**Arthur J. Miller** Scripps Institution of Oceanography University of California, San Diego

Science Board Symposium Boundary Current Ecosystems PICES XV Annual Meeting Yokohama, Japan October 16, 2006

Collaborators:

Hey-Jin Kim, Guillermo Auad, Hyodae Seo (SIO) Emanuele Di Lorenzo (GaTech)

**Unifying Scientific Motivation:** 

How do long-term changes in surface forcing (surface heat fluxes, wind stresses) alter the upwelling cells and consequent upward nutrient fluxes?

#### **Outline**

Observed changes in CalCOFI (Kim and Miller, JPO, in press)

 thermocline depth and T-NO3 relation
 Modeled changes (Di Lorenzo et al., JPO, 2005; Kim et al., in prep)
 stronger winds and surface warming
 eddy statistics

 Predicted changes under greenhouse warming (Auad et al., JGR, 2006)
 downscaled climate model

Funding: NSF, NASA, NOAA, DOE, ONR

#### **Outline**

Observed changes in CalCOFI (Kim and Miller, JPO, in press)

 thermocline depth and T-NO3 relation
 Modeled changes (Di Lorenzo et al., JPO, 2005; Kim et al., in prep)
 stronger winds and surface warming

 eddy statistics

 Predicted changes under greenhouse warming (Auad et al., JGR, 2006)

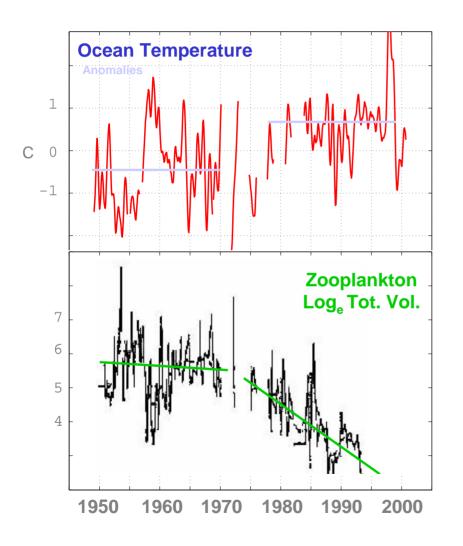
 downscaled climate model

 BONUS: Regional ocean-atmosphere coupling (Seo et al., in press)

 eddy statistics with feedbacks

Funding: NSF, NASA, NOAA, DOE, ONR

### CalCOFI Observations along the Southern California Coast



Over 50 yrs...

1 deg C warming of SST...

...70% decline in macro zooplankton

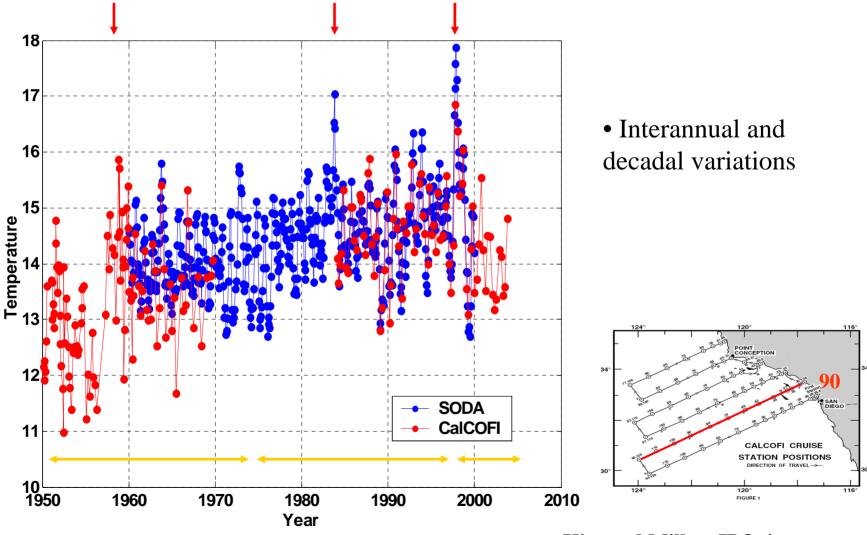
Roemmich and McGowan Science, 1995

### **CalCOFI** Analysis

- What stratification changes occurred in CalCOFI over these recent decades?
- Did changes also occur in the temperature-nitrate (T-NO3) relationship for upwelled waters?

