100 Months of Upper-Ocean Coastal Upwelling Computed From Alongshore Wind-Stress in the Southeast Pacific Ocean

D. Halpern and P. M. Woiceshyn
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Objective

Revisit coastal upwelling:

- does w_{ek} enhance or weaken CU
- does $\tau_{alongshore}$ decrease during El Niño and increase during La Niña

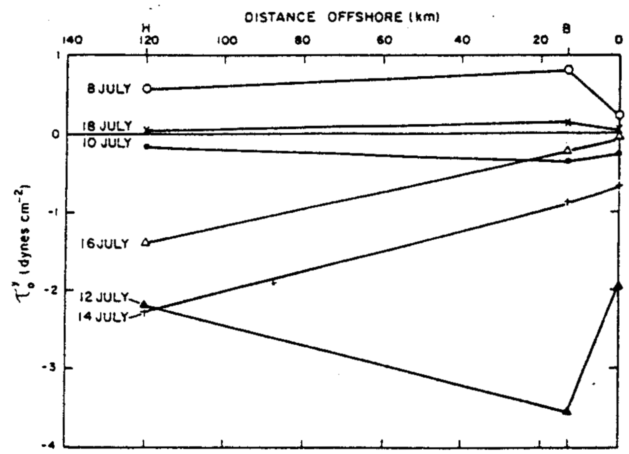


FIG. 3. Zonal gradient of low-pass filtered meridional components of wind stress occurring at 1200 GMT on alternate days during the interval 8–18 July in the region between the coastline and 120 km offshore. Wind stress at the coastline (Sand Lake) is assumed to be equal to the stress measured at Newport, Ore.

was approximately equal to the difference of the north-south wind-stress components; i.e.,

$$\mathrm{curl}_z\tau_0 \sim \frac{\partial \tau_0^y}{\partial x} = \frac{\tau_0^y(\mathrm{B}) - \tau_0^y(\mathrm{H})}{L_{\mathrm{BH}}},$$

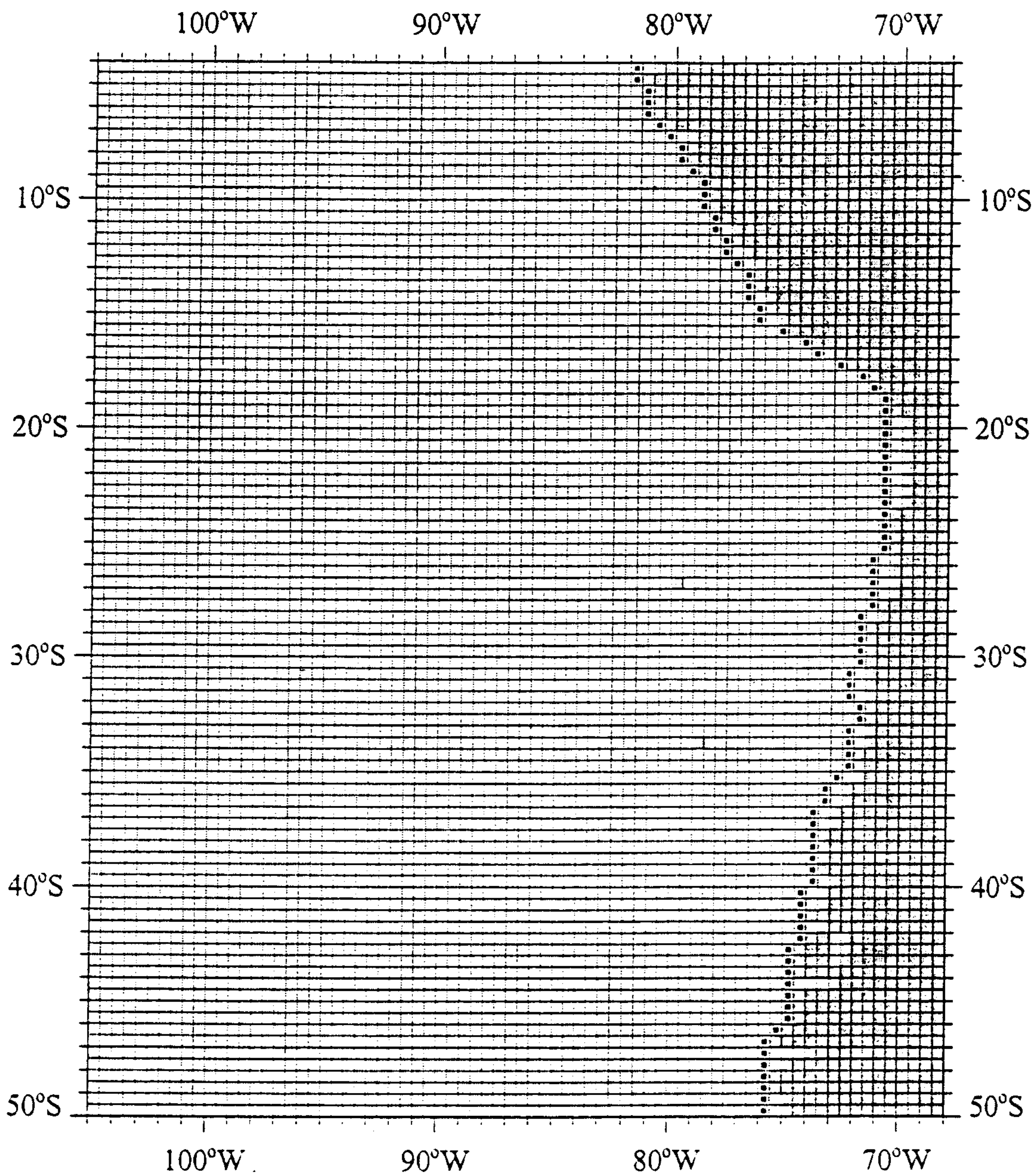
where $(\partial/\partial x, \partial/\partial y)$ are partial derivatives in the eastward (x) and northward (y) directions, $\tau_0^y(\mathrm{B})$ and $\tau_0^y(\mathrm{H})$ are the stresses at stations B and H, and L_{BH} the distance between the two stations. The wind-stress curl (Fig. 2) was computed from the difference of the low-pass north-south component time series. The summertime or seasonal mean value $(0.21\times10^{-7}$ dyn cm$^{-3})$ of the curl was positive and half as great as the standard deviation $(0.44\times10^{-7}$ dyn cm$^{-3})$. At the onshore station the strong southward wind stress associated with the 12 July storm occurred for a relatively short period of about 1.5 days, whereas at the offshore station high values were measured for a much longer period. For about 4 days prior to the occurrence of the maximum wind stress at the onshore station the curl was negative $[\tau_0^y(\mathrm{H}) > \tau_0^y(\mathrm{B})]$, reaching its maximum value of -1.3×10^{-7} dyn cm^{-3} on 12 July. The curl rapidly changed to positive values, reaching a maximum of about 1.3×10^{-7} dyn cm^{-3} on 14 July. Thus, within $\sim$50 h the wind-stress curl varied by 2.6×10^{-7} dyn cm^{-3}.

