Development and Effects of the Northward-Displaced ITCZ

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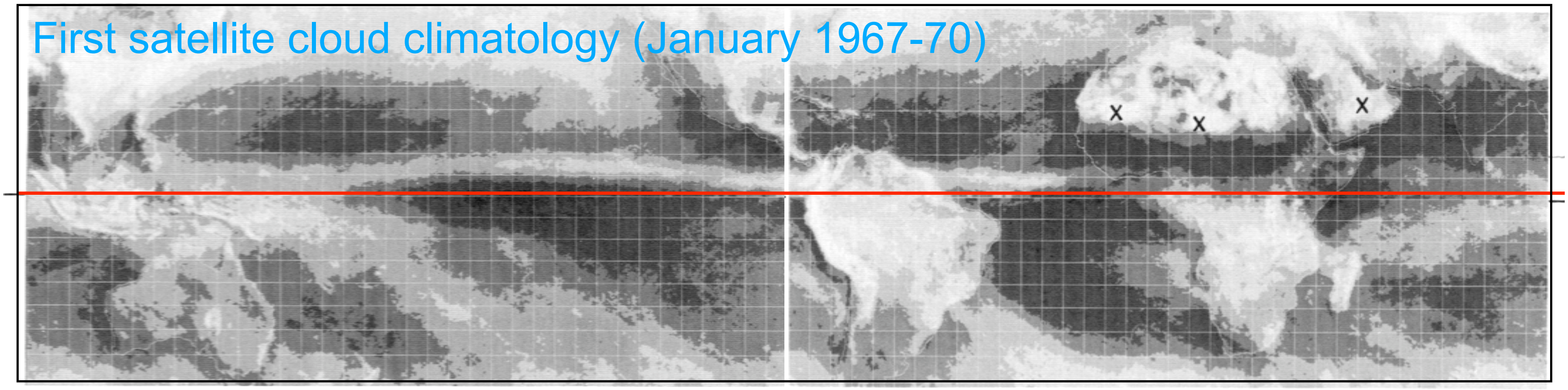
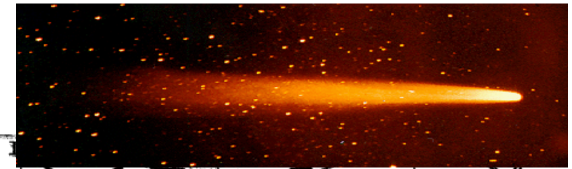


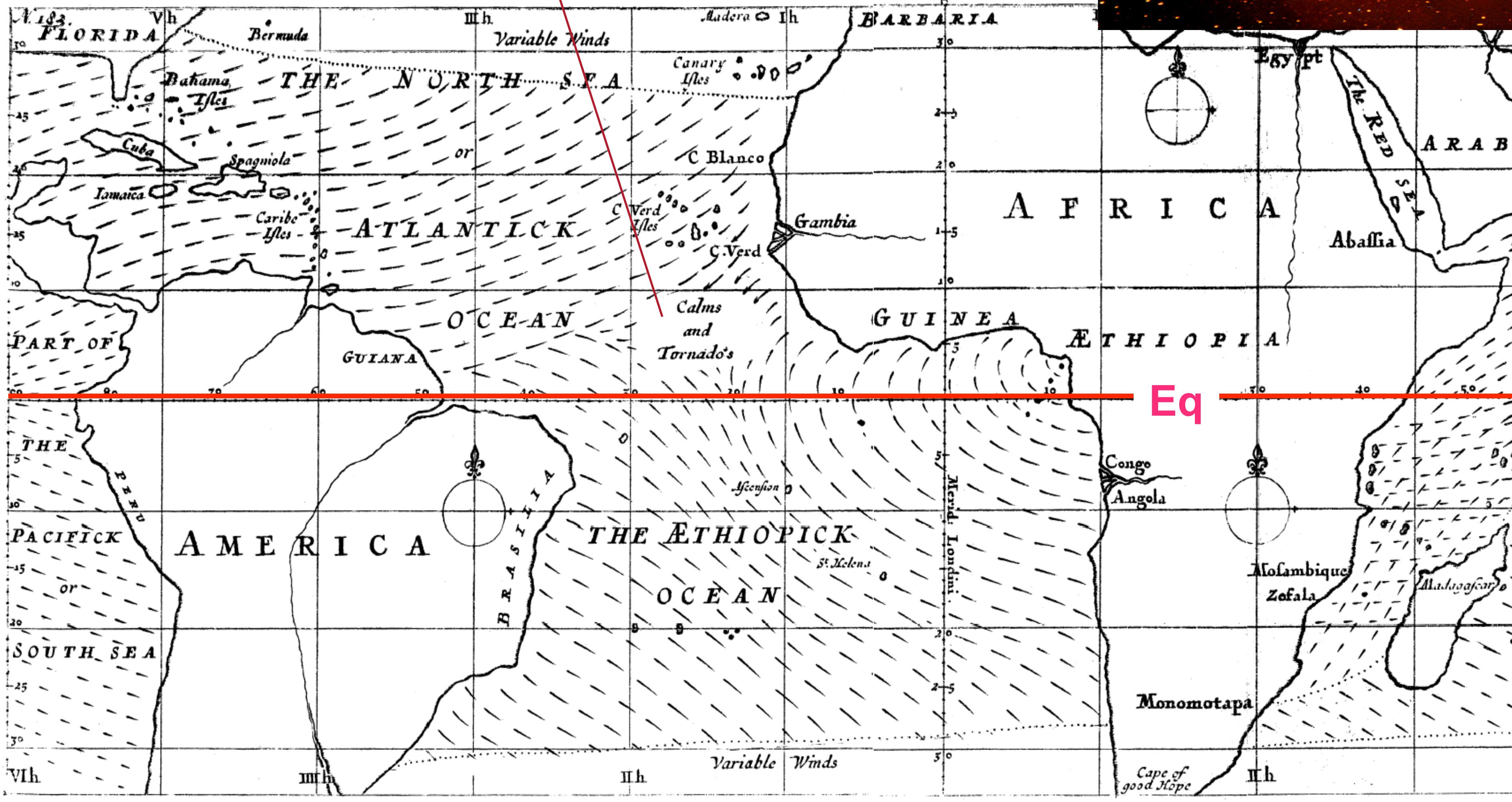
Brightness

- WES & low-cloud feedback → Northward displaced ITCZ
- Consequences: (1) equatorial annual cycle;
  (2) asymmetric ocean circulation.

Calm and Tornado

Halley 1686

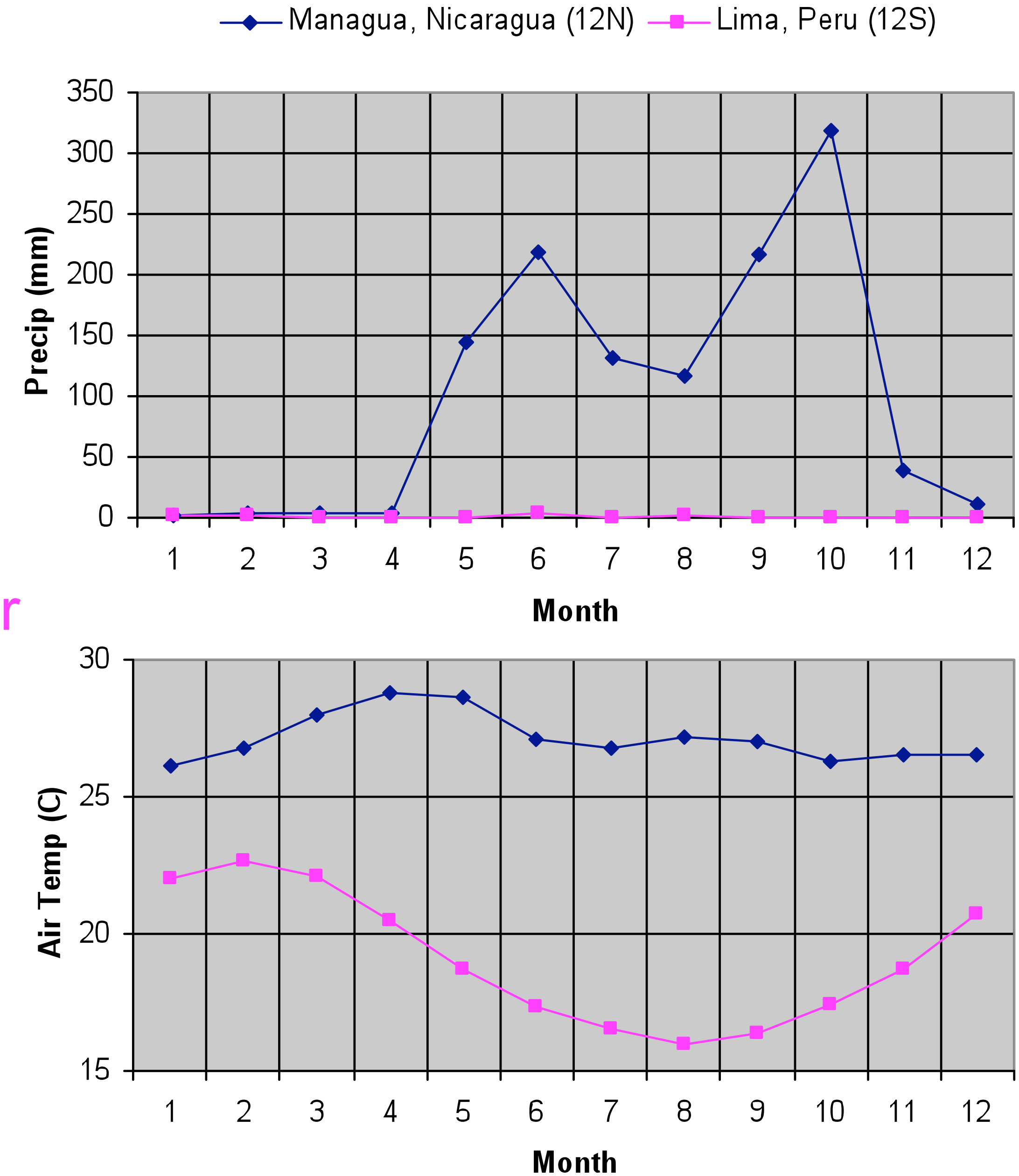




Eq

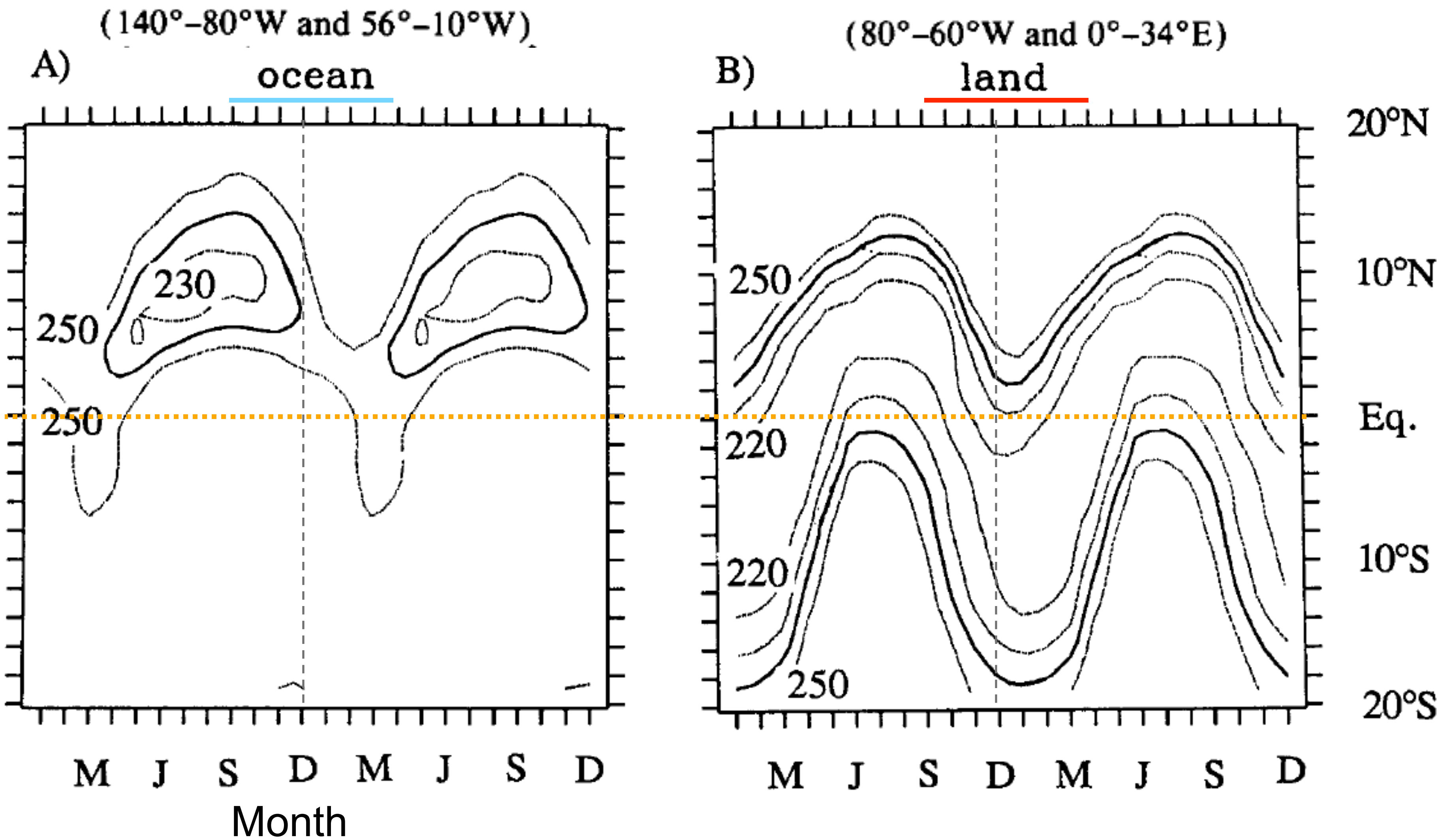
Halley wrote about the ITCZ: “it were improper to say there is any Trade Winds, or yet a Variable; for it seems condemned to perpetual Calms, attended with terrible Thunder and Lightning, and Rains so frequent, that our Navigators from thence call this part of the Sea the *Rains*”.

