Greatly expanded warm pool, permanent El Niño, and weaker Hadley circulation in the early Pliocene

Alexey Fedorov, Chris Brierley, Zhonghui Liu

Yale University

Thanks: Tim Herbert, Kira Lawrence

Christina Ravelo, Petra Dekens, George Philander

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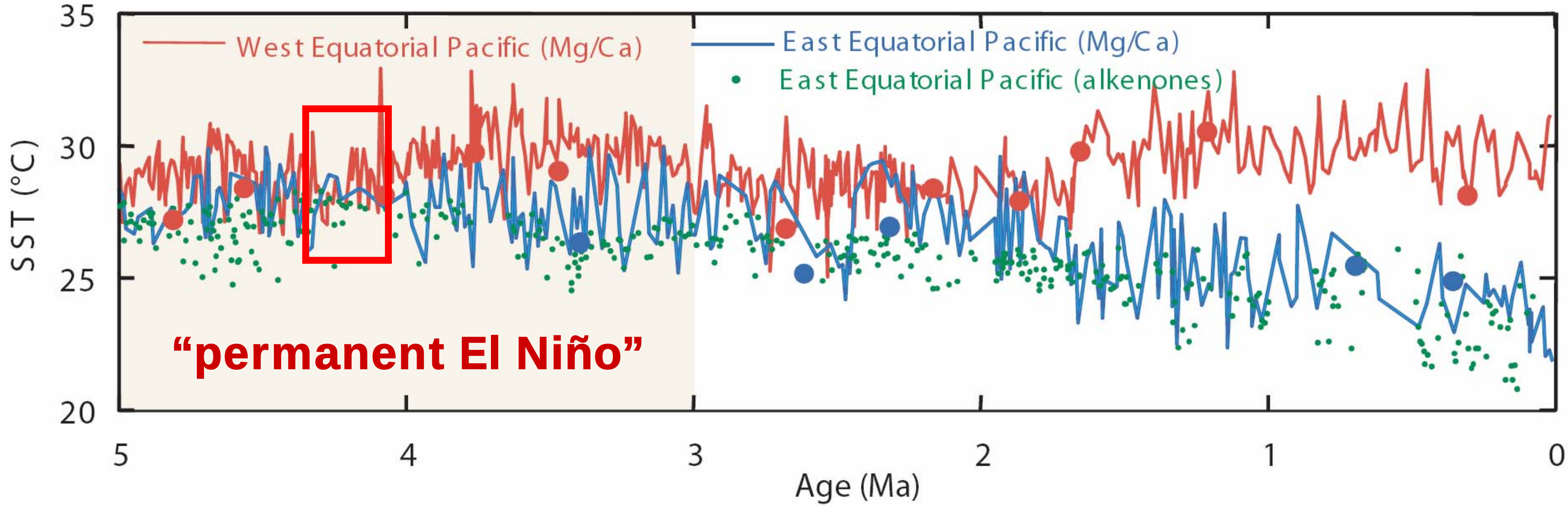
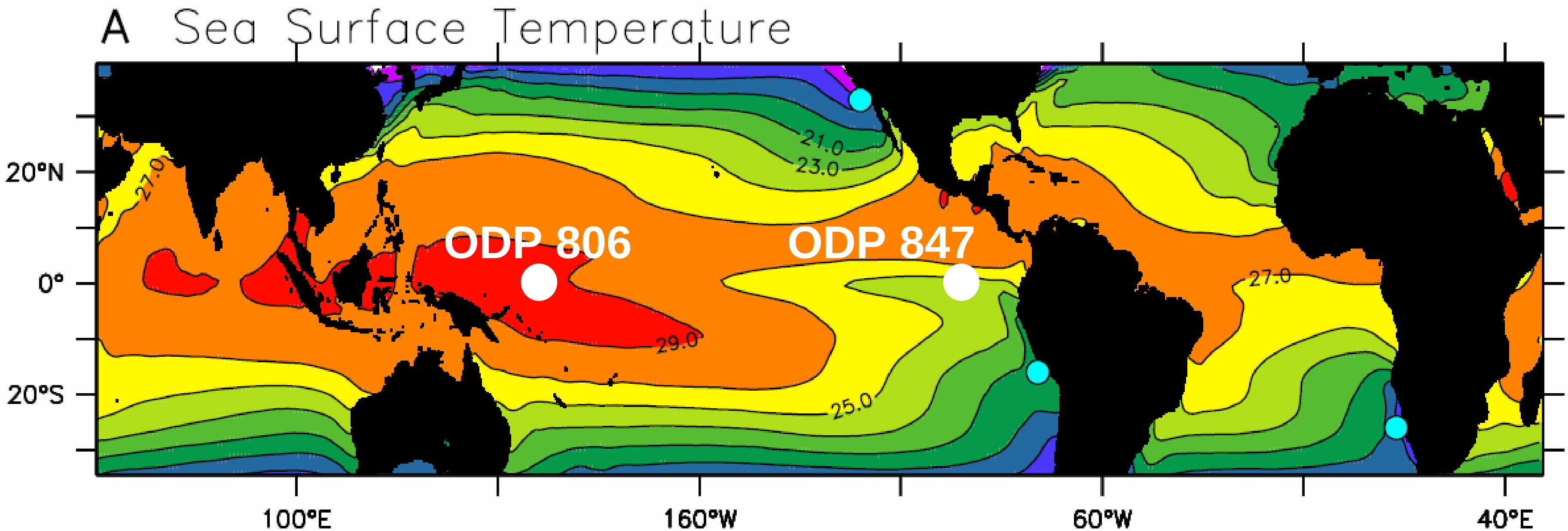
The big question:

How does the tropical Pacific respond to the elevated concentrations of greenhouse gases in the atmosphere (e.g. the SST gradient along the equator)?

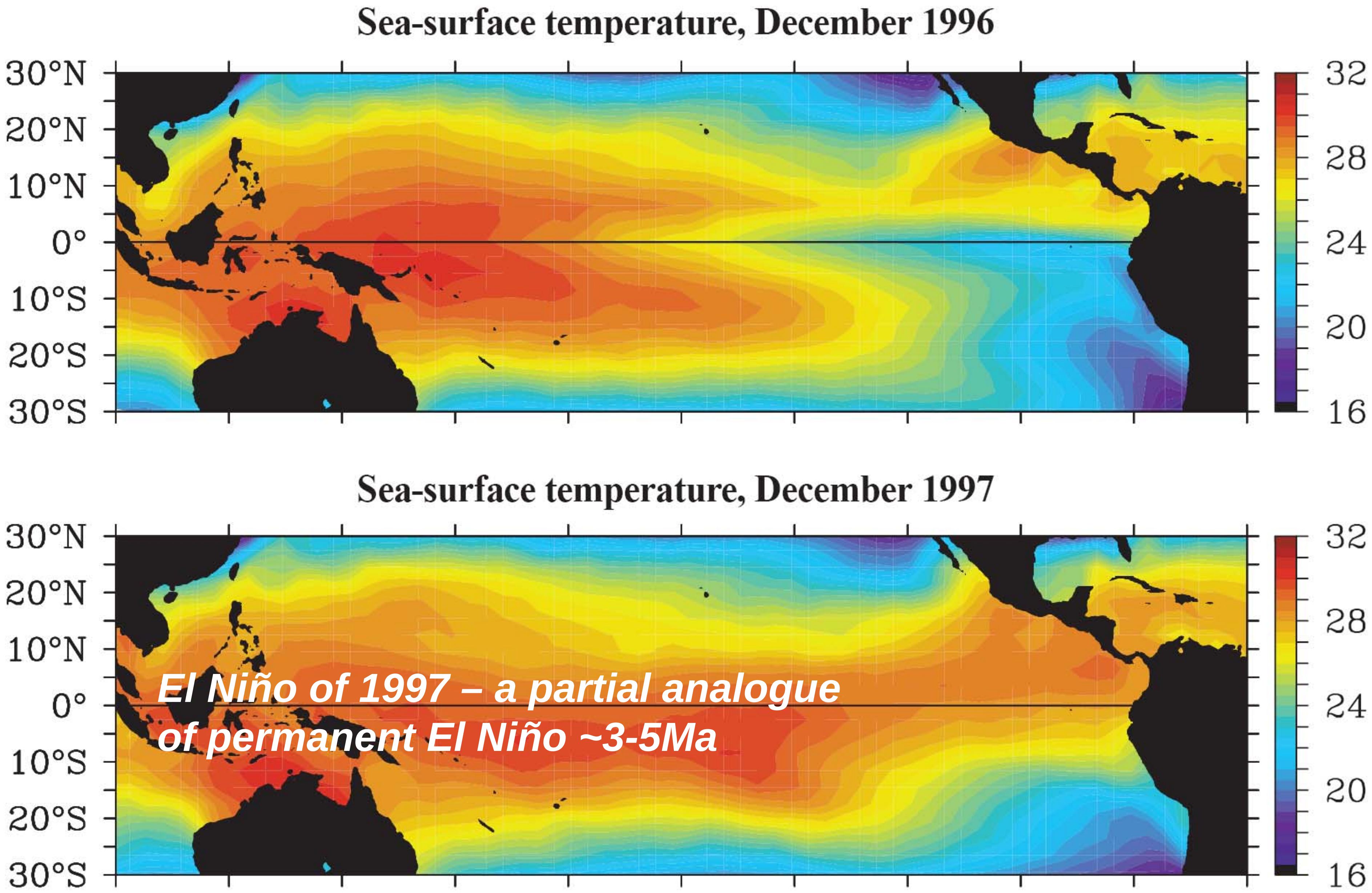
Outline:

- *Paleo-observations of the tropical climate state in the early Pliocene: permanent El Niño and meridional expansion of the tropical warm pool*
- *Mechanisms for sustaining a permanent El Niño: results from ocean modeling*
- *What controls the temperature of the equatorial cold tongue?*
- *Climate impacts: modeling with atmospheric GCMs*
- *A potential role for hurricanes in the early Pliocene climate?*
- *Implications for coupled modeling*
- *Implications for the onset of glacial cycles*

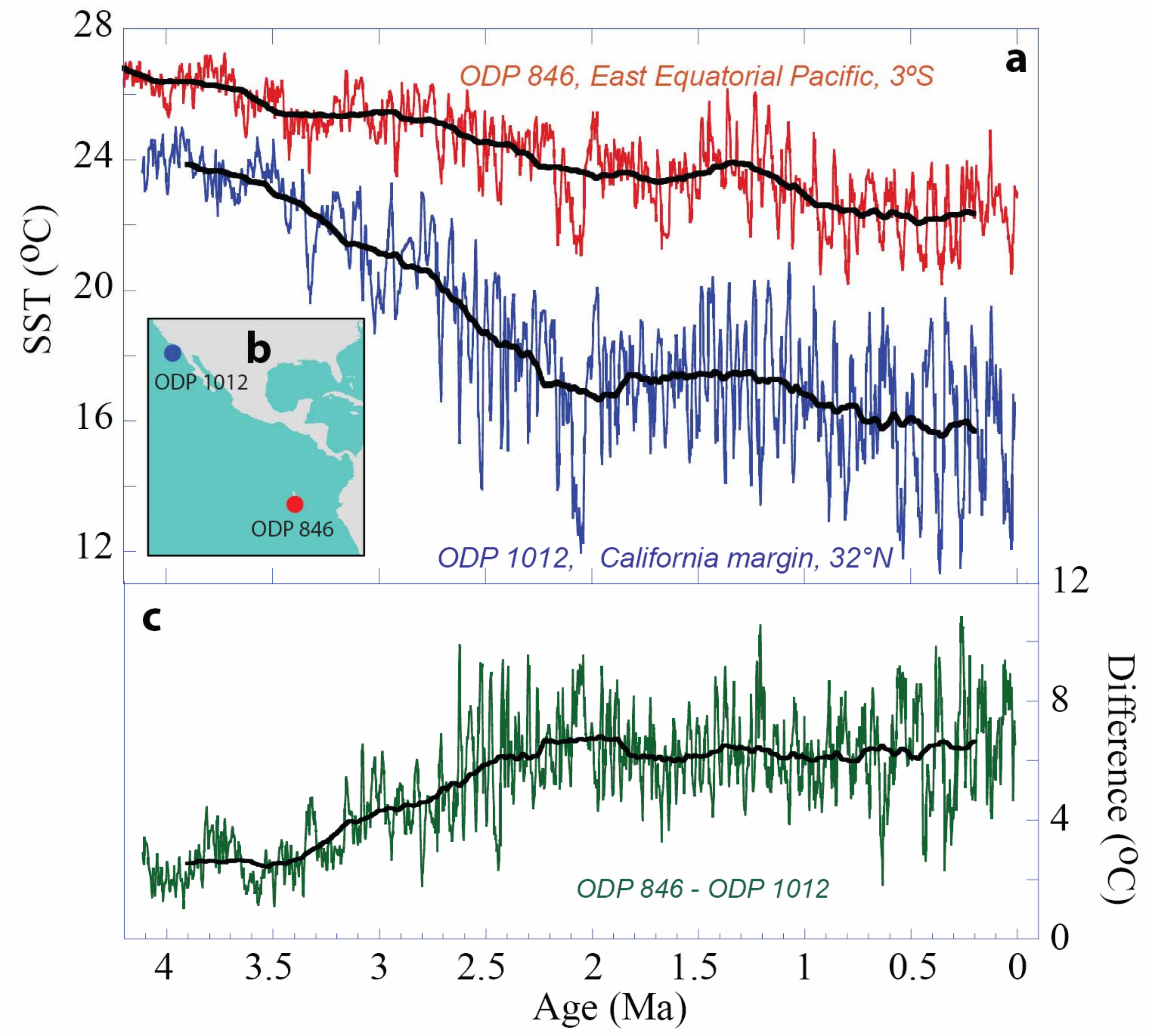




Fedorov, Dekens, McCarthy, Ravelo, Barreiro, Pacanowski, Philander, deMenocal, Science 2006

