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Analysis of Late Summer Heat Waves in the Northeast US

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Honors Thesis

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ABSTRACT

The climatological temperature maximum and heat wave frequency, defined as three or more consecutive days of maximum temperatures at or above 32 degrees Celsius, often peak around mid to late July in the Northeast United States. However, numerous notable heat waves have occurred in late August into early September, including 1953, 1973, and to a lesser extent 2015. An analysis of daily means of 500 hPa geopotential heights from the NCEP-NCAR Reanalysis dataset over a 67–year period (1948–2015), in addition to surface temperatures from numerous stations east of the Mississippi River, shows a secondary peak in mean temperatures, geopotential heights and heat wave frequency over the Northeast and Ohio Valley, and to a lesser extent in the Southeast, during the late summer. This peak is most evident in late August, both on the synoptic scale and on a localized scale in the selected stations. Composite 500–hPa geopotential height and surface analyses of the warmest late August into early September time frames exhibits an anomalous Western US trough and Eastern US ridge, and an anomalous surface high pressure center near the eastern US.

1. INTRODUCTION

Heat waves are of particular interest to study, given their significant societal and economic impacts. The climatological temperature maximum, and the peak frequency of heat waves, often occurs in mid-July. Notably, however, some of the most significant heat waves in recorded history at Albany, NY in terms of intensity and duration occurred in late August into early September, with several notable instances including 1953, 1973, and to a lesser extent 2015.

Research on late summer heat waves is very limited. Petro (2011) researched the connection between late summer heat waves in Georgia and hyperthermia-related football player deaths, and discovered that despite the majority of heat waves occurring in June and July, 20-40% of heat waves occurred in August and September, and in select parts of Georgia late-summer heat waves persisted slightly longer than the average duration of heat waves. This paper seeks to identify and analyze the secondary peak in heat wave frequency and average temperatures in the late summer, in the local and synoptic scale.

2. DATA AND METHODOLOGY

To identify the secondary peak in warmth in late August, daily climate data (Menne 2012) was obtained from the National Climatic Data Center (NCDC) for Albany, NY, spanning a 76-year period from 1939 to 2015, in order to compute raw, unsmoothed daily average temperatures and percentiles, as well as to generate heat wave frequency plots.

Heat wave frequency plots were computed in several instances by counting the number of days that a station was within a heat wave for any given date. In the Northeast US, a heat wave is informally defined as three or more consecutive days with a maximum temperature at or above

32.2 degrees Celsius, or 90 degrees Fahrenheit. Definitions of heat waves significantly vary spatially throughout the United States, however, owing to the different climate patterns and mean temperatures, and there are cases that fall just below the threshold, either in terms of duration or temperature. To account for these borderline cases, the heat wave criteria was computed using multiple thresholds, with three to five days at or above 31 to 33 degrees Celsius; the average of these 15 results was used, and then normalized relative to the number of years in the station. For instance, a 100% value for a single date would imply that all 15 thresholds were met in every single year in the station's database for that date. Using this definition, the eastern half of the United States was split into three regions: Northeast, Ohio Valley, and Southeast, using NCDC daily climate data for stations marked in Figure 1, in order to compute heat wave frequencies.

In order to evaluate the synoptic-scale and mid to upper tropospheric pattern, the National Centers for Environmental Prediction – National Center for Atmospheric Research (NCEP-NCAR) 2.5 degree Reanalysis dataset (Kalnay et al. 1996) was retrieved from the NOAA Earth System Research Laboratory (ESRL). Unsmoothed daily averages for 1000-hPa and 500-hPa geopotential heights were computed using a sample size of 67 years from 1948 to 2015, constituting the available years in the dataset. This dataset was additionally used to obtain the daily mean geopotential heights during the summer season over central New York State, from the nearest gridpoint at 42.5 degrees north latitude and -75.0 degrees west longitude.

Late August warm periods were also analyzed by compiling a list of years that exceeded the 95th percentile for 26-31 August 2-meter temperatures for each NCDC station, and then compiling the years that showed up the most frequently in each region in order to create a regional composite. Geopotential height anomalies for these composites were computed for the aforementioned pressure levels with the climatology retrieved from ESRL.

3. RESULTS / DISCUSSION

a. Late-Summer Heat Waves at Albany

The trend for a secondary peak in temperatures in late August is reflected in the historical data for Albany International Airport (ALB). The daily climate dataset for Albany was used to compute a raw, unsmoothed time series of daily mean temperatures and percentiles (Fig. 2), thus highlighting the daily variations. This time series shows the annual temperature maximum around mid-July, with a pronounced minimum around 20–25 August, followed by a local maximum around 26–31 August. Similarly, the 87.5th percentile exhibits an upward trend and secondary peak in late August. Figure 3 depicts heat wave frequency for Albany, showing a similar minimum in days within a heat wave in mid-August followed by a secondary peak in late August into early September.

This trend is similarly shown in a time series for 500–hPa geopotential heights over Central New York State (Fig. 4), obtained from the nearest gridpoint in the NCEP-NCAR reanalysis. There is an initial peak in geopotential heights during mid-July followed by a gradual decline through mid-August, before a secondary peak is reached in the last several days of the month. Over this specific gridpoint, the second peak actually represents the annual maximum in mean geopotential height.

b. Spatial Extent of Late-Summer Heat Wave Frequency

When dividing the eastern half of the United States into three sections, the Northeast region (Fig. 5a) exhibits a clear tendency for a local minimum in heat wave frequency around 20-25 August, and a secondary maximum around 26 August-4 September. A similar but slightly less evident trend is shown for the Ohio Valley (Fig. 5b). Over the Southeast region (Fig. 5c), there is a slight maximum in late August, although the preceding mid-August minimum in heat wave frequency is not as pronounced as that over the northern regions. This may be partly due to warmer average temperatures in late August, and perhaps a higher temperature threshold may be needed to identify such a signal more clearly.

Notably, the secondary peak in heat wave days for the Northeast and Ohio Valley regions and Albany, New York appears to lag several days following the peak in mean temperature and mid-tropospheric geopotential heights, as shown in Figures 2 and 3. One possible explanation for this discrepancy could be the climatological increase in intensity of cool air advection episodes over the northern United States as the jet stream begins to strengthen and shift equatorward, with non-heat wave years more likely to feature cooler temperatures in early September than in late August, which would decrease the mean temperature and also result in increased variability in temperatures around early September, as suggested to some extent by Fig. 2.

c. Spatial and Vertical Extent of Late-Summer Ridging

Geopotential heights and temperatures were averaged out into two periods, 25–31 August and 18–24 August, with the latter subtracted from the former to obtain a change in these mean daily values in late August. These differences were computed at the 1000 and 500 hPa pressure levels. A comparison of these levels shows a trend for higher geopotential heights and temperatures over the Northeast and Ohio Valley regions extending into Southeast Canada during the last few days of August, with this region of positive trends increasing in magnitude and shifting poleward with height, likely signaling a similar increase in 1000-500 hPa thickness, or the measure of the mean temperature in the low to mid troposphere, over these regions.

