Coupled Ocean-Atmosphere Modeling of the California Current System in Collaboration with UCLA and NRL

Dudley B. Chelton

with input from Jim McWilliams, X. Jin, Alex Hall, Francios Colas, and co-workers at UCLA and Tracy Haack and Jim Doyle at NRL/Monterey

Overview:

1) Global satellite observations of ocean-atmosphere coupling on scales of 100-1000 km

2) Observations and <u>1-way coupled modeling</u> of ocean-atmosphere interaction in the California Current System

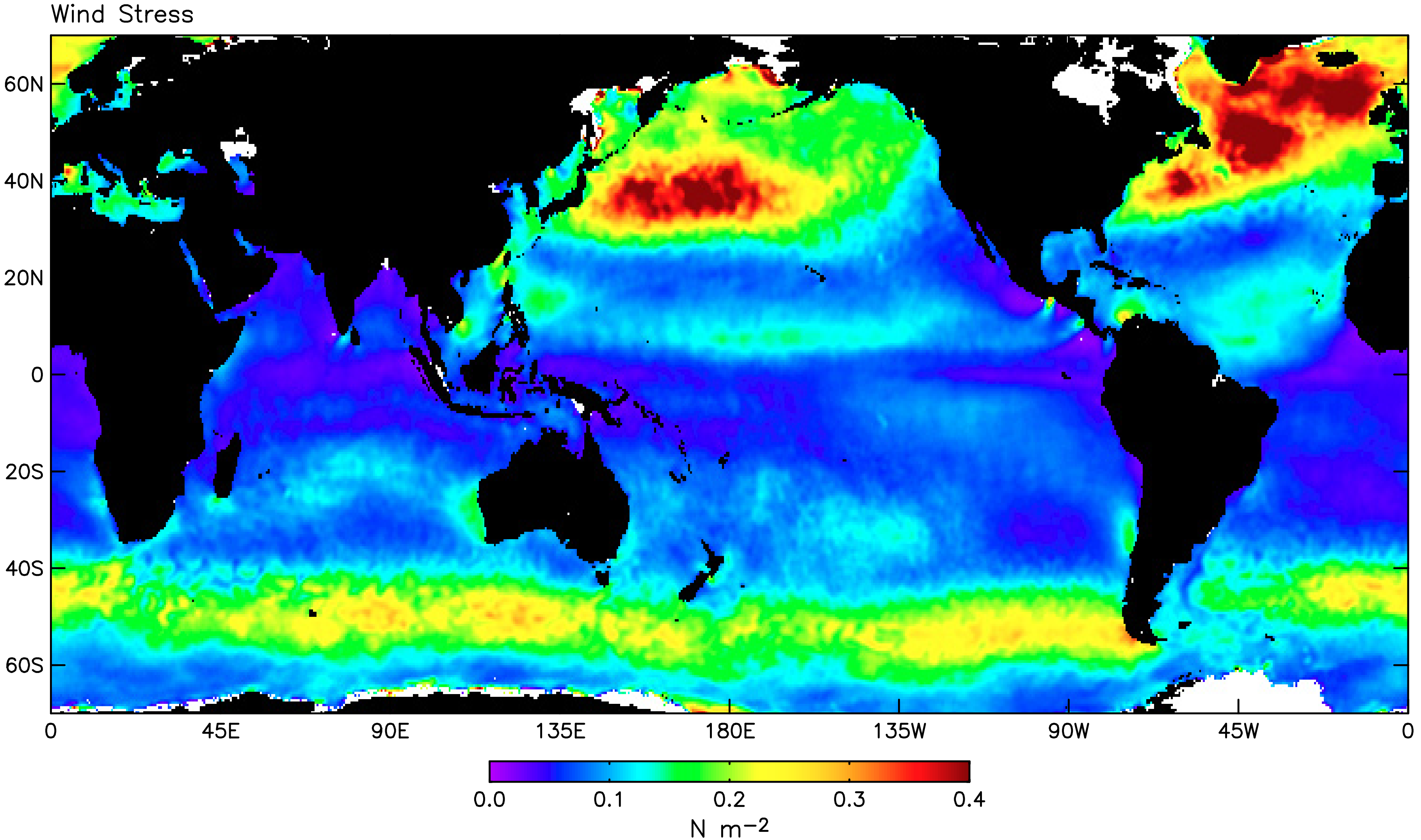
3) Toward <u>2-way coupled modeling</u> of the California Current System

4) Sensitivity studies with a “25-cent” empirical coupled model

1) Global Satellite Observations of Air-Sea Interaction on Scales of 100-1000 km

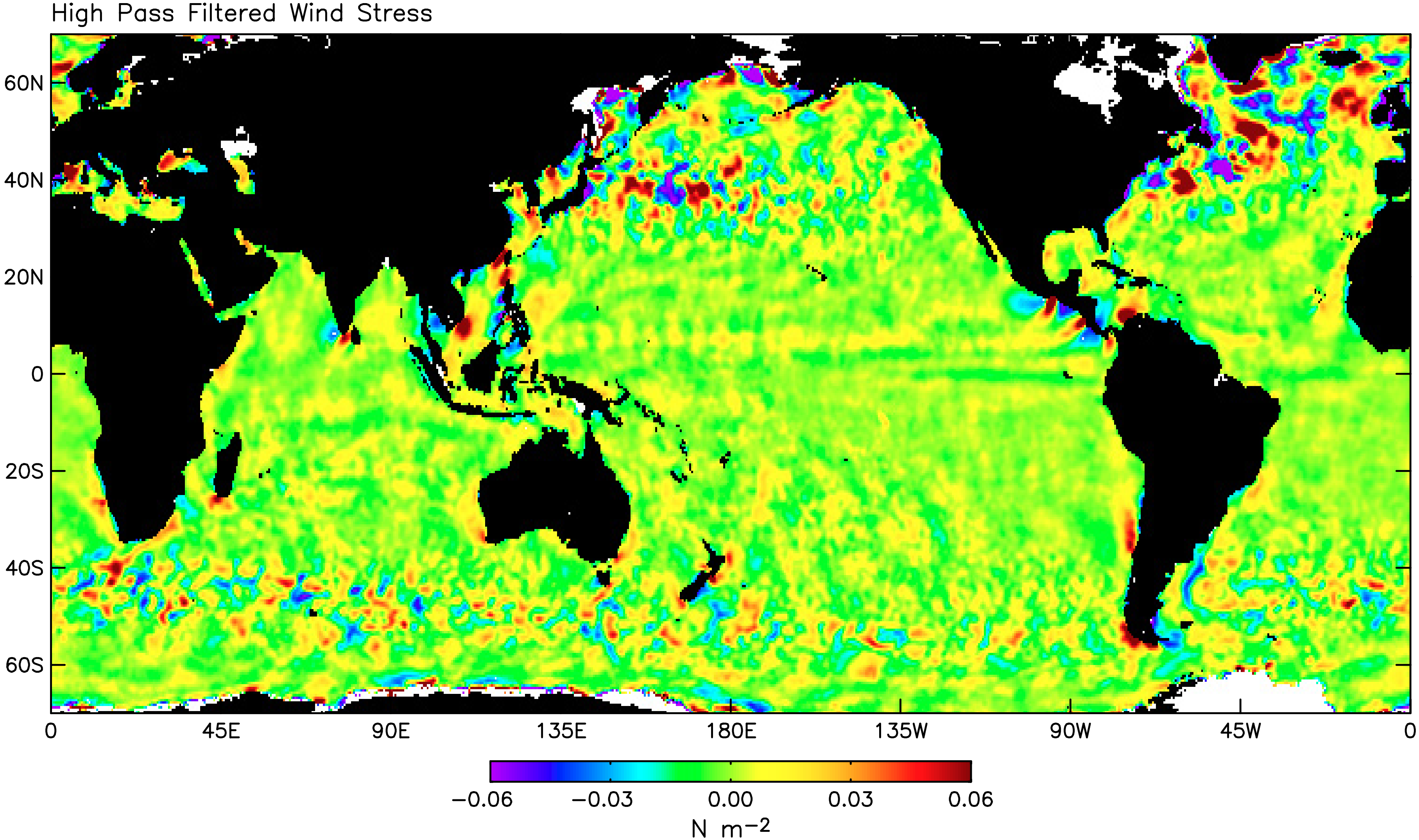
2-Month Average Wind Stress Magnitude

QuikSCAT, January–February 2003



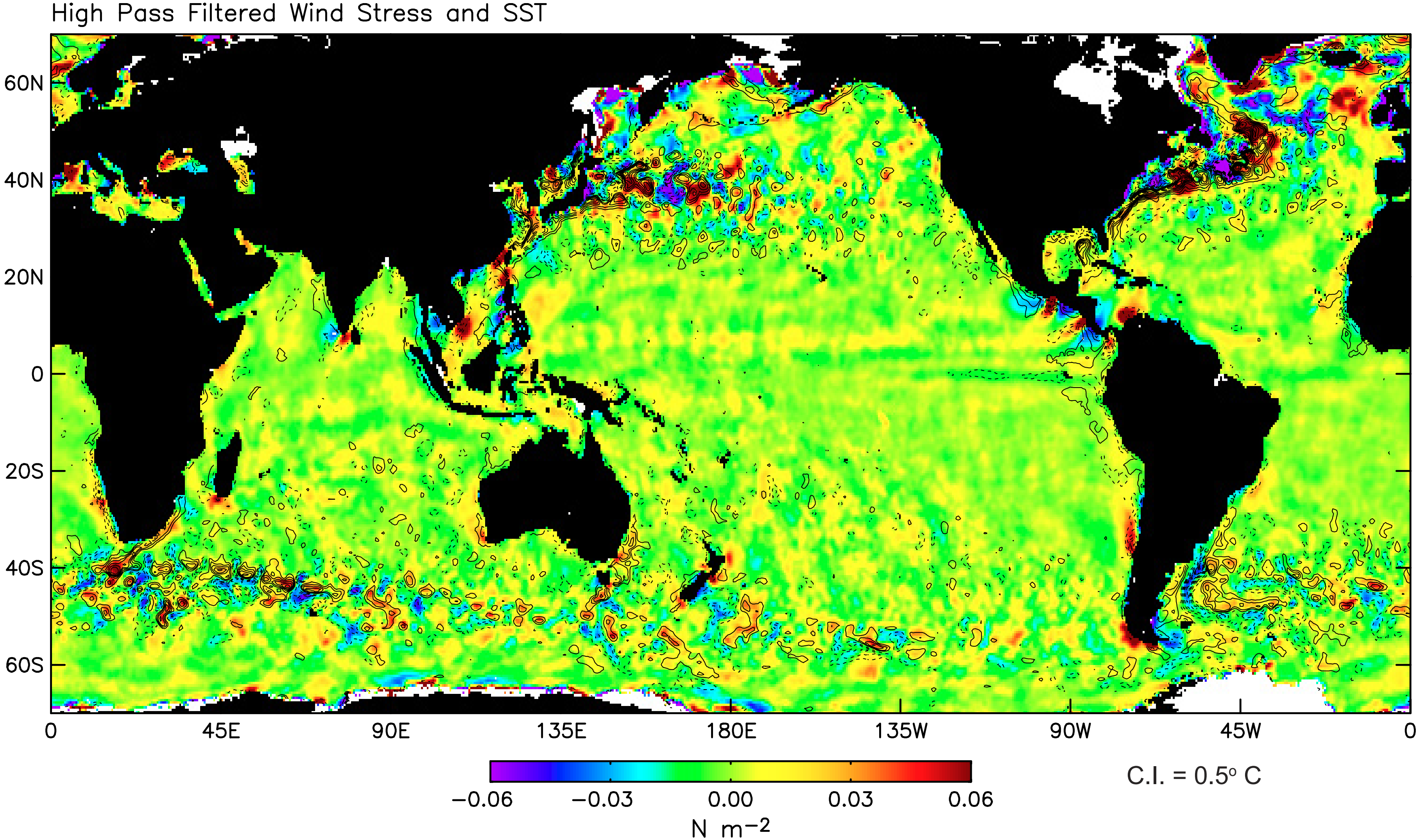
2-Month Average Wind Stress Magnitude
(Spatially High-Pass Filtered)

QuikSCAT, January–February 2003



2-Month Average Wind Stress Magnitude and SST
(Spatially High-Pass Filtered)