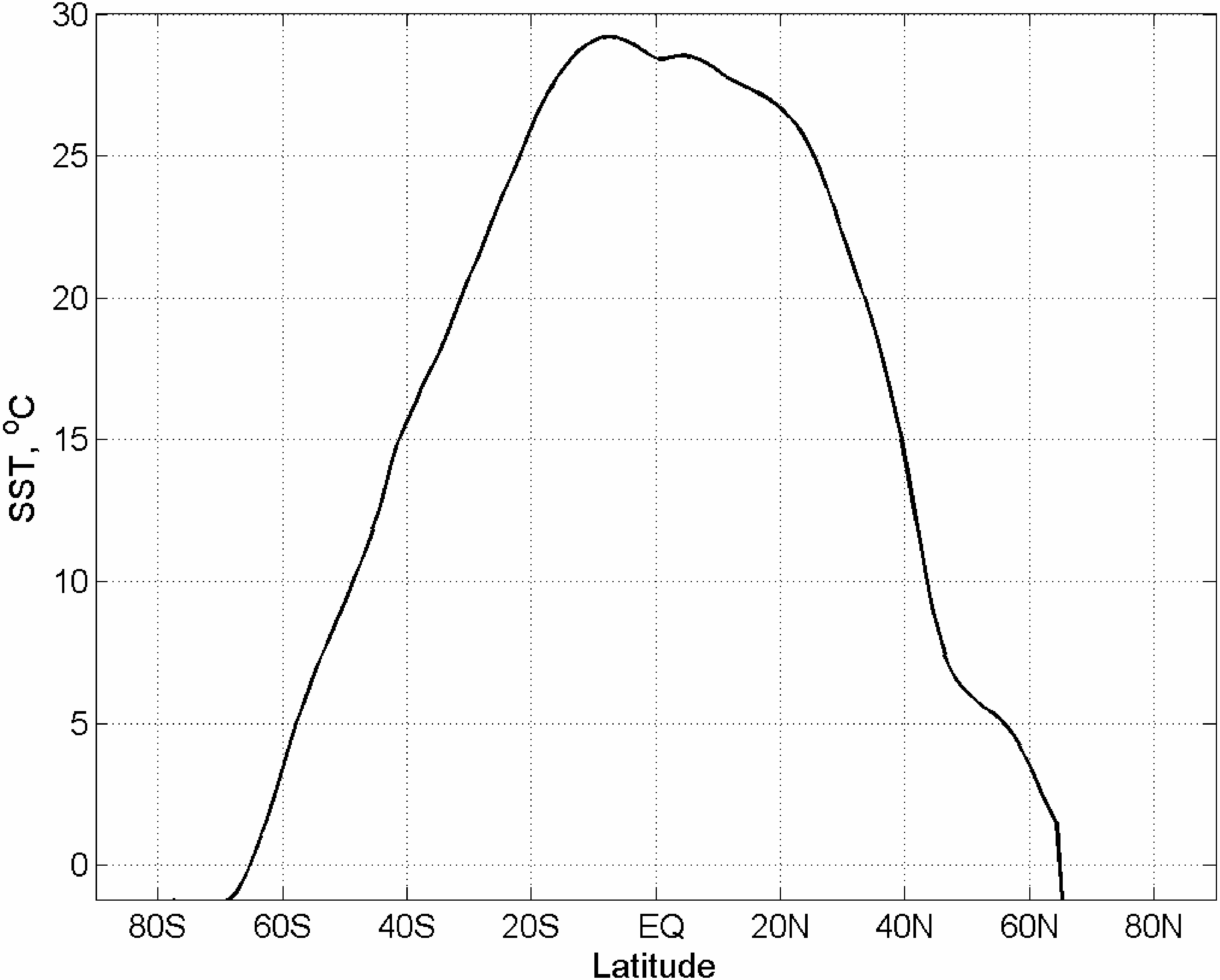


After McPhaden 1998



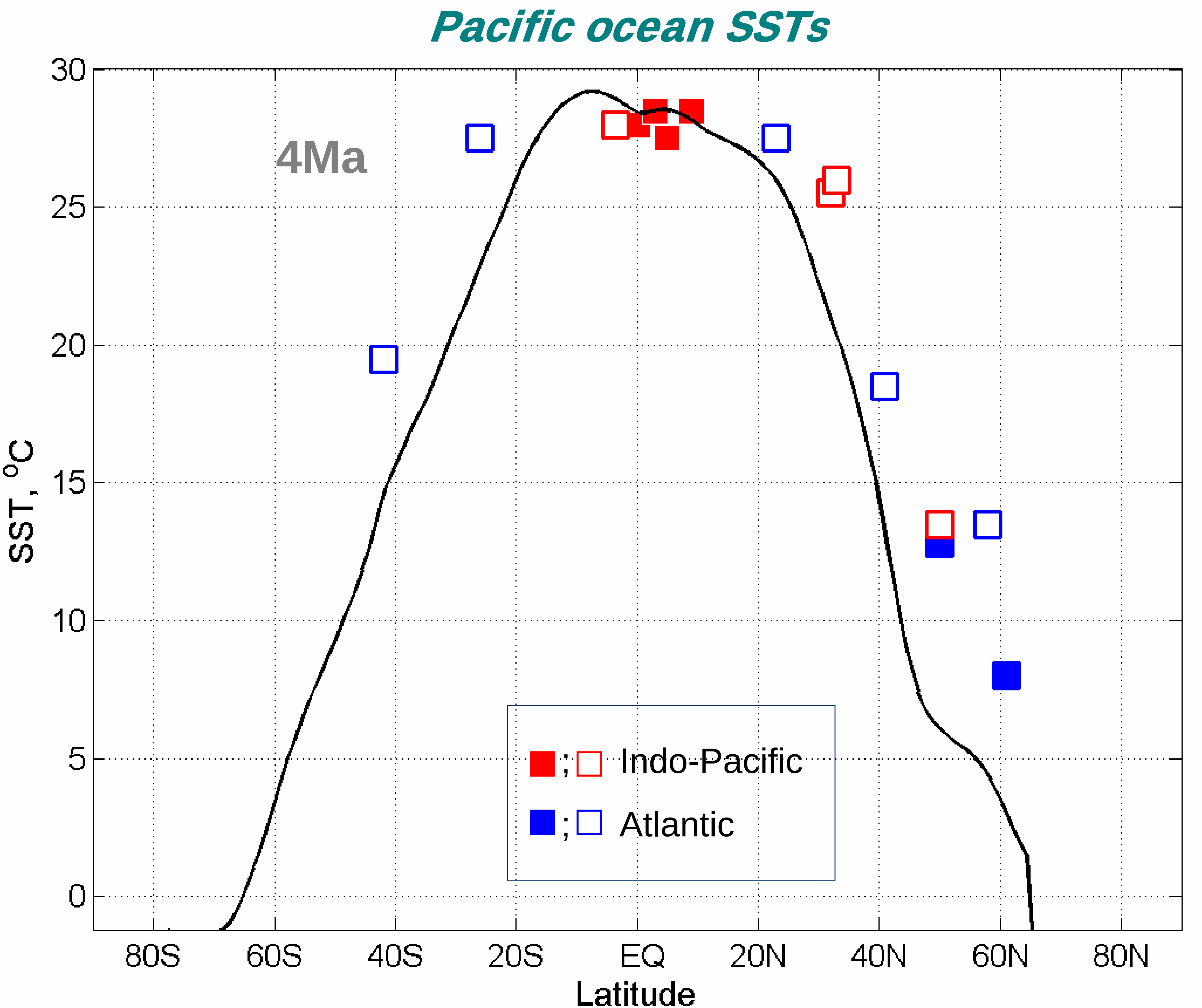
Brierley, Fedorov, Liu, Herbert, Lawrence, LaRiviere 2008, submitted

