

$\overline{u'T}$ Northern Winter

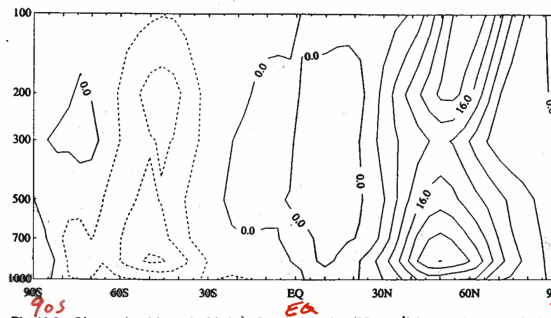


Fig. 10.3 Observed northward eddy heat flux distribution ($^{\circ}\text{C m s}^{-1}$) for Northern Hemisphere winter. (Adapted from Schubert *et al.*, 1990.)

$\overline{u'v'}$ Northern Winter

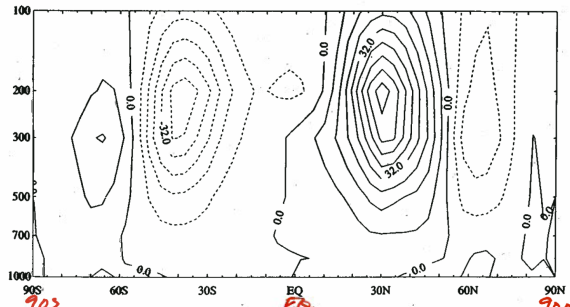
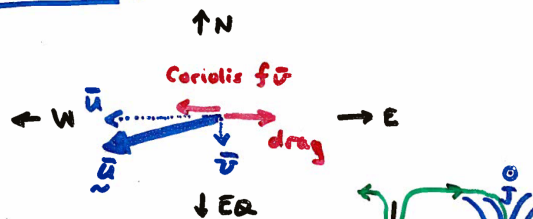


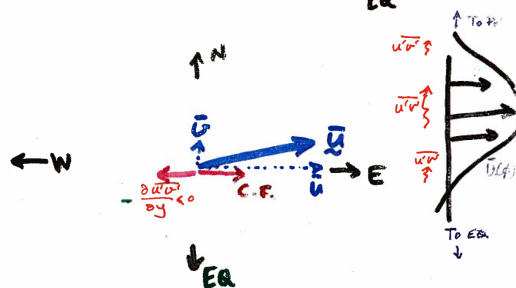
Fig. 10.6 Observed northward eddy momentum flux distribution ($\text{m}^2 \text{s}^{-2}$) for Northern Hemisphere winter. (Adapted from Schubert *et al.*, 1990.)

Zonal Force Balance: Hadley c.

Near Surface



Aloft/Jet Level



Zonal Gradient $\bar{J}$ Diabatic Heating Starts the Circulation - Eddies define it

An uncoupled aquaplanet experiment

Model Description

Community Climate Model, version 1 (CCM1)

Atmospheric General
Circulation
Model

T42 horizontal resolution

12 vertical sigma levels ($\sigma = p / p_s$)

$\sigma = (0.991, 0.926, 0.811, 0.664, 0.500, 0.355,$
 $0.245, 0.165, 0.110, 0.060, 0.025, 0.009)$

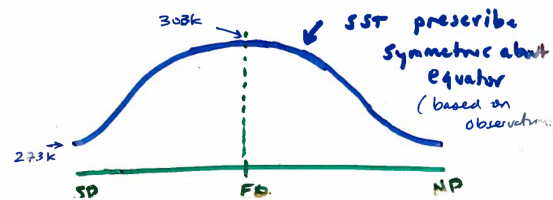
Insolation at perpetual equinox

No diurnal cycle

Kuo convective scheme (see below)

Surface set at water everywhere — “aqua planet”

no orography
SST prescribed
Equatorially Sym. str.

