

Warmer and More Volatile: Why Does Summertime Temperature Variance Increase as the Climate Warms?

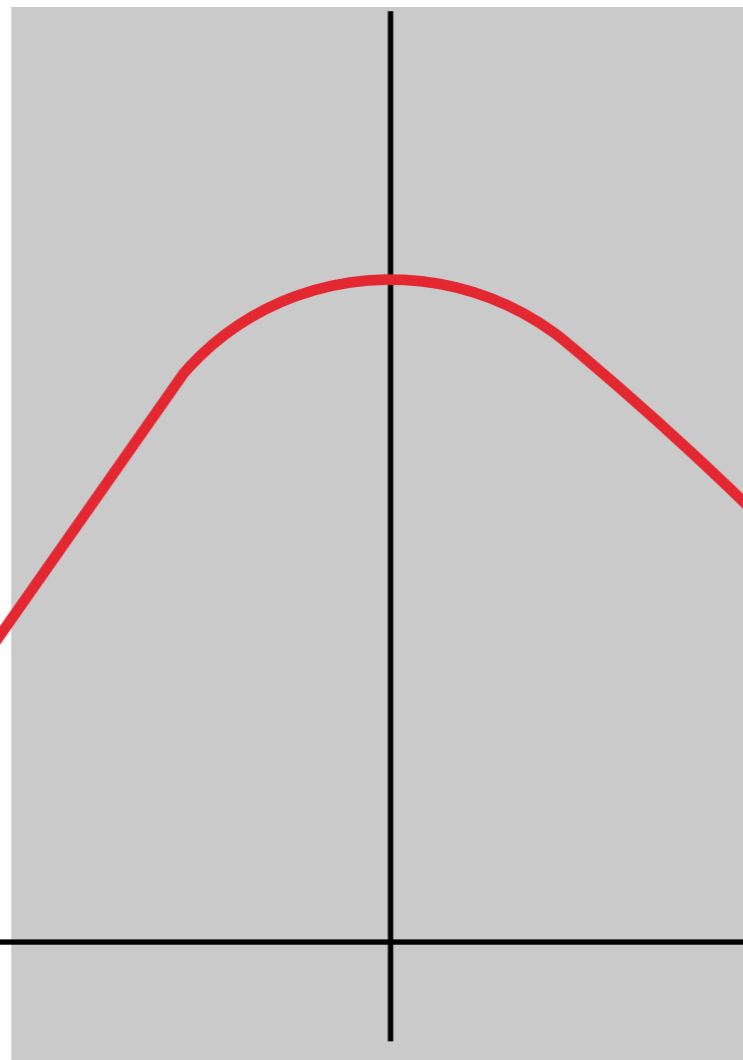
Lucas Vargas Zeppetello, David Battisti, Marcia Baker



WHO CARES ABOUT TEMPERATURE VARIANCE?

Probability density function

Variance



The variance is one way to measure how wide the envelope of variability is

I've been working on skewness as well, which measures the shape of the distribution...that's for another talk.

Cold

Hot

Temperature [°C]

I'M SKIPPING A LOT OF STUFF!

A New Look at the Variance of Summertime Temperatures over Land

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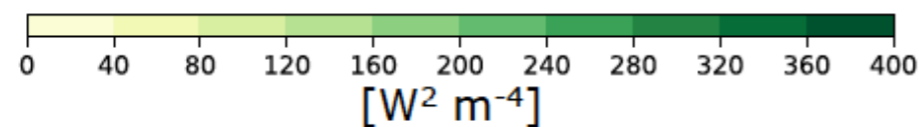
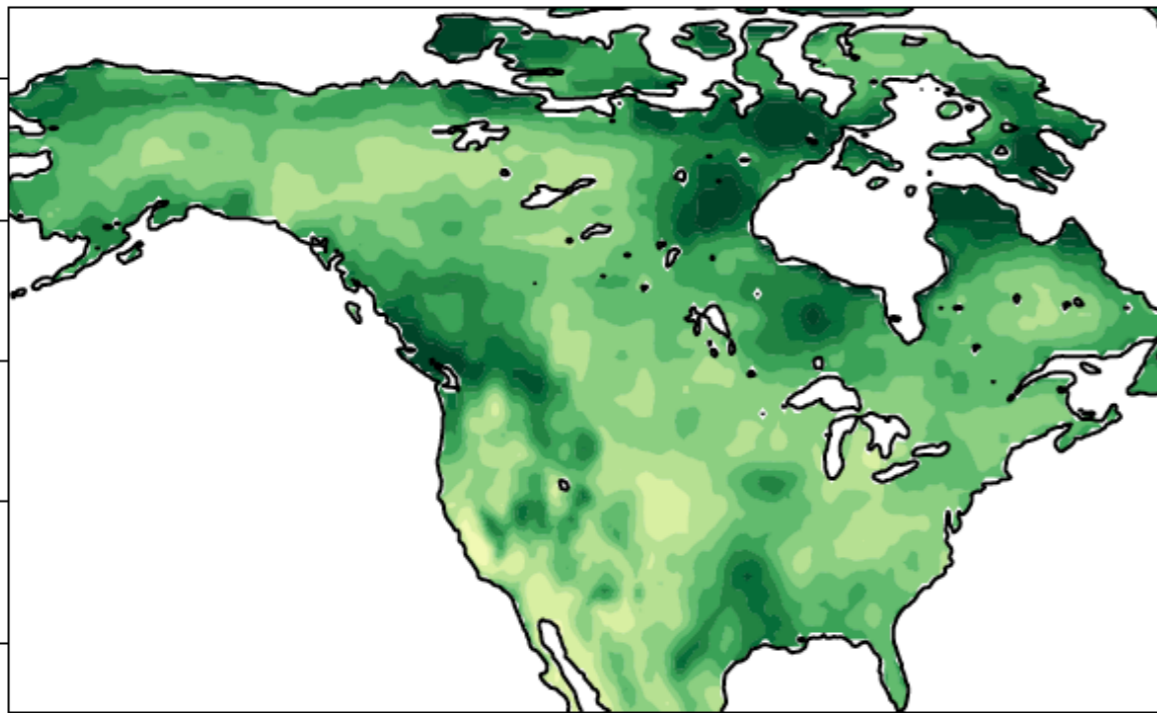
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THREE MODEL FORCINGS