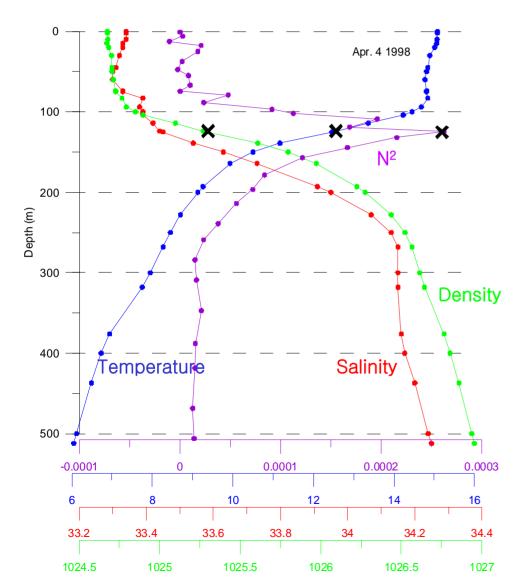
Kim and Miller, JPO, in press

### Upper ocean temperatures: CalCOFI & SODA



Kim and Miller, JPO, in press

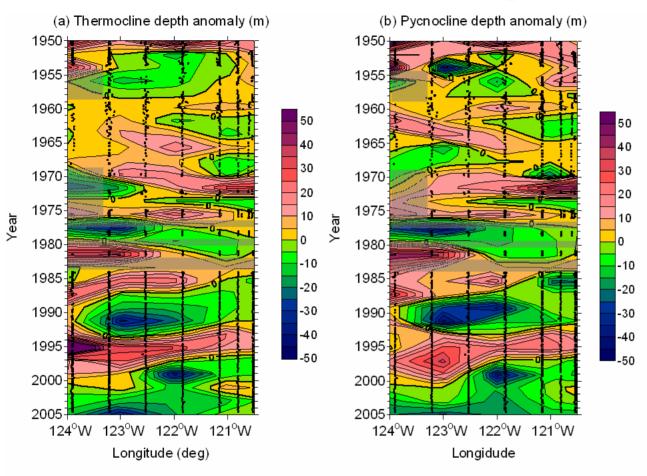
### **Detailed analysis of the CalCOFI thermocline**



- Data : CalCOFI 55 years in-situ observation
- Piece-wise cubic spline method to obtain 1 m vertical resolution
- **Thermocline (pycnocline)** : maximum vertical gradient of temperature (density)
- **Thermocline temperature** : temperature at the thermocline
- **Buoyancy frequency** : maximum buoyancy frequency
- "before & after" : 1977 climate regime shift

