4.7 ANALYSIS OF HEAT IMPACTS AS RELATED TO NATIONAL WEATHER SERVICE EXTREME HEAT ADVISORY AND WARNING CRITERIA IN EASTERN IOWA AND NORTHWEST ILLINOIS

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1. INTRODUCTION

Extreme heat is a significant cause of weather-related illnesses and deaths in the United States. According to the Center for Disease Control and Prevention (CDC), extreme heat causes more deaths in the United States each year than hurricanes, lightning, tornadoes, floods, and earthquakes combined. In addition, the annual number of heat-related deaths nationally is rising (CDC 2013). From 1999 to 2010, a total of 7,415 people died of heat-related issues, an average of about 618 deaths per year. A recent study of ten Midwestern cities by Perera et al. (2012) found that not only are dangerously hot, summer days becoming more common in recent decades, but these events are becoming more hot and humid at night and are lasting longer. While the trend noted by Perera et al. (2012) shows increasing frequency of heat events, for Iowa and Illinois heat-related deaths still do vary greatly from year to year (CDC 2013), depending primarily on the frequency and severity of these extreme heat events.

Regarding vulnerable populations, national statistics indicate that heat illnesses requiring a hospital stay are more common amongst the elderly and very young, males more often than females, and lower income more frequently than higher income populations (Merrill et al. 2008). Ebi and Meehl (2007) similarly reported increased susceptibility for heat illnesses to those populations. But they also noted as at-risk people with a low-level of fitness and/or who are overweight, users of certain drugs which impair the body's cooling ability, people not acclimated to the heat, urban populations, people living alone, and anyone who is dehydrated or excessively exerts themselves outdoor during extreme heat events.

A national study of 2005 hospital data by Merrill et al. (2008) tallied 6,200 hospitalizations due to heat illnesses. Merrill documented that the impact of extreme heat events extends well beyond heat fatalities, also impacting hospital workload with non-fatal illnesses by a factor of roughly thirty-five illnesses for each death. Kovats et al. (2004) assessing the relationship of hot weather as measured by maximum daily temperature to hospital admissions found an increase in hospital visits due to heat for the young and elderly in a London, United Kingdom study, though overall there was no change in admissions. A more recent study from North Carolina (Lippman et al. 2013) compared hospital emergency department admissions with daily mean temperatures and reported the rate of admissions rose rapidly with increasing temperature, peaking in the summer.

Another way to evaluate the impacts of extreme heat events is through Emergency Medical Service (EMS) calls. Bassil et al. (2007 and 2011) studied the relationship between ambulance calls related to heat illnesses and the daily maximum temperature in Toronto, Canada, and found a likely relationship between the two variables. Prior work by Dolney and Sheridan (2006) noted apparent temperature had the strongest relationship with ambulance calls for heat-related illness in Toronto. Golden et al. (2008) using data from Phoenix, Arizona compared heat-related EMS calls to both daily maximum temperature and the daily maximum HI. They found the highest statistical relationship with EMS calls occurred with the HI. Hartz et al. (2013) compared heat-related EMS calls in Phoenix and Chicago and found that both correlated best with the daily maximum apparent temperature. Chicago's EMS calls were more episodic in nature and associated with particular extreme heat events, in contrast to the distribution of calls in Phoenix which were more consistent over time. This was attributed to the nature of the climate in the two cities, i.e., Phoenix being more consistently hot while heat episodes in Chicago's cooler on average climate were more sporadic. Thus the HI appears to be a better impact metric than temperature alone.

Sheridan and Kalkstein (2004) and Tew et al. (2004) noted that in order to improve the heat watch-warning process, it is important to study heat-related impacts and weather at the local level due to the regional sensitivity of the local population. Tew et al. (2004) stated "To improve its excessive heat warnings, National Weather Service (NWS) needs locally tailored guidance that will address the problems of regional sensitivity of the local population and identification of location-specific conditions leading to heat-related mortality." Hartz et al. (2013) further illustrated this

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point by comparing Phoenix and Chicago's EMS call distribution. Indeed current NWS policy supports regional and local adaptation of heat index (HI) values as the basis for watch, warning and advisory thresholds (NWS 2011).

This study was initiated to evaluate local, NWS HI-based watch, warning, and advisory thresholds using two heat-related data sets, hospital emergency room visits and EMS calls from Moline, Illinois (MLI) and the surrounding metropolitan area. These two data sets were chosen for study rather than mortality statistics due to the low number of direct, heat-related fatalities reported in the area of interest relative to the number of extreme heat events. Secondly, to increase understanding of the meteorological environment and climatology of extreme heat events in the NWS Quad Cities county warning area (CWA), a brief climatology and synoptic composites for 100+ °F days at MLI were developed and upper air data analyzed for these extreme heat events.

2. DATA AND METHODS

2.1 *Impact data*

Impact data from emergency management services (EMS) call logs where heat illnesses (fainting, heat cramps, heat exhaustion, and heat stroke) were reported as the chief complaint or primary impression during summers (June, July, August) in 2009-2013 in the Quad Cities area were collected and compared to the daily maximum HI based on hourly observations at MLI. This 5-year period included a total of 293 calls in the two-county metropolitan area with a population of about 317,000 (USDC Census Bureau 2010). Likewise, data on heat-related visits to hospital emergency rooms (ER) in the MLI area were gathered for May-September 2011. 2011 was an active year for extreme heat episodes and heat illnesses with 161 visits. It was also the year with the highest number of EMS calls.

2.2 *Climatological and Meteorological Data*

For comparison with the EMS and ER data, daily maximum HI values observed on the date of services provided were used in the analysis. The HI was chosen since it is the key parameter used by the NWS when deciding to issue heat related watches, warnings or advisories. The HI was also indicated as a better measure than temperature without considering humidity (Dolney and Sheridan 2006, Golden et al. 2008, Hartz et al. 2013) for assessing heat-related impacts.

The HI as used by the NWS (Rothfusz 1990) is based on work by Steadman (1979, 1984). The Steadman model is quite complex, depending on a number of different variables relating to the atmospheric environment, the human body, and human interaction with the environment. Rothfusz (1990) simplified the model to an equation using temperature and relative humidity, and this is the version used in this study:

$$\text{Heat Index (°F)} = -42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783\times10^{-3}T^2 - 5.481717\times10^{-2}R^2 + 1.22874\times10^{-3}T^2R + 8.5282\times10^{-4}TR^2 - 1.99\times10^{-6}T^2R^2 \quad (1)$$

where T = ambient dry bulb temperature (°F) and R = relative humidity (integer percentage).

An analysis of days at or above 100 °F was conducted using the threaded database for MLI (Owen et al. 2006) between 1874 and 2013 (NOAA NCDC 2013). Issues relating to the movement of the official observation site during the period of record were deemed not to be a significant issue for the purposes of this study, particularly since trends in the dataset were not a focus of the analysis. MLI is located in northwest Illinois next to the Mississippi River, and was selected because it is in the center of the CWA, is climatologically representative of the area, has a quality and lengthy period of record, and is also the largest population center in the CWA where EMS data were available. Upper-air data for 38 of the 100+ °F days between 1945 and 2013 (Peoria, Illinois, through 1994; Davenport, Iowa, thereafter) were assessed for several lower tropospheric parameters associated with extreme heat episodes, including 1200 UTC 850-hPa temperature and dew point, 1200 UTC 925-hPa temperature, and surface dew point at maximum temperature. Data from 1200 UTC were selected because this is typically the latest upper-air sounding available to forecasters to aid in forecasting that day's maximum HI.