1207.6 vs. 10.8 mm



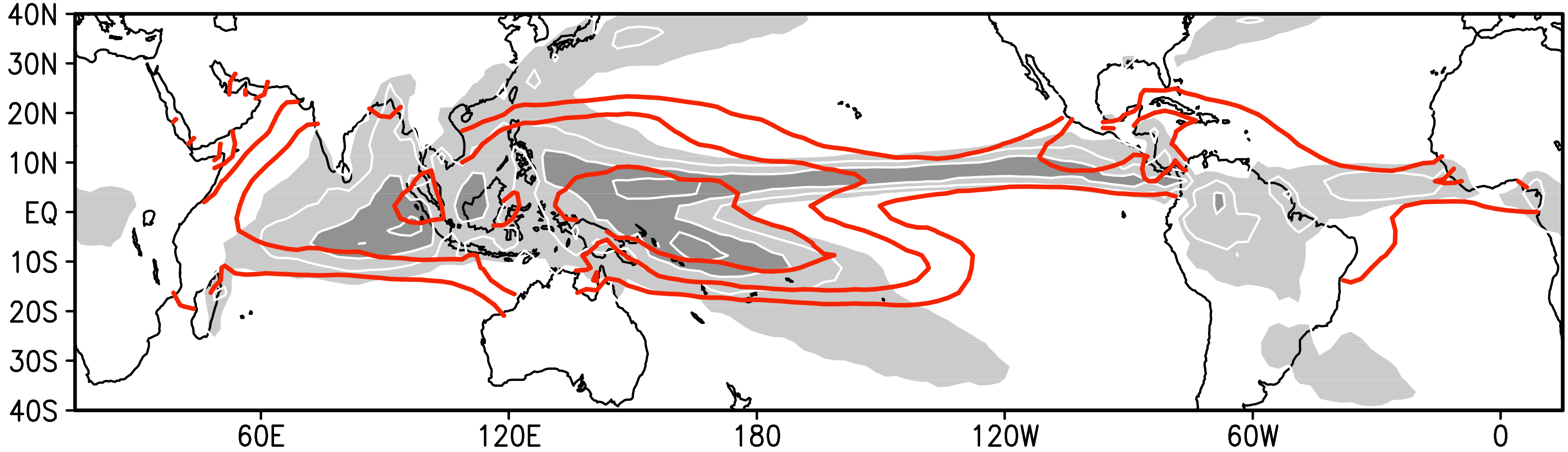
NS asymmetry in East Pacific:
Nicaragua (12N): 1208
Peru (12S): 11 mm/yr

Outgoing longwave radiation (OLR) in the Western Hemisphere



Mitchell and Wallace (1992, JC)

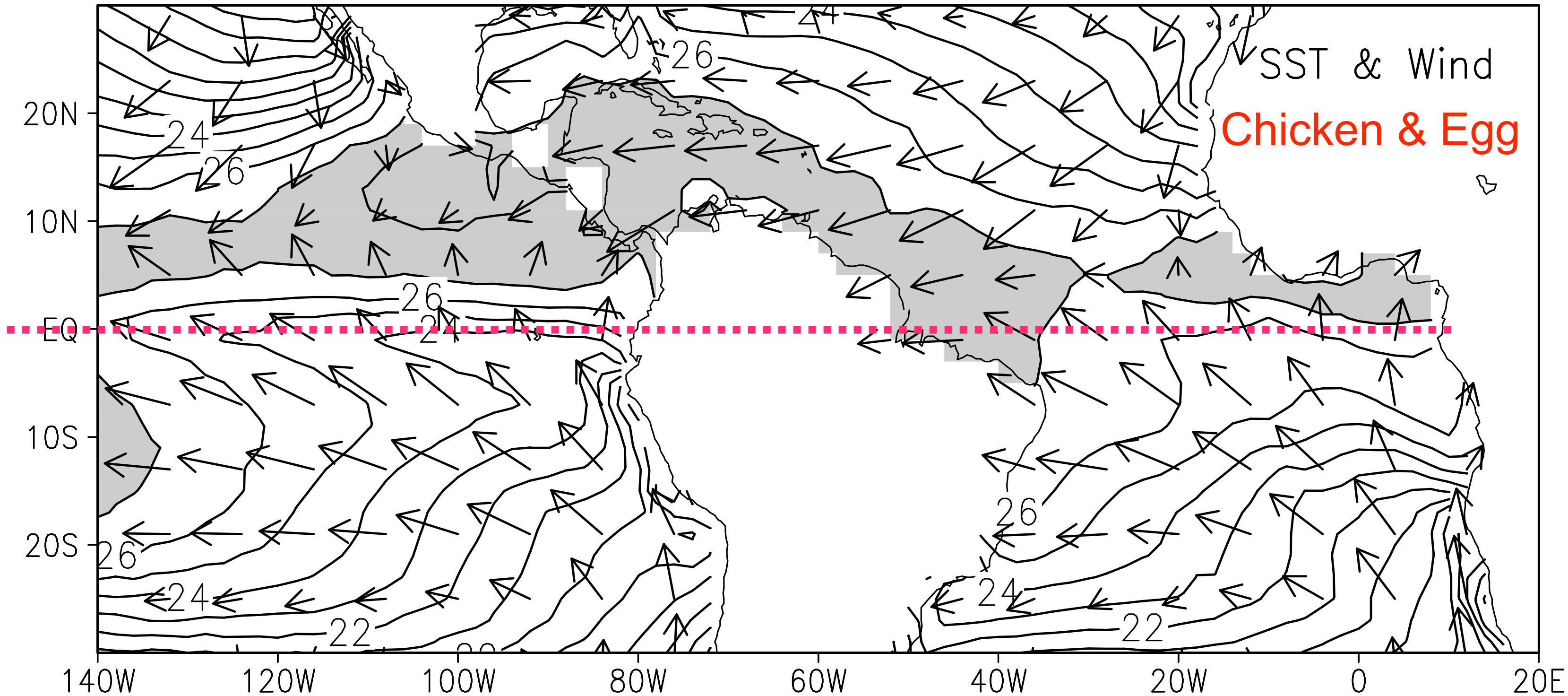
Precip & SST(>27°C)



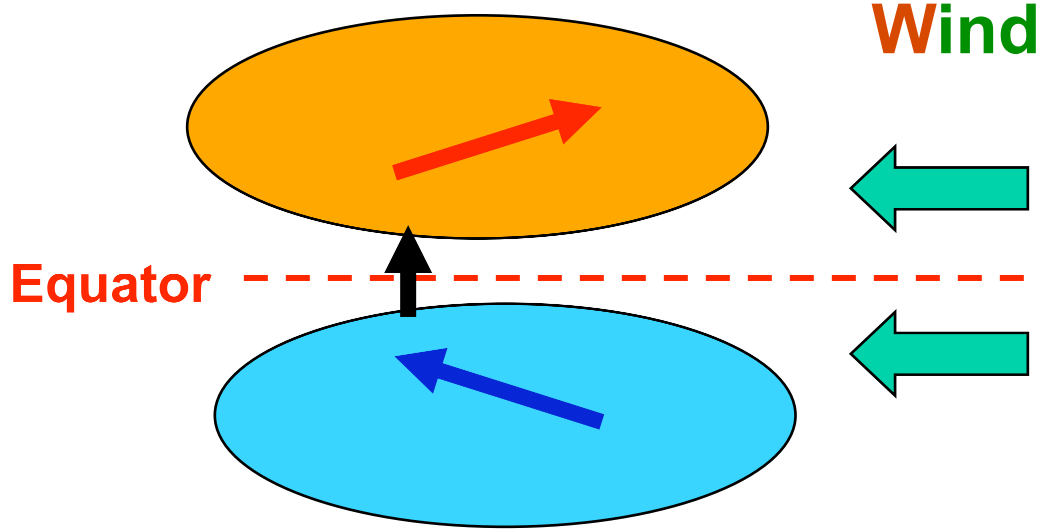
Tropical convection is confined to SST > 27°C.

Manabe et al. (1974, *JAS*)

A secondary rainbelt forms just south of the equator around April when a secondary maximum of sea surface temperature appears in the Southern Hemisphere. The monthly charts of brightness, compiled by Tayler and Winston (1968), as observed by satellites, is most pronounced around April in qualitative agreement with the features of the model atmosphere.

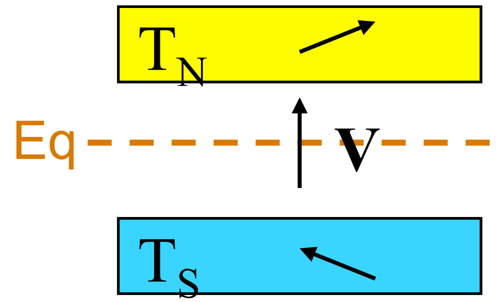


Wind-Evaporation-SST (WES) Feedback



Xie & Philander (1994, *Tellus*)

Two-strip model for WES feedback



Atmosphere

$$\delta U = f\, V / \varepsilon$$

$$V = \alpha (T_N - T_S)$$

$$\frac{\partial T}{\partial t} = aU - bT$$

Ocean

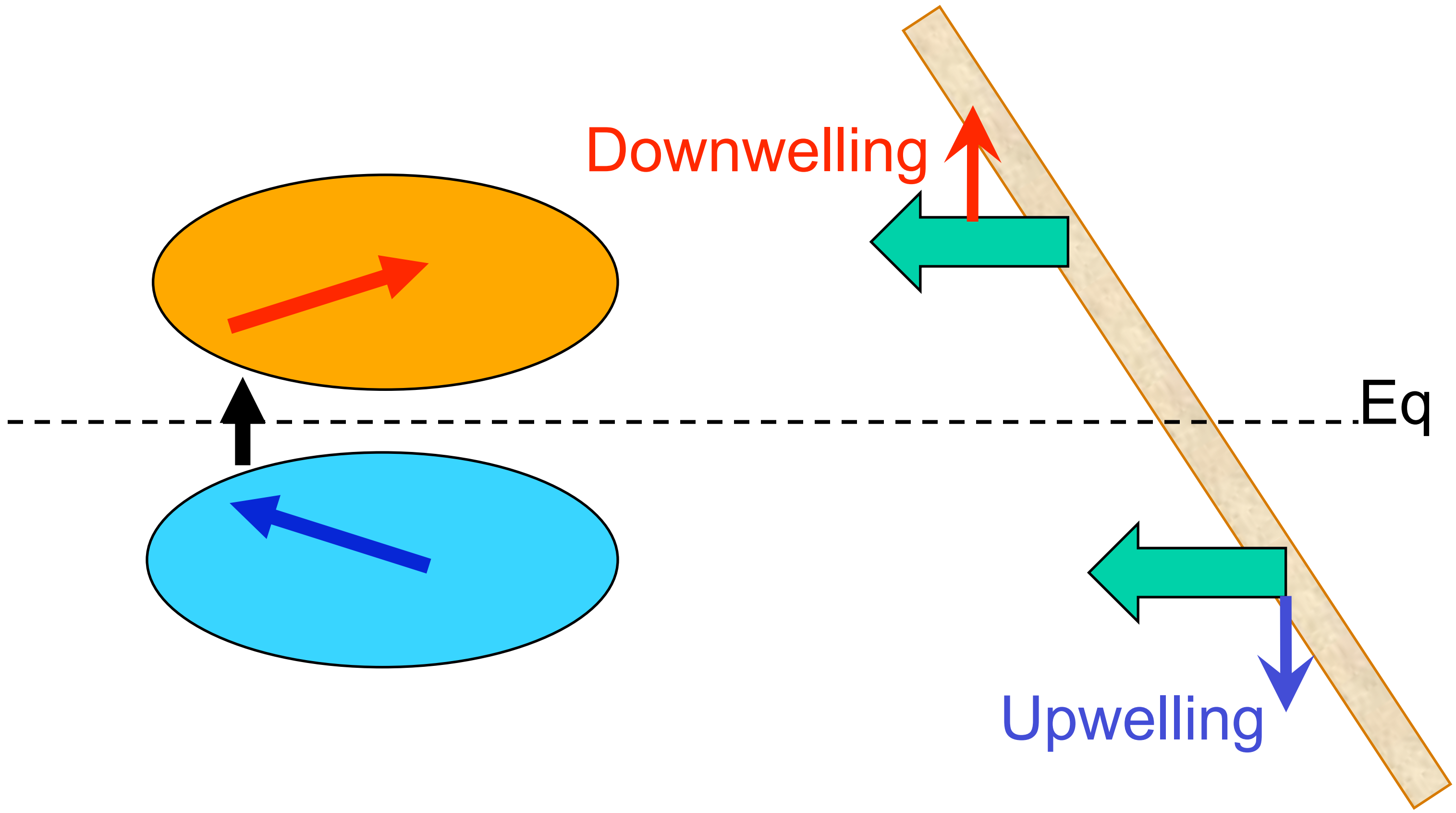
$$\frac{\partial}{\partial t}\delta T = (\sigma - b)\delta T$$