QuikSCAT, January—February 2003



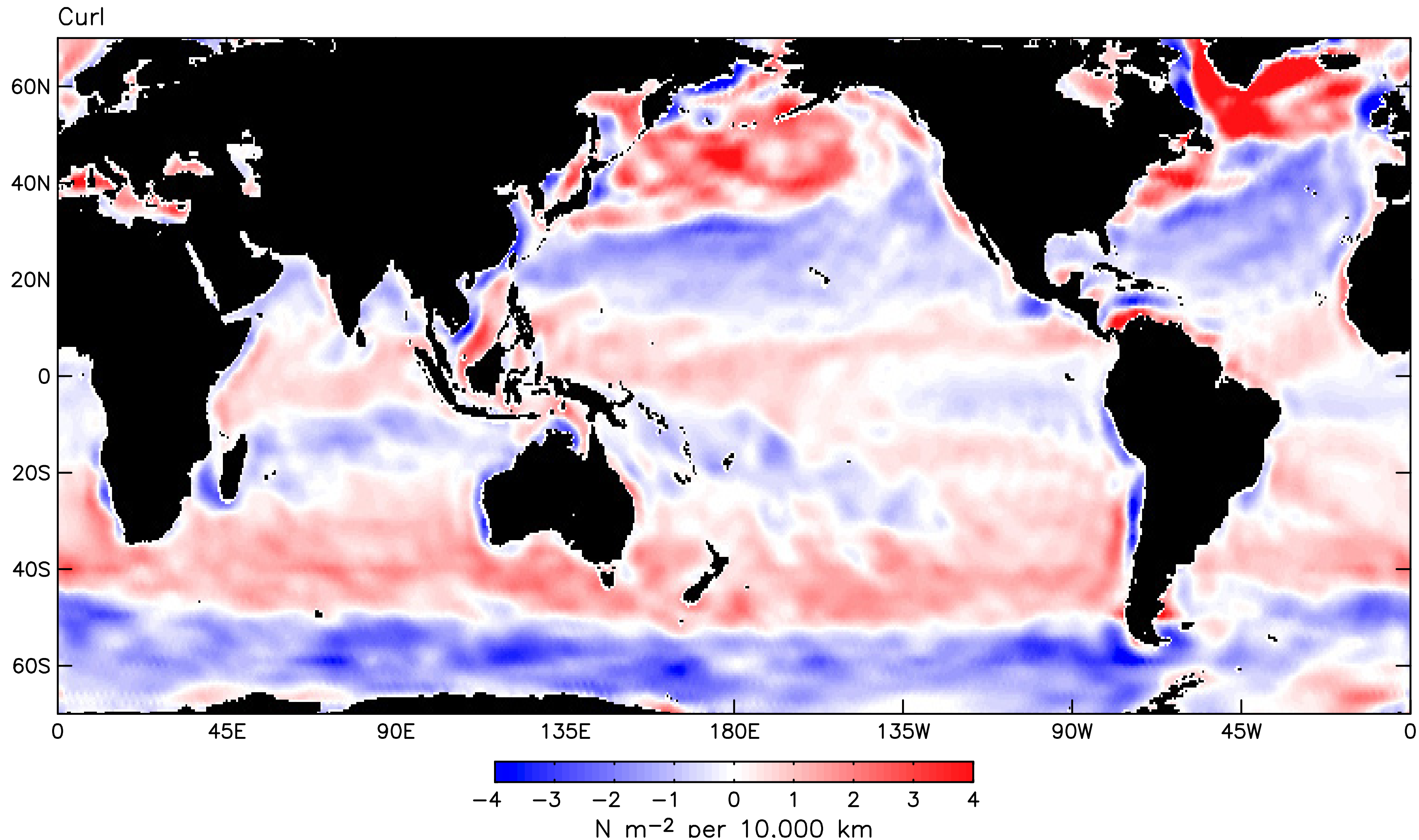
Implications for Ocean Dynamics

Are feedback effects of SST-induced perturbations of the wind stress field onto the ocean important to the ocean circulation?

In other words, is the air-sea coupling 1-way or 2-way?

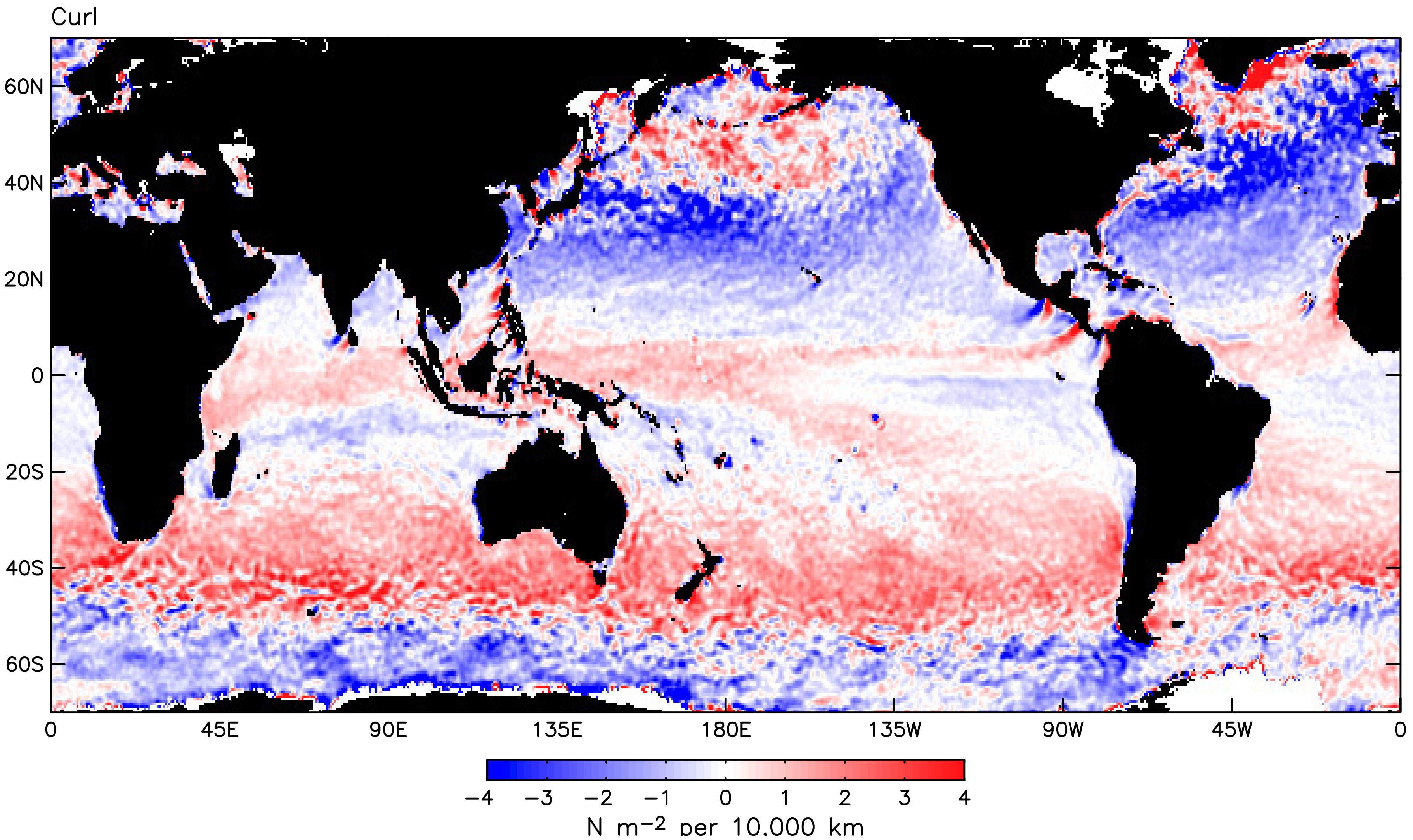
2-Month Average Wind Stress Curl

NCEP Reanalysis, January–February, 2003



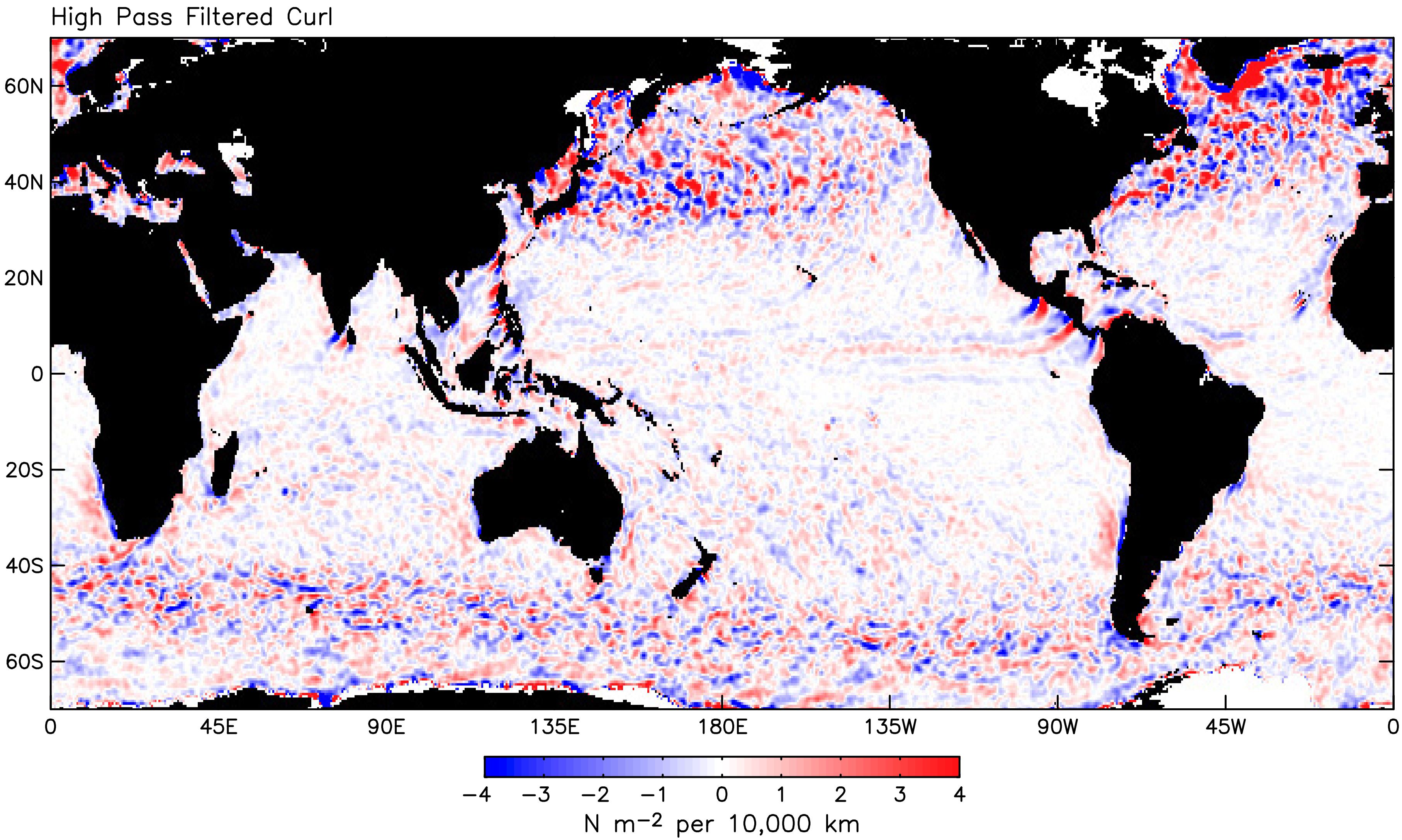
2-Month Average Wind Stress Curl

QuikSCAT, January–February, 2003



2-Month Average Wind Stress Curl
(Spatially High-Pass Filtered)

