

Mechanisms associated with daytime and nighttime heat waves over the United States

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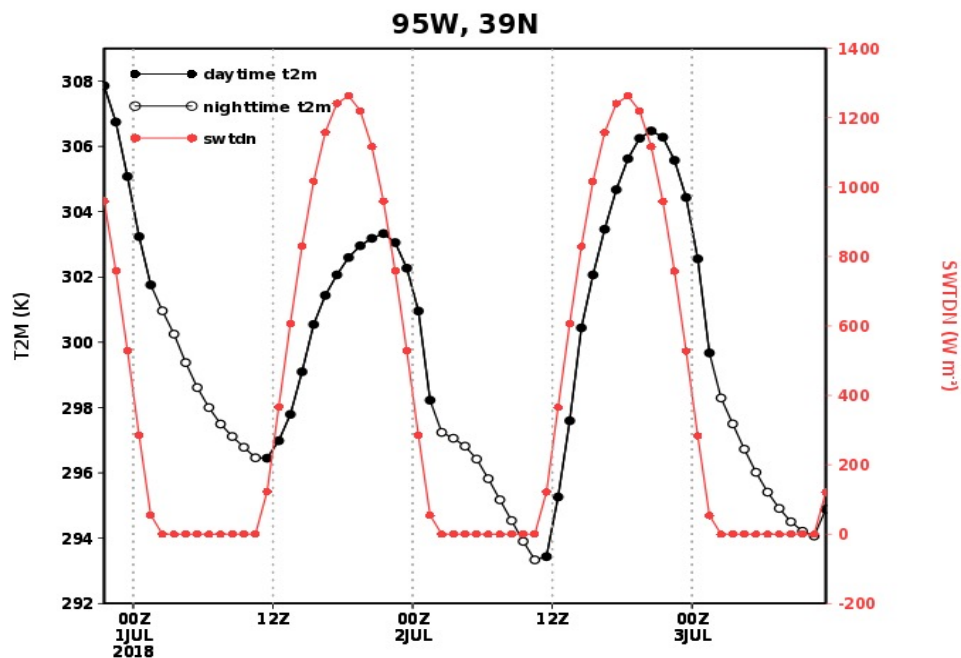
13 September 2021

Background

- Heat waves: extreme climate events which can be detrimental to human health, agriculture, energy systems.
- No single definition of a heat wave, but generally: event where temperature exceeds a threshold for a sustained amount of time.
 - Daily mean, maximum, minimum temperature? Heat Index?
- Motivation:
 1. Previous studies have noted greater increases in the frequency of Tmin- versus Tmax- heat waves
 2. Epidemiological studies have also found a stronger link between minimum temperatures and excess mortality.
- Question: What are the mechanisms associated with daytime vs. nighttime heat waves over the US?

Methodology

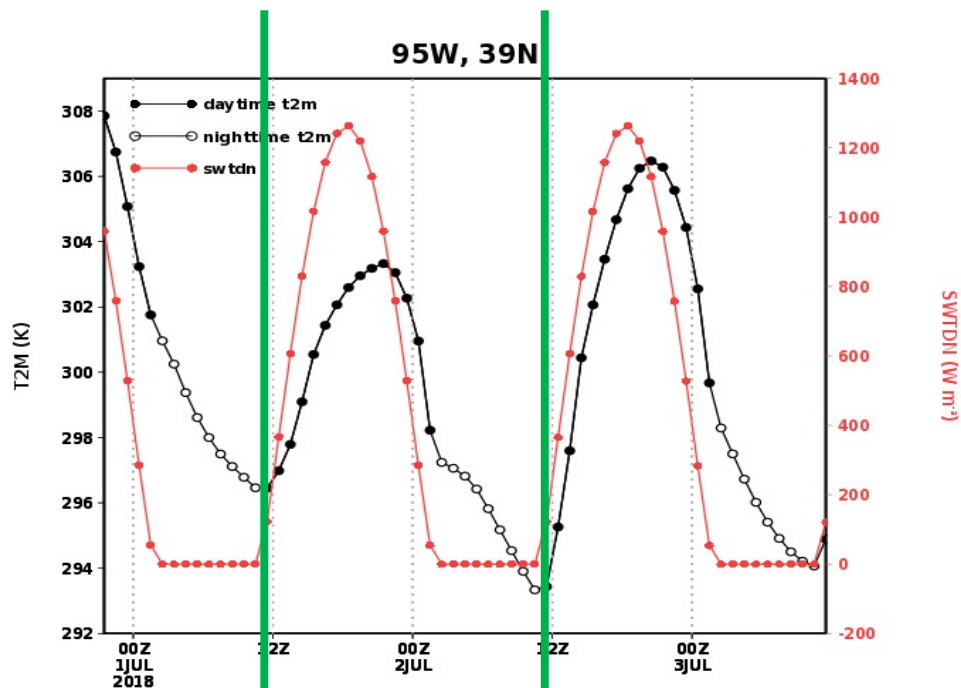
- Modern Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2)
- Use daytime and nighttime temperature to define heat waves



- Daytime and nighttime averages computed using shortwave flux at TOA as a mask
 - $\text{SWTDN} > 10 \text{ W m}^{-2} \rightarrow$ daytime hours
 - $\text{SWTDN} < 10 \text{ W m}^{-2} \rightarrow$ nighttime hours

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 - $\text{SWTDN} > 10 \text{ W m}^{-2} \rightarrow$ daytime hours
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- Daily averages computed at each grid point
 - a day begins at local sunrise; the day ends 23 hours later.

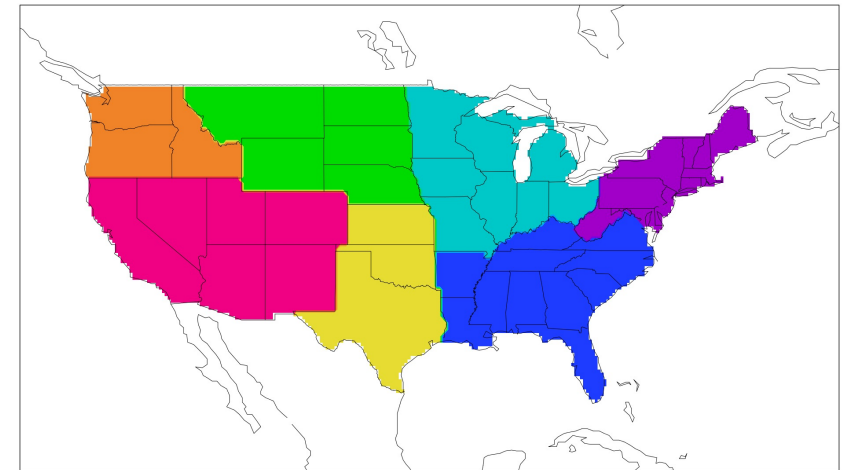
Methodology

➤ 3 independent categories of heat waves:

1. Daytime: $T_{\text{day}} > 90^{\text{th}}$ percentile for at least 3 days; $T_{\text{night}} < 90^{\text{th}}$ percentile
2. Nighttime: $T_{\text{night}} > 90^{\text{th}}$ percentile for at least 3 days; $T_{\text{day}} < 90^{\text{th}}$ percentile
3. Compound: $T_{\text{day}} > 90^{\text{th}}$ percentile AND $T_{\text{night}} > 90^{\text{th}}$ percentile for at least 3 days

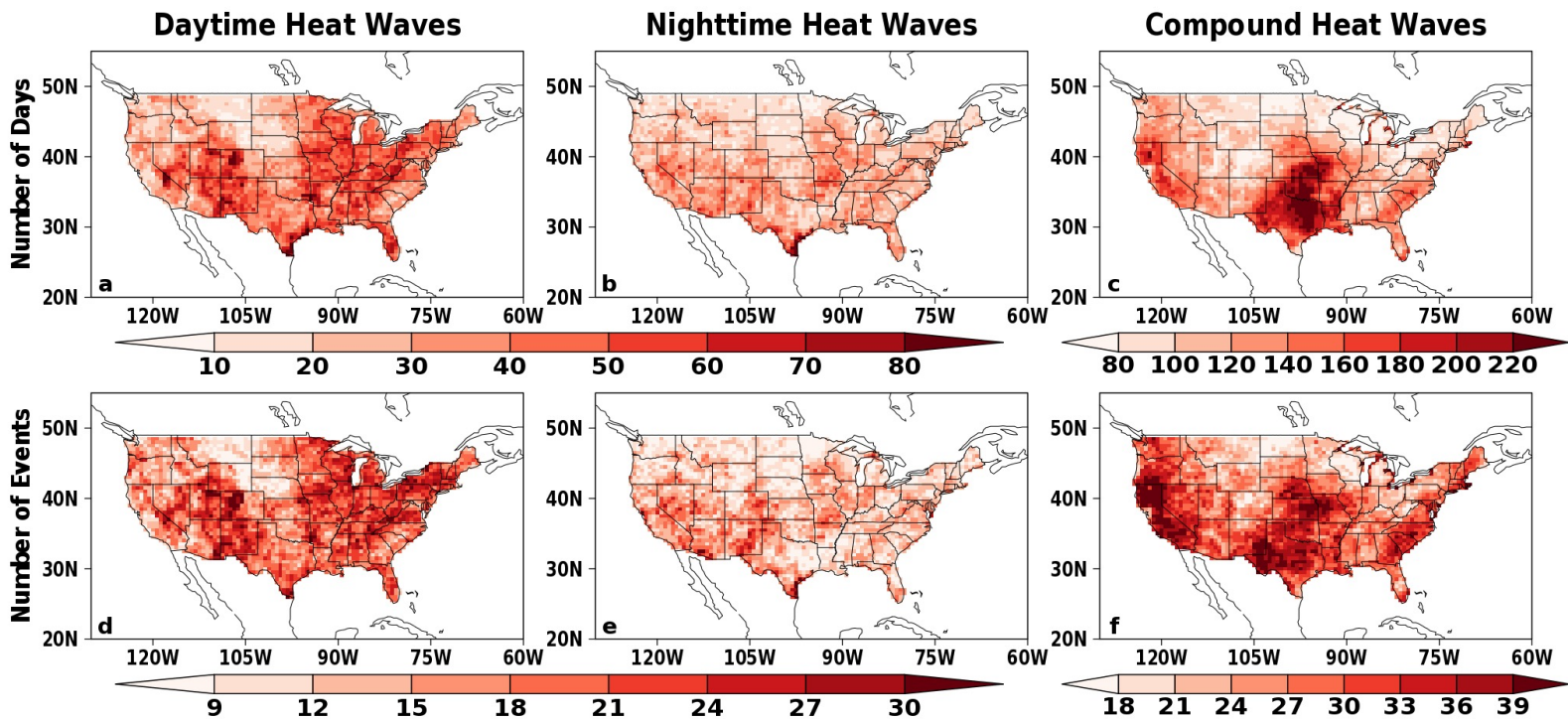
➤ Define heat waves at:

