Session C6
Poster: M200A

Trends in coastal upwelling and sea breeze in the California-Oregon Coast: Land-ocean-atmosphere interactions

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1. Summary

Long-term buoy observations suggest that the summertime water temperatures off the US West Coast have been steadily declining since the 1980s, with the greater cooling trends in central-southern California than Oregon to northern California. While alongshore wind stress exhibits the trends of opposite spatial pattern, wind stress curls in the south have become increasingly cyclonic, implying a possible role of topographically-driven wind stress curls in the pattern of upwelling trend. With cooler coastal waters, the daytime near-coast land air-temperatures have been declining due to stronger sea breezes, in contrast to the continuous inland warming. A popular hypothesis posits that strengthened upwelling and sea breezes are associated with the anthropogenic climate change. Analyzed upwelling fields however exhibit large interannual to multi-decadal variabilities coherent with major modes of climate variability. To objectively attribute the observed variability and trends to these remote, local and anthropogenic causes, the process modeling studies are planned using a high-resolution regional air-sea coupled model over the US. West Coast. This is a critical step toward the robust projection of potential coastal climate responses to various climate change scenarios.

2. Data

- *NDBC buoys*: Hourly SST (0.6 m depth), wind (5 m height), 1980-Present.
- *Global Historical Climatology Network-Monthly* (GHCN-M) V3: Global air temperatures. 1951-Present.
- *NOAA Optimum Interpolation (OI) of SST* with incorporation of Advanced Very High Resolution Radiometer (AVHRR). Daily 25 km 1981-2010.
- *California Reanalysis Downscaling at 10 km (CaRD10)*: Dynamically downscaled 1-hourly analysis of the NCEP Reanalysis. 1948-2010.