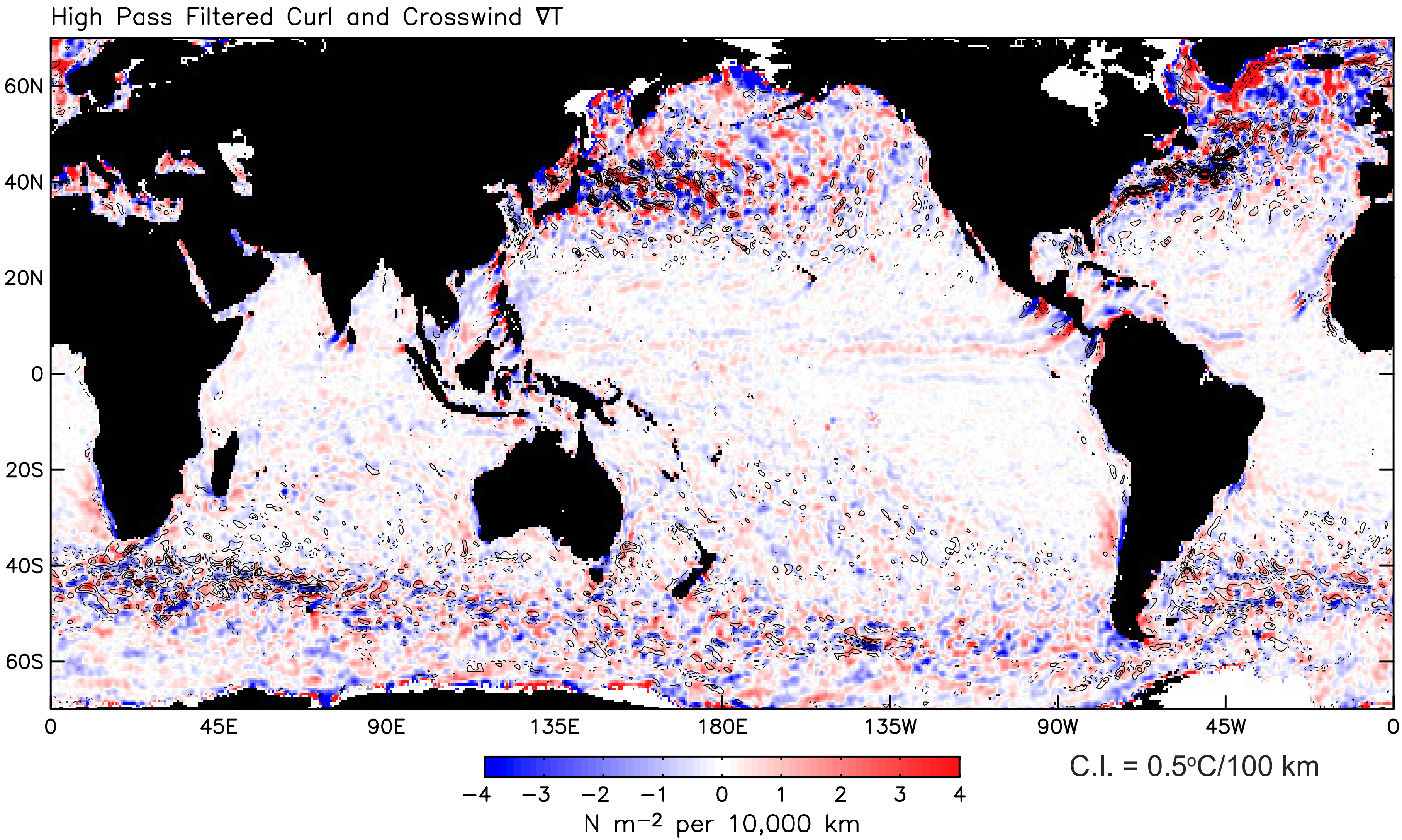
QuikSCAT, January–February 2003



2-Month Average Wind Stress Curl and Crosswind SST Gradient

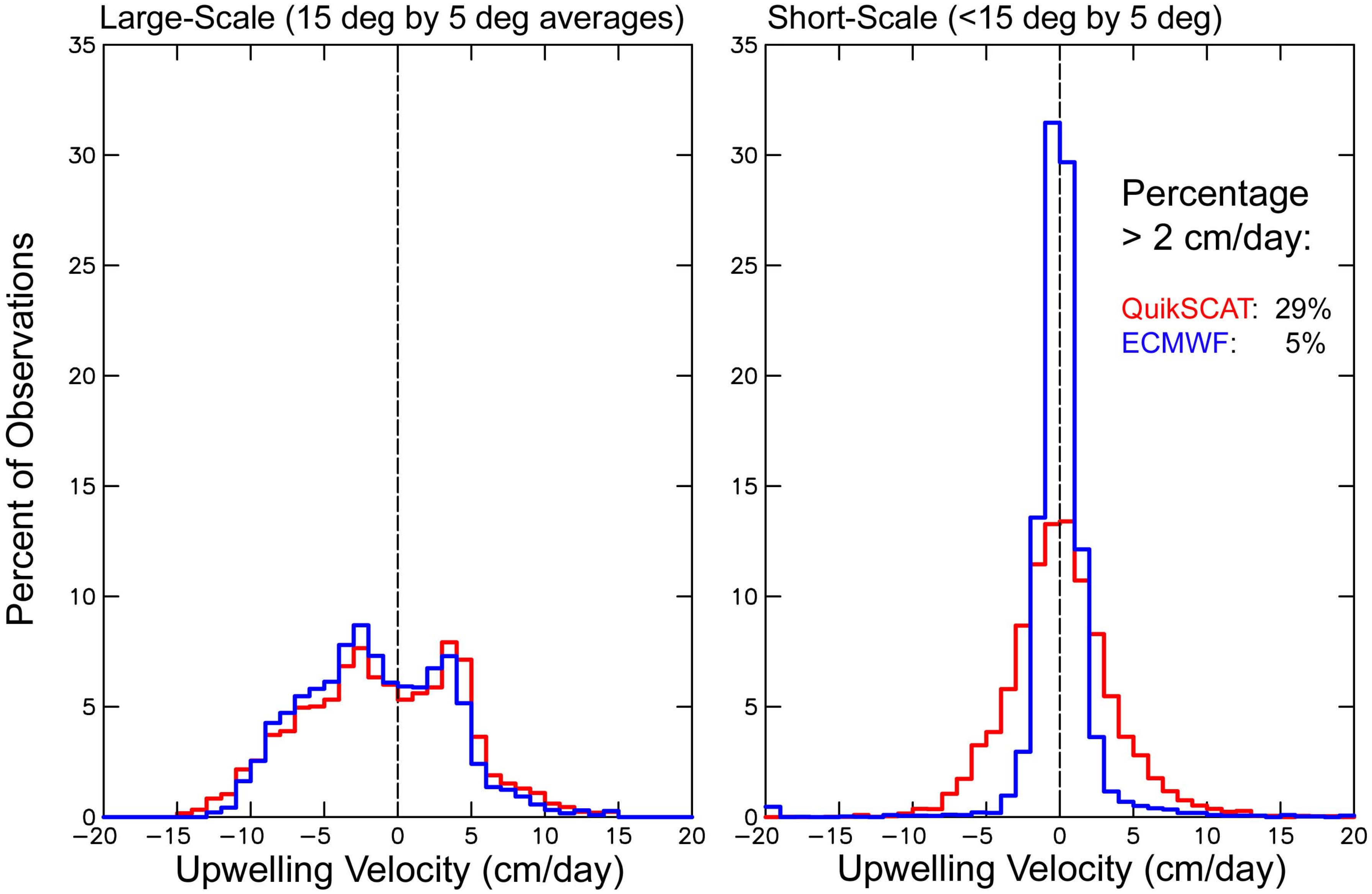
(Spatially High-Pass Filtered)

QuikSCAT, January–February 2003



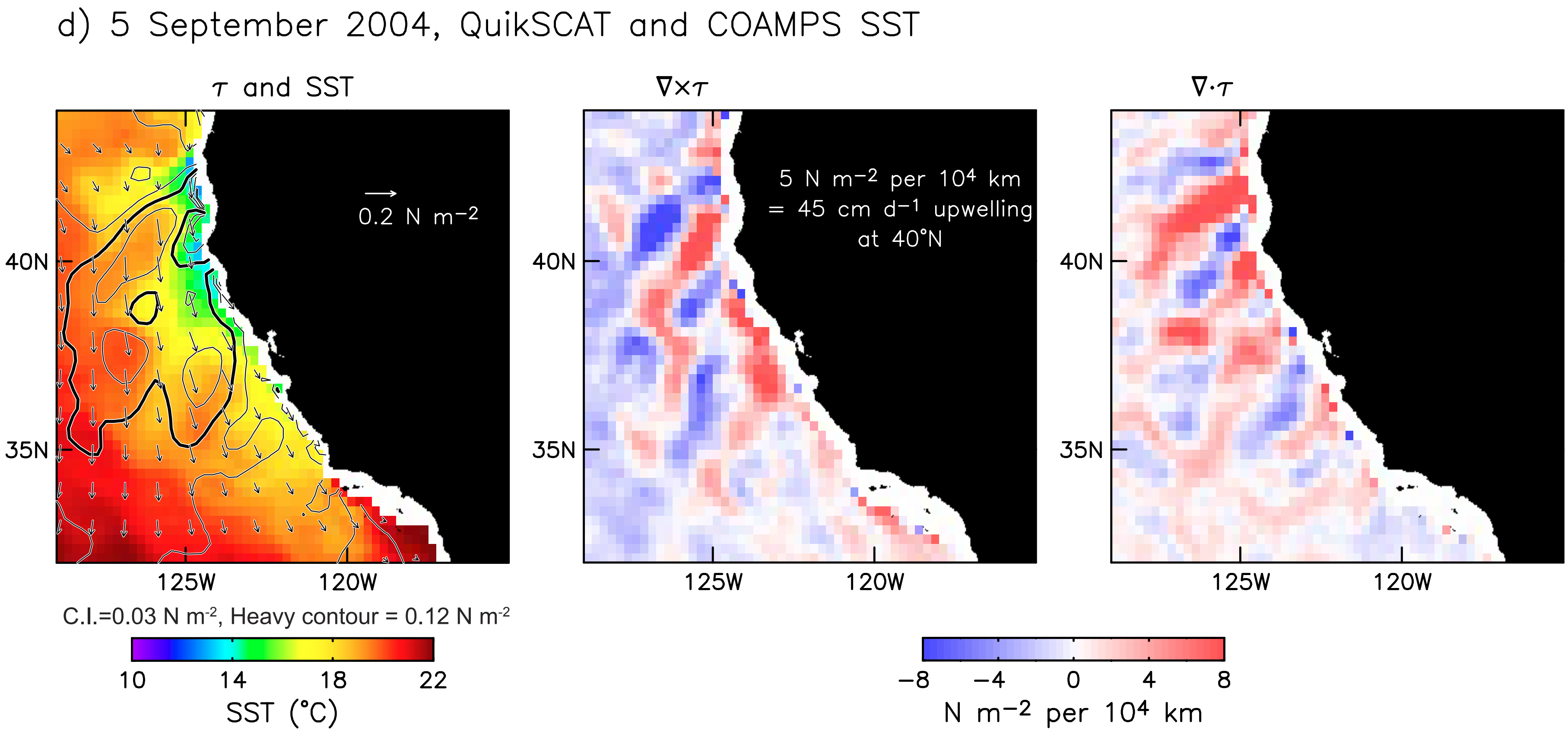
Ekman Upwelling Velocity from QuikSCAT and ECMWF

30°S–60°S, August 1999–July 2001

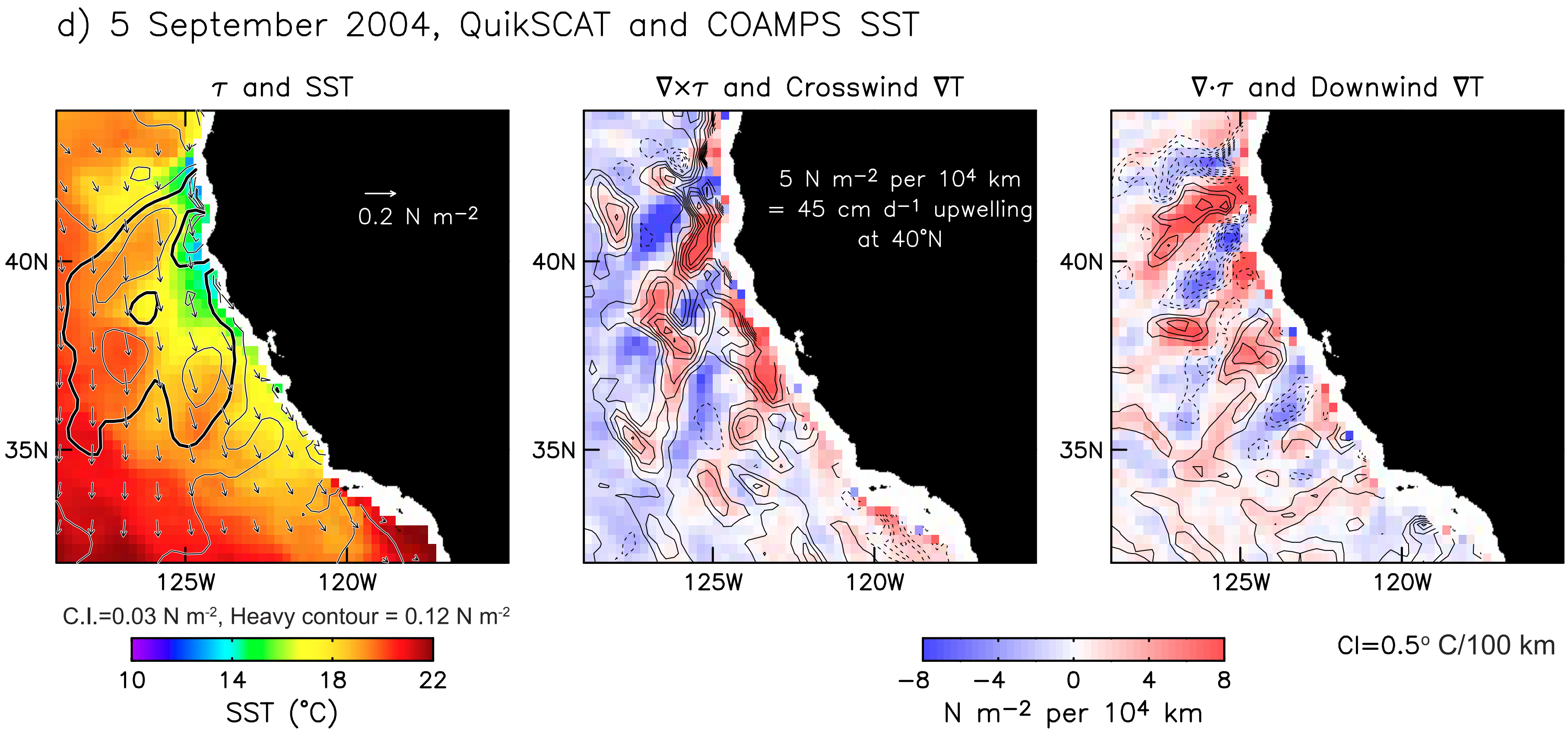


2) Observations and 1-Way Coupled Modeling of Ocean-Atmosphere Interaction in the California Current System

