standard deviation intervals as indicated by the color bars. Return to text.

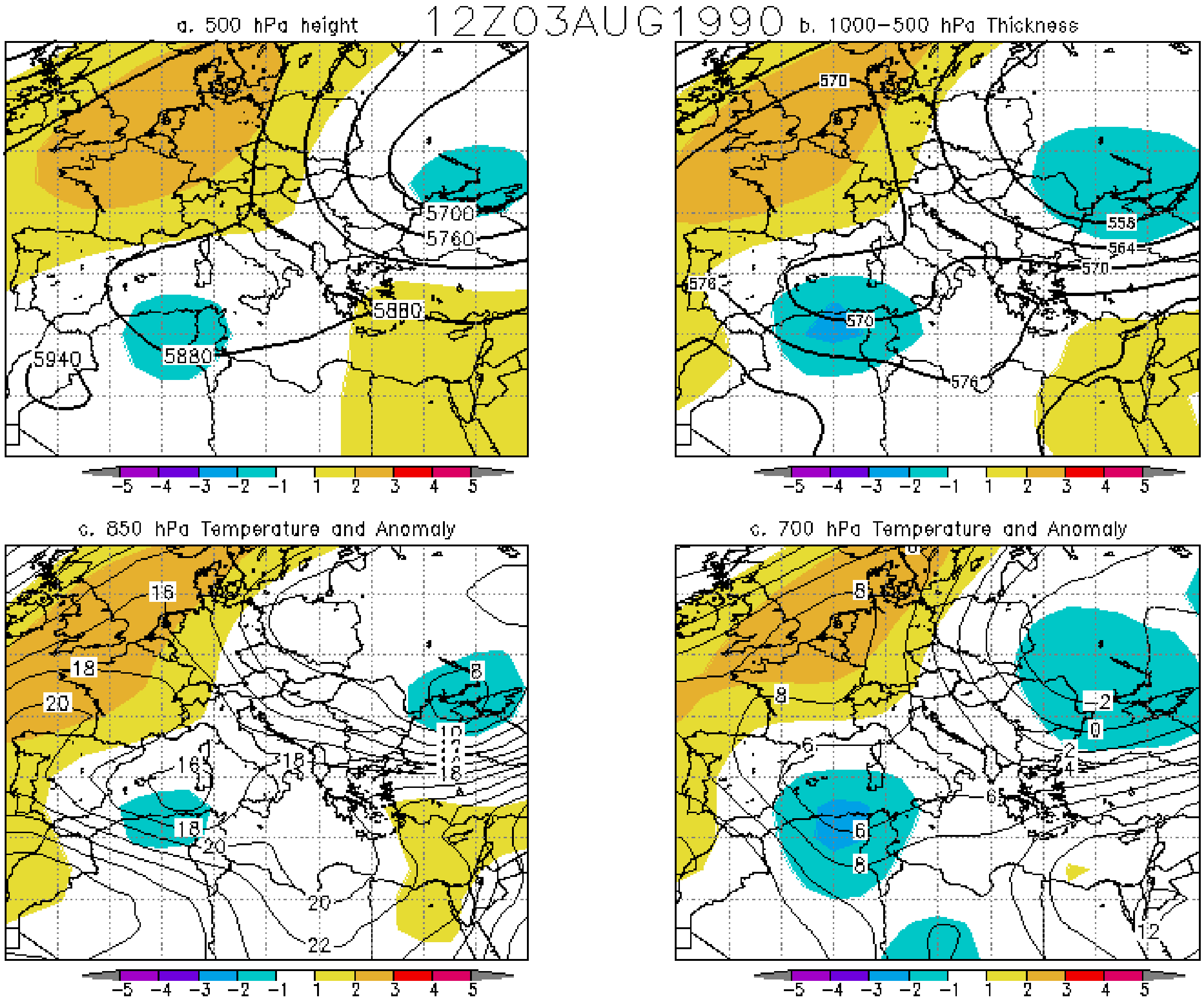

Figure 6. As in Figure 5 except valid at 1200 UTC 3 August 1990. Return to text.

