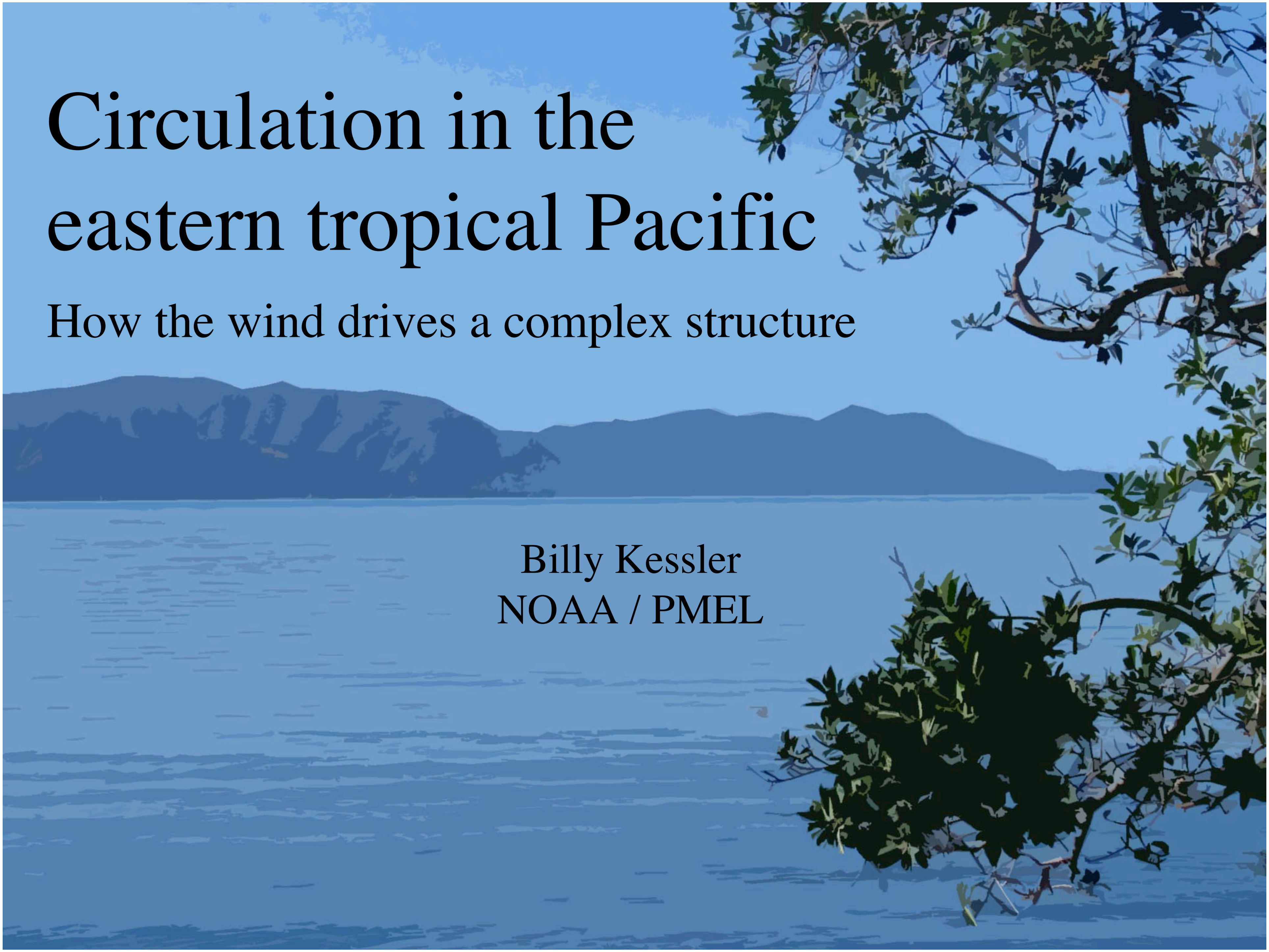


Circulation in the eastern tropical Pacific

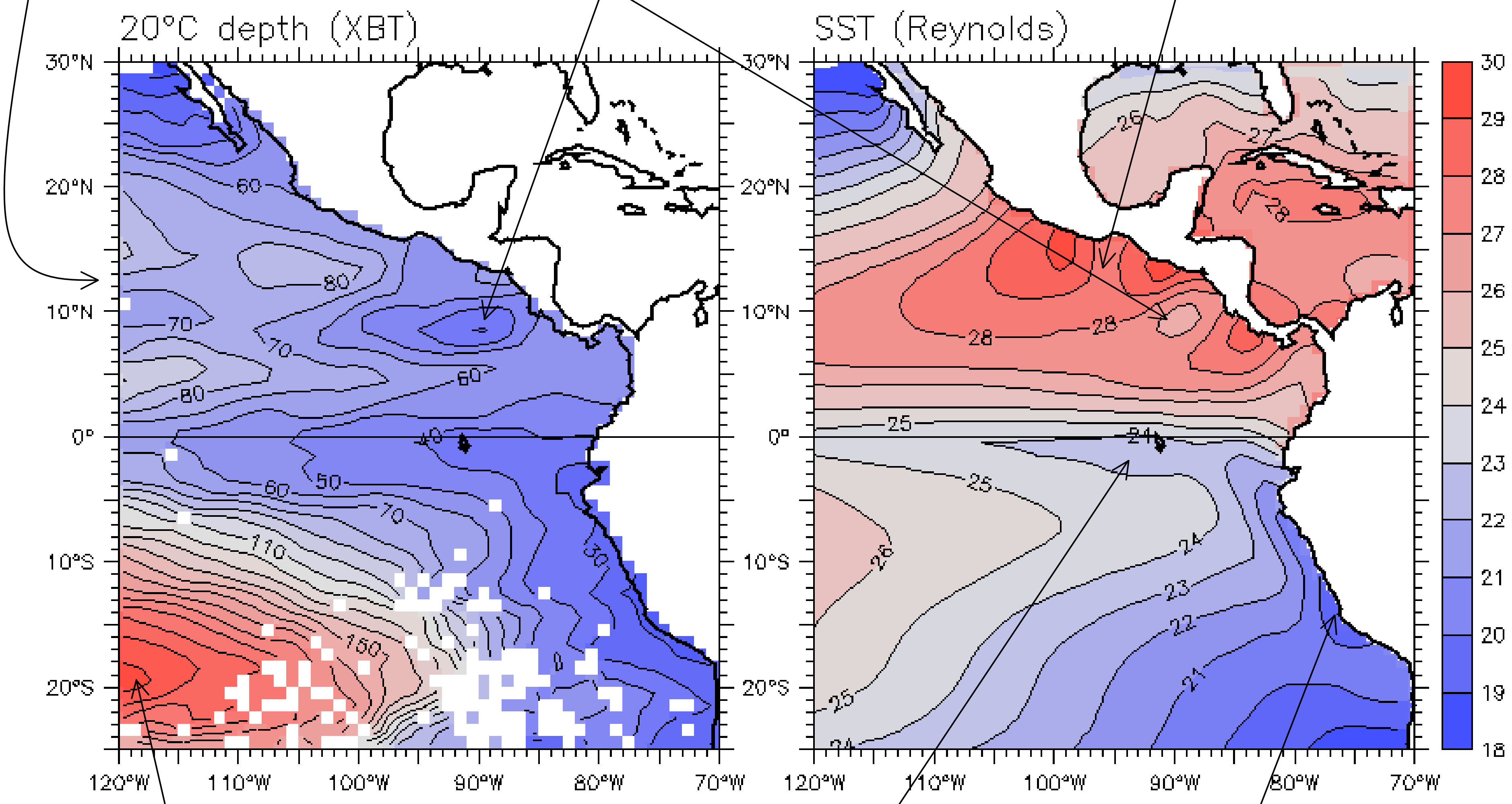
How the wind drives a complex structure

Billy Kessler
NOAA / PMEL

Thermocline ridges and troughs

Costa Rica Dome

East Pacific Warm Pool



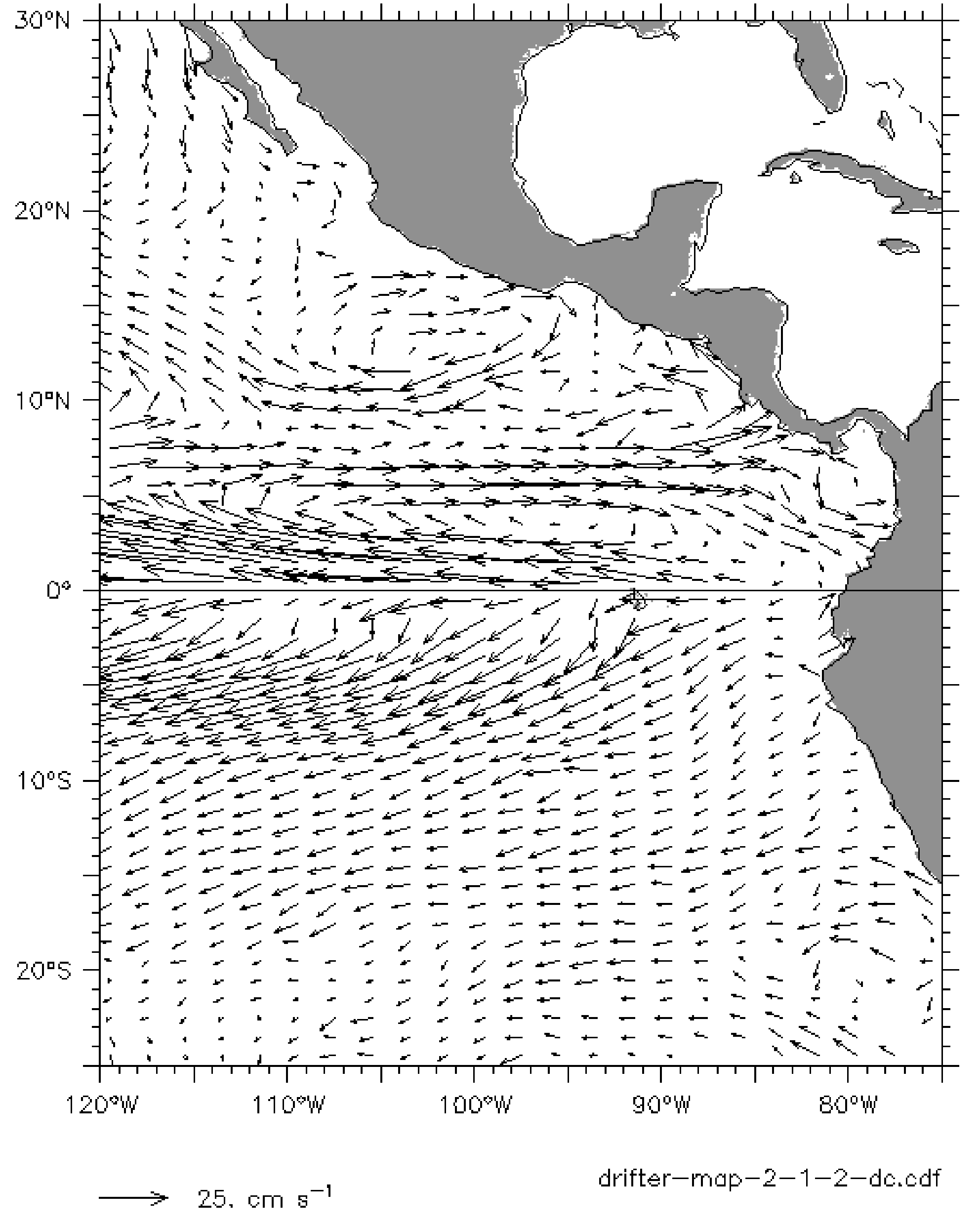
Deep bowl of S Pacific gyre

Equatorial cold tongue

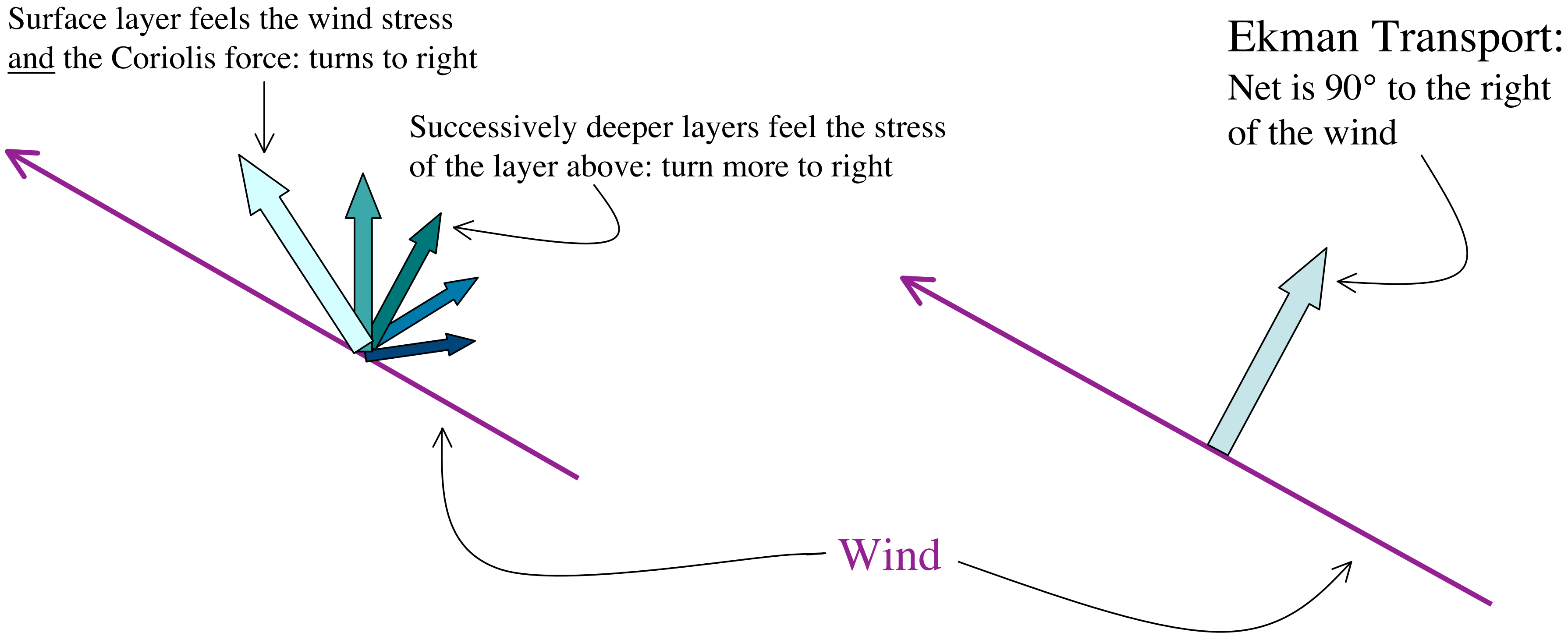
Peru upwelling region

Mean drifter velocity

485,752 kriged drifter positions, Gaussian–mapped with scales 1°x1°



Fundamental wind-driven dynamics: Ekman Transport



Surface layer feels the wind stress
<u>and</u> the Coriolis force: turns to right

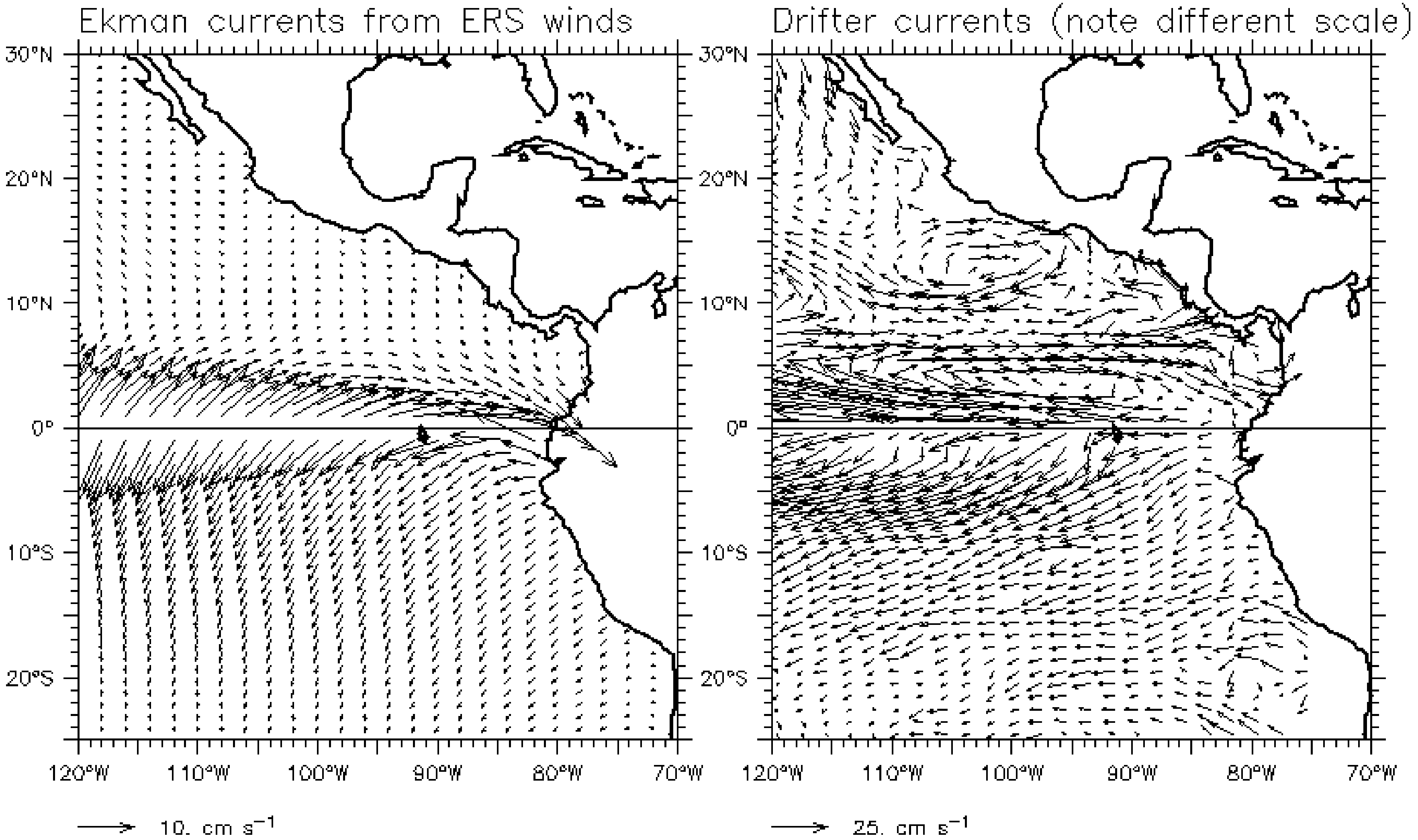
Successively deeper layers feel the stress
of the layer above: turn more to right

