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)
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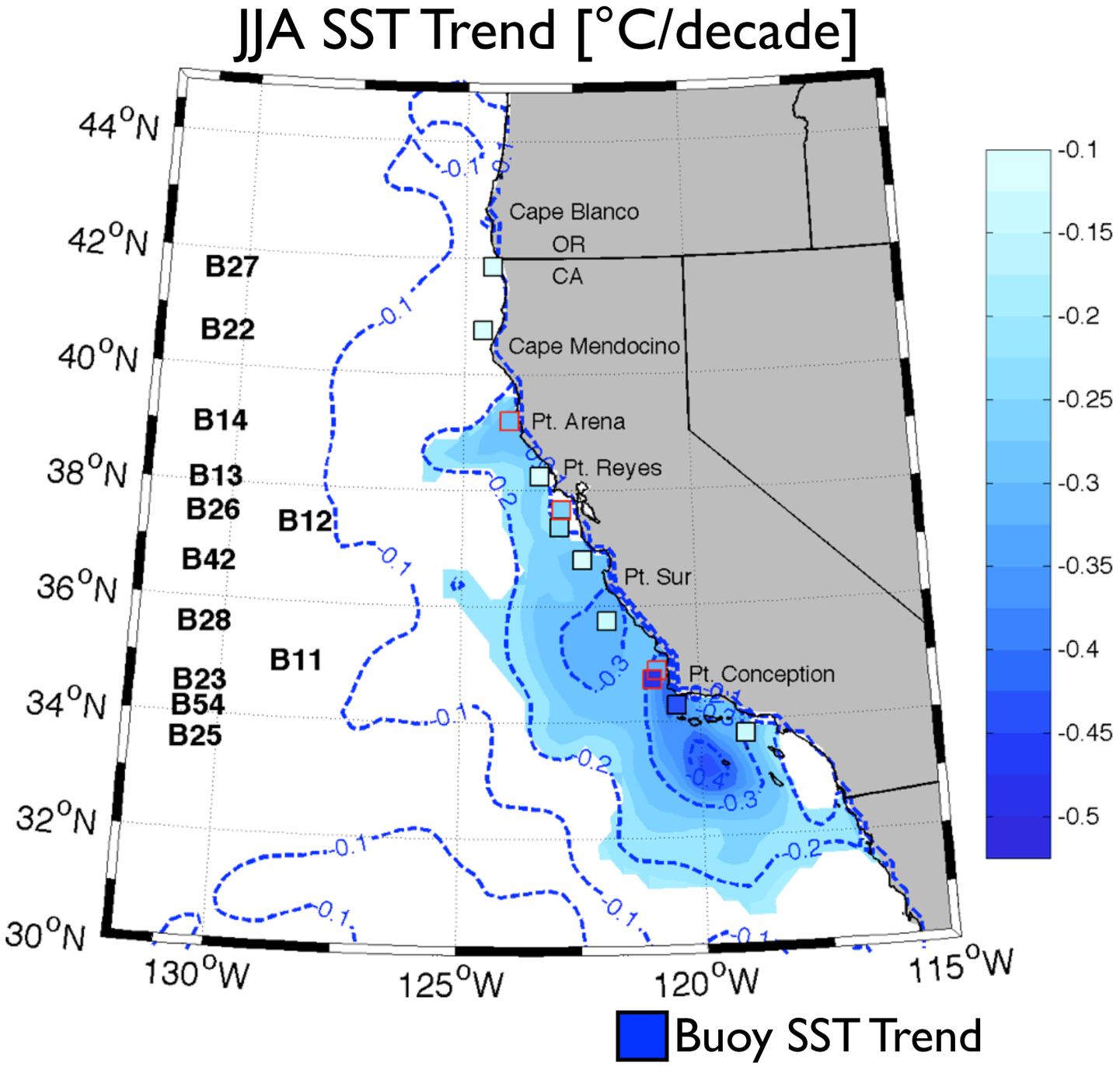
Motivation and Questions

- 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

- SST and wind: National Data Buoy Center (NDBC) buoys. 1981-2010, 1-hourly. http://www.ndbc.noaa.gov
- Satellite SST: NOAA OI SST based on AVHRR, daily 25 km,1982-2010, Reynolds et al. (2007). http://www.ncdc.noaa.gov/oa/climate/research/sst/oi-daily.php Consistent with NDBC buoy SSTs.
- Wind stress and curls: California Reanalysis Downscaling at 10km (CaRD10). Dynamic downscaling of the NCEP/NCAR Reanalysis, 1948-2005 at 1-hourly, 10km res. over California http://g-rsm.wikispaces.com/CaRD10. Good skill over NDBC buoys (Kanamaru and Kanamitsu, 2007).
- Land air-temperatures: California Weather Database. Daily Tmax, Tmin, and Tave, 1951-2010. http://www.ipm.ucdavis.edu

