Heat Waves

Outline

- Definition
  - Heat index
- Large-scale circulation associated with heat waves
- A high-impact heat wave event

Heat Waves: Definition

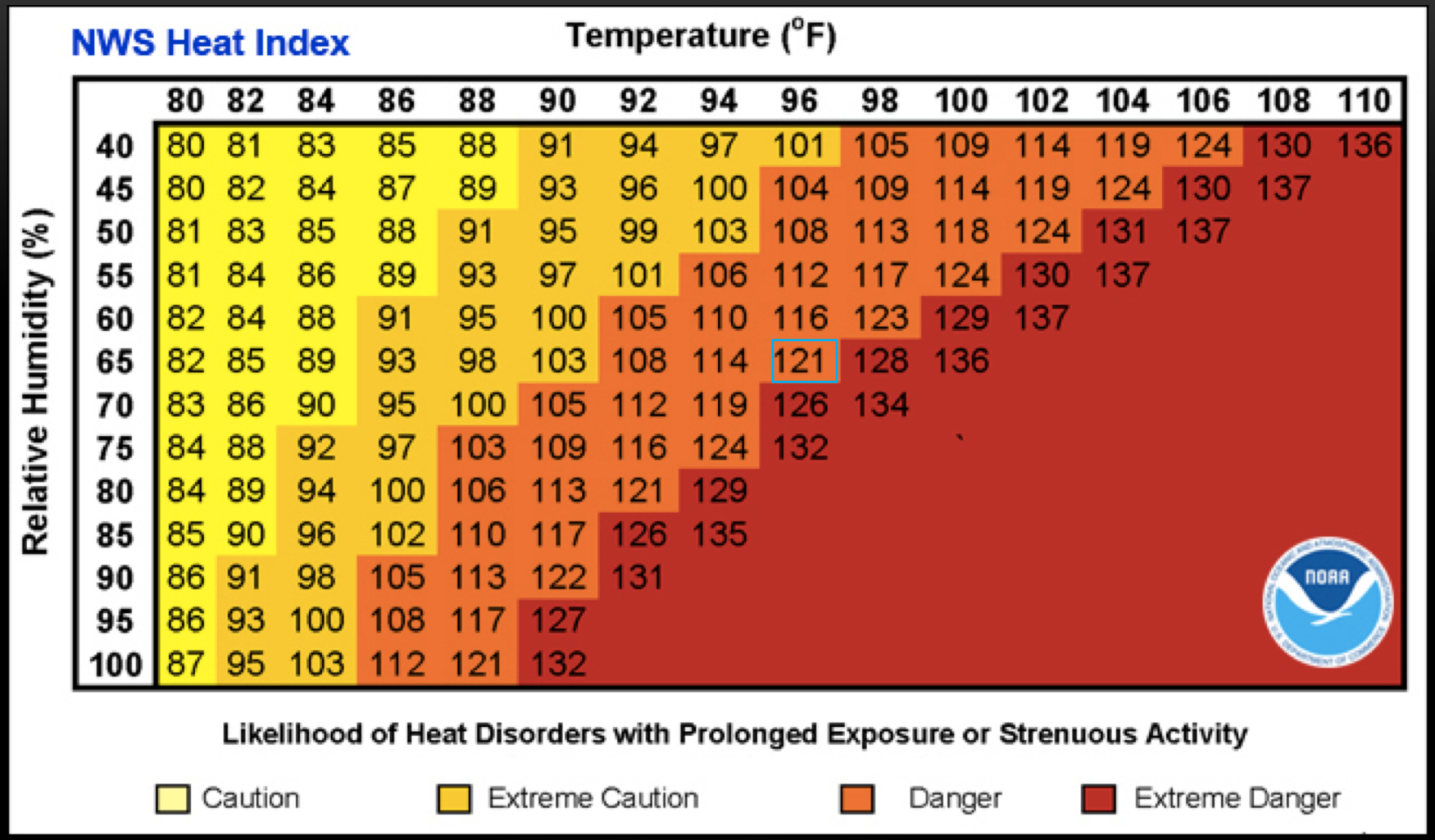
- A heat wave is an extended period of abnormally high atmosphere-related heat stress, which causes temporary modifications in lifestyle and which may have adverse health consequences for the affected population.
- Definitions of heat waves often consider both daytime high and overnight low values and are related to the climatic variability common to the area. The effect of duration also needs to be included (Robinson 2001).

