

Why is the ITCZ in the Northern Hemisphere? Role of the AMOC



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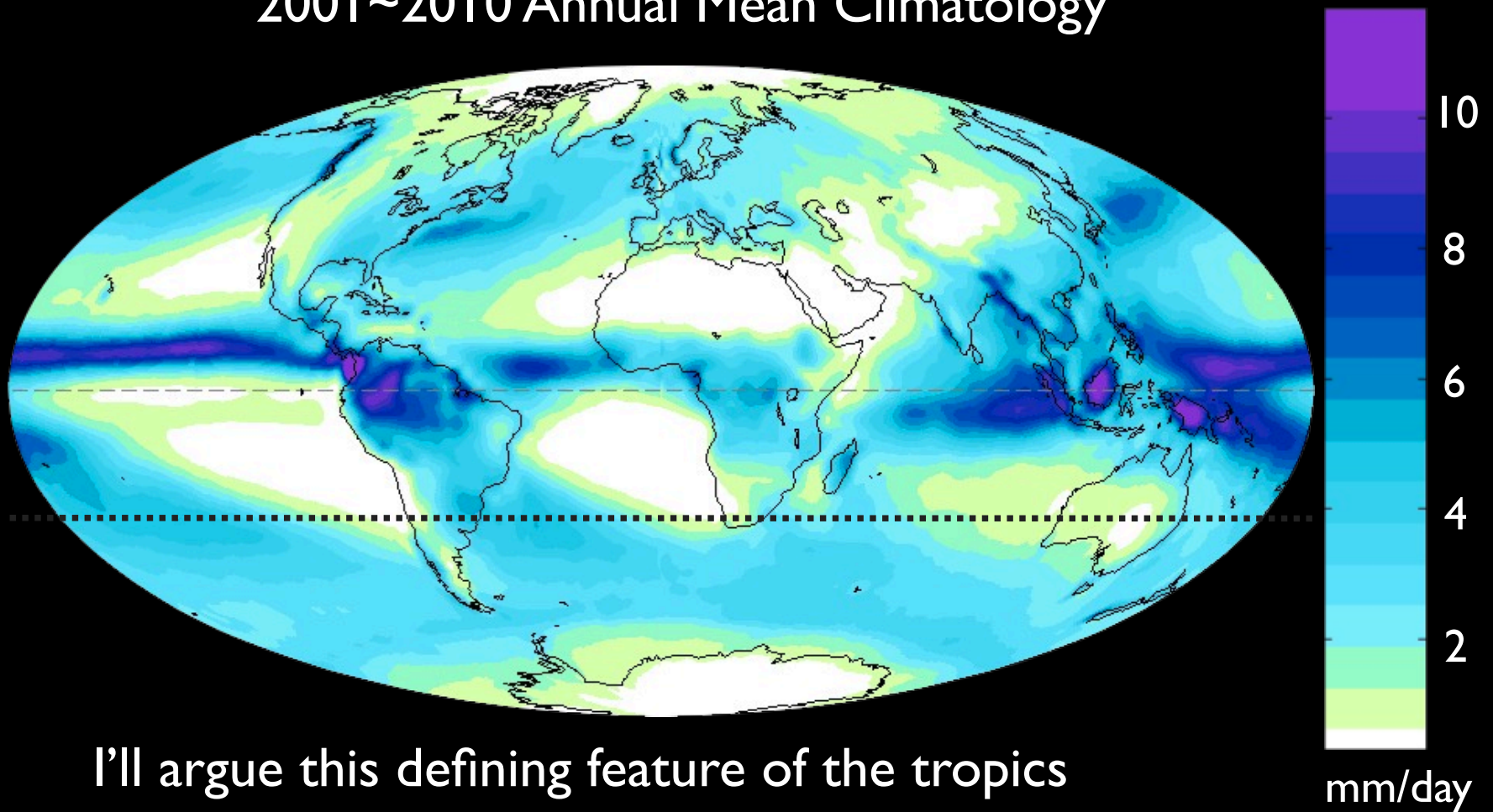
SARAH KANG
**ULSAN NATIONAL INSTITUTE OF SCIENCE AND
TECHNOLOGY**

AND OTHERS...

US AMOC SCIENCE TEAM MEETING, 9-9-14

Tropical rainfall clearly favors the NH

GPCP Precipitation
2001~2010 Annual Mean Climatology



I'll argue this defining feature of the tropics
is due to the AMOC

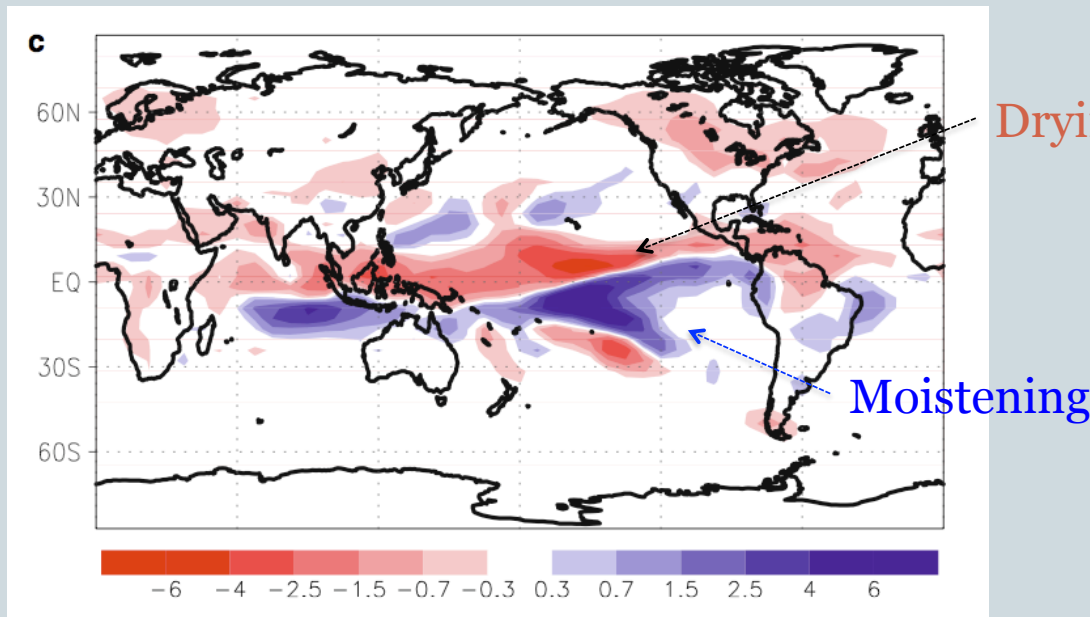
Outline



- Our theoretical framework
 - With some idealized model simulations mixed in
- Why is the ITCZ in the north?
 - An analysis of top-of-atmosphere radiative fluxes and ocean heat transports
 - ✦ Is the NH or SH heated more?
 - Model simulations with modified ocean heat transports
- Main reference: Frierson, Hwang, Fučkar, Seager, Kang, Donohoe, Maroon, Liu, and Battisti, Nature Geoscience, 2013

ITCZ Response to High Latitudes

- Pioneering work by Chiang and Bitz (2005) showed strong sensitivity of ITCZ to high latitude sea/land ice in Last Glacial Maximum conditions



Drying

ITCZ shifts away from cooled NH

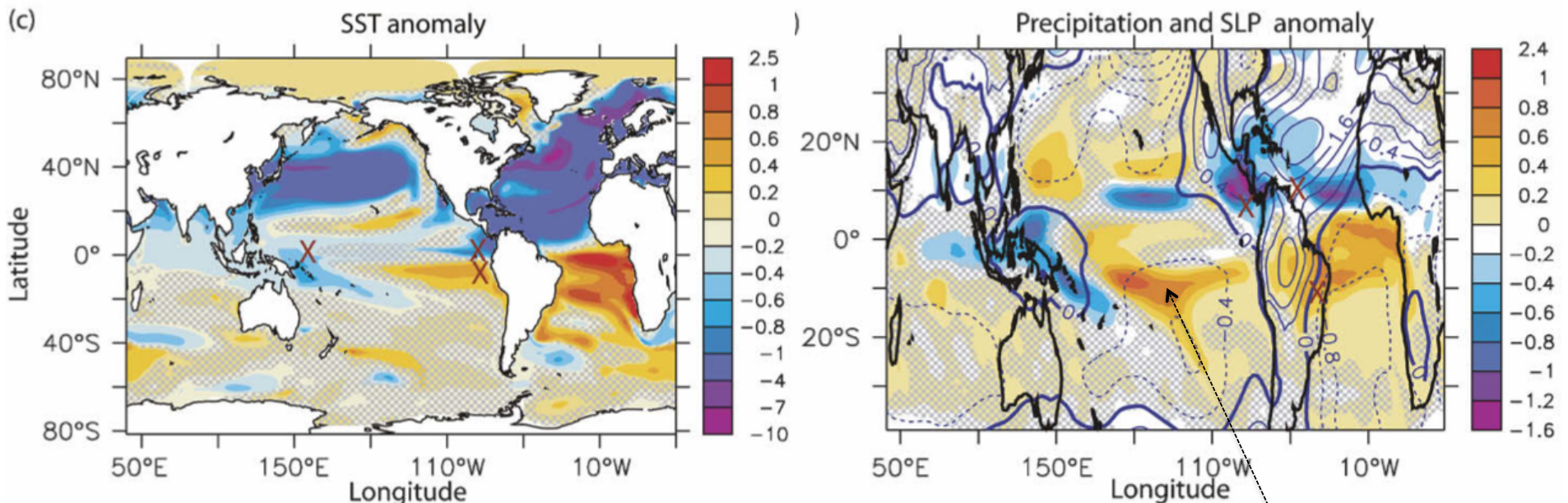
Paleoclimate data is consistent with such a shift

See also simulations by Broccoli et al

From Chiang and Bitz (2005)

ITCZ Responds to Freshwater Hosing

- Zhang and Delworth (2005) added a freshwater flux of 0.6 Sv to the N. Atlantic (55-75° N, 63° W-4° E)
 - Change in SST and precip (avg from yrs 21-60):

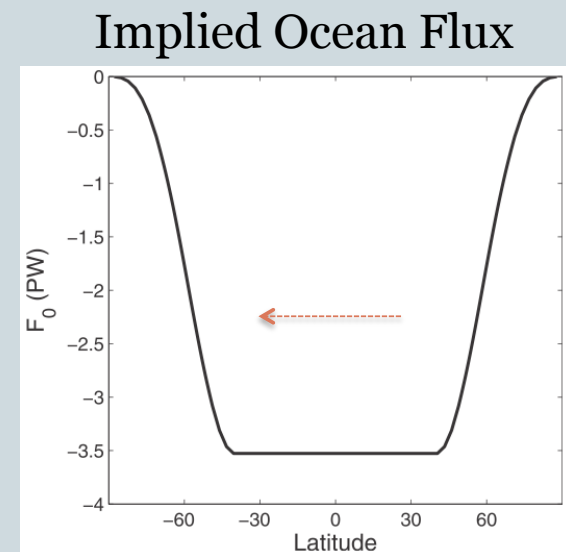
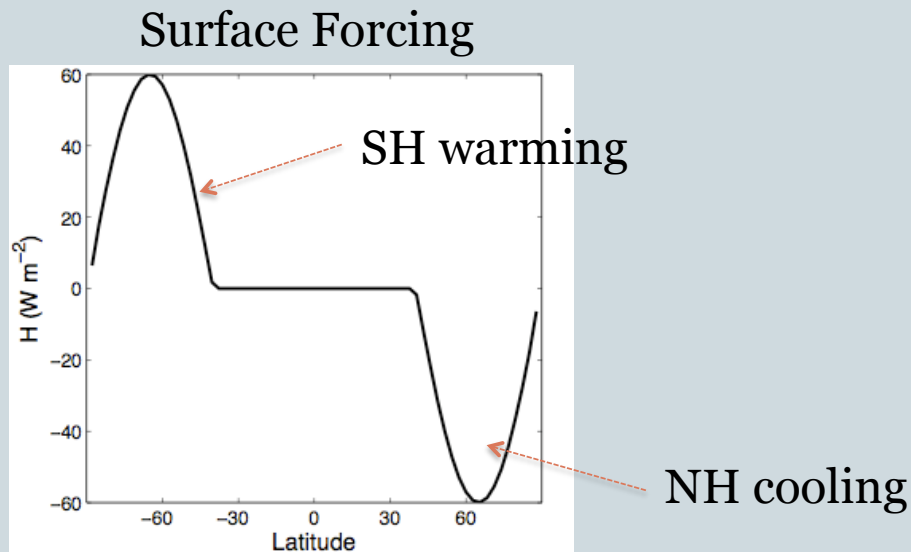


Cooling throughout NH, warming especially in S. Atlantic

Precip shifts southward

Our Studies of Extratropical Influences on ITCZ

- Sarah Kang's thesis (2009):
 - Idealized experiments on the effect of high latitude forcing on ITCZ location
 - **Aquaplanet GCM (AM2)** runs w/ idealized forcing:



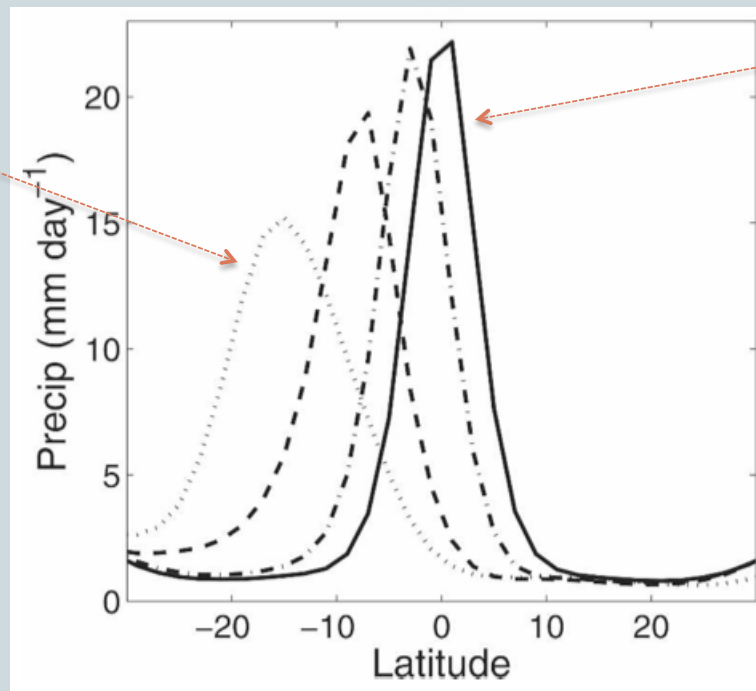
From Kang, Held, Frierson, & Zhao (2008) and Kang, Frierson & Held (2009)

ITCZ Changes

- In response to forcing, ITCZ precipitation shifts towards **warmed hemisphere**

