Tropical cyclone genesis factors: Insights from paleoclimate simulations

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Tropical cyclones and climate

Lines of evidence:

- Geologic evidence (paleotempestology)

Hurricane Carol

Great New England Hurricane

Great September Gale

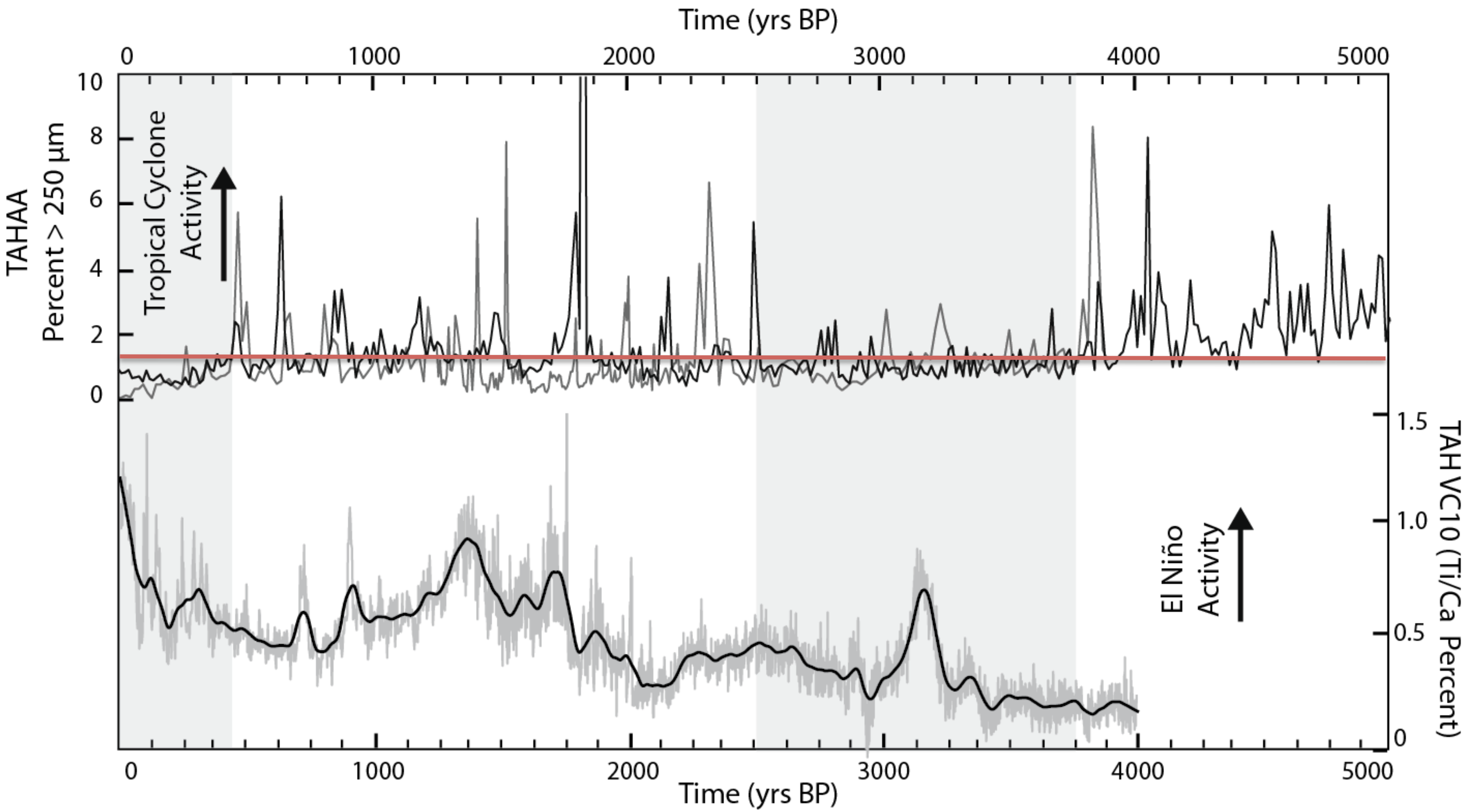
Great Colonial Hurricane

Photos courtesy of Kam-biu Liu (LSU) and Jon Woodruff (U. Mass.).

Holocene sedimentary core from Tahiti (16ºS)

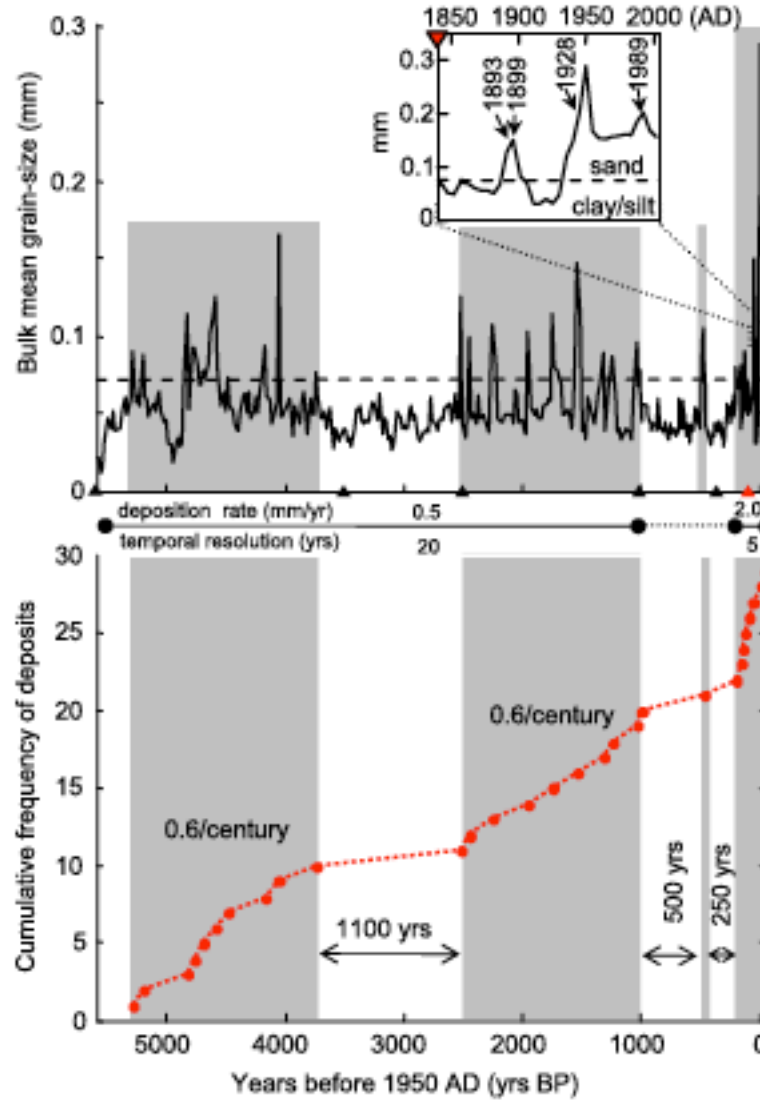
Larger grains deposited when storms over wash site.

Note (for later) highest activity prior to 3.8 kya…

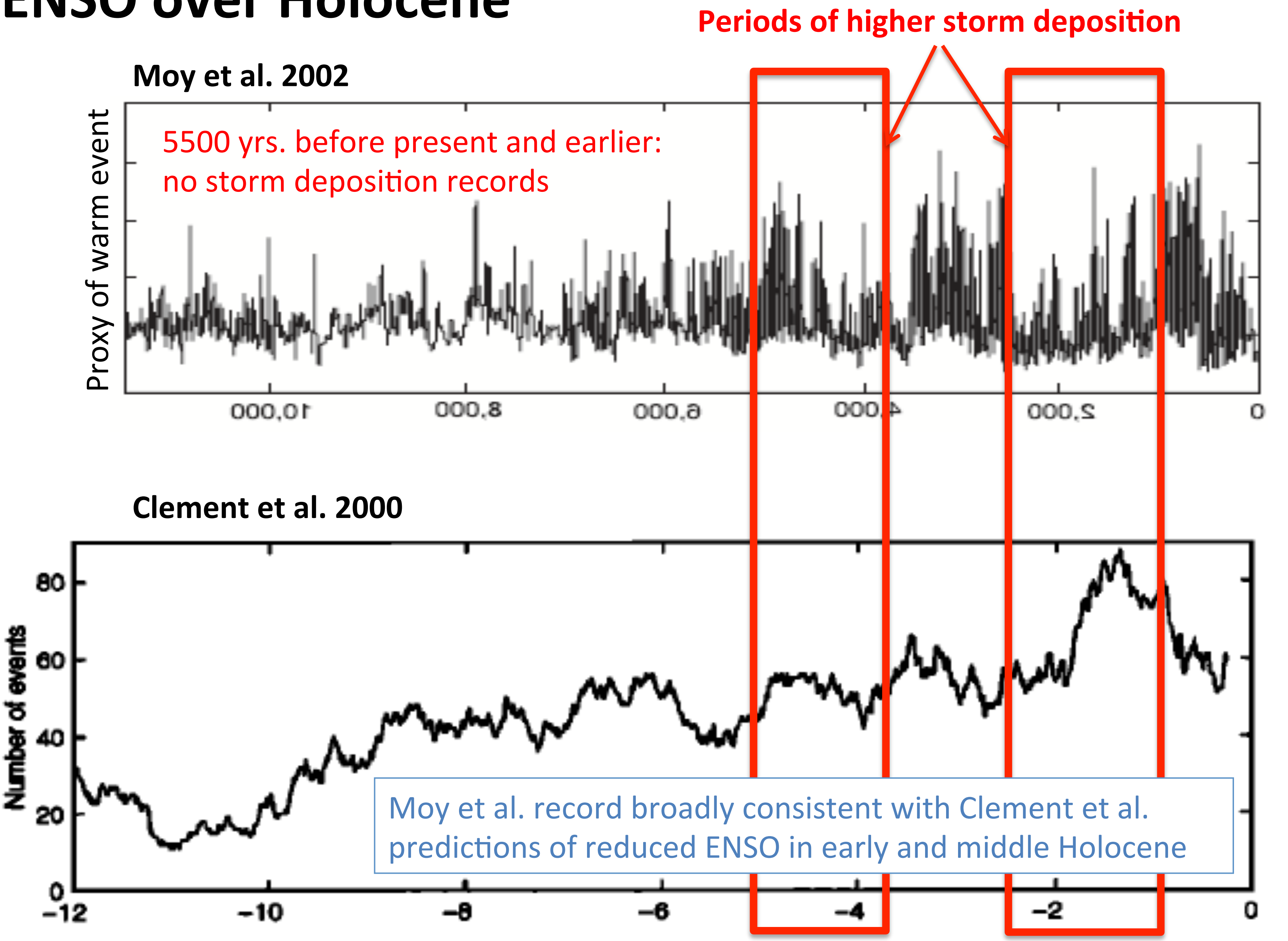


Sedimentary core from Laguna Playa Grande on Vieques, Puerto Rico

Woodruff and Donnelly 2007
Woodruff et al. 2008

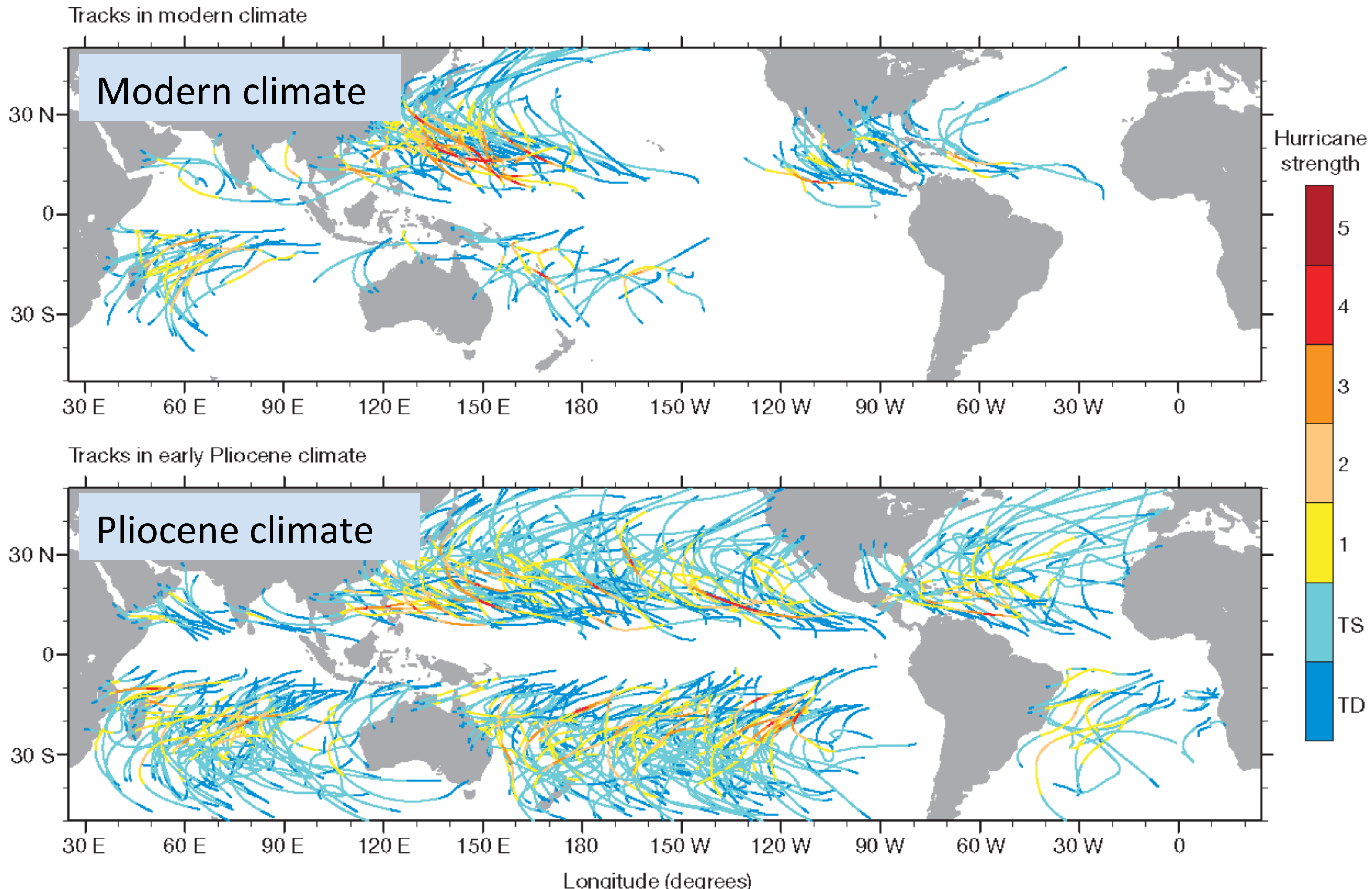


ENSO over Holocene



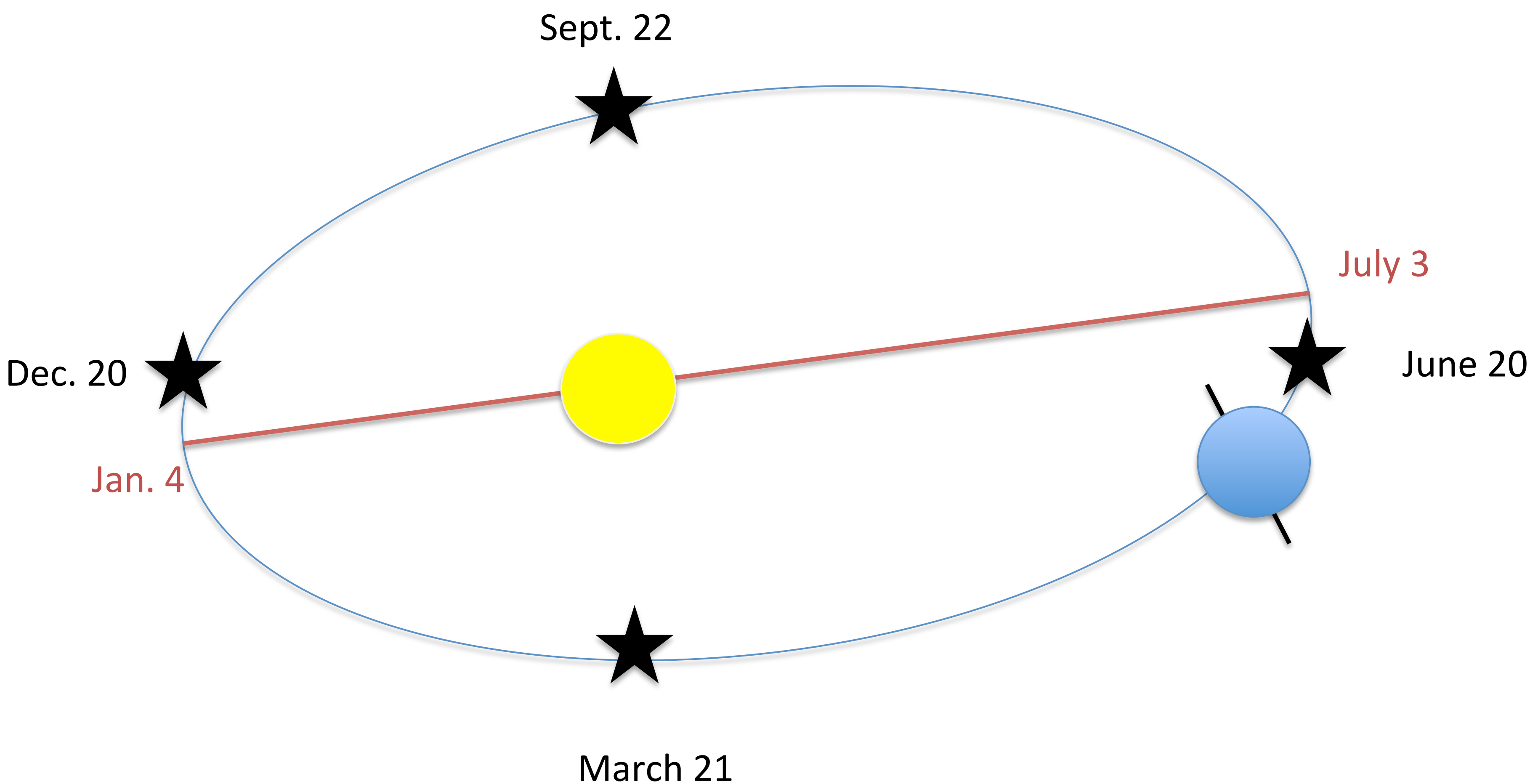
Pliocene climate and permanent El Niño

- Federov et al. (2010) downscaled storms following Emanuel (2006) but for warmer Pliocene conditions.