Heat Index

- The heat index, also known as the apparent temperature, is what the temperature feels like to the human body when relative humidity is combined with the air temperature (https://www.weather.gov/ama/heatindex).
- The heat index adopted by the National Weather Service is obtained by multiple regression analysis and is defined as below

  HI = -42.379 + 2.04901523*T + 10.14333127*RH - .22475541*T*RH - .00683783*T*T - .05481717*RH*RH + .00122874*T*T*RH + .00085282*T*RH*RH - .00000199*T*T*RH*RH

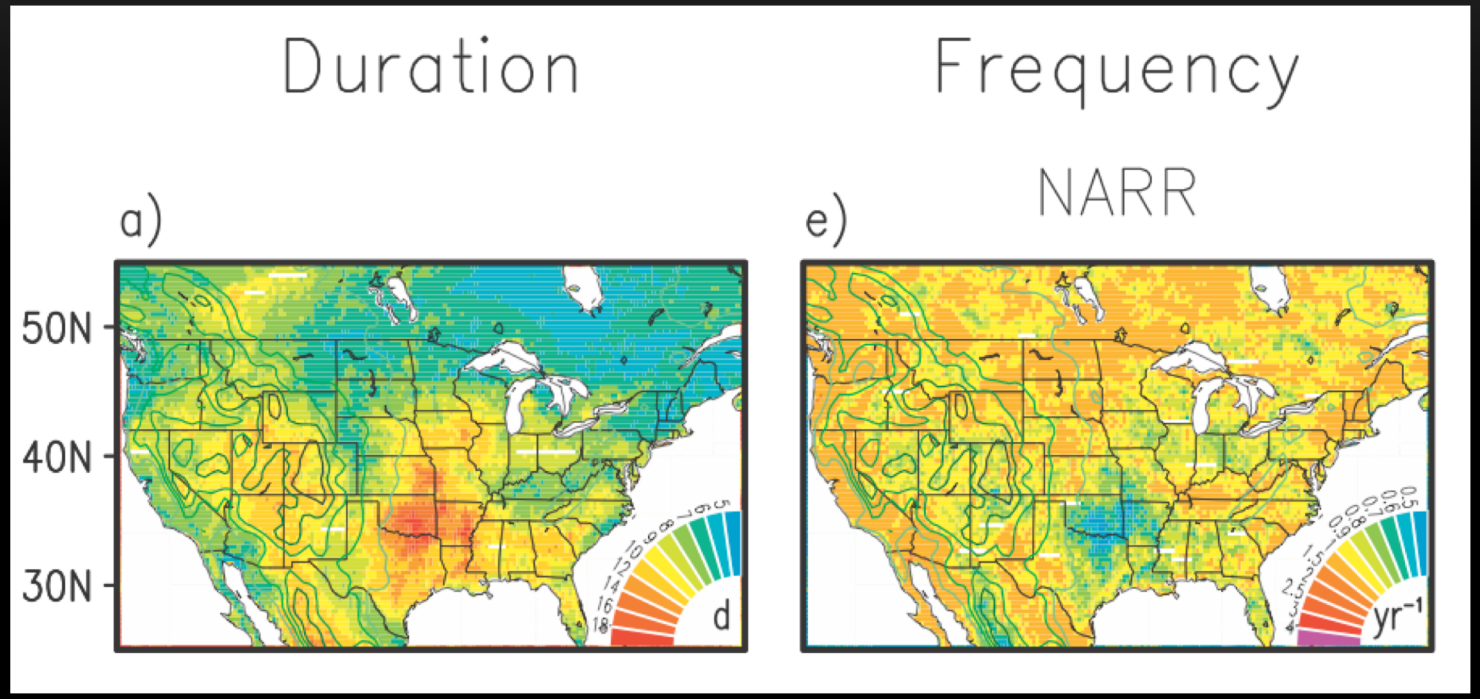
  where **T** is temperature in degrees F, and **RH** is relative humidity in percent. **HI** is the heat index expressed as an apparent temperature in degrees F. A calculator can be found at https://www.wpc.ncep.noaa.gov/html/heatindex.shtml
- Percentile-based on heat wave definitions are often used in research papers. For example, heat waves can be identified when daily mean temperature ≥95th percentile for ≥3 days.

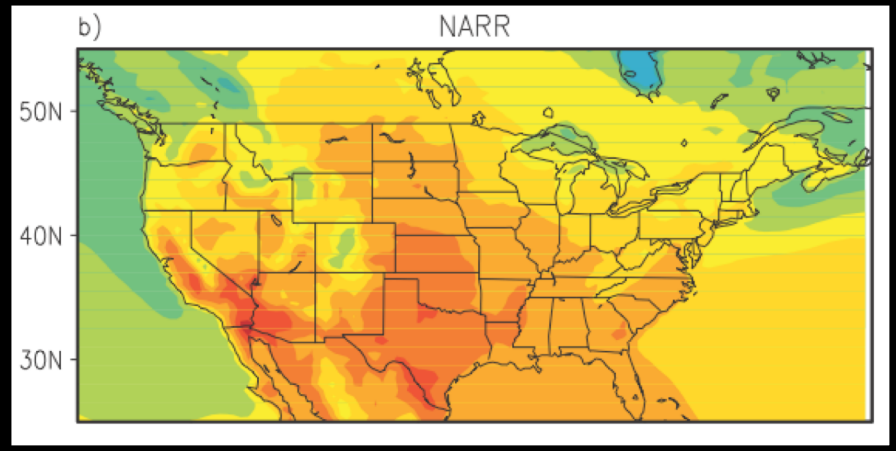


- As an example, if the air temperature is 96°F and the relative humidity is 65%, the heat index--how hot it feels-is 121°F. The red area without numbers indicates extreme danger.
- High humidity can make the heat index much higher than the actual air temperature, but heat waves can happen in dry conditions or along with droughts.

https://www.weather.gov/safety/heat-index

Climatology of Heat Waves over North America (1980-2003)





- Heat waves may last more than ten days,
- The average number of heat waves is about one per year
- The mean duration of heat waves has a similar spatial pattern to the max temperature.