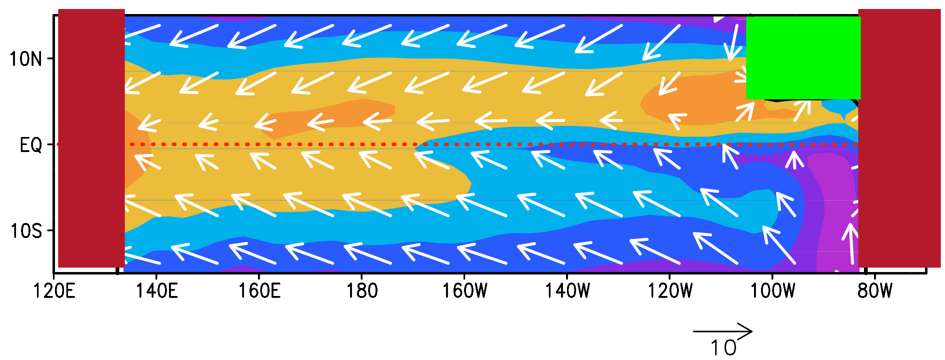
$$\sigma = f\,(a\alpha)/\varepsilon$$

coupling coefficient

Continental forcing triggers WES, displacing ITCZ.

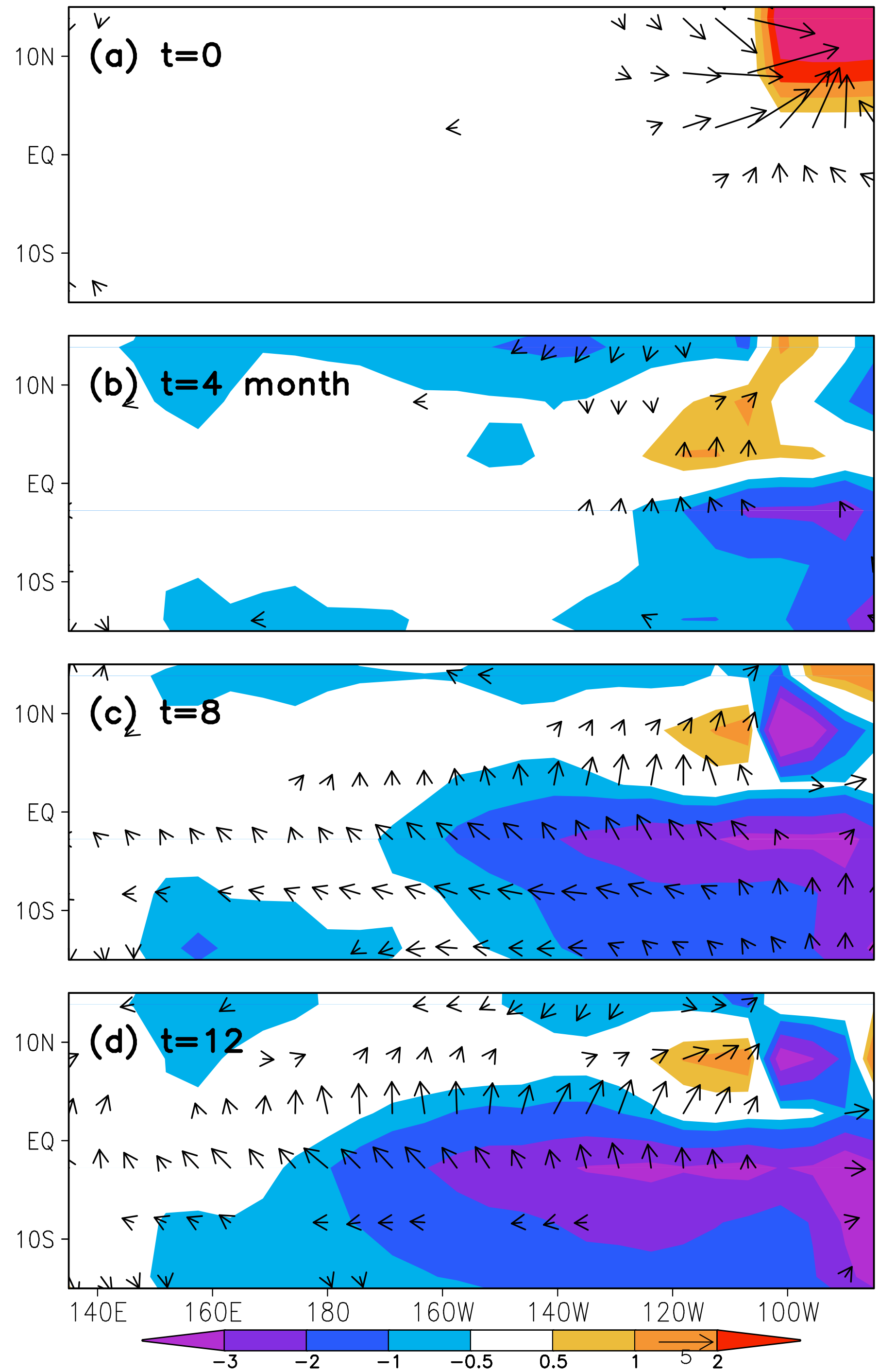
Tilted coastline breaks the equatorial symmetry





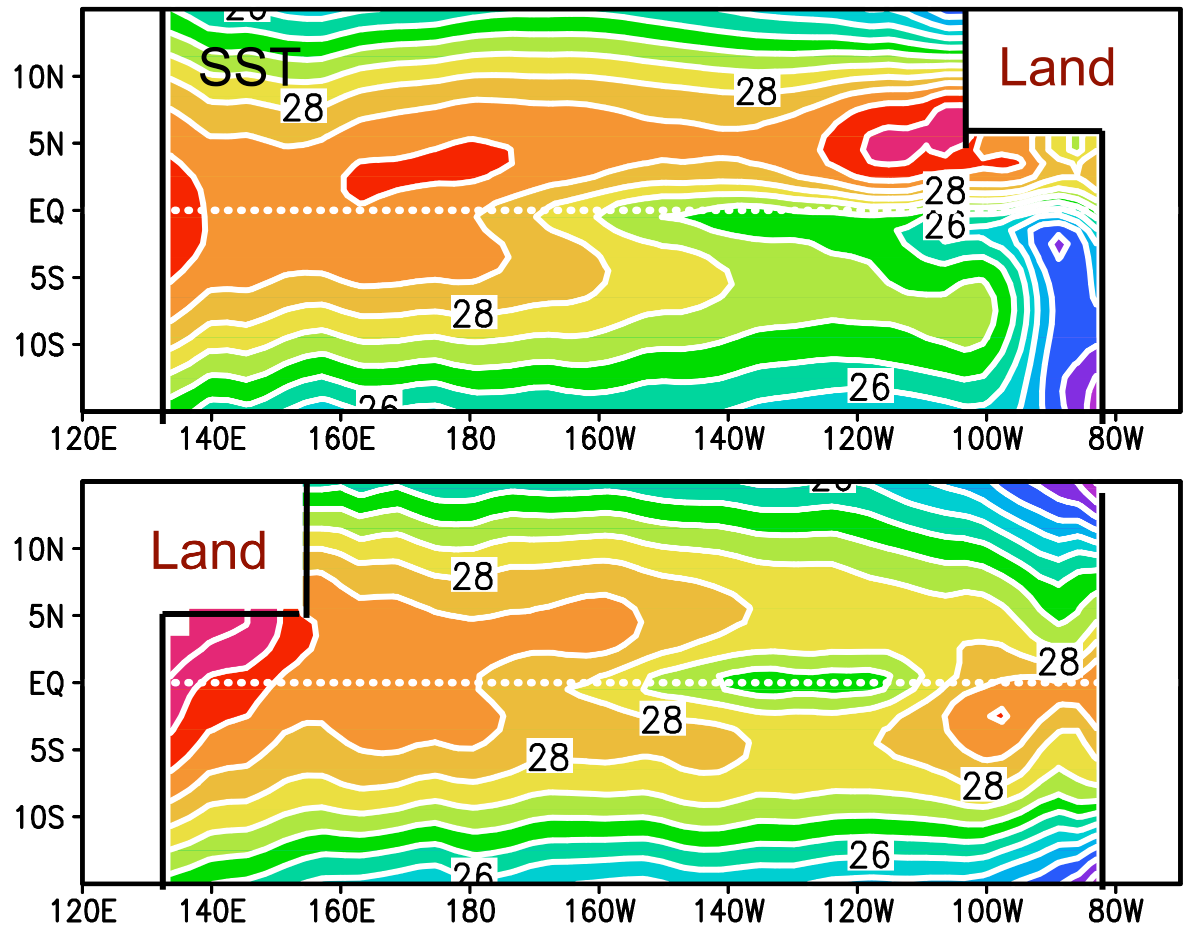
Continental asymmetry excites a westward-traveling coupled wave front.

Xie and Saito, J. Climate (2001)

