Diagnostics and Flavors of U.S. Summer Heat Waves:

The Summers of 2011 and 2012 in Historical Perspective

Anthony Barnston
Bradfield Lyon

IRI, Palisades, New York

Heat Waves

- Lack of a universal definition:
  - Based on Tmax, Tmin,or both (variable)?
  - How hot (magnitude)?
  - Absolute or relative value (scale)?
  - For how long (duration of days)?
  - Include moisture or not?

\- -

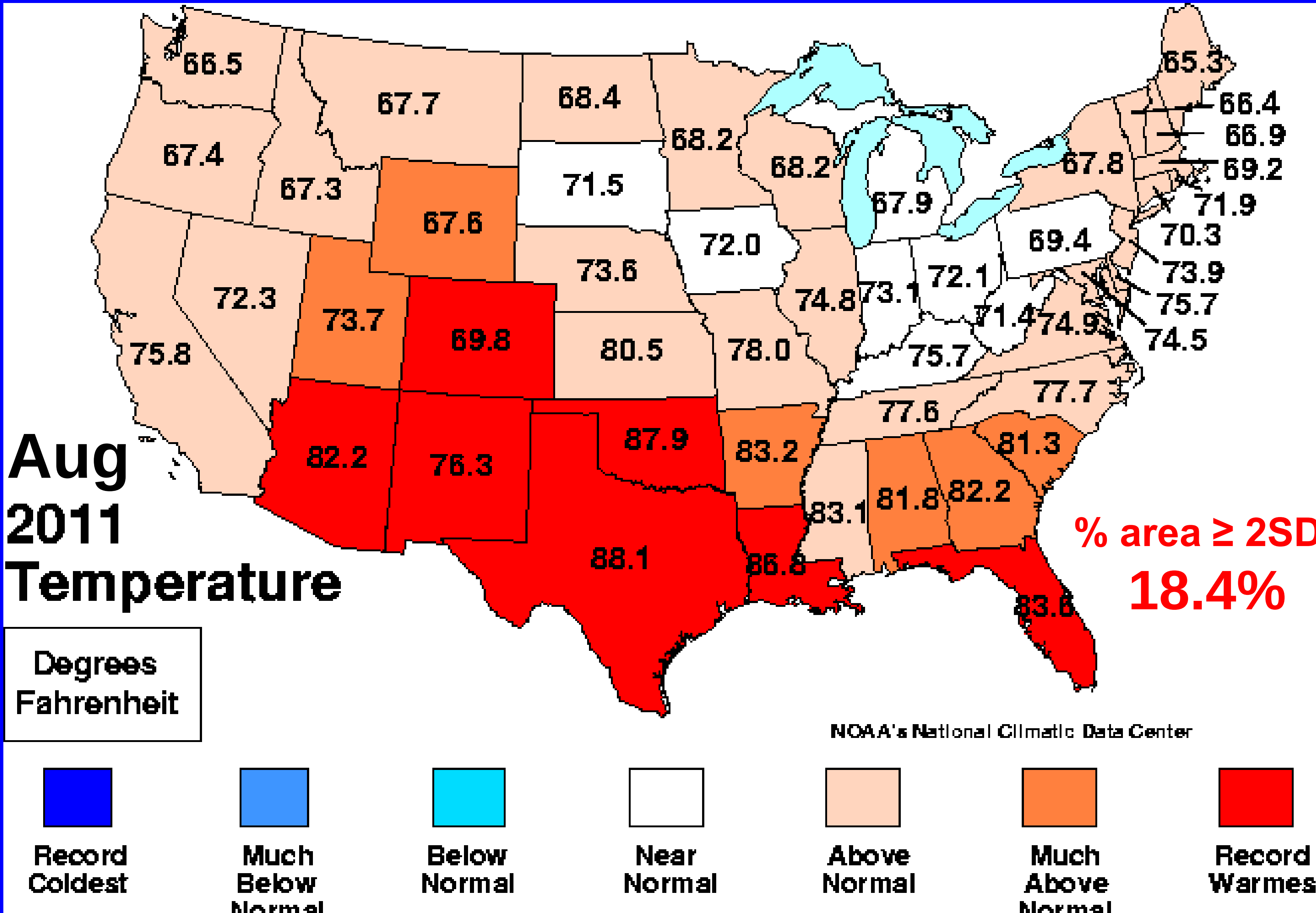
- **First Consider Avg. Monthly Temperatures** (and Drought Indicators)
- **Next consider daily Tmax, Tmin** (separately), and both
- **Look at Daily Equivalent Temperature**, T_e (R1, and NARR)

$$T_e \approx T + L_v/c_p \cdot q$$

"Moist Enthalpy" $H = c_pT + L_vq$

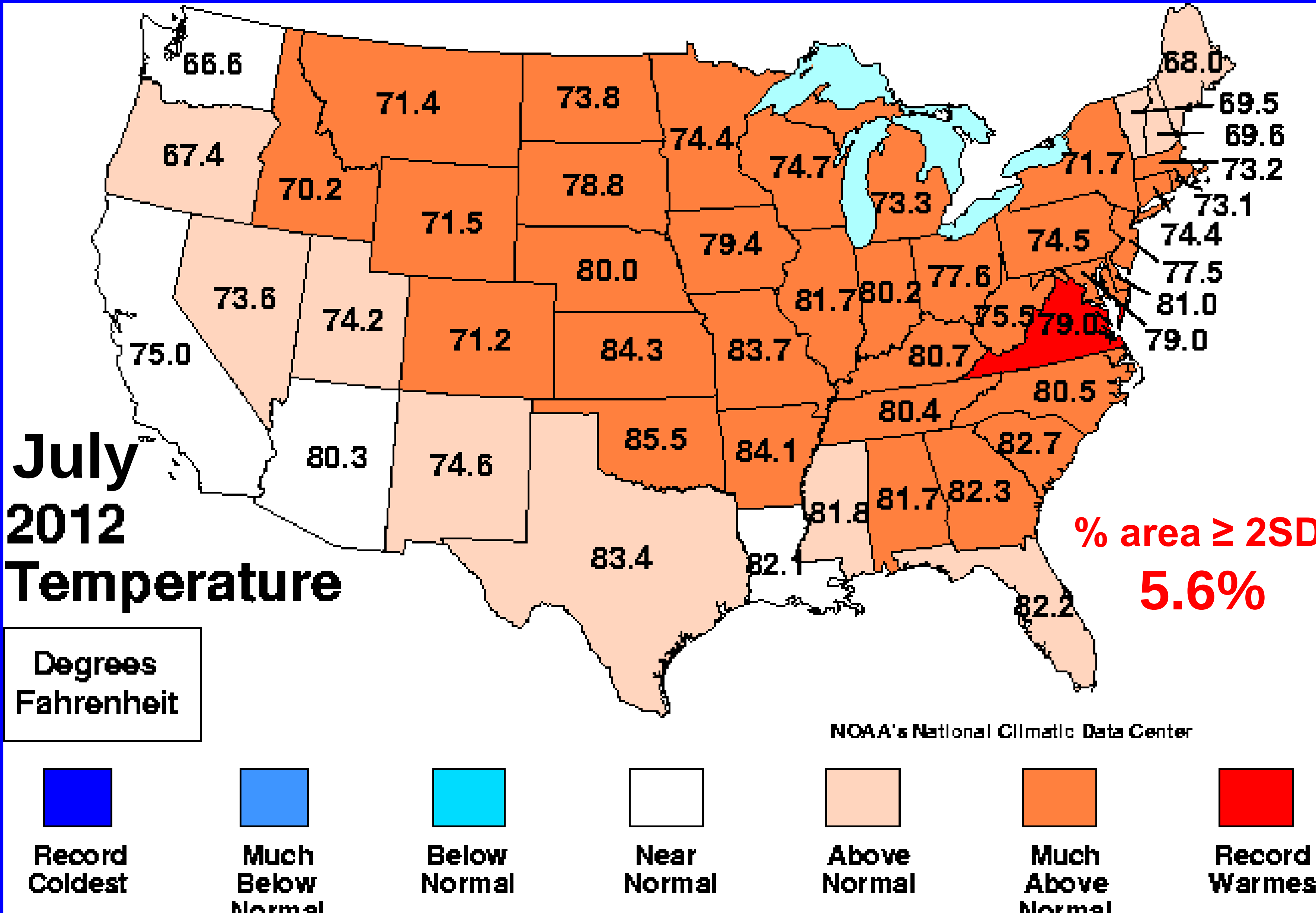
$$H/c_p = T_e = T + L_v/c_p \cdot q$$

Aug 2011 Temperature

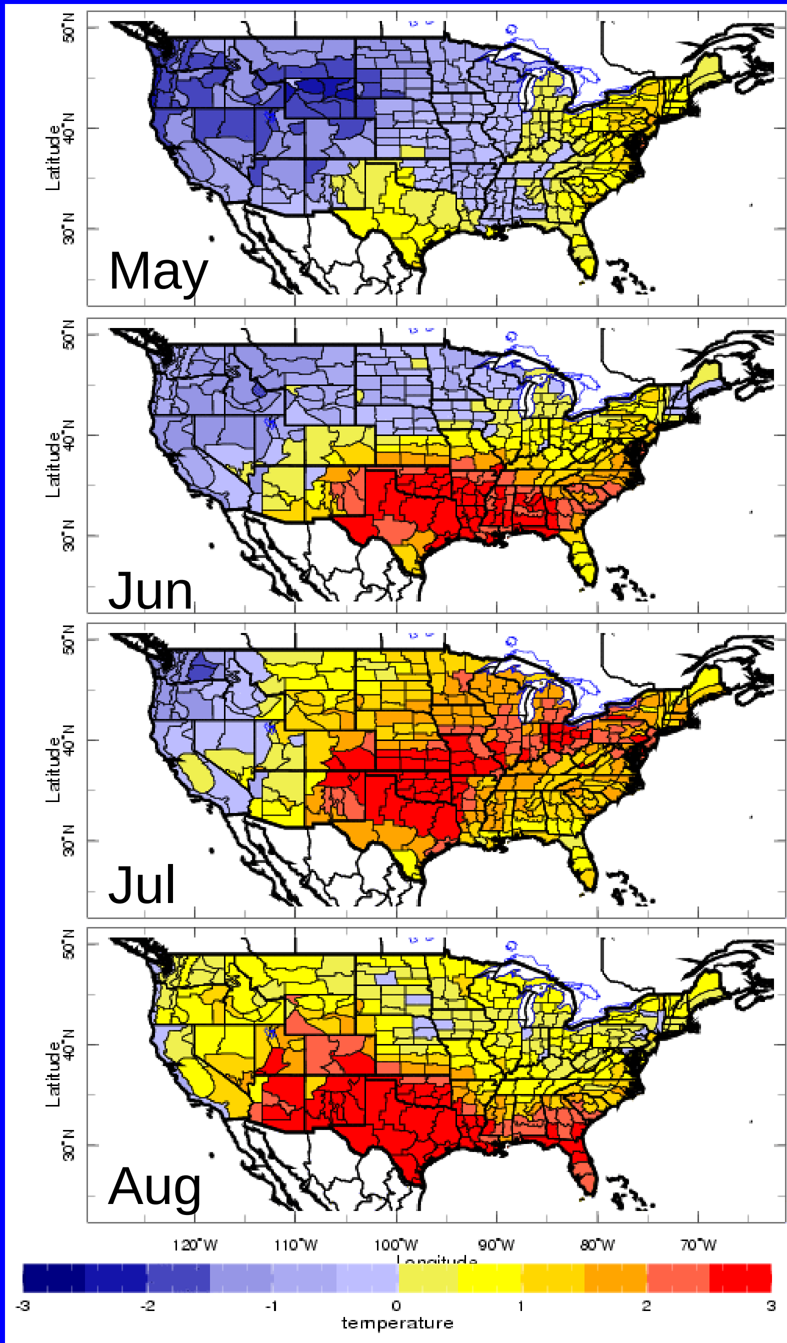


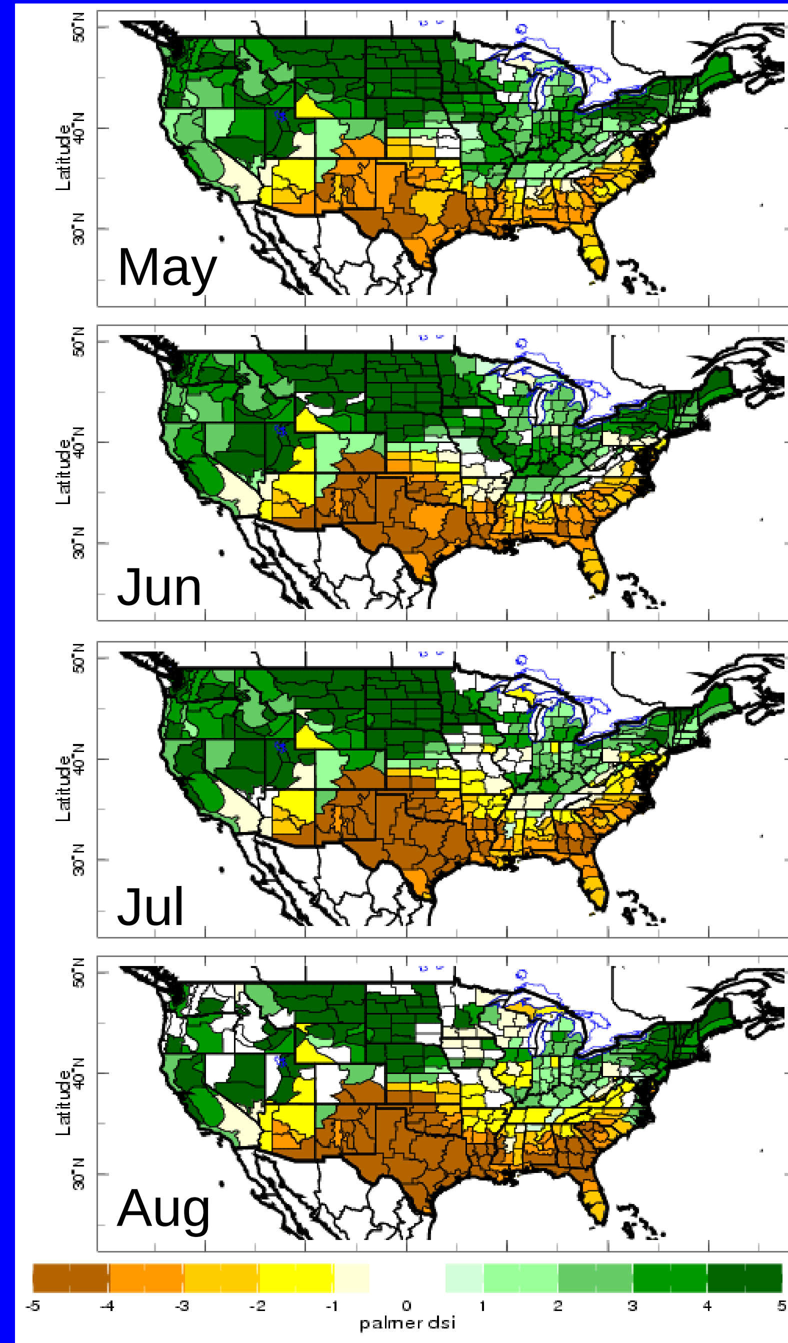
% area ≥ 2SD

18.4%

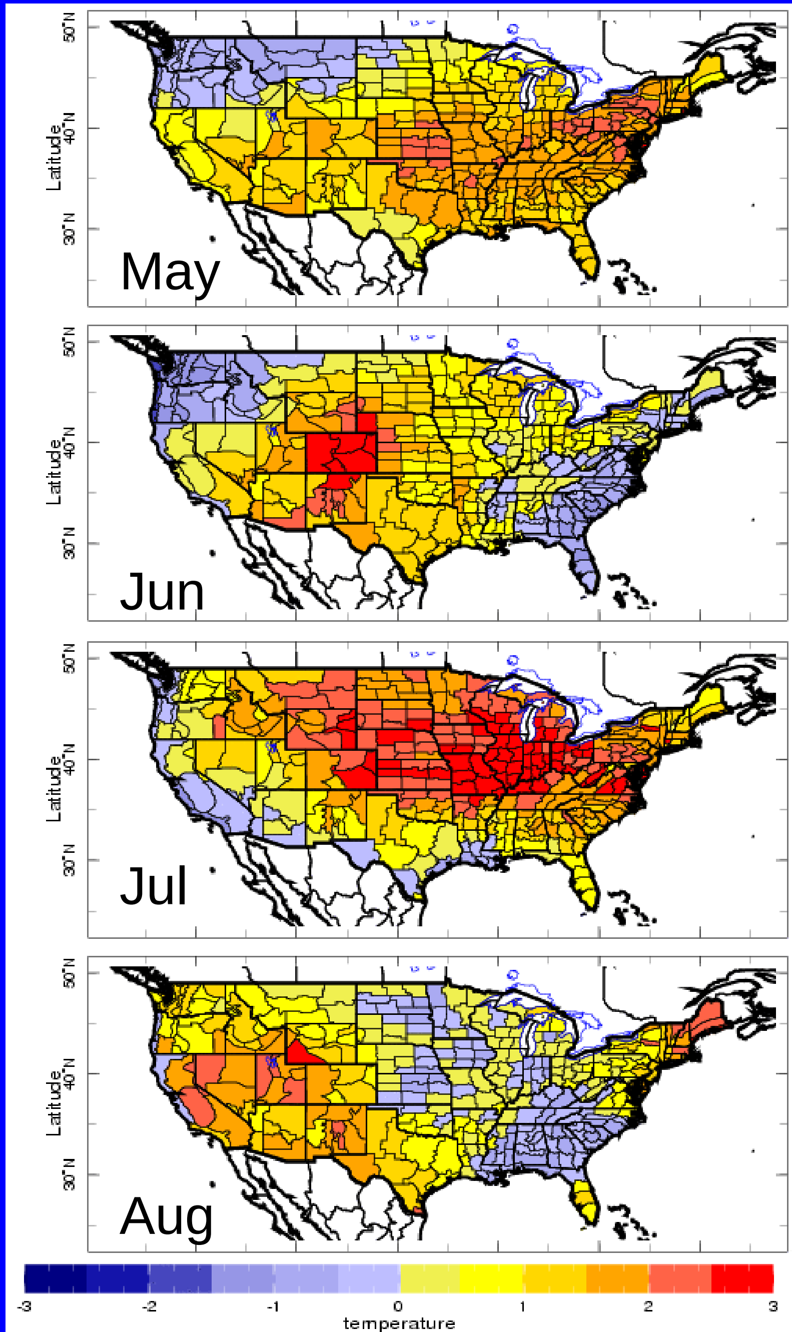

July
2012
Temperature
% area ≥ 2SD
5.6%
Degrees Fahrenheit
66.6
67.4
75.0
73.6
74.2
70.2
71.4
71.5
71.2
80.3
74.6
73.8
78.8
80.0
84.3
85.5
83.4
74.4
79.4
83.7
84.1
82.1
74.7
81.7
81.8
73.3
80.2
80.4
81.7
77.6
80.7
82.3
75.5
79.0
80.5
82.7
82.2
74.5
71.7
68.0
69.5
69.6
73.2
73.1
74.4
77.5
81.0
79.0
NOAA's National Climatic Data Center
Record Coldest
Much Below Normal
Below Normal
Near Normal
Above Normal
Much Above Normal
Record Warmest