QuikSCAT 29-Day Average Centered on 5 September 2004

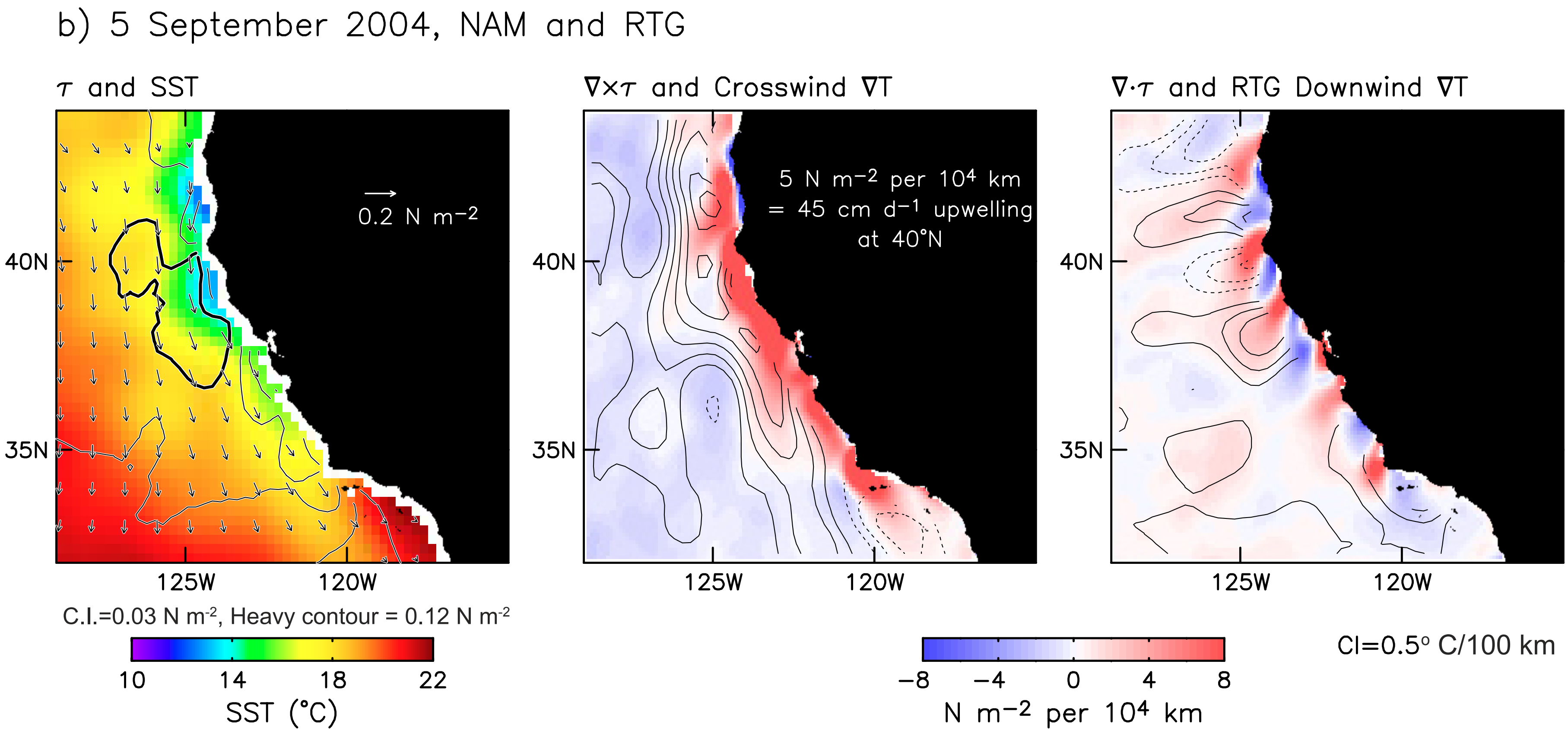


QuikSCAT 29-Day Average Centered on 5 September 2004



QuikSCAT resolution ~25 km (30-km gap near land)

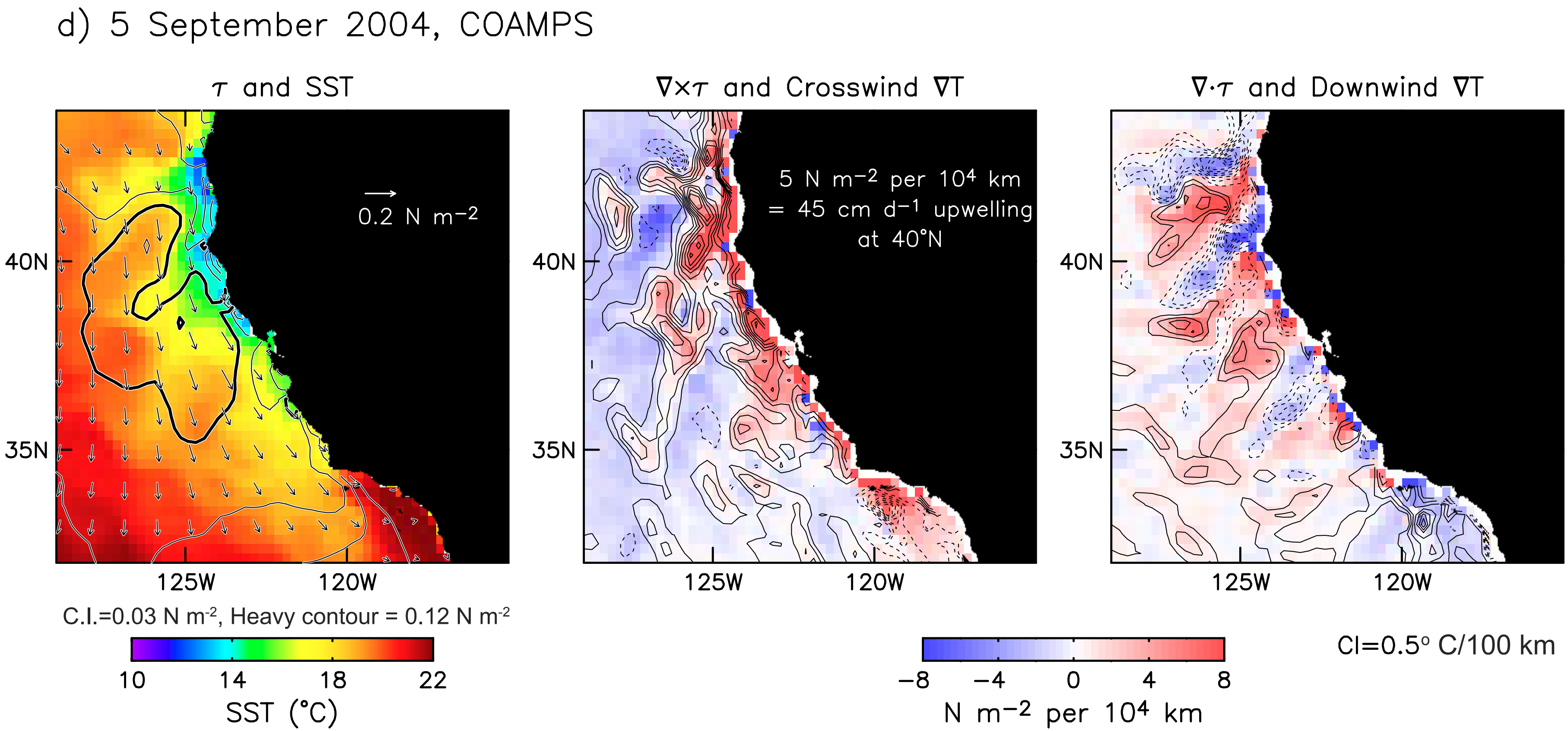
NAM/Eta 29-Day Average Centered on 5 September 2004



NAM/Eta grid resolution = 12 km

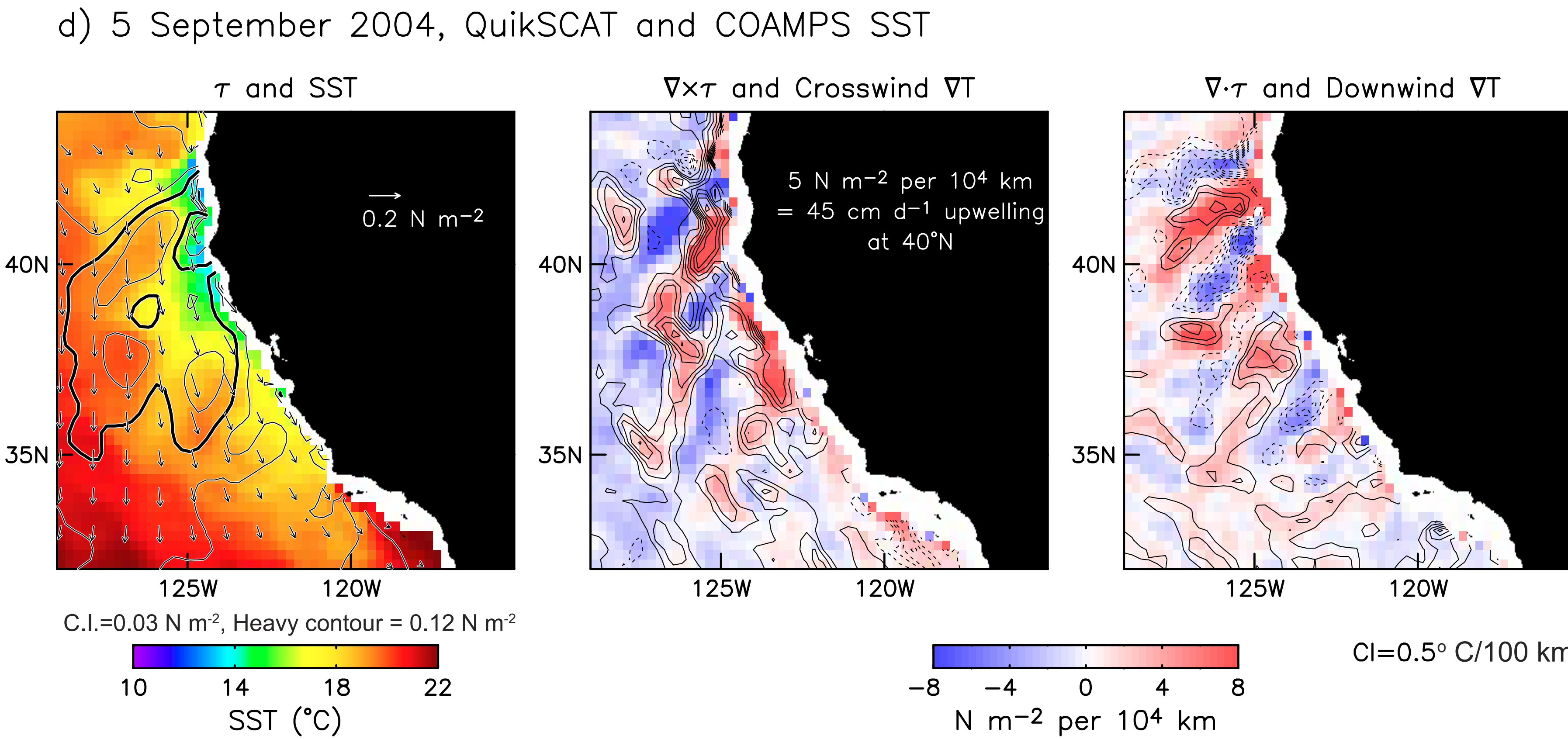
RTG SST grid resolution = 0.5° daily

COAMPS® 29-Day Average Centered on 5 September 2004



COAMPS® grid resolution = 9 km

QuikSCAT 29-Day Average Centered on 5 September 2004



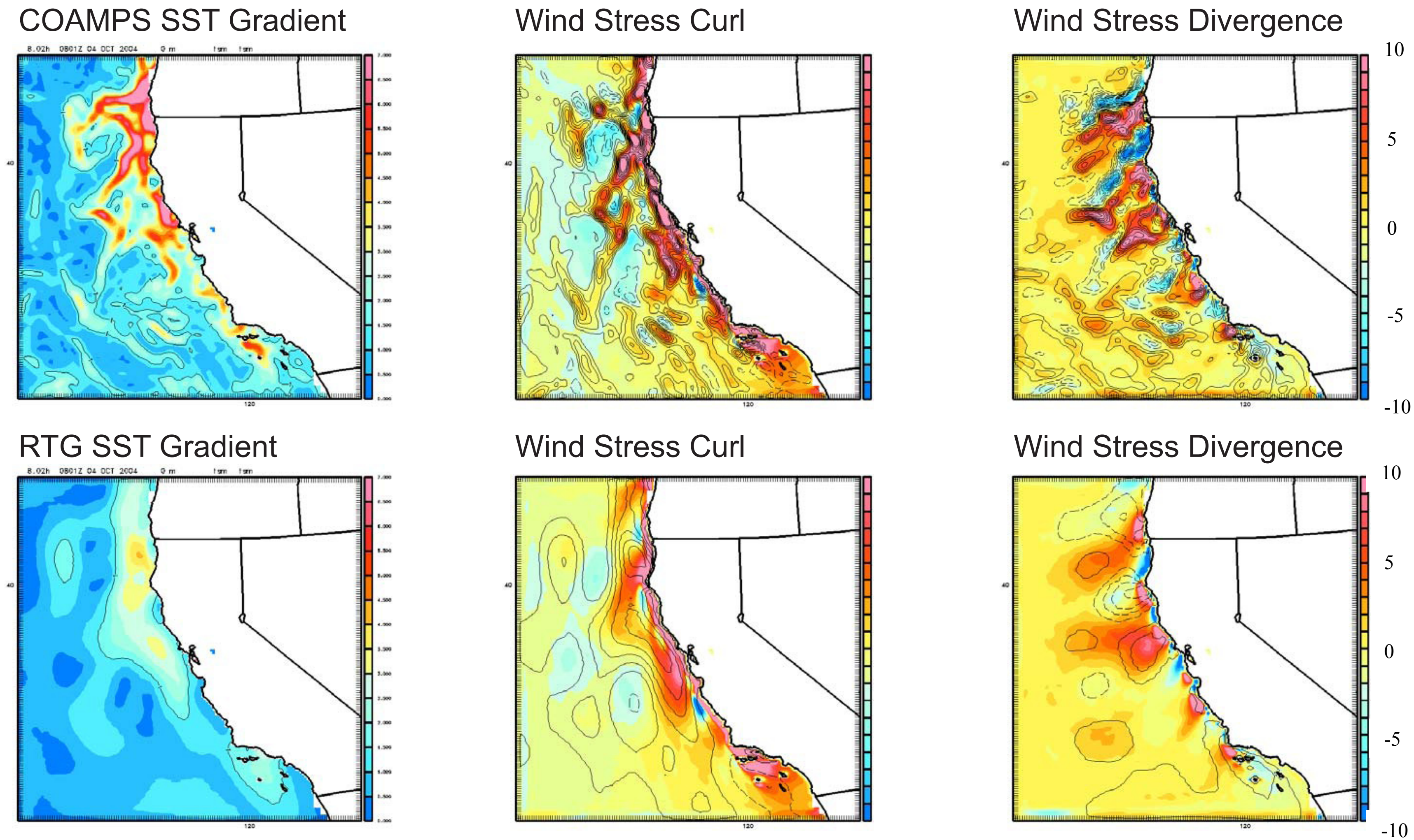
QuikSCAT resolution ~25 km (30-km gap near land)

Conclusion from the 1-Way Modeling Studies:

The accuracy and resolution of the SST boundary condition are crucially important to realistic model simulations of surface wind response to SST.