1. The grid point scale: T2m time series at each grid point used to define heat waves
2. The regional scale: Area-averaged T2m time series used to define heat waves (NCA regions)



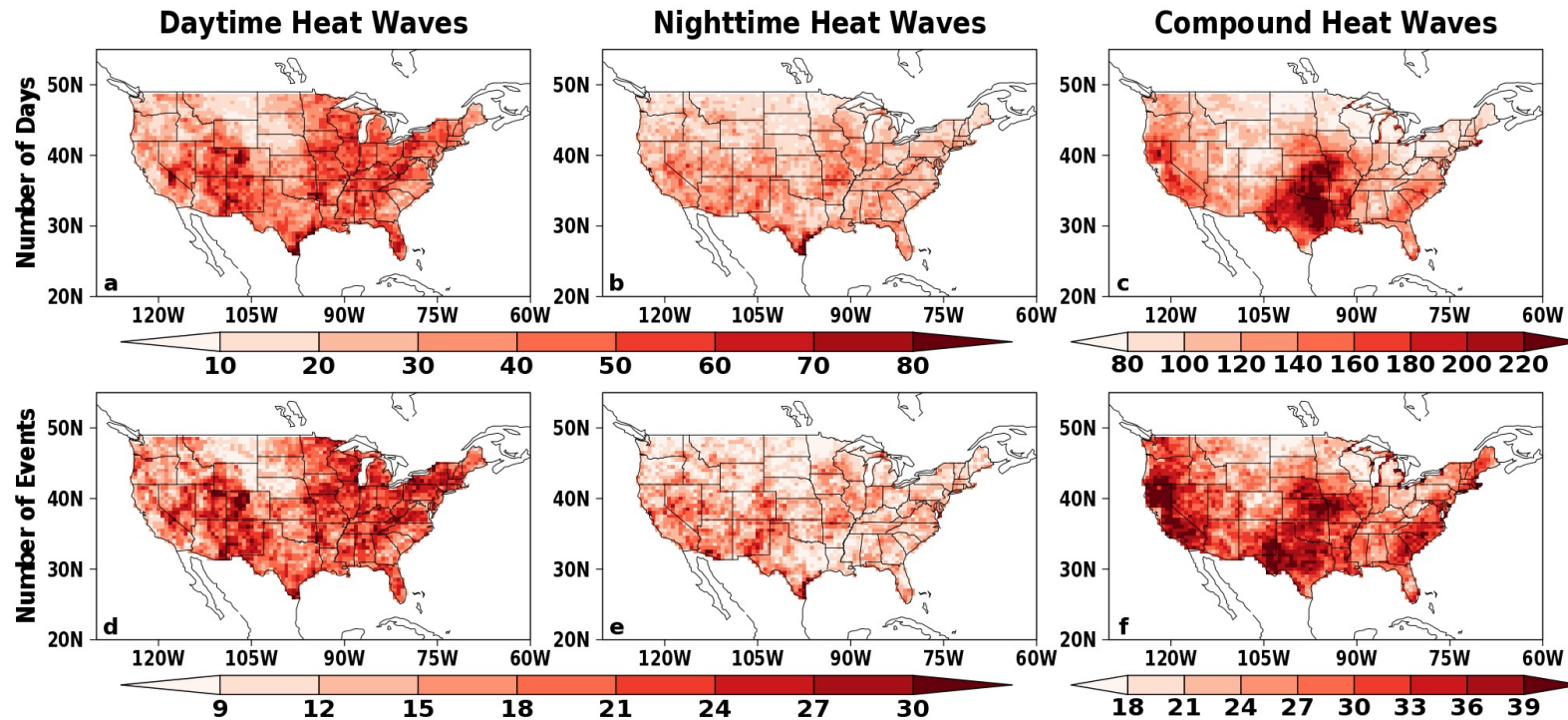


Methodology



Total over
JJA 1980-2018

Methodology

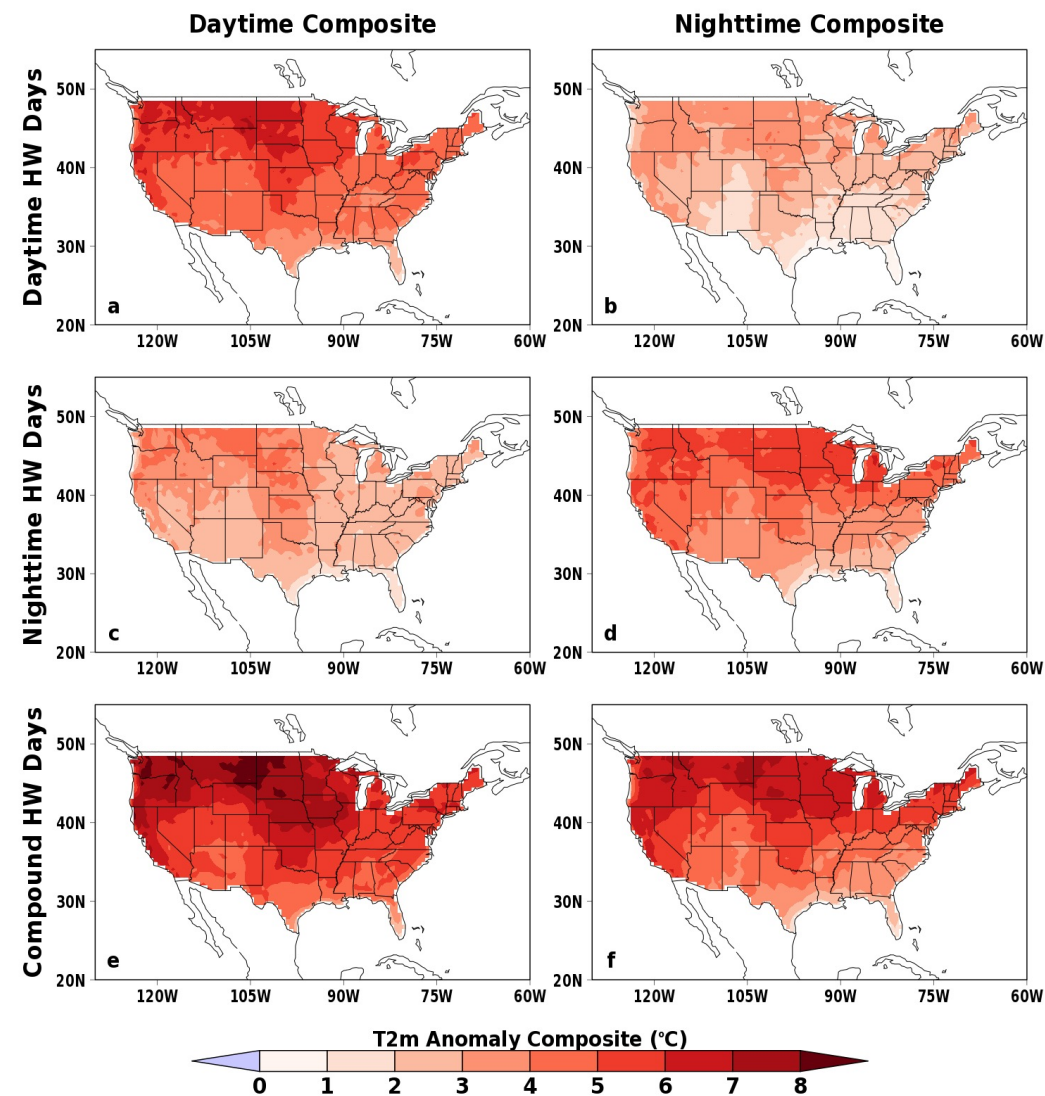


➤ Composite MERRA-2 variables at:

1. Grid scale: Determine regions with similar properties
2. Regional scale: Examine remote influences and large-scale features

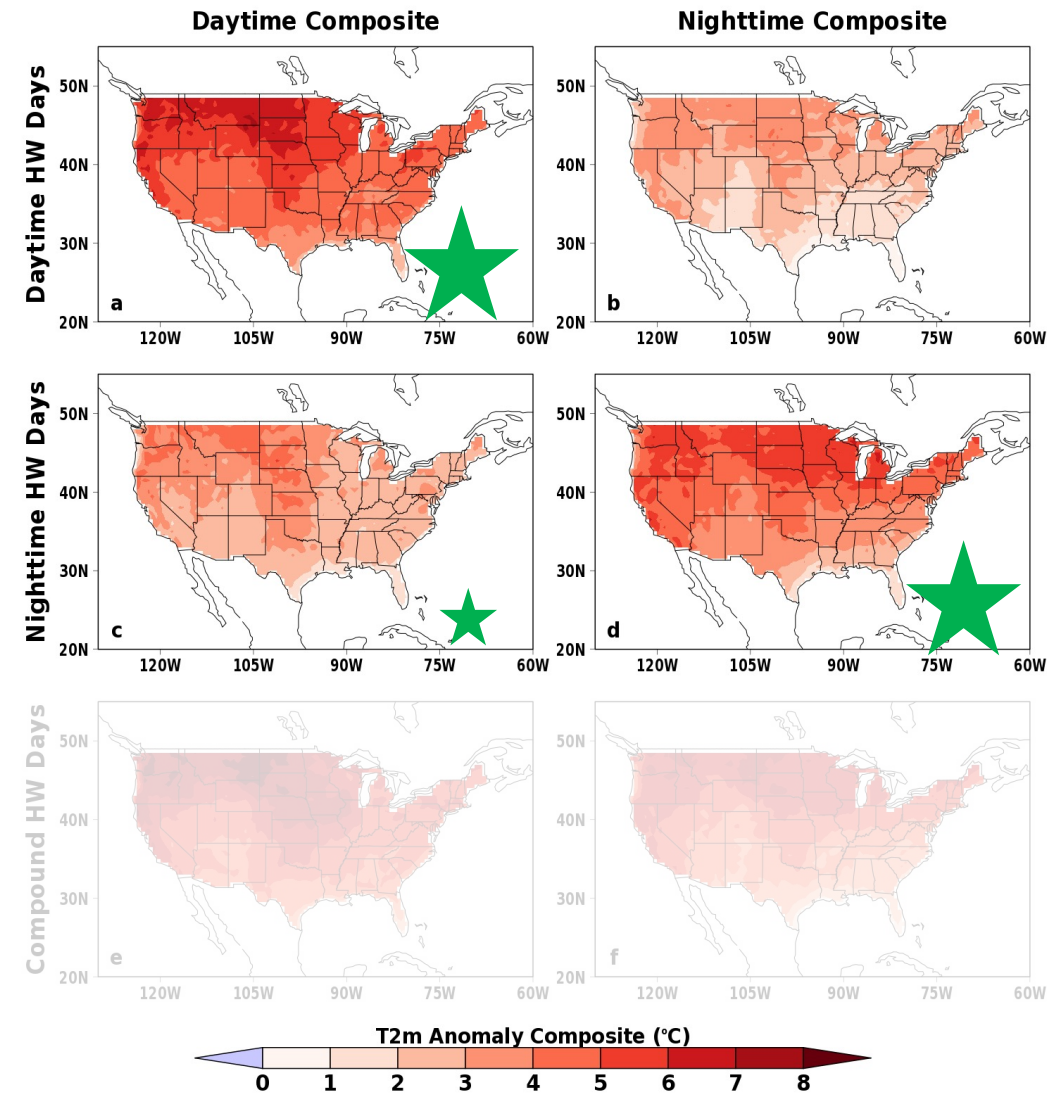
Composites – grid scale

- For a given variable, daytime and nighttime anomalies are separately averaged over the heat wave days for each of the 3 heat wave types, producing six composite fields
- Compound heat waves are associated with the largest anomalies in both daytime and nighttime T2m of all 3 heat wave types



