An Examination of Excessive Heat Occurrences in the Western Carolinas

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ABSTRACT

The National Weather Service issues warnings for excessive heat based on specified criteria, but a rigorous definition of "heat wave" is difficult to establish. In an effort to determine what is a heat wave in the County Warning Area of the National Weather Service Forecast Office at Greenville-Spartanburg, South Carolina, an evaluation of basic climate and weather features was performed. In this preliminary examination, non-meteorological factors that can be considered in establishing a definition were not considered. Synoptic patterns associated with extended periods of high temperatures exceeding subjectively determined local criteria were identified. The basic synoptic pattern contributing to prolonged periods of hot weather was characterized by a nearly stationary 500 hPa ridge, positive 500 hPa height anomalies, a nearly stationary 850 hPa ridge with its axis south of the study area, and a Bermuda high pressure system that advected warm air into the western Carolinas from the southwest. Further evaluation of the length of excessive heat periods should be conducted to develop a meaningful heat wave definition. Consideration also should be given to: 1) the combined effects of high temperature and high relative humidity on human health, 2) urbanization, and 3) temperature-sensitive aspects of the economy.

1. Introduction

A strict definition of "heat wave" is elusive, but the term can be assigned to extended periods during which the National Weather Service (NWS) issues Excessive Heat Warnings. In the NWS Greenville-Spartanburg (GSP) Weather Forecast Office (WFO) County Warning Area (CWA), Excessive Heat Warnings are issued when the daytime Heat Index (HI)[2] of 110°F or more is expected for any length of time. The WFO GSP criterion is a locally-adjusted application of the NWS policy which states that an Excessive Heat Warning is issued when the HI values are forecast to meet or exceed locally defined warning criteria for at least two days (Typical values:

[1] This work was performed while the author (AG) was a summer volunteer at WFO Greenville-Spartanburg in 2013.
[2] The Heat Index (also called Apparent Temperature) is a measure of the combined effects of heat and relative humidity on the human body. More information: http://www.nws.noaa.gov/os/heat/index.shtml#heatindex

1) Maximum daytime HI ≥ 110°F and 2) Minimum nighttime lows ≥ 75°F). Heat waves typically last up to a week and often are associated with droughts (Chen and Konrad 2005).

2. Summary of the Problem: Defining Heat Wave

A generic heat wave definition does not apply equitably to all parts of the United States, and actually one definition does not apply evenly to the entire WFO GSP CWA. That is why the NWS provides flexibility for offices to adapt heat-related watch and warning issuance criteria to local climates. Some regions have periods of hot weather that are considered "excessive" by residents, but the same conditions elsewhere are not considered unusual. A variety of factors can be considered when defining an excessive heat event in a particular location. Among them are: 1) do stated thresholds occur at a specific location, 2) if so, are the thresholds exceeded frequently, 3) does the human body react negatively to the heat, and 4) does urbanization play a role in the heat (Robinson 2001)?

The complex nature of the interaction between the human body and an excessively hot environment creates a challenge when attempting to develop a strict definition of heat wave (Greene et. al. 2011). High temperature and high moisture content of the air occurring together can stress certain segments of the population, particularly the elderly and the very young. As a matter of fact, the combination of heat and high relative humidity is a significant cause of weather-related deaths in the United States. Such an occurrence was the Chicago heat wave of 1995 when the high temperature exceeded 100°F and the low temperature exceeded 80°F on consecutive days (13 and 14 July 1995). The heat wave resulted in 465 deaths (U.S. Department of Commerce 1995; Livezey and Tinker 1996).

In addition to the direct human impact, the economy can be influenced significantly by heat waves. Crops, livestock, and other ecosystems are temperature sensitive. Energy costs and healthcare expenses can rise significantly (Luckerson 2012).

3. Synoptic Pattern Review

Examining all the factors related to occurrences of excessive heat in the WFO GSP CWA is beyond the scope of this work. However, a basic evaluation of the criteria that specifically define a heat wave can begin with an examination of fundamental weather patterns associated with periods of hot weather. The following review of synoptic patterns focuses on excessive heat as it relates to the number of consecutive days with a certain high temperature rather than to the heat index because temperature is a more traditional and more easily understood measure of comfort level. The temperatures in this study are extreme to the point that they would cause heat stress in some individuals. Subsequent work on this topic can examine the role of humidity and its relationship with temperature to create dangerous heat conditions in the WFO GSP CWA.

On a large scale, heat waves generally are caused by a nearly stationary mid- and upper-level ridge (e.g., McQueen and Pope 1957; Livezey 1980). The weak pressure gradient and subsidence in the anticyclone produce light wind and clear sky which induce dry weather conditions. Light antecedent precipitation results in higher temperatures because there is less soil moisture and evapotranspiration. Thus, it is no surprise that heat waves often occur with droughts (Chen and Konrad 2005). The 1995 Chicago heat wave, however, did not occur with dry conditions, but with moist conditions. Abundant soil moisture caused the boundary layer to moisten resulting in dew points that raised the heat indices to dangerous levels (Livezey and Tinker 1996).

In a manner similar to the occurrence of excessive heat in other parts of the country, extended periods of above normal temperature in the Carolinas usually occur when the region is situated under the downstream flow of a 500 hPa ridge. Such a pattern is associated with convergence aloft and subsidence at the lower levels. At 1000 hPa, a Bermuda high typically extends from the Atlantic Ocean to the Gulf of Mexico causing a southwest surface flow to advect warmer air into the Carolinas. Similar thermal advection patterns have been observed in extended periods of hot weather elsewhere (Meehl and Tabaldi 2004). Chen and Konrad (2005) found that 60% of the hottest events in the region were accompanied by downslope flow east of the Blue Ridge Mountains. Also, the composite synoptic patterns are not conducive to low level flow that advects substantial moisture into the western Carolinas from either the Gulf of Mexico or the Atlantic Ocean.

4. Method

The largest metropolitan areas in the WFO GSP CWA are Asheville and Charlotte, North Carolina, and the Greer area (Greenville-Spartanburg) in South Carolina. The following factors are considered to evaluate weather patterns associated with excessive heat at these locations: 1) a definition of excessive heat, 2) the number of days experiencing excessive heat, and 3) the synoptic pattern on the days of excessive heat.