Distributions of the climatological mean of the maximum surface air temperature field for the June–August season,

From Lau and Nath 2012 © American Meteorological Society. Used with permission

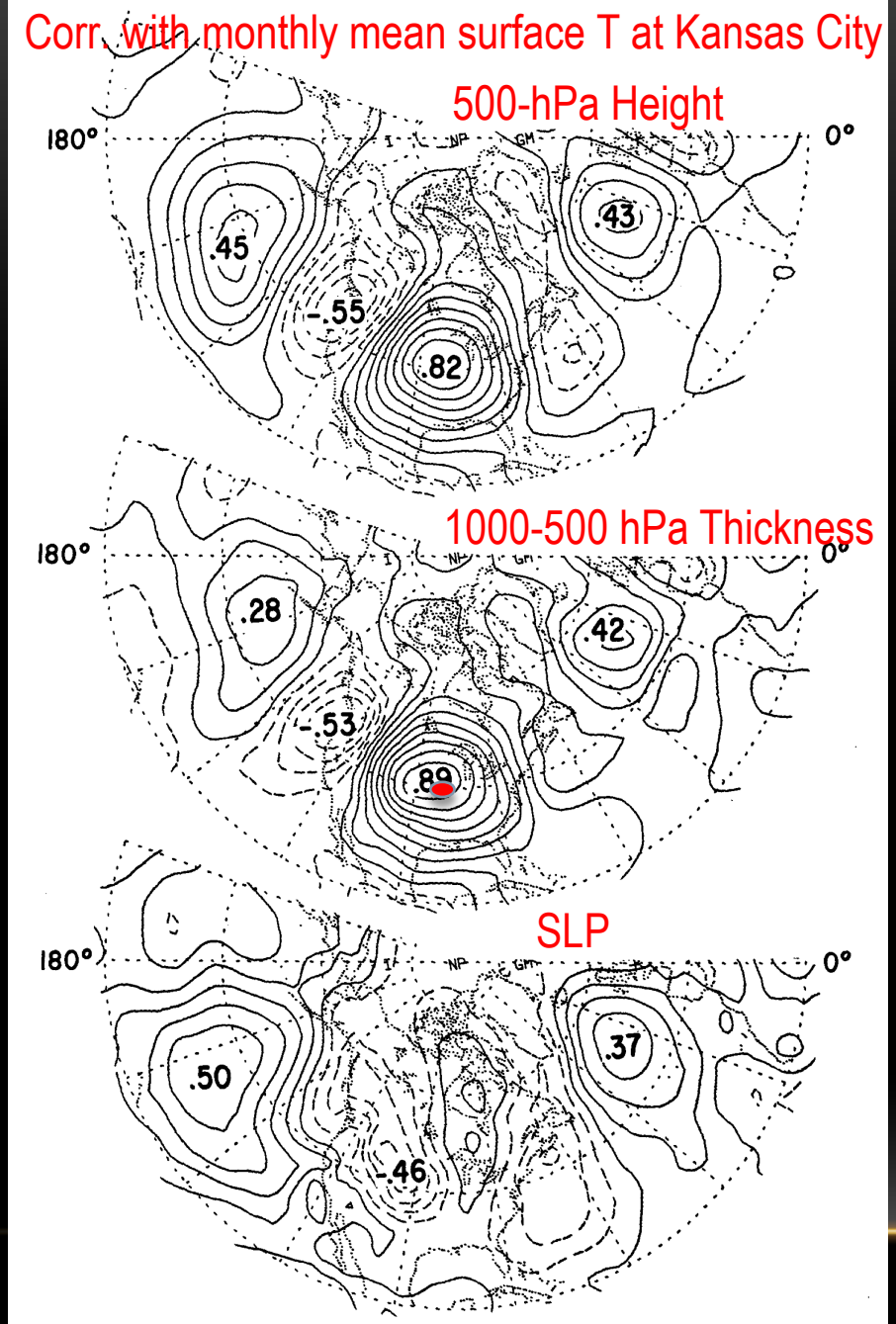


FIG. 3. Monthly mean surface air temperature at Kansas City (39°N, 95°W) correlated with 500 mb height (top), 1000–500 mb thickness (middle) and sea level pressure (bottom) for an array of gridpoints. Based on anomalies for 93-month dataset (June, July, August of the summers 1946–76). Contour interval 0.1; dashed contours are negative.