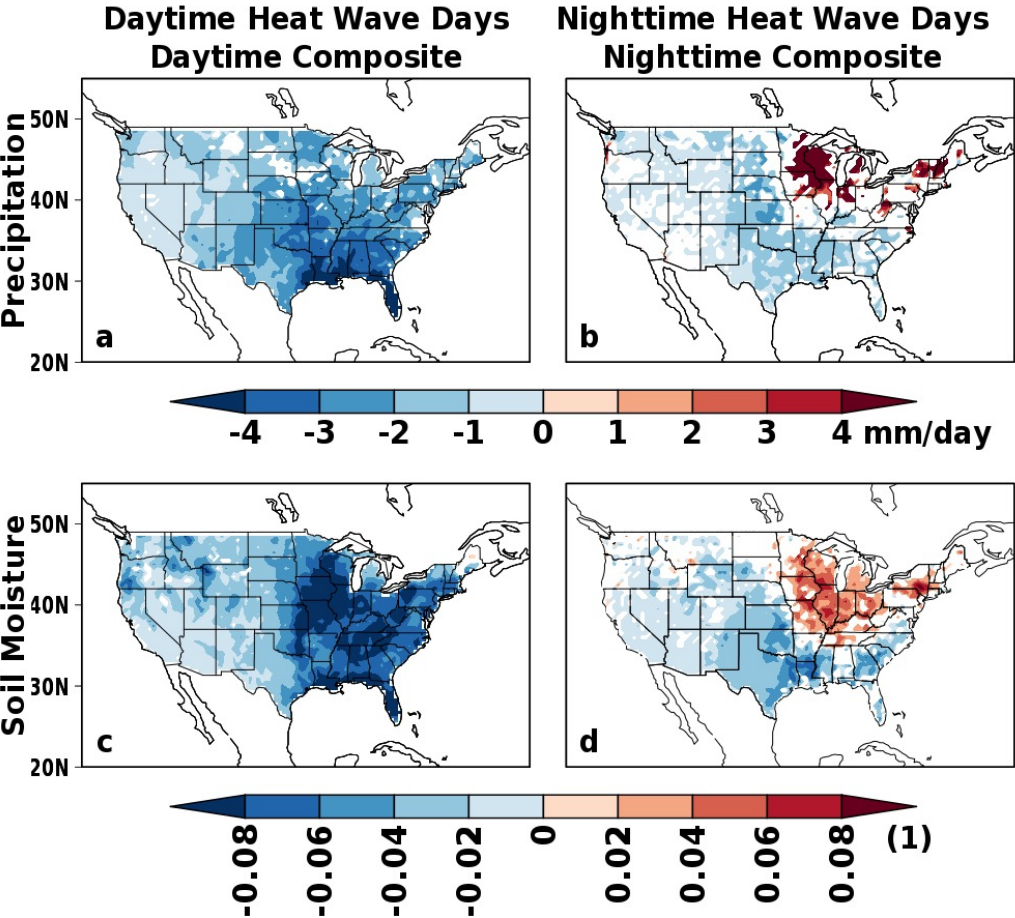
Composites – grid scale

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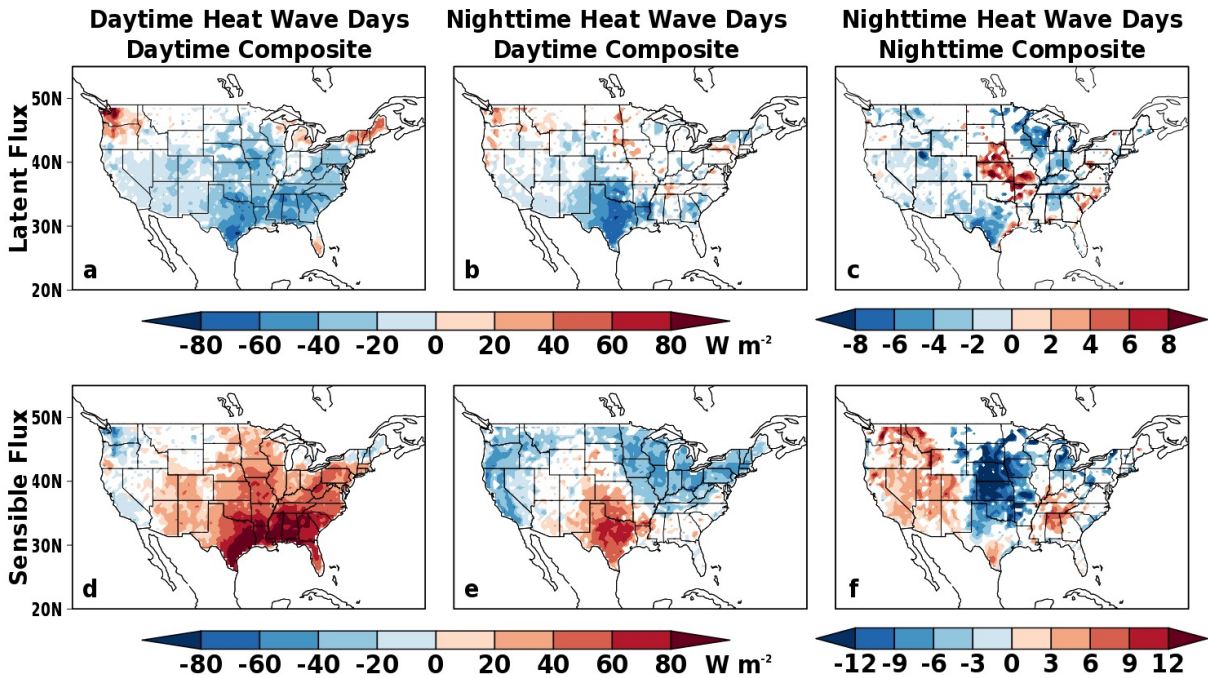
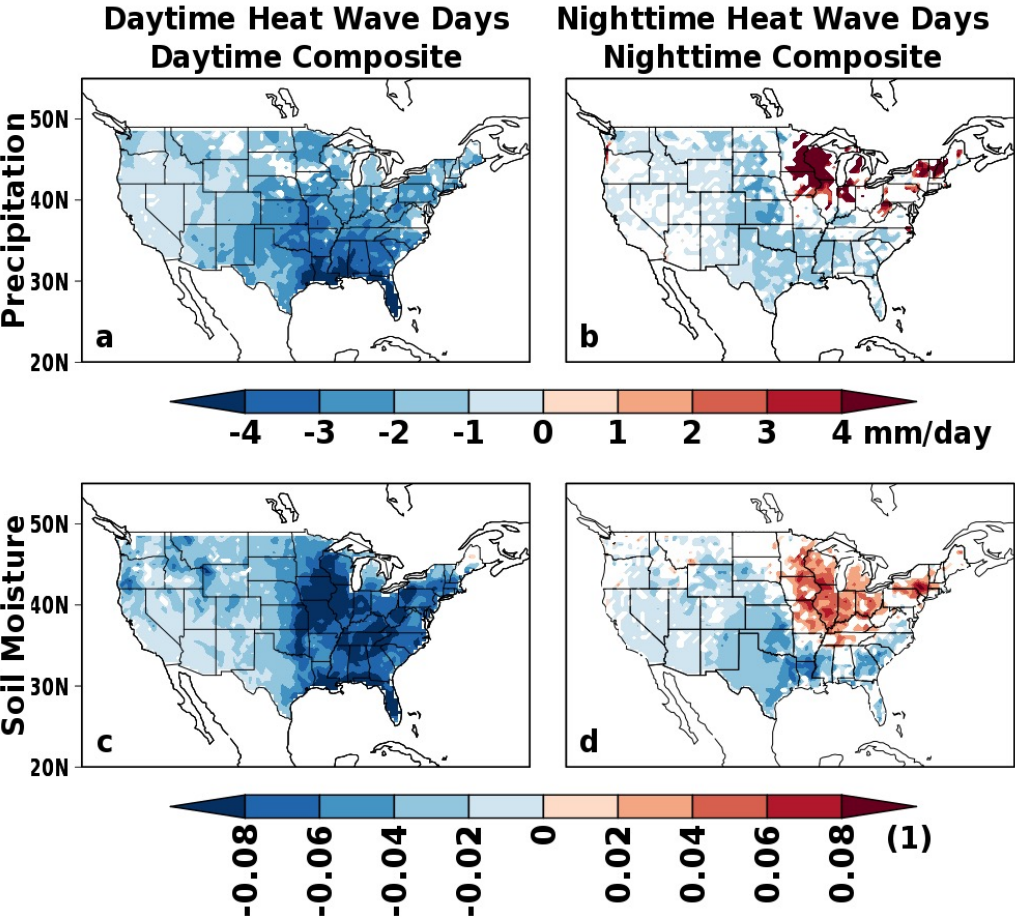
Composites – grid scale



*Regions where composite mean is not significantly different from 0 at 95% level are masked out in white