Tropical precip in aquaplanet GCM

With strong forcing, ITCZ shifts up to 18 degrees



Control case: ITCZ located on the equator

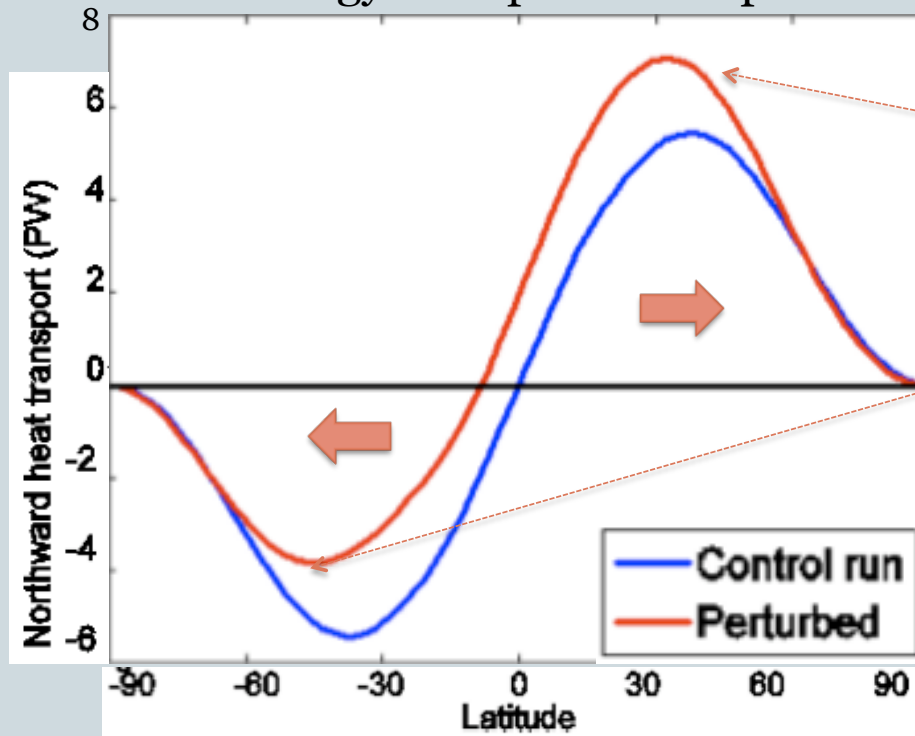
Maximum amplitude of forcing = 0, 10, 30, 60 W/m²

From Kang, Held, Fri., & Zhao (2008, J Clim) and Kang, Fri. & Held (2009, JAS)

Mechanism for ITCZ Response

- We argue **energy transport** is of key importance

Northward energy transport in simplified GCM



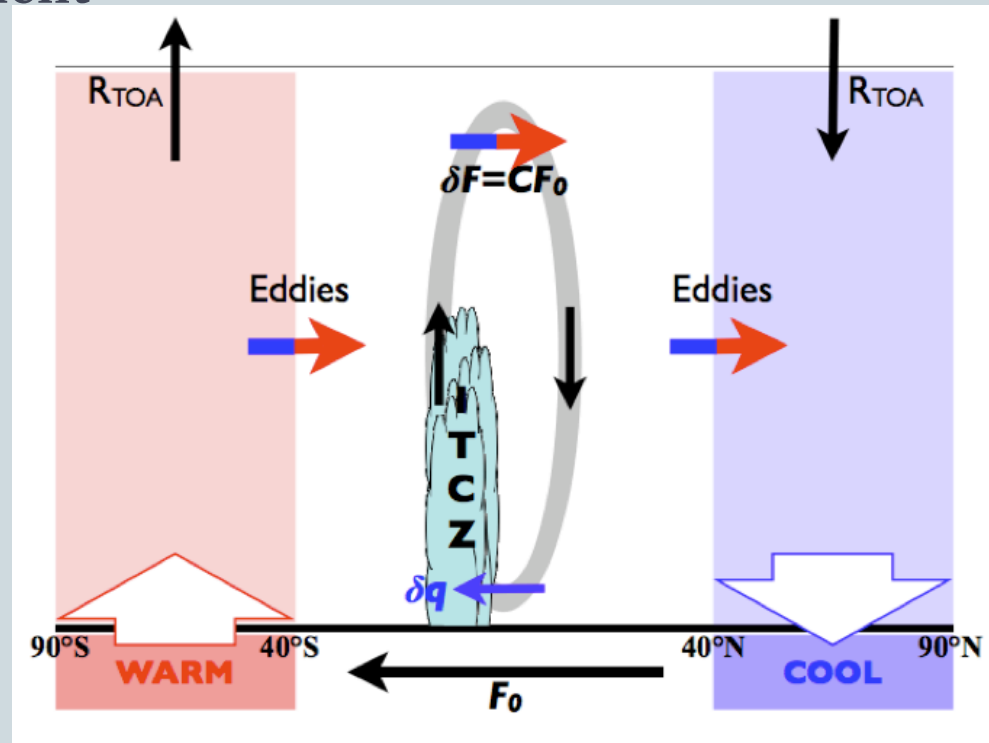
Anomalous energy transport into cooled region

Less transport into warmed region

These act to spread cooling/warming into lower latitudes...

Mechanism for Energy Transport Change

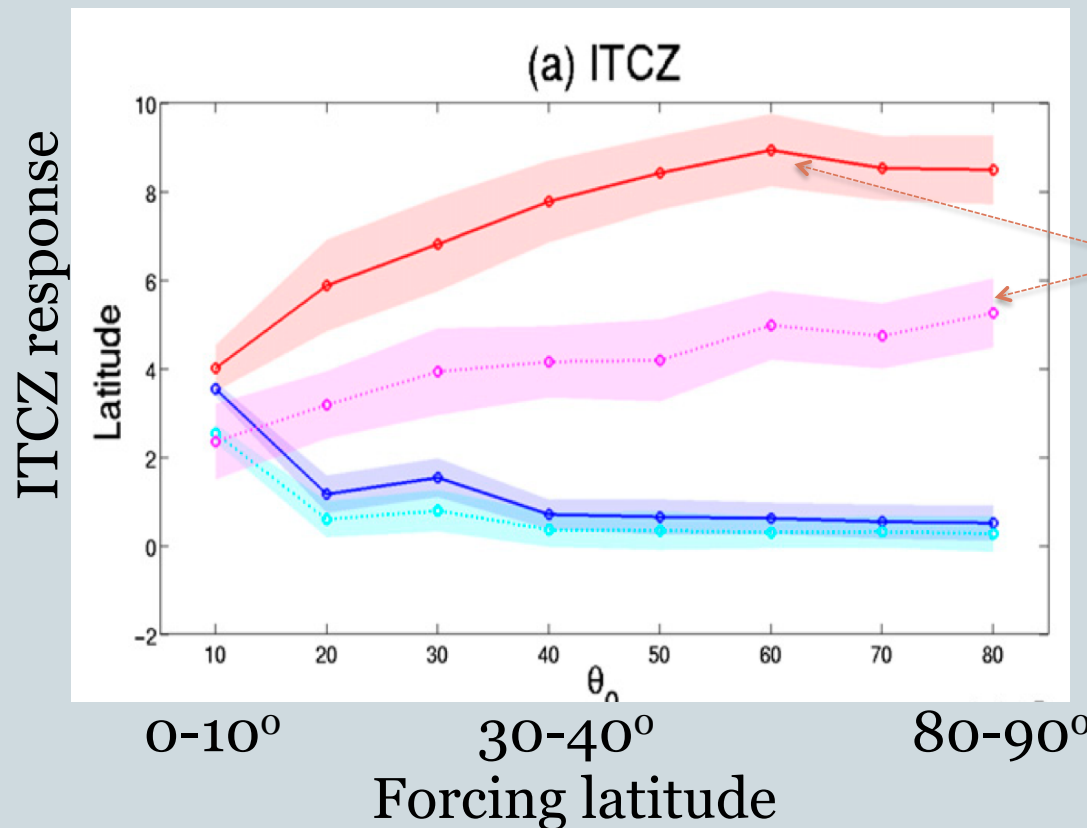
- Eddies modify fluxes in midlatitudes
 - Quasi-*diffusively*: moist static energy transport proportional to moist static energy gradient
- Anomalous **Hadley circulation** modifies fluxes in tropics



See Kang, Held, Fri., & Zhao (2008, J Clim) & Kang, Fri. & Held (2009, JAS) for more

Which Latitudes are Most Important?

- Ocean forcing applied to different ranges of latitudes:



Largest response for **high latitude** forcing!

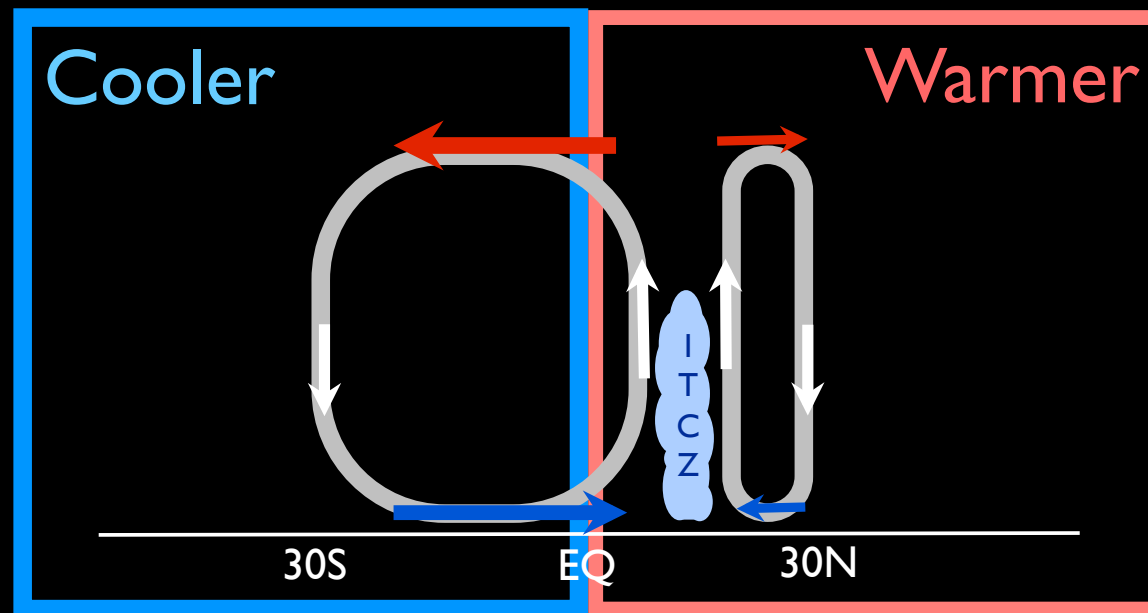
Clouds amplify the surface heating more at higher latitudes

Theoretical Framework Based on Energetics



- We predict tropical rain will shift towards the hemisphere with **more heating**
 - Heating not just at the **surface** though – also SW/LW effects of **clouds**, & clear-sky SW/LW
- Let's examine the heating of the NH/SH at **TOA**, and at the **surface**

Claim: Whatever **heats** the NH atmosphere **more** than the SH also causes the ITCZ to be in the NH



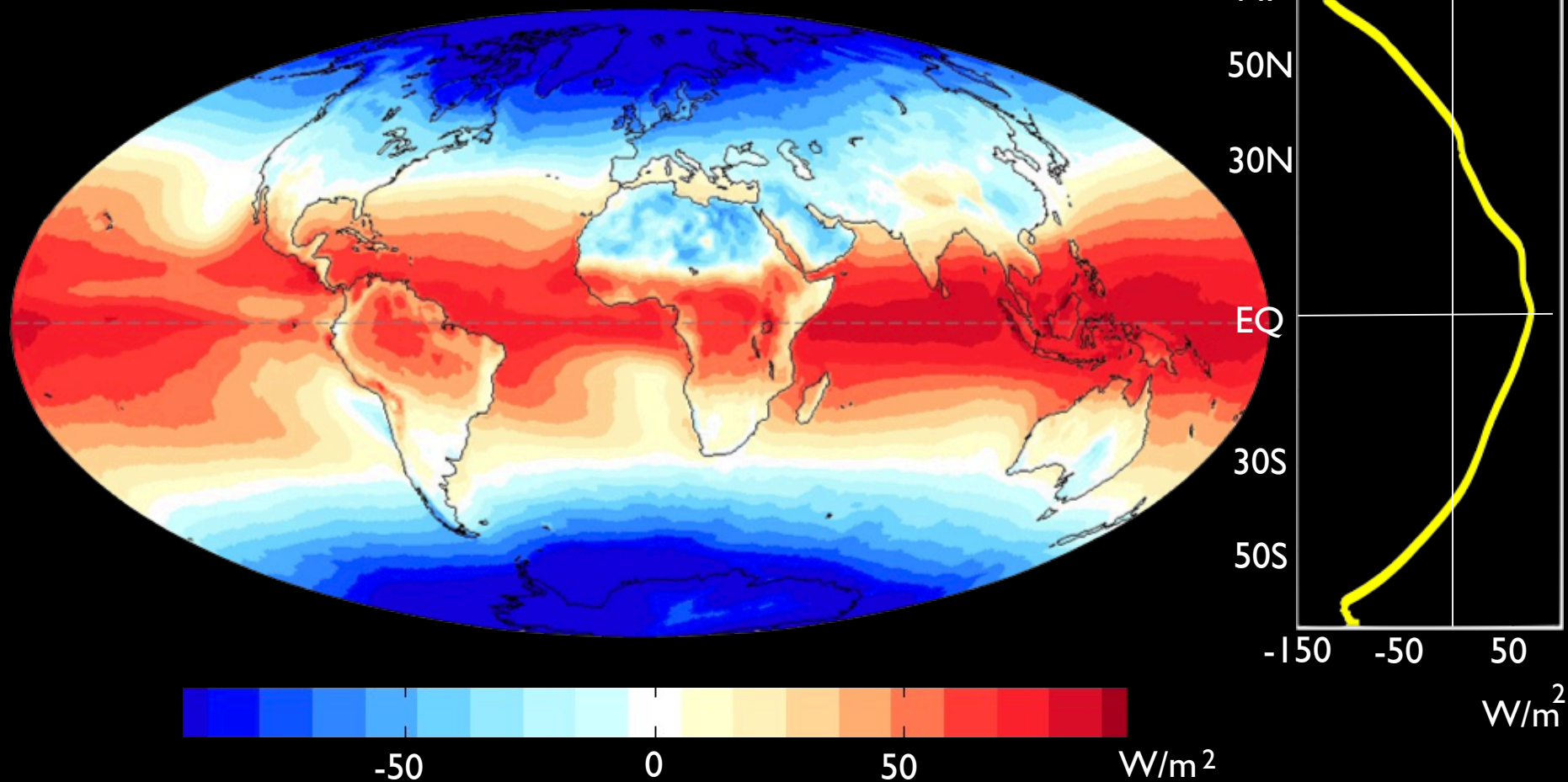
Studies that demonstrate southward cross-EQ energy transport in the atmosphere:

Fasullo and Trenberth 2008, Trenberth and Caron 2001

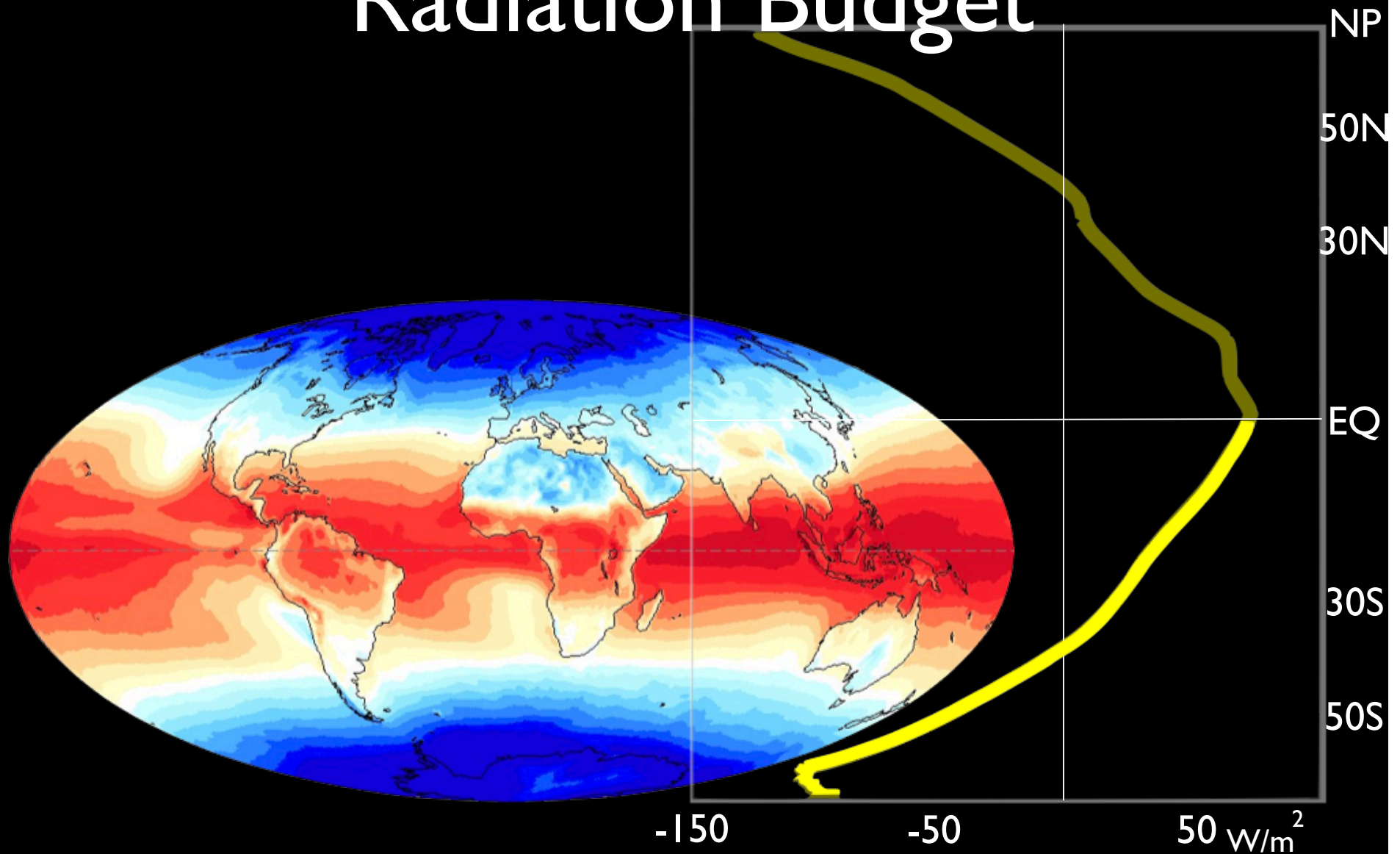
Top of Atmosphere Radiation Budget

Net radiation (net SW minus OLR)

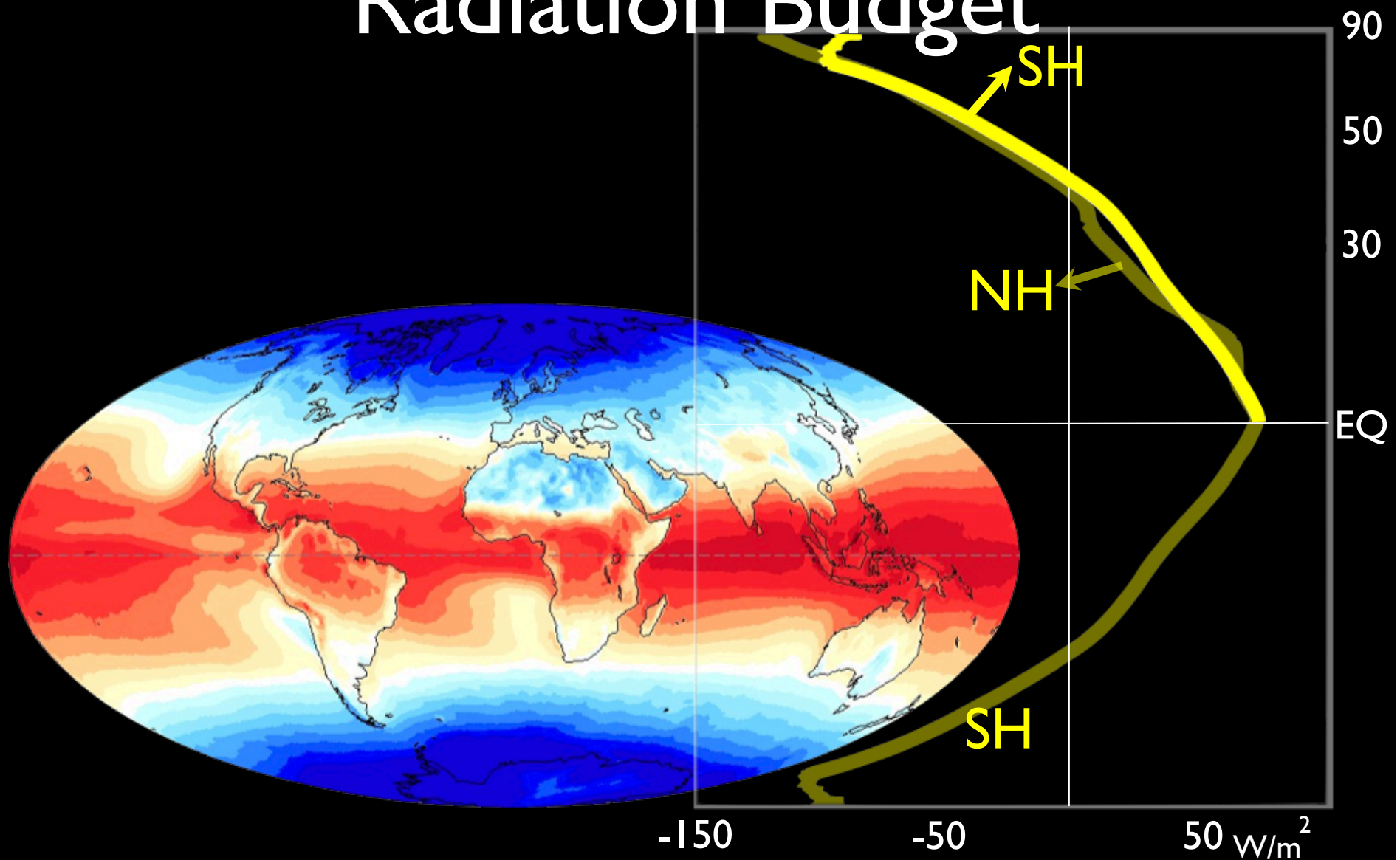
TOA Net Radiation from CERES EBAF
2001~2010 Annual Mean Climatology



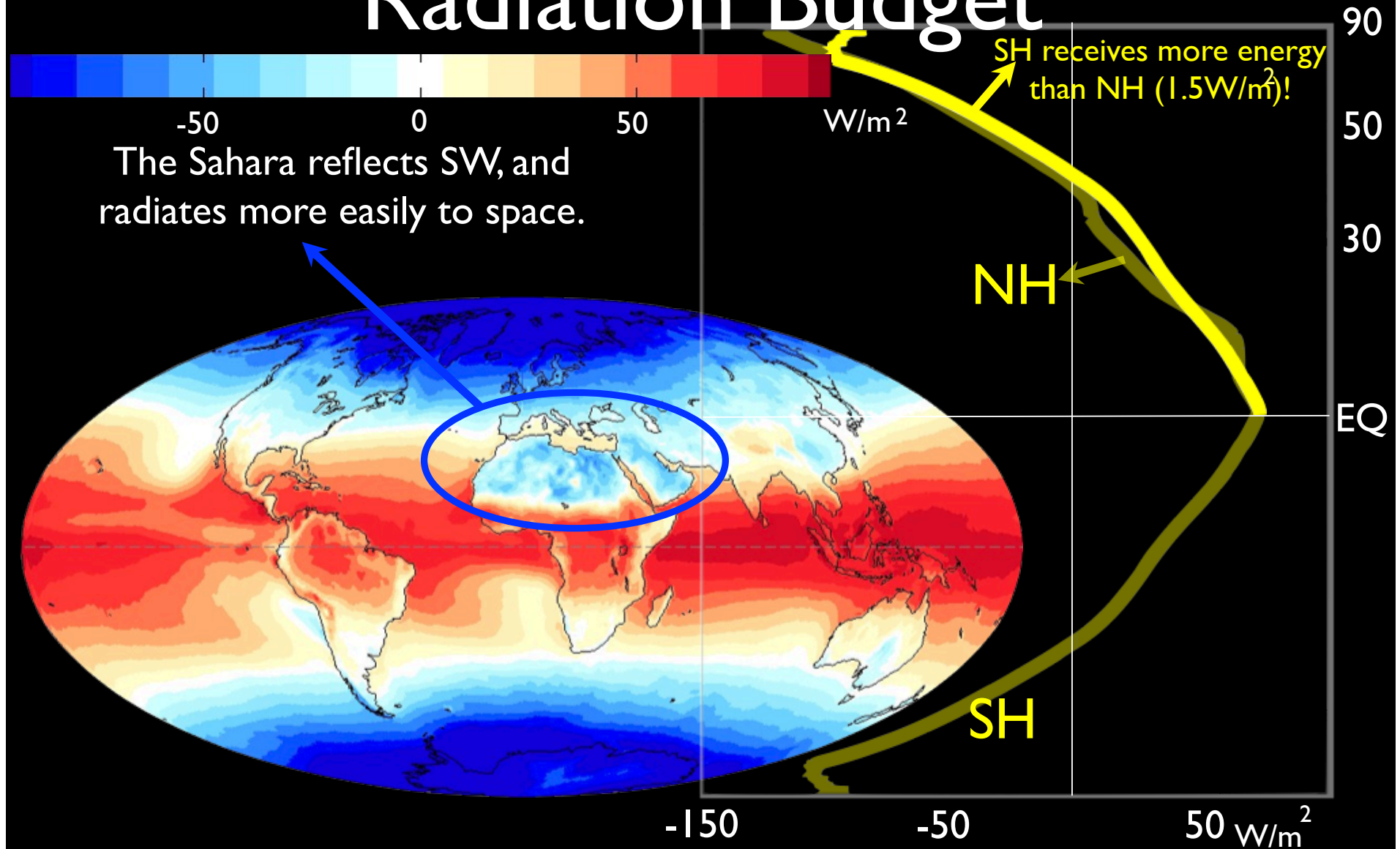
Top of the Atmosphere Radiation Budget

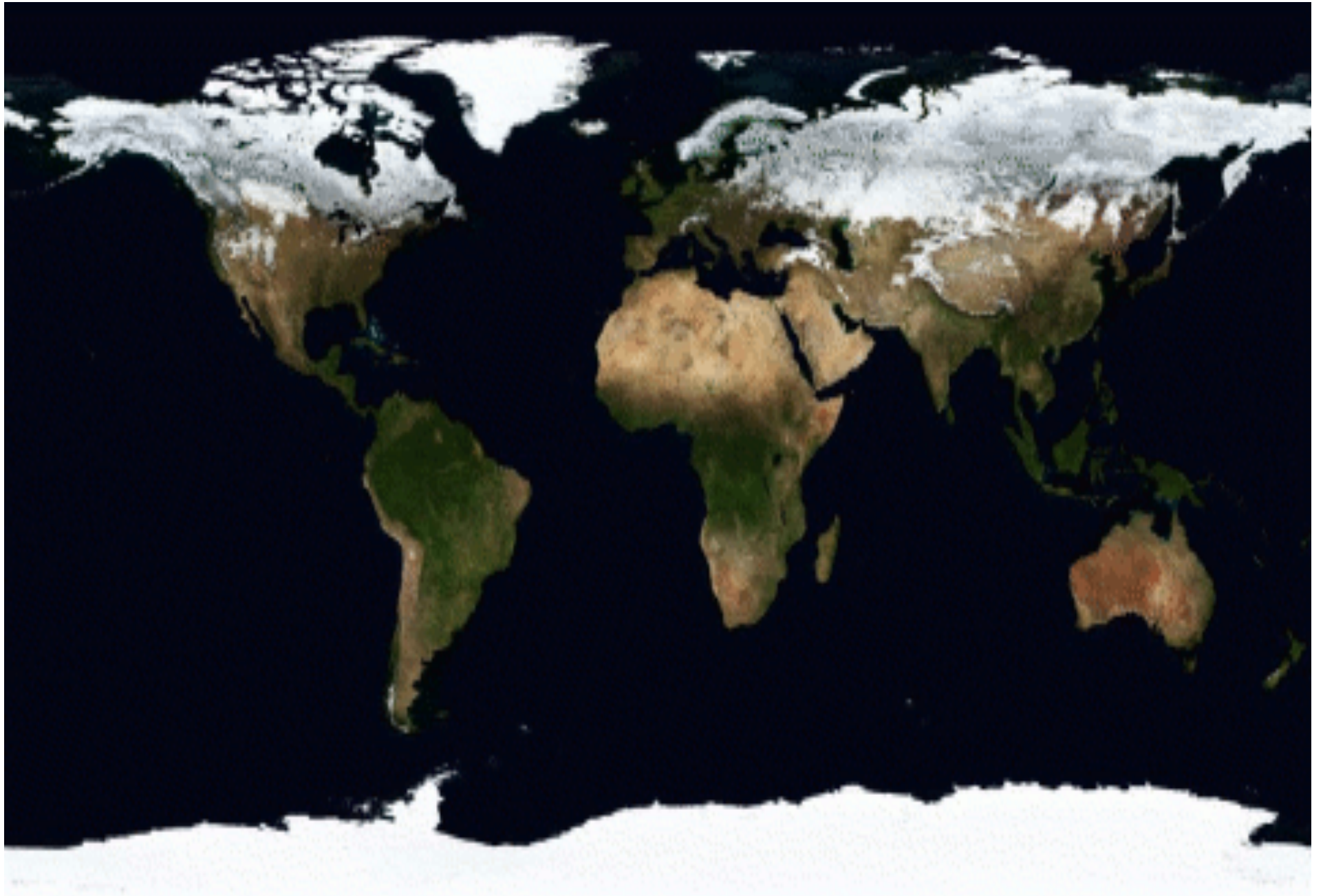


Top of the Atmosphere Radiation Budget



Top of the Atmosphere Radiation Budget





NASA Terra “Blue Marble Next Generation” (cloud-free conditions in 2004)

Recognized by Nimbus III Team

First observation that the Sahara is a net radiation sink, even in summer (1-15 July 1969)

If not radiation,
must be the
ocean??