Large-scale Circulation Pattern

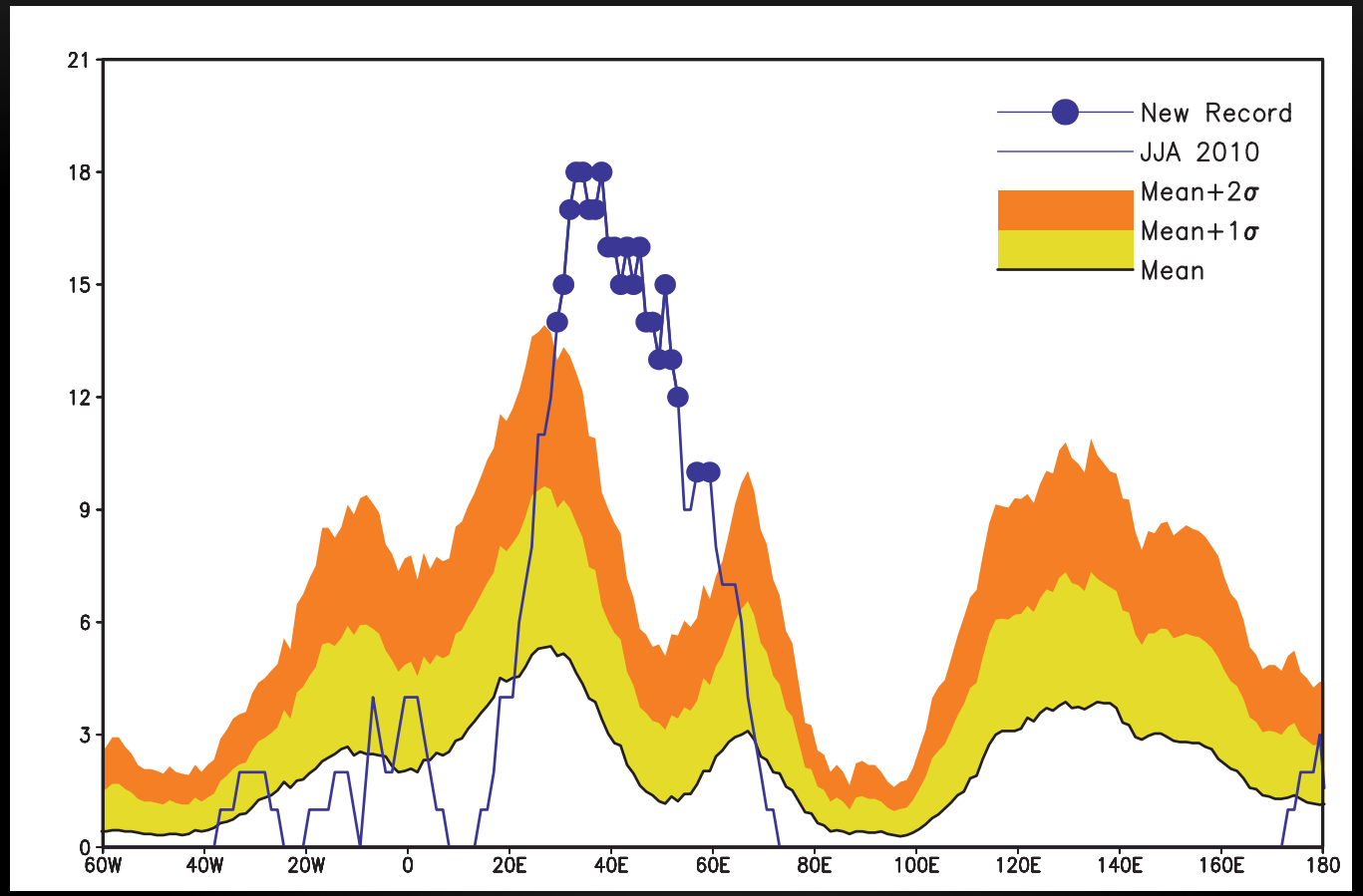
1. dominant by an anticyclone (possibly a blocking high) at 500 hPa, which induces subsidence
2. Low-level low to the west and high in the east, which induce warm advection from the south
3. Larger thickness between 500-1000 hPa.

Russian Heat Wave and Pakistan Flood in Summer 2010

- Western Russia was struck by a record heat wave and a prolonged drought. Intense and extensive wildfires raged over more than 5000 km^2 of forested area over western Russia.
  - In 2010, the heat wave over Russia resulted in more than 15,000 deaths, including more than 1,600 drowning deaths as people entered the water in an attempt to escape the heat, and caused severe economic losses due to damage to crops such as wheat. More than 600 wildfires resulted in smog levels that were five to eight times higher than normal, leading to widespread illness [Gilbert, 2010] (State of the Climate Global Hazards). (Matseuda 2011)
  - Moscow (55.5°N, 37.4°E, Russia) recorded its highest temperature of 39°C on 30th July during the prior 90 years, Joensuu (62.4°N, 29.4°E, Finland) recorded 37.2°C on 30th July, Gomel (52.2°N, 30.6°E, Belarus) recorded 38.9°C on 7th August, and Jaskul (46.1°N, 45.2°E, Russia) recorded 42.2°C on 8th August
  - The Russian heat wave and forest fires cost the economy more than $15 billion.
- During late July and early August 2010, Pakistan suffered a cluster of torrential rain events, causing the worst flooding in 100 years. 1700 people perished and 1.8 million homes were lost, rendering 20 million people homeless, with an economic loss estimated to be more than $40 billion (U.S. dollars).