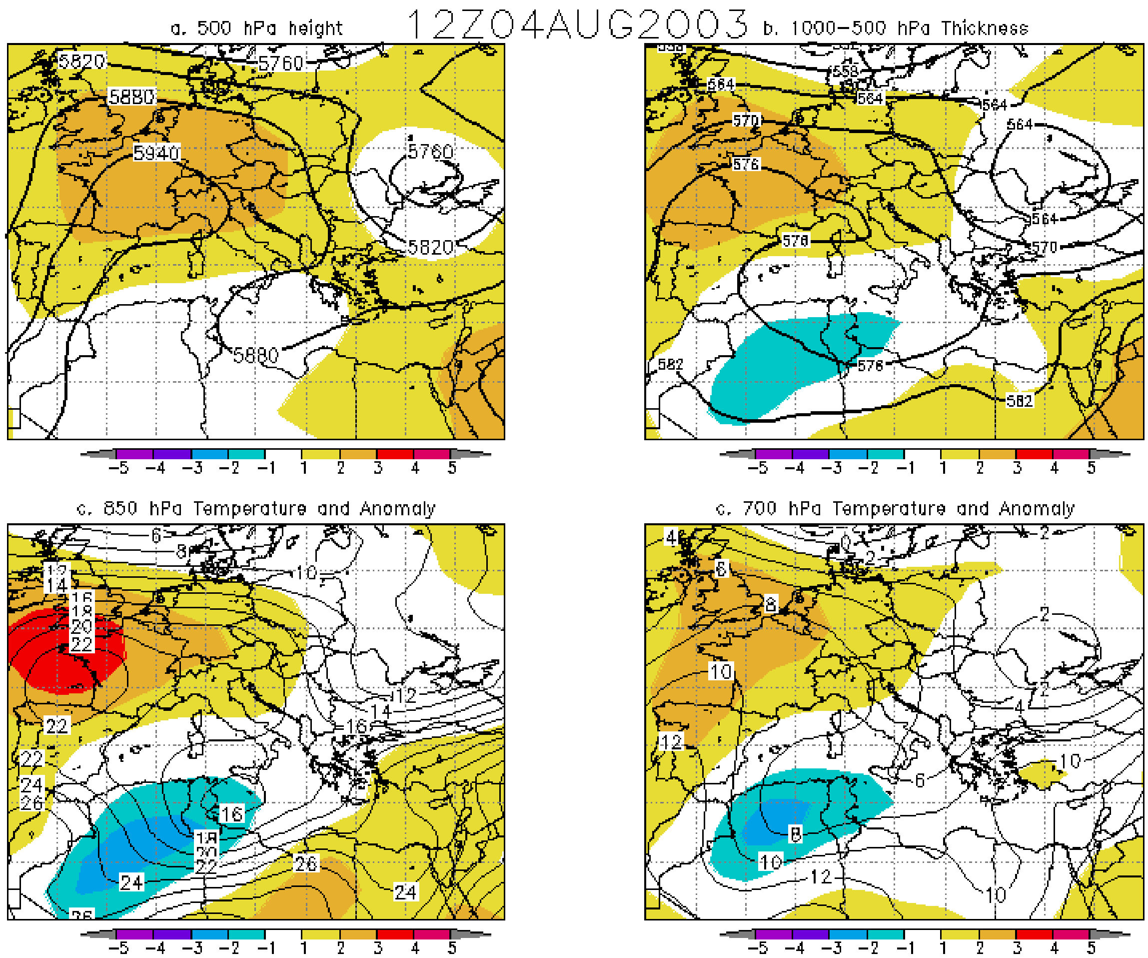

Figure 7. Reanalysis data showing the conditions valid at 1200 UTC 4 August 2003 including a) 500 hPa heights, b) 1000-500 hPa thickness, c) 850 hPa temperatures, and d) 700 hPa temperatures. Heights in meters, thickness in decameters, temperatures in ^{o}C. Shading shows the departure of each field from the 30 year climatological mean in standard deviations from normal. Return to text.