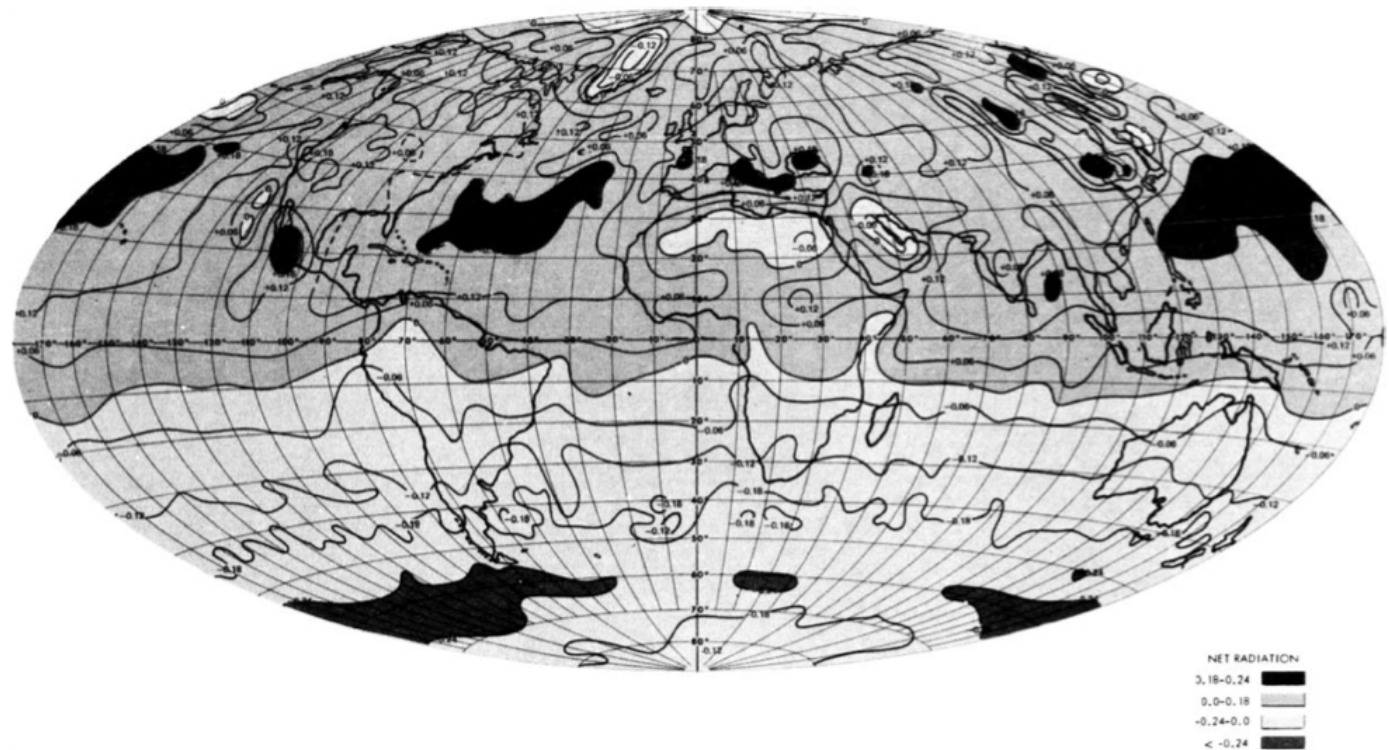
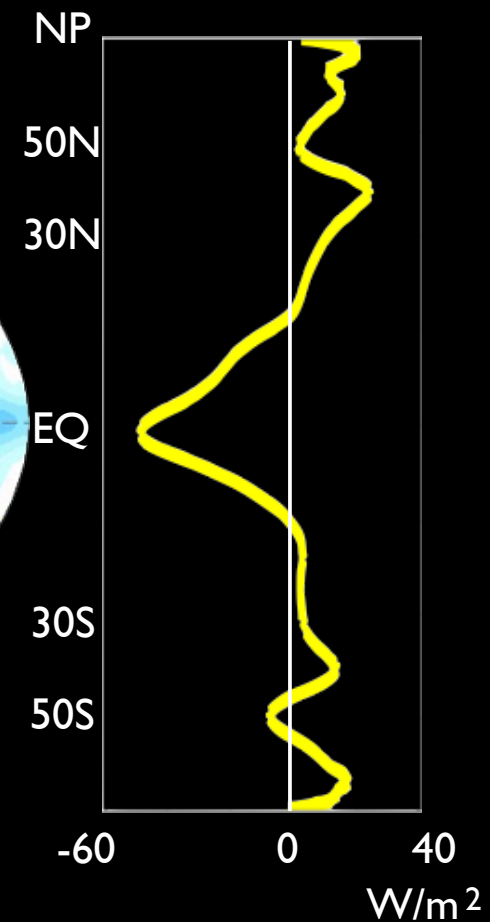
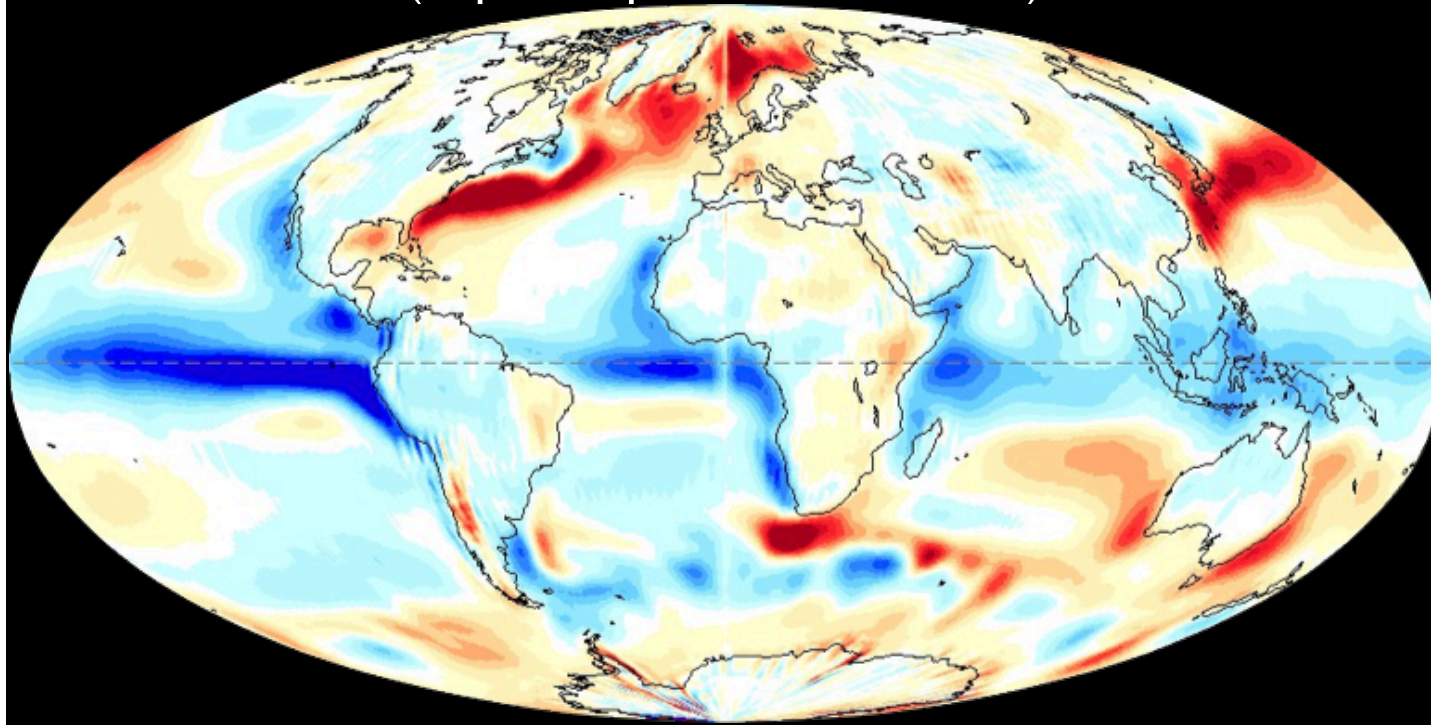


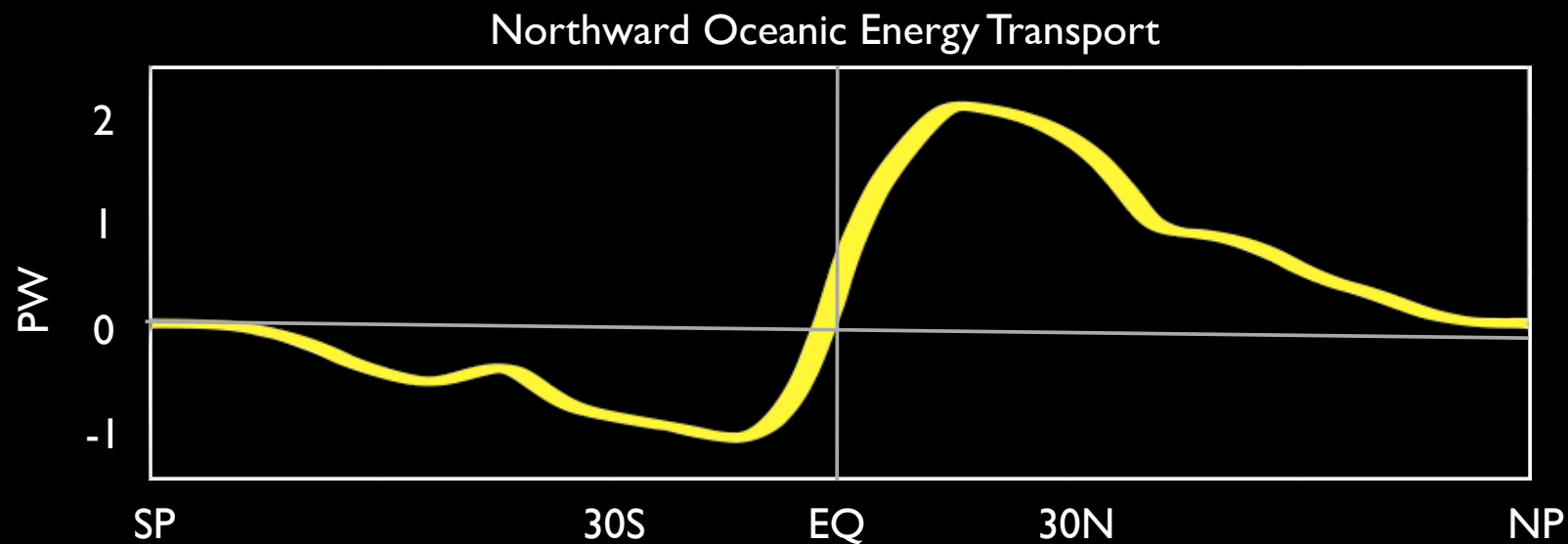
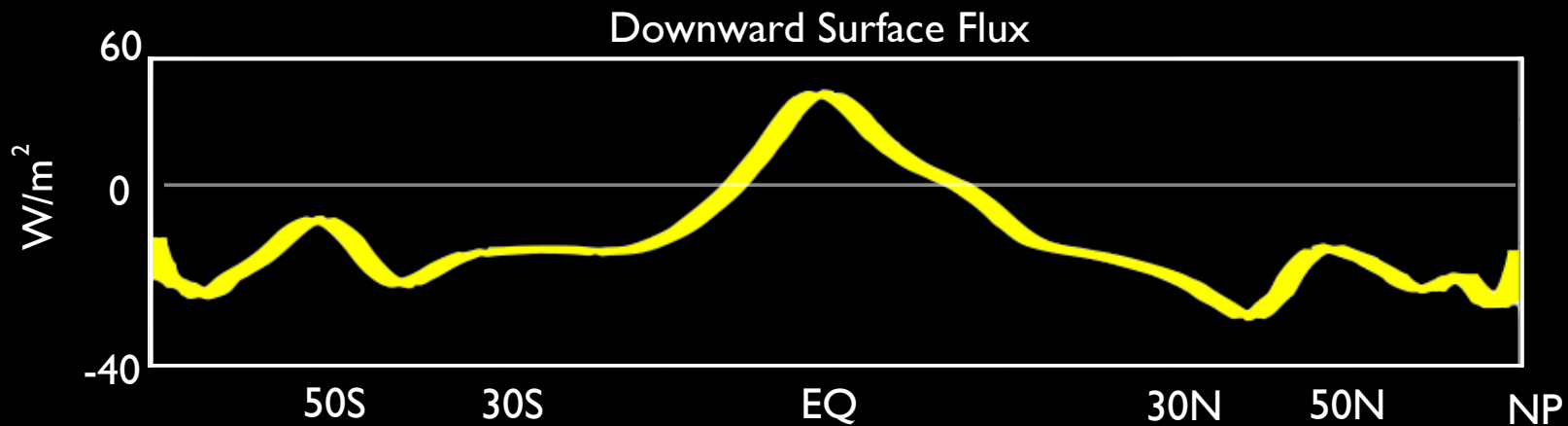
Figure 1. Net radiation at the top of the atmosphere ($\text{cal}/\text{cm}^2/\text{min}$) measured from Nimbus III, 1-15 July 1969.