The definition of excessive heat applied in this work was chosen subjectively by examining observed daily maximum temperatures from 1982 through 2012 to ascertain a relative frequency of occurrence and number of consecutive days (run length). A lower limit of 100°F was selected for both Charlotte and Greer, and a lower limit of 93°F was chosen for Asheville.

These temperatures were 5°F to 7°F below the long-term climate record maximum (Charlotte, 104°F; Greer, 107°F; Asheville, 100°F).

The excessive heat events defined in the above manner were ranked according to the number of consecutive days meeting the maximum temperature threshold. A data query tool, xmACIS (Eggleston 2008), was used to search the database from 1982 through 2012 and to rank the temperatures. Finally, significant level composite maps from all days meeting the criterion at the three locations were created using the NCAR reanalysis[3].

5. Results

a. Duration and Rank of Excessive Heat Events

Lists of consecutive days with excessive heat as defined above from 1982 through 2012 at Asheville, Charlotte, and Greer (Greenville-Spartanburg) are in Tables 1, 2, and 3. Each event is ranked according to the number of consecutive days the maximum temperature met the criterion.

Table 1. Number of consecutive days at Asheville Regional Airport, North Carolina, with maximum temperature ≥ 93°F from 1982 through 2012. Run length indicates number of consecutive days in each event. Ending date indicates last day of string. (Modified from xmACIS.)

Number of Consecutive Days Maximum Temperature ≥ 93°F
Asheville Regional Airport, North Carolina

Rank	Run Length	Ending Date
1	5	1986-07-21
-	5	1983-08-23
-	5	1983-07-24
4	4	2012-07-01
-	4	1995-08-18
6	3	1993-07-08
-	3	1983-08-11
8	2	2008-06-09
-	2	2007-08-16
-	2	1993-07-29
-	2	1993-07-22
-	2	1988-08-18
-	2	1988-07-16
-	2	1988-06-26
Period of record: 1982-01-01 to 2012-12-31		

[3] http://www.esrl.noaa.gov/psd/data/reanalysis/reanalysis.shtml

Table 2. Number of consecutive days at Charlotte/Douglas International Airport, North Carolina, with maximum temperature ≥ 100°F from 1982 through 2012. Run length indicates number of consecutive days in each event. Ending Date indicates last day of string. (Modified from xmACIS.)

Number of Consecutive Days Maximum Temperature ≥ 100°F
Charlotte\Douglas International Airport, North Carolina

Rank	Run Length	Ending Date
1	5	1986-07-21
2	4	1983-08-23
3	3	2012-07-01
-	3	2007-08-10
-	3	1986-07-13
6	2	2011-07-30
-	2	2007-08-22
-	2	2005-07-27
-	2	1998-06-27
-	2	1993-07-29
-	2	1993-07-10
-	2	1988-08-19
Period of record: 1982-01-01 to 2012-12-31		

Table 3. Number of consecutive days at Greer (Greenville-Spartanburg Airport), South Carolina, with maximum temperature ≥ 100°F from 1982 through 2012. Run length indicates number of consecutive days in each event. Ending Date indicates last day of string. (Modified from xmACIS.)

Number of Consecutive Days Maximum Temperature ≥ 100°F
Greer (Greenville-Spartanburg Airport), South Carolina

Rank	Run Length	Ending Date
1	5	2007-08-11
2	4	1986-07-21
3	3	2012-07-01
-	3	2007-08-17
-	3	1999-08-01
-	3	1986-07-09
-	3	1983-08-23
8	2	2007-08-22
-	2	1999-08-14
-	2	1995-07-25
-	2	1993-07-29
-	2	1993-07-07
-	2	1987-07-24
Period of record: 1982-01-01 to 2012-12-31		

b. Composite Charts

Composite mean geopotential height and height anomaly charts for 500 hPa, 850 hPa, and 1000 hPa for the excessive heat days at Asheville, Charlotte, and Greer revealed essential characteristics of the synoptic scale pattern (Figs. 4 – 9).