This approach was used to generate a map of 500 hPa geopotential height differences between 25-31 August and 18-24 August (Fig. 6). An expected result is the differential decrease in height with increasing latitude, as the decreasing sun angle and surface heating in the polar regions by late August results in a faster cooling rate and decrease in low to mid tropospheric thickness relative to the tropics, accompanied by a strengthened height gradient and intensification of the jet stream. Notably, however, geopotential heights increased in this time frame over the Northeast United States and the Ohio Valley into Southeast Canada. Along with Figure 3, this pattern suggests a slightly increased likelihood of ridging over the Northeast United States into Southeast Canada during late August. Following the same approach for the 1000 hPa geopotential heights (Fig. 7) shows a similar theme, with a shift towards higher pressure off the East Coast and a decrease in geopotential heights over the central US indicative of a stronger anticyclonic flow over the eastern US during late August, which enables warmer and more moist low-tropospheric air to be advected (moved) from the Gulf of Mexico poleward.

d. Anomalous Late August Warmth Composite

To assess synoptic-scale features associated with the warmest late August periods, three regional lists were created for years where a majority of the stations exceeded the 95th percentile for 26-31 August temperatures (Table 1). In the Northeast US, the top 5 years were 1953, 1973, 1993, 1959 and 1948; these years were used to generate a composite of geopotential height mean and anomalies at 500 hPa (Fig. 8a) and 1000 hPa (Fig. 8b).

The 500 hPa geopotential height composite indicates an enhanced North Pacific jet aiding in trough amplification over the Western US, with an anomalous southwesterly flow over the central US enhancing the ridge downstream with significant positive height anomalies over southern Ontario and the northern Hudson Bay. The mean flow at 500 hPa over the Rockies is southwesterly, suggesting the existence of a warming and drying downsloping flow off of the Rockies, with the air mass aloft adiabatically warmed by descent as it is advected into the

Eastern US. At 1000 hPa, a slight positive height anomaly is present over the Southeast US with a negative height anomaly indicative of a lee trough east of the Rockies, implying an anomalous anticyclonic flow over the eastern US with lower-tropospheric warmer and more moist air advected from the Gulf of Mexico into the Northeast US.

Given the late August minimum in temperatures and late August secondary temperature maximum, one feature that may be associated with late summer heat waves is a transition from a cool Autumn-like Canadian surface high pressure to a warm subtropical high pressure centered off the coast, as described by Boyle and Bosart (1983). A subjective analysis of the aforementioned top 5 warmest late August years in the Northeast US (Fig. 9) shows a tendency for a surface high pressure over southern or eastern Canada in the several days preceding the heat wave, inducing a northeasterly or easterly flow over the Northeast US which would advect a cool maritime or continental air mass, respectively, into the region. Several days later, the high pressure center shifts off the Northeast US coast and settles offshore, transitioning into a warm subtropical high with a southwesterly flow advecting warmer and more moist air into the Northeast US.

4. CONCLUSIONS

Observations of a recurring tendency for significant late-summer heat waves at Albany, NY are supported by a time series of 1939-2015 mean temperatures and number of heat wave days, with both exhibiting a secondary peak in late August, while the annual maximum in mean 500 hPa geopotential heights over central NY, as analyzed from the NCEP-NCAR reanalysis, is reached in late August. This pattern was similarly shown in the synoptic scale, with anomalously warm late Augusts exhibiting an anomalous western US trough and southeast Canada ridge along with an enhanced North Pacific jet stream, while the mean geopotential heights over the Northeast US into Southeast Canada countered the larger scale trend by slightly increasing over the last several days of August. Additionally, the warmest years in late August were associated with a cool Canadian surface anticyclone transitioning into a subtropical anticyclone as it shifted off the East Coast and established a low-tropospheric southerly to southwesterly flow over the East US.

There are several limiting factors to this study, namely the relatively short period of reanalysis data limiting the sample size, spanning a 67-year period from 1948 to 2015. It is possible that several significant daily anomalies may have slightly influenced the long-term mean, which a larger sample size would be able to eliminate more effectively. Additionally, one factor that was not examined in this paper is precipitation, which may potentially have some correlation with the late August secondary temperature peak.

ACKNOWLEDGMENTS

This project originated from a class project for Professor Lance Bosart's ATM 305 course, who provided help and guidance with this project. Appreciation is extended to Kevin Tyle, who helped with the data sources that were used for this project as a part of independent ATM 498 research, and to Philippe Papin for help with learning NCL scripting for the plots that were used in this study.

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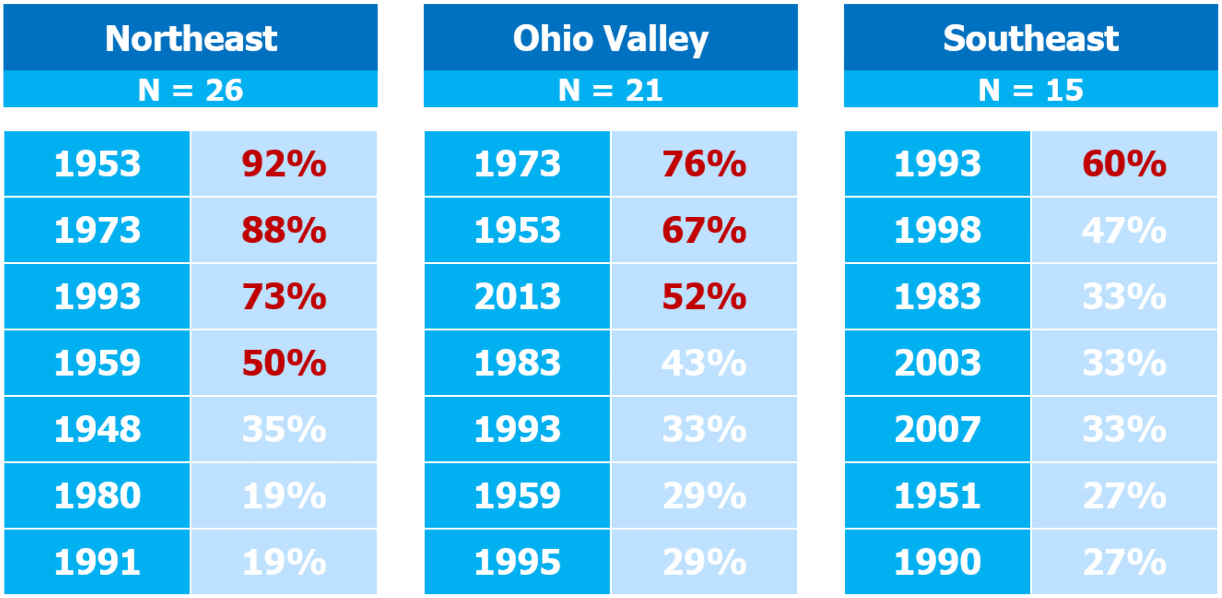

Northeast	
N = 26	
1953	92%
1973	88%
1993	73%
1959	50%
1948	35%
1980	19%
1991	19%

Ohio Valley	
N = 21	
1973	76%
1953	67%
2013	52%
1983	43%
1993	33%
1959	29%
1995	29%

Southeast	
N = 15	
1993	60%
1998	47%
1983	33%
2003	33%
2007	33%
1951	27%
1990	27%

Table 1. Percentage of stations that exceeded the 95th percentile for 26-31 August temperatures for the given year in each region.

