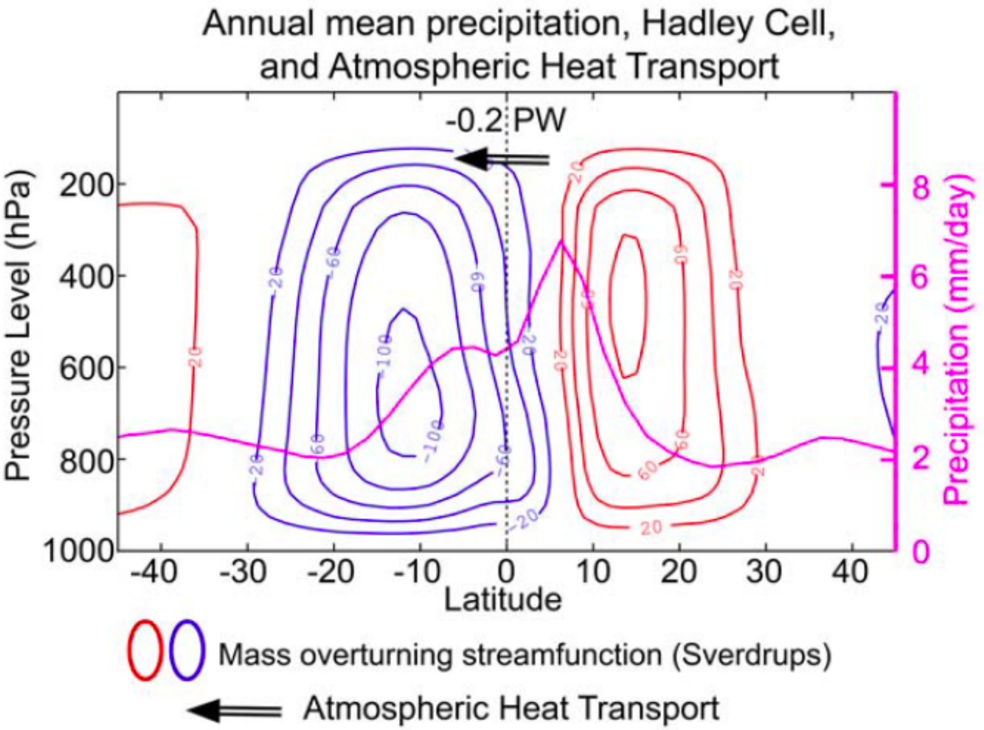
# Tracing tropical precipitation changes in past climates:

## From individual lake basins

## to the zonal mean




David McGee, MIT

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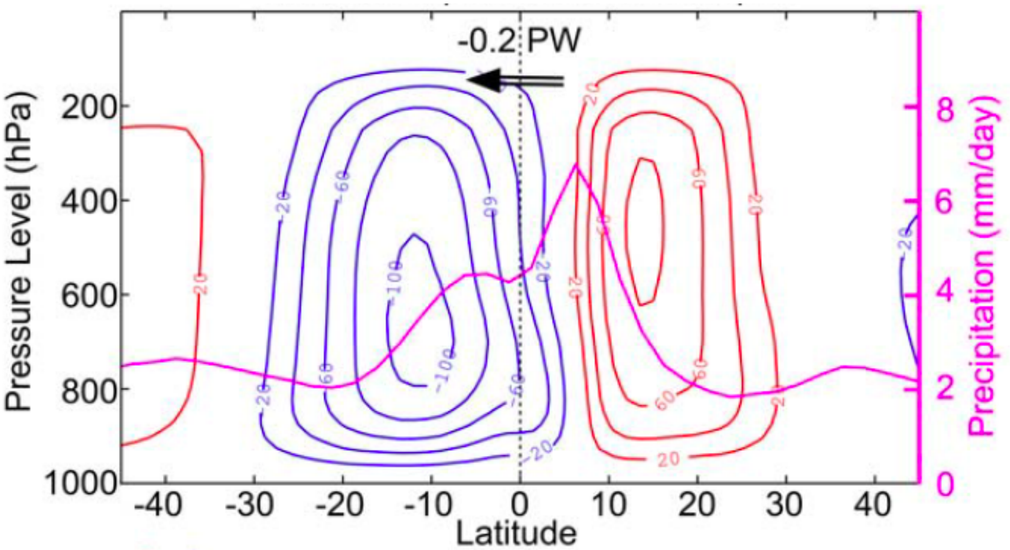
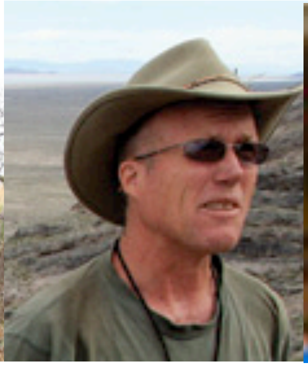


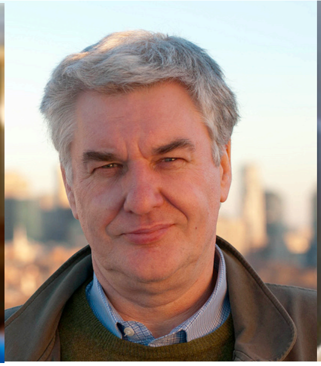

Elena Steponaitis

Christine Chen

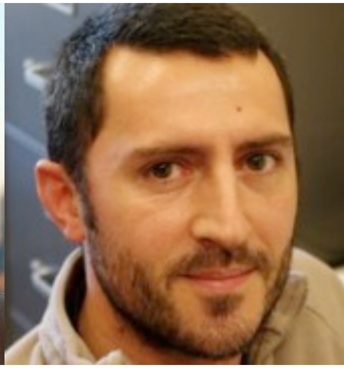


Jay Quade

Aaron Donohoe

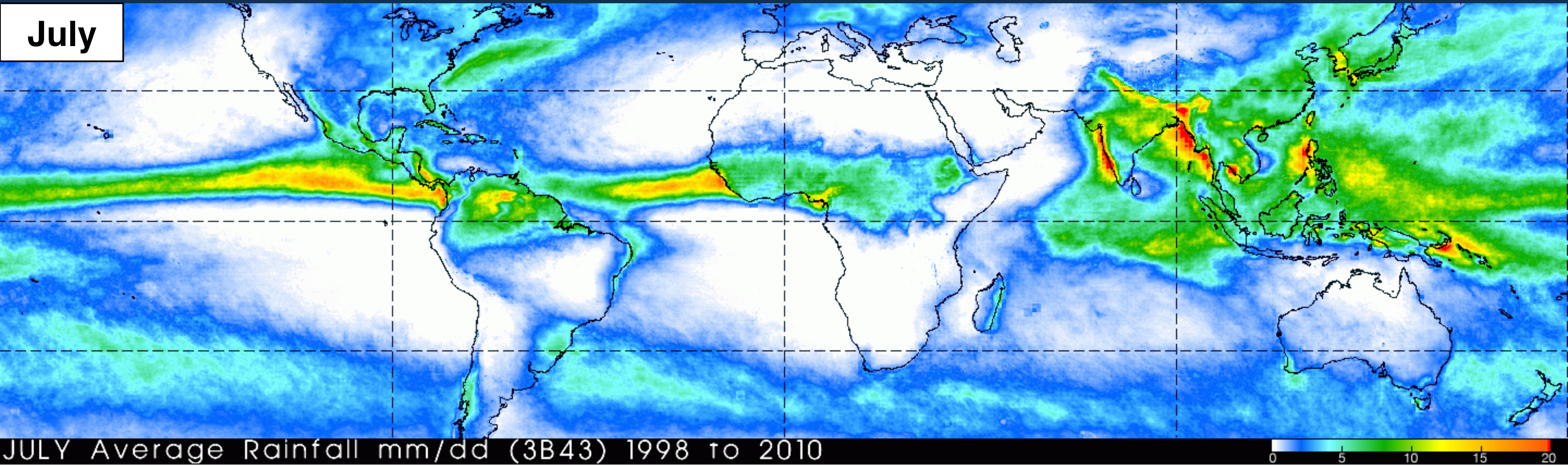


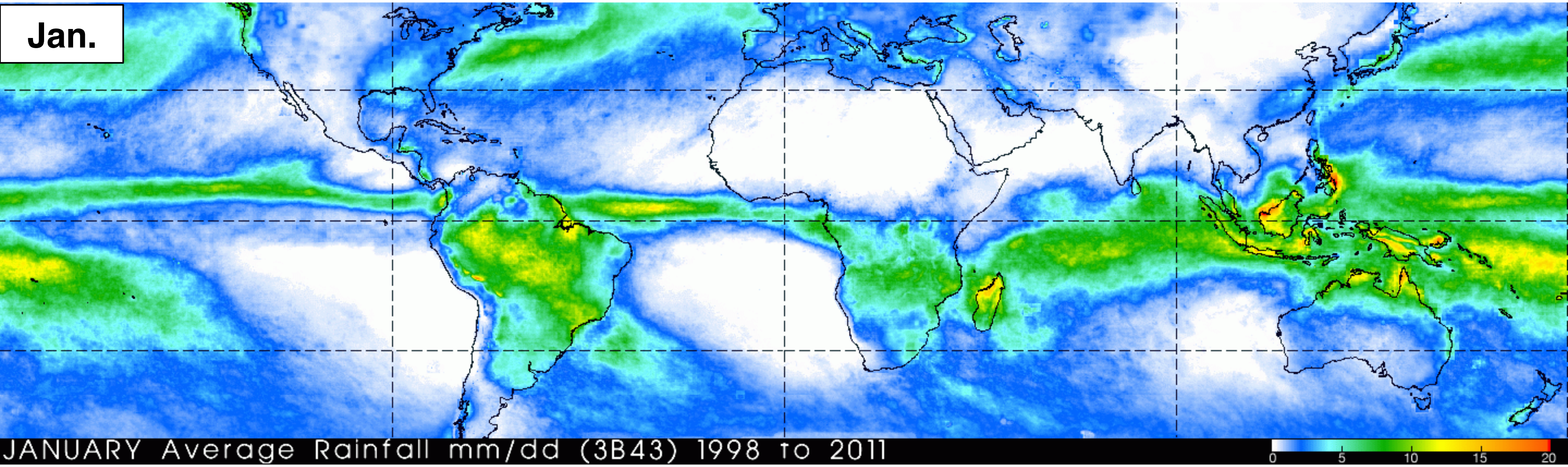
John Marshall



David Ferreira

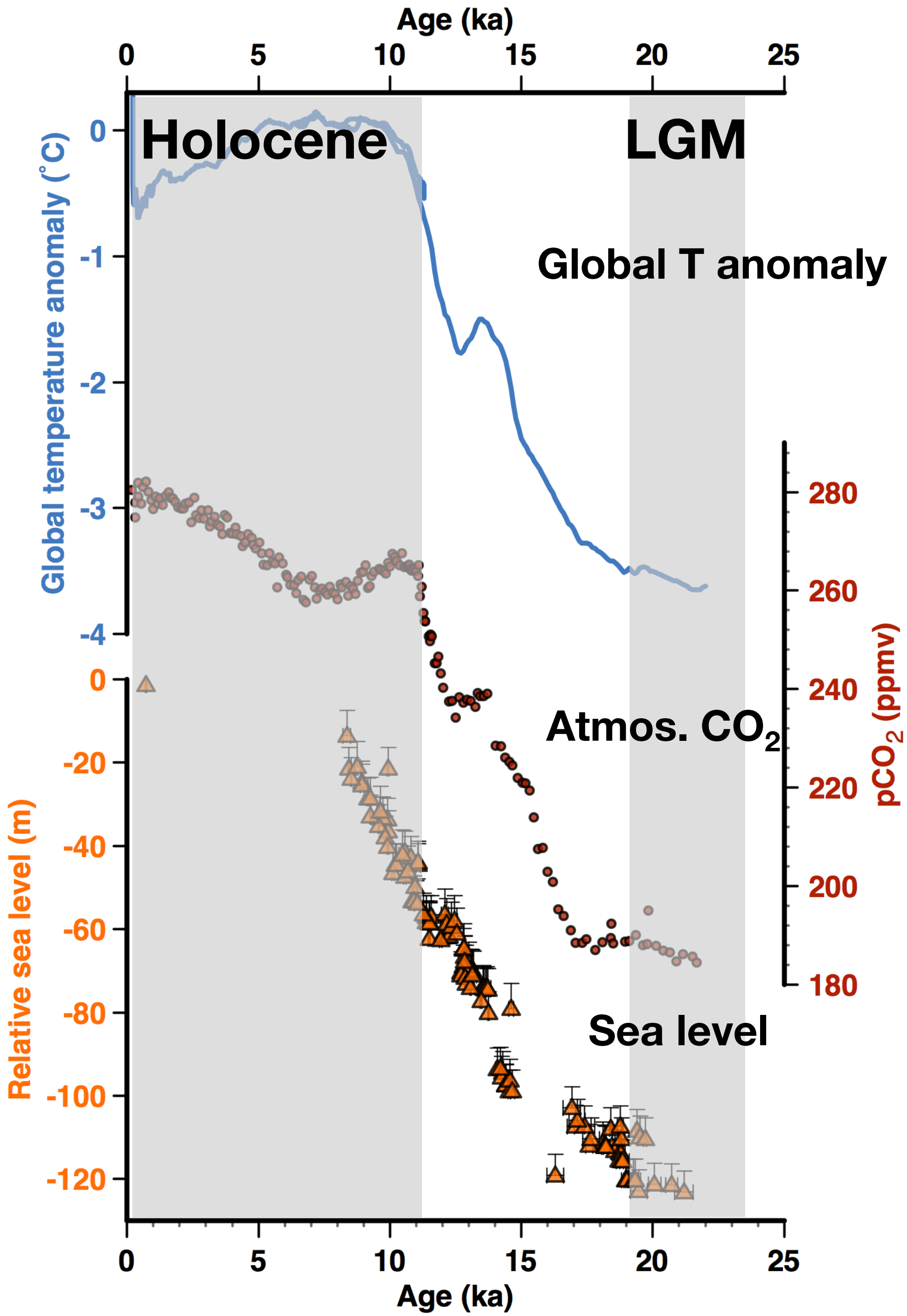
# Modern-day precipitation patterns from satellite observations




TRMM Avg. July and Jan precip., 1998-2010/11

# Climate change over the last 25 ka

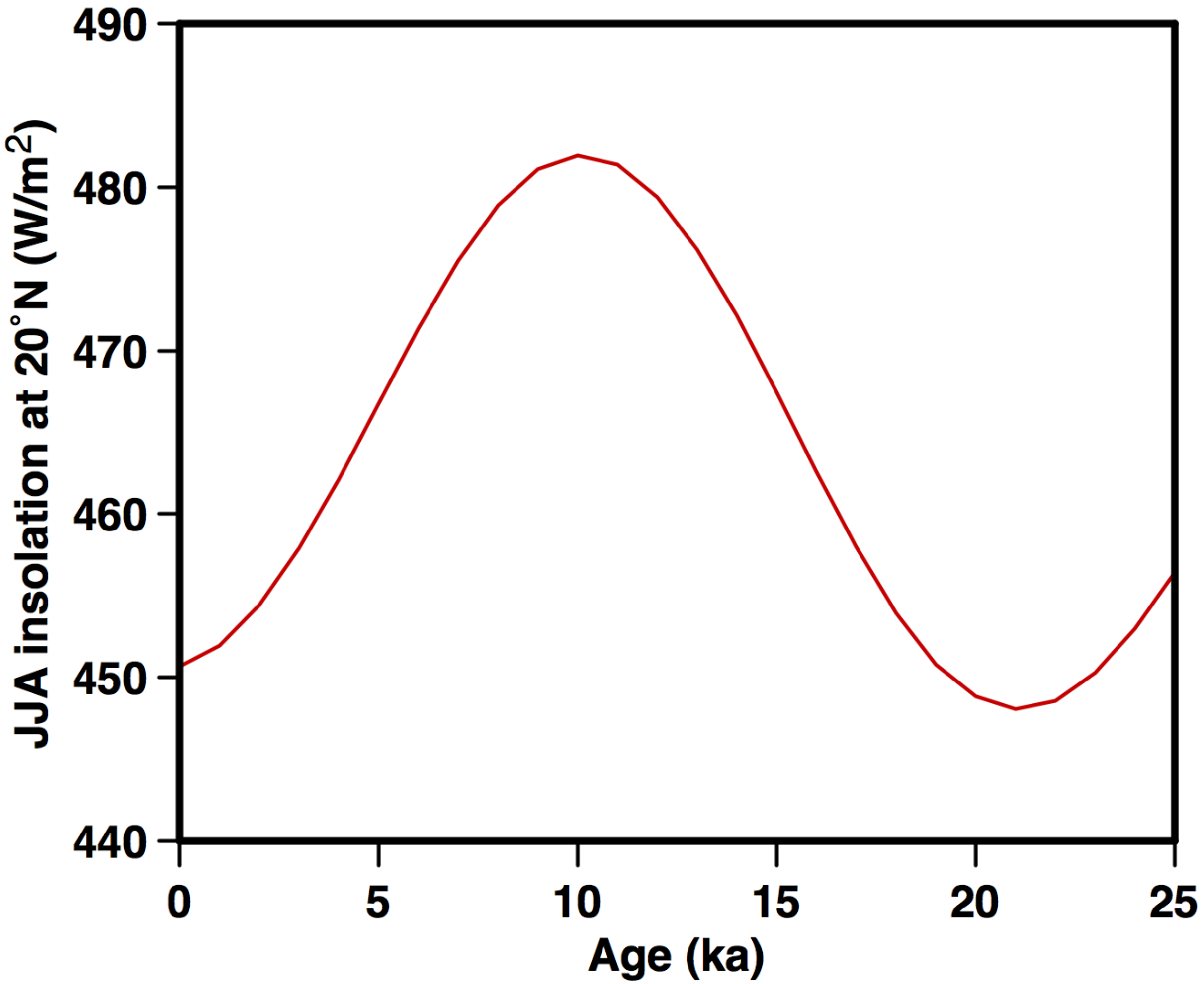



Glacial-interglacial transition

Jouzel et al., Science 2007
Monnin et al., Science 2001
Peltier and Fairbanks, QSR 2006