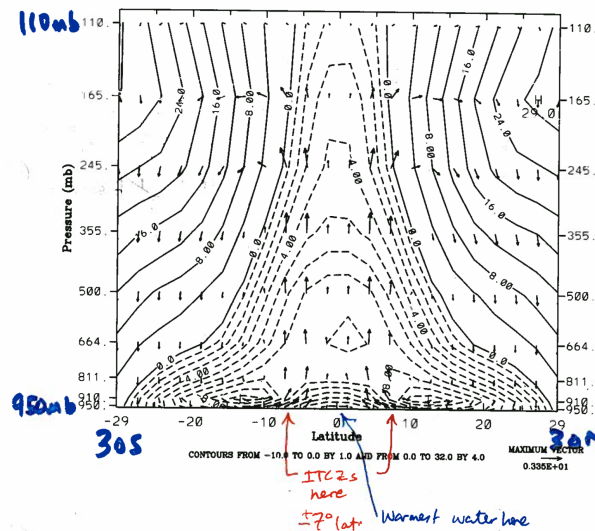


Zonal Mean Circulation

Wind $\bar{u}$ (contours) and

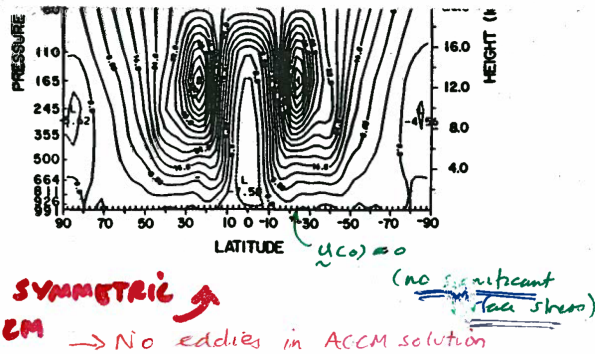
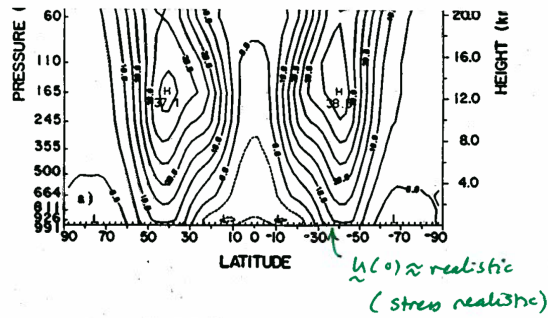
KUO-STD
Contours of U and
V-W Vector Winds
ZONAL AVERAGE FROM -30.0 TO 0.0 DEGREES

$\bar{v}, \bar{w}$ (vectors)



Zonal Averaged Zonal Wind

FULL
ACCM
↳



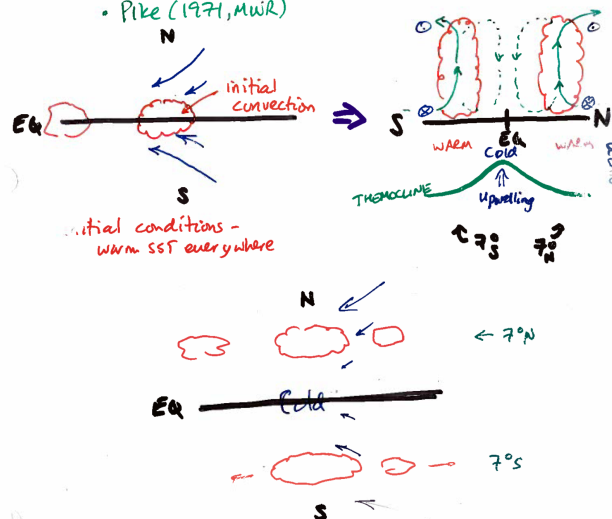
ZONALLY SYMMETRIC
ACCM
→ No eddies in ACCM solution

Introduction to the coupled system

"ITCZs will avoid the equator"

(1) A coupled atmosphere-ocean system

• Pike (1971, MWR)

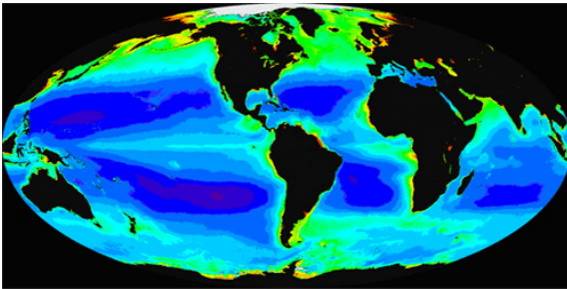
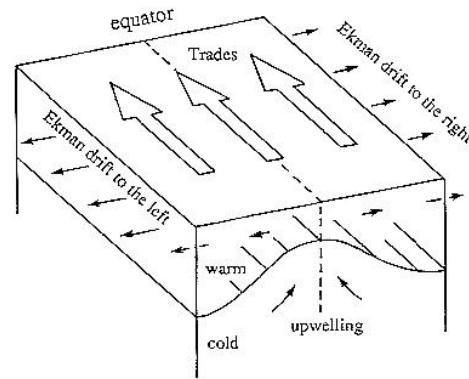


ITCZ over the warmest water?

Equatorial Upwelling

Schematic of equatorial upwelling.

Figure from Cushman-Roisin et al. (1994).



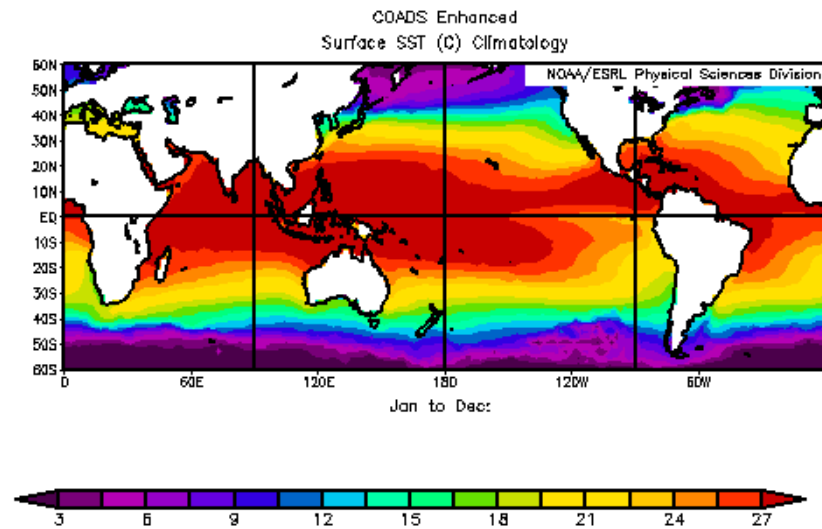
Global distribution of chlorophyll gathered from the first 6 years (September 1997-September 2003) of SeaWiFS