An order of magnitude calculation of the mean upward vertical velocity at the bottom of the Ekman layer [e.g., at about 20 m depth (Halpern, 1976; Smith *et al.*, 1971)] shows it to be about 10^{-4} cm s^{-1} offshore of Station B and 10^{-3} cm s^{-1} inshore of this site. On a shorter time scale, such as the period 12–16 July, the maximum offshore wind-stress curl $(1.3\times10^{-7}$ dyn cm$^{-3})$ may have produced an upward motion of magnitude 1×10^{-3} cm s^{-1} for a few days. However, the maximum nearshore wind curl (10^{-6} dyn cm^{-3}; Fig. 3) could have been sufficient to account for the 10^{-2} cm s^{-1} vertical velocity inferred (Halpern, 1976) on 13 July from a time series of hydrographic data.

Halpern, 1976, JPO

Original Map

▪ Cell 1 location



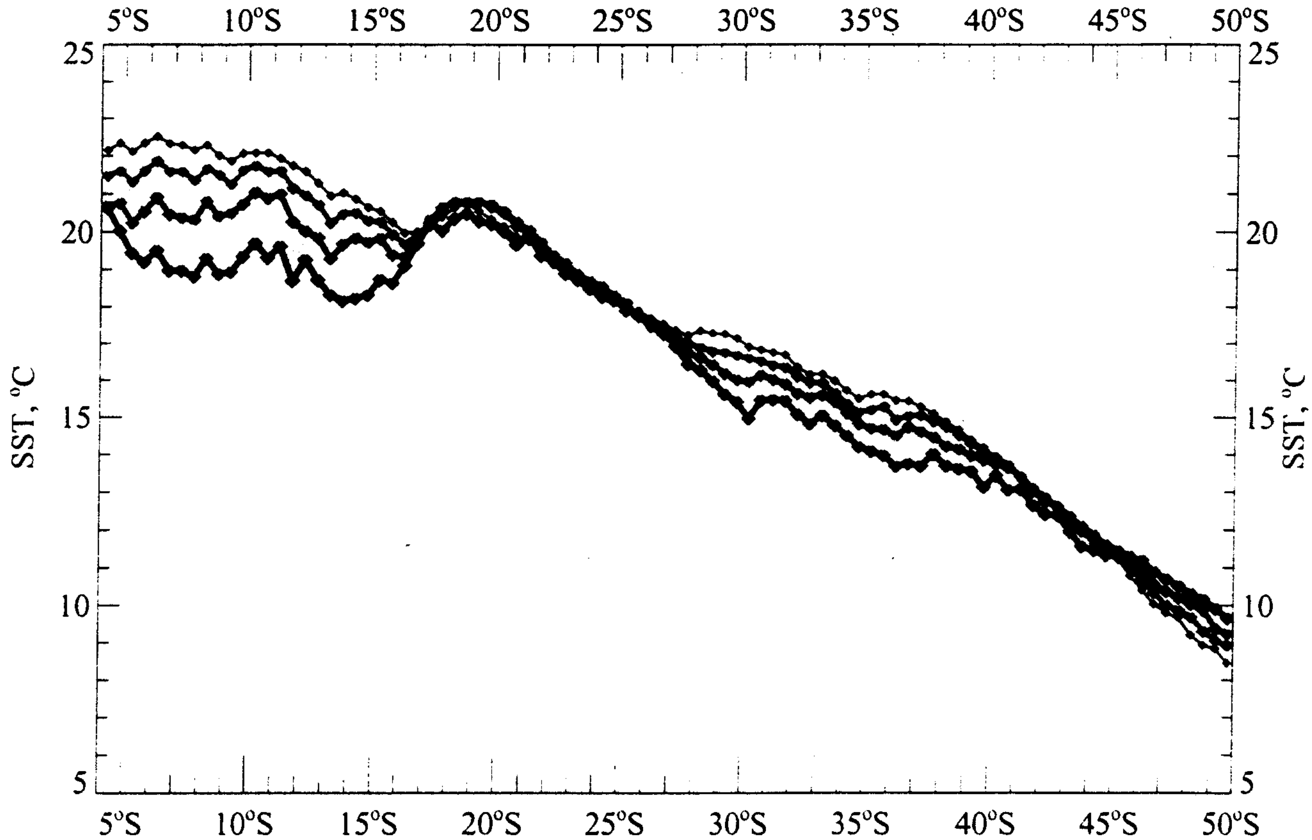
Mean (5/1992-4/1997) Conditions

El Niño (1997-1998)

La Niña (1998-1999)

Conditions

AVHRR/Pathfinder <SST> 5/1992 - 4/1997, °C



i = 1 Black (thick)

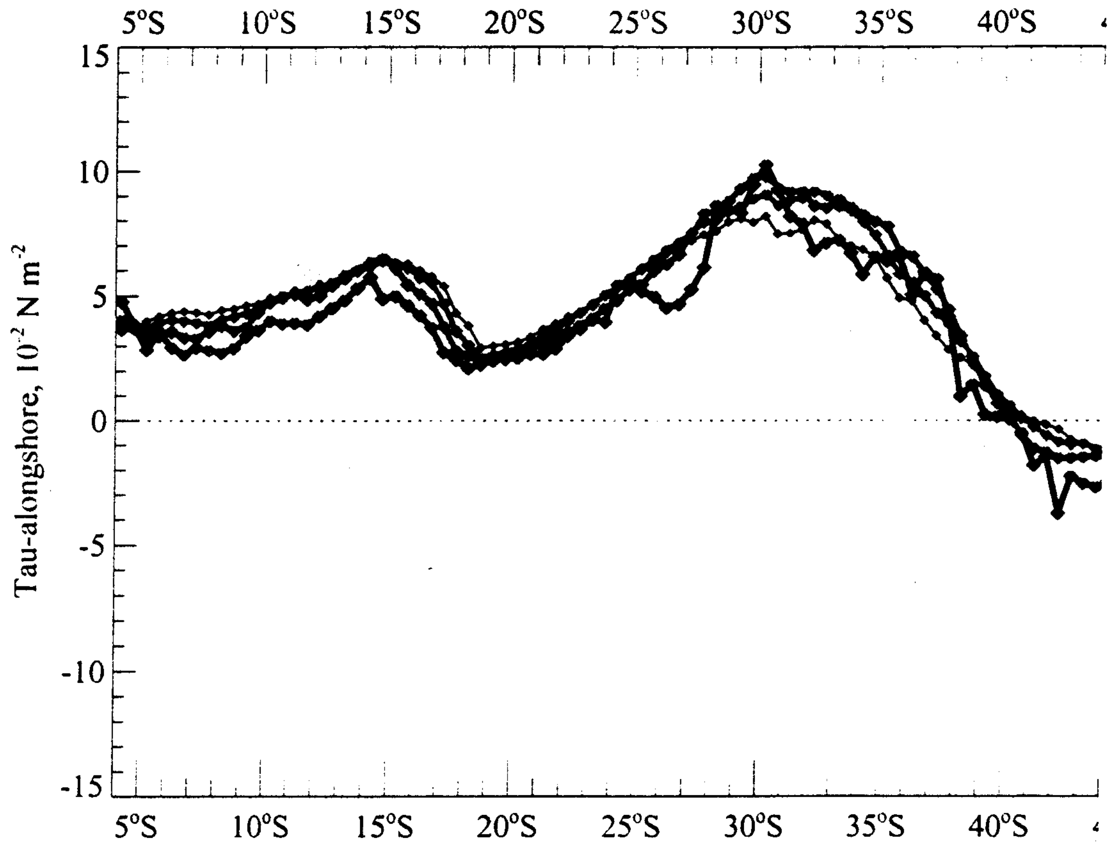
i = 3 Red (thick)

i = 5 Blue (thick)

i = 7 Black (thin)