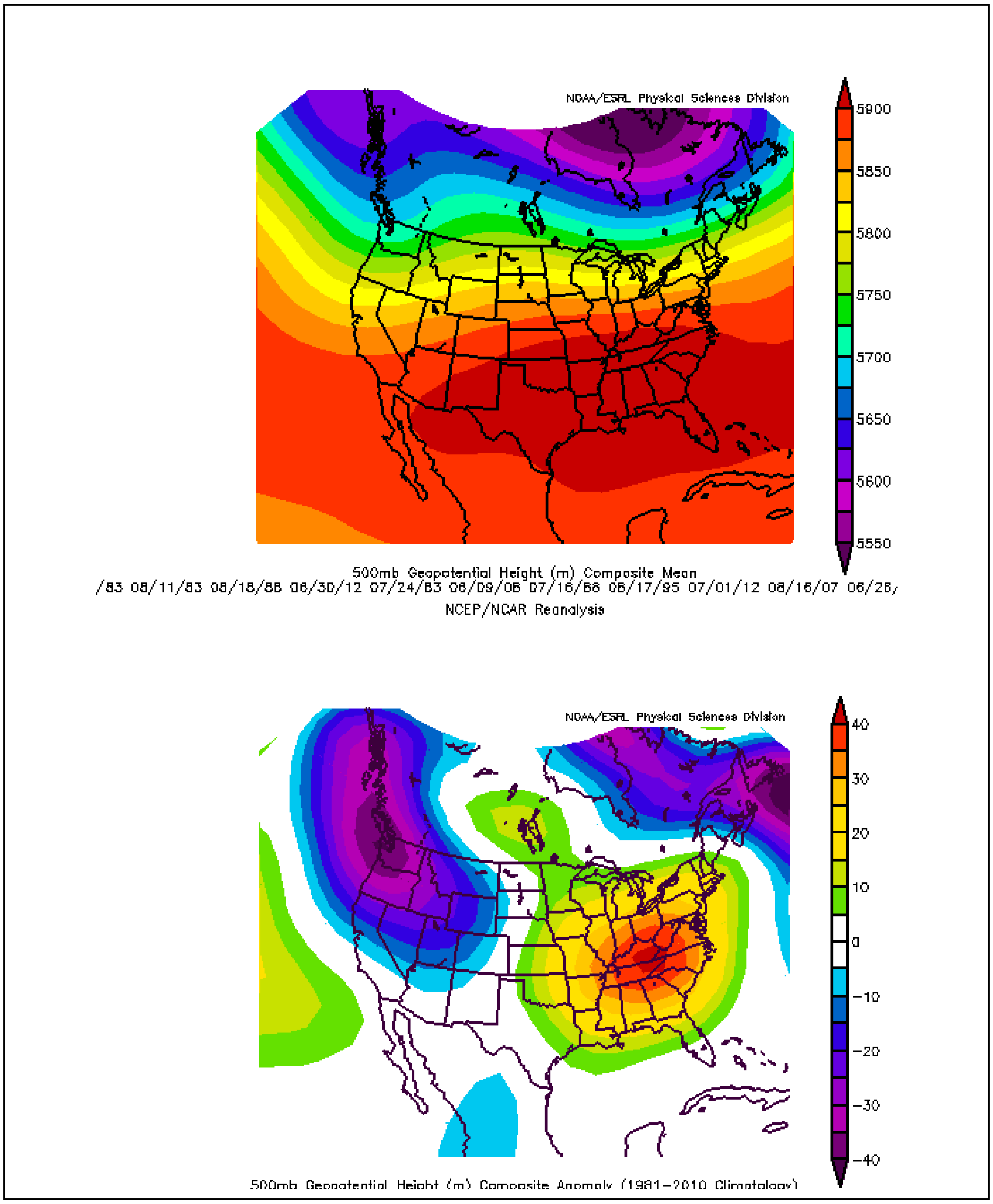

Fig. 1. Composite mean 500 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days from 1982 through 2012 at Asheville Regional Airport, North Carolina. (NCEP/NCAR Reanalysis)

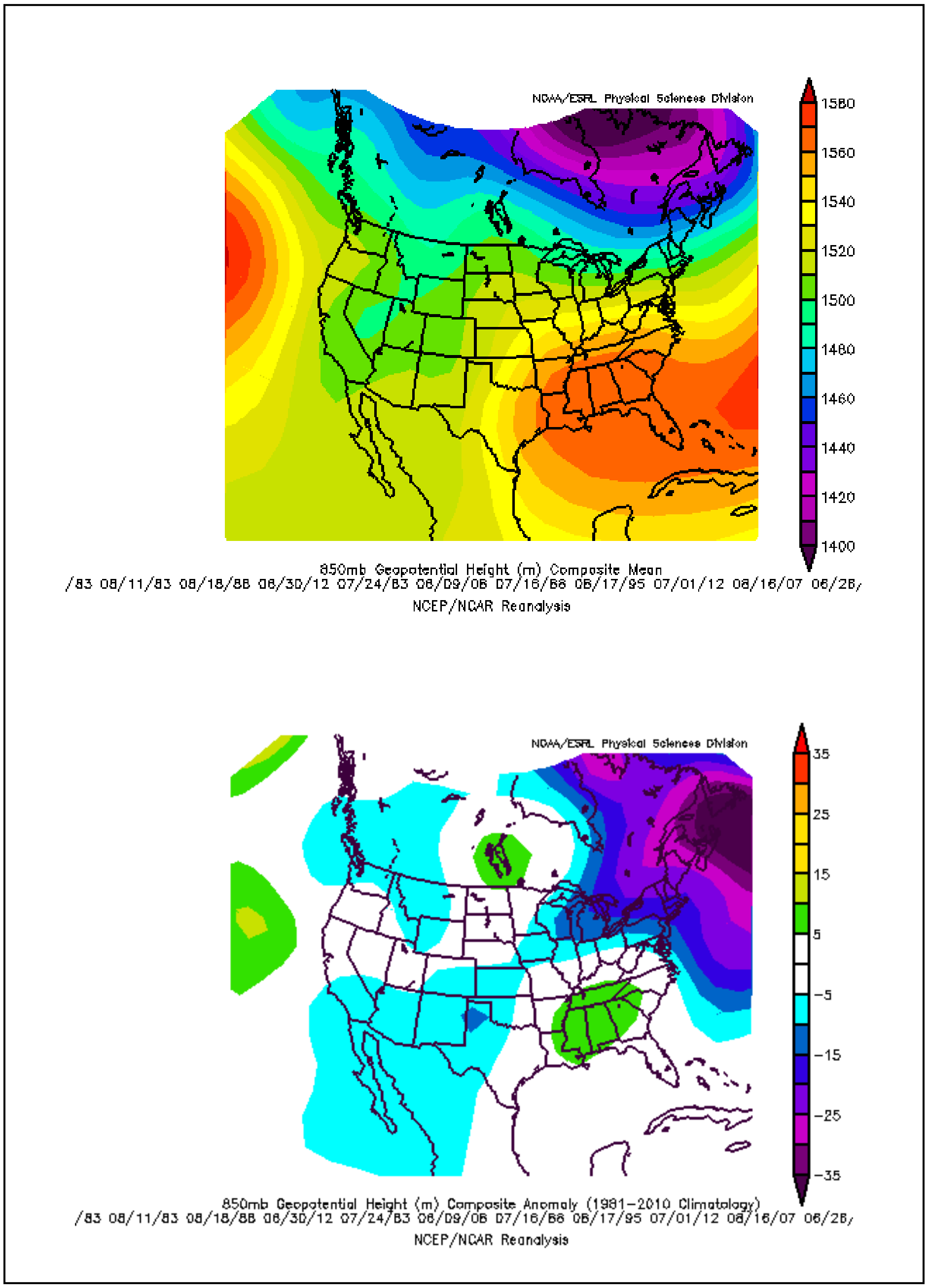

Fig. 2. Composite mean 850 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 1 at Asheville Regional Airport, North Carolina. (NCEP/NCAR Reanalysis)