Lau and Kim (2012) DOI: 10.1175/JHM-D-11-016.1

A Record-breaking Blocking



Blue dots indicate longitudinal locations where the blocks in 2010 were at an all-time high since 1979.

i) Blocking frequency exceeds mean +2*stdev
ii) An eastward shift

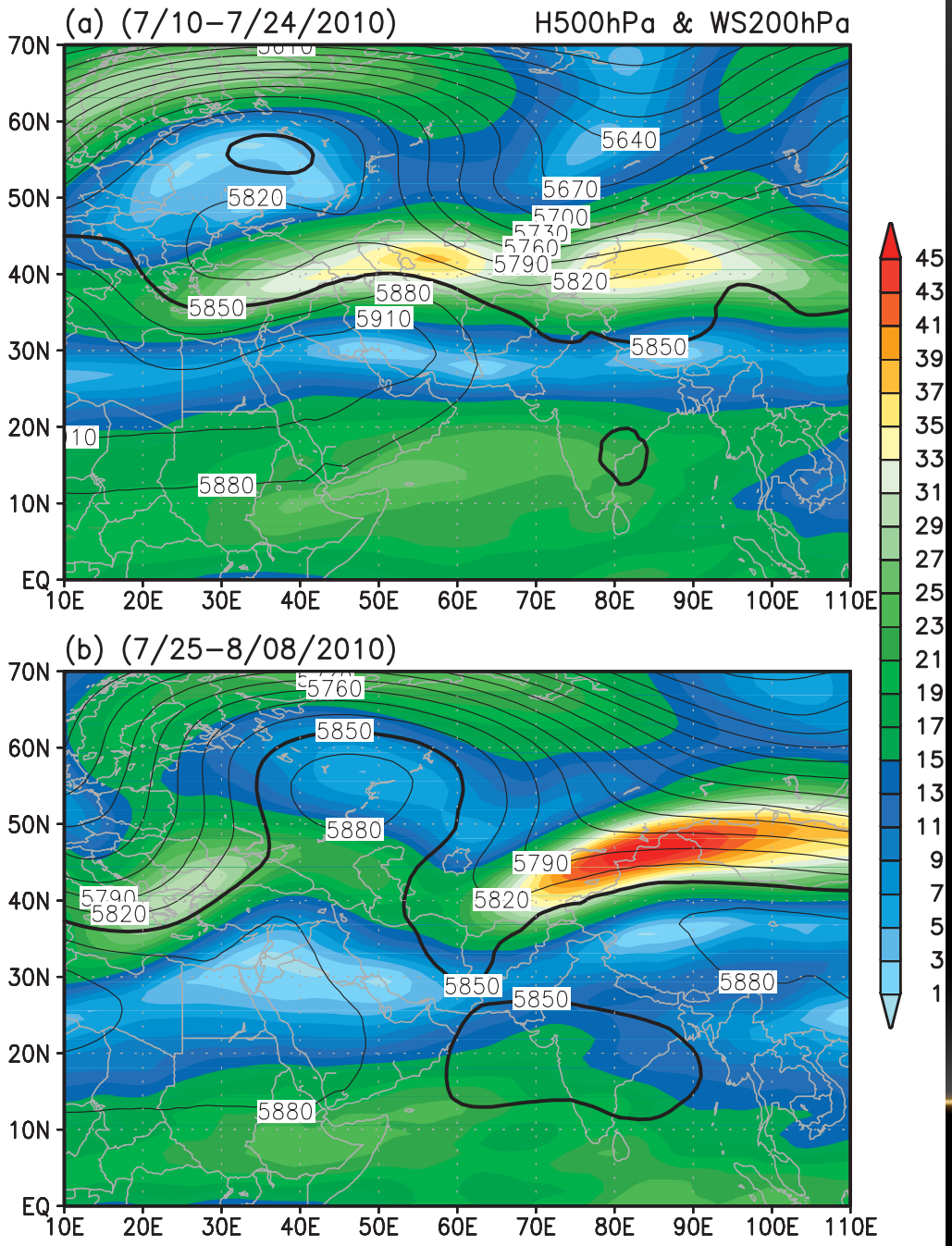


FIG. 3. Spatial patterns of 500-hPa geopotential height (contours) and 200-hPa wind speeds

Evolution of the Large-scale Flow

Can you describe the classic features of a blocking on this figure?

the classic features of a blocking high:

- development of a omega-high
- split of the jet, or weakening of the subtropical jet, which will divert the storm track

Spatial patterns of 500-hPa geopotential height (contours) and 200-hPa wind speeds (colors). From Lau and Kim 2012 © American Meteorological Society. Used with permission

A Wavetrain Pattern: H500 and Wind Anomalies

- The blocking high (H) is part of an extratropical wavetrain over the Eurasian Continent.
- With the strengthening of the blocking, a cyclonic circulation develops southeastward (c1+c2). This is associated with a monsoonal trough at 850 hPa, which enhances the moisture transport and contribute to the Pakistan flood.

