Observations and Modeling of Coupled Ocean-Atmosphere Interaction over the California Current System

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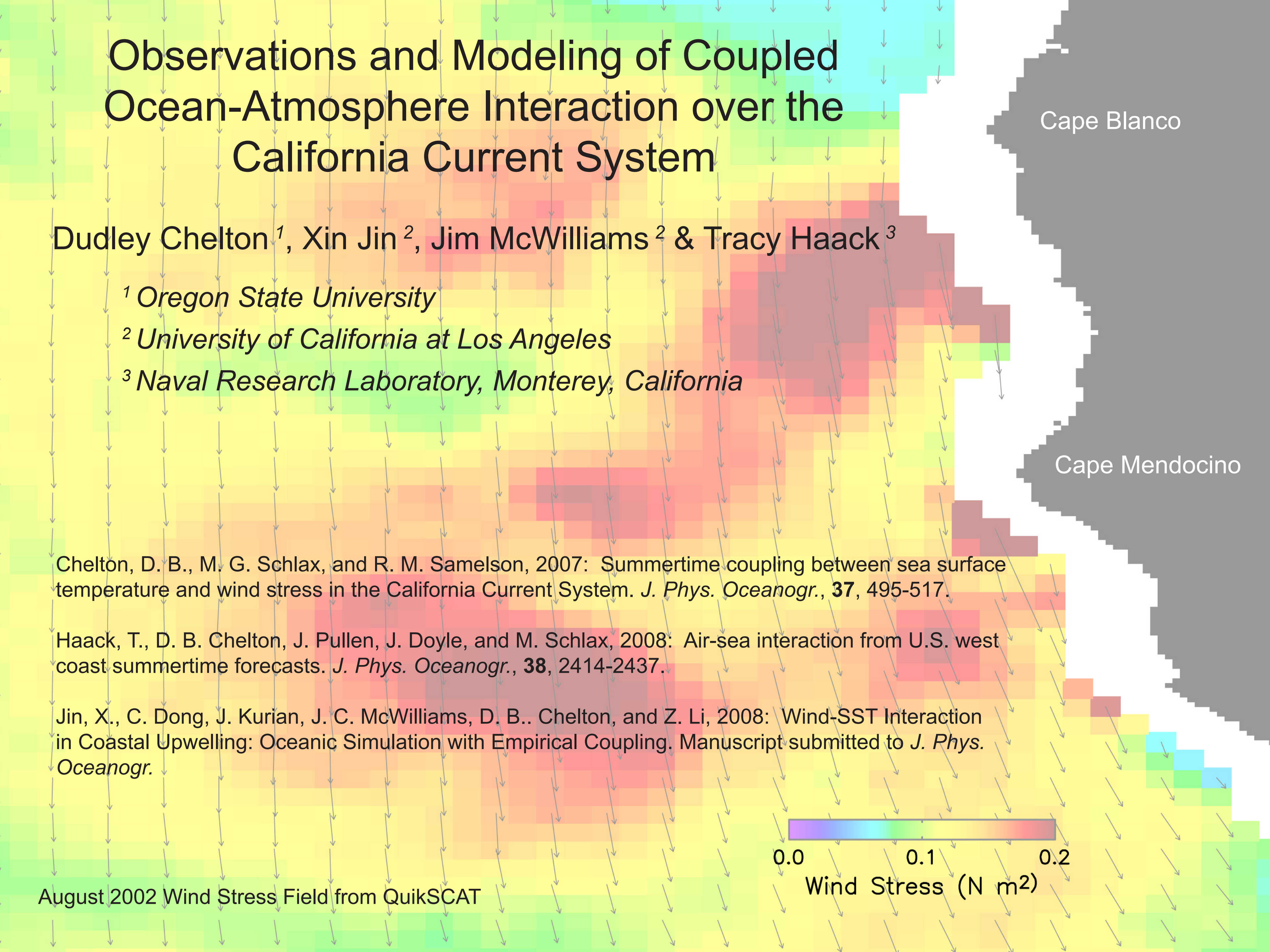
Chelton, D. B., M. G. Schlax, and R. M. Samelson, 2007: Summertime coupling between sea surface temperature and wind stress in the California Current System. *J. Phys. Oceanogr.*, **37**, 495-517.

Haack, T., D. B. Chelton, J. Pullen, J. Doyle, and M. Schlax, 2008: Air-sea interaction from U.S. west coast summertime forecasts. *J. Phys. Oceanogr.*, **38**, 2414-2437.

Jin, X., C. Dong, J. Kurian, J. C. McWilliams, D. B.. Chelton, and Z. Li, 2008: Wind-SST Interaction in Coastal Upwelling: Oceanic Simulation with Empirical Coupling. Manuscript submitted to *J. Phys. Oceanogr.*