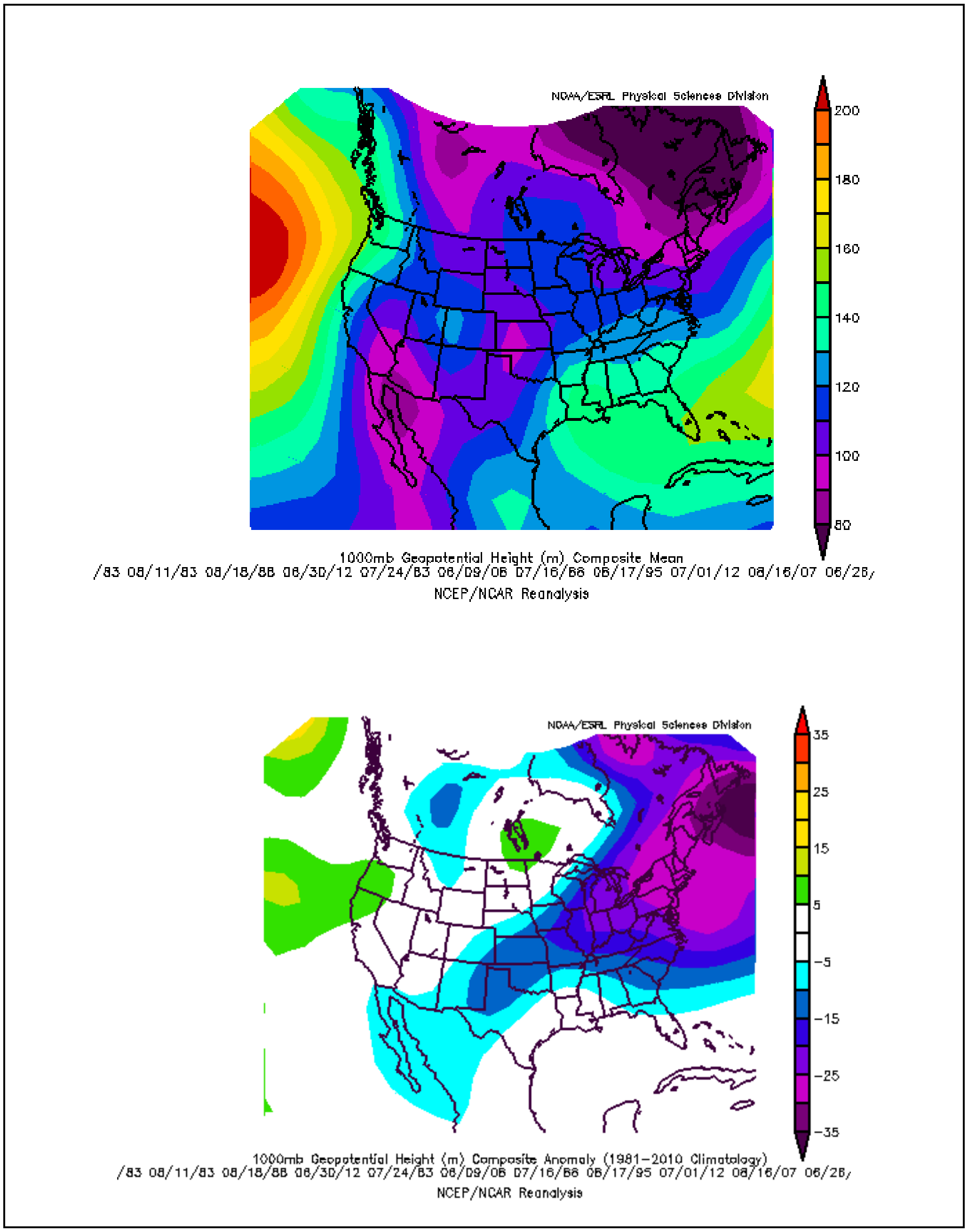

Fig. 3. Composite mean 1000 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 1 at Asheville Regional Airport, North Carolina. (NCEP/NCAR Reanalysis)