Pacific ocean SSTs

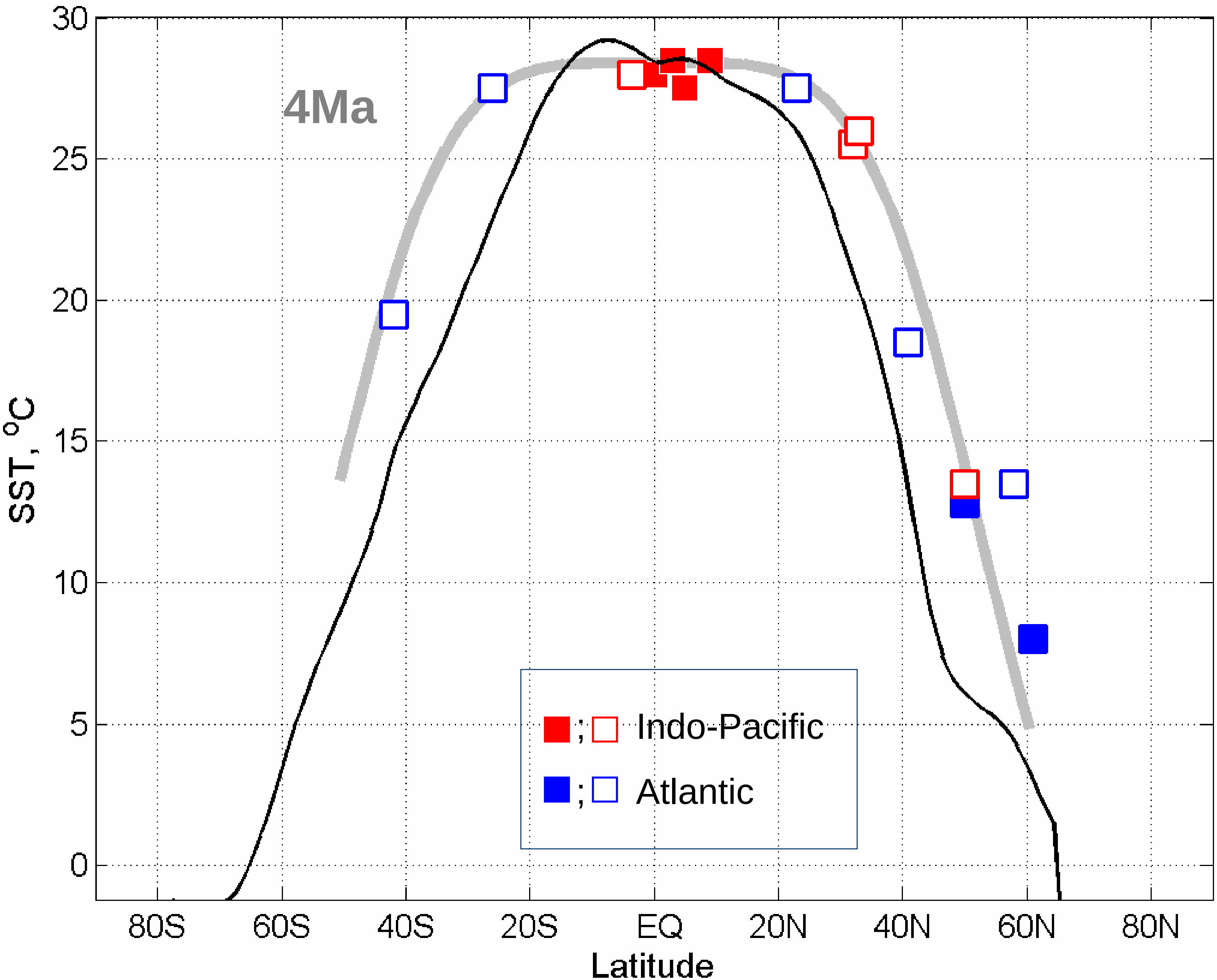


New Data Available in past few years

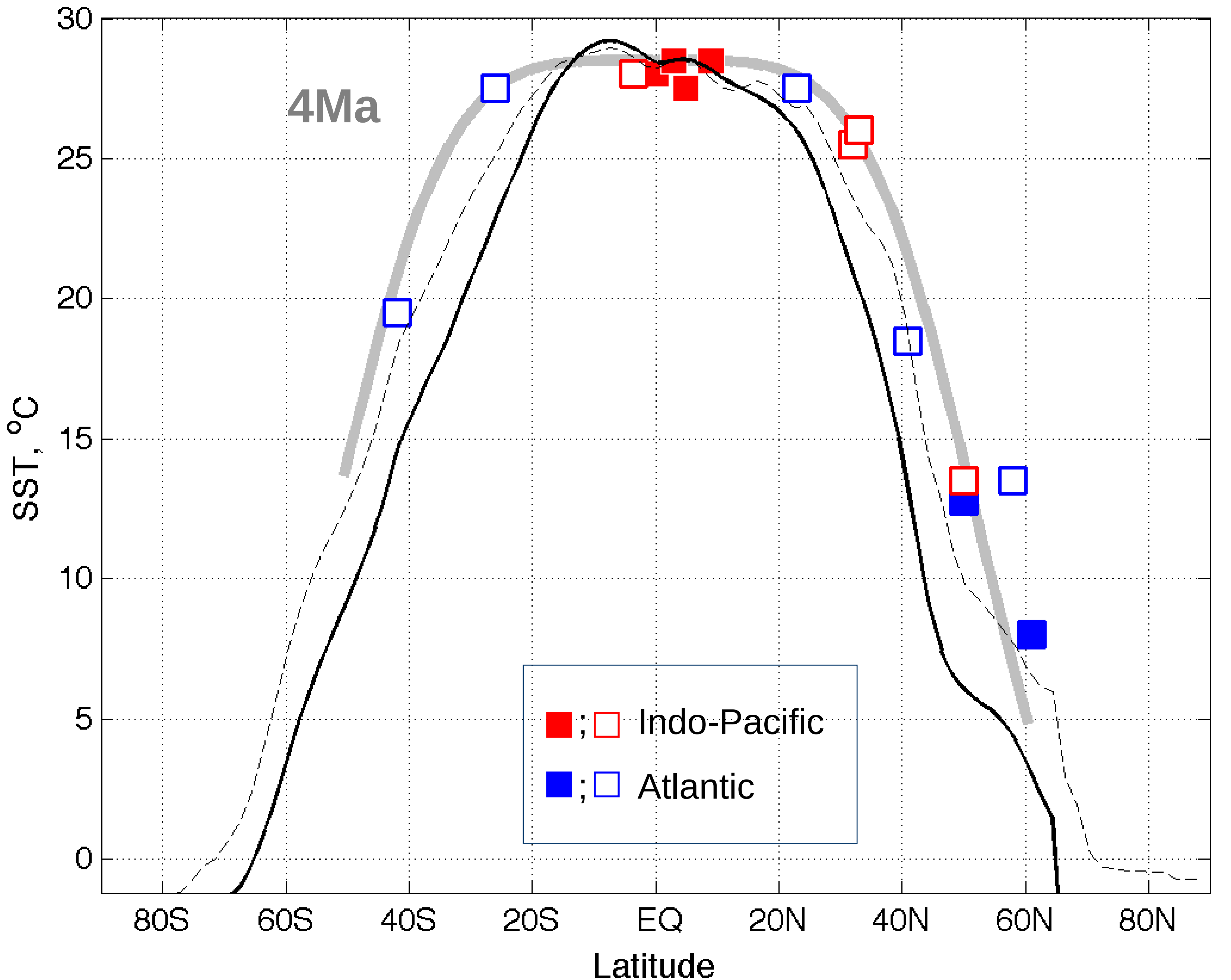
Reference	Method used	Site	Location	Latit.
Herbert and Schuffert 1998	Alkenones	ODP 958A	North-West African margin	23^{o}N
This study/ Lawrence et al	Alkenones	DSDP 607	Mid- North Atlantic	41^{o}N
Bartoli et al. 2005	Mg/Ca	DSDP 609	Northern Atlantic	50^{o}N
This study/ Lawrence	Alkenones	ODP 982	Northern Atlantic	58^{o}N
Bartoli et al. 2005	Mg/Ca	ODP 984	Northern Atlantic	61^{o}N
Marlow et al. 2001	Alkenones	ODP 1084	South-West African margin	26^{o}S
This study/ Lawrence et al	Alkenones	ODP 1090	Southern Atlantic	42^{o}S
Fedorov et al. 2006	Alkenones	ODP 847	Eastern Equatorial Pacific	0^{o}
Wara et al. 2005	Mg/Ca	ODP 847	Eastern Equatorial Pacific	0^{o}
Wara et al. 2005	Mg/Ca	ODP 806	Western Equatorial Pacific	0^{o}
Lawrence et al. 2006	Aleknones	ODP 846	Eastern Equatorial Pacific	3^{o}S
Groeneveld et al. 2006	Mg/Ca	ODP 1241	Eastern Equatorial Pacific	3^{o}N
Tian et al. 2006	Mg/Ca	ODP 1143	South China Sea	9^{o}N
This study/ Zhonghui et al	Alkenones	ODP 1012	California margin	32^{o}N
Fedorov et al 2006, Dekens et al 2007	Alkenones	ODP 1014	California margin	33^{o}N
Haug et al. 2005	Alkenones	ODP 882	Northern Pacific	50^{o}N
Dekens 2007	Mg/Ca	ODP 758	Indian Ocean	5^{o}N


Pacific ocean SSTs
4Ma
SST, °C
Latitude
30
25
20
15
10
5
0
80S
60S
40S
20S
EQ
20N
40N
60N
80N
; Indo-Pacific
; Atlantic

Pacific ocean SSTs



Pacific ocean SSTs



Pacific (4Ma):

Zonal temperature gradient (between the East and West Pacific):

Present: $\Delta T \sim 6^{o}C$
Pliocene (~4Ma): $\Delta T < 1^{o}C$ - permanent El Niño!

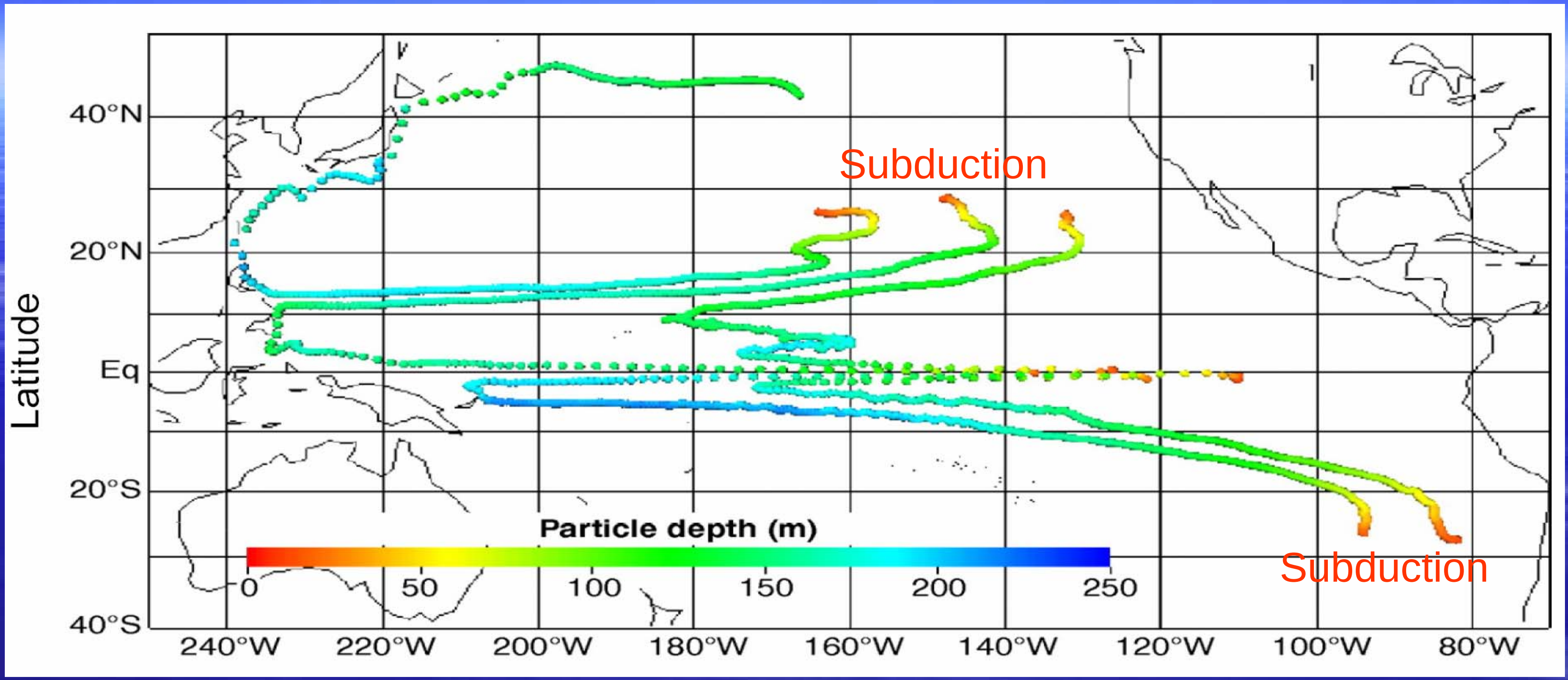
Meridional temperature gradient (between 0^{o} and 30^{o}N/S):

Present: $\Delta T \sim 10^{o}C$
Pliocene: $\Delta T \sim 2^{o}C$ - meridional expansion of the warm pool!

All of these with CO_2 at 350-400ppm!

Mechanisms for sustaining a Permanent El Niño: Results from ocean modeling

Wind-Driven Circulation:

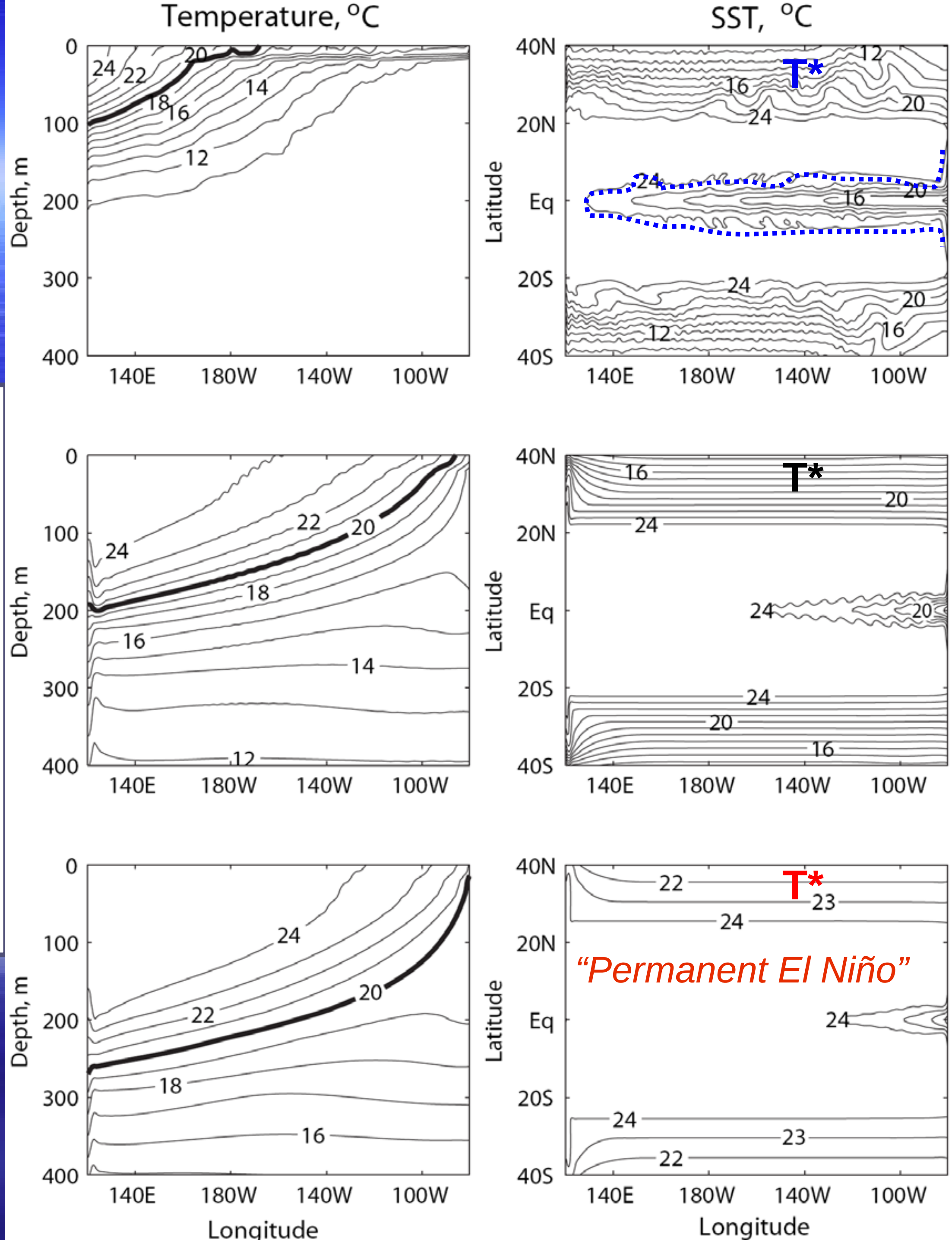


Trajectories of water parcels (after Harper 2000). After subduction induced by Ekman pumping some water parcels join the subtropical gyre; other parcels travel towards the equator (wind-driven overturning, or the shallow Subtropical Cell - STC).

Calculations with idealized ocean GCM:

Temperature along the equator and SSTs (ºC)

when anomalously warm / cold temperatures (T*) are imposed in the extra-tropical Pacific.