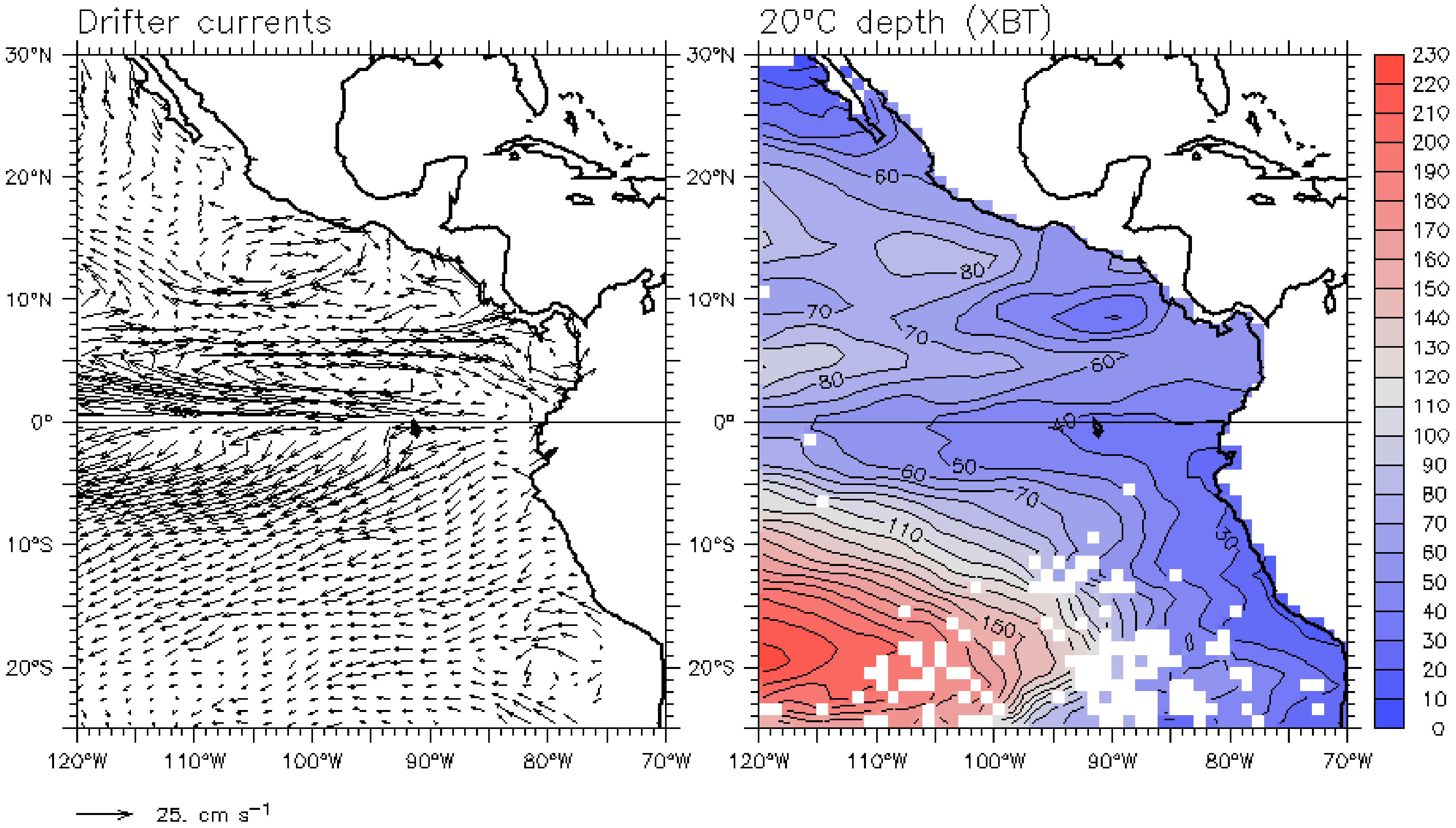
Ekman Transport:
Net is 90° to the right
of the wind

Wind

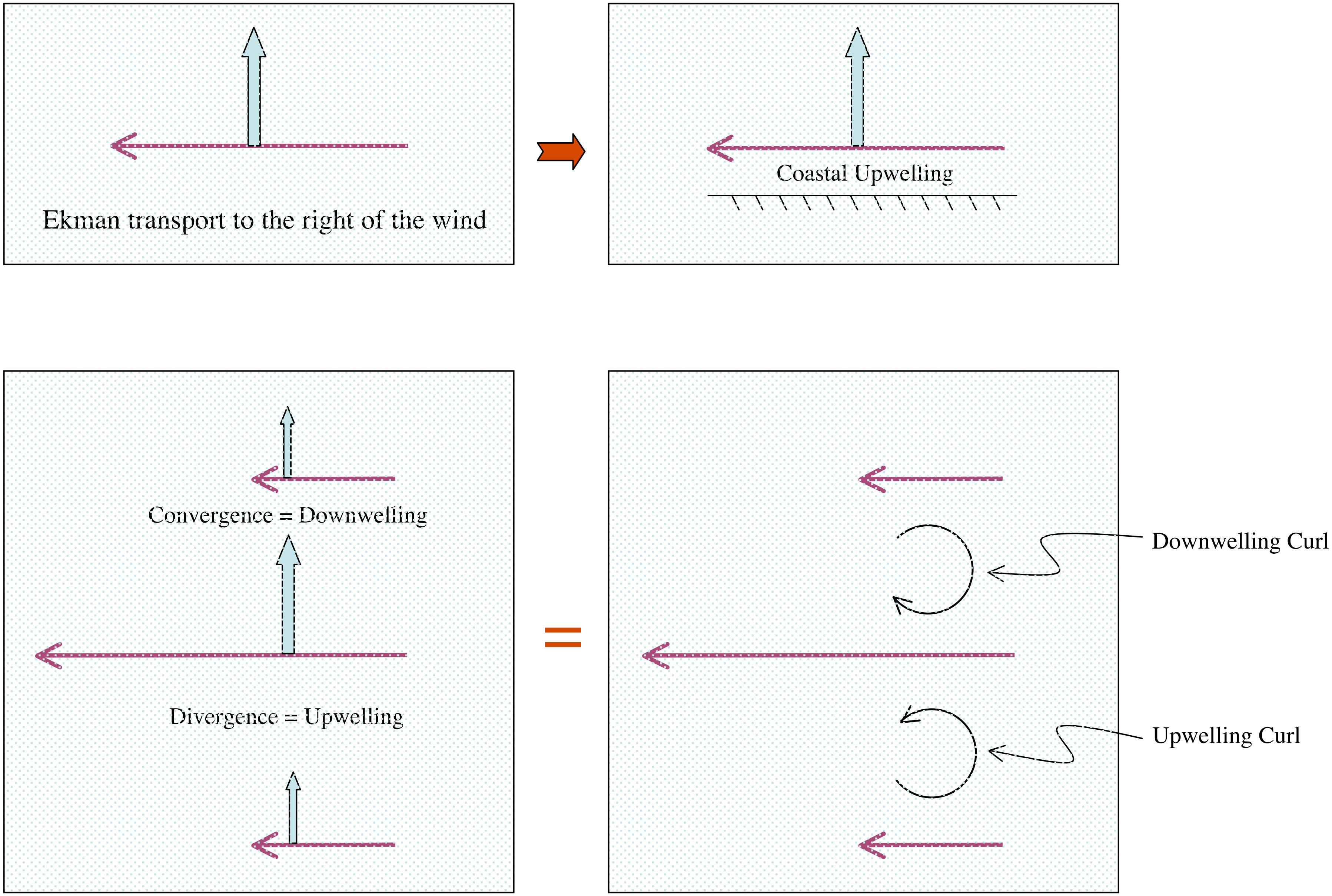
Ekman transport to the right of the wind
(in the northern hemisphere)

Compare Ekman and surface drifter currents




Drifter currents
20°C depth (XBT)
30°N
20°N
10°N
0°
10°S
20°S
120°W
110°W
100°W
90°W
80°W
70°W
25. cm s^{-1}
60
80
70
80
70
60
40
50
60
70
110
150
30
0
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0

Why the wind stress Curl is so important:



Ekman transport to the right of the wind

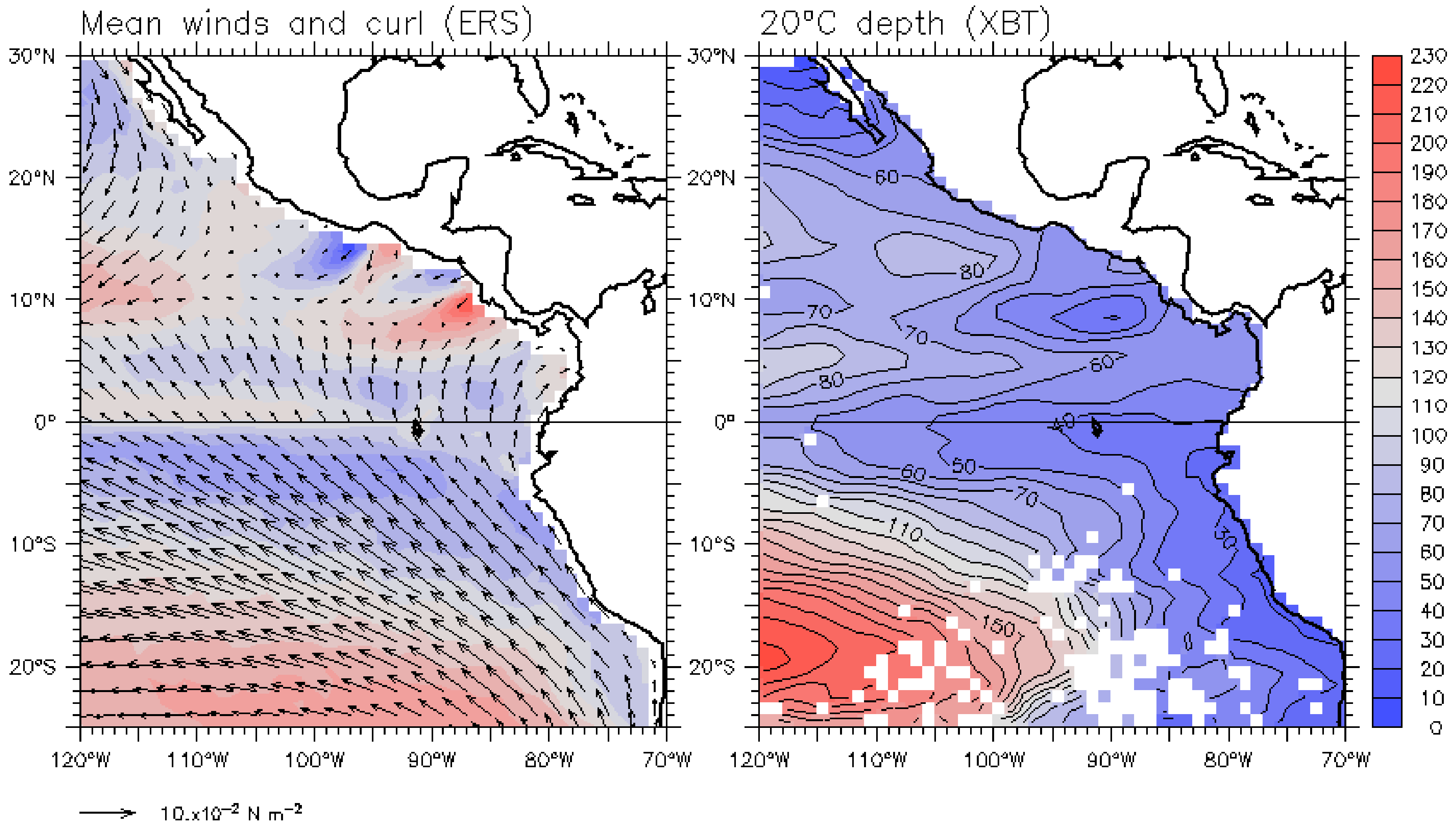
Coastal Upwelling

Convergence = Downwelling

Divergence = Upwelling

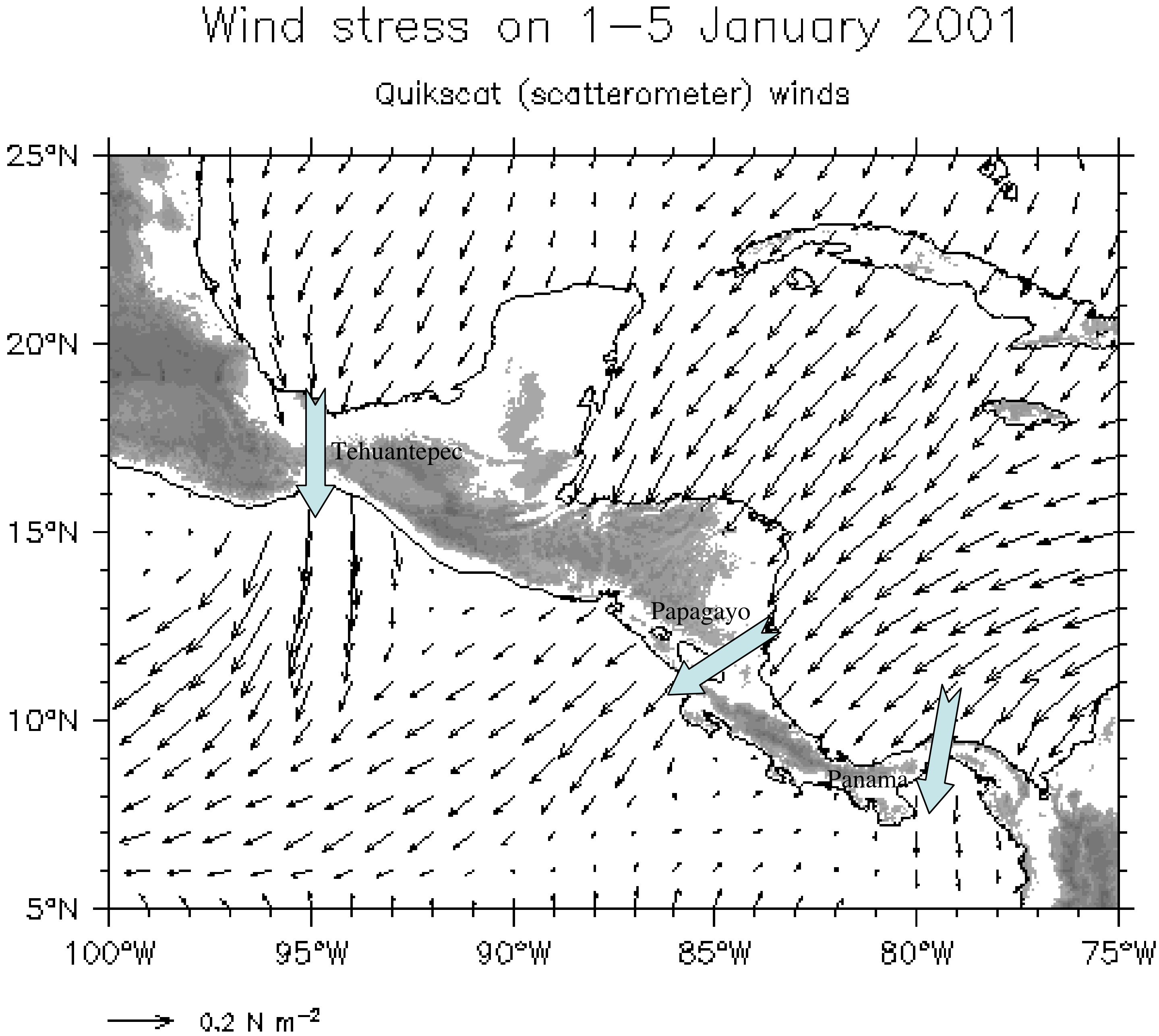
Downwelling Curl

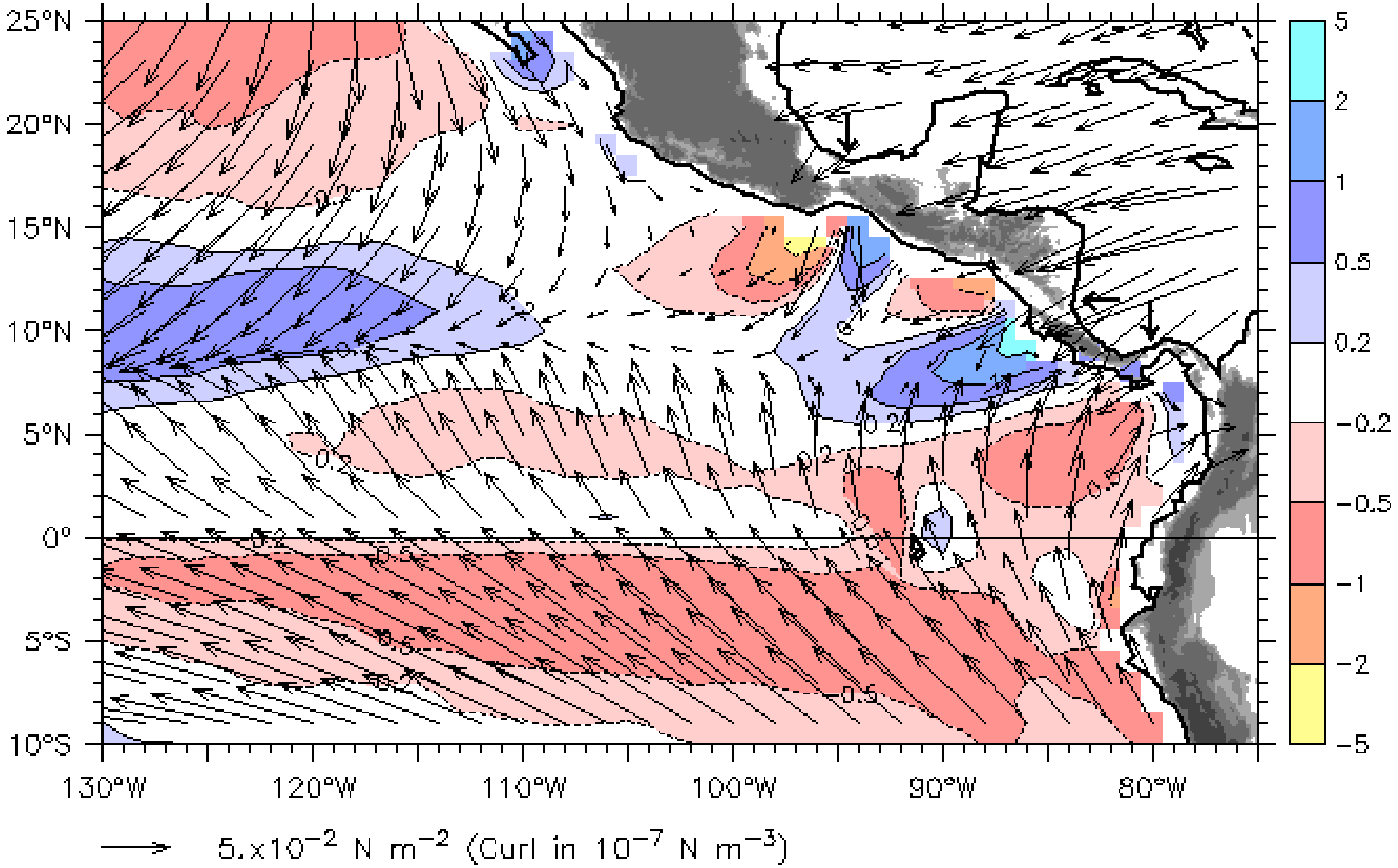
Upwelling Curl



Mean winds and curl (ERS)