Trend and spatial pattern in JJA SST 1980-2010



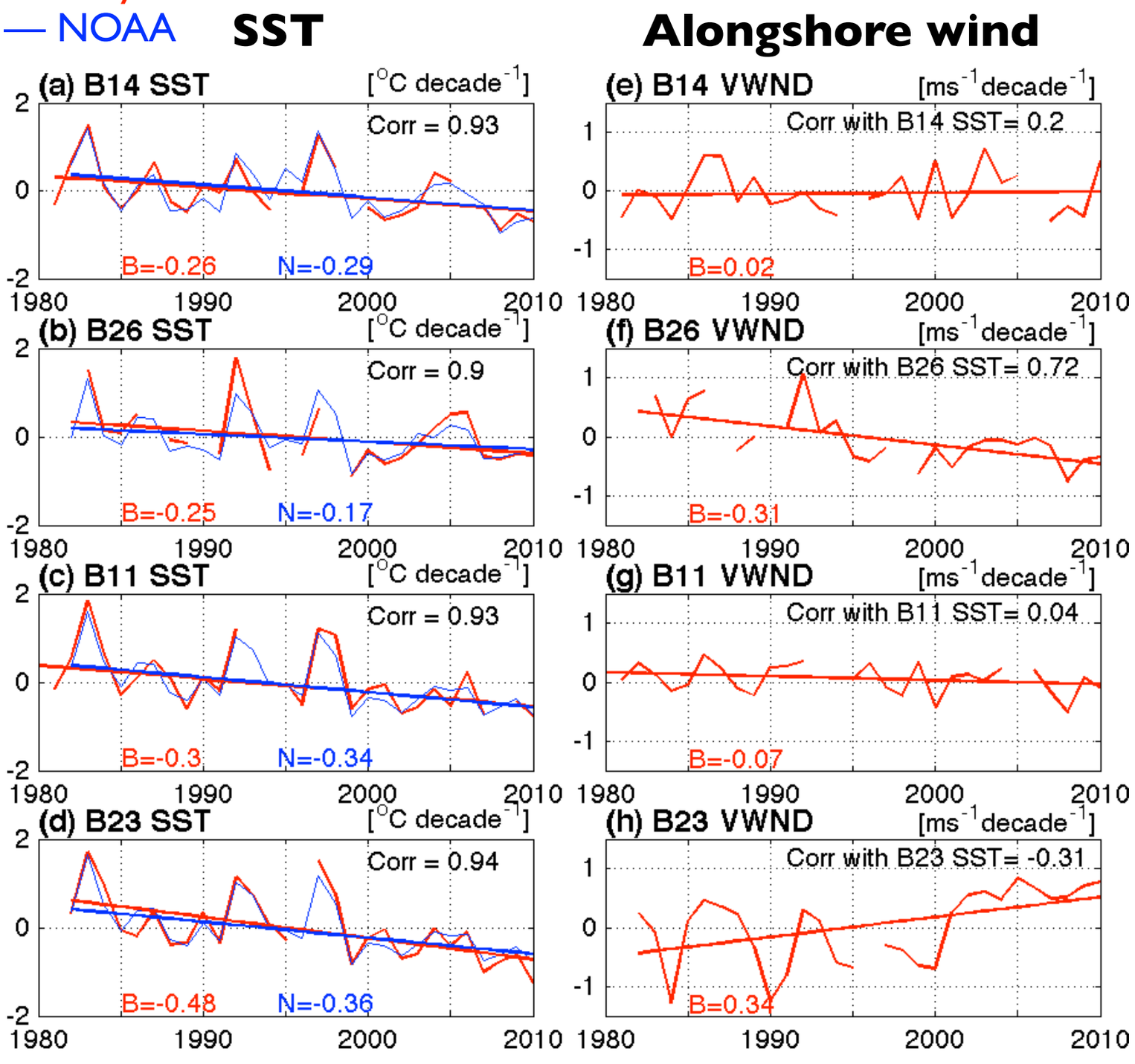
- Over-shelf buoys and NOAA SST both show a coast-wide cooling trend.
- This cooling trend has a greater magnitude in the central and southern California.

	Buoy SST	NOAA SST
All 12 buoys	-0.19	-0.26
Northern 6 buoys	-0.14	-0.19
Southern 6 buoys	-0.24	-0.32

[°C/decade]