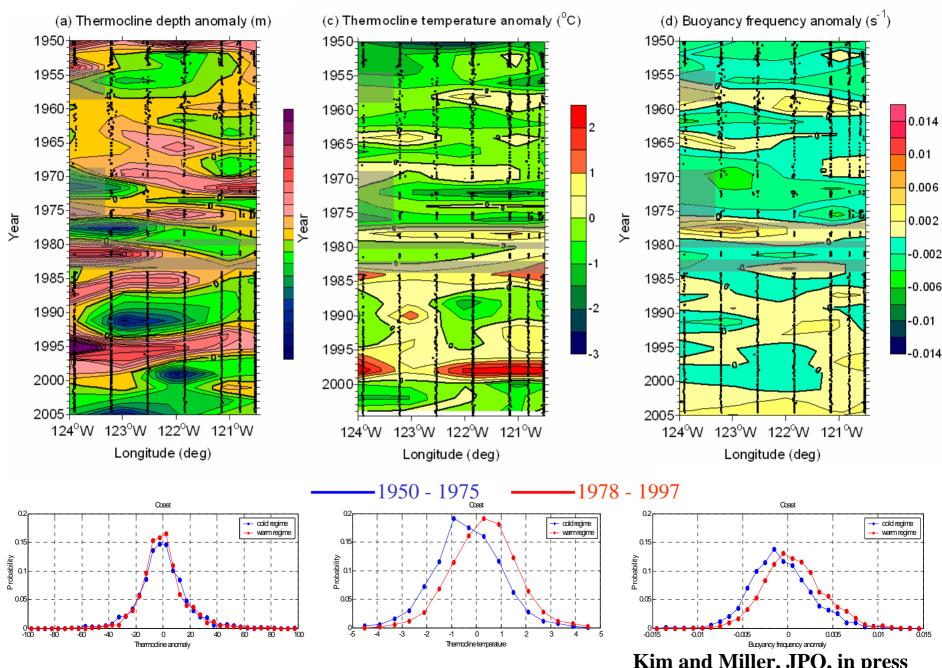
Hey-Jin Kim, 2006

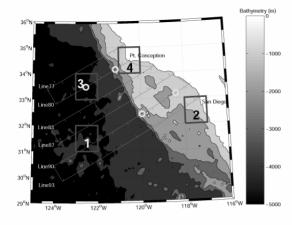
### **Thermocline : not deepened**



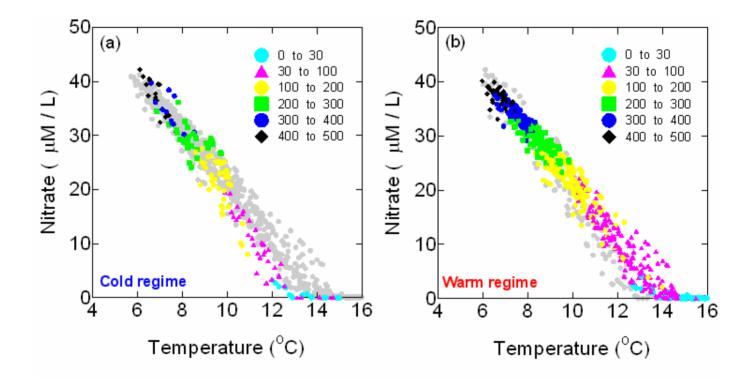
Kim and Miller, JPO, in press

### **Thermocline : not deepened but warmed**



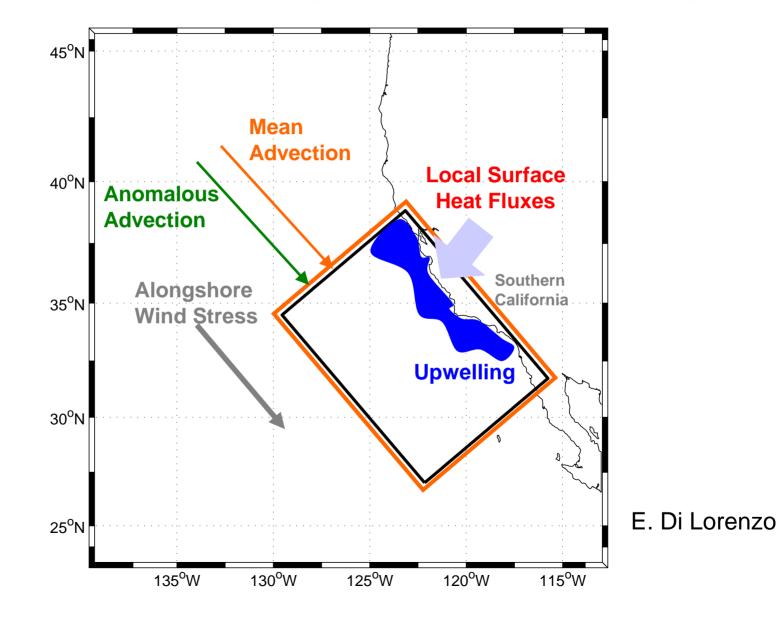


**Temperature vs. NO3 changes:** After 76-77, *Mid-depth waters* (30m-200m) have *higher NO3* for a given temperature due to the surface heating