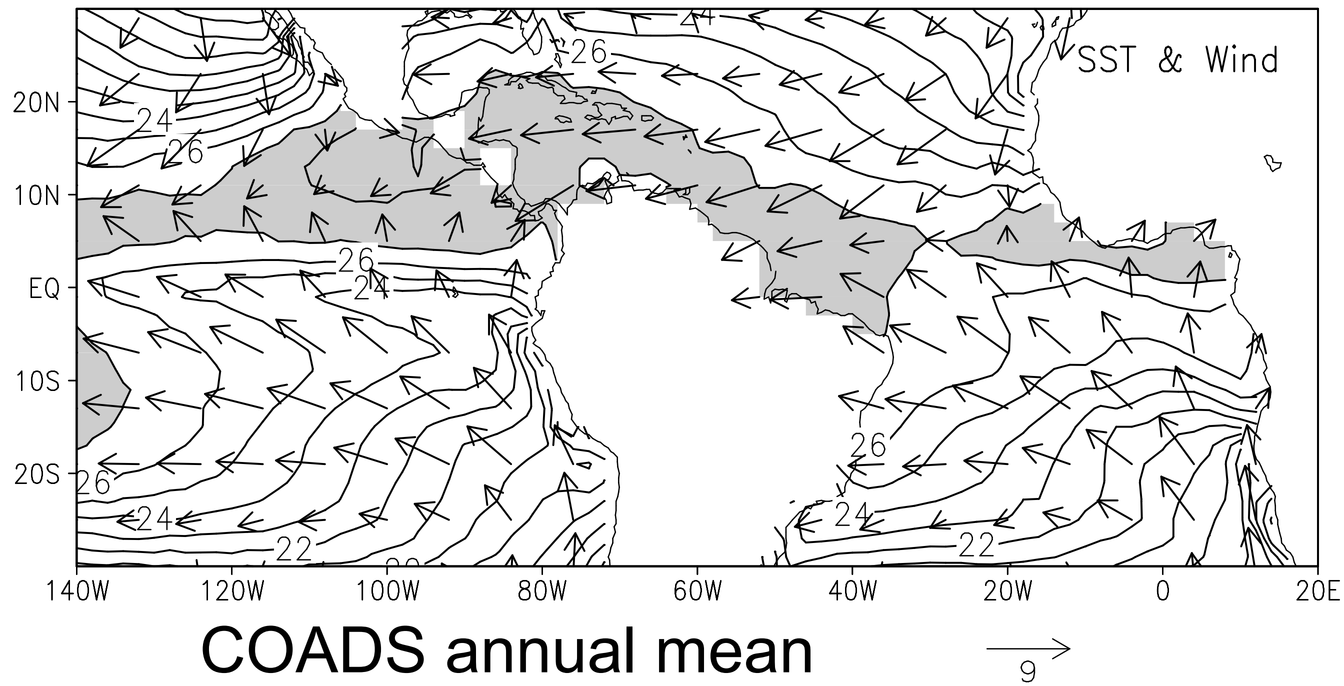


Westward control by continental geometry

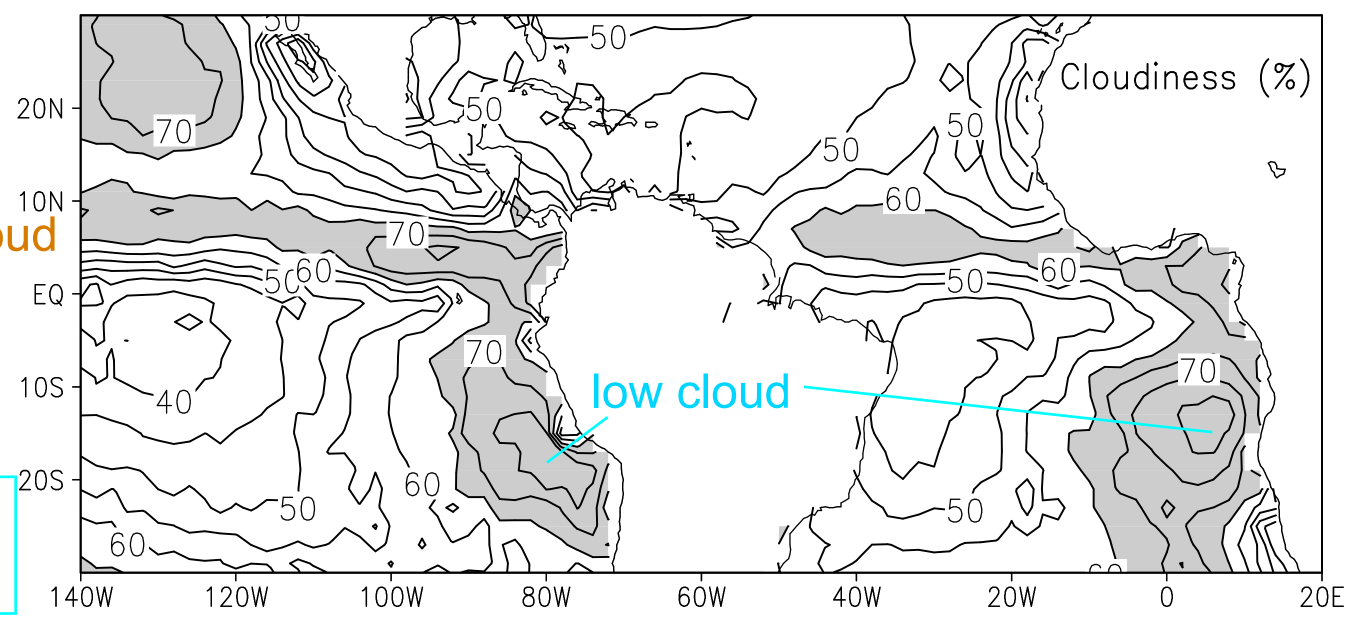
Xie & Saito (2001, J. Clim)