biologyeducation.net/News and Articles/el_nino.htm

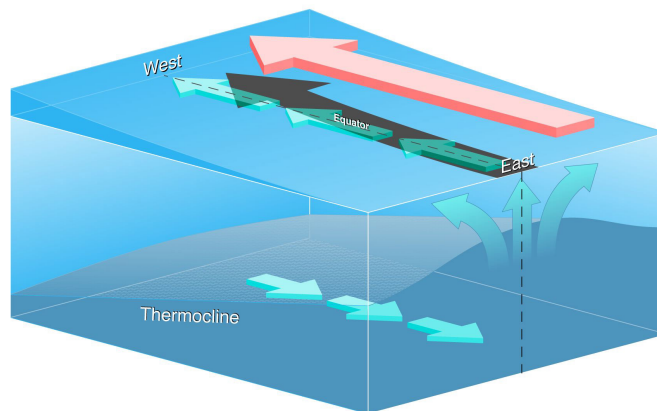
Basics of Tropical Climatology

- Hadley Circulation
 - Instigated by meridional gradients in absorbed solar radiation
 - But fundamentally shaped by (and governed by?) eddies
- East - West Asymmetries and the Walker Circulation
 - Due to coupled atmosphere-ocean processes
- North-South Asymmetries
 - Mainly to the effects of asymmetry in geometry (orography and land distribution) on the atmosphere

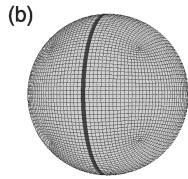
What about the east-west asymmetry in the Pacific and Atlantic Oceans?



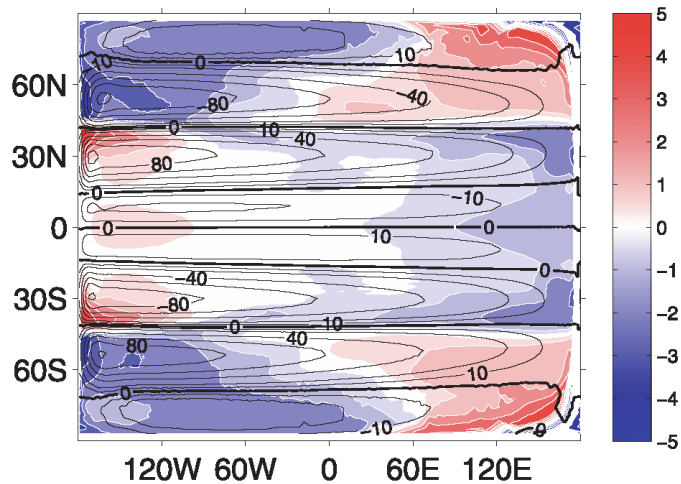
Equatorial Upwelling plus meridional boundaries (bounded basin)



