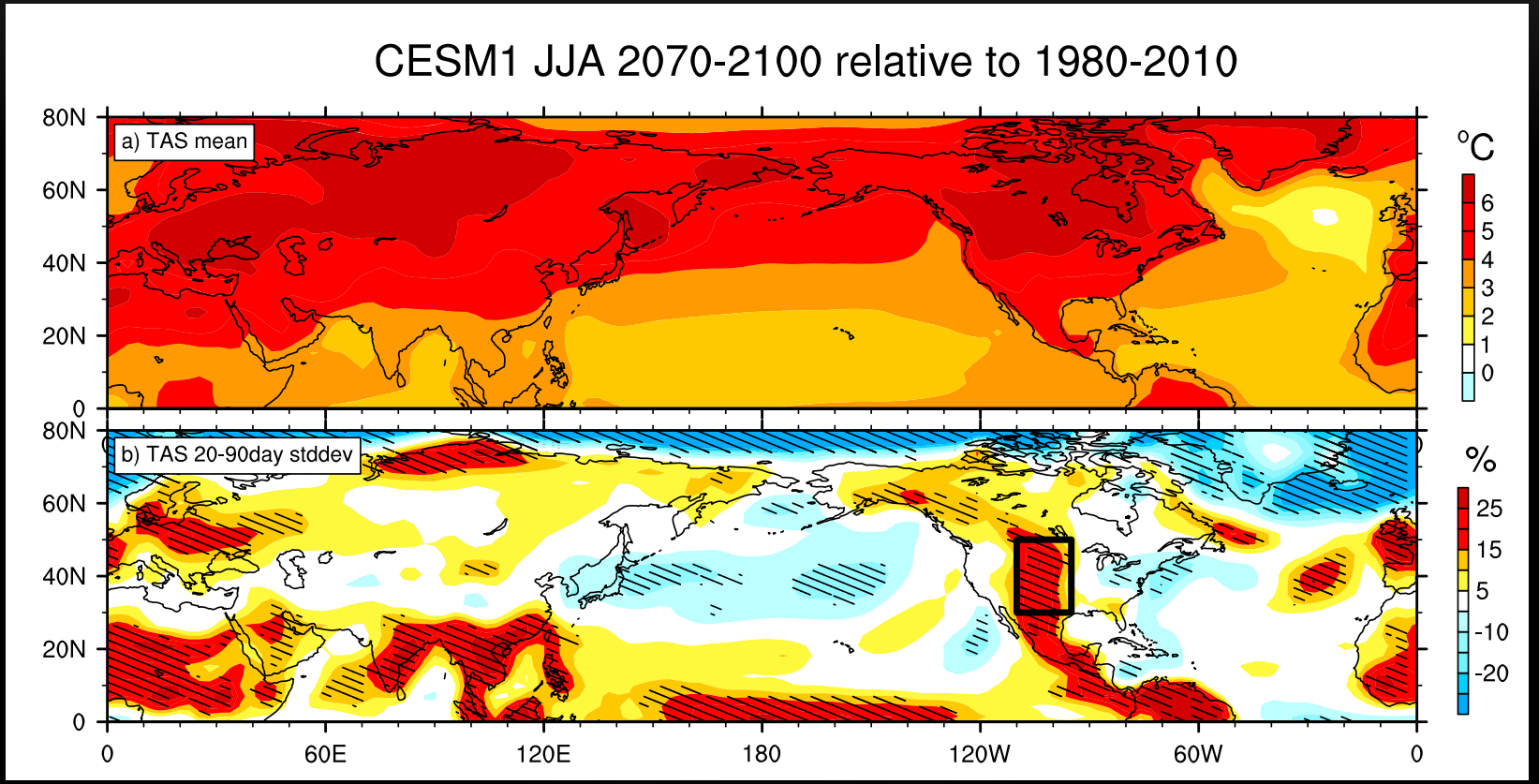
Heat waves in a warming climate

- Teng et al. (2016): Projected intensification of subseasonal temperature variability and heat waves in the Great Plains.
- Meehl and Tebaldi (2004): More intense, more frequent, and longer lasting heat waves in the 21st century.