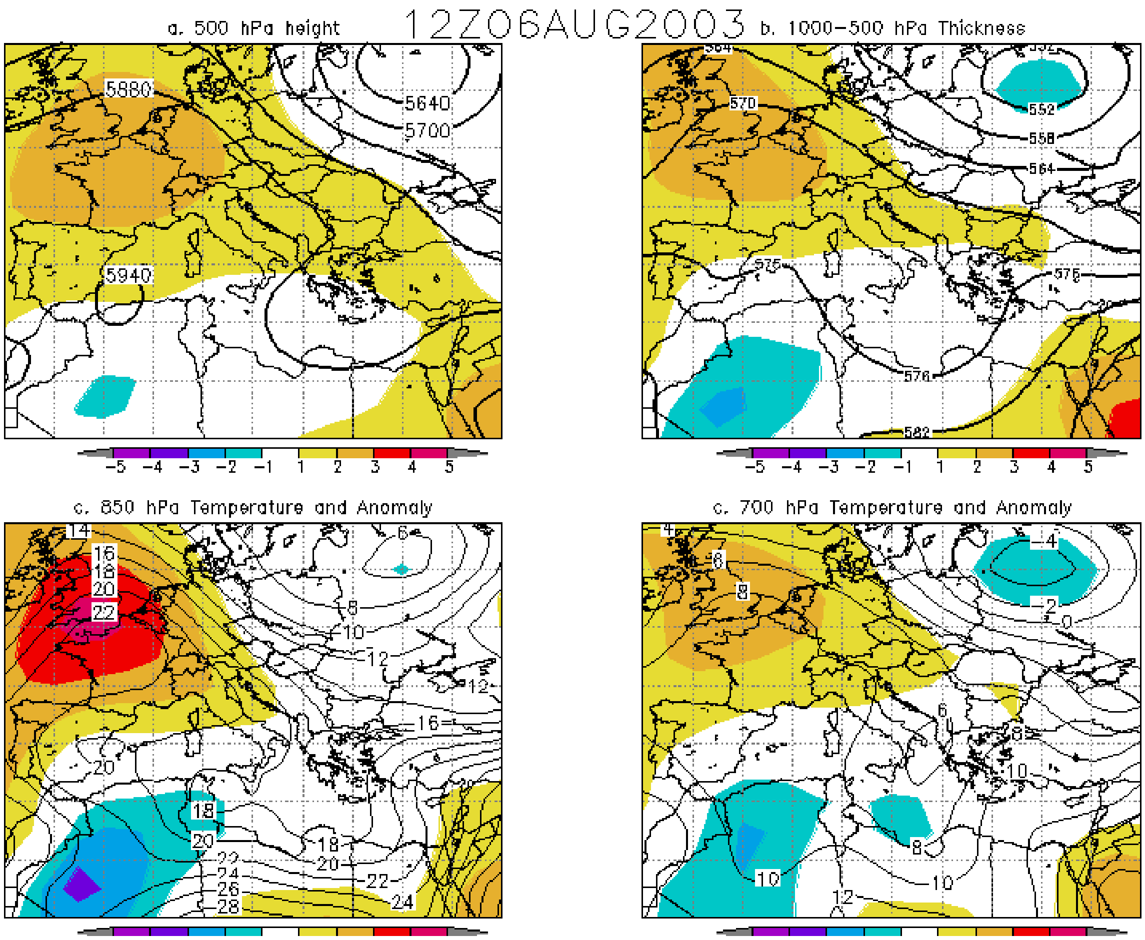

Figure 8. As in Figure 7 except valid at 1200 UTC 6 August 2003. Return to text.