Surface Flux (Ocean)

2001~2010 ERA-I MSE Divergence minus
CERES TOA Budget
(Implied Upward Surface Flux)

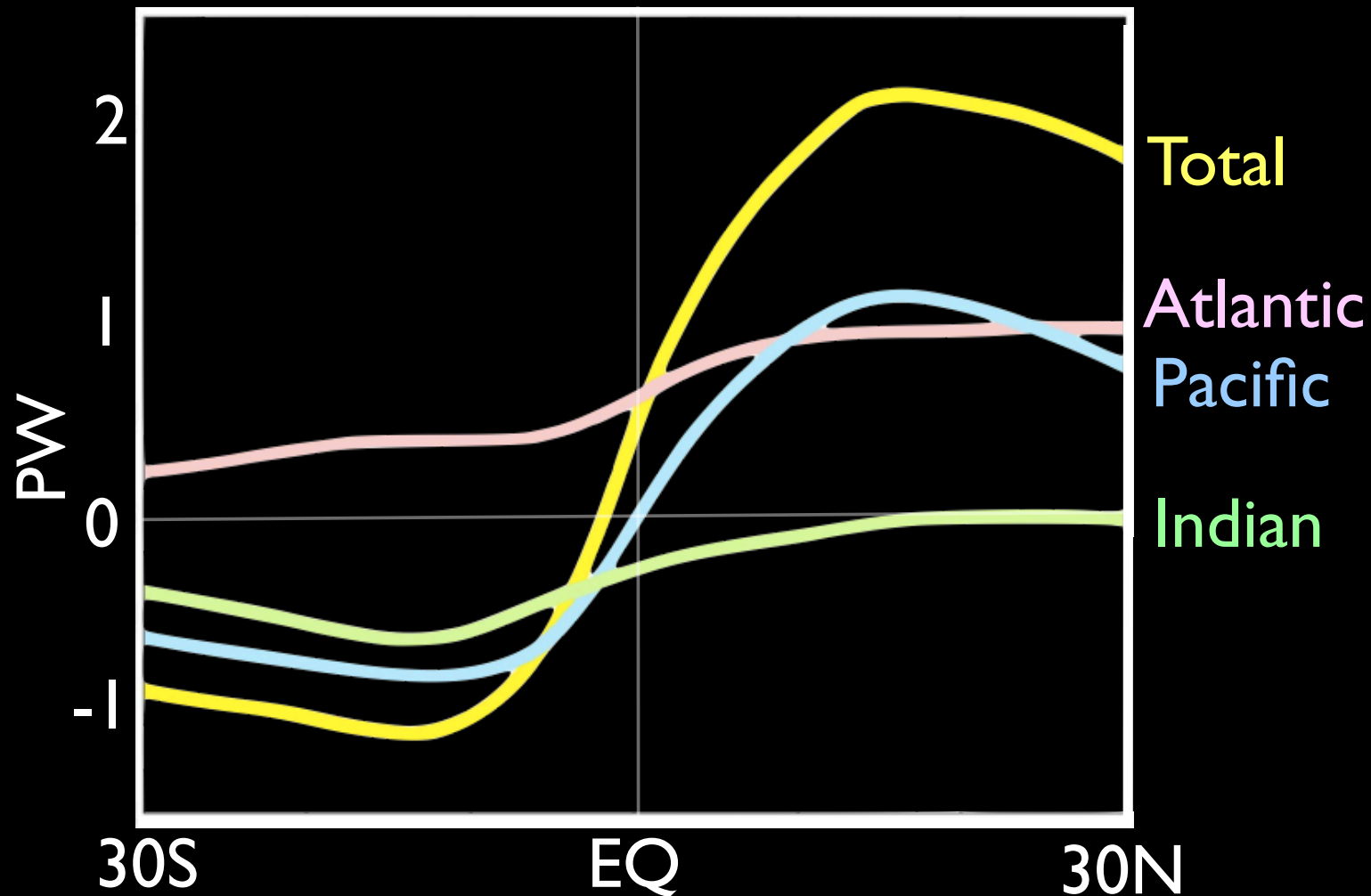


The Ocean Transports Energy Northward Across the Equator (due to the Meridional Overturning Circulation, MOC)



Cross-equatorial Transport Happens Entirely in Atlantic

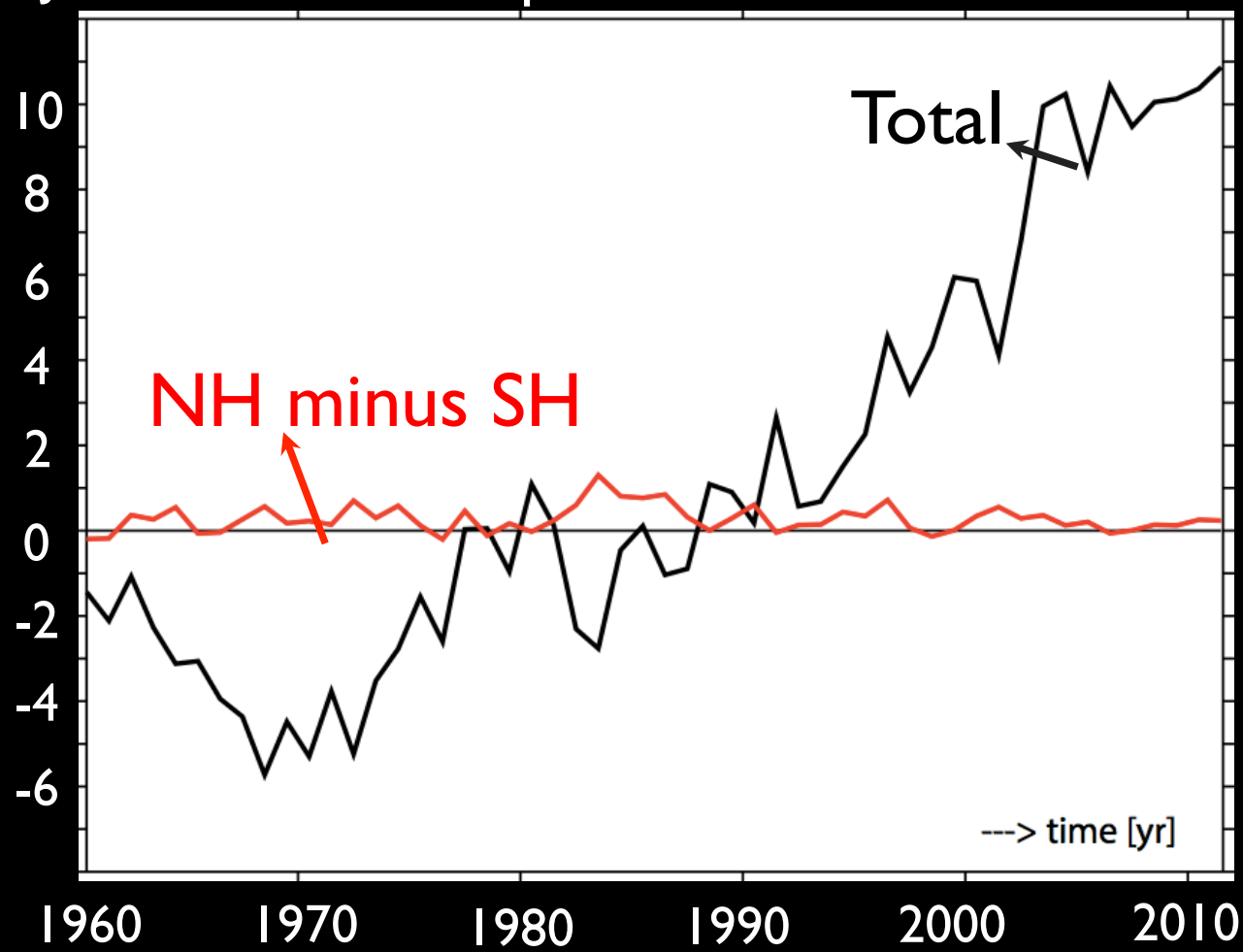
(Where the Sinking from the MOC Occurs)



Ocean Heat Uptake?

Heat Uptake Over
the Top 700m of Ocean

10^{22} Joules



Ocean heat uptake has
been remarkably
symmetric...

Data from top 2000m
only available since 2005,
and the NH minus SH
difference is less than 0.4
 $\times 10^{22}$ Joules.

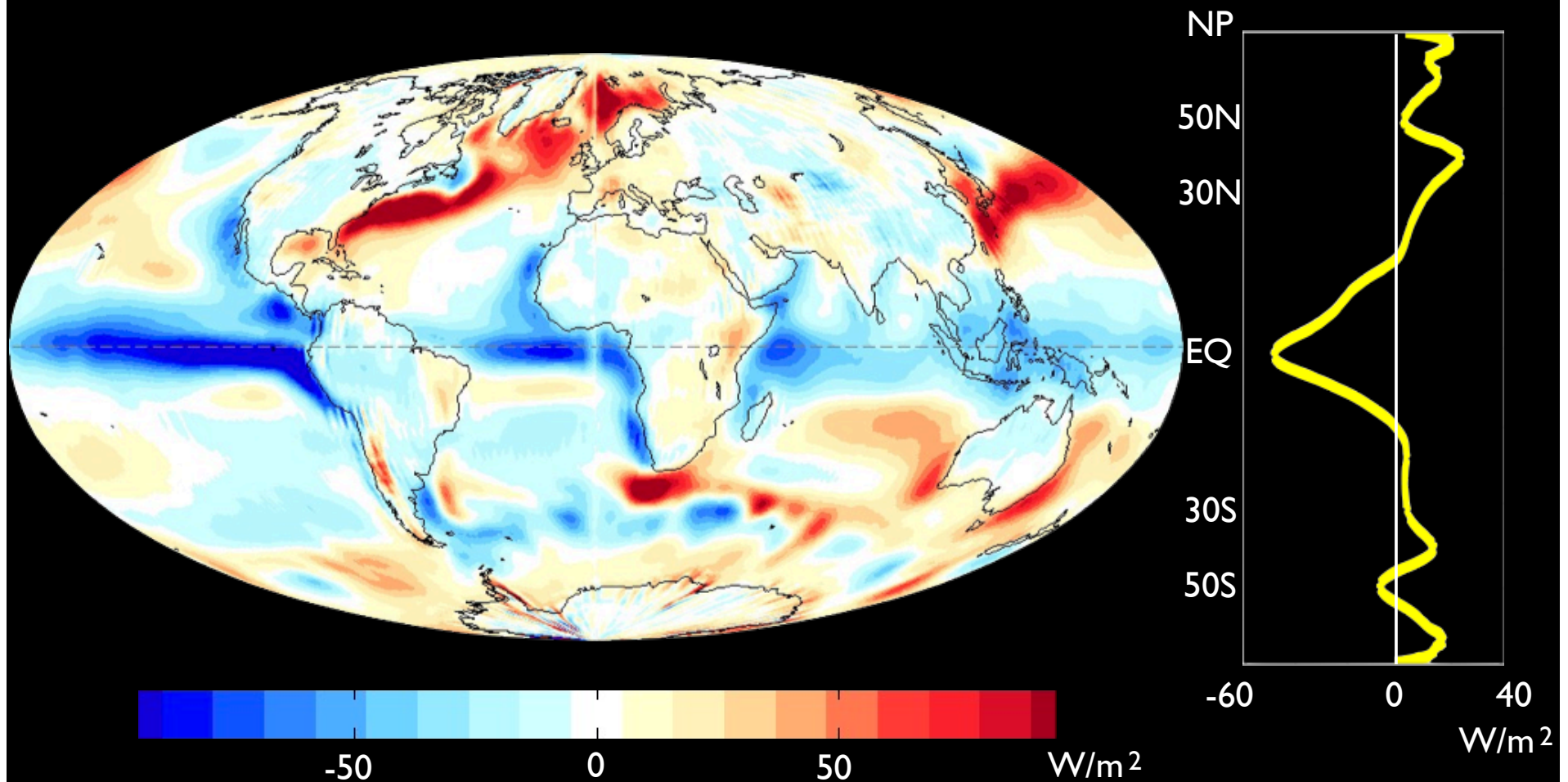
Data Source: NOAA/NEDIS/NODC Ocean Climate Laboratory

Ocean Heat Transport



- Observational estimates suggest cross-equatorial ocean heat transport is plenty large enough to overcome the effect of TOA radiation
 - So the NH atmosphere is heated more than the SH
- Don't believe the obs? 35/35 CMIP3/5 models have more surface flux out of the NH (despite very different ocean circulations)

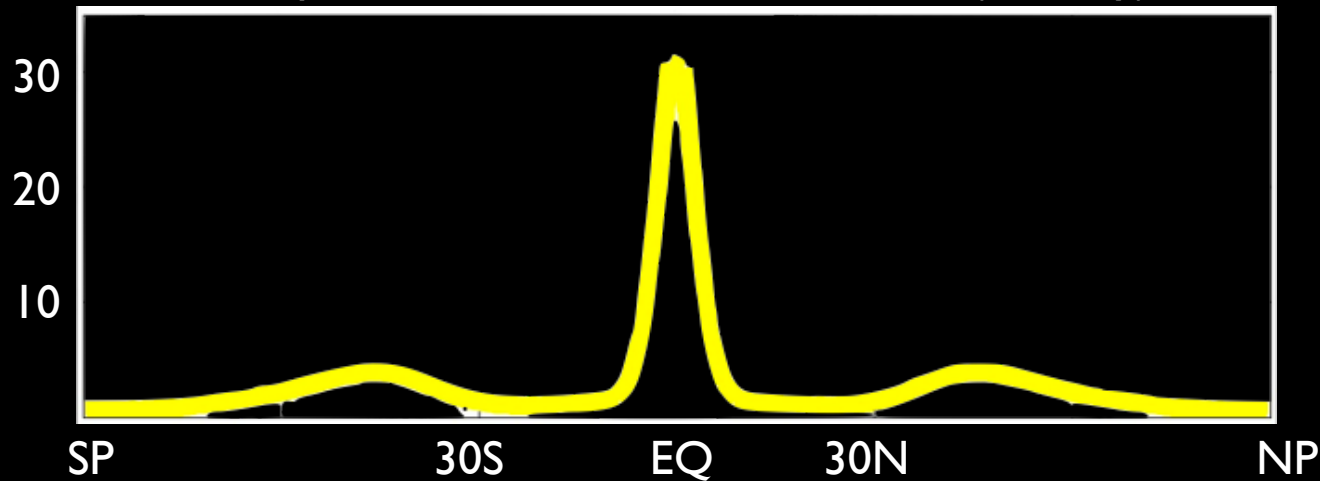
Let's put the observed surface heat flux
into an aquaplanet GCM
Will it be enough to shift the ITCZ into the NH?