# Climate change over the last 25 ka

Orbital changes

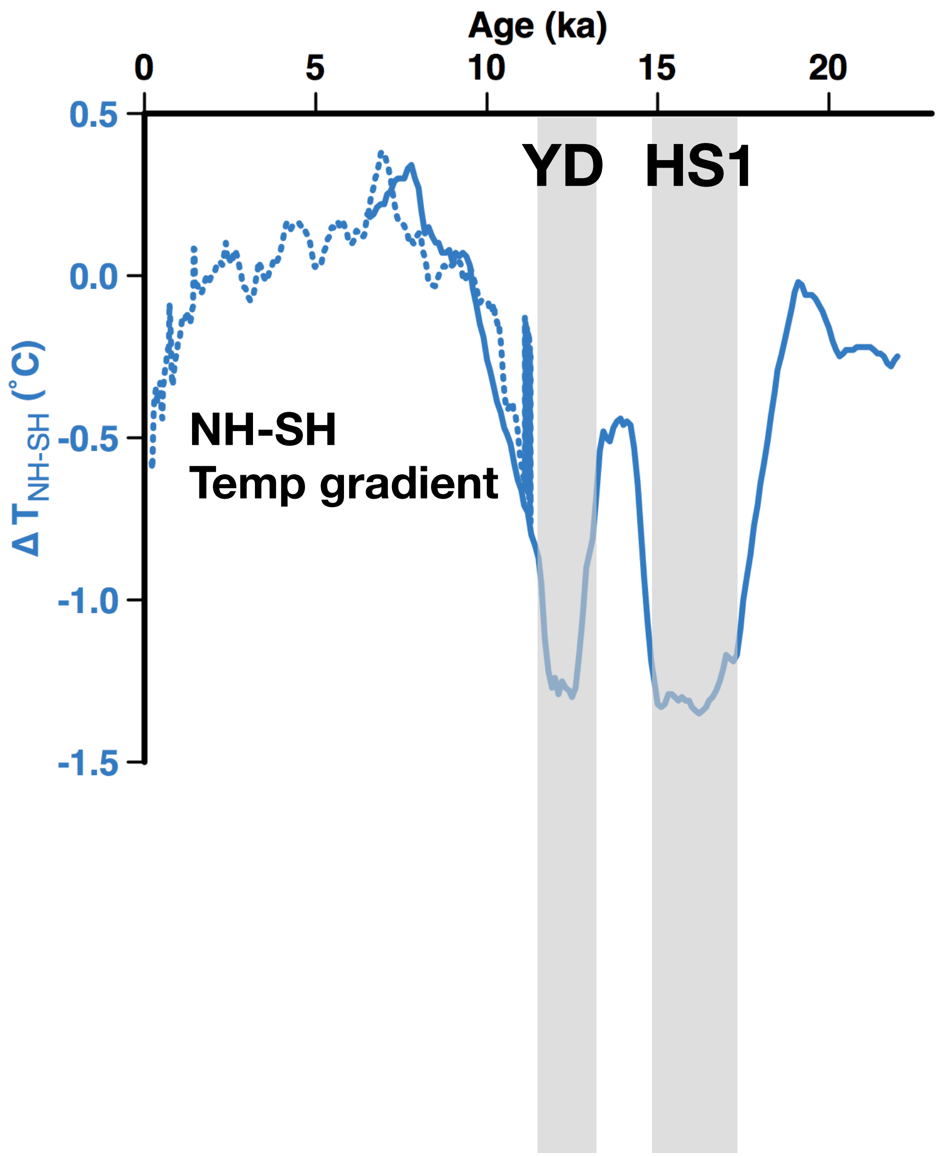



Laskar et al., Astron. & Astrophys. 2004

# Climate change over the last 25 ka

Changes in the interhemispheric temperature gradient

**YD:** Younger Dryas
**HS1:** Heinrich Stadial 1




Shakun et al., Nature 2012
Marcott et al., Science 2013

# Climate change over the last 25 ka

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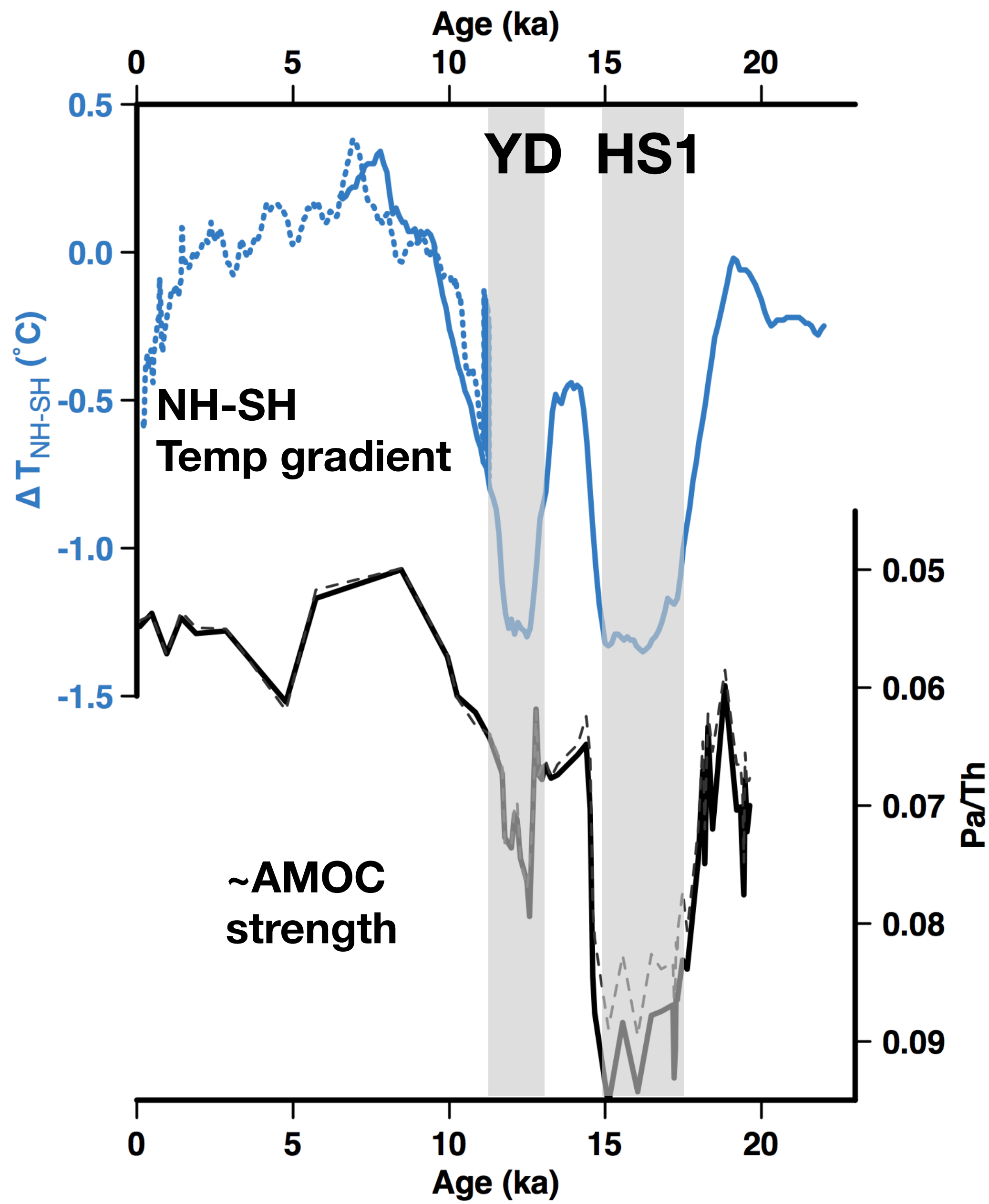
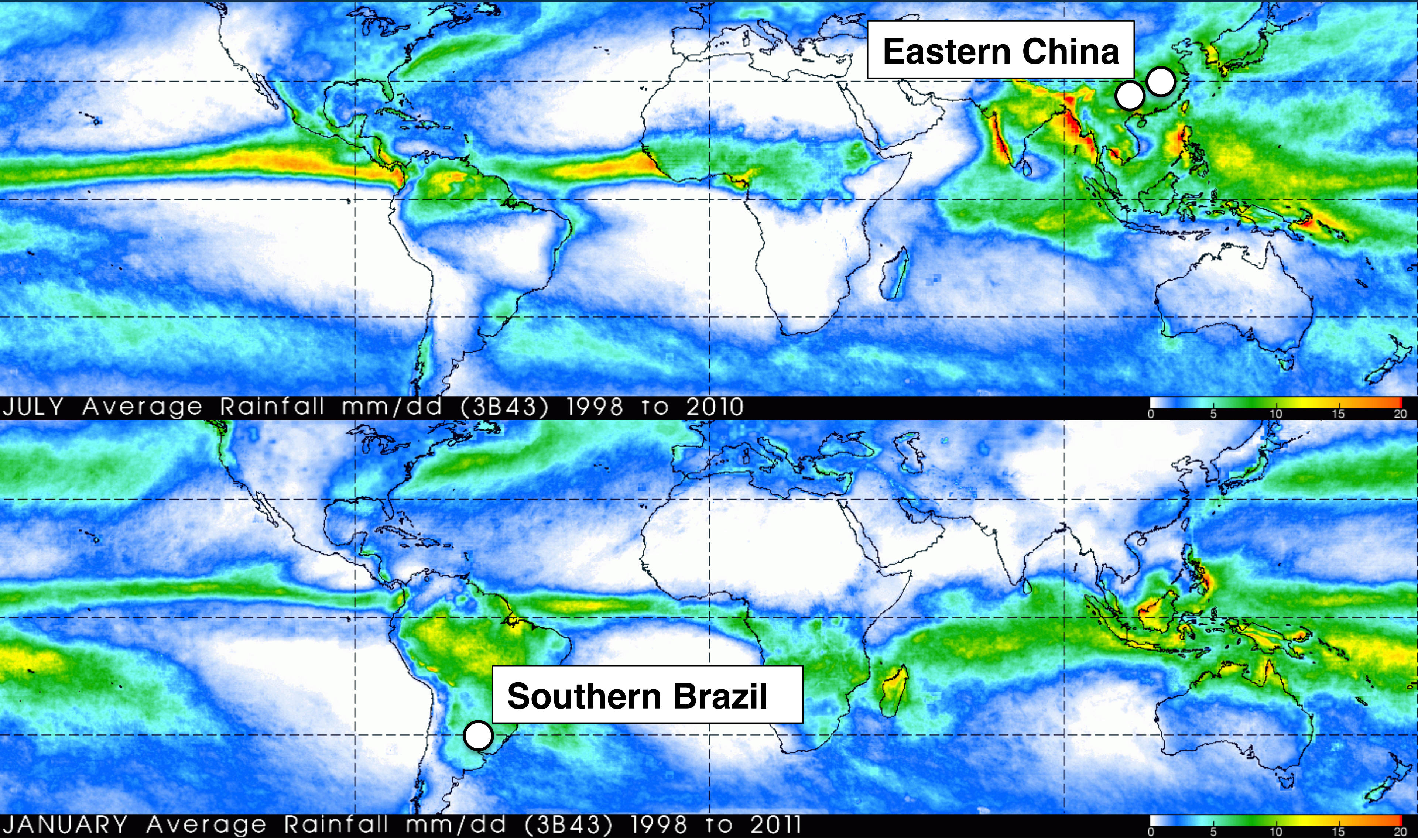


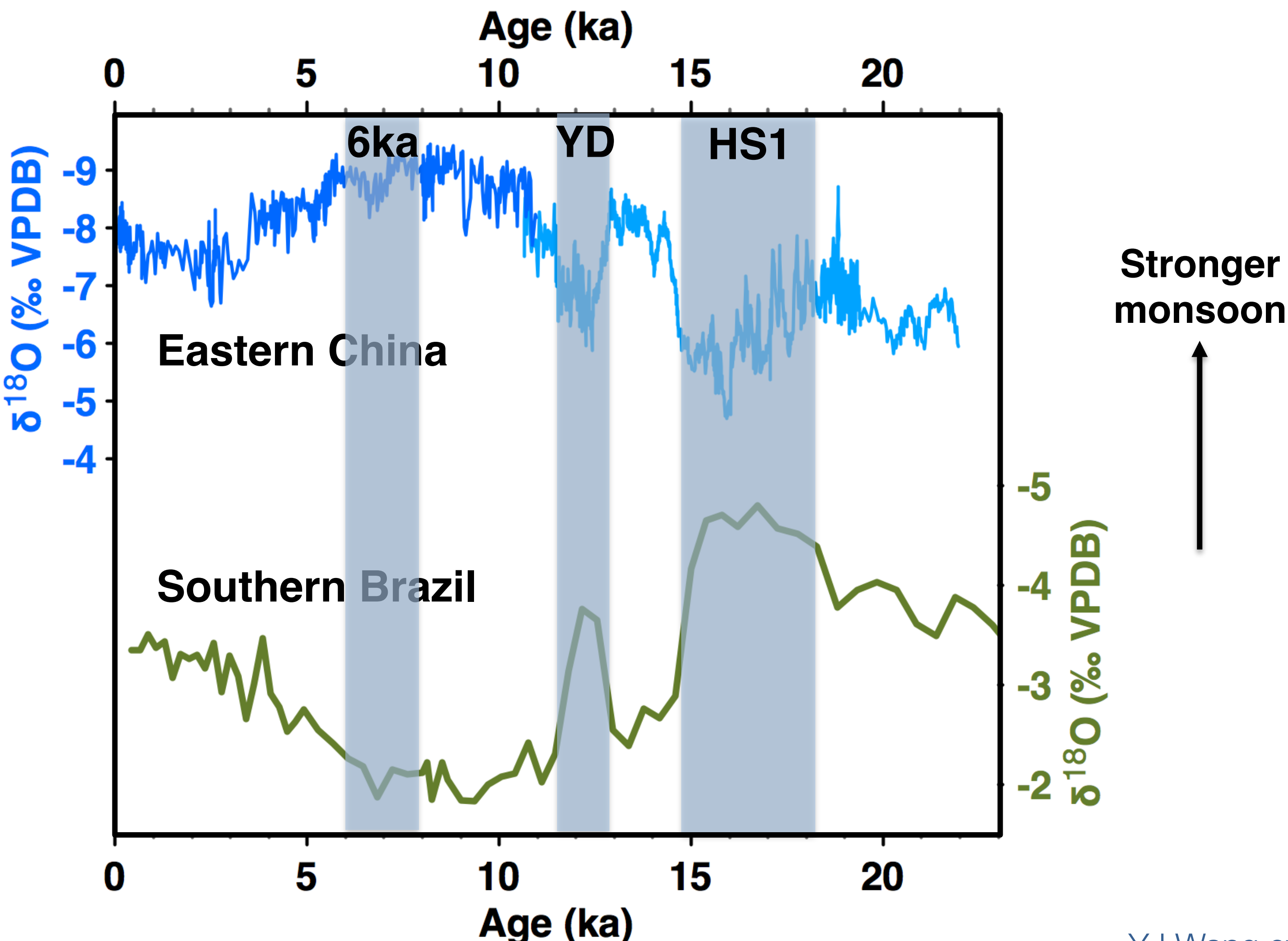

Shakun et al., Nature 2012
Marcott et al., Science 2013
McManus et al., Nature 2004