The daily mean composites tool using NCEP/NCAR Reanalysis data (Kalnay et al. 1996; NOAA ESRL 2013) was utilized to develop composites of standard synoptic-scale fields, relative to the 1981-2010 mean, using dates of occurrence for maximum temperatures of 100+ °F between 1948 and 2013 (see Appendix A for dates). While compositing may smooth out features that are important to a specific heat episode, the technique allows identification of features common to most heat events; and the presence of these features in a forecast should raise forecaster awareness of the potential for extreme heat. Composites created using all available dates in the data set were compared to composites using only a single date representing each heat episode. Only slight differences in the magnitude of a few variables were observed between the two sets of composites. The latter approach may be preferred when compositing synoptic events where multiple data points per synoptic episode occur frequently in the data set, which was not the case in this study.

3. ANALYSIS AND DISCUSSION

3.1 *Impact Data*

Figure 1 depicts a plot of EMS calls in the Quad Cities vs. daily maximum HI at MLI for June, July and August of 2009-2013. While it is not uncommon to see one or two EMS calls for HIs below 100 °F, there is a cluster of three or more calls per day observed at HI values above 100 °F. With this value serving as the NWS threshold for issuance of a heat advisory in this area, the data suggest this threshold is in agreement with an increased frequency of heat-related EMS calls. Two of the three busiest days for EMS calls occurred on the two days with the highest HIs in the data set and well exceeded the threshold used for issuance of excessive heat warnings.

Analysis of outliers in this data set is informative. The seven calls received with a maximum HI of 89 occurred the day of the 2009 Quad City Airshow. It is possible most of these calls were related to the crowd of 10,000 people attending the show during a sunny afternoon at the Davenport, Iowa, Airport, where little shade is available and EMS had set up a treatment center. Most of the calls did not require transport to the hospital. The 21 calls with a HI of 96 occurred on a day when the Register's Annual Great Bike Ride Across Iowa (RAGBRAI) with 15,000 bicyclists and the Bix 7 Road Race (seven-mile run) with 21,000 runners converged on downtown Davenport, Iowa. The point gleaned from analysis of these outliers is that special events with large crowds (especially where physical exertion and/or alcohol are involved) are additional factors that impact EMS call workload. During such events, NWS offices may consider relaxing HI watch, warning or advisory issuance thresholds slightly to better align with potential impacts.

Figure 2 depicts the number of ER visits in the Quad Cities between May and September 2011 compared to the daily maximum HI from MLI. Again, one or two visits per day are not uncommon at lower HI values. But when HI values reach 95 °F, which is the 95th percentile for MLI based on the study by Rieck (2008), the number of visits begins to increase above 1-2 per day with 4-5 or more visits per day becoming more common. With one exception, the four highest number of visits per day occurred when the HI equaled or exceeded warning criteria of 105 °F.

As with the EMS data, analysis of the outliers provides is enlightening. The one exception is a day with fifteen visits and a HI of 96 °F. This is the same day of the RAGBRAI and Bix 7 events noted as an outlier in the EMS call analysis. Other outliers were related to an early season (May) event and another two days which followed an extreme heat day. Early season events can result in a higher degree of impacts than the HI (or other measure of heat stress) may suggest since the population will not have had time to acclimate to warmer conditions, and most heat-susceptible persons will not survive the initial event of the new warm season (Sheridan and Kalkstein (2004) and others cited therein).

Analysis of impact data did not consider possible effects from heat accumulated over more than one day, nor did it consider seasonal acclimation to heat. EMS data indicate current thresholds for issuance of heat advisories (HI = 100-104 °F) or extreme heat warnings (HI =/> 105 °F) in the Quad Cities CWA are associated with an increase in workload from 1-2 calls per day to 3 or more calls per day. A similar analysis of ER hospital visits also suggests the current criteria are reasonable or perhaps a little high. An argument can be made that the HI 95th percentile value of 95 °F from Rieck (2008) may too be an appropriate threshold for the Quad Cities which is supported by the ER data. Typically the NWS issues Special Weather Statements to raise public awareness for sub-advisory events at this threshold. Since numerous studies note that heat impacts are a function of the characteristics of local climate, local population, and even local environment (urban vs. rural; size of urban area), it is clear that thresholds appropriate for the Quad Cities CWA may not necessarily be appropriate elsewhere. However, the approach used in this study would indeed be appropriate elsewhere.

3.2 *100+ °F Days*

For the period of record, 1874-2013, one or more 100+ °F days occurred in 34 of the 139 years of record with a total of 129 days. Thus, 100+ °F are somewhat uncommon at MLI, occurring only in about one summer in four. The top four years had 10 or more days at or above 100 °F, with the record of 21 set in 1936 followed by 15 in 1934. Not surprisingly, all of these years were associated with severe to extreme summer droughts based on the Palmer Drought Severity Index (Palmer 1965; NOAA NCDC 2013).

Typically if one 100+ °F day is observed in a summer, odds favor the occurrence of at least another day, as only 12 of the 34 years tallied just one 100+ °F day for the entire June-July-August timeframe.

The average value, standard deviation, and range of lower tropospheric parameters including the 1200 UTC 850-hPa temperature and dew point, 1200 UTC 925-hPa temperature, and the surface dew point at maximum temperature are shown in Table 1. For the temperature variables, the standard deviation was low, only around 2 °C, indicating that most heat events clustered toward the average value of 22 °C for 850-hPa temperature and 27.6 °C for the 925-hPa temperature. Interestingly, variability was higher with 850-hPa dew points with an average of 13.7 °C, standard deviation of 3.8 °C and a range of 20 °C, which was about twice that of 850 and 950-hPa temperatures. Quantitative knowledge of these parameters, when assessed via observed soundings or soundings from numerical weather forecasts, should alert forecasters in the region to the potential of a 100+ °F days.

For the CWA under study, NWS highlight issuance criteria are HIs of 100-104 °F for an advisory and 105+ °F for an excessive heat warning (NOAA NWS 2013). However, these criteria may be flexed to account for early season heat episodes, lengthy periods of extreme heat, or other sociological factors that might lead to greater societal impacts than would be inferred from the HI alone. Assuming a maximum temperature of 100 °F and utilizing the average surface dew point at the time of maximum temperature from Table 1 (rounded to 70 °F), the resulting HI would be 109 °F. In fact for dew point temperatures of 56 °F or higher (which encompasses all 100+ °F days), the HI with an air temperature at or above 100 °F would always equal or exceed the air temperature. Thus, in eastern Iowa and northwest Illinois, a forecast of 100+ °F temperatures is essentially a forecast of an extreme heat event requiring issuance of either an advisory or warning.

3.3 *Composite Analyses of 100+ °F Days*

The analysis and figures in this section are based on dates of occurrence for maximum temperatures of 100+ °F between 1948 and 2013 and compared to the 1981-2010 mean.