20°C depth (XBT)


Wind stress on 1–5 January 2001
Quikscat (scatterometer) winds
25°N
20°N
15°N
10°N
5°N
100°W
95°W
90°W
85°W
80°W
75°W
Tehuantepec
Papagayo
Panama
0.2 N m⁻²

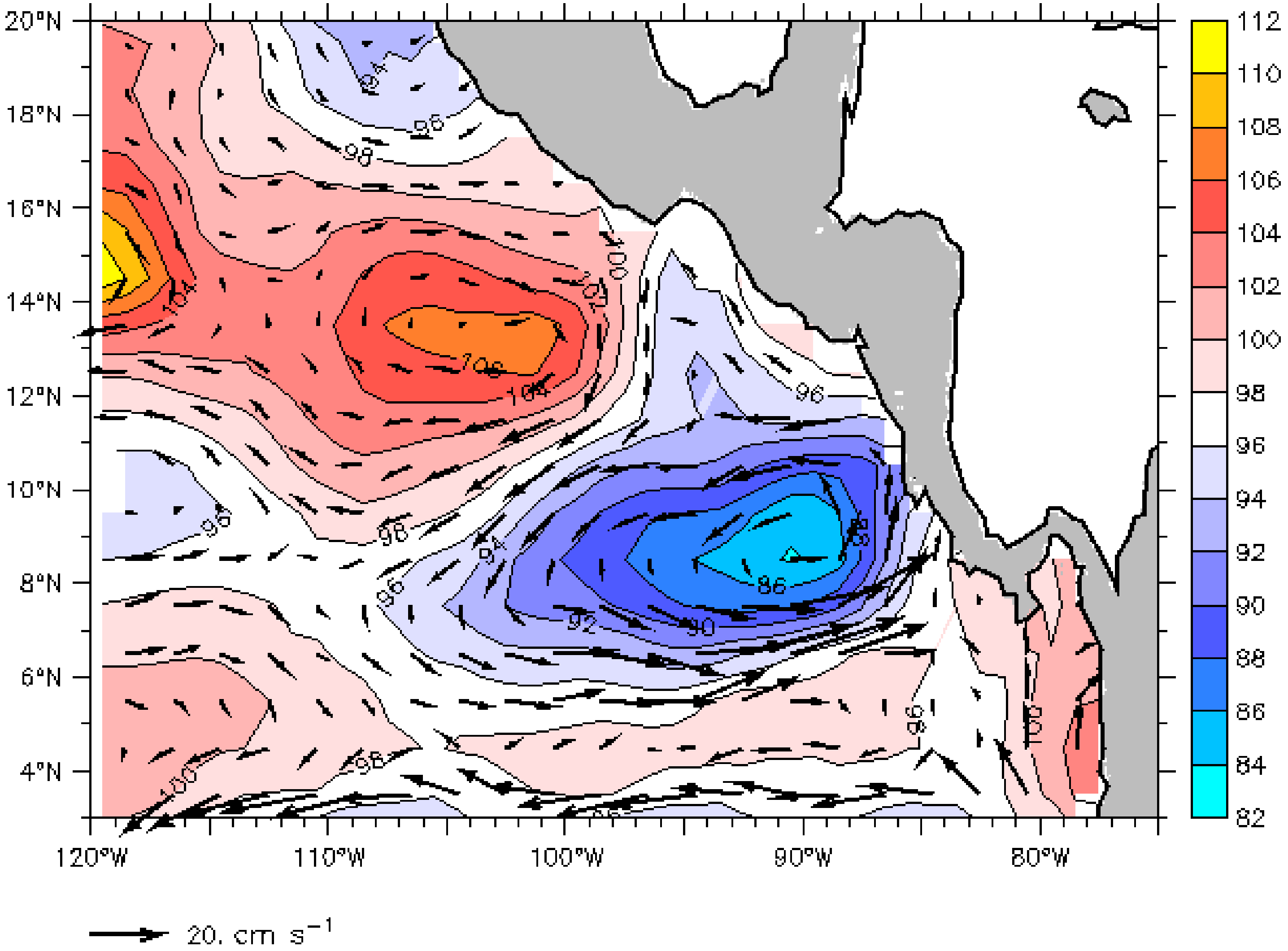


Mean Curl and Vector Wind Stress

Quikscat winds (Aug 1999 – Aug 2002)

Mean 0/450m DH and Geostrophic Currents

AOML XBT data set



The physical ocean changes have effects on the atmosphere and biology

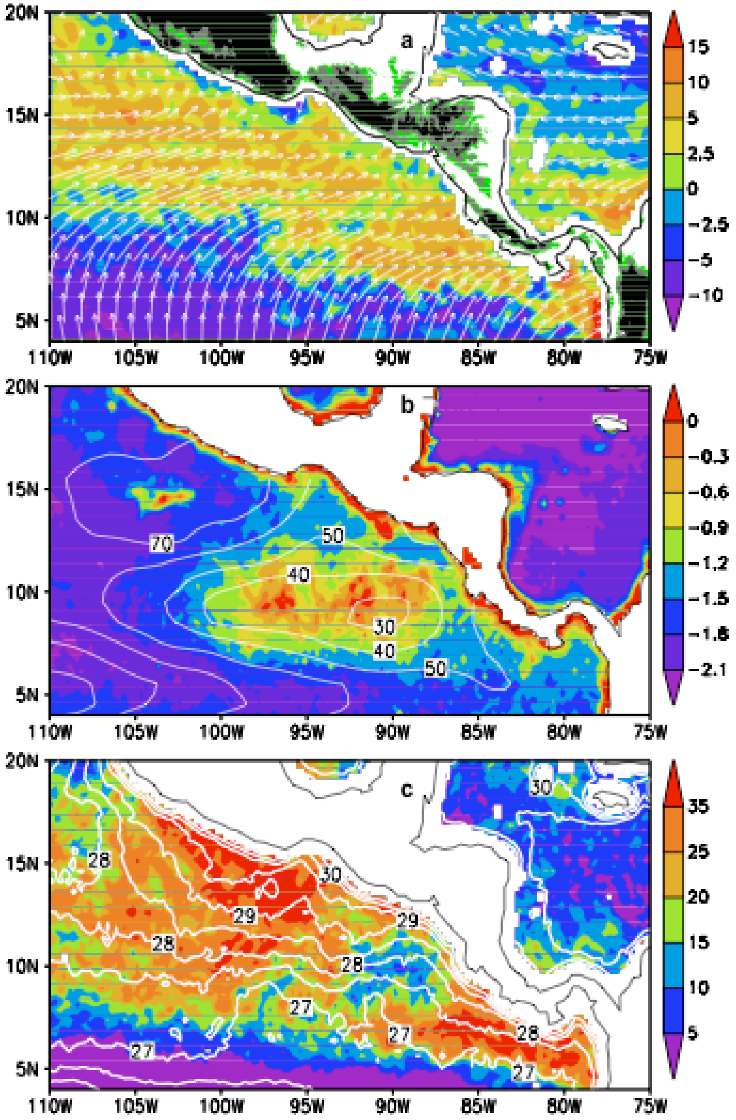
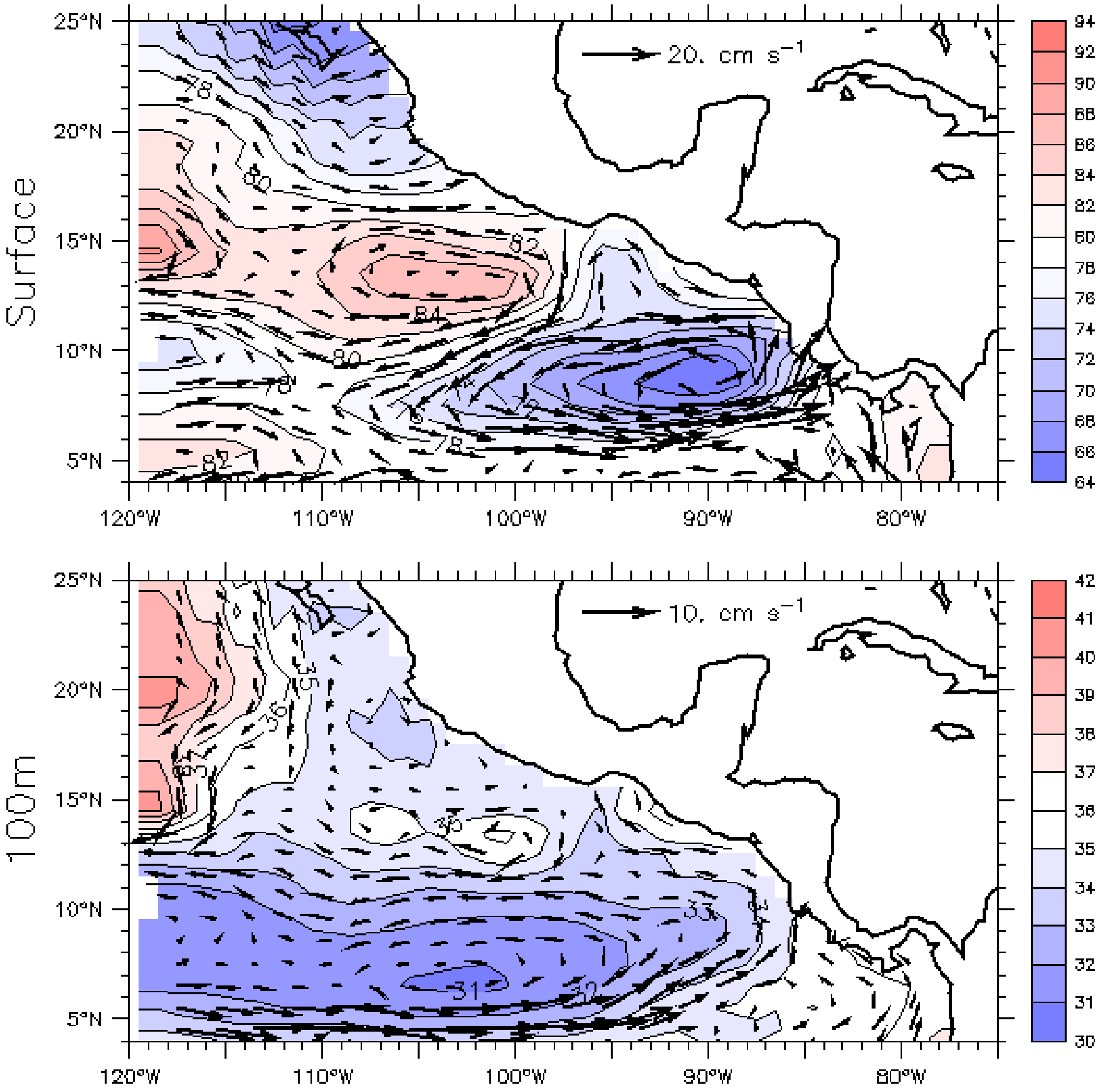


Fig. 9. September Climatology. (a) QuikSCAT pseudo wind stress (vectors in m^2s^{-2}) and Ekman pumping velocity (color in 10^{-6} m/s); (b) SeaWiFS chlorophyll in natural logarithm (color in mg/m^3) and 20°C isothermal depth (contours in m); (c) TMI precipitation (color in mm/day) and SST (contours in °C).