Cloud effects



COADS annual mean

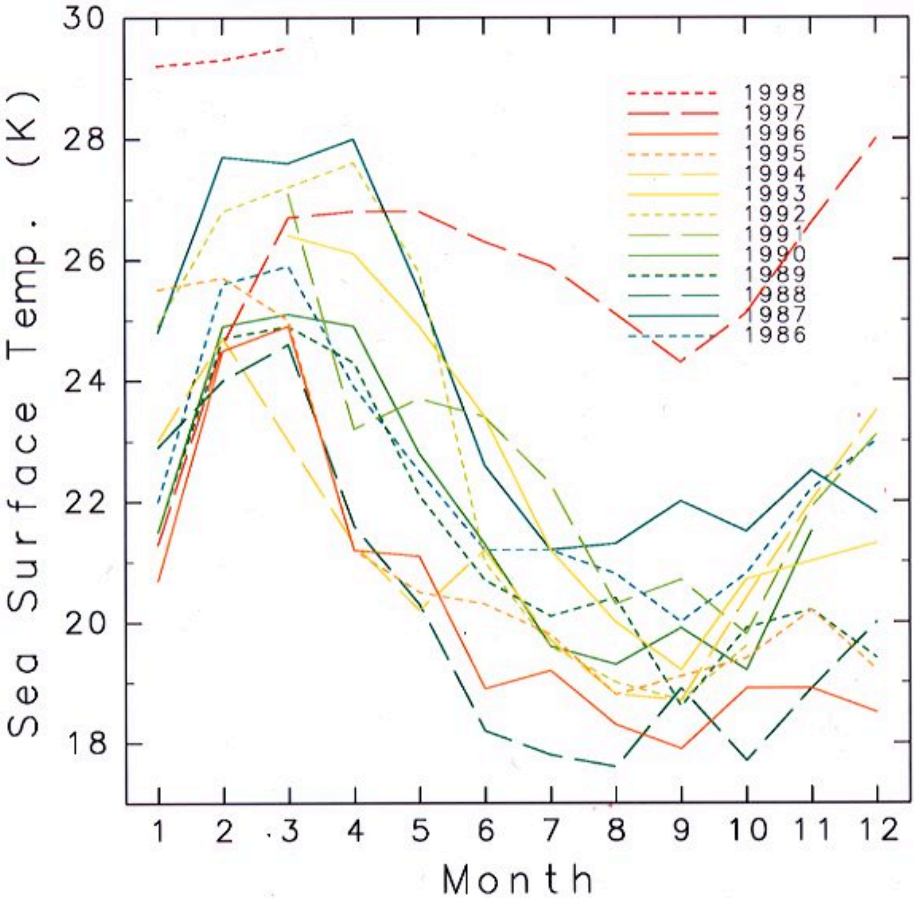


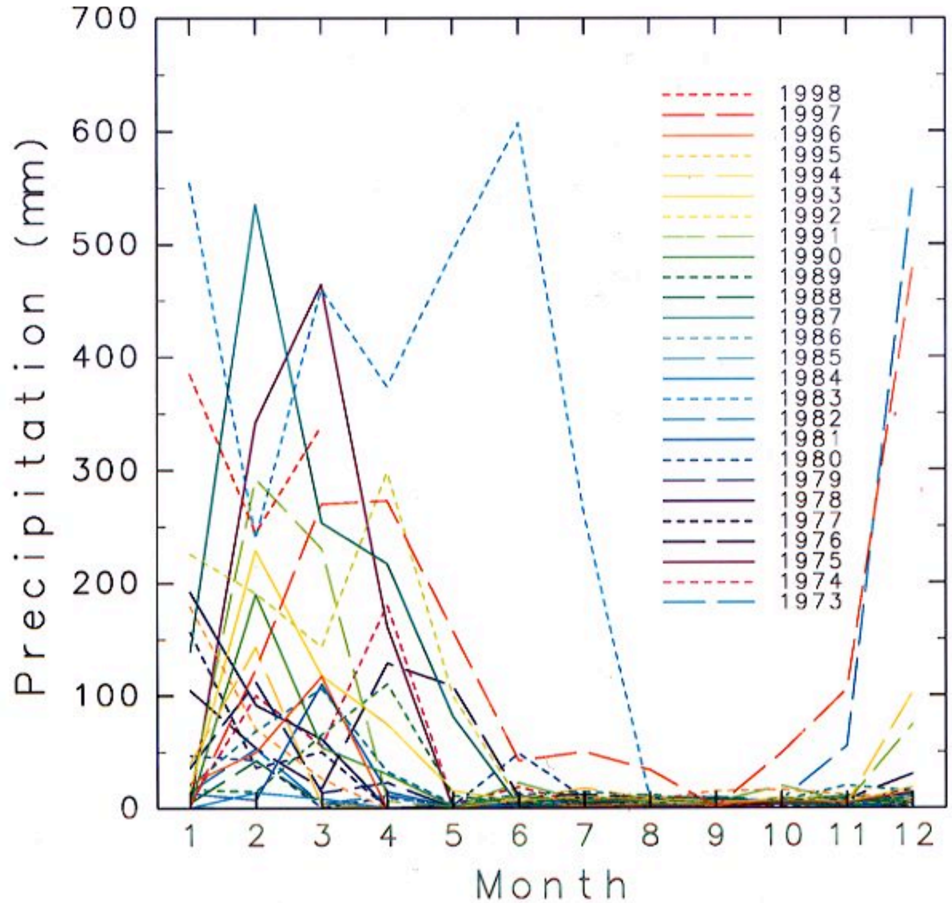
Low cloud cools the SE ocean

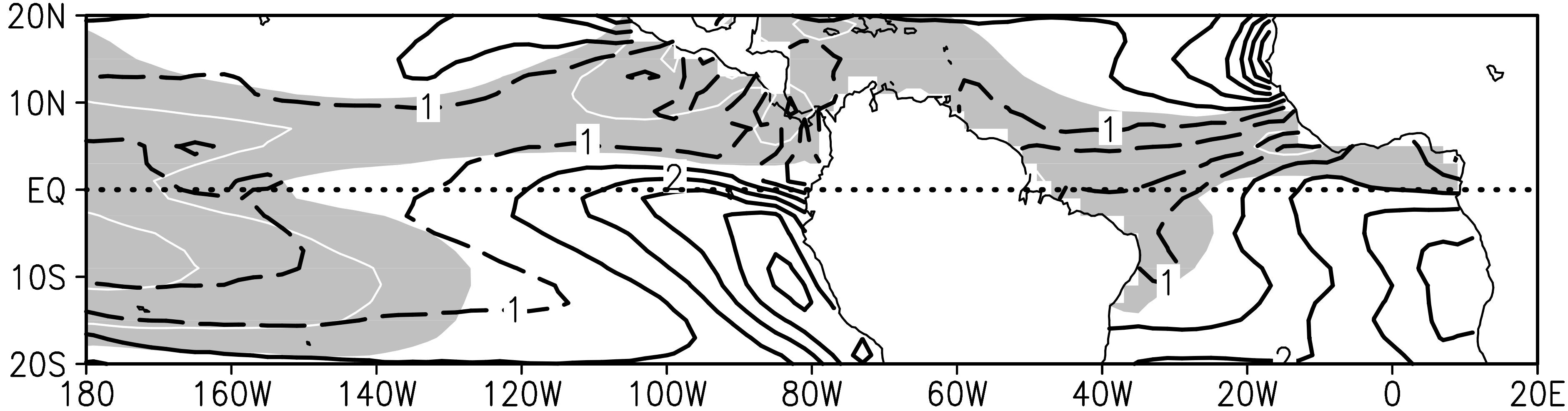
↓

Strength meridional asymmetry

Consequence 1: Annual cycle



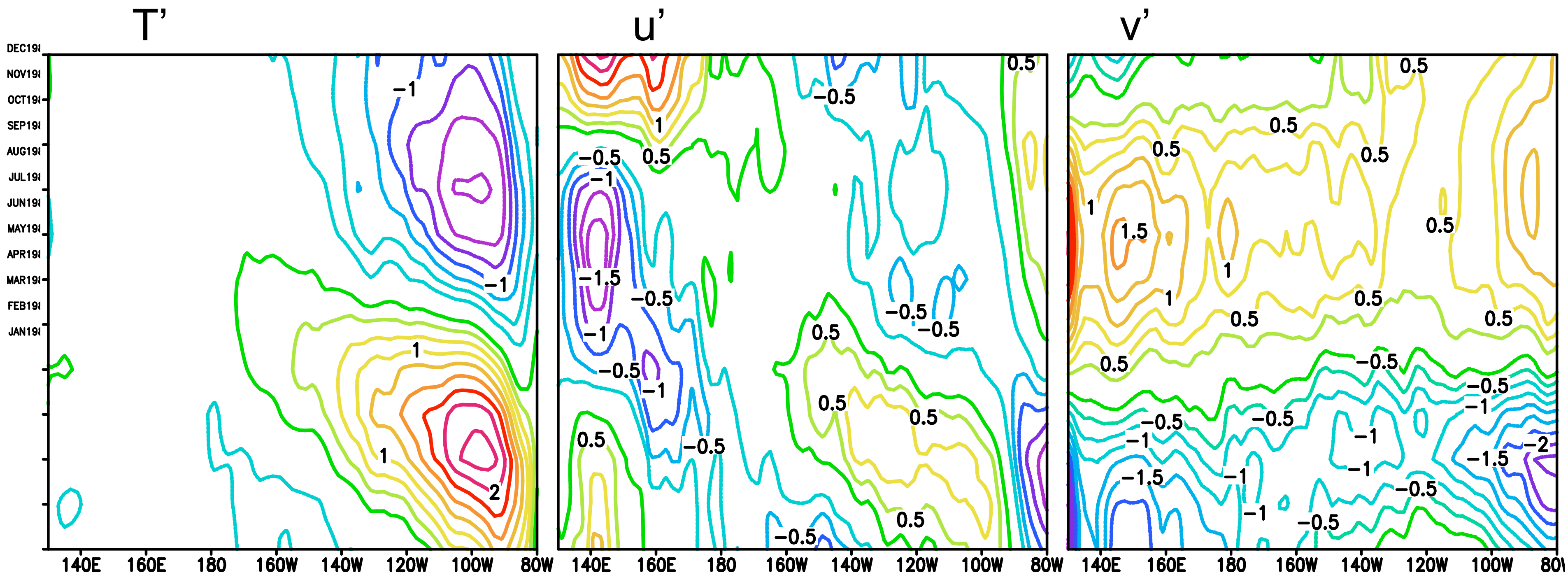




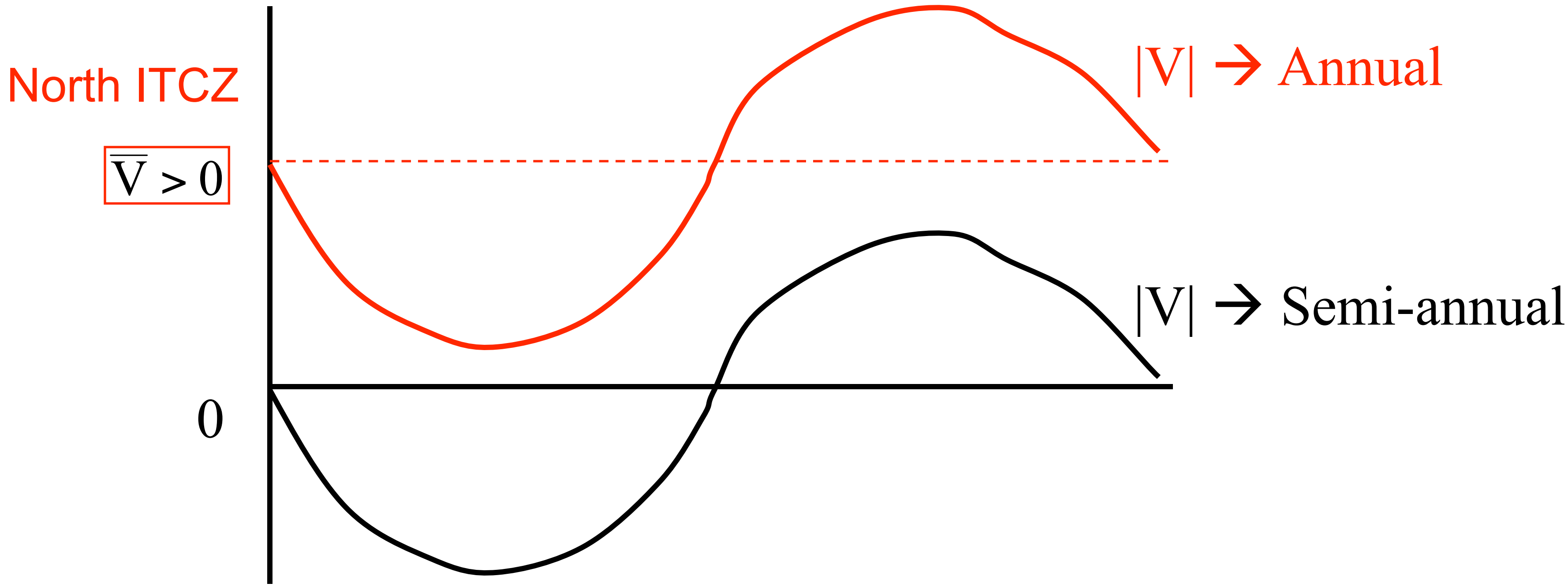
SST: Mean (>26°C) & Annual Harmonic

Xie (2004, in *Hadley Circulation* ...)

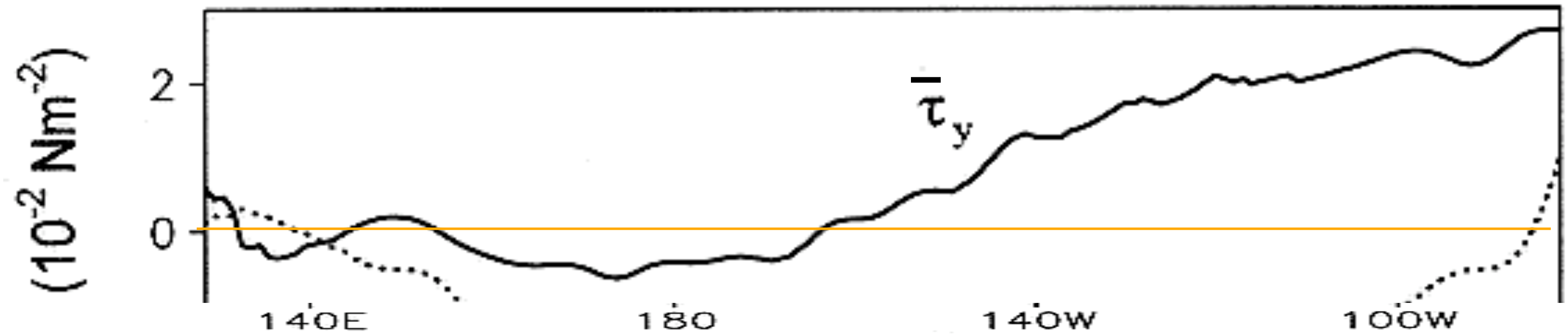
Equatorial Annual Cycle



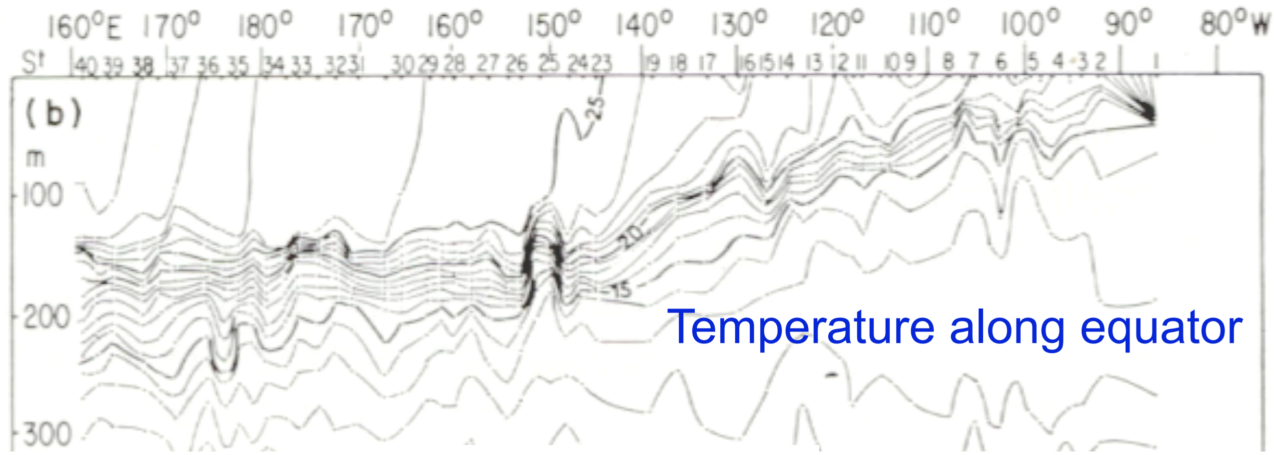
- Why annual?
- Why Strong in the east?
- Why propagate westward?



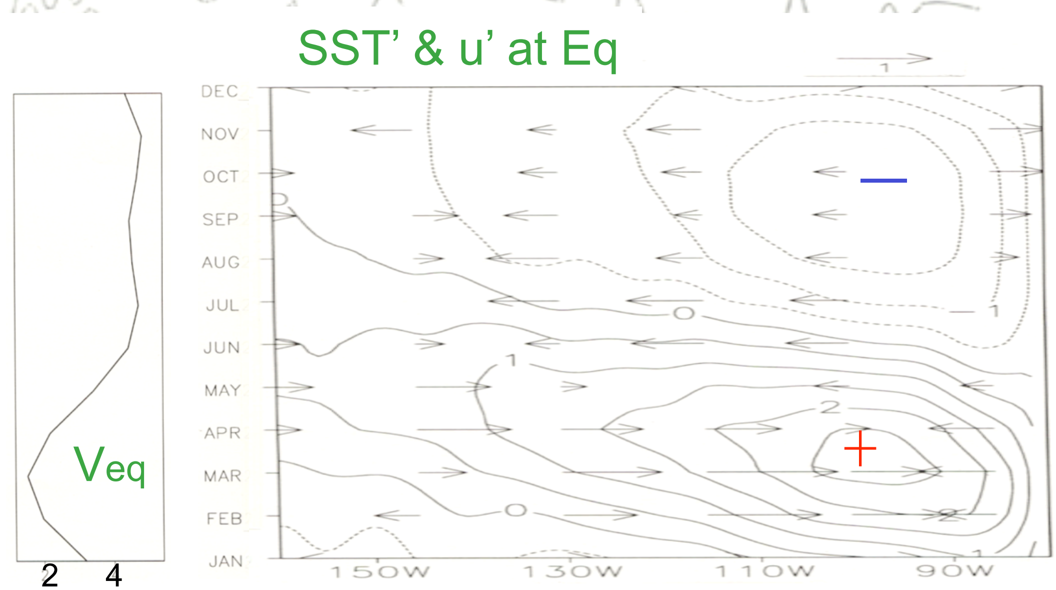
Annual V’ in both cases



$(10^{-2}\ Nm^{-2})$
2
0
$\bar{\tau}_y$
140E
180
140W
100W



160°E 170° 180° 170° 160° 150° 140° 130° 120° 110° 100° 90° 80°W
(b)
m
100
200
300
Temperature along equator

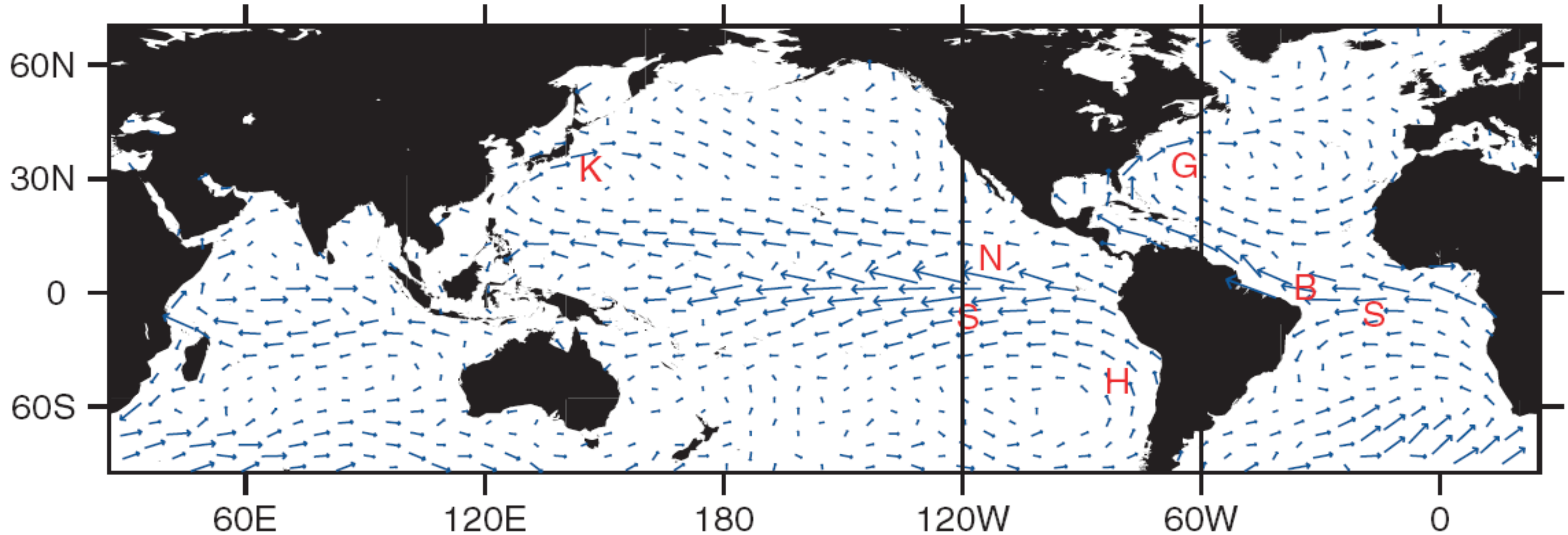


SST' & u' at Eq
Veq
2
4
DEC
NOV
OCT
SEP
AUG
JUL
JUN
MAY
APR
MAR
FEB
JAN
150W
130W
110W
90W

Consequence 2:

Asymmetries in ocean circulation:

North Equatorial Countercurrent (NECC)



Annual-mean surface currents based on ship drift. K: Kuroshio, G: Gulf Stream, N and S: North and South Equatorial Currents, B: Brazil Current, and H: Humboldt Current. (WH05)