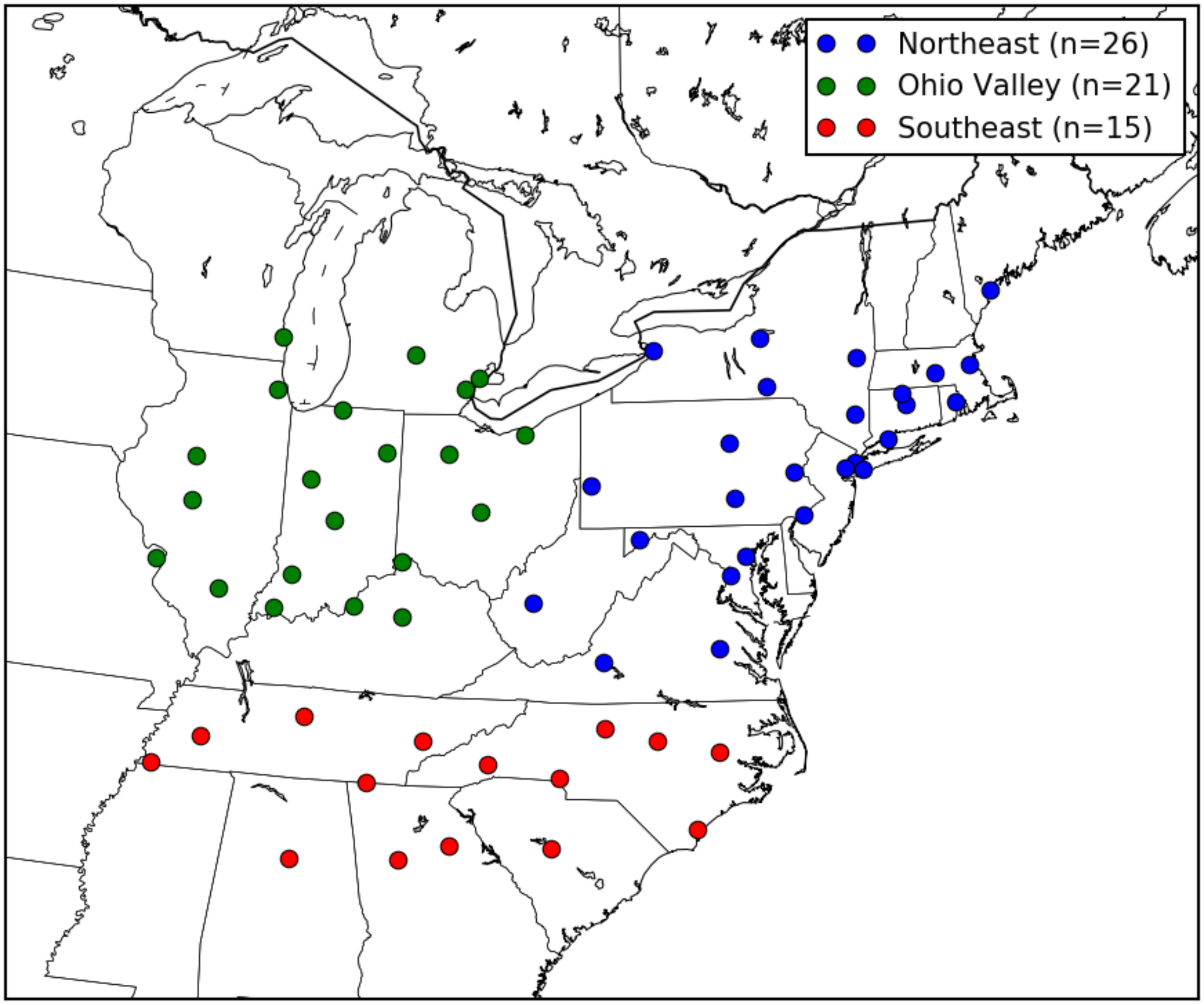

Figure 1. Spatial distribution of airport stations, using data obtained from the National Climatic Data Center (NCDC), used to generate a composite of heat wave frequency graphs for the three regions: Northeast (blue), Ohio Valley (green), and Southeast (red).

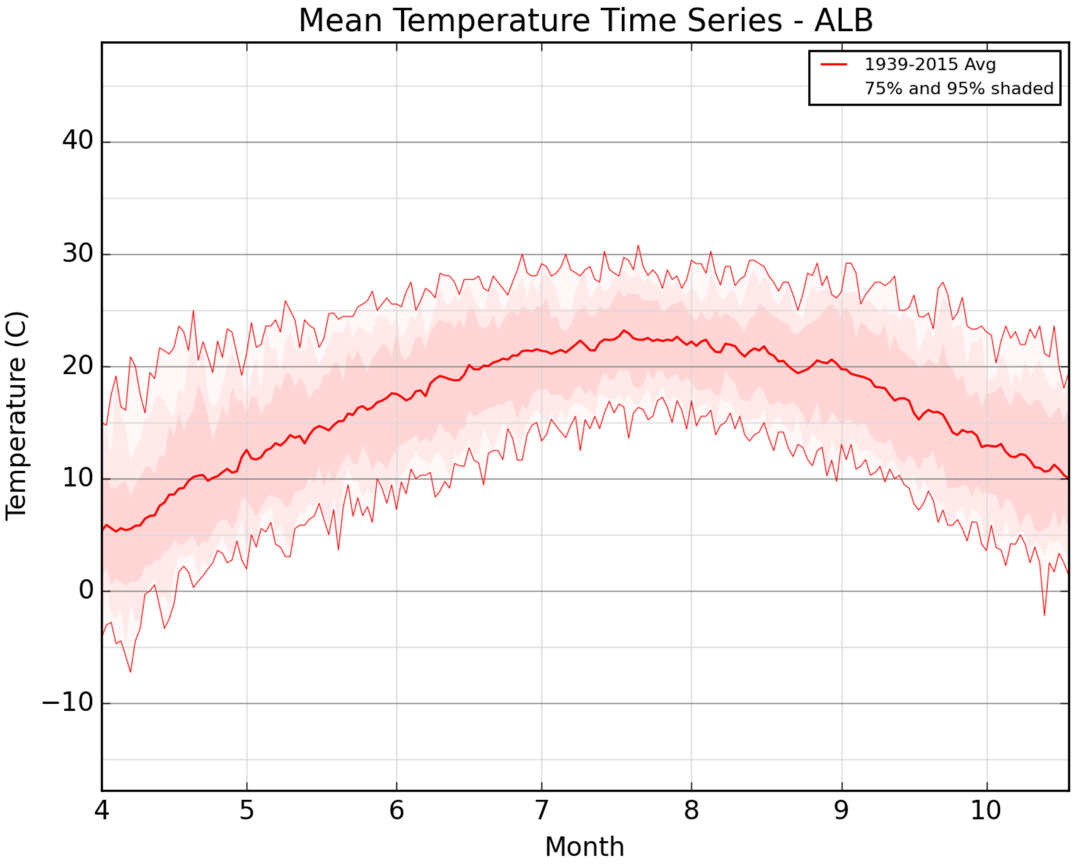

Figure 2. Mean temperature time series at Albany International Airport, New York. The thick red line represents the unsmoothed daily mean temperature computed over a 76-year period, the thin red lines represent the temperature extrema for Albany within the database, and the red shadings represent the 75% and 95% confidence intervals.