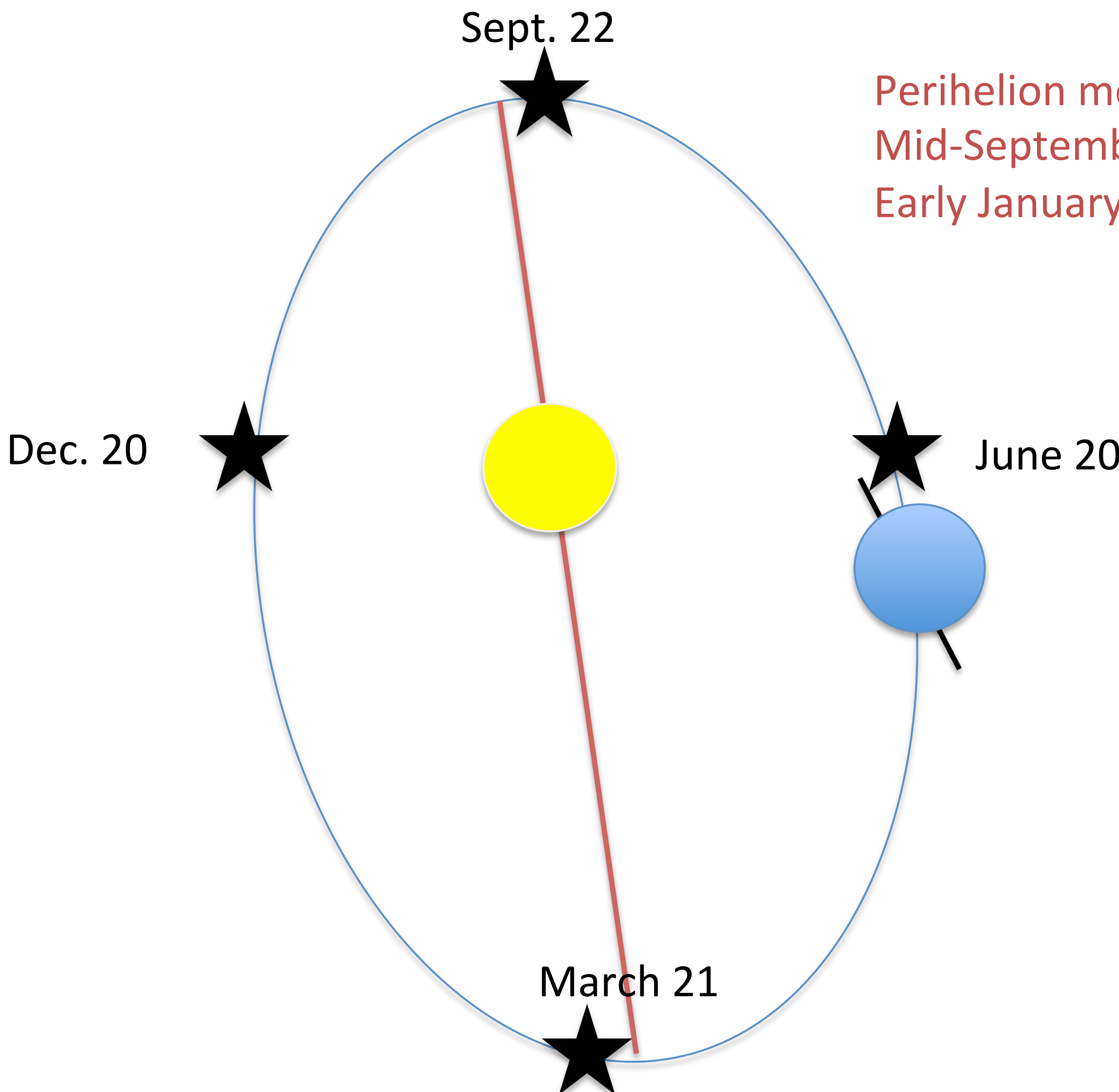


from Federov et al. 2010

Present-day orbital geometry



Middle Holocene orbital geometry

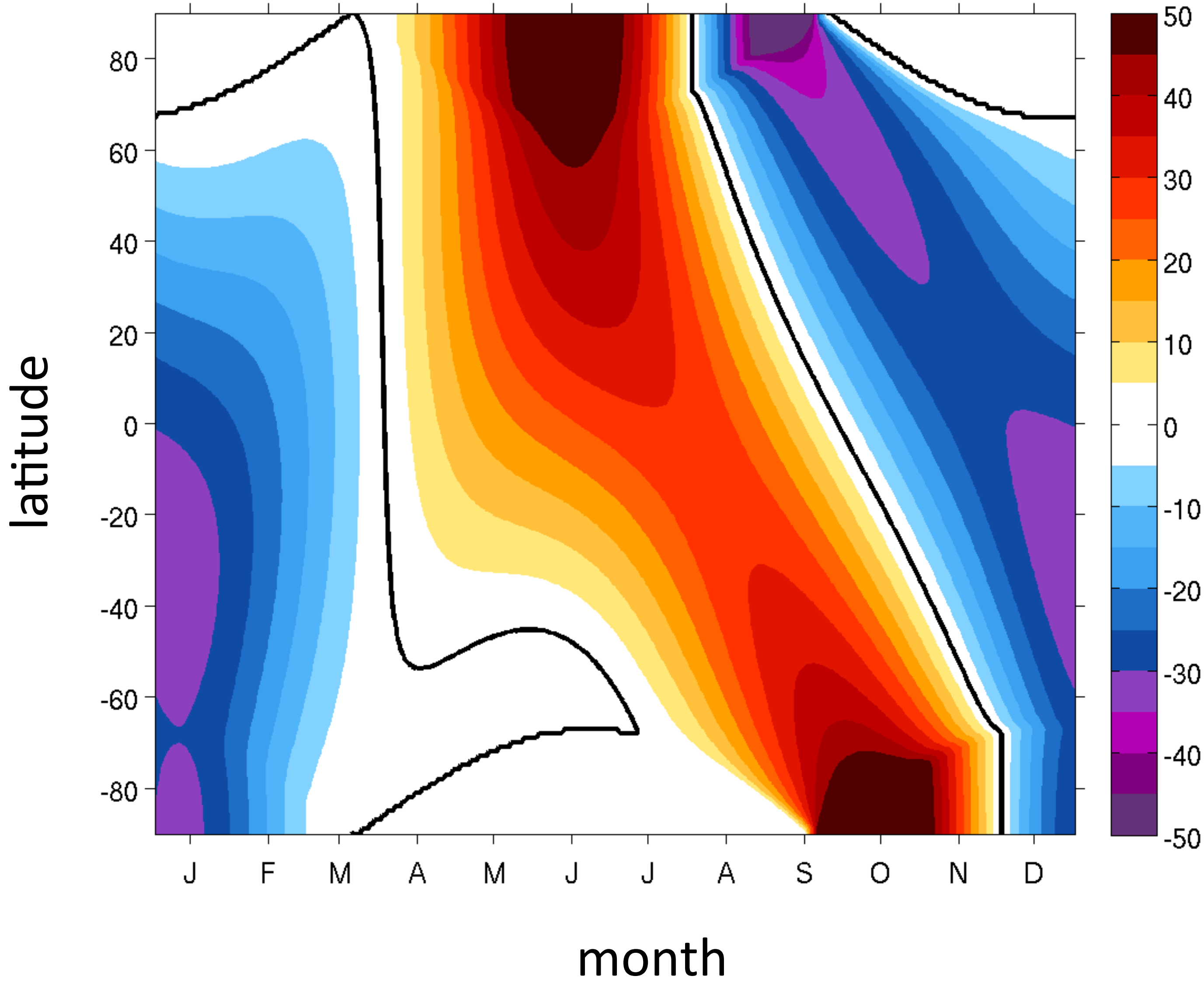


Perihelion moves 1 day every ~57 years

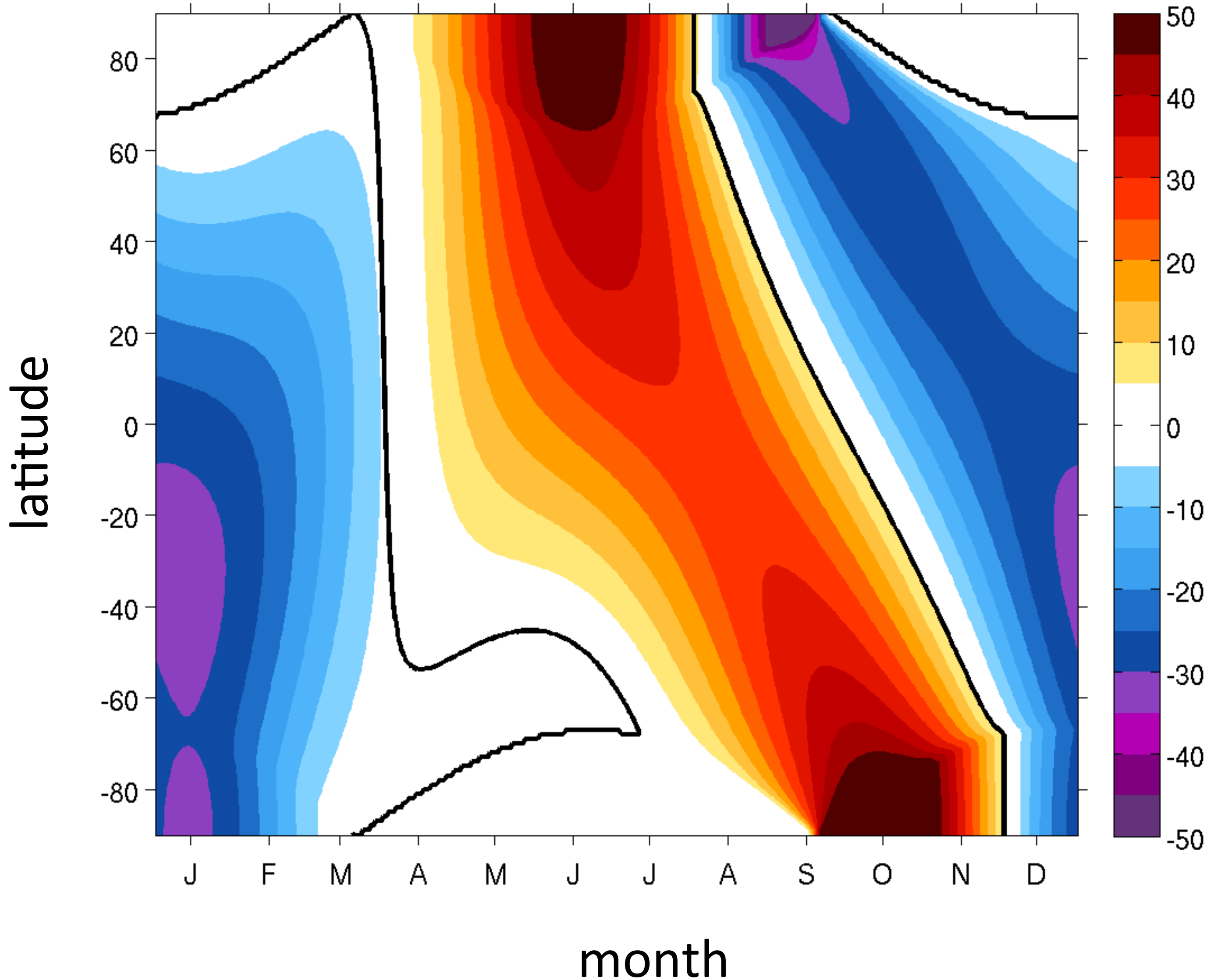
Mid-September 6ka

Early January today

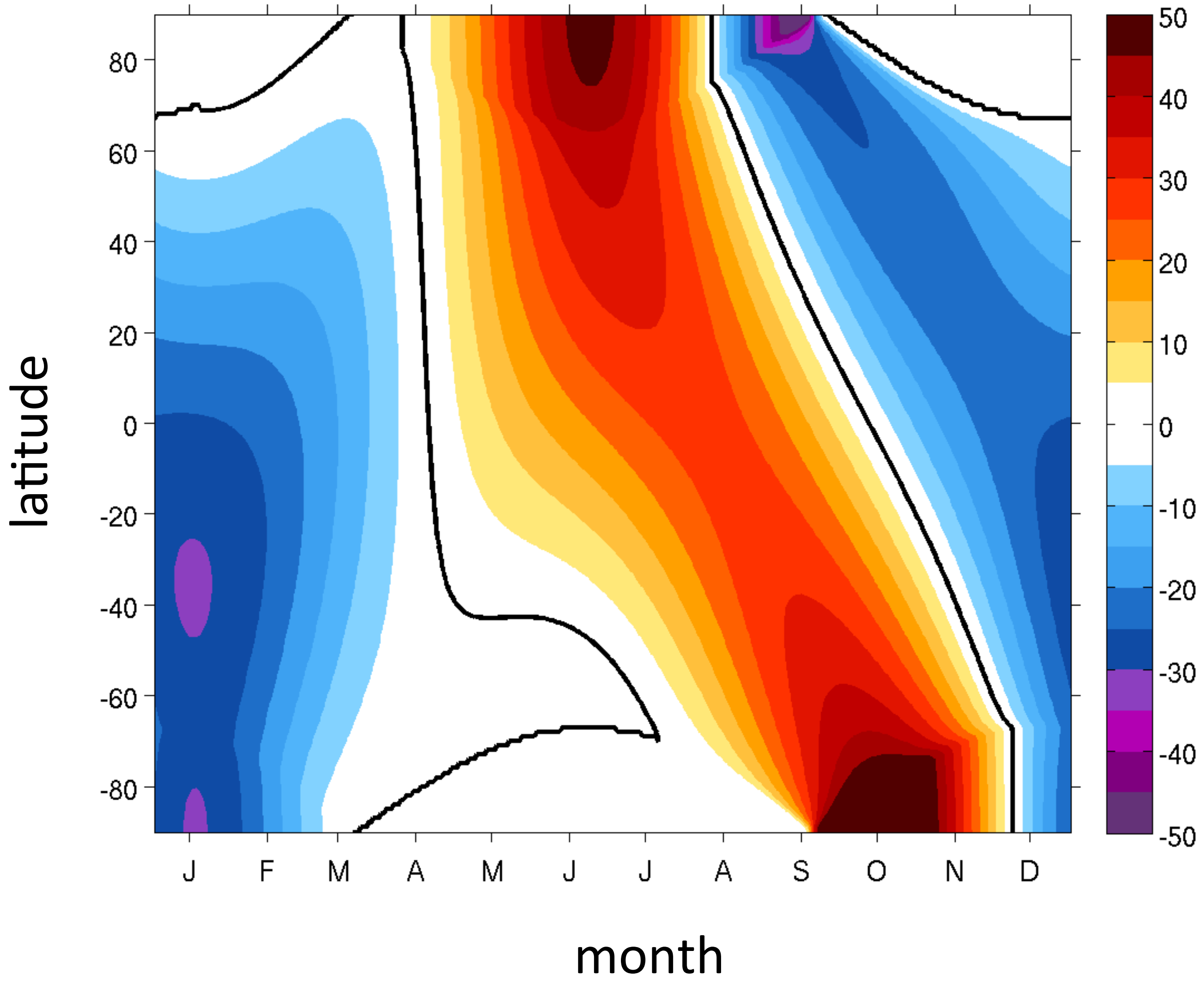
TOA solar radiation anomalies 10000 BP



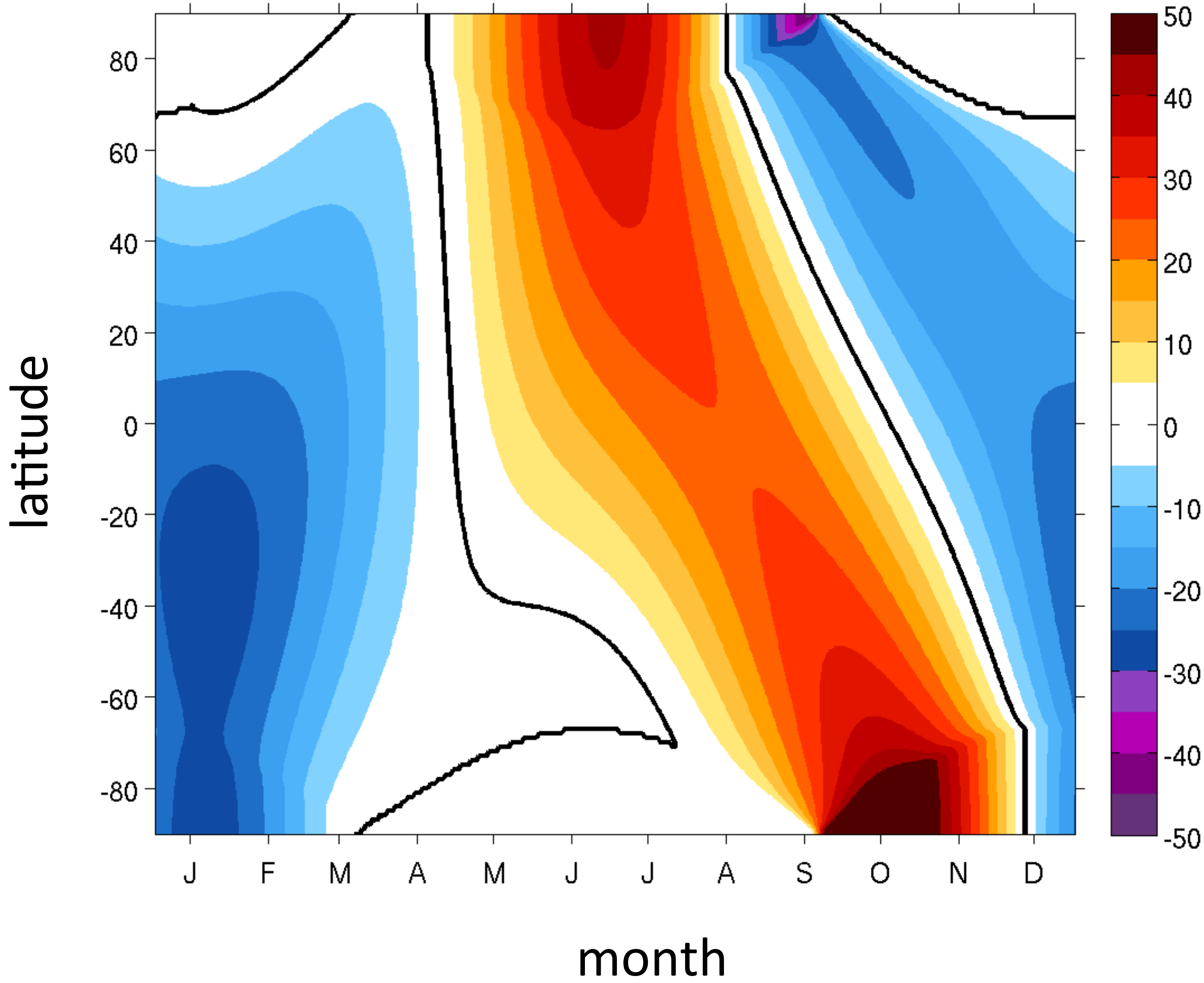