# Insights from high-resolution, well-dated records: Stalagmite data from China and Brazil



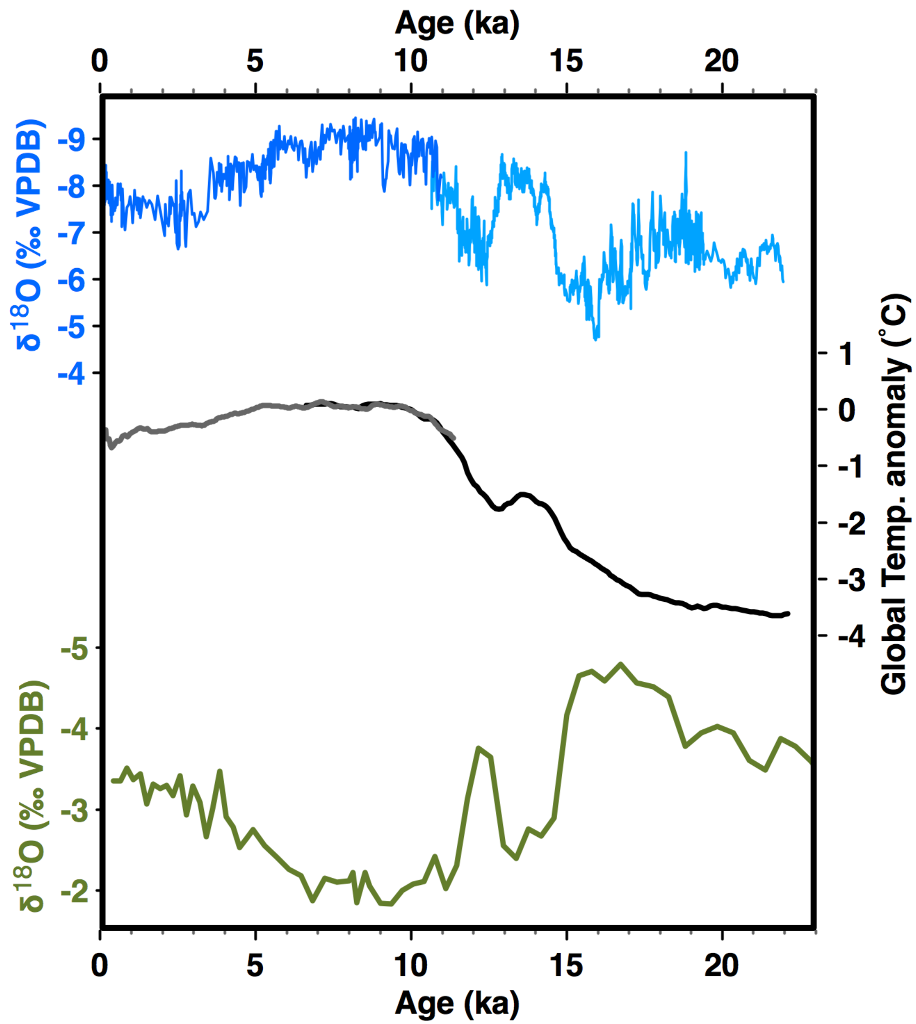

TRMM Avg. July and Jan precip., 1998-2010

# Antiphasing of NH vs. SH monsoons



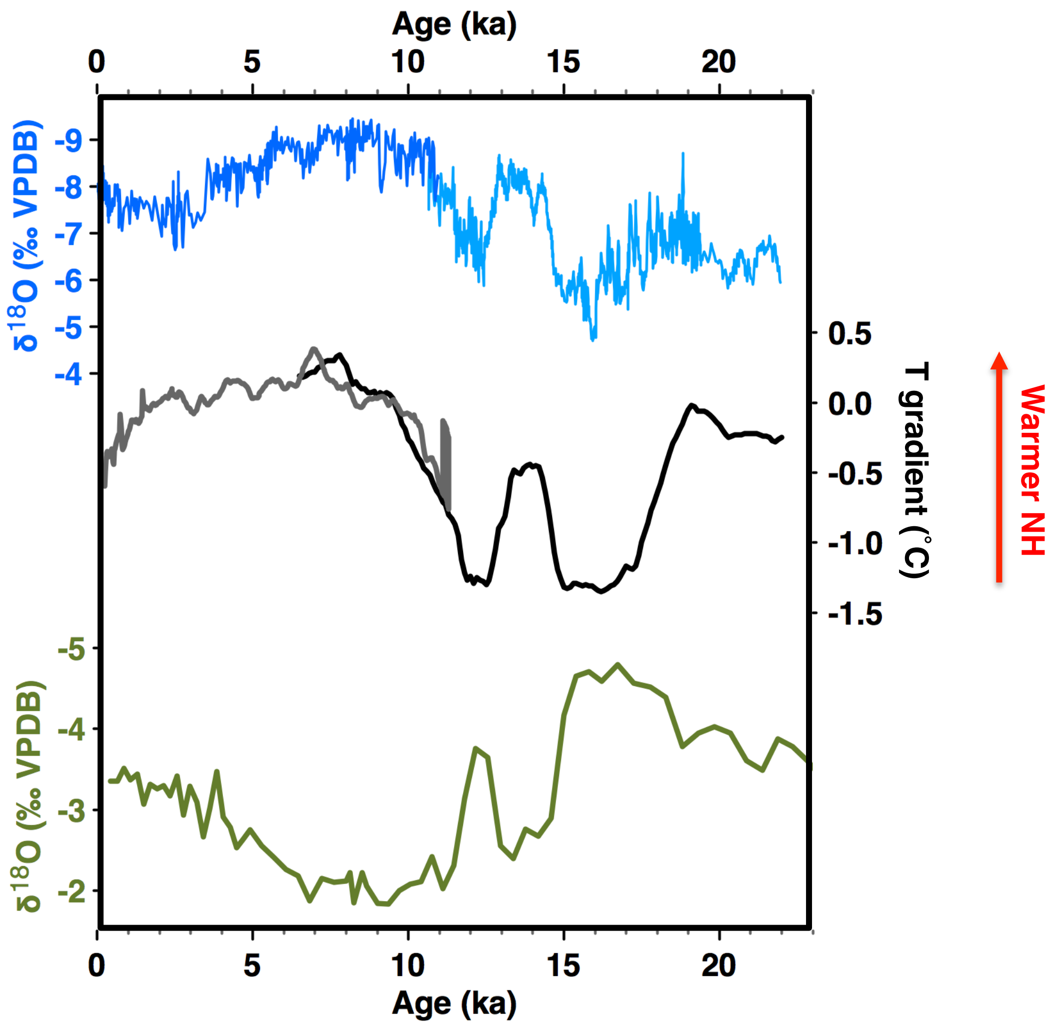

YJ Wang et al., Science 2001;
Dykoski et al., EPSL 2006
XF Wang et al., GRL 2007

# Tropical precipitation changes suggest weak relationship with mean global temperature




Shakun et al.,Nature 2012;
Marcott et al., Science 2013

# Tropical precipitation changes show strong correlation with NH-SH temperature gradient



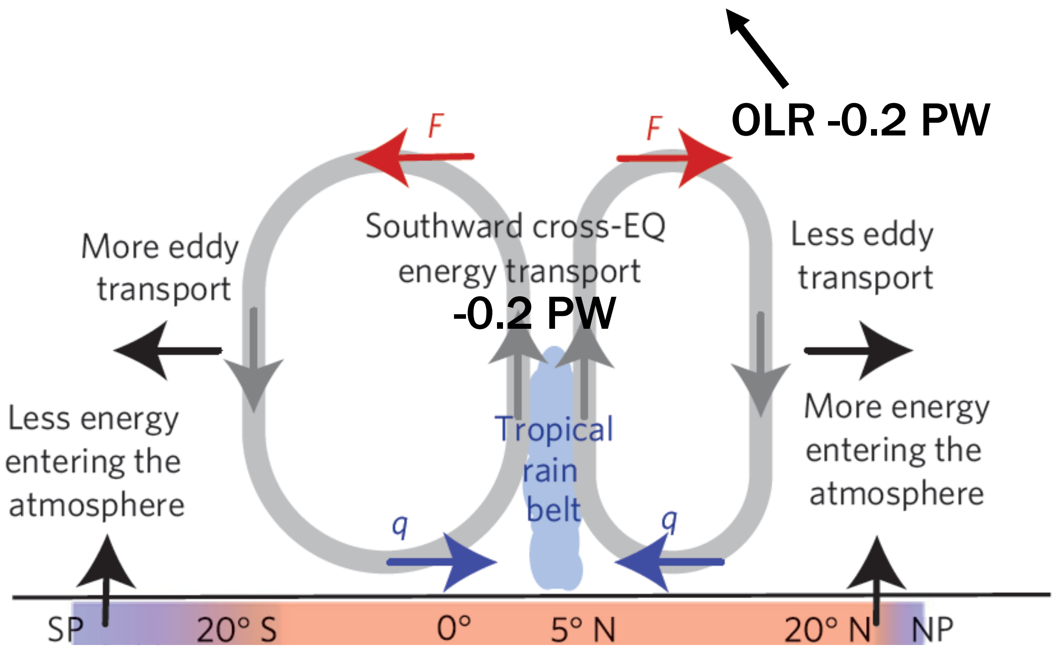

Shakun et al.,Nature 2012;
Marcott et al., Science 2013

# If proxies suggest N-S antiphasing of tropical precipitation, how far can the tropical rain belt move meridionally?

# Ocean circulation as a control on annual-mean position of the rain belt

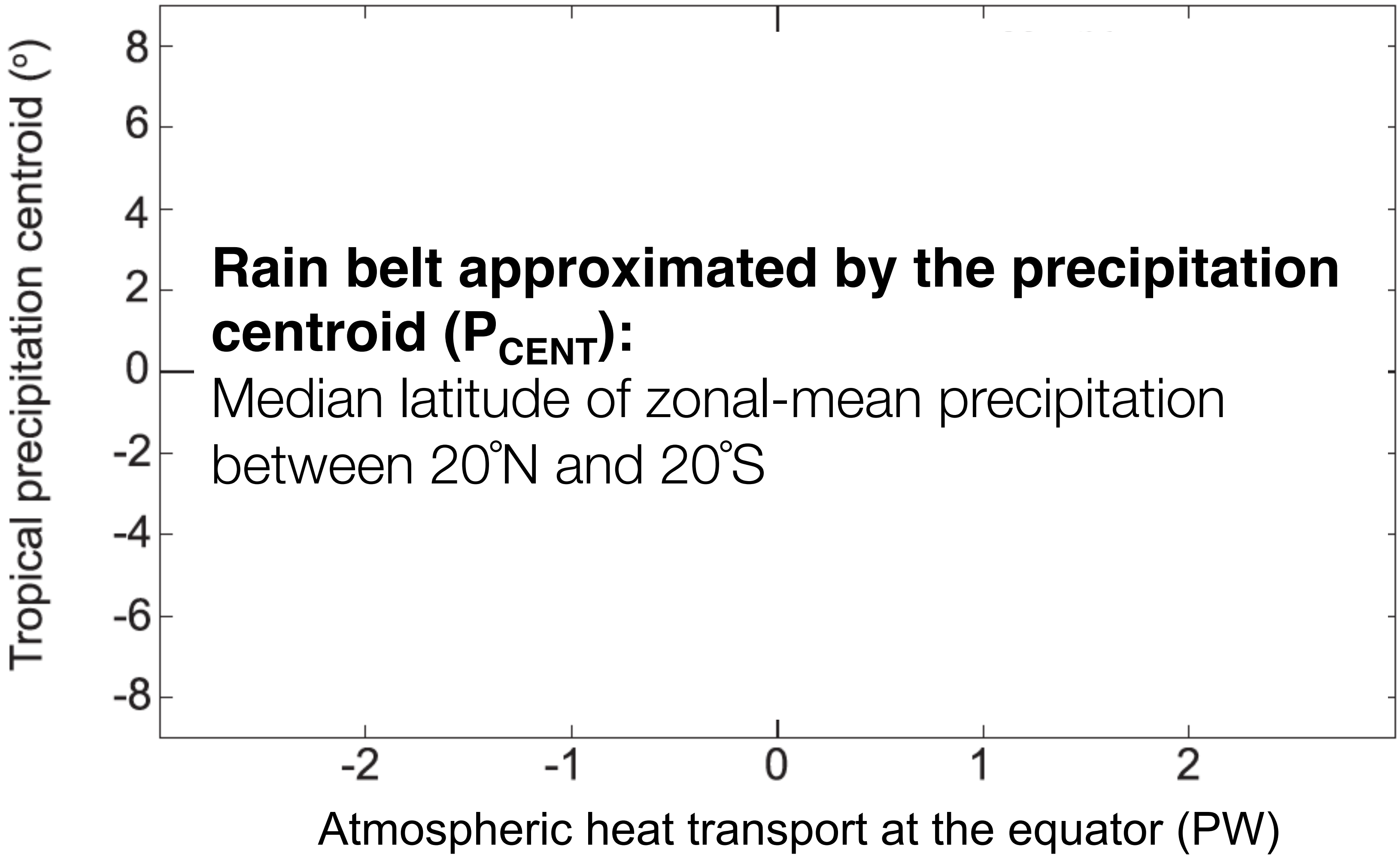
**Mean rain belt is in NH due to higher energy inputs to NH atmosphere…**

**which in turn is due to northward heat transport by the ocean, chiefly in the Atlantic.**




Frierson et al., Nat. Geosci. 2013;
See also Marshall et al., Clim. Dyn. 2013

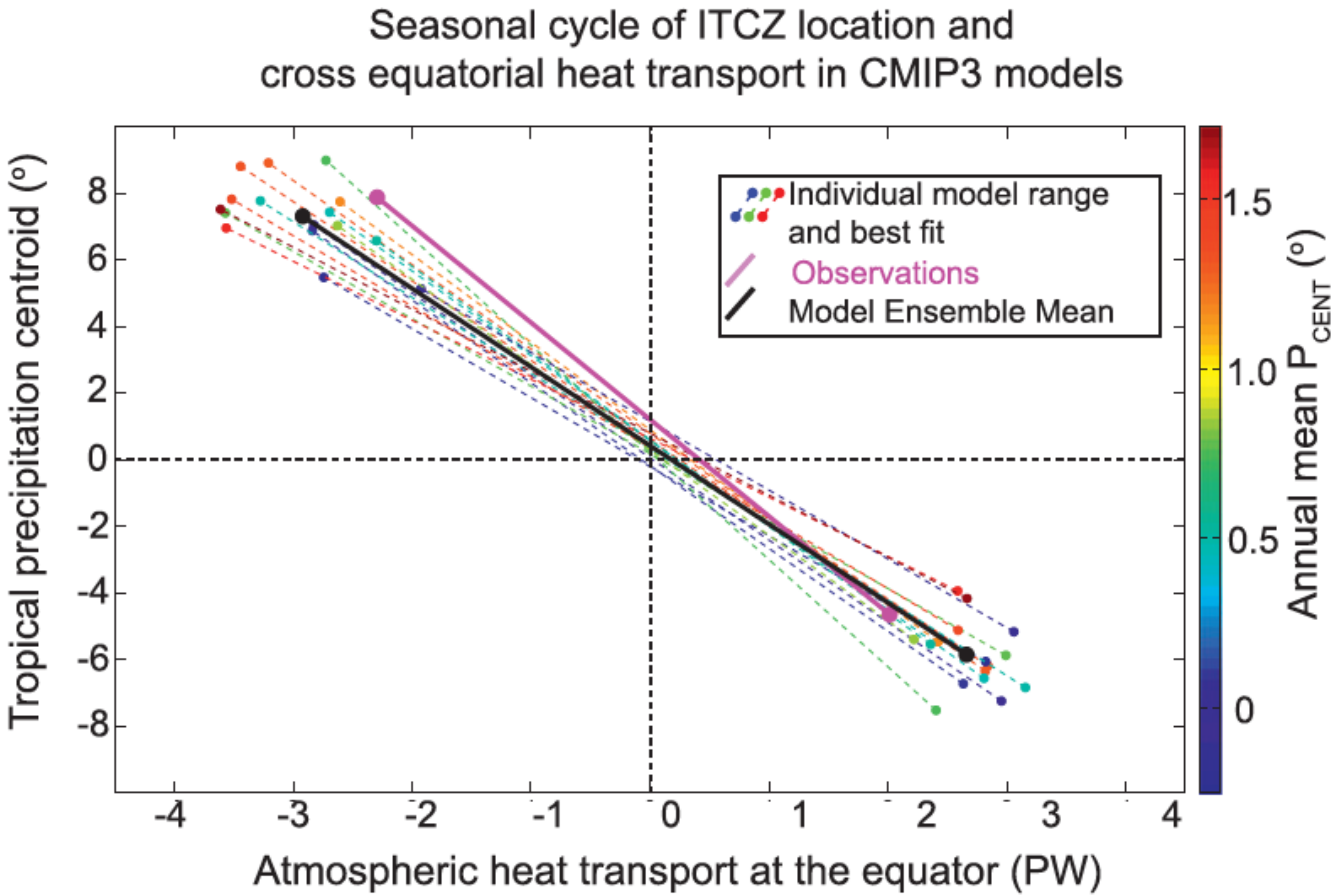
# Strong relationship between rain belt position and heat transport in the annual mean




**Rain belt approximated by the precipitation centroid ($P_{CENT}$):**
Median latitude of zonal-mean precipitation between 20°N and 20°S