Asymmetry in ocean currents

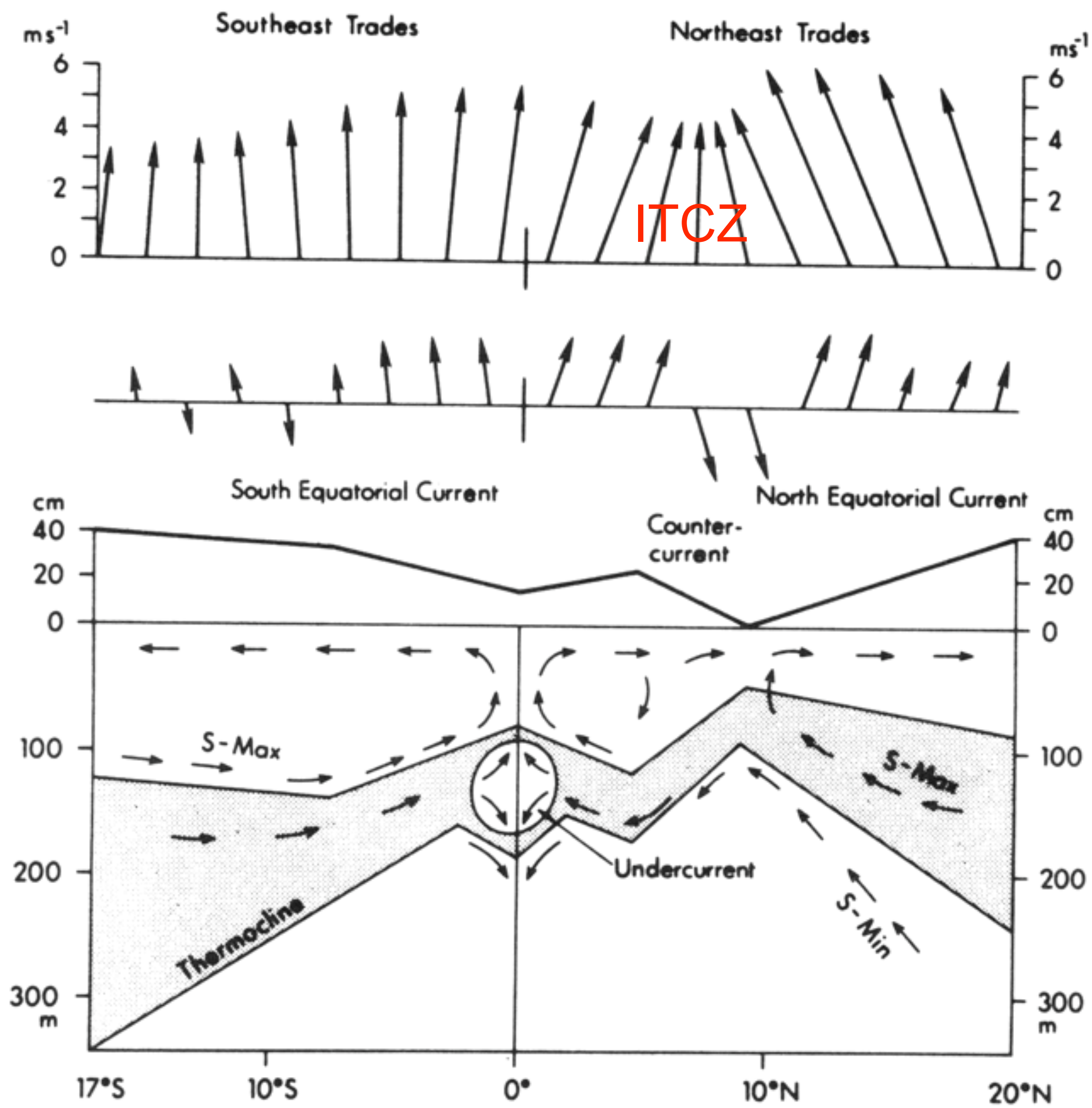


FIG. 7.38. Schematic meridional section across the equator with (top) plan view showing the mean trade winds, surface circulation, and (bottom) vertical section with surface slopes, basic temperature structure and meridional circulation below the surface. (N.B. "Countercurrent" = "NECC" in our notation.) (From Wyrtki and Kilonsky, 1984.)

Subtropical cells

- Equatorial upwelling as manifested in SST minimum
- Cold/salty water converges onto the equator to compensate the upwelling, along the thermocline from the subtropics.
- The ventilation and upwelling maintain a sharp thermocline in the equatorial oceans.

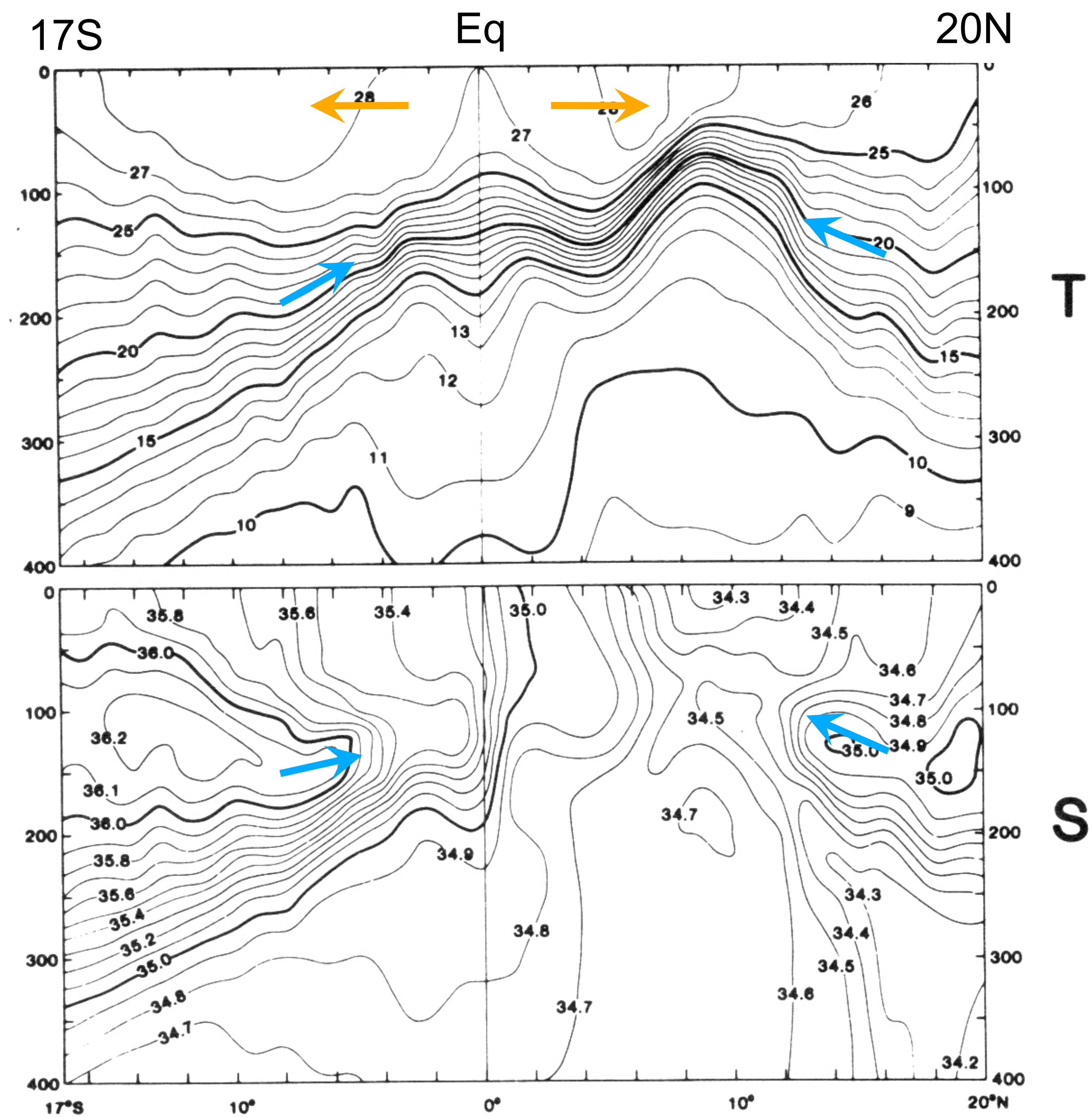
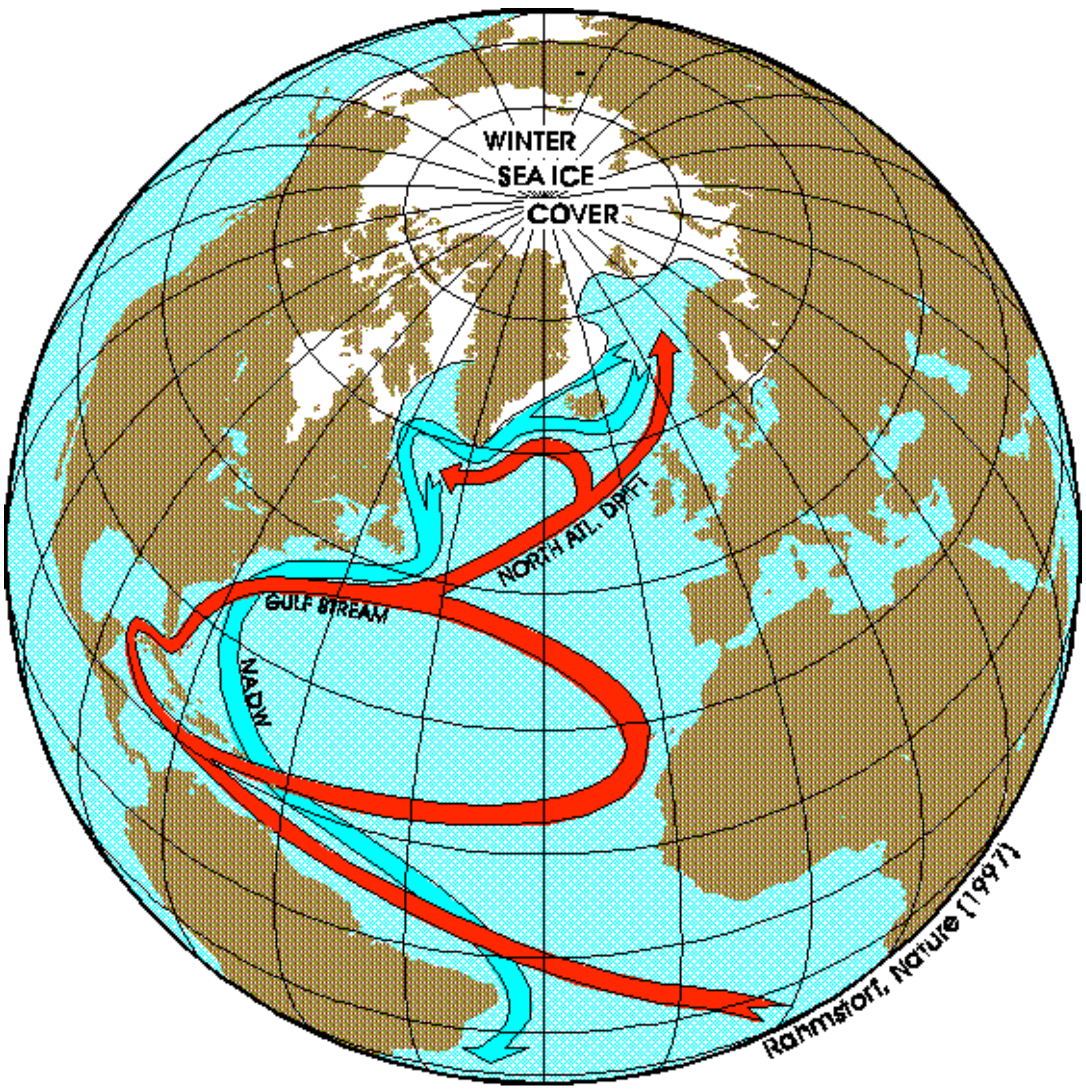
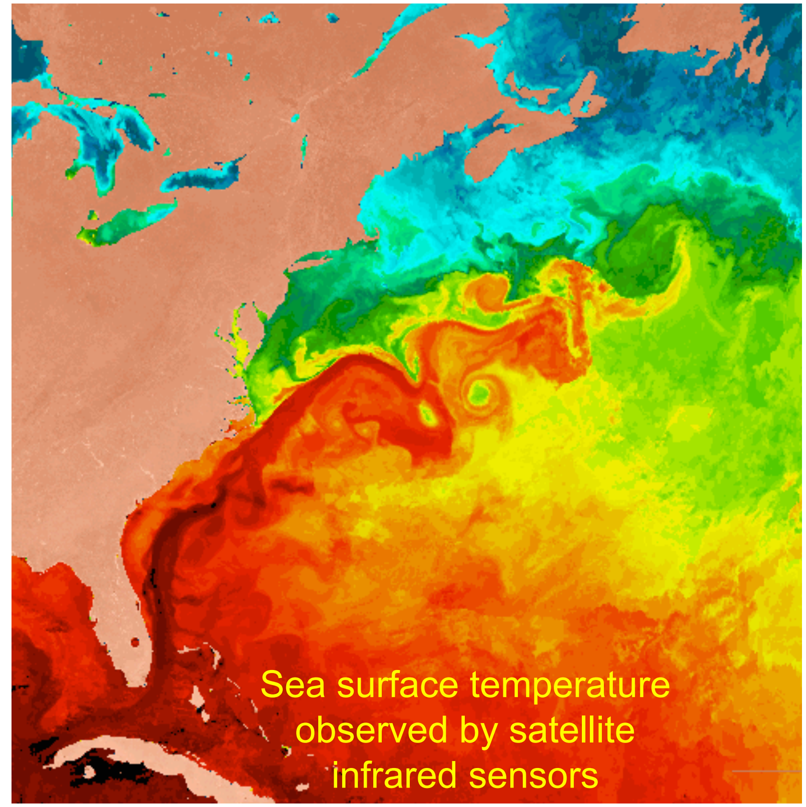


FIG. 7.33. Mean distributions of surface dynamic height (ΔD dyn. cms.) relative to 1000 db (dyn. cm.) and vertical meridional sections of zonal geostrophic flow (U cm/s), temperature (t°C) and salinity (S) between Hawaii and Tahiti, for 12 months from April 1979. (Wyrtki and Kilonsky, 1984.)