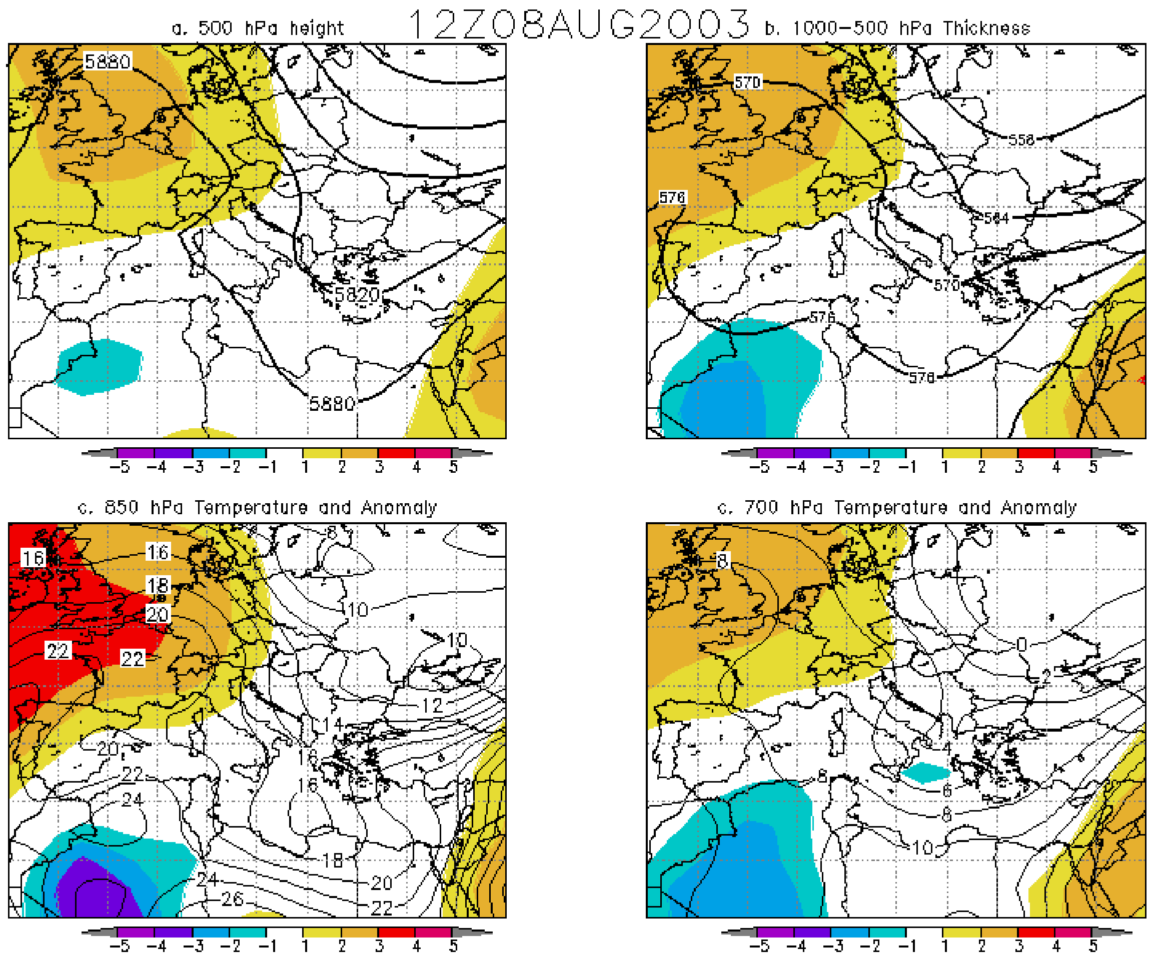

Figure 9. As in Figure 7 except valid at 1200 UTC 8 August 2003. Return to text.