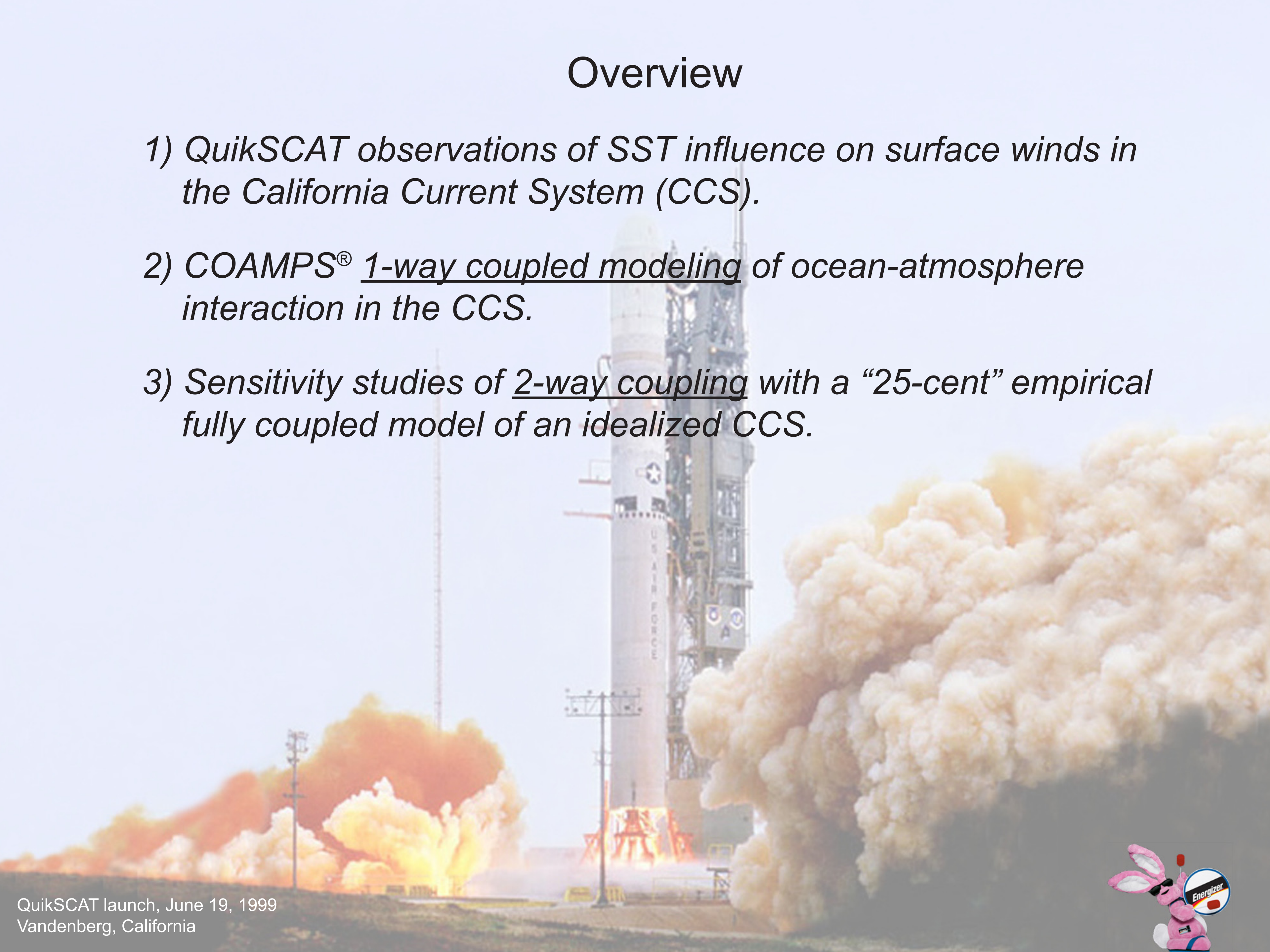
August 2002 Wind Stress Field from QuikSCAT

Overview

1) *QuikSCAT observations of SST influence on surface winds in the California Current System (CCS).*

2) *COAMPS® 1-way coupled modeling of ocean-atmosphere interaction in the CCS.*

3) *Sensitivity studies of 2-way coupling with a “25-cent” empirical fully coupled model of an idealized CCS.*



QuikSCAT launch, June 19, 1999
Vandenberg, California

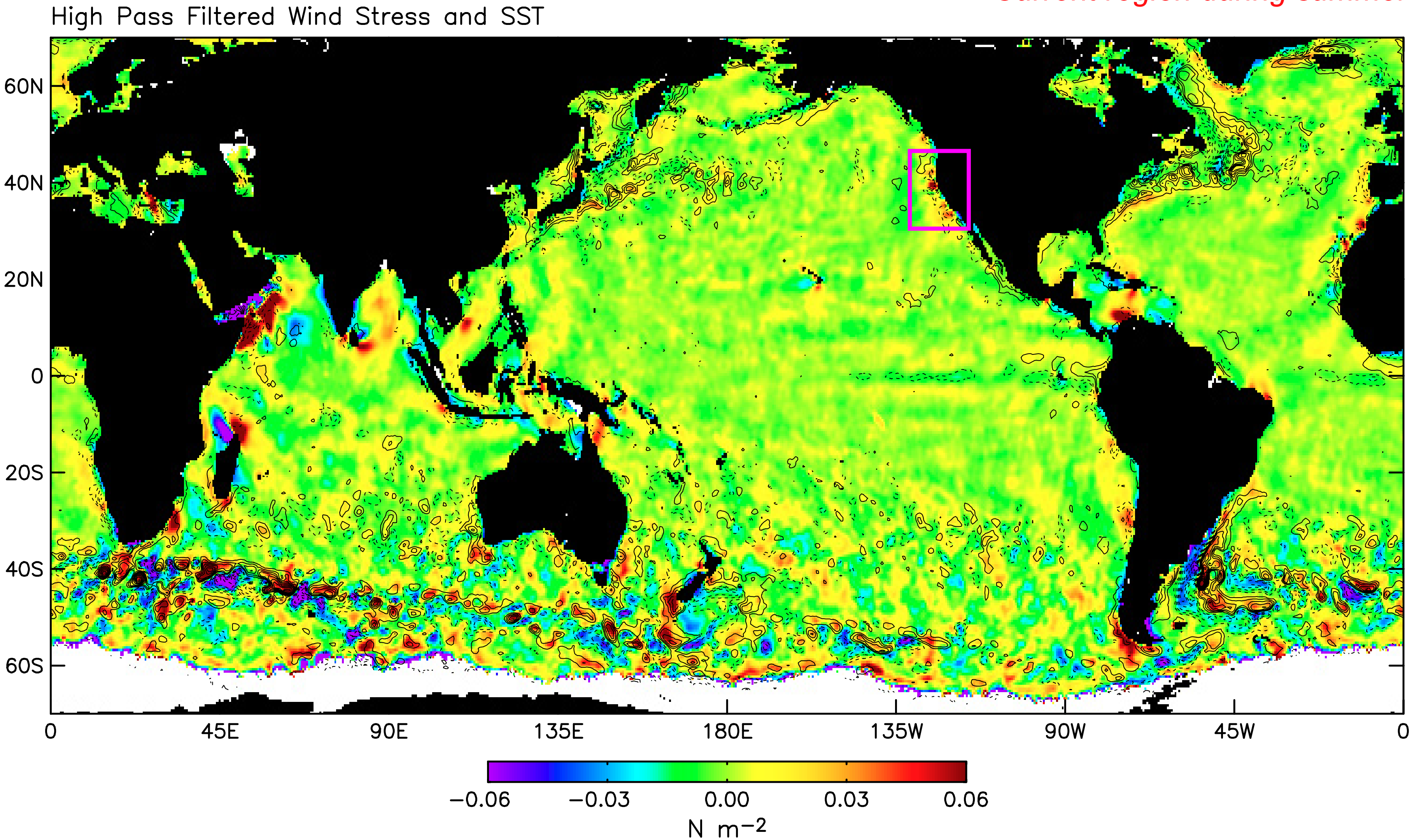
2-Month Average Wind Stress Magnitude and SST Contours