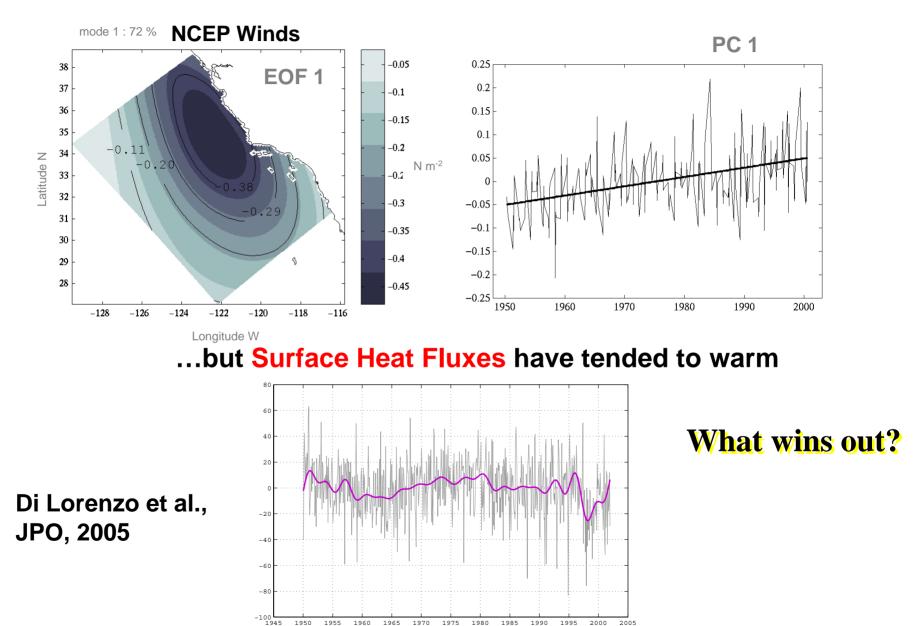


Kim and Miller, JPO, in press

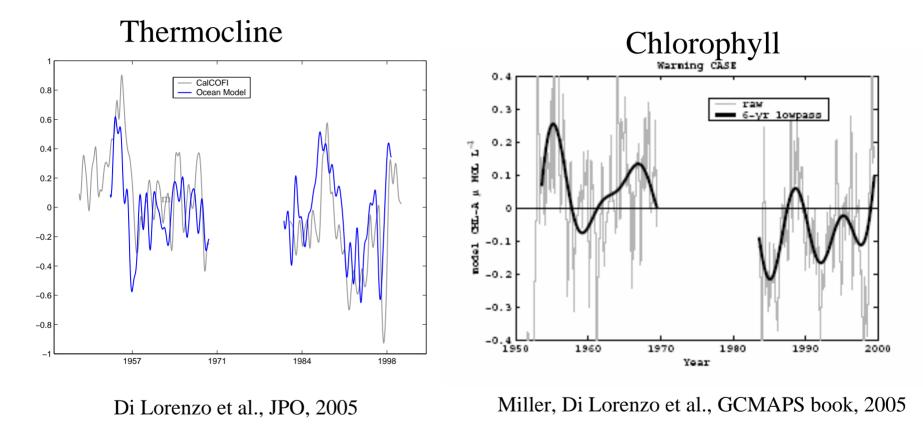
### Local Atmospheric and Remote Oceanic Forcings That Can Affect the Regional Oceanic Heat Budget



#### **Upwelling favorable winds** have increased in the CCS.....



### An eddy-permitting ocean model hindcast reveals that the surface warming beats the wind stress increase: Upwelling is reduced