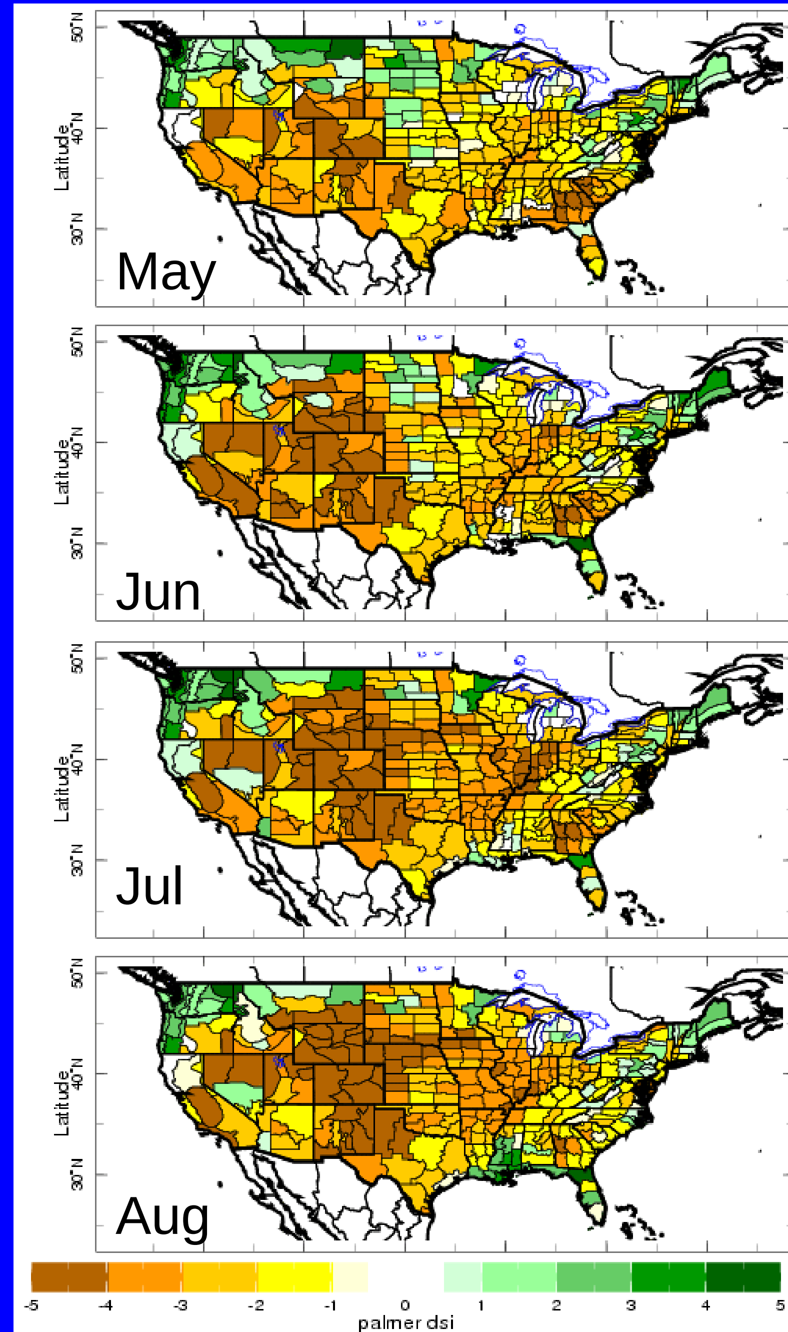
MJJA 2011: Std Temp. Anomaly and PDSI



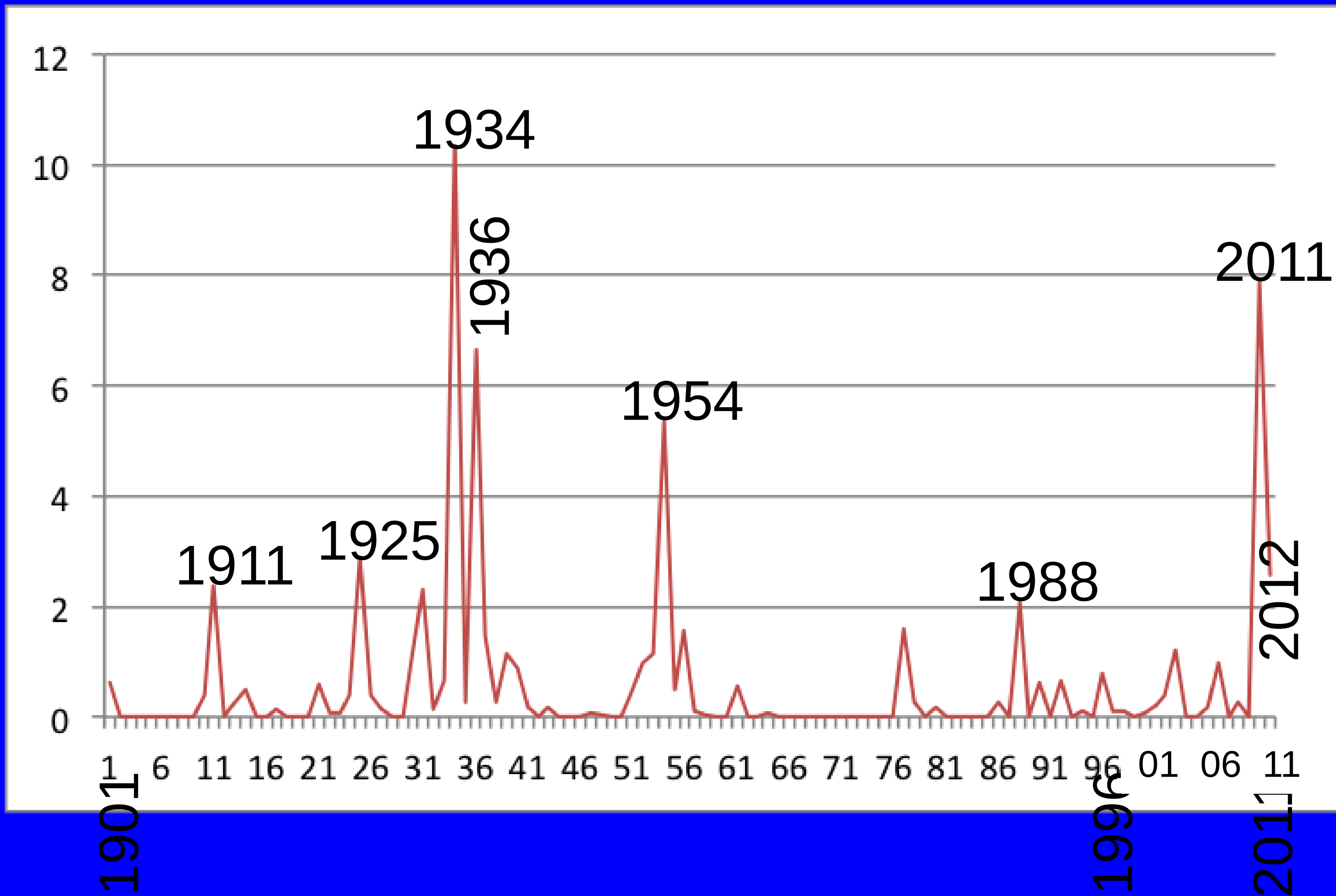


MJJA 2012: Std Temp. Anomaly and PDSI



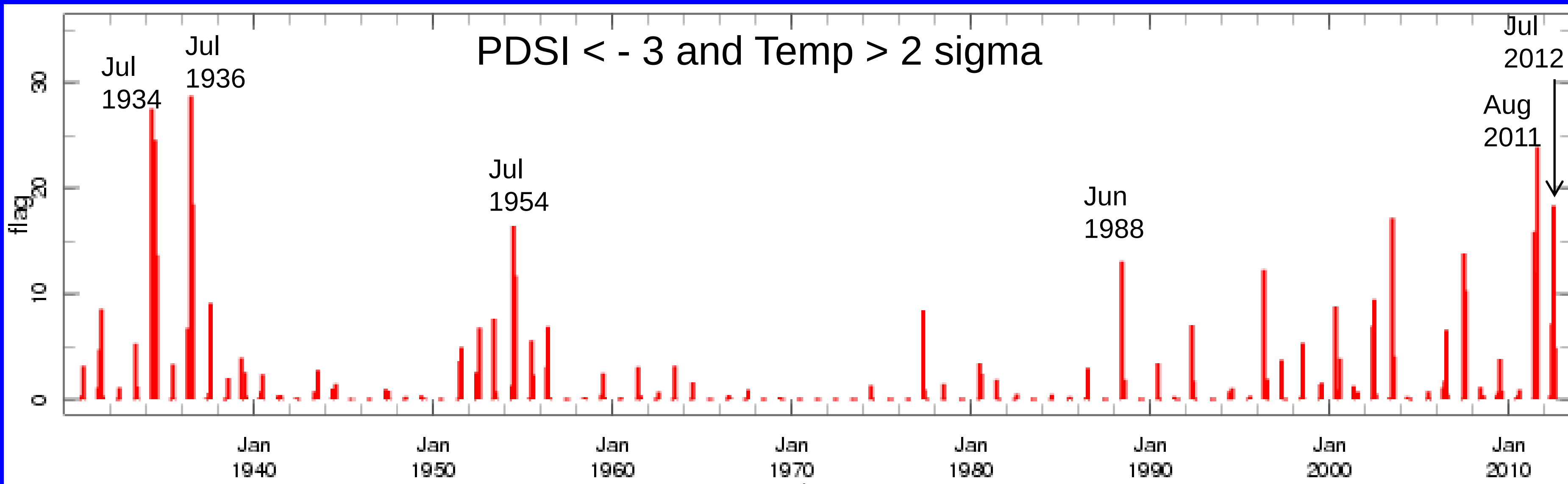


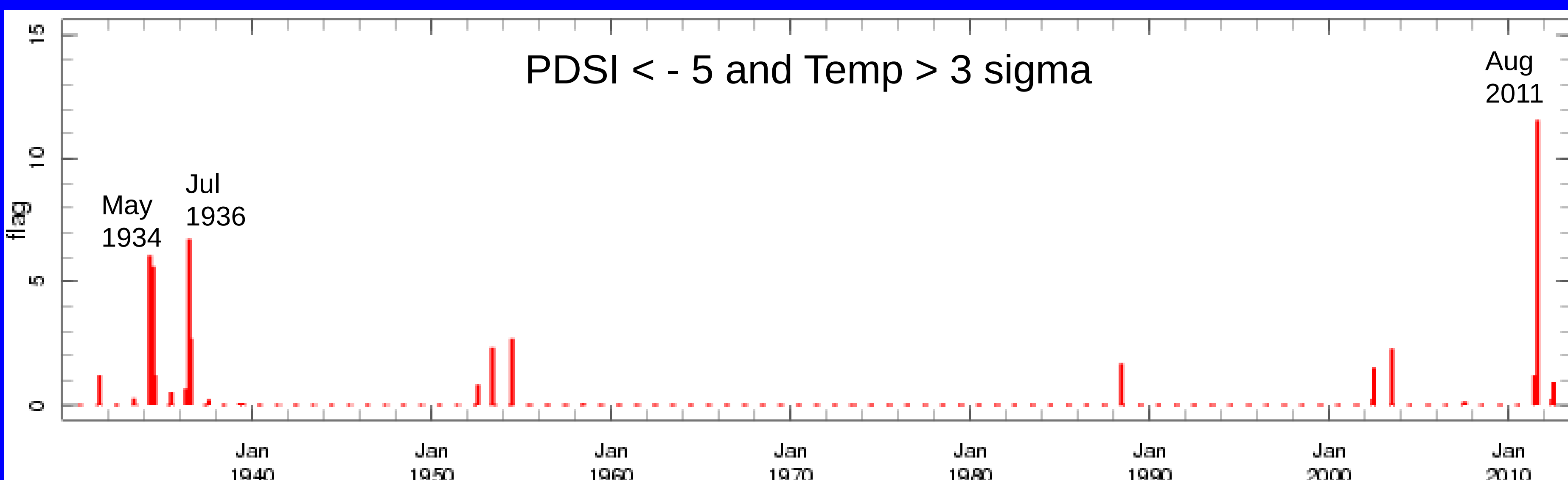
Percent Area in CONUS with ≥2 SD for monthly mean temperature: Avg for MJJAS



MJJA Percent Area of CONUS with Joint Drought & Heat

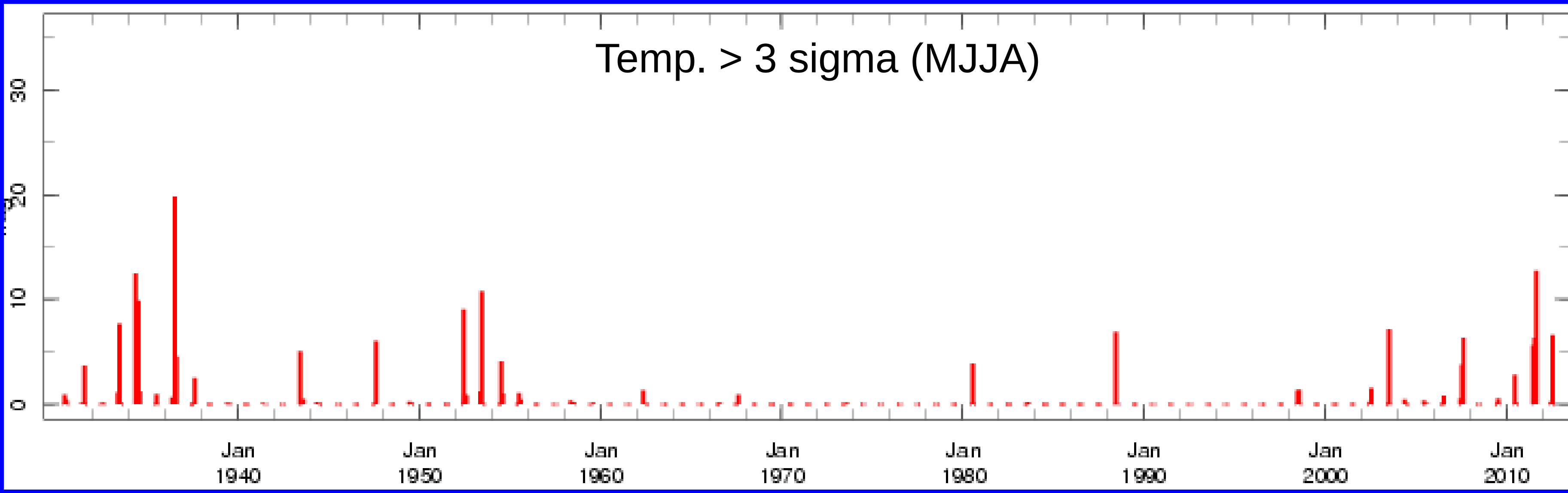
(1971-2000 base period for Temp.)

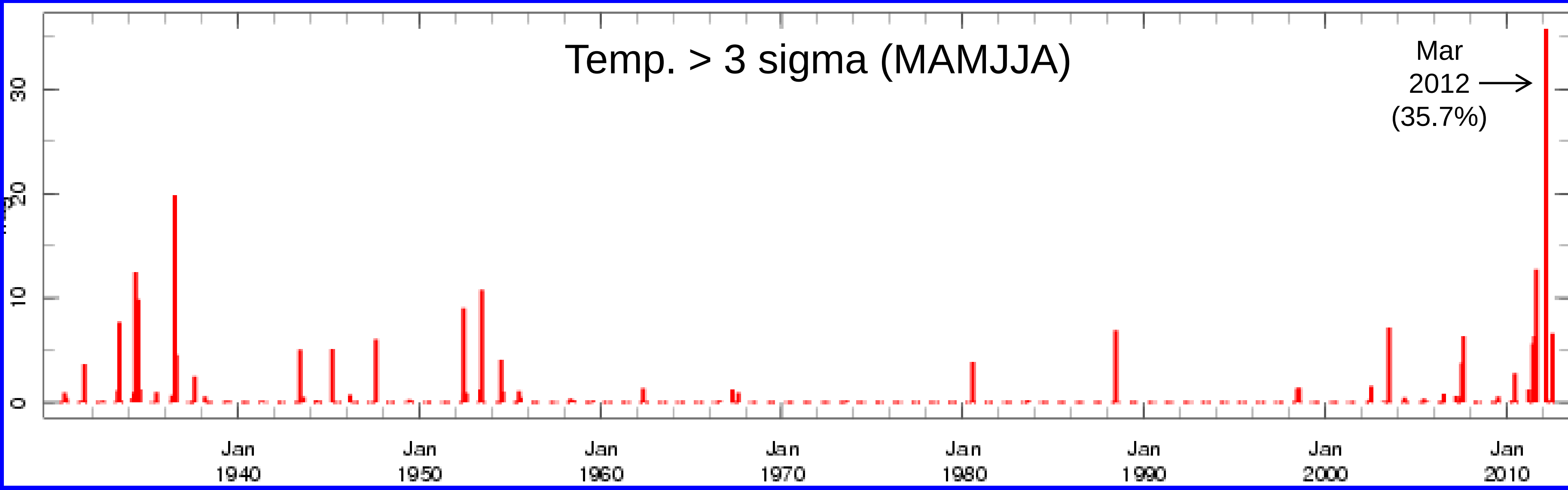




Percent Area of CONUS with Temp. > 3 sigma

(1971-2000 base period)





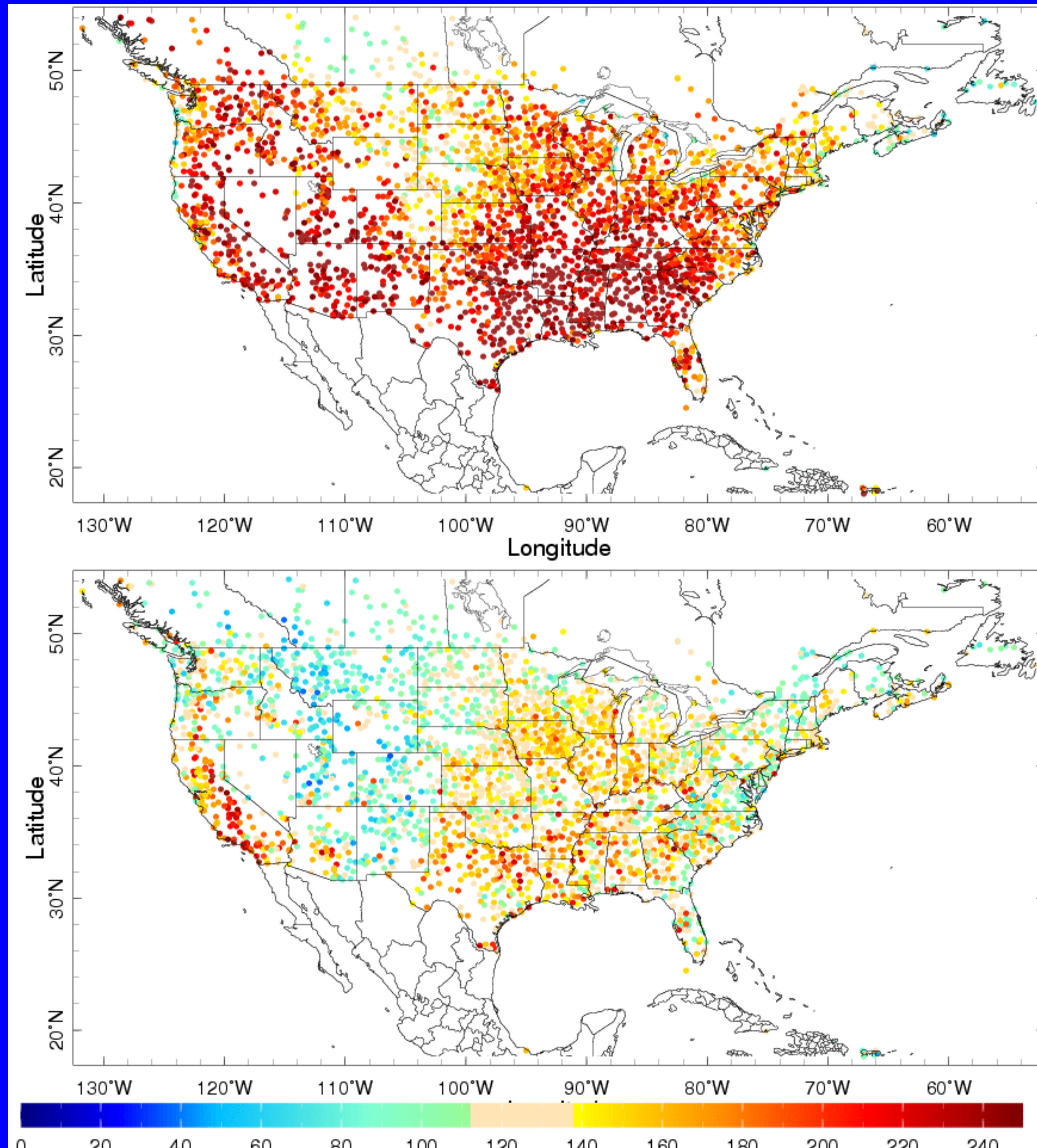
Daily Data

- Heat Waves: *n*+ consecutive days above daily percentile threshold (3+ days, > 90^{th} percentile)
- Geographical variation: Tmax vs Tmin
- Station data (Tmax, Tmin) from GHCN
- Reanalysis T_{eq} data (examine the Midwest 2012 & historical)

(> 90th %' ile, 3+ days) Total "Heat Wave Days" 1960-2000

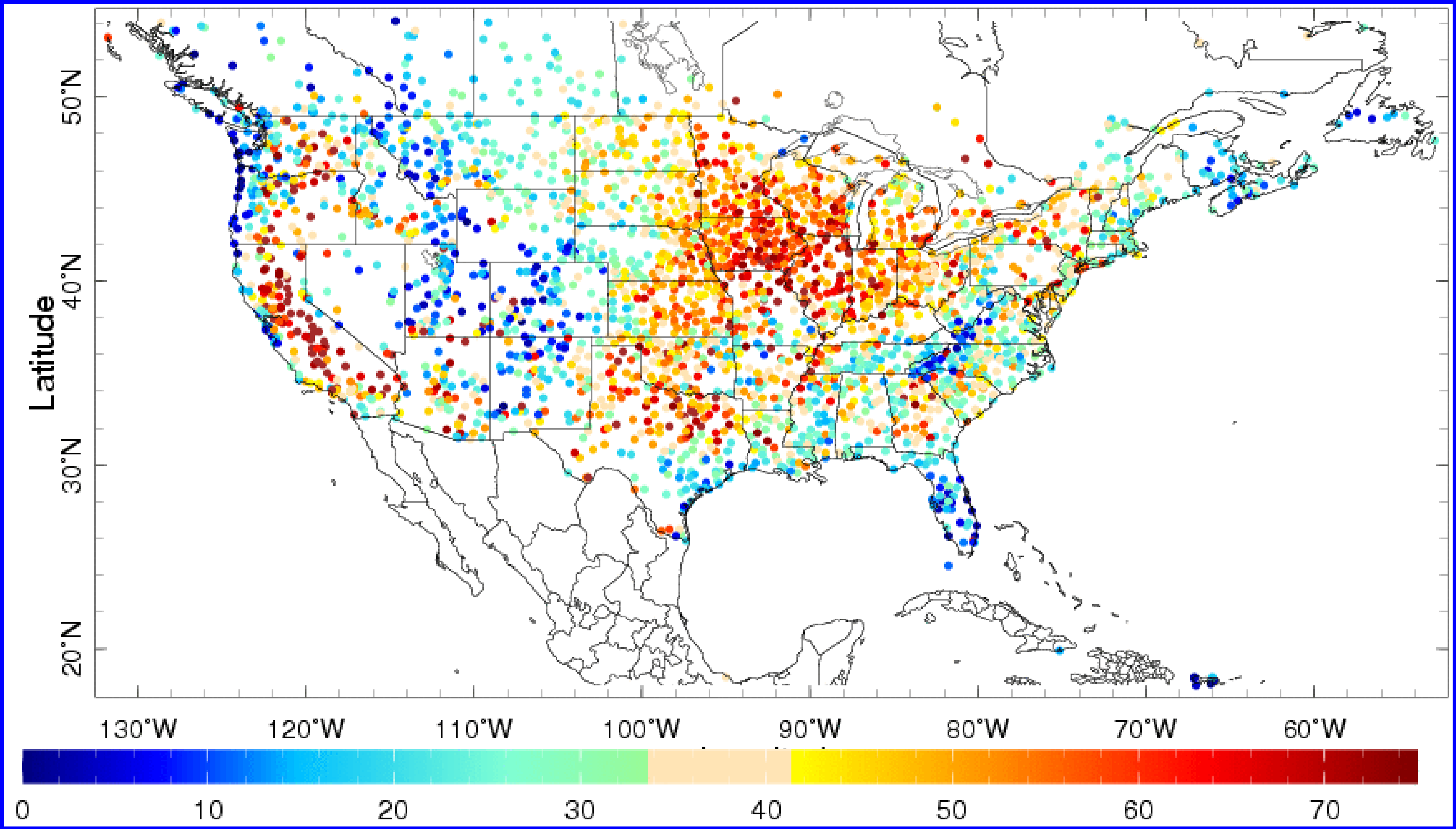
Maximum Temp.

Minimum Temp.

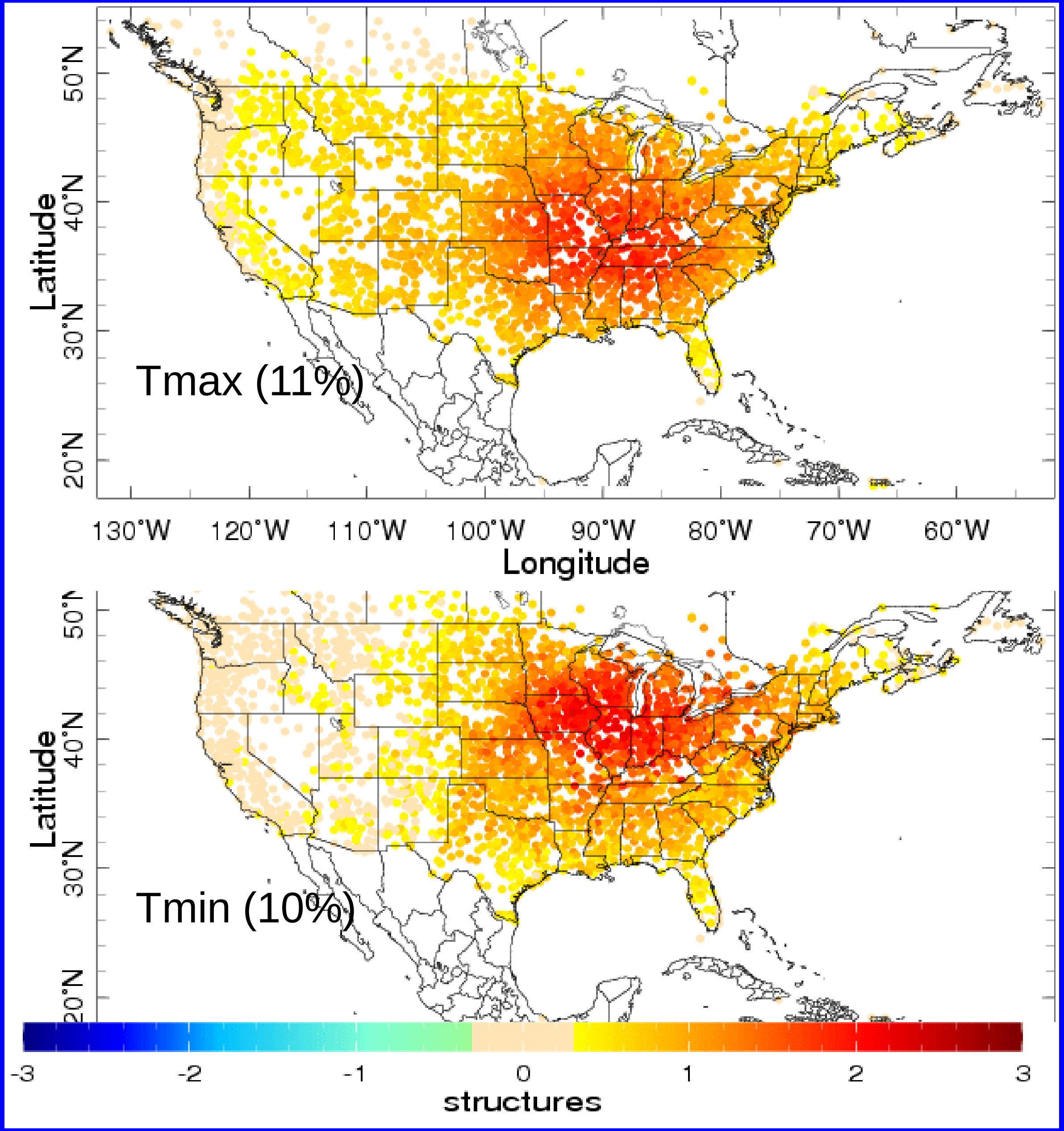


(> 90th %' ile, 3+ days) Total "Heat Wave Days" 1960-2000

Maximum <u>and</u> Minimum Temperature



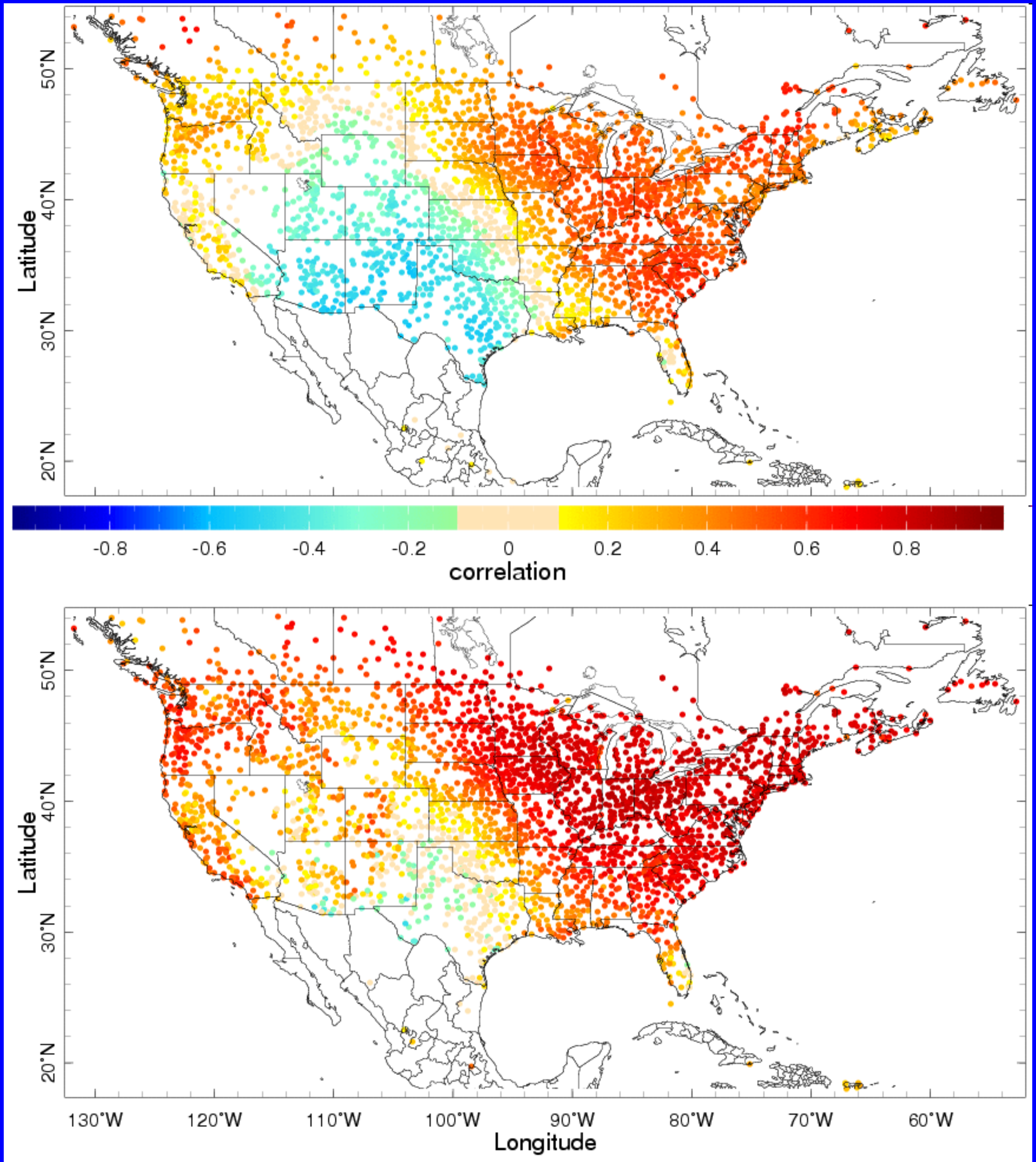
1st EOF Heat Wave Days (May-Sept 1960-2000)