3. Evidence of upwelling trends

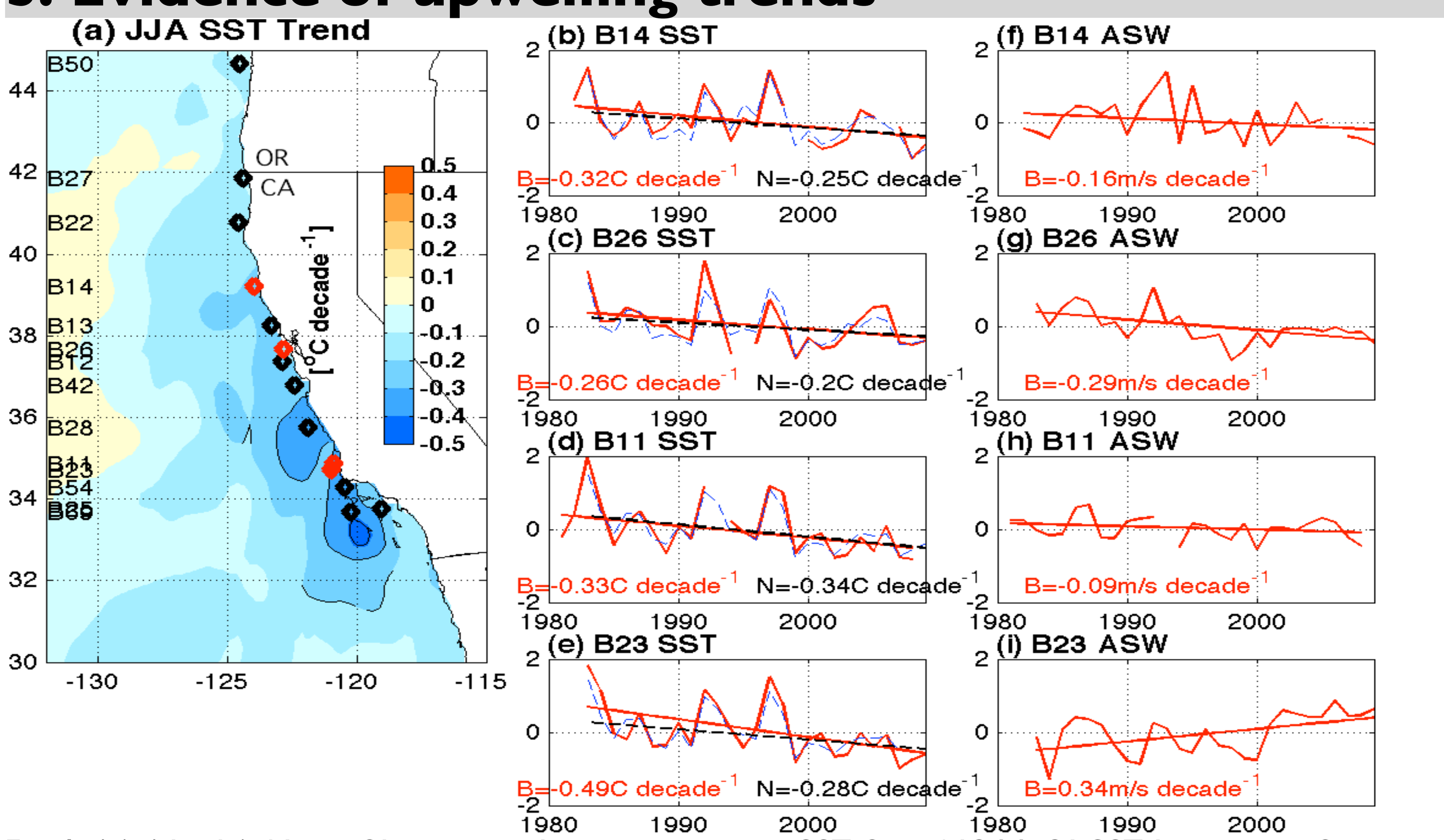


Fig. 1. (a) (shade) Map of linear trend in summer time SST from NOAA OI SST. Locations of individual NBDC buoys are marked as dots. The time-series of SST and alongshore wind (ASW) from the four red buoys are shown in (b-h) from 1981 to 2010

The coastal SSTs have been significantly cooling since the 1980s with the greater trends of -0.5 °C decade^{-1} in the south than -0.1 °C decade^{-1} in the north. The mean trend is -0.23°C decade^{-1} coast-wide. *What are the physical mechanisms for the observed upwelling trends?* SST anomalies in the north tend to be more positively correlated with the along-shore wind (ASW, southward negative) anomalies than those in the south (the last column in Table 1), suggesting that the observed negative SST trends in Oregon and northern California are consistent with the conventional description of coastal upwelling. Two other buoys in central and southern California exhibit larger cooling; however the corresponding ASW has weaker trends and is, in general, less correlated with SST. This indicates that other mechanism(s) may be at work in driving the stronger SST trends there. *What mechanisms are responsible for determining the spatial pattern of upwelling trends?*

	Buoys Numbers [NDBC 460##]	NOAA SST Trend	Buoy SST Trend	Buoy ASW Trend	r(SST,ASW)
OR & N. CA	50, 27, 22, 14, 13, 26, 42	-0.19	-0.16	-0.15	0.24
C. & S. CA	28, 11, 23, 54, 25, 69	-0.33	-0.31	-0.08	0.02

Table 1. Trends in JJA SST [°C decade^{-1}] and ASW (negative equatorward, [m s^{-1} decade^{-1}]) over Oregon-northern California and central-southern California. The correlation coefficient (r) between the de-trended buoy SST and ASW is shown in the last column.