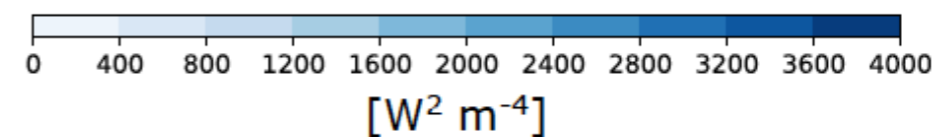
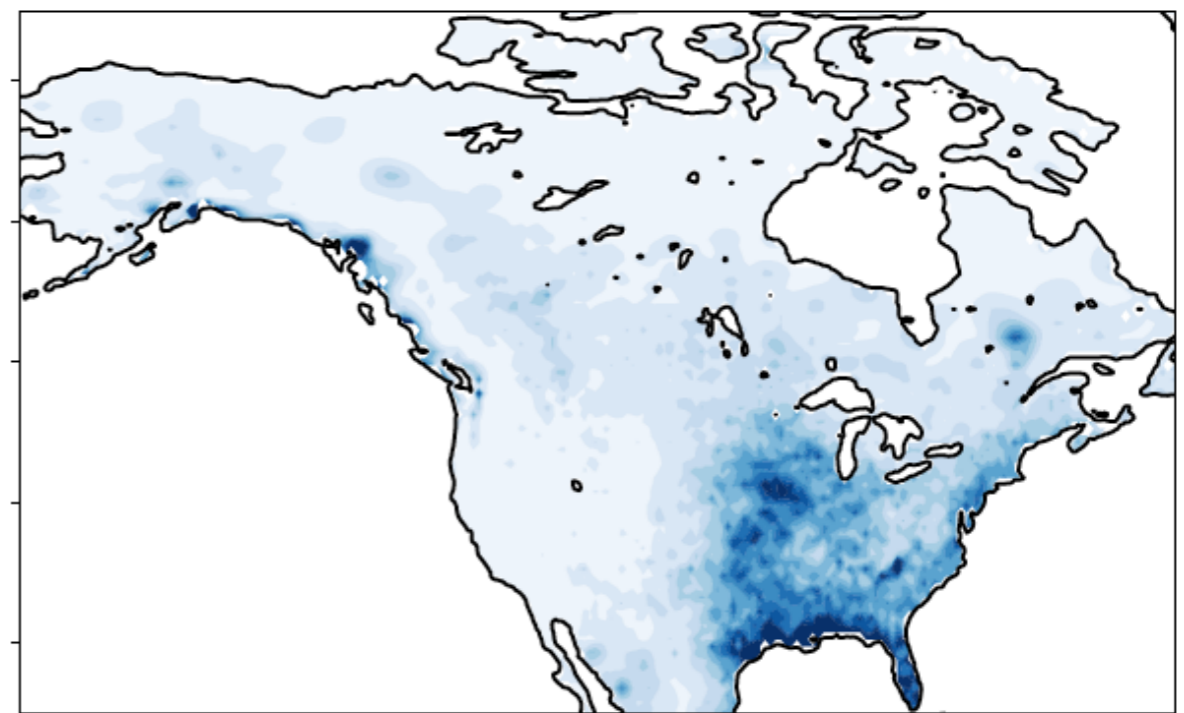
$$\sigma^2(T) = \frac{1}{\Gamma^2} \left[\sigma^2(\mathcal{F}_p) - 2 \overline{\mathcal{F}_p' L \mathcal{P}'} \zeta + \sigma^2(L \mathcal{P}) \zeta^2 \right]$$