July Daily Temp. and 2m q Anomaly (Reanalysis) Correlation 1979-2000

Tmax

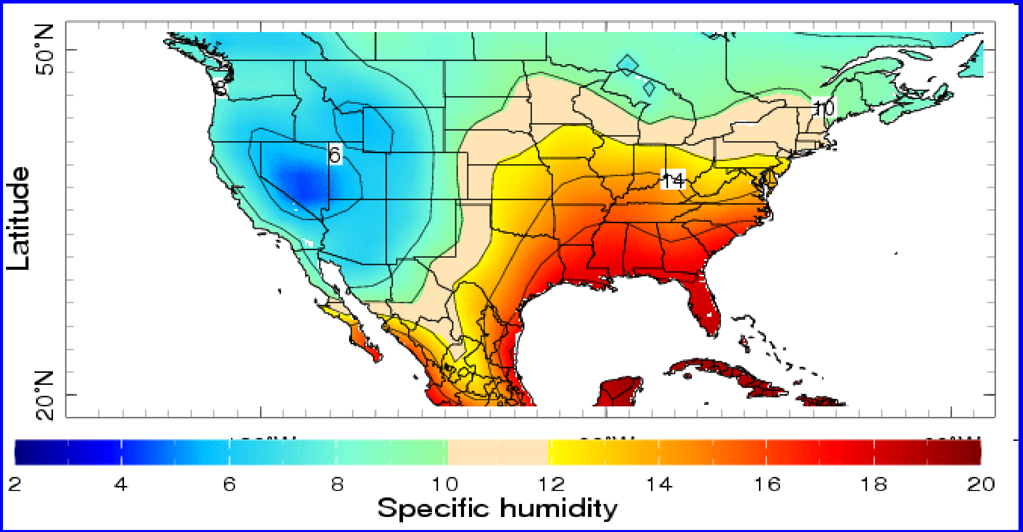
Tmin



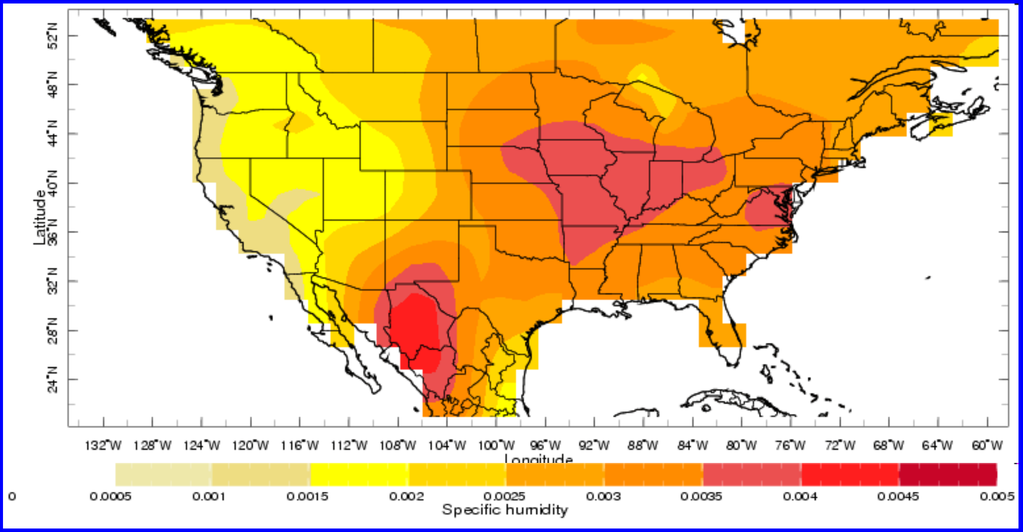
May-Sept 2m Specific Humidity

NCEP-NCAR Reanalysis (1979-2009)

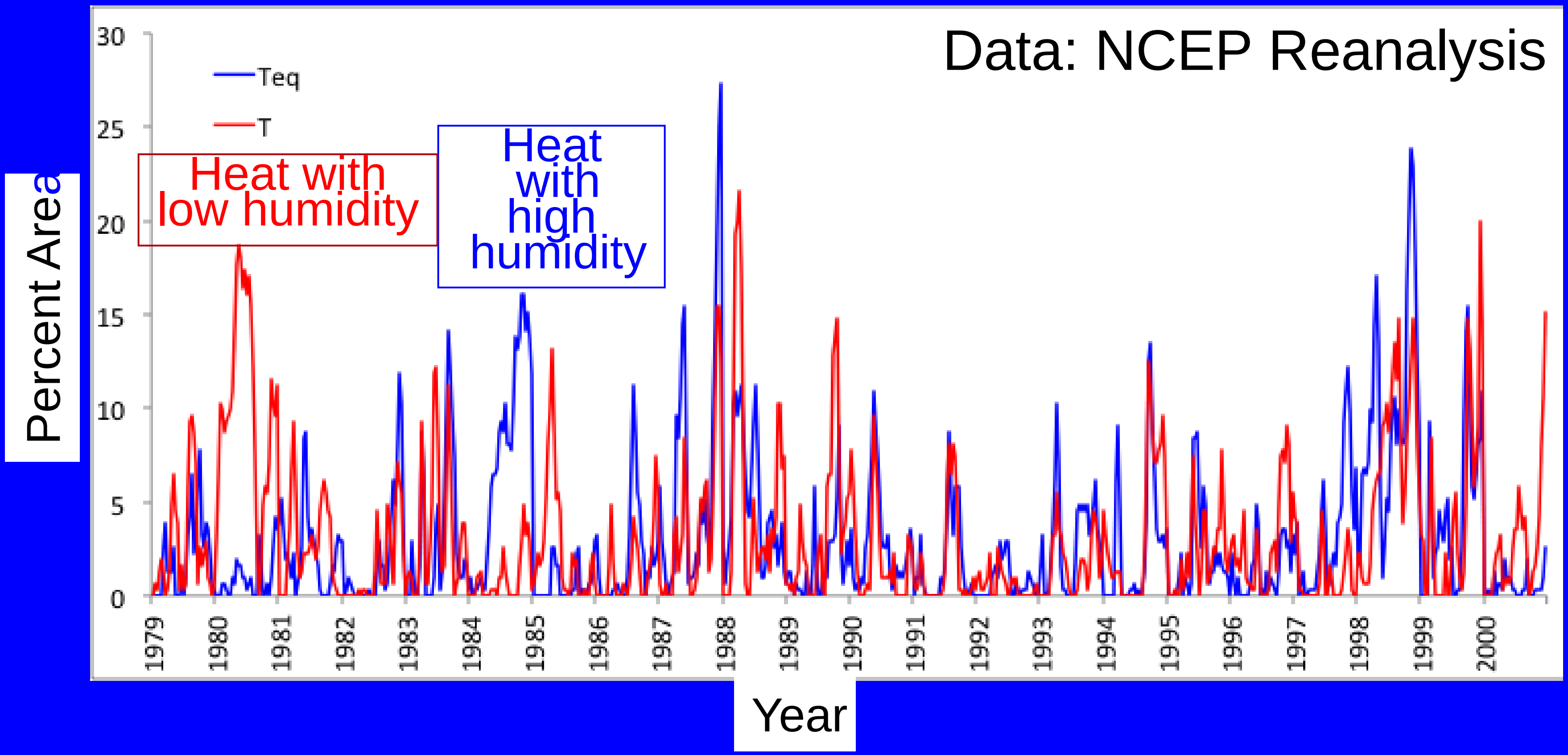
Mean



Variance

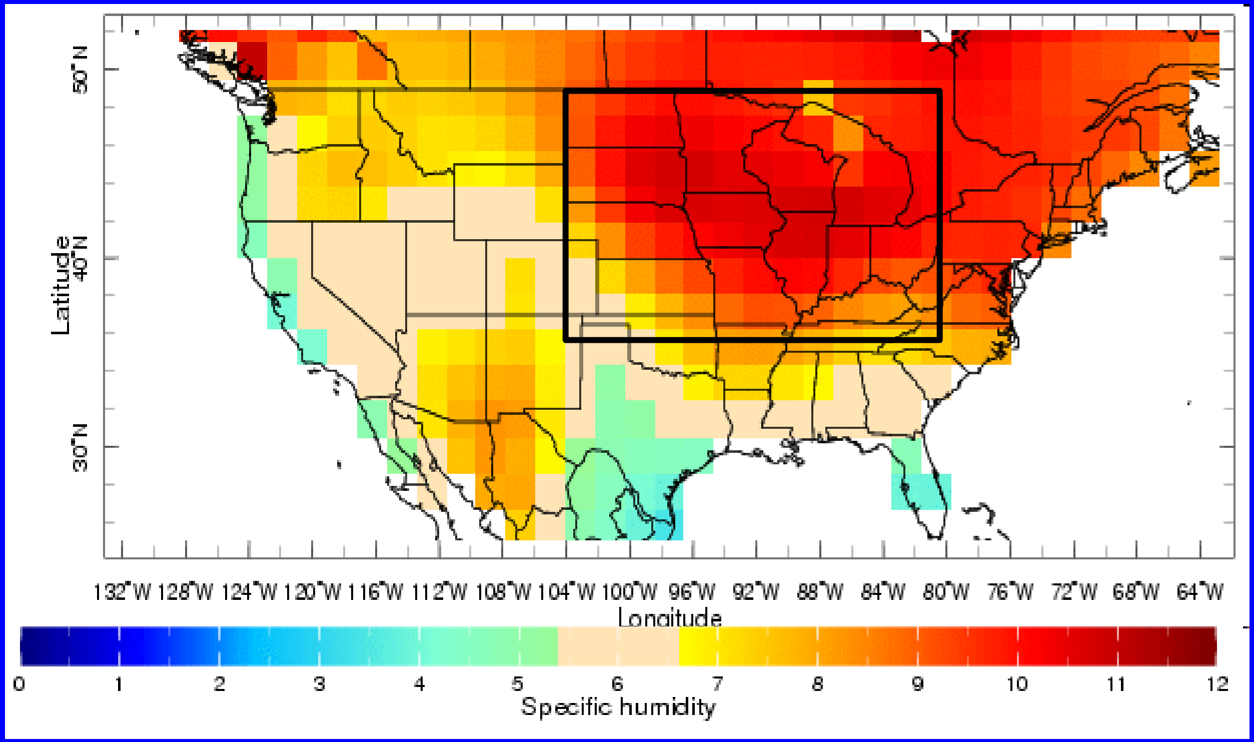


Percentage of area in CONUS having ≥3 consecutive days of daily temperature or equivalent temperature exceeding the 90th %ile during July (1979-2000).



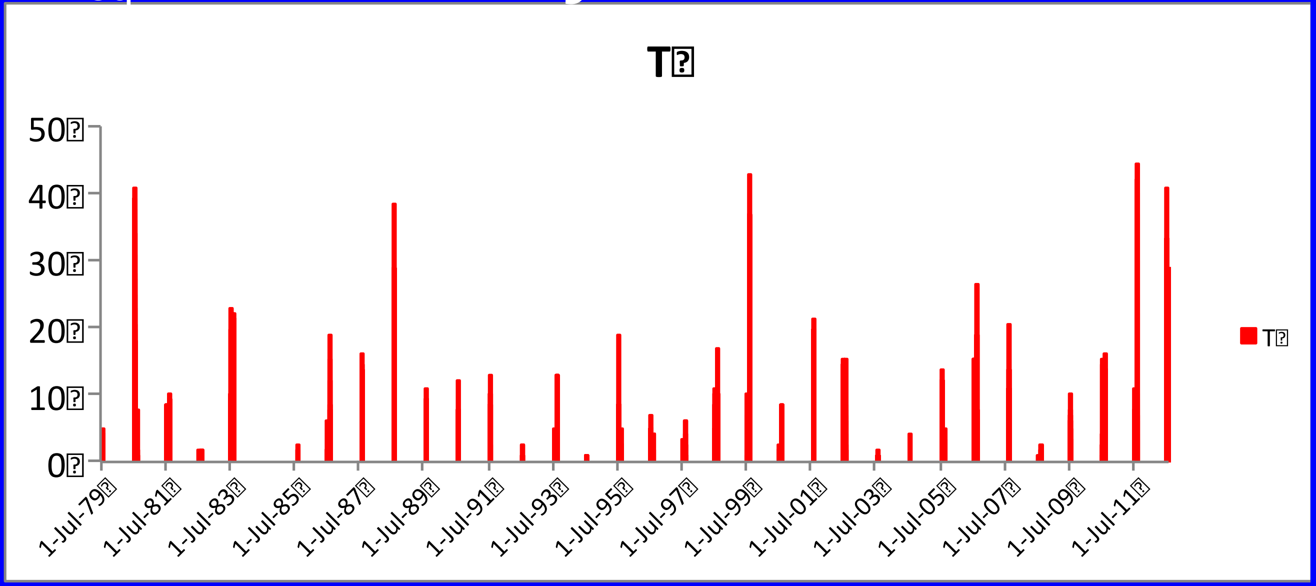
Daily T_e Variance JJA 1979-2009

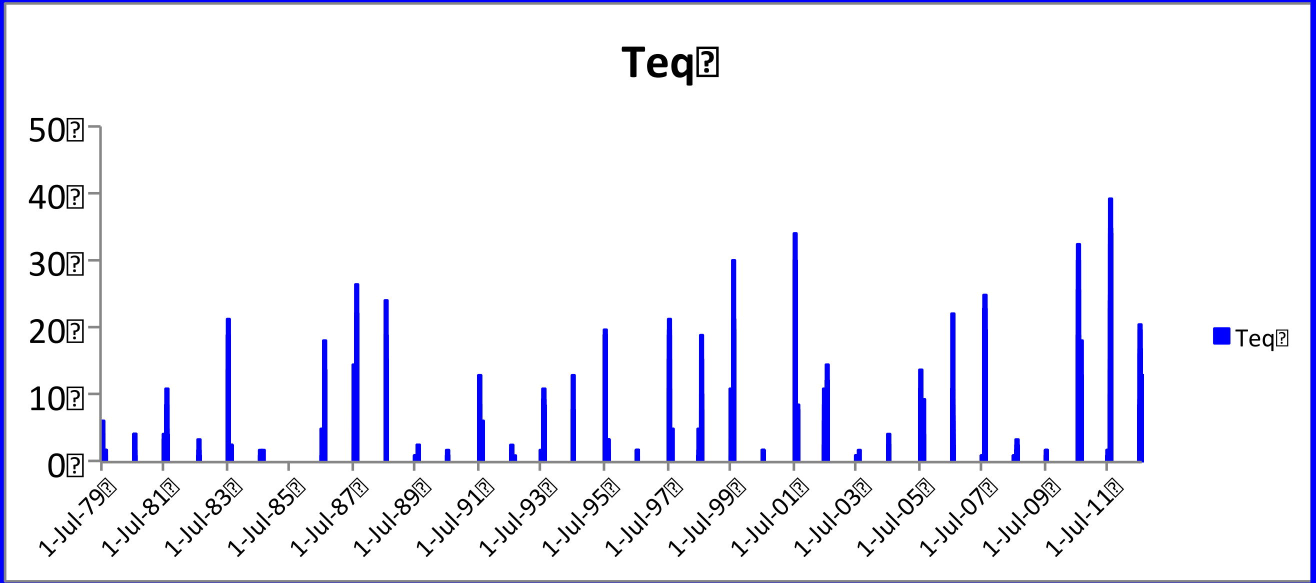
Reanalysis 2m



% Area of US Midwest in Heat Wave (3+ days, > 90th %ile)

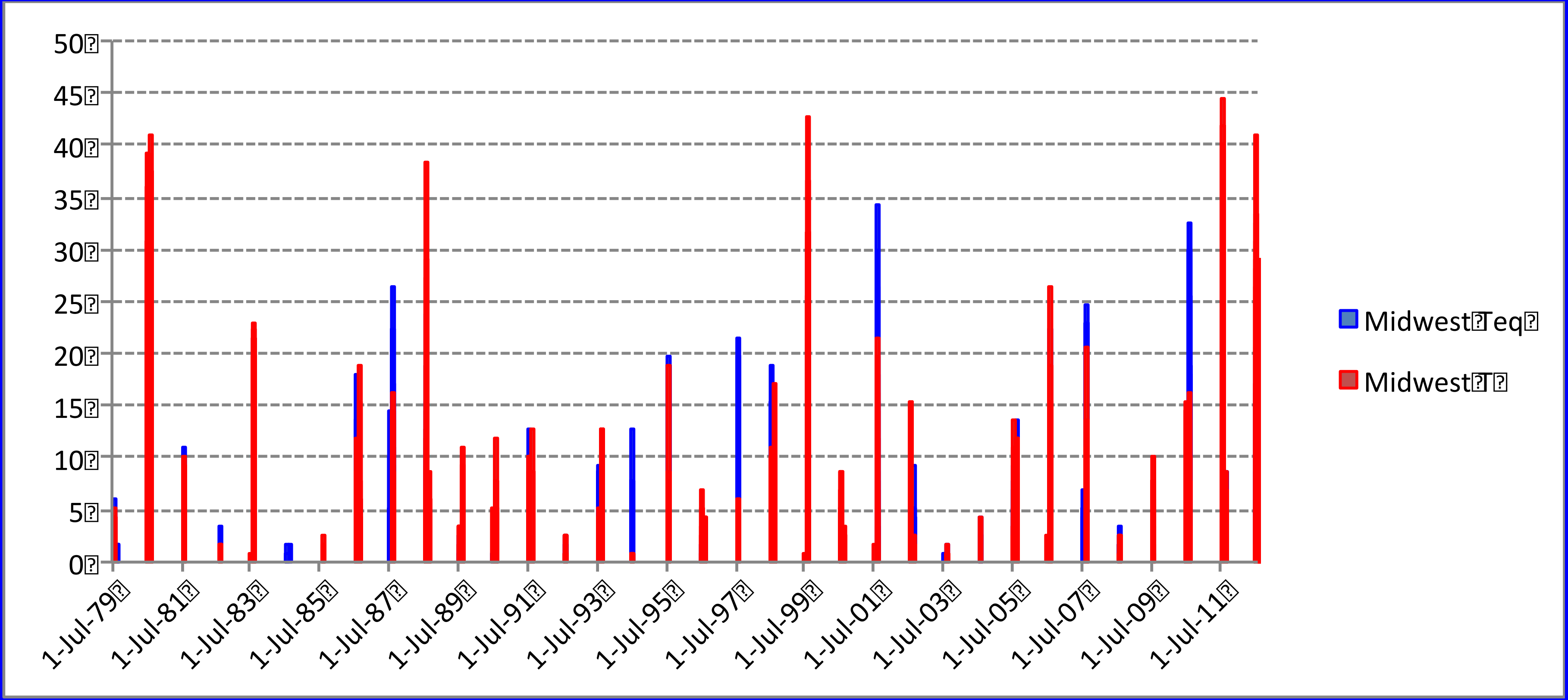
T_{eq} vs. T (For July based on Reanalysis)





% Area of US Midwest in Heat Wave (3+ days, > 90th %ile)

T_{eq} vs. T (For July based on Reanalysis)



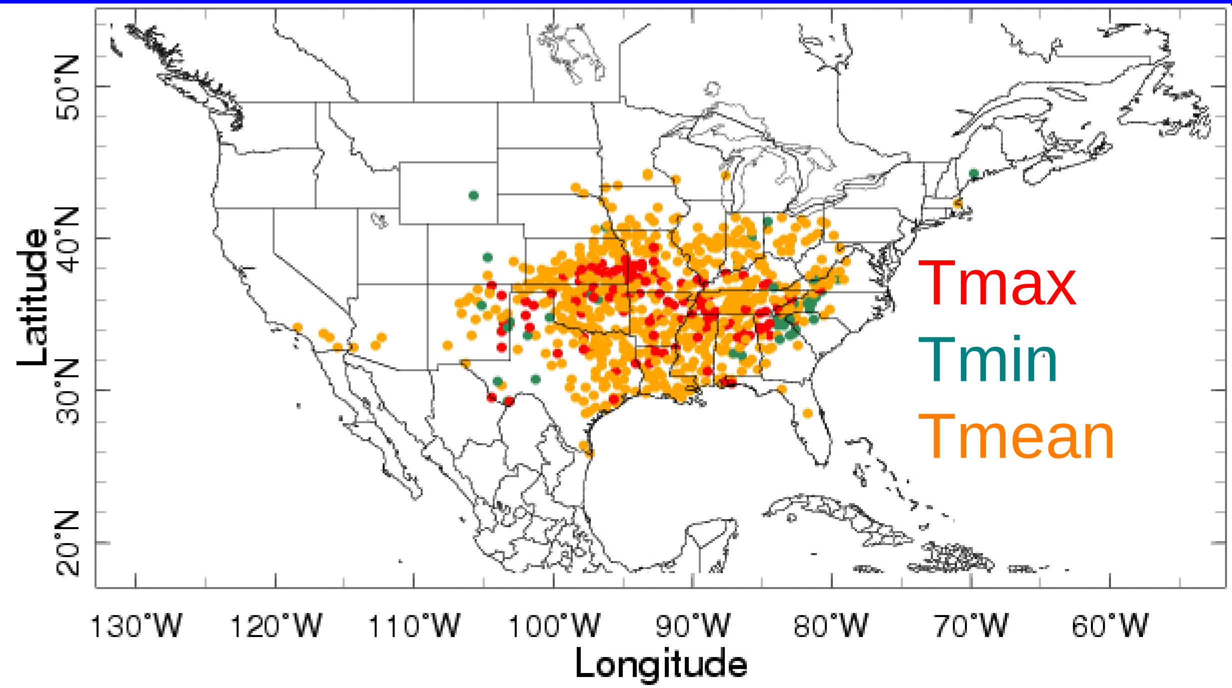
r (T area, Teq area) = 0.55

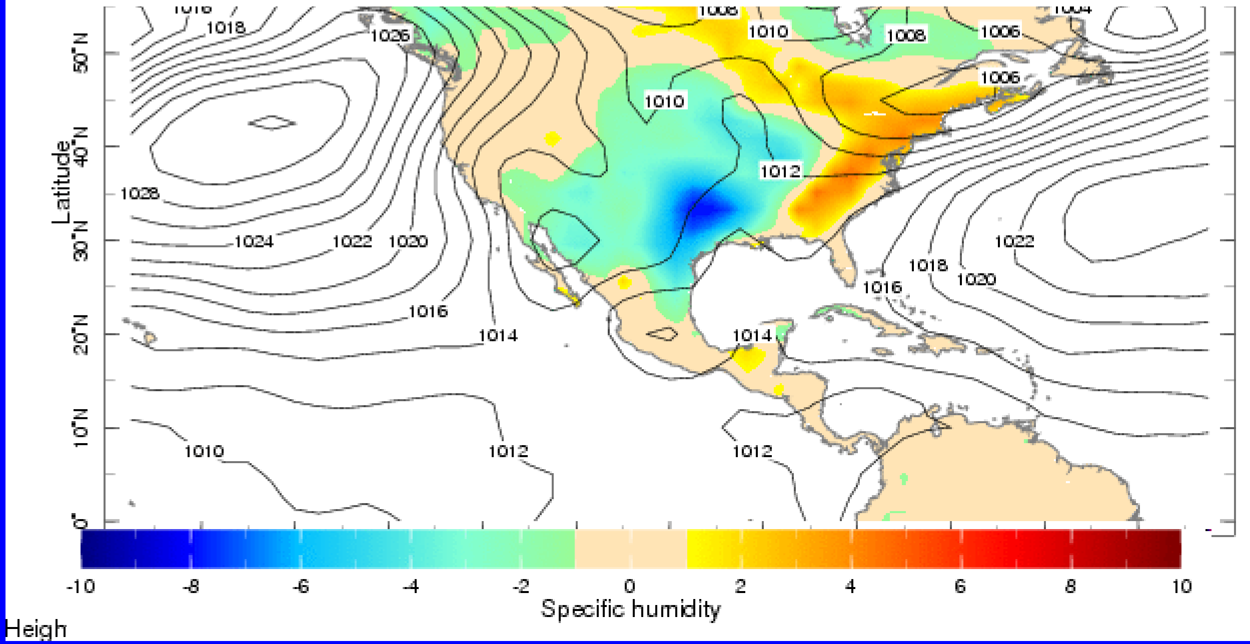
July 21, 1980

**Station Temps.
> 90th %' ile**

A "dry"
heat wave
(Tmax more
than Tmin)