(Spatially High-Pass Filtered)

Northern Hemisphere Summer

QuikSCAT, July–August 2003

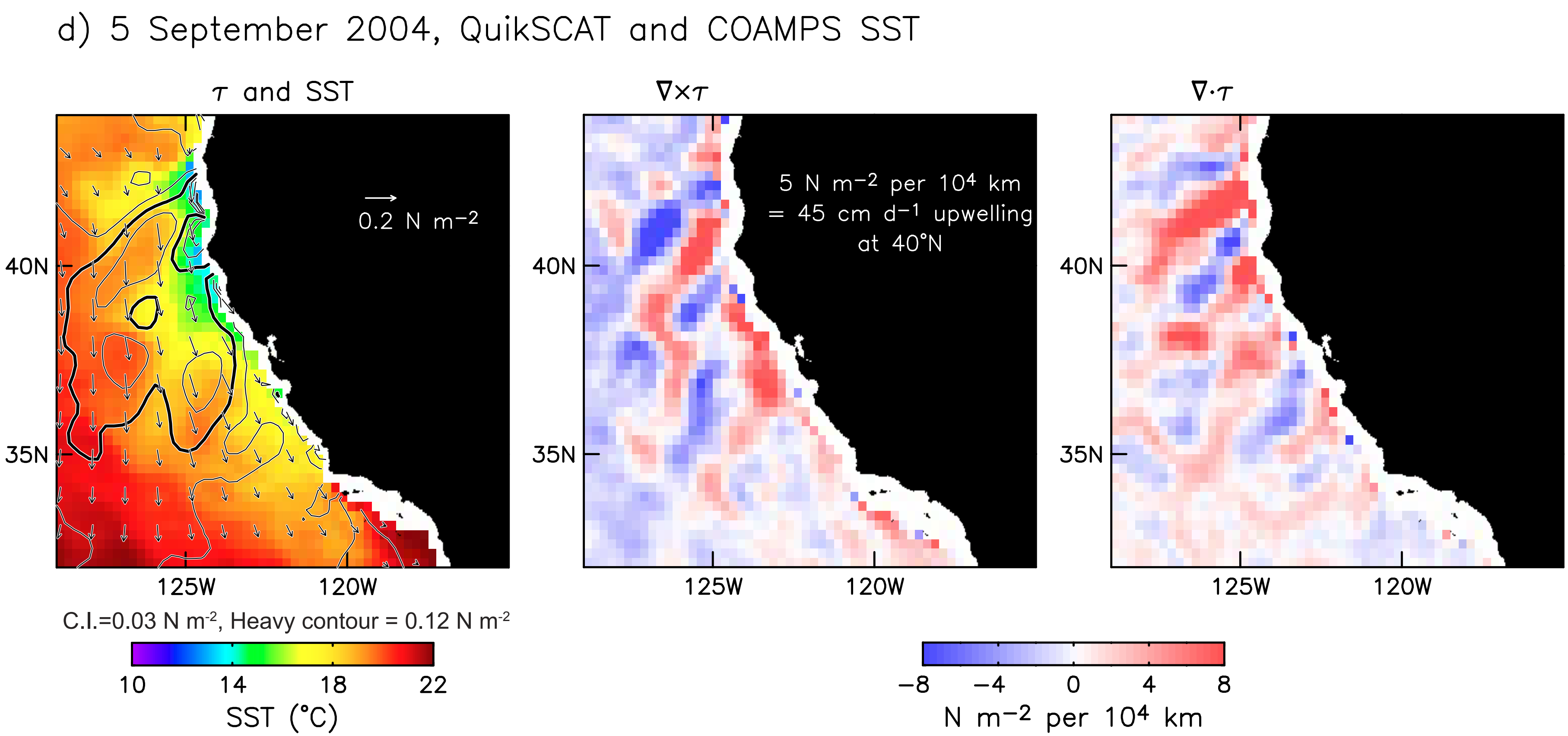
Small-scale structure is well developed in the California Current region during summer