Radiation Variance
Precipitation Variance

Covariance



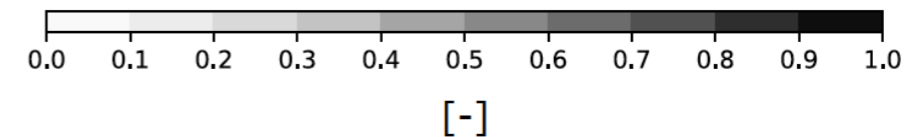
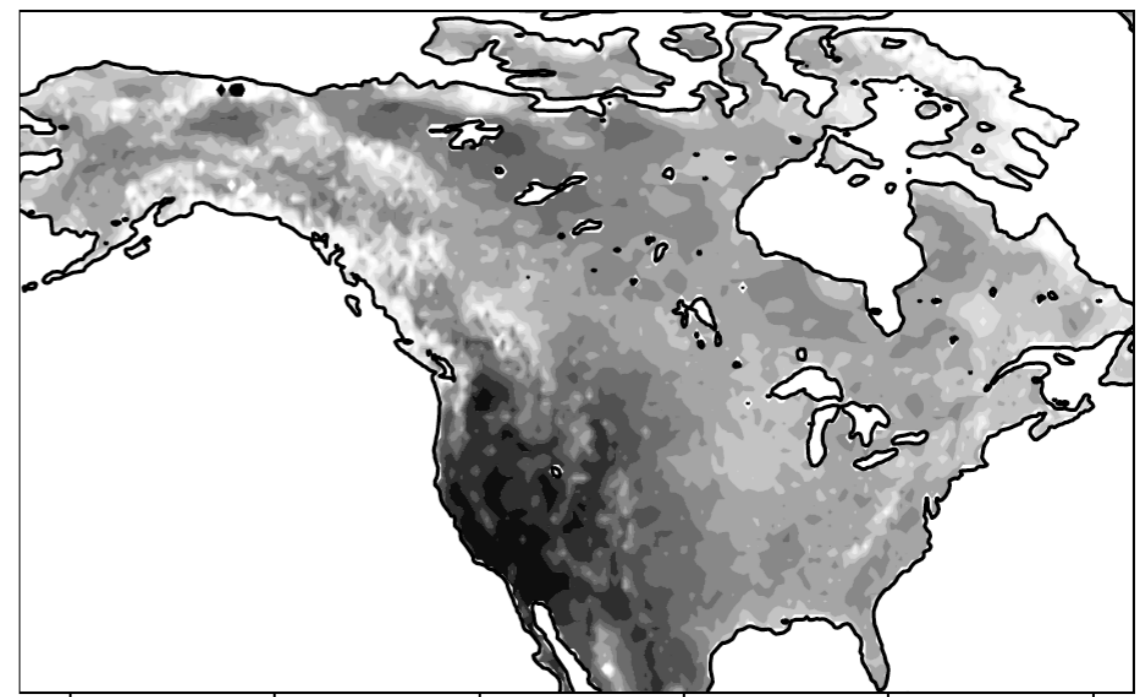
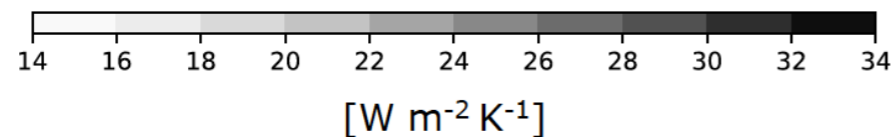
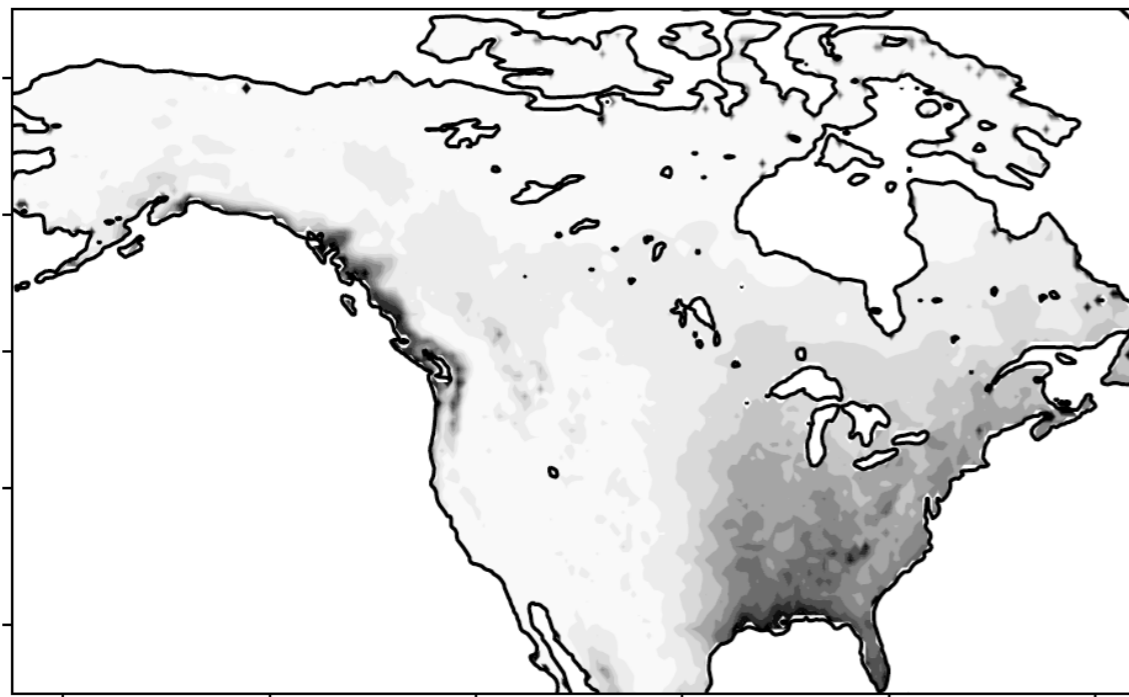
CERES satellite JJA 2000-2017