Aqua-planet Experiments

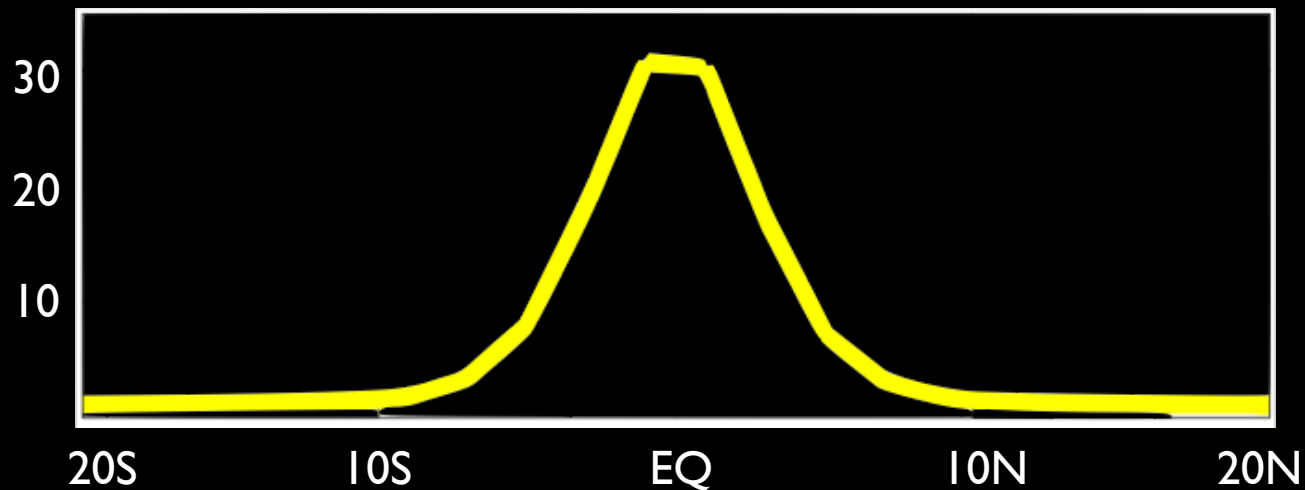
no land!!

Precipitation in the Control Simulation (mm/day)



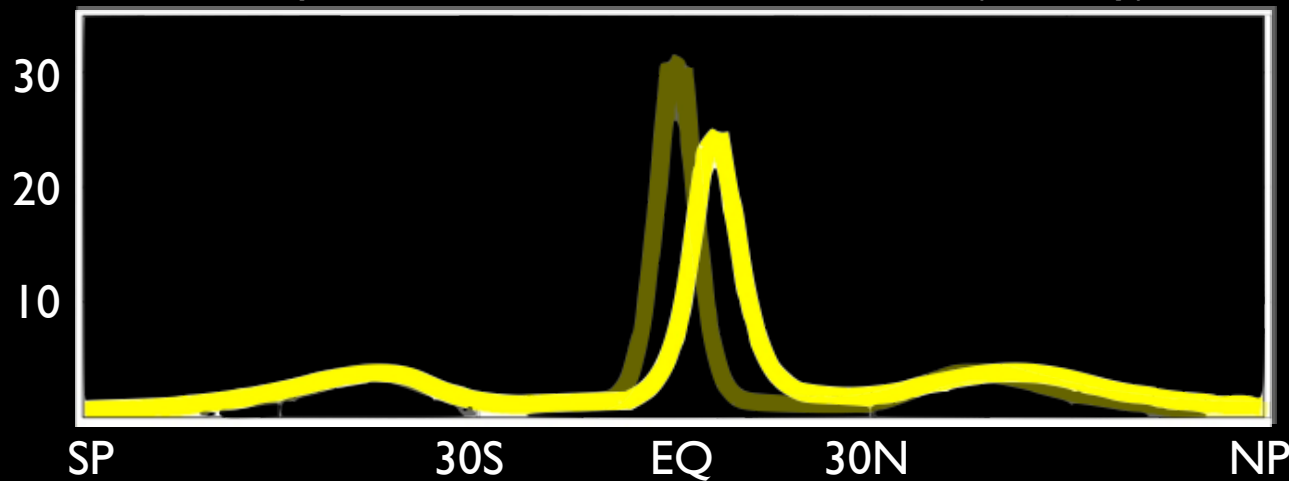
Precipitation in an
aquaplanet atmospheric
GCM
(GFDL's AM2 model)

Zoom in to the Tropics

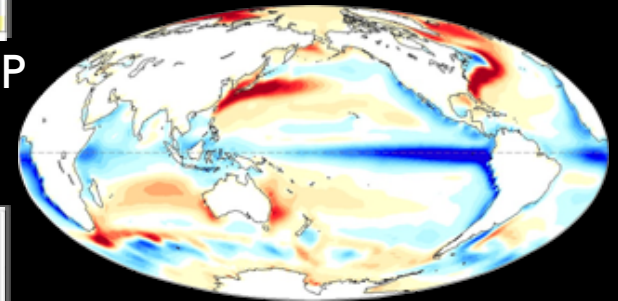


Aqua-planet Experiments

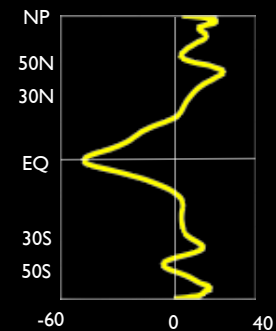
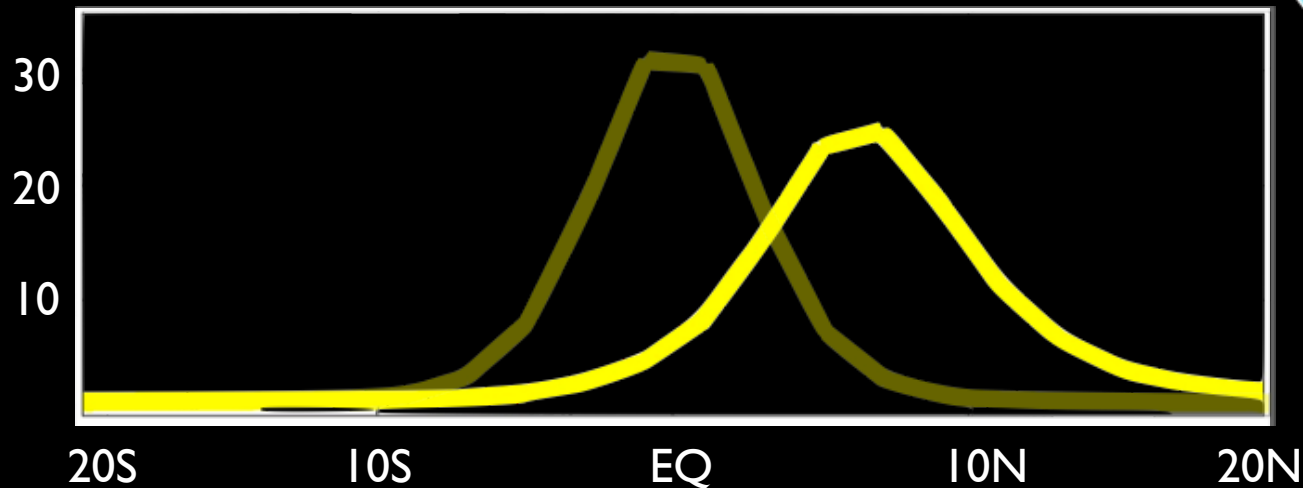
Precipitation in the Control Simulation (mm/day)



Surface flux is quite sufficient to move the ITCZ to the NH

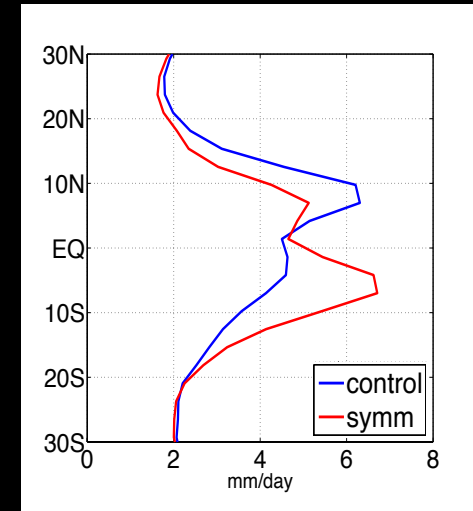


Zoom in to the Tropics



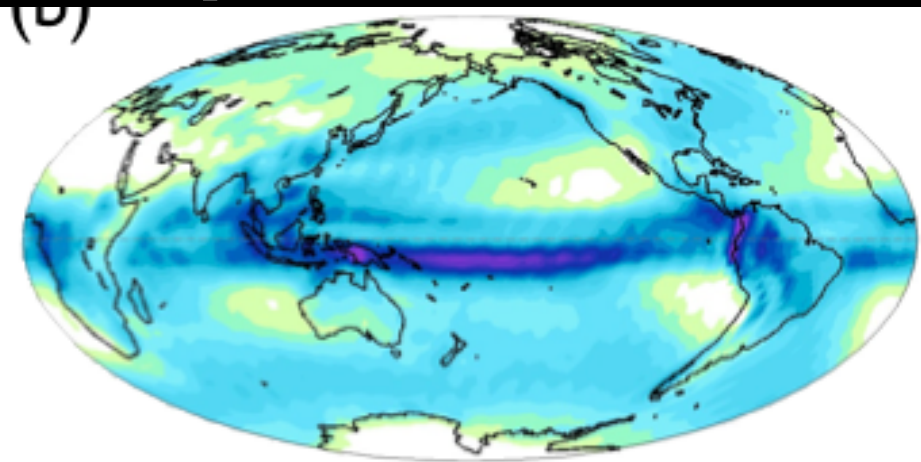
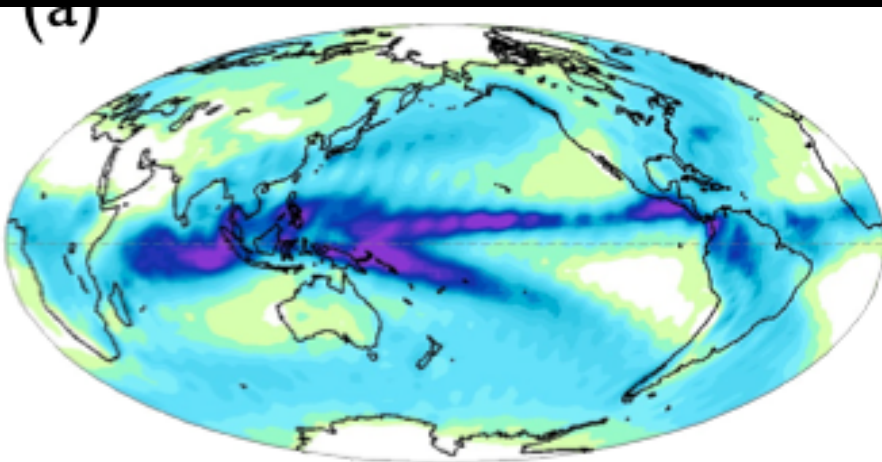
How about *removing* the ocean heat divergence from a full GCM?

- Experiments with **full** and **symmetrized** surface heat flux



Control

Symmetrized

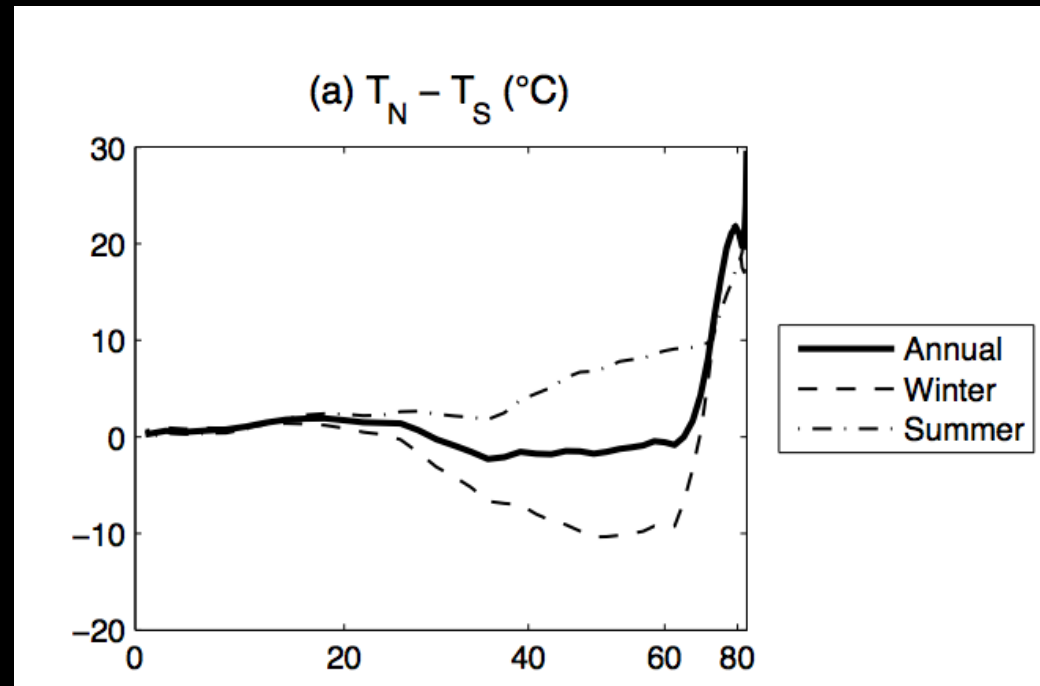


The Hemispheric Temperature Difference

Northern Hemisphere is warmer than the Southern Hemisphere

This is also related to the cross-equatorial ocean heat transport

SH becomes warmer than NH when the cross-equatorial OHT is made to be zero



(from Kang, Seager, Frierson & Liu, 2014)

Experiments with a **Dynamical Ocean**

Coupled, idealized physics
model “GrAM-MOM”

Slanted coastlines produces
ITCZ in the *south*

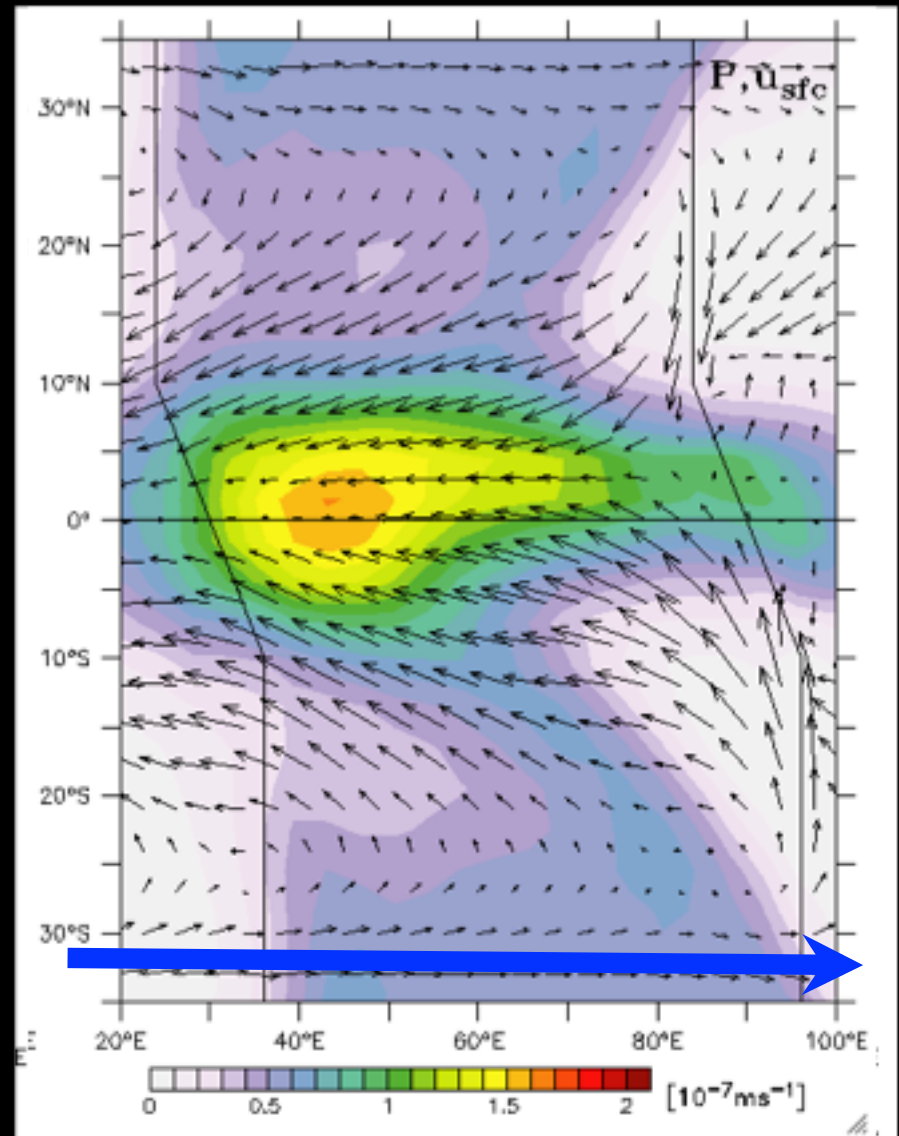
Contrary to Philander et al
(1996) argument

Adding a **Drake passage**
anchors the sinking of the
oceanic MOC in the **NH**

Giving northward
cross-equatorial ocean heat
transport

And the ITCZ shifts northward!