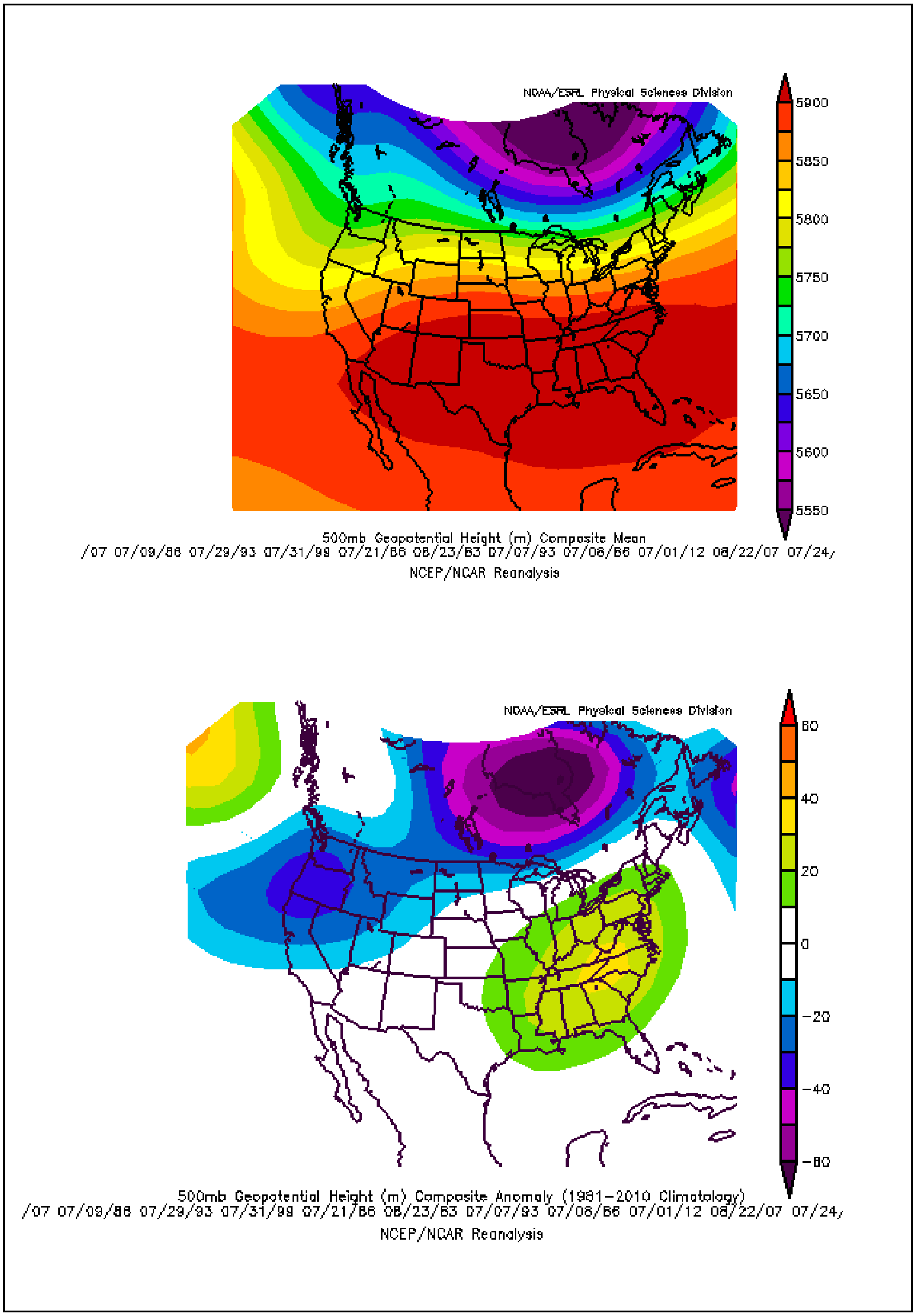

Fig. 4. Composite mean 500 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 2 at Charlotte/Douglas International Airport, North Carolina. (NCAR/NCEP Reanalysis)

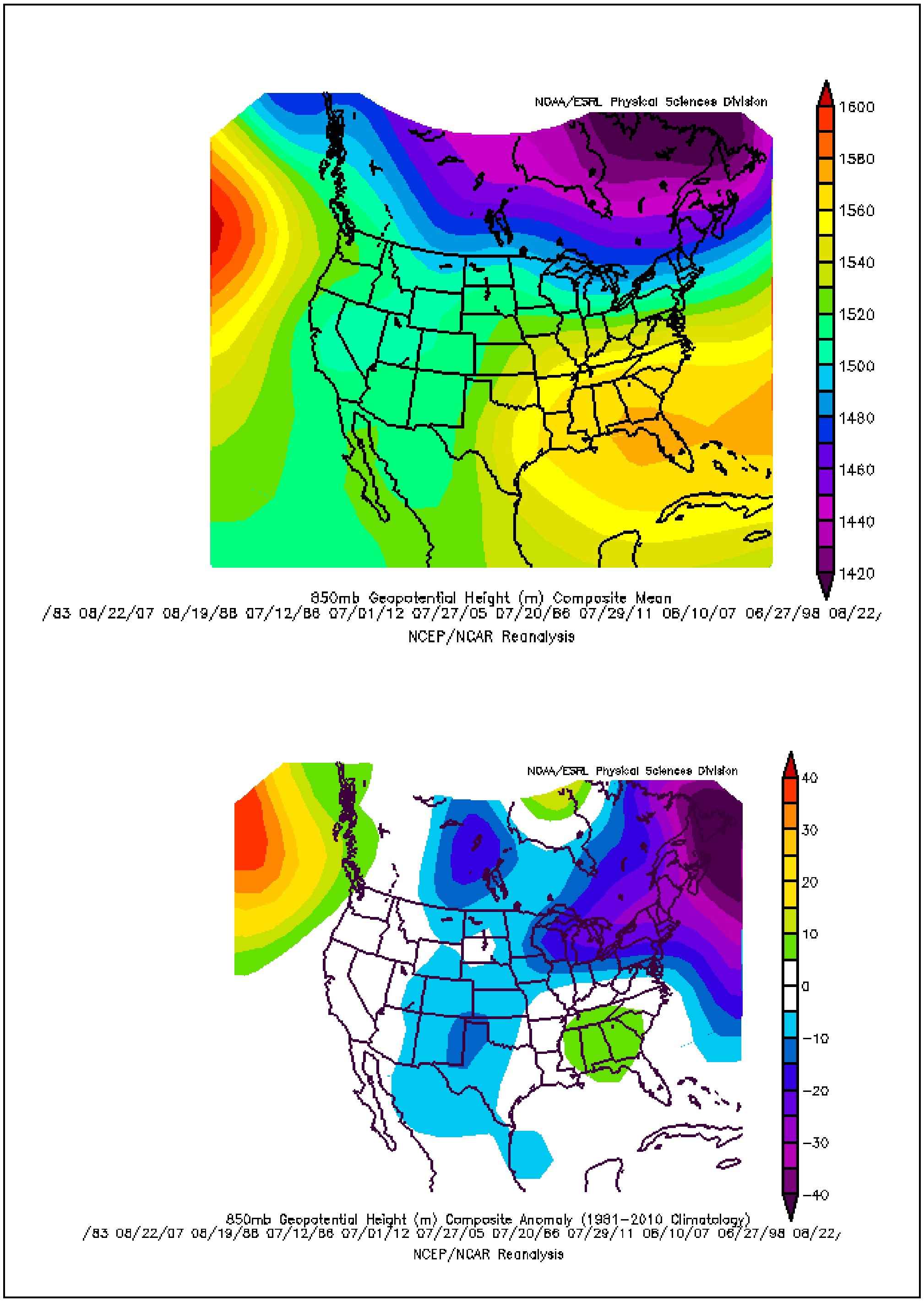

Fig. 5. Composite mean 850 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 2 at Charlotte/Douglas International Airport, North Carolina. (NCEP/NCAR Reanalysis)