Gridded weather stations JJA
2000-2017

TWO LAND SURFACE PARAMETERS

$$\sigma^2(T) = \underbrace{\frac{1}{\Gamma^2}}_{\text{Moist sensitivity}} \left[\sigma^2(\mathcal{F}_p) - 2 \overline{\mathcal{F}_p' L \mathcal{P}'} \underbrace{\zeta}_{\text{Dryness index}} + \sigma^2(L \mathcal{P}) \underbrace{\zeta^2}_{\text{Dryness index}} \right]$$

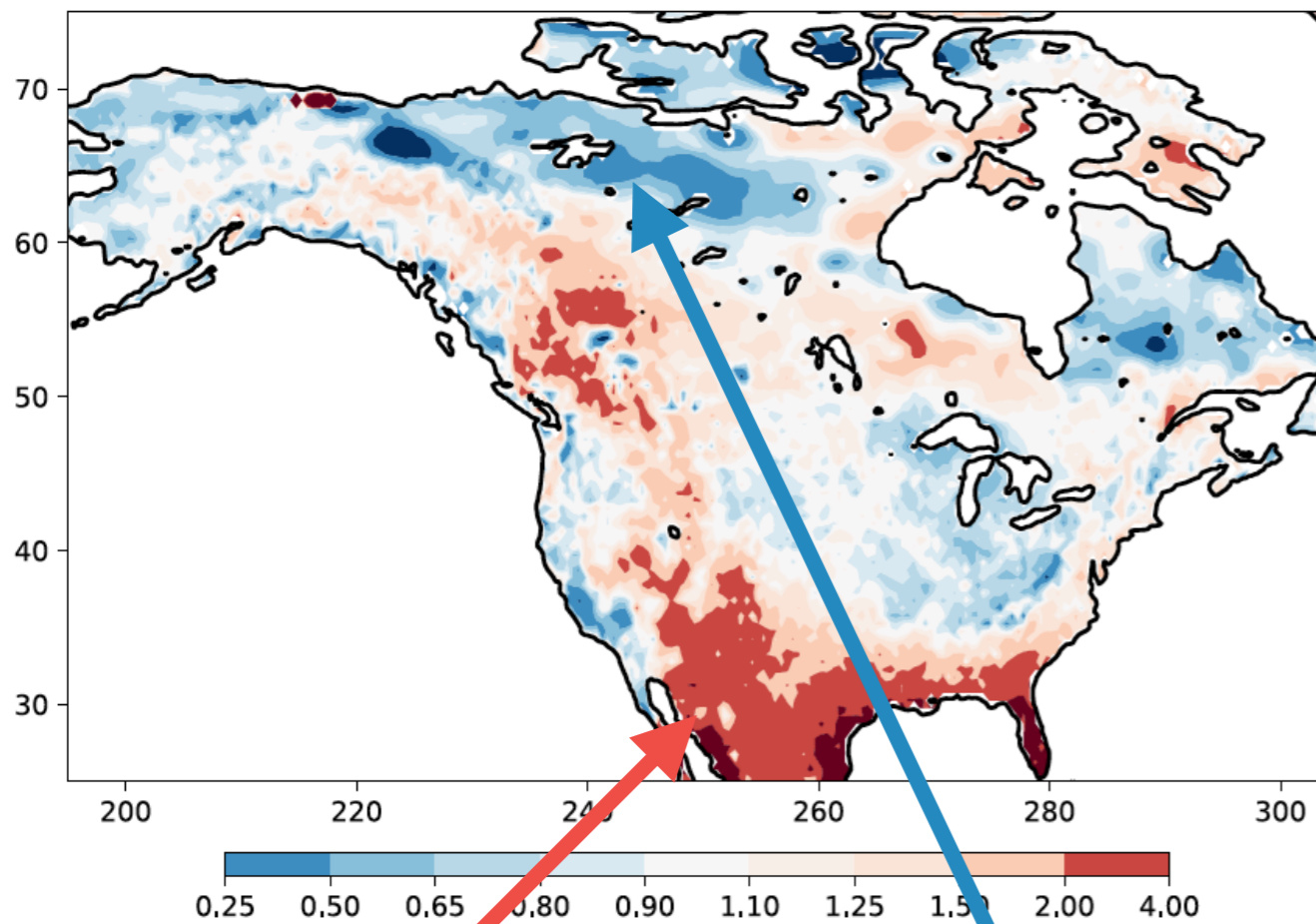


Both of these parameters are functions of mean temperature and soil moisture.