4. Trends in wind and wind stress curls

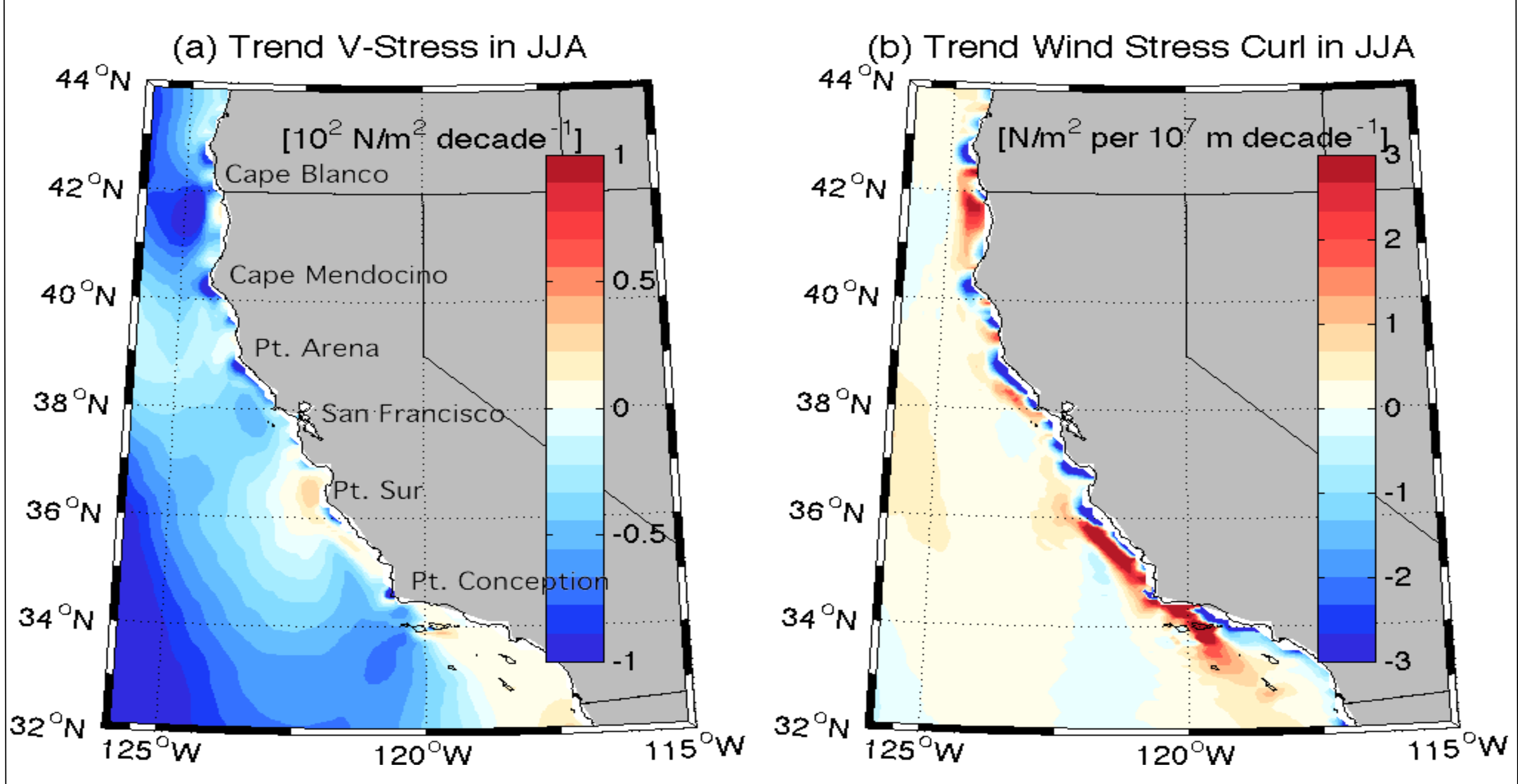


Fig. 2 (a) JJA-mean meridional wind stress (10-2 N m^{-2}, contour) and its trends (10-2 N m^{-2} decade^{-1} color) and (b) trends in wind stress curl [N m-2 per 104 km decade^{-1}] (1980-2008).