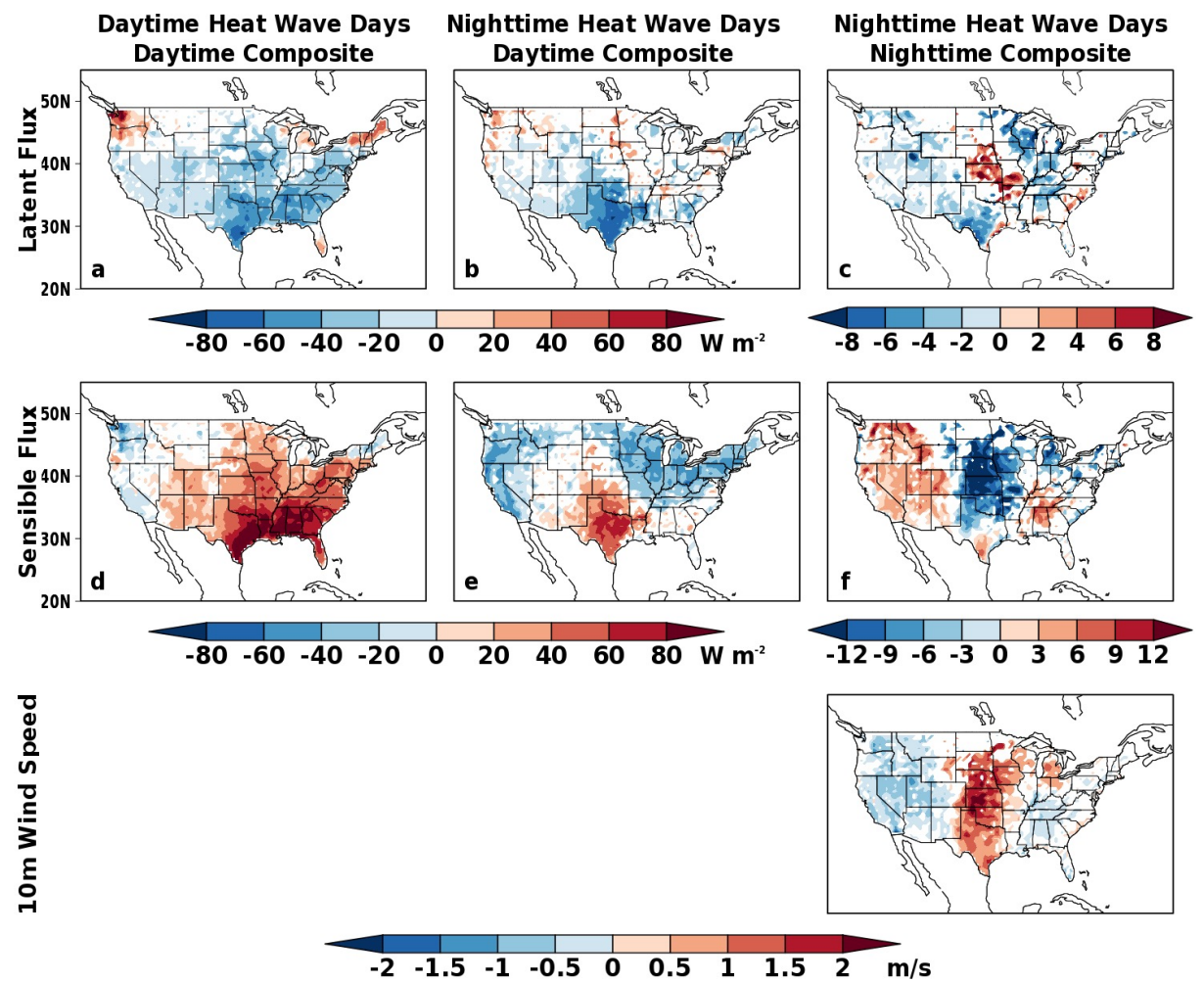
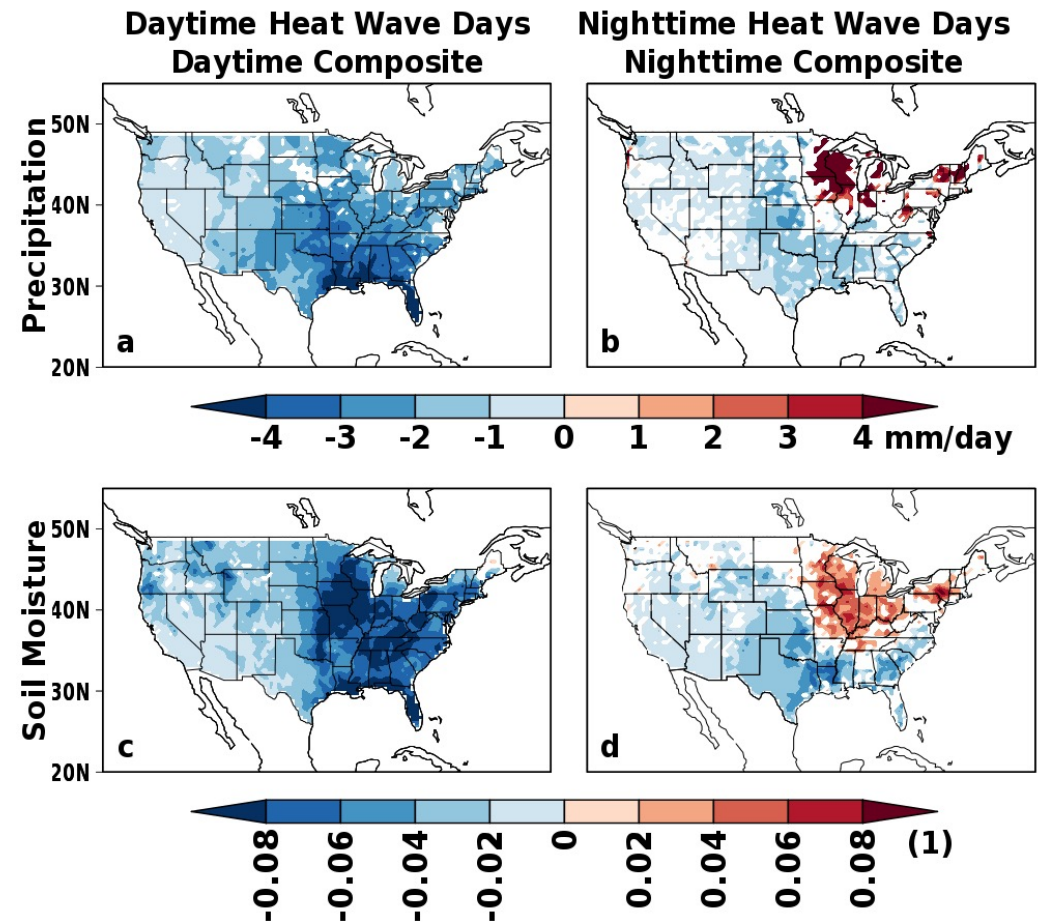


Composites – grid scale



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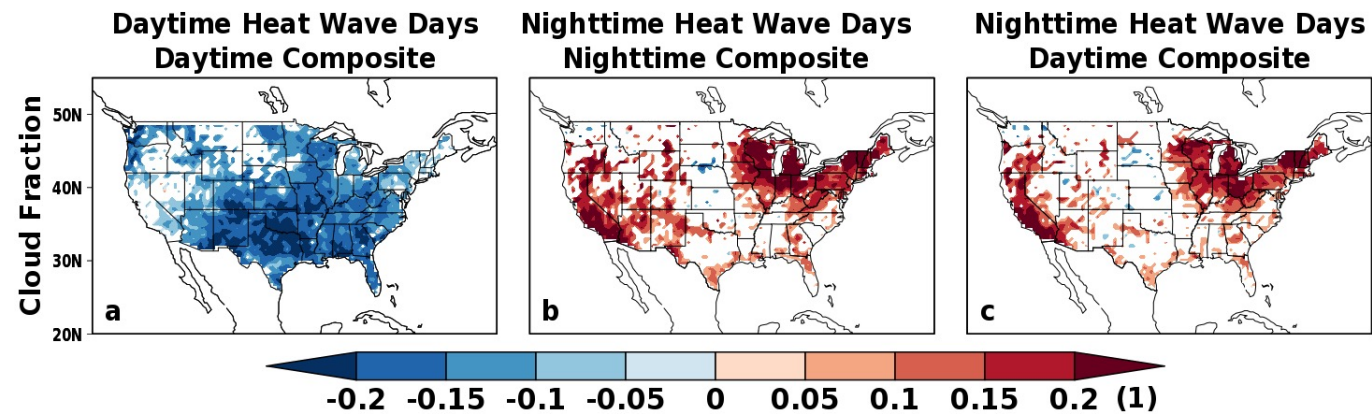
Composites – grid scale



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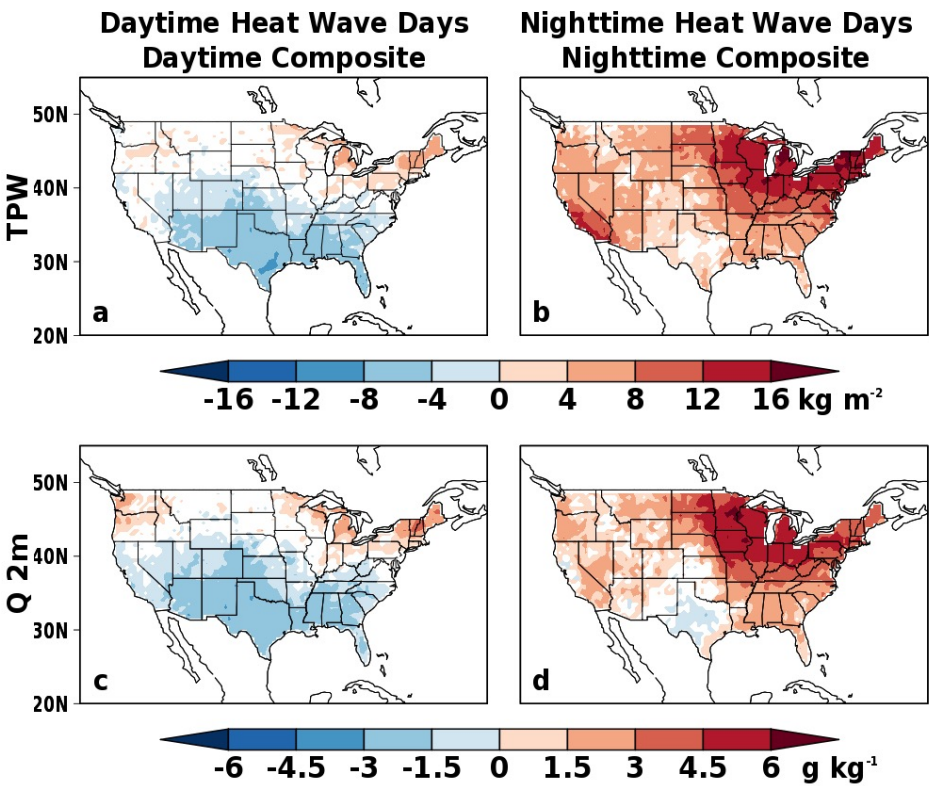
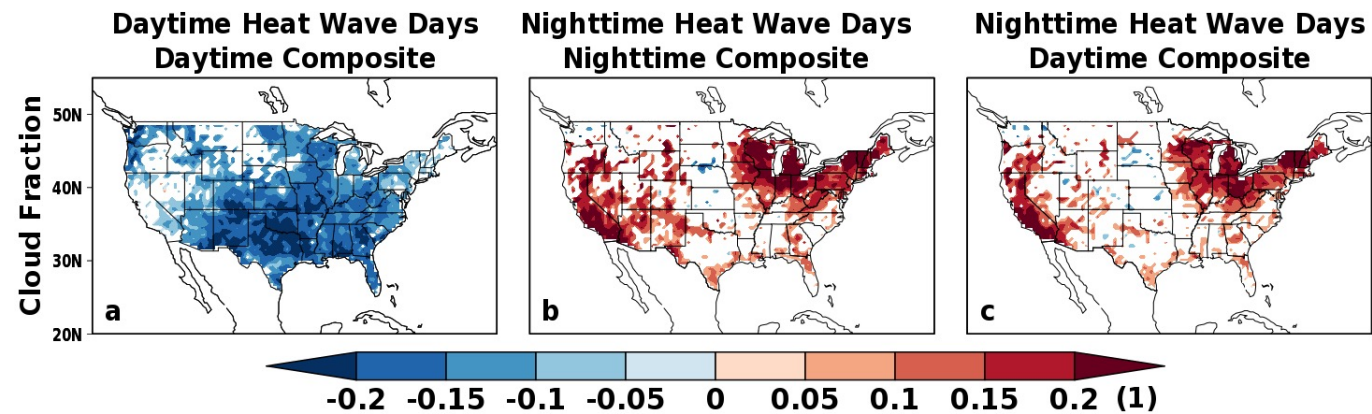