At 250-hPa the composite jet is located along the U.S.-Canadian border, anticyclonically curved, and stronger than the climatological mean (Fig. 3a-b). The jet is in a position that supports northward thermal advection by the low-level jet at 850-hPa over the central United States (Beebe and Bates 1955; Moore and VanKnowe 1992). In the mid-troposphere at 500-hPa, a broad ridge in the central U.S. results in above normal heights across the upper Midwest and western Great Lakes (Fig 4a-b). Subsidence implied by this feature is reflected at 850-hPa by a heat dome in the Rocky Mountains and central Great Plains, and a positive temperature anomaly across the Midwest and western Great Lakes (Fig. 5a-b). Abnormally strong southwest flow in the composite mean at 850-hPa advects warm temperatures from the western heat dome into the Midwest and western Great Lakes (Fig. 5-c-d). Similar features were also observed at 925-hPa (not shown).

Below-normal mean sea level pressure is noted in the composite in the central and northern Great Plains and upper Midwest, with the CWA well within the warm sector of the surface low pressure system (Fig. 6a). South-to-southwest surface winds are abnormally strong in this warm sector (Fig. 6b-c), and this results in a positive precipitable water anomaly north of the area in the western Great Lakes (Fig. 6d), presumably due to pooling of moisture along the warm front. One can infer that the stronger than normal surface flow could reflect deeper mixing heights, which also would support higher surface temperatures. Negative soil moisture anomalies indicate drier than normal soils in the 0-10-cm and 10-200-cm layers (Fig. 7a-b). With less soil moisture available for evapotranspiration, radiant energy from the sun would be used in sensible heating rather than latent heat exchange, thus resulting in higher air temperatures. This is the physical relationship driving the observed association between drought and a high frequency of 100+ °F days noted previously in section 3.2.

To examine the variability within the composite data set and assess whether or not individual cases vary substantially from the mean, surface and 500-hPa charts from each of the dates were visually inspected. That review found the surface mean sea-level pressure patterns and 500-hPa height fields for all cases varied little, if at all, from the composite mean in a spatial sense, though minor variations were noted quantitatively, as can be inferred from Table 1.

4. CONCLUSION

This two part study evaluated the frequency of EMS calls and ER visits relative to the daily maximum heat index and developed a simple climatology and synoptic composite of 100+ °F days at MLI which represent extreme heat events in the Quad Cities CWA. Findings indicate the current NWS criteria for issuance of heat advisories and warnings are generally in line with increased frequency of impacts as observed by EMS calls and ER visits. Outliers in the data appear to be associated with large venue events involving physical exertion and/or alcohol consumption, early season occurrences, or near to sub-threshold multi-day events. The synoptic pattern for 100+ °F days places the region in the warm sector of a surface low pressure system with abnormally dry soils, strong lower-tropospheric thermal moisture advection, mid-tropospheric ridging over the central U.S. and upper-tropospheric jet north of the area.

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6. TABLES AND FIGURES

Parameter	Average Value	Standard Deviation	Range
850 hPa temperature at 1200 UTC	22 °C	1.9 °C	18 – 28 °C
850 hPa dew point at 1200 UTC	13.7 °C	3.8 °C	2 – 22 °C
925 hPa temperature at 1200 UTC	27.6 °C	2.0 °C	22 – 30 °C
Surface dew point at maximum temperature	69.6 °F	4.4 °F	57 – 79 °F

Table 1. Average value, standard deviation and range of lower tropospheric parameters occurring on 100+ °F days at Moline, Illinois based on 1200 UTC soundings from Peoria, Illinois, (1945-1994) and Davenport, Iowa, (1995-2013).

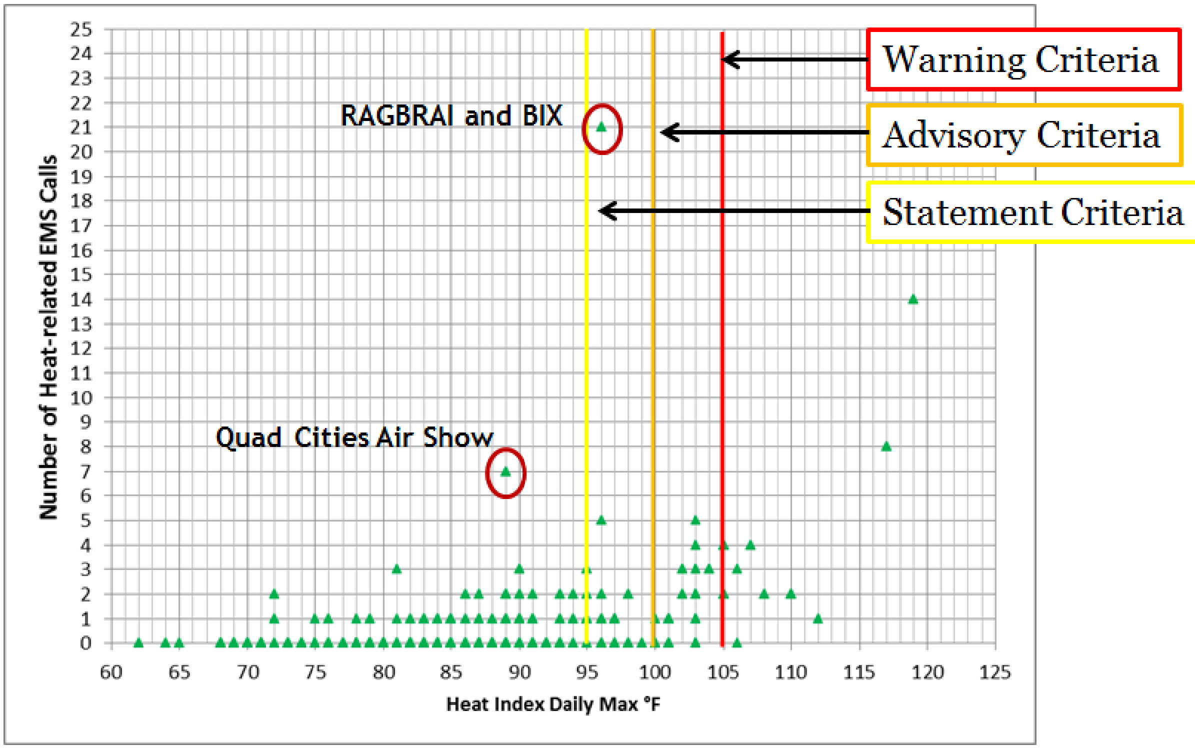

Figure 1. Number of EMS calls relating to heat illness vs. the daily maximum heat index in the Quad Cities for 2009-2013. The colored vertical lines represent local NWS heat index criteria for issuing special weather statements (yellow), heat advisories (orange), and excessive heat warnings (red).