Period I

Period II

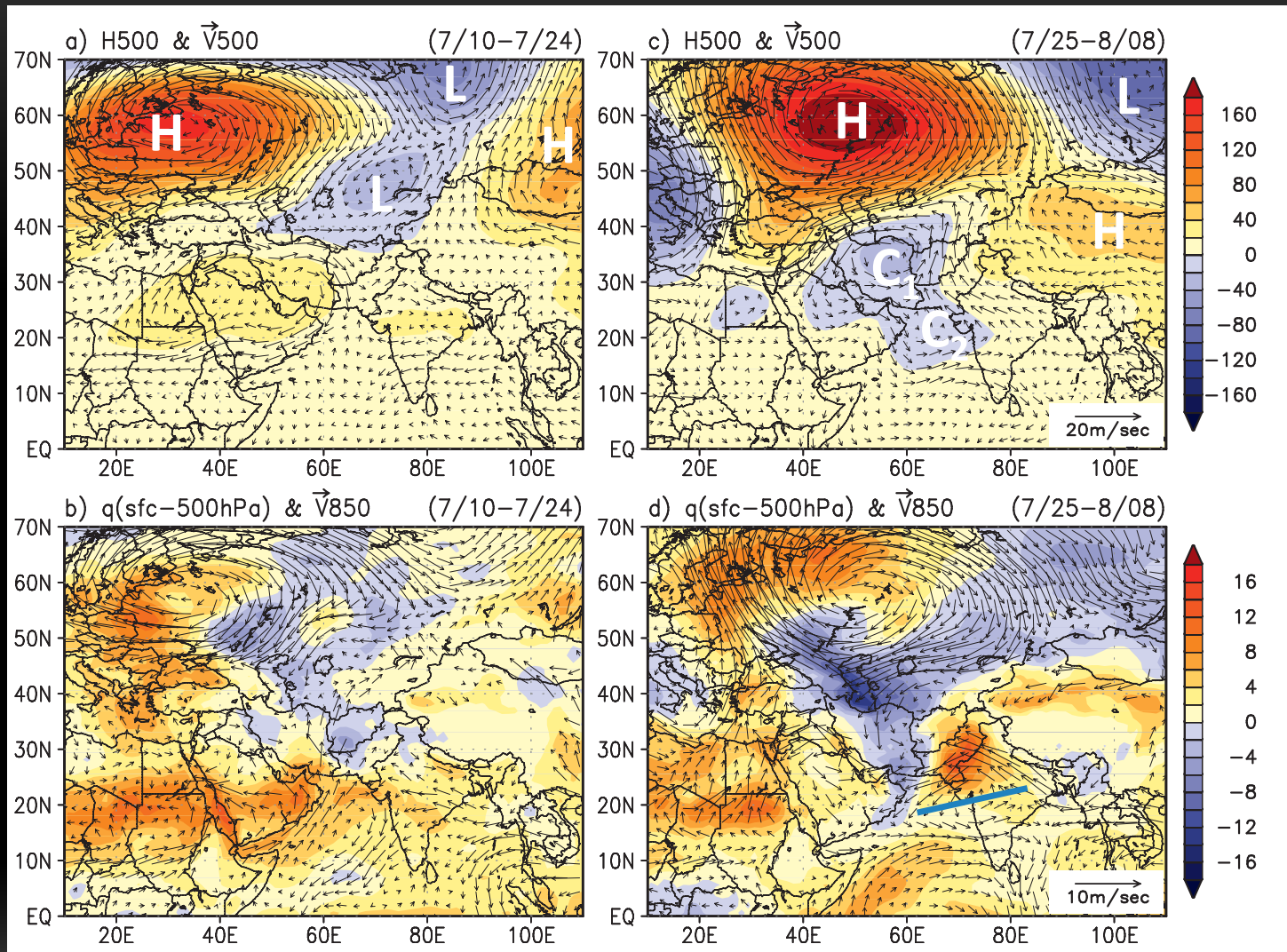


FIG. 4. Spatial patterns of (a) 500-hPa geopotential height (m) and wind anomalies during period I, (b) 850-hPa wind and precipitable water (mm) below 500 hPa during period I, (c) 500-hPa geopotential height and wind anomalies (m s^{-1}) during period II, and (d) anomalous 850-hPa wind and precipitable water during period II. Centers of the blocking high (H) and low (L) and the midtropospheric cyclones (C_1 and C_2) are marked. Thick line in Fig. 4d indicates the location of monsoon front. Anomalies were computed based on the climatology of 1979–2009.