TOA solar radiation anomalies 9000 BP



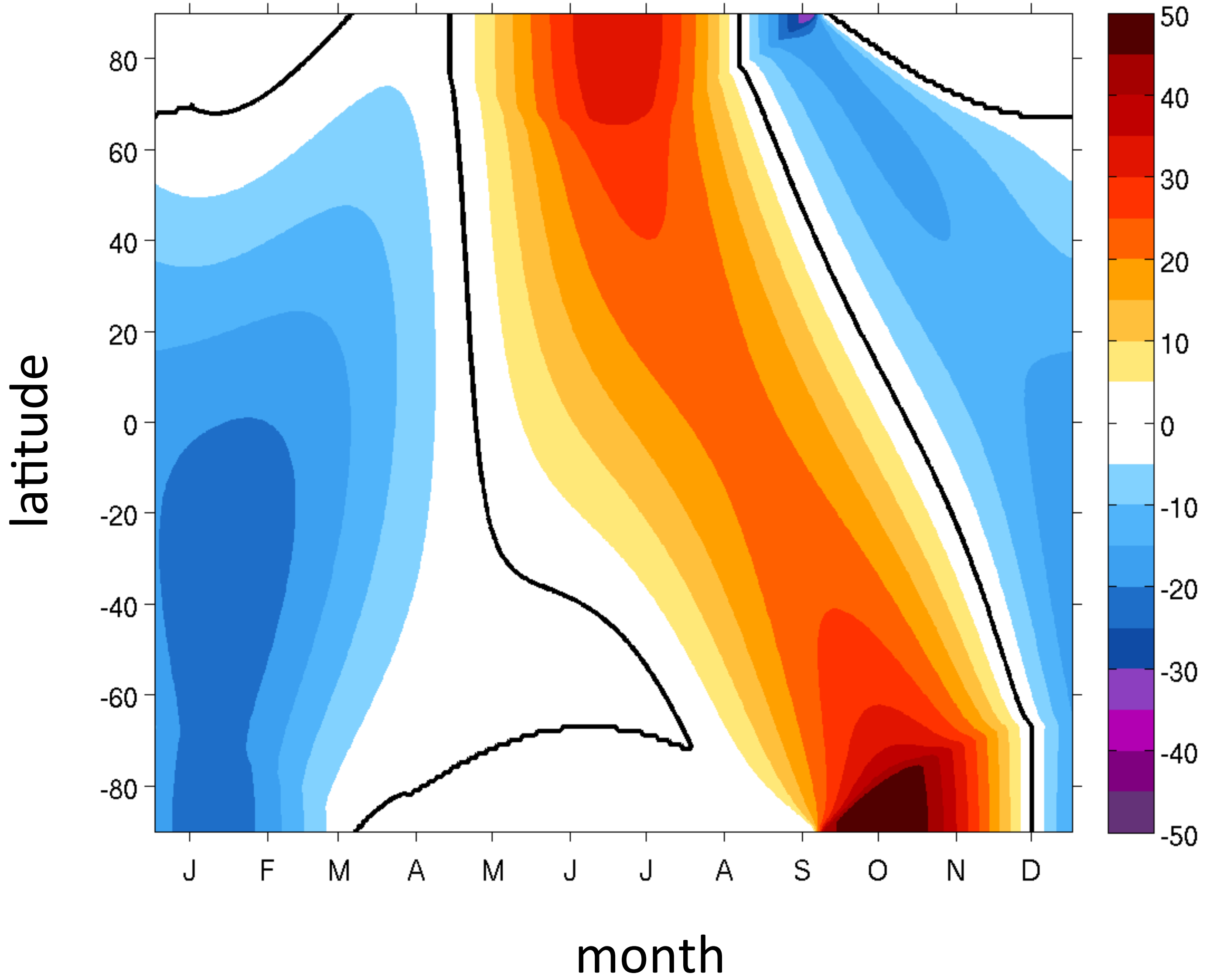
TOA solar radiation anomalies 8000 BP



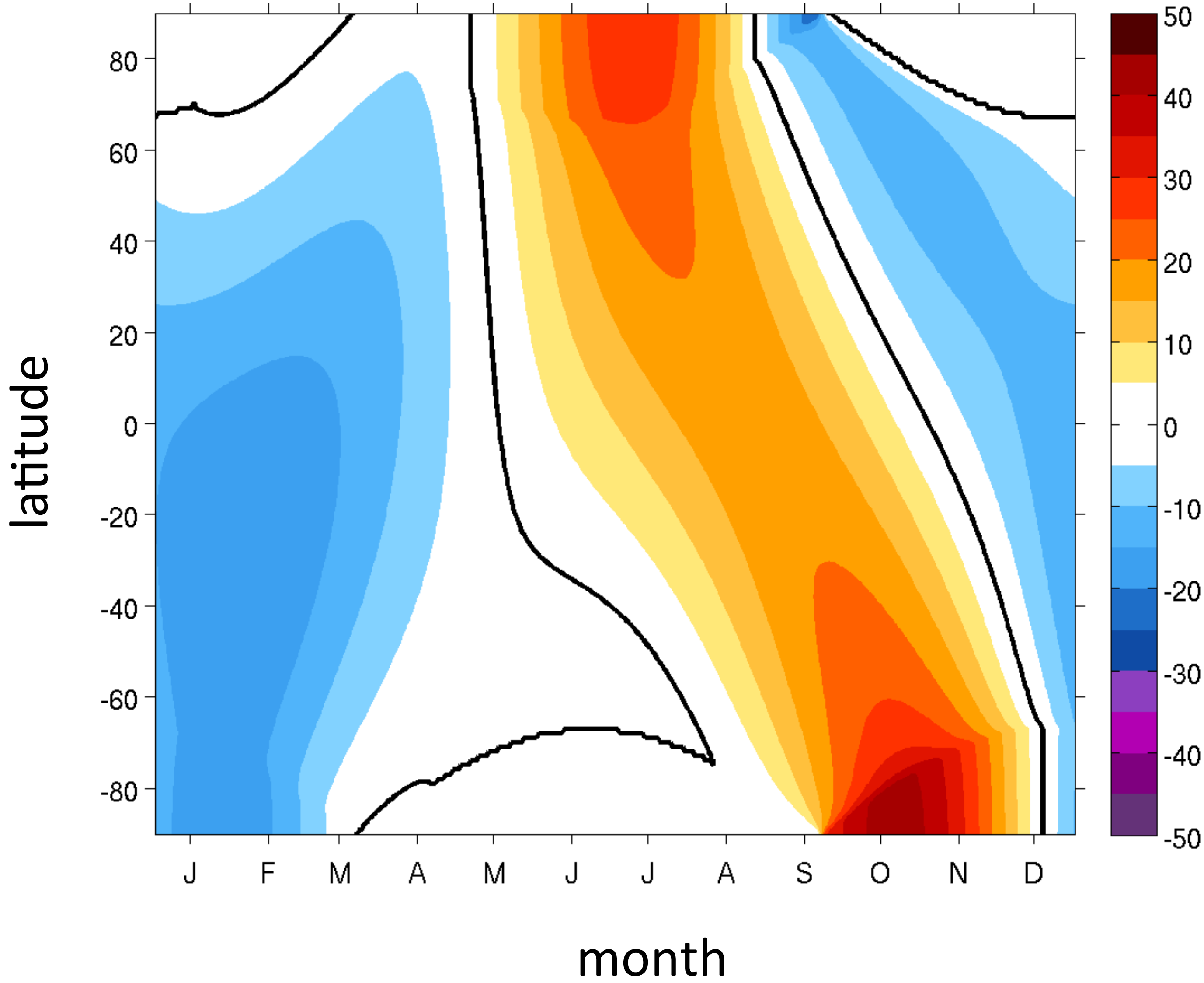
TOA solar radiation anomalies 7000 BP



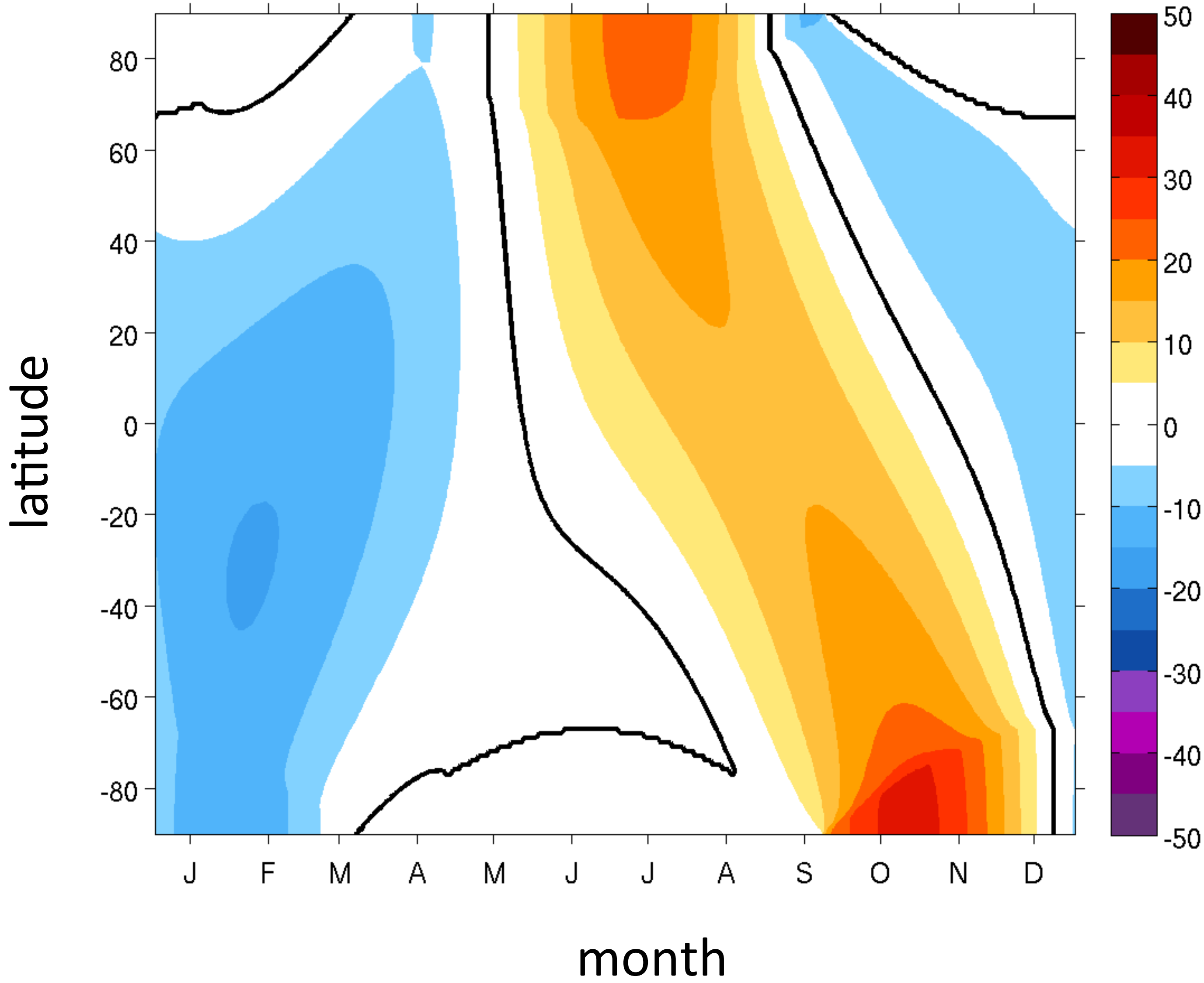
TOA solar radiation anomalies 6000 BP



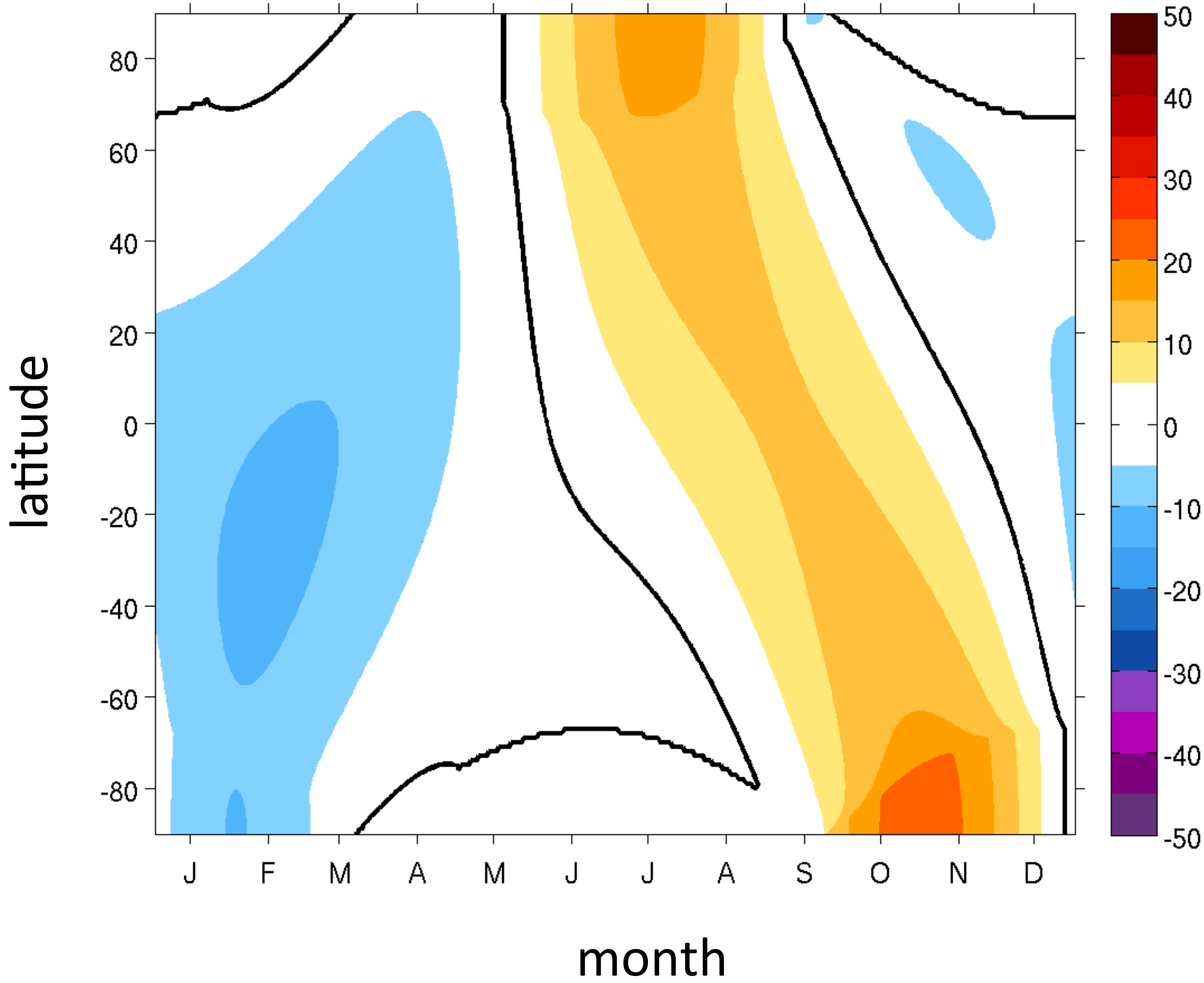
TOA solar radiation anomalies 5000 BP



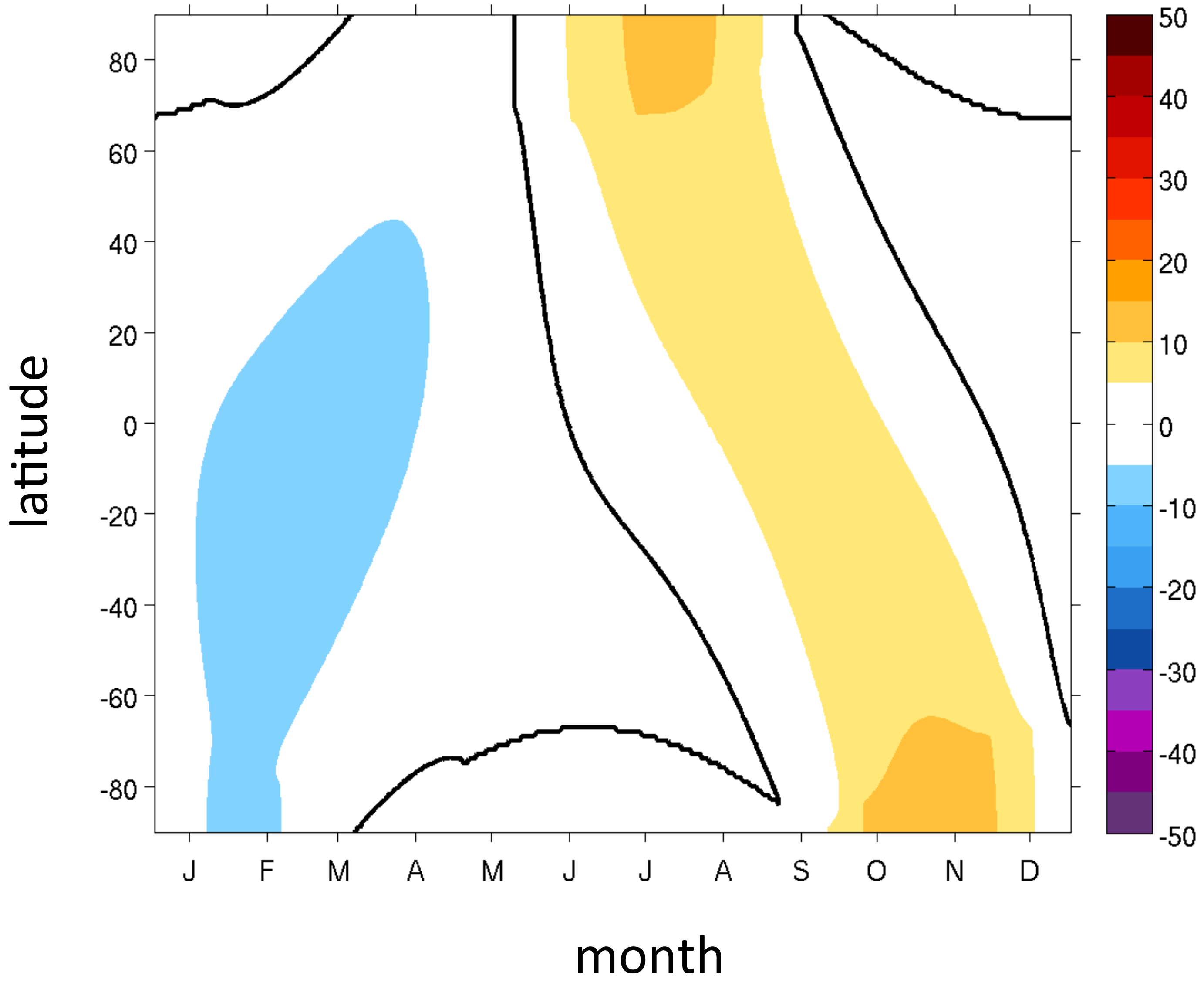