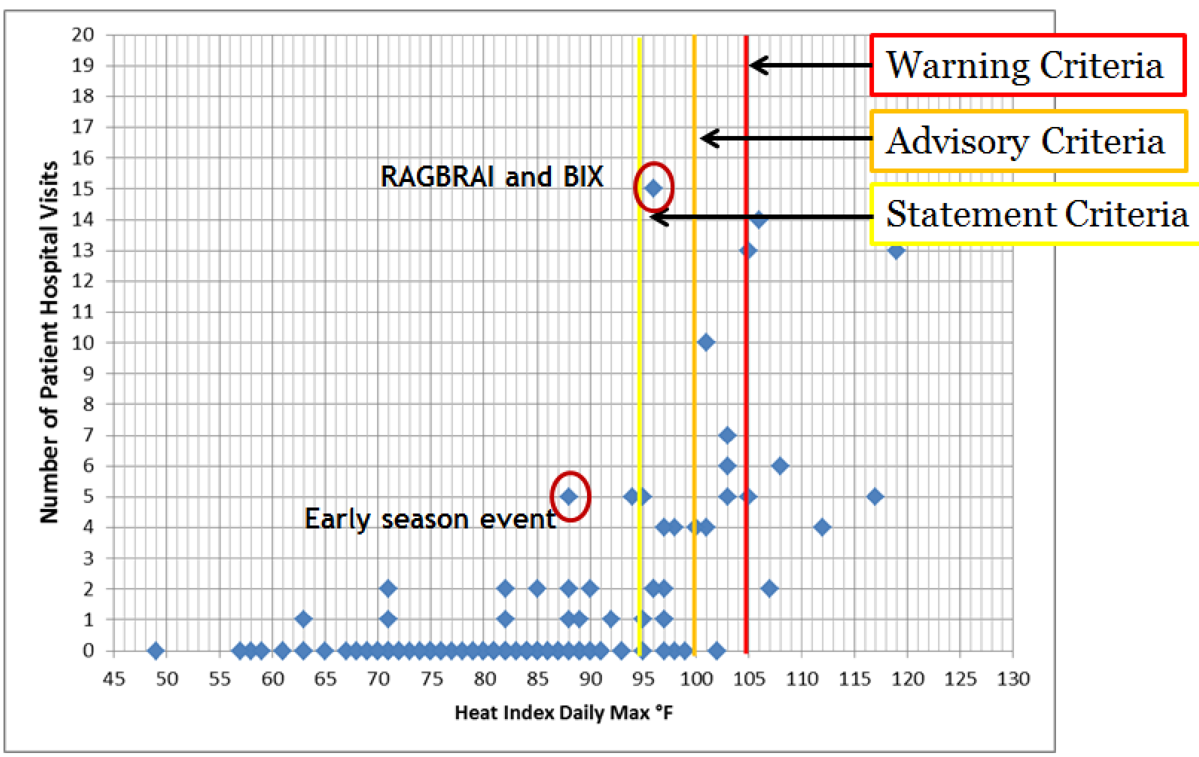

Figure 2. Number of hospital emergency room visits relating to heat illness vs. the daily maximum heat index in the Quad Cities in 2011. The colored vertical lines represent local NWS heat index criteria for issuing special weather statements (yellow), heat advisories (orange), and excessive heat warnings (red).

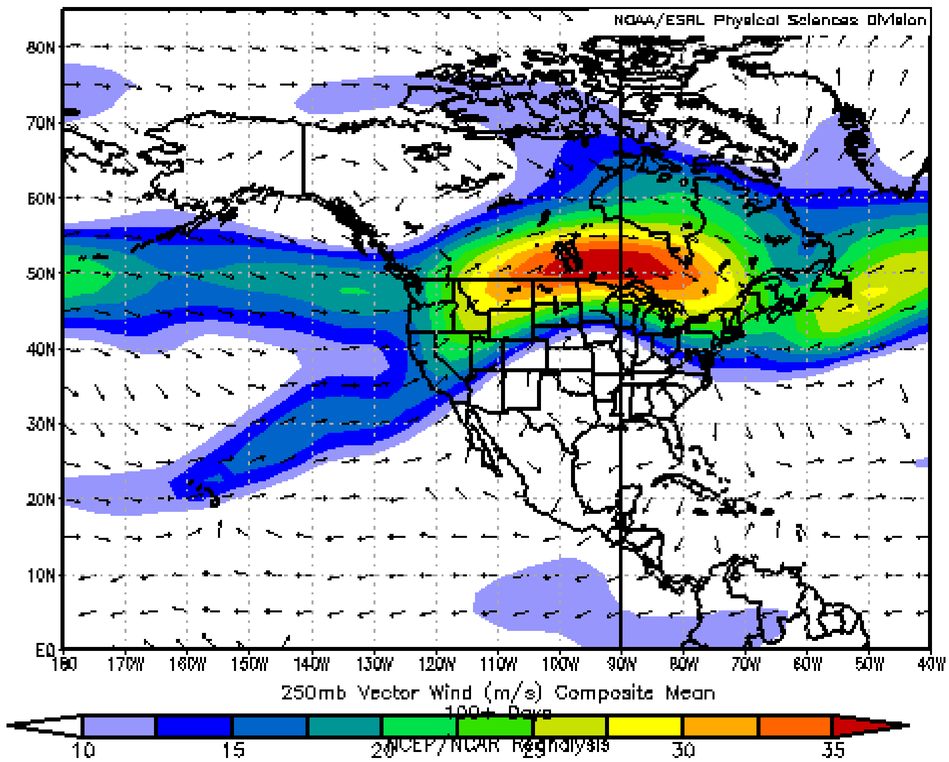

Figure 3a. Composite of 250-hPa winds (m s^{-1}) for 100+ °F days at Moline, Illinois.

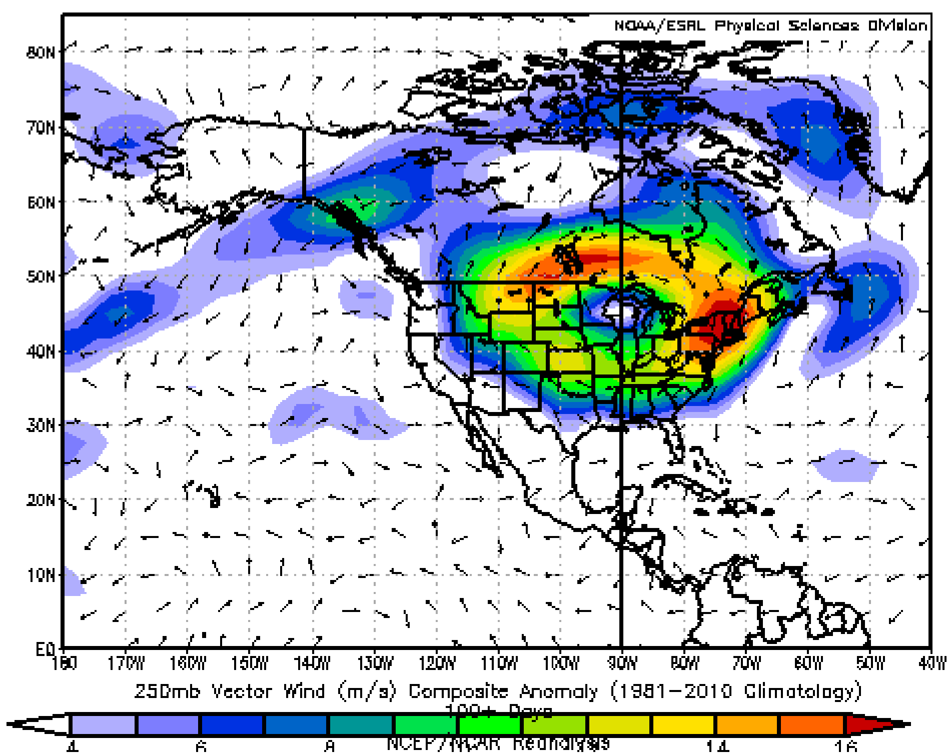

Figure 3b. Composite of 250-hPa wind anomaly (m s^{-1}) for 100+ °F days at Moline, Illinois.