COMPARISON WITH OBSERVATIONS

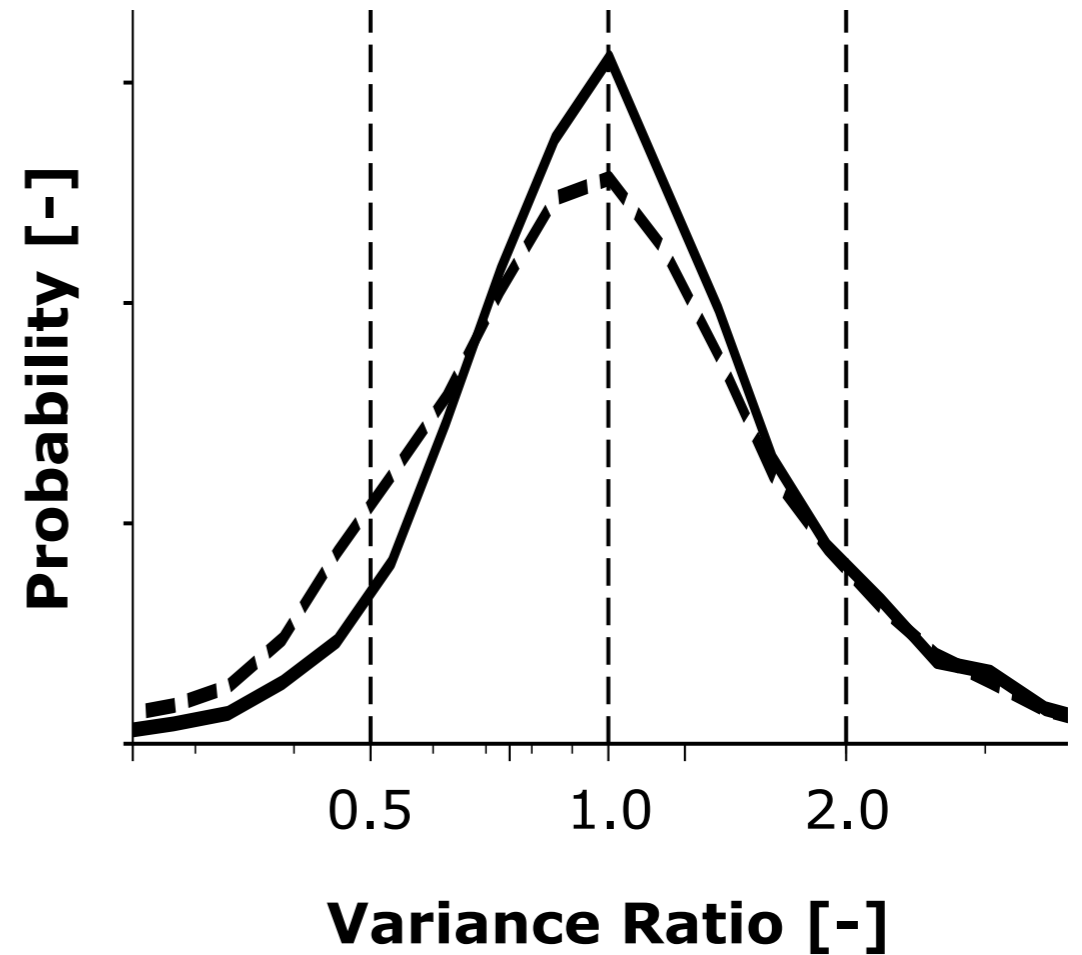
$$\frac{\sigma^2(T)_{\text{Model}}}{\sigma^2(T)_{\text{Obs.}}}$$