Aquaplanet GCM with one thin pole-to-pole ocean fence

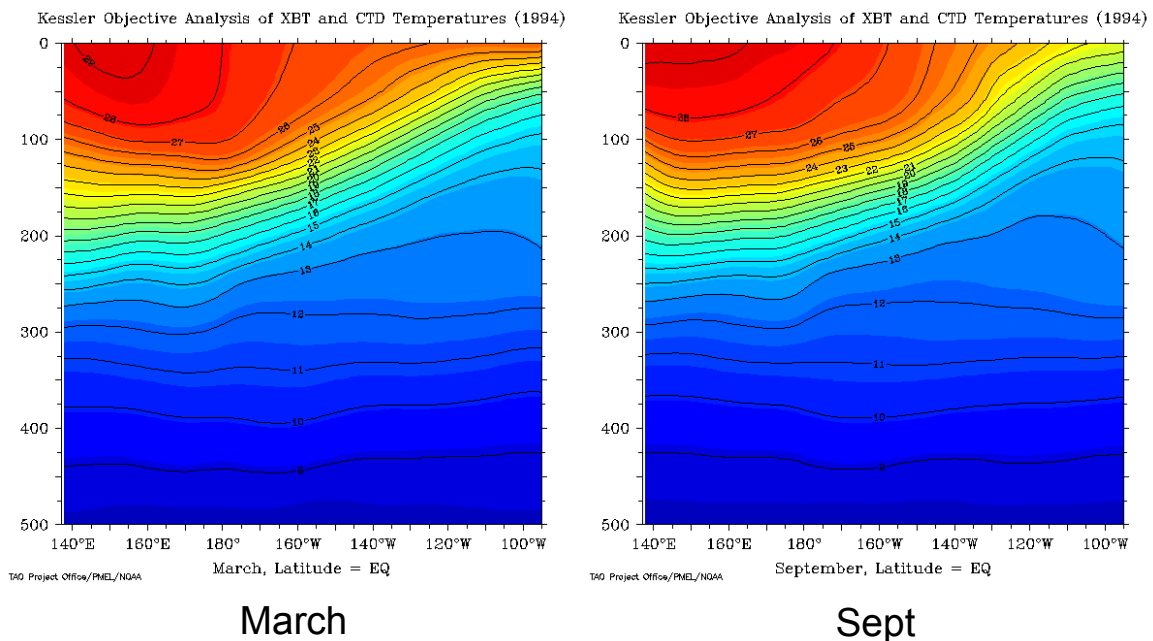


Shaded: departure of SST from zonal average
Contour: ocean stream function



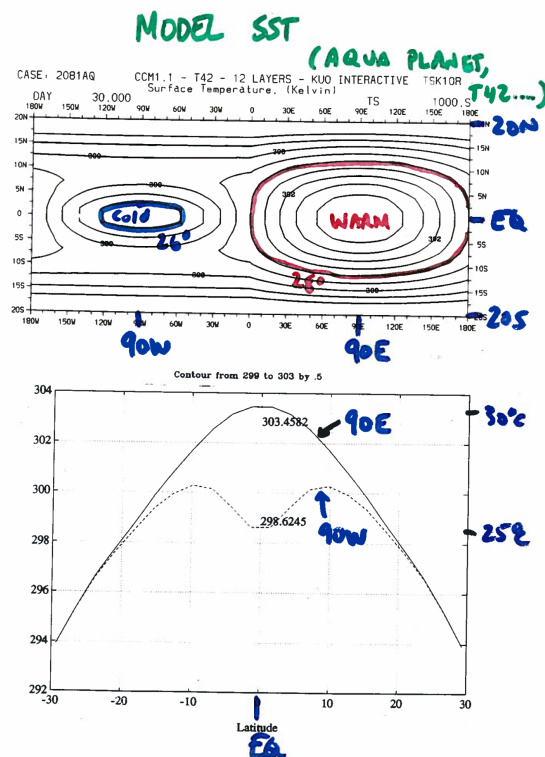
Enderton and Marshall 2009

Ocean temperature along the equator in the Pacific



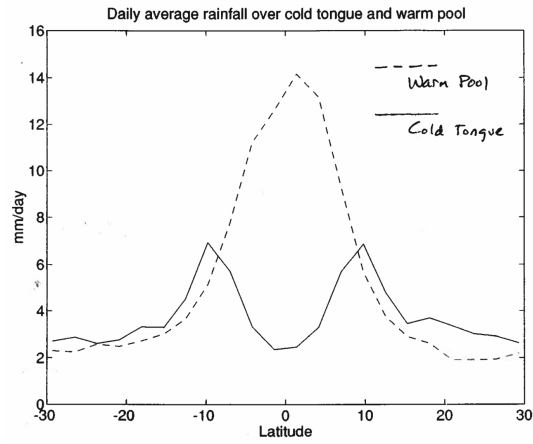
Bjerknes Feedback

- The Walker Circulation significantly enhances the Trade winds *along the equator* east of the warm maritime continent (compared to the zonally symmetric case)
- This further enhances upwelling and increases the thermocline tilt in the Pacific -- both of which further cools the eastern Pacific along the equator
- An open question: what is more important for the Walker circulation?
 - The low level pressure gradients in the boundary layer associated with gradients in low level temperature?
 - Elevated heating associated with enhanced convection in the western Pacific?



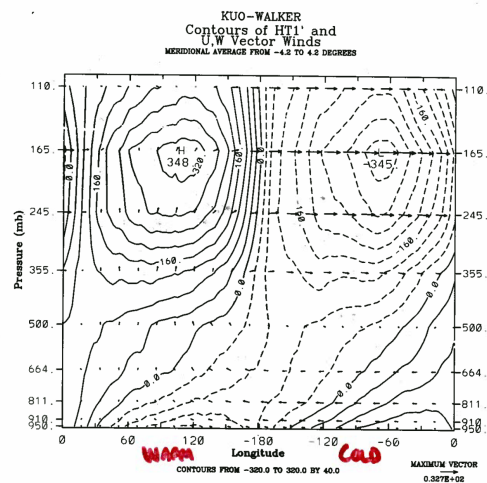
Bjerknes + O'Brien (1995)