Thu Mar 30 15:05:07 2000

ERS(IFR2) <TAU$_{alongshore}$> 5/1992 - 4/1997, 10^{-2} N m^{-2}



i=1 < i=7

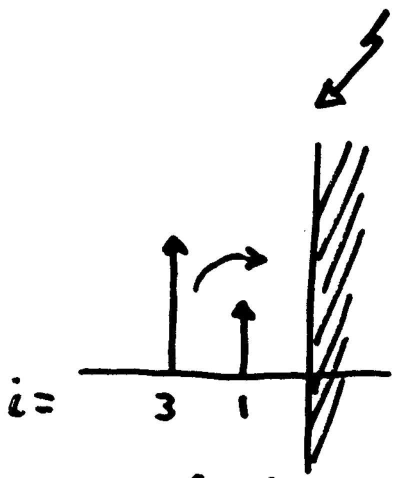
i=1 > i=7

i = 1 Black (thick)

i = 3 Red (thick)

i = 5 Blue (thick)

i = 7 Black (thin)



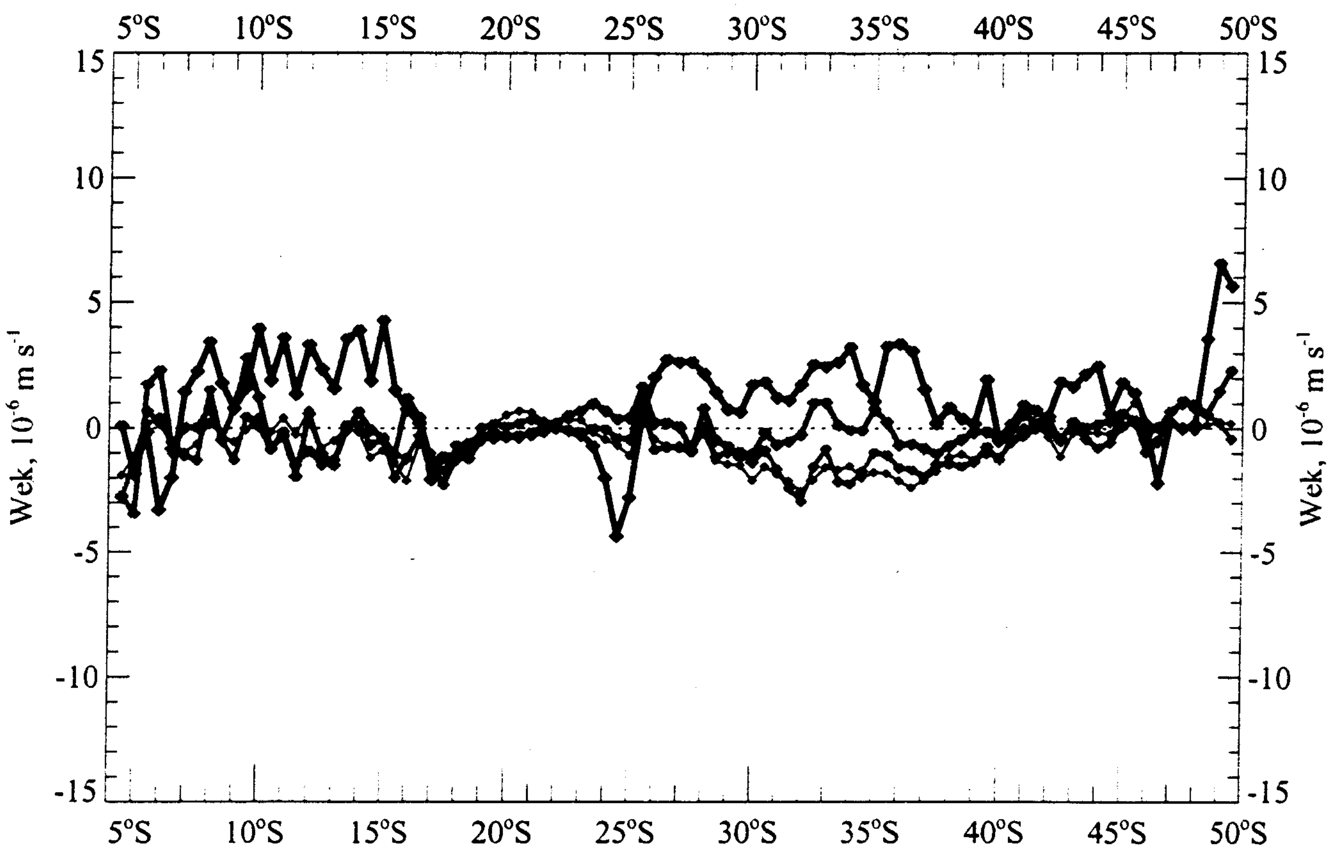
frictional retardation

$$\text{curl}\,\tau = \frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \approx \frac{\partial}{\partial x}\tau_y < 0$$

$$w_{ek} \propto \frac{\text{curl}\,\tau}{f} = \frac{<0}{<0} = >0 \text{ upward}$$