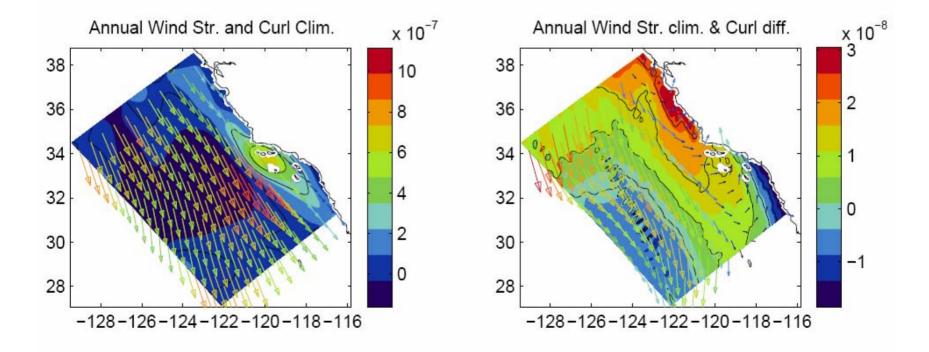
...but this result depends on the details of the forcing changes...

## California Current Circulation in a Downscaled Global Warming Scenario

Auad, Miller, Di Lorenzo, JGR, 2006

**Baseline**: NCEP 50-yr climatology of wind stress and curl

Perturbation: ACPI PCM 2040-2050 climate minus 1986-1996 climate downscaled with RSM

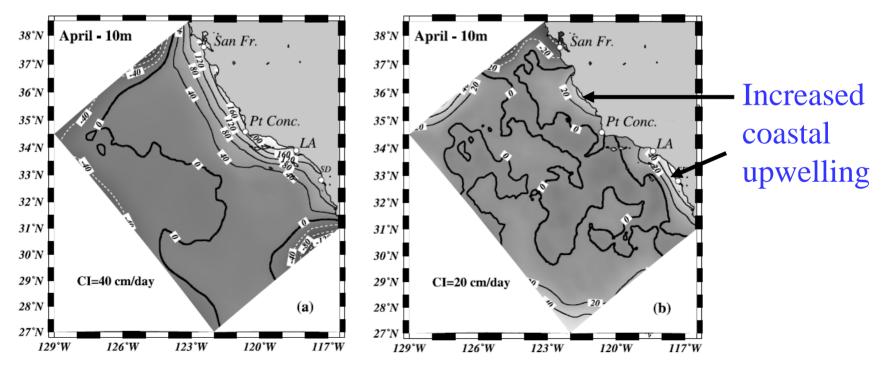


## Regional Upwelling Increases in a Downscaled Global Warming Scenario An eddy-permitting ocean model hindcast reveals that the wind stress increases beat the surface warming

Upwelling is increased

**Baseline**: April mean upwelling from present climate conditions

**Perturbation**: Forced by 2040-50 winds, surface heat fluxes, and BC changes: SST warmed 0.4 - 0.7 deg C



Auad, Miller, Di Lorenzo, JGR, 2006

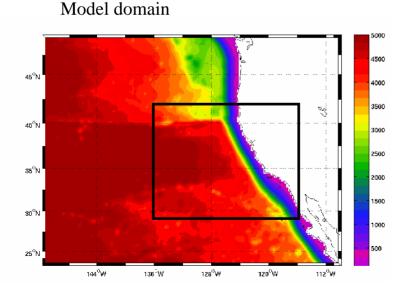
### **Mesoscale Eddy Statistics in the CCS**

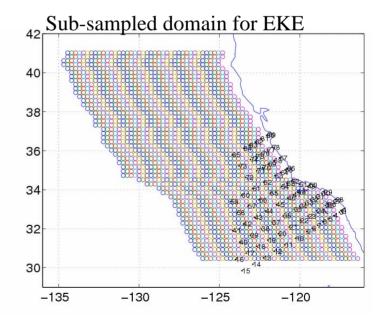
Hey-Jin Kim, Miller and Di Lorenzo, in prep

Di Lorenzo et al. (2005), JPO showed that eddy kinetic energy (EKE) of surface currents increased after the 1976-77 shift

Were there changes in preferred eddy wavelengths?

