Understanding the climate extremes of 55 million years ago with CESM and proxy data

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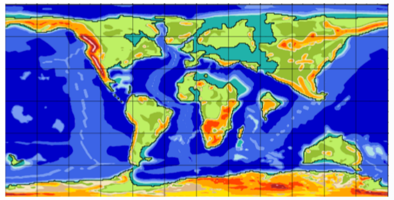
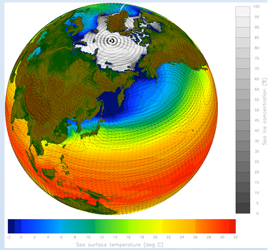


Outline



Our Science Question:
The climate 55 Ma (PETM) was very warm with a robust hydrological cycle. Can we disentangle whether this was due to Greenhouse gas forcing? Or differences in the orbit around the earth?

- ❑ What can models tells us that proxy data can't?

- ❑ How can we use models and data together to answer our question?

What can models tell us that proxy data can’t?

- Proxy data is a measurement typically latitude and longitude specific (fossils of flora and fauna, sediments, etc.)
- Models estimate climates   a) globally b) regionally diverse areas (topography, biomes) assuming the model has the appropriate resolution
- Models test mechanisms, i.e. what causes the monsoon? Land-sea temperature gradient or oceanic warm pool?

How can we use proxy data and models together?

- Validate the model at the paleo latitude and longitude
- Models test theories born from synthesizing proxy data
- Models sensitivity tests (to understand mechanisms) can be designed using proxy data and uncertainties around the proxy data

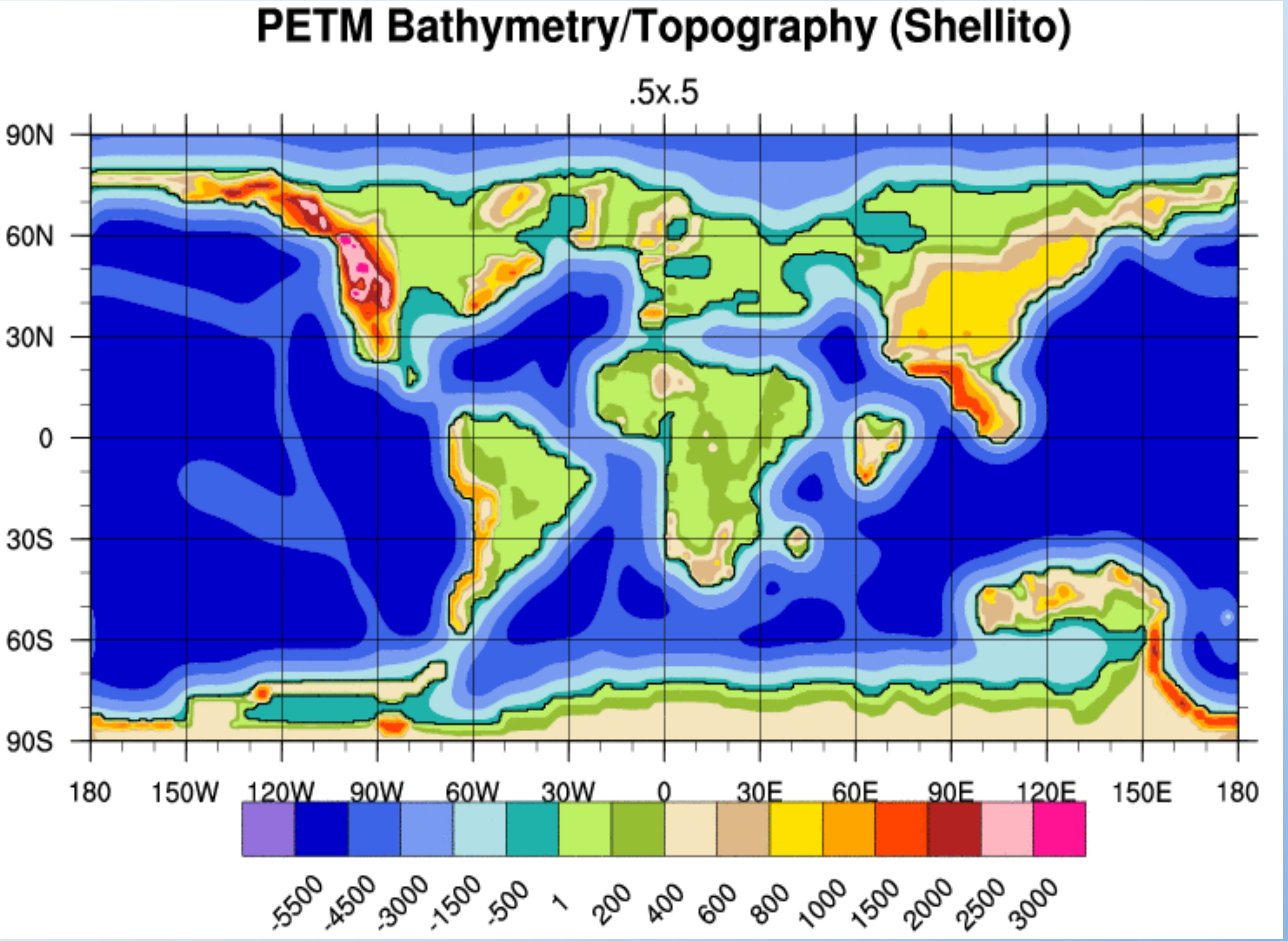
Model Details

Model:

CAM4/CLM4, 50km

Foring datasets:

- SSTs, topography from earlier version of CESM (CCSM3) fully coupled long simulations (Kiehl and Shields, 2013)
- Aerosols from CAM4-BAM (Bulk Aerosol Model, prognostic aerosol model that was a predecessor to MAM now in CESM)