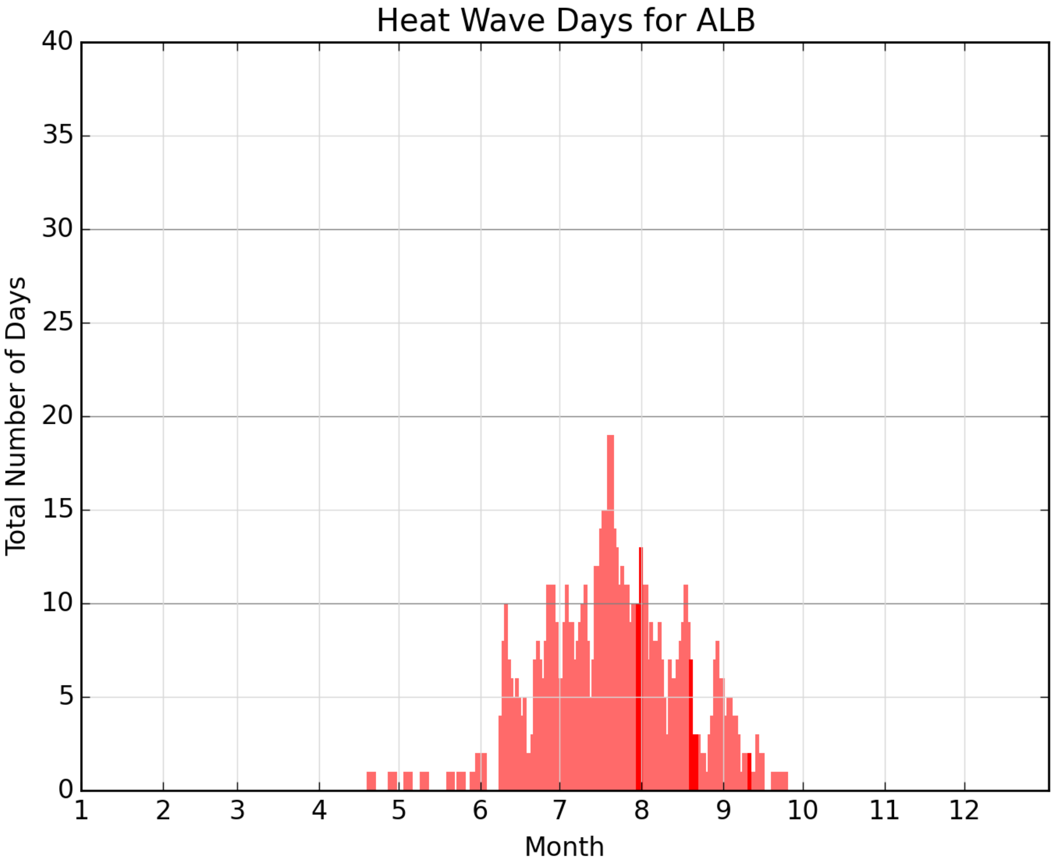

Figure 3. Heat wave day count for Albany, New York, using archived daily conditions from the National Climatic Data Center (NCDC) from 1939 to 2015. Darker red days highlight heat waves during 2015.

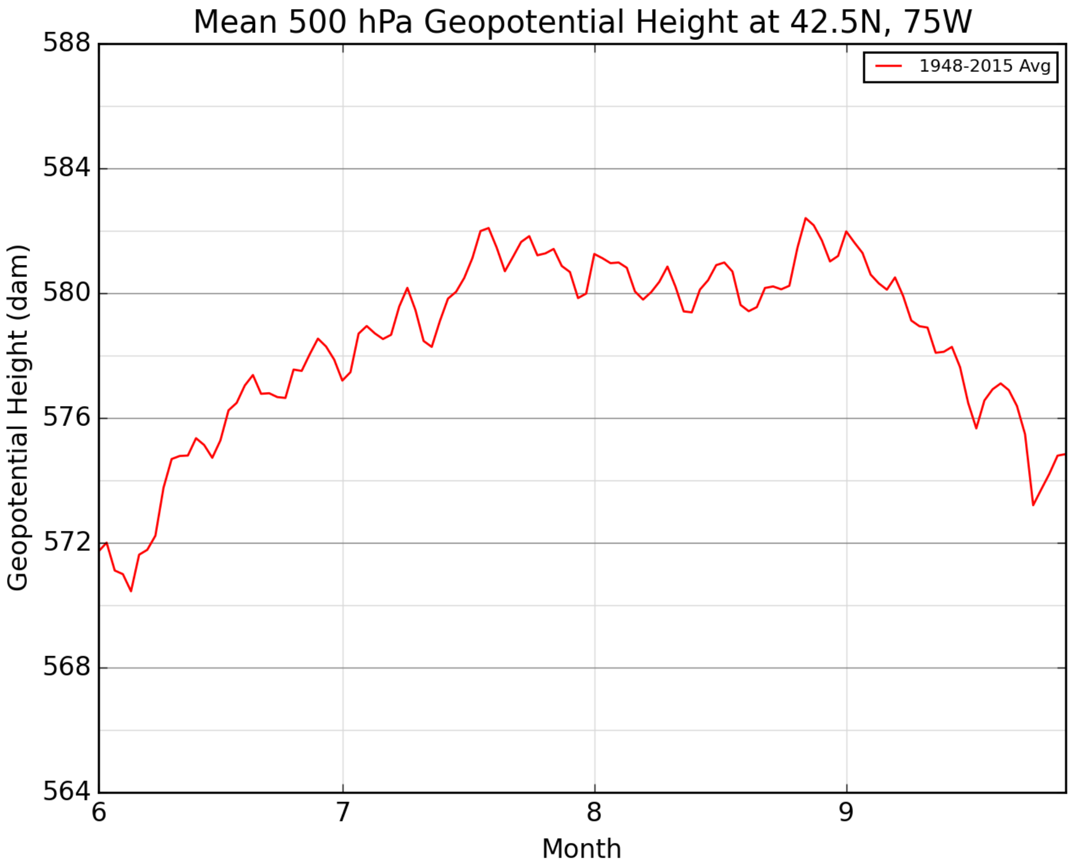

Figure 4. Mean 500 hPa geopotential height time series over Central New York, computed over a 67-year period from 1948 to 2015 using the NCEP-NCAR reanalysis dataset. Data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/.