Rainfall Rate

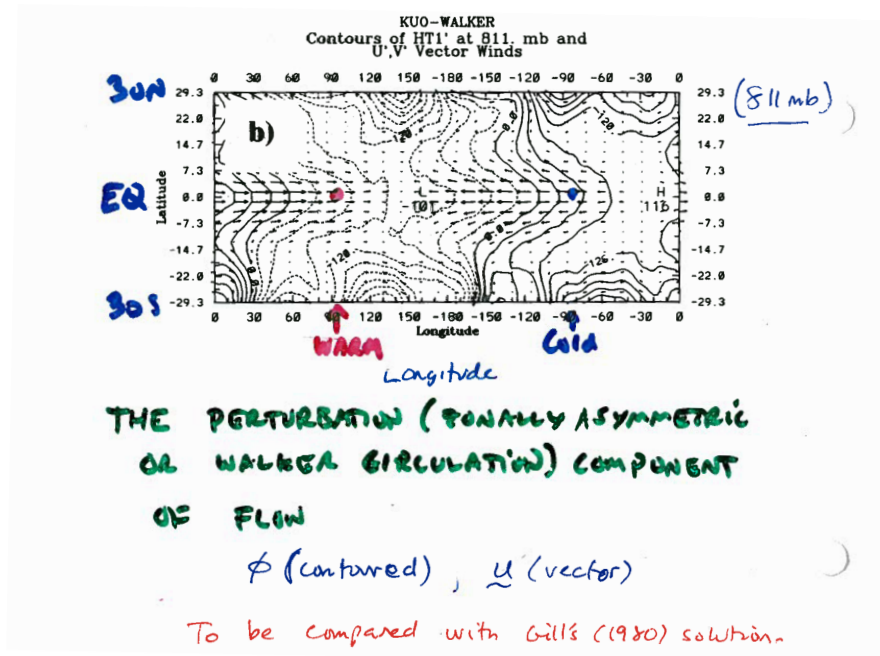


The Walker Circulation

LONGITUDE - HEIGHT CROSS SECTION ALONG EQUATOR



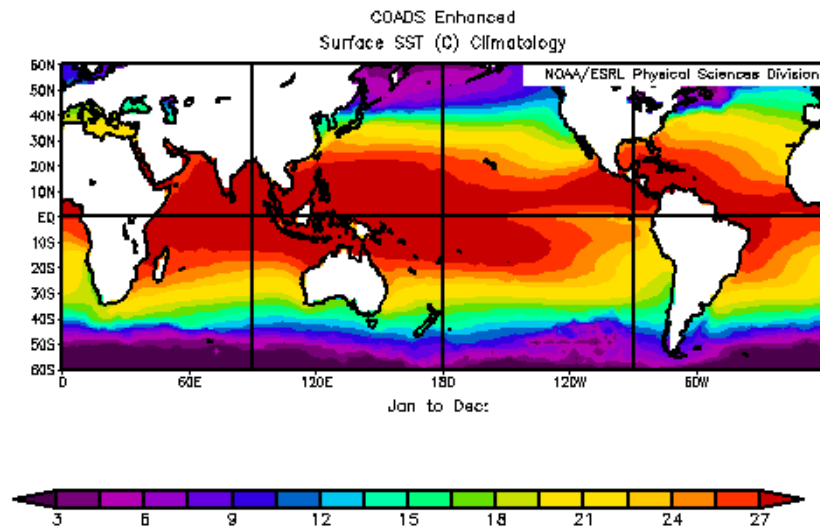
The Walker Circulation (cont)



Basics of Tropical Climatology

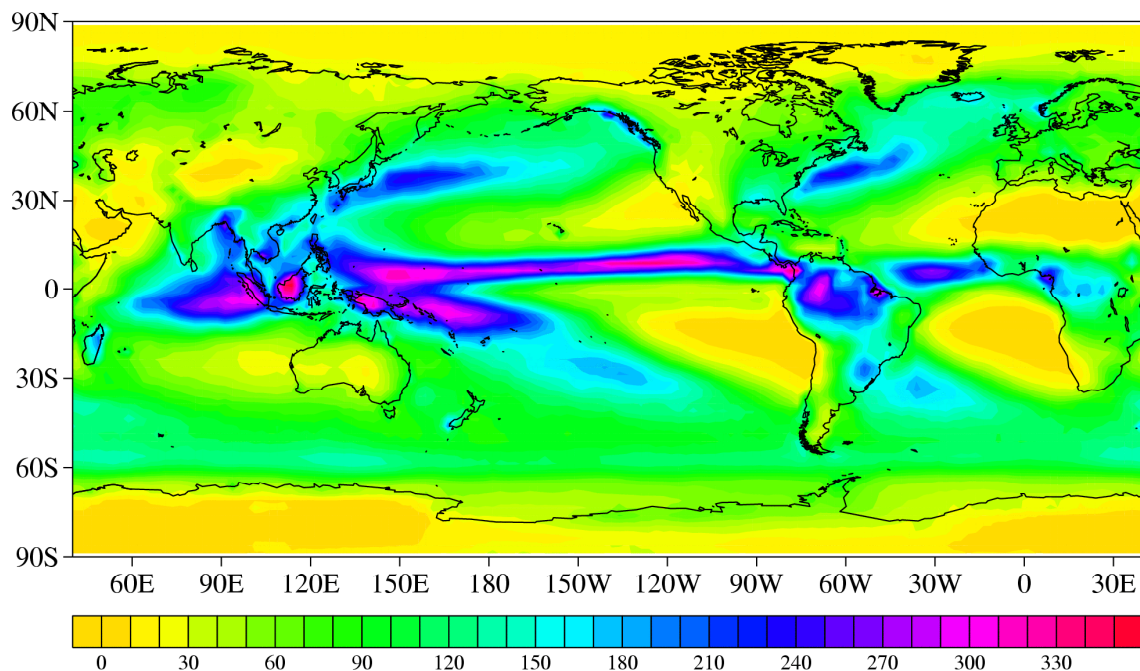
- Hadley Circulation
 - Instigated by meridional gradients in absorbed solar radiation
 - But fundamentally shaped by (and governed by?) eddies
- East - West Asymmetries and the Walker Circulation
 - Due to coupled atmosphere-ocean processes
 - Why is there no east west asymmetry in the Indian Ocean (where is the Indian Ocean cold tongue)?
- North-South Asymmetries
 - Mainly to the effects of asymmetry in geometry (orography and land distribution) on the atmosphere