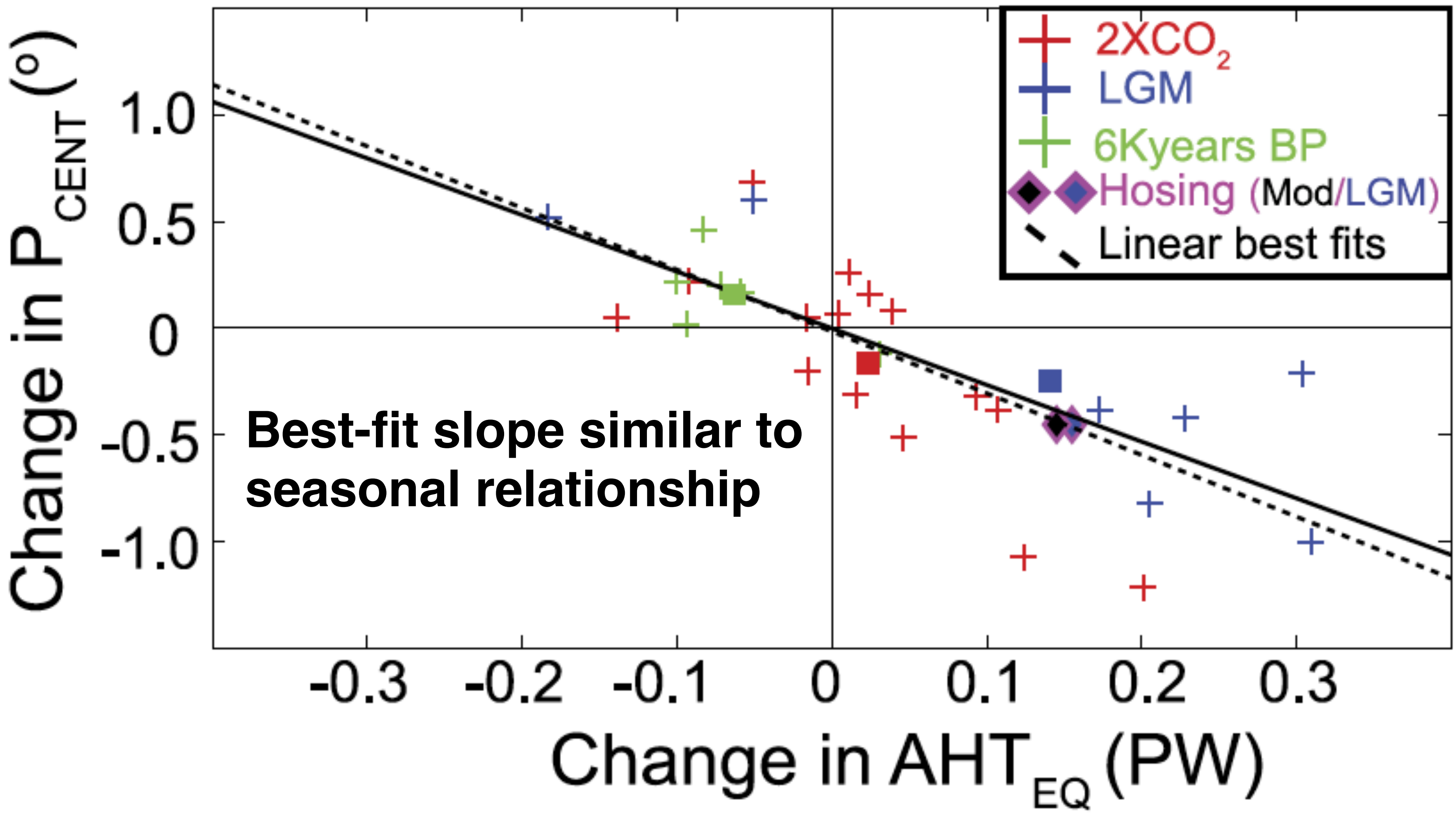
Donohoe et al., J. Clim 2013

# Seasonal relationship captured reasonably well by GCMs



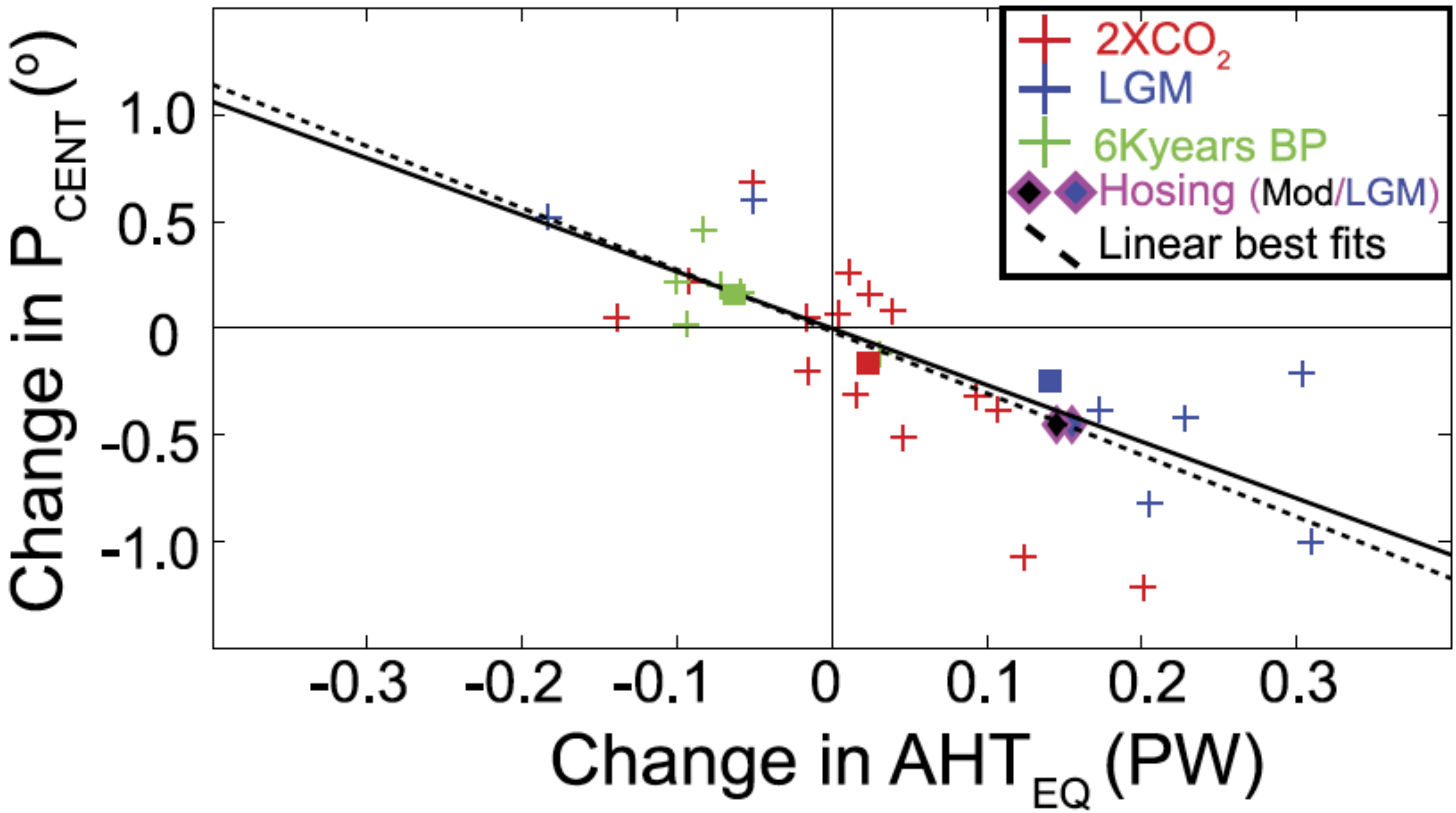

Donohoe et al., J. Climate 2013

# Annual mean responses in climate change experiments



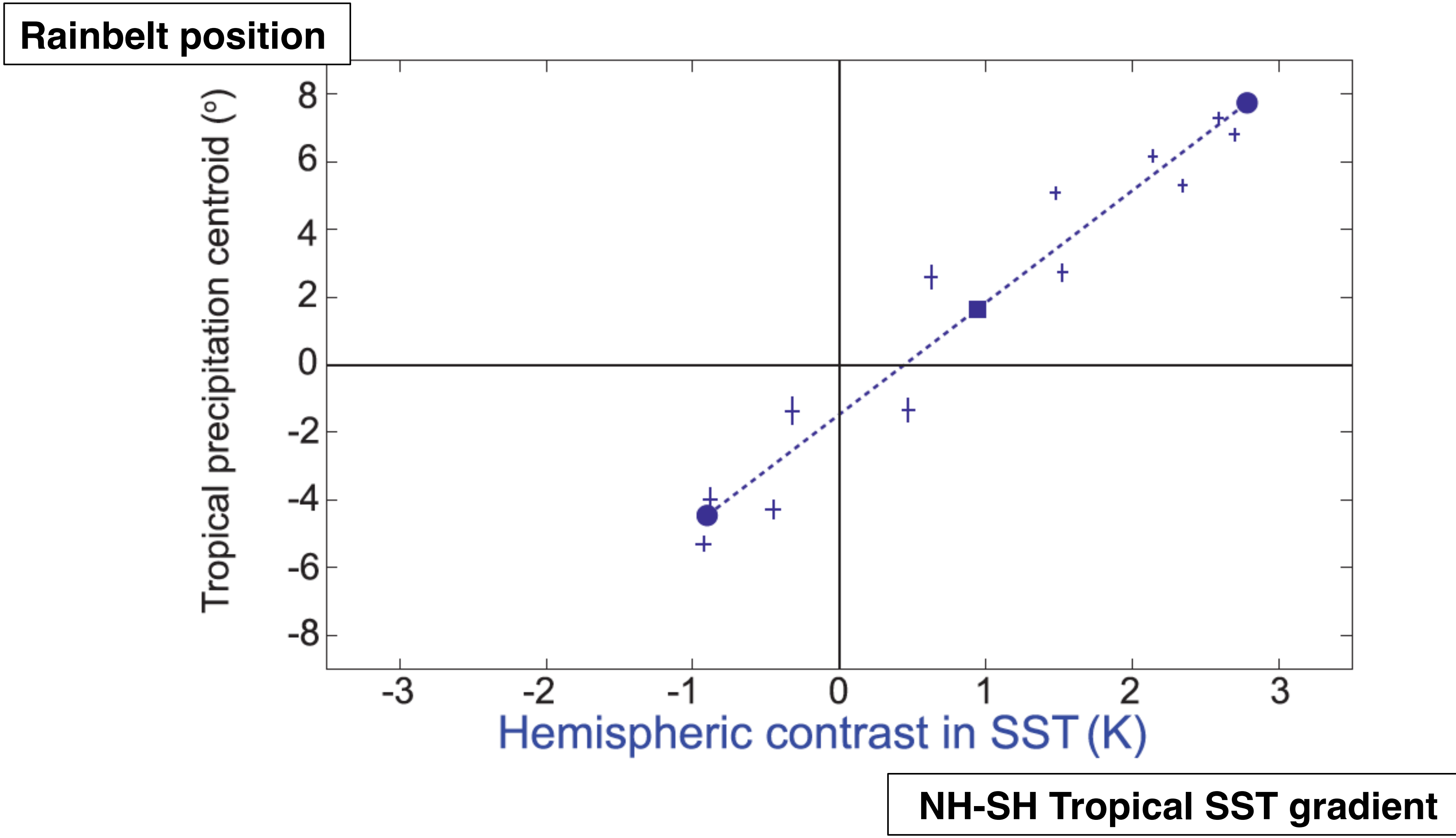

McGee et al., EPSL 2014

# Even large changes in ocean circulation should have small impact on mean rainbelt position




McGee et al., EPSL 2014

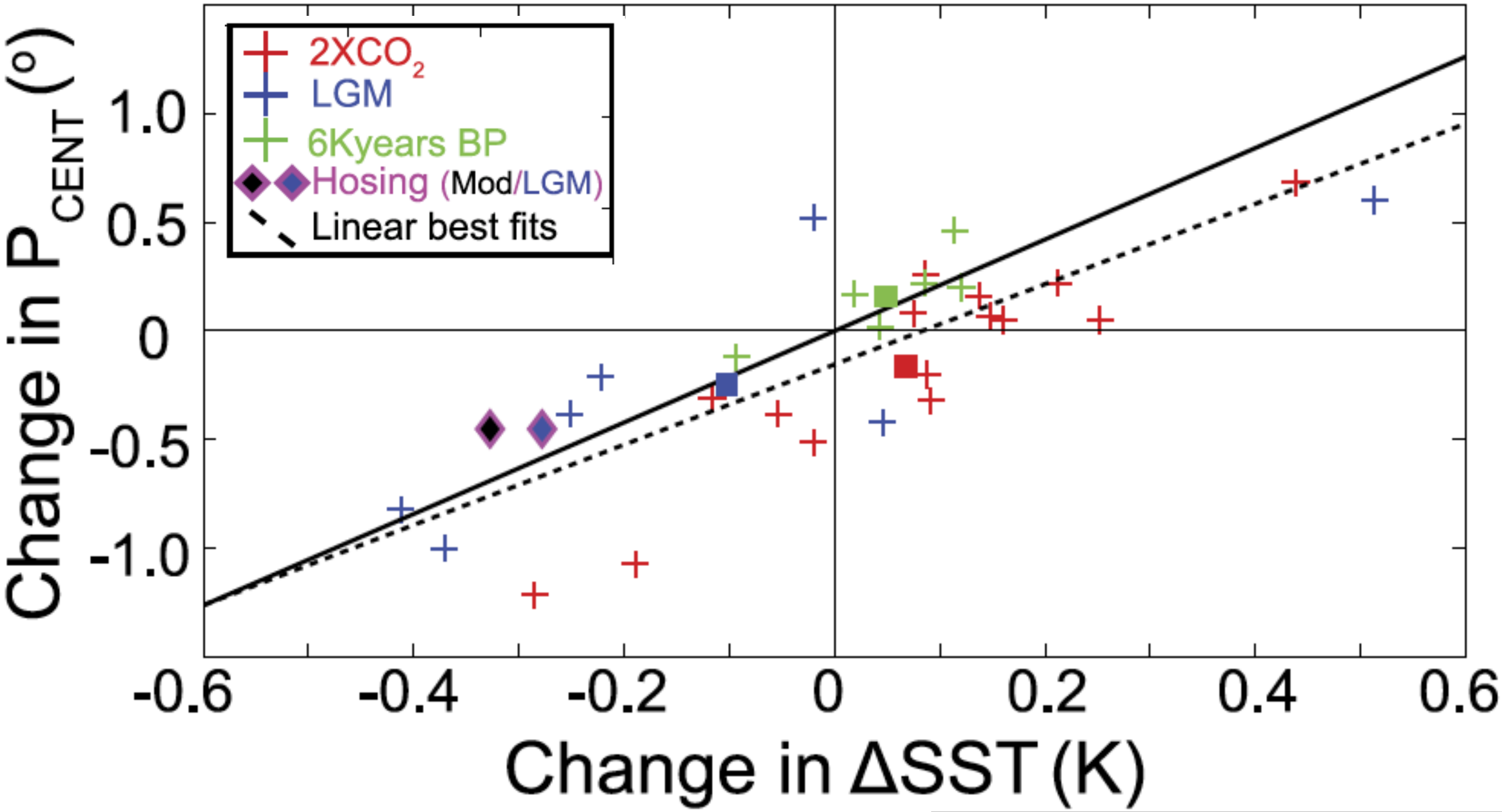
# Tropical SST gradients also correlate with rainbelt position in the annual mean…




Donohoe et al., J. Climate 2013

# …and in climate change experiments

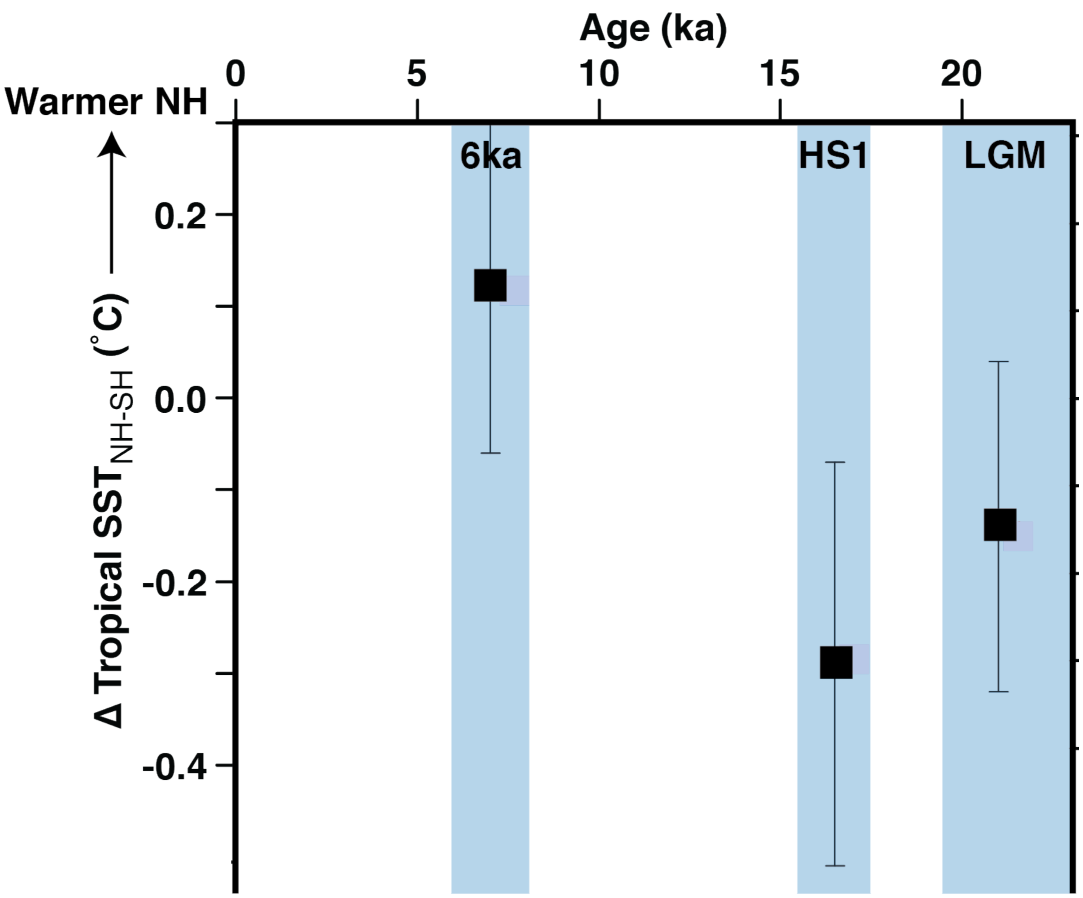
**Rainbelt position**




**NH-SH Tropical SST gradient**

Donohoe et al., J. Climate 2013

# Reconstructed SST gradients in selected timeslices

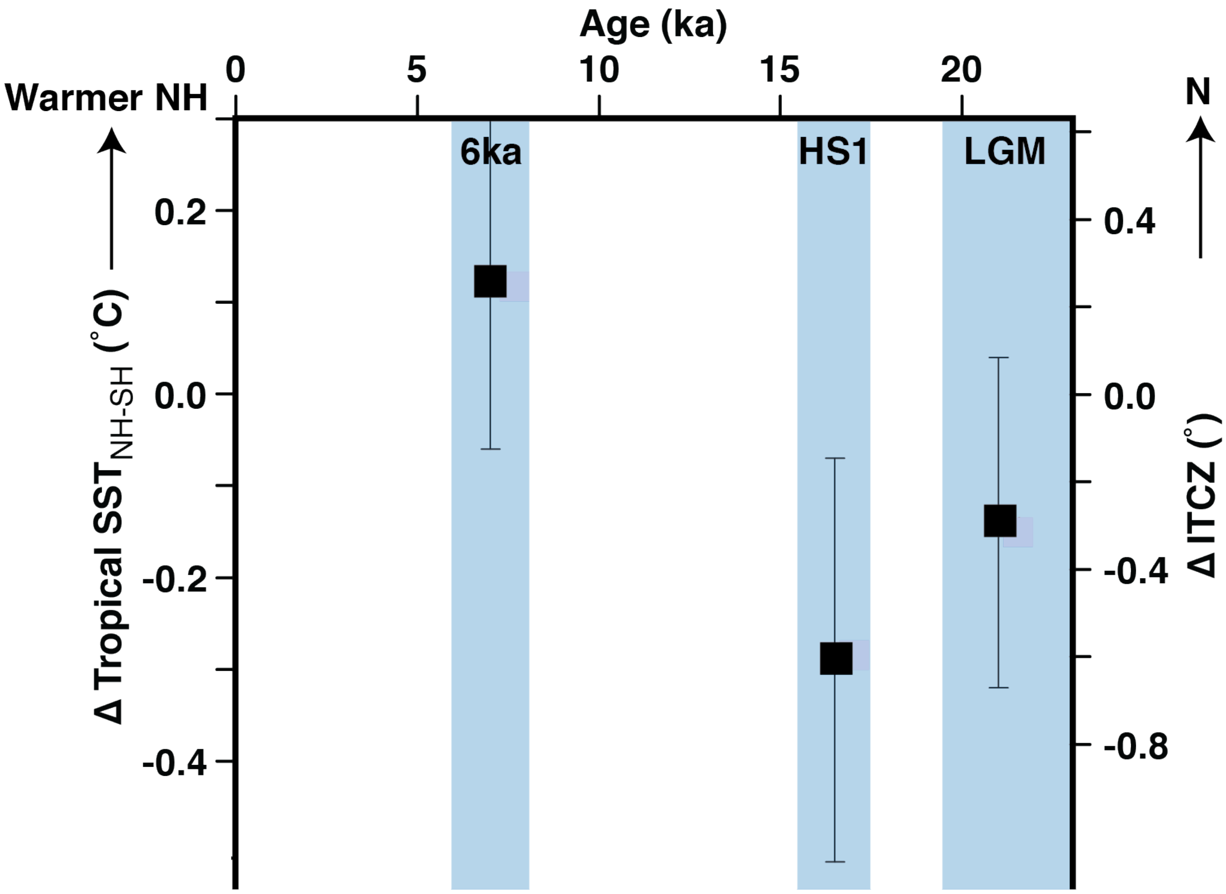



Estimated from 25 SST reconstructions based on Mg/Ca and alkenone unsaturation from the tropical Atlantic and Pacific.