Along-shore distribution of trend in upwelling and wind

— buoys
— NOAA

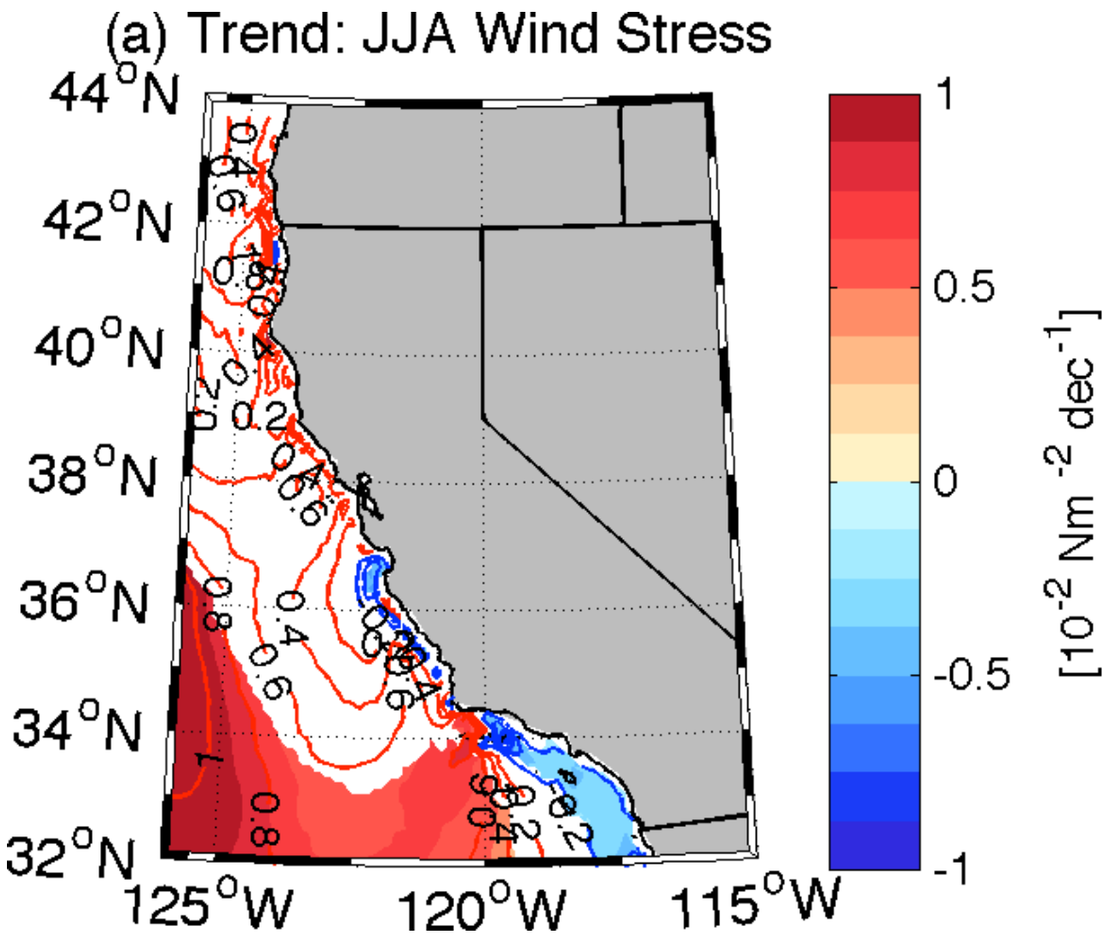


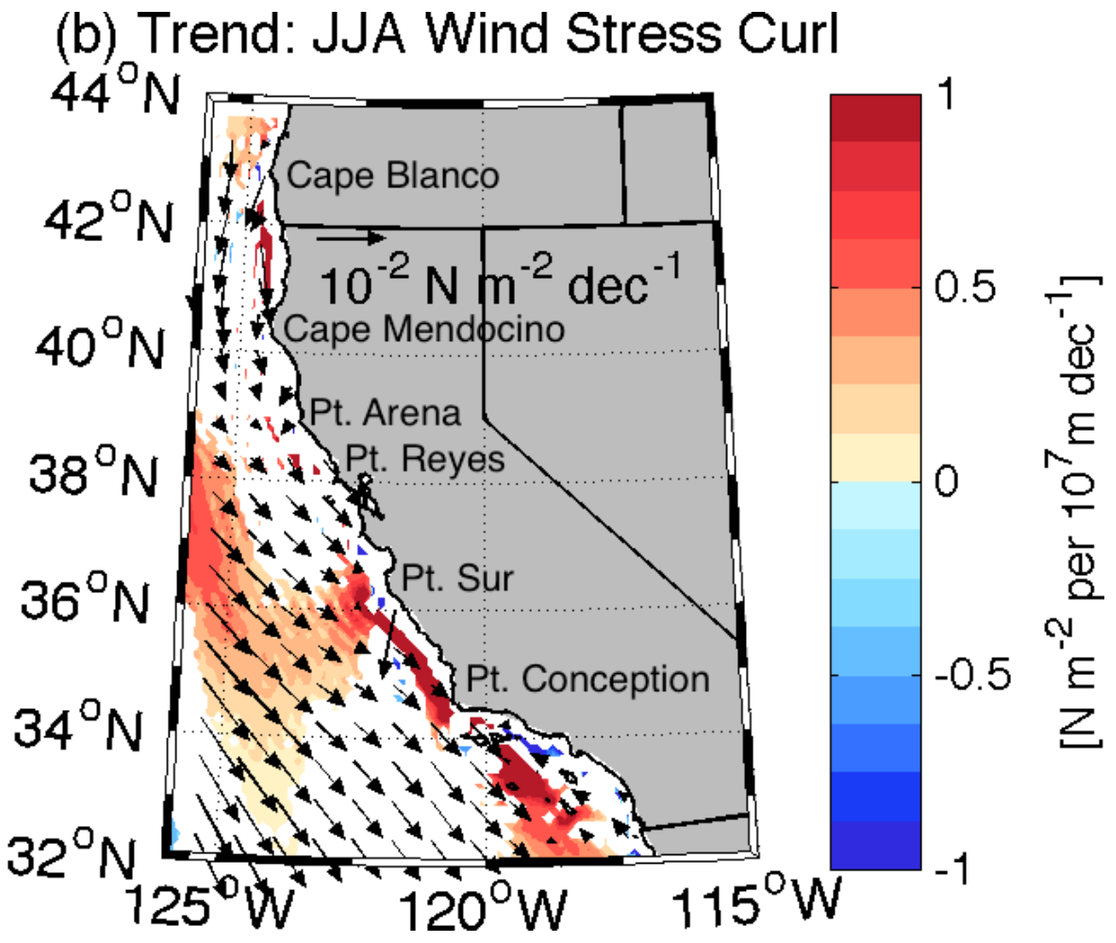
- North: The variability and trend in SST are positively correlated with those of the equatorward wind.
  - Indicative of a role of offshore Ekman transport.
- South: Even stronger trend and variability are associated with winds with weak or opposite trends and correlations.