QuikSCAT 29-Day Average Centered on 5 September 2004

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

Navy Coupled Ocean Data Assimilation (NCODA) SST grid resolution 9 km



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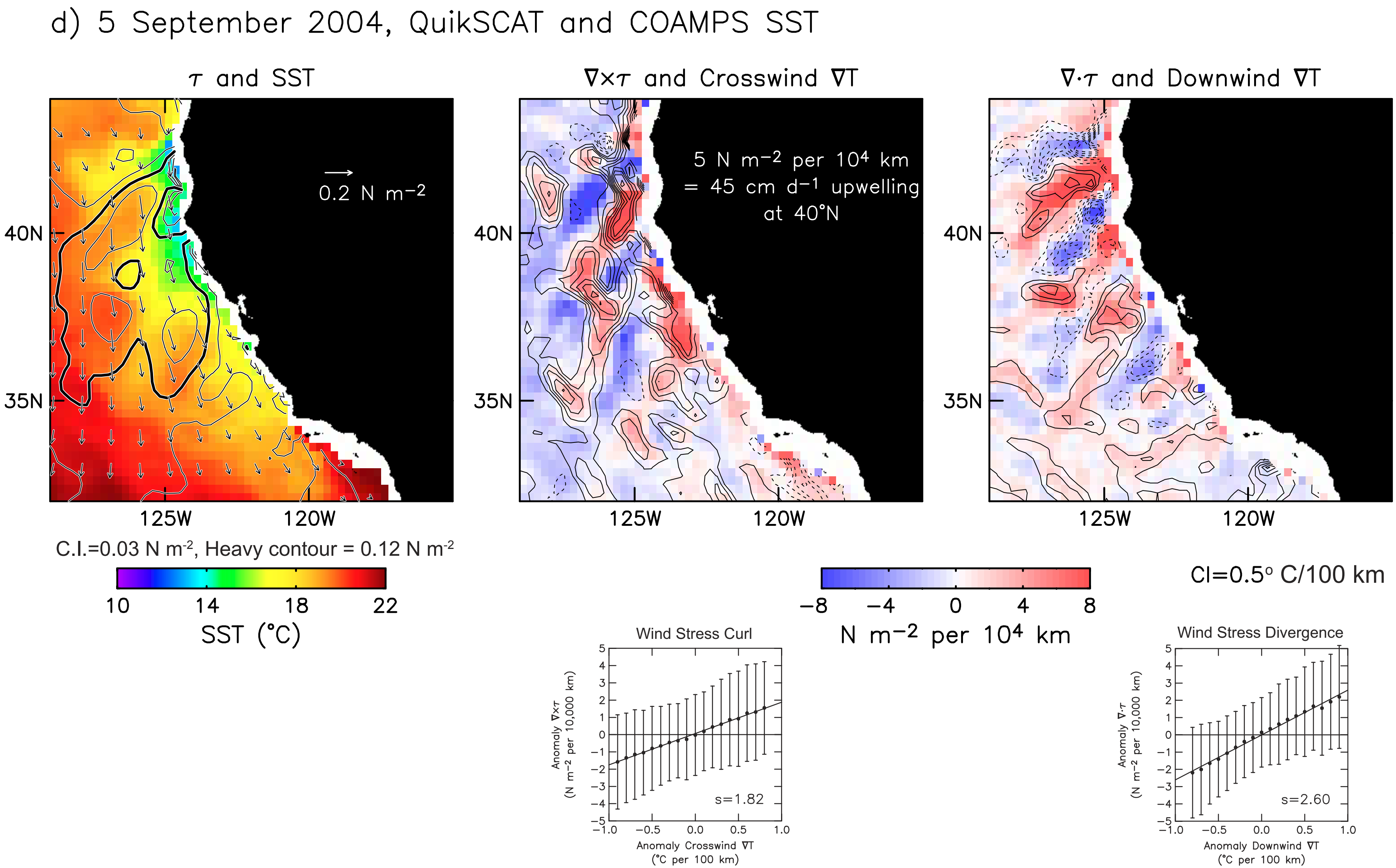
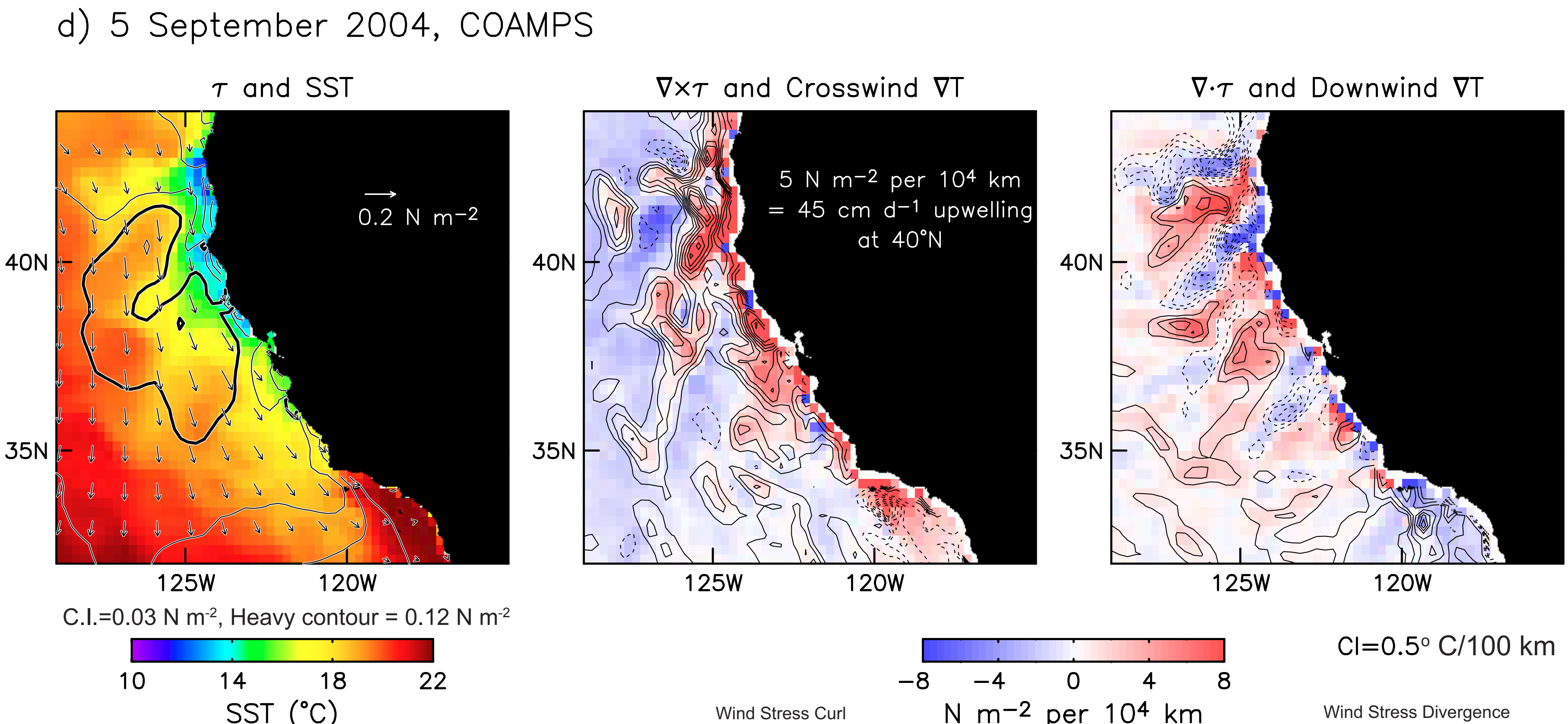
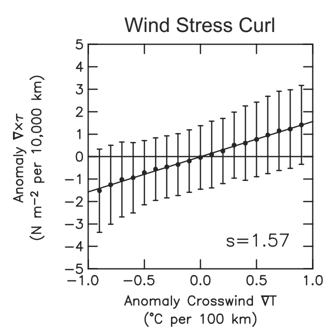


COAMPS® 29-Day Average Centered on 5 September 2004

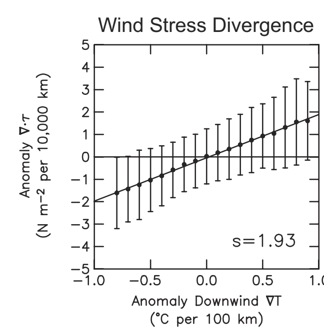
Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) grid resolution = 9 km
Navy Coupled Ocean Data Assimilation (NCODA) SST grid resolution 9 km