1σ uncertainties estimated using Monte Carlo + jackknife method.

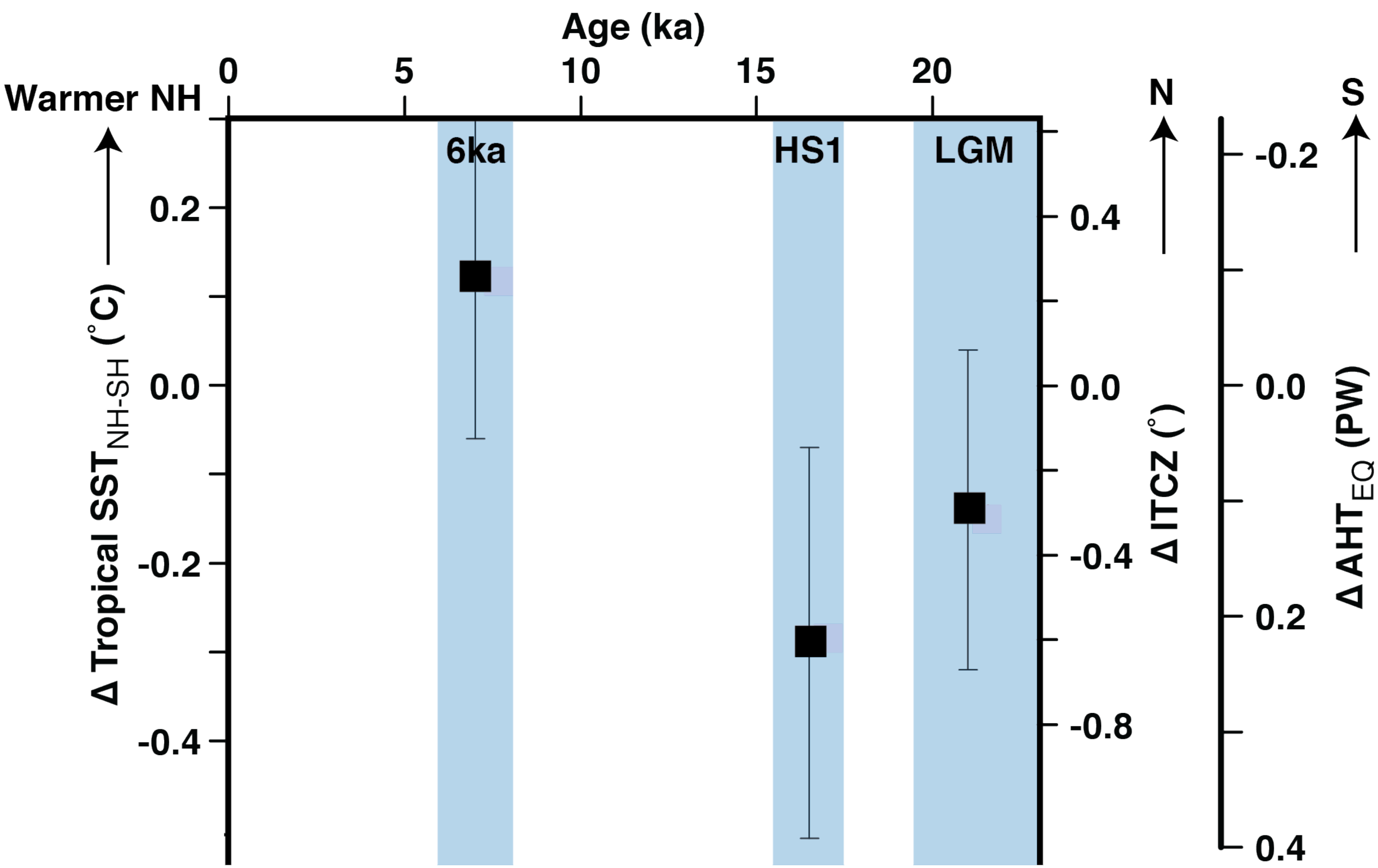
McGee et al., EPSL 2014

# Estimated rain belt changes are small




McGee et al., EPSL 2014

# Estimated changes in heat transport are large

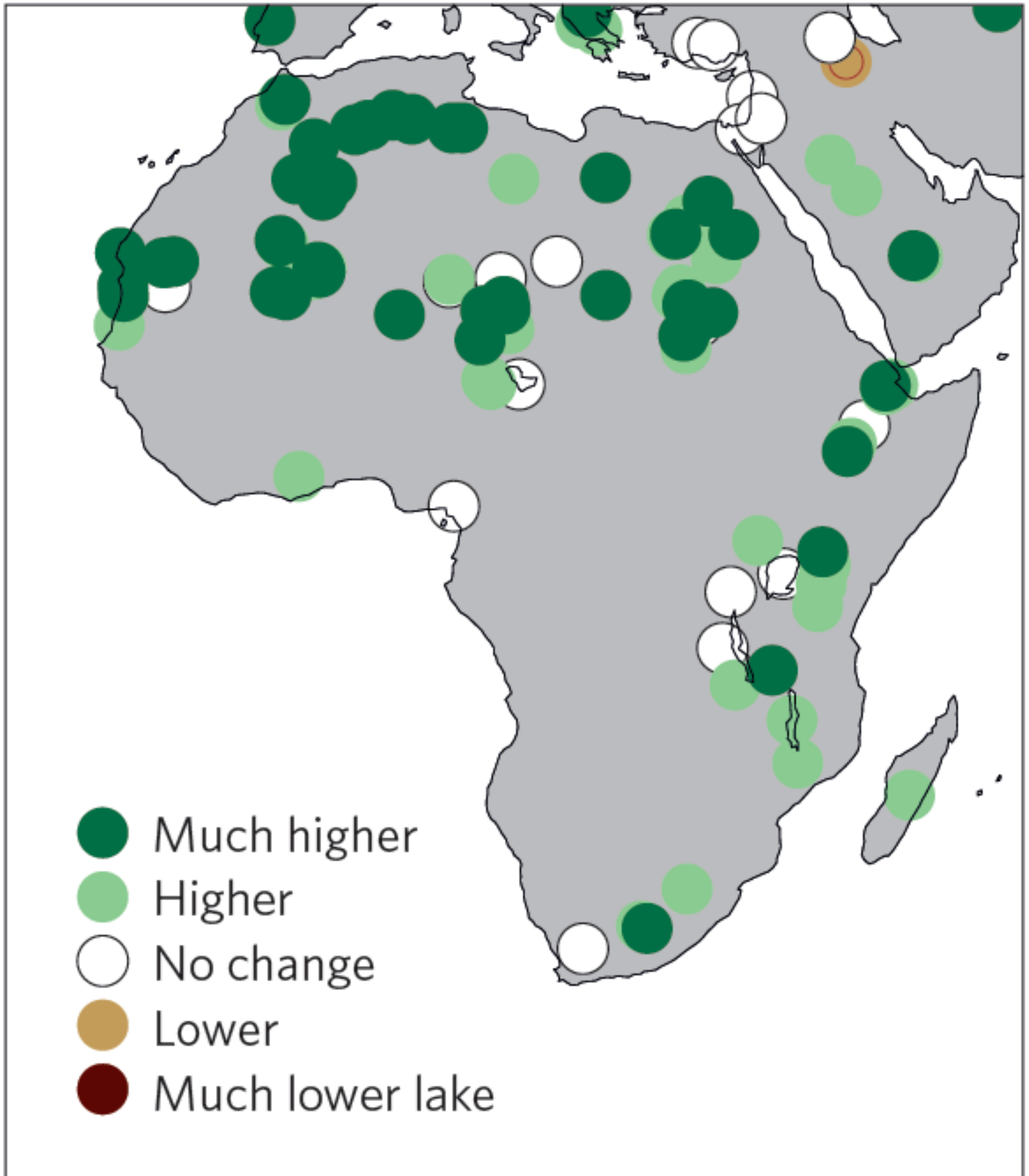



**Compare to modern value of -0.2 PW**

**Change in AHT during HS1 roughly consistent with substantial reduction in AMOC.**

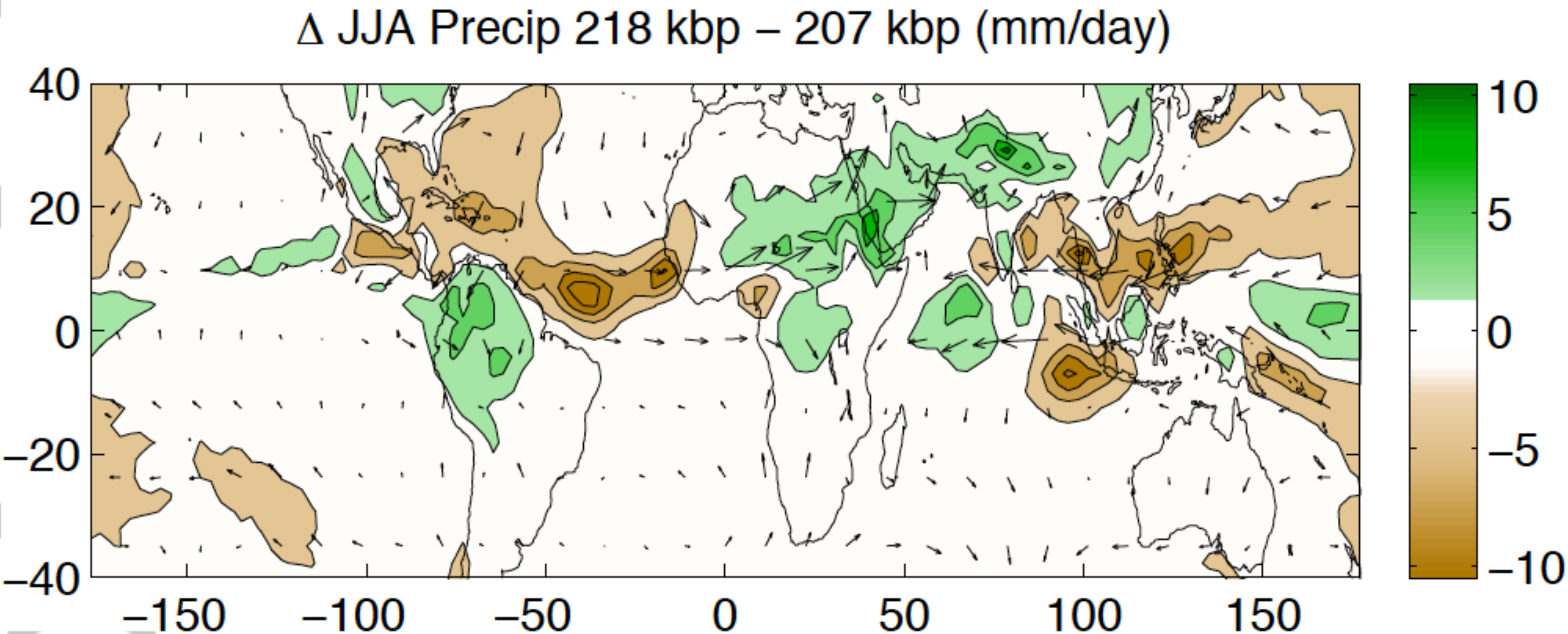
McGee et al., EPSL 2014

# 6 ka lake level anomalies




Kohfeld and Harrison, QSR 2000
Oxford Lake Level Database
Replotted by Bony et al., 2015

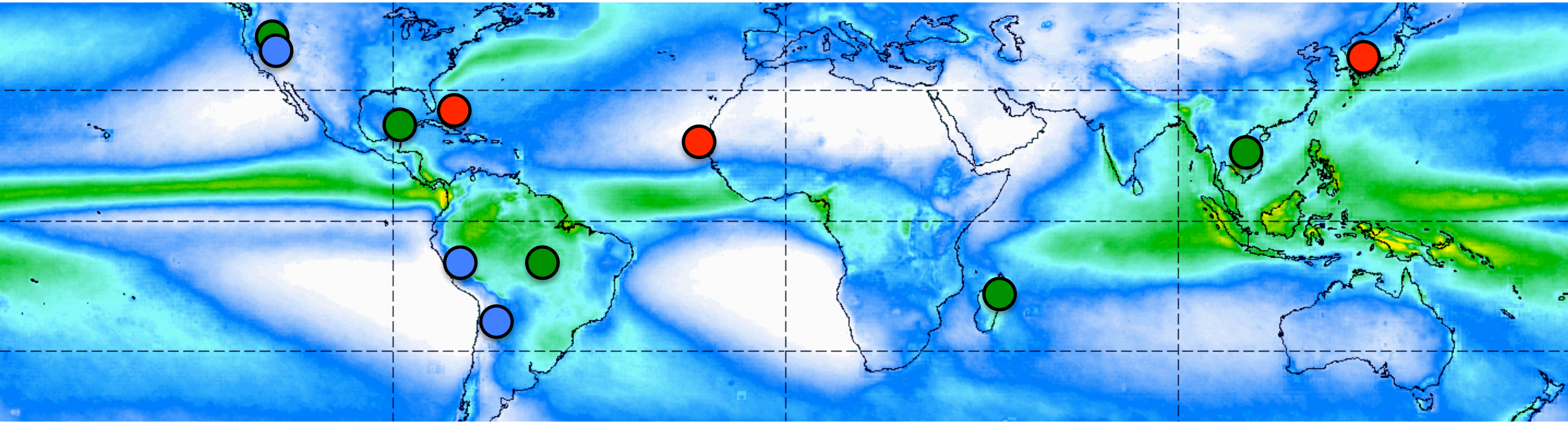
# Modeled boreal summer precipitation response to precessional variations




Biggest response is movement of precipitation from oceans onto land (see also Oppo et al., GRL 2007)

Battisti et al., JGR 2014

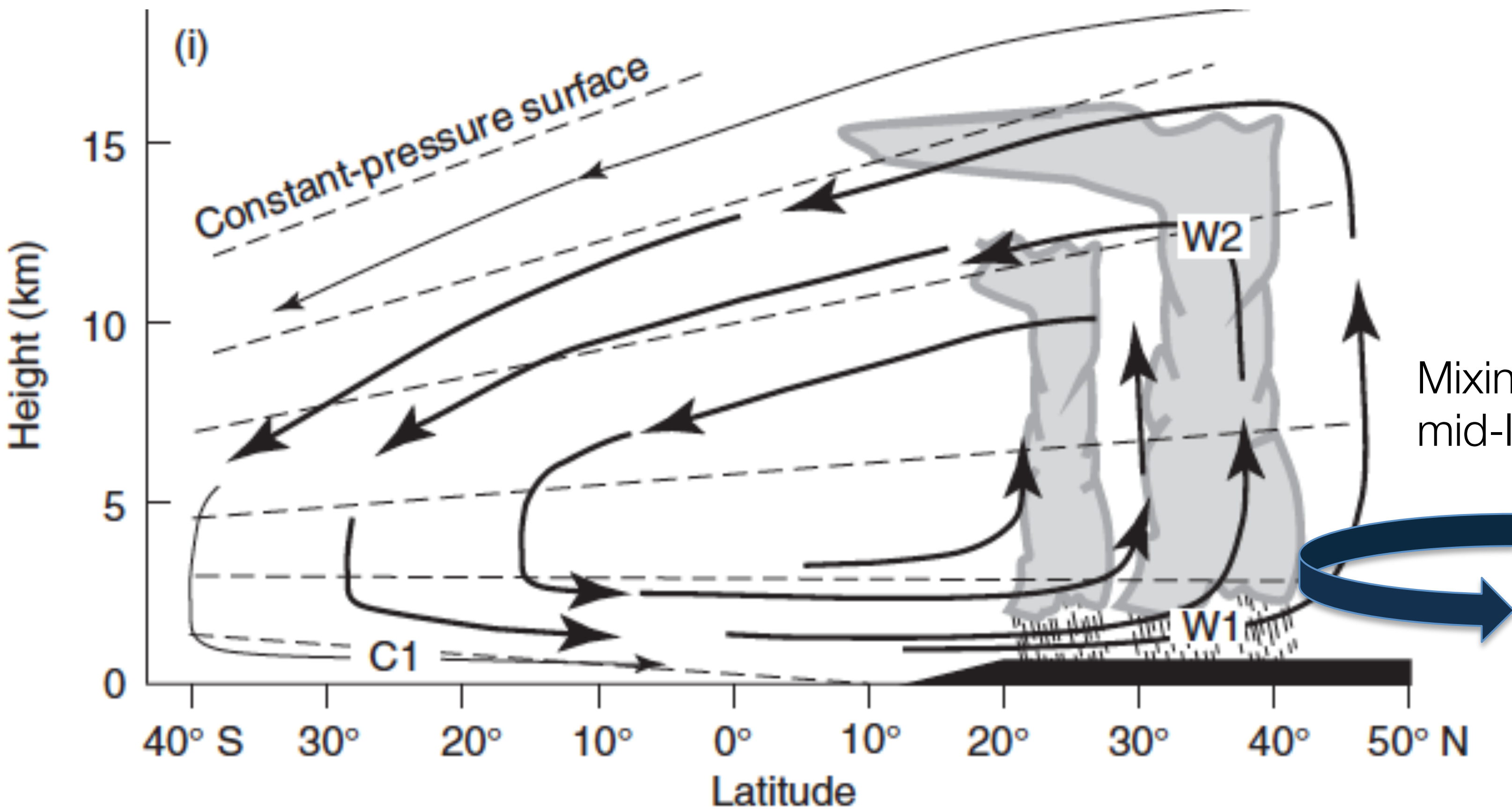
# Fingerprinting past atmospheric changes





