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

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Objective

Revisit coastal upwelling:
• does $w_{ek}$ enhance or weaken CU
• does $\tau_{alongshore}$ decrease during El Niño and increase during La Niña
was approximately equal to the difference of the north-south wind-stress components; i.e.,

$$\text{curl}_x \tau = \frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \frac{L_{BH}}{L_{BH}}$$

where \((\partial / \partial x, \partial / \partial y)\) are partial derivatives in the eastward \((x)\) and northward \((y)\) directions, \(\tau_x(B)\) and \(\tau_y(H)\) 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 \((0.21 \times 10^{-7} \text{ dyn cm}^{-2})\) of the curl was positive and half as great as the standard deviation \((0.44 \times 10^{-7} \text{ dyn cm}^{-2})\). 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 \([\tau_y(H) > \tau_y(B)]\), reaching its maximum value of \(-1.3 \times 10^{-7} \text{ dyn cm}^{-2}\) on 12 July. The curl rapidly changed to positive values, reaching a maximum of about \(1.3 \times 10^{-7} \text{ dyn cm}^{-2}\) on 14 July. Thus, within \(-50\) h the wind-stress curl varied by \(2 \times 10^{-7} \text{ dyn cm}^{-2}\).

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 \(10^{-4} \text{ cm s}^{-1}\) offshore of Station B and \(10^{-3} \text{ cm s}^{-1}\) inshore of this site. On a shorter time scale, such as the period 12-16 July, the maximum offshore wind-stress curl \((1.3 \times 10^{-7} \text{ dyn cm}^{-2})\) may have produced an upward motion of magnitude \(1 \times 10^{-4} \text{ cm s}^{-1}\) for a few days. However, the maximum nearshore wind curl \((10^{-4} \text{ dyn cm}^{-2}; \text{Fig. 3})\) could have been sufficient to account for the \(10^{-3} \text{ cm s}^{-1}\) vertical velocity inferred (Halpern, 1976) on 13 July from a time series of hydrographic data.
Original Map
- Cell 1 location

La Niña (1998-1999)
Conditions

i = 1  Black (thick)
i = 3  Red  (thick)
i = 5  Blue  (thick)
i = 7  Black (thin)
ERS(IFR2) $<\text{TAU}_{\text{alongshore}}>$ 5/1992 - 4/1997, $10^{-2}$ N m$^{-2}$

\begin{align*}
\tau_{i=1} & > \tau_{i=7} \\
i &= 1 \quad \text{Black (thick)} \\
i &= 3 \quad \text{Red (thick)} \\
i &= 5 \quad \text{Blue (thick)} \\
i &= 7 \quad \text{Black (thin)}
\end{align*}

$\text{fisc_S} = \frac{\varepsilon_T}{\varepsilon_T_x} - \frac{\varepsilon_T}{\varepsilon_T_y} \approx \frac{\varepsilon}{\varepsilon_T} < 0$

$\omega \propto \frac{\text{fisc}_S}{f} = \frac{\omega_0}{\omega_0} > 0 \quad \text{upward}$

Wed Mar 29 17:50:34 2000
ERS(IFR2) <Wek> 5/1992 - 4/1997, $10^{-6}$ m s$^{-1}$ C

\[ i = 1.5 \quad \text{Black (thick)} \]
\[ i = 3.5 \quad \text{Red (thick)} \]
\[ i = 5.5 \quad \text{Blue (thick)} \]
\[ i = 7.5 \quad \text{Black (thin)} \]

Ekman suction enhances Ekman upwelling
ERS(IFR2) <TAU\textsubscript{alongshore}> 5/1992 - 4/1997, 10^{-2} \text{ N m}^{-2}

\[ \Delta = 5 \times 10^{-2} \text{ N m}^{-2} \]

\[ \bar{C}_{UI} \text{ m}^{2} \text{s}^{-1} \]

\[ \bar{W}_{ok} \text{ 10}^{-6} \text{ m s}^{-1} \]

\[ \Delta = 1.5 \times 10^{-2} \text{ m s}^{-1} \]

\[ [1 < 2 \text{ and } 2 > 1] \]

<table>
<thead>
<tr>
<th></th>
<th>15°S</th>
<th>30°S</th>
</tr>
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<tbody>
<tr>
<td>(\tau_{\text{alongshore}})</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>(\tau_{\text{along}} = 1/\tau_{\text{along}})</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>CUI</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(W_{ek})</td>
<td>2</td>
<td>1</td>
</tr>
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</table>
During El Niño, alongshore increased in the coastal zone. Magnitude of increases decreases with offshore distance.

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

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

\[
\begin{align*}
\text{i} &= 1 \quad \text{Black (thick)} \\
\text{i} &= 3 \quad \text{Red (thick)} \\
\text{i} &= 5 \quad \text{Blue (thick)} \\
\text{i} &= 7 \quad \text{Black (thin)}
\end{align*}
\]
Anomalies of SST and TAU\textsubscript{alongshore}, 14.5\textdegree S - 15.5\textdegree S, \( i = 1 \)

SST Anomaly (RED), °C \hspace{1cm} \text{TAU\textsubscript{alongshore} Anomaly (BLUE), 10\textsuperscript{-2} N m\textsuperscript{-2}}


\begin{align*}
\text{Mean} & \quad \text{Std. Dev.} \\
\text{SST} & \quad 0.00 \quad 0.62 \quad \text{oC} \\
\text{TAU\textsubscript{Alongshore}} & \quad 0.00 \quad 1.34 \quad 10\textsuperscript{-2} \text{ N m}\textsuperscript{-2}
\end{align*}
$15^\circ S$

\[ i = 3 \quad i = 1 \]

\[ < > = 5/1992-4/1997 \]

$\langle \text{SST} \rangle$ (°C) \quad 20 \quad 18

$\langle \text{atm press} \rangle$

L \quad H

$\langle \tau_{\text{alongshore}} \rangle$ (10^{-2} N m^{-2}) \quad 5 \quad 4

**El Niño (Jul-Aug 1997)**

\text{SST (°C)} \quad 24 \quad 24

\text{atm press} \quad H \quad H

$\tau_{\text{alongshore}}$ (10^{-2} N m^{-2}) \quad 10 \quad 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}

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
<th>Std. Dev.</th>
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<tr>
<td>Wek</td>
<td>-0.00</td>
<td>3.38</td>
</tr>
<tr>
<td>SSH</td>
<td>-0.01</td>
<td>2.79</td>
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