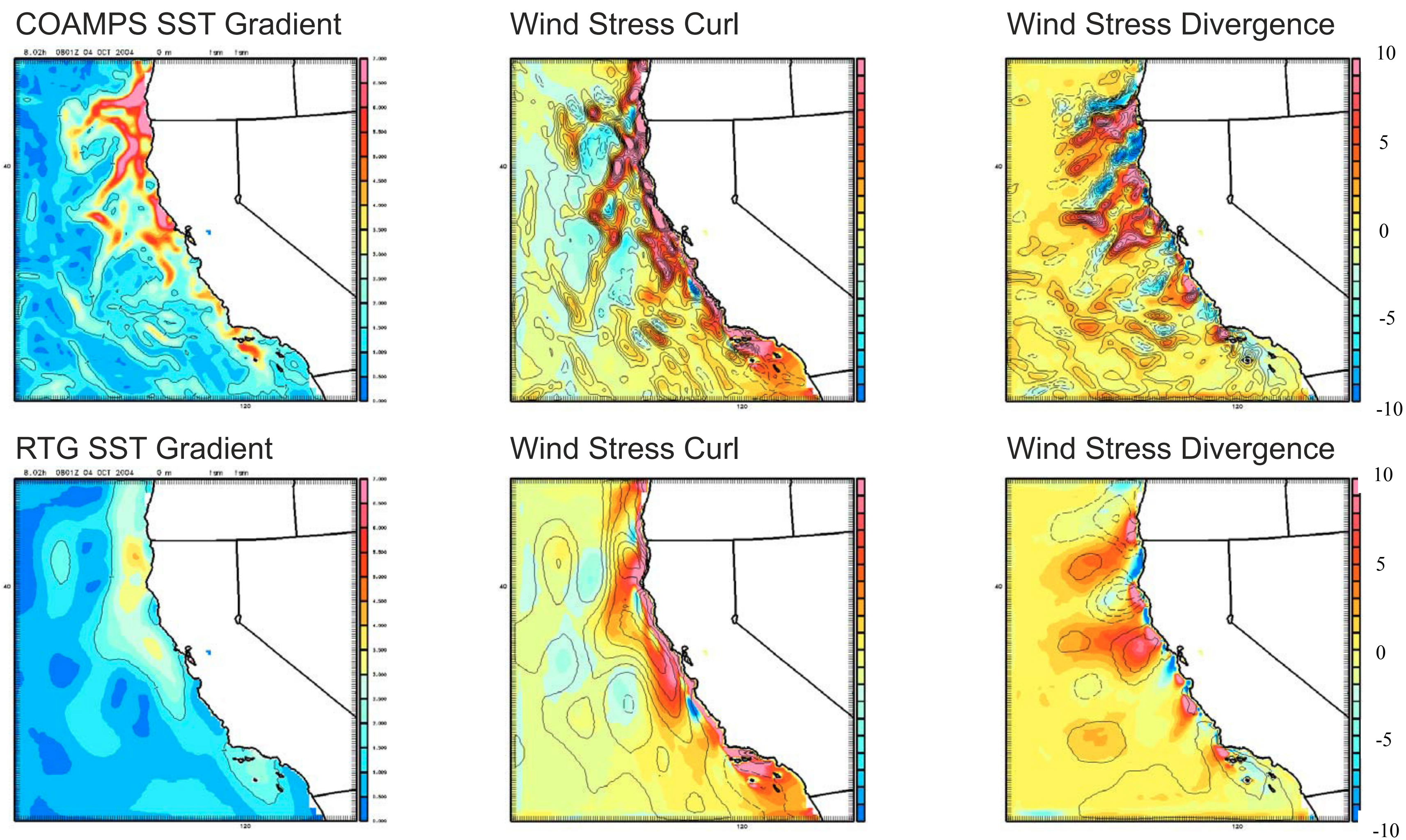
The COAMPS® model underestimates the curl response by 14% and the divergence response by 26%.

- *This may be attributable to inadequacies in the parameterization of vertical mixing.*



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

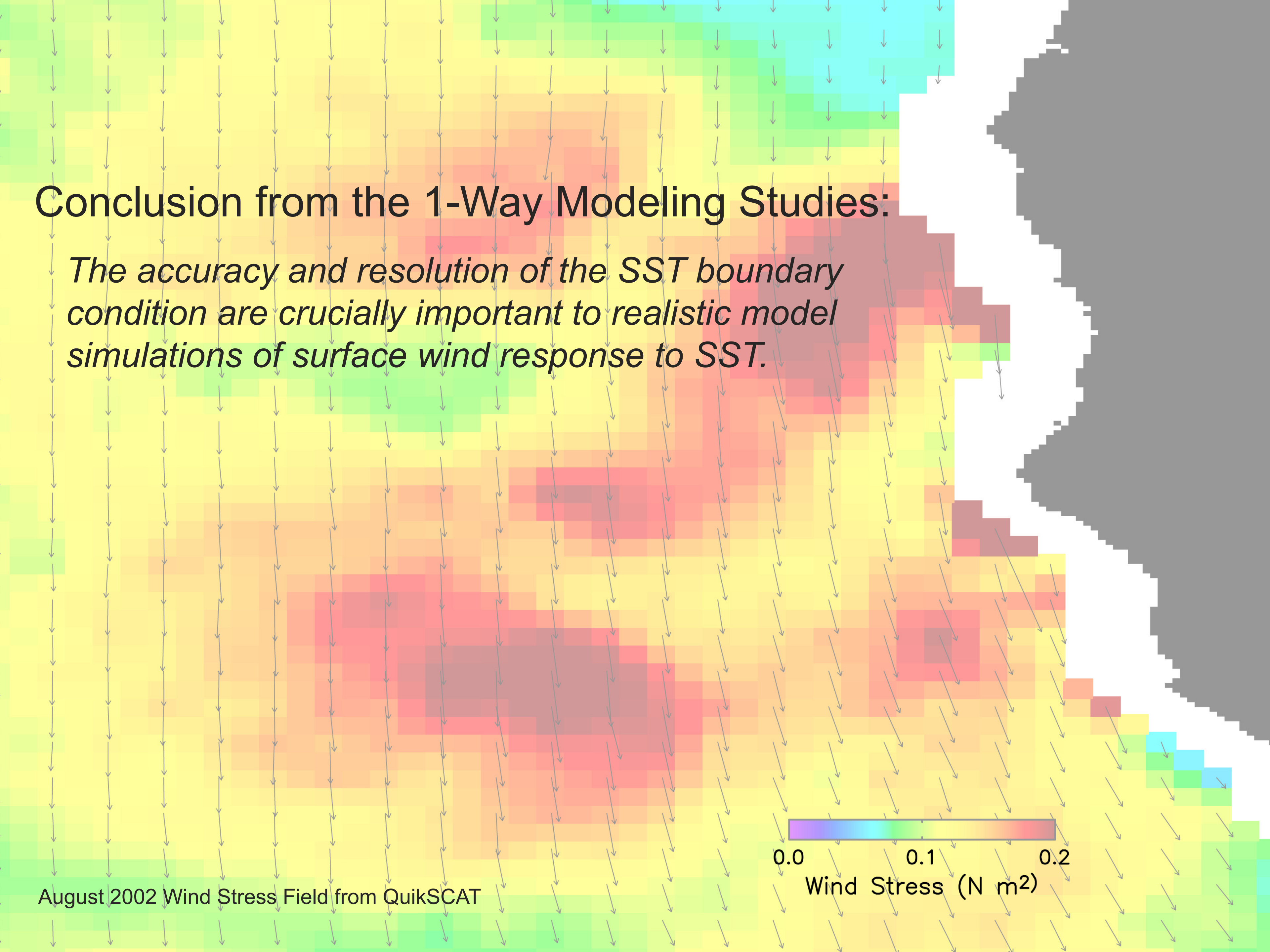
$|\nabla SST|$ (°C per 100 km) | $\nabla \times \tau$ and Crosswind $|\nabla SST|$ | $\nabla \bullet \tau$ and Downwind $|\nabla SST|$