COAMPS Model Run with Two Different SST Boundary Conditions:
COAMPS SST Analyses and NOAA/RTG SST Analyses

|∇SST| (°C per 100 km) ∇xτ and Crosswind |∇SST| ∇•τ and Downwind |∇SST|



(N m^{-2} per 10^4 km (color) and °C per 100 km (contour))

Note:

The sensitivity of vertical mixing to atmospheric stability is also crucially important to realistic model simulations of surface wind response to SST

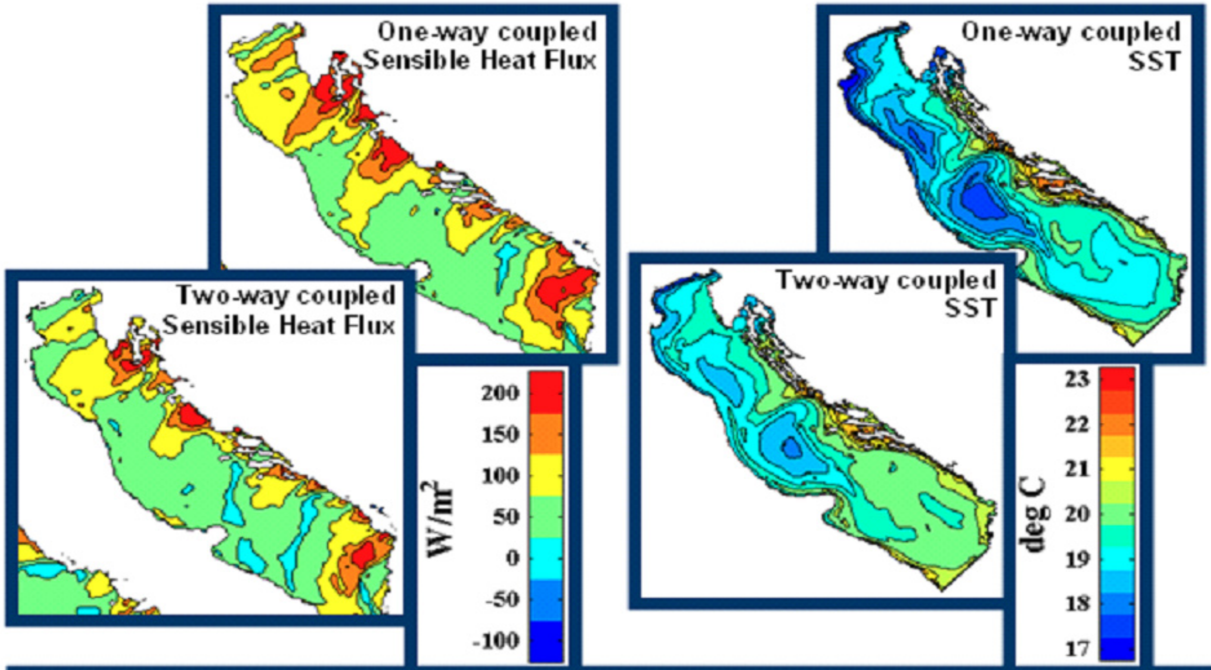
- see Wednesday presentation by Qingtao Song

3) Toward 2-way coupled modeling of the California Current System

- *The NRL COAMPS model*
- *The UCLA ROMS/WRF model*

Fully Coupled Modeling of the California Current System with the COAMPS Model at NRL

- A research version is available now.
- The timeline for the operational transition is fall 2009.



Two-way coupling exhibits smaller sensible heat fluxes (left), presumably from mutual adjustment in atmosphere and ocean mixed layers. As a result, NCOM SSTs (right) from the two-way coupled system are slightly warmer than those from the one-way coupled system.

Fully Coupled Modeling of the California Current System at UCLA

(Alex Hall, Francois Colas and Jim McWilliams)

Based on the ROMS model for the ocean and the WRF model for the atmosphere

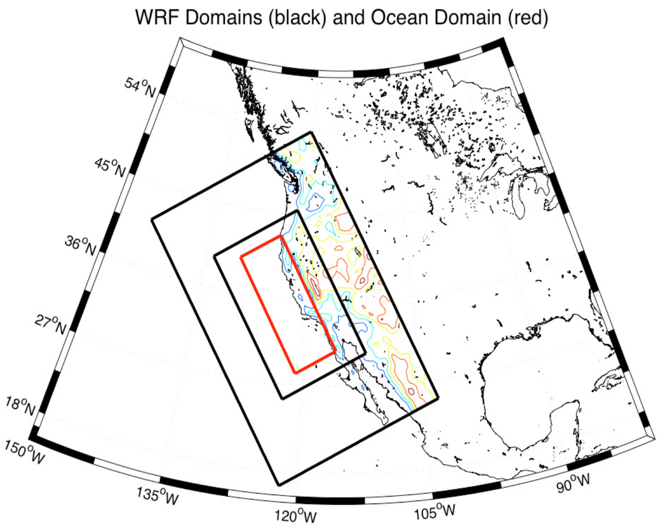


Figure 1. The standard grid configuration for all our simulations. The WRF grids are shown in black. We nest a 12-km resolution WRF domain covering the California region within a 36-km resolution domain covering a much larger region of the Pacific coast. The 4-km resolution ROMS grid is shown in red.

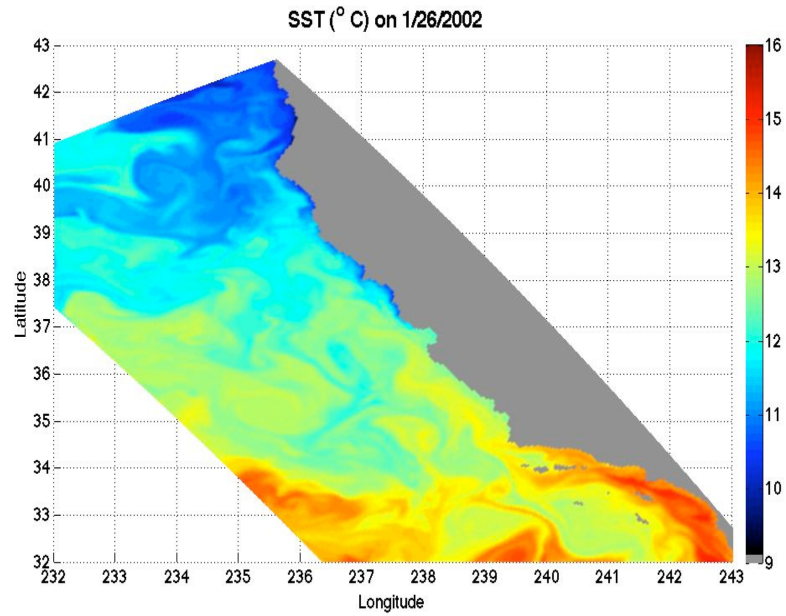


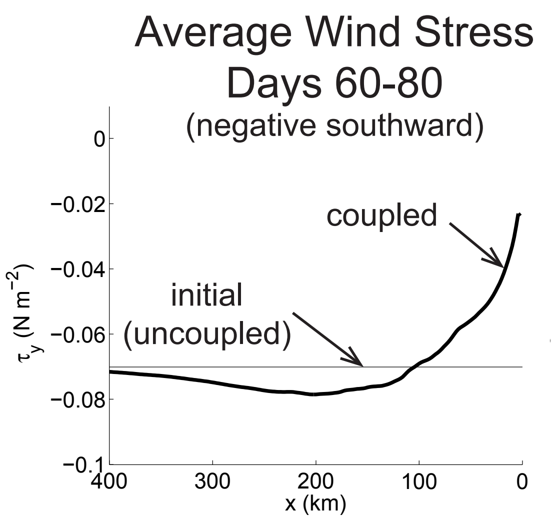
Figure 2. Sea surface temperature simulated by the WRF-ROMS coupled model on the model day corresponding to January 26, 2002.

4) Sensitivity Studies with a "25-Cent" Empirical Coupled Model

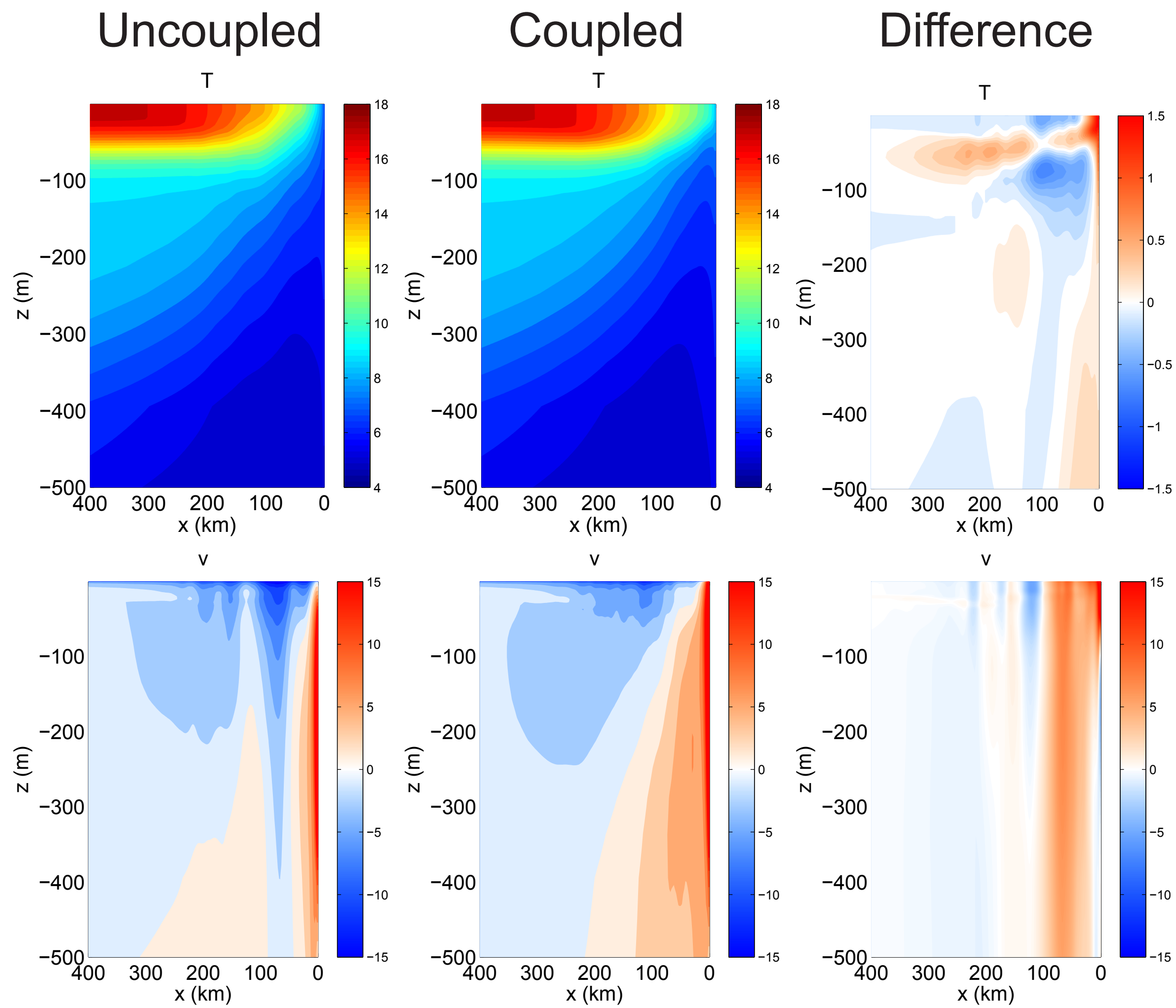
(X. Jin, C. Dong, J. Kurian, J. McWilliams, D. Chelton and Z. Li)

- Based on the ROMS model for the ocean and QuikSCAT-based empirical coupling coefficients for feedback effects on the ocean.
- The procedure consists of forcing the ocean model with large-scale winds and then correcting the winds to include small-scale SST-induced perturbations.
- The results presented here are for an idealized rectangular domain with a meridional eastern boundary.
  - more sophisticated model runs have been done for a realistic California Current System and Peru-Chile Current System.