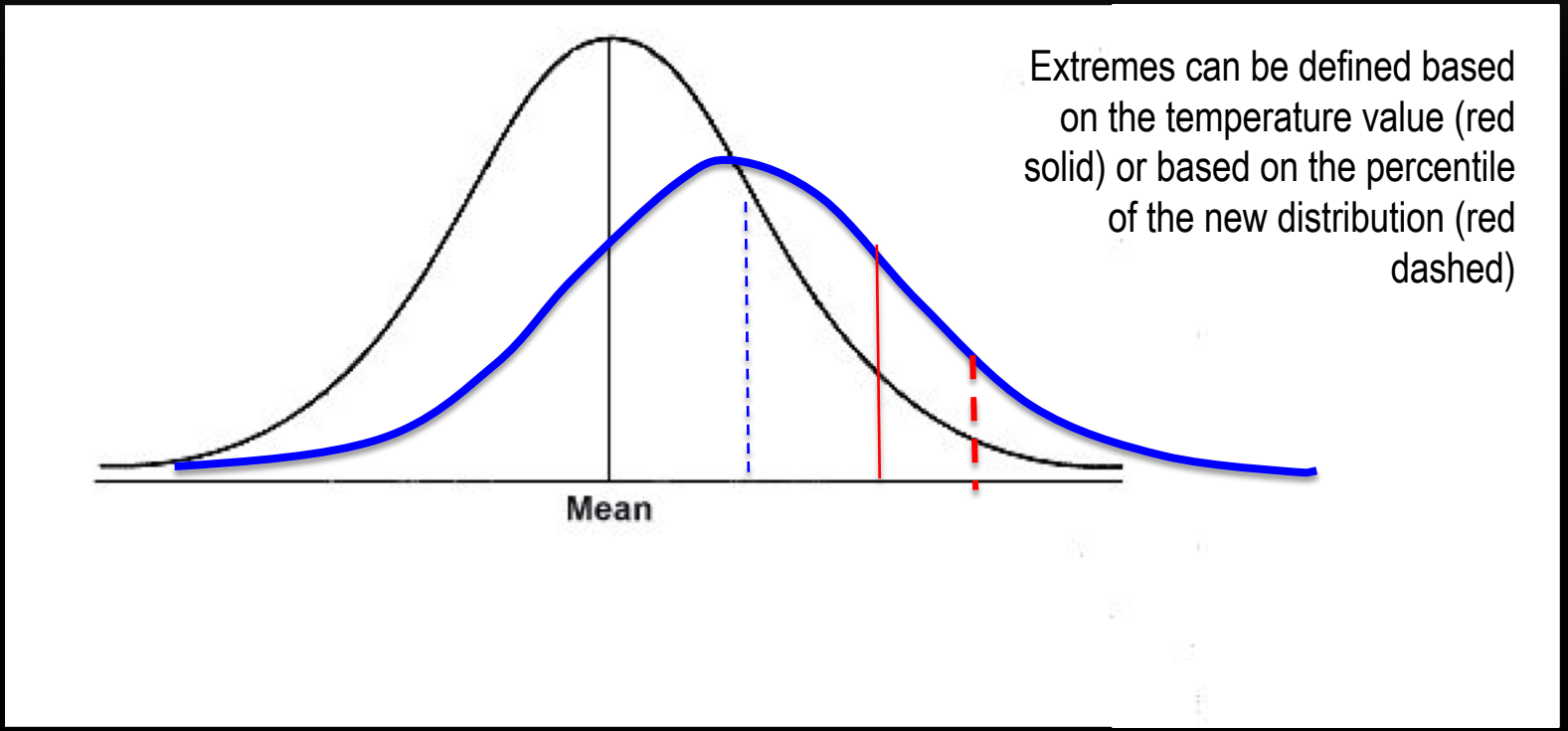
Surface Air Temperature (TAS) Mean and Subseasonal Variability: (2070-2100) – (1980-2010)



Change in the summer (June-August) seasonal mean TAS and subseasonal variability (percentage change in standard deviation) from 1980–2010 to 2070–2100 in CESM1-LE. Both the mean and the variability increase in many regions.