T*=10ºC

Colder Extra-tropics

T*=15ºC

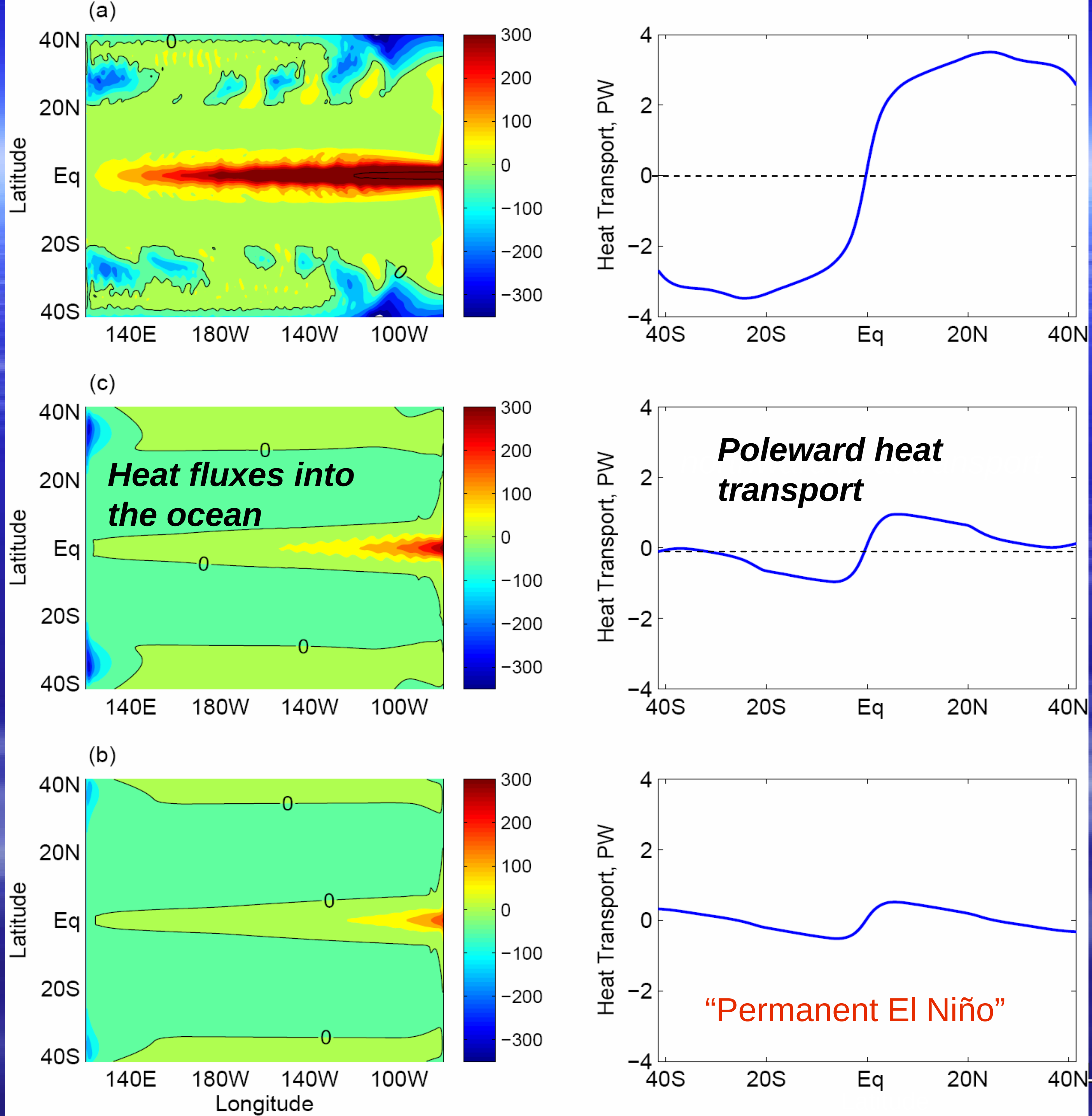
Standard case

T*=20ºC

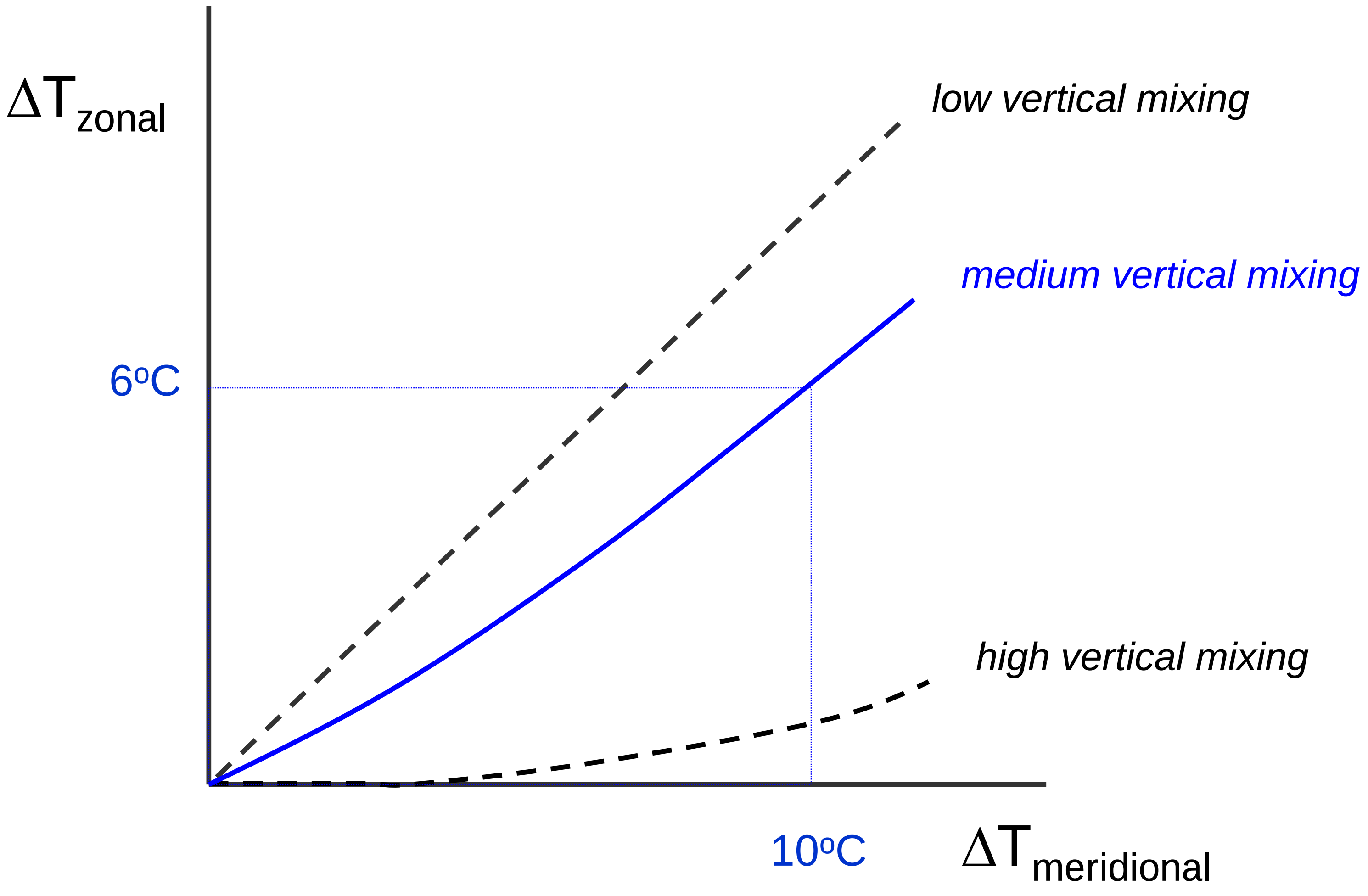
Warmer extra-tropics

From the point of view of the ocean:

A permanent El Niño implies a reduced poleward heat transport by the ocean



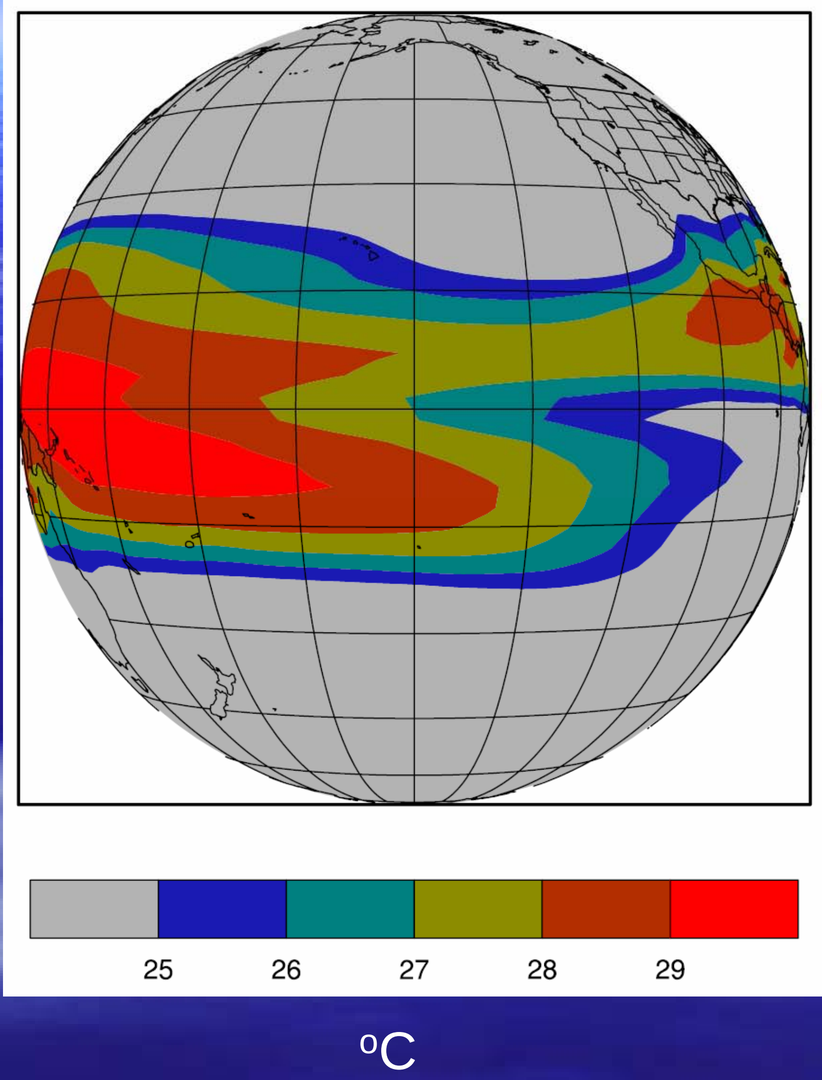
The dependence of zonal SST gradient on the meridional SST gradient