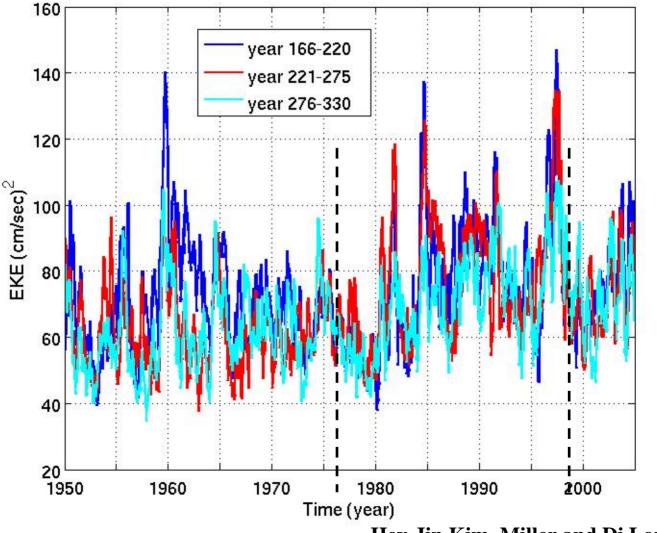
**Consider an ensemble of 3 EPac 50-yr hindcasts (Di Lorenzo)** 