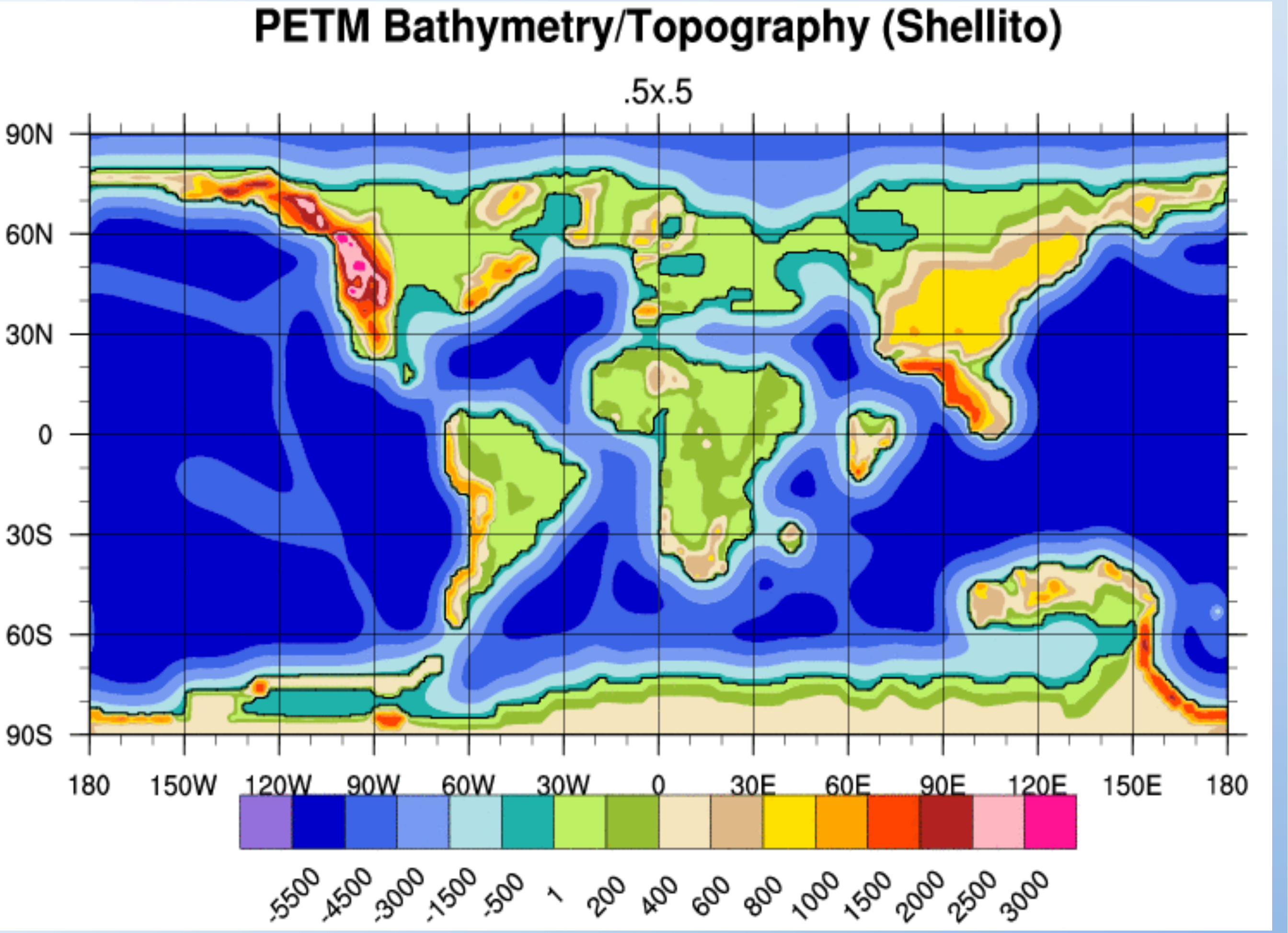


Model Simulations

Physical forcings

Control

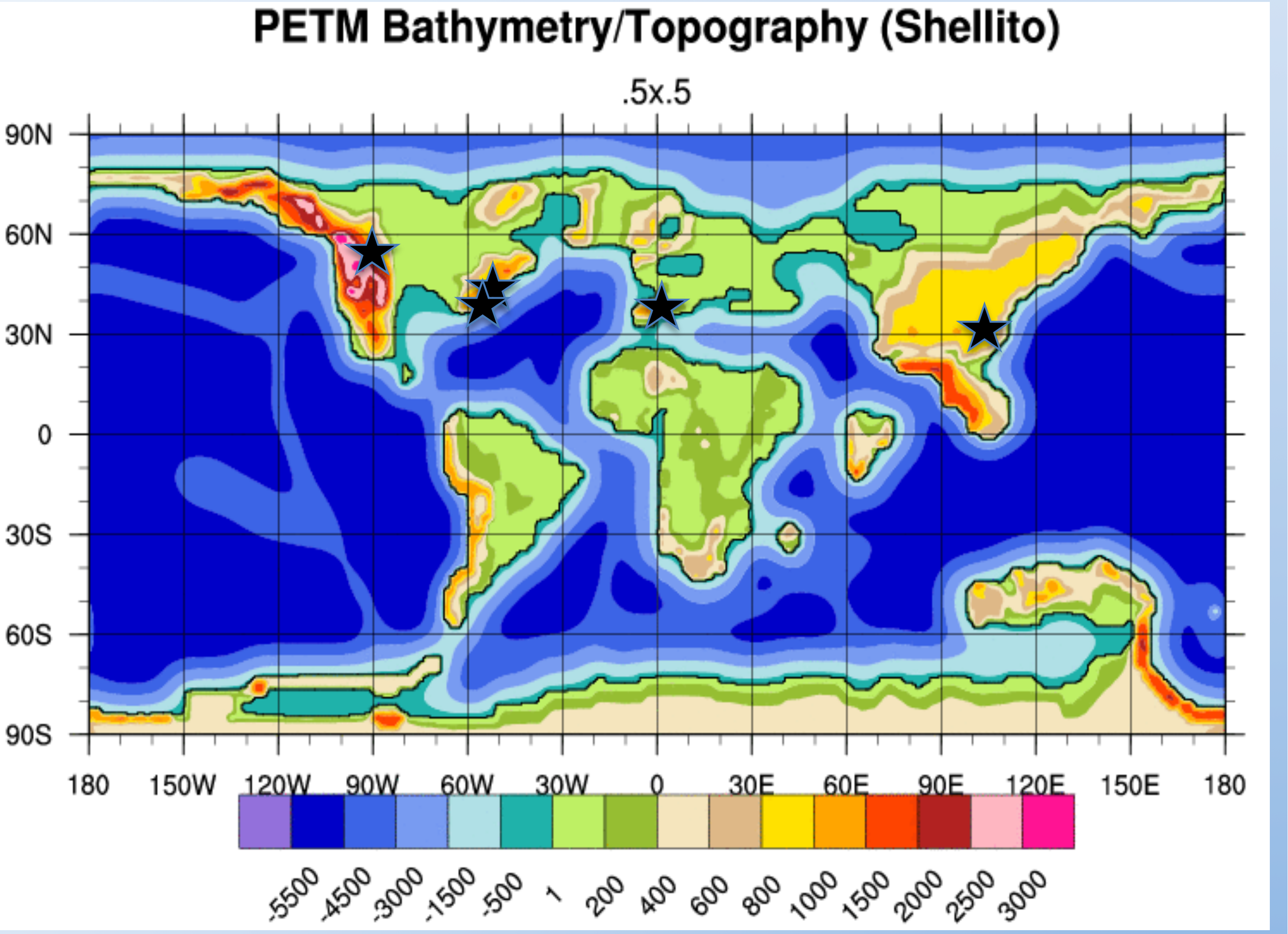
	PRE-PETM	PETM	PETM_ORBMAX
CO_2 (ppmv)	1375	2250	2250
CH_4 (ppmv)	.76	16	16
Obliquity (°)	23.5	23.5	24.5
Eccentricity	0	0	.06
Vernal Equinox (°)	0	0	270.



Note: 2250ppmv =~ 8x Pre-Industrial (PI) Levels of CO_2
1375ppmv =~ 5x PI

Proxy Details

