Tracing tropical precipitation changes in past climates:

From individual lake basins to the zonal mean

David McGee, MIT
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From individual lake basins to the zonal mean
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

Changes in the interhemispheric temperature gradient

**YD:** Younger Dryas  
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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

More winter precipitation in SW USA
Antiphasing of NH vs. SH monsoons

Eastern China

Southern Brazil

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.
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.

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
Seasonal relationship captured reasonably well by GCMs

Seasonal cycle of ITCZ location and cross equatorial heat transport in CMIP3 models

Donohoe et al., J. Climate 2013
Annual mean responses in climate change experiments

Best-fit slope similar to seasonal relationship
Even large changes in ocean circulation should have small impact on mean rainbelt position.
Tropical SST gradients also correlate with rainbelt position in the annual mean...
...and in climate change experiments

Rainbelt position

![Graph showing relationship between change in tropical SST gradient and change in rainbelt position.](image)

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
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.
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)
Fingerprinting past atmospheric changes
Dust and lake records track poleward edges of monsoons

Mixing in of dry mid-latitude air
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., Palaeo³ 2009
Central Andes lakes: A window into the SH subtropical mid-troposphere

Garreaud et al., Palaeo3 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
A meridional transect of high-elevation lakes
Laguna Agua Caliente III (23°S)
gravel barriers
incised alluvial fan
Agua Caliente III

Modern area: ~10.6 km$^2$
Ancient area: ~93 km$^2$
~9x area increase
Laguna de Tara
Modern area: ~36.2 km²
Ancient area: ~179 km²
~5x area increase
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.