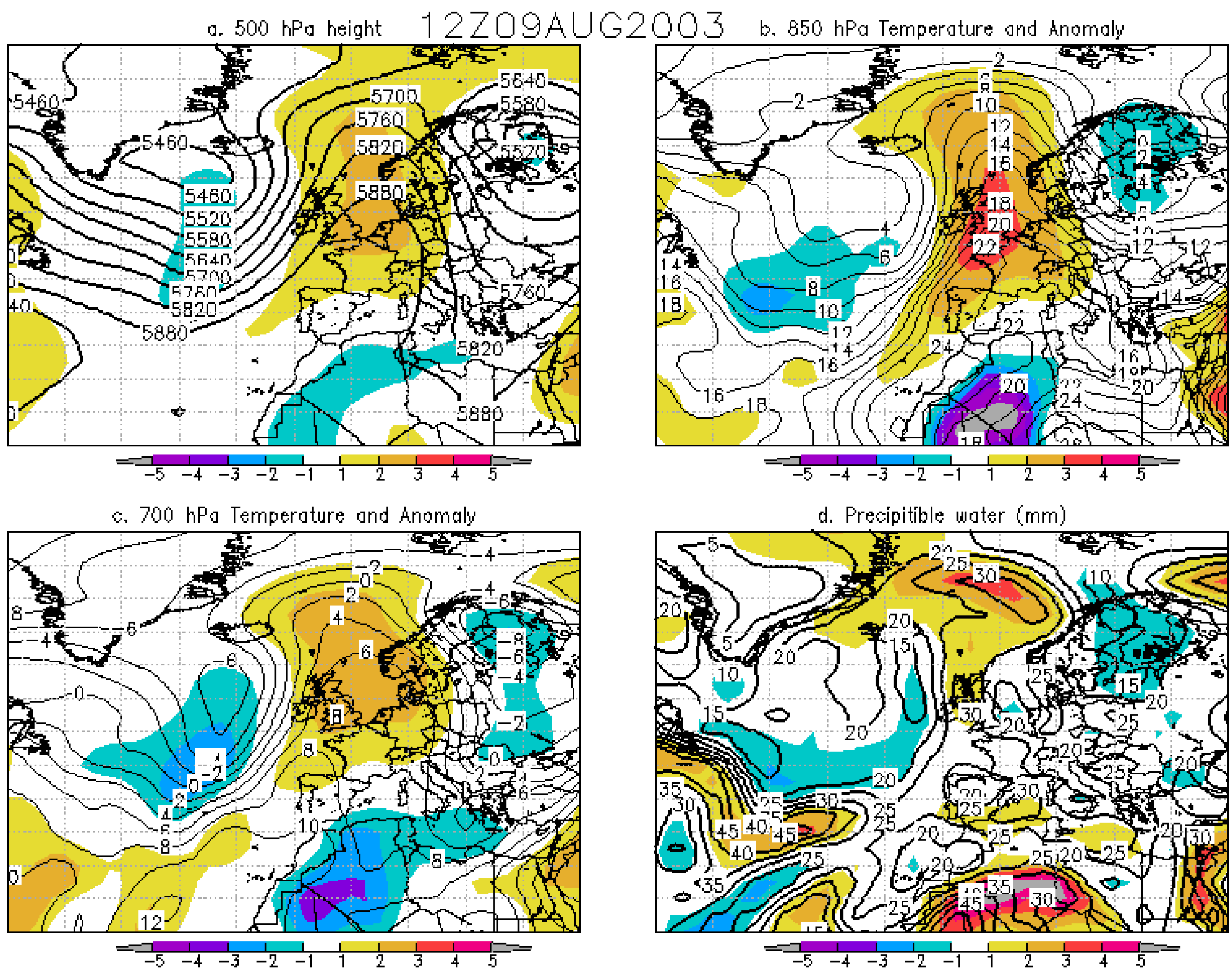

Figure 10. As in Figure 1 except valid at 1200 UTC 09 August 2003 for a larger projection covering Europe and the eastern Atlantic basin. Return to text.