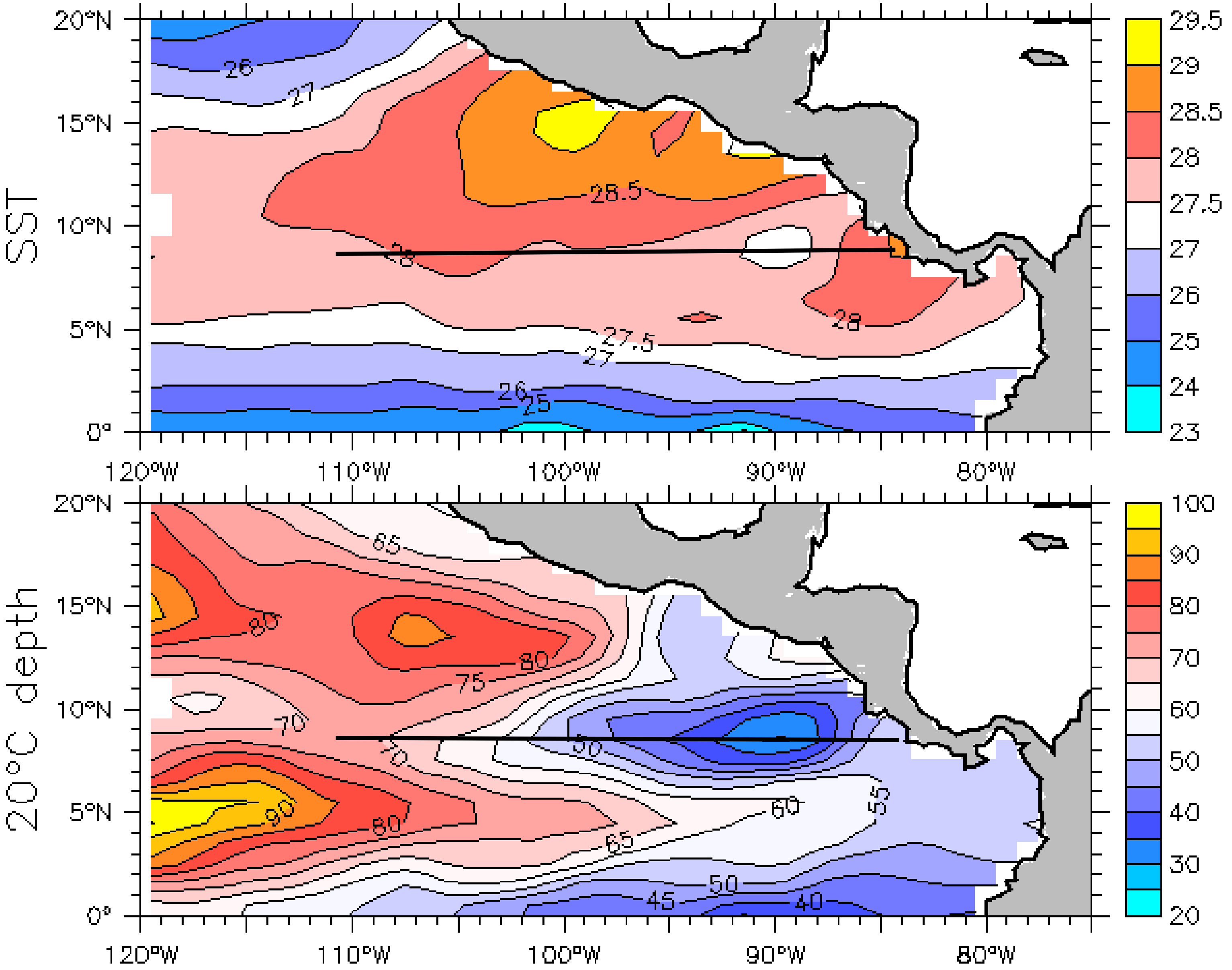
Mean DH and Geostrophic Currents

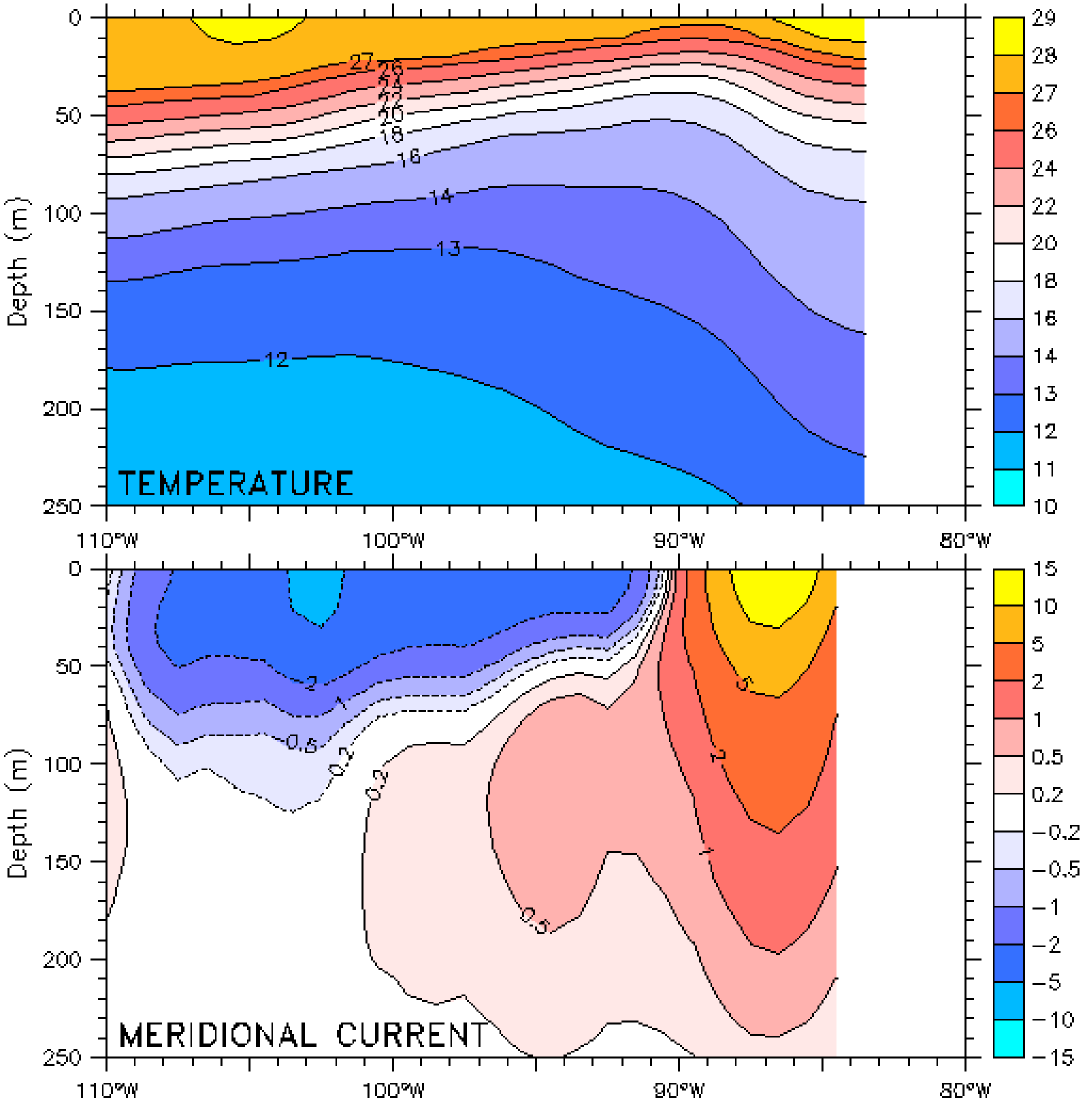
AOML XBT data set. DH rel. 300m



Mean SST and 20°C depth

AOML XBT data set

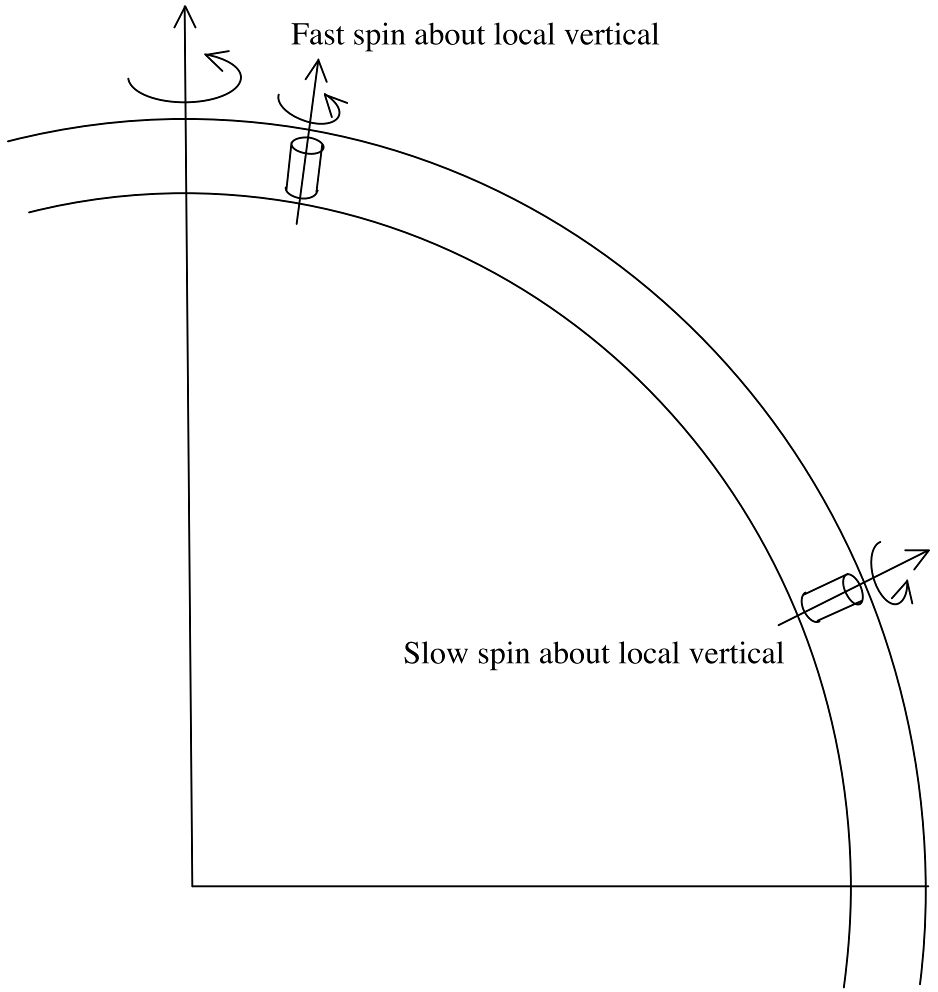




Mean Temperature and Meridional current along 8.5°N

AOML XBT observations

Moving poleward on the earth is equivalent to acquiring a faster spin:

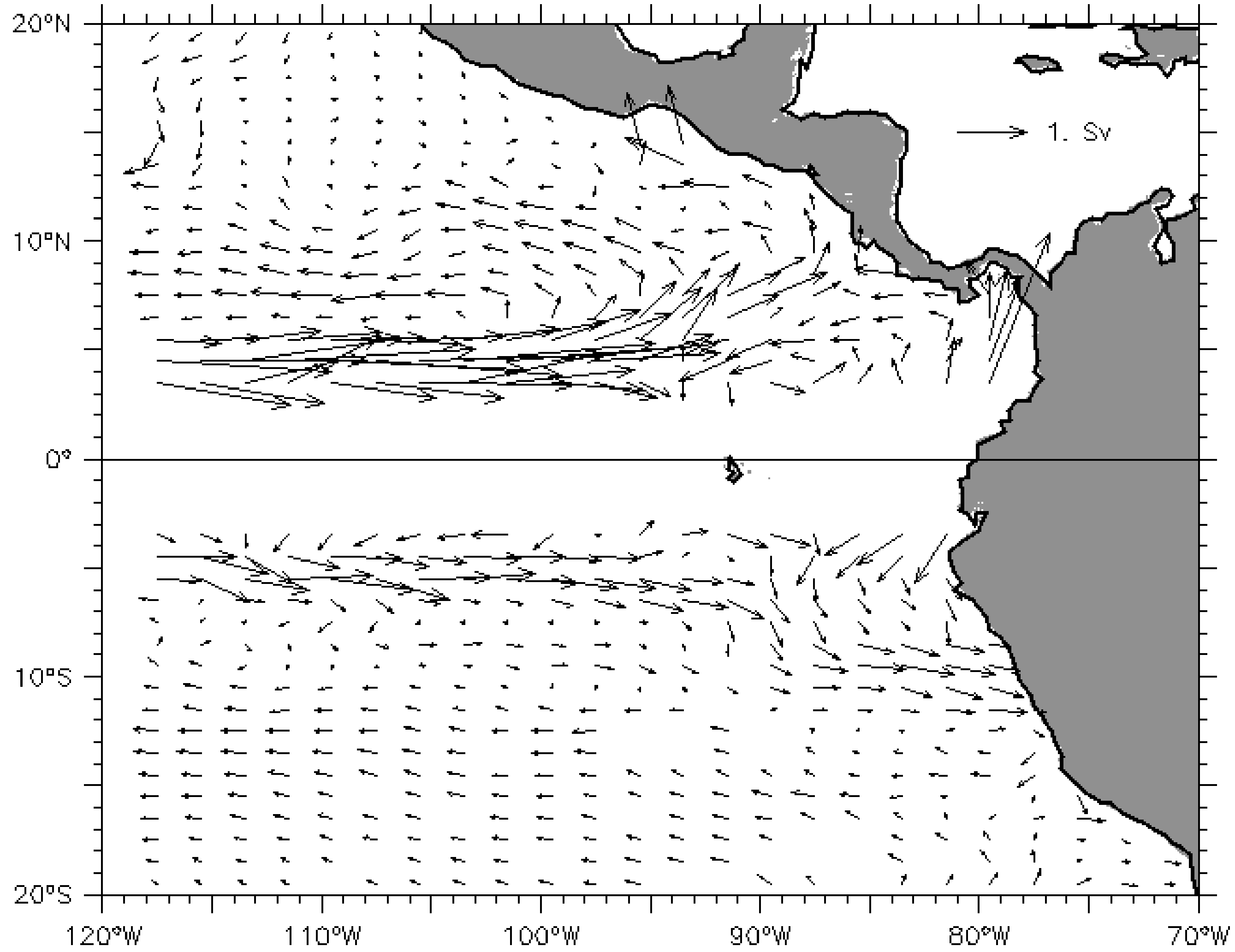


When the water column of the Costa Rica Dome is stretched by the upwelling curl of the Papagayo Jet, it lengthens and thins and its spin accelerates.

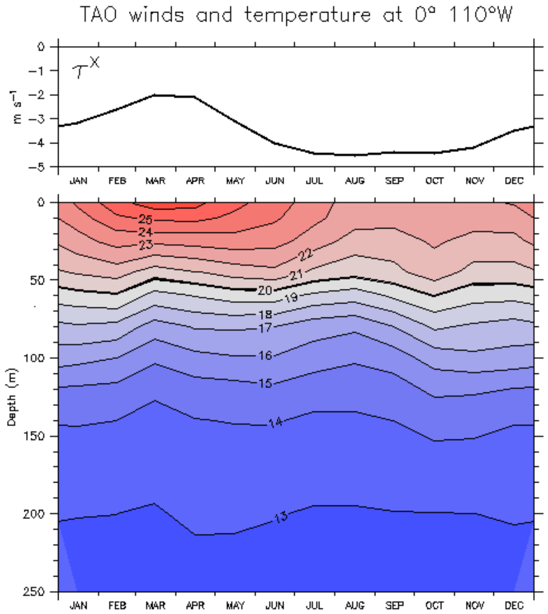
To remain in steady balance, it must move poleward to a latitude where the faster spin equals the spin of the earth.

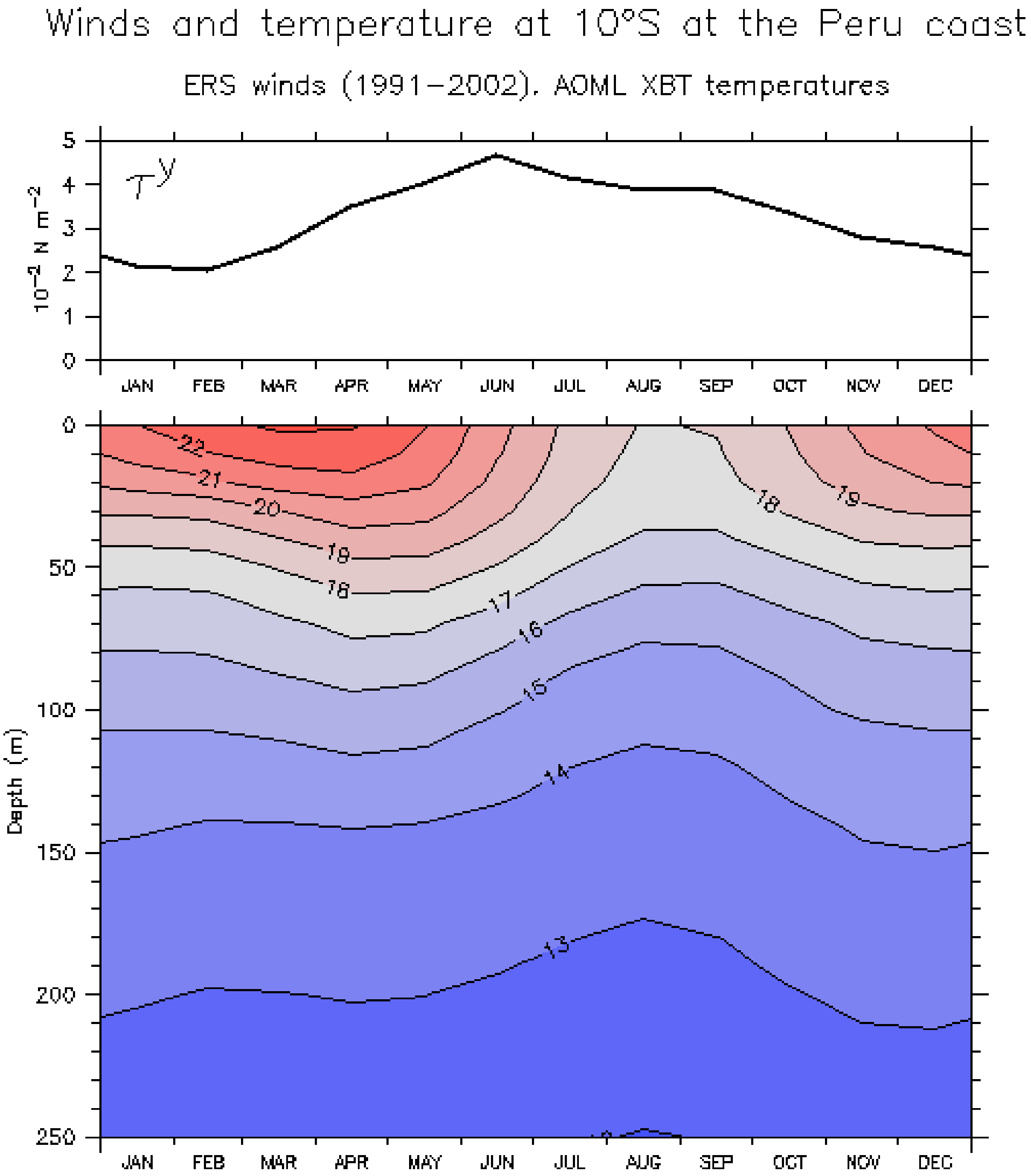
Circulation below the thermocline

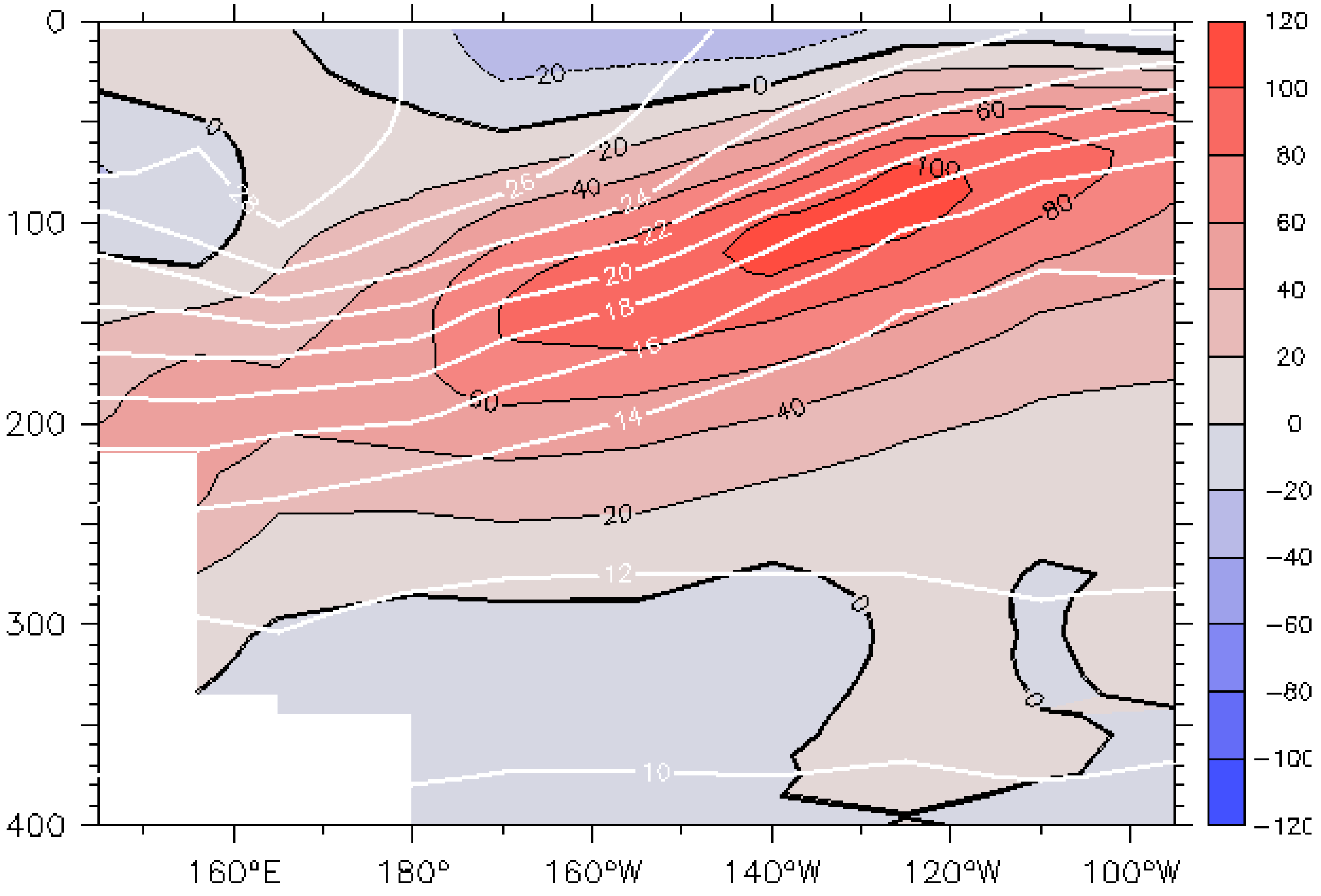
Transport between 450m and 17°C (XBT geostrophy)



The annual thermal structure off Peru is consistent with upwelling reaching deep into the thermocline.
(Unlike equatorial upwelling)