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

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.



August 2002 Wind Stress Field from QuikSCAT

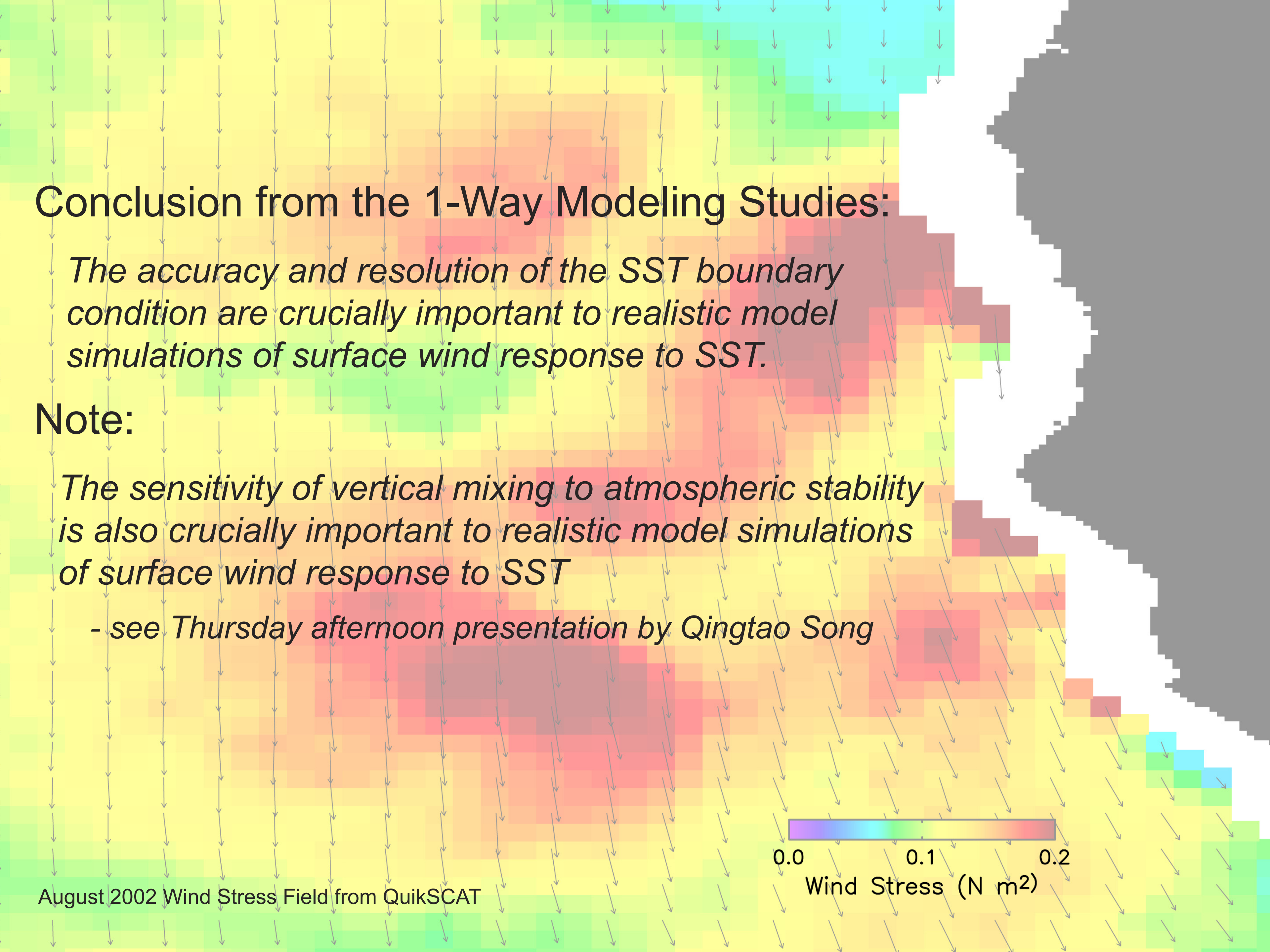
Conclusion from the 1-Way Modeling Studies:

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

Note:

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

- see Thursday afternoon presentation by Qingtao Song

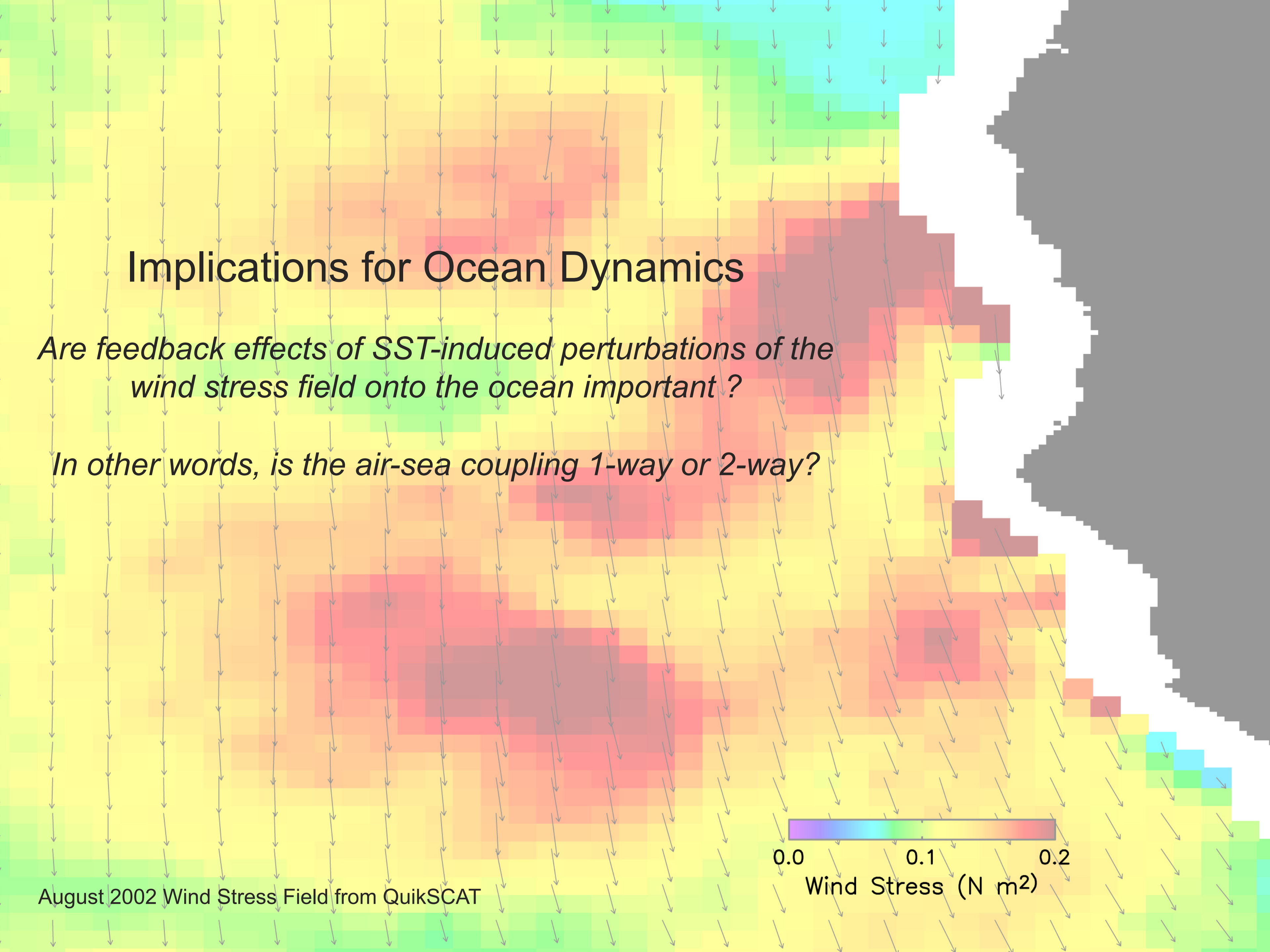


August 2002 Wind Stress Field from QuikSCAT

Implications for Ocean Dynamics

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

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



August 2002 Wind Stress Field from QuikSCAT

A "25-Cent" Empirical Coupled Model

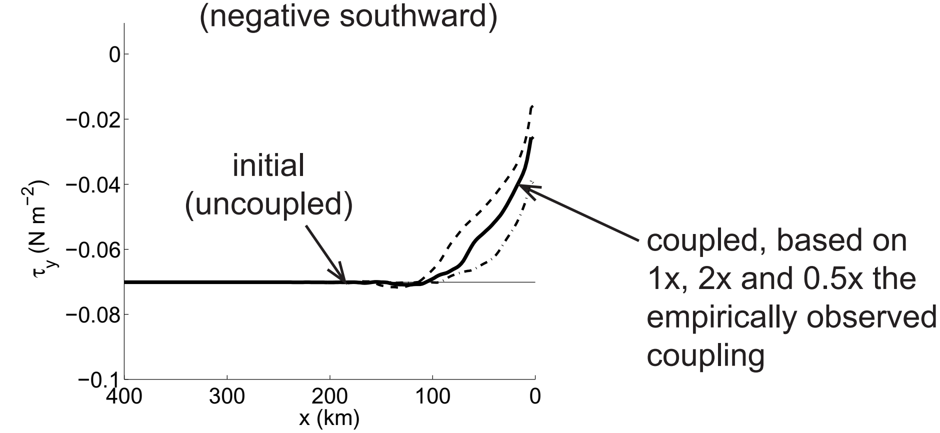
(Xin et al., manuscript submitted to J. Phys. Oceanogr.)

- 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 are under development for a realistic California Current System and Peru-Chile Current System.*