Climatic Feedback

- Climatic feedback helps to maintain/amplify the blocking high: cloud-radiation feedback; Soil moisture feedback
- For example, the reduced clouds increased downward surface solar radiation (SW), enhancing surface warming there.
- The reduced soil moisture (SM) led to a reduction in evaporation (LH) and contributes to the rapid warming of the land and surface air.

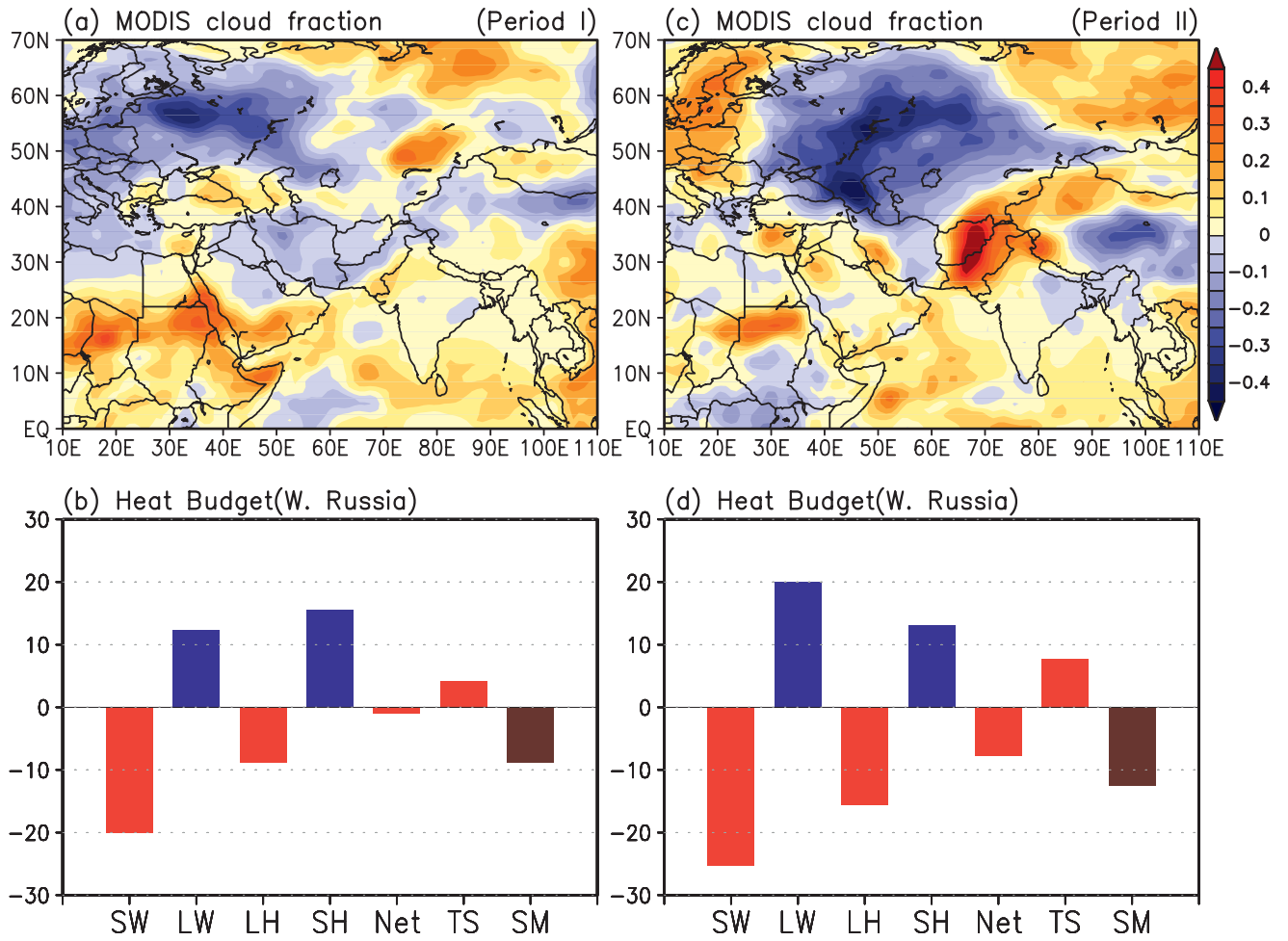
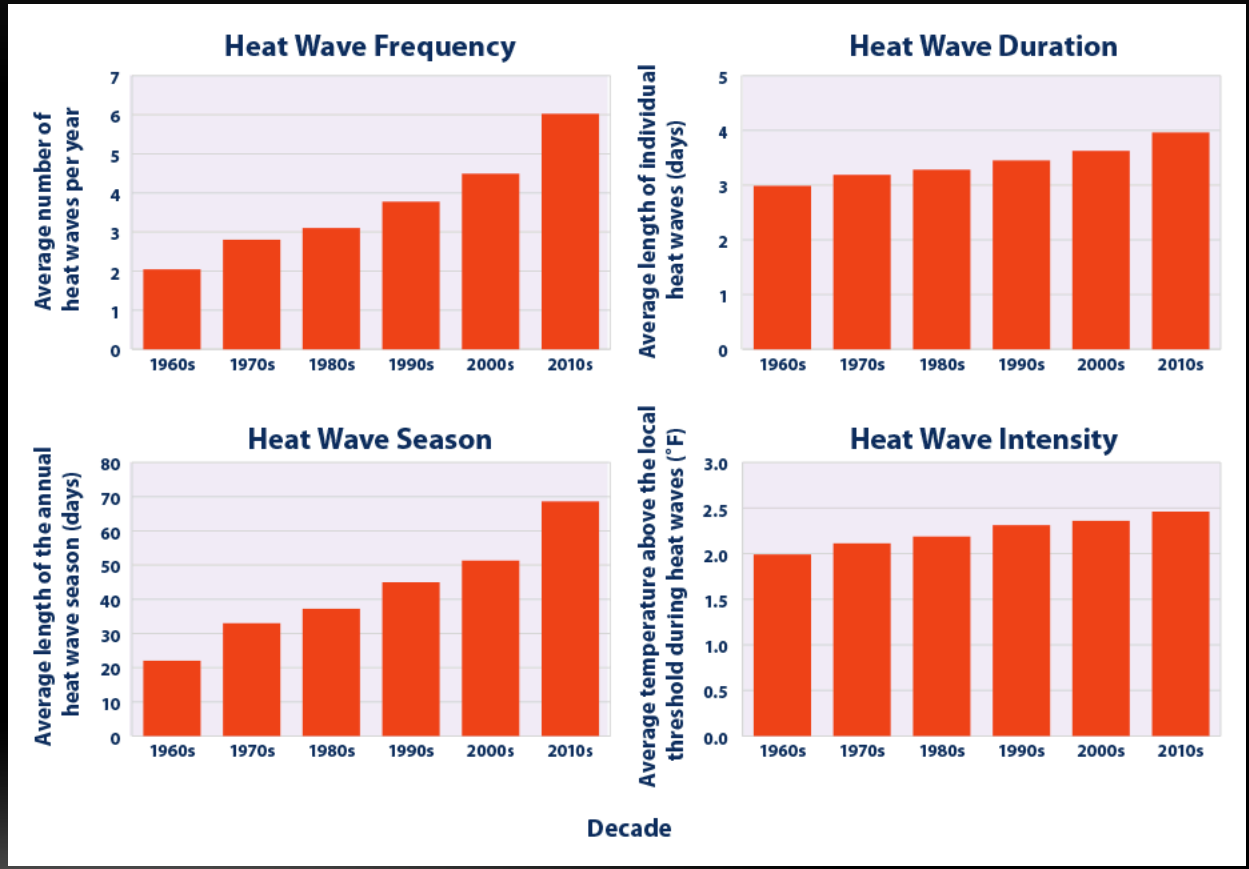