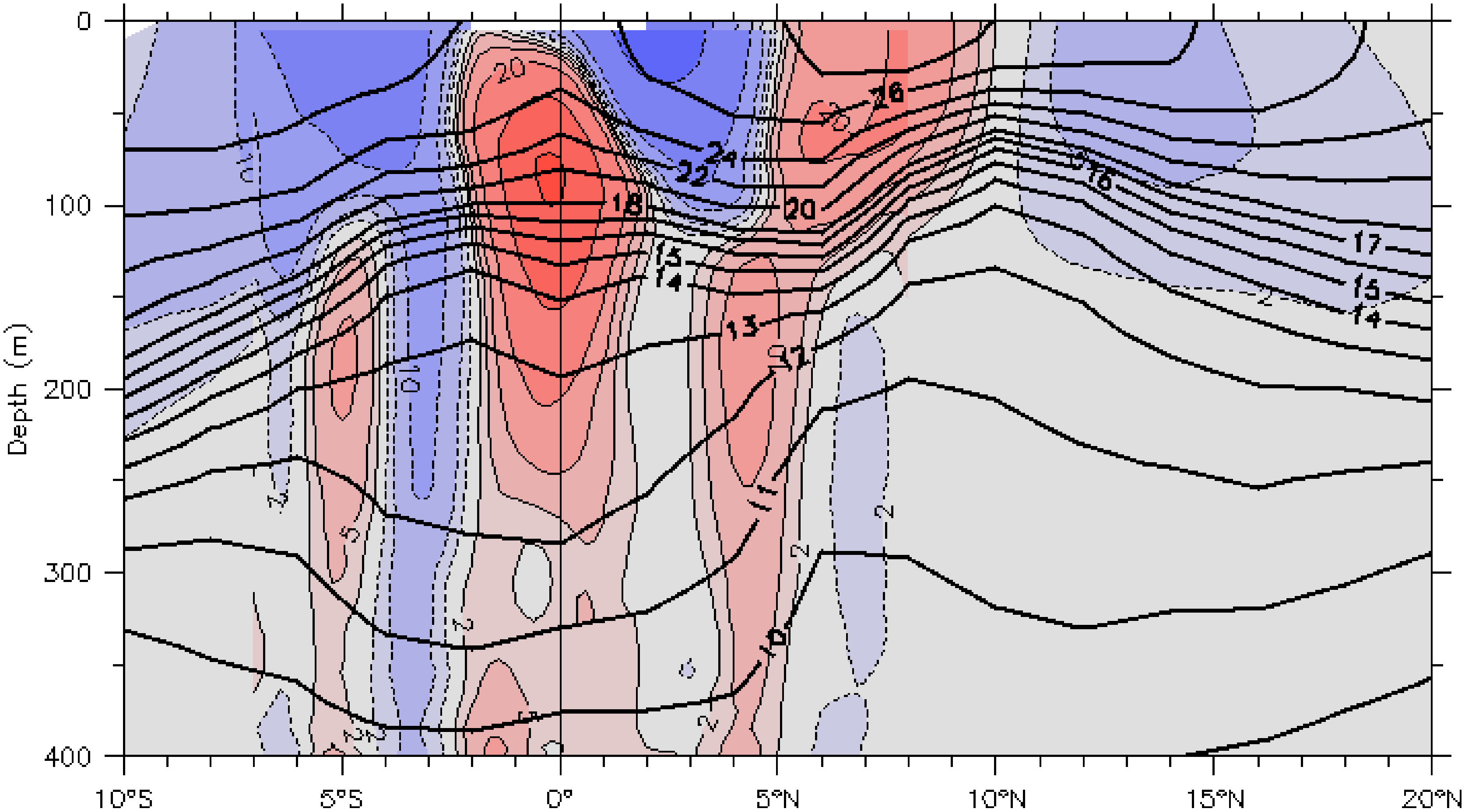


Mean u and T along the equator

Johnson ADCP/CTD compilation

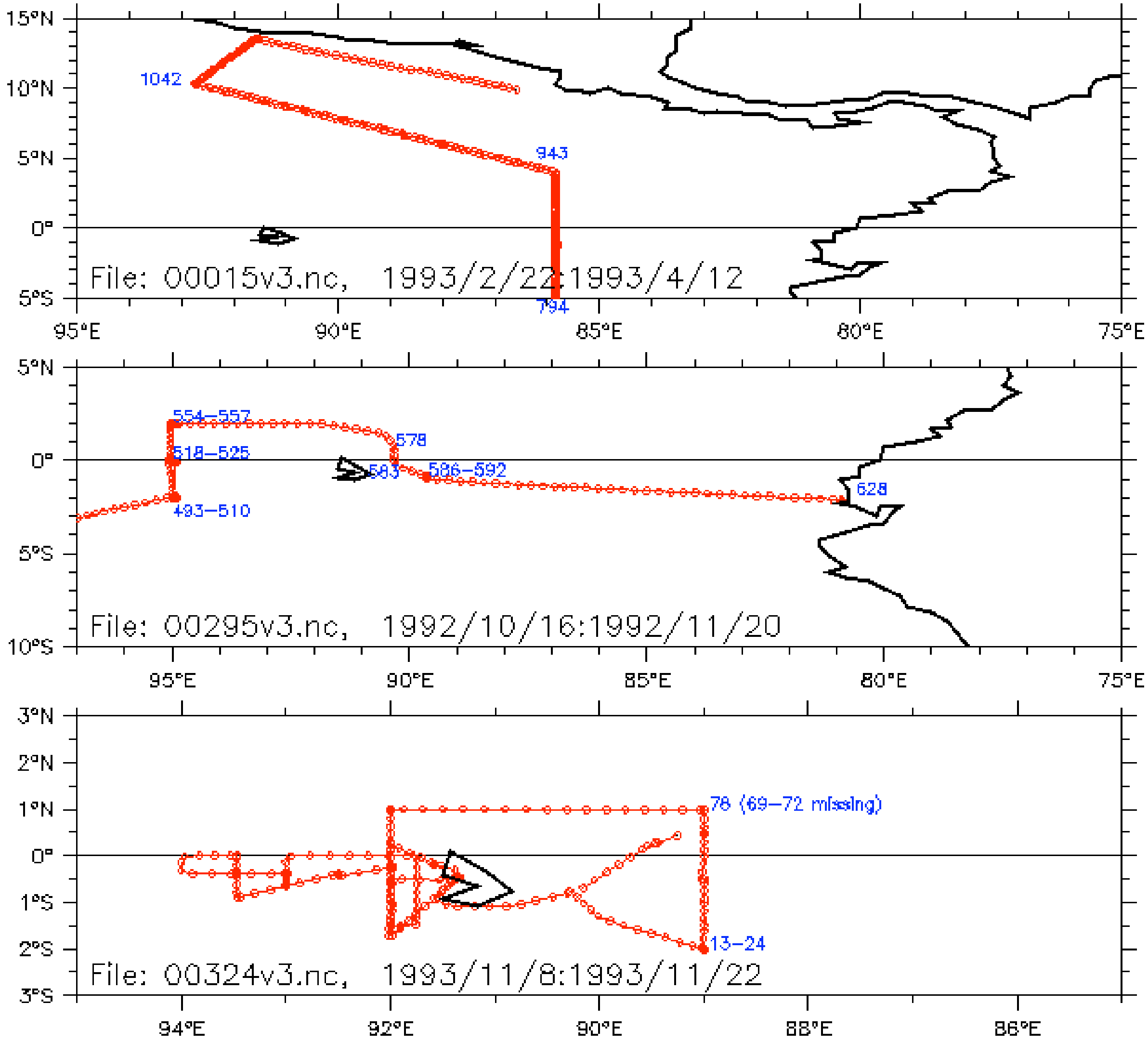
Temperature and zonal current at 125°W

XBT temperatures and u_g. ADCP u within 7°S–8°N



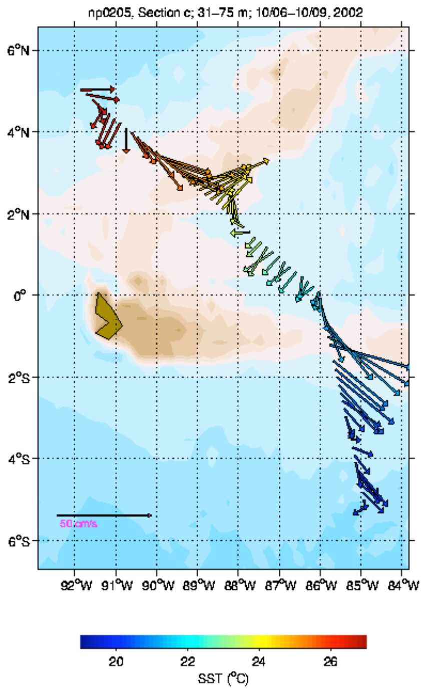
Shipboard ADCP cruises crossing the EUC E of the Galapagos

From website http://ilikai.soest.hawaii.edu/sadcp/

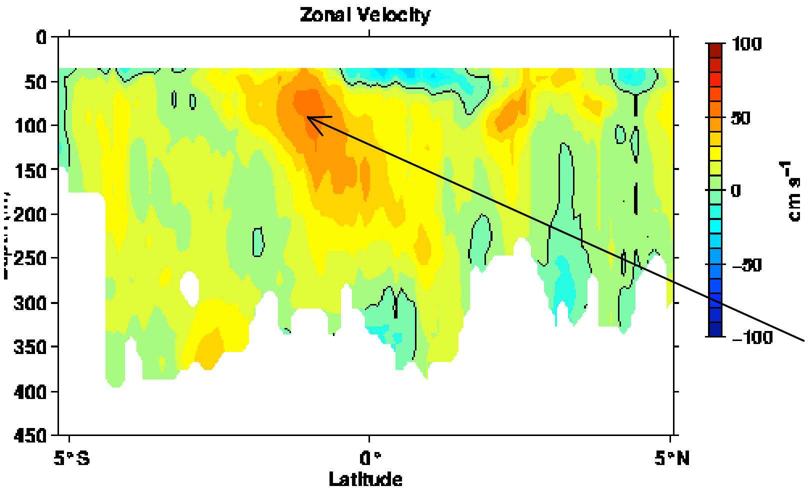


Where is the EUC east of the Galapagos?

Vectors at 150m

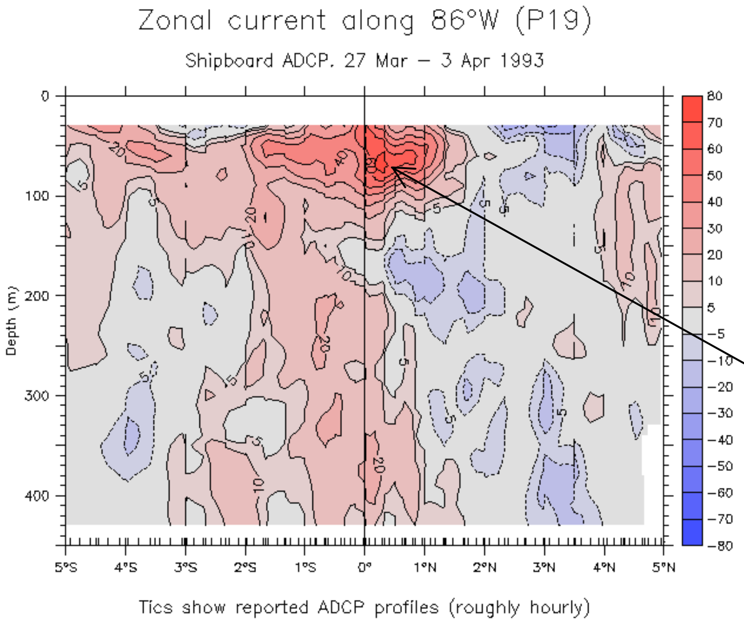


Preliminary processing at Univ. of Hawaii



N.B. Palmer section
Oct 2002

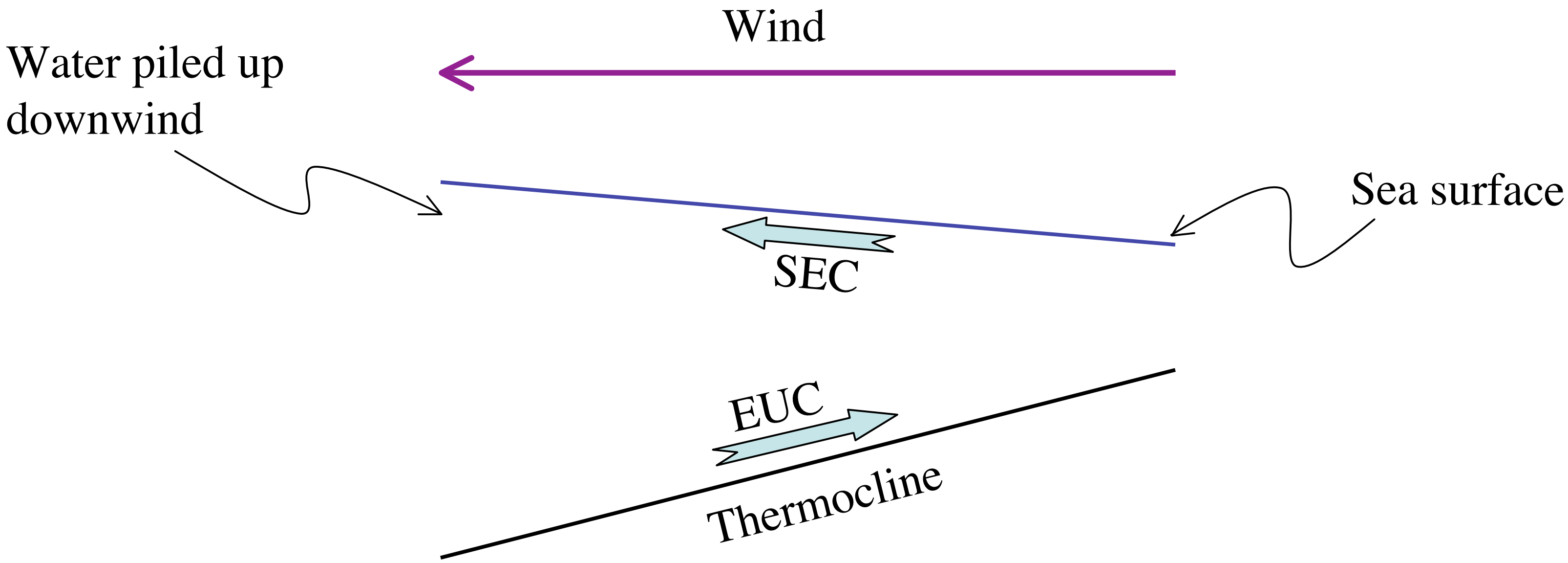
EUC centered south



WOCE P19 section
Mar-Apr 1993

EUC centered north

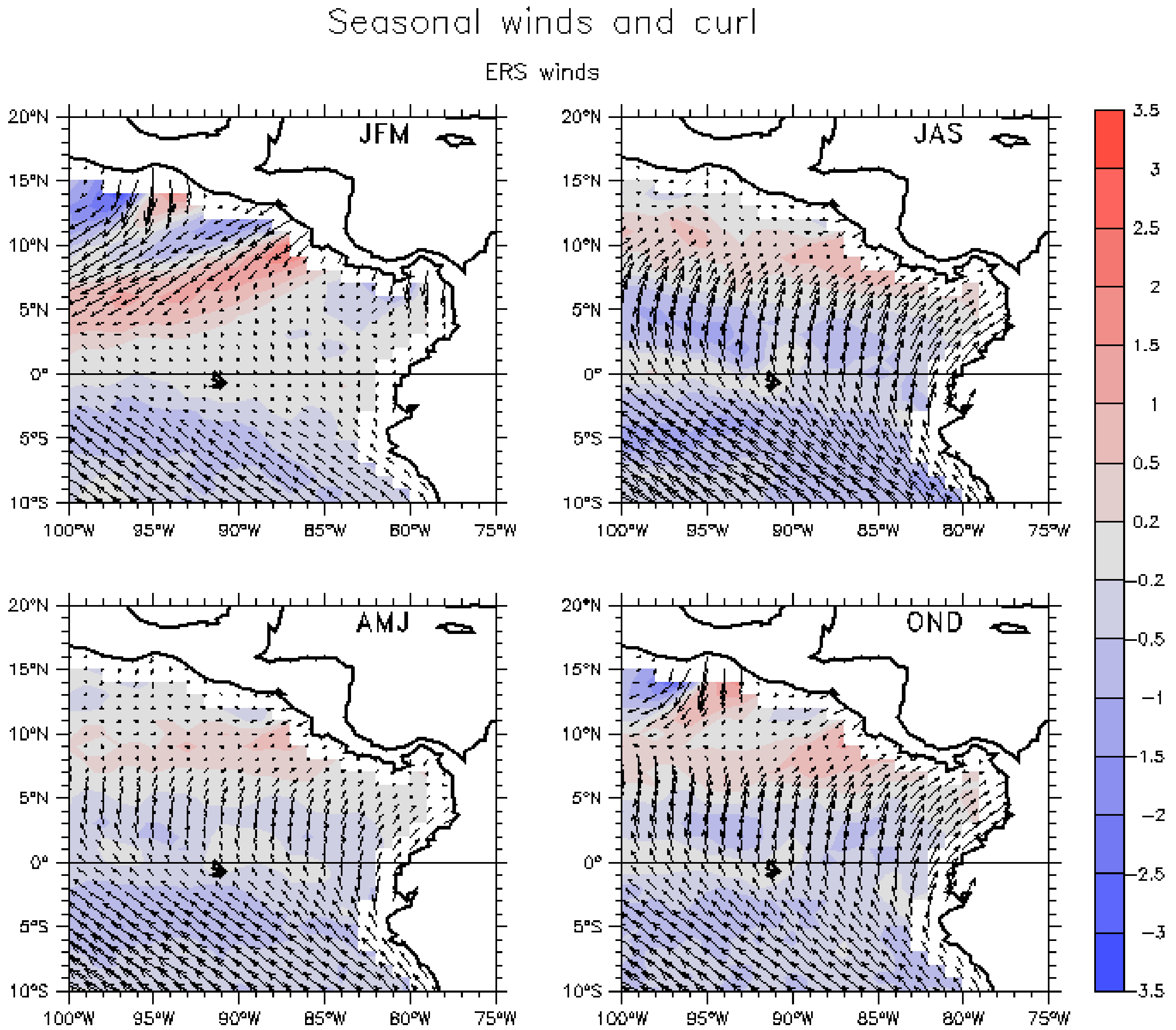
Why is there an EUC east of the Galapagos?



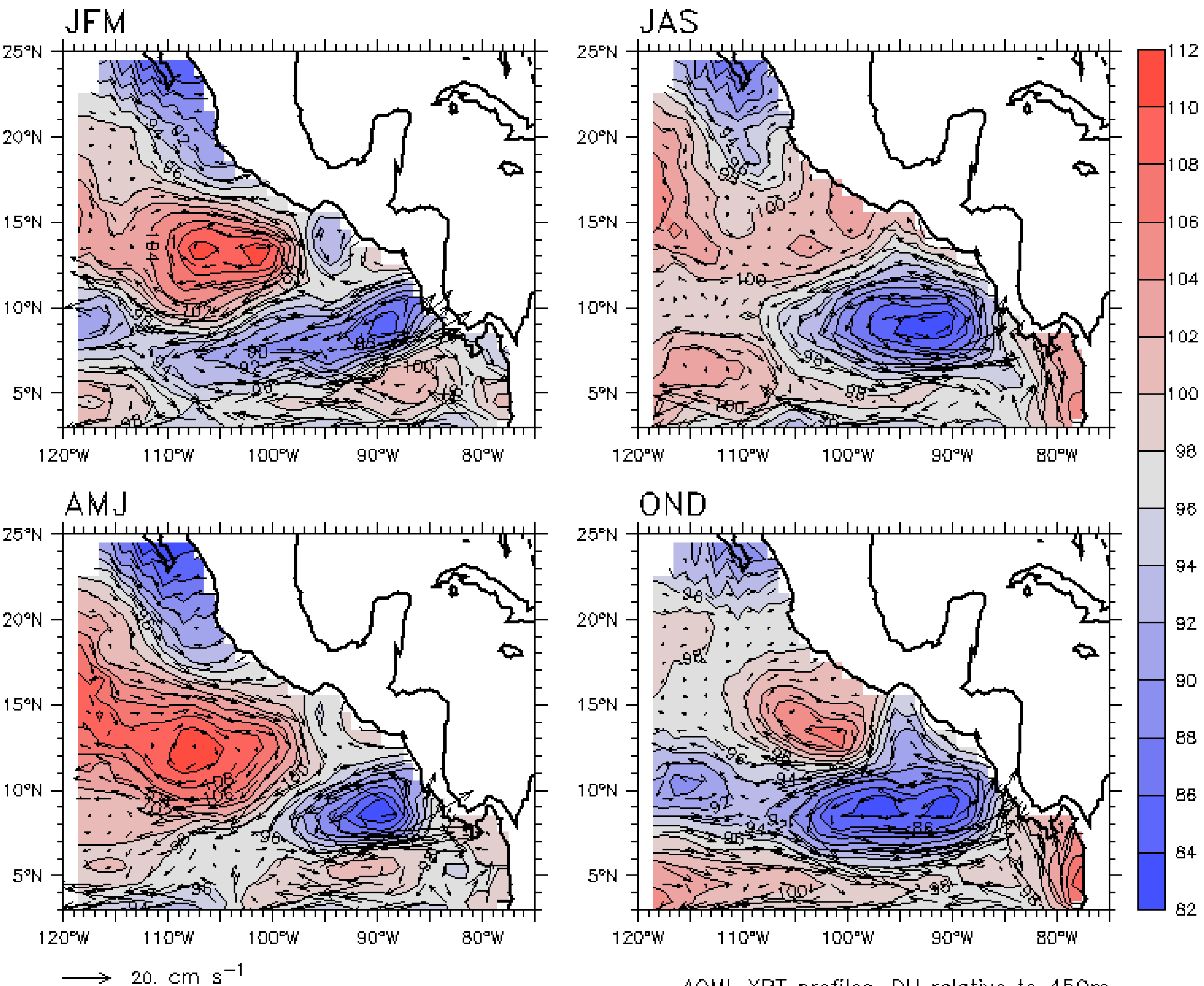
On the equator, Ekman transport is directly downwind.