**Specific Humidity
Anomaly
and
SLP**



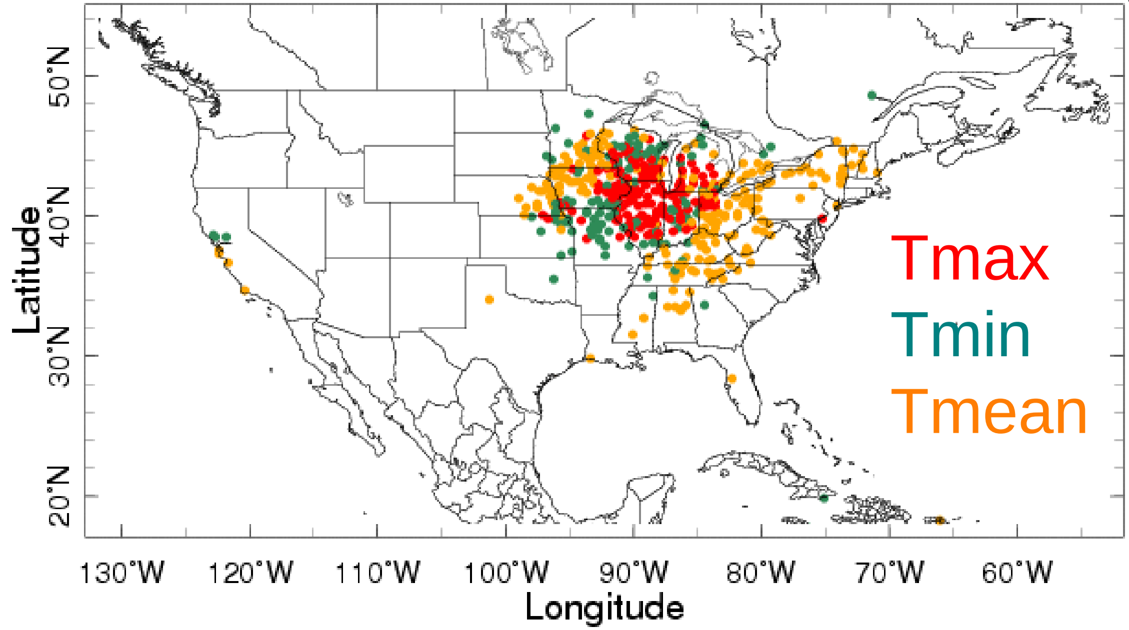


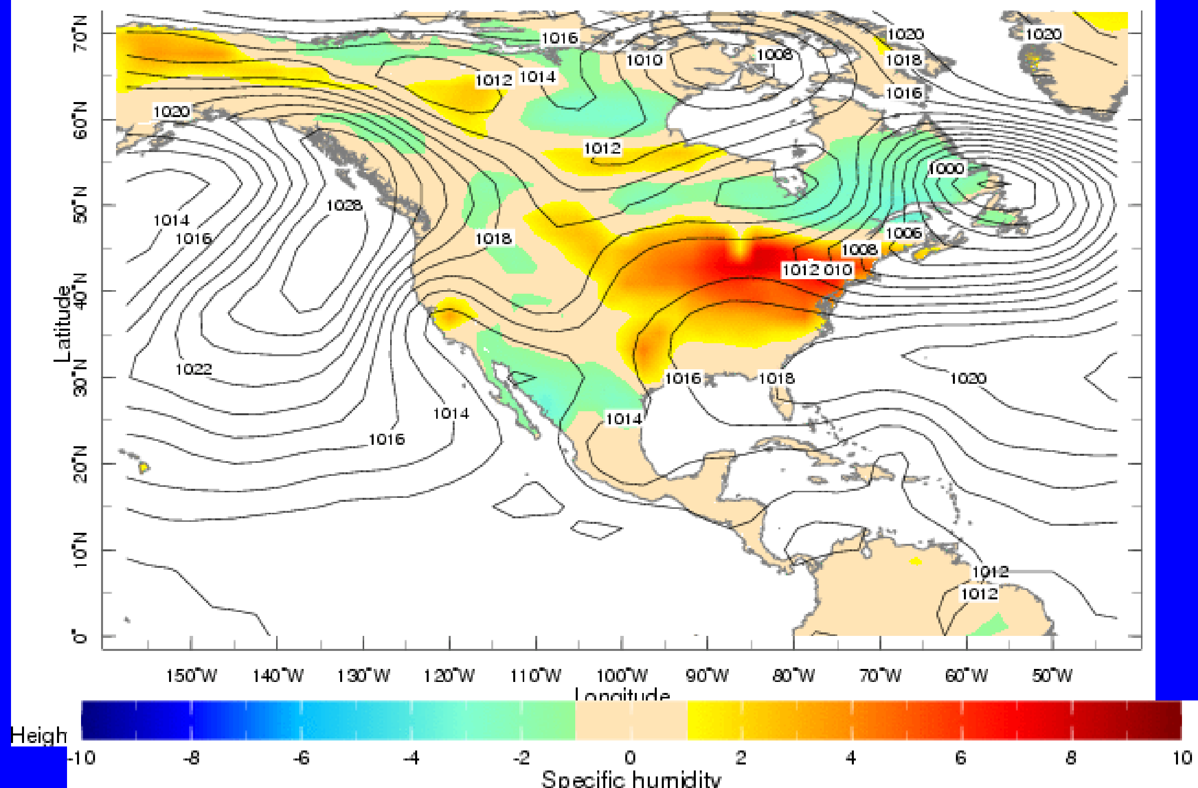
July 15, 1995

Station Temps.
> 90th %' ile

High humidity and Tmin, Tmax in "Chicago Heat Wave"

Specific Humidity Anomaly and SLP



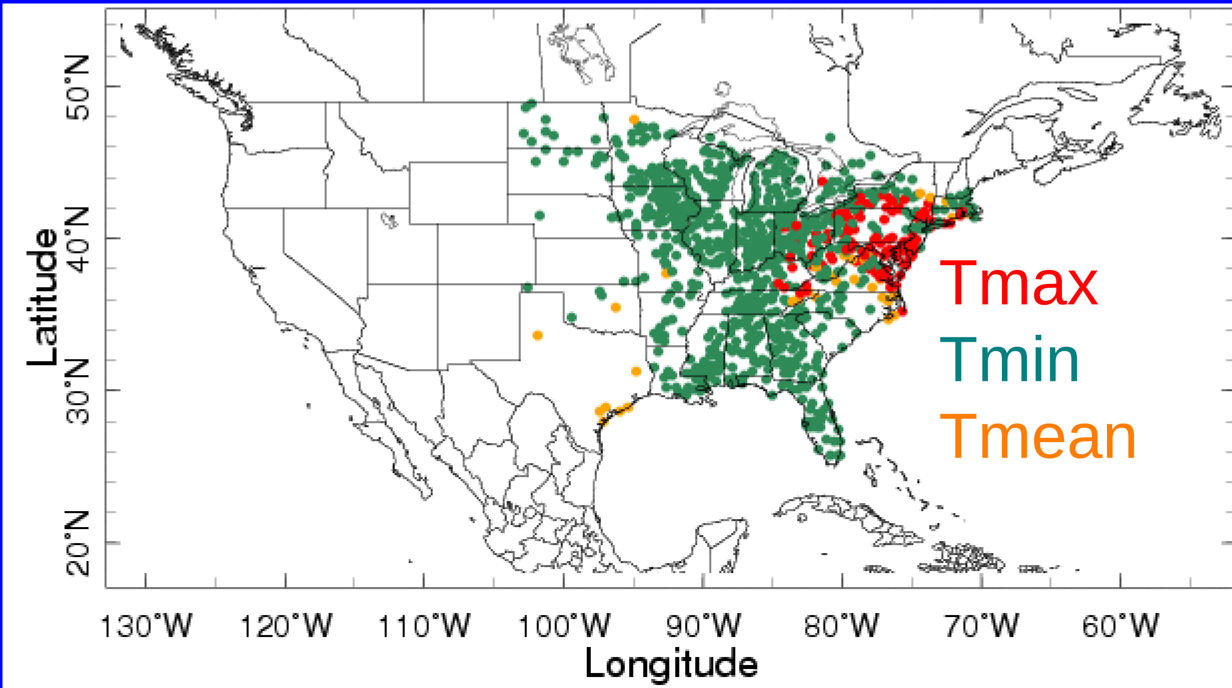


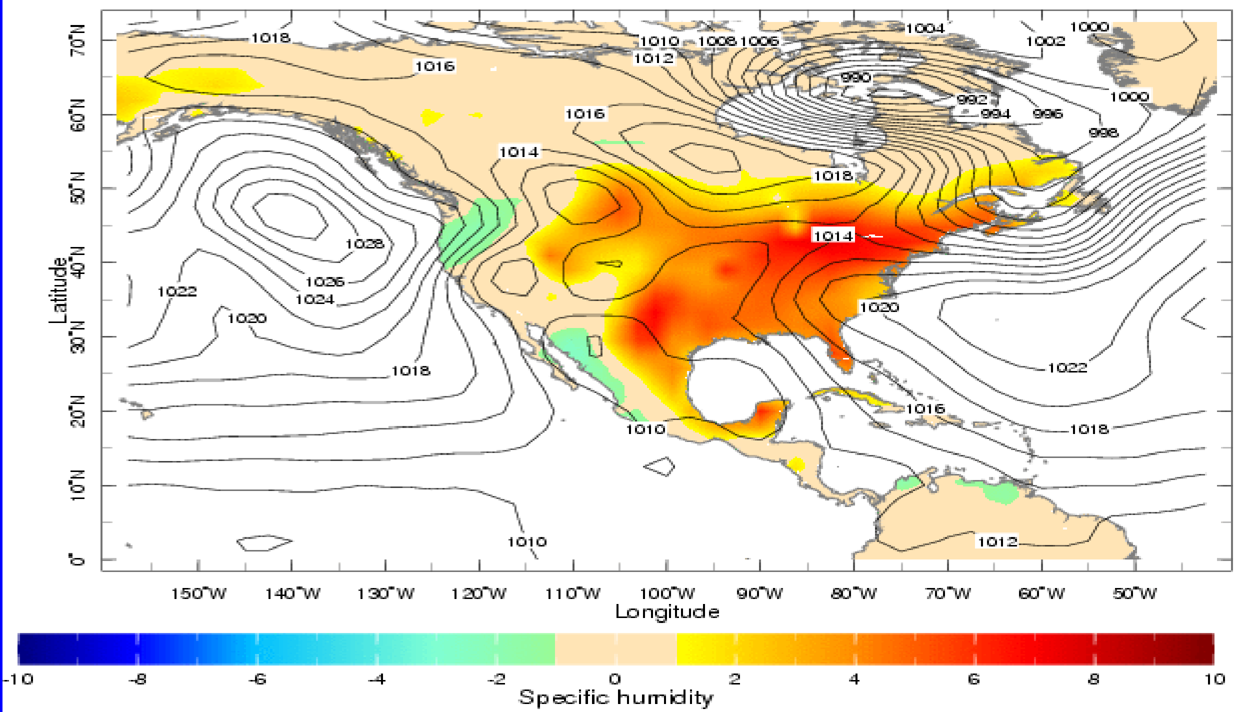
May 21, 1991

Station Temps. > 90th %' ile

High humidity and Tmin in East

Specific Humidity Anomaly and SLP



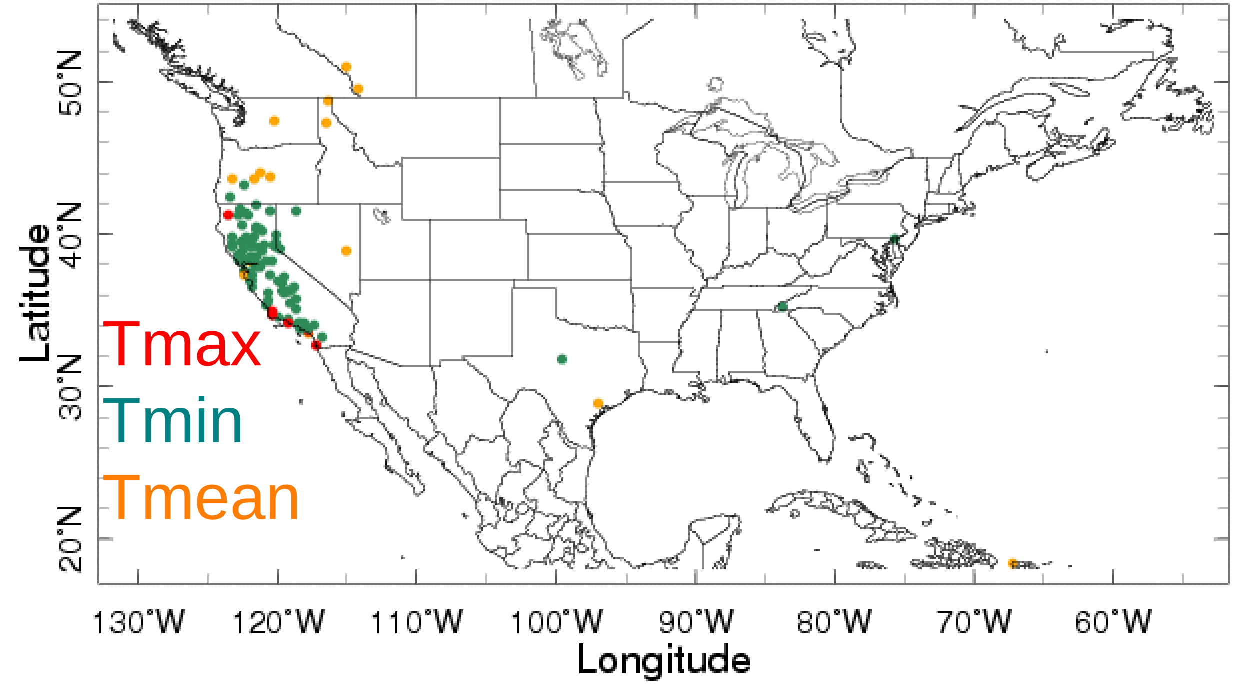


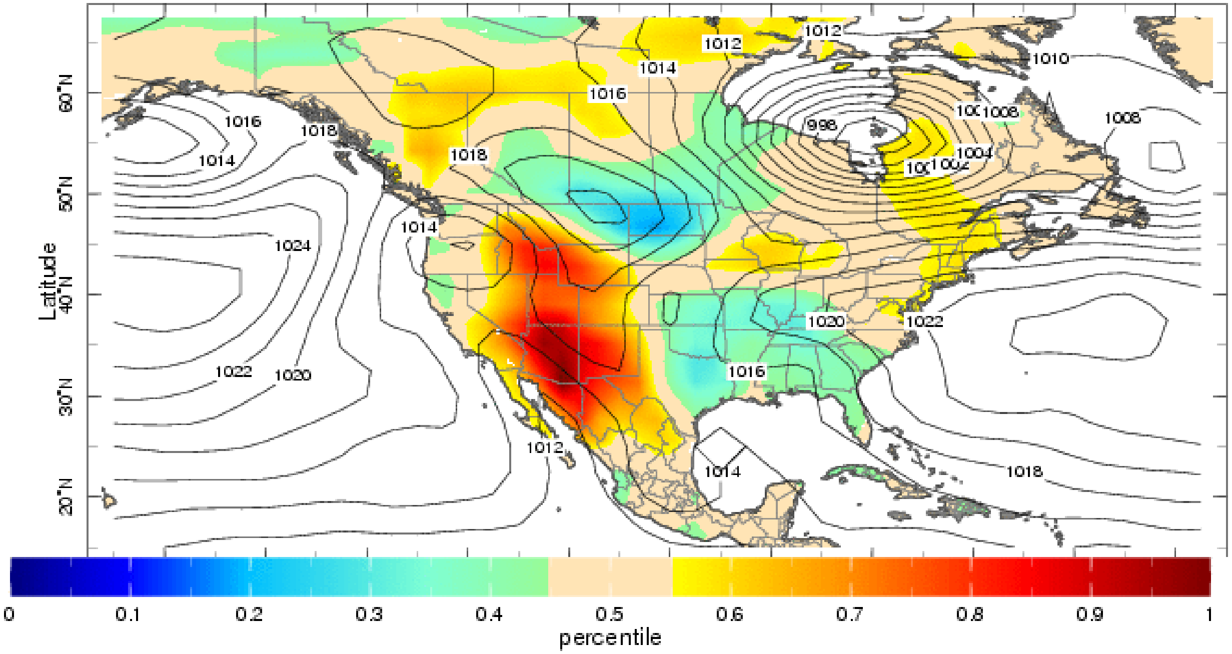
July 22, 1984

Station Temps.
> 90th %' ile

Extreme q and T_e in Southwest, very high Tmin

Specific Humidity Anomaly and SLP





Conclusions

Heat waves: defined by daily temperature exceeding a percentile threshold (e.g. 90 %ile) for a given number of consecutive days.

The 2011 summer heat wave (and drought) was competitive with the conditions of the Dust Bowl years (1934, 36). **The 2012 summer heat wave** was less severe in temperature, but the drought was among worst on record.

Heat waves defined using daily Tmax are **most frequent**, and tend to occur most in central/**southern Plains and eastward**, while those defined by daily Tmin are less frequent and locate more in the **Midwest.** For daily Tmean, the preferred location is spread broadly throughout the **midsection of the U.S.**

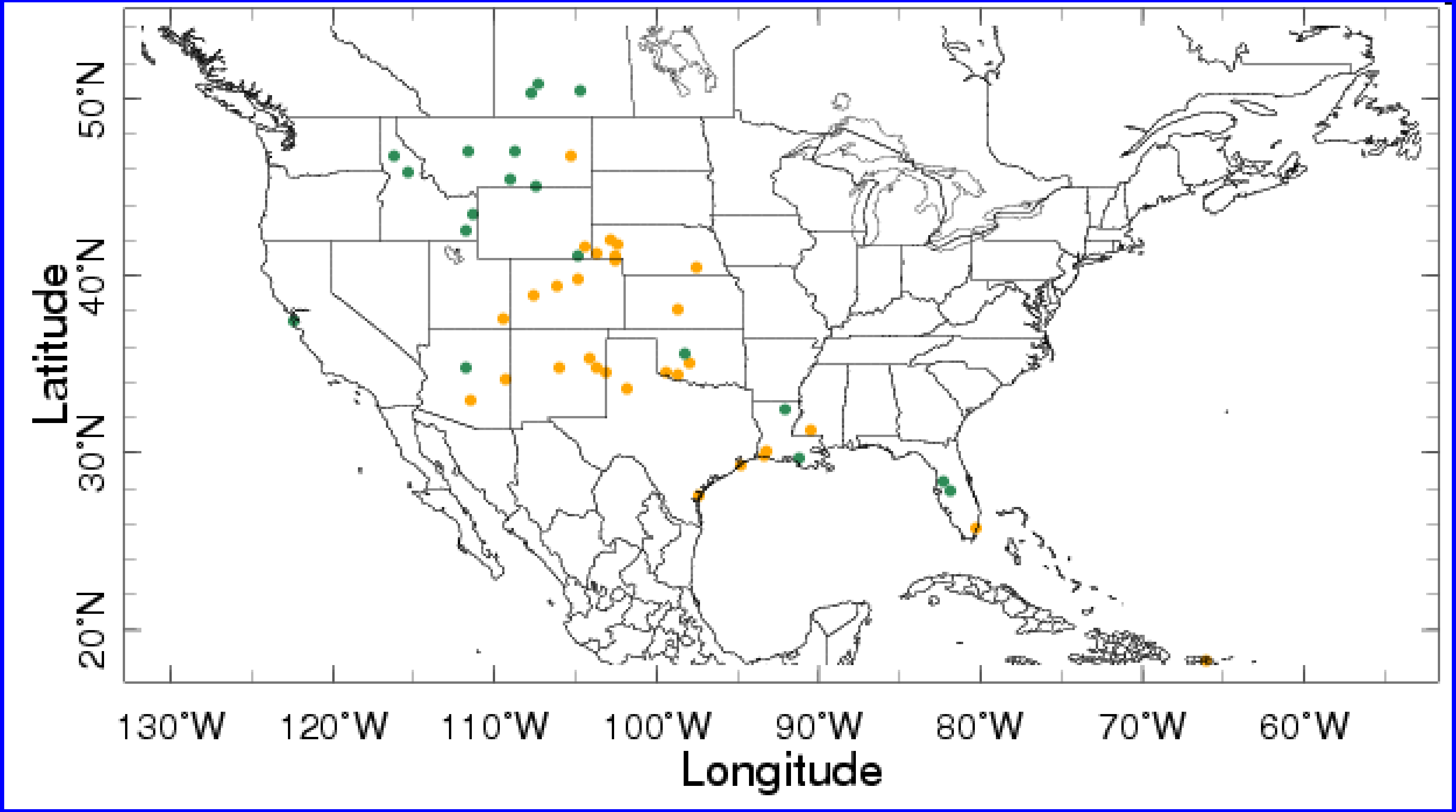
When moisture content (T_e) is incorporated in heat waves, Tmin is affected more than Tmax, and locations farther north (i.e., the Midwest) are emphasized.

Examples of heat wave “flavors” were shown (“dry” 1980, “moist 1984, 1995”).

A more systematic study leading to better understanding of the evolution and prediction of heat waves (identification, spatial and temporal description, “flavor” diagnosis, relationship with drought, and forecastability) in the U.S. is needed.

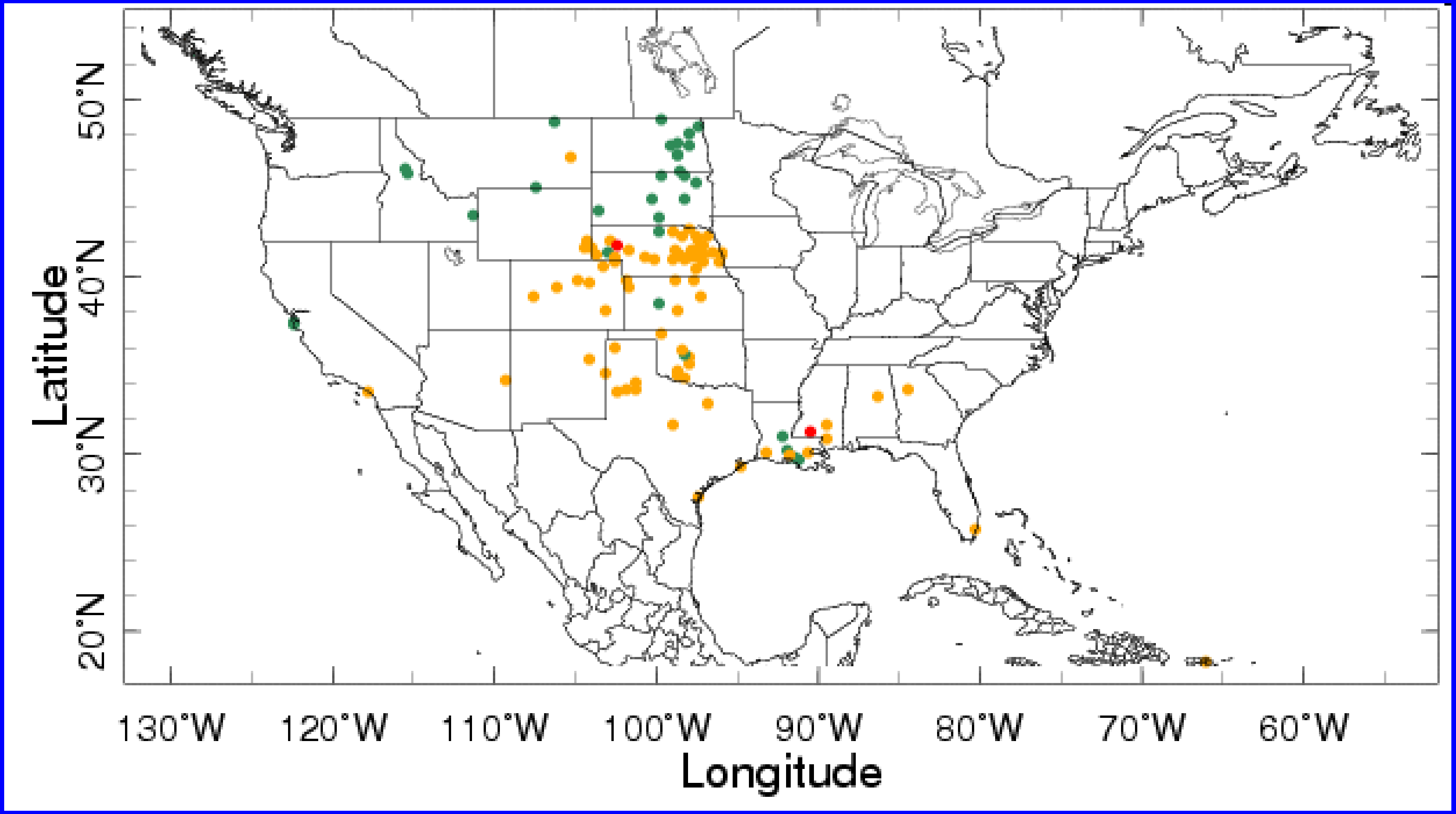
11 July 1995

"Chicago Heat Wave"