TRMM annual mean precip., 1998-2011

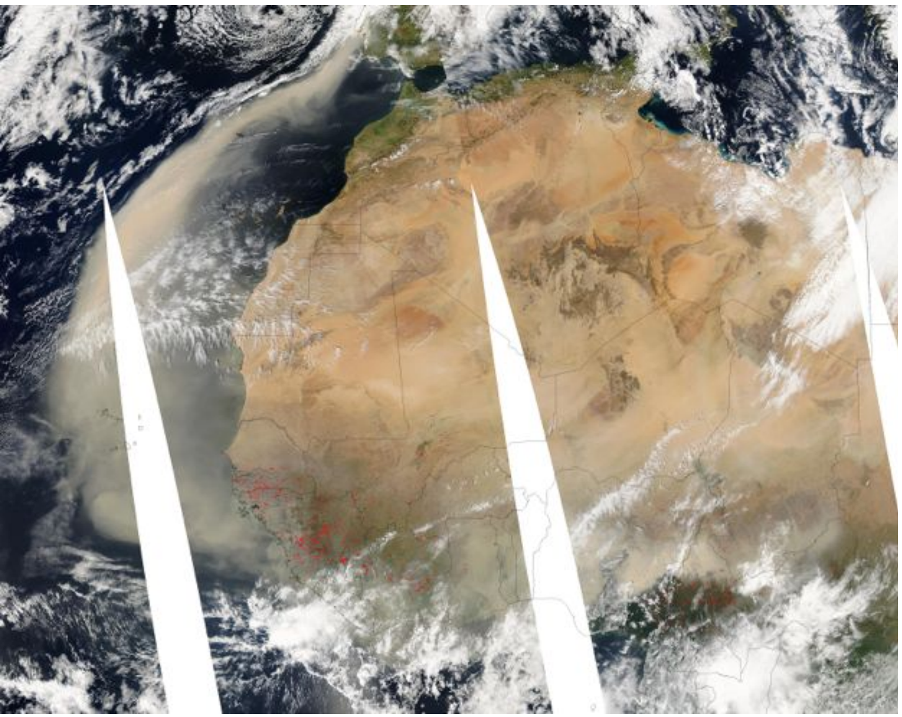
# Dust and lake records track poleward edges of monsoons

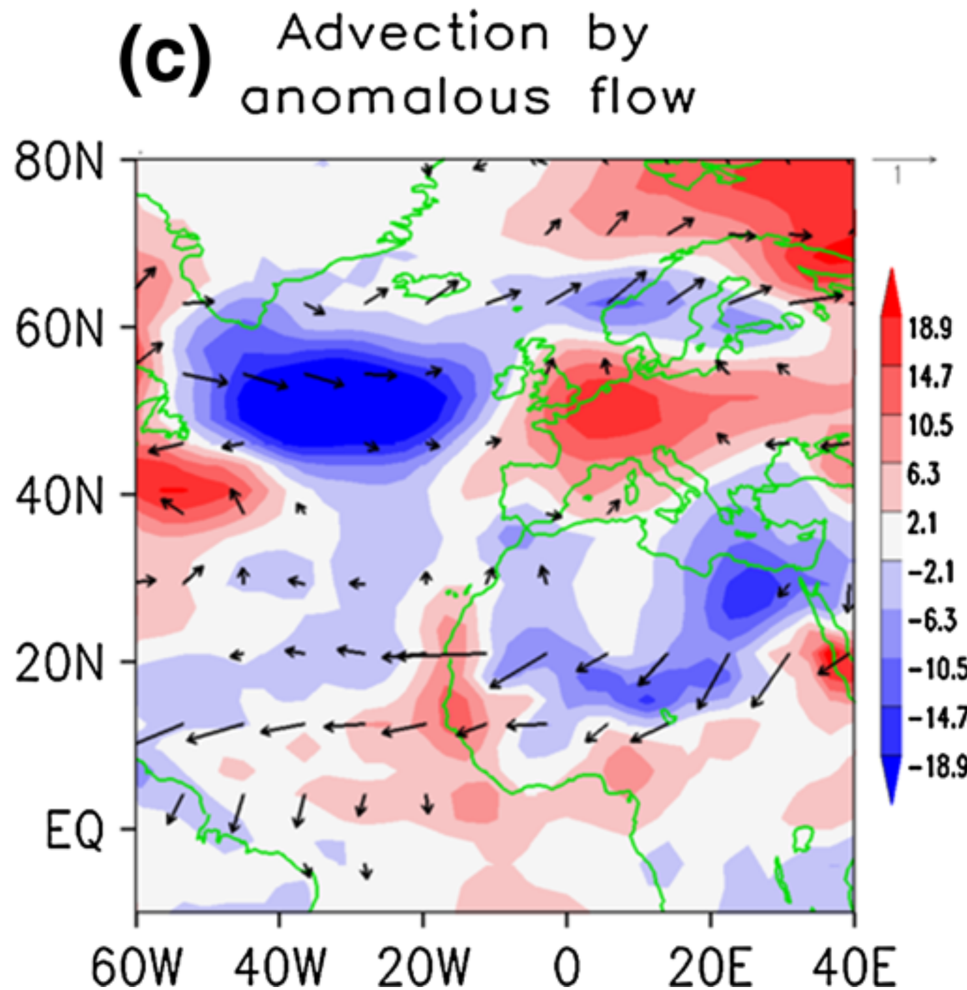



Mixing in of dry mid-latitude air

Webster and Fasullo, 2003

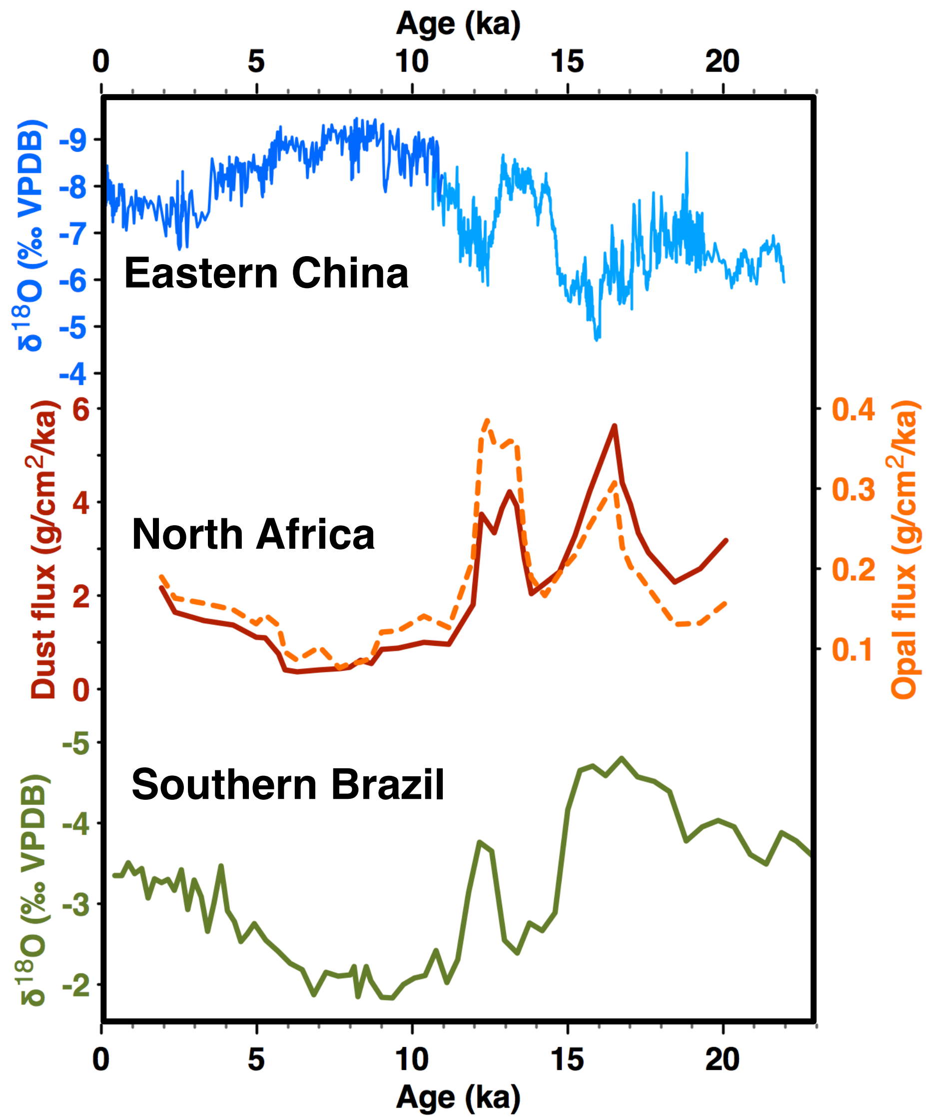
# Wind changes drive both dust export and anomalous MSE advection in North Africa





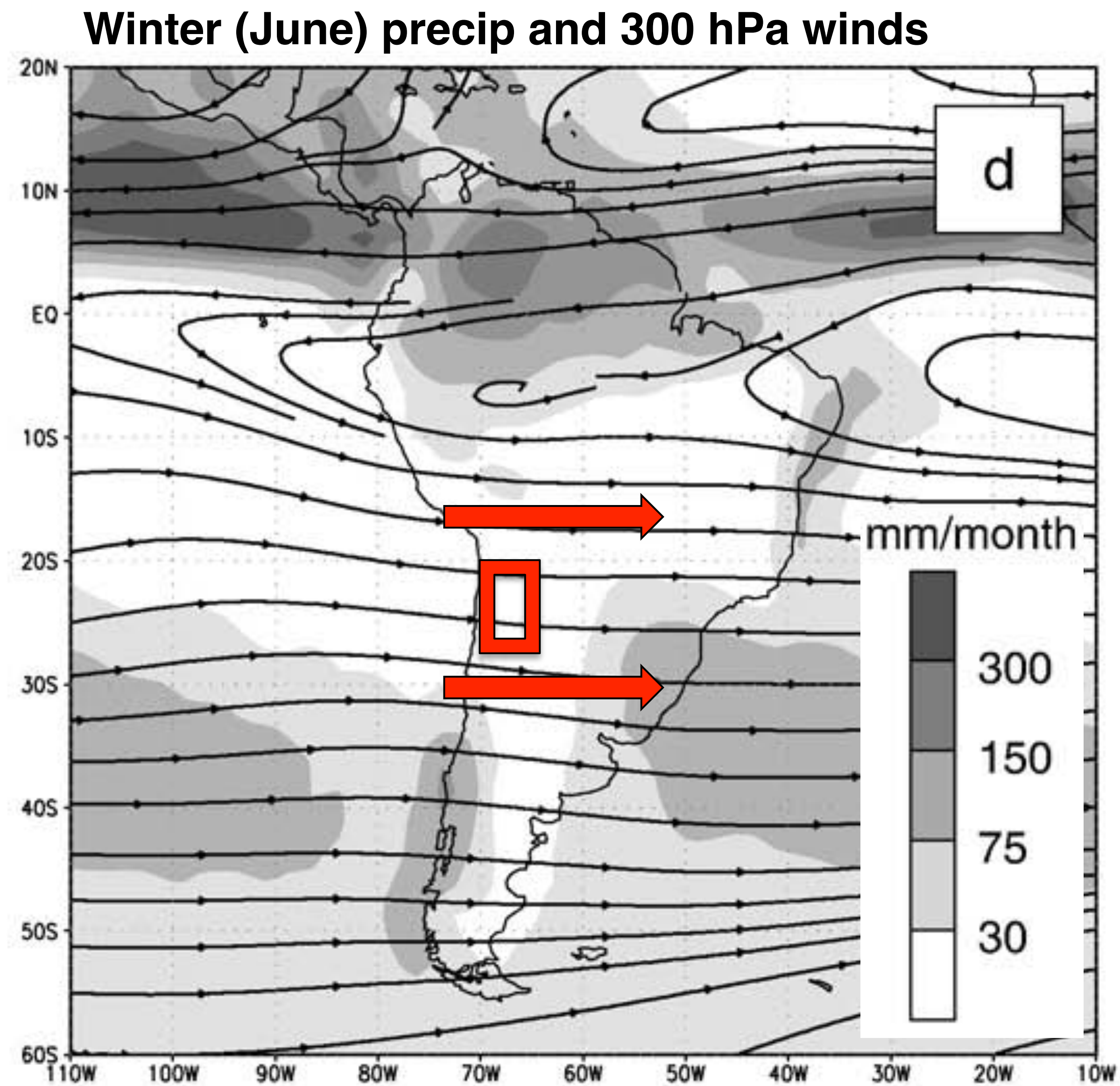

Liu et al., Clim. Dyn. 2014

# Covariation of N African surface wind proxies and hydrological proxies




N. Africa: McGee et al., EPSL 2013
See also Adkins et al., 2006

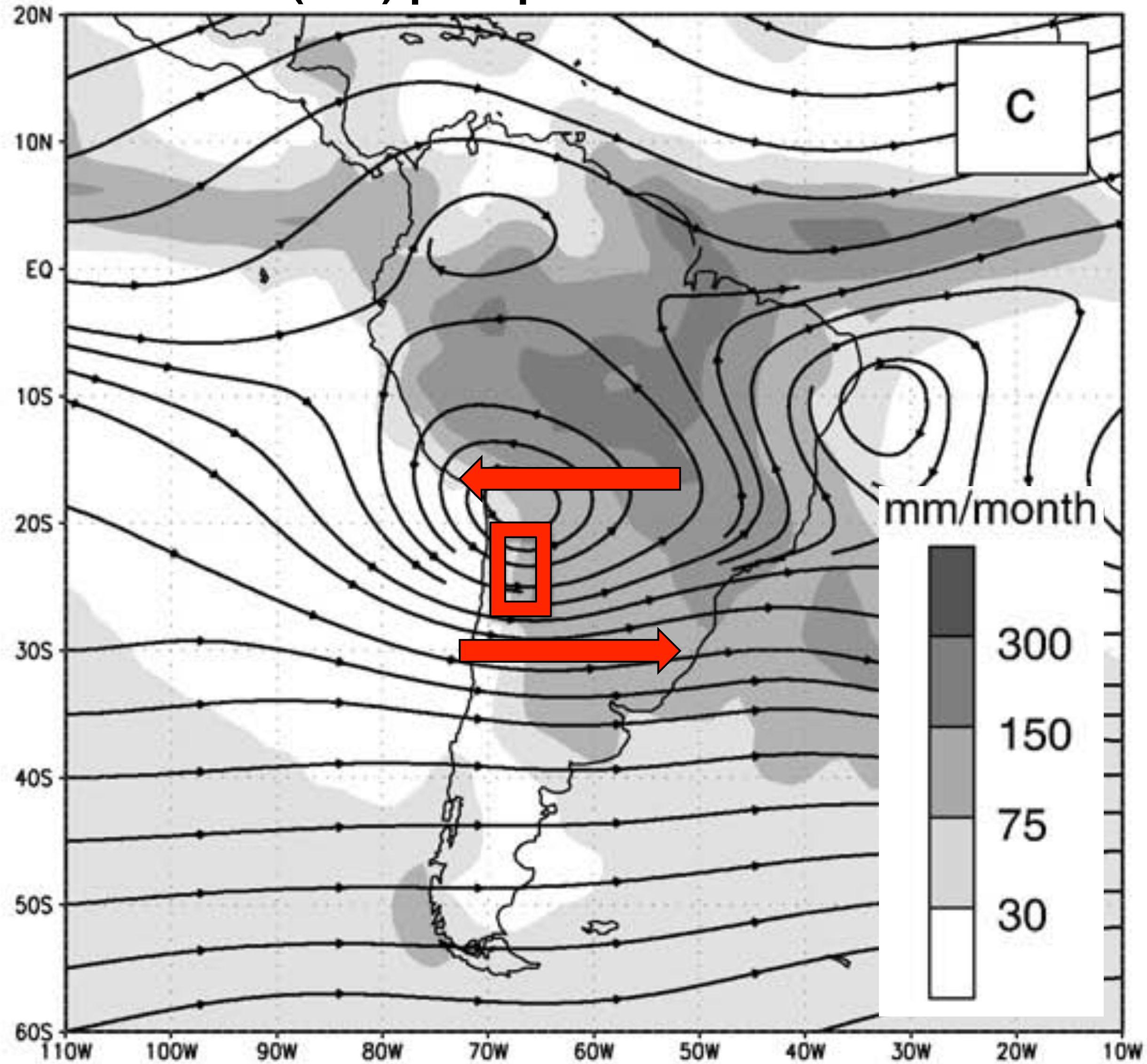
# Central Andes lakes:
# A window into the SH subtropical mid-troposphere