Teng et al. 2016, GRL

Changes in PDF and Climate Extremes



- To the extent that the T variability follows a Gaussian distribution, the higher mean T and stronger variability both will contribute to more intense and more frequent extremes.
- Many studies suggested that more intense and more frequent heat waves are expected in a warmer climate, which can be attributed to the increase in the mean and standard deviation.

Possible Mechanisms

- Two mechanisms have been proposed by which climate change can affect summertime subseasonal temperature variability.
  - Local land-atmosphere feedback: the strength of the feedback is sensitive to the mean soil moisture [Schaïr et al., 2004; Koster et al., 2004; Seneviratne et al., 2006, 2010; Fischer et al., 2007, 2012].
  - Changes in atmospheric circulation characteristics: such as more frequent occurrence of blocking highs.

Composite of daily anomalies of 200 hPa streamfunction (contour), Ts (shading), and Plumb flux (vector]) from present-day and future heat waves

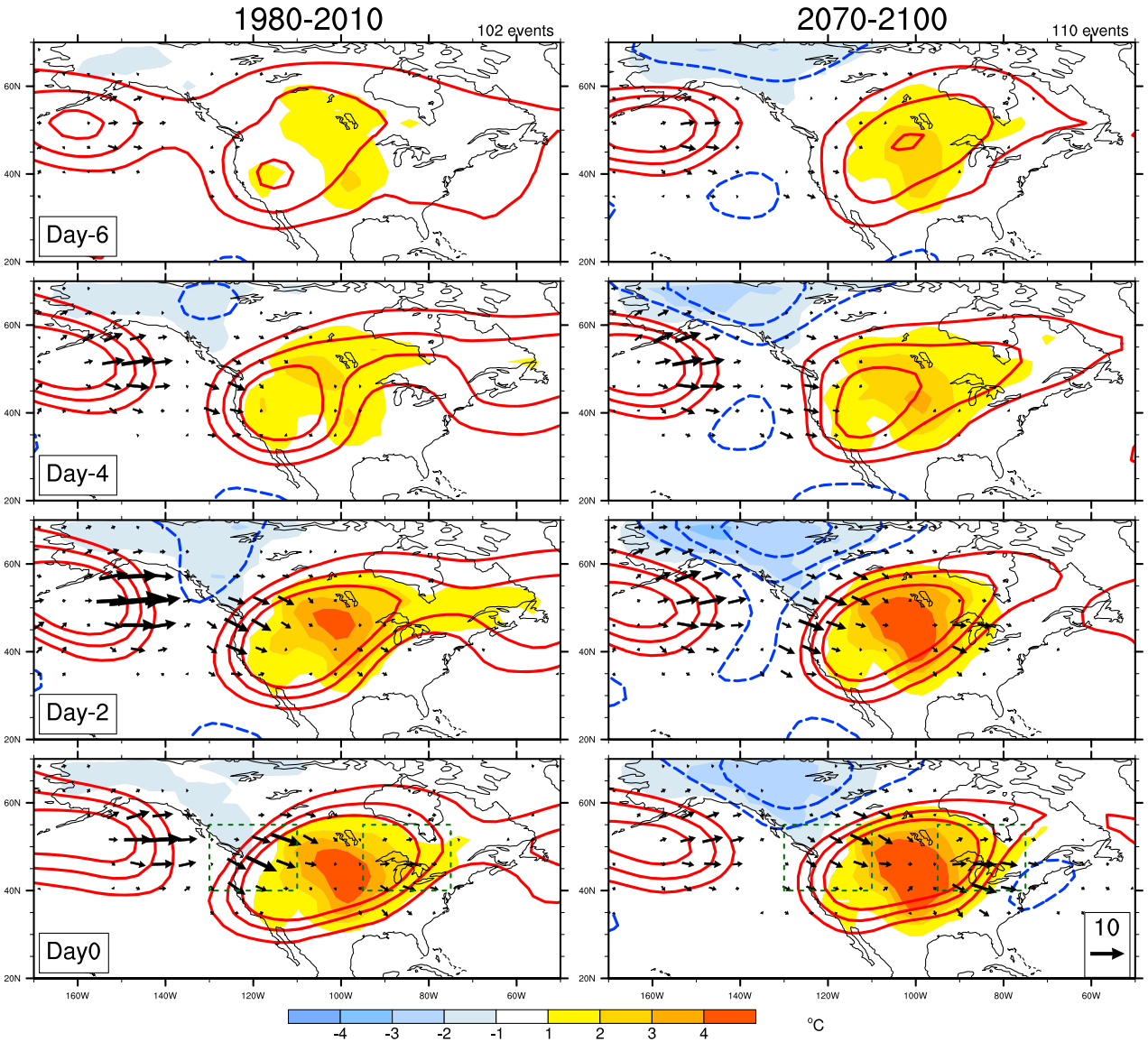
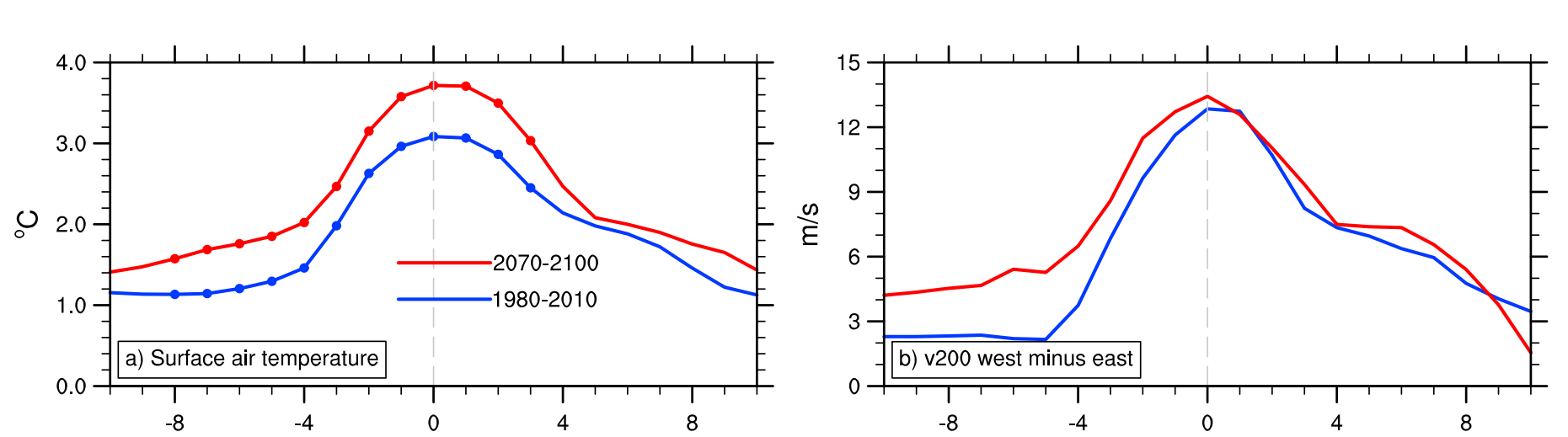