Region	Paleo-Latitude Range (degrees)	Paleo-Longitude Range (degrees)	Reference
Bighorn Basin	53-55N	89-90W	Snell et al., 2013
New Jersey	41-43N	49-51W	John et al, 2008
Maryland	40-42N	52-54W	Self-Trail et al., 2017
China	30-32N	110-112E	Chen et al., 2016
Spanish Pyrenees	34.5-36.5N	0-2E	Pujalte et al, 2015



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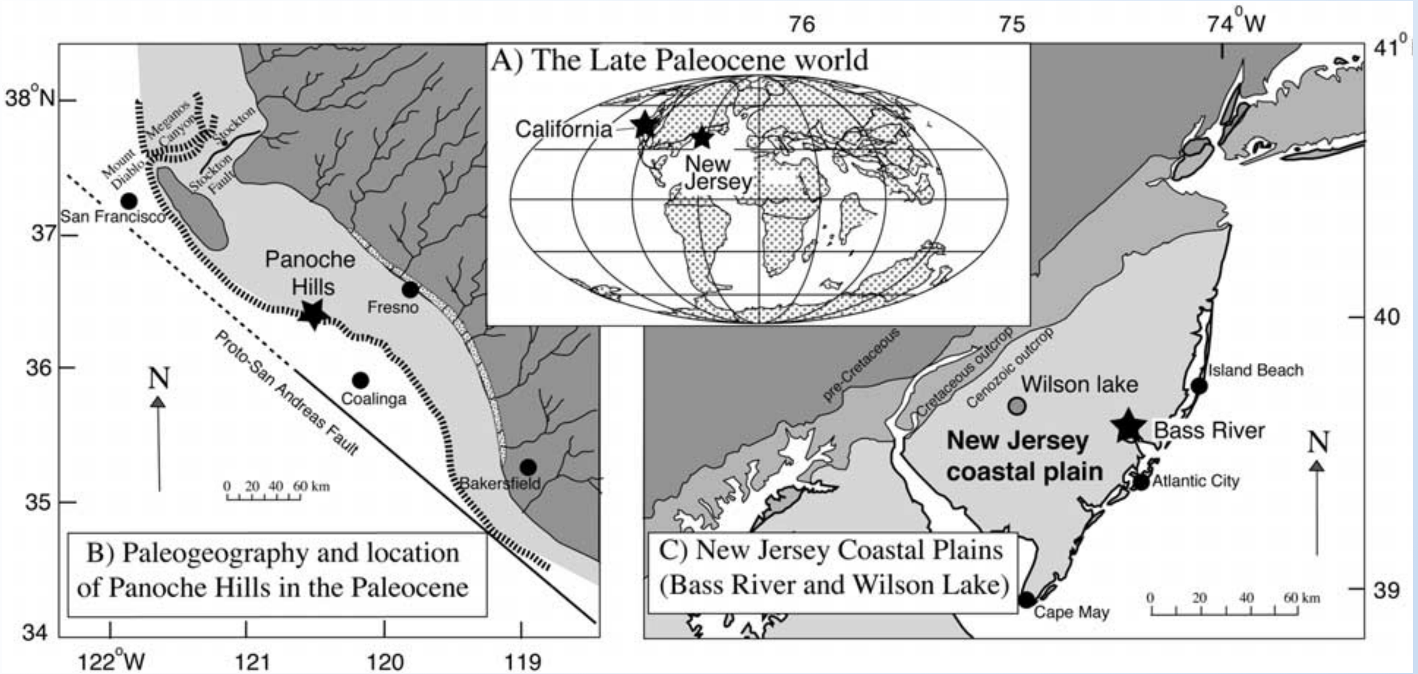
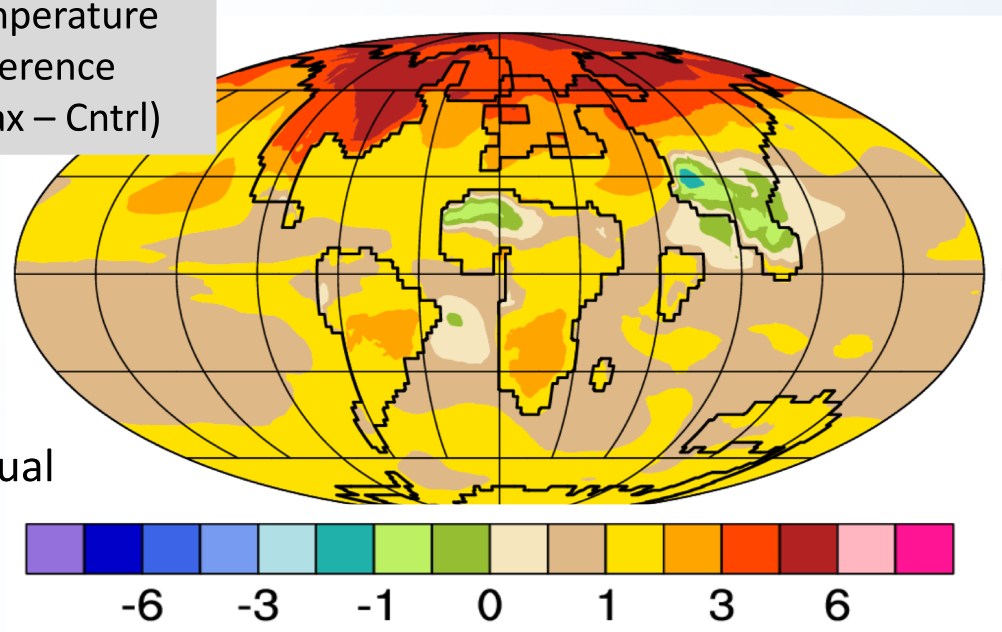