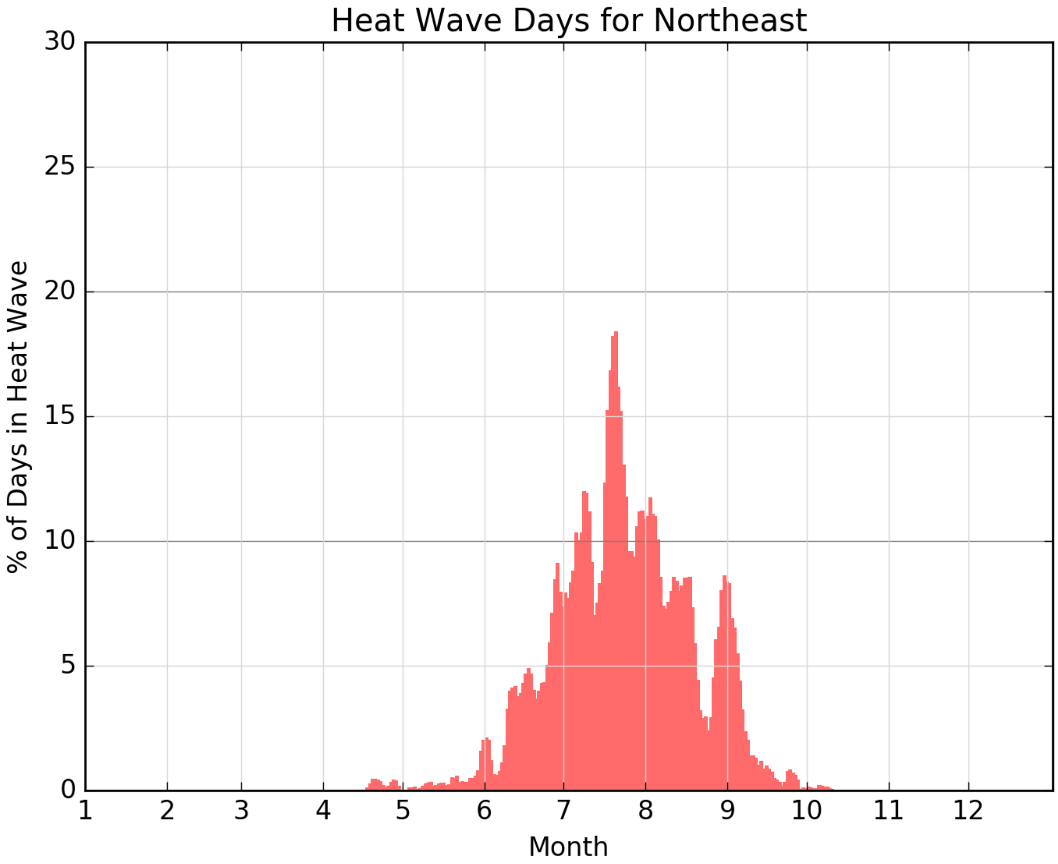

Figure 5a. Heat wave day count over the Northeast region, using archived daily temperatures from the National Climatic Data Center (NCDC).

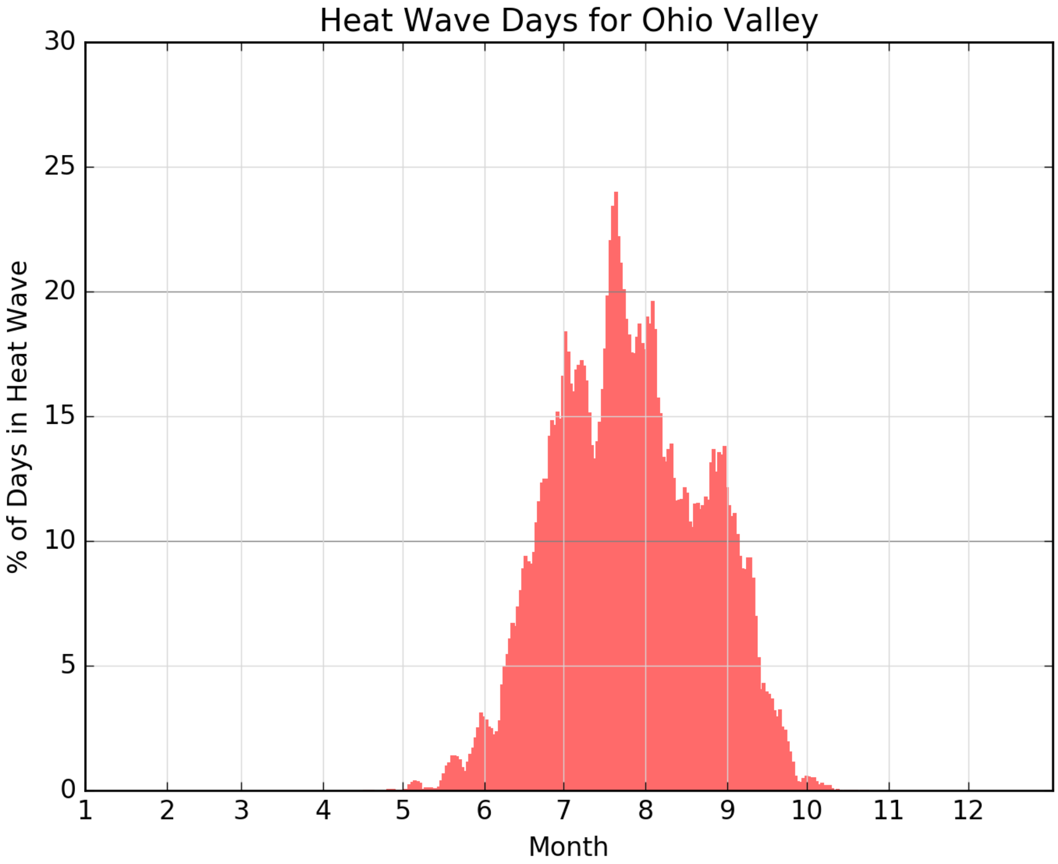

Figure 5b. Heat wave day count over the Ohio Valley region, using archived daily temperatures from the National Climatic Data Center (NCDC).