Wed Mar 29 17:50:34 2000

ERS(IFR2) <Wek> 5/1992 - 4/1997, 10^{-6} m s^{-1}C



i = 1.5 Black (thick)

i = 3.5 Red (thick)

i = 5.5 Blue (thick)

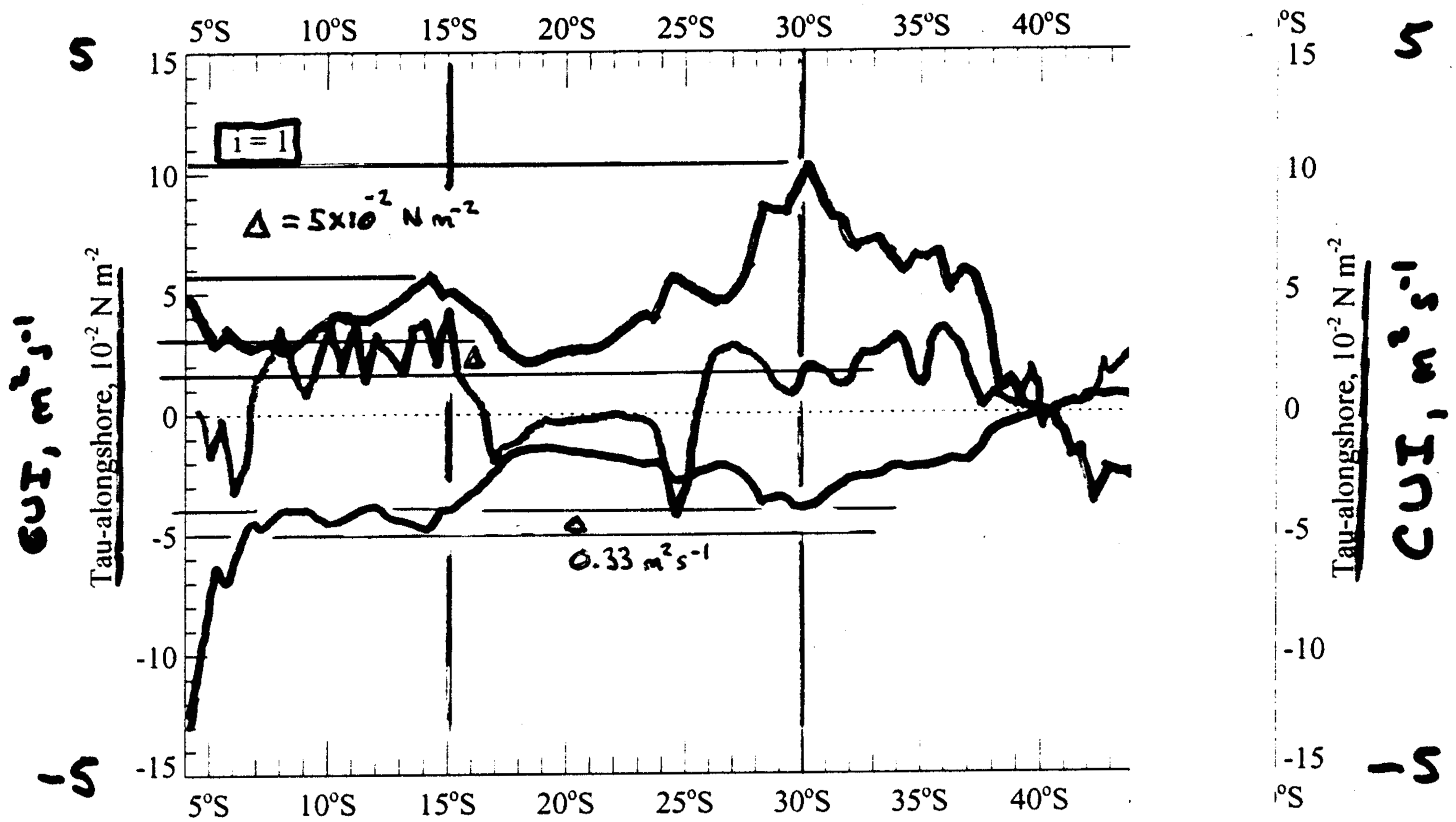
i = 7.5 Black (thin)