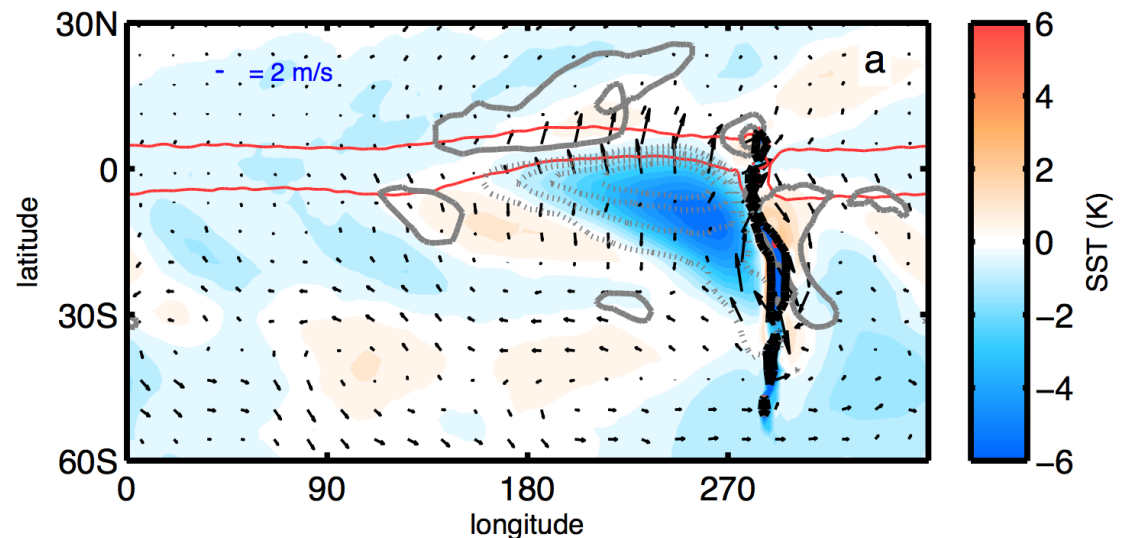
(from Fučkar, Xie, Farneti, Maroon &
Frierson, J. Climate 2013 and Fučkar et
al in prep)



Effect of mountains?



- Maroon, Frierson and Battisti (submitted) studied the relative importance of **mountain ranges** and **ocean heat transport**
 - Mountains shift precip **regionally**, but not much in the zonal mean
 - Ocean heat transport confirmed as dominant control on zonal average precip



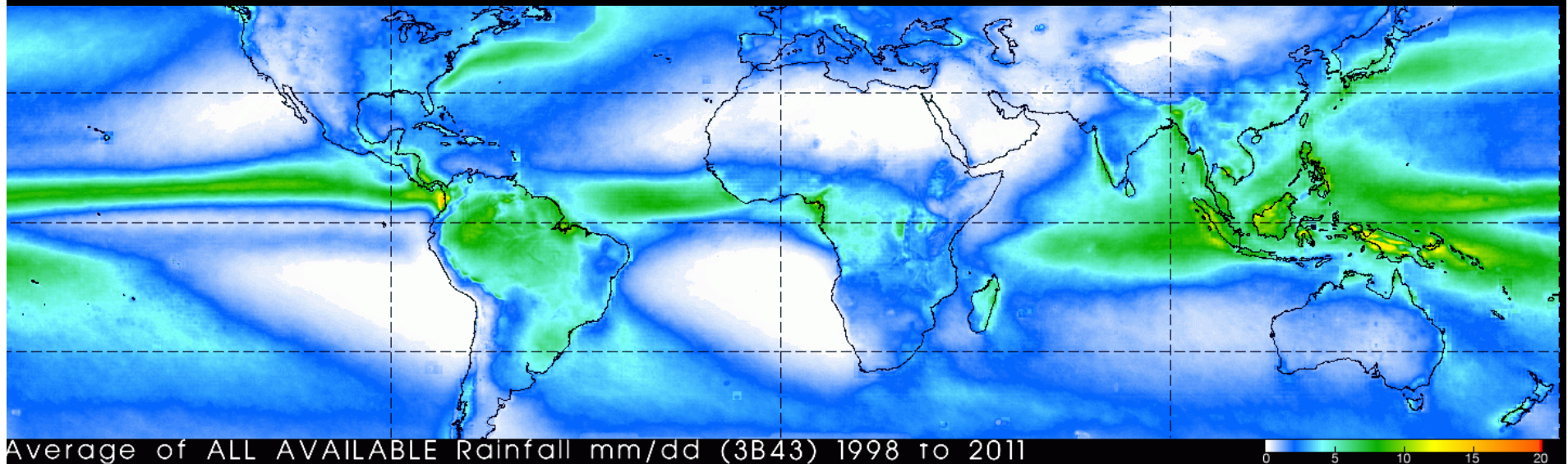
Other applications of our theory



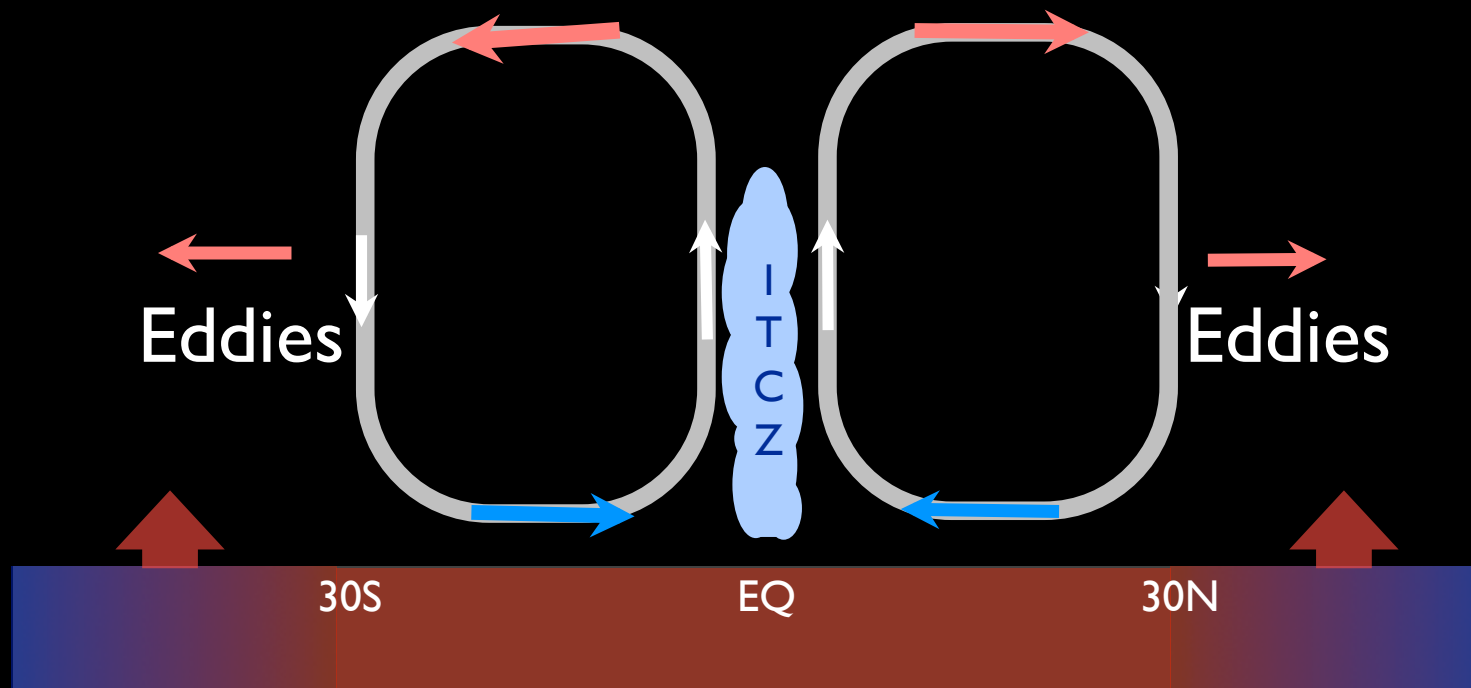
- The double ITCZ problem is mostly due to **Southern Ocean cloud biases** (Hwang and Frierson 2013)
 - Too little cloud → too much radiation into S. Ocean → warmth spreads and shifts the ITCZ south
- **Aerosols** forced a southward shift of tropical rain in late 20th century (Hwang, Frierson and Kang 2013)
 - But is AMOC variation also important in the real world?

recap

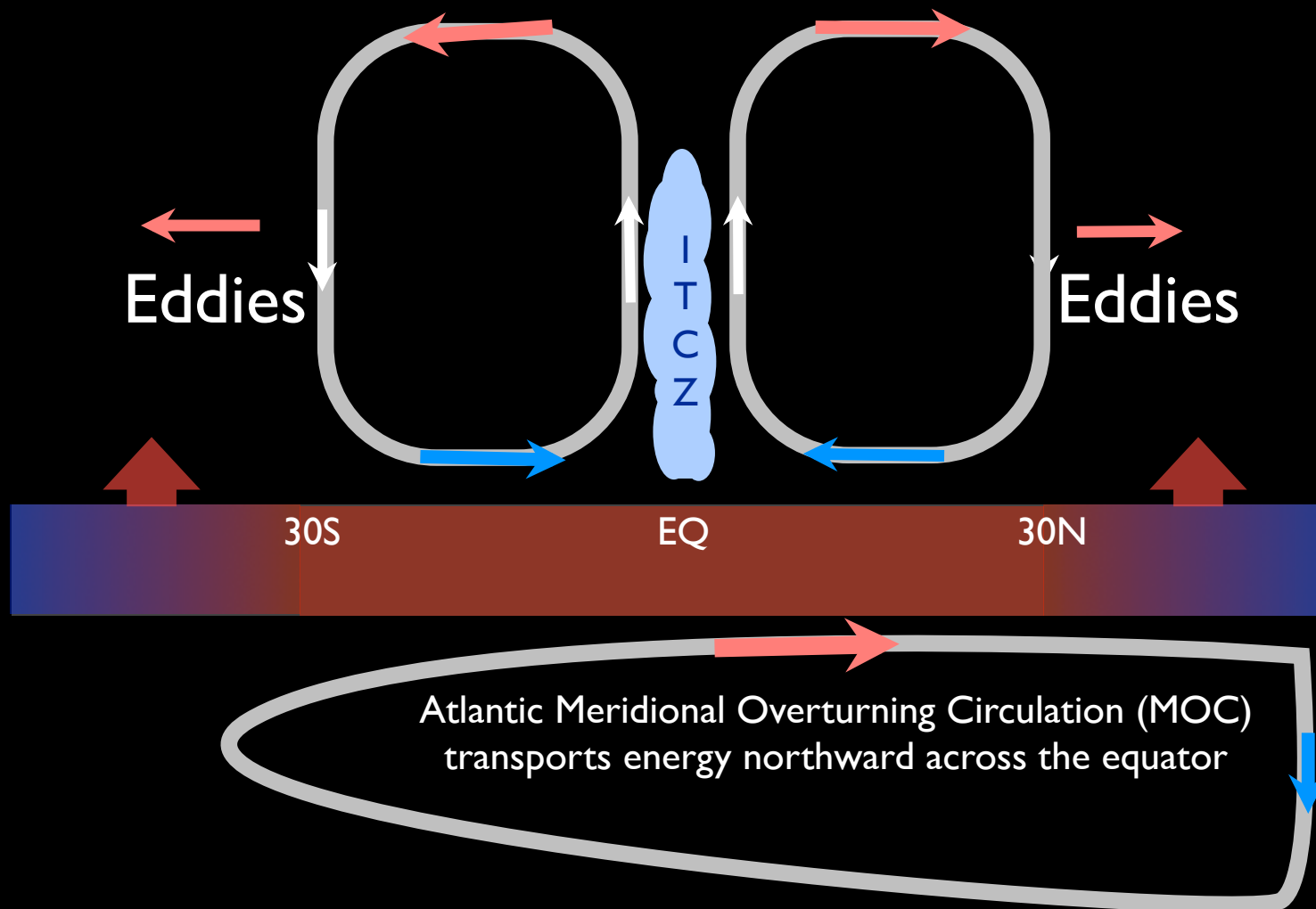
- Tropical rainfall shifts towards heating, even in high latitudes.
- Radiation alone would cause the ITCZ to be in the SH.
- The ocean MOC warms the NH and puts the ITCZ in the NH.