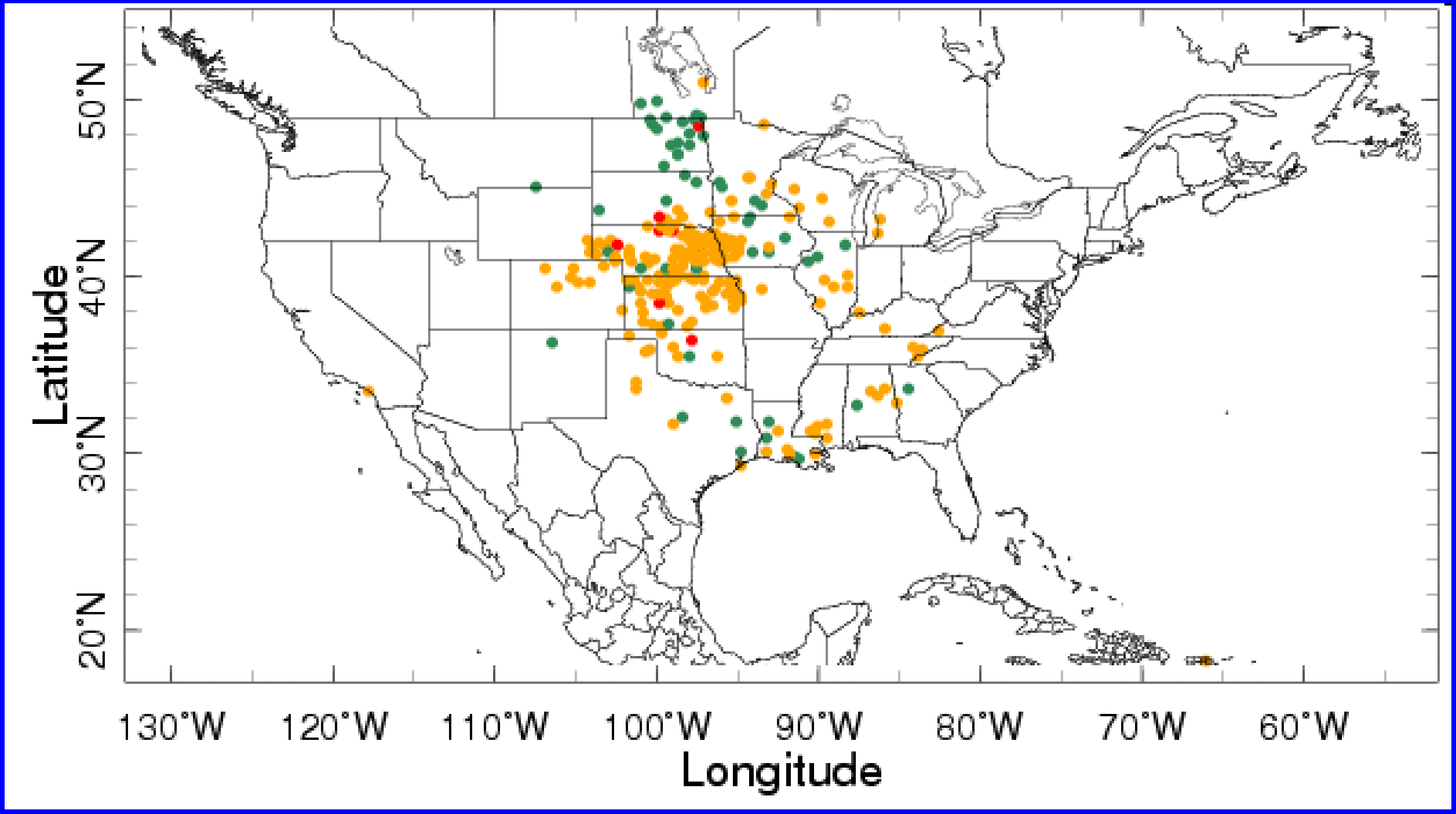
12 July 1995

"Chicago Heat Wave"



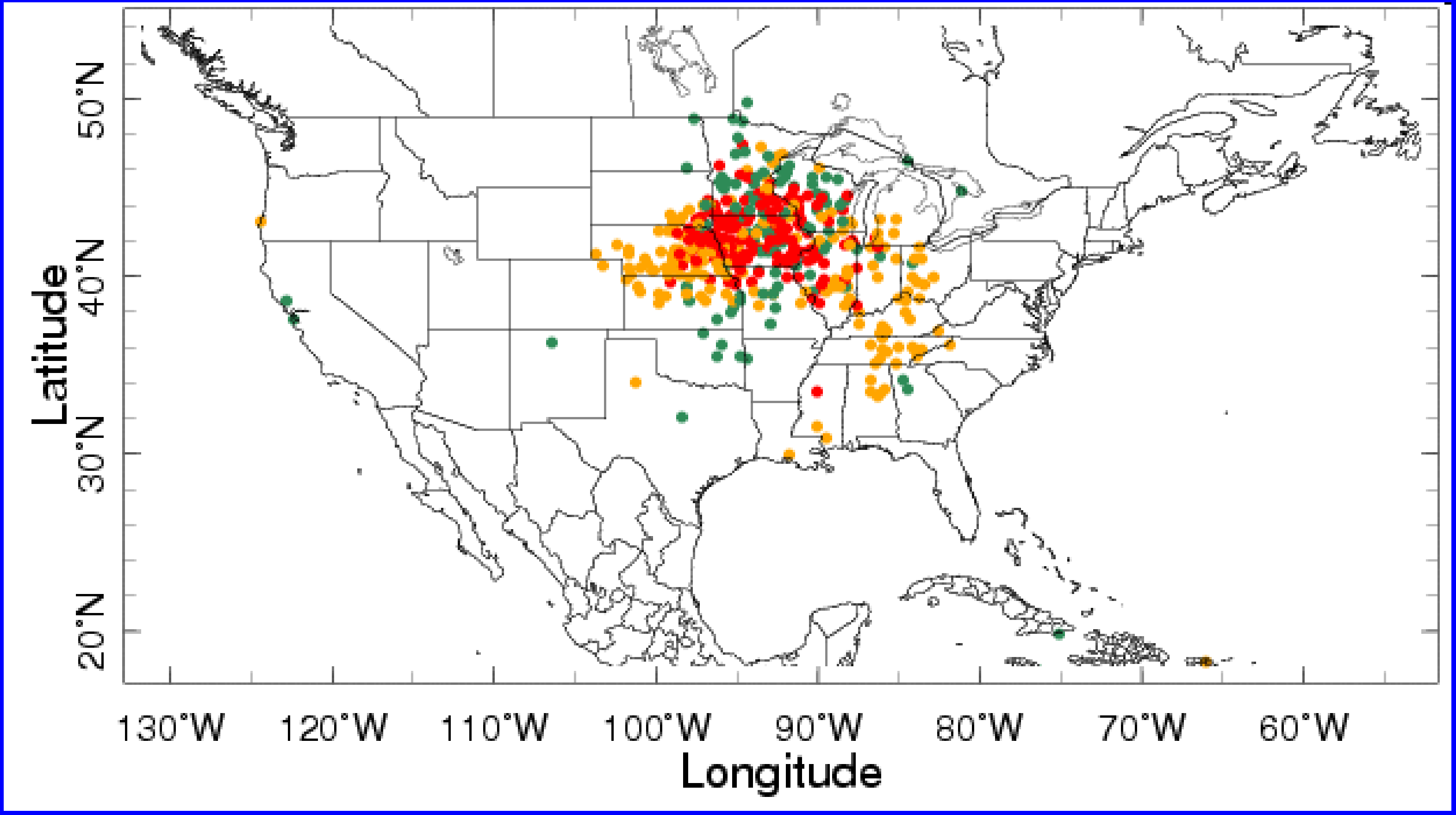
13 July 1995

“Chicago Heat Wave”



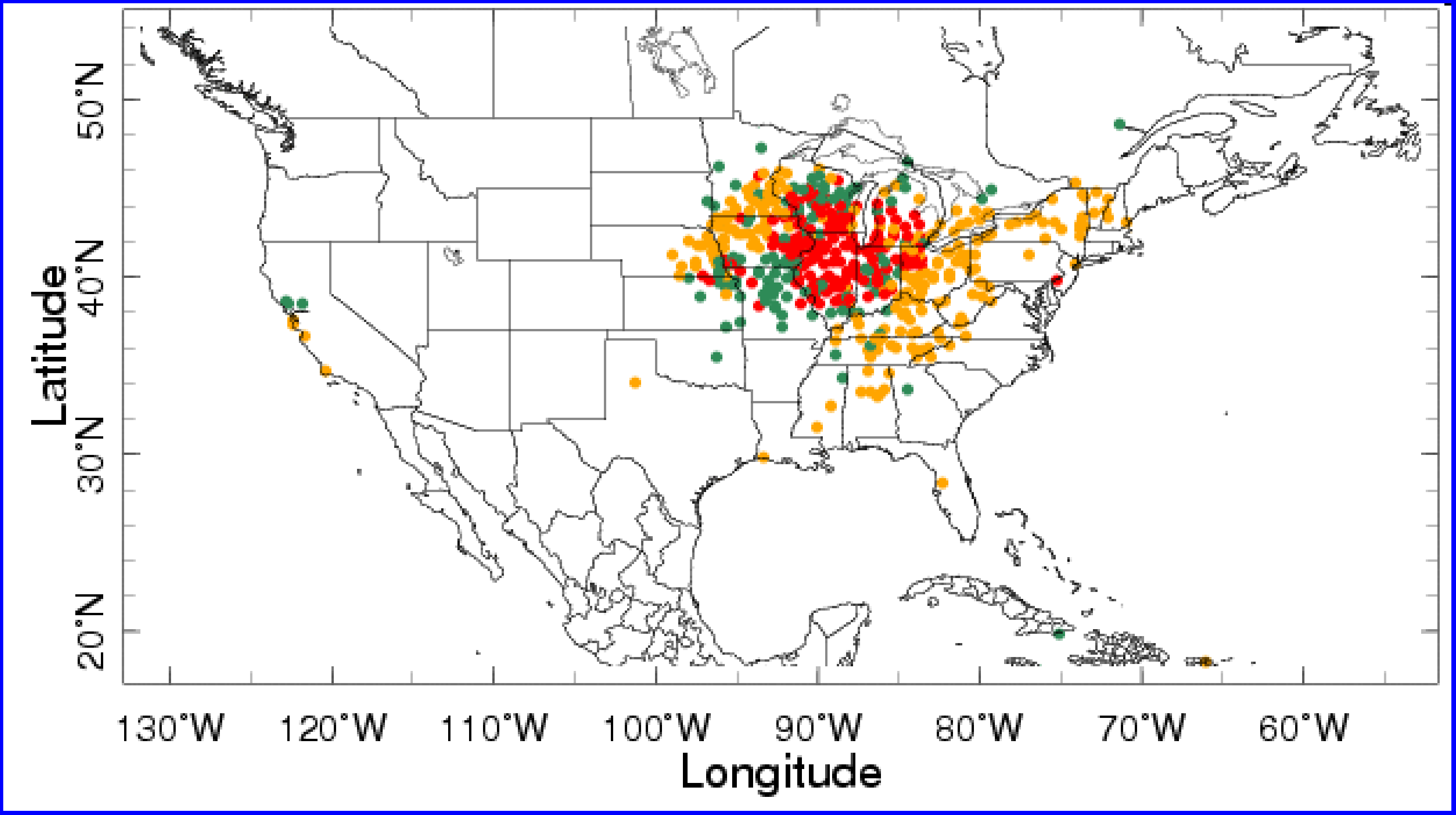
14 July 1995

“Chicago Heat Wave”



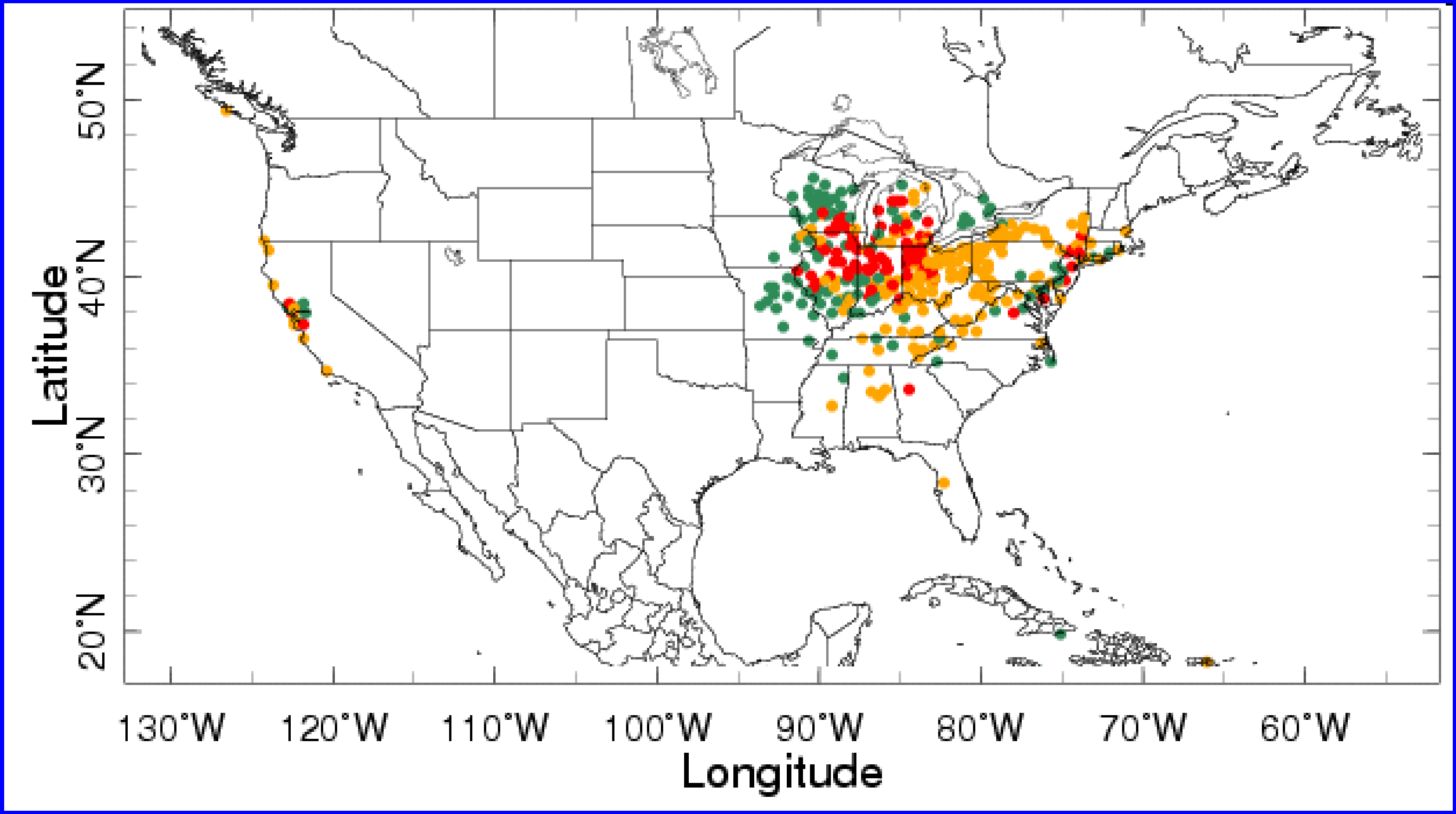
15 July 1995

“Chicago Heat Wave”



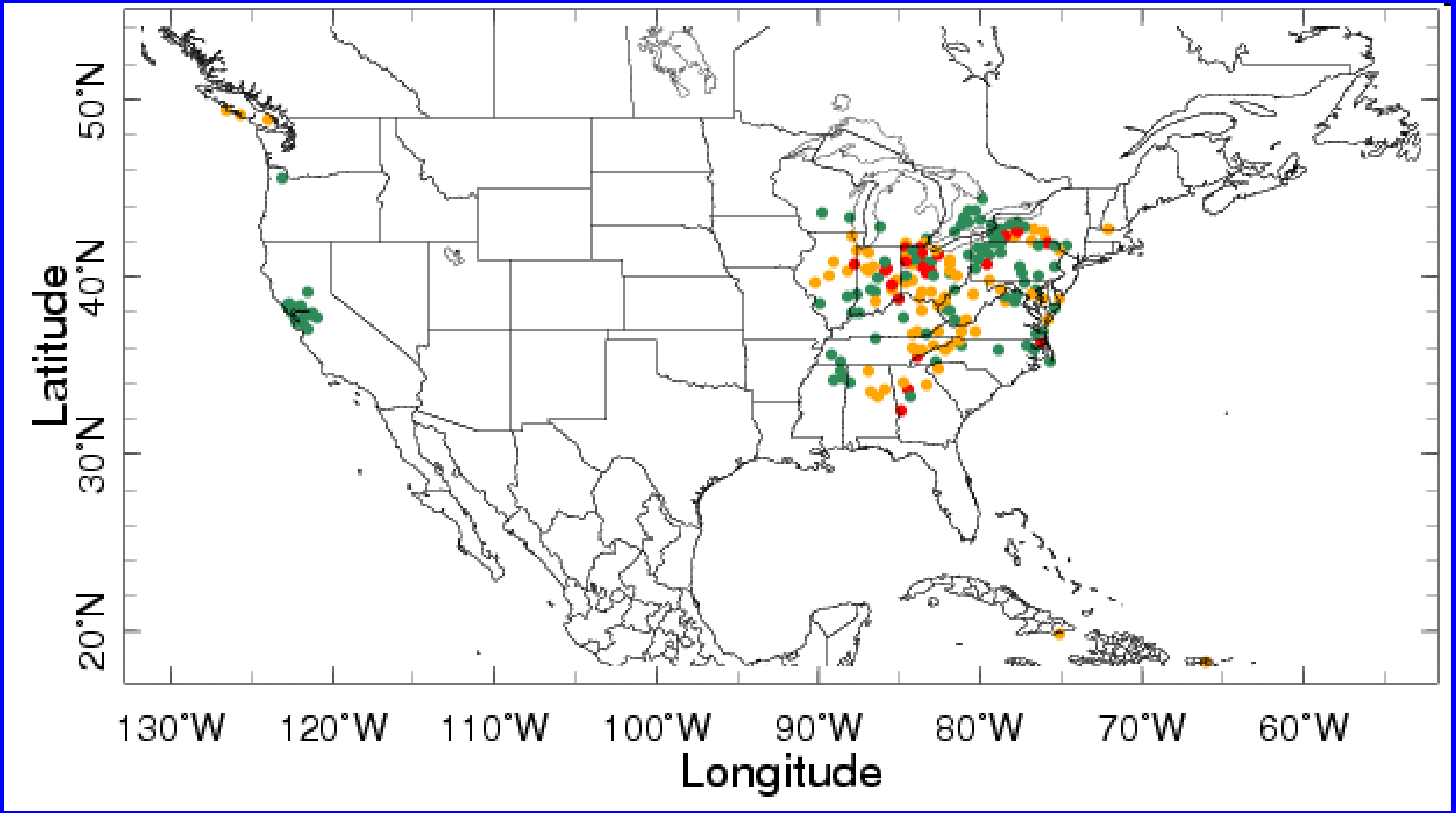
16 July 1995

“Chicago Heat Wave”



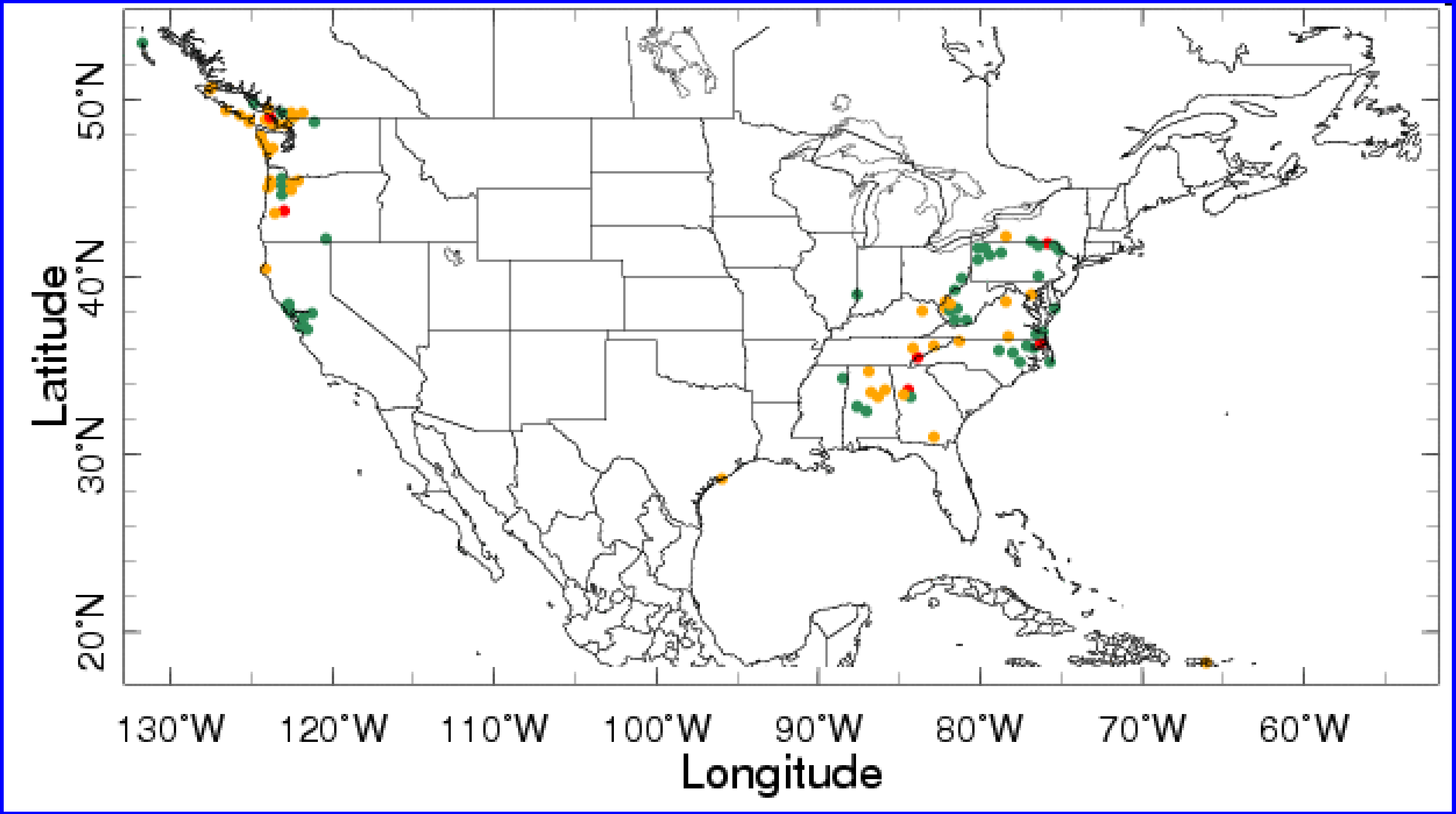
17 July 1995

“Chicago Heat Wave”



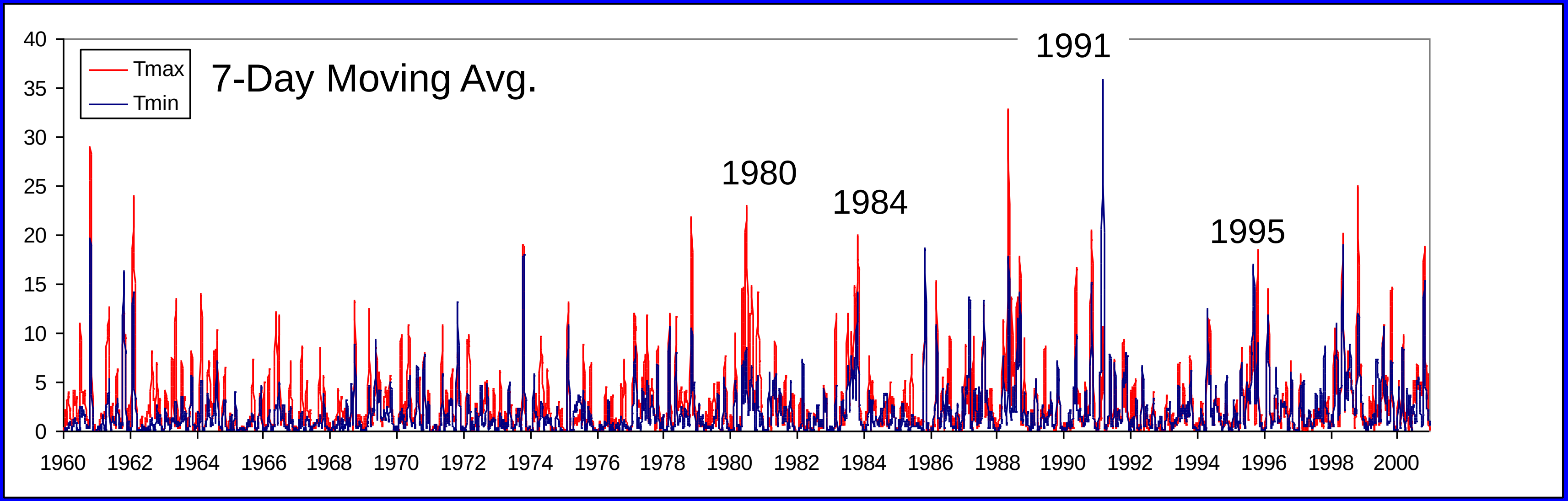
18 July 1995

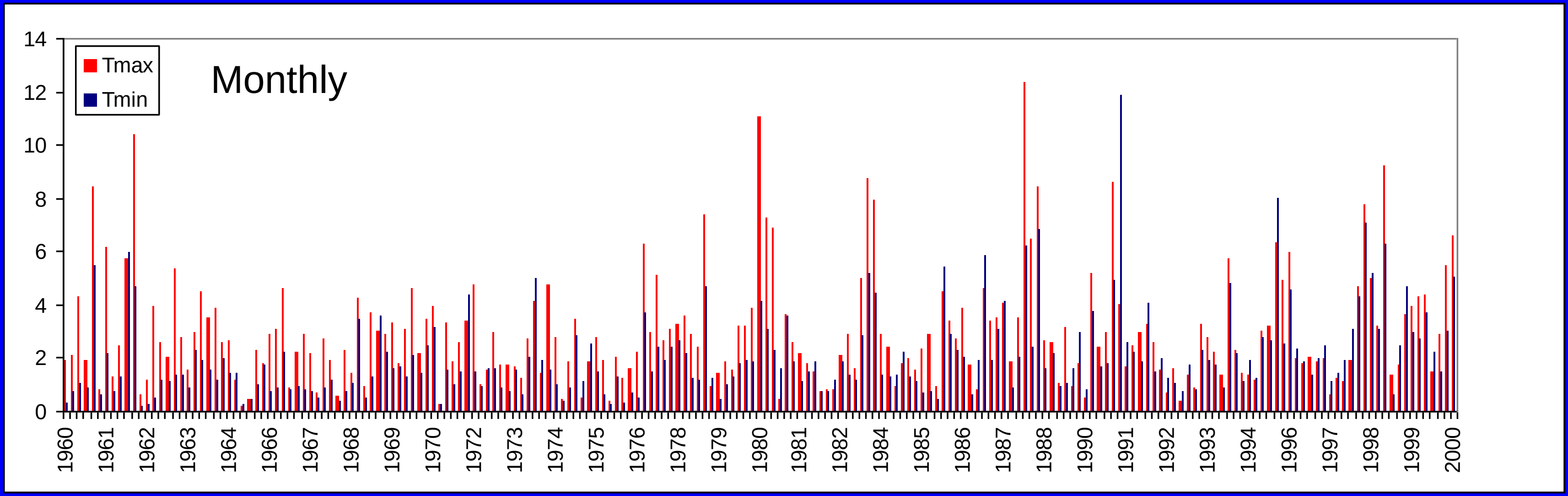
"Chicago Heat Wave"