Ekman suction enhances Ekman upwelling

Fri Mar 31 11:41:55 2000

i=1

ERS(IFR2) <TAU$_{alongshore}$> 5/1992 - 4/1997, 10^{-2} N m^{-2}



<CUI> $m^2 s^{-1}$

<w_{ek}> 10^{-6} m s^{-1} Δ 1.5×10^{-5} $m^2 s^{-1}$

Wed Mar 29 17:50:34 2000

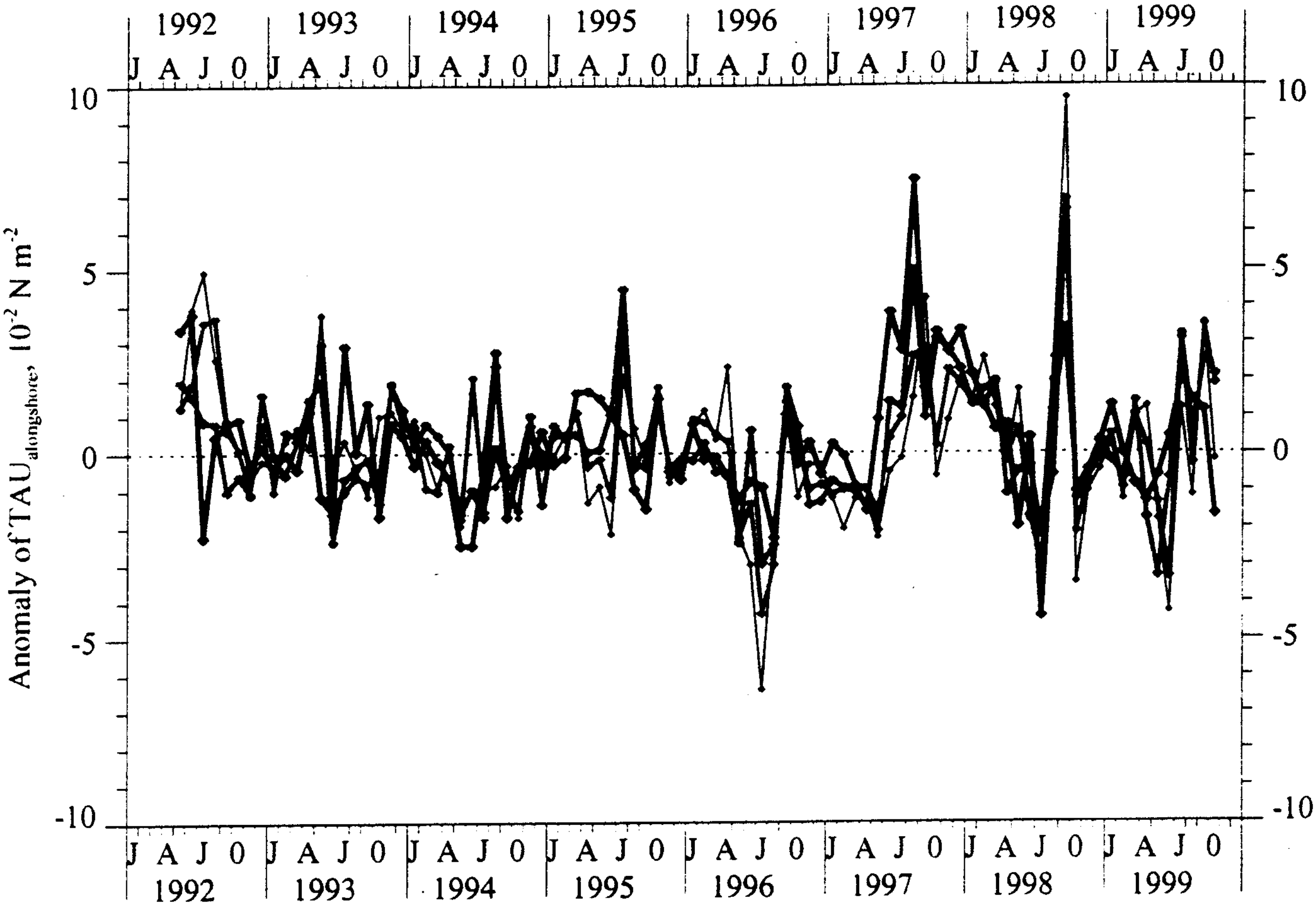
Mean (5/1992-4/1997) Conditions

[1 < 2 and 2 > 1]

	15°S	30°S
$\tau_{alongshore}$	1	2
τ_{along}i=1/τ_{along}i=7	2	1
CUI	1	1
w_{ek}	2	1

During El Niño, $\tau_{alongshore}$ increased in the coastal zone. Magnitude of increases decreases wit[h] offshore distance.

Anomaly of $TAU_{alongshore}$, 10^{-2} N m^{-2}, 14.5°S - 15.5°S



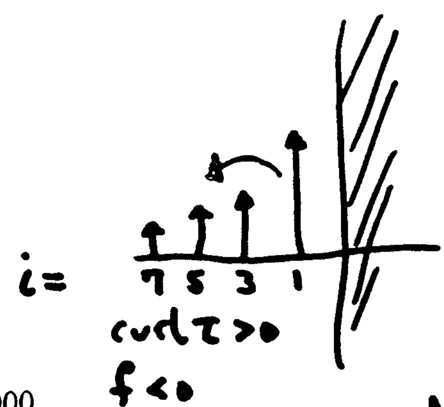
During El Niño, at 15°S, $\tau_{alongshore}$ dramatically increased at i=1-7. The increase was maximum at the coast, and became progressively smaller with offshore distance.

i = 1 Black (thick)

i = 3 Red (thick)