### **Mesoscale Eddy Statistics in the CCS**

Eddy kinetic energy averaged over the region for each of 3 hindcasts

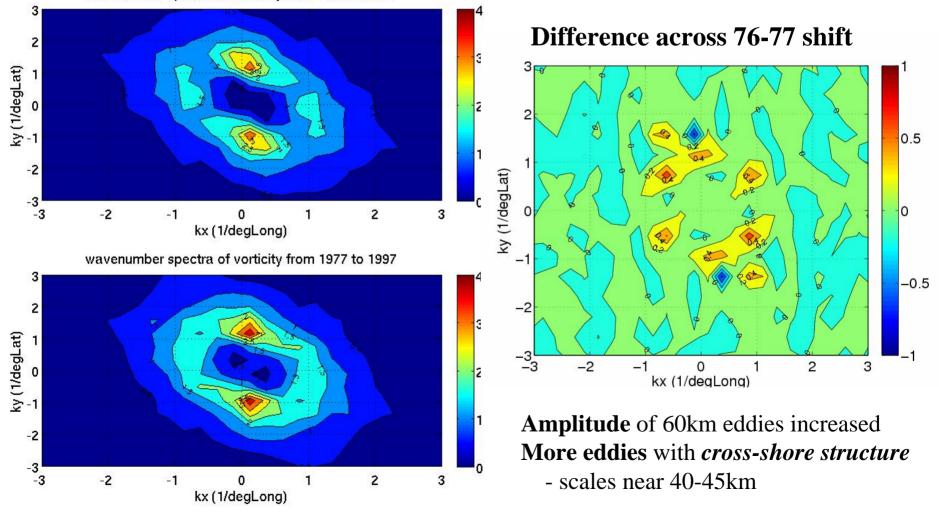


Hey-Jin Kim, Miller and Di Lorenzo, in prep

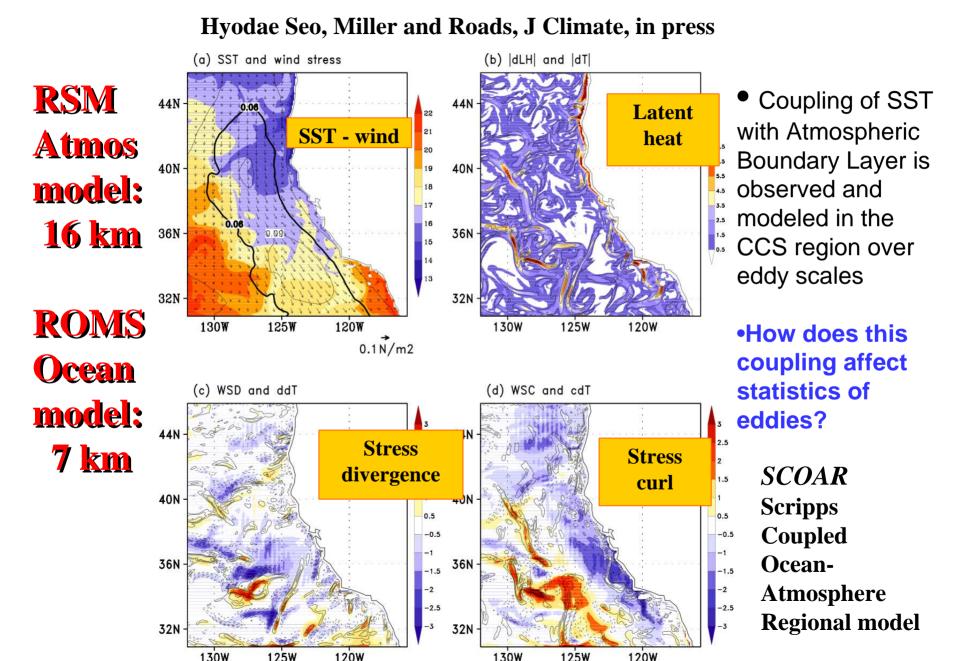
### **Mesoscale Eddy Statistics in the CCS**

### Wavenumber spectra averaged over the region and 3 hindcasts Hey-Jin Kim, Miller and Di Lorenzo, in prep

wavenumber spectra of vorticity from 1950 to 1975

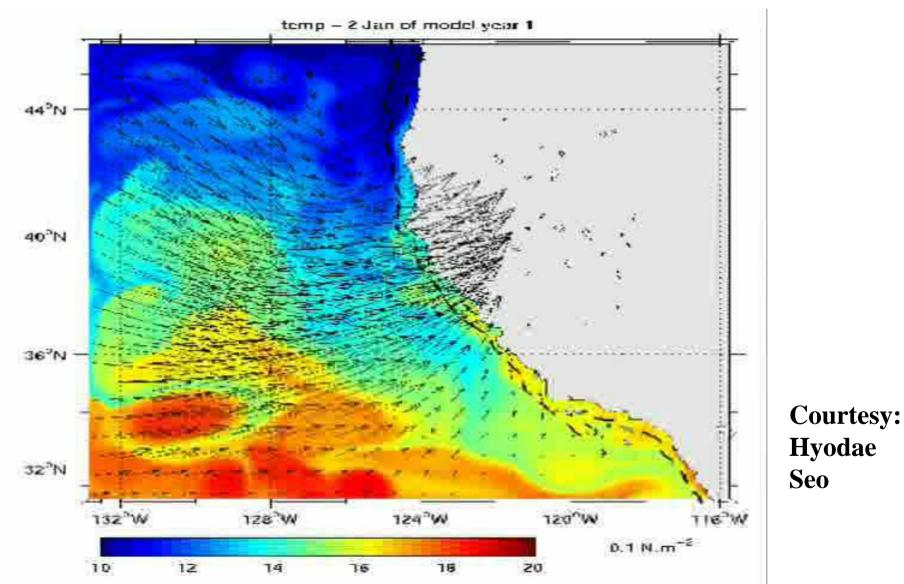


### **BONUS: Air-Sea Coupling in the CCS**



# **SCOAR Model Simulation of Coupled Eddies**

SST and Wind Stress: Ocean frontal feedbacks on local winds and low-level clouds



How does perturbed surface forcing affect CCS upwelling?

eddy statistics with feedbacks

Funding: NSF, NASA, NOAA, DOE, ONR

Science Board Symposium Boundary Current Ecosystems PICES XV Annual Meeting

Thanks!