Fraction (%) of Stations in Synchronous Heat Wave

All Stations May-Sept Seasons 1960-2000





Apparent Temperature Indices

Physically-based, "Equivalent Temperature" (T_e):

$$T_e = T + \frac{L_v}{c_p} q$$

Human Comfort-based, "Apparent Temperature" (HI) used by NWS:

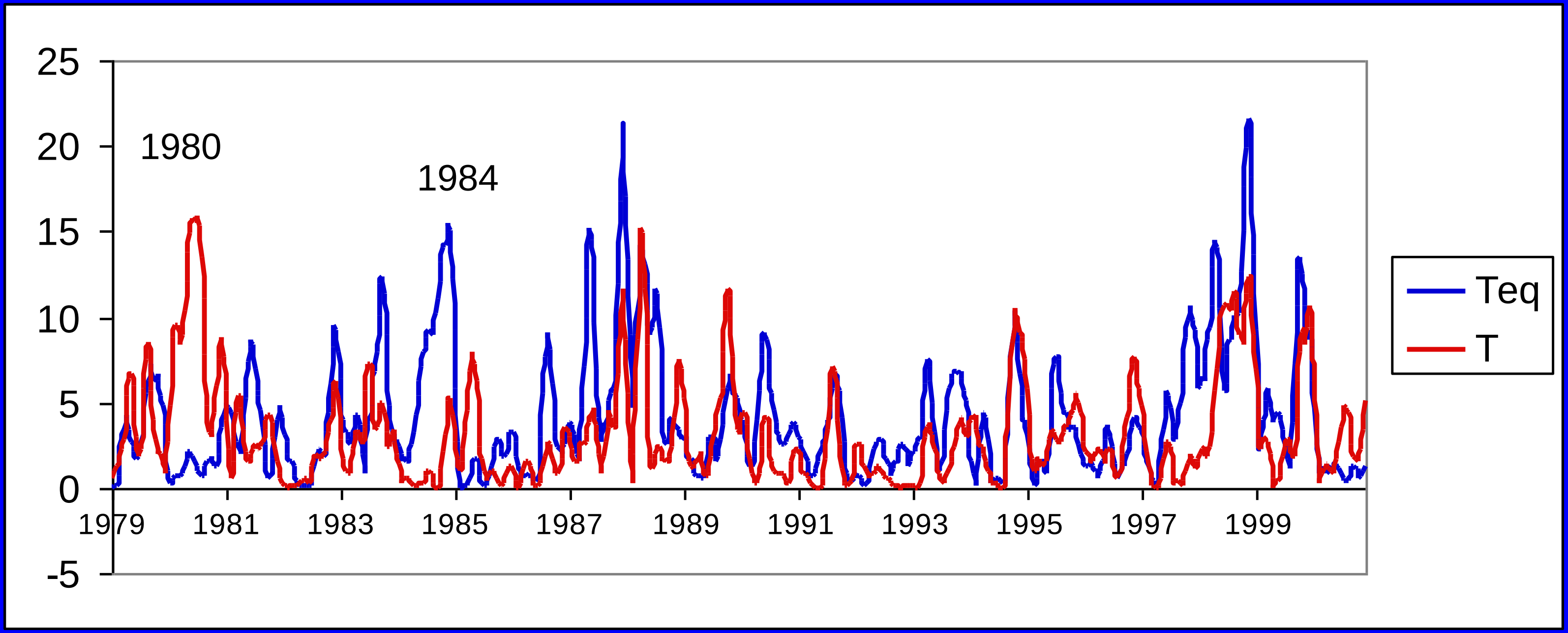
$$\boldsymbol{AT = c_1 + c_2T + c_3R + c_4TR + c_5T^2 + c_6R^2 + c_7T^2R + c_8TR^2 + c_9T^2R^2 + \ldots}$$
$$\boldsymbol{\ldots + c_{16}T^3R^3}$$

Where: T = temperature, R = Relative Humidity

→Also called the "**Heat Index**"
→Temp. should be > 80 F, RH > 40%

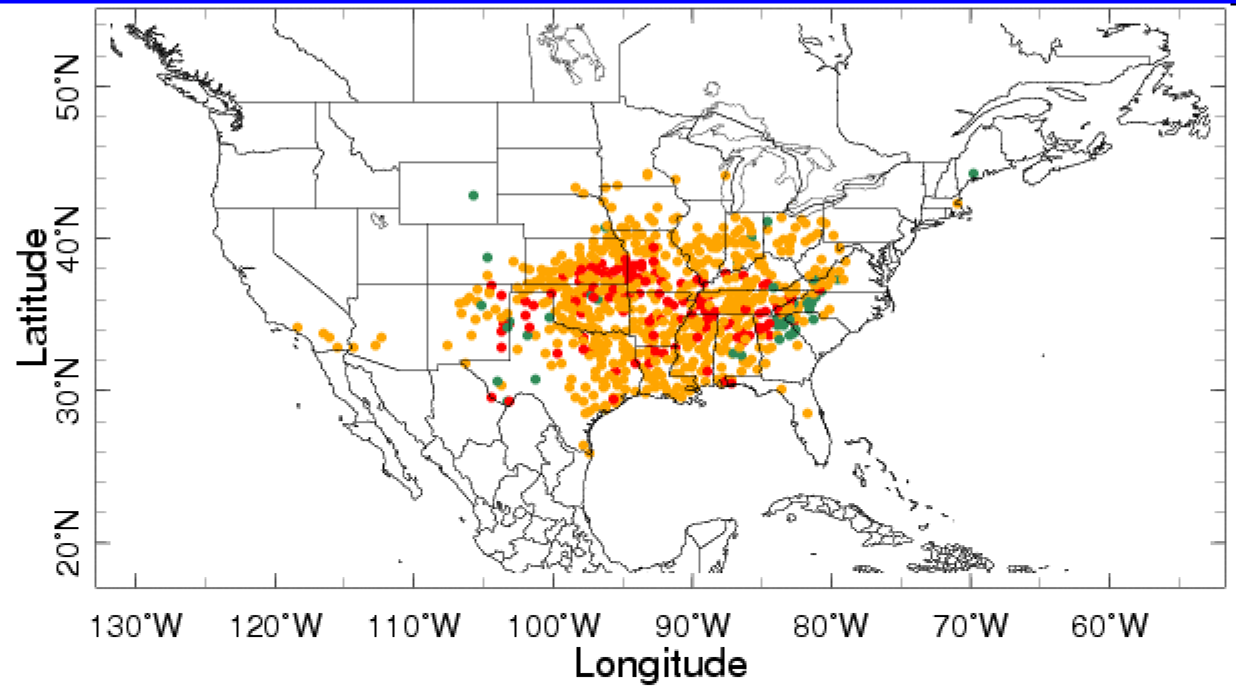
July Reanalysis 2m Temp and T_e
Fraction of US grid points > 90th percentile, 3+ days

5-day Moving Average 1979-2000

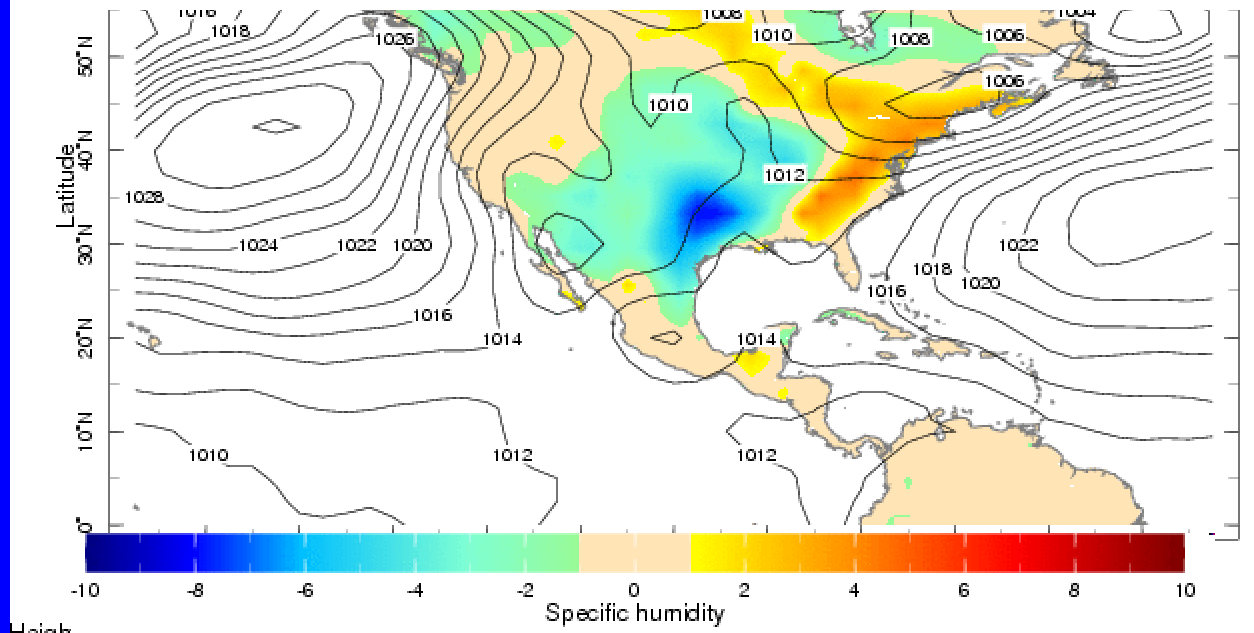


July 21, 1980

Station Temps. > 90th %' ile

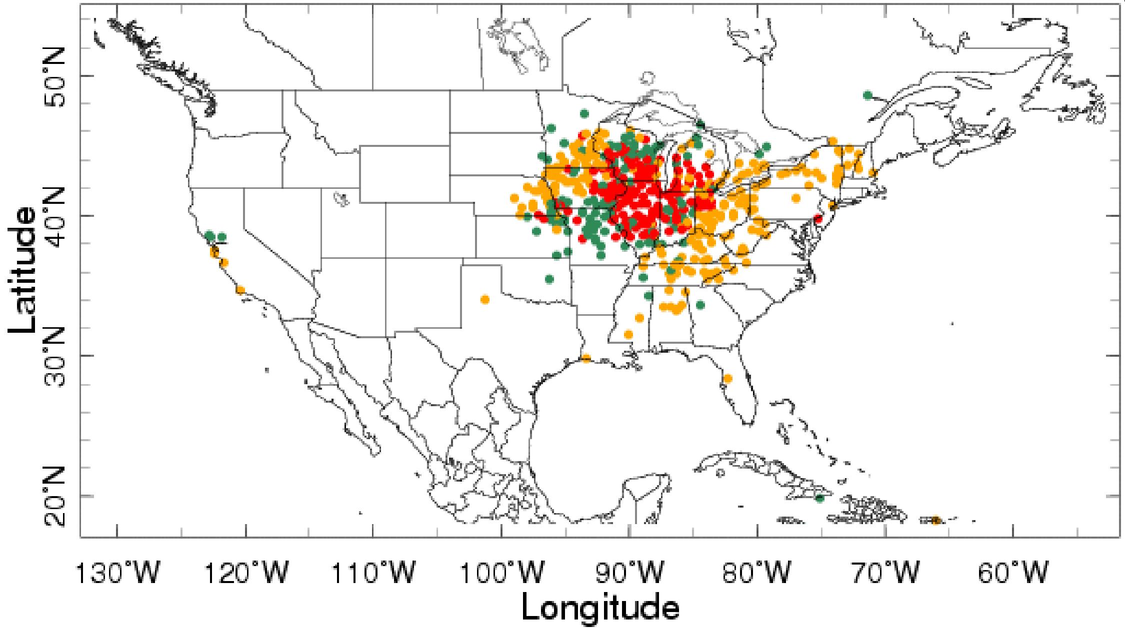


Specific Humidity Anomaly and SLP

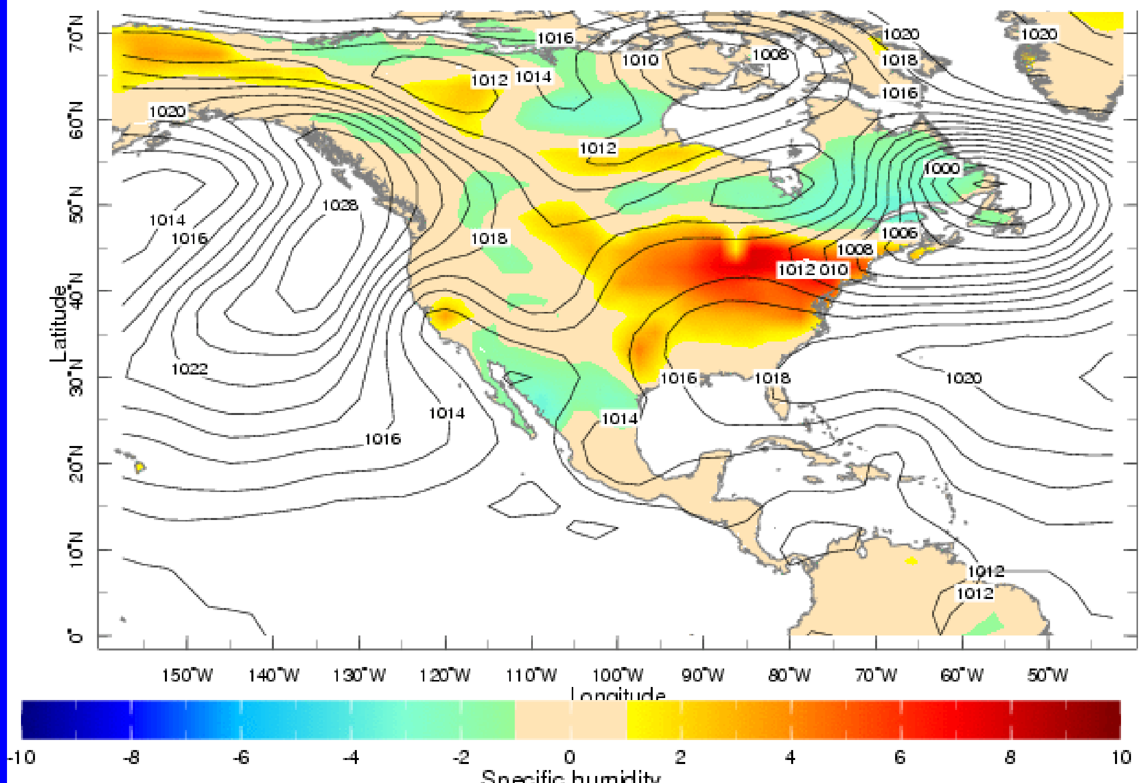


July 15, 1995

Station Temps.
> 90th %' ile

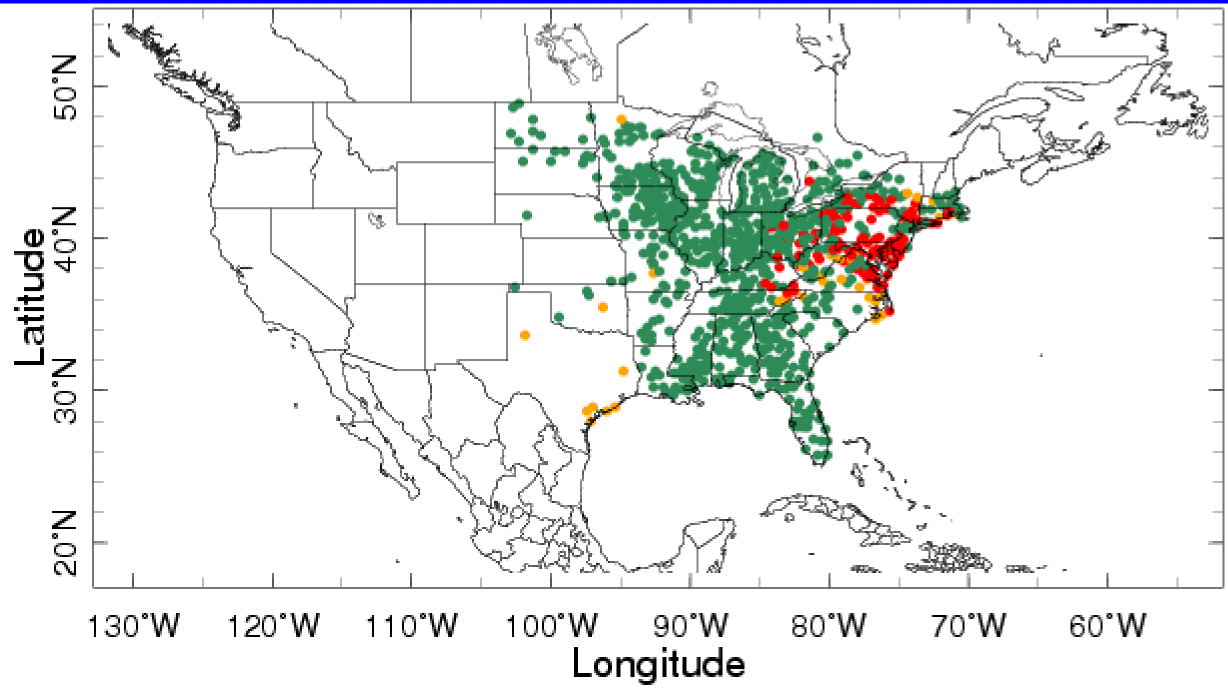


Specific Humidity
Anomaly
and
SLP

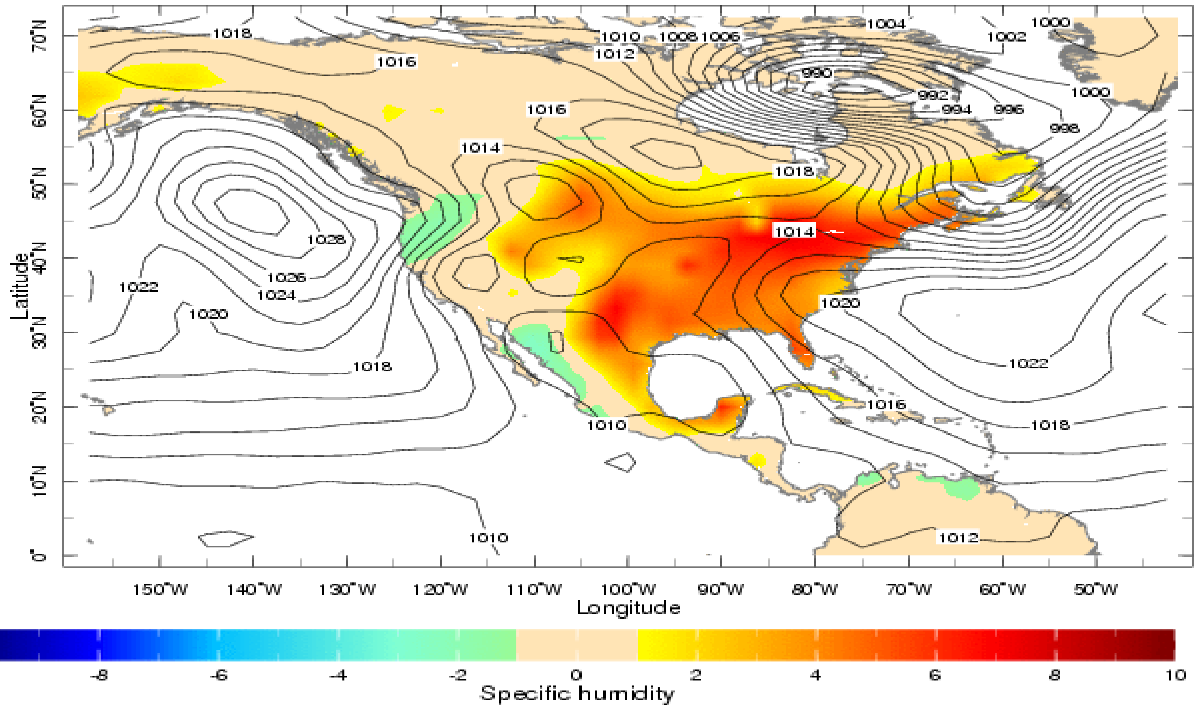


May 21, 1991

Station Temps.
> 90th %' ile



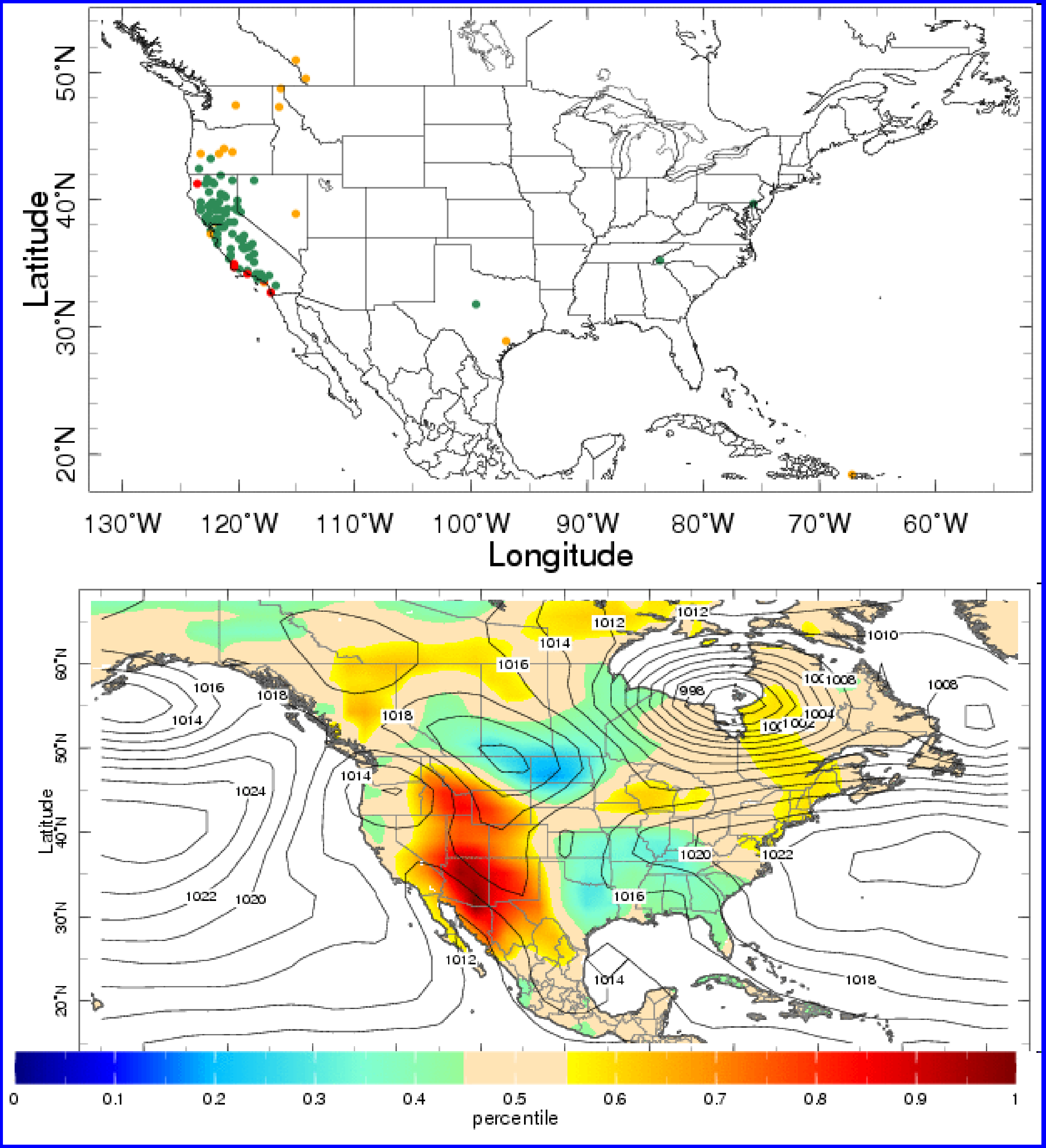
Specific Humidity Anomaly and SLP



July 22, 1984

Station Temps.
> 90th %' ile

Specific Humidity Anomaly and SLP



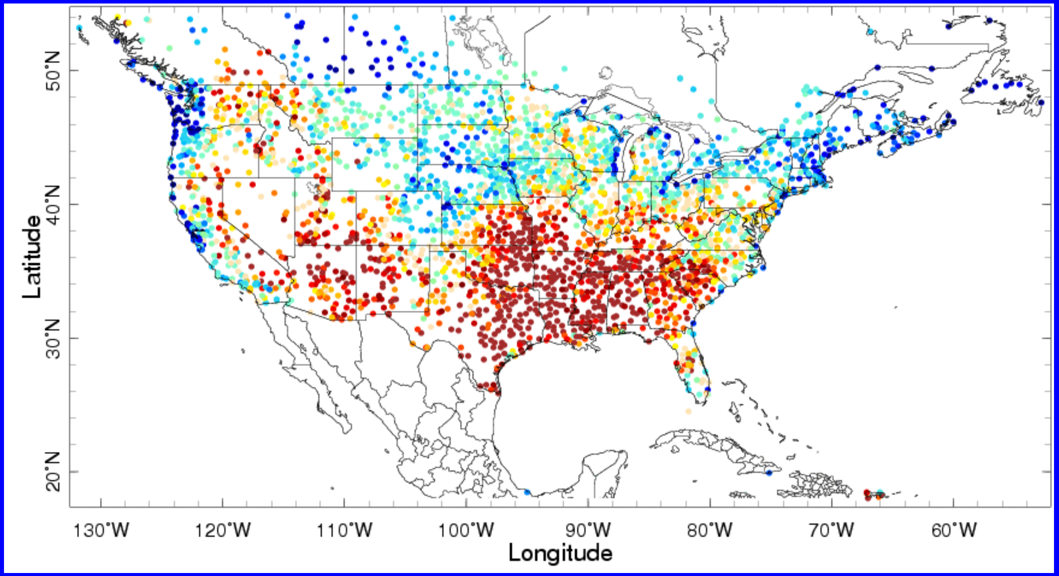
Conclusions

- Tmax extremes are more persistent than Tmin
- Tmax AND Tmin most likely in east-central US (and inland west coast)
- Tmin more highly correlated with low-level moisture than Tmax and predominantly in the eastern US
- Te shows maximum variance in eastern US (where moisture variance is highest). Implications for heat stress.
- Different heat wave flavors:
  - "Dry" and protracted (July 1980), associated with drought; tendency for more Tmax extremes than Tmin
  - "Moist" (May 1991, July 1995), more Tmin extremes than Tmax
  - Short-lived (July 1995, "Chicago" heat wave)
- Understanding the evolution of heat waves from a climate perspective (onset, duration, spatial scale, causes, predictability) using variables relevant to health is the ultimate goal of this work