Figure 1. Location and paleogeography. (a) Location during the Paleocene-Eocene of the two margins discussed in this article. (b) Paleogeography of the Lodo formation (California) during the late Paleocene to early early Eocene. (c) New Jersey margin sites.

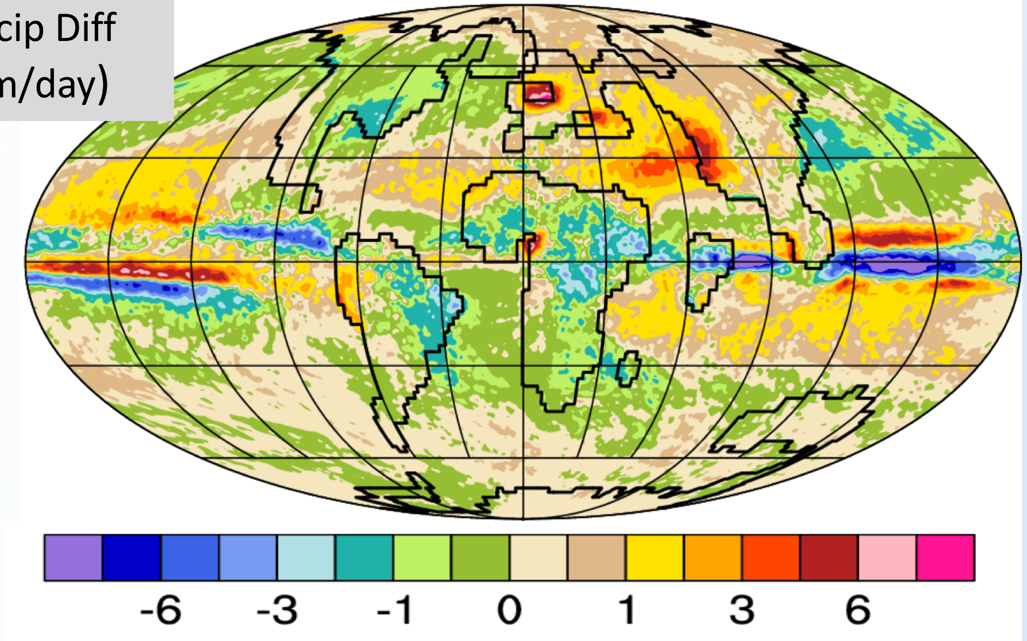
Example of proxy data points translated to geography of the time, i.e. “Paleogeography”

Model: Orbital Forcing Impacts

Surface Temperature Difference (Max – Cntrl)



Precip Diff (mm/day)