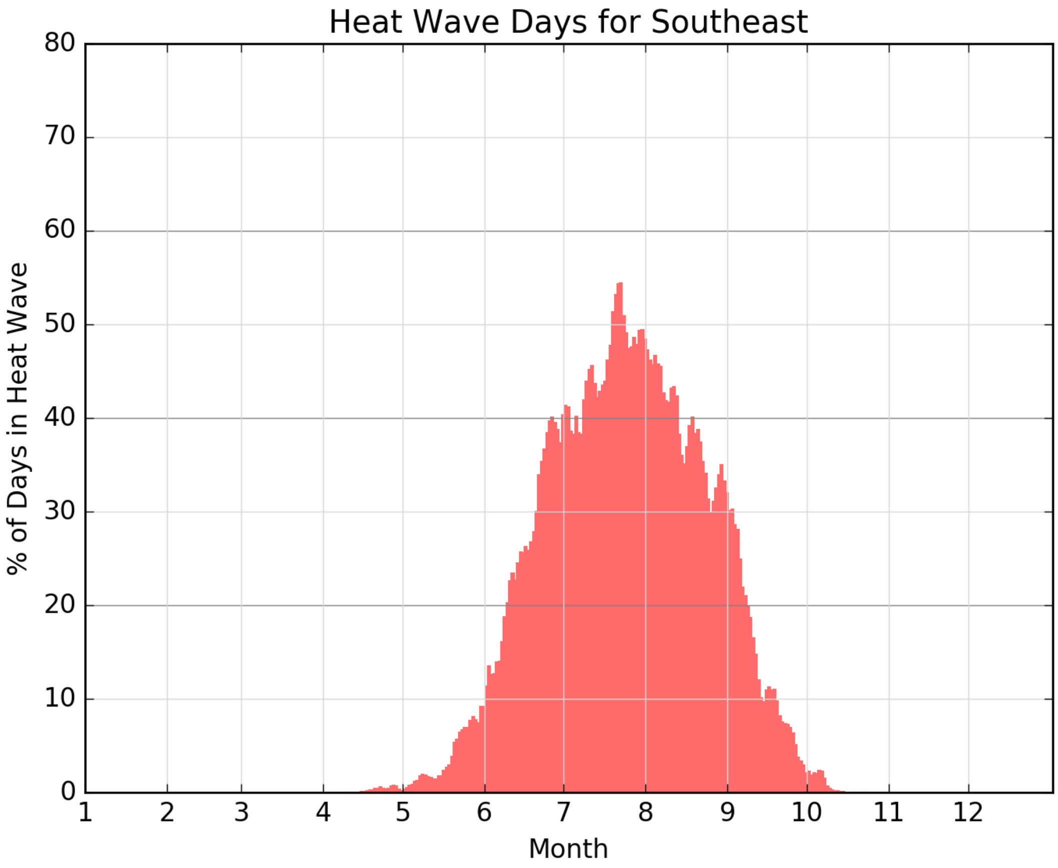

Figure 5c. Heat wave day count over the Southeast region, using archived daily temperatures from the National Climatic Data Center (NCDC). Note the different y-axis compared to figures 7a and 7b.

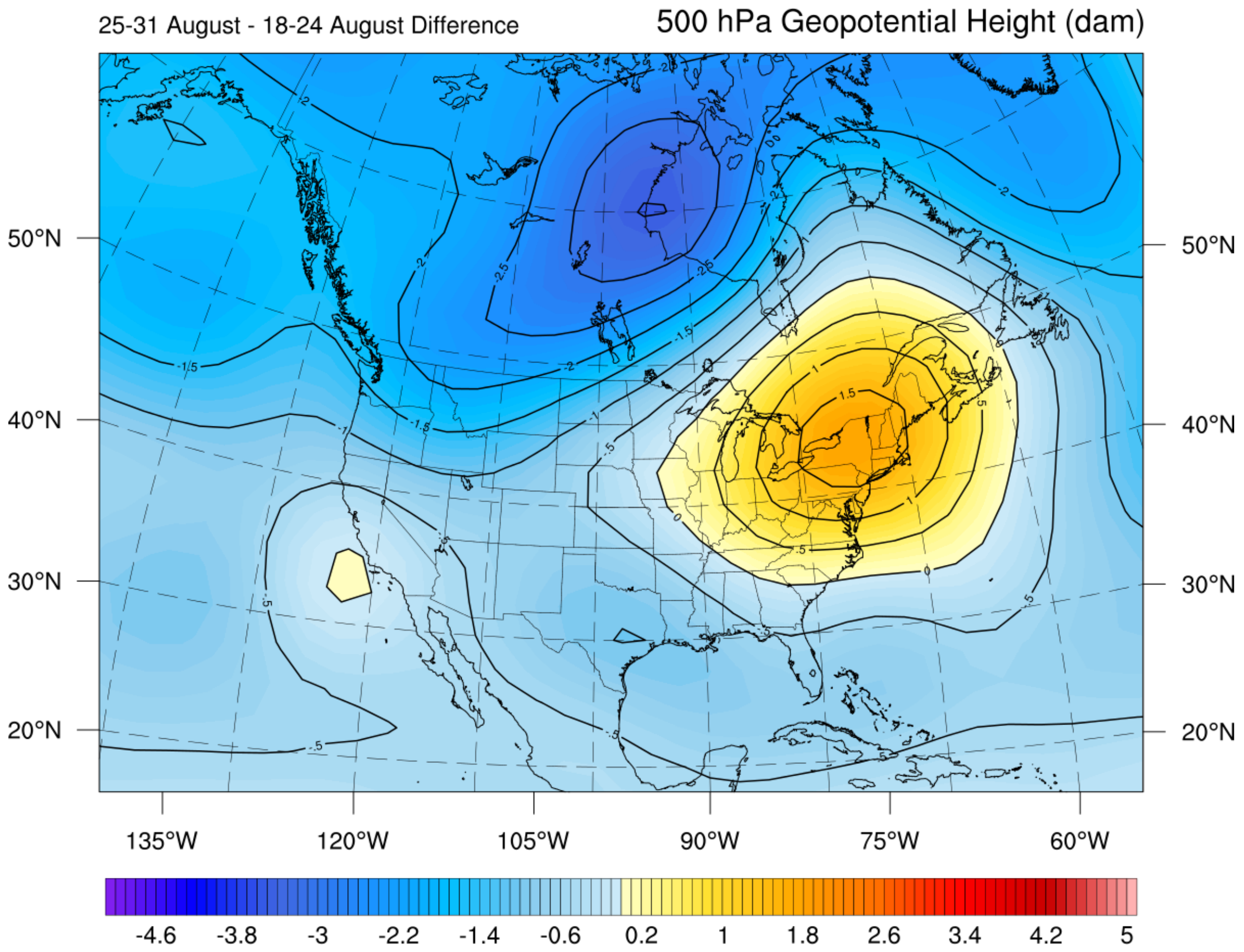

Figure 6. Unsmoothed mean daily 500 hPa geopotential heights between 18-24 August subtracted from the 25-31 August mean geopotential heights. Means were computed using the NCEP-NCAR 2.5 degree reanalysis obtained from ESRL over a 67-year period. Data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/.