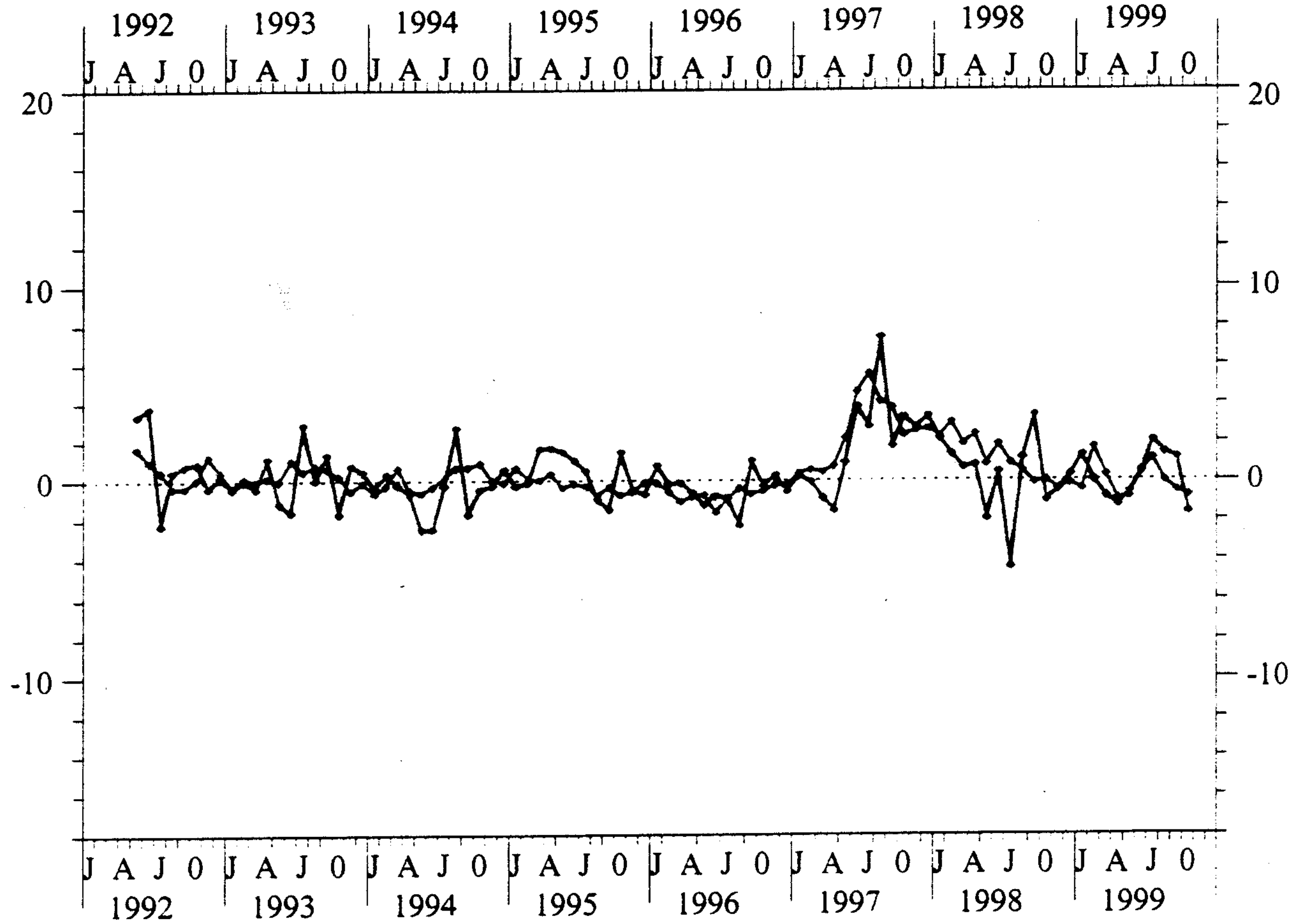
i = 5 Blue (thick)

i = 7 Black (thin)



Thu Mar 30 18:37:19 2000

Anomalies of SST and $TAU_{alongshore}$, 14.5°S - 15.5°S, i = 1



SST Anomaly (RED), °C $TAU_{alongshore}$ Anomaly (BLUE), 10^{-2} N m^{-2}

Anomalies 5-YR Mean & Standard Deviation [5/1992 - 4/1997]