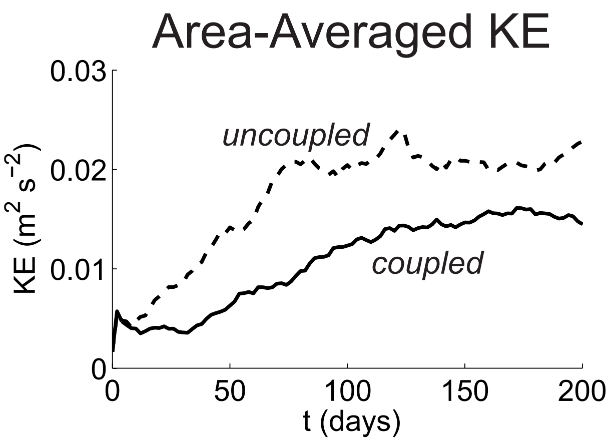
Wind Stress, Temperature and Alongshore Velocity



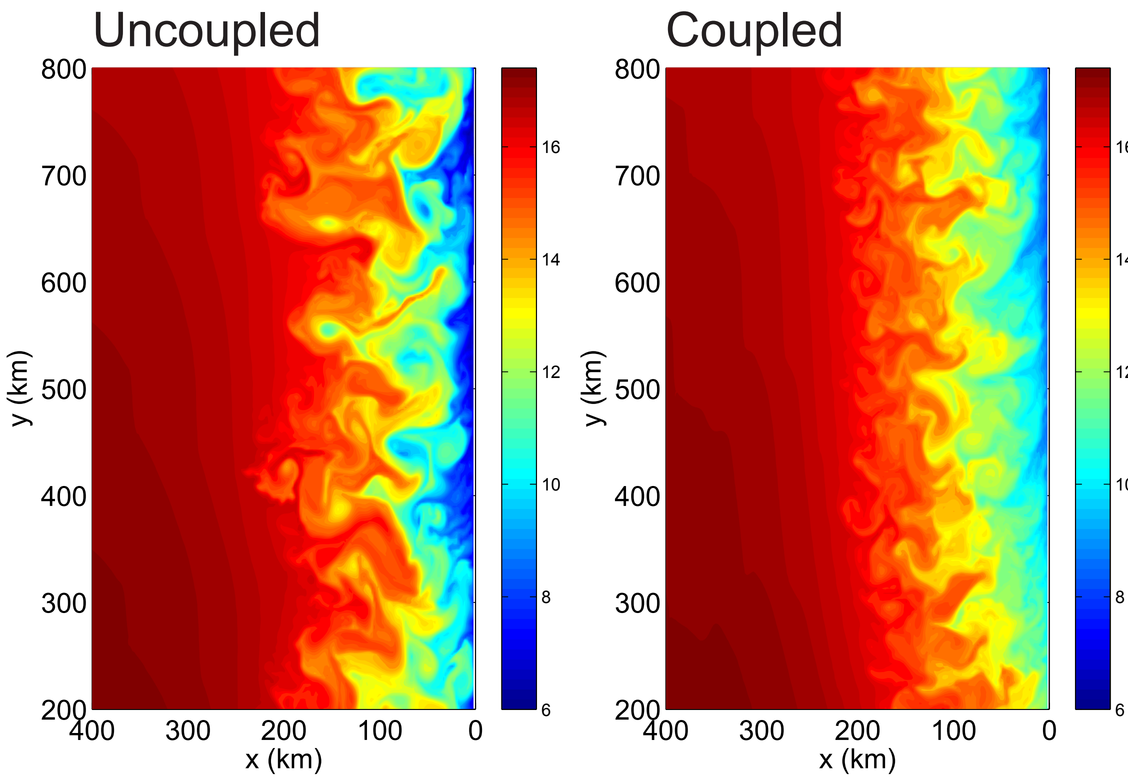
- *Wind stress is initially -0.07 N m^{-2} and uniform equatorward.*
- *The cold upwelled water at the coast generates a crosswind SST gradient that creates a nearshore positive wind stress curl.*
- *This reduces the coastal upwelling but creates nearshore Ekman pumping.*
- *The broadening of the nearshore upwelling reduces the intensity of the alongshore SST front, thus slowing the development of baroclinic instability.*
- *The positive curl also intensifies the poleward undercurrent by Sverdrup dynamics.*



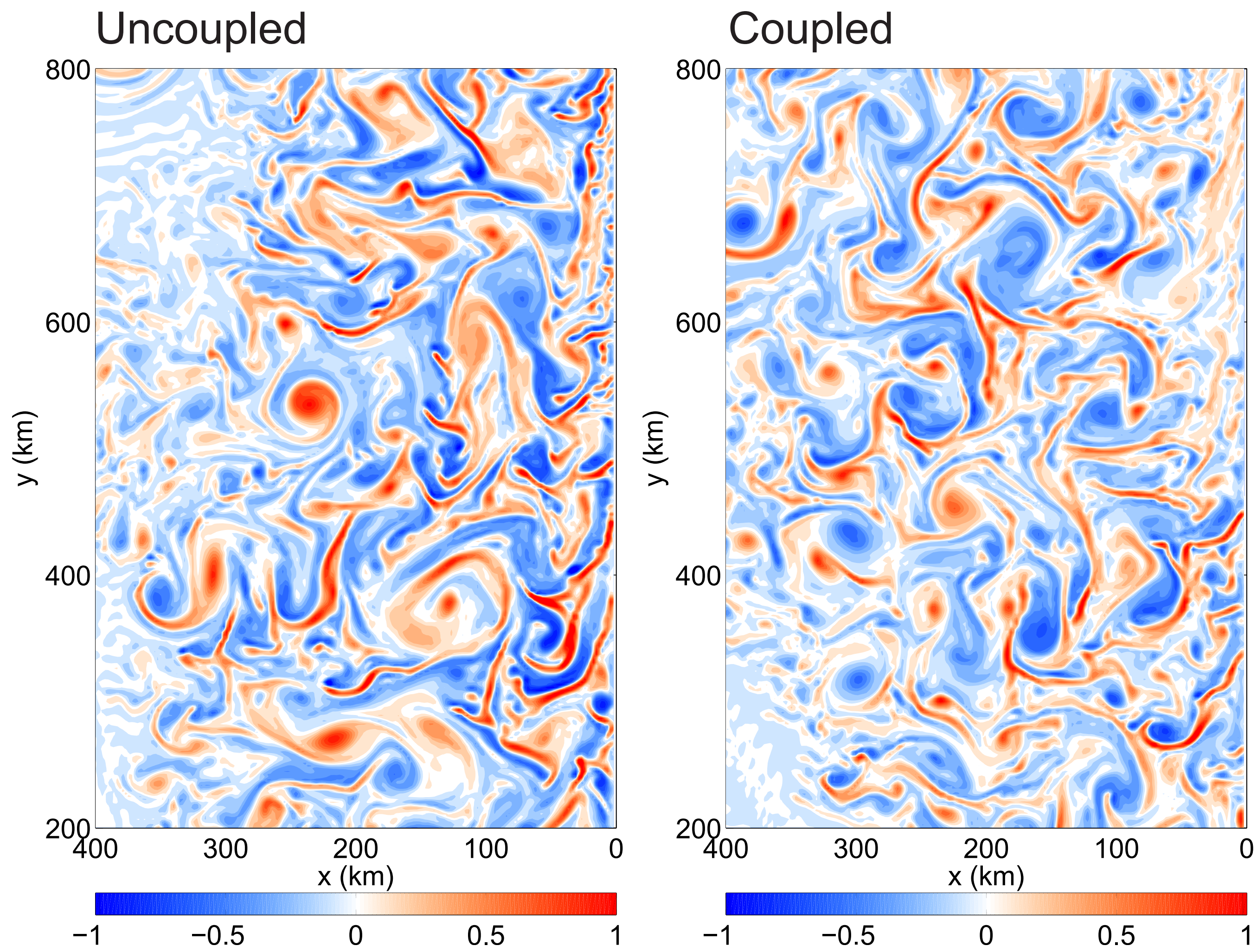
Temporal Evolution of the Eddy Field



Sea-Surface Temperature, Day 60



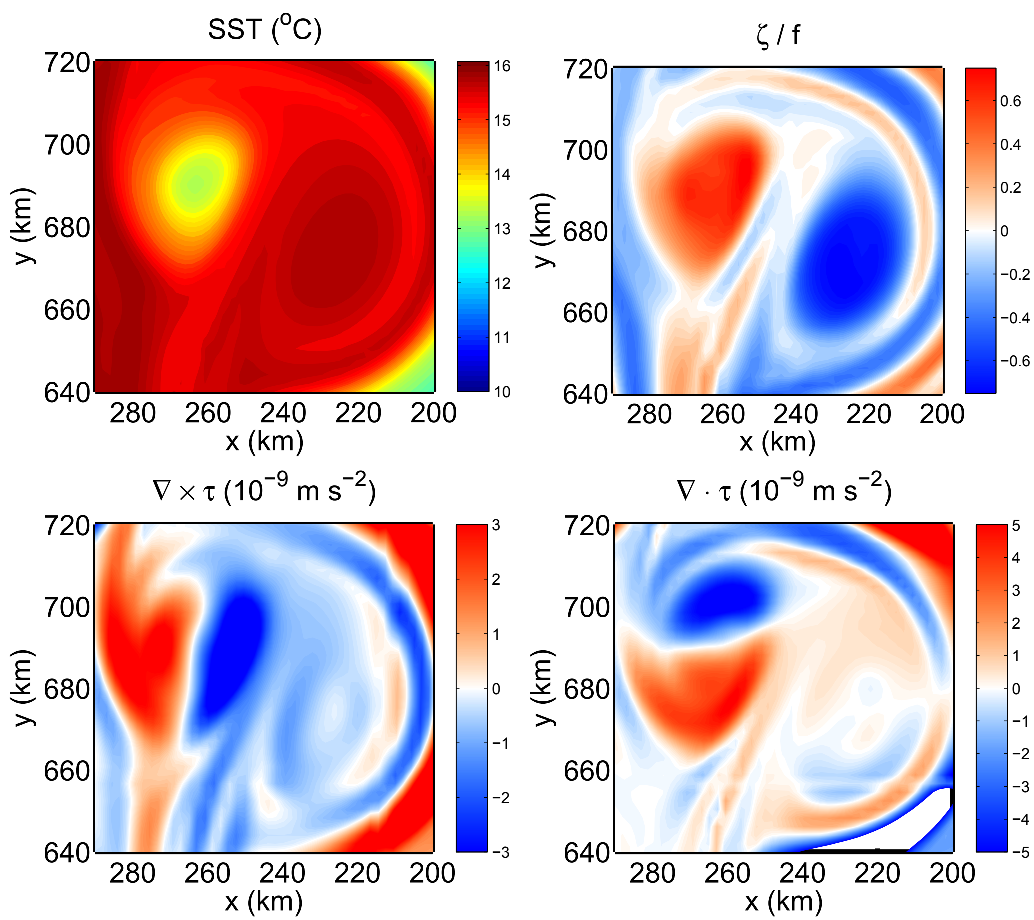
Surface Vorticity (Normalized by f) on Day 150



In the coupled simulation, cyclonic eddies are weakened and there is a much greater abundance of anticyclonic eddies.

SST-Induced Wind Stress Forcing of an Eddy Dipole Pair

- *The SST signature of cyclonic eddies is typically about 3 times stronger than that of anticyclonic eddies.*
- *The associated stronger SST gradients generate stronger wind stress curl perturbations that act to force the eddy away from its axisymmetric shape, which is a disruptive force to further evolution.*



Conclusions

- *The SST influence on surface winds results in O(1) perturbations of the wind stress curl field.*
  - *It would be very surprising if the feedback of these curl variations on the ocean did not have a strong effect on the circulation.*

- *Fully 2-way coupled models to investigate the feedback effects on the ocean are under development.*

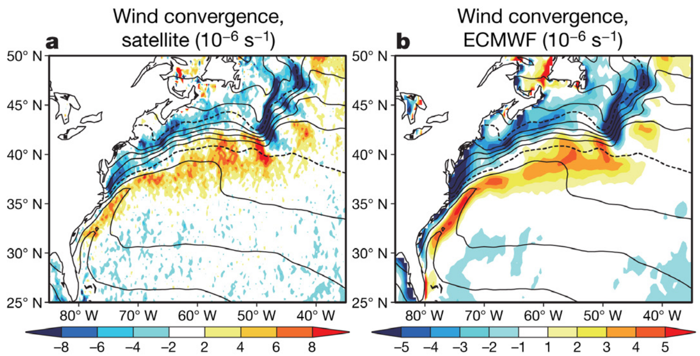
- *Results from an "25-cent" fully coupled model of an idealized eastern boundary current upwelling regime indicate that:*
  - *The cold upwelled water at the coast causes the nearshore winds to diminish, generating a nearshore positive wind stress curl that weakens the alongshore SST front and drives a poleward undercurrent.*
  - *The coupling over oceanic eddies weakens cyclonic eddies and increases the abundance of anticyclonic eddies.*

Influence of the Gulf Stream on the troposphere

Shoshiro Minobe[1], Akira Kuwano-Yoshida[2], Nobumasa Komori[2], Shang-Ping Xie[3,4] & Richard Justin Small[3]