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



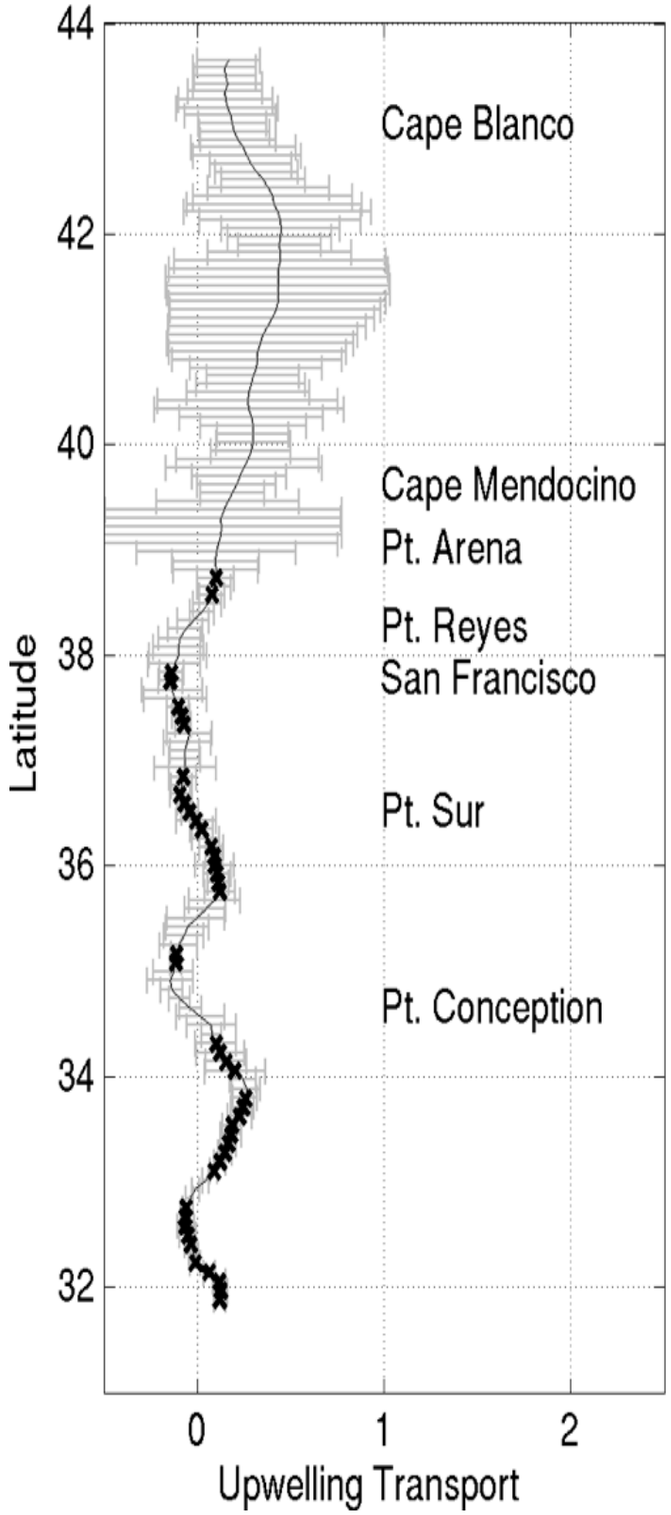


- Wind stress has southeastward trend coast-wide, except in the lee of capes, which show poleward trend.
- These regions are associated with trend in positive wind stress curls.

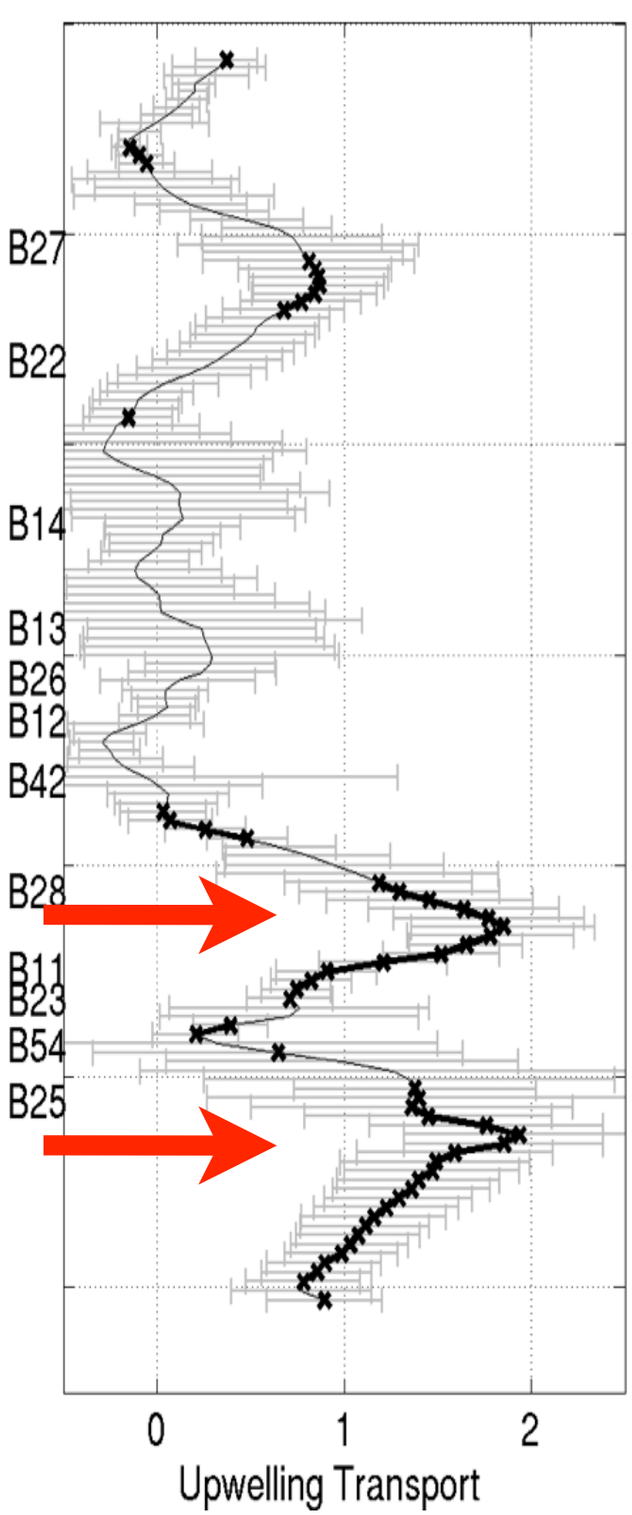
Can Ekman pumping account for greater upwelling trend in the south?