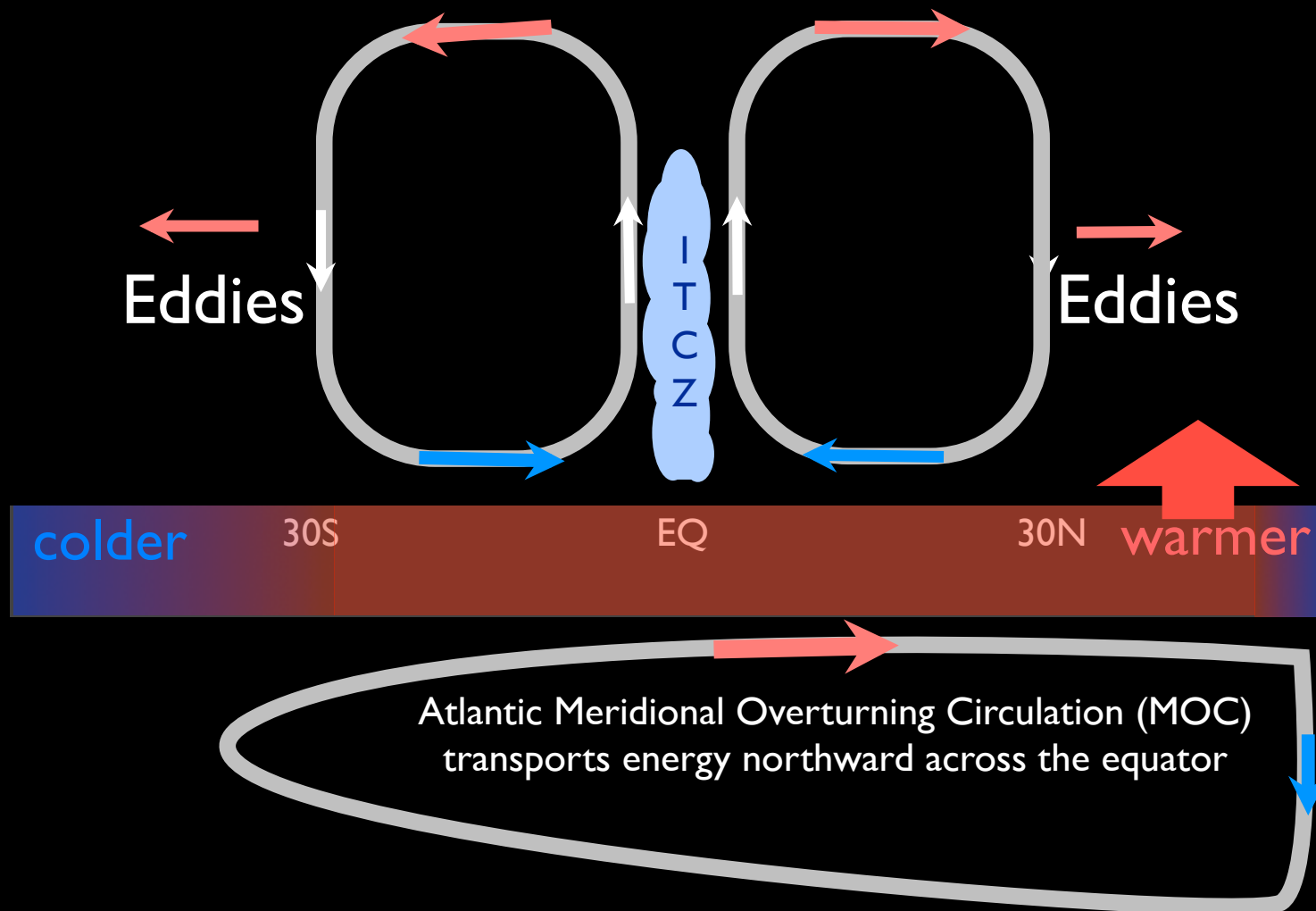
The Effect of MOC on ITCZ



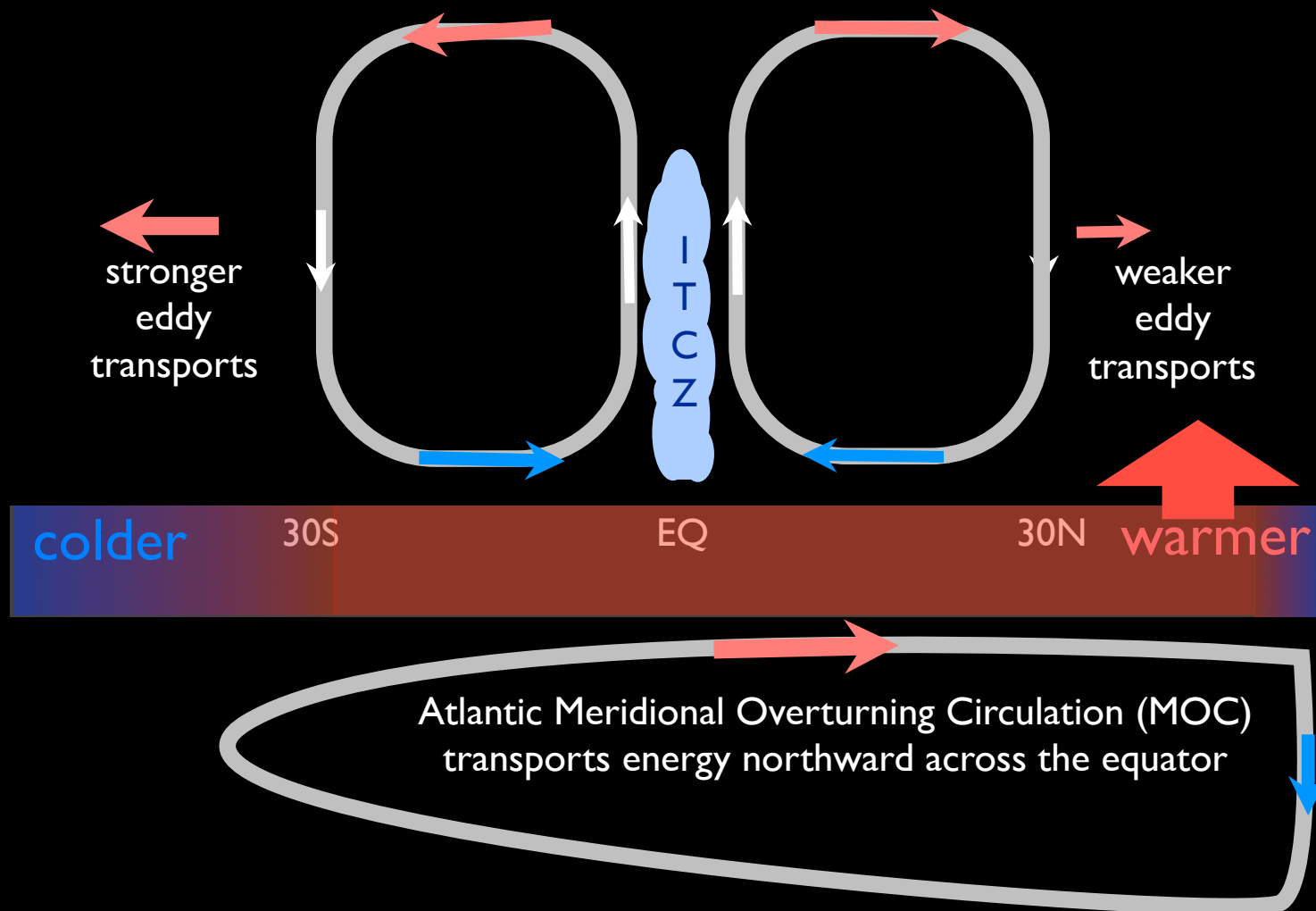
The Effect of MOC on ITCZ



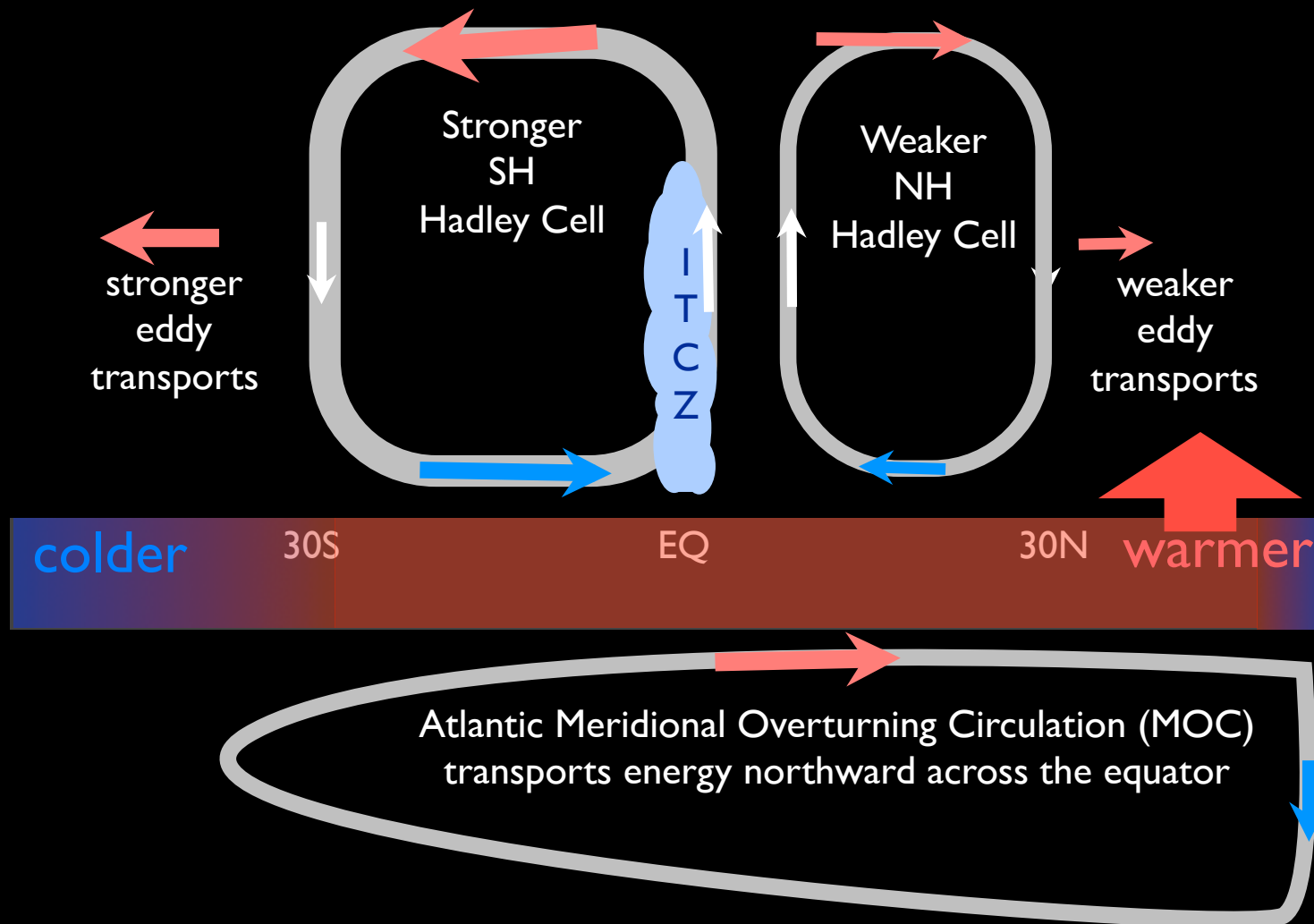
The Effect of MOC on ITCZ



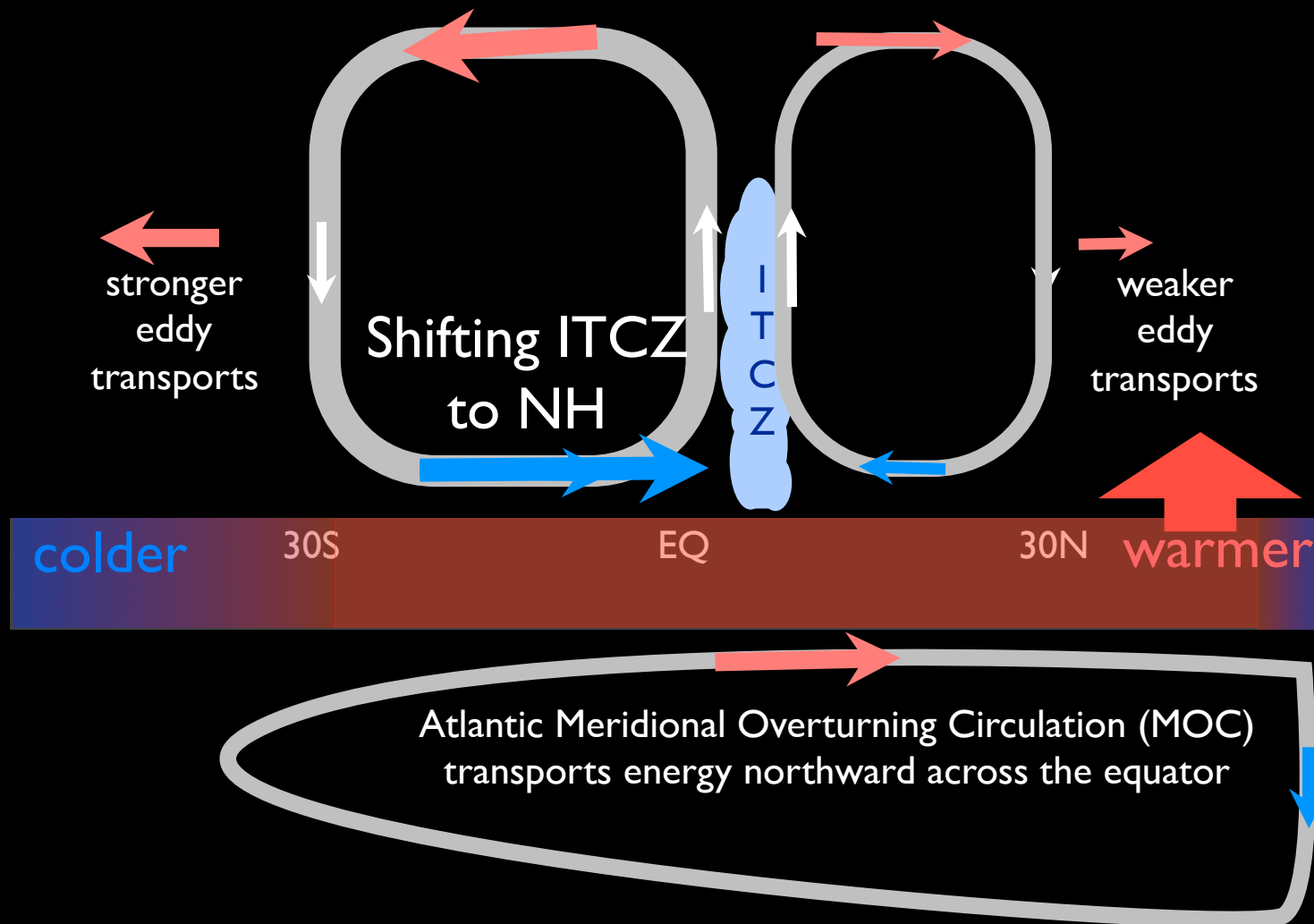
The Effect of MOC on ITCZ



The Effect of MOC on ITCZ



The Effect of MOC on ITCZ



Thanks for listening.
Questions?