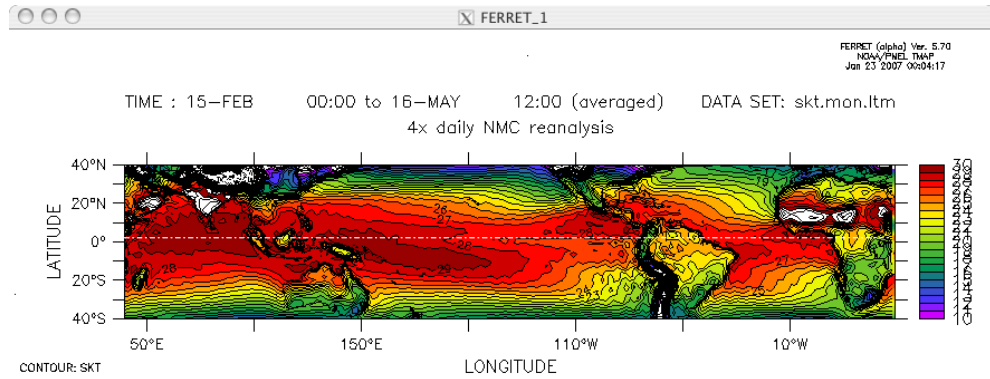
What about the asymmetry in the Atlantic and Indian Oceans?



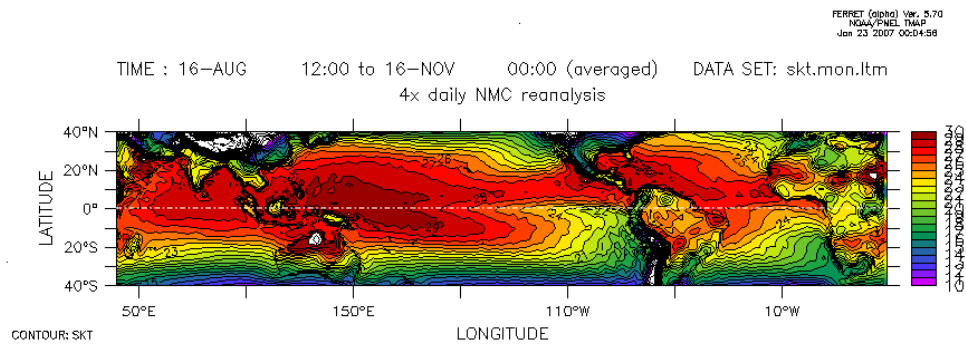
Why is there no cold tongue on the equator in the eastern Indian Ocean?

Annual total precipitation (cm, GPCP)

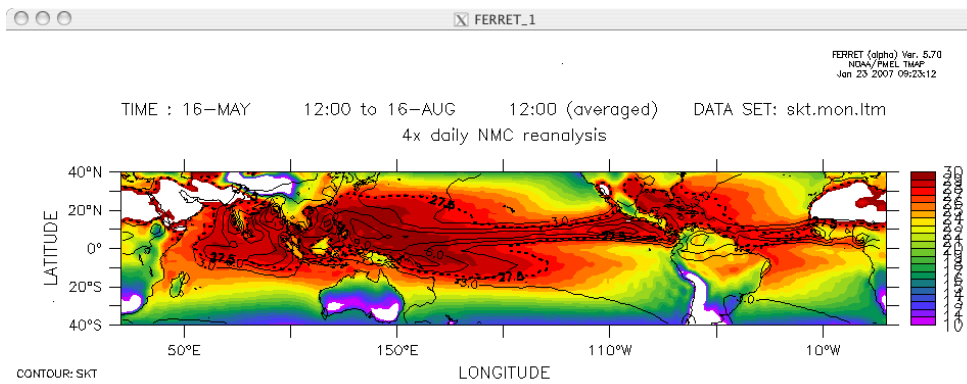




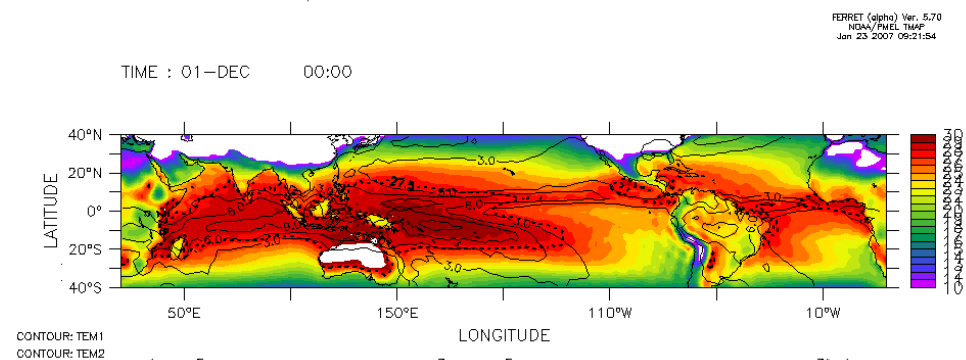
Monthly Longterm Mean of Skin Temperature (degC)