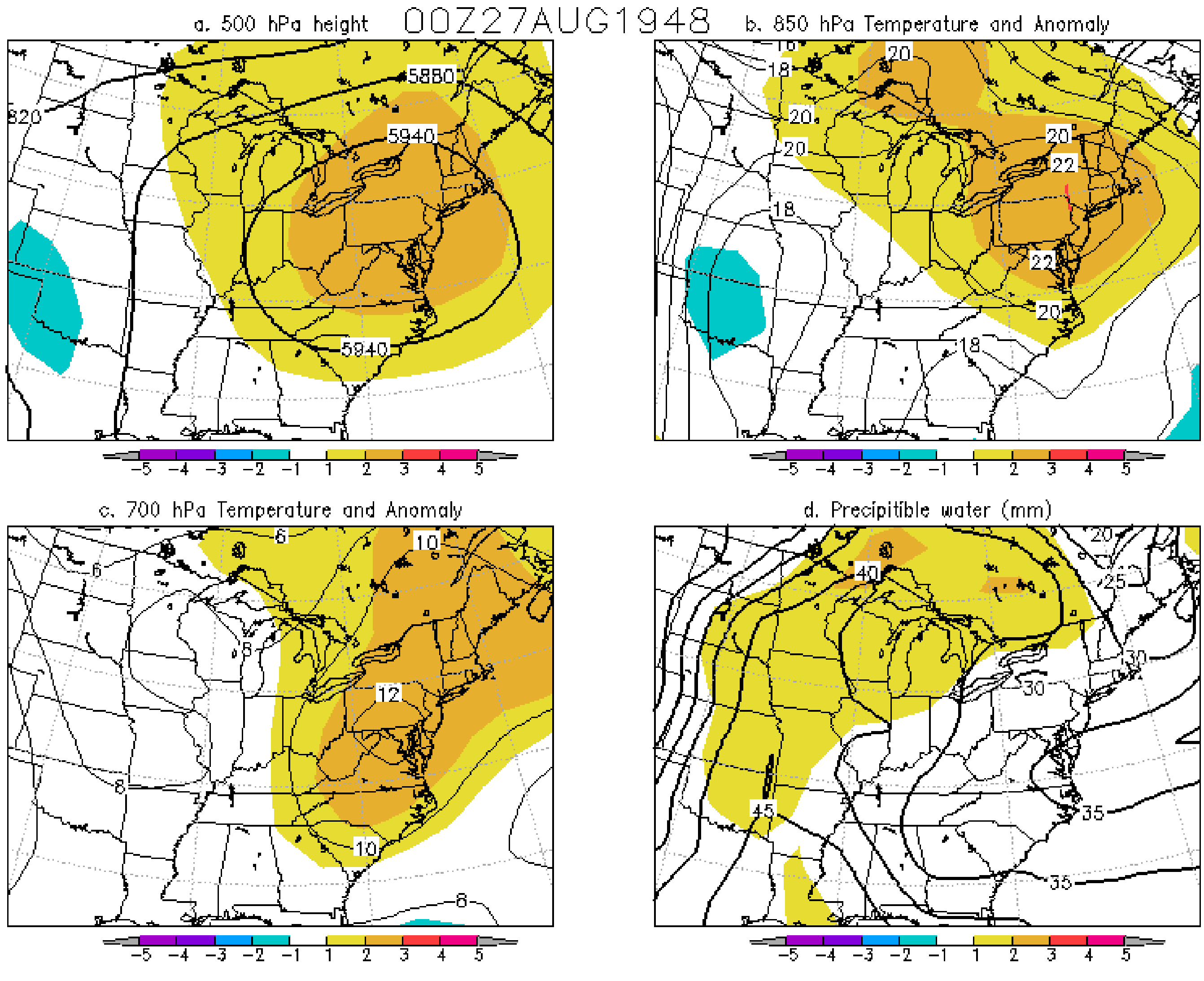

Figure 11. As in Figure 1 except valid at 0000 UTC 27 August 1948. **Return to text.**

