Circulation in the eastern tropical Pacific

How the wind drives a complex structure

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East Pacific Warm Pool

Costa Rica Dome

Thermocline ridges and troughs

Deep bowl of S Pacific gyre

Equatorial cold tongue

Peru upwelling region

SST (Reynolds)
Mean drifter velocity

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

→ 25 cm s⁻¹

drifter-map-2-1-2-do.cdf
Fundamental wind-driven dynamics: Ekman Transport

Surface layer feels the wind stress and the Coriolis force: turns to right

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

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

Ekman Transport:
Net is 90° to the right of the wind
Compare Ekman and surface drifter currents

Ekman currents from ERS winds

Drifter currents (note different scale)

→ 10. cm s⁻¹

→ 25. cm s⁻¹
Why the wind stress Curl is so important:

Ekman transport to the right of the wind

Divergence = Upwelling

Convergence = Downwelling

Coastal Upwelling

Downwelling Curl

Upwelling Curl
Wind stress on 1–5 January 2001

Quikscat (scatterometer) winds
Mean Curl and Vector Wind Stress

Quikscat winds (Aug 1999 – Aug 2002)

5.0 \times 10^{-2} \text{ N m}^{-2} \text{ (Curl in } 10^{-7} \text{ N m}^{-3})
Mean 0/450m DH and Geostrophic Currents

AOML XBT data set

20°N
18°N
16°N
14°N
12°N
10°N
8°N
6°N
4°N
120°W
110°W
100°W
90°W
80°W

20 cm s⁻¹
The physical ocean changes have effects on the atmosphere and biology.

Fig. 9. September Climatology. (a) QuikSCAT pseudo wind stress (vectors in m$^3$s$^{-2}$) 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 SST and 20°C depth
AOML XBT data set
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?

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 an upwind undercurrent.
Seasonal winds and curl

ERS winds

[Wind charts for different seasons (JFM, JAS, AMJ, OND)]

Color scale: 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
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
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Annual cycle of 20°C depth anomalies

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

\[ \frac{\partial h}{\partial t} + c_r \frac{\partial h}{\partial x} + Rh = -\text{Curl} \left( \frac{\tau}{f \rho} \right) \]
Mean SST with artificial wall at 4.5°S

700 km wall separates coastal upwelling from equator

Gent/Cane model run with full annual cycle forcing: FSU winds, ISCCP clouds, Sun
Dynamic height and surface geostrophic currents

26 cm s⁻¹
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

Correlation
with value at $0^\circ, 95^\circ W$
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
Wyrtki (1966)

Kessler (2006)
Mean dynamic ht and surface geostrophic velocity

Kessler (1990) XBT data