Monthly Longterm Mean of Skin Temperature (degC)

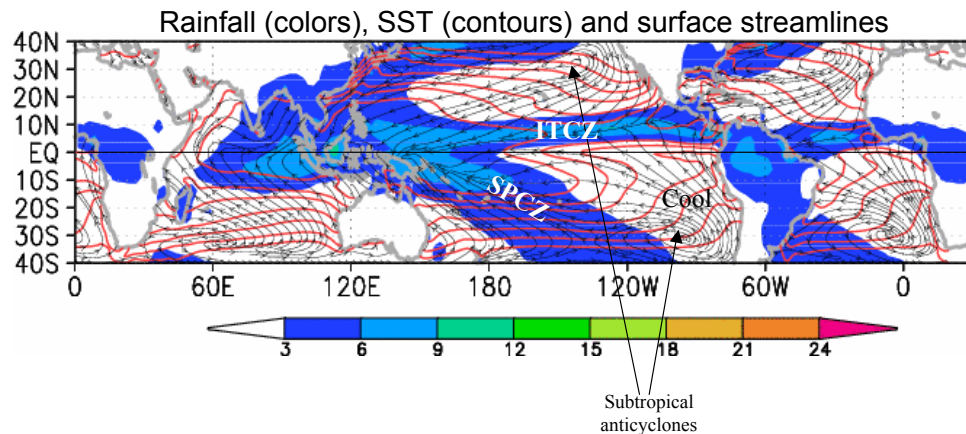


Monthly Longterm Mean of Skin Temperature (degC)



(SKT[D=skt.mon.ltm,L=12]+SKT[D=skt.mon.ltm,L=1:2@SUM])/3

The Andes and the Observed Annual Mean State in the Tropical Pacific



Why is the ITCZ in the northern hemisphere, and why is the SE Pacific so cold?

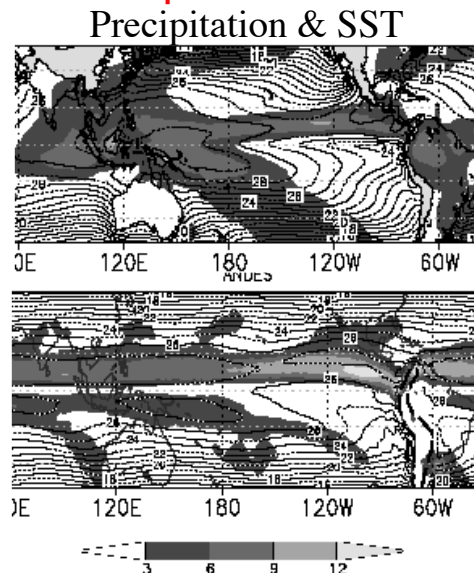
Note: this mean state asymmetry is fundamental for the existence of El Nino and its' attendant global climate anomalies.

Data: GPCP, NCEP OI SST, QSCAT

There is only one ITCZ in the eastern-central Pacific and it is north of the equator ...

Observed
Climatology

Simulated Climatology: an atmospheric GCM coupled to a slab ocean. Only Andes *orography* is included; there is no land.



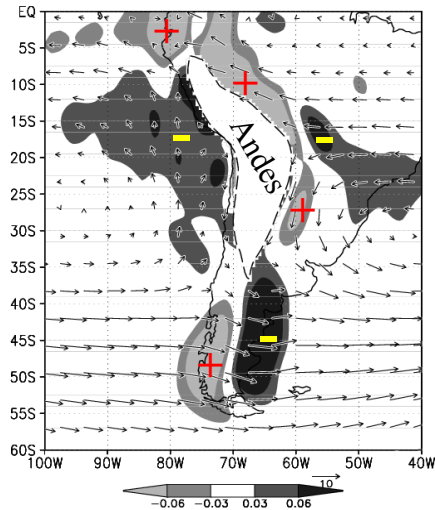
... because of the mechanical affect of the Andes on the atmosphere and the resulting *thermodynamic* feedbacks with the ocean.