TOA solar radiation anomalies 4000 BP



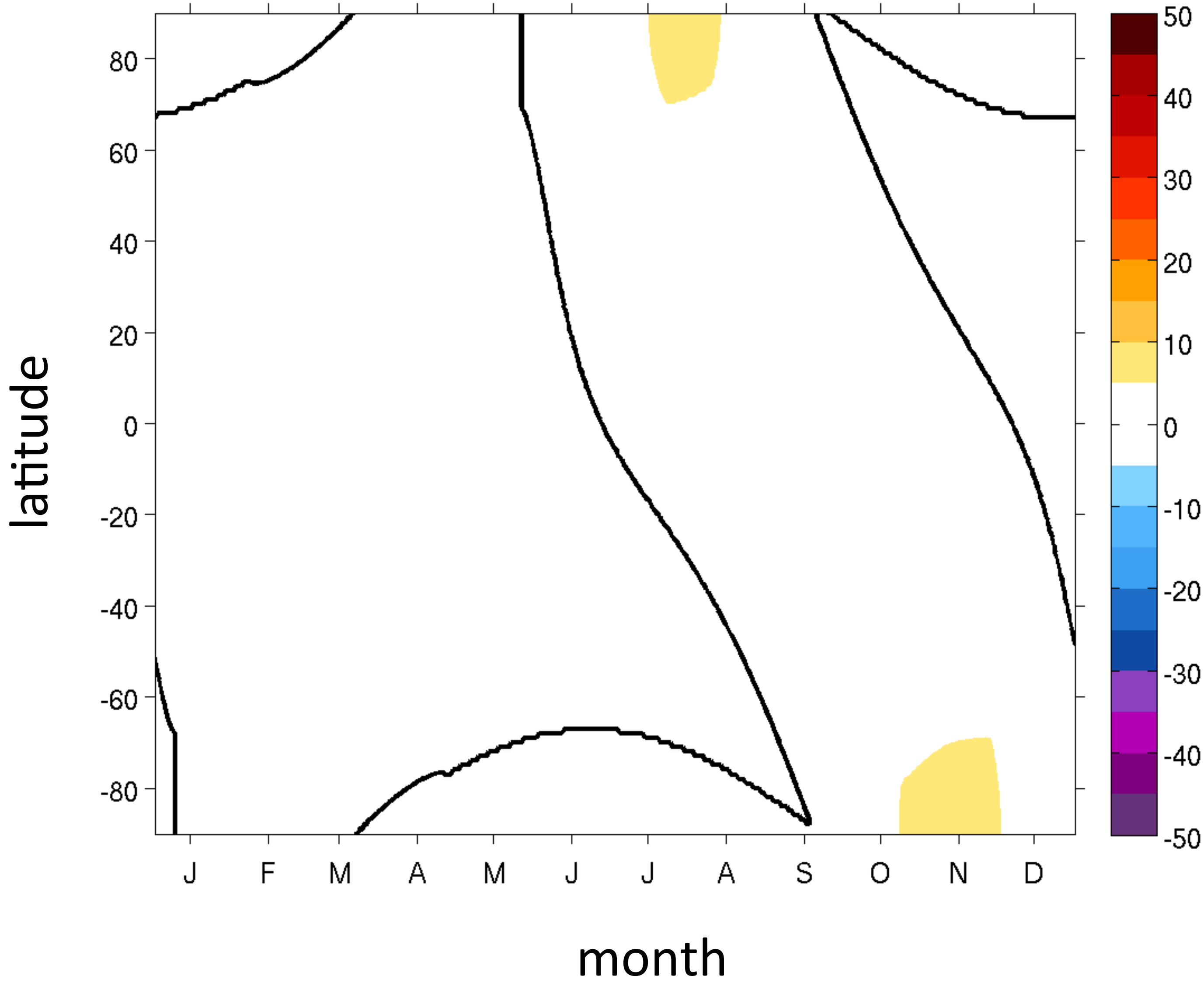
TOA solar radiation anomalies 3000 BP



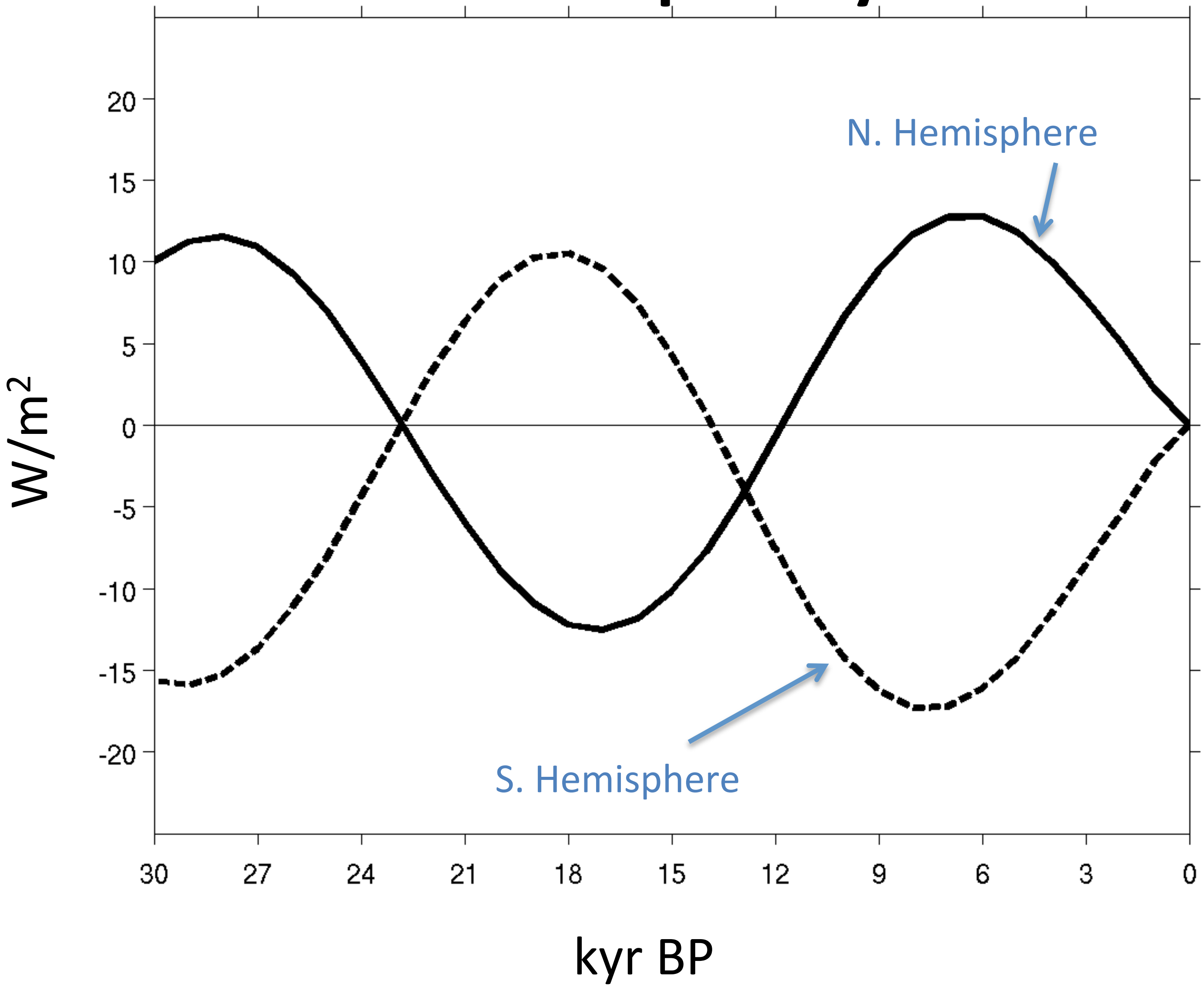
TOA solar radiation anomalies 2000 BP



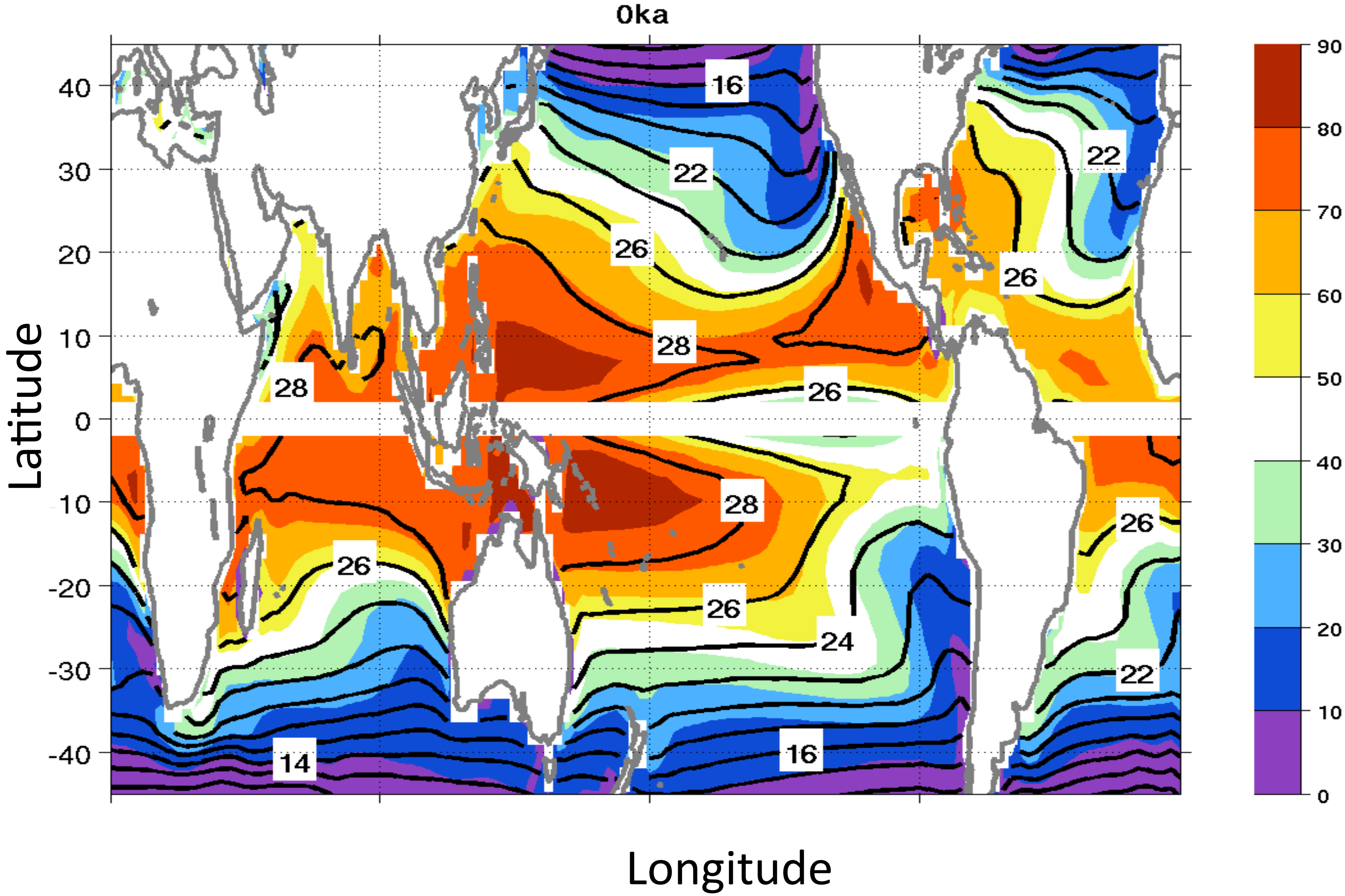
TOA solar radiation anomalies 1000 BP



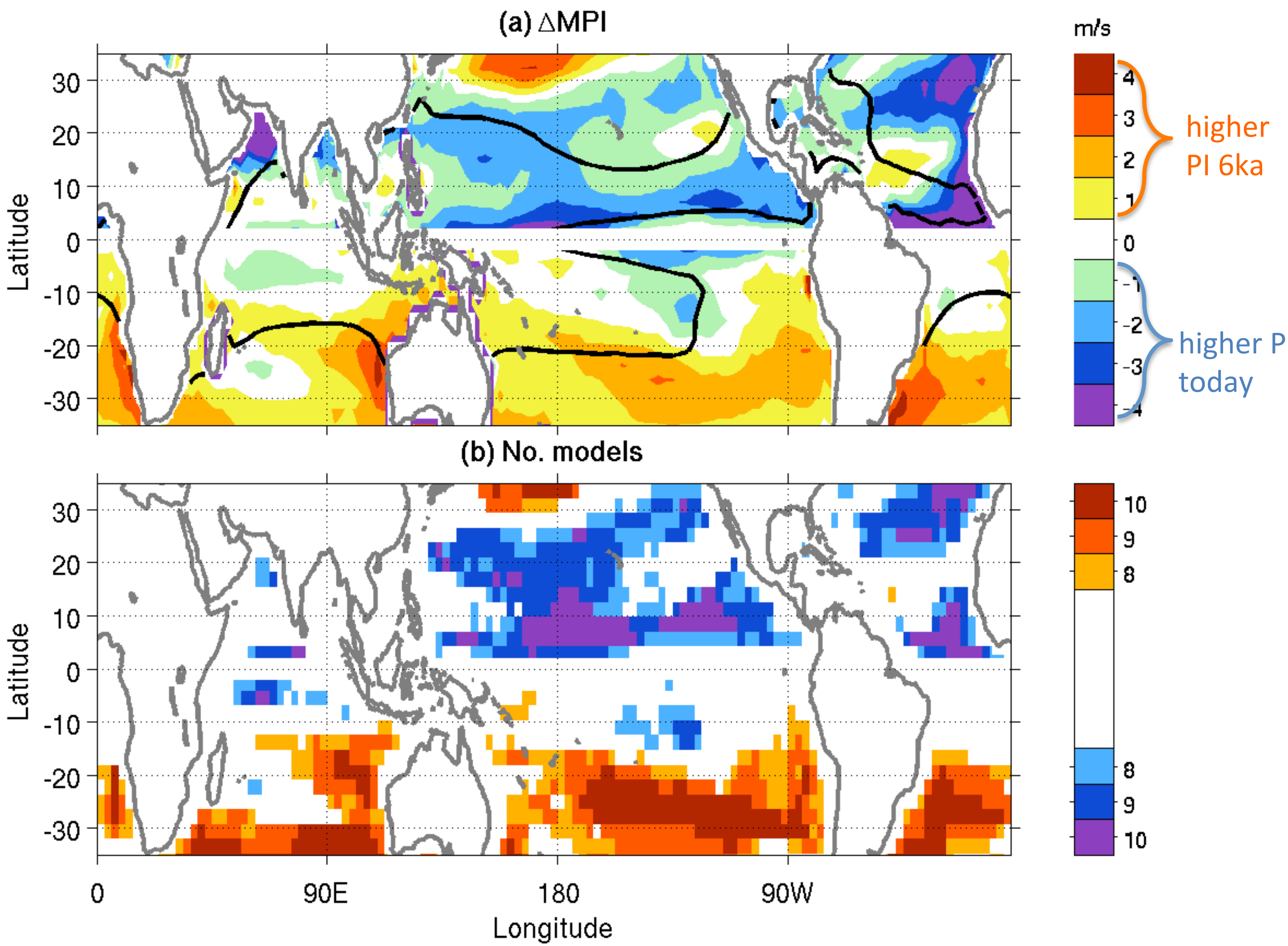
TOA solar radiation anomalies over the months of current tropical cyclone seasons