The frictional surface flow is downwind.

The result is to pile up water; below the frictional surface layer the pressure gradient drives aan upwind undercurrent.


Seasonal winds and curl
ERS winds
JFM
JAS
AMJ
OND
20°N
15°N
10°N
5°N
0°
5°S
10°S
100°W
95°W
90°W
85°W
80°W
75°W
3.5
3
2.5
2
1.5
1
0.5
0.2
-0.2
-0.5
-1
-1.5
-2
-2.5
-3
-3.5

Seasonal DH and Geostrophic Currents at 0m

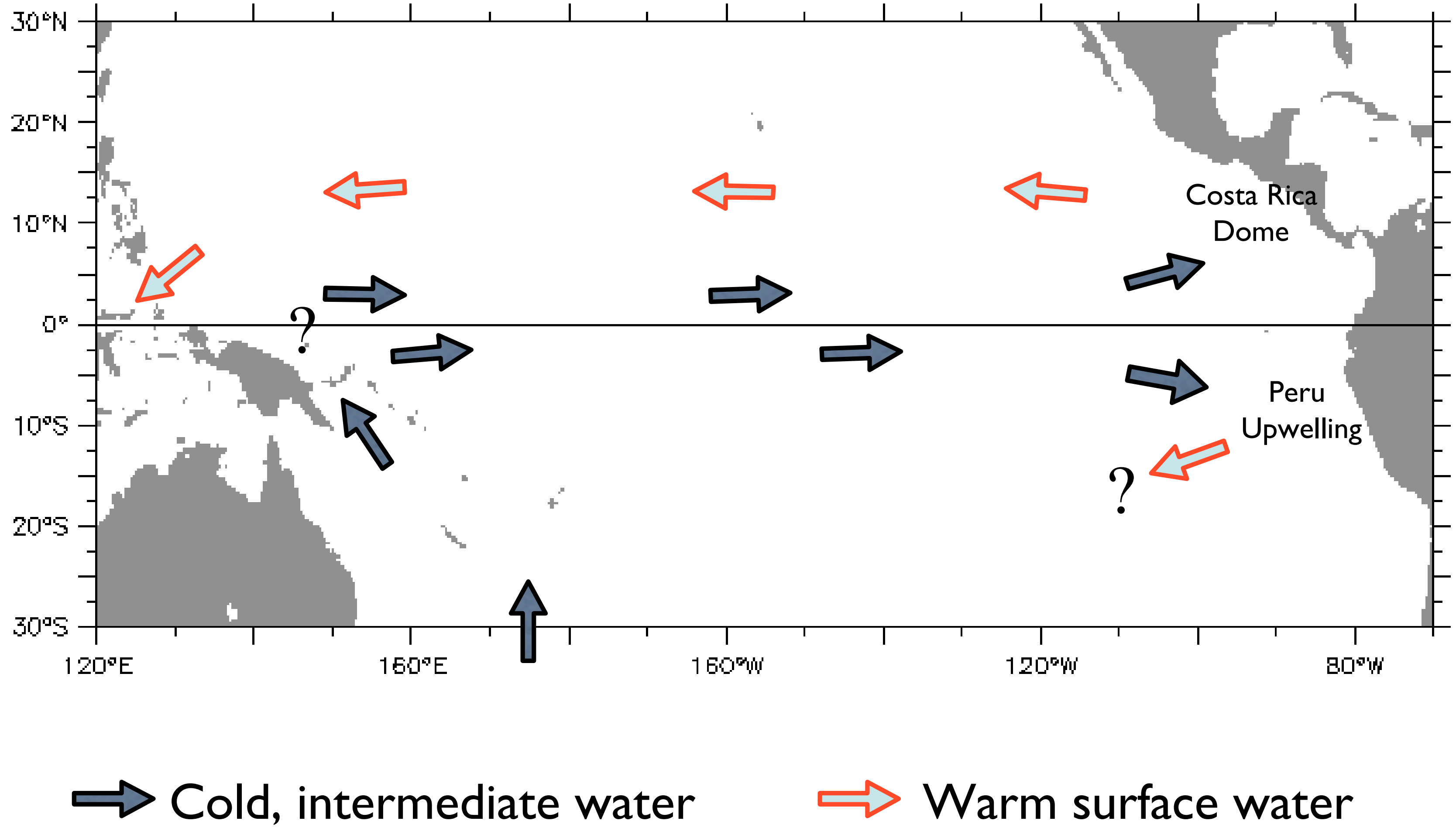


AOML XBT profiles. DH relative to 450m

The big picture:

How do these regional features influence the basin-scale circulation?

~10 Sv of intermediate water enters the Pacific in the southwest and leaves the Pacific as surface water in the Indonesian Throughflow



Circulation in the eastern tropical Pacific

- Complex interconnections as the long zonal currents of mid-basin meet the coast
- Large topographic influence on the wind forcing
- Regions of strong upwelling through a deep layer: easy communication from below the thermocline to the surface

Remaining questions:

- How do the long zonal currents of mid-Pacific interconnect in the east?
- What is the source of the SEC?
  Is it EUC upwelling or the NECC or the Peru coast?
- What is the role of off-equatorial upwelling in the general circulation of the Pacific?

http://www.pmel.noaa.gov/~kessler ⇨ Latest talk

Extra

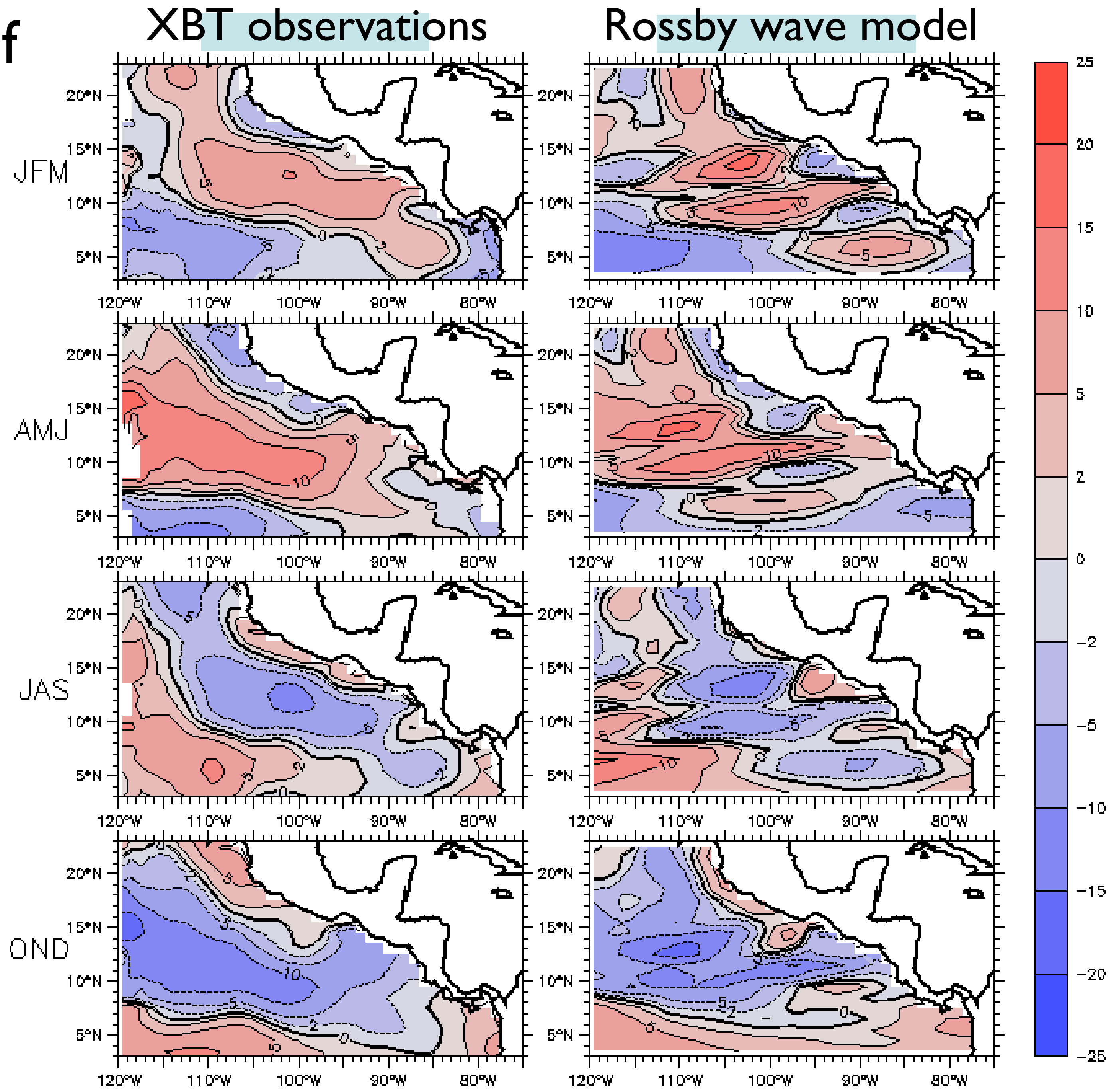
Figures

Follow

Annual cycle of 20°C depth anomalies

A simple Rossby model represents much of the observed annual thermocline depth variability

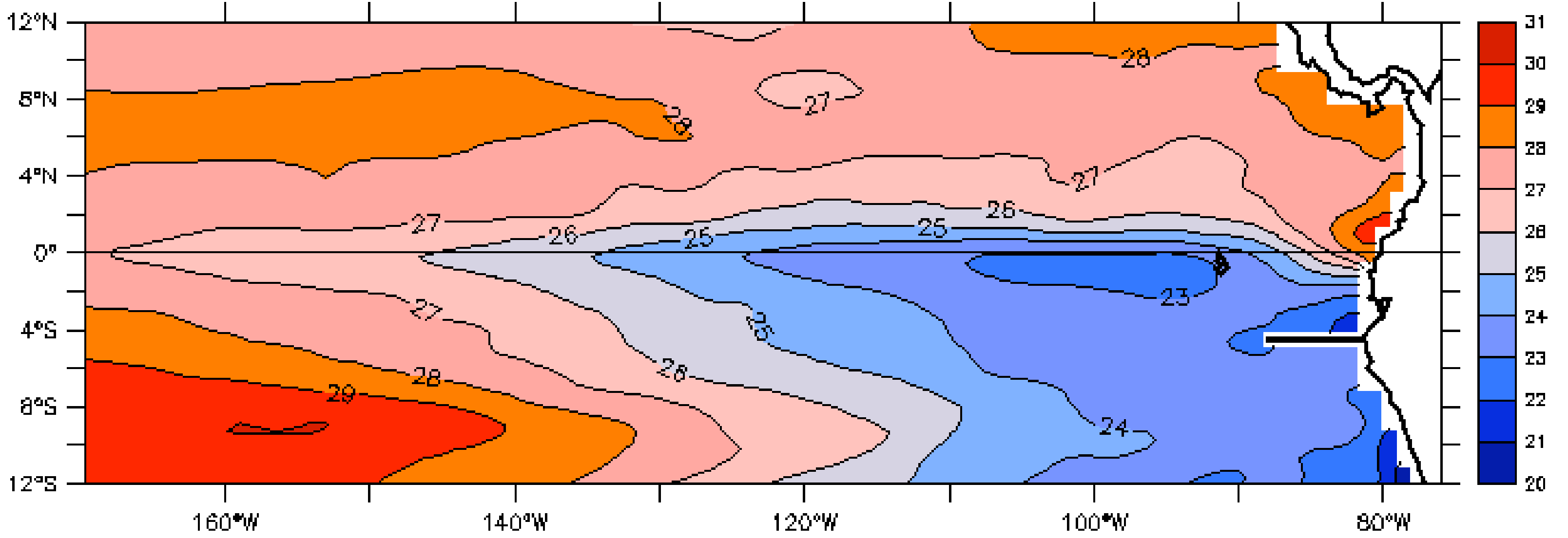
$$\frac{\partial h}{\partial t} + c_r \frac{\partial h}{\partial x} + Rh = -Curl\left(\frac{\tau}{f\rho}\right)$$


XBT observations

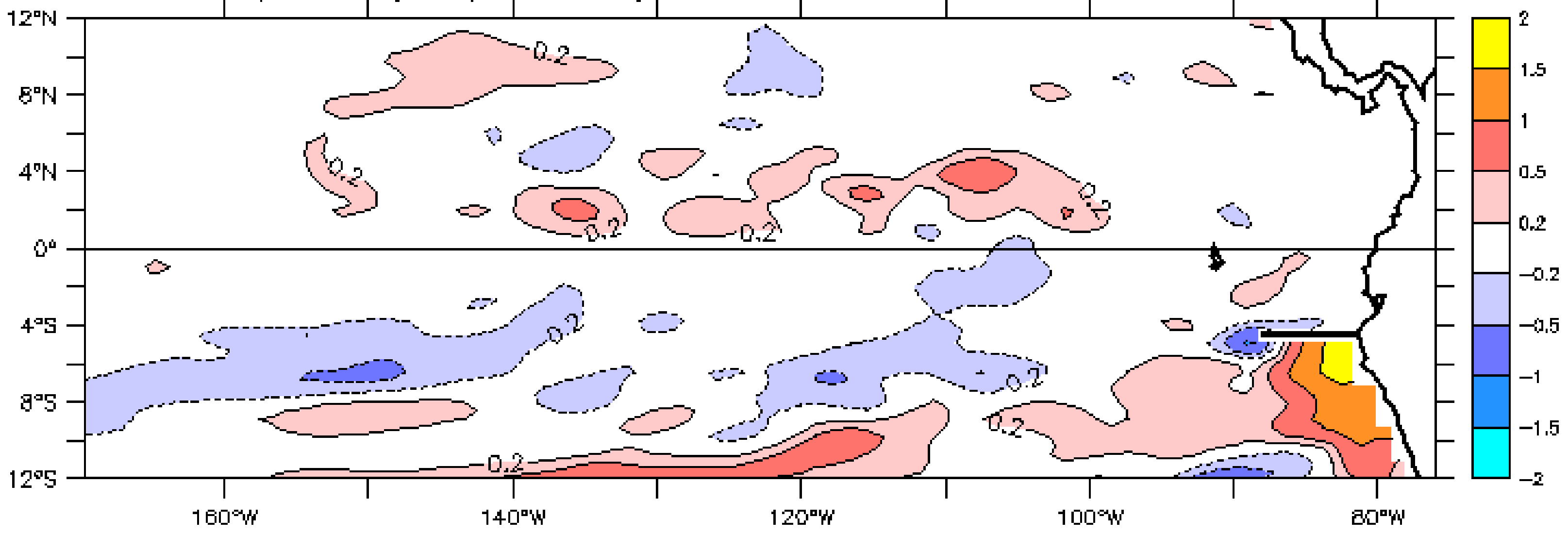
Rossby wave model

Mean SST with artificial wall at 4.5°S

700 km wall separates coastal upwelling from equator



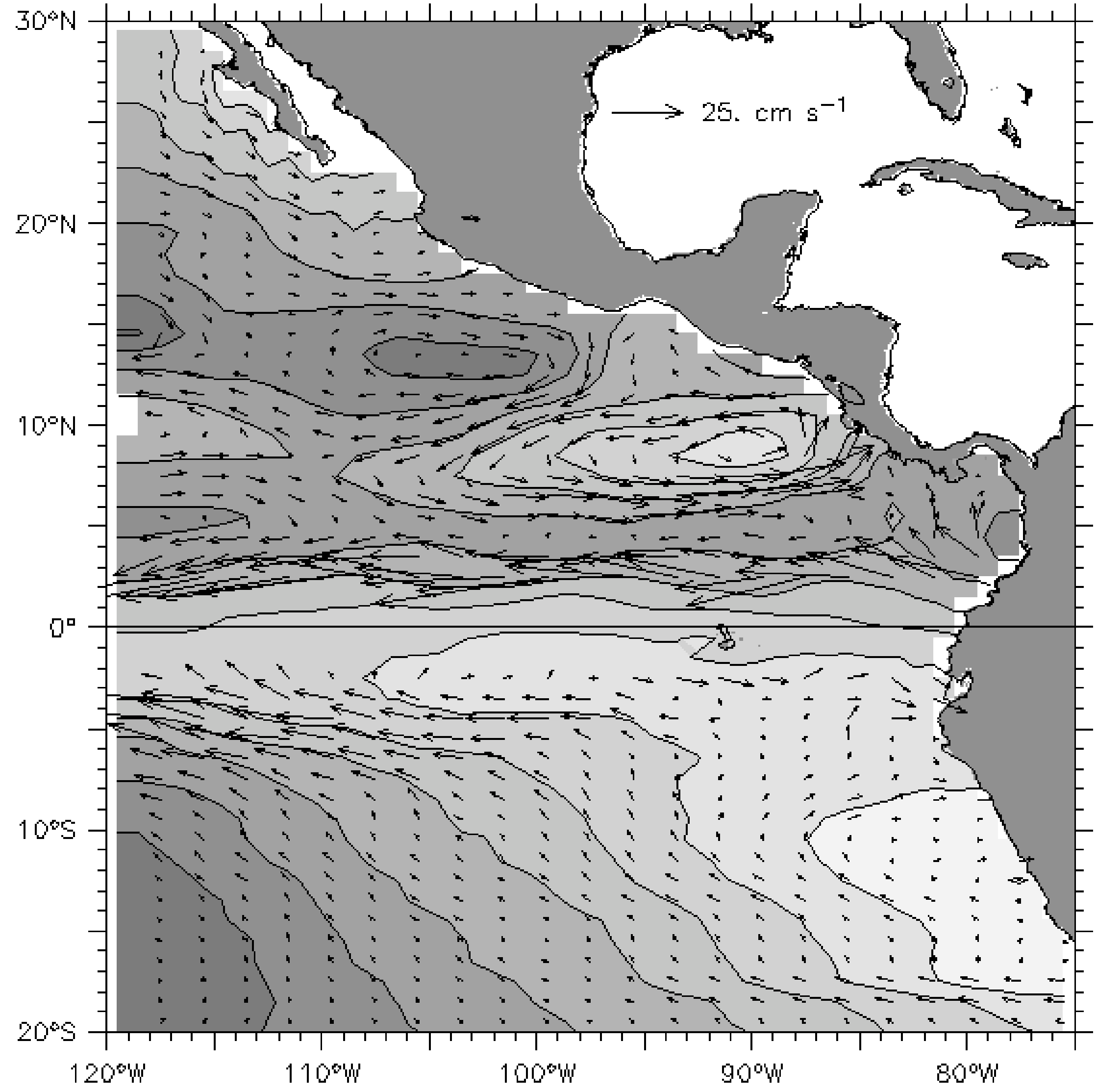
Mean SST with wall



Difference (with wall) − (withot wall)