Ekman transport by along-shore wind stress vs *Ekman pumping* by curl?

Trend in JJA EkT



Trend in JJA Integrated EkP



JJA 1980-2010

$$EkT = \frac{1}{\rho_w f}\tau \times \hat{k} \qquad EkP = \int_0^d \frac{1}{\rho_w}\left(\nabla \times \frac{\tau}{f}\right)dx$$

unit: $m^3\ s^{-1}$ per 100 m of coastline

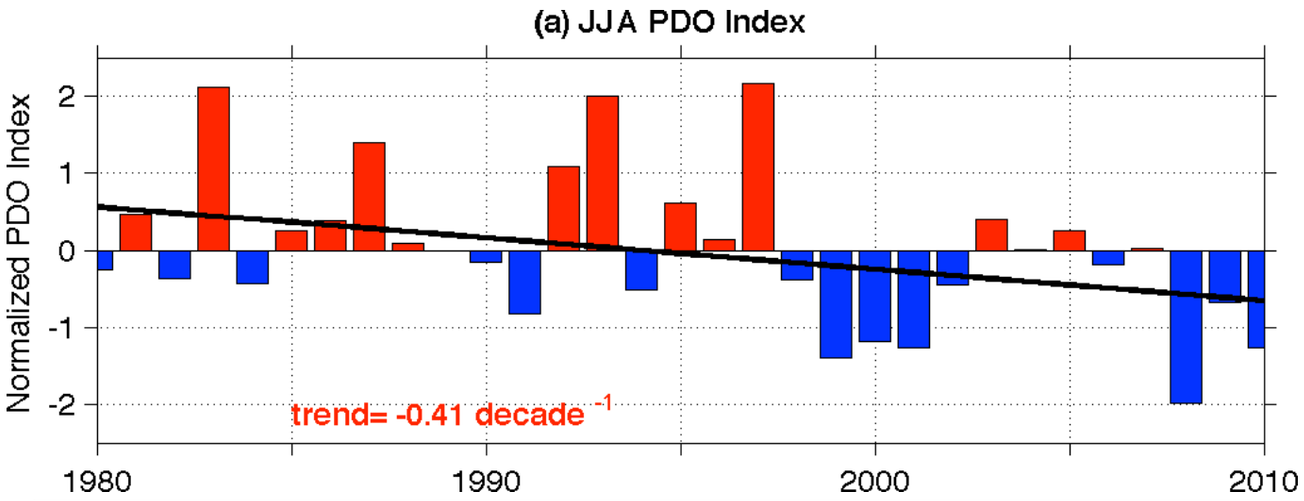
d=cross-shelf-distance where curl>0

e.g., Puduan and Pickett, 2003

- 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.

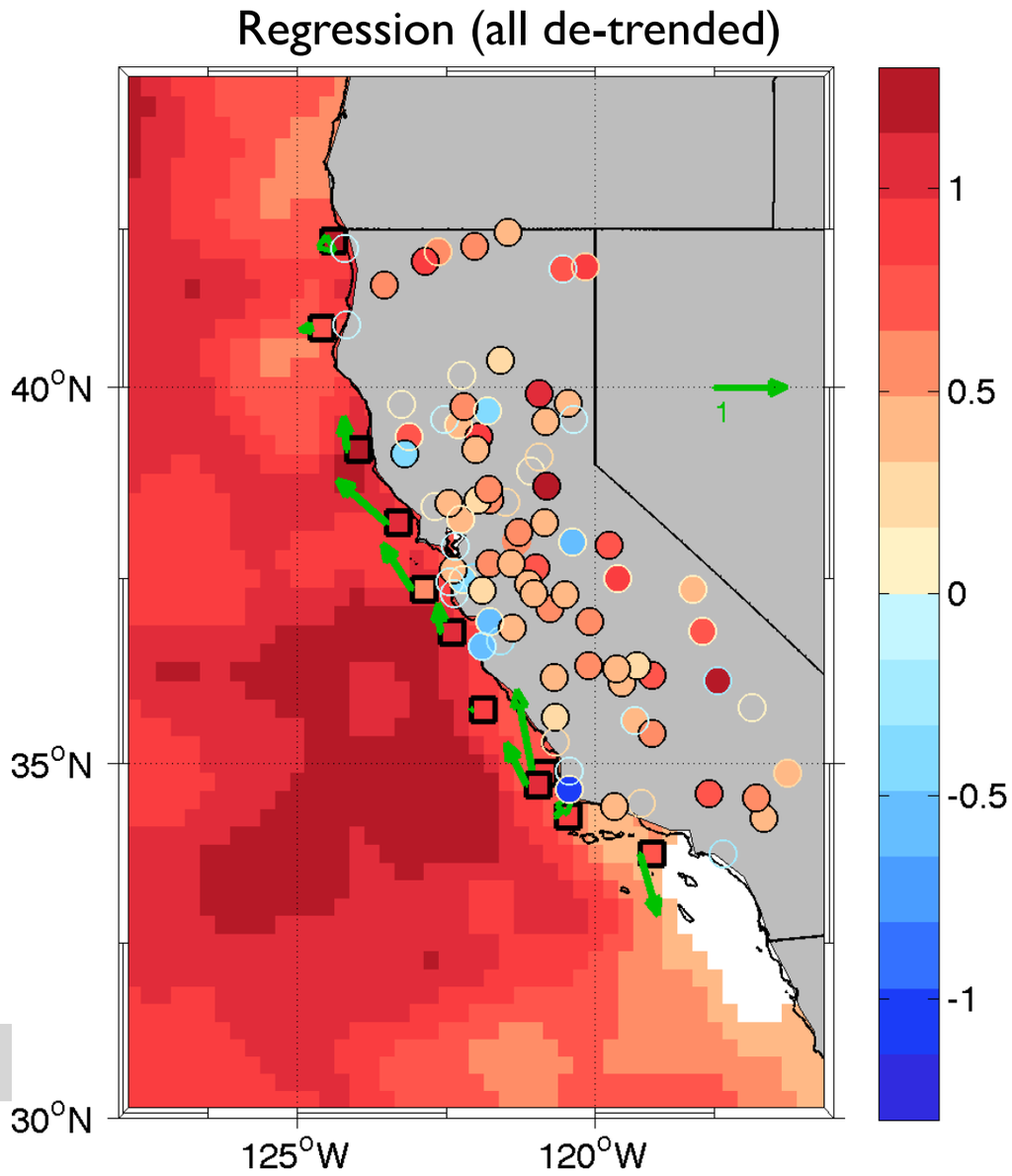
What is the role of large-scale modes of climate variability?