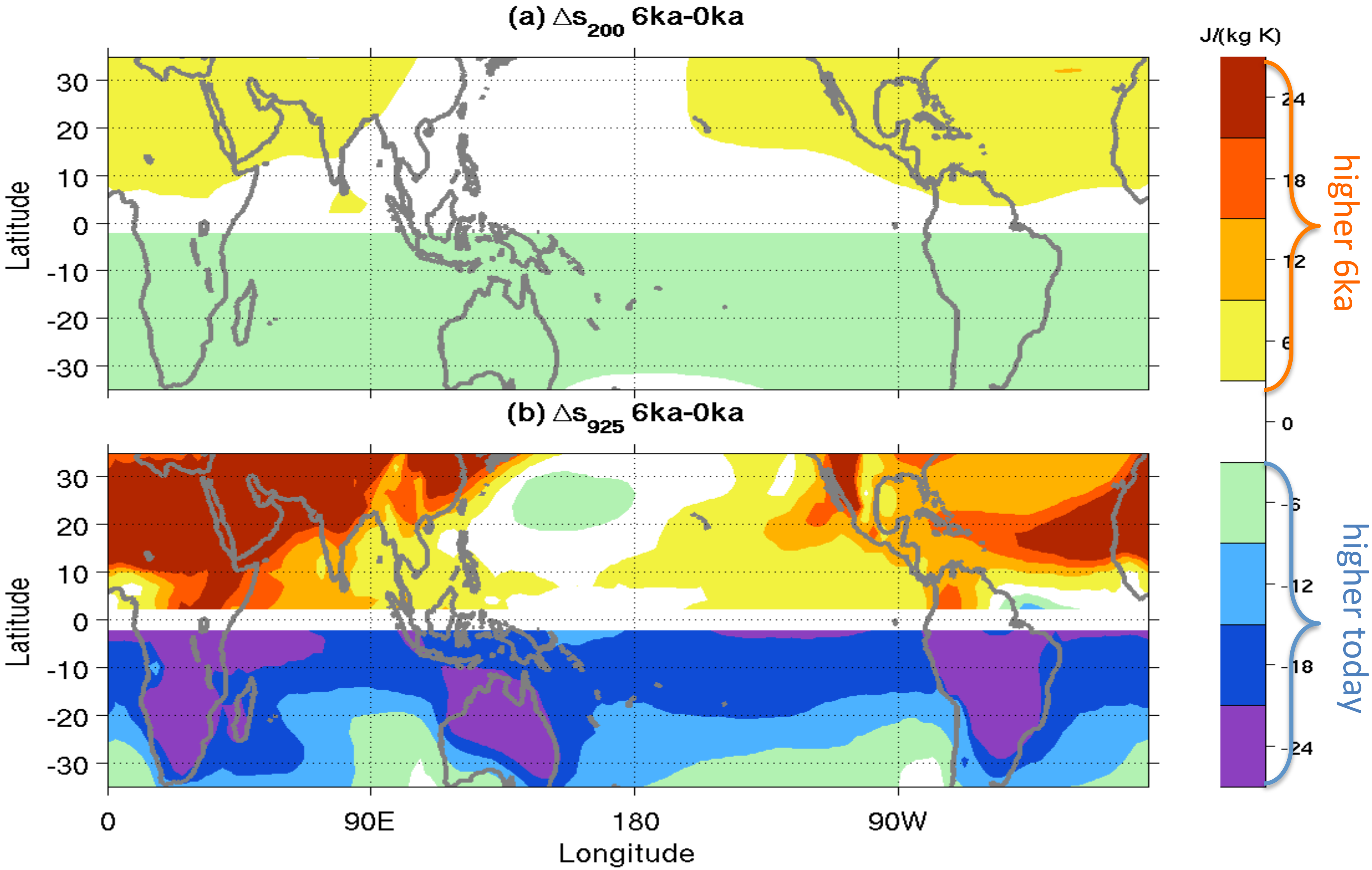
Storm Season potential intensity and SST



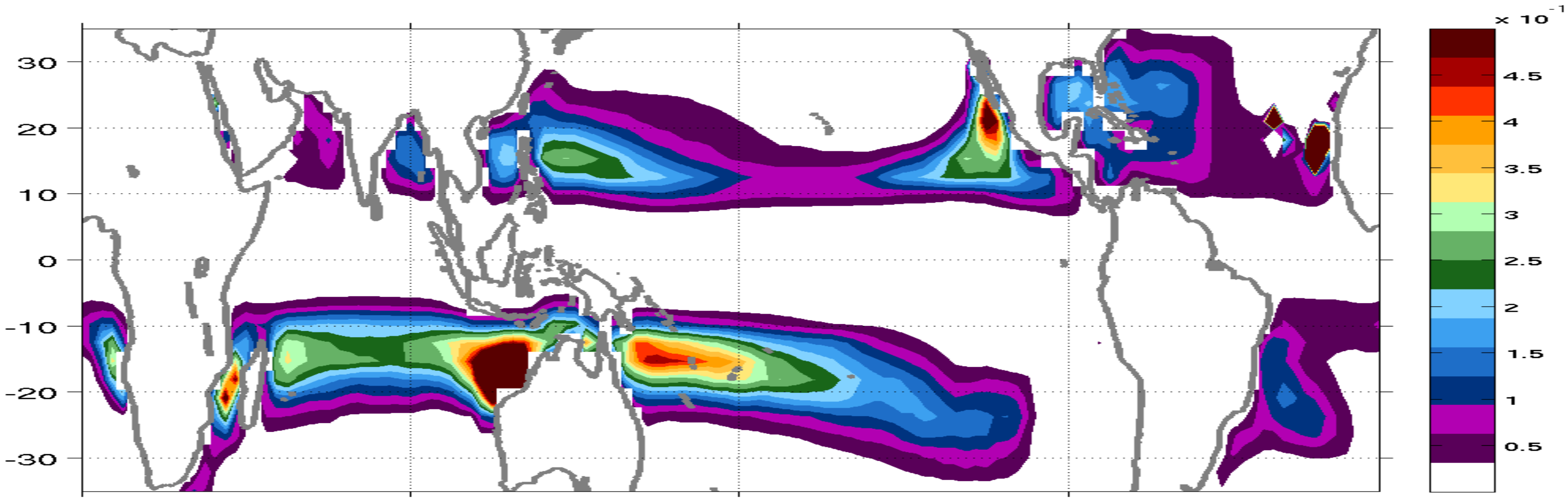
Difference in potential intensity at Mid-Holocene