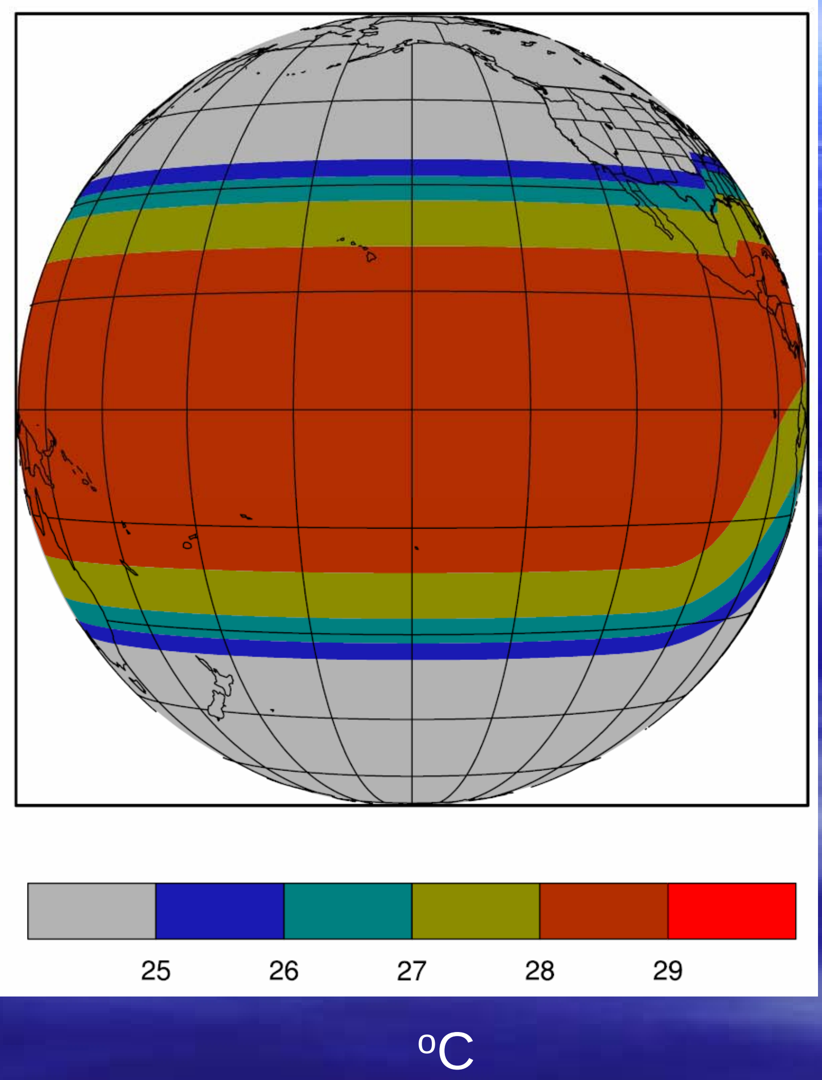


Climate impacts: modeling with atmospheric GCMs

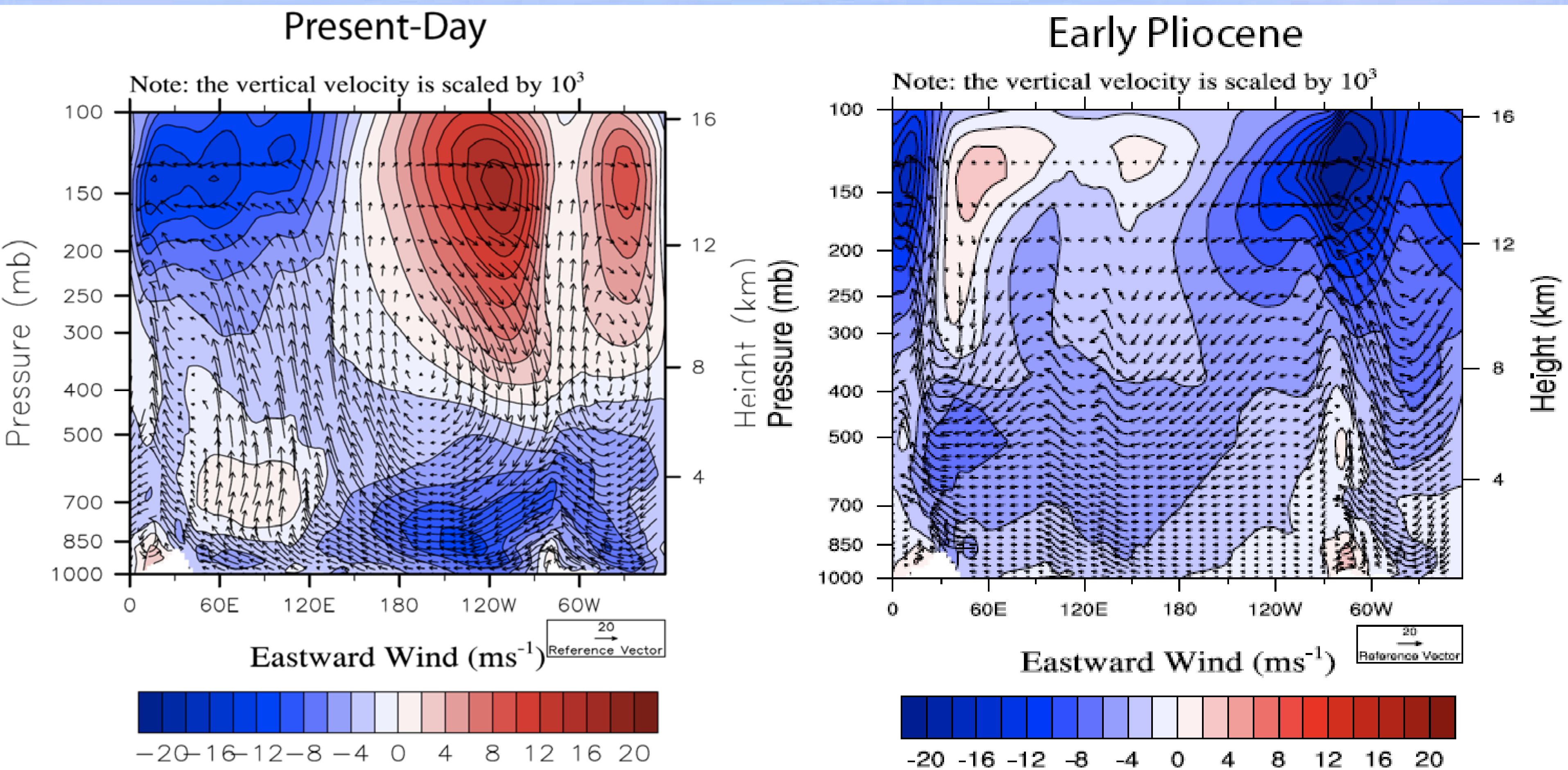
Tropical warm pool (observations)

Hypothetical warm pool in the early Pliocene (~4Ma)



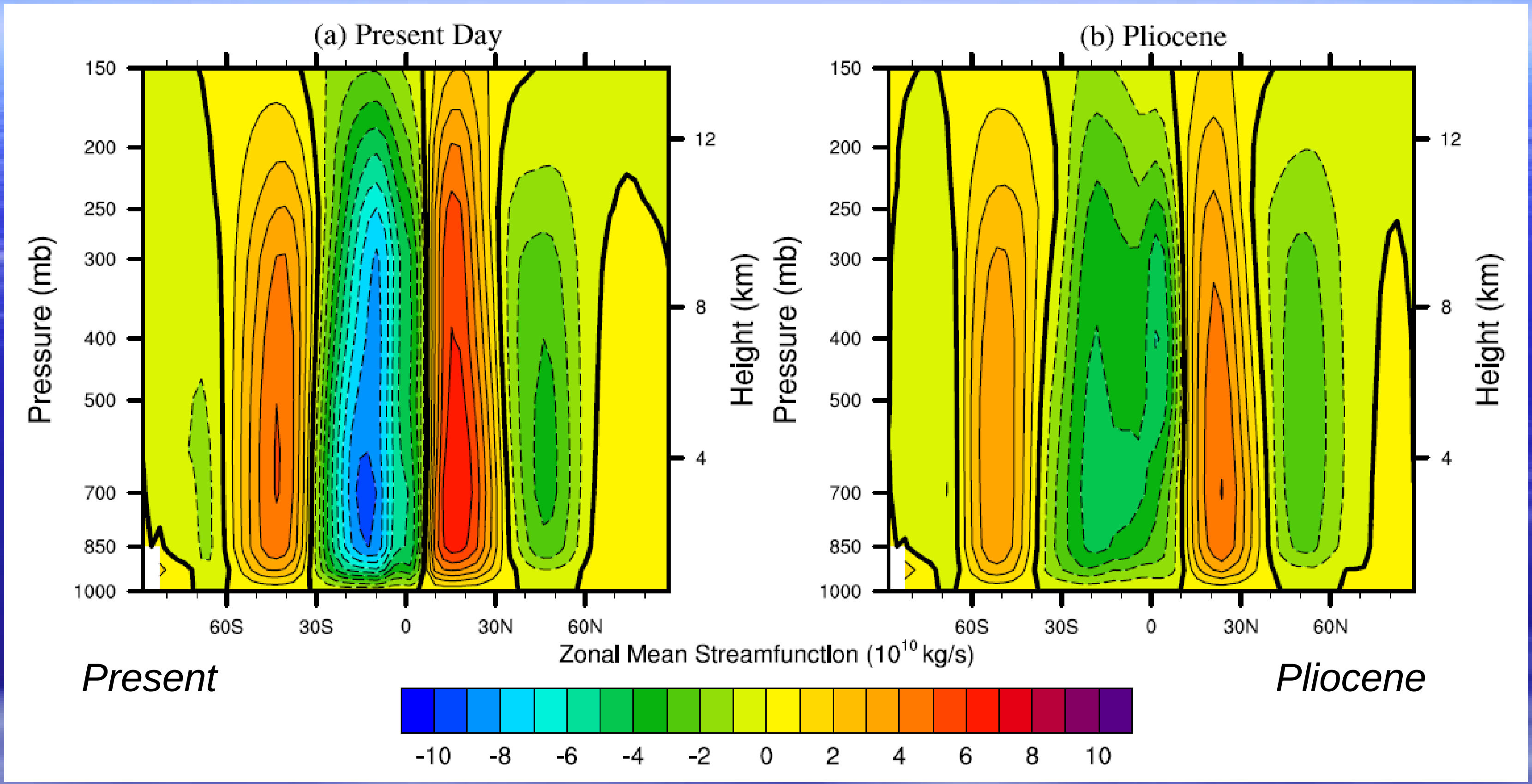


Calculations with an atmospheric GCM:

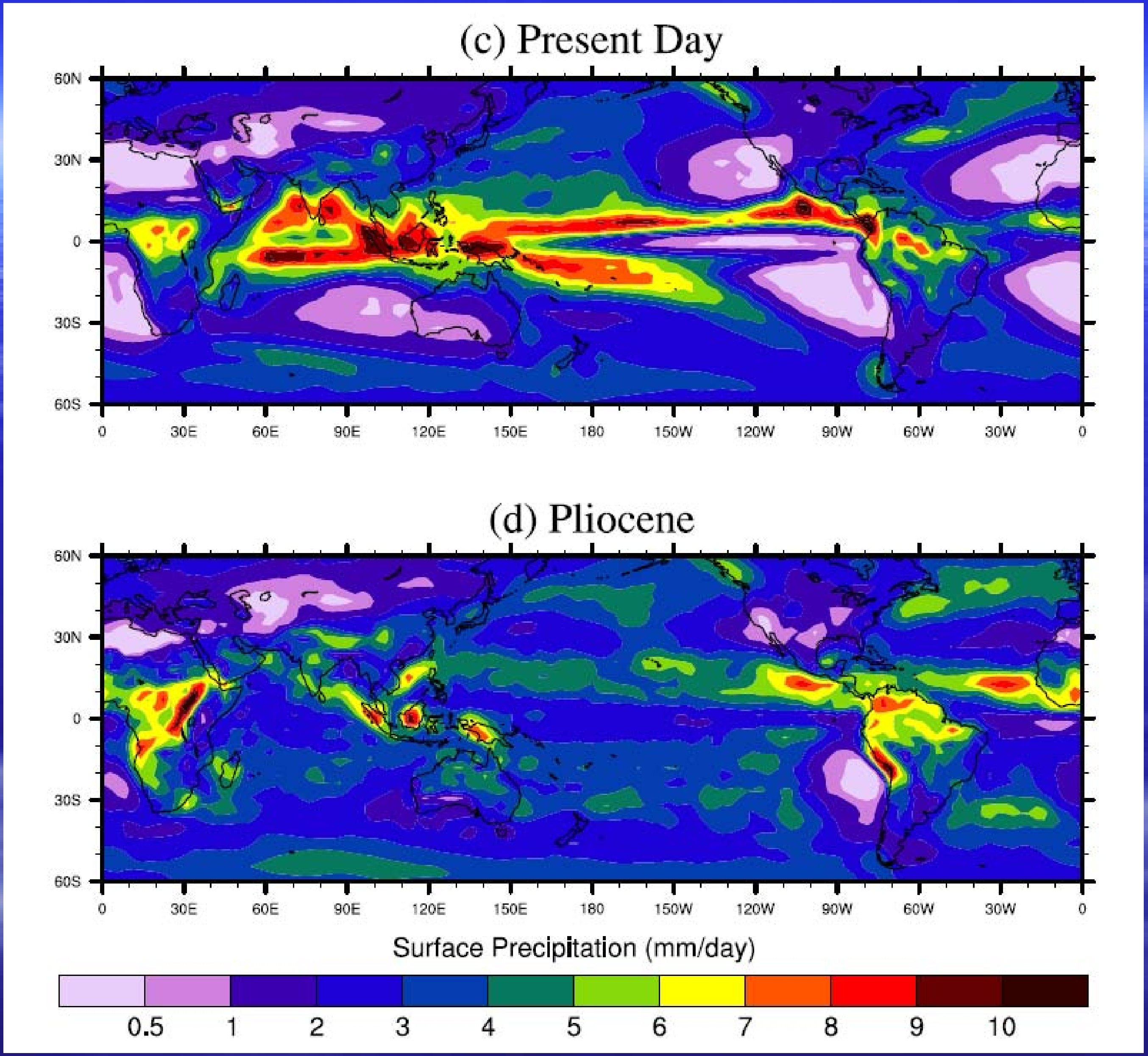


Atmospheric circulation along the equator -
the collapse of the Walker circulation

Calculations with an atmospheric GCM:

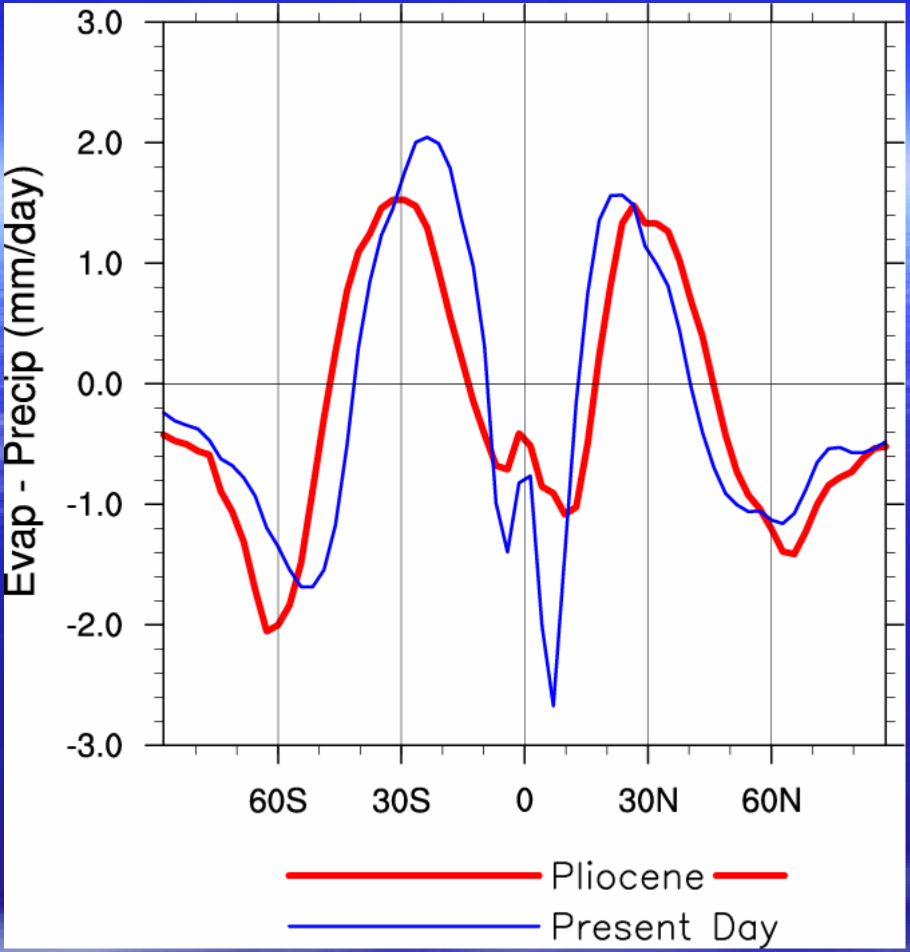


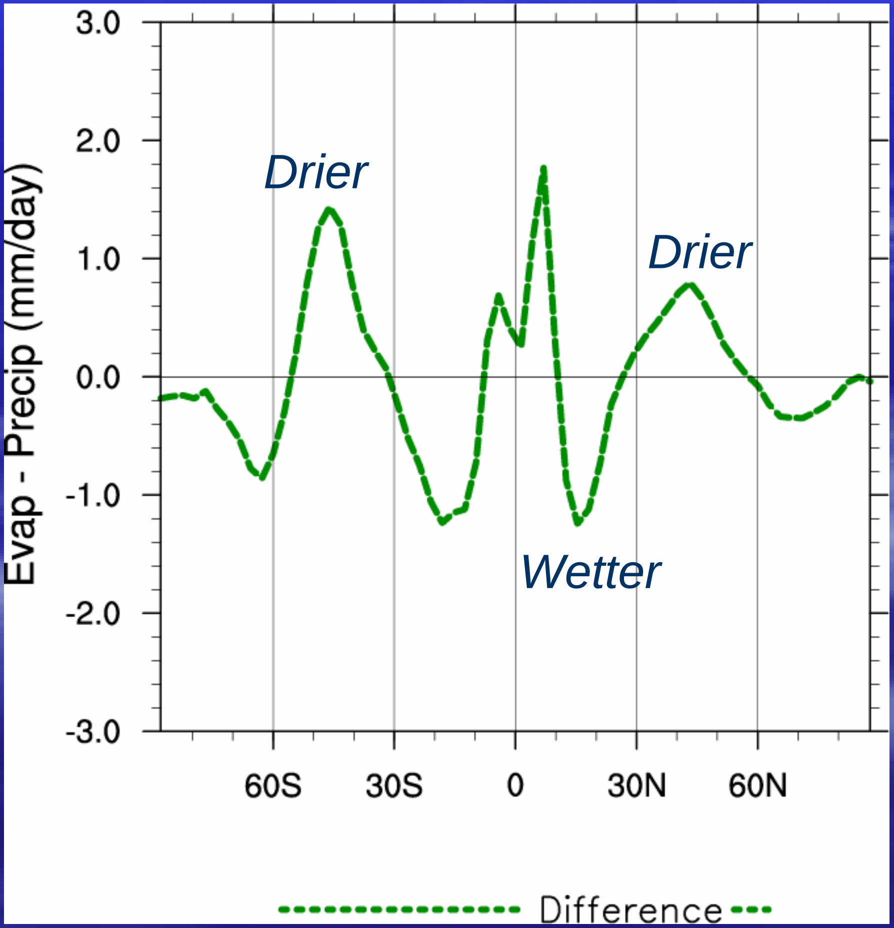
Overturning streamfunction for the present-day simulation (left) and the early Pliocene (right) showing weaker Hadley circulation in the Pliocene

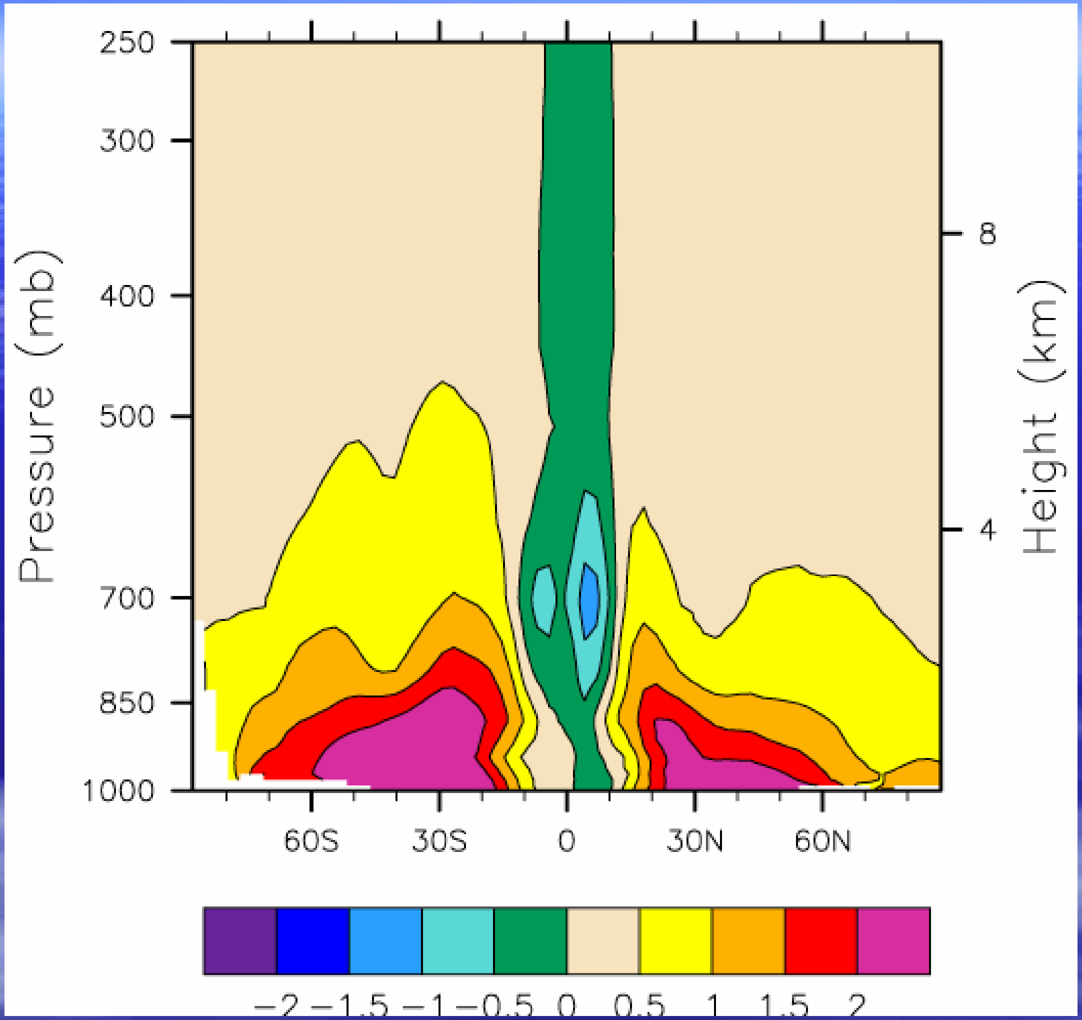


Precipitation: present-day (top) and the Pliocene (bottom)

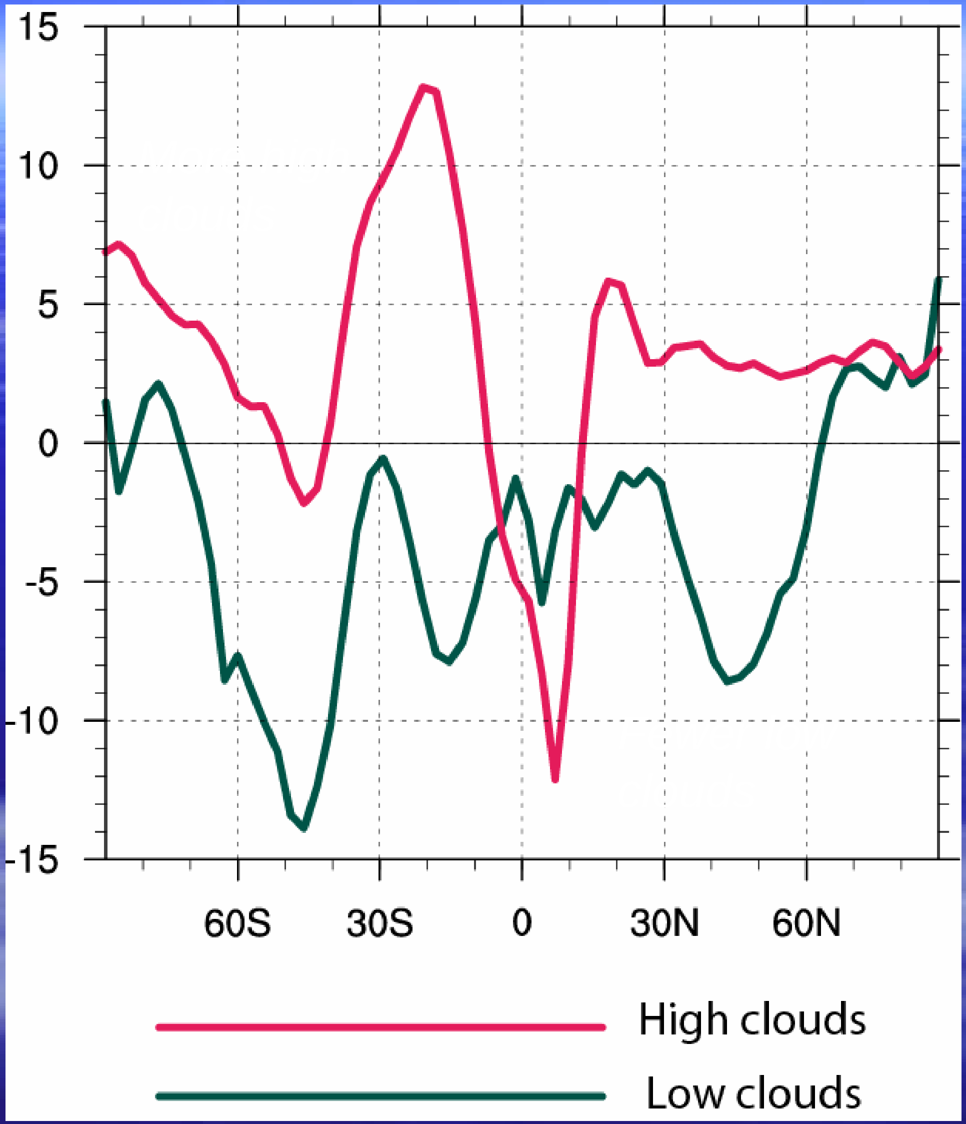
Changes in E-P (Pliocene – present)







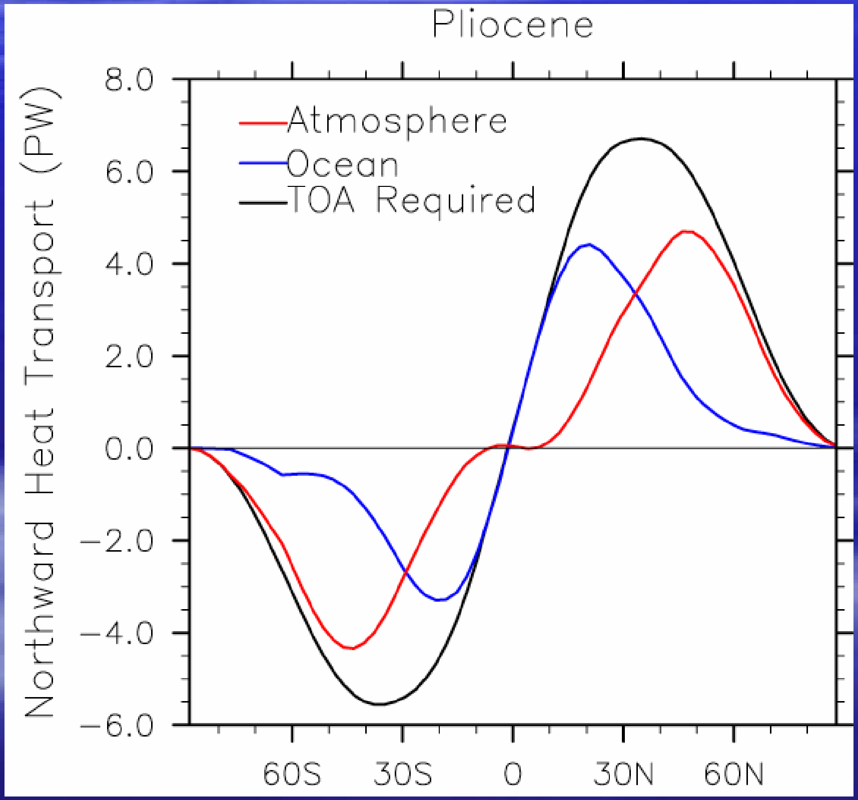
Changes in water vapor, g/kg (Pliocene – present)