ORBMAX vs. Control

Holding CO_2 steady at 8 X PI for both

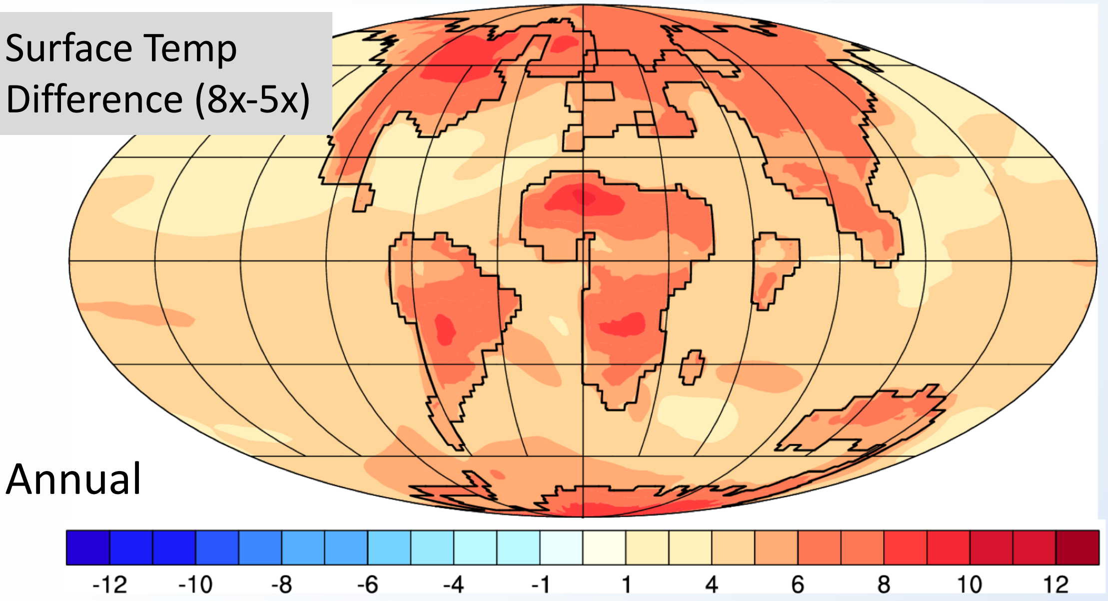
Testing impact of solar forcing alone

- ❑ Obliquity (axial tilt) = 24.5 vs 23.5º
- ❑ Vernal Equinox (axial precession) = 270º vs 0º
- ❑ Eccentricity (shape of orbit) = 0.06 vs. 0.

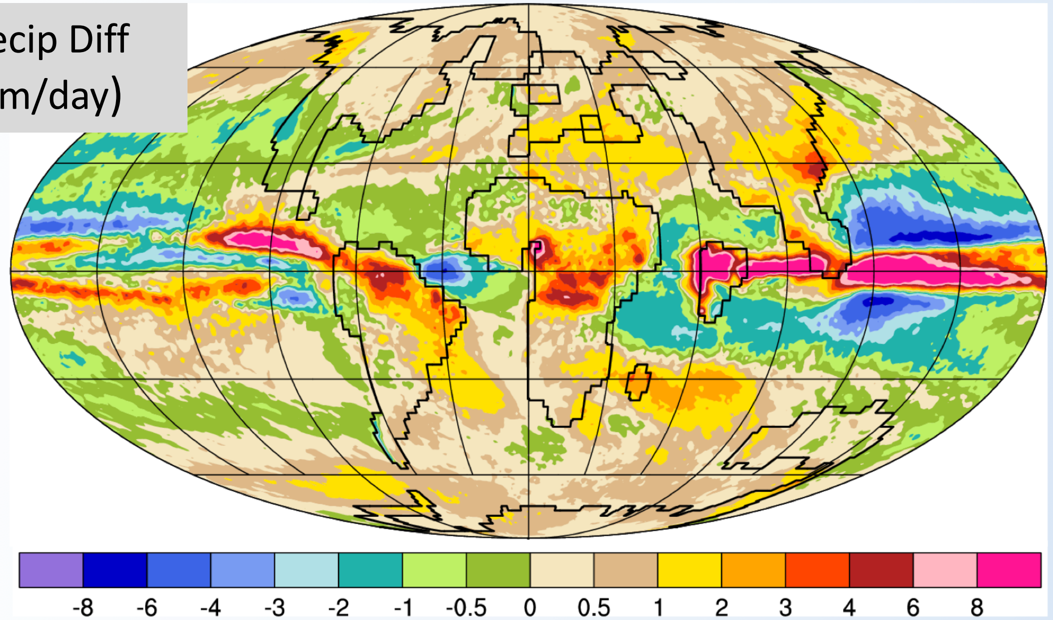
Kiehl et al. 2018, in press

Model: Greenhouse Gas Forcing Impacts

Surface Temp Difference (8x-5x)



Precip Diff (mm/day)