Example of Pacific Decadal Oscillation (JJA 1980-2010)



	Regression Coefficients	Inferred SST trend
All 12 buoys	+0.88	-0.42
Northern 6 buoys	+0.87	-0.41
Southern 6 buoys	+0.90	-0.42

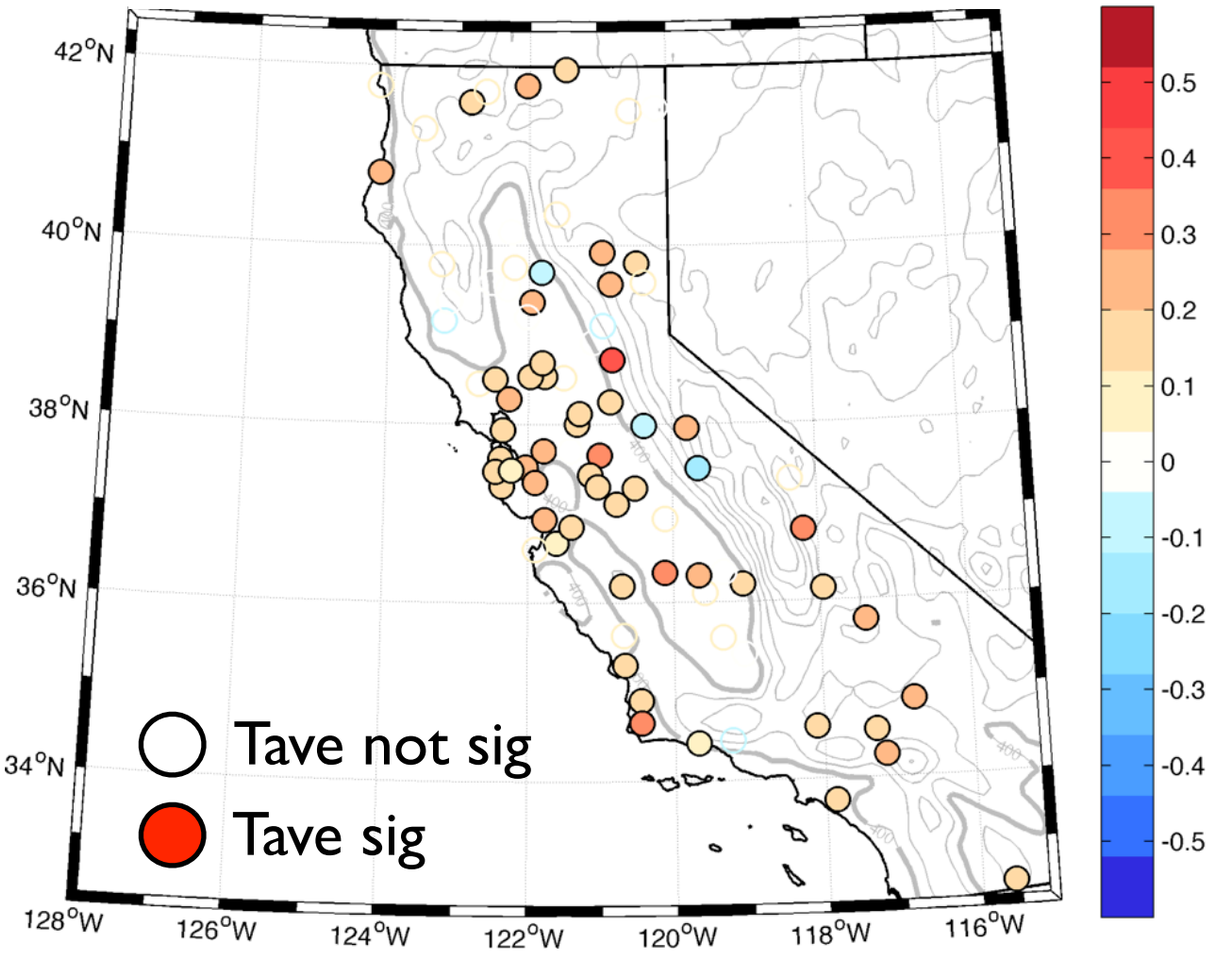
PDO-induced buoy SST trend = de-trended reg. coef X PDO trend