- North America
- - - Midlatitudes

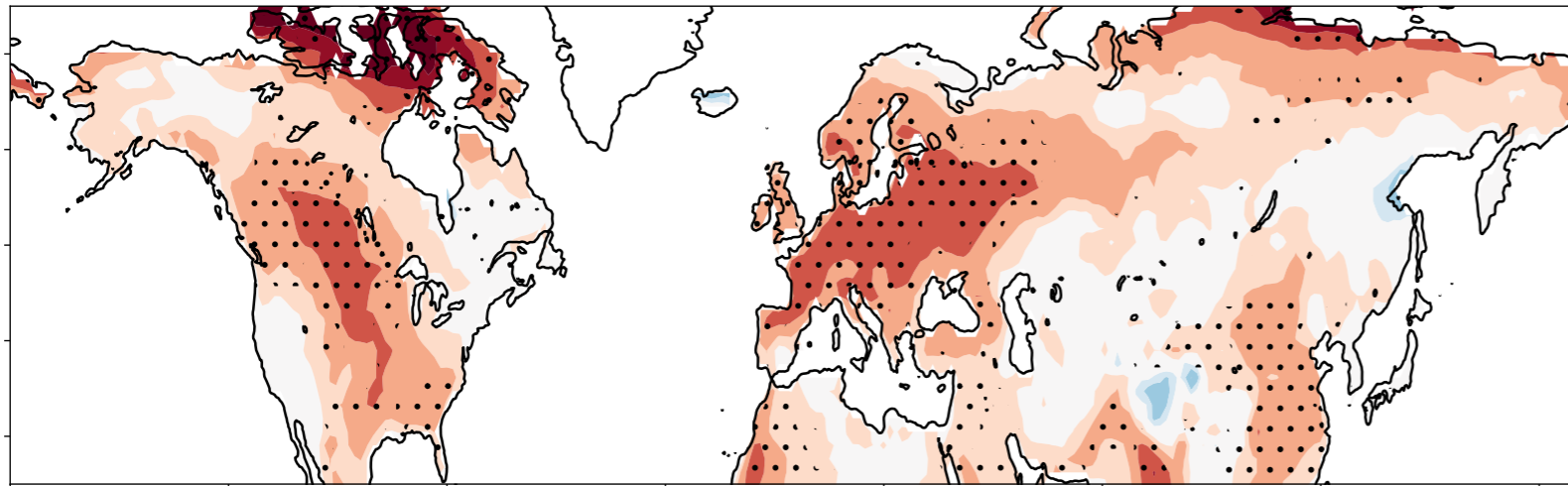


Over Predicting

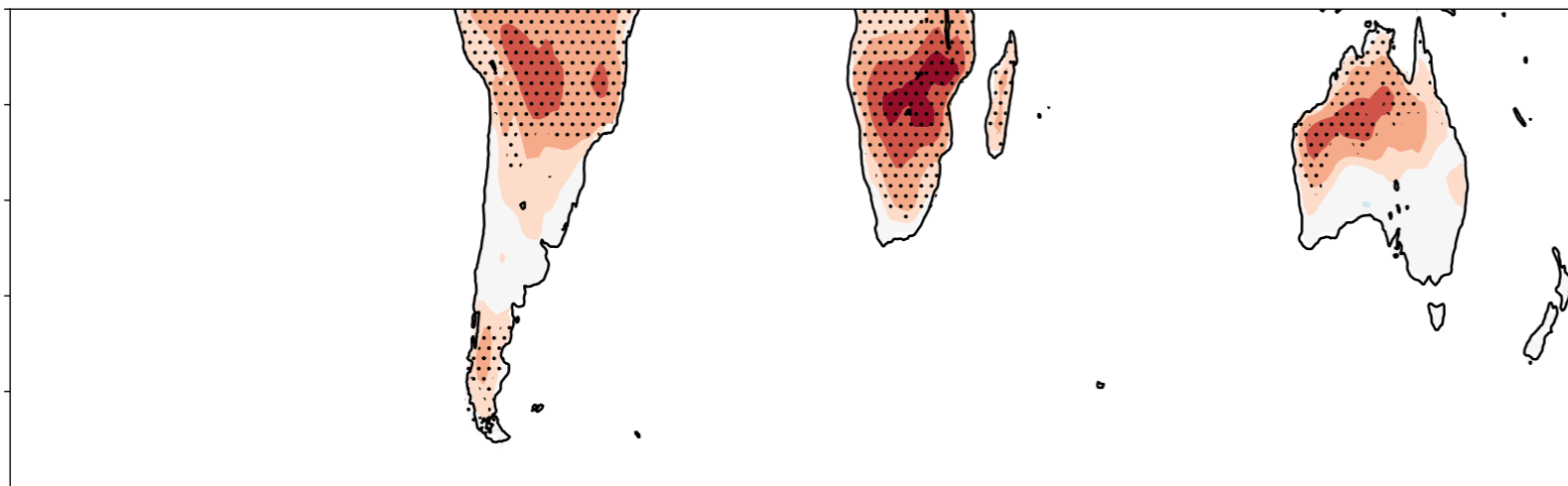
Under Predicting



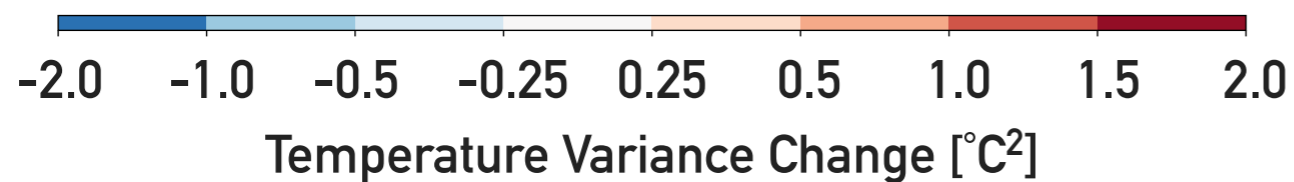
CMIP6 MULTI-MODEL-MEAN TEMPERATURE VARIANCE CHANGE



Summertime temperature variance increases dramatically in the CMIP6 by the end of the 21st century.



These are big increases! 30-50% increases in variance are present in North America, Europe, Australia, Africa, and South America.