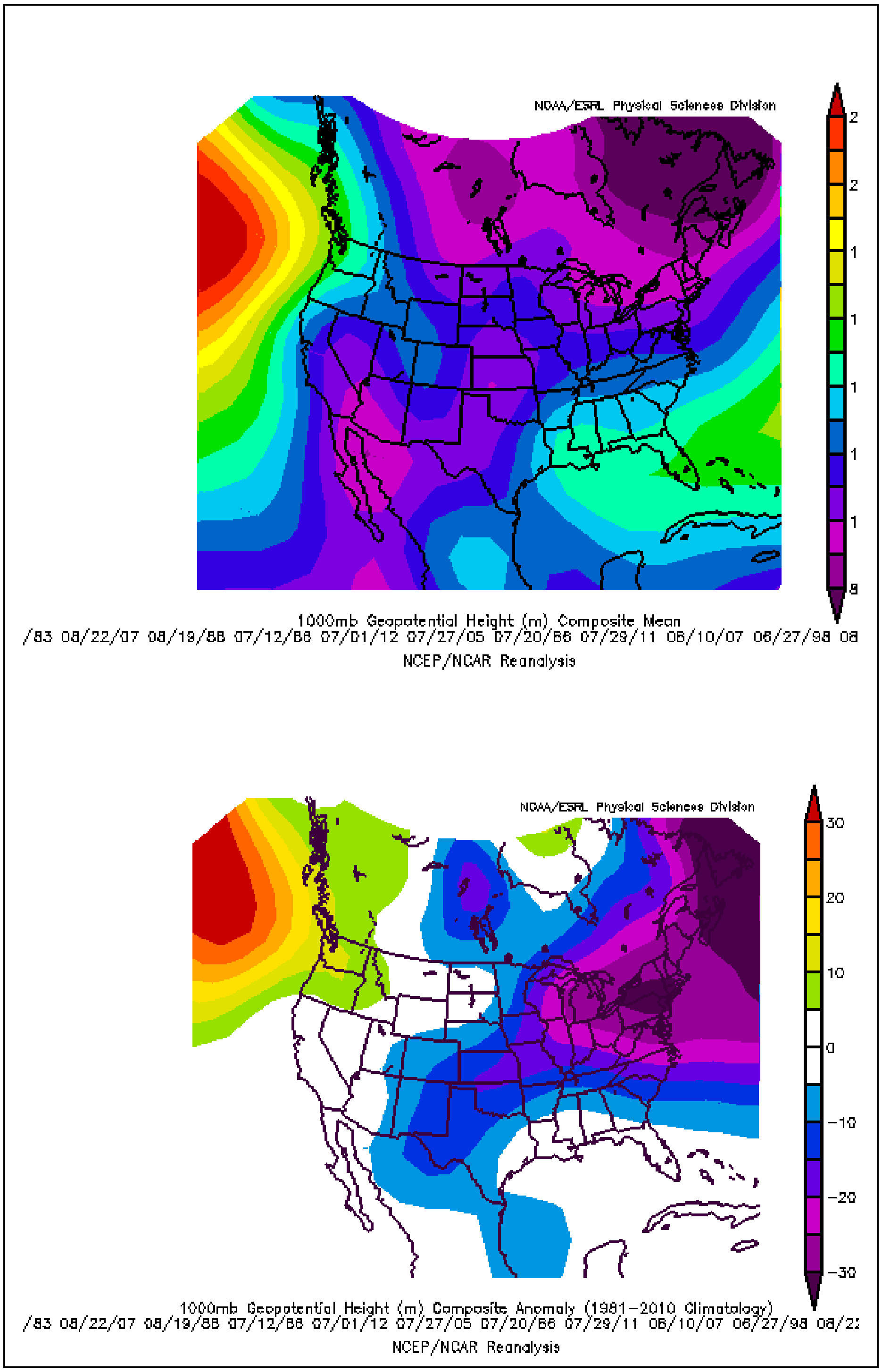

Fig. 6. Composite mean 1000 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 2 at Charlotte/Douglas International Airport, North Carolina. (NCEP/NCAR Reanalysis)