Garreaud et al., Palaeo[3] 2009

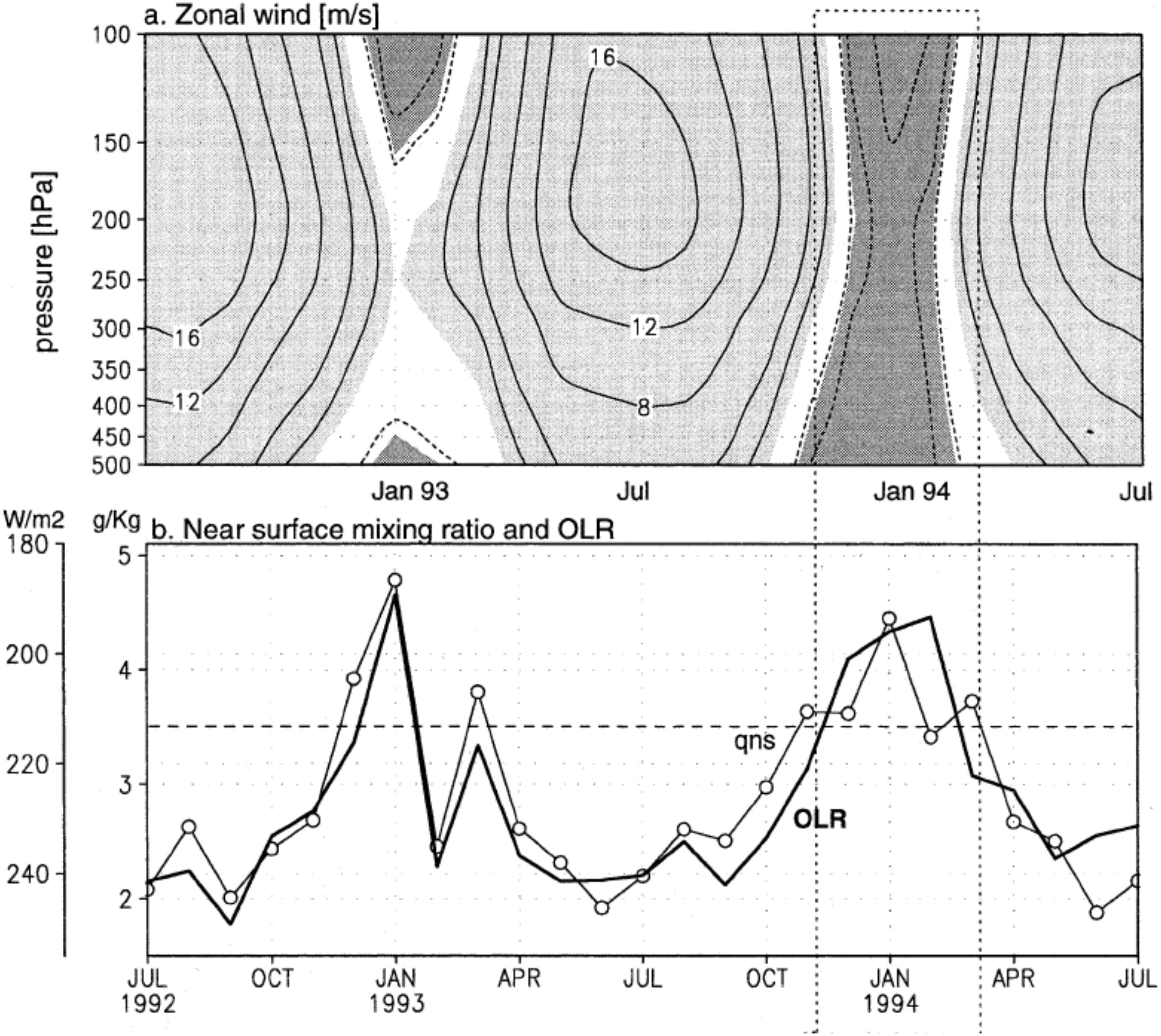
# Central Andes lakes:
# A window into the SH subtropical mid-troposphere


Summer (Jan) precip and 300 hPa winds




Garreaud et al., Palaeo[3] 2009

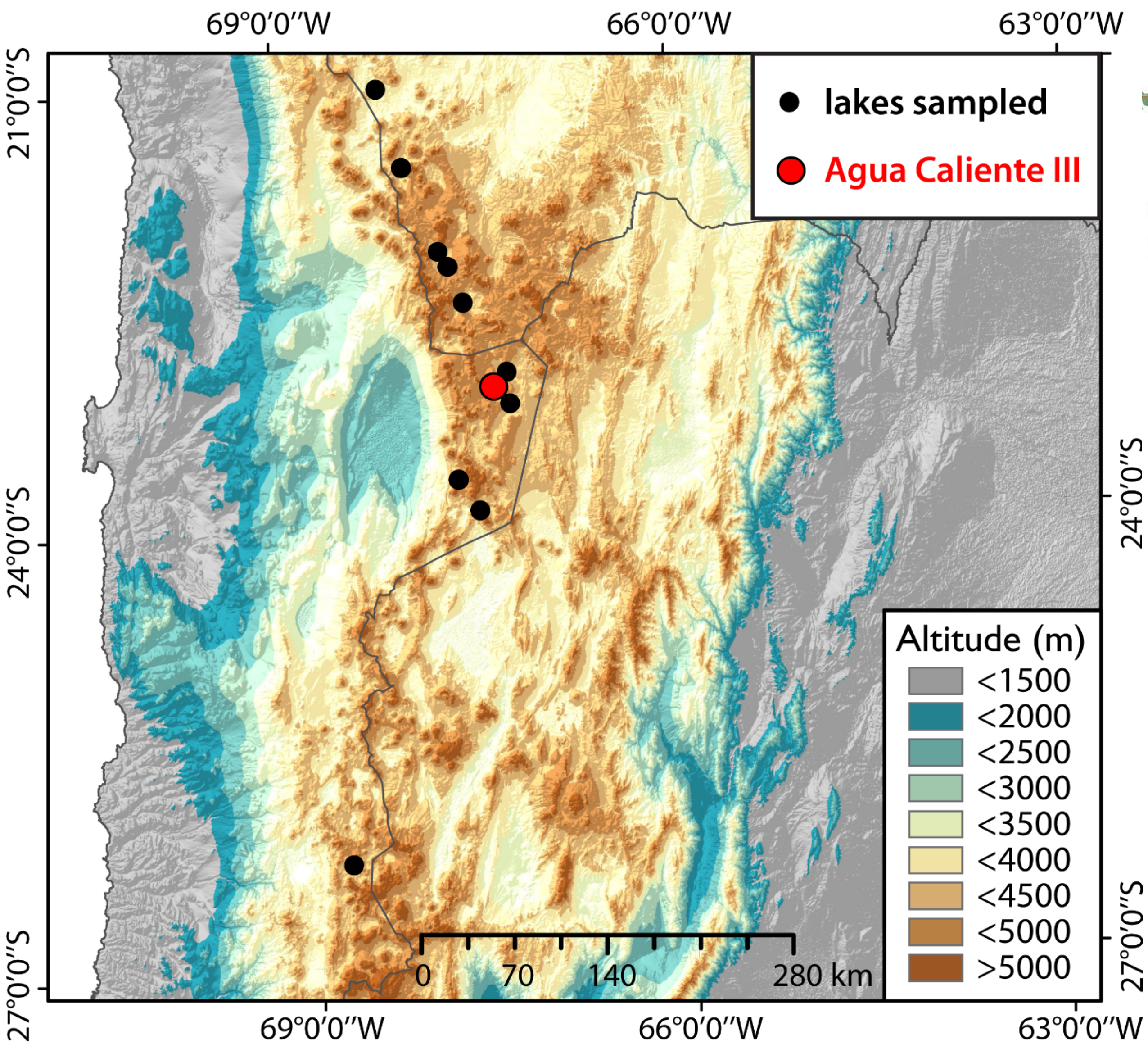
# Seasonal, interannual and spatial precipitation patterns governed by westerly vs. easterly winds