Takahashi and Battisti 2007a

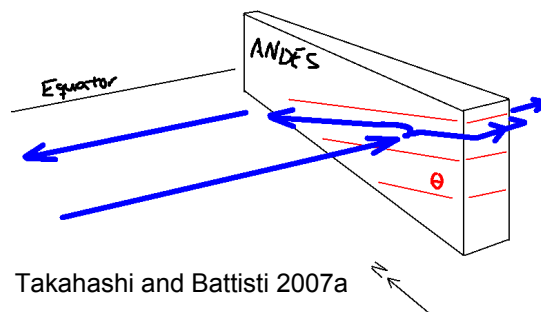
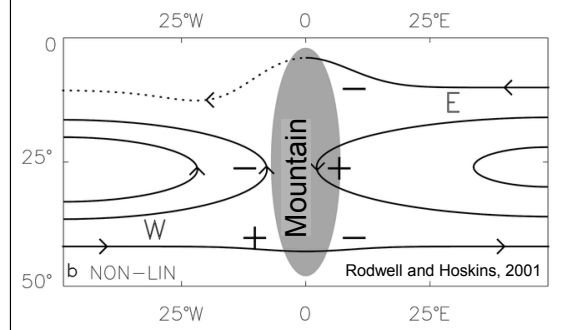
The Andes and the South Pacific Anticyclone

AGCM with *fixed* zonally symmetric SST plus Andes

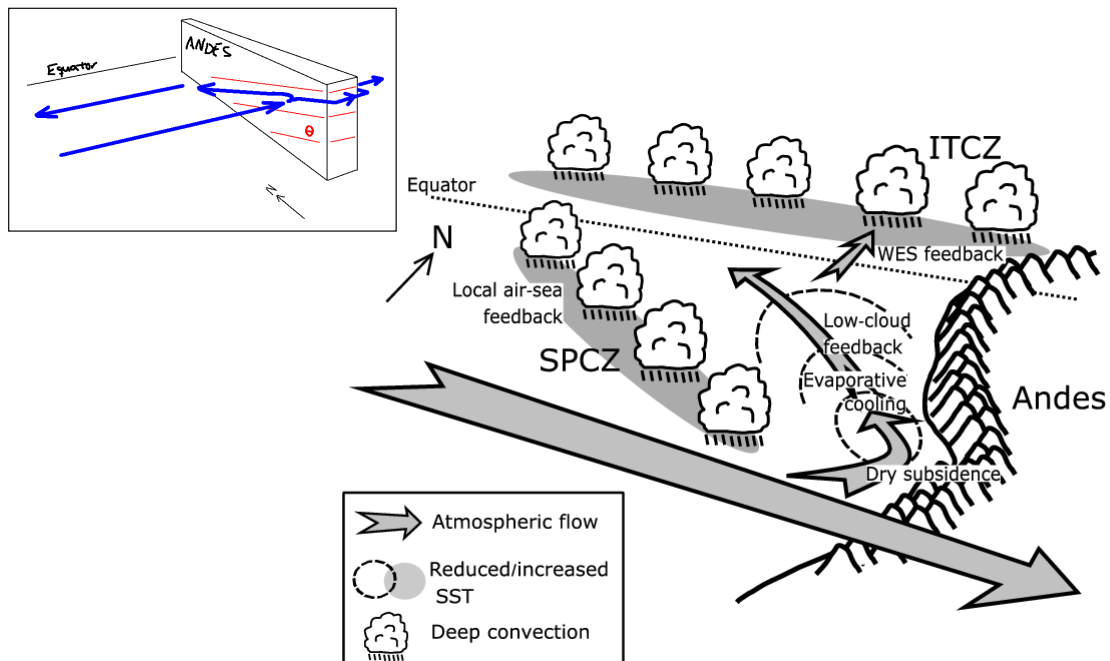
850 mb winds (m/s) and omega (Pa/s)



Dry P.E. model

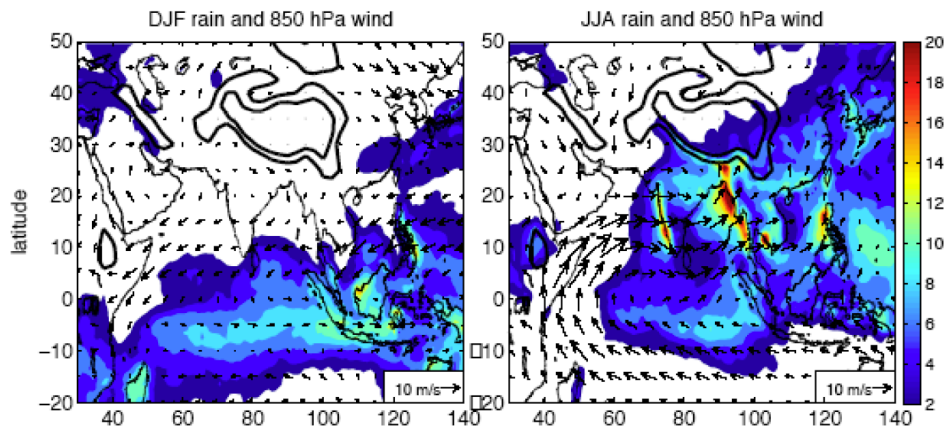


Summary of main mechanisms



Takahashi and Battisti 2007a,b

What about the Indian Ocean?



So why is there no cold tongue on the equator in the eastern Indian Ocean?

Why do we care about the asymmetry about the equator in the Pacific?

- A symmetric mean state would not support ENSO
 - Application? most IPCC models should have weak ENSOs
- A mean state that features a SH bias would have ENSO, but relatively weak teleconnections to the NH

THE MEAN OCEAN CIRCULATION

DYNAMICS

The circulation of the upper ocean follows immediately from the response of the aqua planet AGCM to prescribed SST.