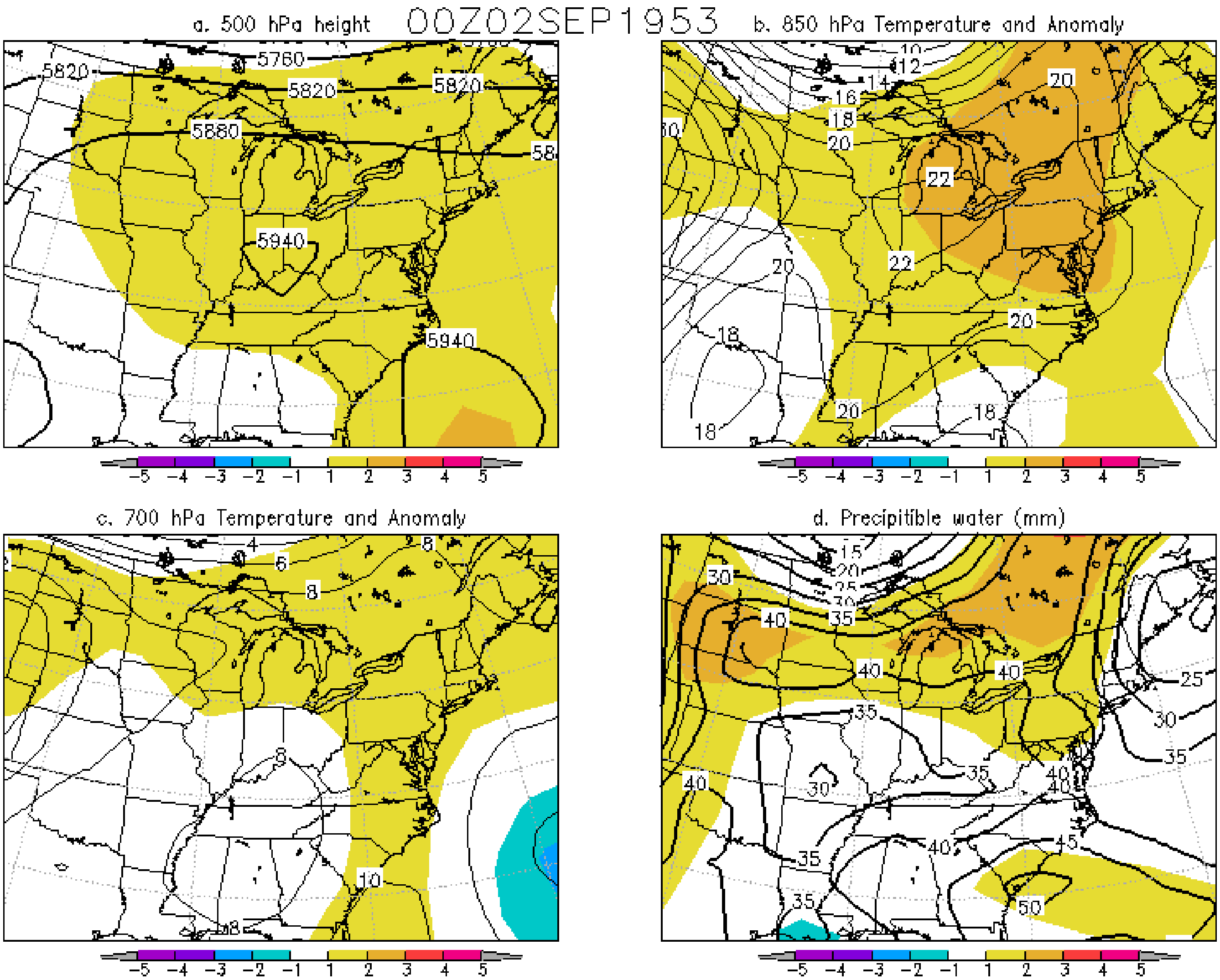

Figure 12. As in Figure 1 except valid at 0000 UTC 2 September 1953. Return to text.