Figure 3. Composite of daily anomalies of 200 hPa streamfunction (contour), surface air temperature (shading), and Plumb flux (vector [*Karoly et al.*, 1989]) from 102 present-day and 110 future heat waves in the Great Plains. For clarity only contour levels of the stream function anomalies at $\pm 1,2,3 \times 10^6 m^2 s^{-1}$ are displayed, and Plumb flux vectors with magnitude less than $1\ m^2\ s^{-2}$ are not shown.

For both epochs, the continental U.S. is dominated by a quasi-stationary anticyclonic circulation anomaly

Teng et al. 2016, GRL

Surface Air T and Stationary Wave Amplitude: future vs. present (domain averaged anomalies)

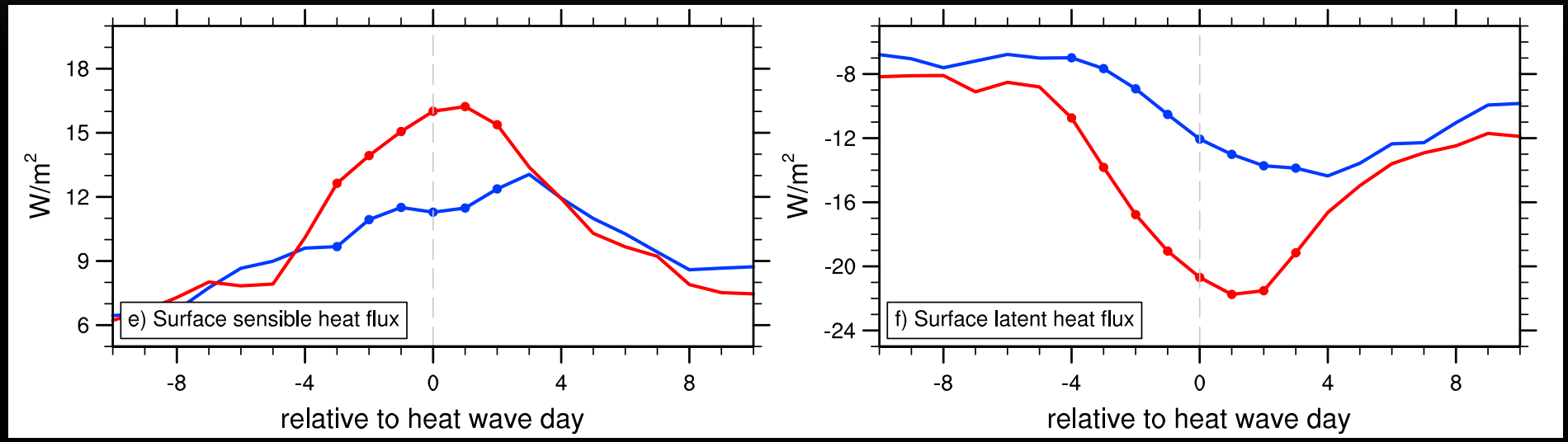


Dots denote the composite values that are significantly different at the 95% level between 1980–2010 and 2070–2100.

Although heat waves become more intense (a), the anticyclonic anomalies show no significant change in the two time periods (b).

Teng et al. 2016, GRL

Surface Sensitive Heat Flux and Latent Heat Flux: future vs. present (domain averaged anomalies)



- In the future climate there are significantly increased surface sensible heat flux anomalies compensated by reduced latent heat anomalies before and during the heat waves (i.e., warm and dry conditions)
- Even without amplified planetary waves in the future climate, subseasonal TAS variability can be enhanced due to reduction in the mean soil moisture and enhanced surface air T-soil moisture coupling.