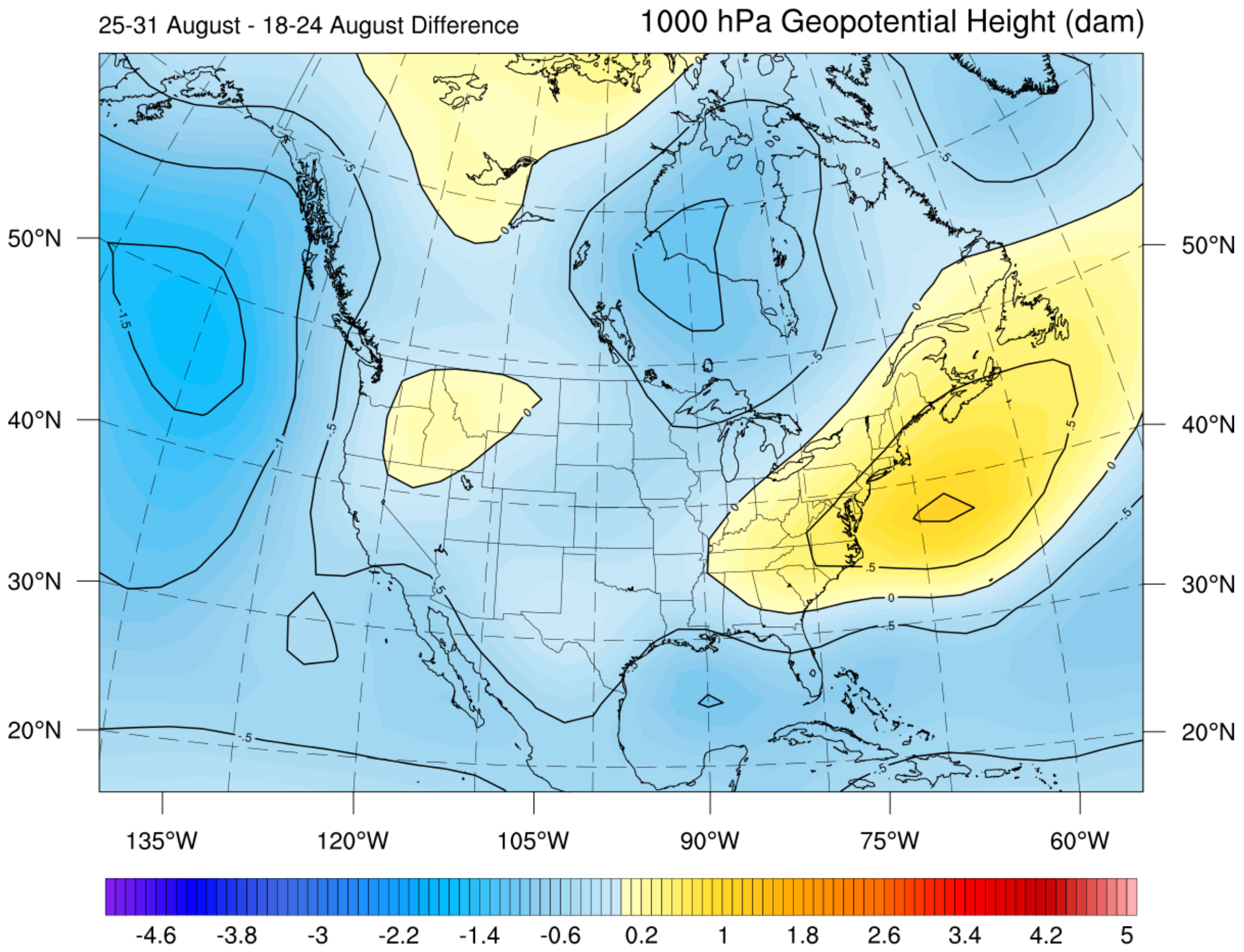

Figure 7. Unsmoothed mean daily 1000 hPa geopotential heights between 18-24 August subtracted from the 25-31 August mean geopotential heights. Means were computed using the NCEP-NCAR 2.5 degree reanalysis obtained from ESRL over a 67-year period. Data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/.

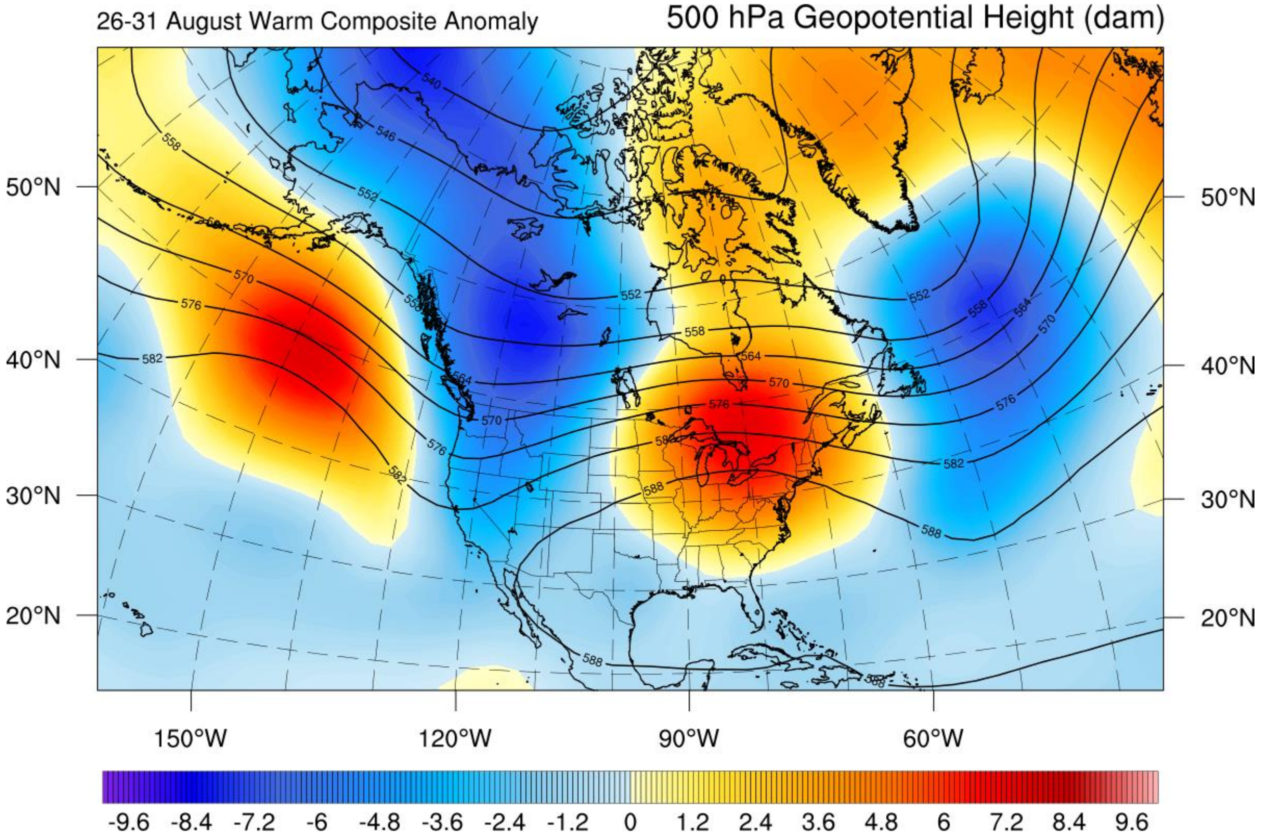

Figure 8a. 500 hPa geopotential height mean (contoured) and anomaly (shaded) for the Northeast US late August warm composite (1948, 1953, 1959, 1973, 1993).