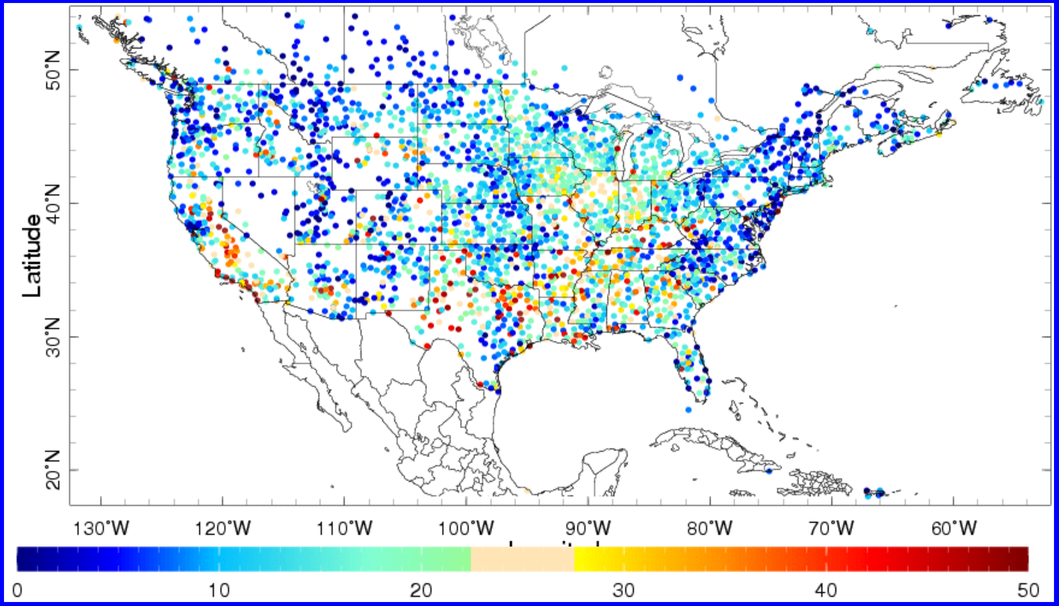
Supplemental Slides

(> 90th %' ile, 7+ days) Total "Heat Wave Days" 1960-2000

Maximum



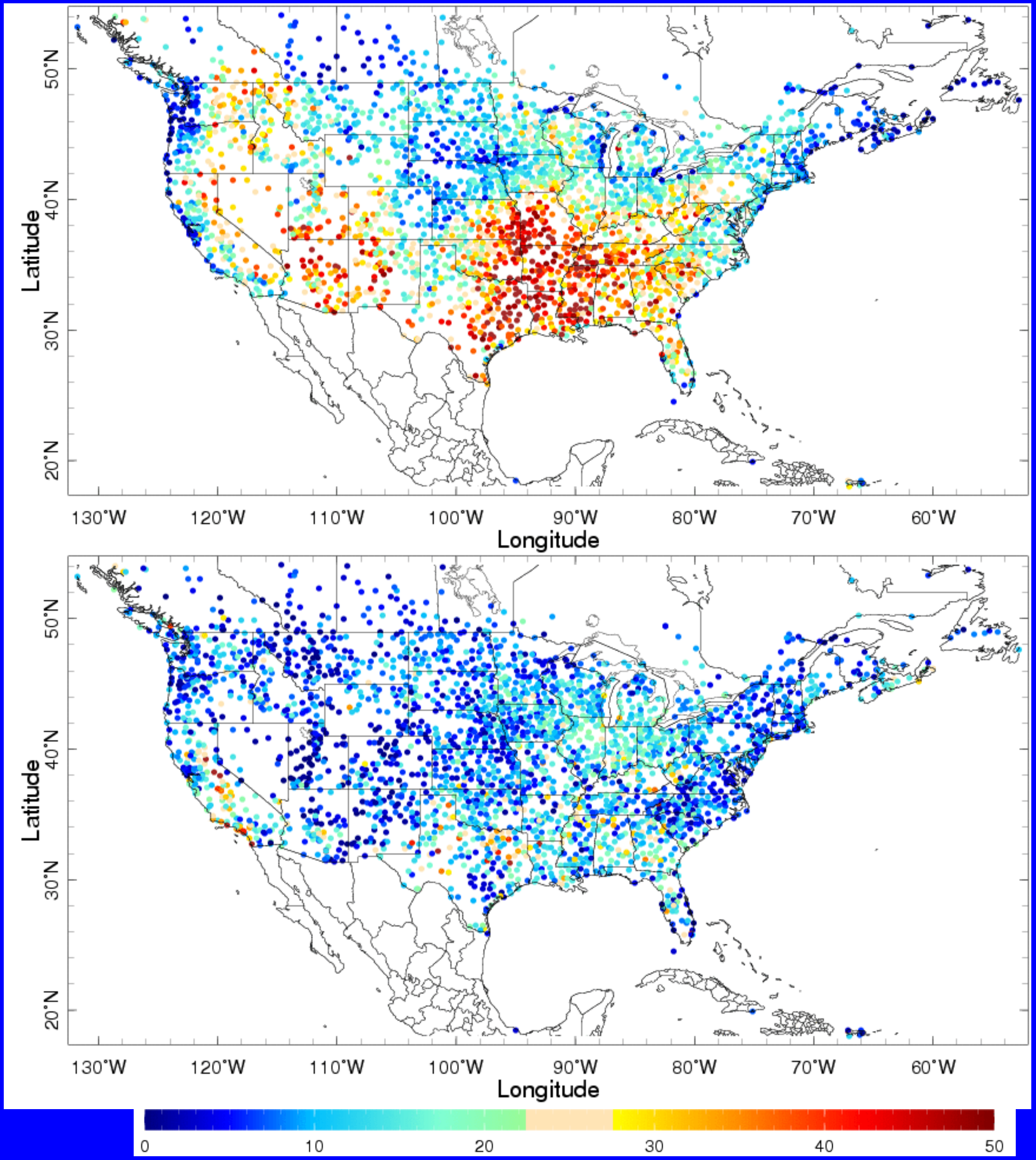
Minimum



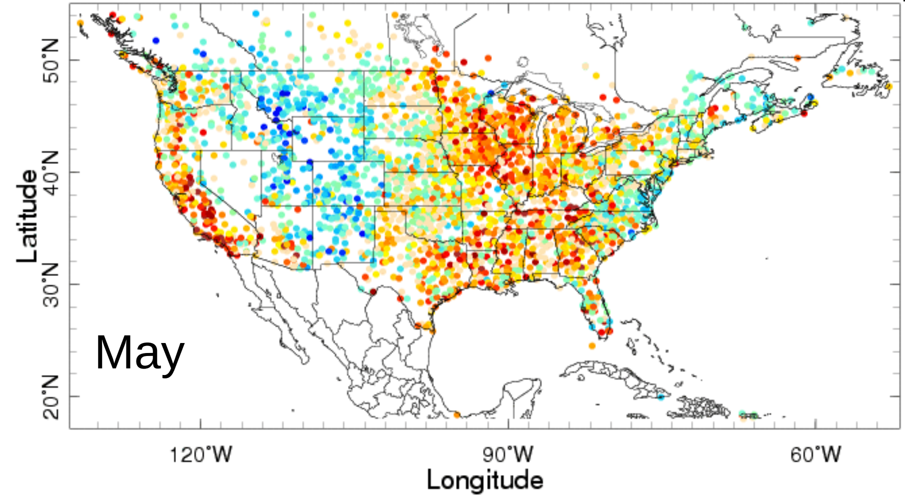
(> 95th %’ ile, 5+ days) Total “Heat Wave Days” 1960-2000

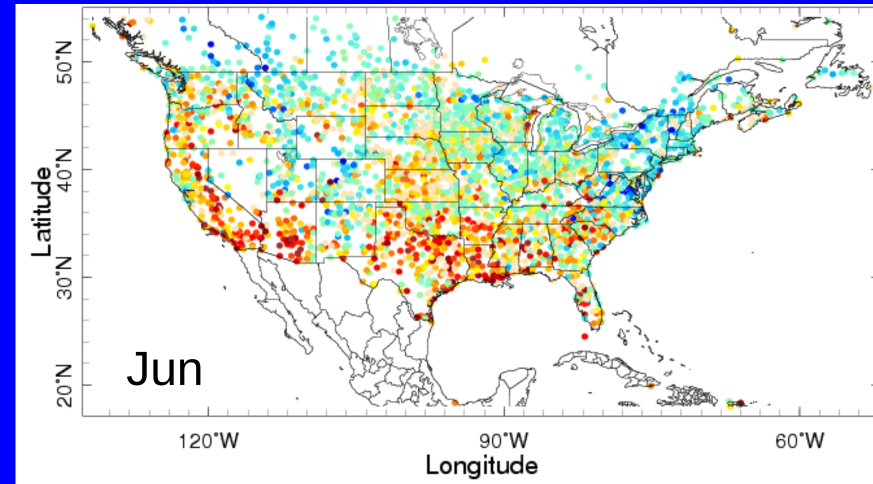
Maximum

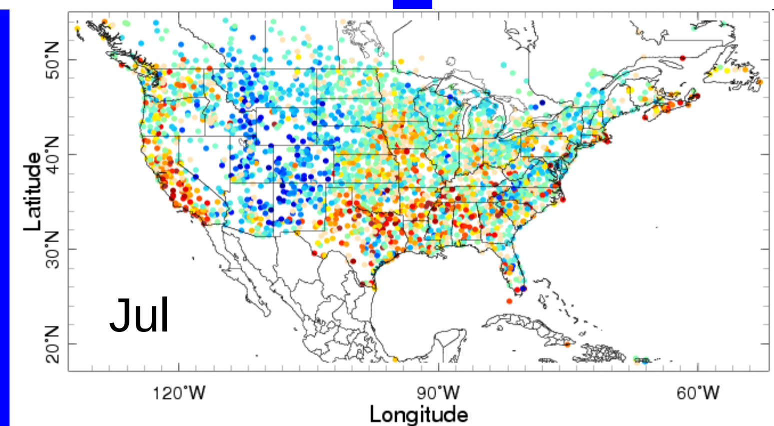
Minimum

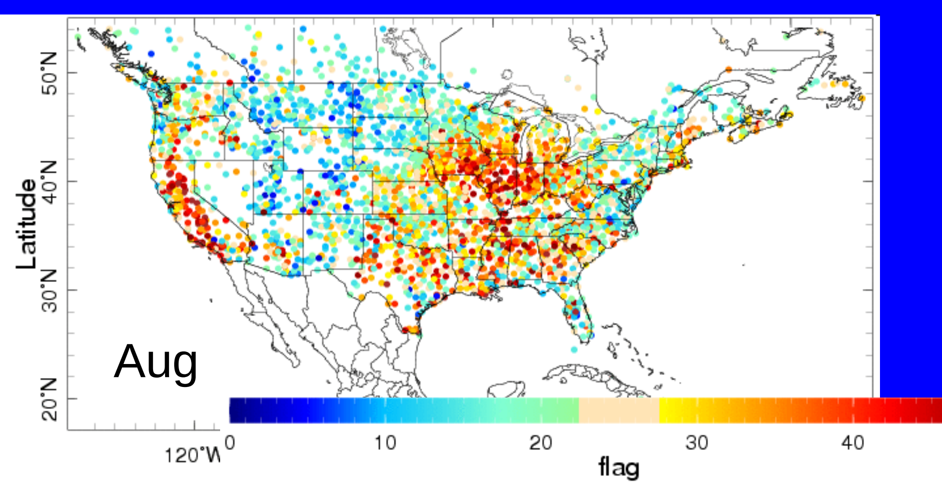


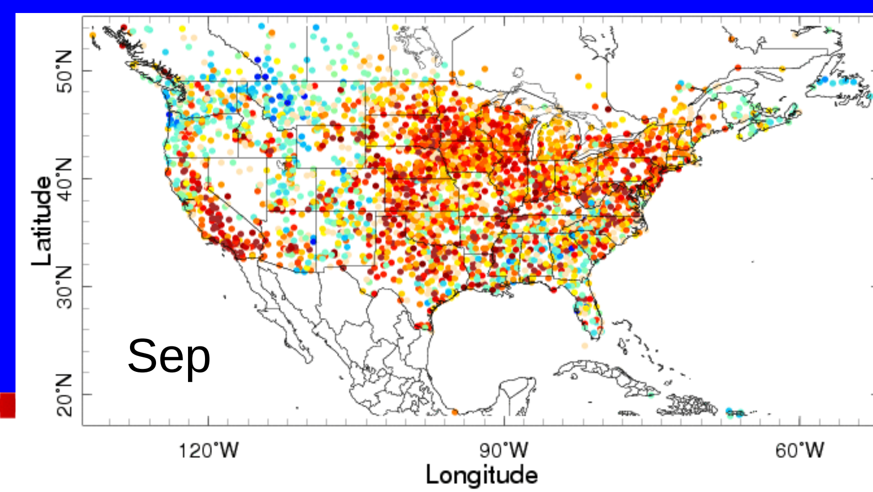
Tmin 90th, 3+ days

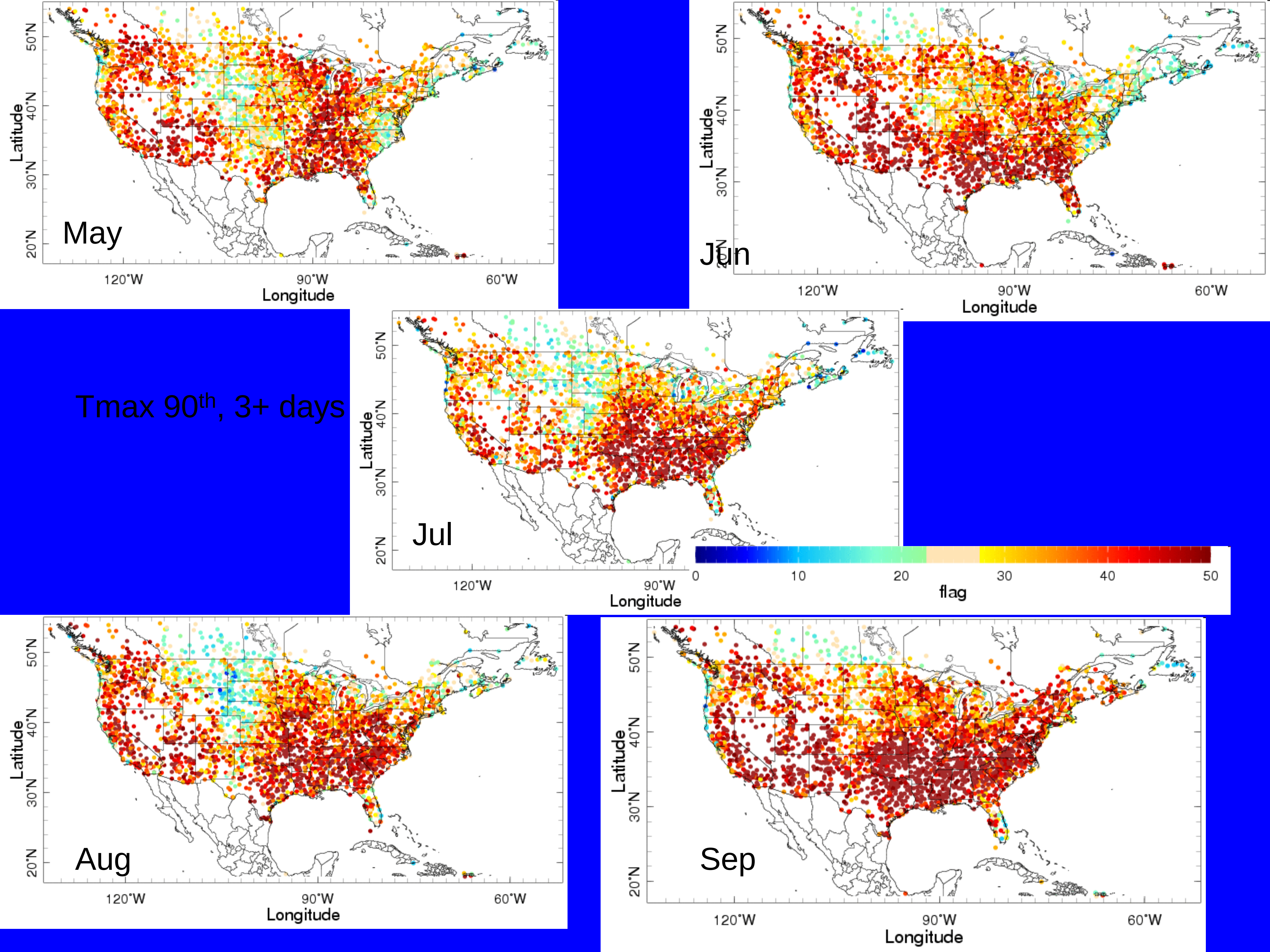




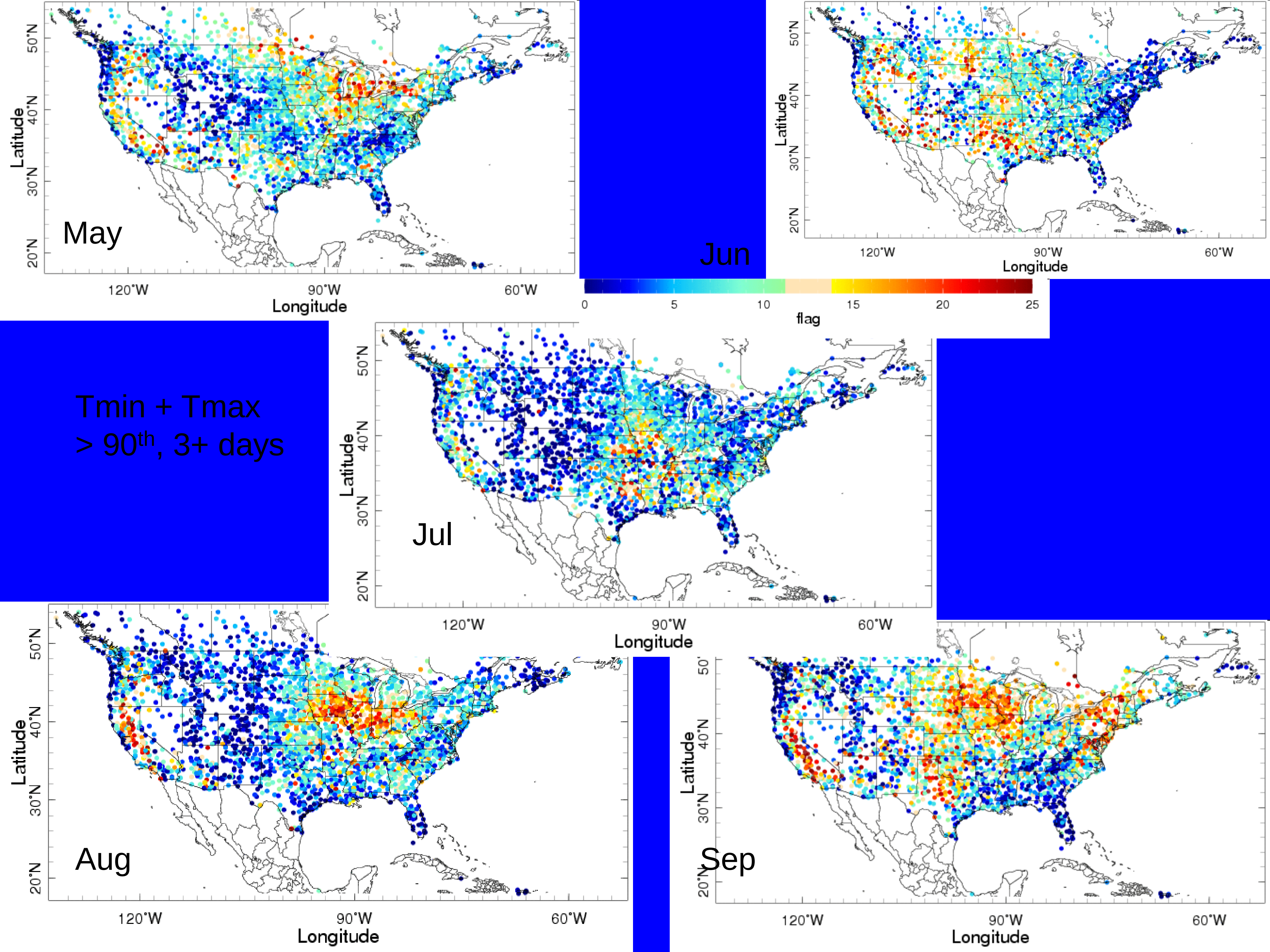




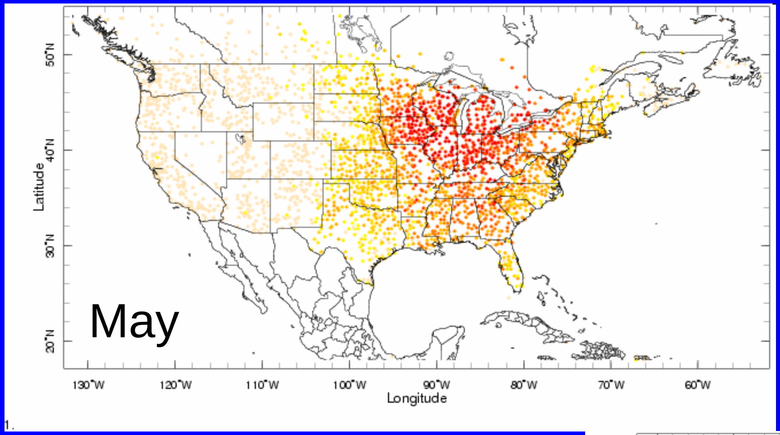


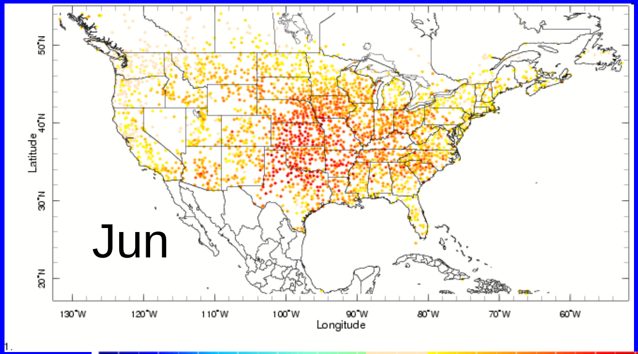


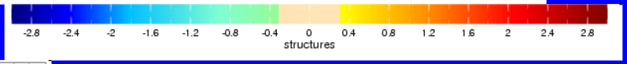
Tmax 90th, 3+ days
May
Jun
Jul
Aug
Sep
Latitude
Longitude
50°N
40°N
30°N
20°N
120°W
90°W
60°W
0
10
20
30
40
50
flag