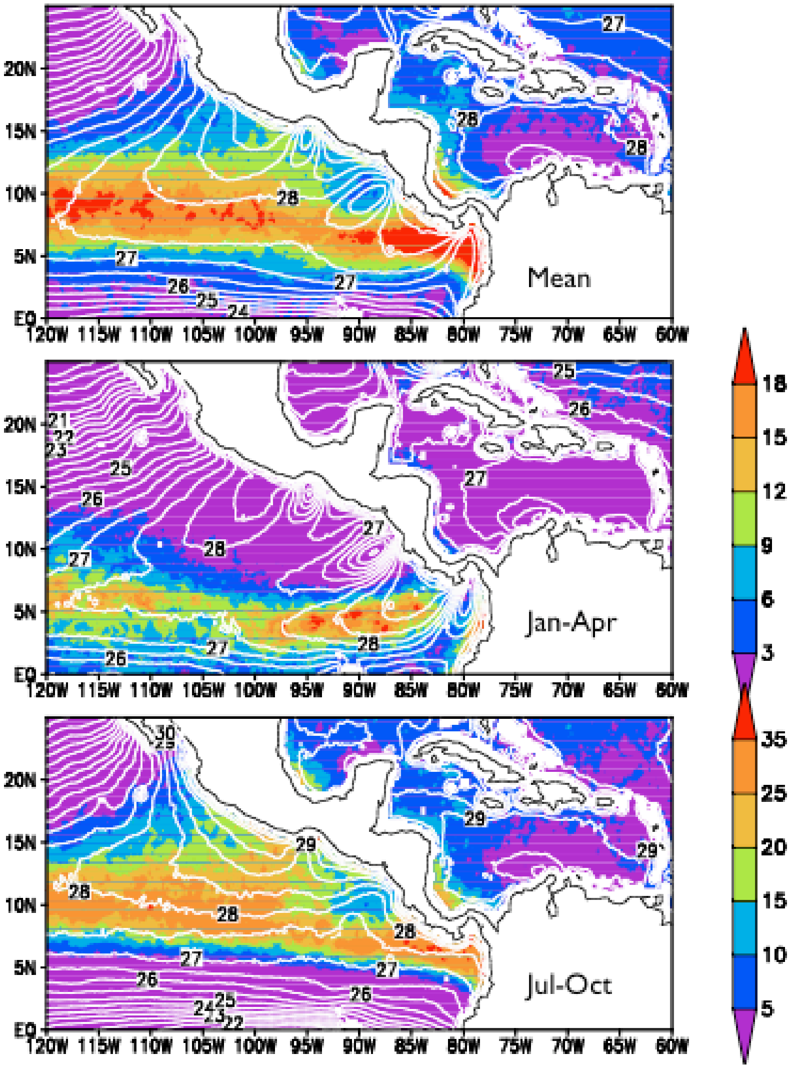
Gent/Cane model run with full annual cycle forcing: FSU winds, ISCCP clouds, Sun

Dynamic ht and surface geostrophic currents



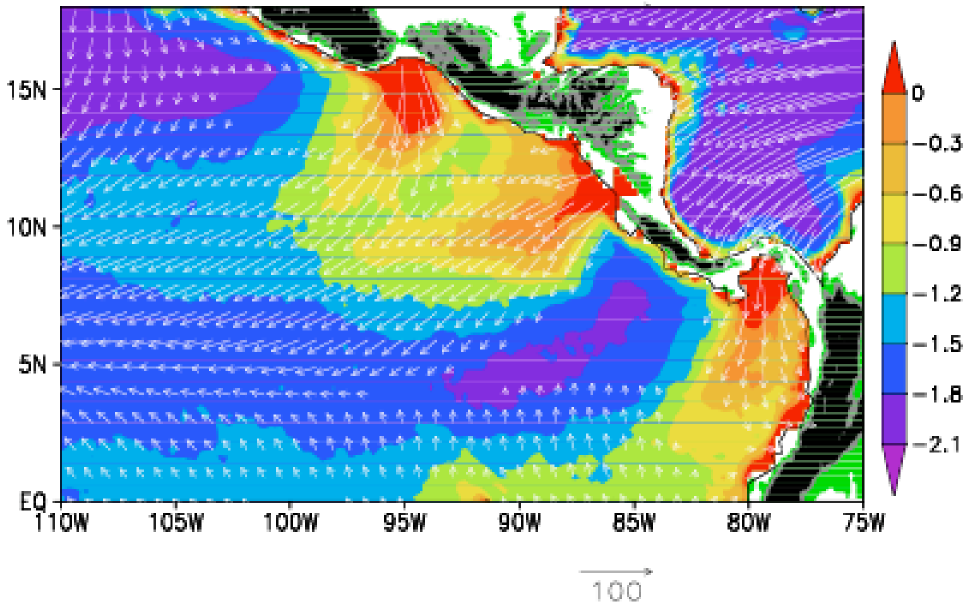
SST (white contours) and Precip (color)

As the ITCZ moves north and south across the cool SST due to the wind jets, “holes” are created in the precipitation fields

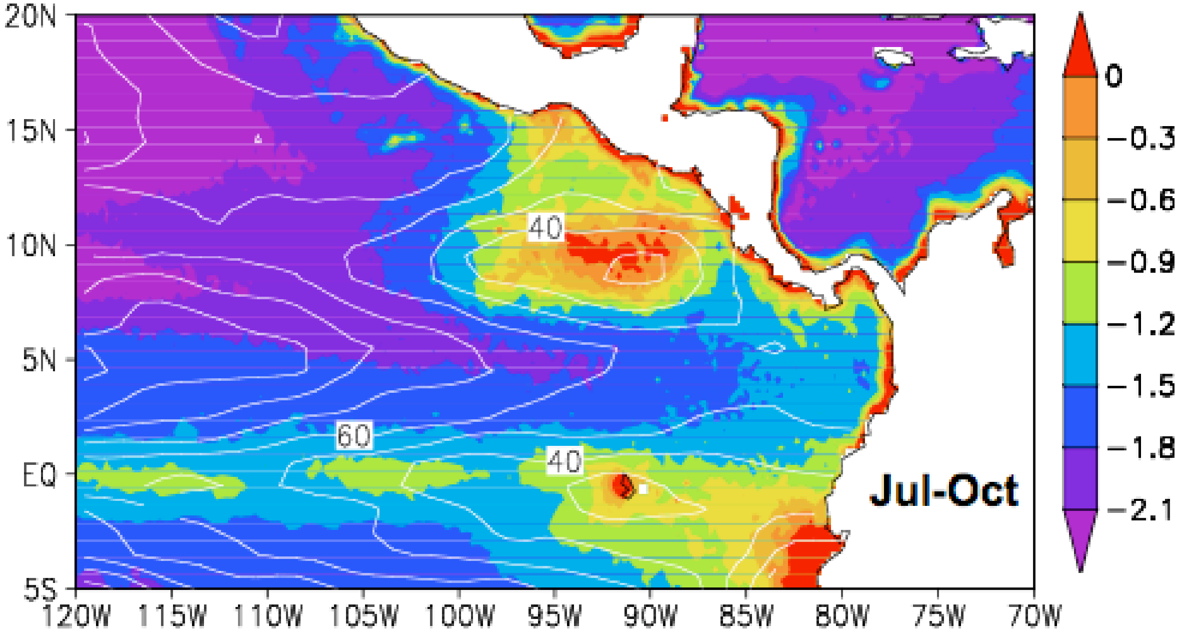


SeaWiFS chlorophyll climatology

Jan-Mar
(overlay Quikscat winds)

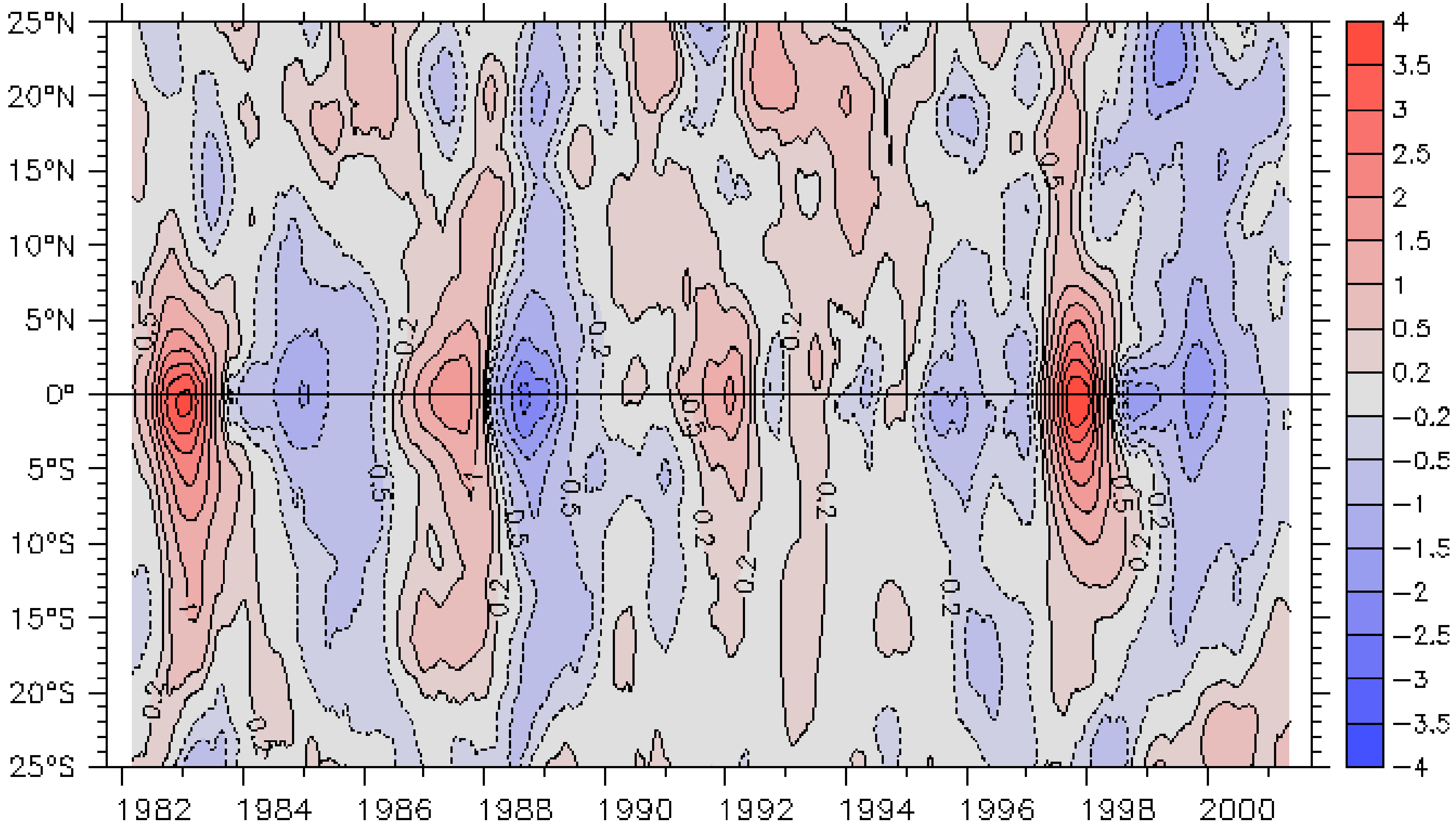


Jul-Oct
(Overlay XBT 20°C Depth)



SST anomalies along 120°W

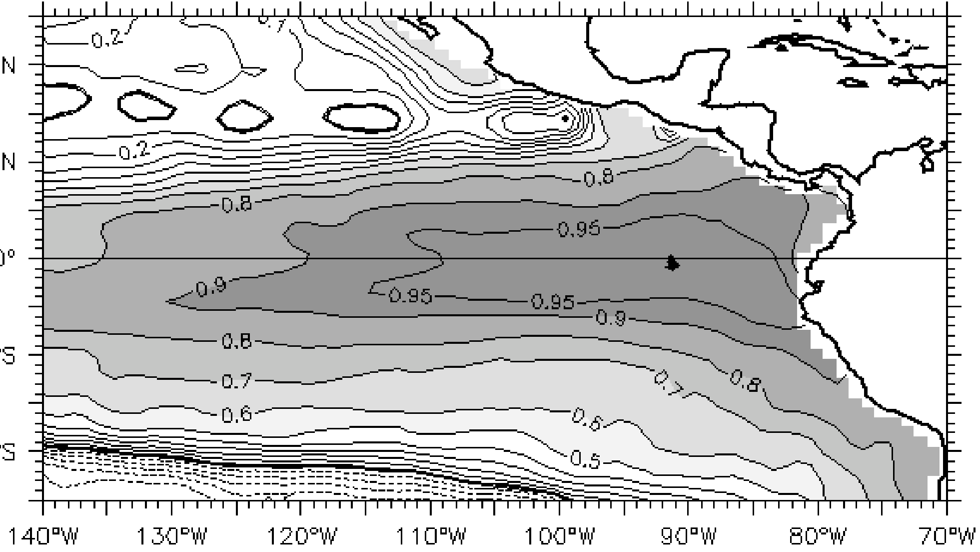
Reynolds SST 1980–2002. Climatology and 9–month running mean removed



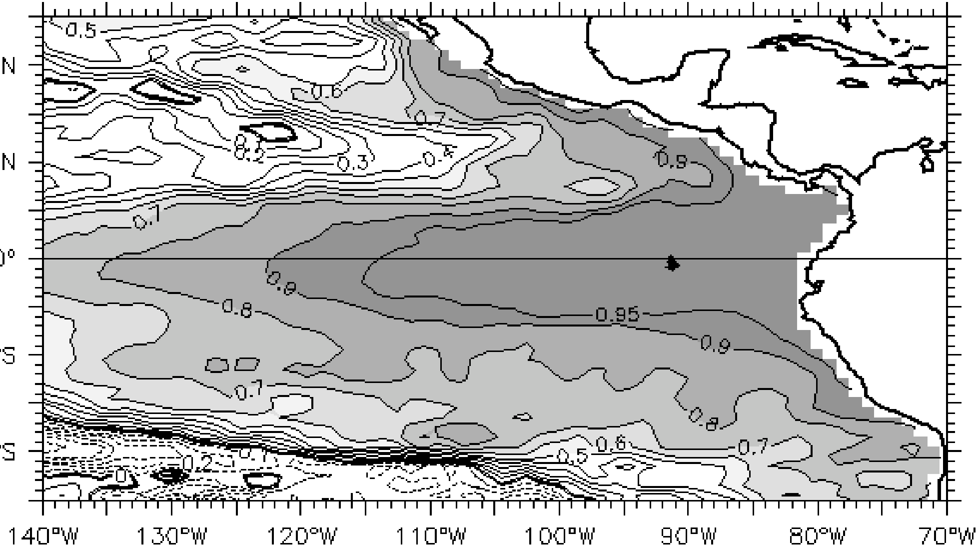
Correlation

with value at 0°, 95°W

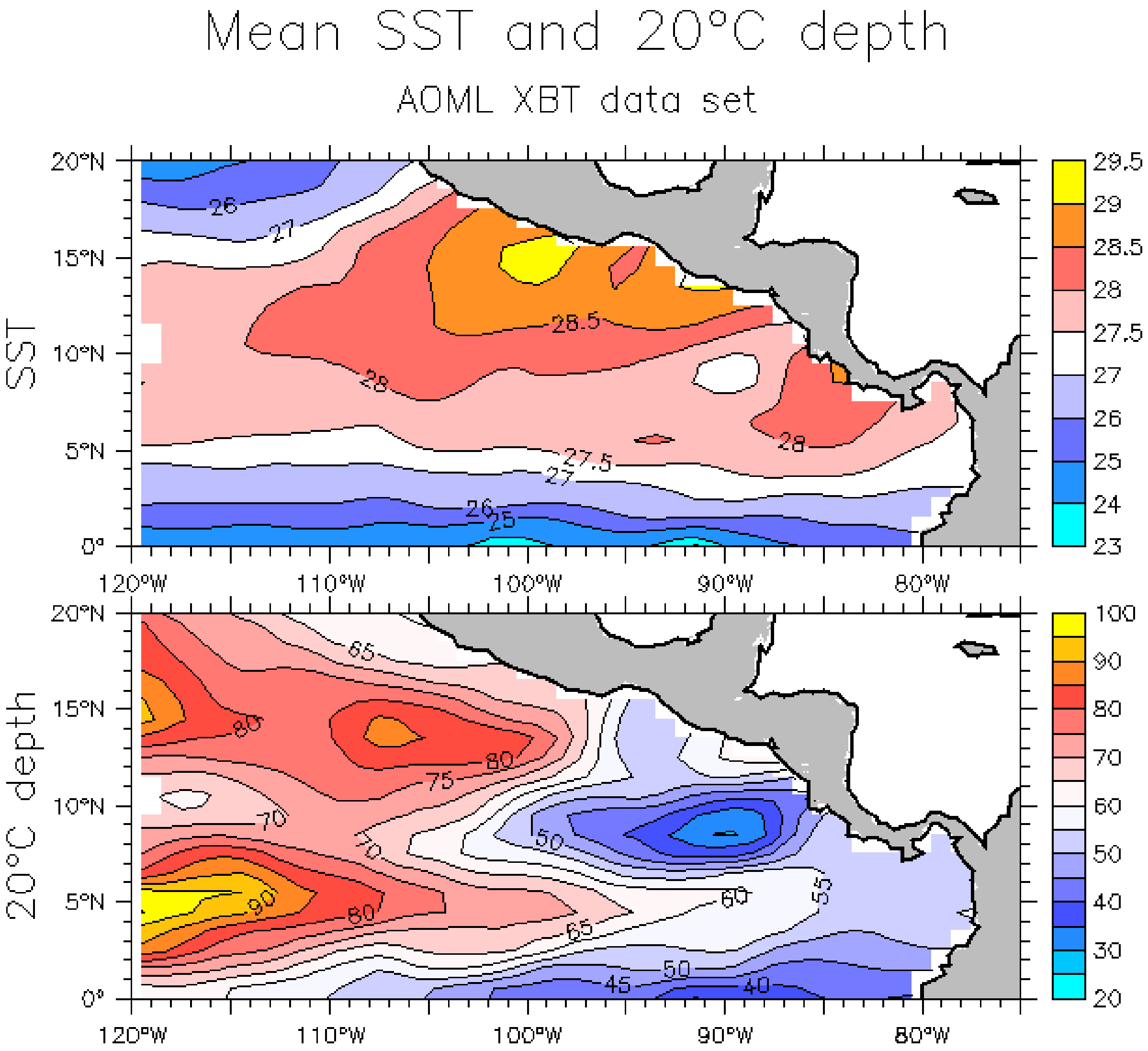
SST (1981–2004)