Composites – grid scale



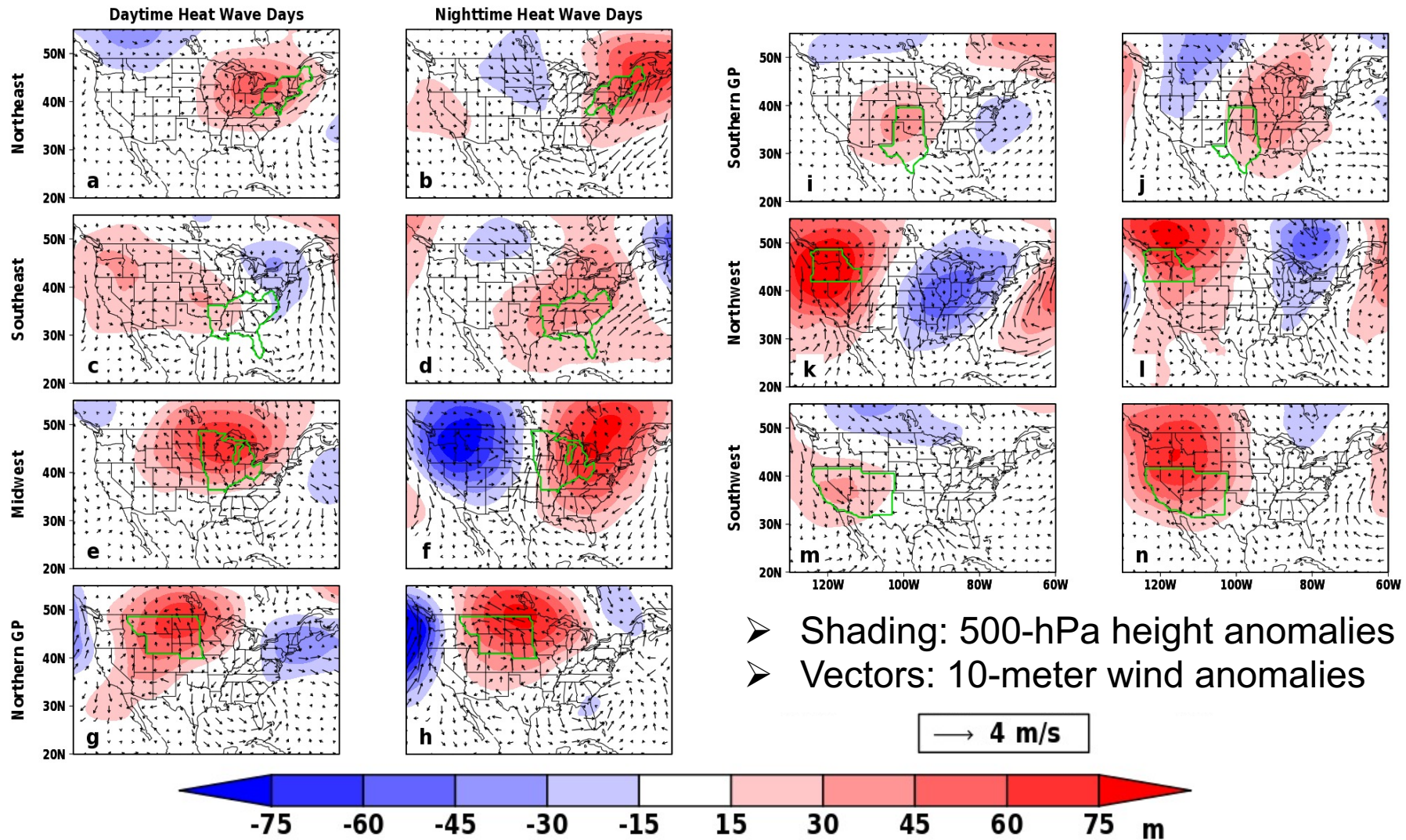
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Composites – grid scale



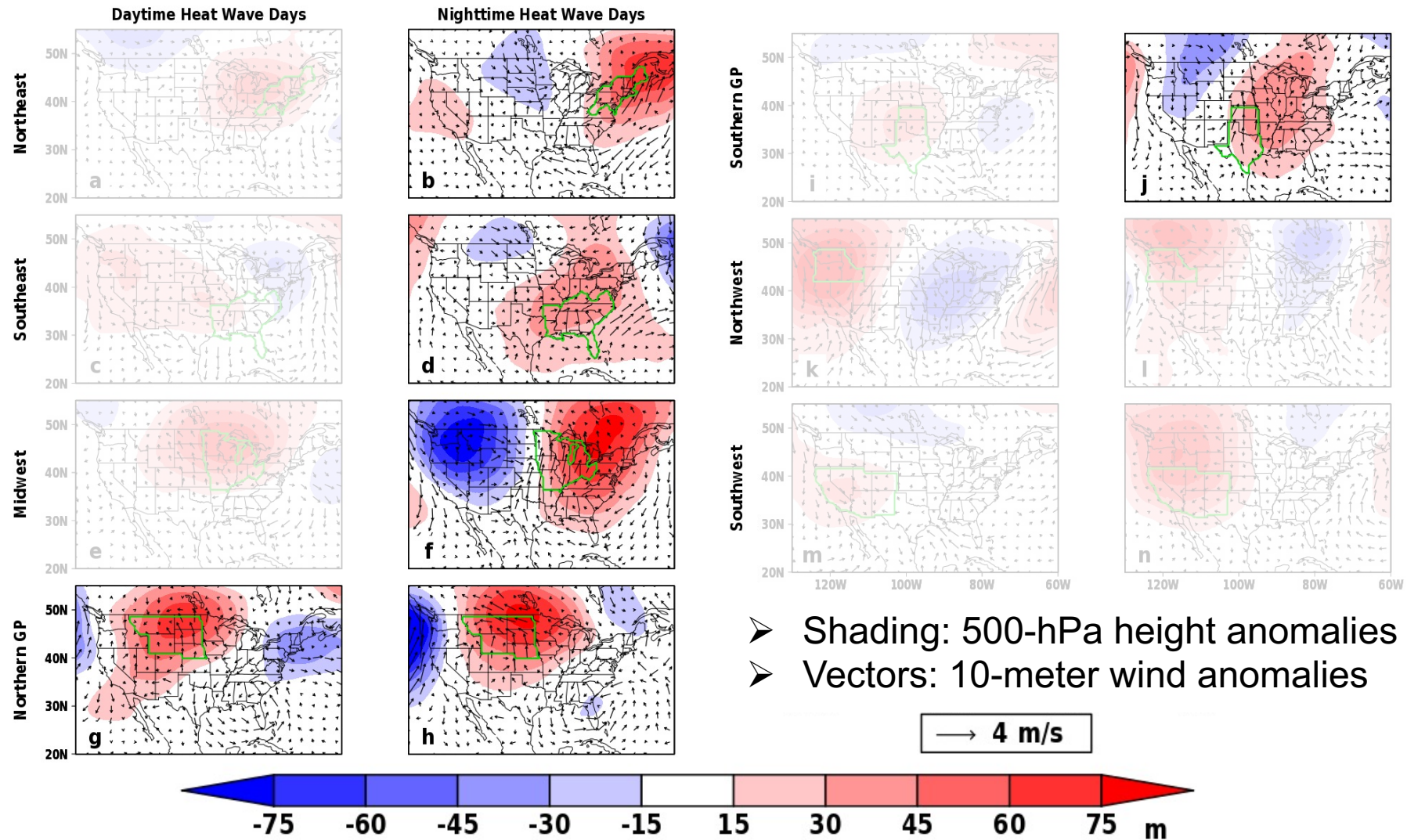
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Composites – Regional scale