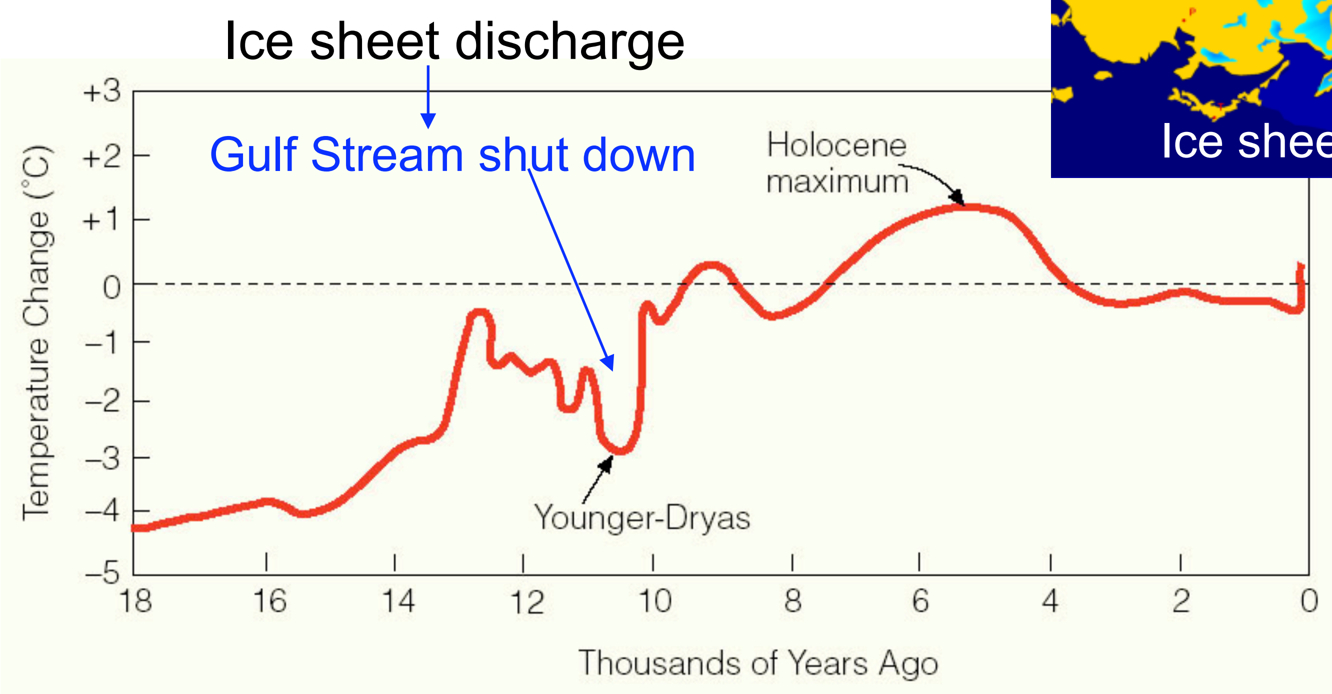
Atlantic Meridional Overturning Circulation (AMOC)

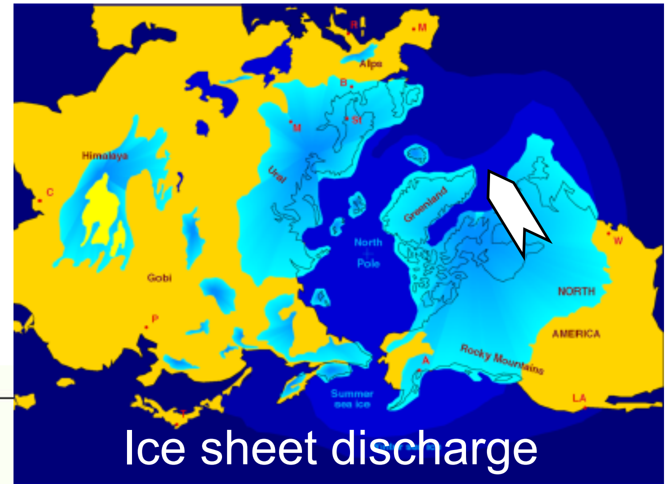


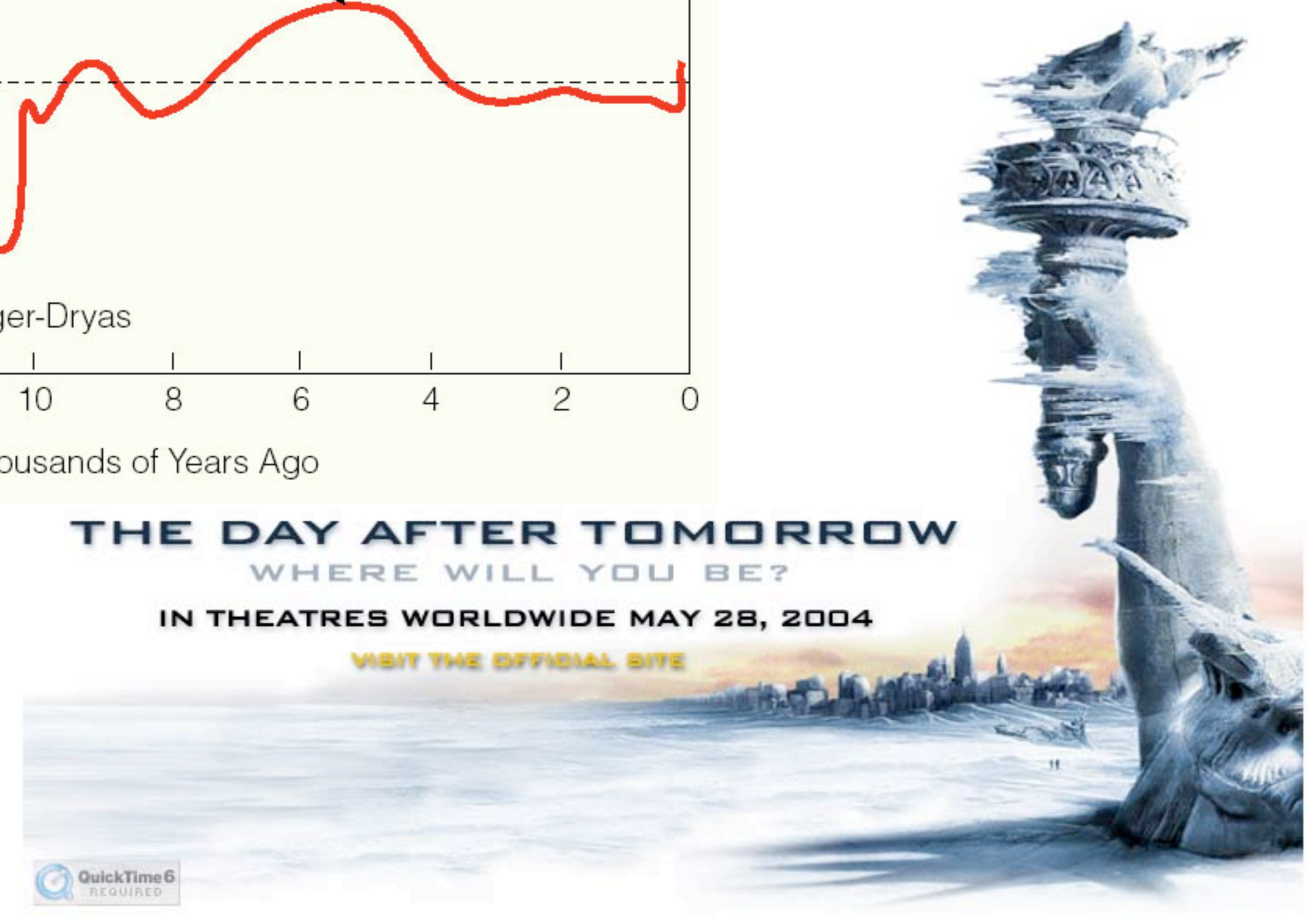


Europe's heating system:
warmer Gulf Stream (red) transports heat north while cold deep water flows south underneath (blue).