FIG. 6. (top) Distribution of MODIS cloud fraction anomalies for periods (a) I and (c) II. Anomalies were computed based on the climatology of March 2000–February 2010. (bottom) Area mean MERRA shortwave (SW) and longwave (LW) radiation, latent heat (LH) and sensible heat (SH) flux, net flux (Net) at the surface, and soil moisture (SM) averaged over western Russia (45–65°N, 30–60°E) for periods (b) I and (d) II. Units are W m^{-2} for fluxes and fraction (×100) for soil moisture. Red (blue) color denotes warming (cooling) of the land surface.

Climate Change and Heat Waves

- This figure shows changes in heat wave frequency (the number of heat waves per year), duration (in days), heat wave season length (the number of days between the first and last heat wave of the year); and intensity (how hot the heat waves were).
- Heat waves occur more frequently, with longer duration and stronger intensity from 1961 to 2019, and the heat wave season has also become longer.



https://www.epa.gov/climate-indicators/climate-change-indicators-heat-waves

Major References

- Chang, F.-C., , and J. M. Wallace, 1987: Meteorological conditions during heat waves and droughts in the United States Great Plains. Mon. Wea. Rev., 115, 1253–1269.
- Lau, N.-C., and M. J. Nath, 2012: A model study of heat waves over North America: Meteorological aspects and projections for the twenty-first century. J. Climate, 25, 4761–4784, doi:10.1175/ JCLI-D-11-00575.1.
- Lau, W. K. M., and K.-M. Kim, 2012: The 2010 Pakistan flood and Russian heat wave: Teleconnection of hydrometeoro- logical extremes. J. Hydrometeor., 13, 392–403, doi:10.1175/ JHM-D-11-016.1.
- Matsueda, M. (2011), Predictabil- ity of Euro-Russian blocking in summer of 2010, Geophys. Res. Lett., 38, L06801, doi:10.1029/2010GL046557.
- Robinson, P. J. (2001). On the Definition of a Heat Wave, *Journal of Applied Meteorology*, *40*(4), 762-775.