TEMPERATURE VARIANCE CHANGE FROM THE DIAGNOSTIC MODEL

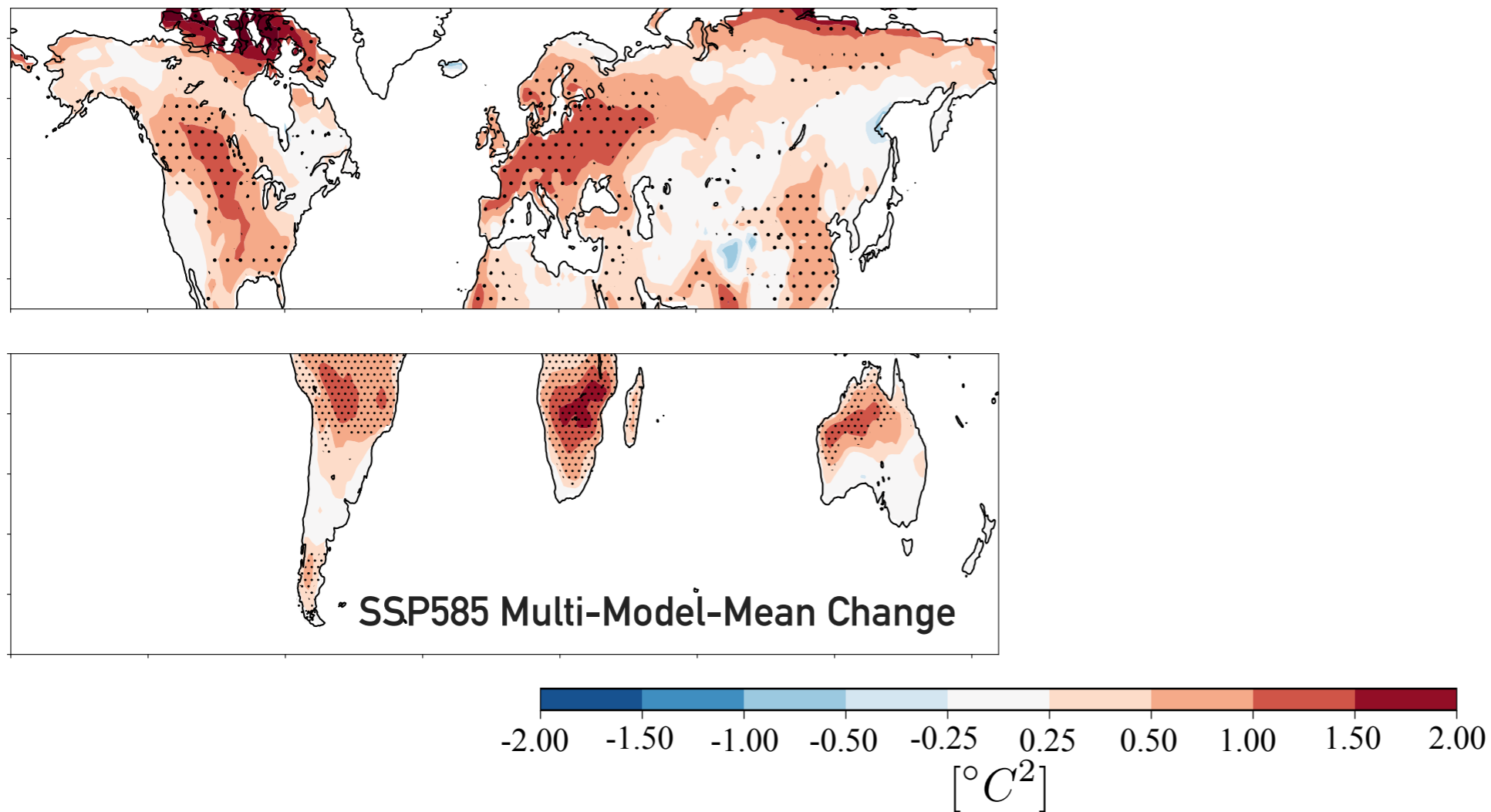
$$\frac{\partial \sigma^2(T)}{\partial \bar{T}} \cdot \Delta \bar{T} = \Delta \sigma^2(T)$$

Sensitivity of the variance equation to mean temperature calculated shown before

Taken from the models, along with change in climatological mean relative humidity change

Absolute temperature variance change predicted by the model

PREDICTED TEMPERATURE VARIANCE CHANGE



The diagnostic equation predicts the changes in temperature variance from climate models. Slight under-predictions in a few places, but overall the spatial pattern and order of magnitude is fairly accurate.

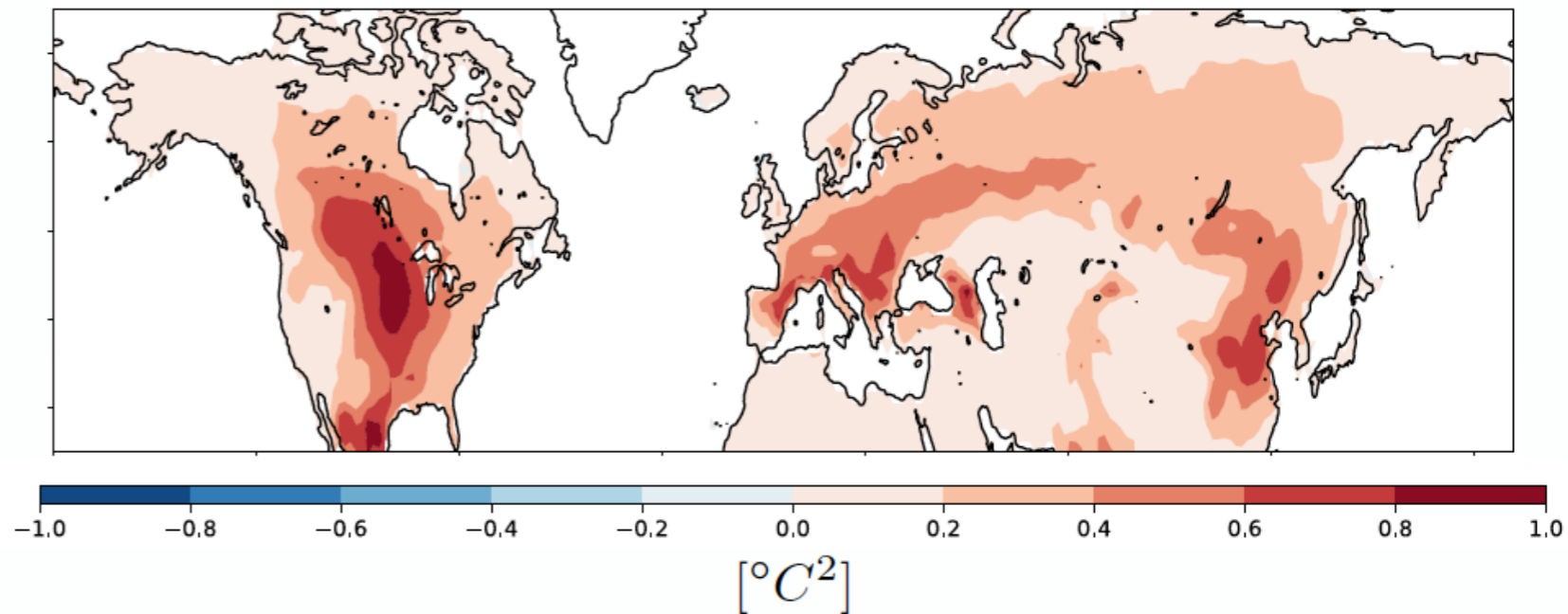
WHAT'S THE MECHANISM FOR INCREASING VARIANCE?