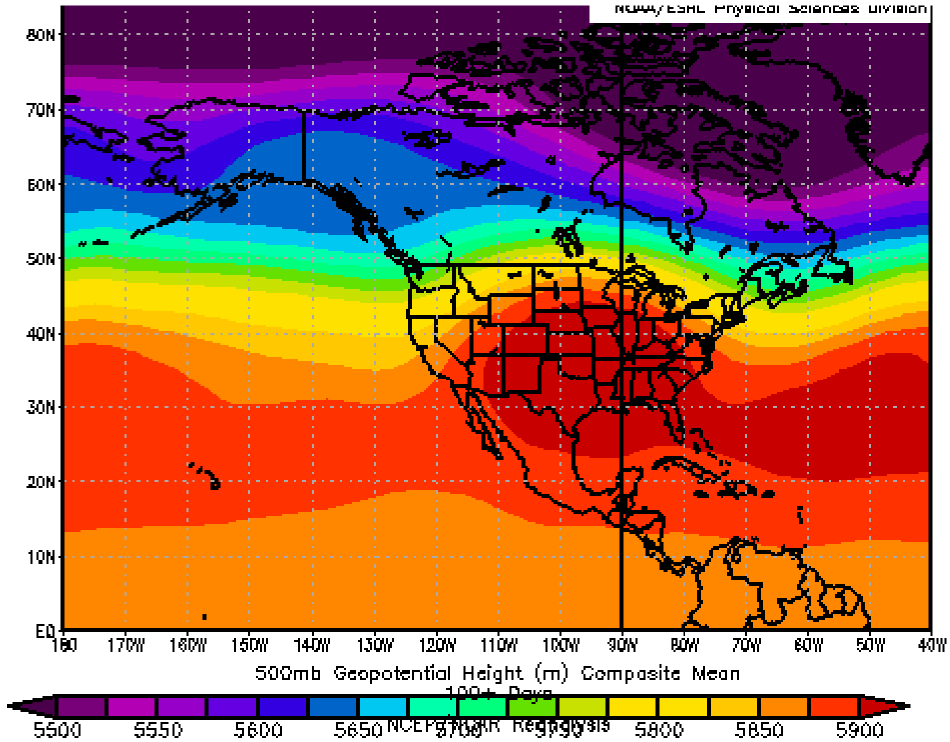

Figure 4a. Composite of 500-hPa geopotential height (m) for 100+ °F days at Moline, Illinois.

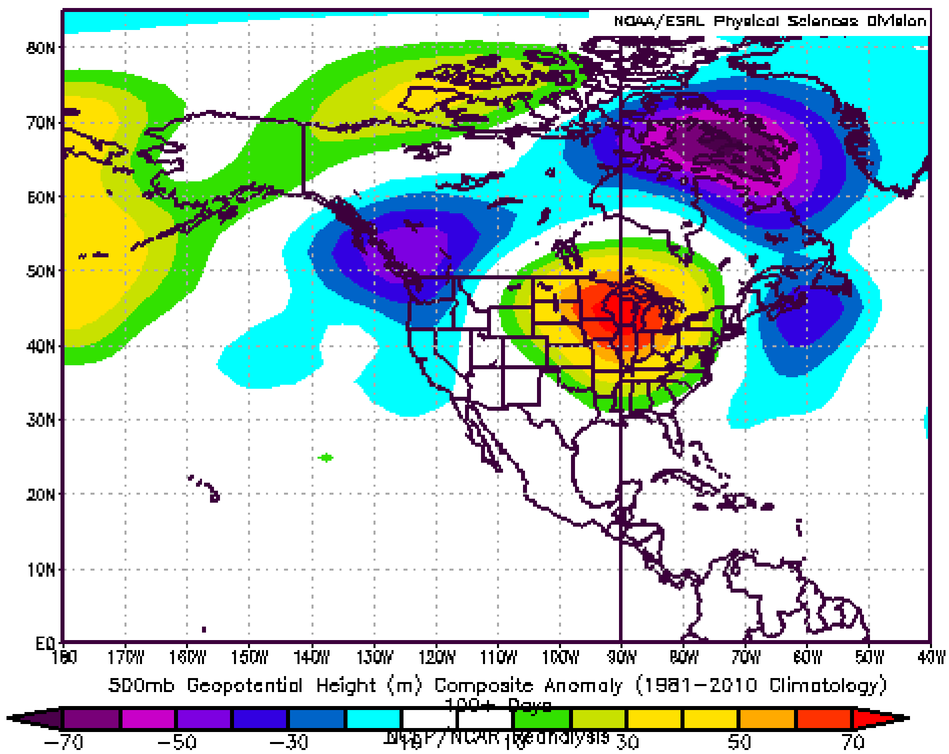

Figure 4b. Composite of 500-hPa geopotential height anomaly (m) for 100+ °F days at Moline, Illinois.

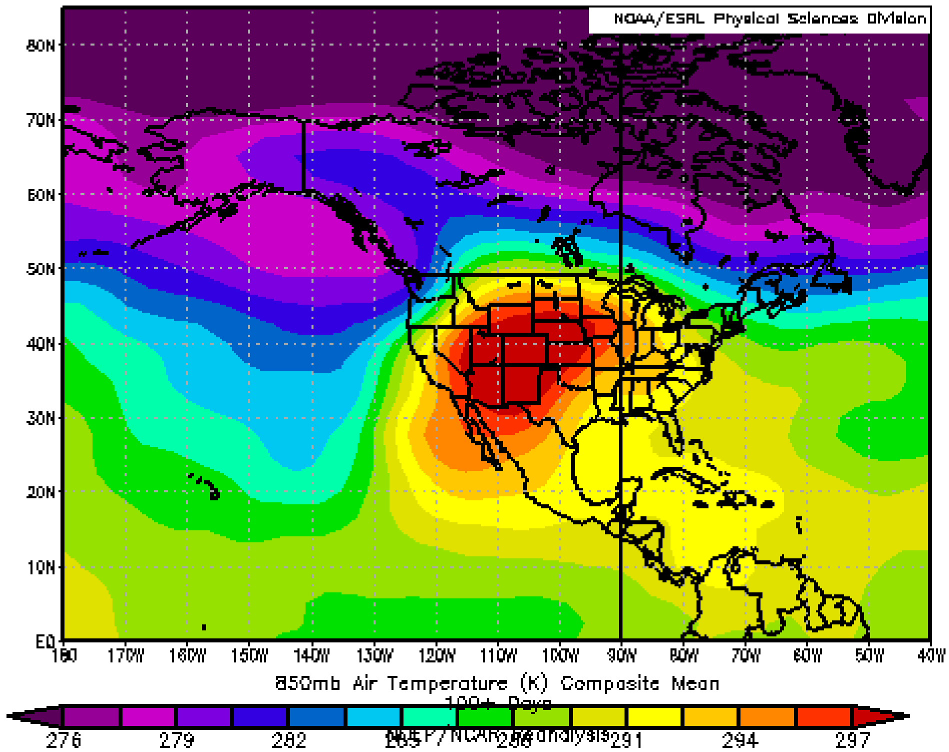

Figure 5a. Composite of 850-hPa temperature (K) for 100+ °F days at Moline, Illinois.