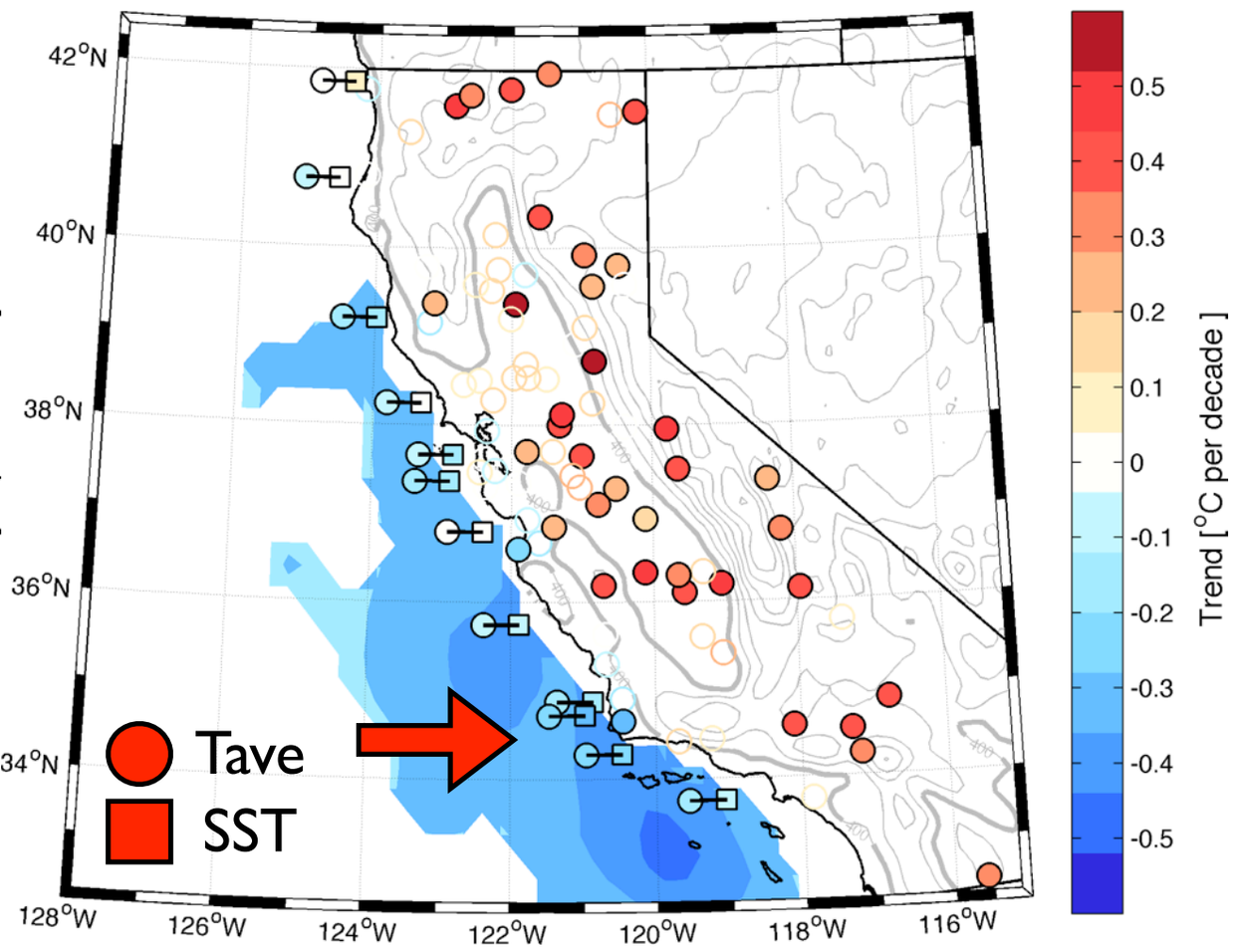
- West Coast SST has positive reg. coeffs. with PDO index.
- The SST trends inferred from PDO are comparable in the south and north,
  - PDO would not likely explain 70% greater trend in the south as in buoys.
- The topographic wind stress curl could be a factor for local trend pattern.

Upwelling trend and over-land daily mean air-temperatures (Tave)