Vol 452|13 March 2008|doi:10.1038/nature06690

Surface Wind Convergence



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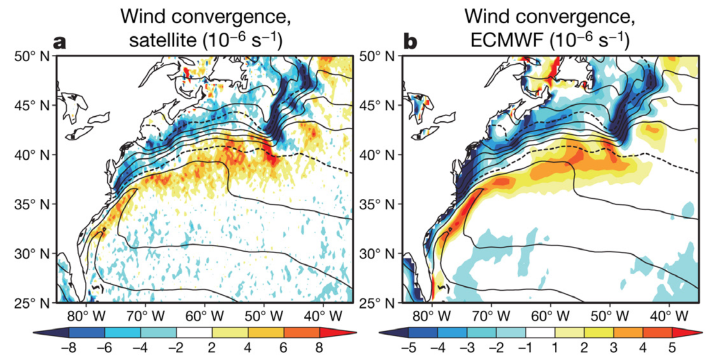
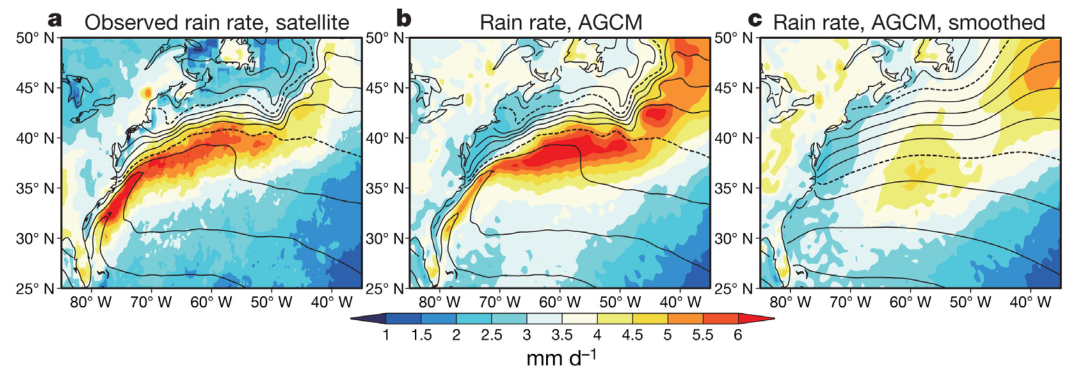


Rain Rate



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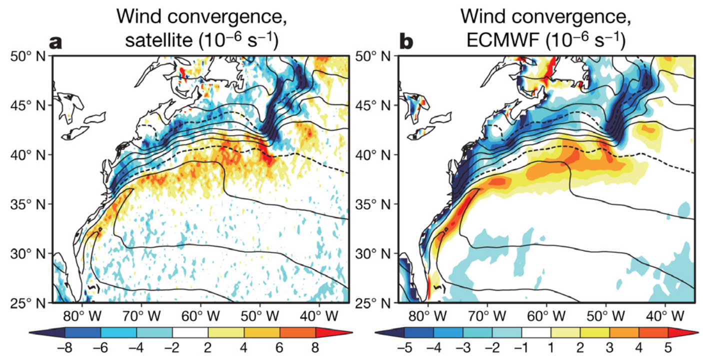

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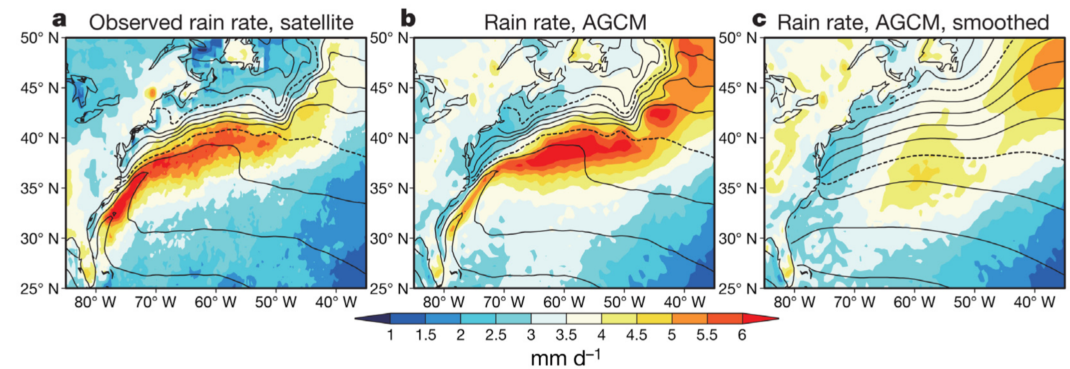
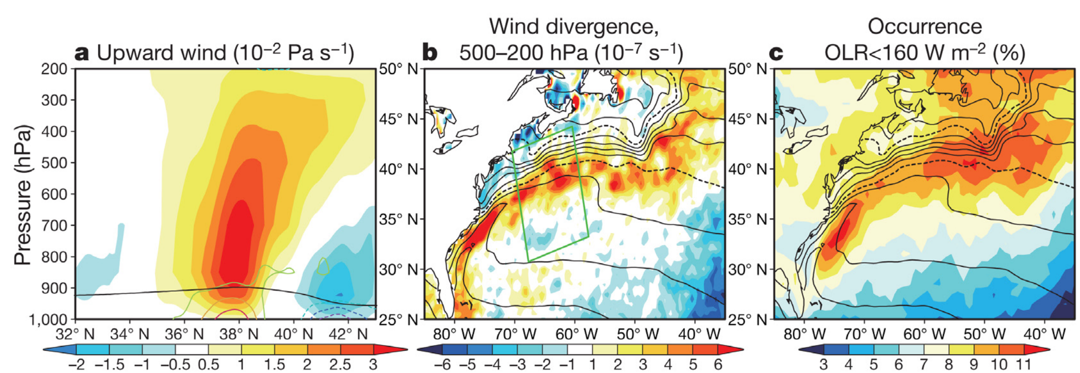
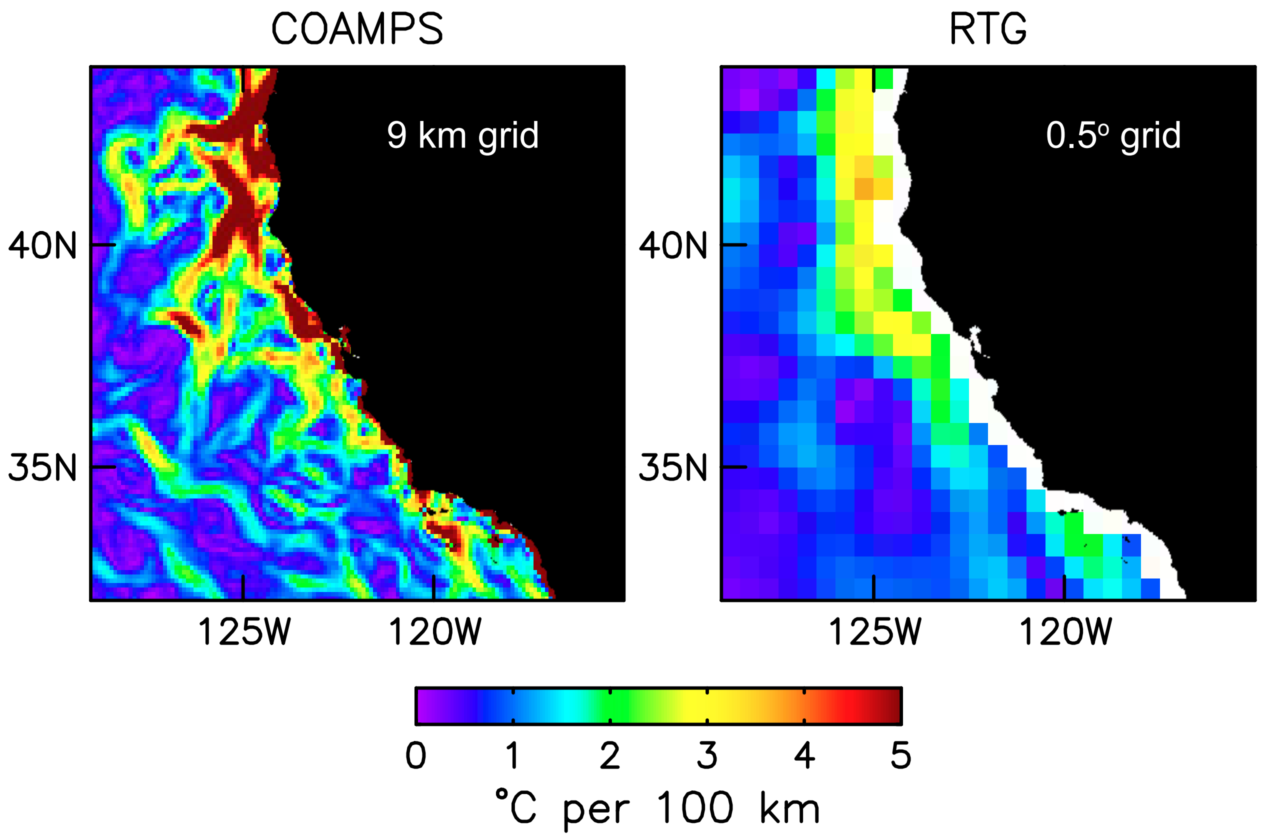


Upward Velocity, Tropospheric Divergence and Cold OLR



29-Day Average SST Gradient Magnitude, 5 September 2004



The resolution of the SST boundary condition has a major impact on the accuracy of surface winds in mesoscale models:

COAMPS® is far superior to NAM/Eta

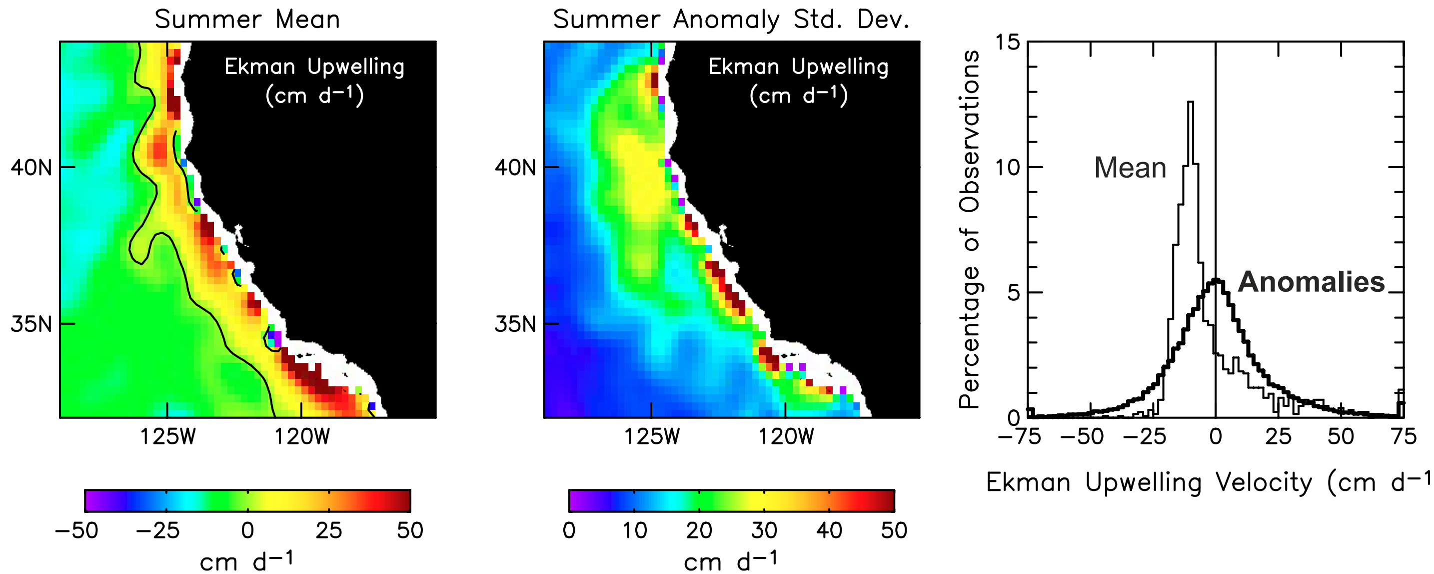
Question:

Are the SST-induced perturbations of the wind stress curl field important to the ocean circulation and biology of the CCS?