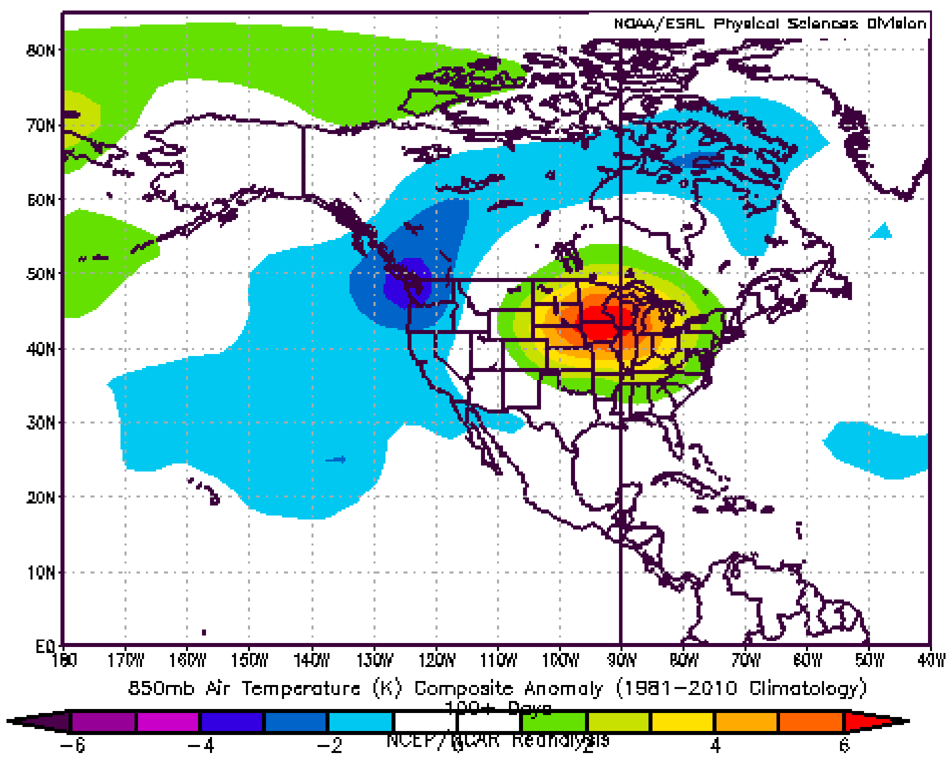

Figure 5b. Composite of 850-hPa temperature anomaly (K) for 100+ °F days at Moline, Illinois.

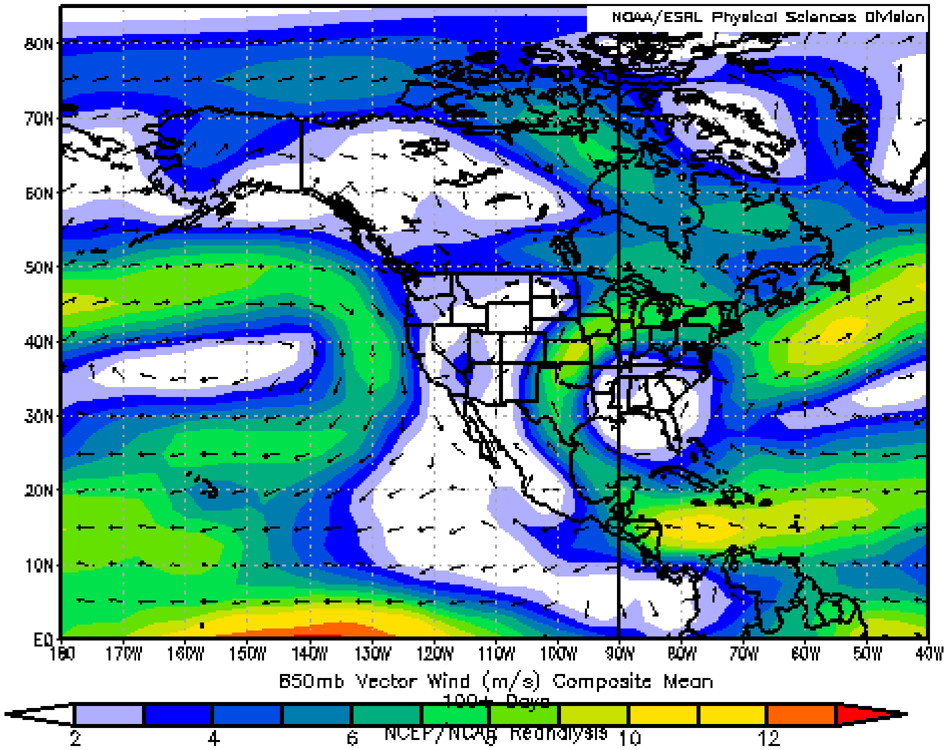

Figure 5c. Composite of 850-hPa wind (m s^{-1}) for 100+ °F days at Moline, Illinois.

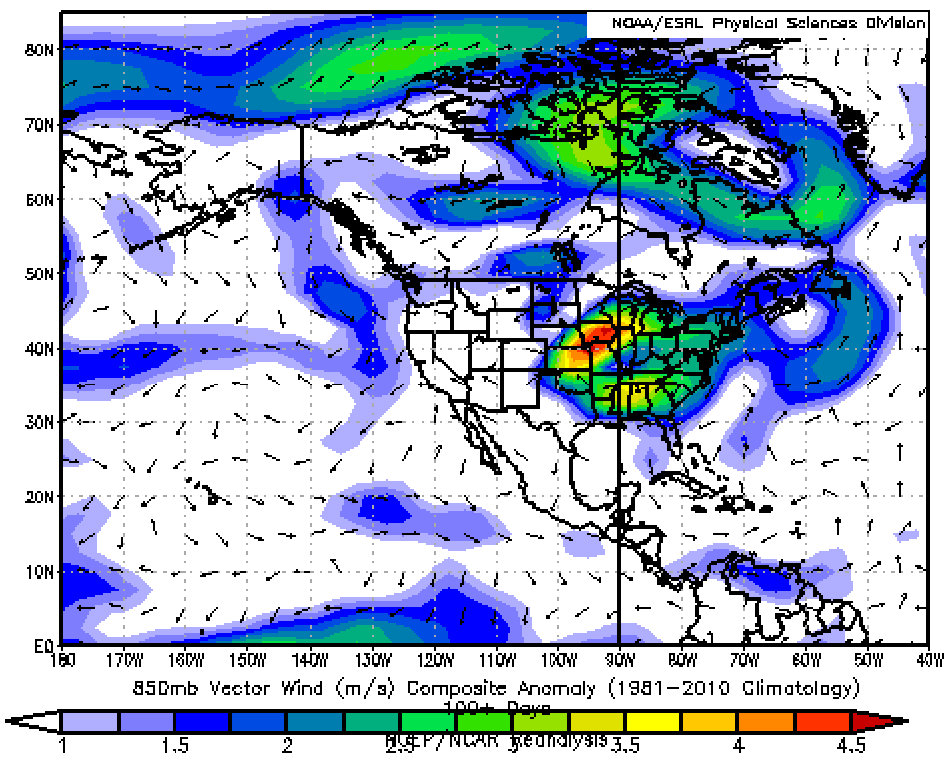

Figure 5d. Composite of 850-hPa wind anomaly (m s^{-1}) for 100+ °F days at Moline, Illinois.