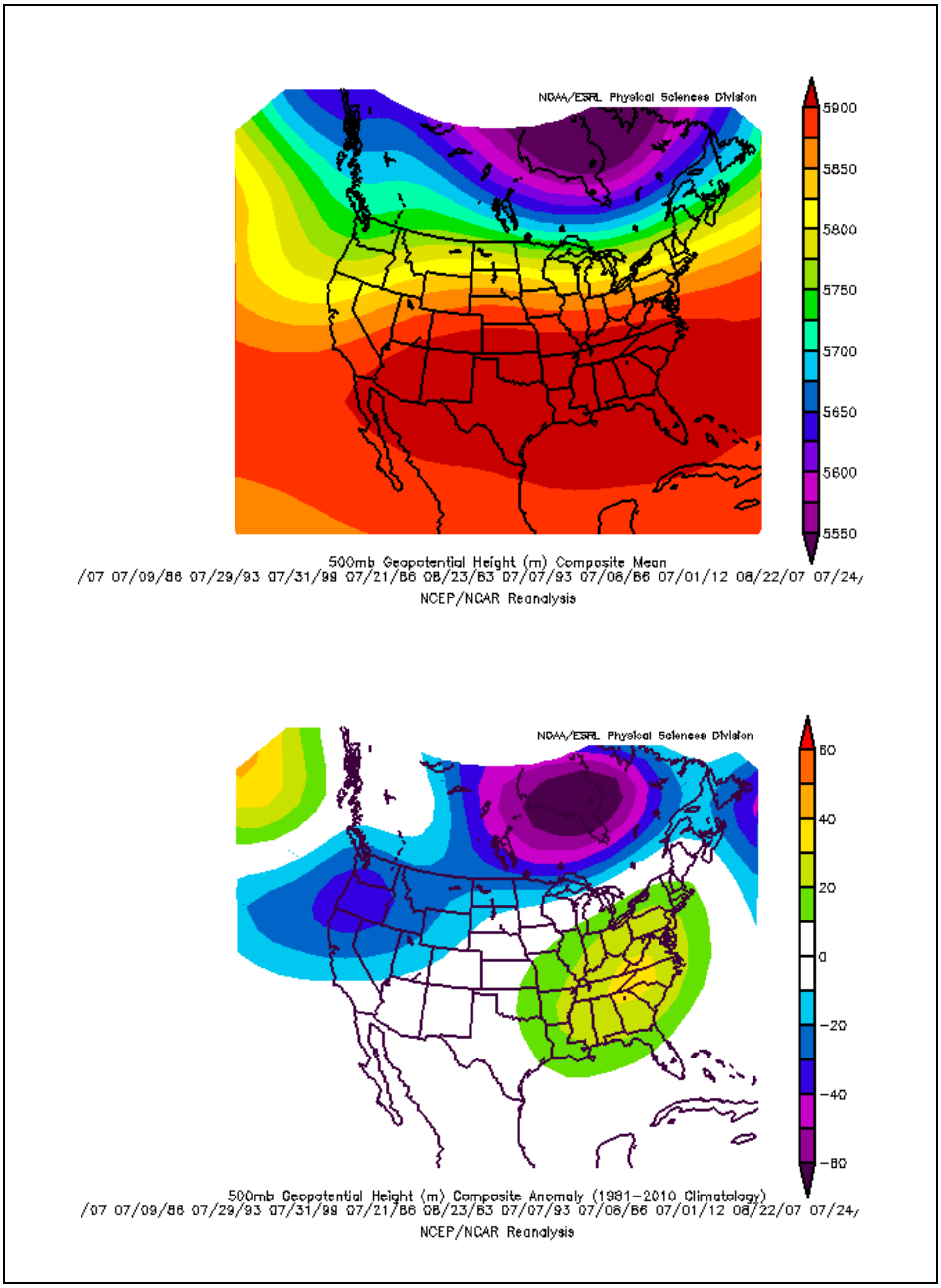

Fig. 7. Composite mean 500 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 3 at Greer (Greenville-Spartanburg Airport), South Carolina. (NCEP/NCAR Reanalysis)

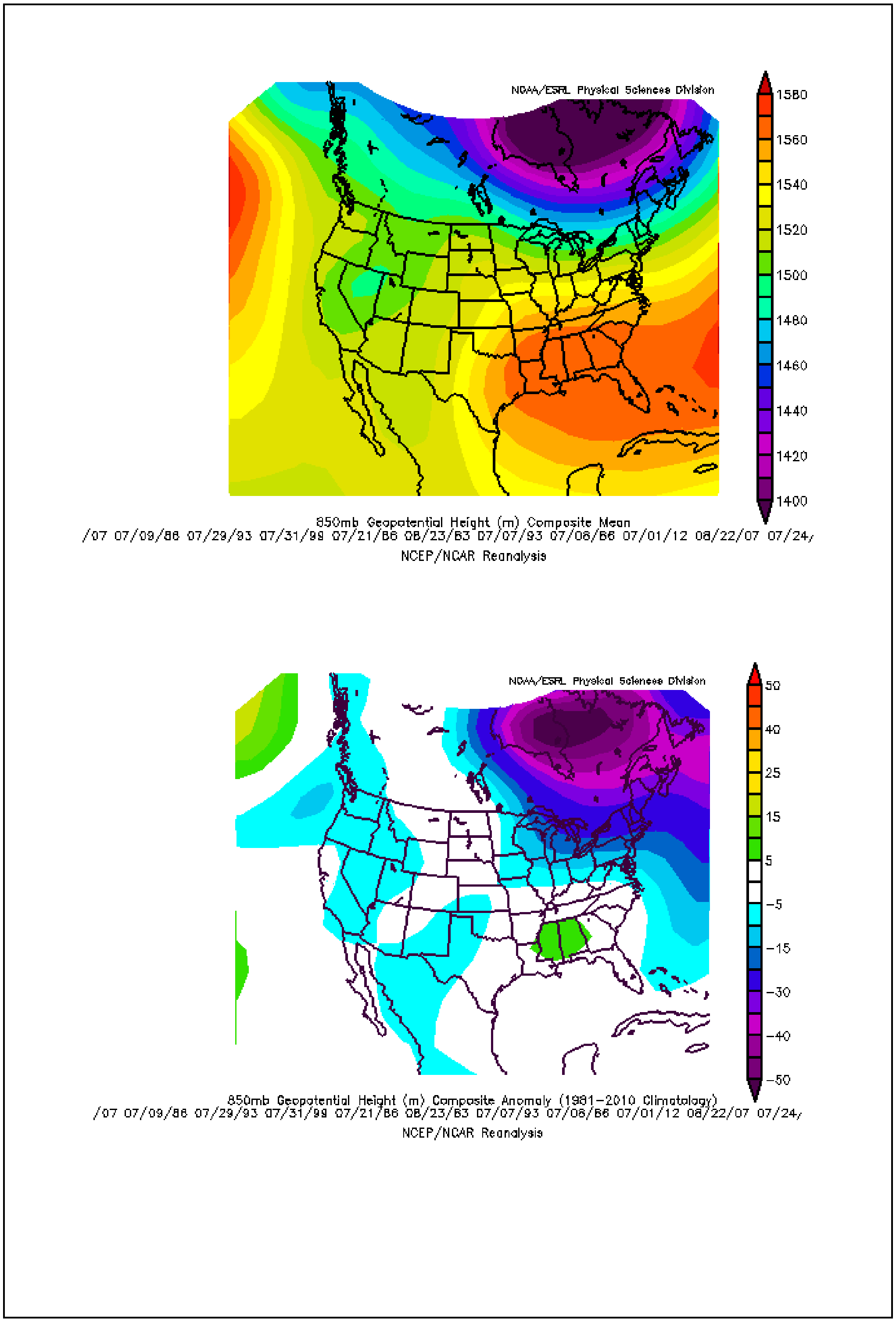

Fig. 8. Composite mean 850 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 3 at Greer (Greenville-Spartanburg Airport), South Carolina. (NCEP/NCAR Reanalysis)