	Mean	Std. Dev.	
SST	0.00	0.62	°C
$TAU_{Alongshore}$	0.00	1.34	10^{-2} N m^{-2}

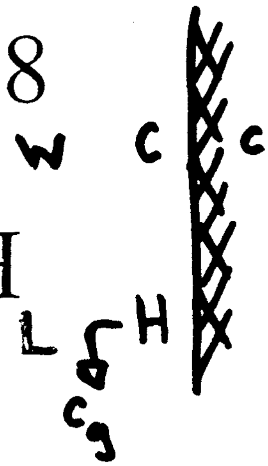
Thu Mar 30 11:14:53 2000

15°S

	i=3	i=1

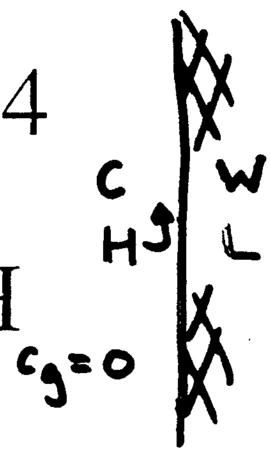
< > = 5/1992-4/1997

<SST> (°C)	20	18
<atm press>	L	H
<$\tau_{alongshore}$> (10^{-2} N m^{-2})	5	4



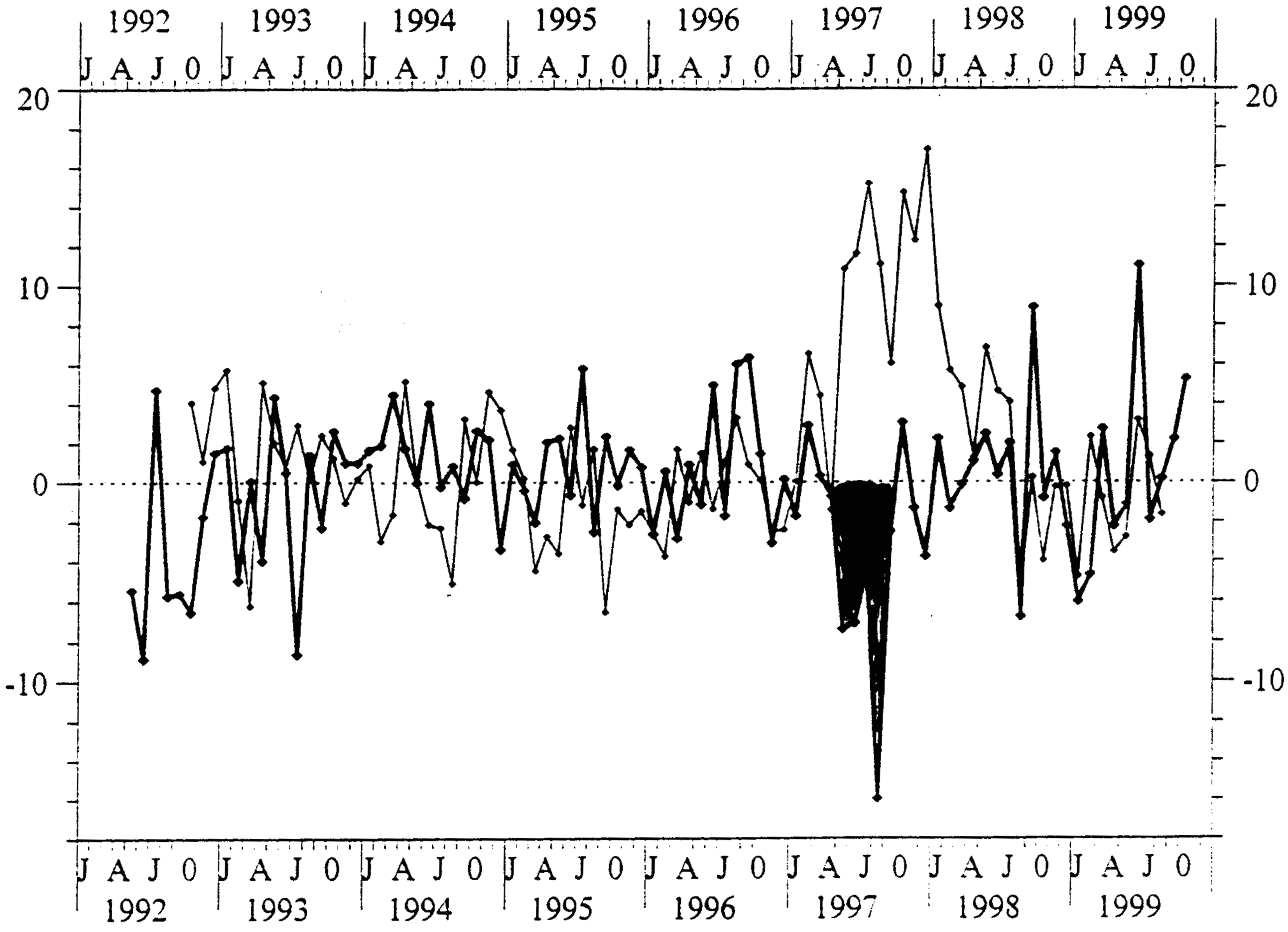
El Niño (Jul-Aug 1997)

SST (°C)	24	24
atm press	H	H
$\tau_{alongshore}$ (10^{-2} N m^{-2})	10	11



Anomalies of SSH, 16.0°S - 17.0°S, i = 1

Anomalies of Wek, 14.25°S - 15.25°S, i = 1.5



SSH Anomaly (THIN BLACK), cm

Wek Anomaly (THICK BLACK), 10^{-6} m s^{-1}

Anomalies 5-YR Mean & Standard Deviation [5/1992 - 4/1997]

	Mean	Std. Dev.	
Wek	-0.00	3.38	10^{-6} m s^{-1}

Anomalies 4-YR Mean & Standard Deviation [5/1993 - 4/1997]

	Mean	Std. Dev.	
SSH	-0.01	2.79	cm

Thu Mar 30 11:23:56 2000