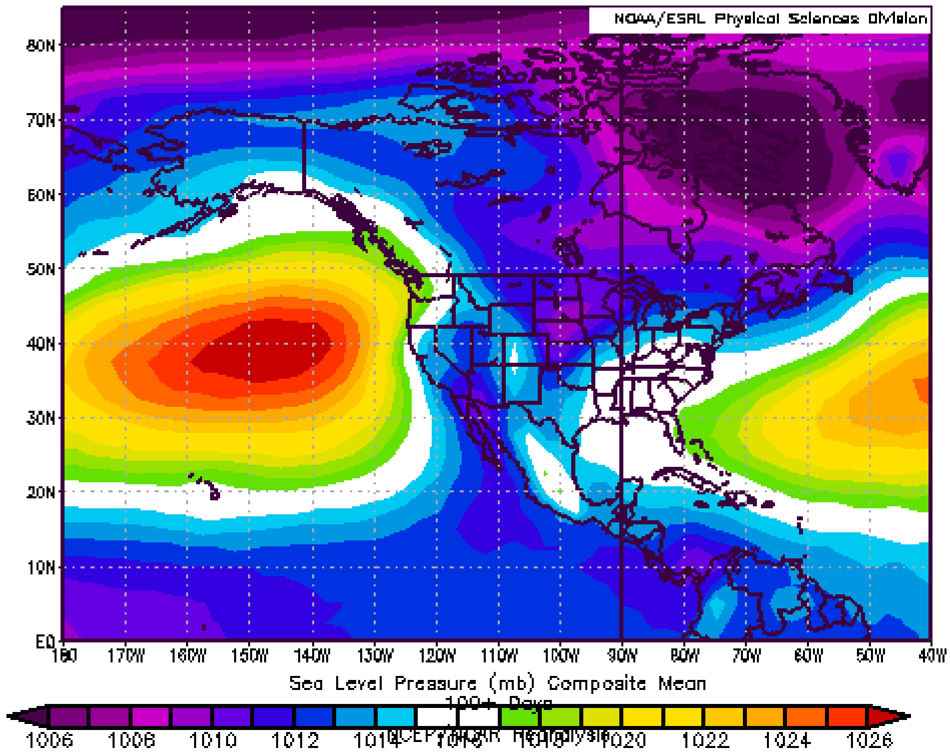

Figure 6a. Composite of mean sea-level pressure (hPa) for 100+ °F days at Moline, Illinois.

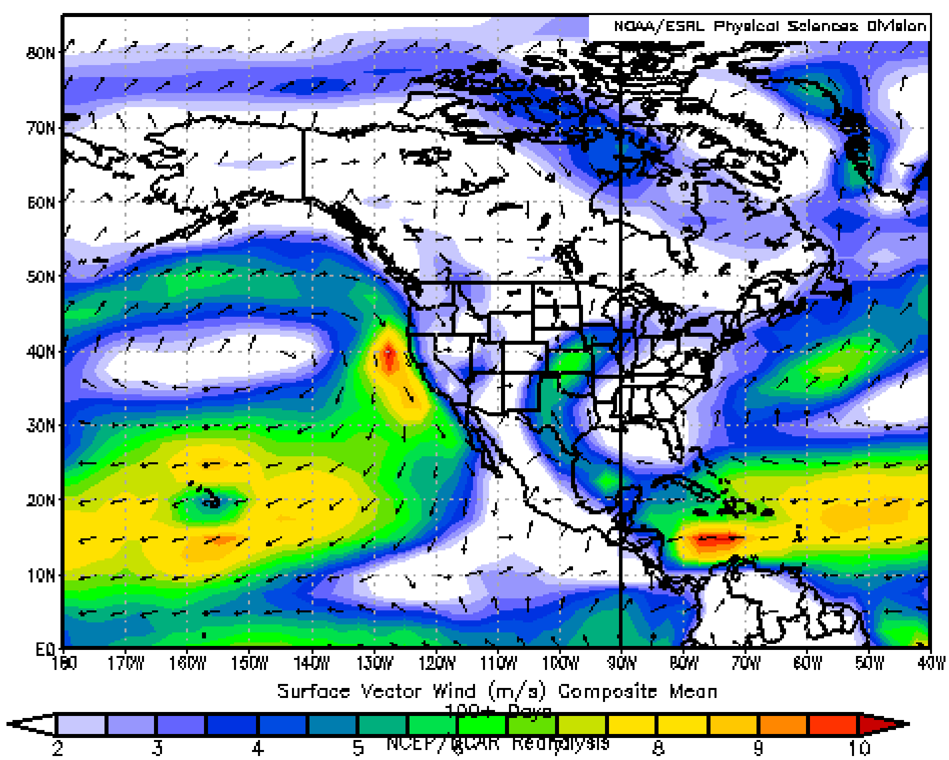

Figure 6b. Composite surface wind (m s^{-1}) for 100+ °F days at Moline, Illinois.

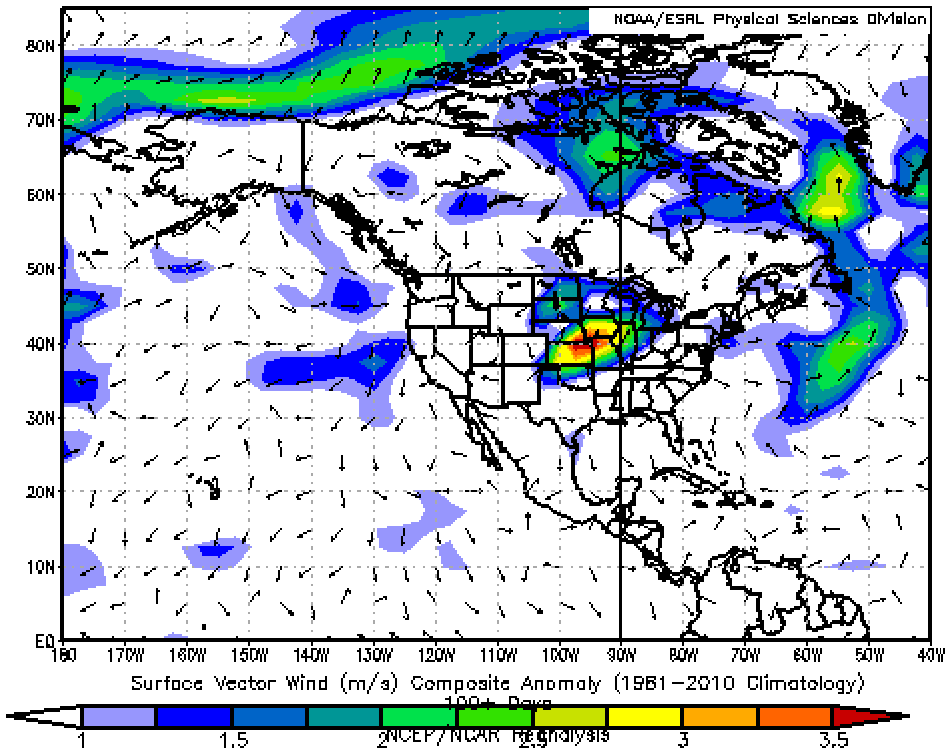

Figure 6c. Composite surface wind anomaly (m s^{-1}) for 100+ °F days at Moline, Illinois.