Summertime Ekman Upwelling Velocities

June - September 2002-2005

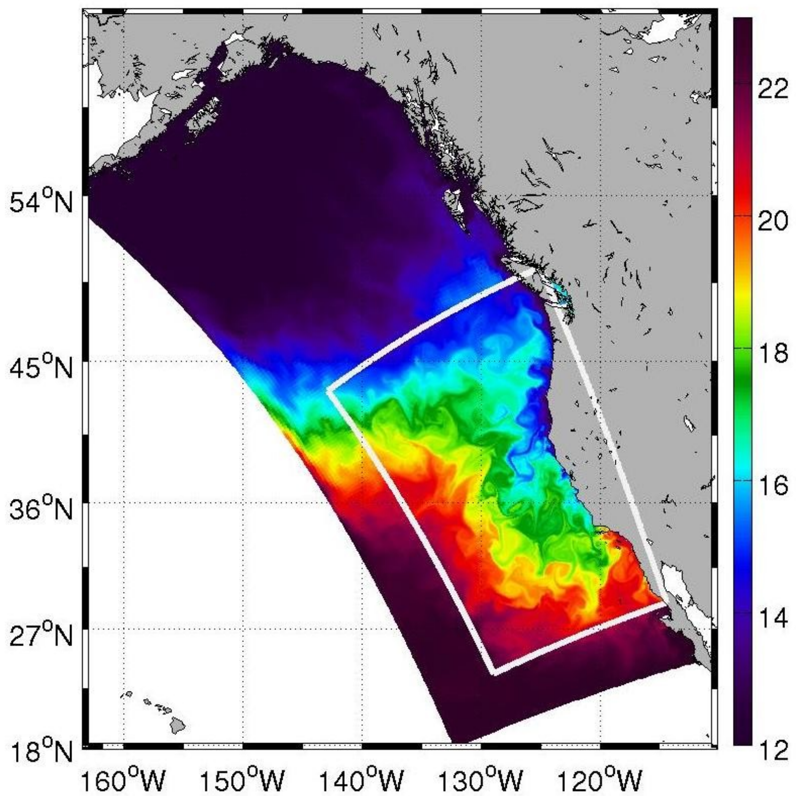
QuikSCAT



Wind / SST Empirical Relation in ROMS

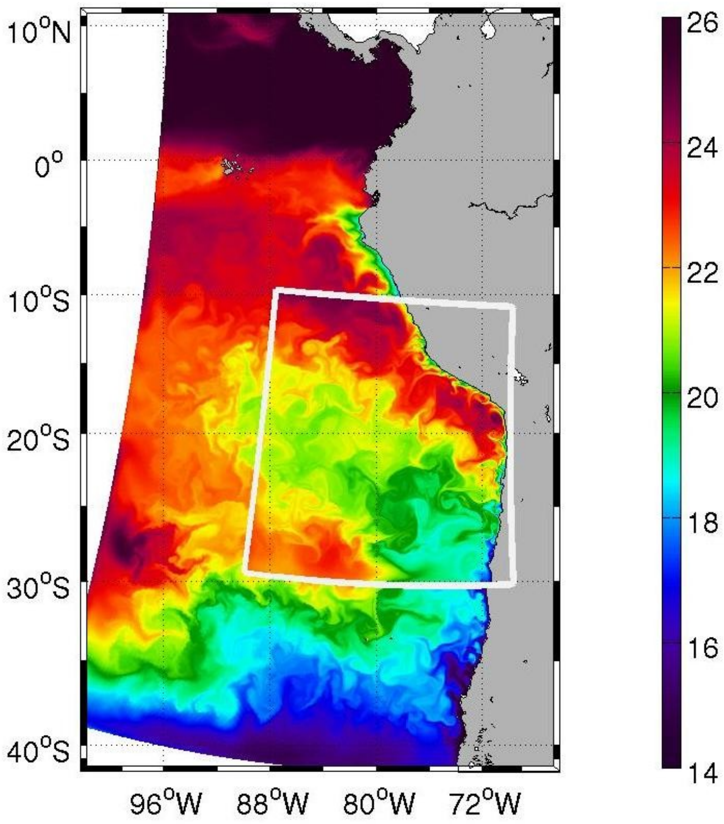
2 ROMS configurations – climatological conditions

California (5 km)



(Capet et al. 2008)

Peru/Chile (4 km)
(VOCALS region)



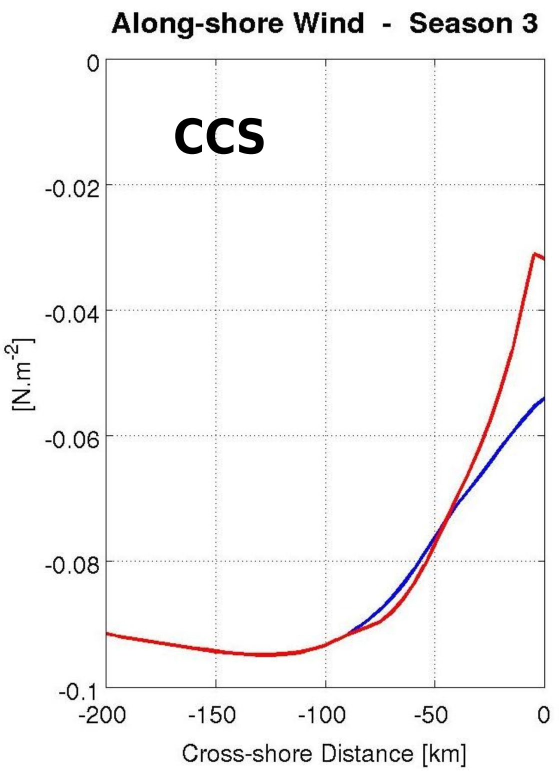
(Colas et al. 2008)

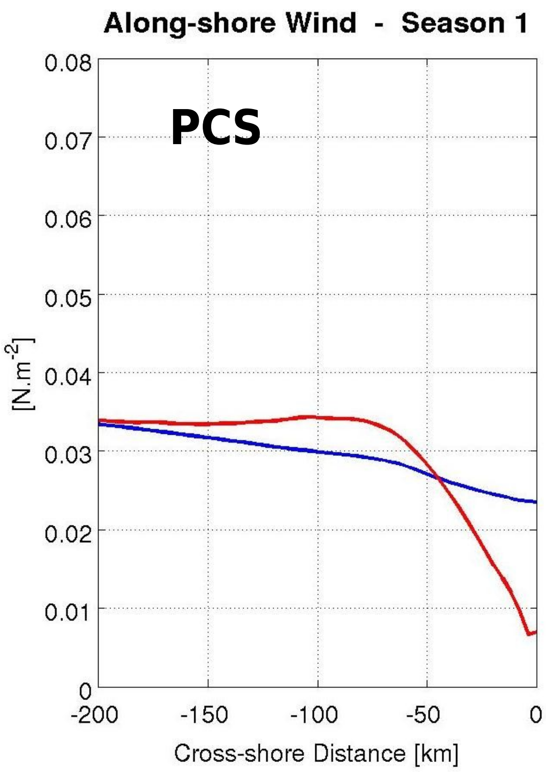
Near-shore wind drop-off

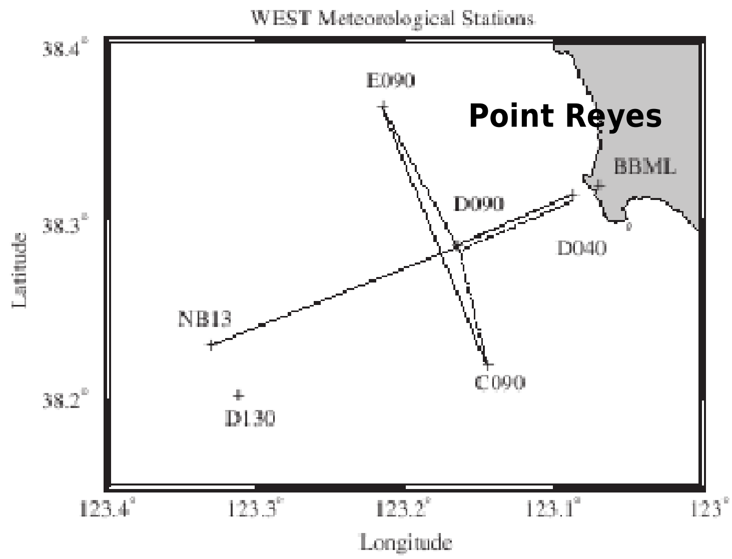
Cross-shore profile
ROMS empirical
coupling

QSCAT

COUPLED





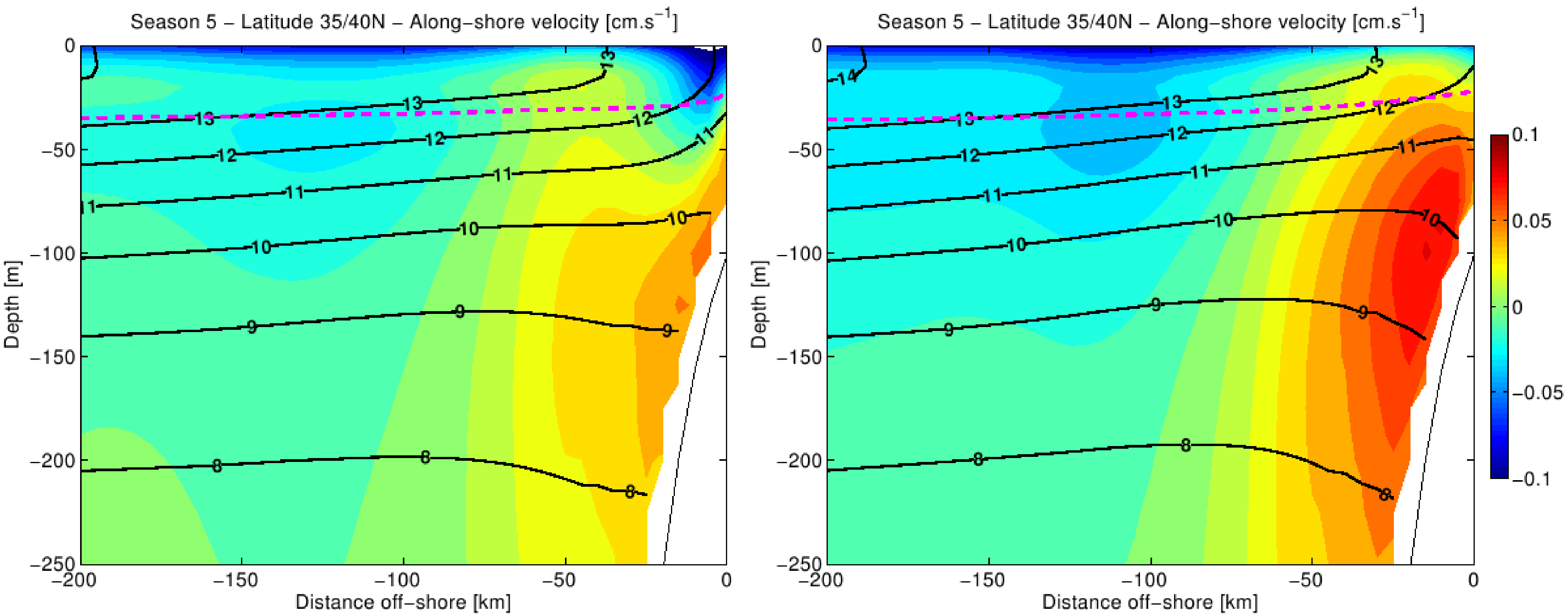


Dever et al. (2006), Dorman et al. (2006)

Summer: $\tau/4$ within ~ 25km

Winter: $\tau/2$ within ~ 25km

Near-shore current sensitivity (CCS)



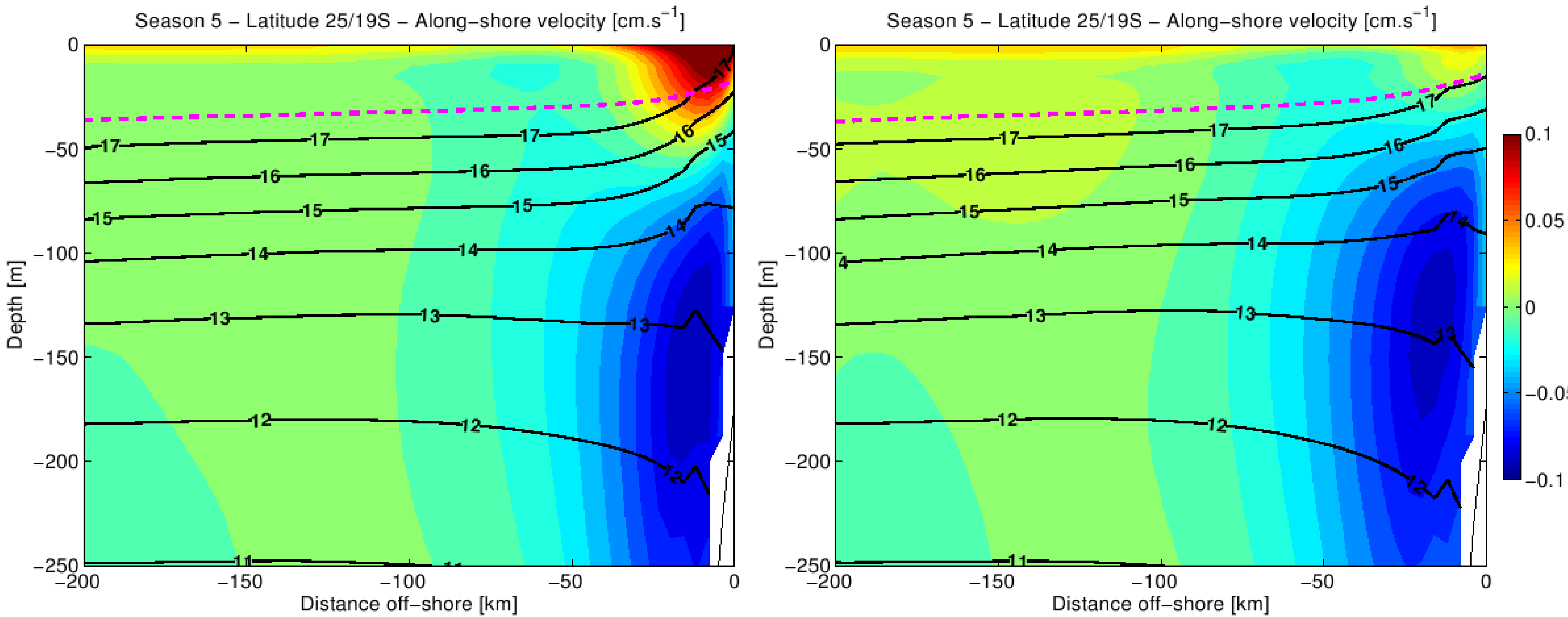
original QSCAT winds

corrected winds

Significant changes in near-shore current structure

(Capet et al. 2004)

Near-shore current sensitivity (PCS)



original QSCAT winds

corrected winds

Similar changes in current structure for PCS & CCS

Consequences on :

biological implications (retention patterns)

& *eddy activity* (?)