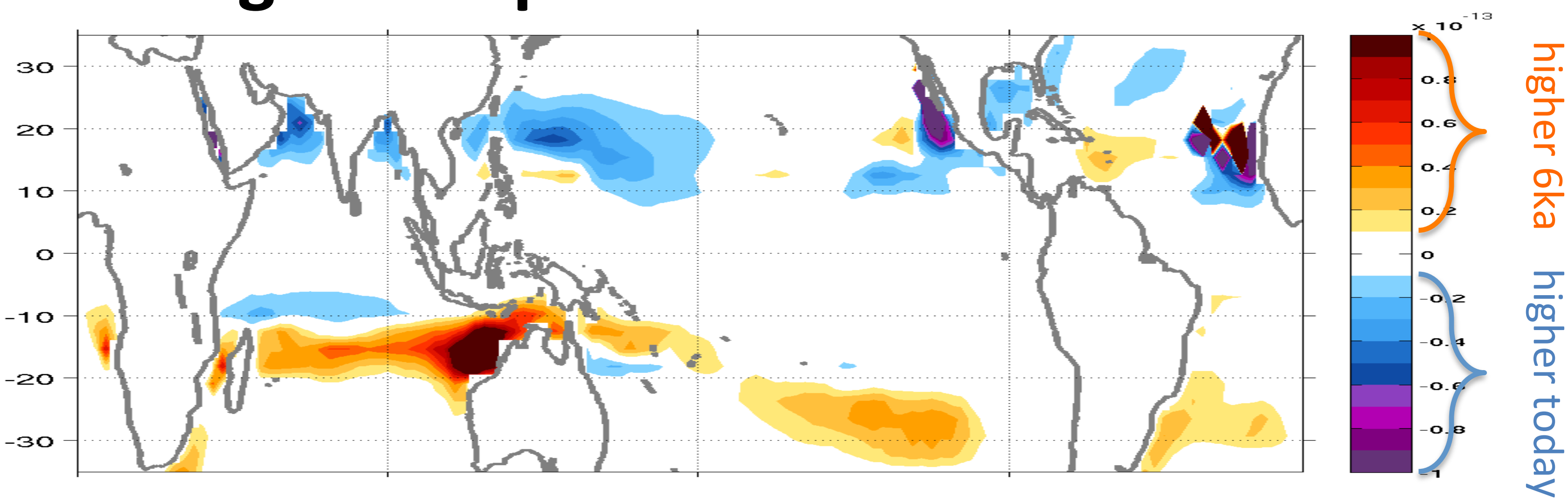
Change in moist entropy at Mid-Holocene



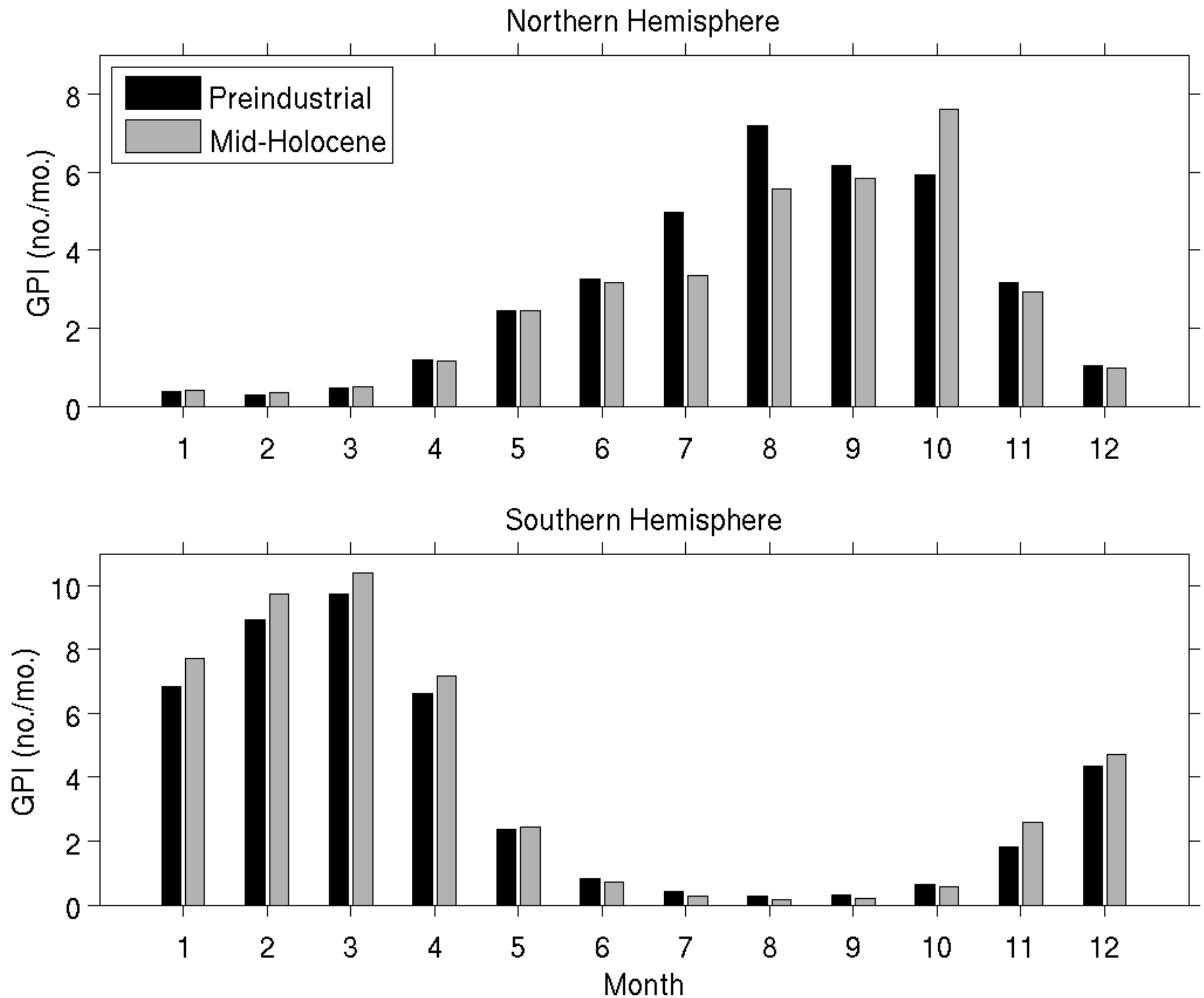
Genesis potential during Mid-Holocene



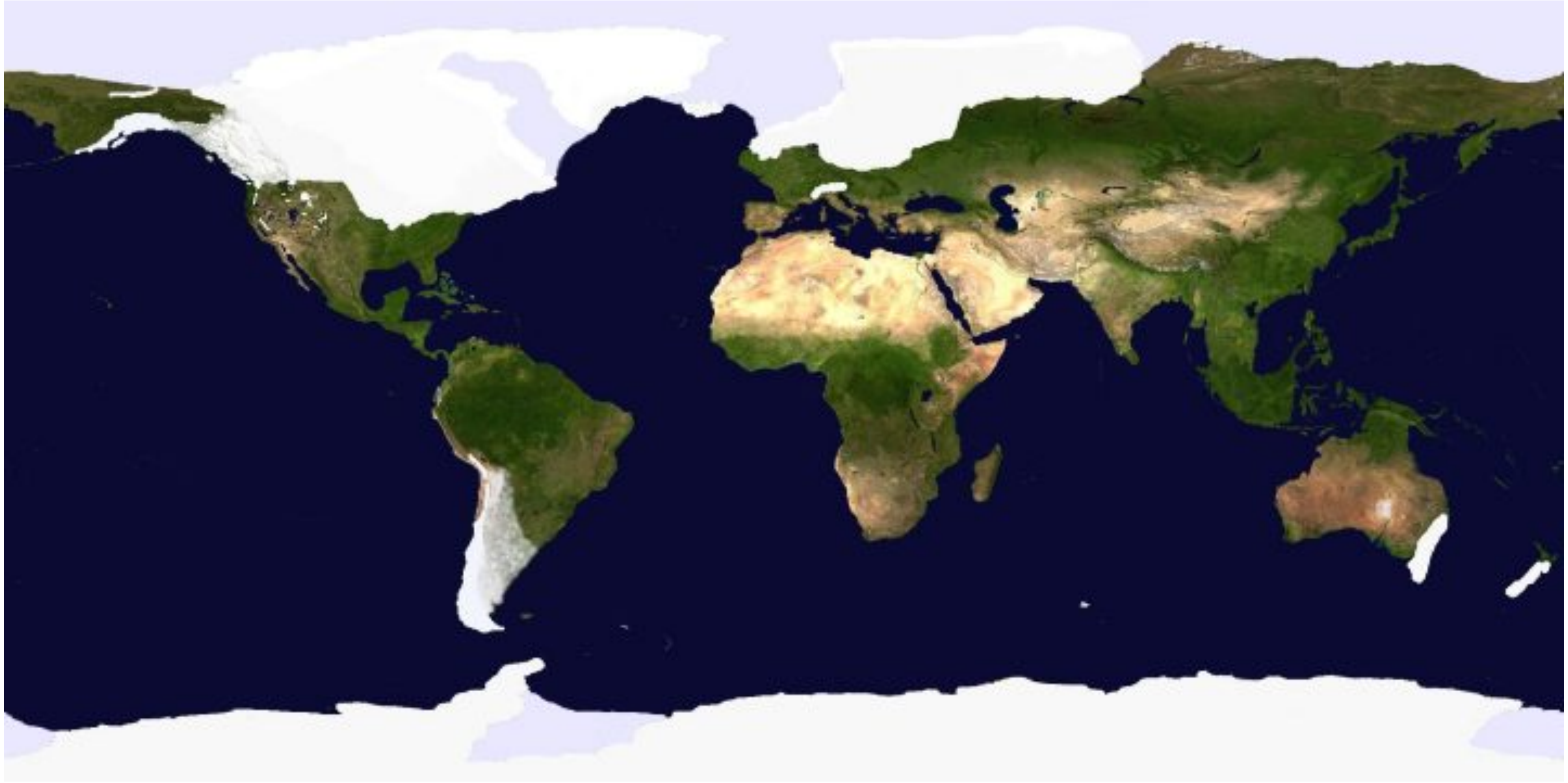
Change from pre-industrial era control



Seasonal cycle of genesis potential during Holocene



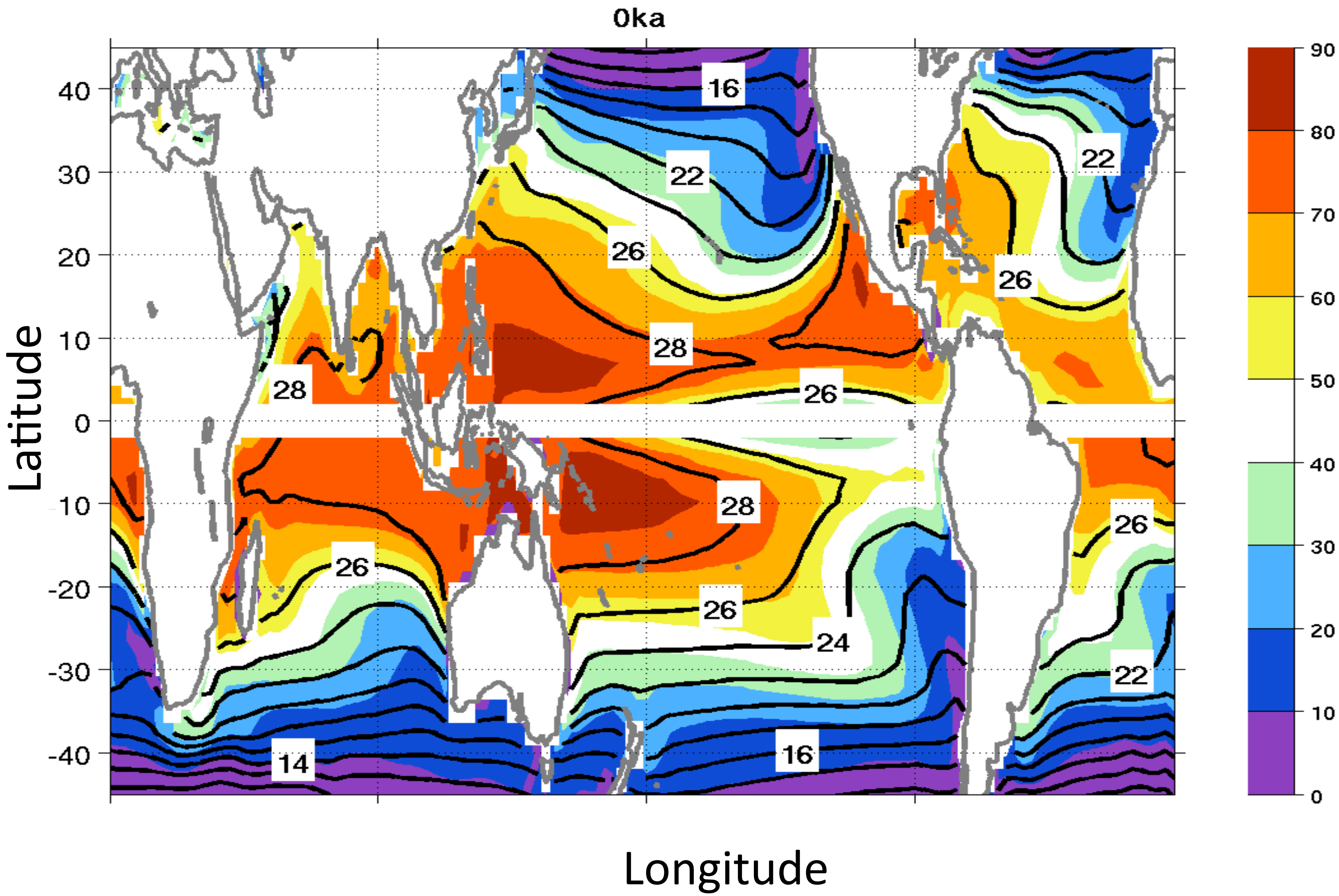
Last Glacial Maximum: 21,000 years ago



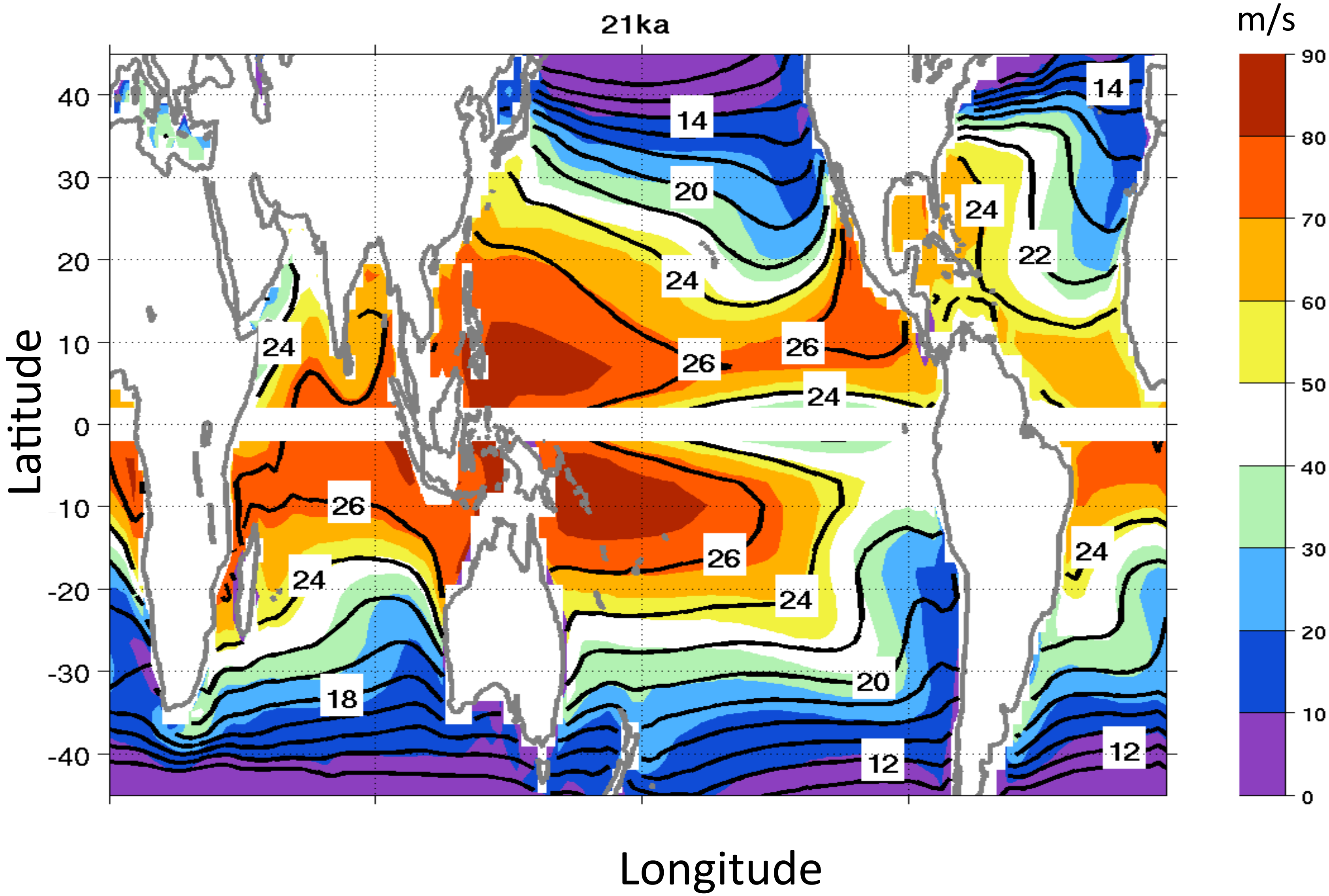
Second Paleoclimate Model Intercomparison Project (PMIP2):

- 7 coupled ocean-atmosphere models form an ensemble here
- CO_2 was 185 ppm
- Tropical temperatures were 2-3^{o}C cooler than today
- As much as 30^{o}C colder over land where there was ice

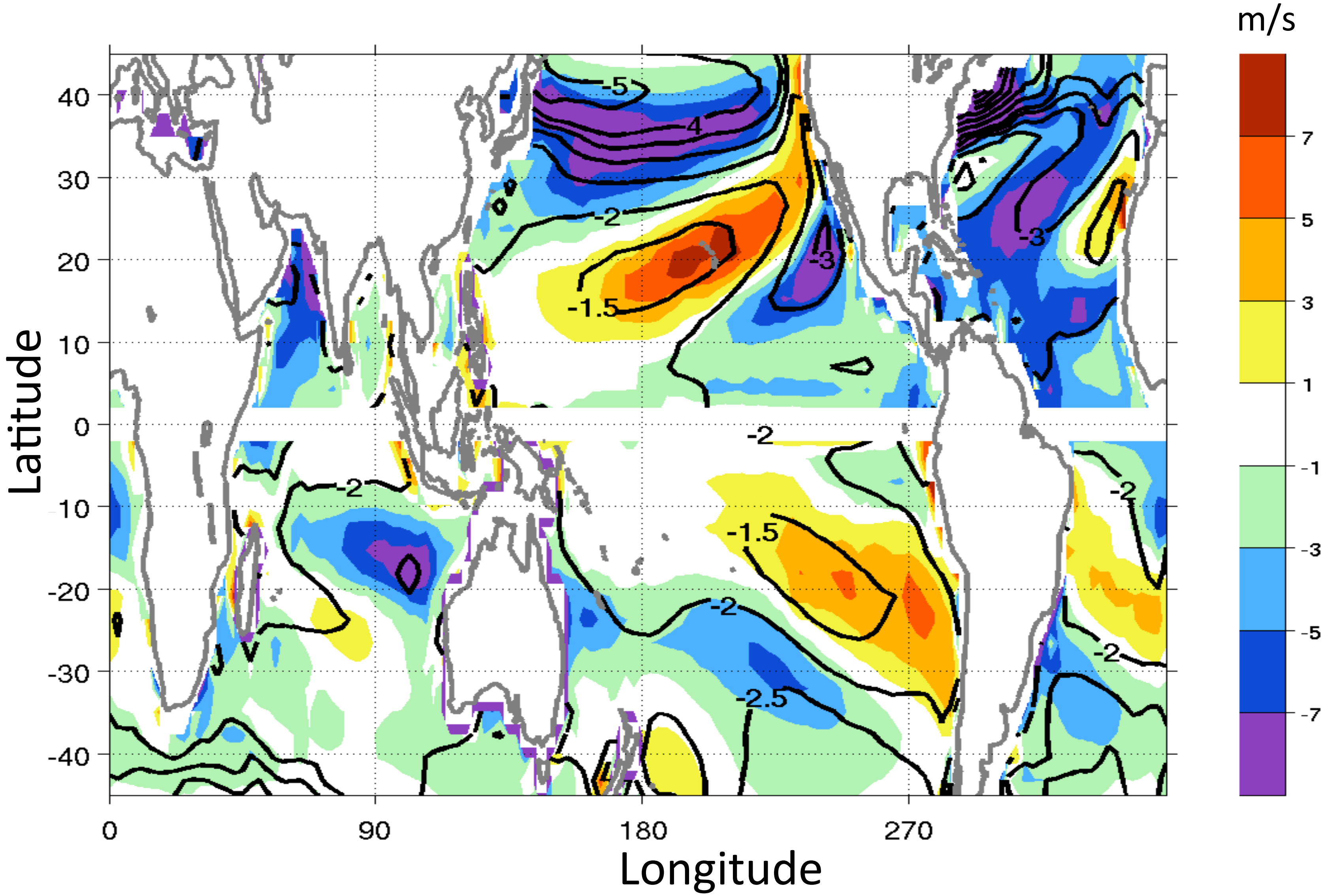
Potential intensity and SST today



Potential intensity and SST at the LGM



LGM – control: potential intensity and ΔSST



Incubation parameter

Vertical wind shear, entropy (humidity) deficits, and potential intensity can be combined into a non-dimensional parameter

$$\frac{V_{sh}\left(s^{*}-s_{m}\right)}{V_{PI}\left(s_{0}^{*}-s_{b}\right)}$$

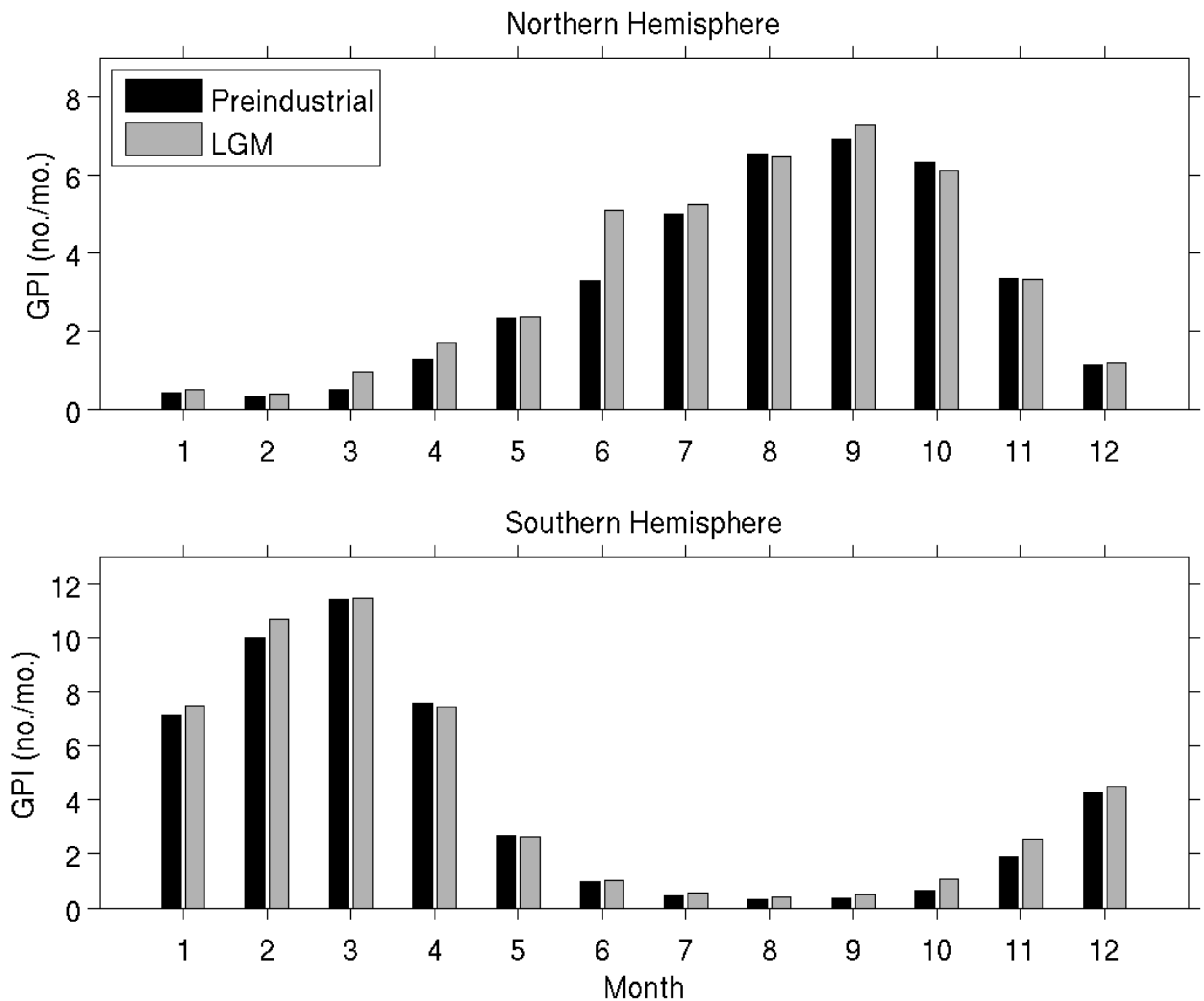
The smaller it is, the faster development occurs (Rappin et al. 2010)

Cold climates have smaller $s^* - s_m$ than warm ones (RH ~ constant)

Several empirical genesis potential indices have forms inversely proportional to this parameter (Tang and Emanuel 2012)

$$GP \sim \left|\zeta_{abs}\right| / \gamma$$

Seasonal cycle of genesis potential at LGM



Behavior in hot climates

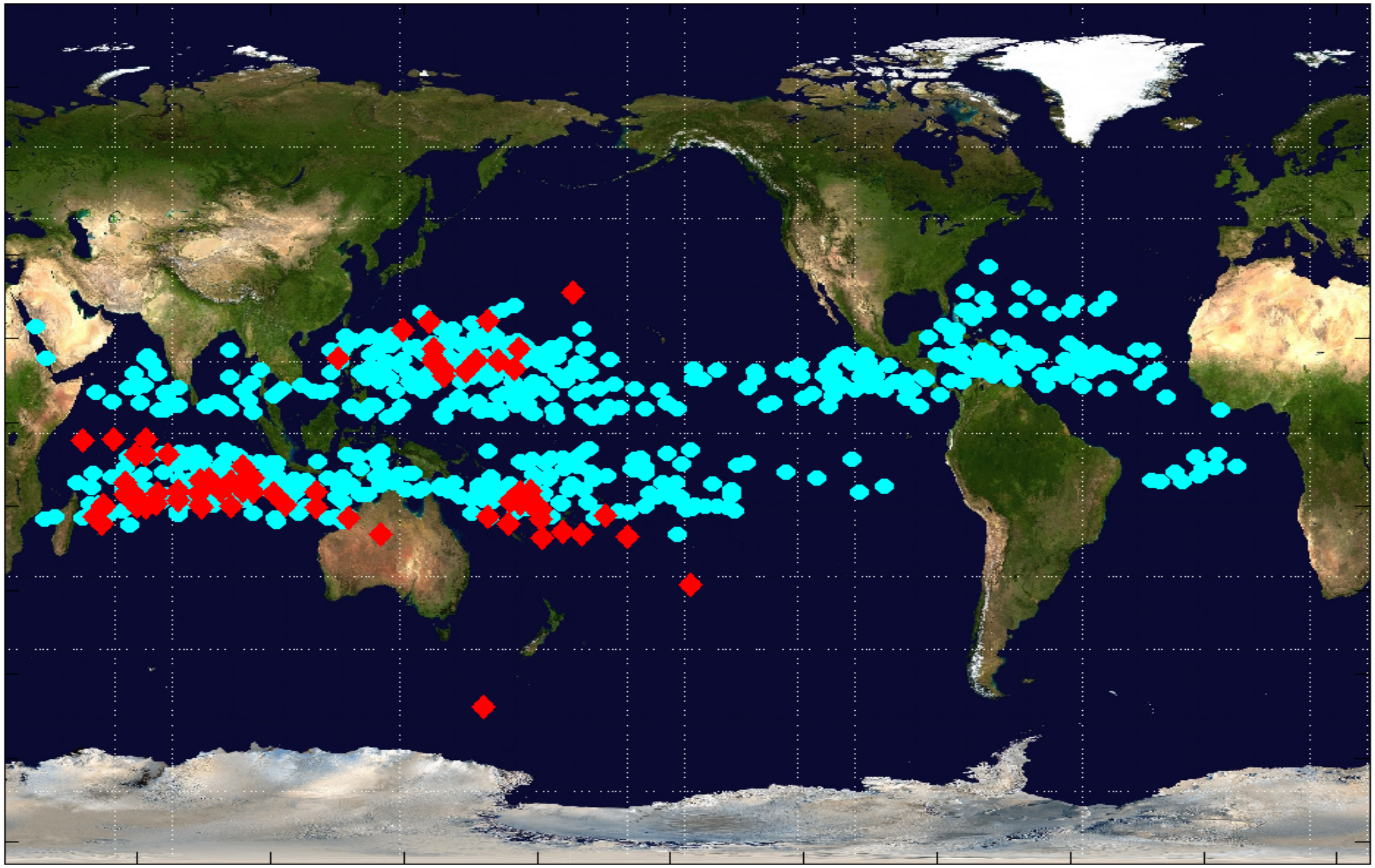
In collaboration with Matthew Huber (Purdue), we have also calculated genesis factors for simulations designed to replicate aspects of early Cenozoic climate with CCSM.