Teng et al. 2016, GRL

Reduced Soil Moisture and Strong Soil-T Coupling

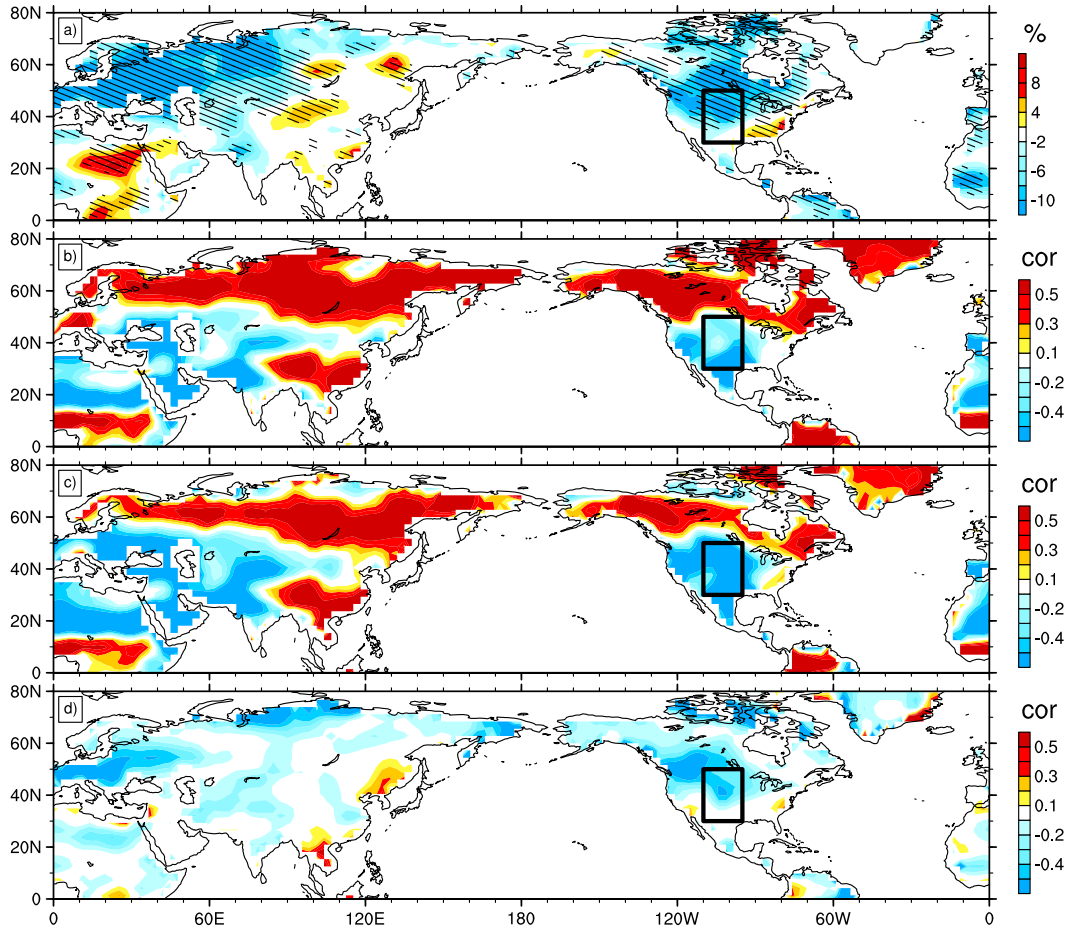


Figure 5. Percentage change in (a) JJA-averaged upper 10 cm soil water and correlation coefficients between JJA subseasonal monthly TAS and evaportranspiration anomalies in (b) 1980–2100, (c) 2070–2100, and (d) their difference in Figure 5c minus Figure 5b. The 99% significance level for correlation coefficients with 2790 degree of freedom (30 member × 31 years × 3 months) is approximately 0.05.

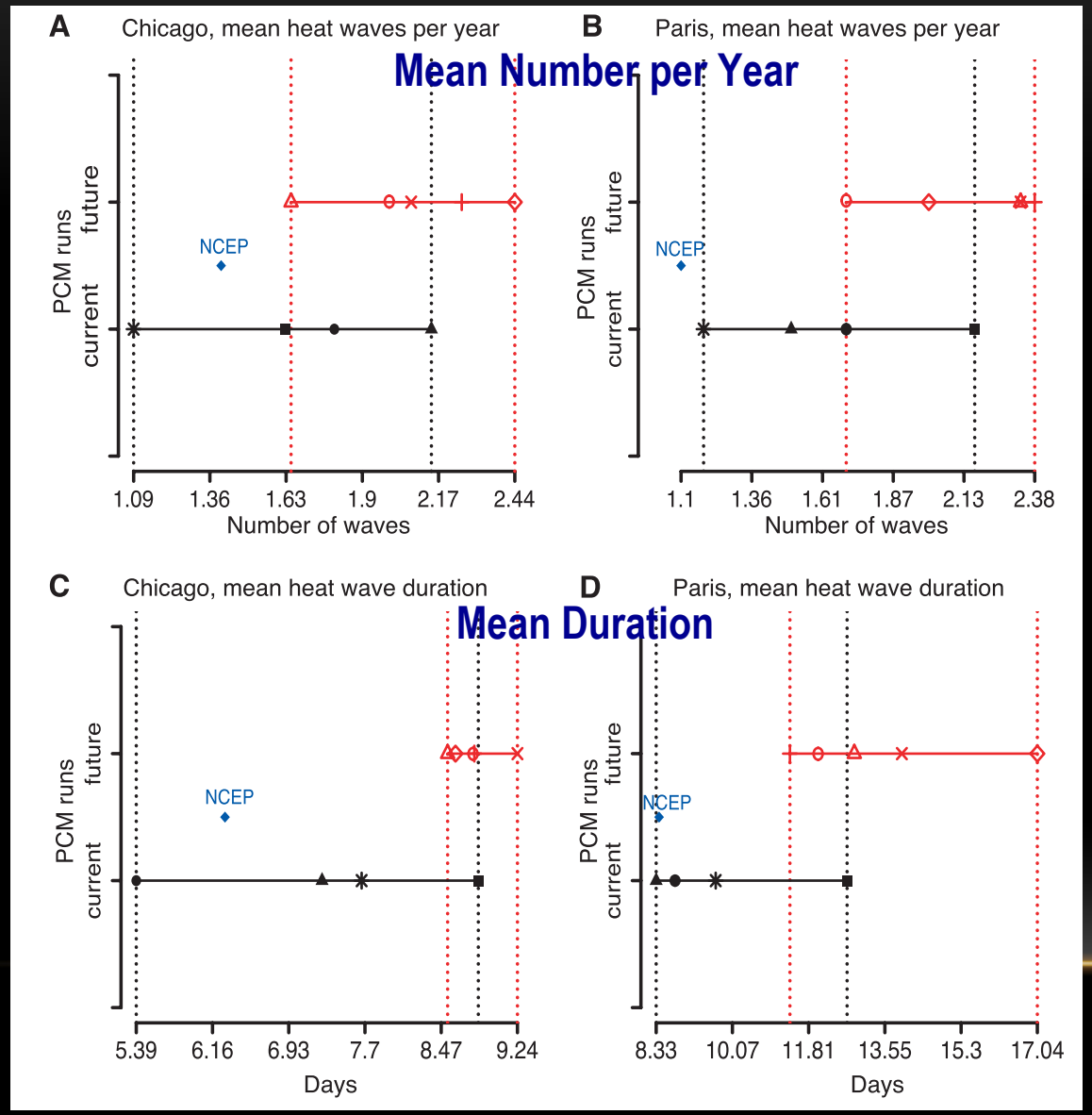
- The mean soil moisture is significantly reduced in many land regions in the future.
- Negative correlations in (b) and (c) indicate drier soil can reduce evapotranspiration, which leads to an increase in sensible heat flux and thus an increase in surface air temperature.
- Greater surface air temperature may potentially further decrease soil moisture, leading to a positive feedback between soil moisture and surface air temperature.
- The coupling will be strengthened in the future climate over the Central US.