An analysis of wind stress and curl using the CaRD10 suggests *a possible role of coastal topography in trends of wind and upwelling.* The well-known summer hydraulic flow features (Dorman 1985) associated with an upwind compression bulge and a downwind expansion fan off the main capes (contours in Fig. 2a,) are clearly visible in the map of trends in ASW (shading in Fig. 2a). The trends in wind stress curls tend to be greater and more cyclonic in the central and southern California compared to the northern regions (Fig. 2b). *What are the the dynamical process behind such a pattern in wind stress and curls, and their impact relative to other upwelling drivers?*

5. Role of upwelling on coastal land temperature

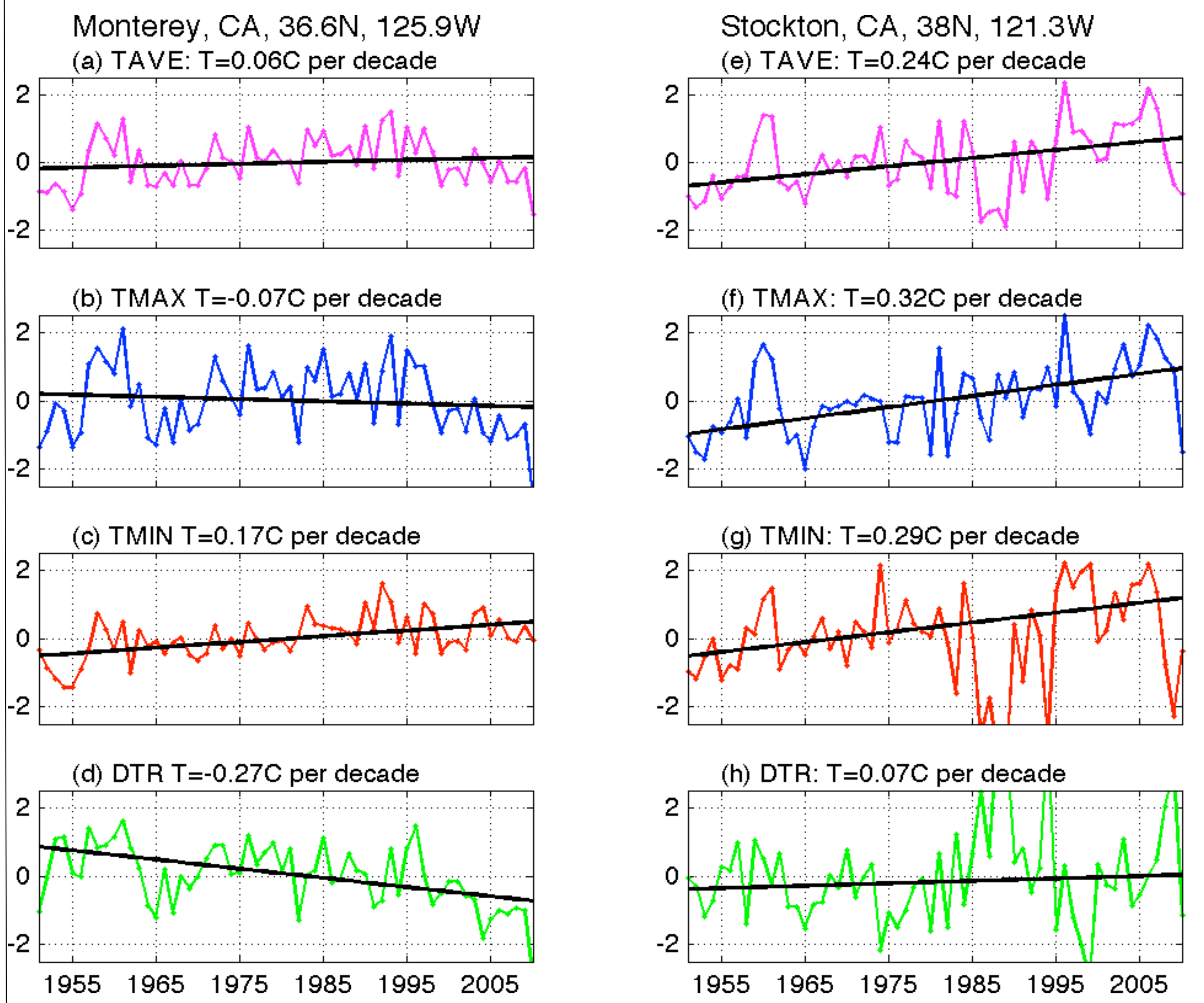
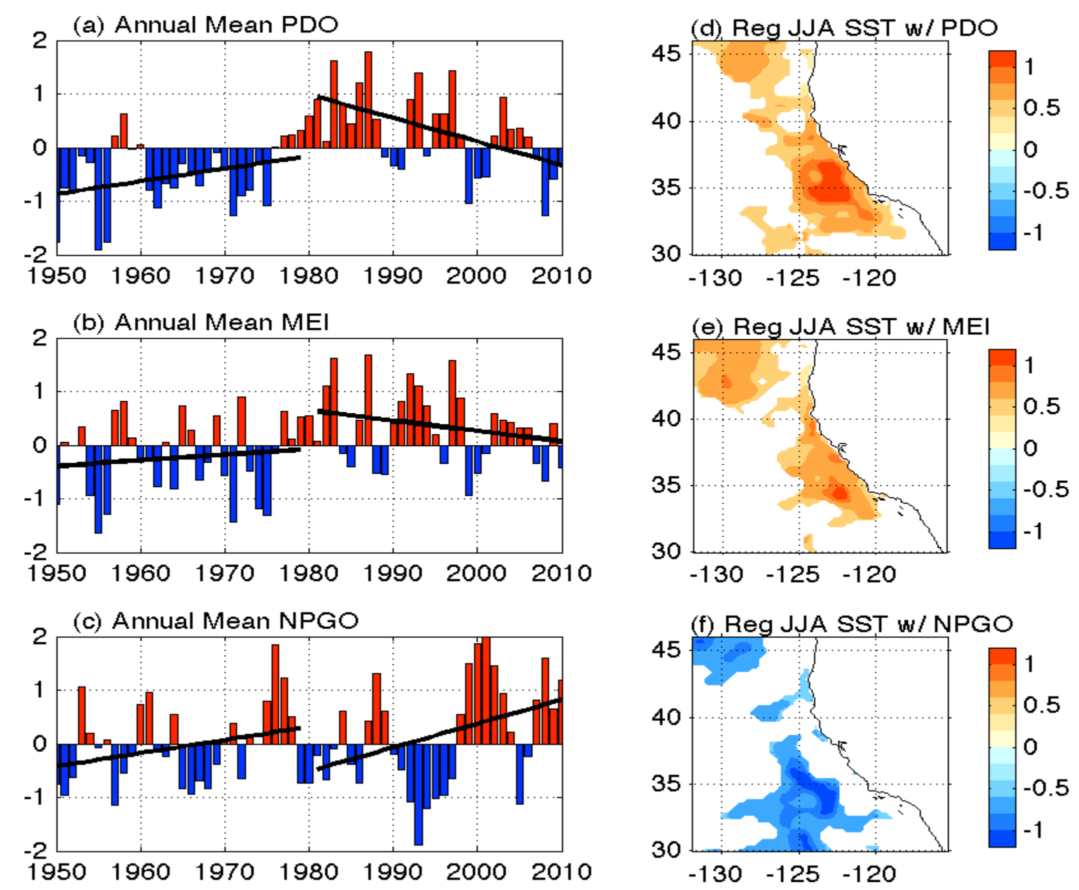


Fig. 3 JJA Tair in (left) Monterey, CA (385 ft.), and (right) Stockton, CA (12 ft.). (a,e) Tave (b,f) Tmax, (c,g) Tmin, and (d,h) DTR. These two stations are about 500 km apart.