JJA Tave Trend **1951-2010**

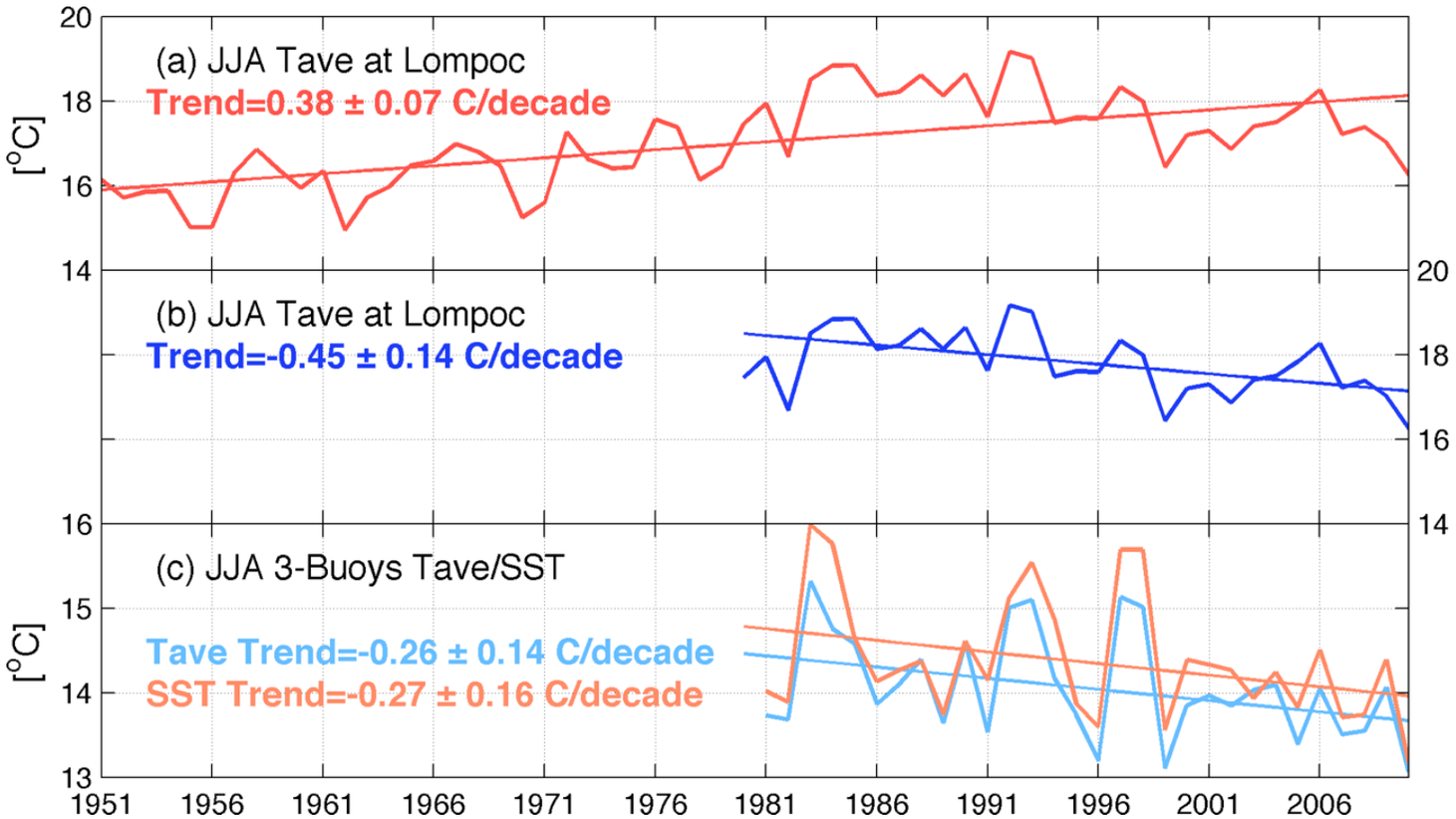


JJA Tave Trend **1980-2010**

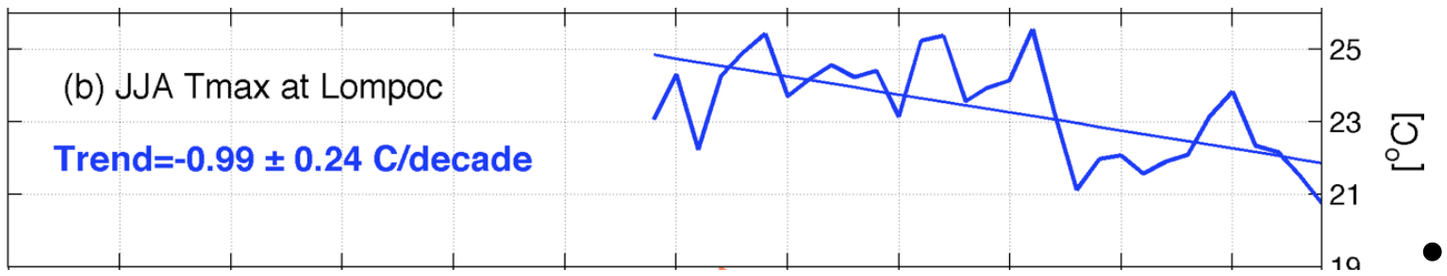


- Daily-mean air-temperatures have been rising significantly (p=0.1).
  - Greater inland warming trends in 1980-2010 than 1951-2010
- In 1980-2010, near-coast stations show weaker warming or even cooling trends, in agreement with cooling trend in air-temperatures over buoys.

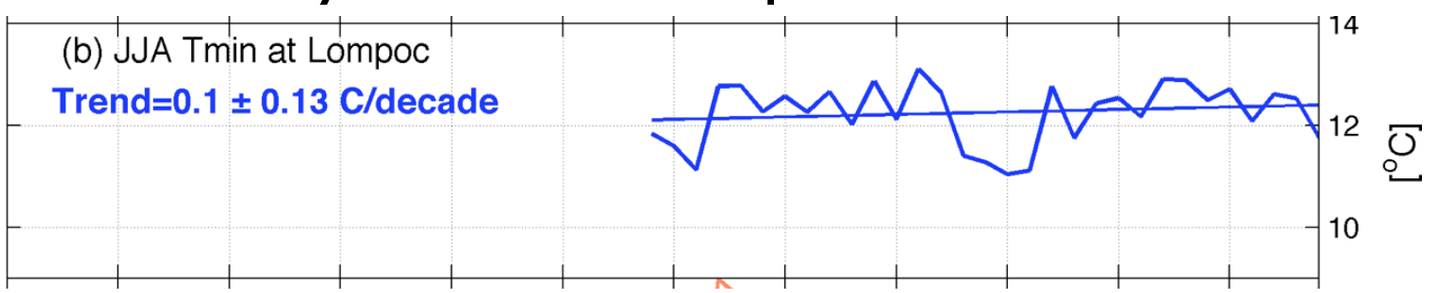
Daily averaged temperature: Tave



Daily maximum temperature: Tmax



Daily minimum temperature: Tmin



City of Lompoc

- Tave has a cooling trend of -0.5C/decade in 1980-2010.
- Coincident with the cooling in over-shelf air/water temperatures.
- Only Tmax shows substantial cooling trend of -1C/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