Teng et al. 2016, GRL

heat waves in the 21st century

Meehl and Tebaldi (2004)

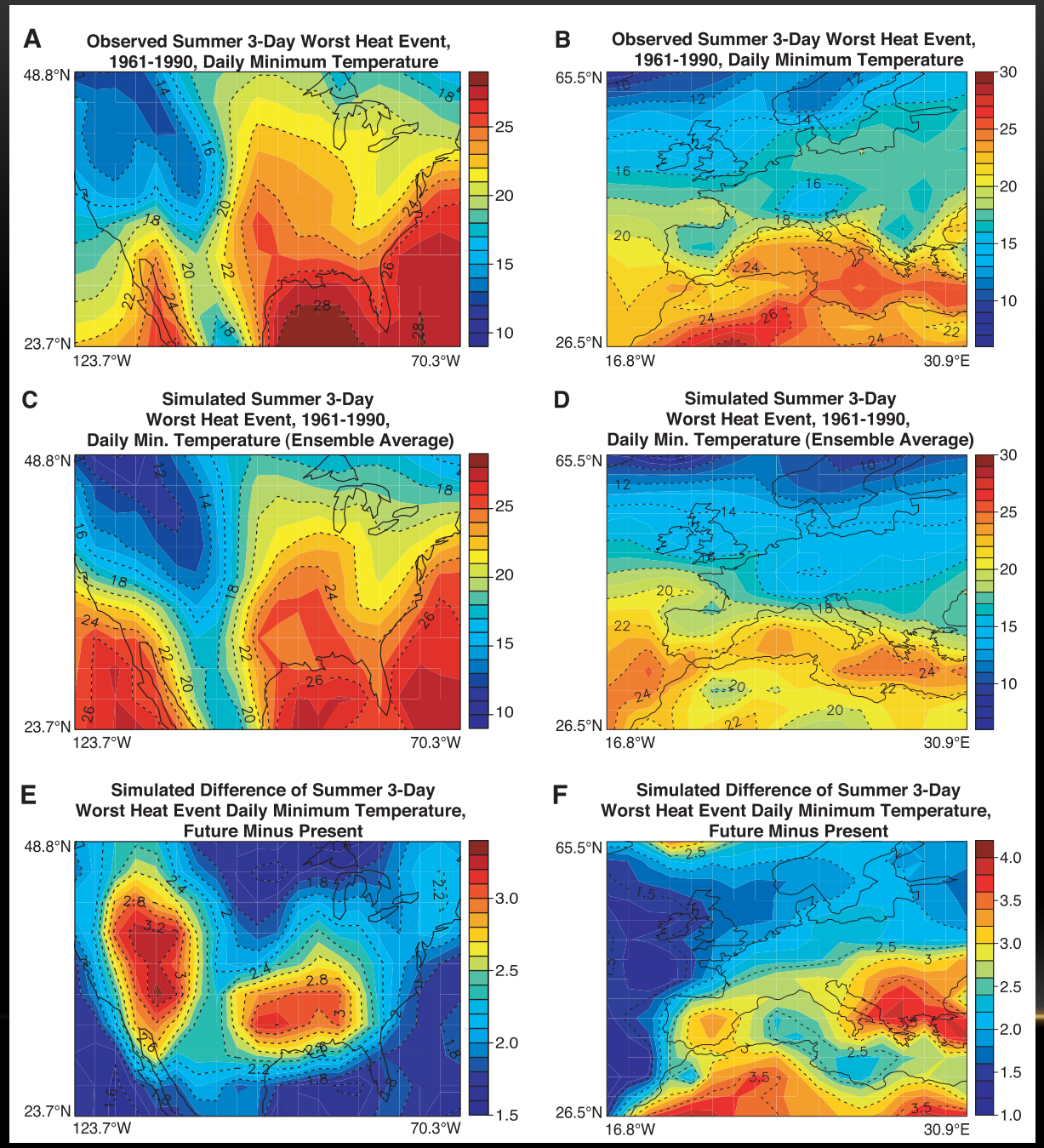
Frequency and Duration of Heat Waves



This figure shows the mean number of heat waves per year near Chicago (**A**) and Paris (**B**) and mean heat wave duration near Chicago (**C**) and Paris (**D**) are shown. In each panel, the blue diamond represents observations from the NCEP/NCAR reanalysis. The black and red segments indicate the model ensemble range for the present-day and future climate, respectively.

1. The models do a reasonable job representing the heat wave frequency and duration in the present climate.
2. Heat waves will become more frequent and more persistent in future, which is true in both locations.

Meehl and Tebaldi 2004



Intensity of Heat Waves: The mean nighttime minimum T of three consecutive (annual) warmest nights

- Differences are positive in all areas, indicative of the general increase of nighttime minima
- The heat wave severity change shows a distinct spatial pattern, increasing more in the western and southern United States and in the Mediterranean region.

Meehl and Tebaldi 2004

Key Points

- Heat waves (a period of abnormally and uncomfortably hot weather) are a major cause of fatality in recent years in the US.
- Heat waves are generally associated with specific atmospheric circulation patterns represented by semi-stationary 500-hPa positive height anomalies that dynamically produce subsidence, clear skies, light winds, warm-air advection, and prolonged hot conditions at the surface.
- Quasi-stationary Rossby wave trains are an important large-scale circulation feature associated with heat waves over the US, which may serve as an important source of predictability.
- Atmosphere-land interaction is an important process for such extreme events.

References

- Meehl, G. A., and C. Tebaldi (2004), More intense, more frequent, and longer lasting heat waves in the 21st century, Science, 305, 994–997.
- Seneviratne, S.I., T. Corti, E.L. Davin, M. Hirschi, E.B. Jaeger, I. Lehner, B. Orlowsky, and A.J. Teuling. 2010. Investigating soil moisture-climate interactions in a changing climate: A review. Earth-Science Reviews 99, 3-4:125-161, doi:10.1016/j.earscirev.2010.02.004
- Teng, H., G.W. Branstator, H. Wang, G.A. Meehl, and W.M. Washington, 2013: Probability of US heat waves affected by a subseasonal planetary wave pattern. Nature Geoscience, 6, 1056-1061, DOI: 10.1038/ngeo1988.