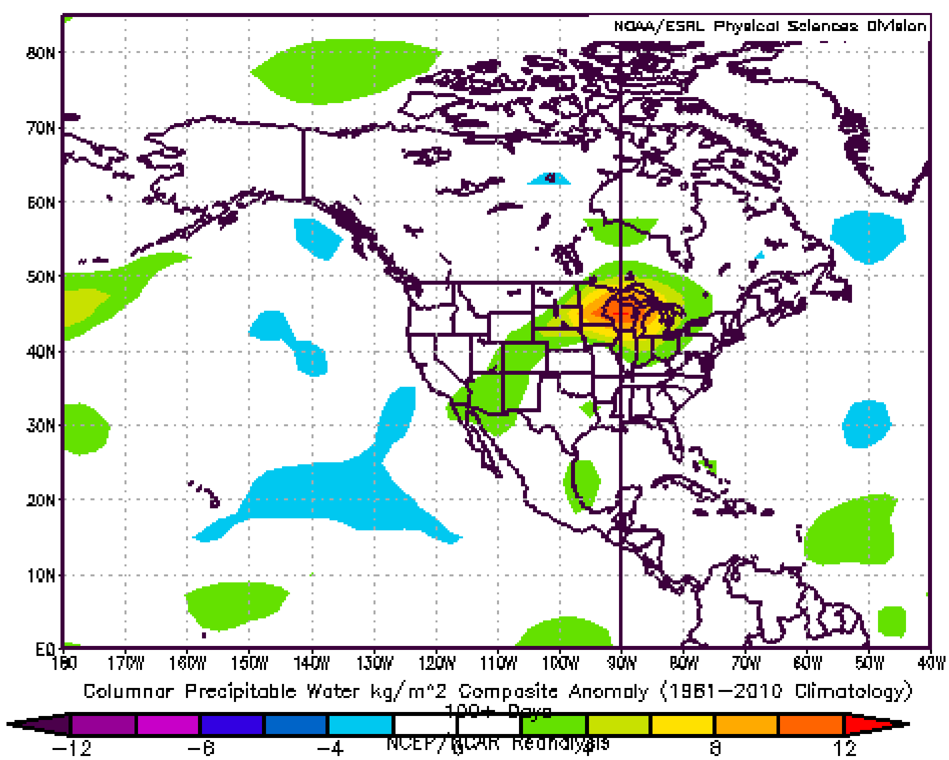

Figure 6d. Composite of precipitable water anomaly (kg m^{-2}) for 100+ °F days at Moline, Illinois.

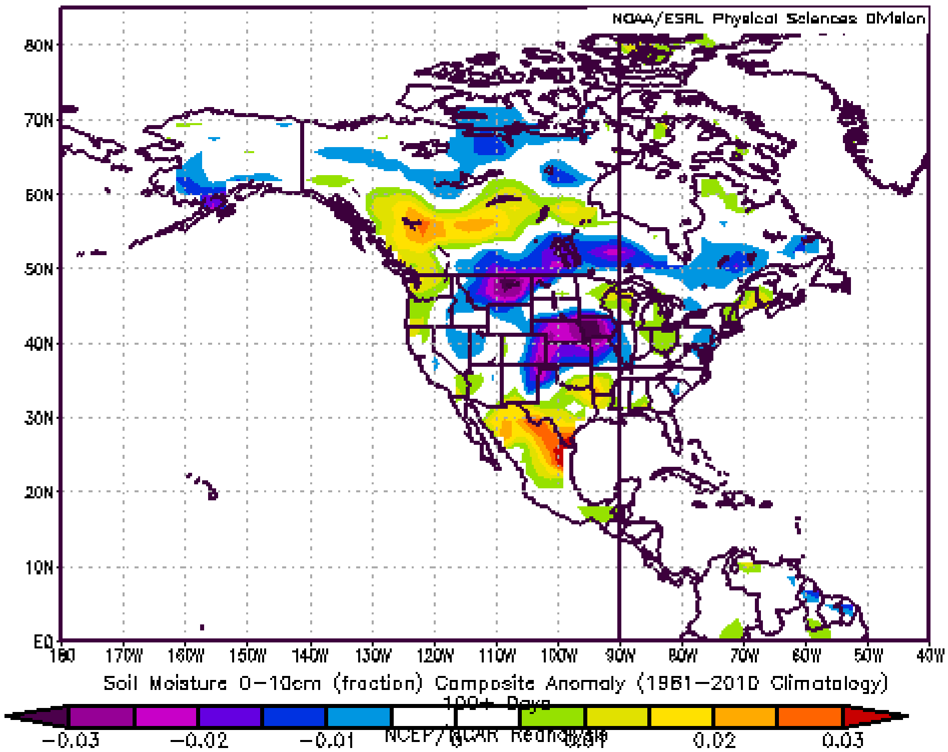

Figure 7a. Soil moisture anomaly at the 0-10-cm layer (fraction). Cooler shades indicate negative anomalies or dryness; warmer shades indicate positive anomalies or wetness.

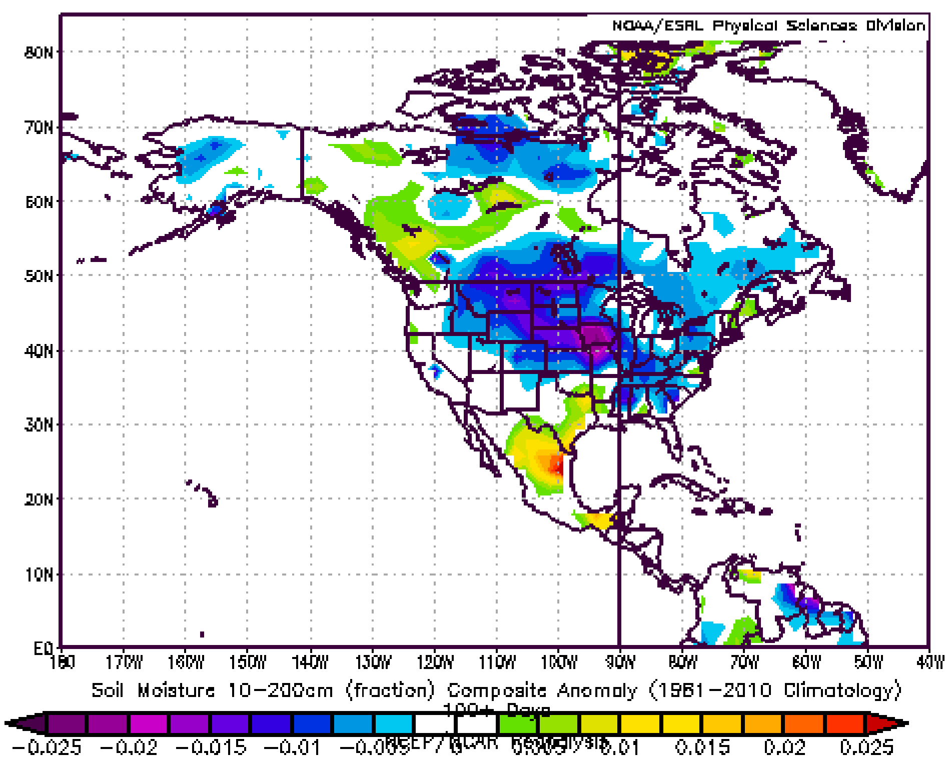

Figure 7b. Soil moisture anomaly at the 10-200-cm layer (fraction). Cooler shades indicate negative anomalies or dryness; warmer shades indicate positive anomalies or wetness.