$$\sigma^2(T) = \frac{1}{\Gamma^2} \left[\sigma^2(\mathcal{F}) - 2\overline{\mathcal{F}'L\mathcal{P}'}\zeta + \sigma^2(L\mathcal{P})\zeta^2 \right]$$

As the climate warms, the dryness parameter that amplifies the precipitation component of temperature variance increases!

$$\frac{\partial \sigma^2(T')}{\partial \bar{T}} = \frac{2}{\Gamma^2} \left[\zeta \frac{\partial \zeta}{\partial \bar{T}} \sigma^2(LP') \right]$$

“The warming amplifier!”



WHAT HAVE WE LEARNED?

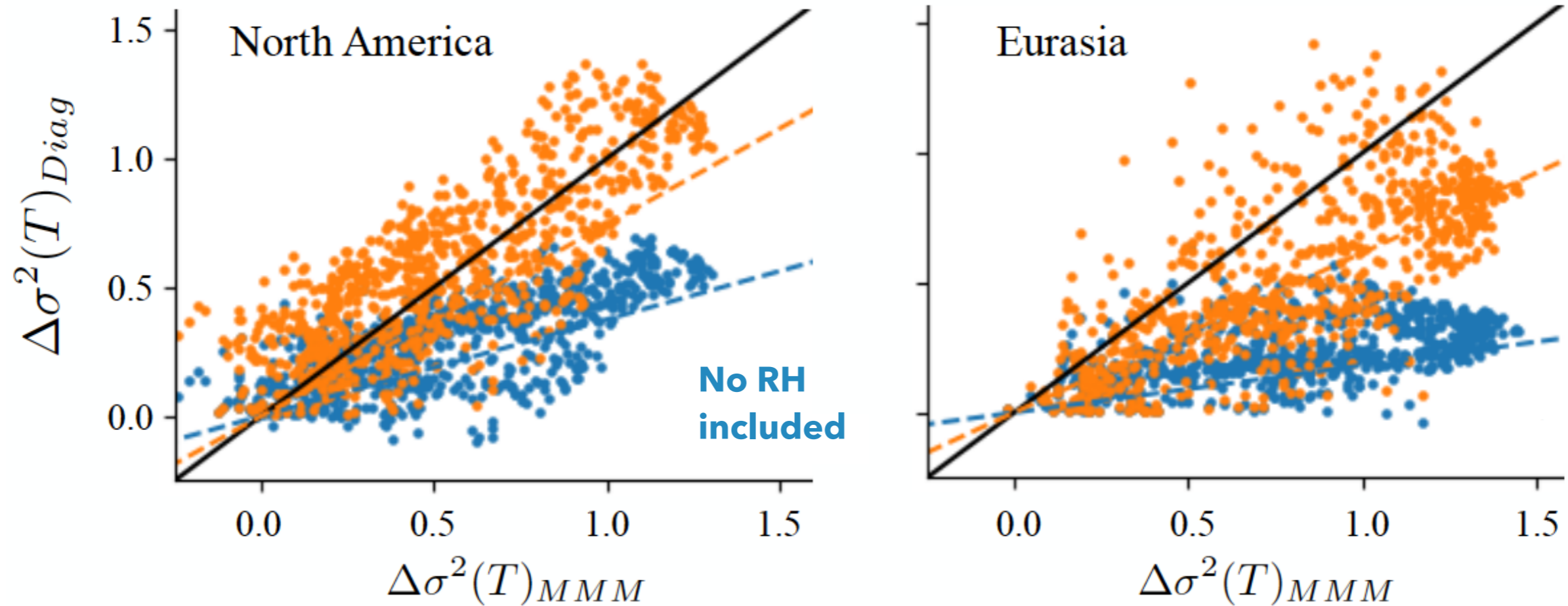
A simple model of the land surface energy and moisture budgets can reproduce the observed pattern of temperature variance, reanalysis, and climate models without too many tunable parameters.

Because the model is sensitive to mean temperature and relative humidity, changes in these variables can be used to predict how variance will change as the mean climate warms.

Summertime temperature variance is increasing due to climate change, and the multi-model mean signal is driven almost entirely by the warming impacts on relative humidity.

These changes are significant and contribute to risk for vulnerable communities and agriculture.

THE ROLE OF RELATIVE HUMIDITY



Relative humidity contributes about half of the temperature variance change by amplifying vapor pressure deficit, particularly in regions with plentiful soil moisture.