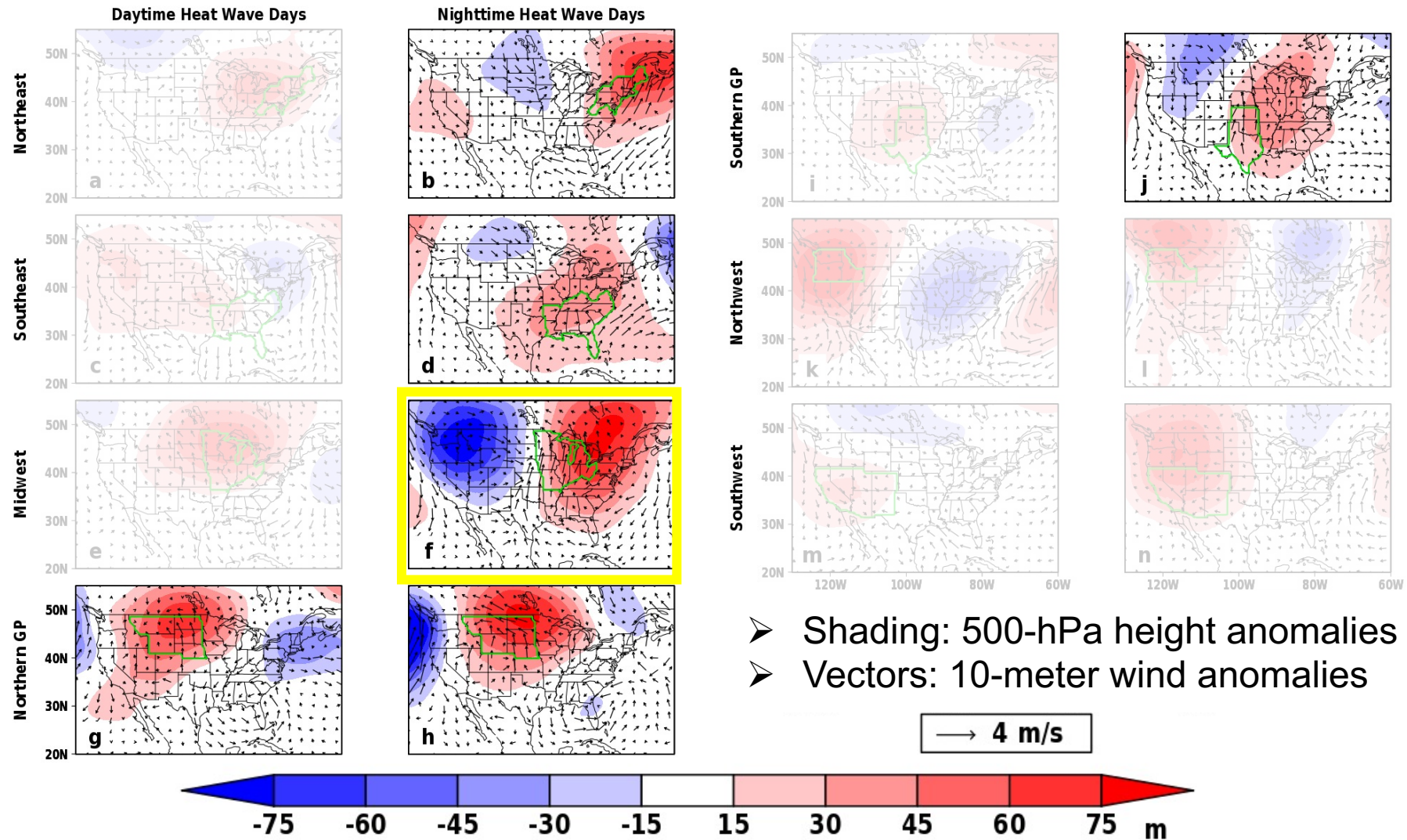
Composites – Regional scale

Warm air
advection
relevant in
many
regions

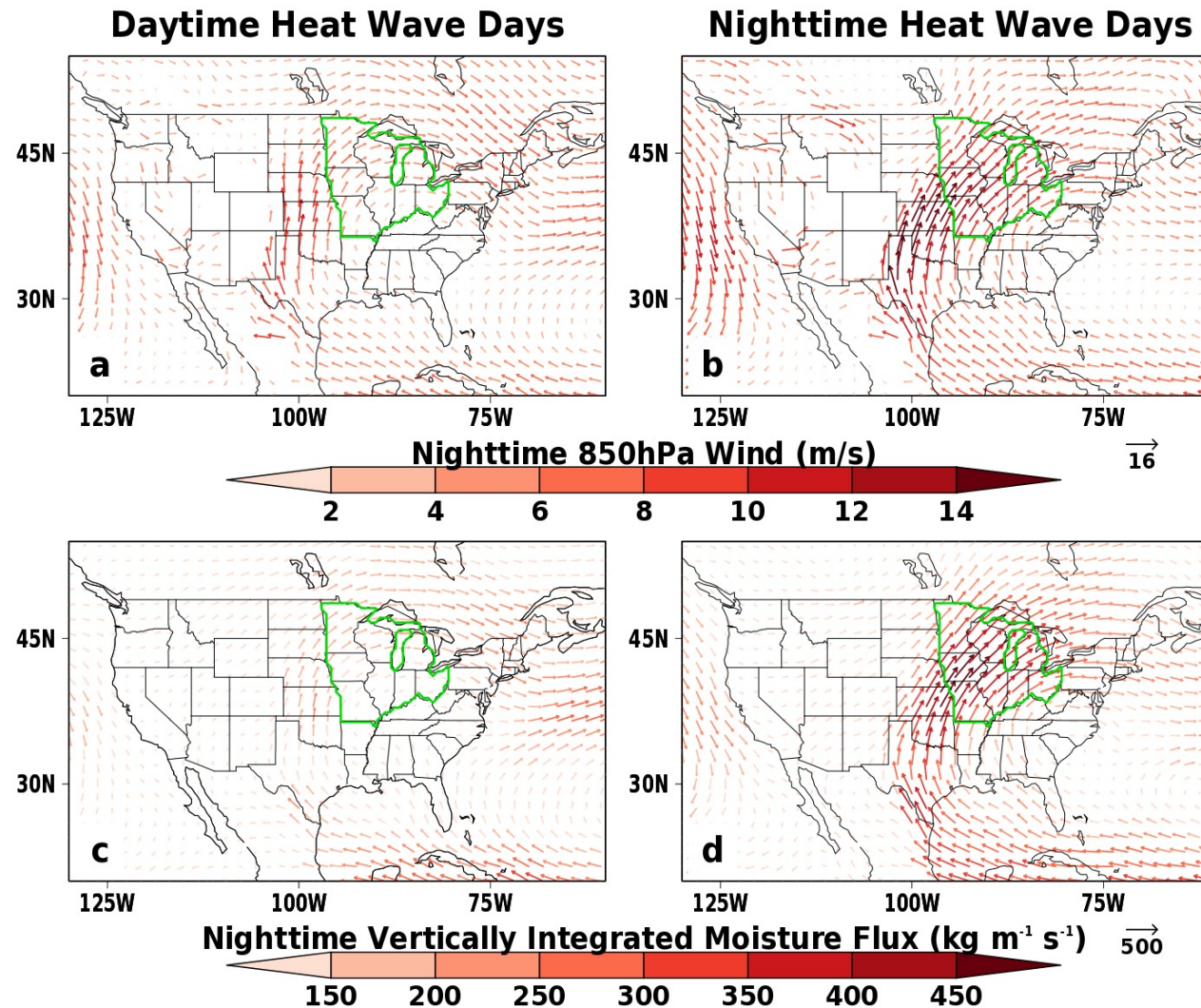


Composites – Regional scale

Focus on
Midwest
US

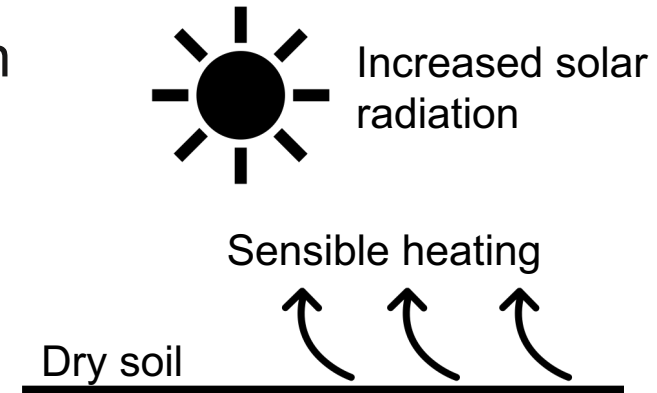


Composites – Midwest US



Conclusions

- Hourly reanalysis data from MERRA-2 facilitates diurnally-stratified study of heat wave mechanisms
- **Daytime HW days:** mechanisms consistent with previous research:



- **Nighttime HW days:** mechanisms vary regionally:

Southwest



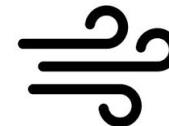
Increased clouds,
downwelling longwave

Northeast/Midwest



Increased clouds, precipitation, soil
moisture, water vapor. Moisture
transport from Gulf of Mexico

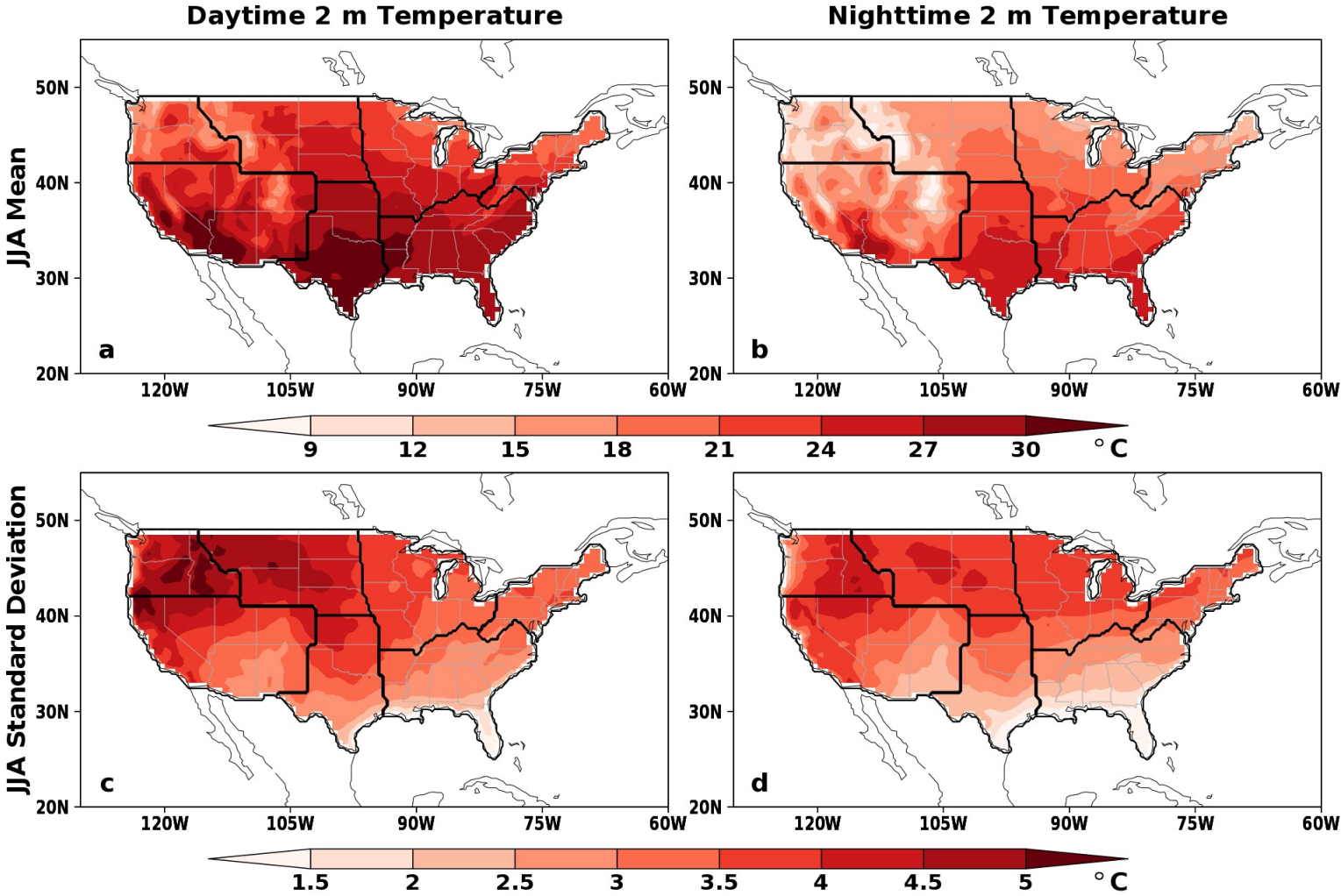
Great Plains



Increased low-level wind speed.
Warm air advection and
increased sensible heat flux