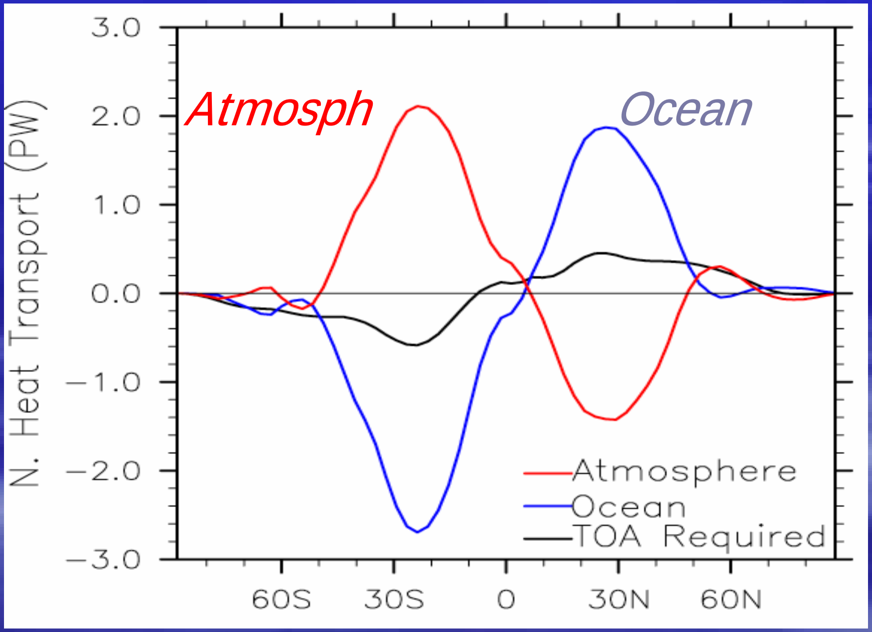
Changes in low and high clouds (Pliocene – present)

Implied northward heat transport by the ocean and the atmosphere (from atmospheric GCM)

Pliocene:

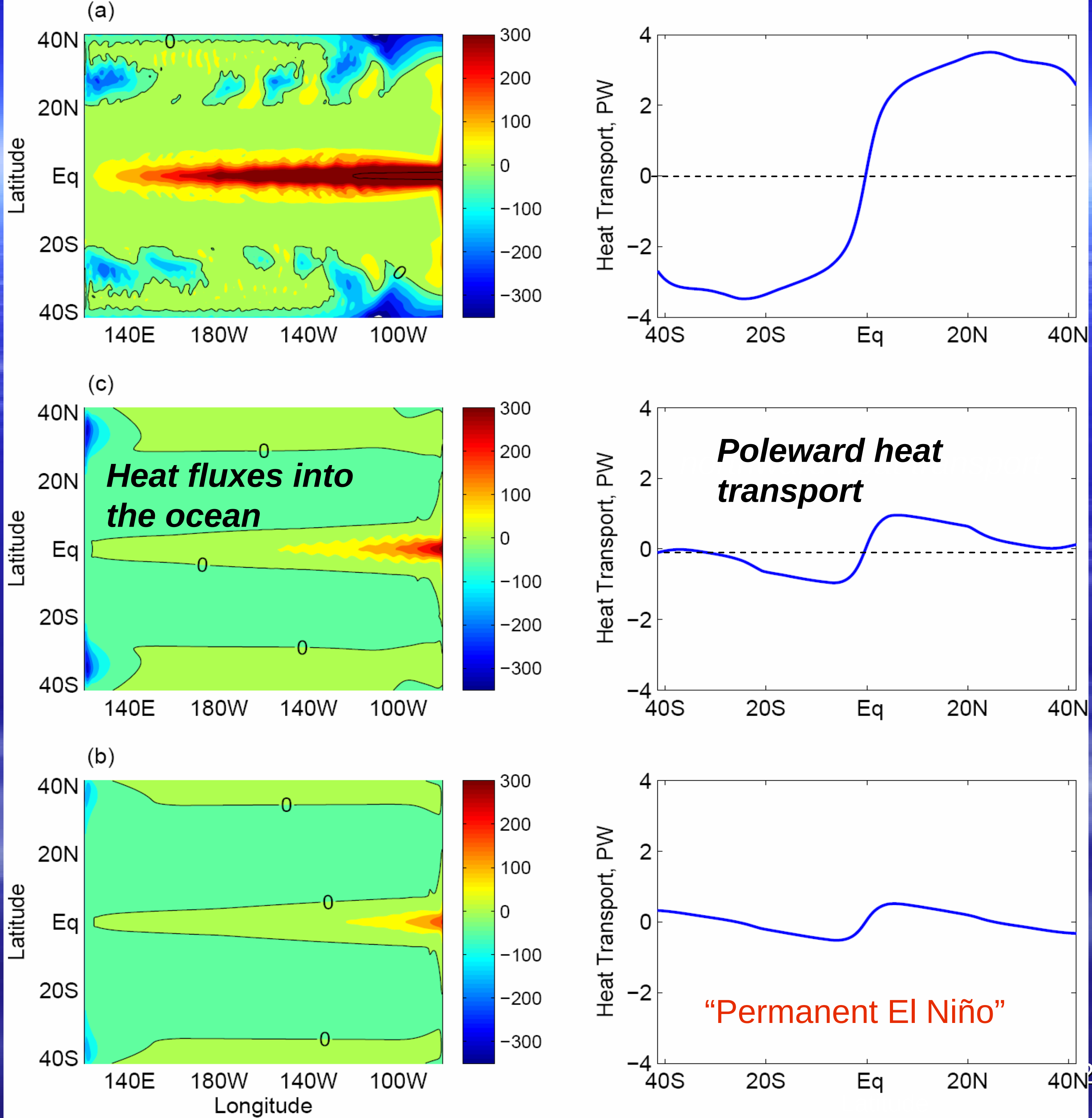


The difference (Pliocene - Present):



From the point of view of the ocean:

A permanent El Niño implies a reduced poleward heat transport by the ocean



The poleward heat transport paradox for the Pliocene tropical state:

(1) the atmosphere requires the ocean to increase its poleward heat transport (in an atmospheric GCM)

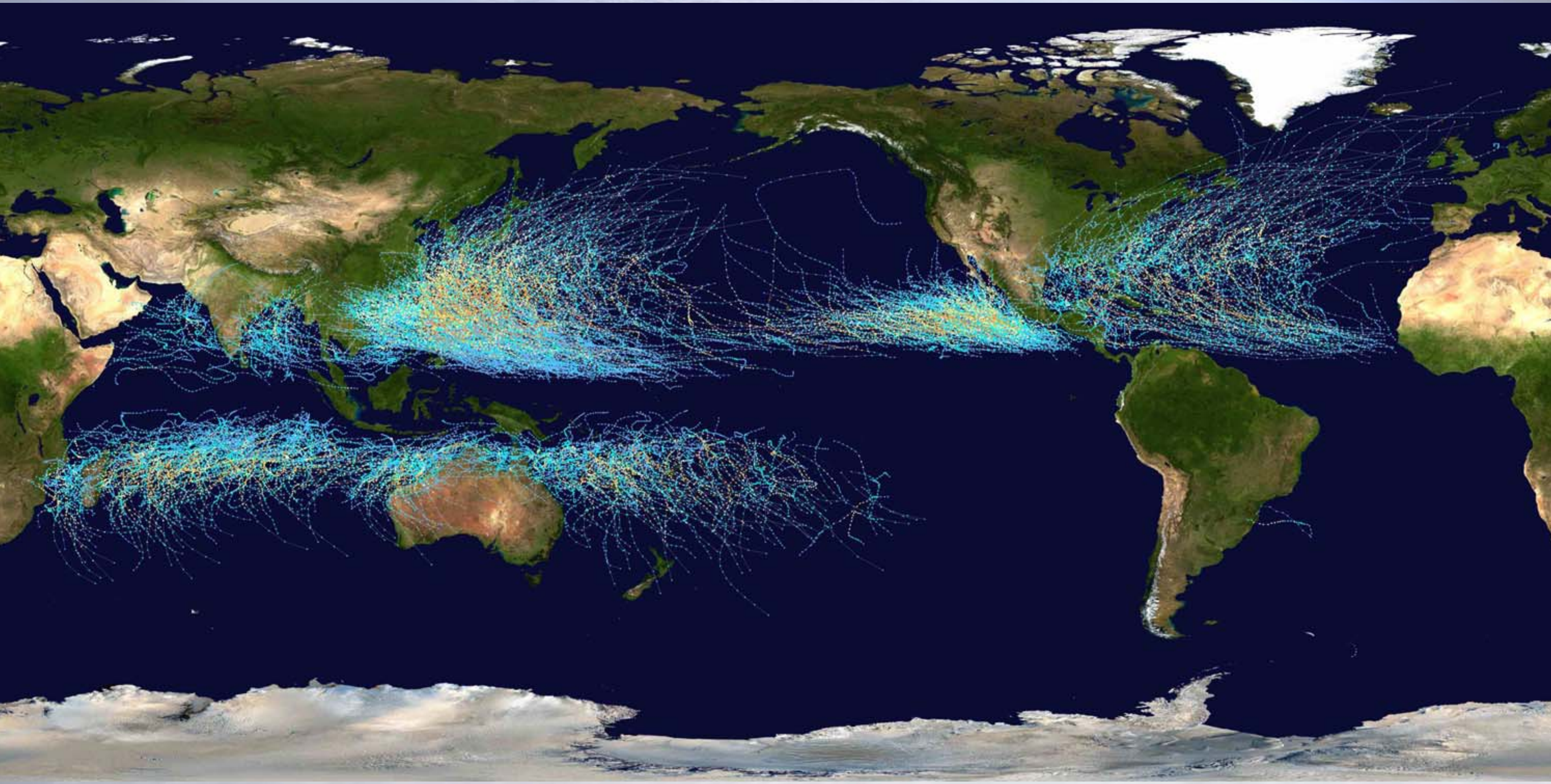
(2) the ocean needs to reduce its heat transport (in an ocean GCM)

(1) contradicts (2)

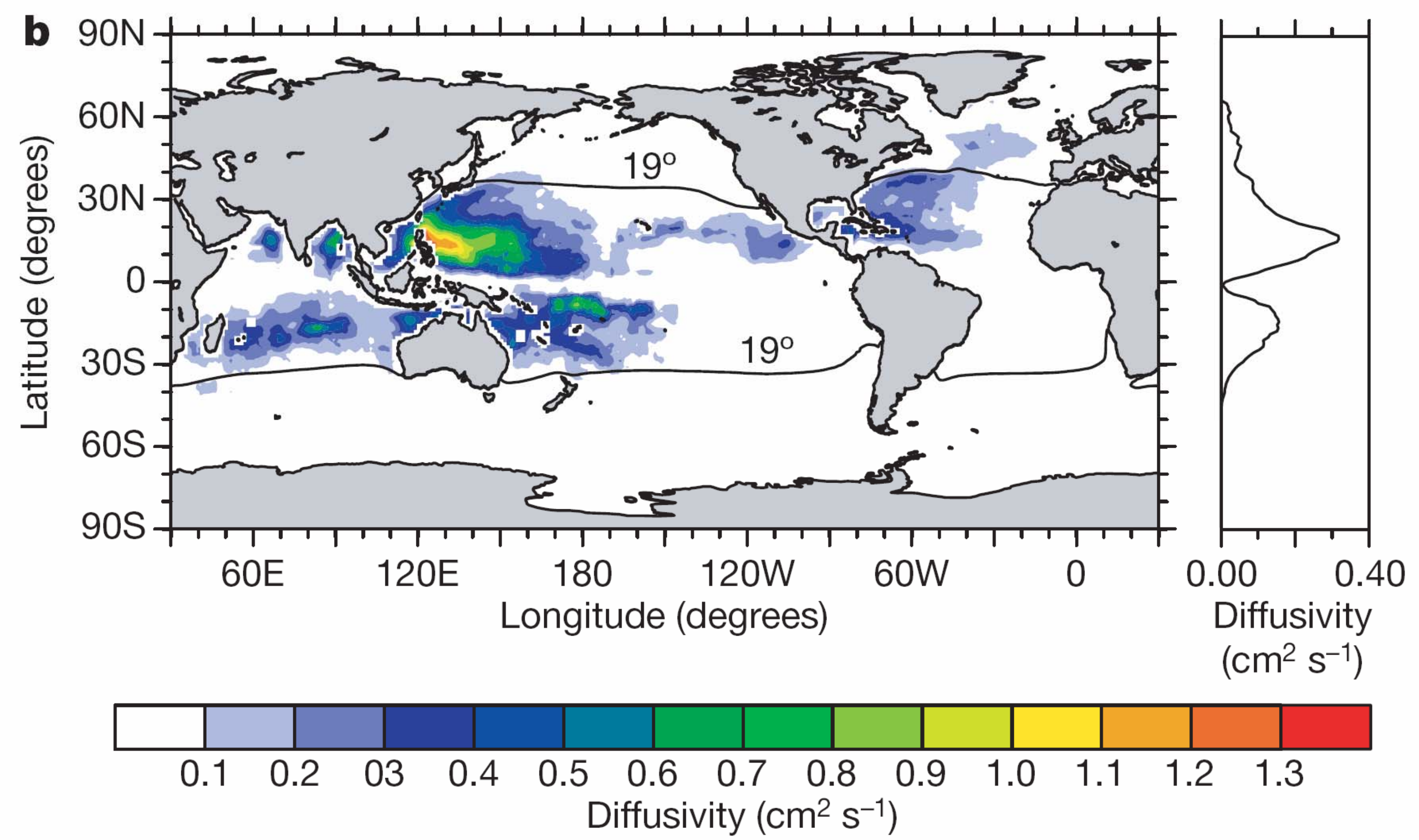
Thus, an additional mechanism is needed for transporting heat either by the ocean or the atmosphere or simply an increased heat uptake by the ocean. This mechanism is presumably absent in the current generation of coupled models.