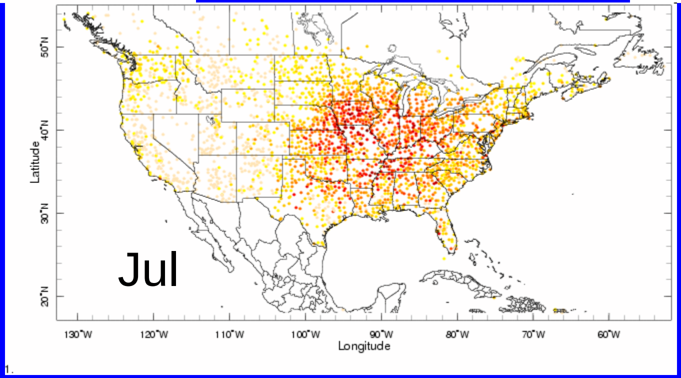

Tmin + Tmax
> 90th, 3+ days
May
Jun
Jul
Aug
Sep
Latitude
Longitude
50°N
40°N
30°N
20°N
120°W
90°W
60°W
flag
0
5
10
15
20
25

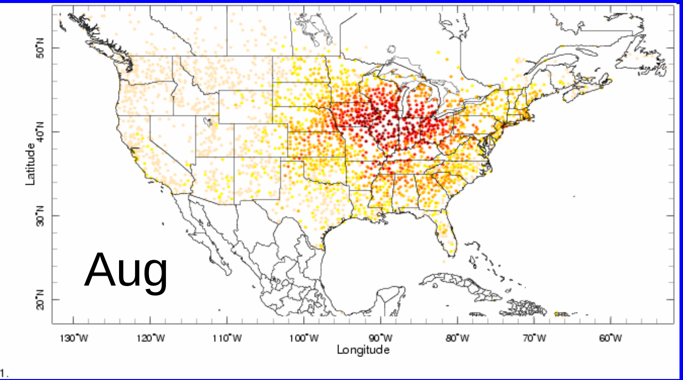
EOF 1 Tn90_3 by Month

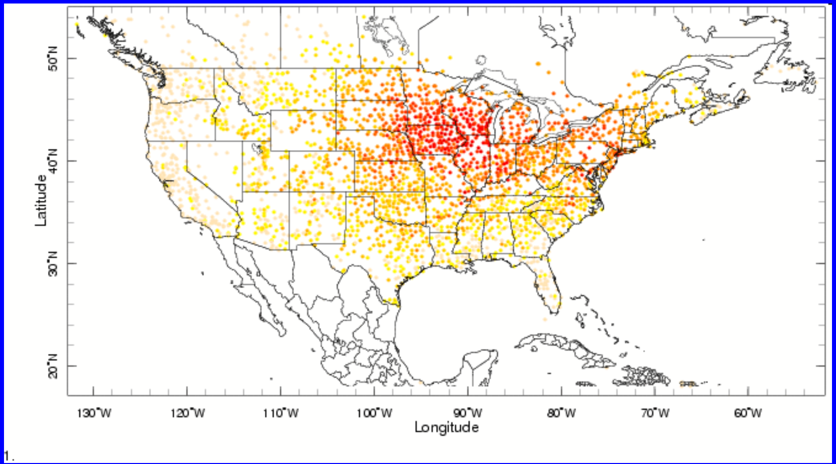


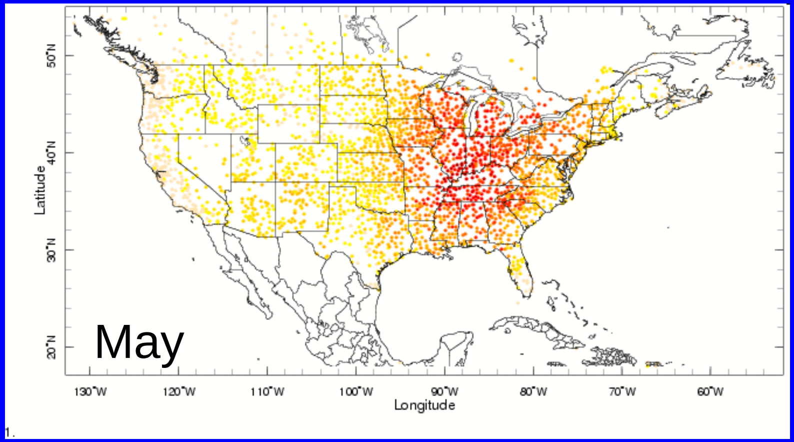


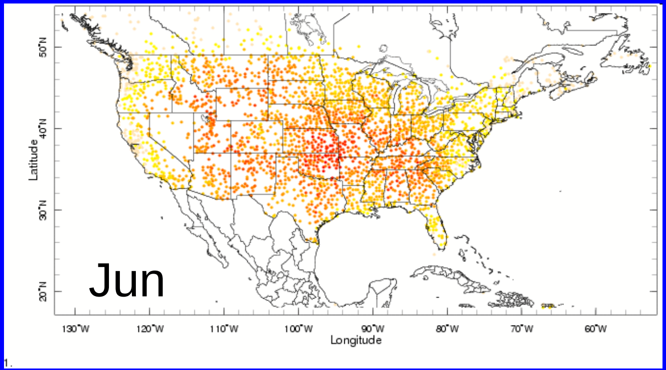


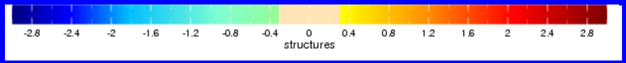




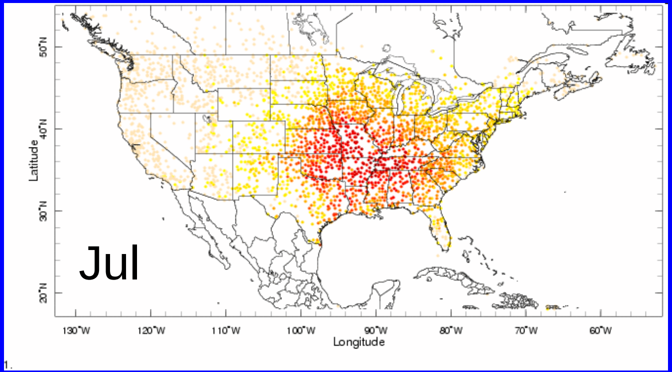


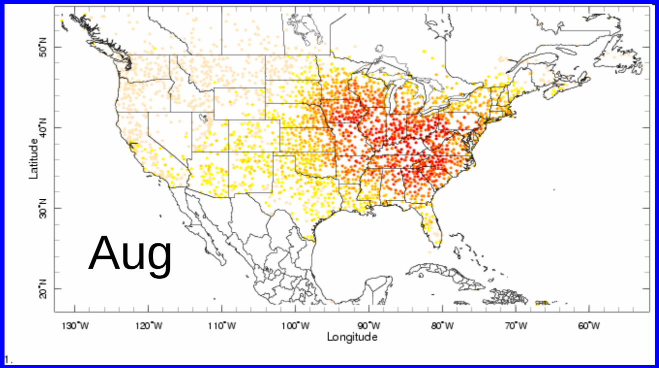


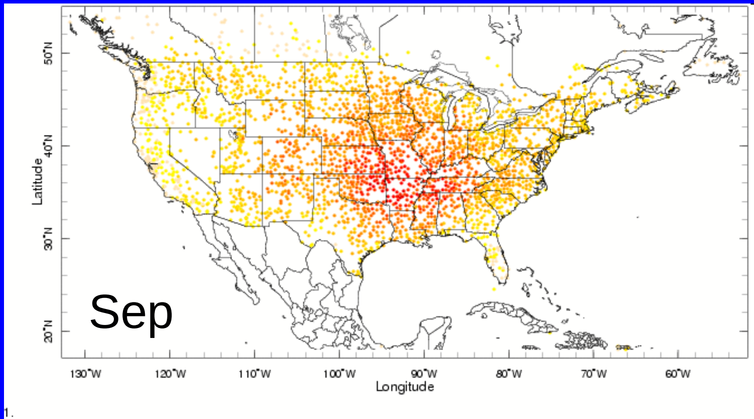




EOF 1 Tx90_3 by Month

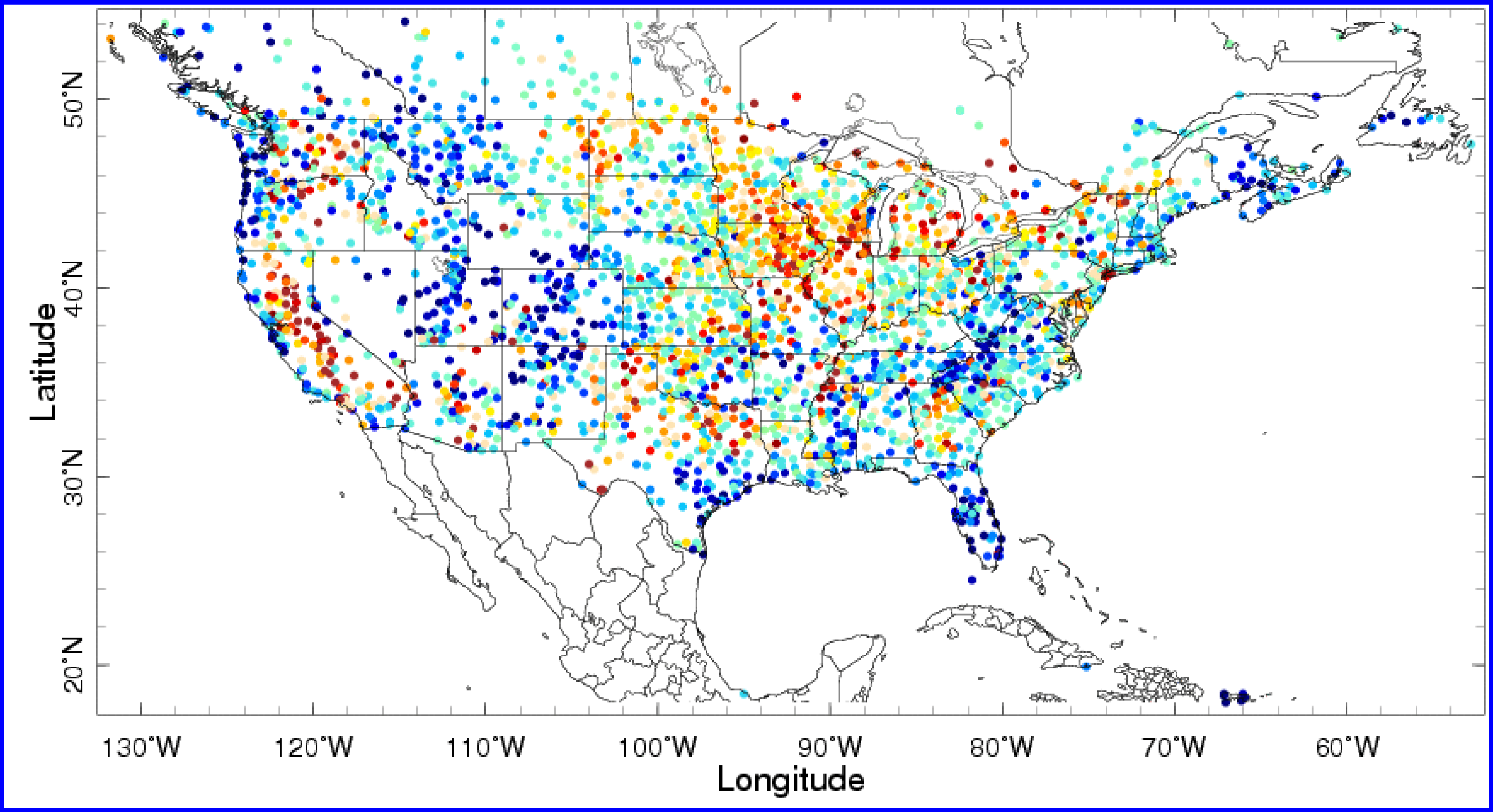




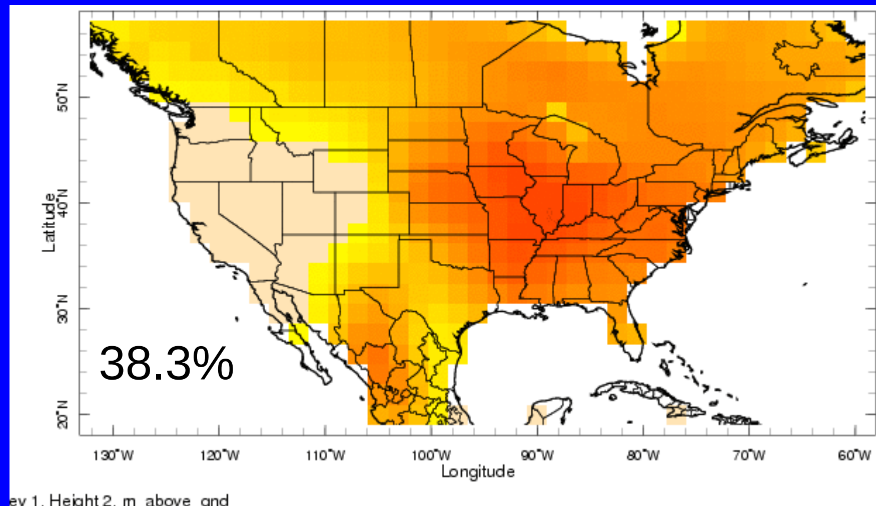


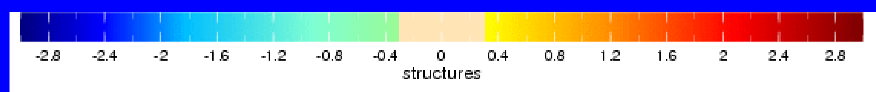
(> 95th %’ ile, 3+ days) Total “Heat Wave Days” 1960-2000

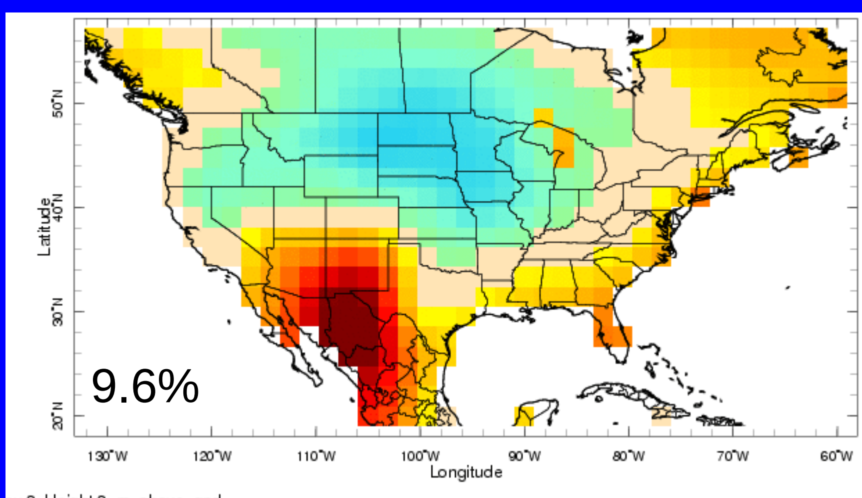
Maximum <u>and</u> Minimum Temperature

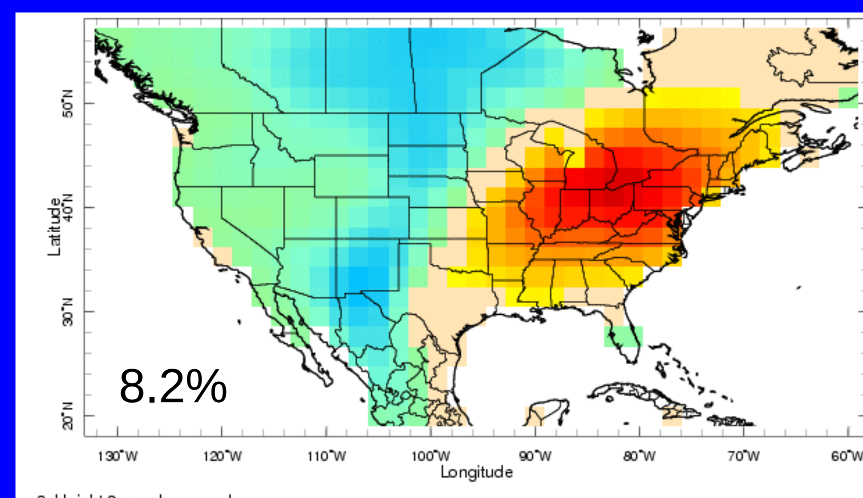


First 3 EOFs 2m qa Reanalysis (JJA)



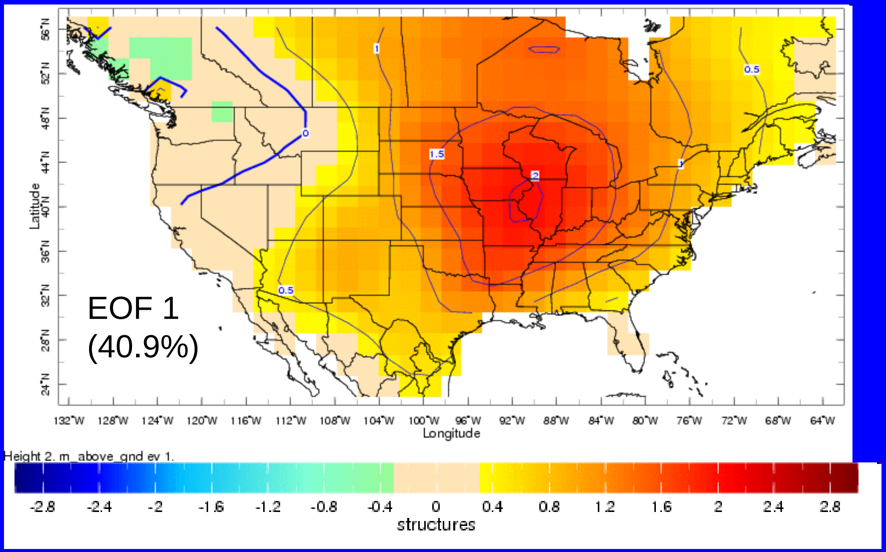


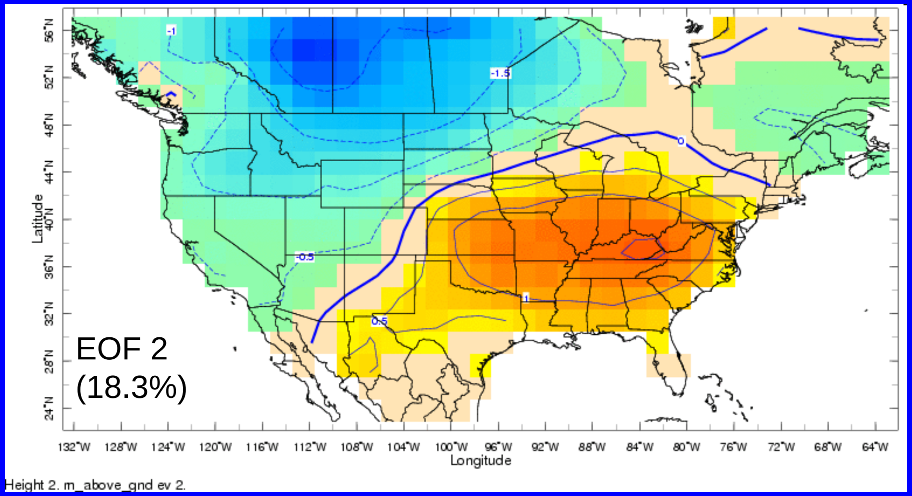


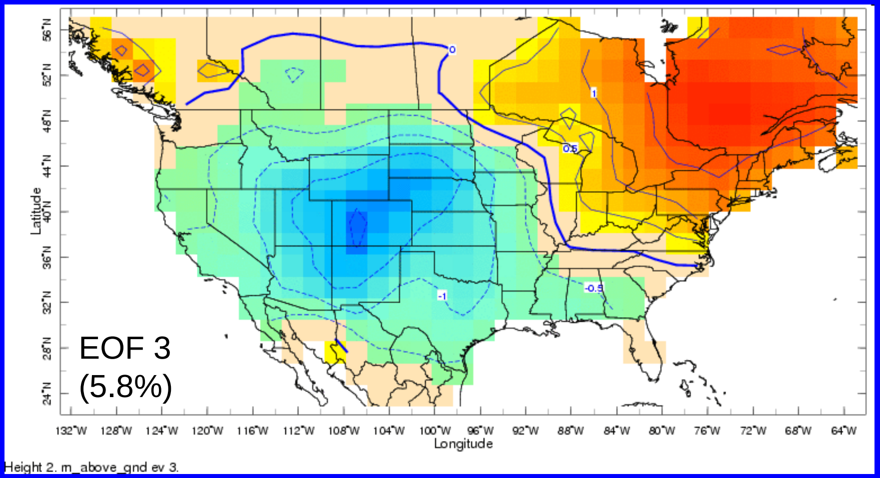


JJA Leading EOF of Equivalent Temperature (T_e)

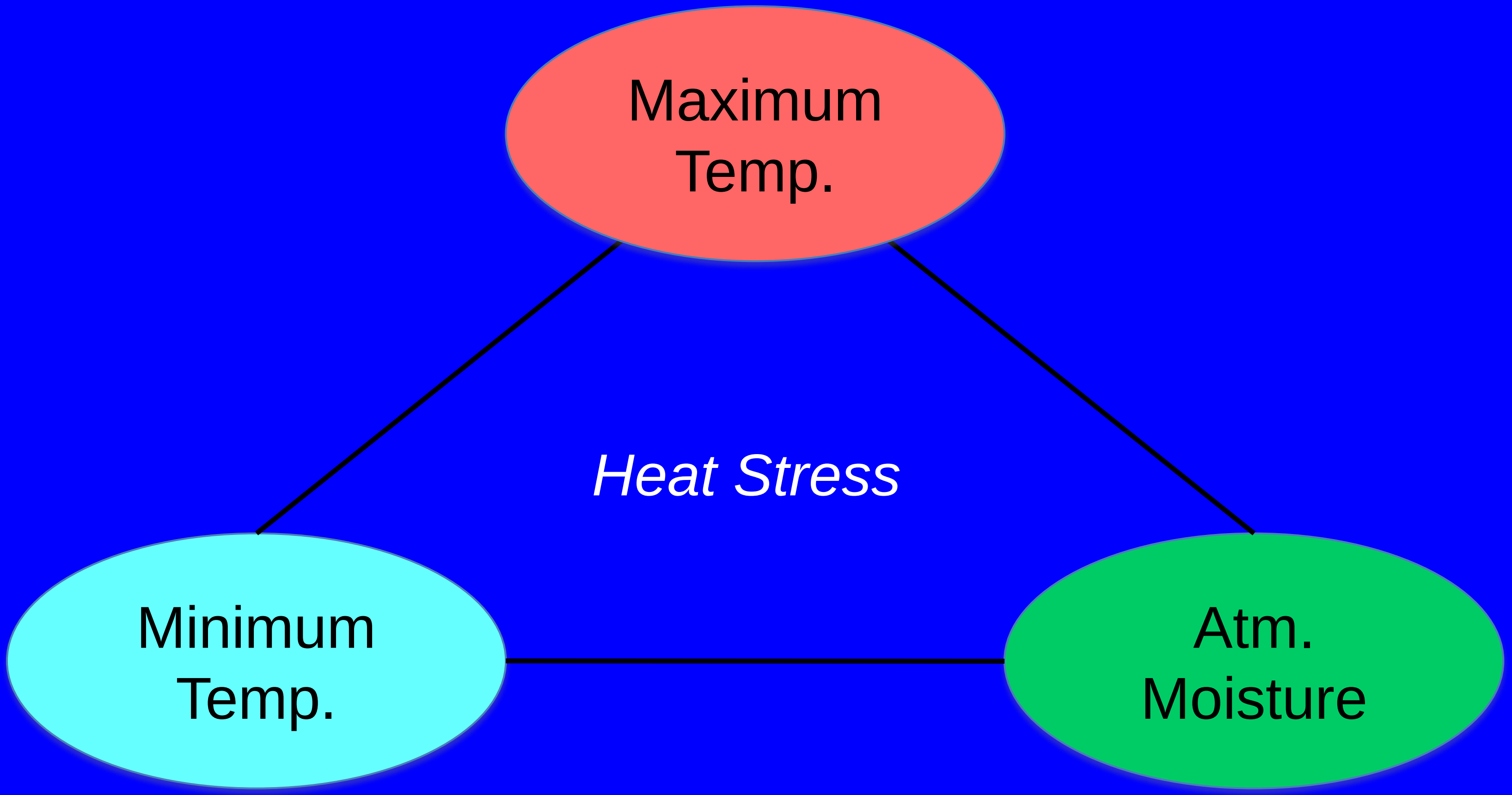
Reanalysis
2m 1979-2010







Heat Waves, Climate and Health: Interaction Between 3 Meteorological Variables



This Study:

- Define heat wave as 3+ (5+, 7+) days > 90th (95th) percentile of Tmax, Tmin (percentiles obtained by ranking daily data)

- Examine the spatial distribution of heat wave frequency based on these different definitions

- Examine the relationships between Tmax, Tmin and humidity

- Consider the influence of humidity by using apparent temperature indices (again, using percentiles)

- Contrast 4 events:
  - "Chicago" heat wave 1995 (short, "humid") ;
  - Southern Plains 1980 (protracted, "dry");
  - Eastern US 1981 (largely minimum temperature)
  - Western US 1984 (extreme equivalent temperature)

Analysis based on ~2,500 stations having > 95% complete daily data for May-Sept 1960-2000 (GHCN Daily, NCDC)

Results for humidity using Reanalysis (here) and NARR (not shown)

% Area of US Midwest in Heat Wave (3+ days, > 90th %ile)

T_{eq} vs. T (For July based on Reanalysis)