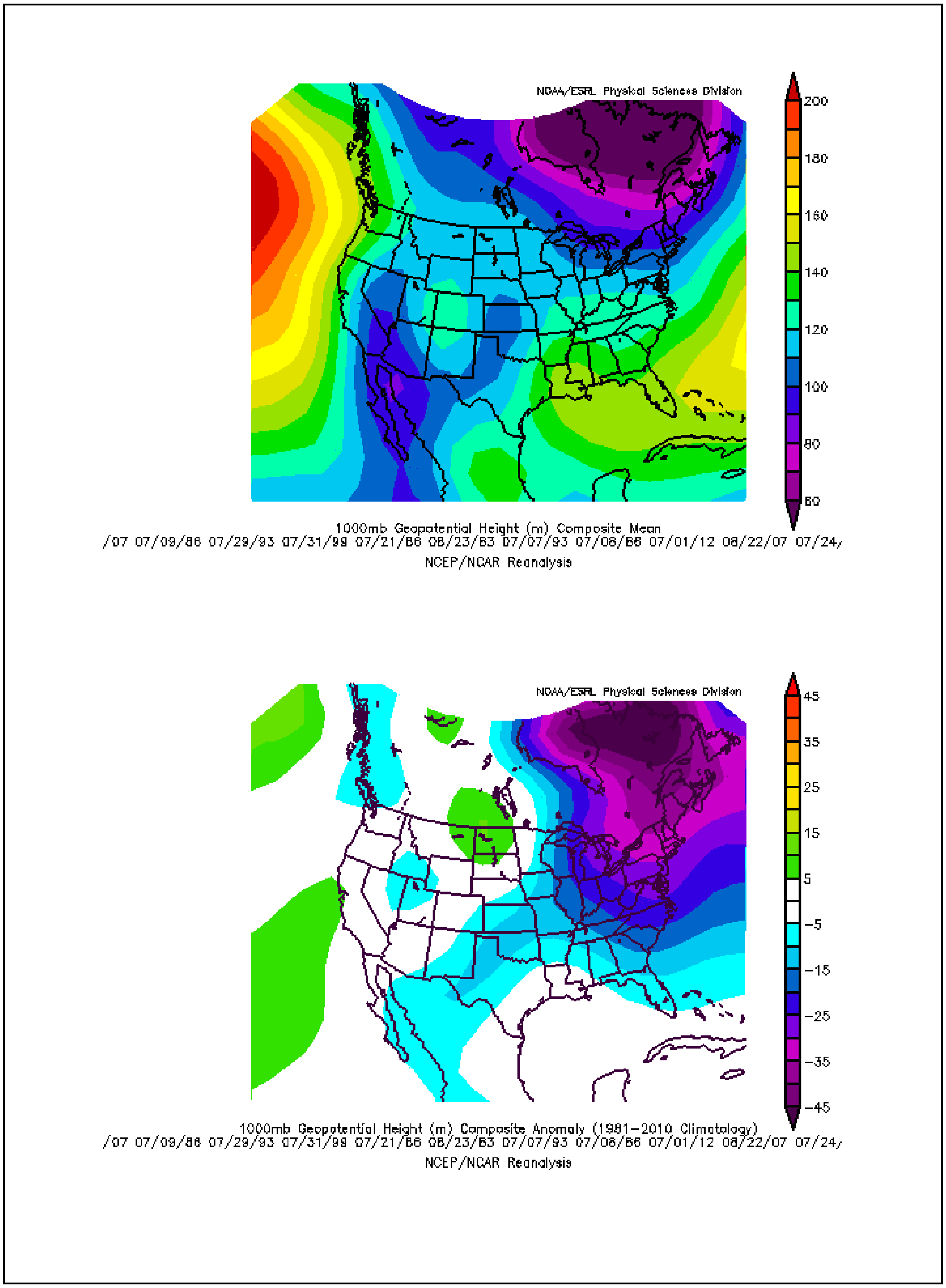

Fig. 9. Composite mean 1000 hPa geopotential height (top) and height anomaly (bottom) for excessive heat days in Table 3 at Greer (Greenville-Spartanburg Airport), South Carolina. (NCEP/NCAR Reanalysis)

The composite maps for Asheville, Charlotte, and Greer (Greenville-Spartanburg) showed that all excessive heat events were associated with a strong 500 hPa ridge over a majority of the continental United States. The 500 hPa ridge produced subsidence that contributed to clear skies and efficient insolation. At the 850 hPa level, a ridge of high pressure was centered over the Atlantic Ocean, but the axis of the ridge extended westward across the Gulf Coast states. The 1000 hPa composite maps indicated the presence of a strong Bermuda high off the Atlantic coast that extended south of the study area into the Gulf of Mexico. The height anomaly maps all showed positive anomalies indicative of the long periods of hot weather that occurred under strong upper ridges. The advection patterns indicated by the composite charts favored a very warm and dry flow from the southwest, particularly in the lower levels. The Gulf of Mexico, a potential source of moisture, was not tapped.

4. Discussion and Conclusion

Highlighting the complex set of interrelated factors associated with periods of excessive heat clearly demonstrates the difficulty in assigning a rigid definition to the term heat wave. The combination of heat and high relative humidity, human health, urbanization, and economic issues were not examined in this limited study. Even the run length of excessively hot periods, which ranged from two to five days at each location, should be scrutinized more closely to formulate a meaningful definition of "heat wave." Nonetheless, key features of the region's hot weather climatology were revealed.

Knowledge of the mean heights and height anomalies during periods of hot weather will enhance the issuance of watches and warnings for excessive heat. Even though the excessive heat definitions (viz., high temperature of 100°F at Charlotte and Greer; high temperature of 93°F at Asheville) used in this study were developed subjectively and were not overly rigorous, they suggest that locally-tuned criteria for the issuance of heat products can improve both forecasting and communicating risks to the public. An informed public can adapt effectively to stresses that accompany abnormally high temperatures. New suggestions for updated excessive heat-related definitions should not overlook the fact that current NWS policies were developed based on extensive research, and they were applied in a manner that allows some flexibility in application across the varied climates of the United States.

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