PETM vs. Pre-PETM

Standard orbital for both

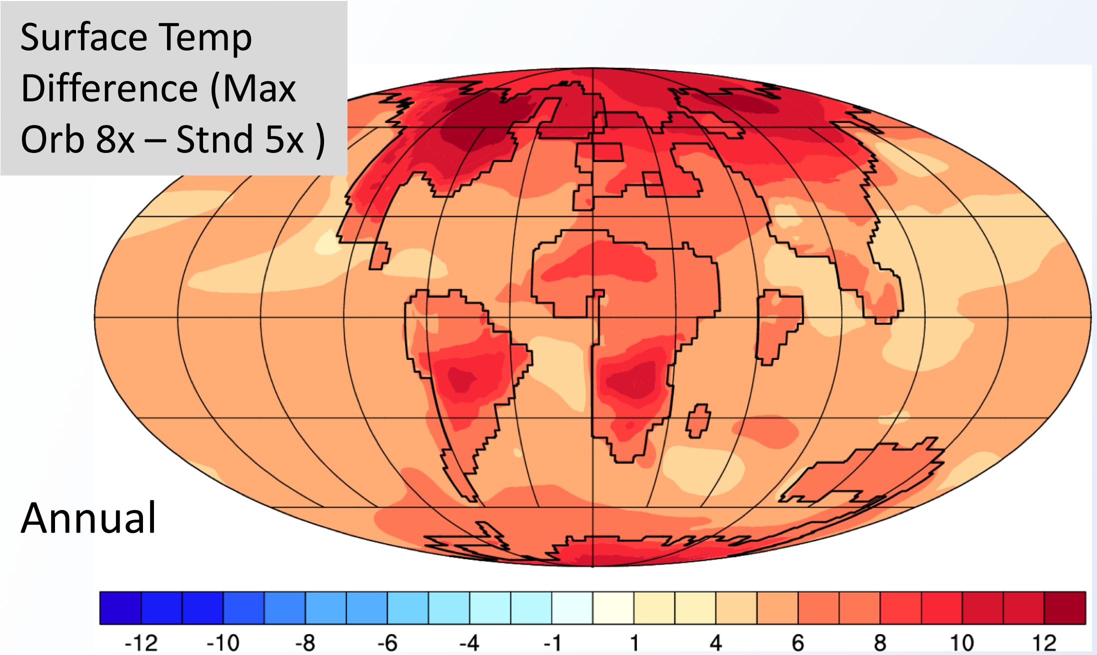
Testing impact of greenhouse gas alone

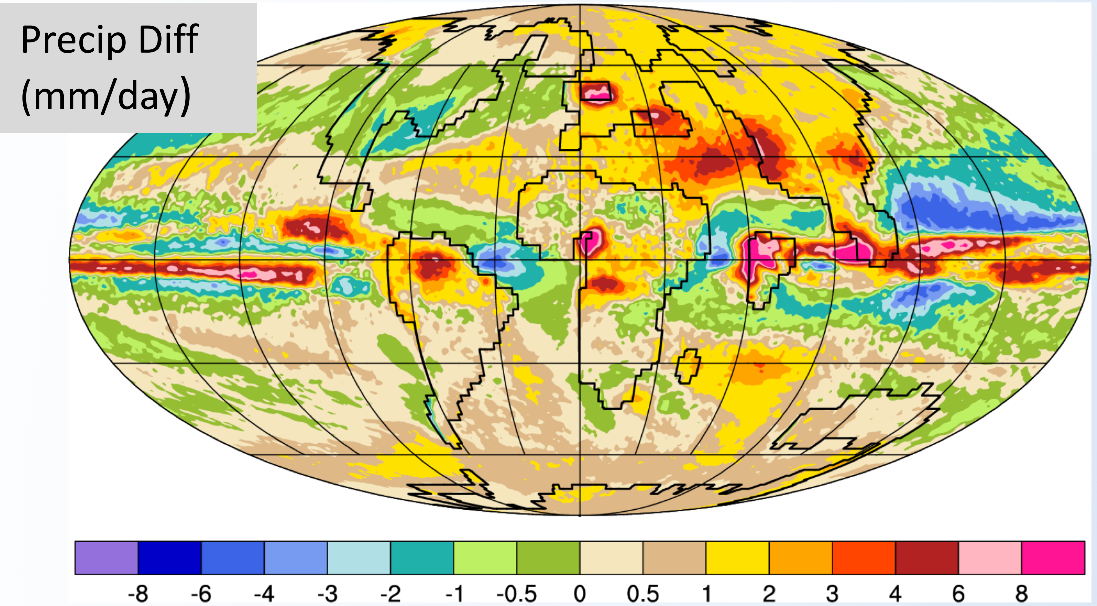
Where:

PETM ”Control” =
8 x Pre-Industrial CO_2 = ~2250 ppmv

Pre-PETM “Low CO_2” =
5 x Pre-Industrial CO_2 =~ 1375 ppmv

Model: Greenhouse + Orbital Forcing Impacts





ORBMAX vs Pre-PETM

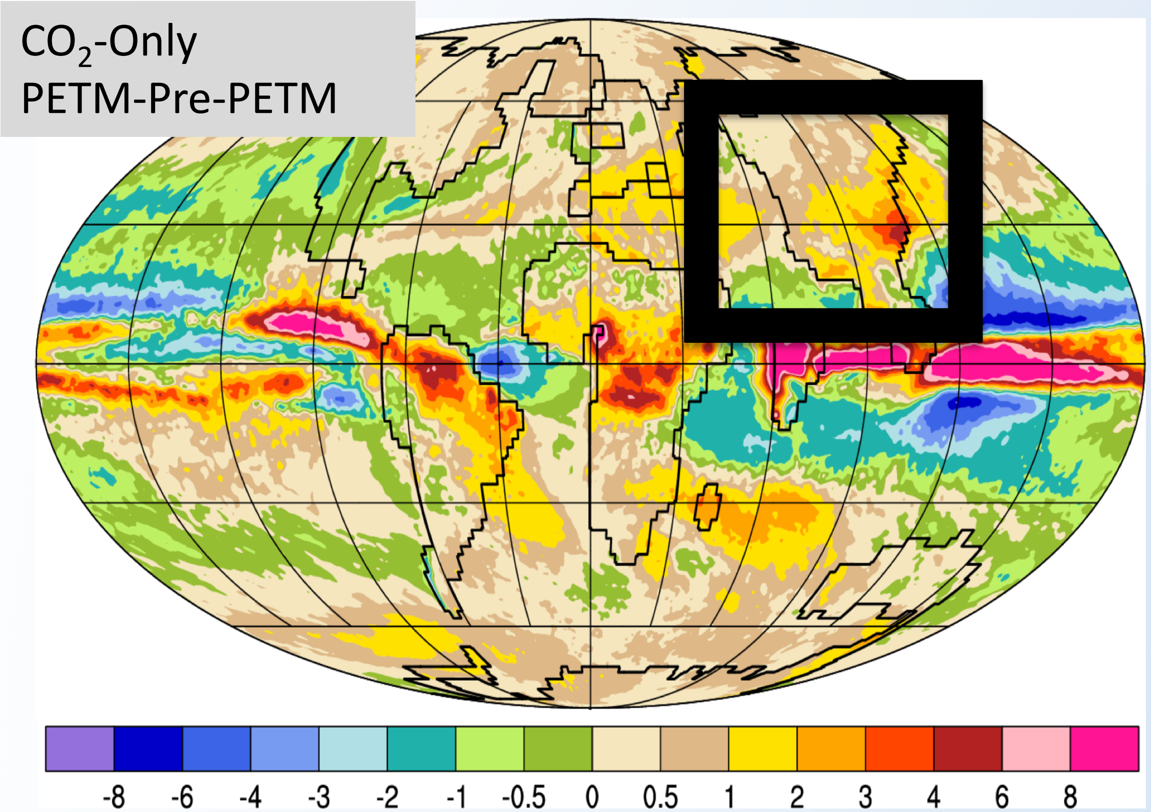
Maximizing the difference in total forcing to the NH