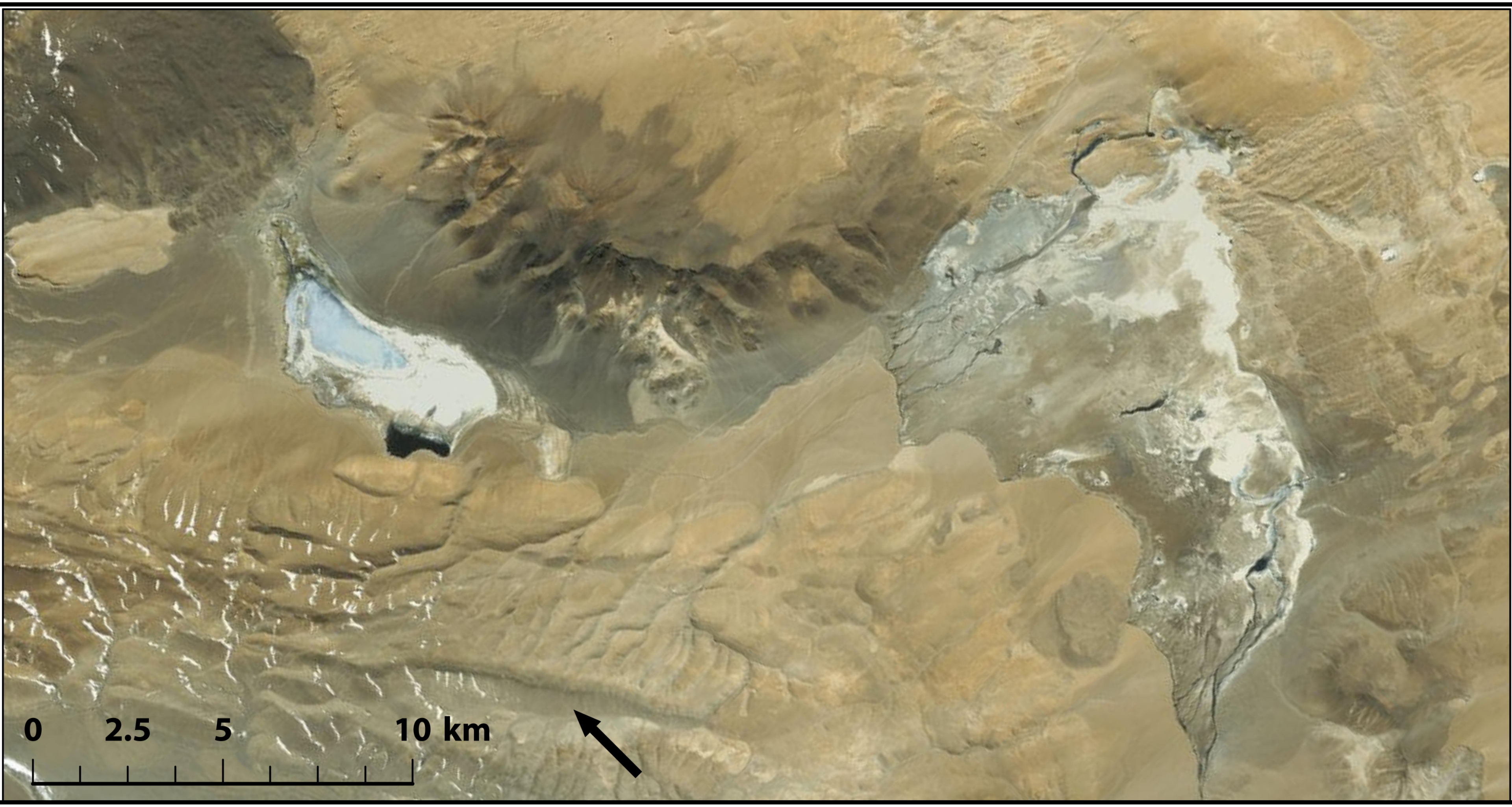

All values averaged between 17.5-20°S in the Andean Altiplano

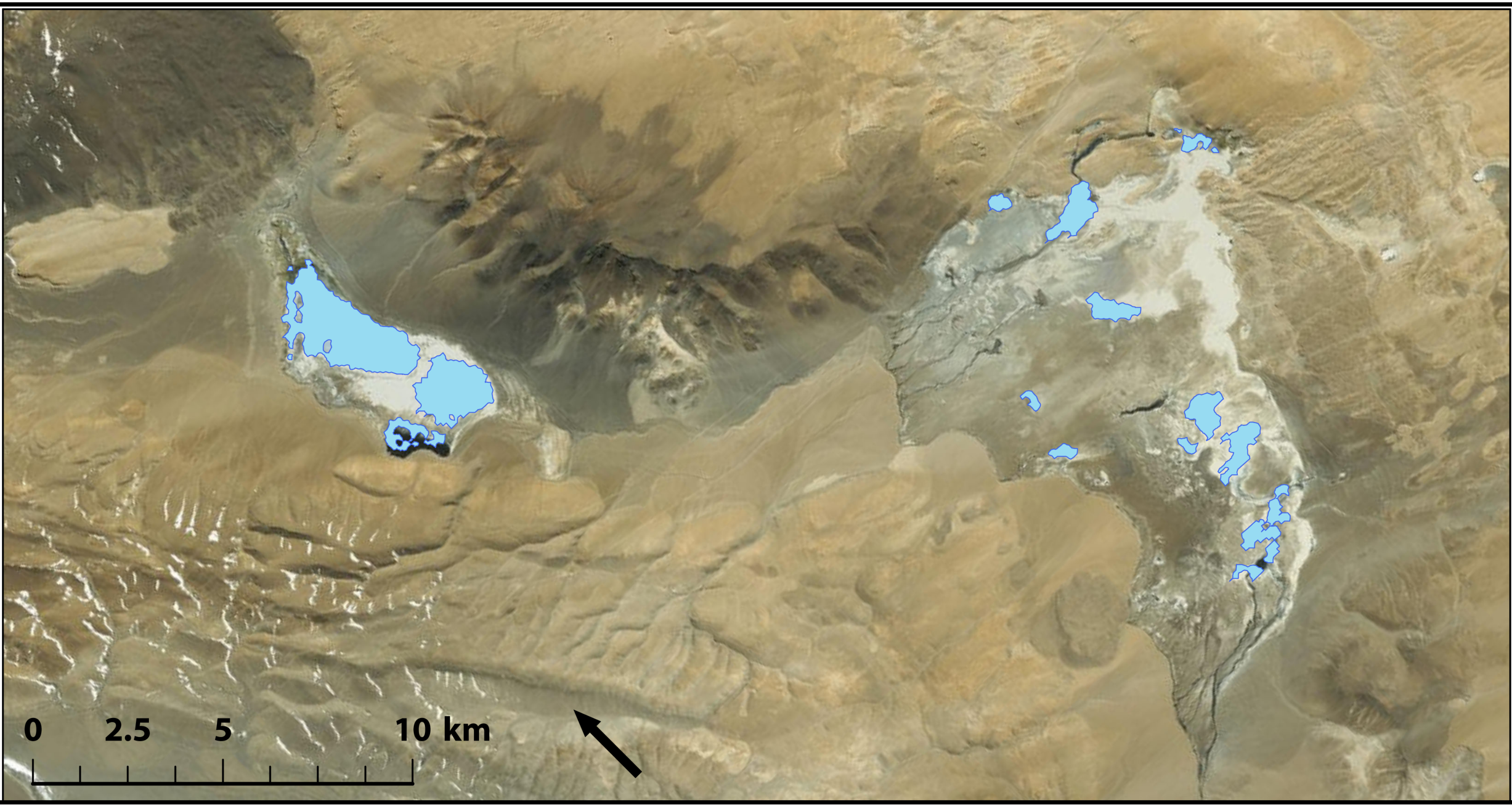
Garreaud et al., Palaeo³ 2003

# A meridional transect of high-elevation lakes

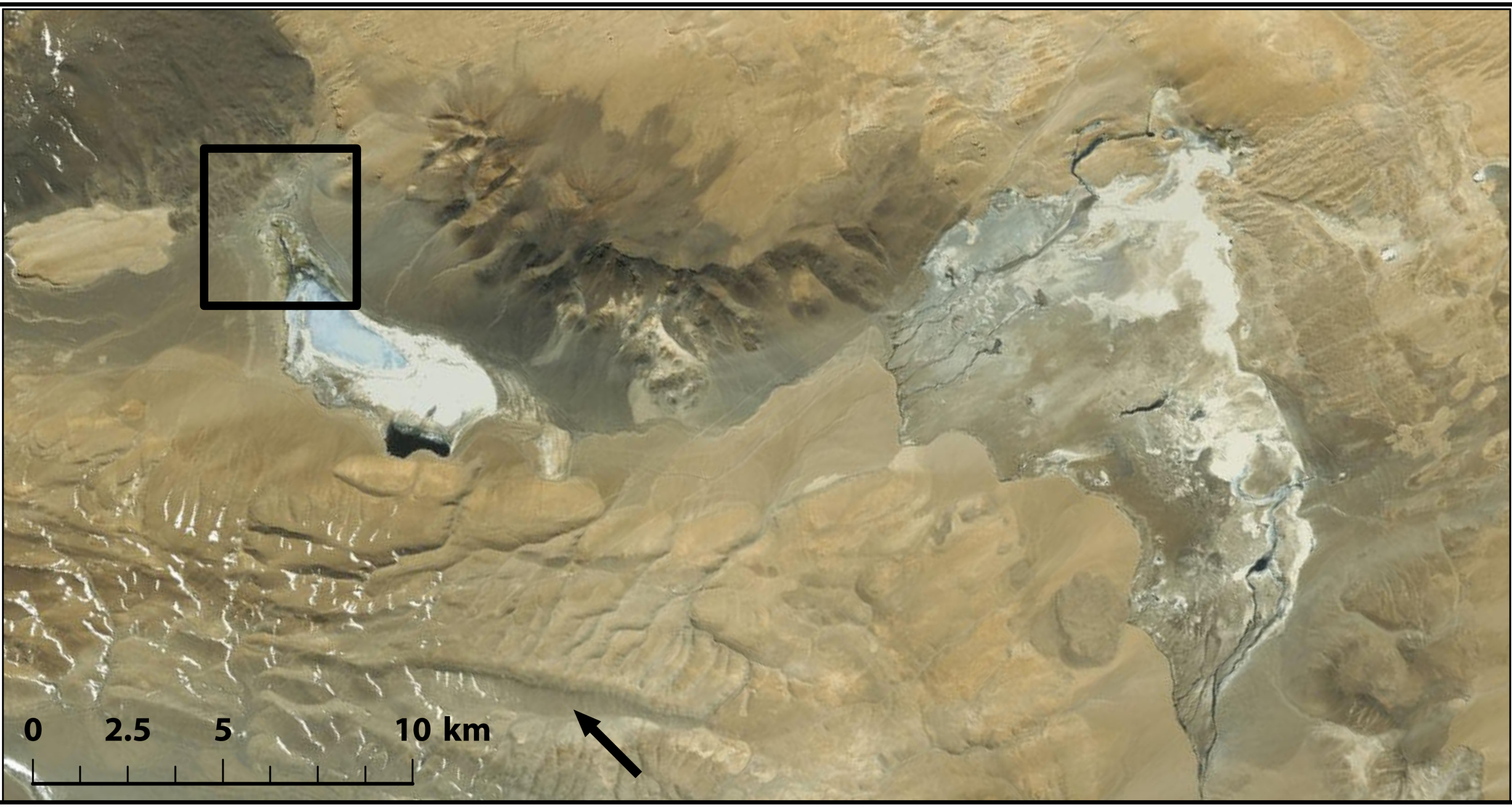


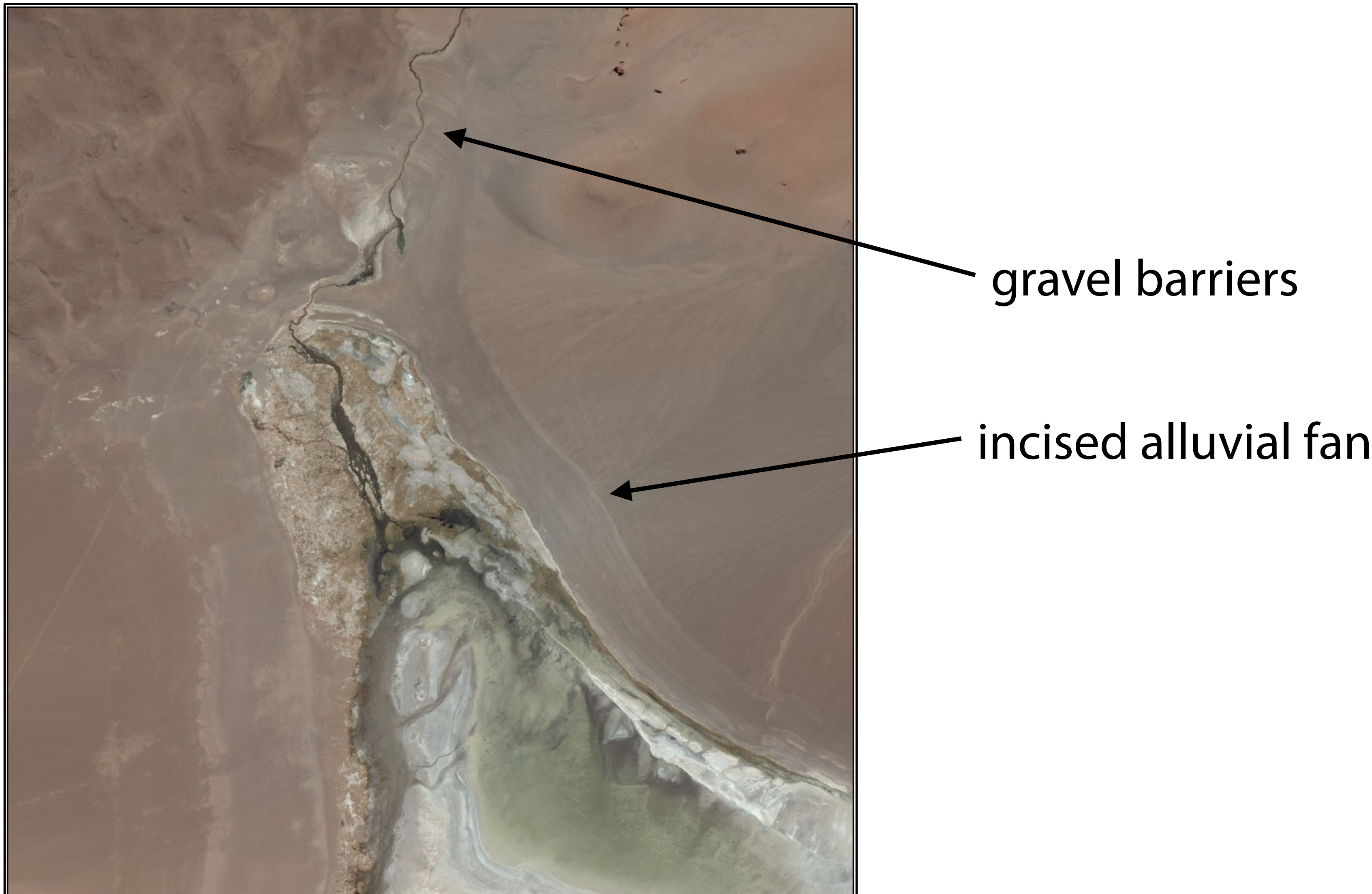

# Laguna Agua Caliente III (23°S)

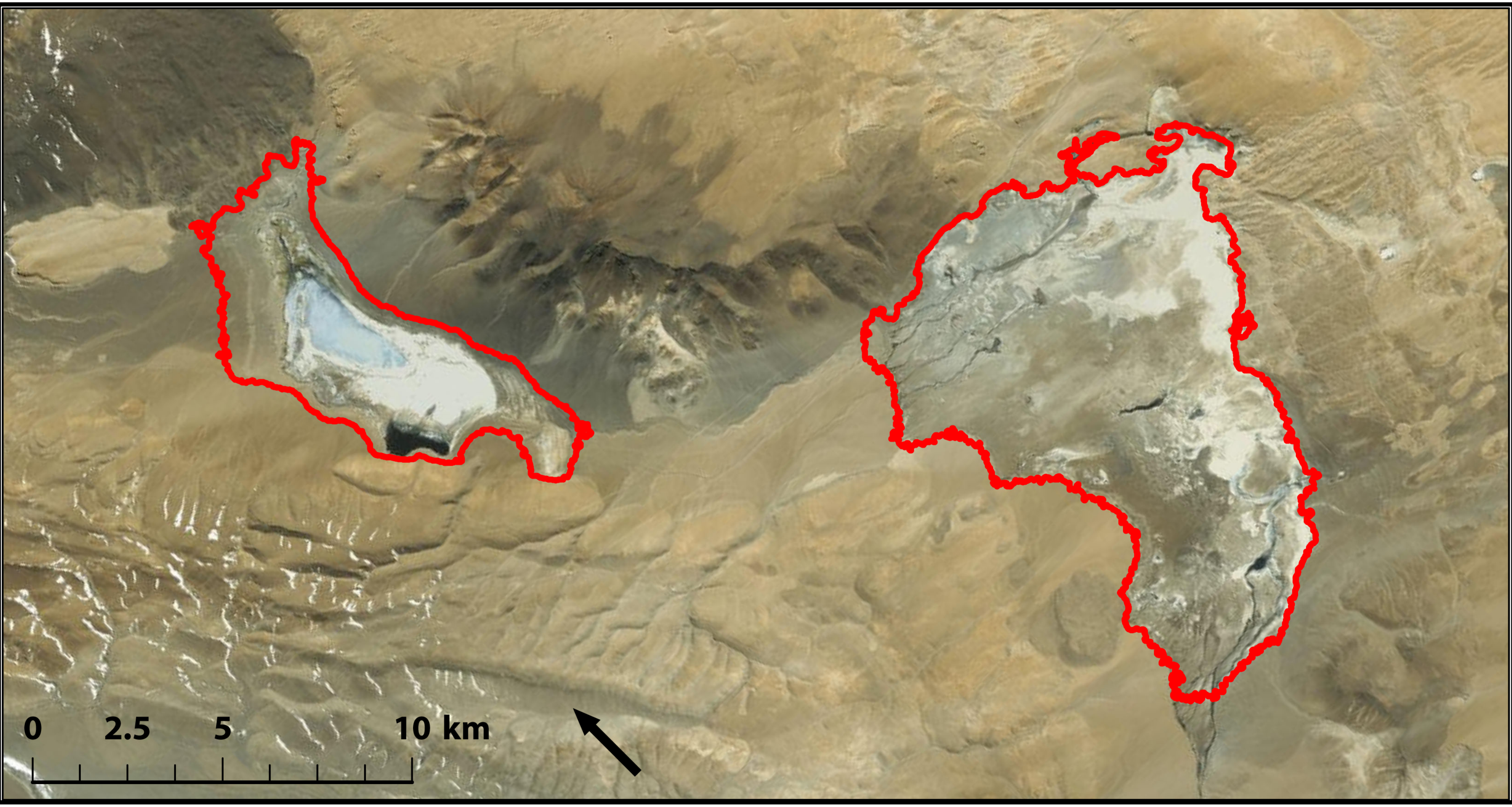




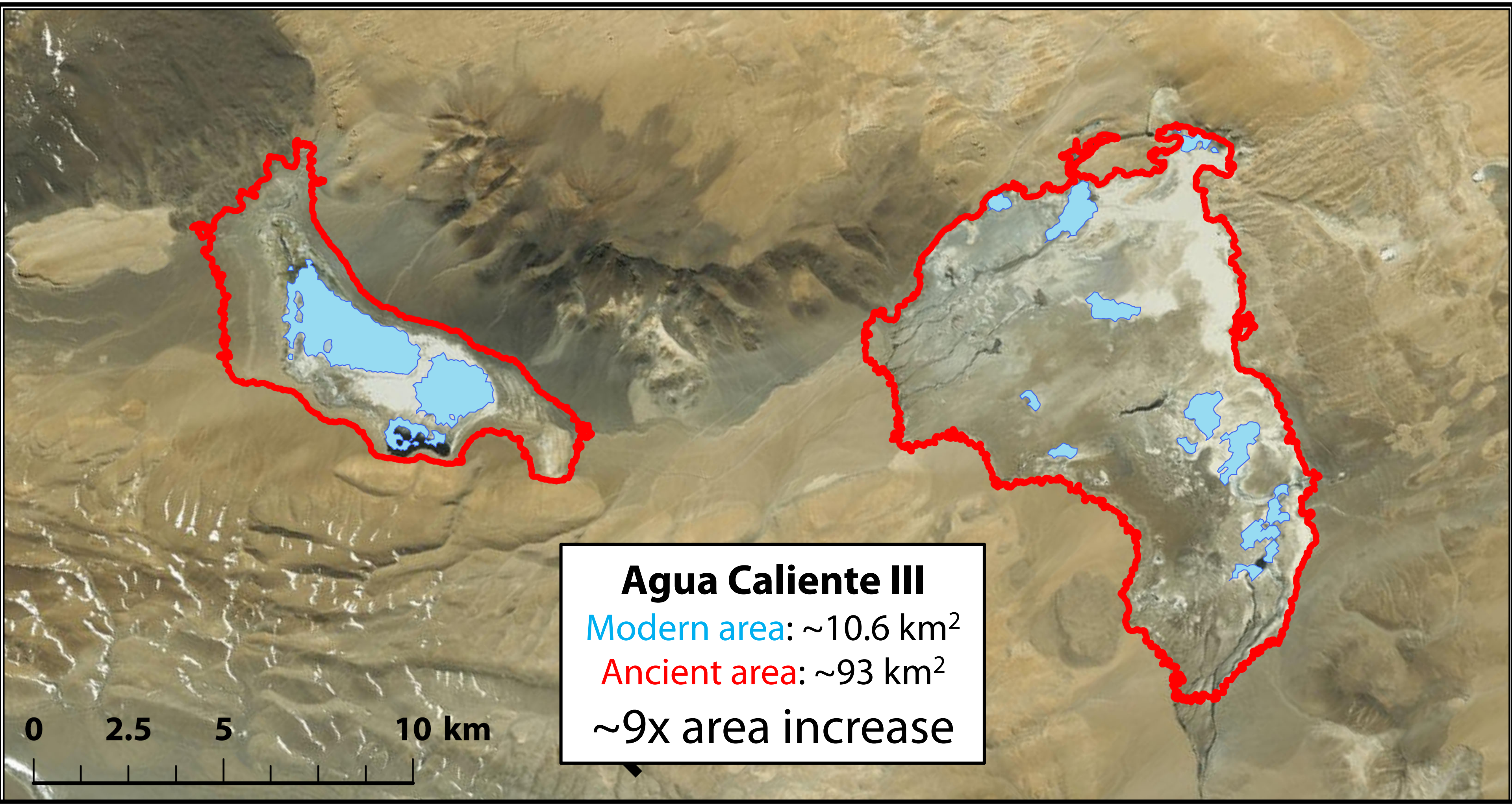
0
2.5
5
10 km

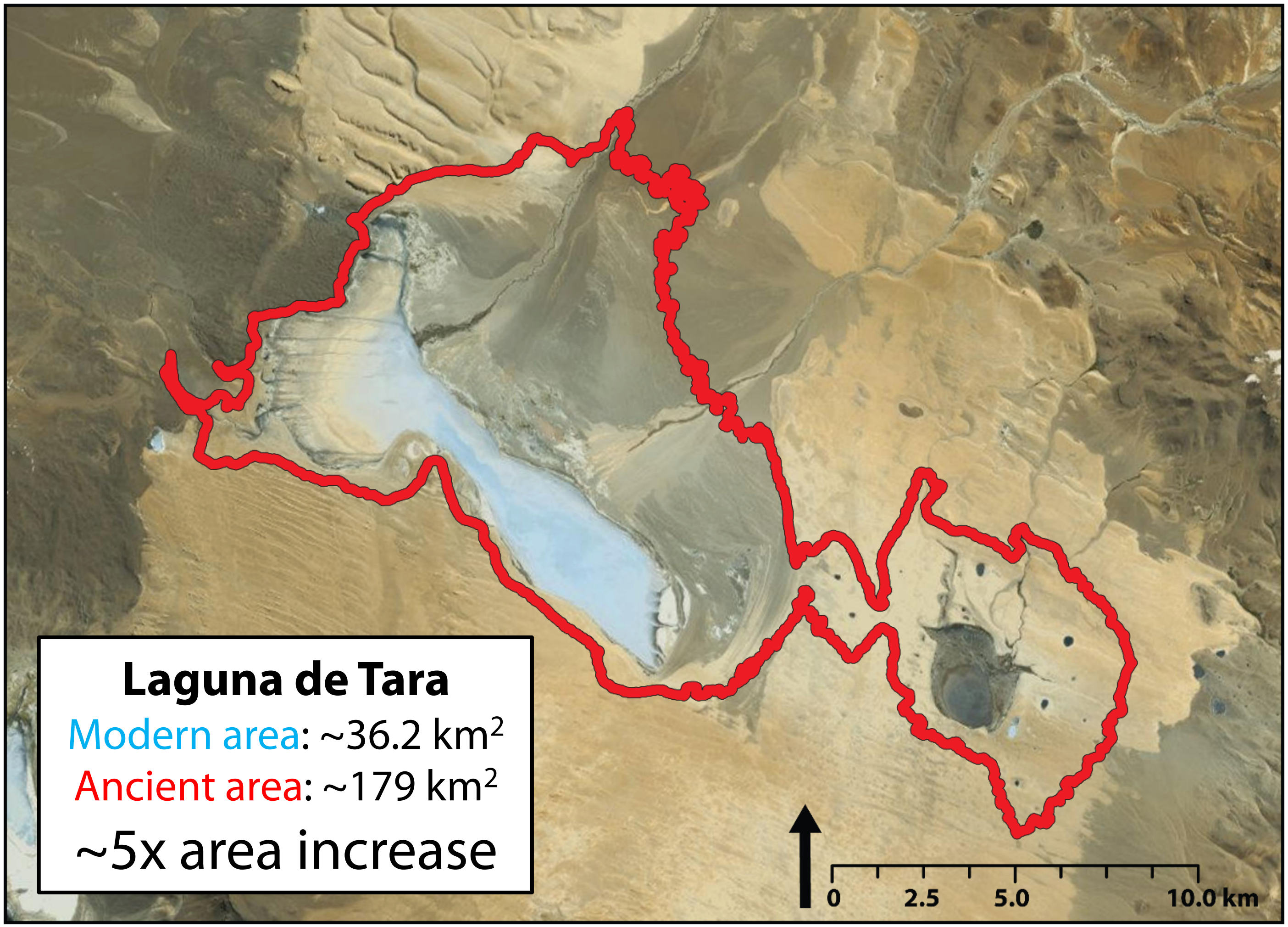

0
2.5
5
10 km


gravel barriers
incised alluvial fan



0
2.5
5
10 km


Agua Caliente III
Modern area: ~10.6 km²
Ancient area: ~93 km²
~9x area increase
0 2.5 5 10 km


Laguna de Tara
Modern area: ~36.2 km²
Ancient area: ~179 km²
~5x area increase
0
2.5
5.0
10.0 km

# Previous dating efforts hampered by $^{14}C$ reservoir effects (1-10 kyrs)

# Conclusions

- Zonally and annually averaged tropical rain belt location changes on millennial timescales over the last 25,000 years were likely $\leq 1^{\circ}$.
- Cross-equatorial AHT changes may have been substantial, and changes in HS1 allow for a partial or complete shutdown of cross-equatorial ocean heat transport by the Atlantic's overturning circulation.
- Large changes in regional and seasonal precipitation associated with monsoons still likely, in part due to ocean-land shifts in precipitation.
- Central Andes lakes suggest maximum southward displacement of subtropical mid-tropospheric westerly winds over South America during cold events in NH.