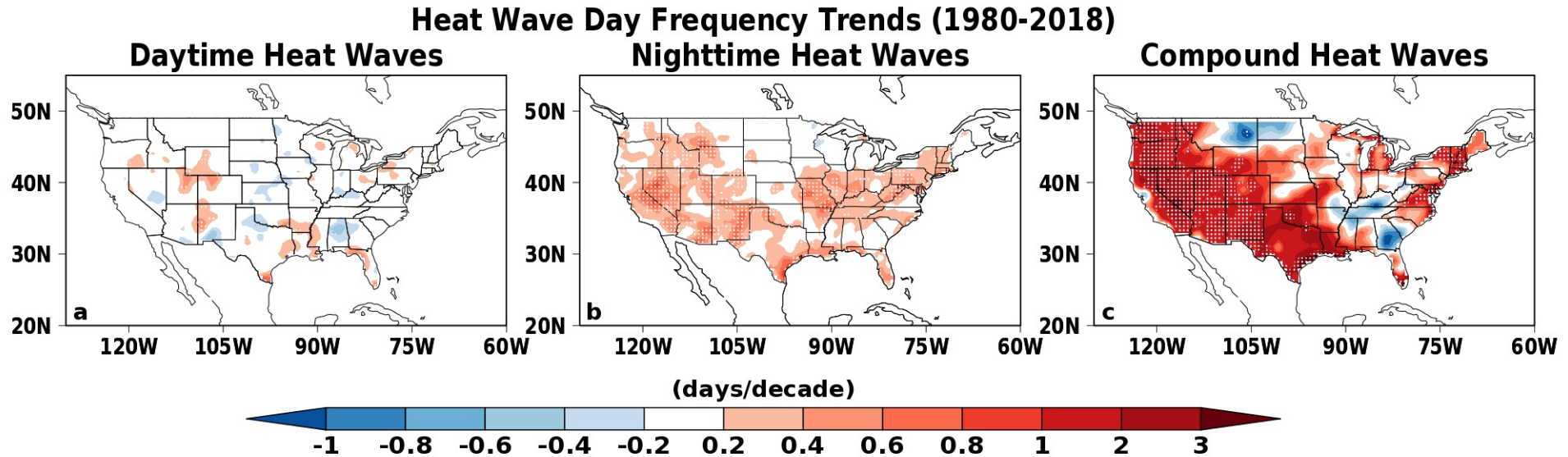
Extra Slides



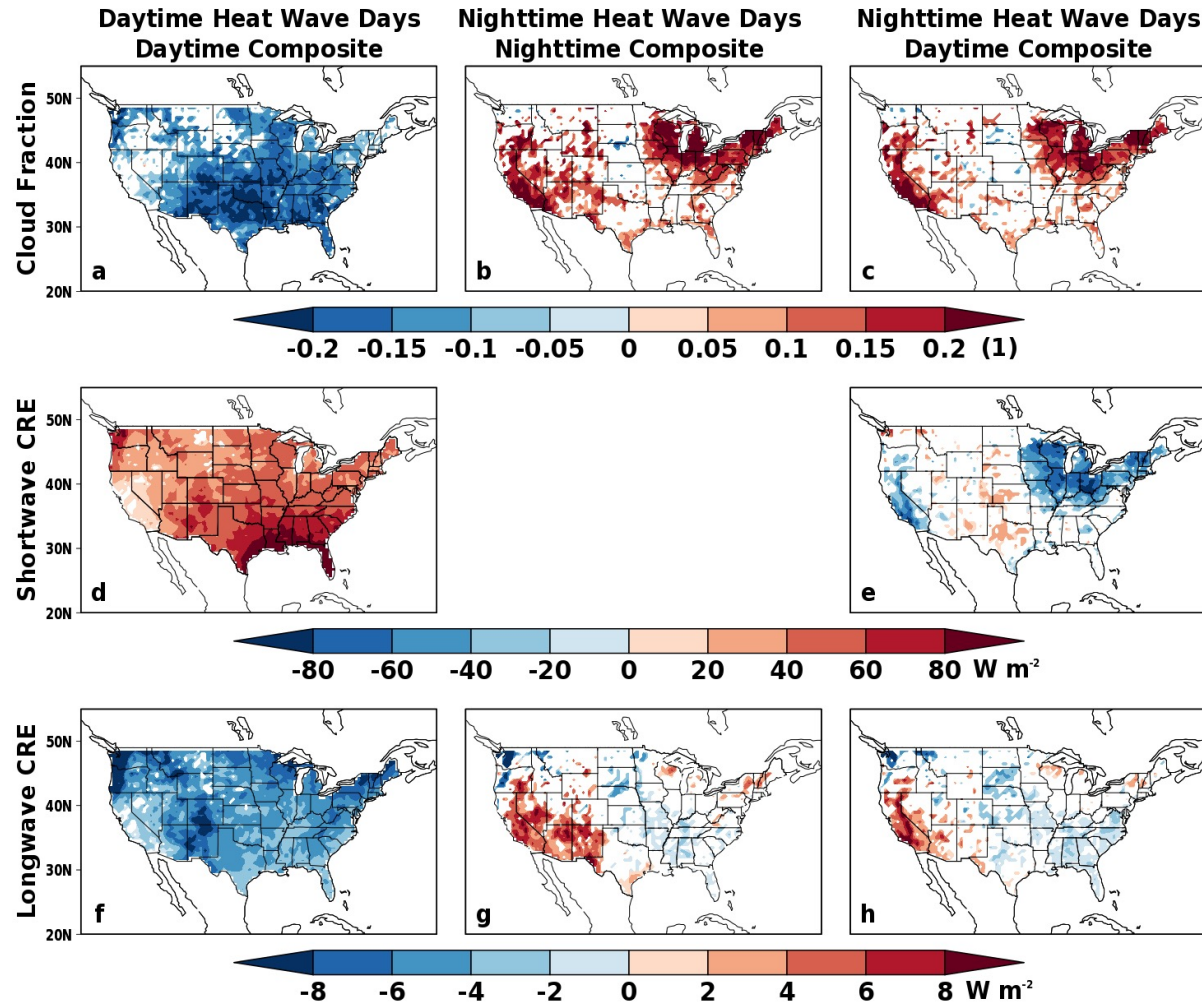
Mean (top row) and standard deviation (bottom row) of daytime 2-meter temperature (left column) and nighttime 2-meter temperature (right column) of all JJA days in 1980-2018 (i.e., $92 \times 39 = 3588$ days). The black lines denote the boundaries of the seven NCA regions, used for analysis of regional-scale heat waves.

NCA Region	Number of HW Days			Number of HW Events			Average Event Duration			Maximum Event Duration		
	D	N	C	D	N	C	D	N	C	D	N	C
Northeast	45	24	131	24	13	36	3.8	3.4	5.1	8	6	9
Southeast	27	33	210	10	13	42	3.5	3.6	6.4	6	6	19
Midwest	48	33	158	21	19	35	3.9	3.3	5.9	7	4	12
N. Great Plains	18	19	169	11	13	34	3.3	3.5	5.9	5	6	17
S. Great Plains	61	25	279	22	11	41	4.3	3.5	8.8	12	6	44
Northwest	15	20	178	12	9	47	3.5	3.6	4.7	6	5	13
Southwest	32	48	222	16	20	44	3.5	3.5	6.8	5	10	21

The number of heat wave days, number of heat wave events, average event duration, and maximum event duration for each NCA region and for each of the 3 heat wave types: daytime (D), nighttime (N) and compound (C).



Trends in the number of summer (JJA) heat wave days for heat waves expressed during daytime (left), nighttime (middle) and both daytime and nighttime (right) in MERRA-2. Trends are for 1980-2018. Trends significant at the 0.05 level according to the Mann-Kendall test and indicated with white dots. Trends are smoothed once by a 9-point smoother.