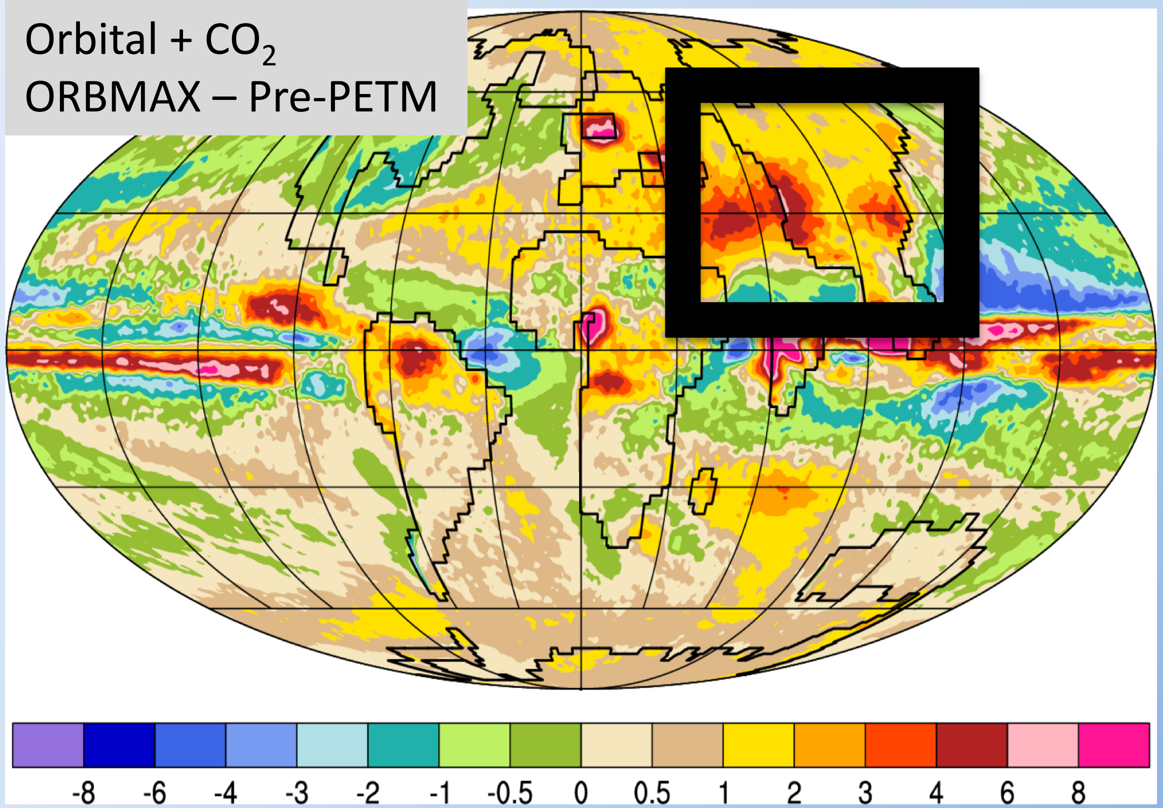
- Obliquity (axial tilt) = 24.2 vs 23.5º
- Vernal Equinox (axial precession) = 270º vs 0º
- Eccentricity (shape of orbit) = 0.06 vs 0.
- CO_2 = 8x vs 5x
- CH_4 = 16x vs 1x

How can we use proxy data and models together?

Explain something we see in the observations with a physical process….

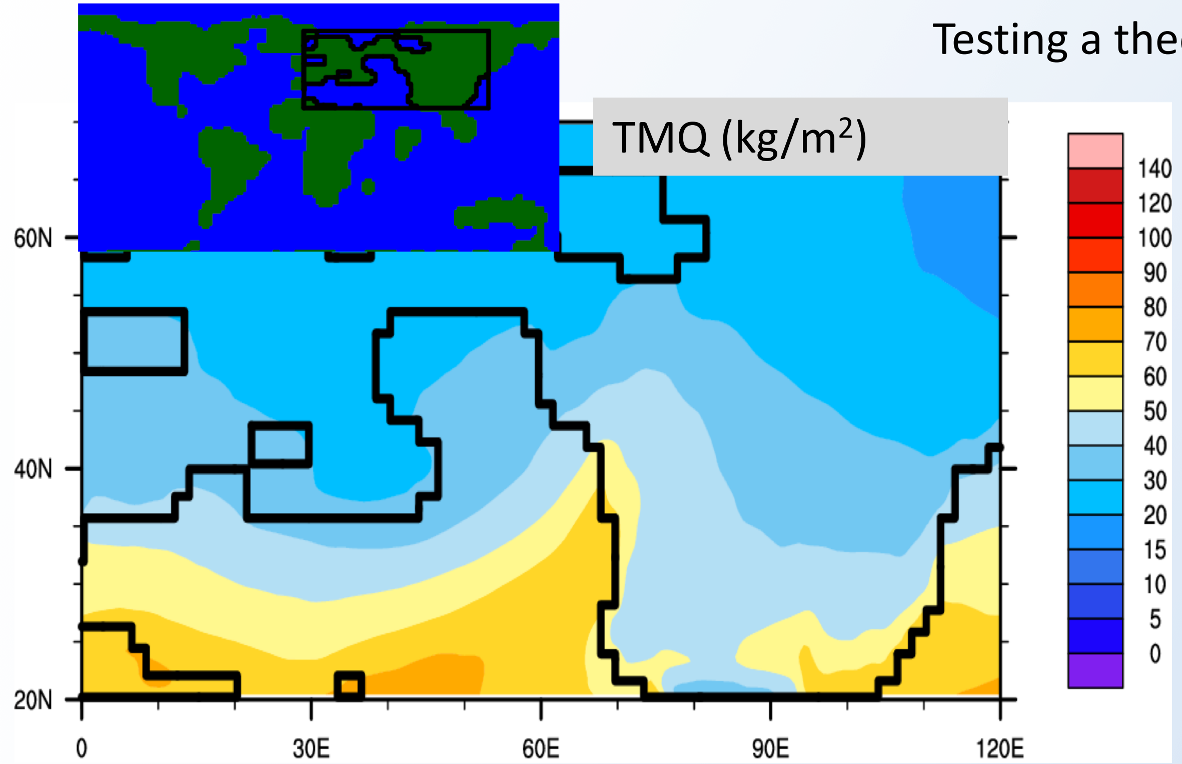
Observations for this region by Chen et al., 2016 indicate enhanced precipitation at the PETM boundary, i.e. transitioning from Pre-PETM to PETM. Do we see this in the model? Yes! But why?