Fig. 3 shows the time-series and trends of the JJA air temperatures since 1951 measured in (left) Monterey, CA, representing the open coast stations, and in (right) Stockton, CA for the California Central Valley stations. Both coastal and inland stations show increasing Tave trends (Fig. 3 a,e), with a greater trend in Stockton (0.24 °C decade^{-1}) than Monterey (0.06 °C decade^{-1}). Note that *Tmax has decreased in Monterey (Fig. 7b), in contrast to Stockton (Fig. 3f), likely due to the intrusion of marine air via day-time sea breezes* (Lebassi et al., 2009). Tmin in Monterey has increased (Fig. 3c), leading to a reduced diurnal temperature range (Fig. 3d). At inland stations outside of the marine air, such as Stockton, Tmax and Tave have both increased, consistent with anthropogenic global warming.

6. Role of large-scale modes of climate variabilities



Shifts in natural climate variability strongly influence the local surface forcings, oceanic stratification, and SST. Fig. 4 shows time-series of Pacific Decadal Oscillations (PDO) and Multivariate ENSO (MEI), and North Pacific Gyre Oscillations (NPGO) indices and the associated SST pattern estimated. PDO was in a negative phase from the 1950 to mid 1970s with a positive trend, which then sharply switched in 1975 to the positive phase with a negative trend. A negative (positive) trends in PDO/ENSO (NPGO) is consistent with the coast-wide cooling since 1980. Therefore, *the observed coast-wide cooling trends can be seen as a part of the basin-wide climate variabilities.*

Fig. 4 (a) Annual mean (a) PDO and (c) Multivariate ENSO index with trends (solid) in two periods (1950-1979 and 1981-2010). JJA SST (°C) regressed (p=0.01) onto the (b) PDO and (d) MEI (1950-2010).