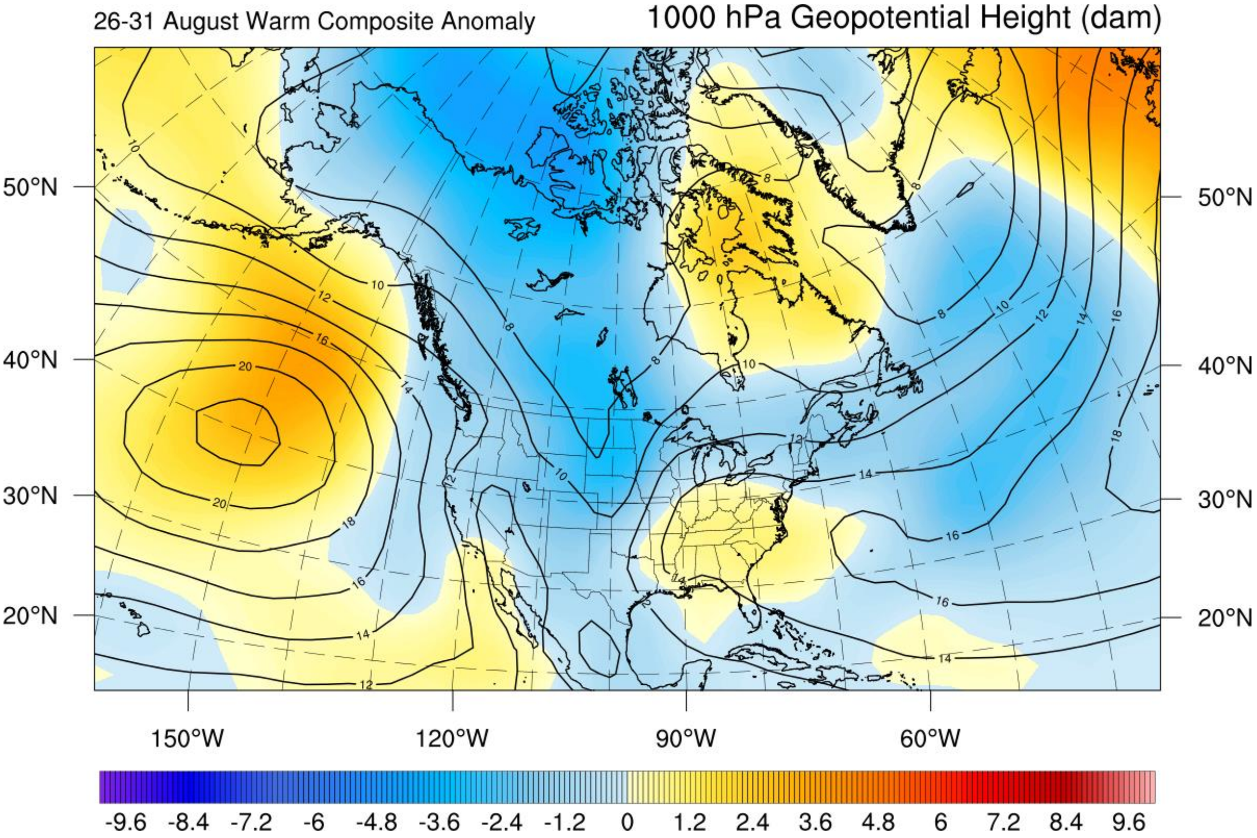

Figure 8b. 1000 hPa geopotential height mean (contoured) and anomaly (shaded) for the Northeast US late August warm composite (1948, 1953, 1959, 1973, 1993).

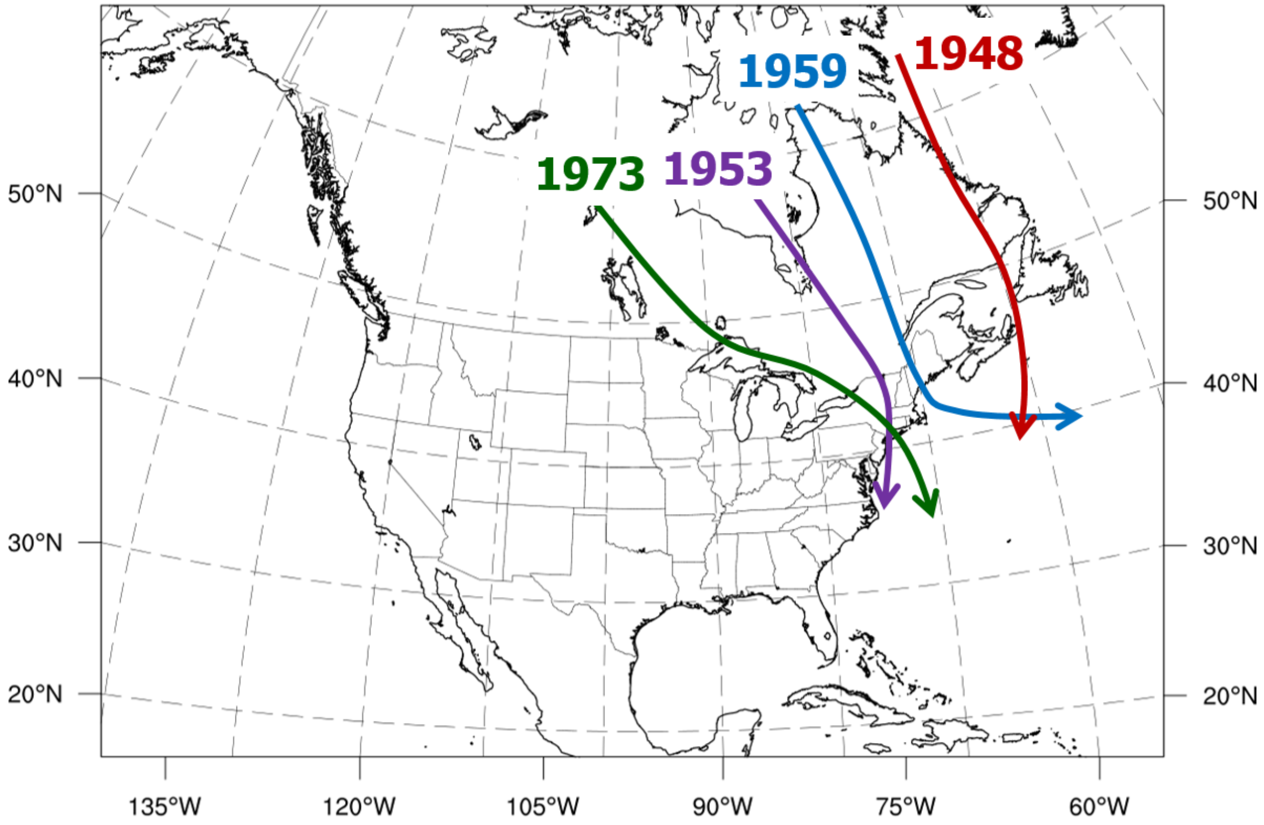

Figure 9. Subjectively analyzed approximate progression of the surface anticyclone in the several days preceding the heat waves for select years in the Northeast US warm composite.