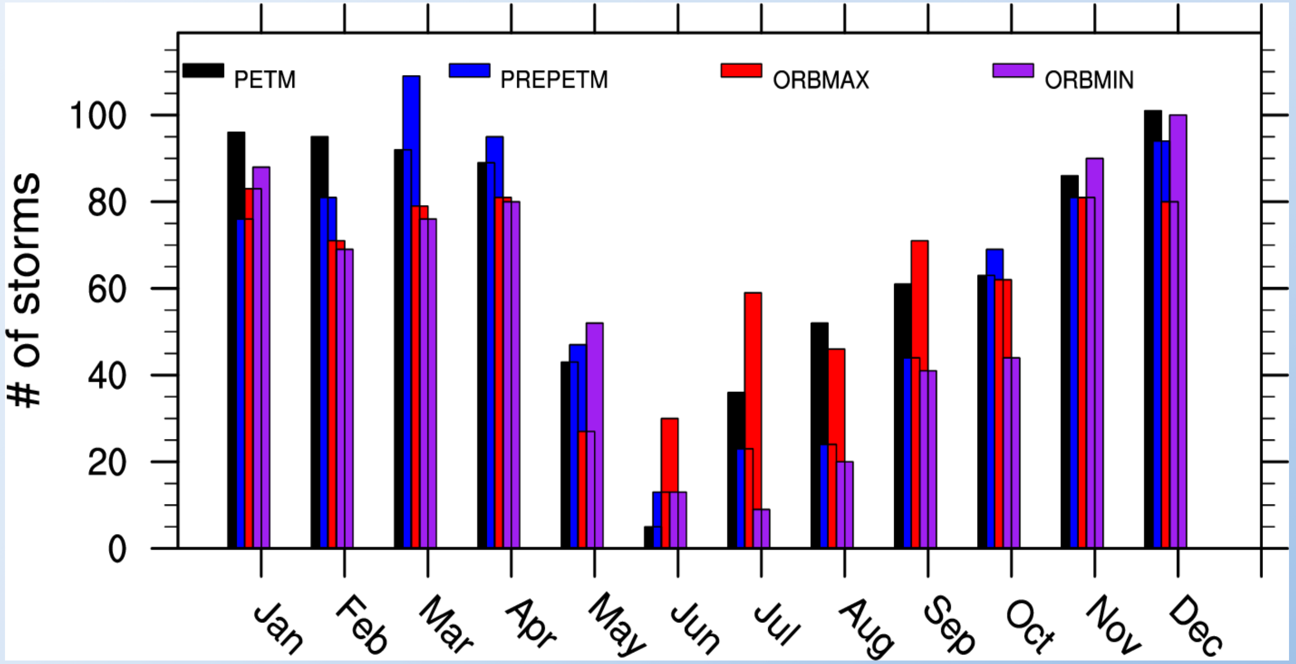




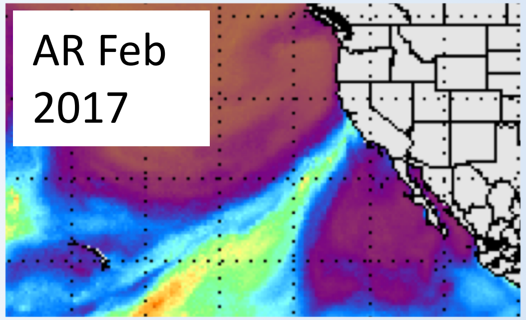
How can we use proxy data and models together?

Testing a theory, a possible explanation….





Composites of atmospheric river (AR) storms for west Asian coastlines.



Seasonal distribution of atmospheric river storm events. PETM Peak AR activity is from Nov – April (similar to modern). However, ORBMAX ARs increase significantly in summertime, where absolute values of moisture transport are higher.

Summary

- CESM can be used for deep time paleoclimate applications to help understand extreme climates of the past.

- CESM can be used to disentangle temperature and precipitation extremes attributable to orbital and greenhouse gas forcing, respectively.

- Using high resolution CAM4, we can compare the model's climate to observational proxy data at specific locations.

- We can use CESM and proxy data together to try and explain a climate signal. Example: proxy data over China indicates an enhanced hydrological cycle at the PETM boundary. This is potentially explained by increase in moisture transport, via atmospheric rivers, into this region as seen by analyzing model data.