Among the set are some that retain present-day geography but have increasingly high levels of CO_2. They are coupled to a slab ocean model with fixed ocean heat transport.

The series begins with a run using preindustrial era values (280 ppm) and subsequent runs consecutively double levels five times.

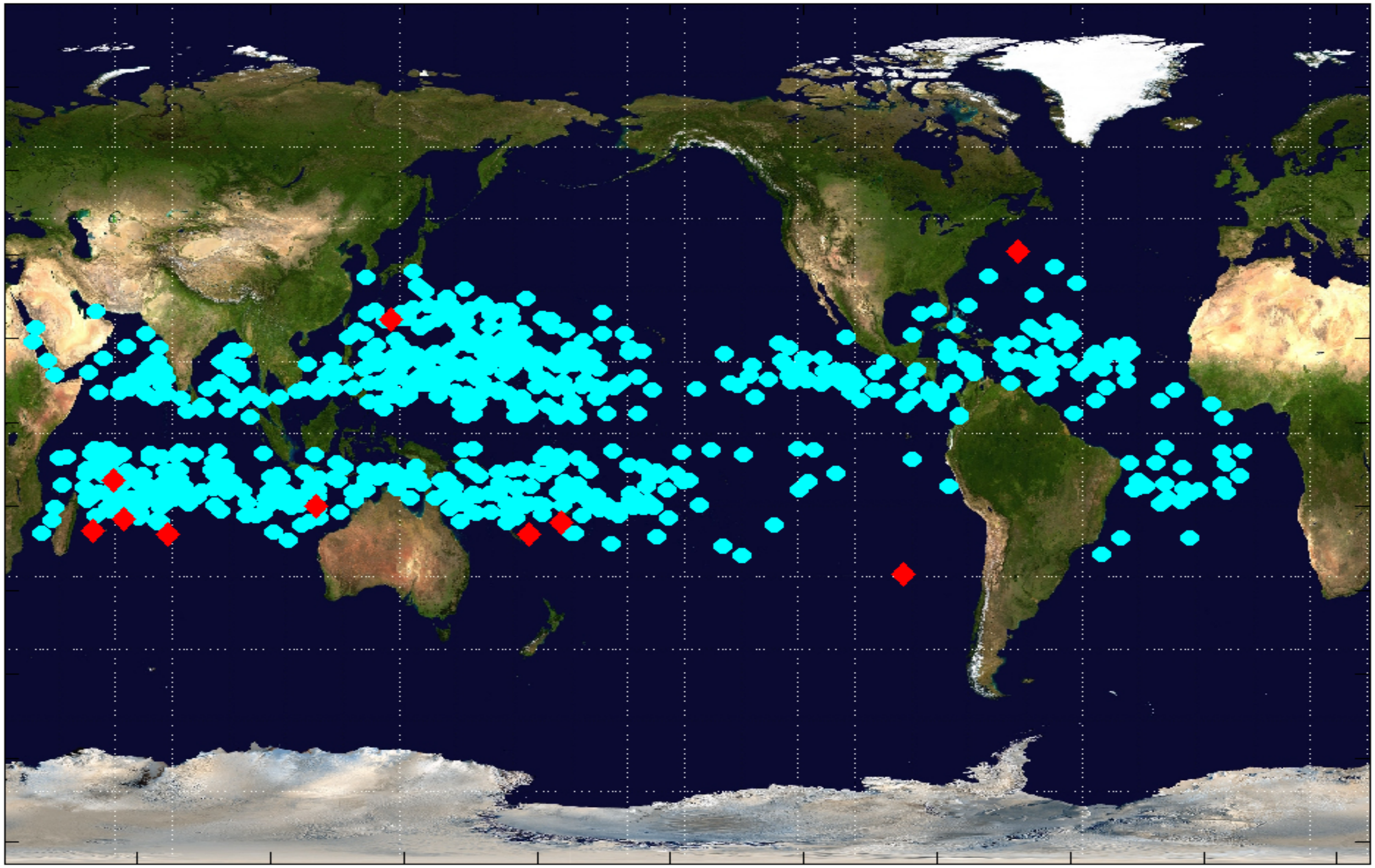
- 560 ppm
- 1120 ppm
- 2240 ppm
- 4480 ppm
- 8960 ppm

Genesis locations (355 ppm)



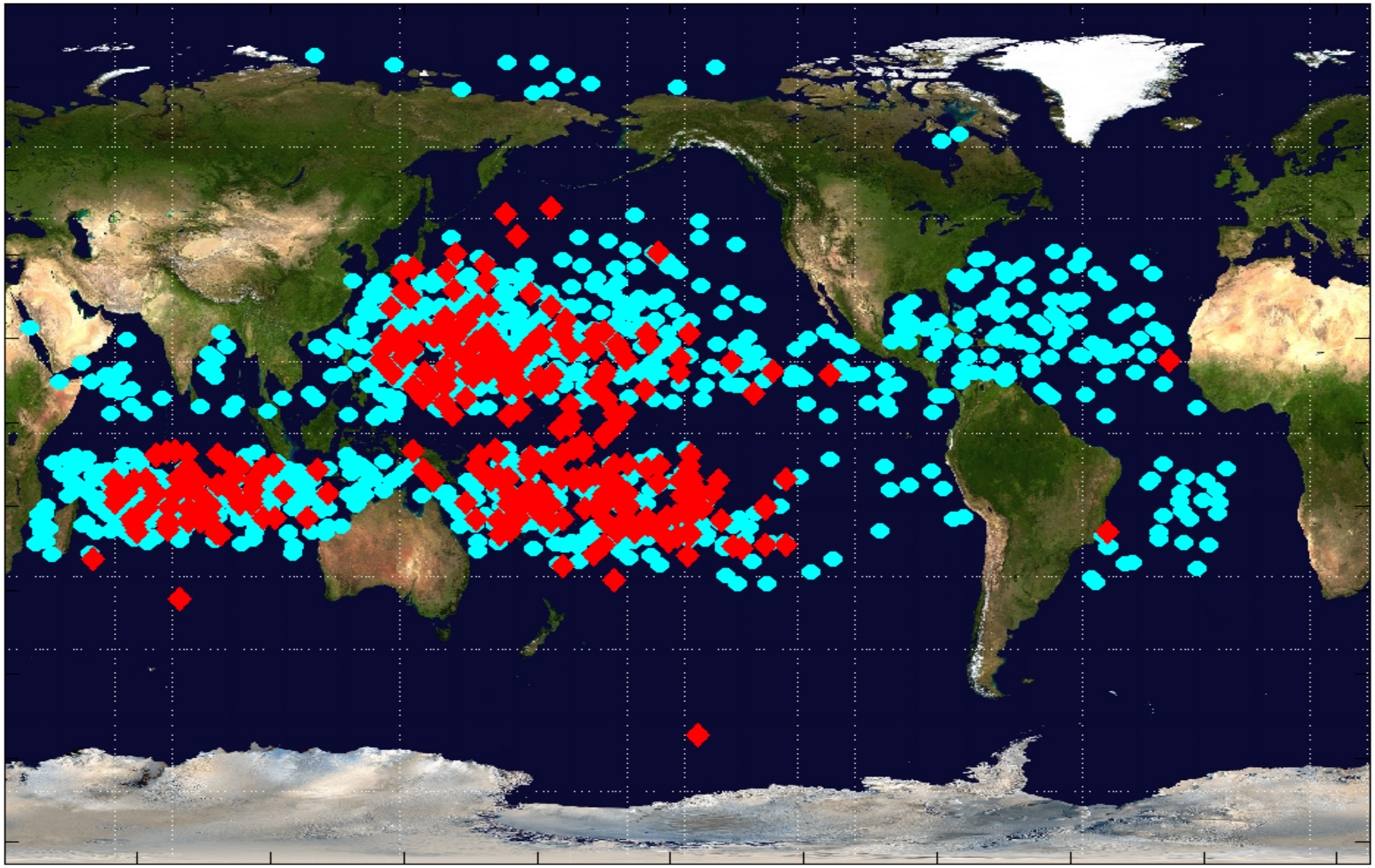
Cyan: downscaled events
Red: explicit vortices

Genesis locations (2240 ppm)



Cyan: downscaled events
Red: explicit vortices

Genesis locations (8960 ppm)



Cyan: downscaled events
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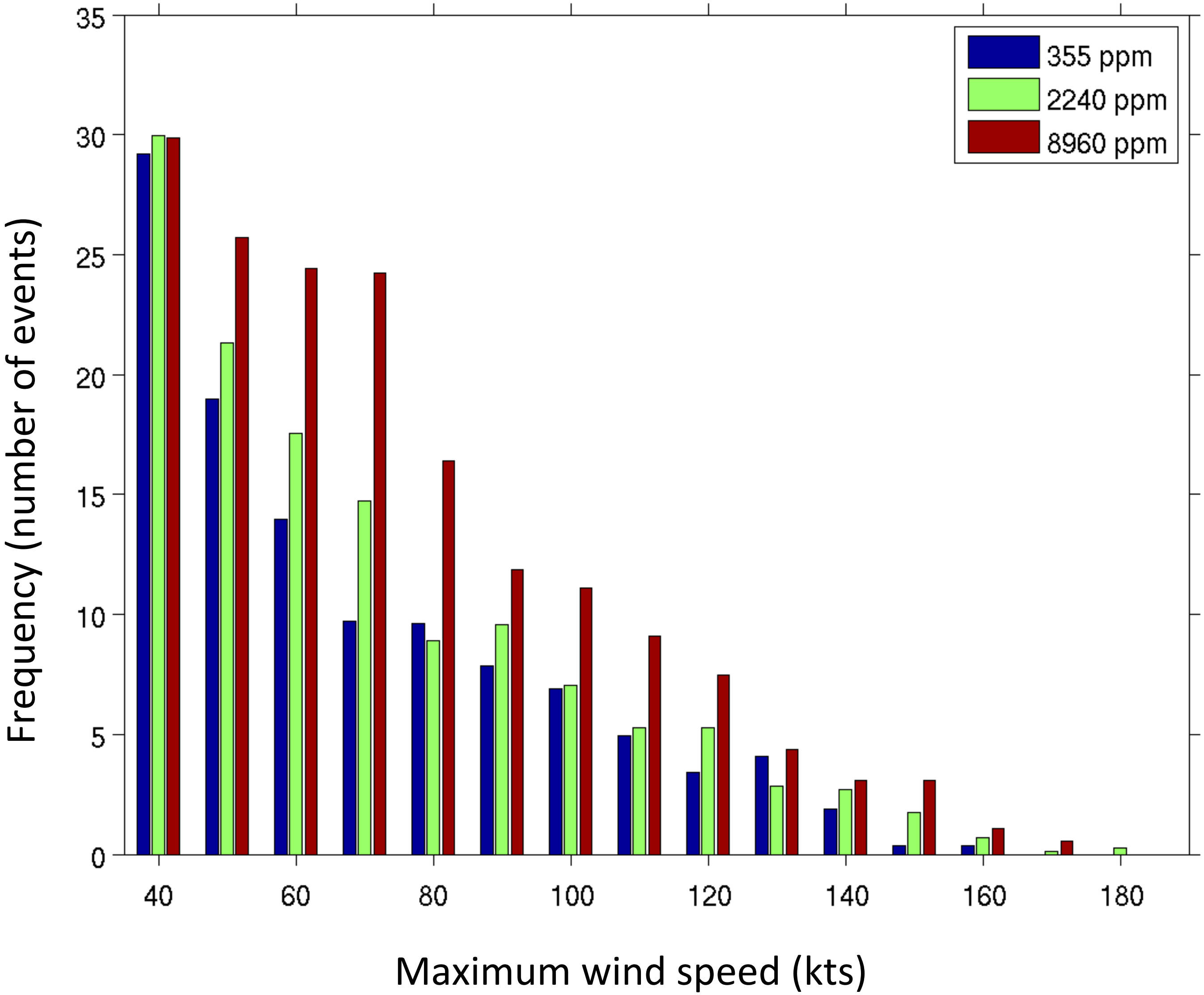
Downscaled storms



Lessons from paleoclimate model simulations

Last several millennia (Holocene epoch):

- Top of atmosphere radiation anomalies owing to perihelion cycle
- Shifts seasonal cycle of genesis factors, but not annual potential

At LGM, potential intensity changes coarsely follow ‘relative SST’

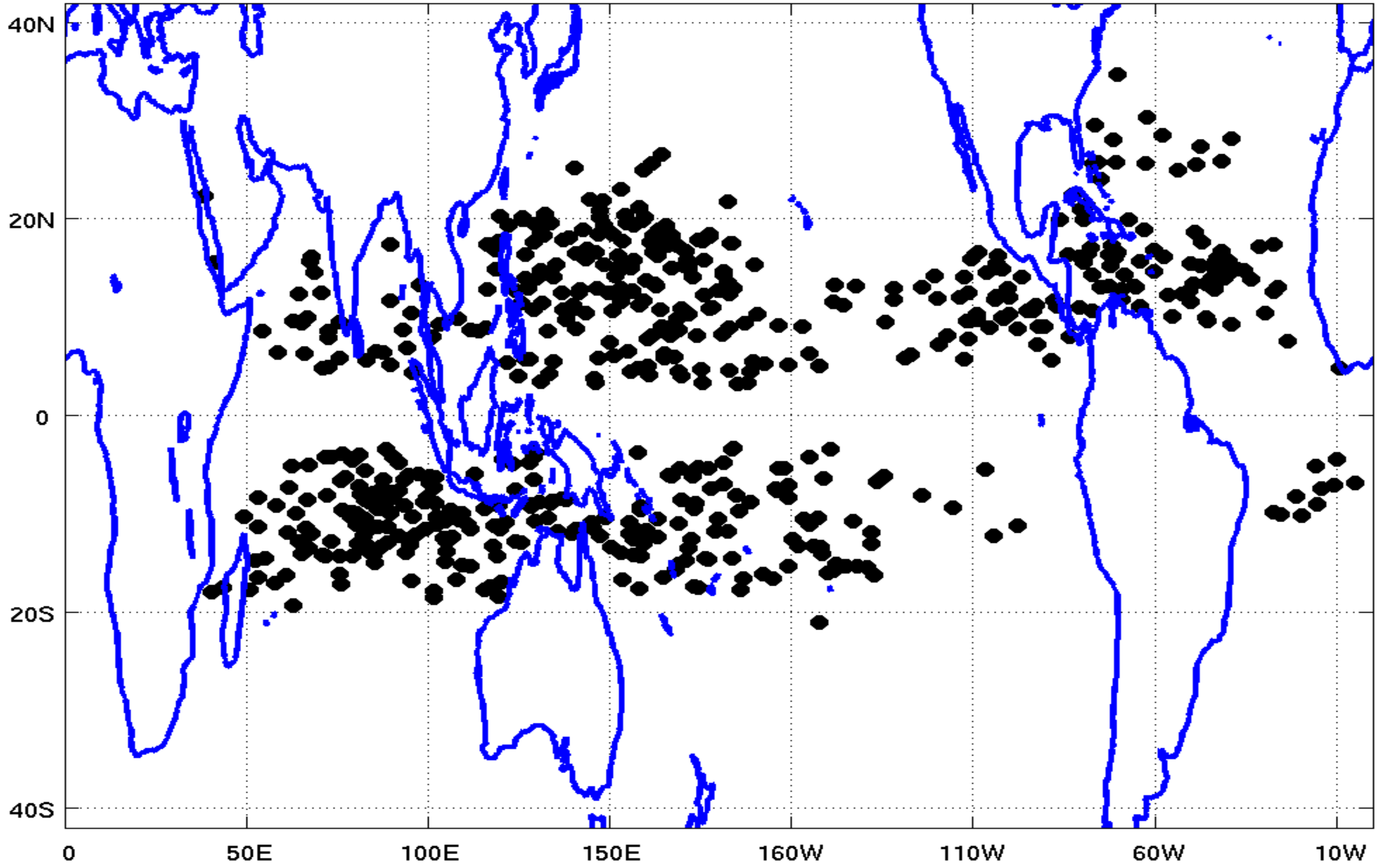
In hot periods, total count responds differently through 8 x CO_2:

- Declines in explicitly tracked vortices
- Increases slightly in downscaled experiments
- But rises in the hottest states using both techniques
- Moist adiabatic lapse rates allow extratropical genesis in hot case
- Both weak and strong downscaled events increase in hotter cases

Summary

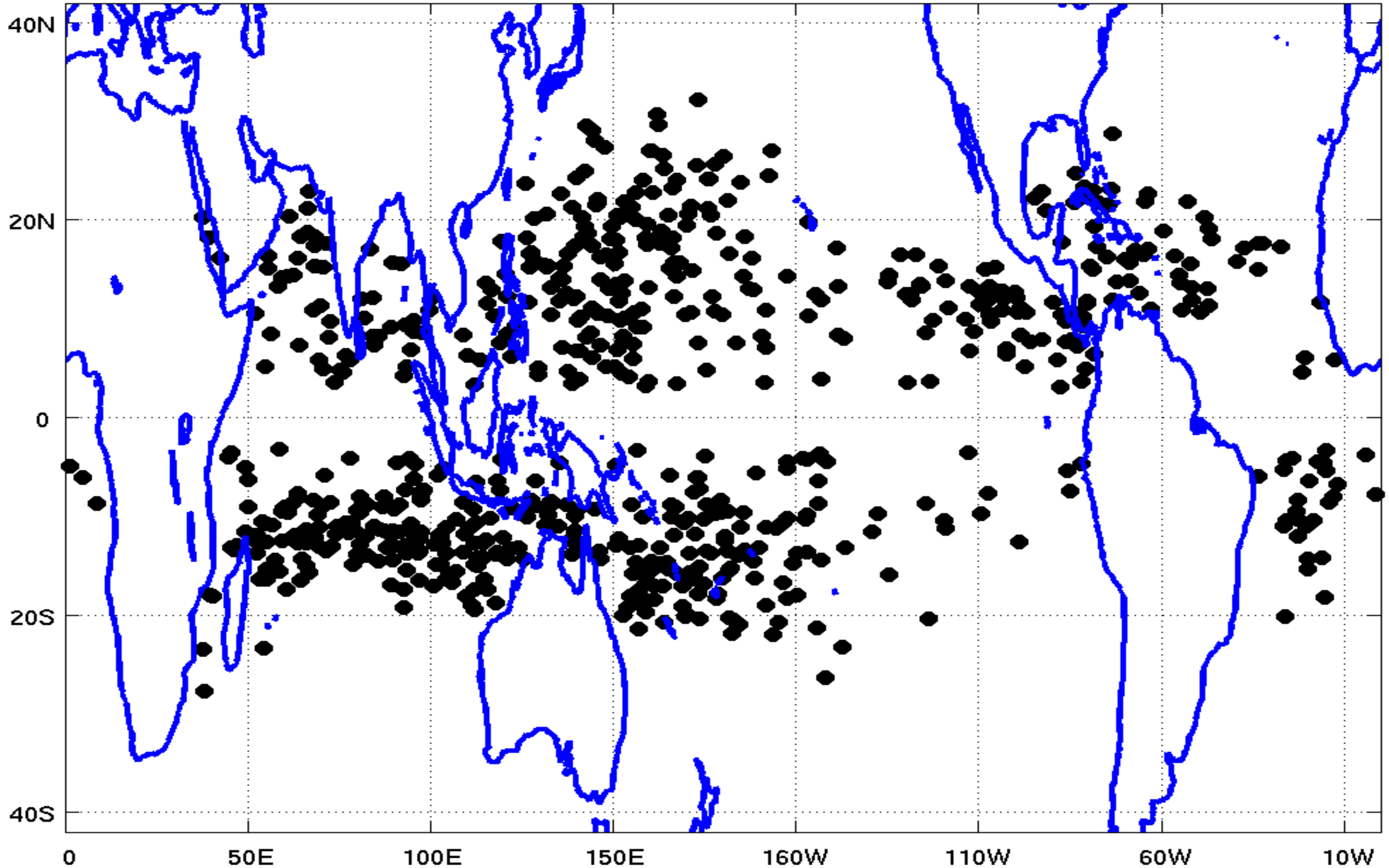
- Shift in seasonal cycle of genesis potential from the large-scale environment's response to Mid-Holocene TOA deviations
- Major equatorial volcanic eruptions have the potential for substantial but short-lived effects on tropical cyclones
- Downscaled cyclones respond differently from explicitly simulated events, exhibiting no decline in weak systems.
- LGM genesis factors have mixed signs—areas that cooled less than tropical mean become more favorable despite the colder state.