Sea level (1993–2004)

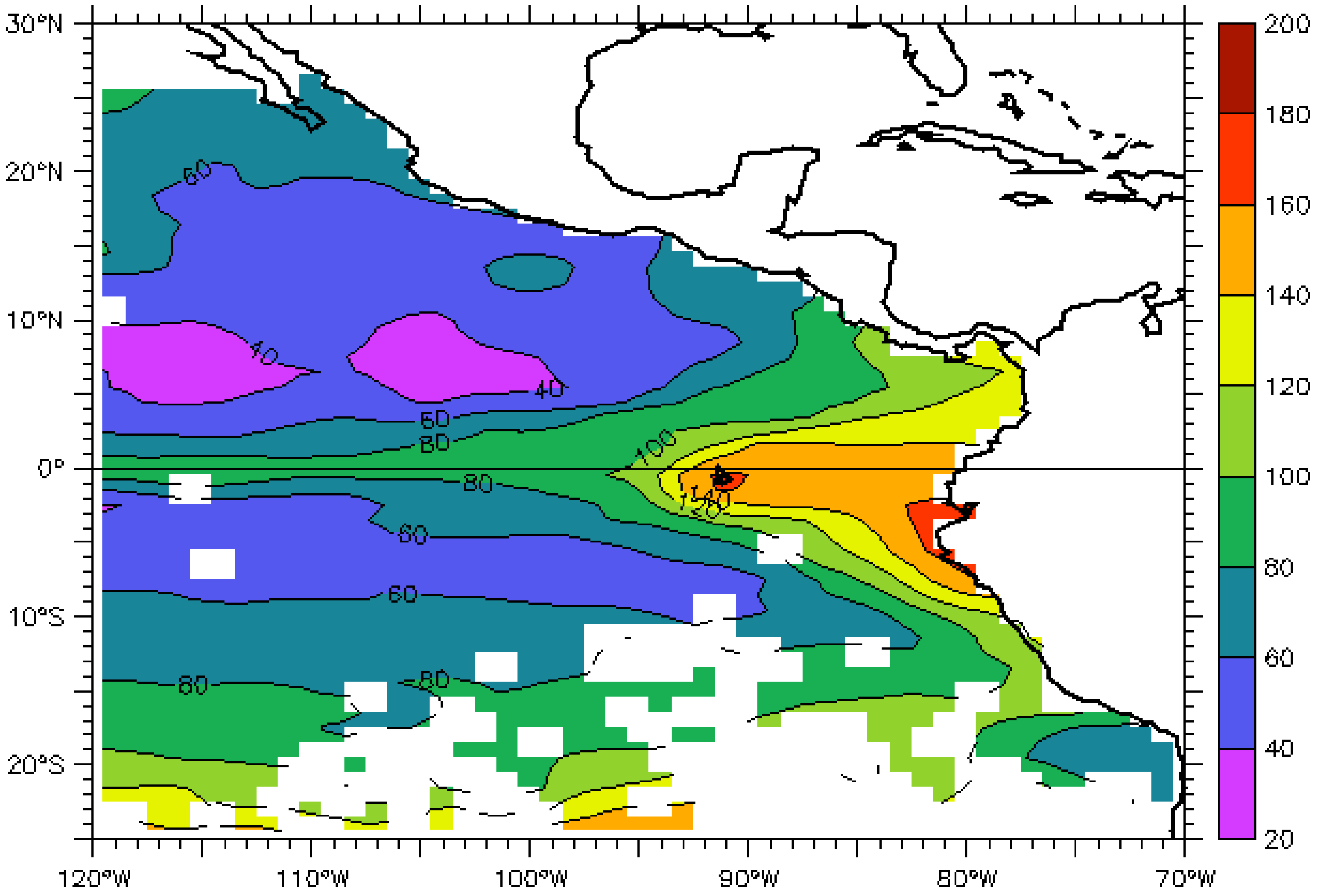


There is little relation between thermocline depth and SST in the ETP

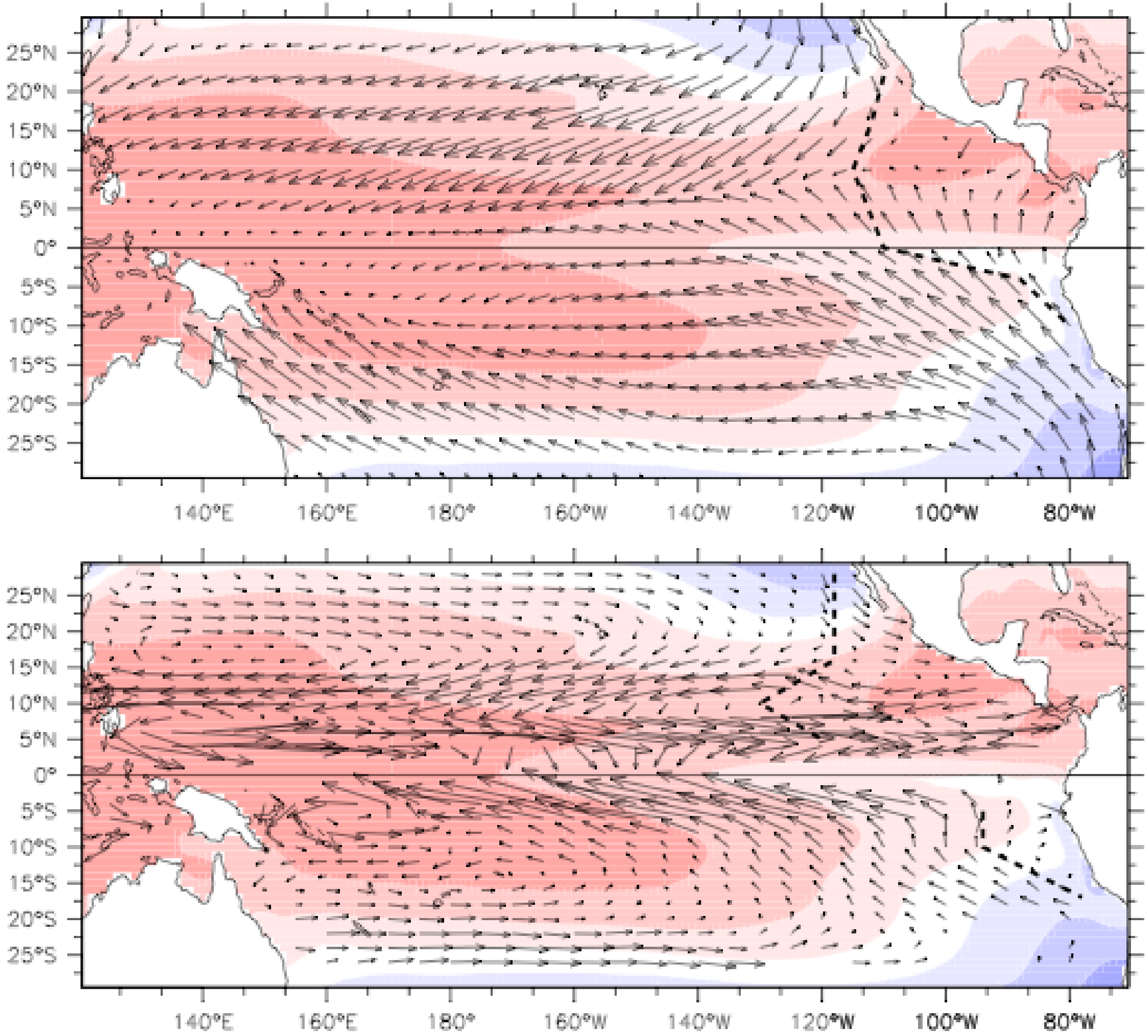


Thickness between 14°C and 20°C in the eastern Pacific

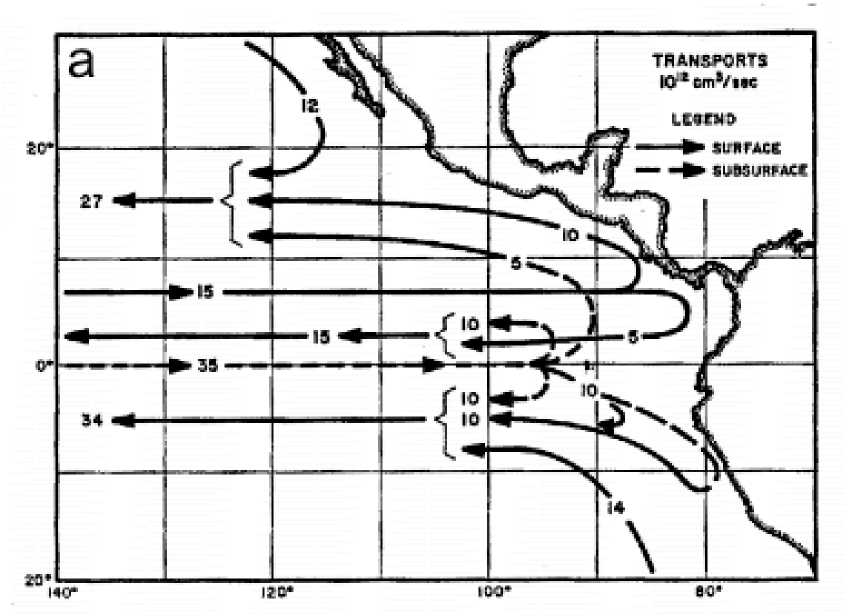
AOML XBT data



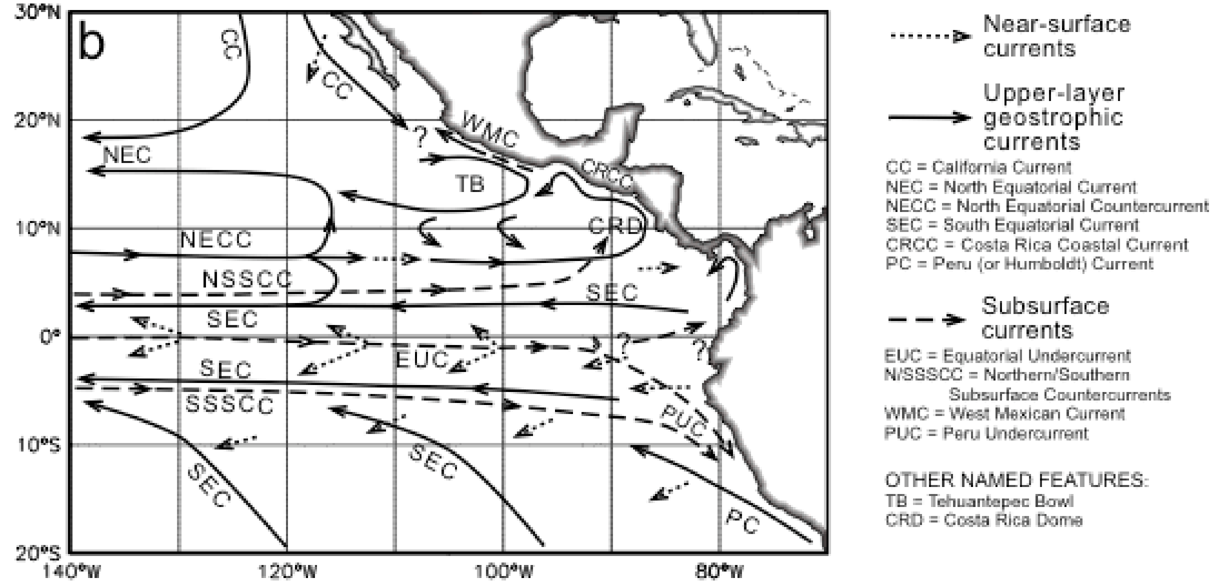
Mean Winds (top) and Surface u_g (bottom)



Wyrtki (1966)

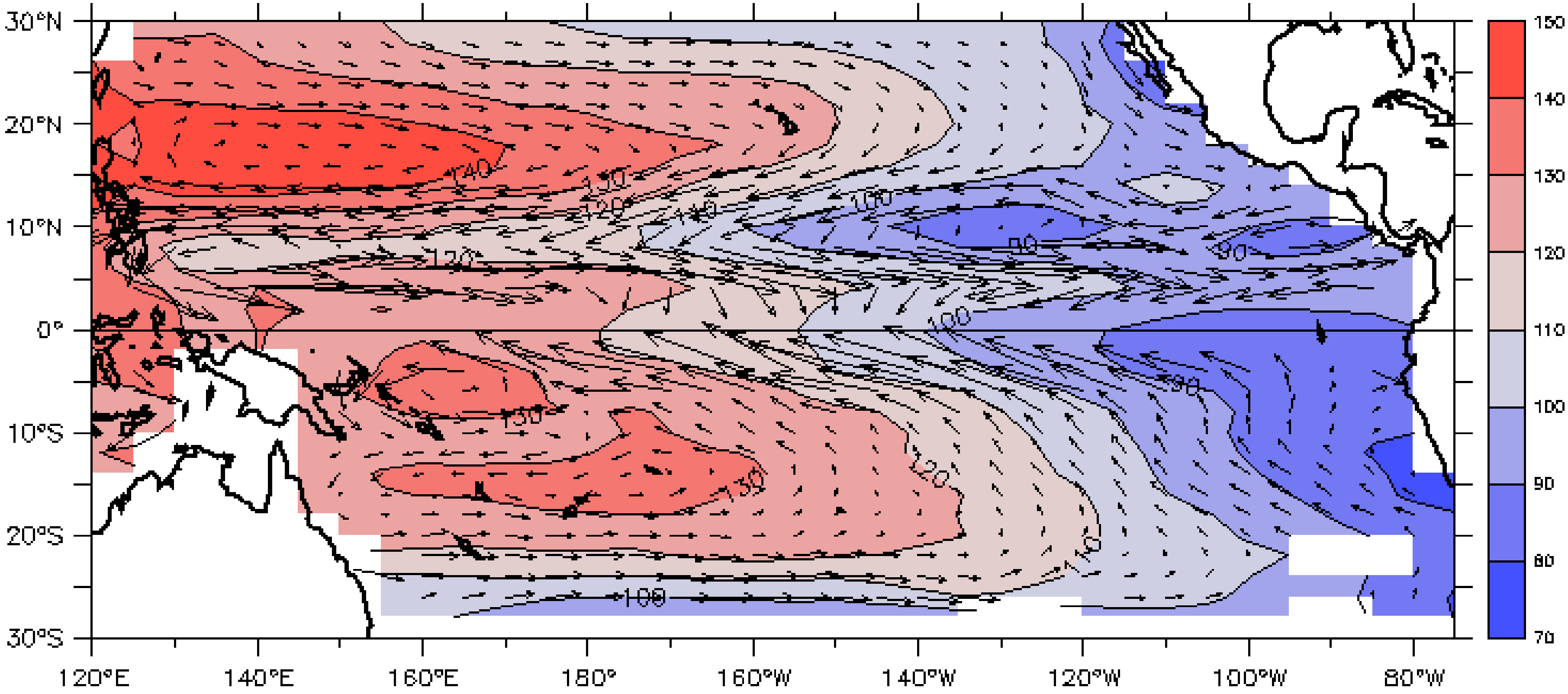


Kessler (2006)



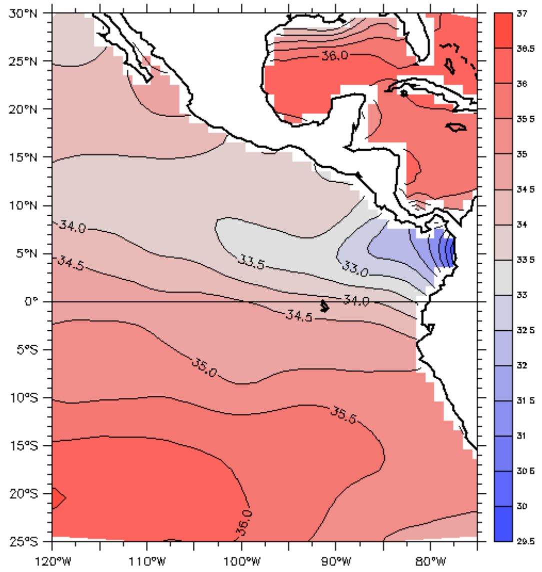
Mean dynamic ht and surface geostrophic velocity

Kessler (1990) XBT data



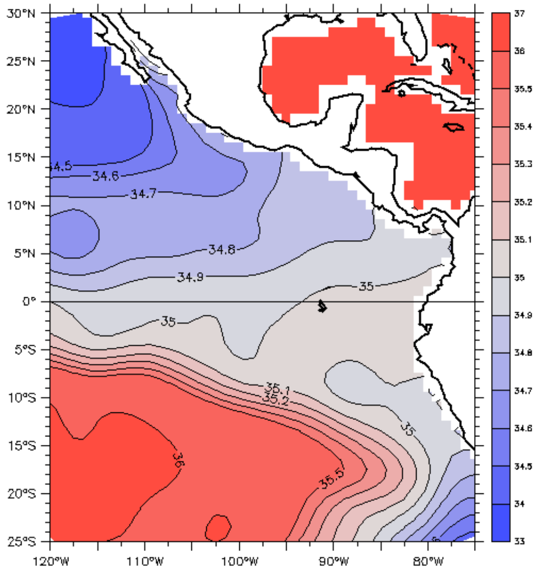
Mean Surface Salinity

Levitus (1994)



Mean 100m Salinity

Levitus (1994)



Mean 250m Salinity

Levitus (1994)