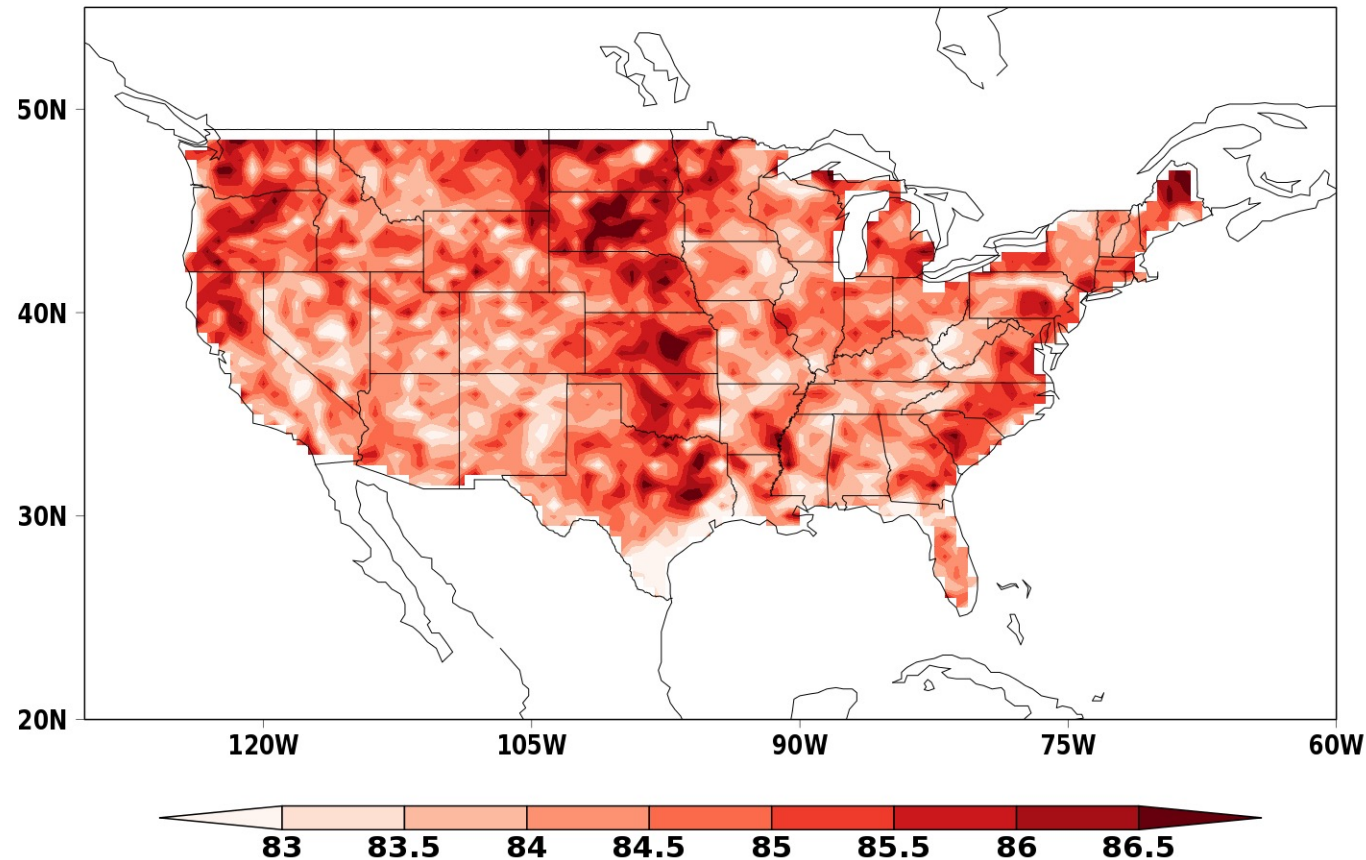


SWCRE: difference between surface net downward shortwave flux and that assuming clear sky
Always negative; more clouds → more negative

LWCRE: difference between surface absorbed longwave radiation and that assuming clear sky (model defined)
Always positive; more clouds → more positive

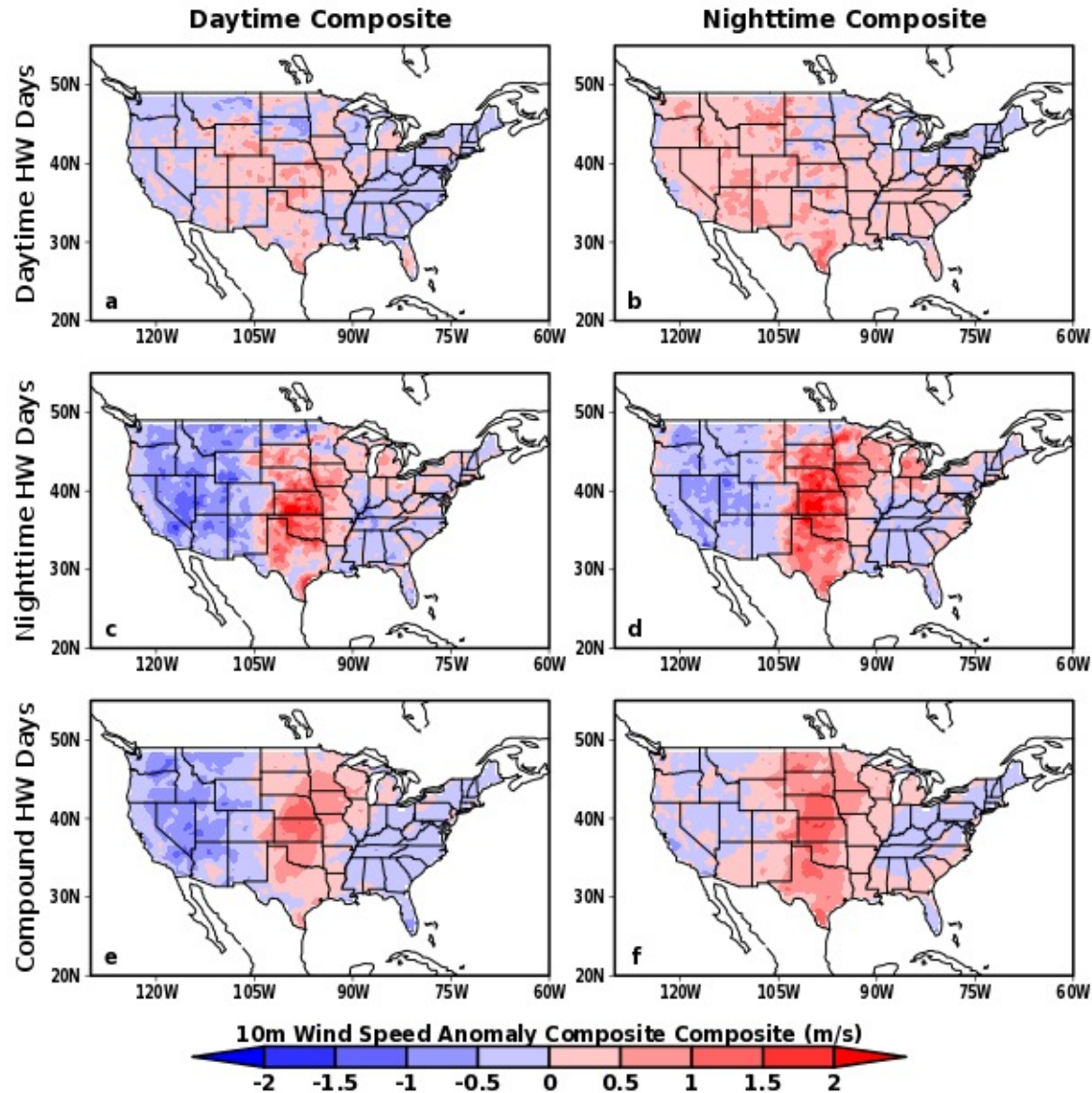
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Daytime Temperature Percentile Composite



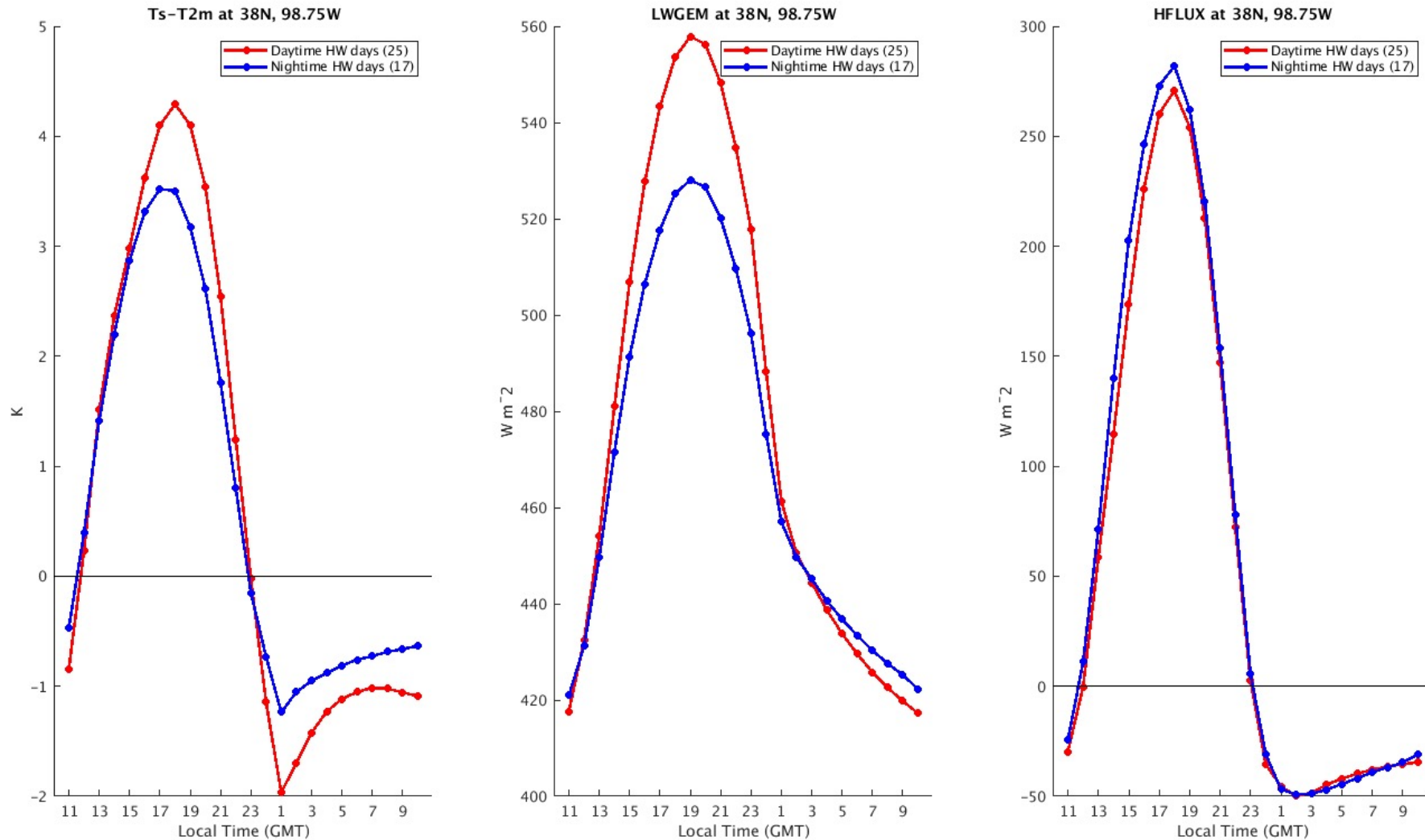
Average percentile of daytime temperature preceding nighttime heat wave days – i.e., for all nighttime heat wave days at a given point, find percentile of daytime temperature preceding the heat wave and average over all days.

Daytime temperatures preceding nighttime heat wave days are warmest over the Central US.



Composites of 10-meter wind speed anomalies during daytime and nighttime hours of all 3 types of heat waves.

Nighttime heat waves over the central US are associated with enhanced 10-meter wind speeds during both daytime and nighttime hours.



Hourly averages of variables composited over all hours on daytime and nighttime heat wave days for a single point in the Great Plains of the US