7. Projection of coastal climate in coupled climate models

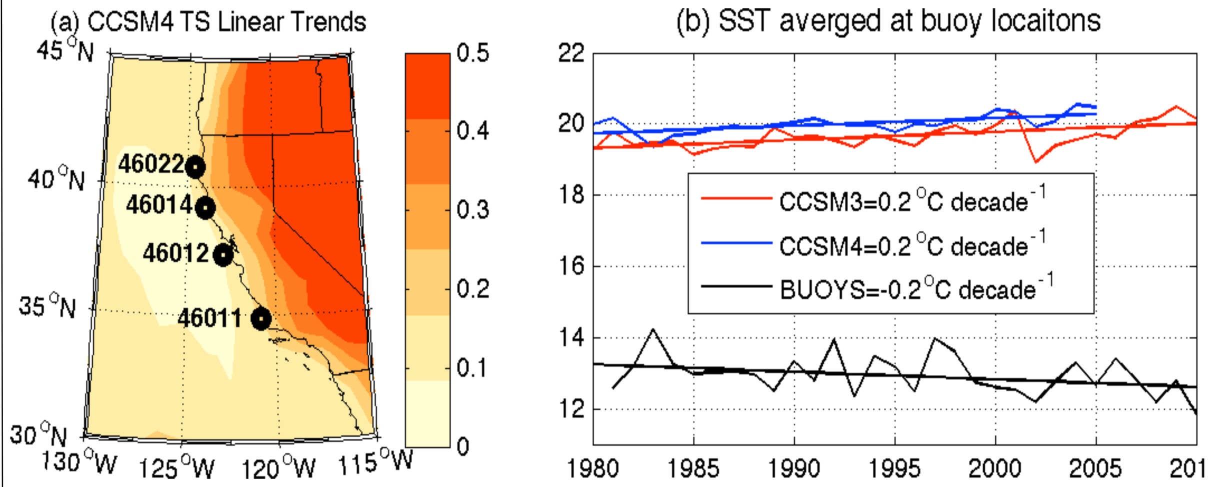
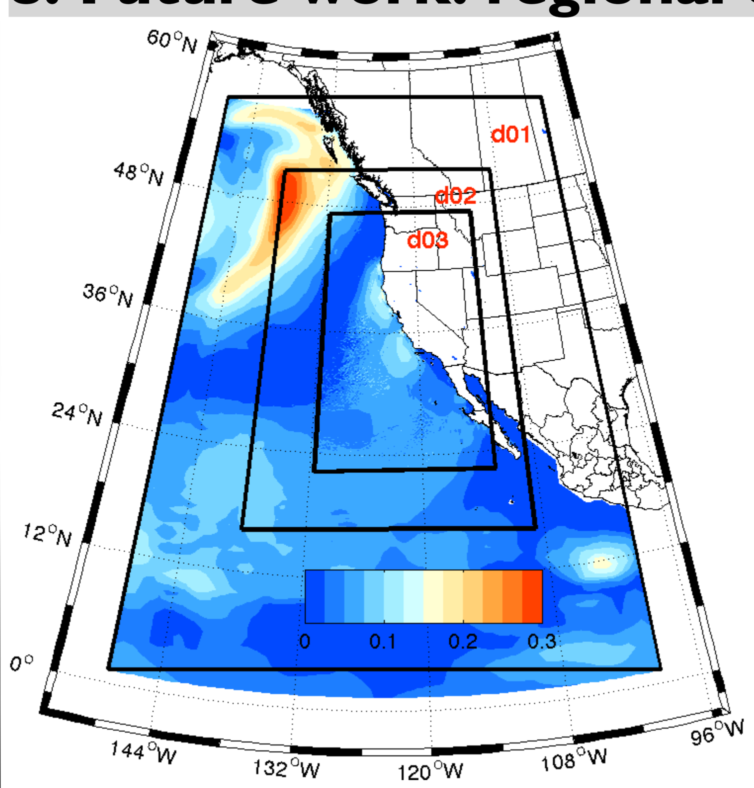


Fig. 5 (a) JJA-trend of the 6-member ensemble mean surface temperatures [Ts, °C decade^{-1}] in CCSM4 (1980- 2005). (b) Ts time series from (blue) CCSM4, (red) CCSM3 (1980 – 2010), and (black) averaged at the 4 buoy locations.

AOGCMs, designed primarily to study global scale climate variability and change, are unable to capture the scales of the observed coastal processes. Fig. 5a shows the trends in surface temperatures from the NCAR CCSM3 and CCSM4 in comparison to the buoy data. There is no coast-wide cooling trend in CCSMs (Fig. 5a). Both versions of CCSM have an opposite warming trend of +0.2 °C decade^{-1}, in contrast to the buoy- measured cooling trends of -0.2 °C decade^{-1}. *The warm bias and opposite trend pattern in the coastal regions is a robust feature across all the AOGCMs*, and is evidently due to insufficient model resolution of oceanic and atmospheric processes and of their coupling.

8. Future work: regional coupled model



A regional bias in AOGCMs has been recognized as one of the key aspects of global climate models that could influence the large-scale climate by upscaling effect (e.g., Large and Danabasoglu 2006). The uncertainty associated with the AOGCM biases can be potentially reduced by *1) accurately representing the multiple forcing factors important for coastal climate* and 2) *robustly attributing coastal climate variability and change in terms of these forcings.* The full-physics SCOAR simulations (Fig. 6 is the proposed domain) are proposed to address these two issues.

Fig. 6 The example triple-nested domain from the WRF –ROMS based SCOAR model. The inner most domain covering the entire US West coast will have 5 km horizontal resolutions. Shading denotes the simulated wind stress (N m^{-2}) on June 5, 2002.

9. Reference and acknowledgement

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