Downscaled storms; CO_2 355 ppm



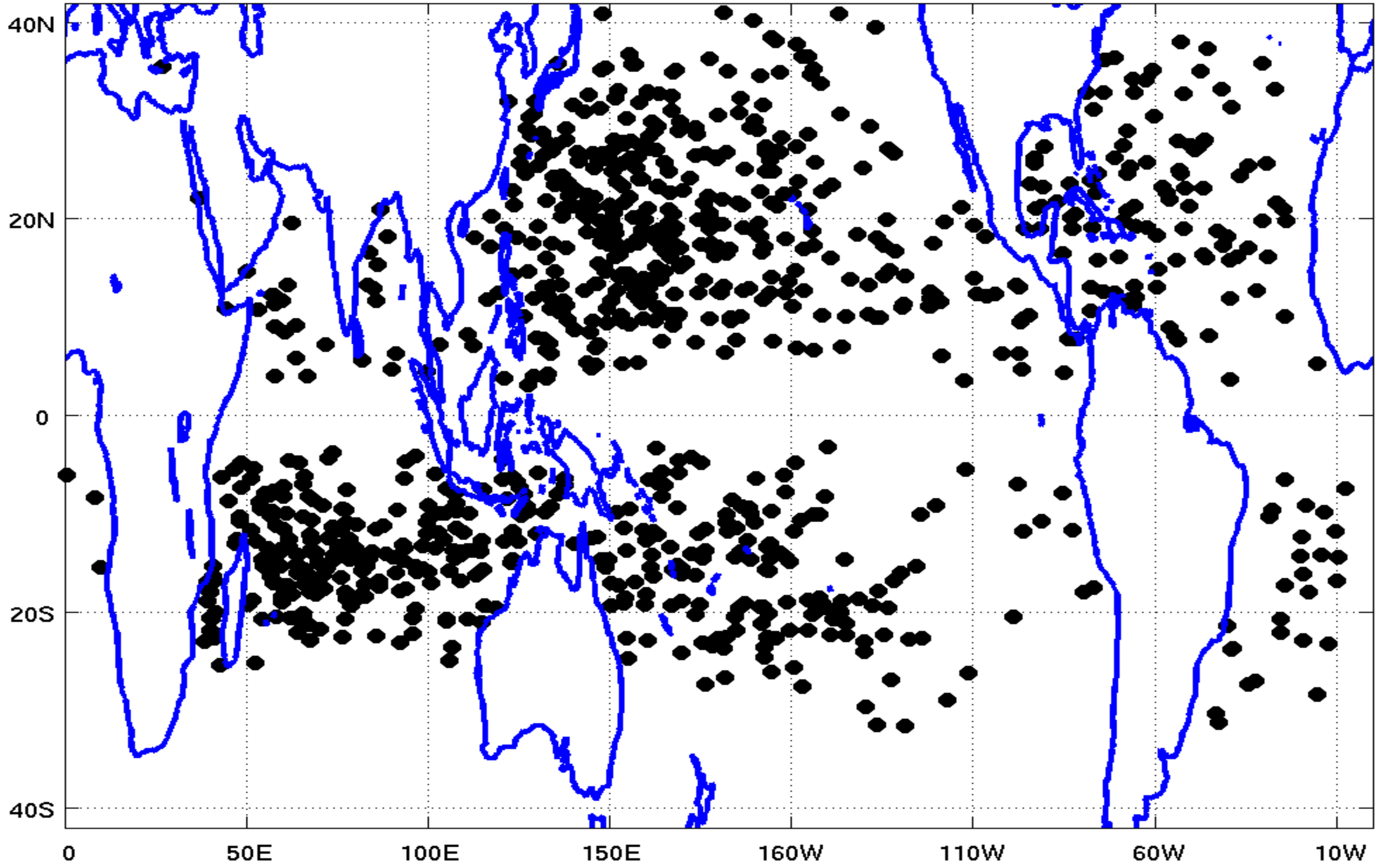
Emanuel (2006) seeding technique

Downscaled storms; CO_2 2240 ppm



Emanuel (2006) seeding technique

Downscaled storms; CO_2 8960 ppm



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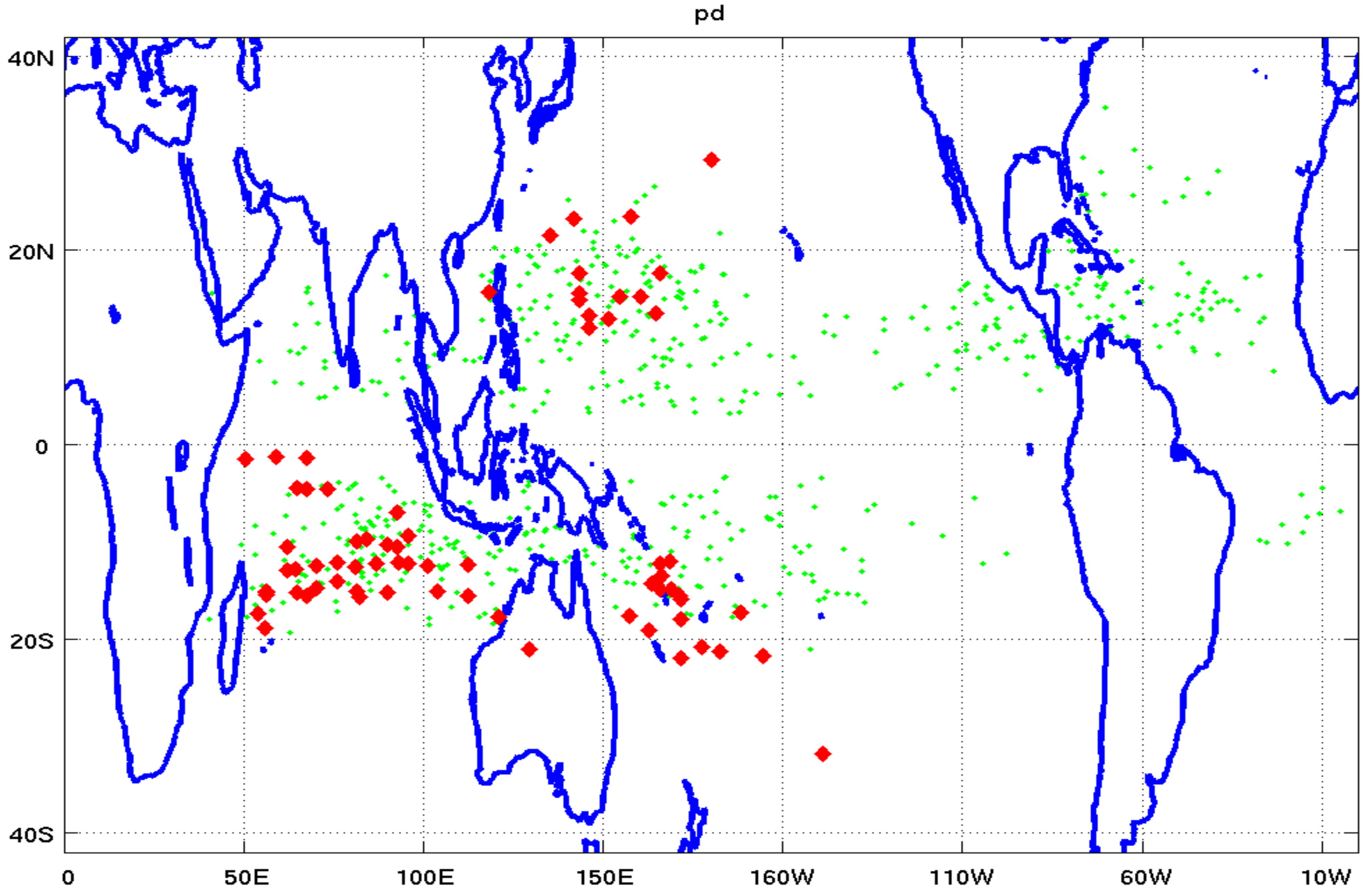
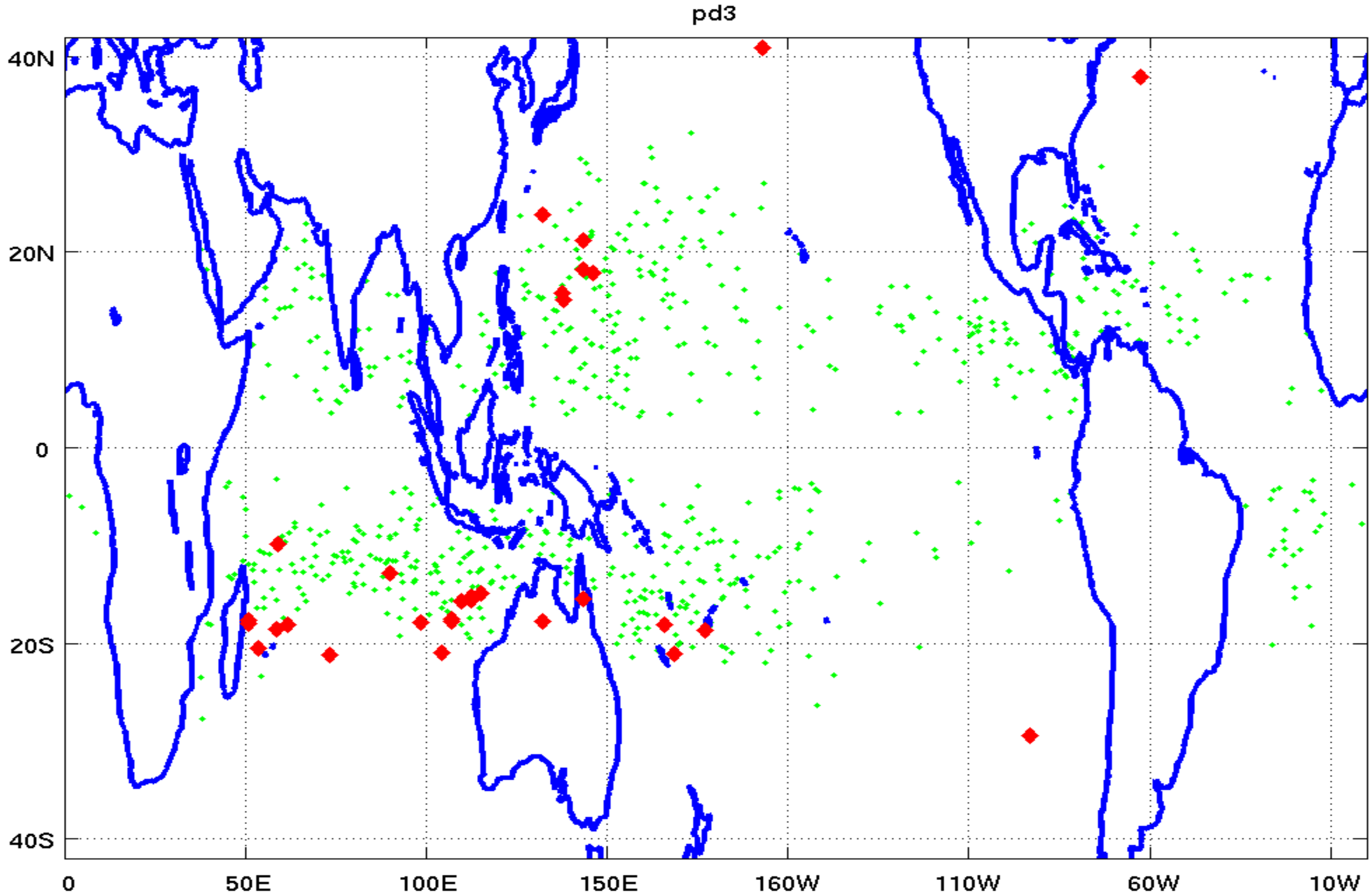


Explicitly resolved “TCs” (T42 resolution)

Downscaled storms; CO_2 2240 ppm



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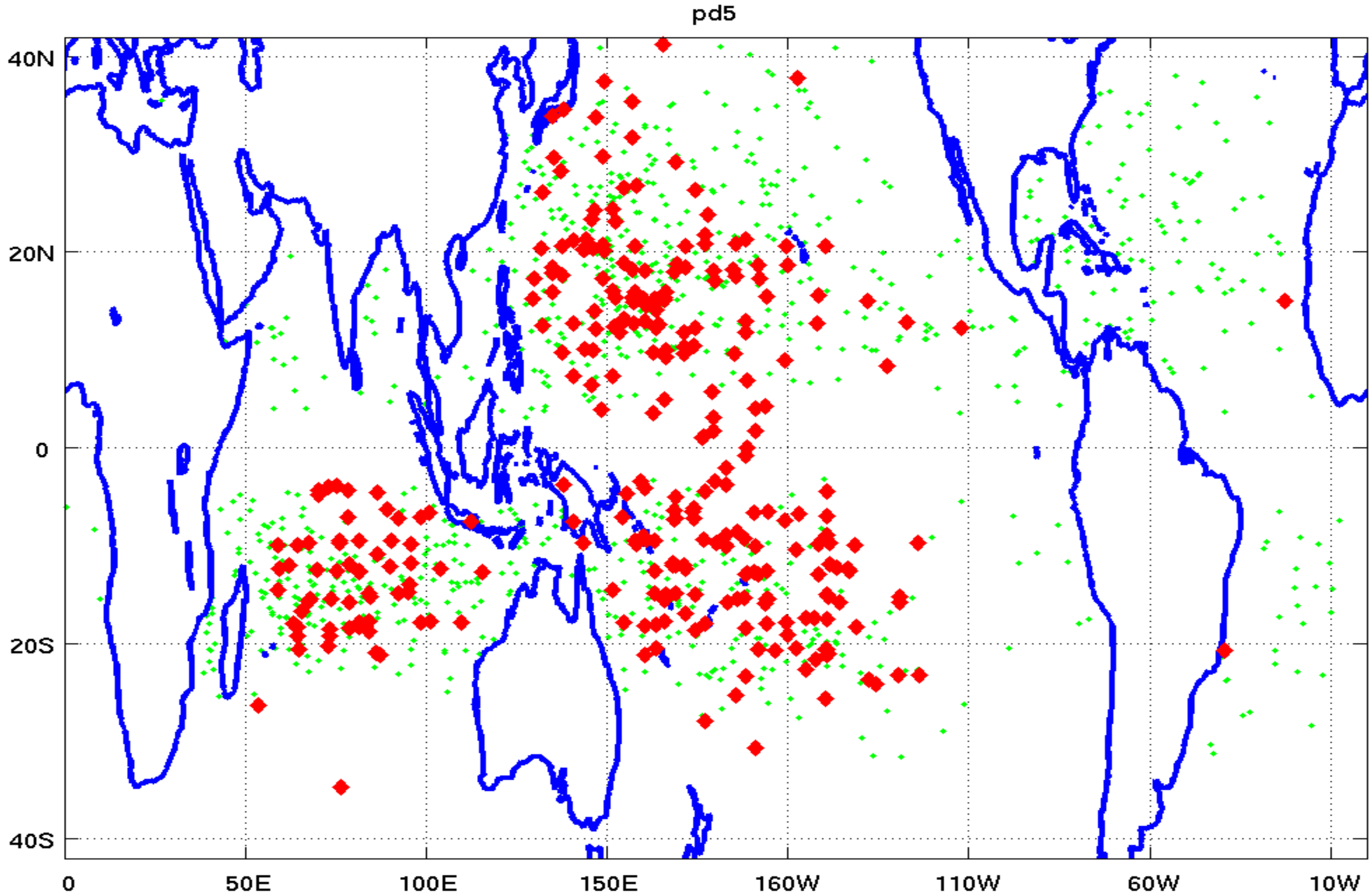

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