Sustaining the Pliocene (and other equable) climate : Is there a role for hurricanes?

Tracks of all tropical cyclones, 1985-2005

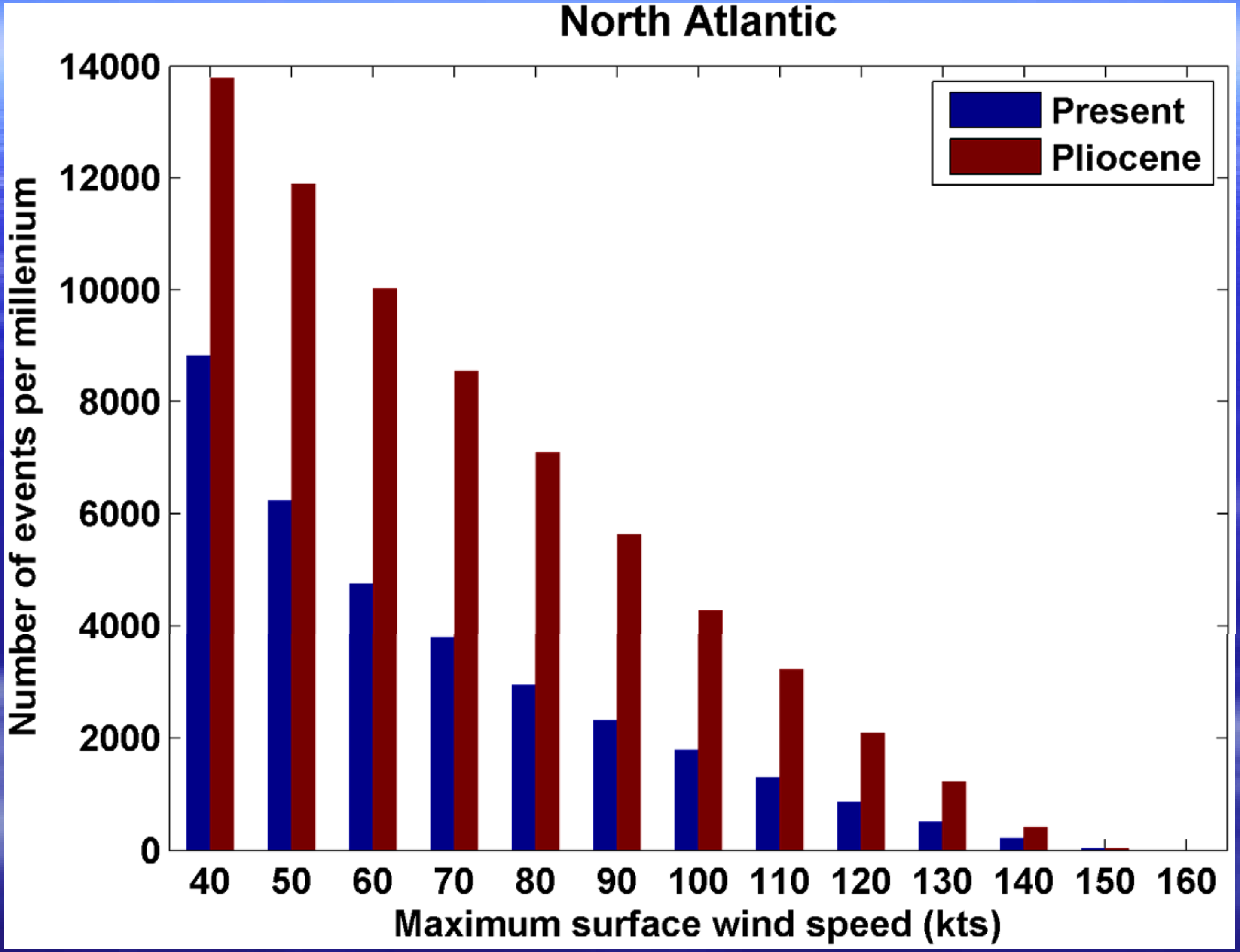


Source: Wikipedia

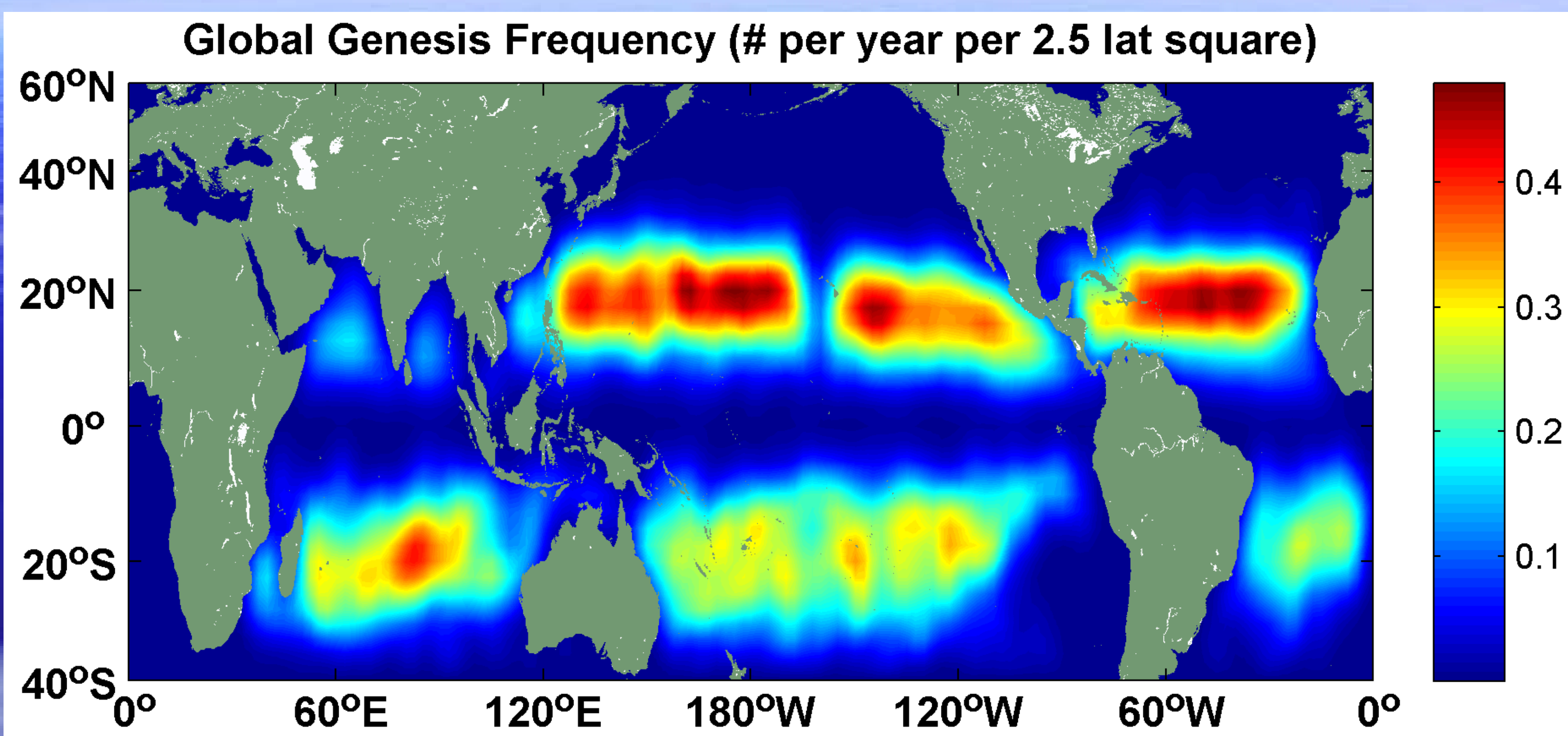


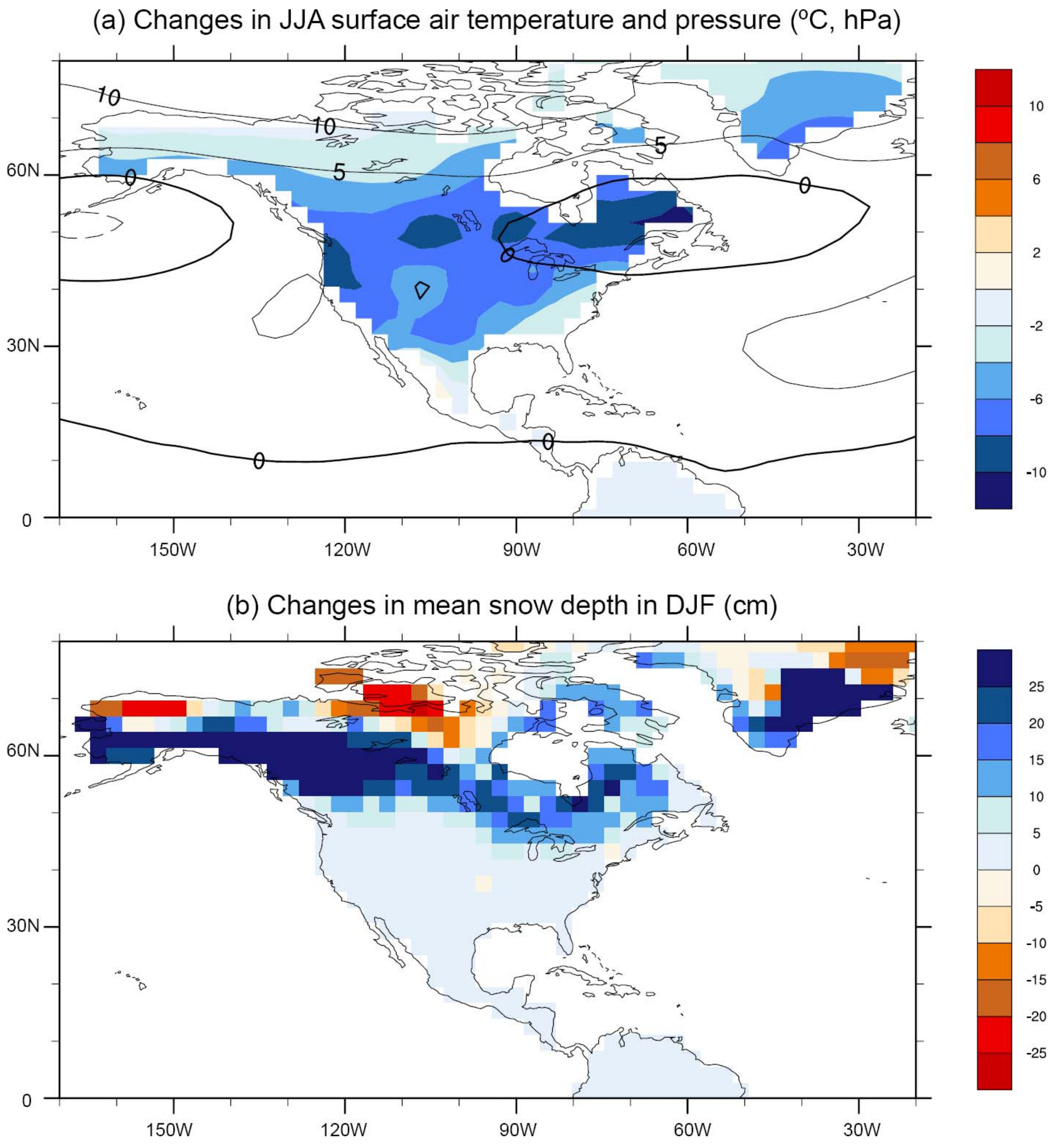
Annual average of vertical diffusivity attributable to cyclone mixing (Sriver and Huber 2007)

Statistical downscaling model



Pliocene Hurricanes - preliminary results with Kerry Emanuel and Chris Brierley


Global Genesis Frequency (# per year per 2.5 lat square)
60°N
40°N
20°N
0°
20°S
40°S
0°
60°E
120°E
180°W
120°W
60°W
0°
0.4
0.3
0.2
0.1



Meridional contraction of the warm pool between 4 and 2 Ma and its impacts on North America:

implications for the onset of Northern Hemisphere Glaciation

Summary:

If the proxy temperature data are correct:

- The early Pliocene (4Ma) is characterized by significantly reduced zonal (along the equator) and meridional (from the equator to the subtropics) SST gradients (for CO_2 concentrations ~ 350-400ppm)

- This implies a significant poleward expansion (50-100%) of the tropical warm pool concurrent with permanent El Niño-like conditions

- This has large climatic implications for the Hadley circulation, ITCZ, precipitation, clouds, water vapor, albedo, summer and winter temperatures and snow cover over North America

- To fully reproduce this climate state an additional mechanism for poleward heat transport/ heat uptake by the ocean is probably needed. This mechanism appear to be absent in the current generation of coupled GCMs