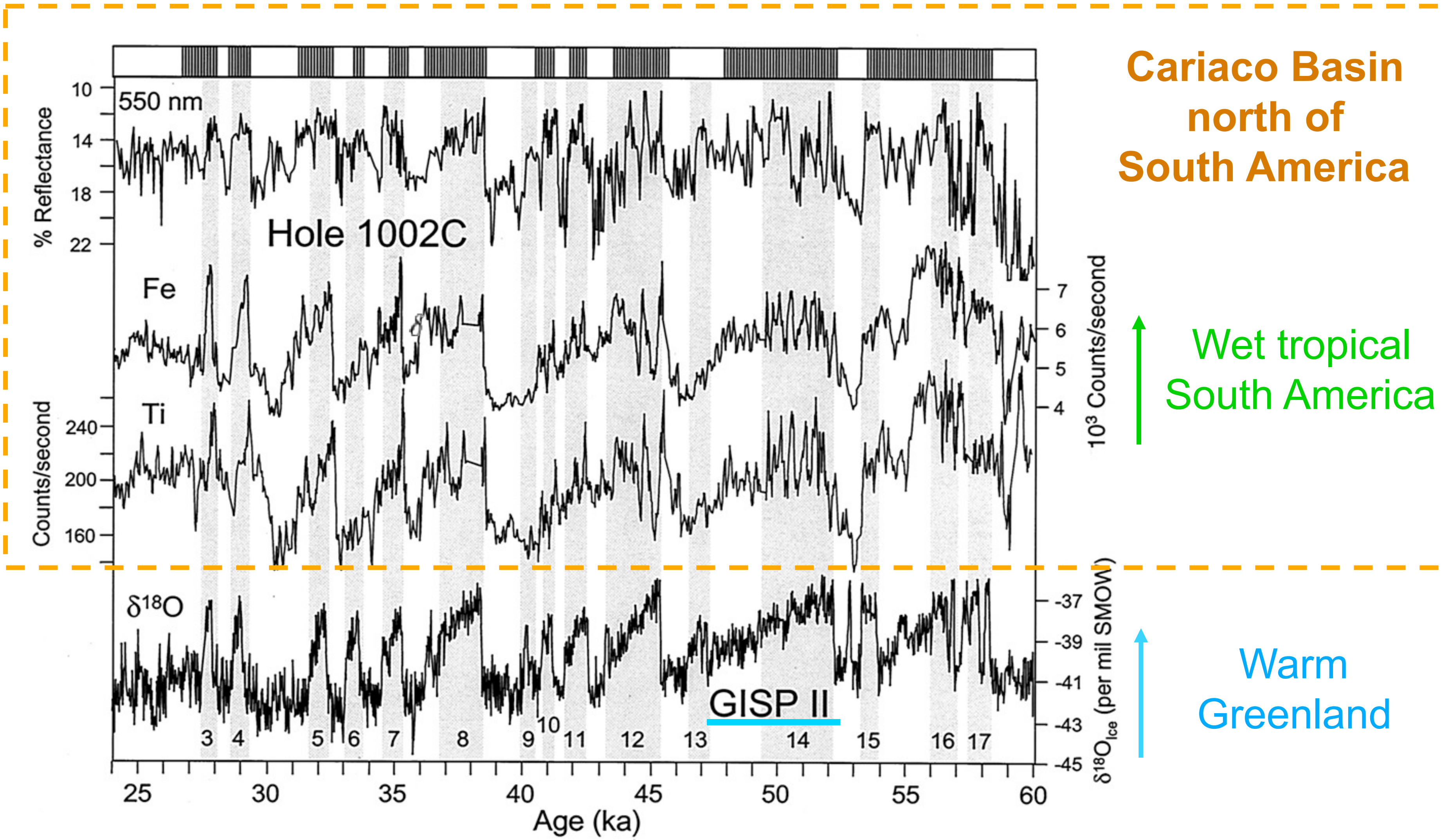
Rapid Climate Change







Close connection between the subpolar and tropical North Atlantic

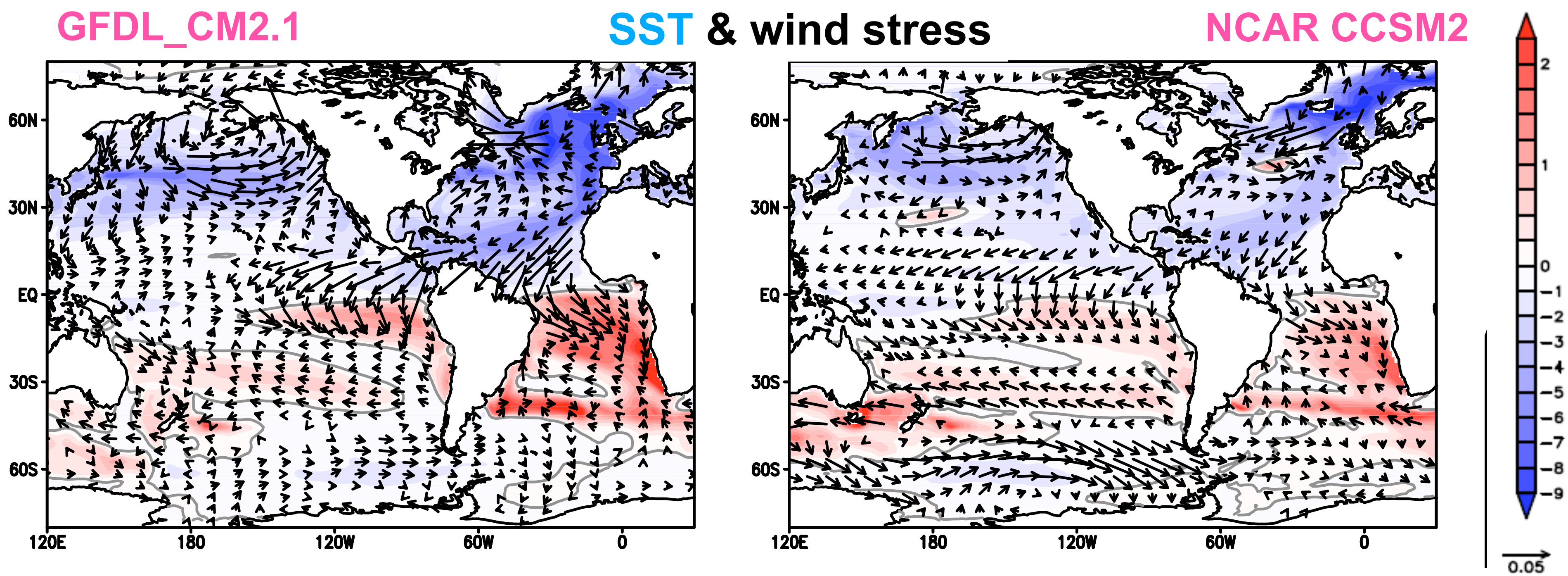


Peterson et al. (2000, *Science*)

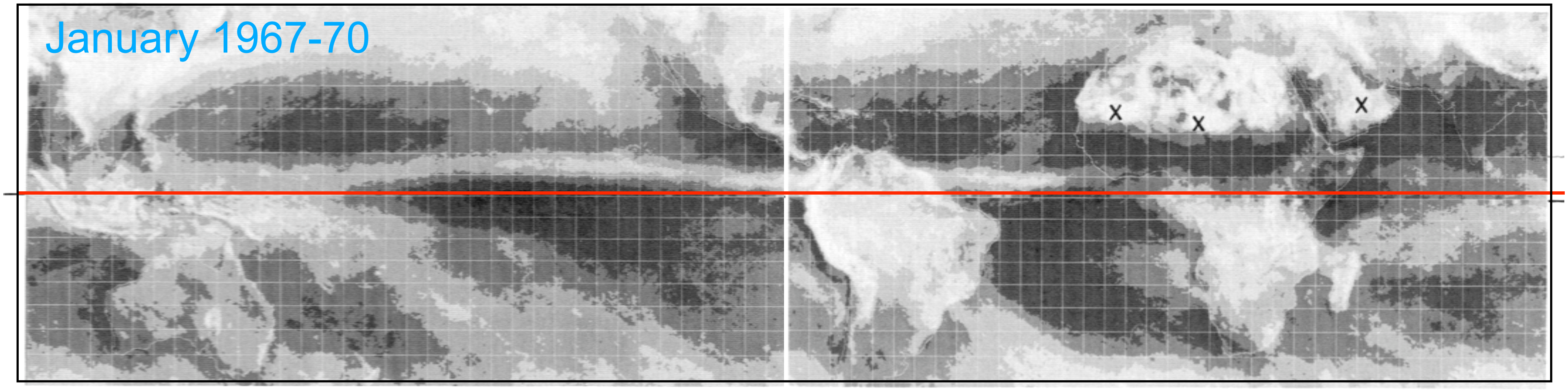
Chiang (2004, Hadley circulation book)

Water-hosing response (Yr 81-100)

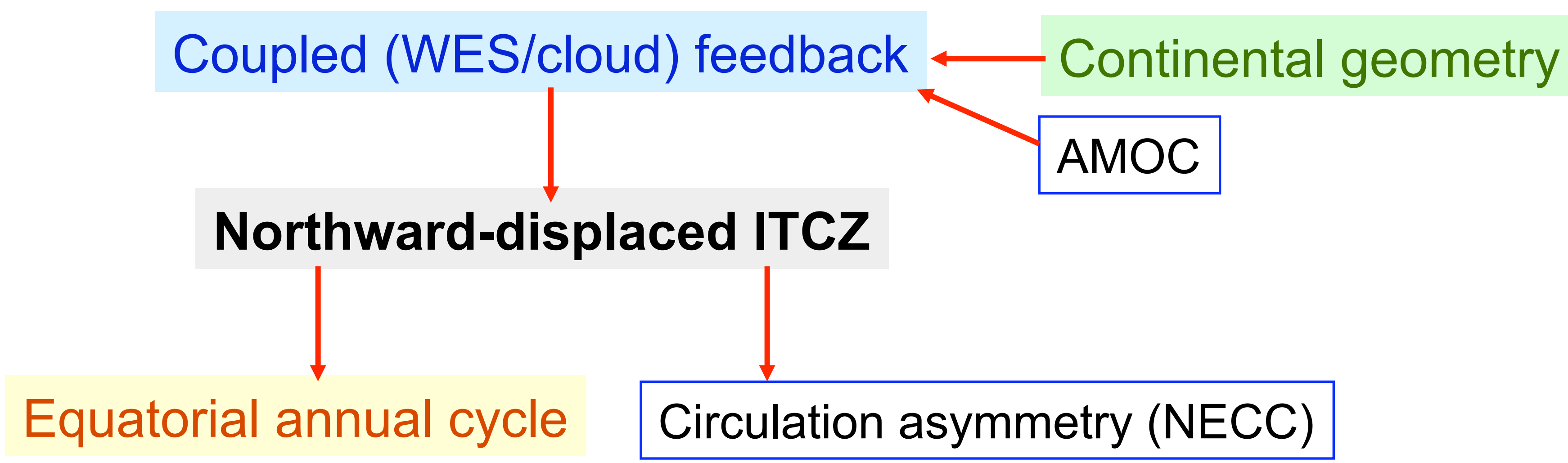
A. Timmermann, Y Okumura, et al. 2007

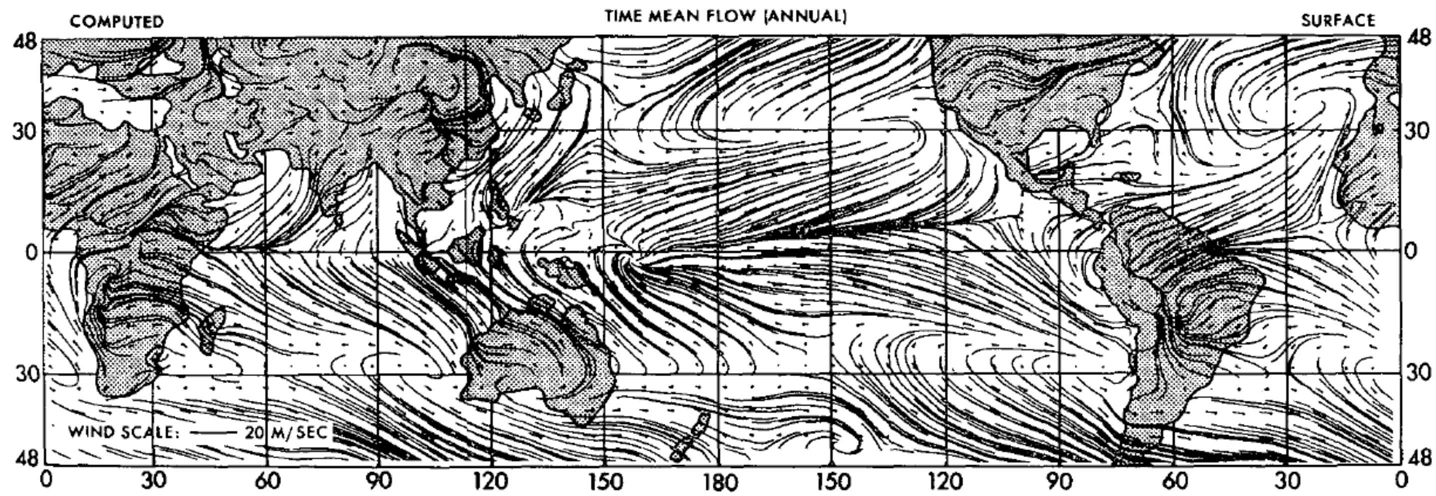


- Meridional (WES) mode & reduced NS asymmetry
- Southward displaced ITCZ, indicating a role of AMOC

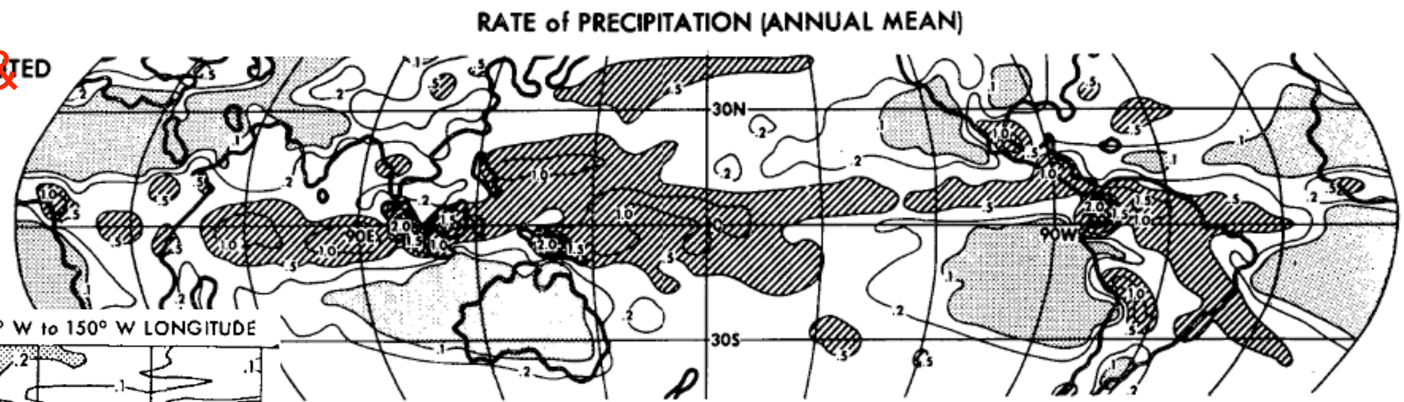

January 1967-70

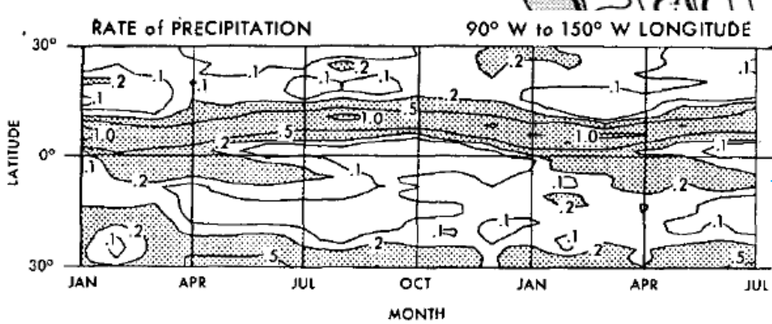
Summary


Coupled (WES/cloud) feedback
Continental geometry
AMOC
Northward-displaced ITCZ
Equatorial annual cycle
Circulation asymmetry (NECC)

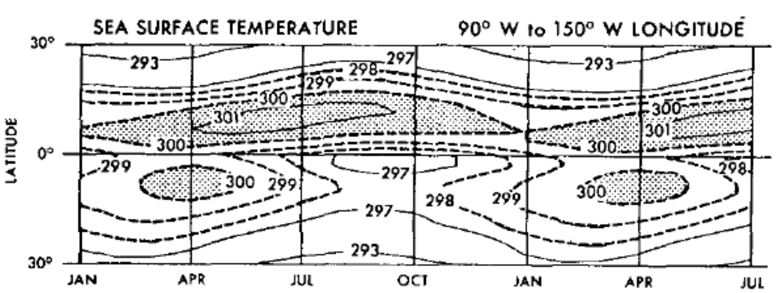


First AGCM with a hydrological cycle & seasonal cycle





← SST-forced double ITCZ



Manabe et al. (1974, *JAS*)

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Bjerknes feedback & zonal asymmetry