What determines the spatial pattern in summer upwelling trends on the U.S. West Coast?

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Seo, Brink, Dorman, Koracin, and Edwards (2012)
What determines the spatial pattern in summer upwelling trends on the U.S. West Coast?
J. Geophys. Res.-Oceans, 117, C08012
Motivation and Questions

- Coastal upwelling is a fundamental oceanographic process for cold over-shelf SST during summer seasons.
  - A robust assessment of long-term variability and trend in upwelling remains difficult due to short spatial scales (~10 km).
  - On the U.S. West Coast, long-term in situ data are more abundant.

- Main questions of the study:
  - Long-term trend and pattern of upwelling?
  - Possible mechanisms?
  - Impacts on near-coast land air temperatures?
Data and reanalysis


Trend and spatial pattern in JJA SST 1980-2010

- Over-shelf buoys and NOAA SST both show a coast-wide cooling trend.
- This cooling trend has a greater magnitude in the central and southern California.

<table>
<thead>
<tr>
<th></th>
<th>Buoy SST</th>
<th>NOAA SST</th>
</tr>
</thead>
<tbody>
<tr>
<td>All 12 buoys</td>
<td>-0.19</td>
<td>-0.26</td>
</tr>
<tr>
<td>Northern 6 buoys</td>
<td>-0.14</td>
<td>-0.19</td>
</tr>
<tr>
<td>Southern 6 buoys</td>
<td>-0.24</td>
<td>-0.32</td>
</tr>
</tbody>
</table>
Along-shore distribution of trend in upwelling and wind

- **North**: The variability and trend in SST are positively correlated with those of the equatorward wind. A role of offshore Ekman transport. 
- **South**: Even stronger trend and variability are associated with winds with weak or opposite trends and correlations.

Then, what determines the long-term SST trend in the south?
What determines the southward intensified upwelling trend pattern?

*JJA Trends (1980-2010) in wind stress and wind stress curls in CaRD10*

- Wind stress has southeastward trend coast-wide, except in the lee of capes, which show poleward trend.

- These regions are associated with trend in positive wind stress curls.

Can Ekman pumping account for greater upwelling trend in the south?
Ekman transport by along-shore wind stress vs Ekman pumping by curl?

- Much stronger contribution to the total upwelling transport from integrated Ekman pumping
- Most pronounced in the lee of Pt. Sur and Pt. Conception
- Curl-driven Ekman pumping is a possible mechanism for greater upwelling trend in the south.

\[
EkT = \frac{1}{\rho_w f} \vec{\tau} \times \vec{k} \\
EkP = \int_0^d \frac{1}{\rho_w} \left( \nabla \times \frac{\vec{\tau}}{f} \right) dx
\]

unit: m³ s⁻¹ per 100 m of coastline

where \( \vec{\tau} \) is the along-shore wind stress

e.g., Puduan and Pickett, 2003
West Coast SST has positive reg. coeffs. with PDO index.

The SST trends inferred from PDO are comparable in the south and north,

- PDO would not likely explain 70% greater trend in the south as in buoys.
- The topographic wind stress curl could be a factor for local trend pattern.
Upwelling trend and over-land daily mean air-temperatures (Tave)

- Daily-mean air-temperatures have been rising significantly (p=0.1).
  - Greater inland warming trends in 1980-2010 than 1951-2010
- In 1980-2010, near-coast stations show weaker warming or even cooling trends, in agreement with cooling trend in air-temperatures over buoys.
Daily maximum temperature: Tmax

City of Lompoc

- Tmax has warmed.
- Day-time maximum air-temperatures (Tave too) near Pt. Conception has cooled far more than Monterey in 1980-2010.
- Coincident with greater cooling in the near-shelf waters.

- What is the mechanism linking the near-coasts water and inland air-temperatures?

Daily minimum temperature: Tmin

City of Lompoc

- Tave has a cooling trend of -0.5°C/decade in 1980-2010.
- Coincident with the cooling in over-shelf air/water temperatures.

- Only Tmax shows substantial cooling trend of -1°C/decade.
- Tmax trend influenced by a stronger intrusion of marine air via sea breeze (e.g., Lebassi et al. 2009).
Summary and Discussion

- In situ and remote-sensing data both indicate that summer-time WC SSTs have been cooled at -0.19~0.26 C/decade in 1980-2010 (e.g., García-Reyes and Largier 2010).

- Off Oregon and northern California coast, cooling trend is consistent with the upwelling response to the equatorward alongshore wind stress.

- In central and southern California, pattern and trend in wind stress curl seem to better account for even stronger (70%) upwelling trend.
  - Caveat 1) Uncertainty in trend of wind stress curl,
  - Caveat 2) Other factors not considered: alongshore pressure-gradient and currents.

- The coast-wide trends in SST and wind are associated with PDO,
  - but, not their alongshore distributions.

- Upwelling trend may have some impacts on long-term trend in over-land diurnal temperature variability possibly through sea-breeze intrusion.
Thanks