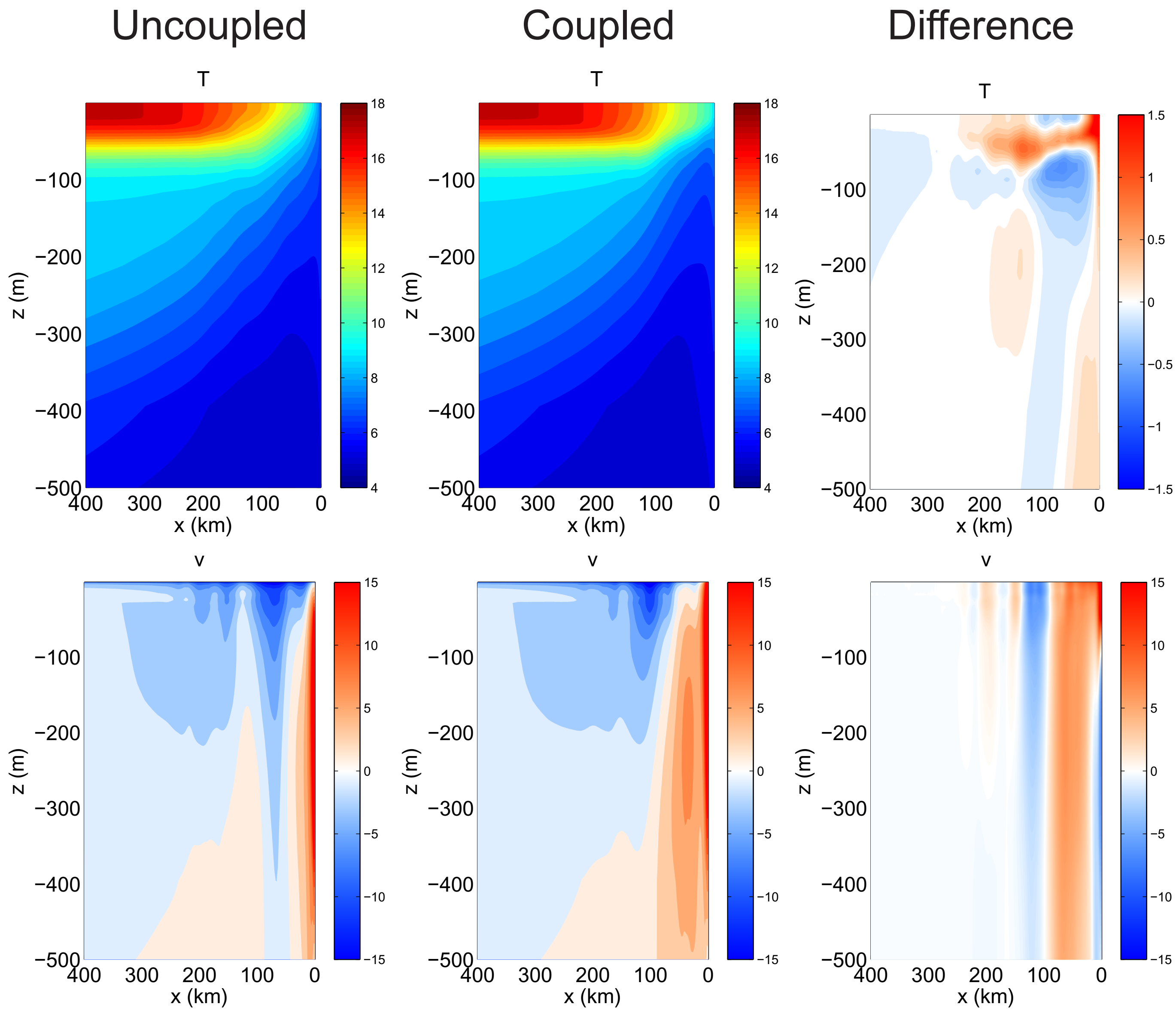
Overview of Model Results

- *The 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 and weakening the mesoscale eddy field.*
- *The nearshore positive wind stress curl also:*
  - *causes the equatorward surface current to become shallower and weaker*
  - *broadens and increases the transport of the poleward undercurrent by Sverdrup dynamics.*

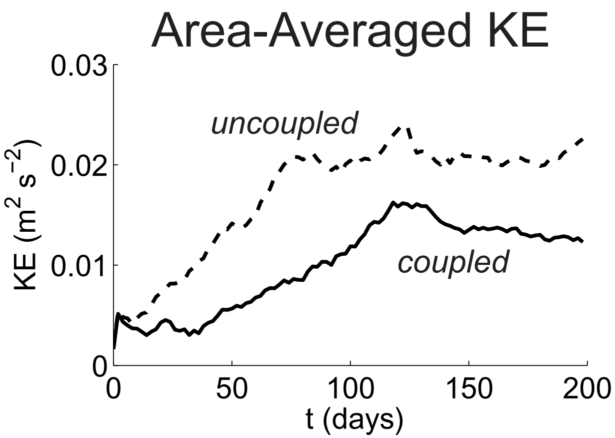
Average Wind Stress
Days 40-80
(negative southward)



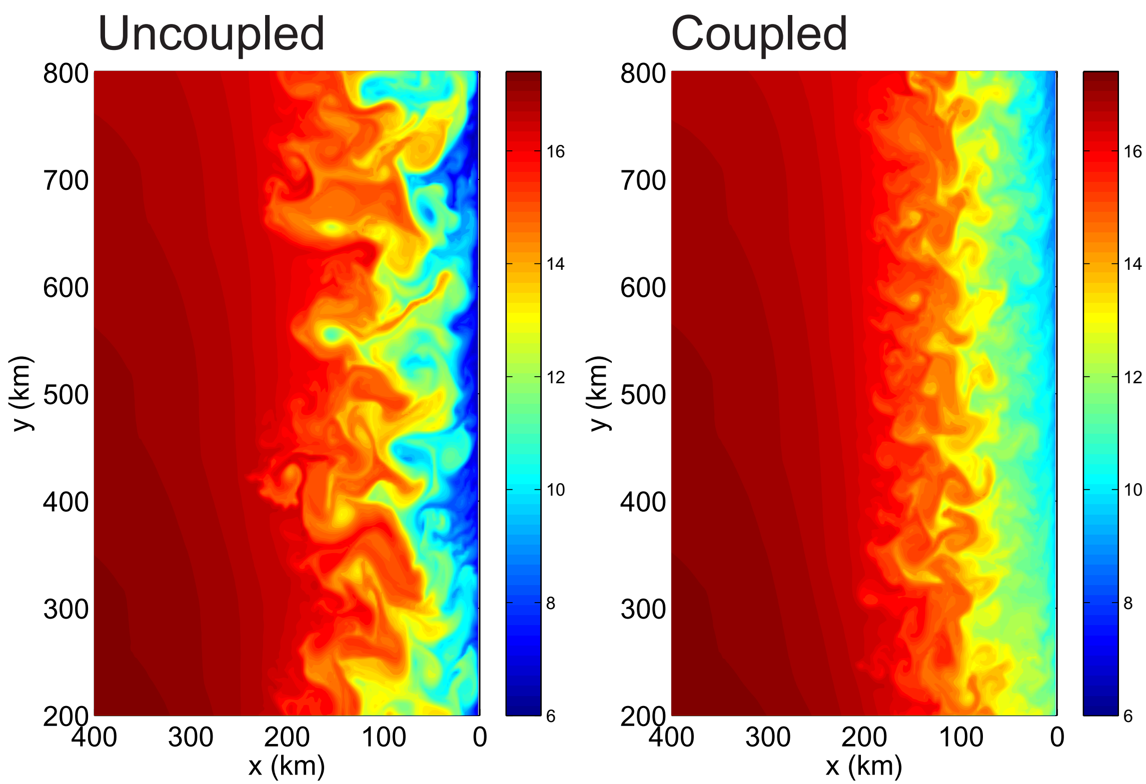
Wind Stress, Temperature and Alongshore Velocity



Temporal Evolution of the Eddy Field

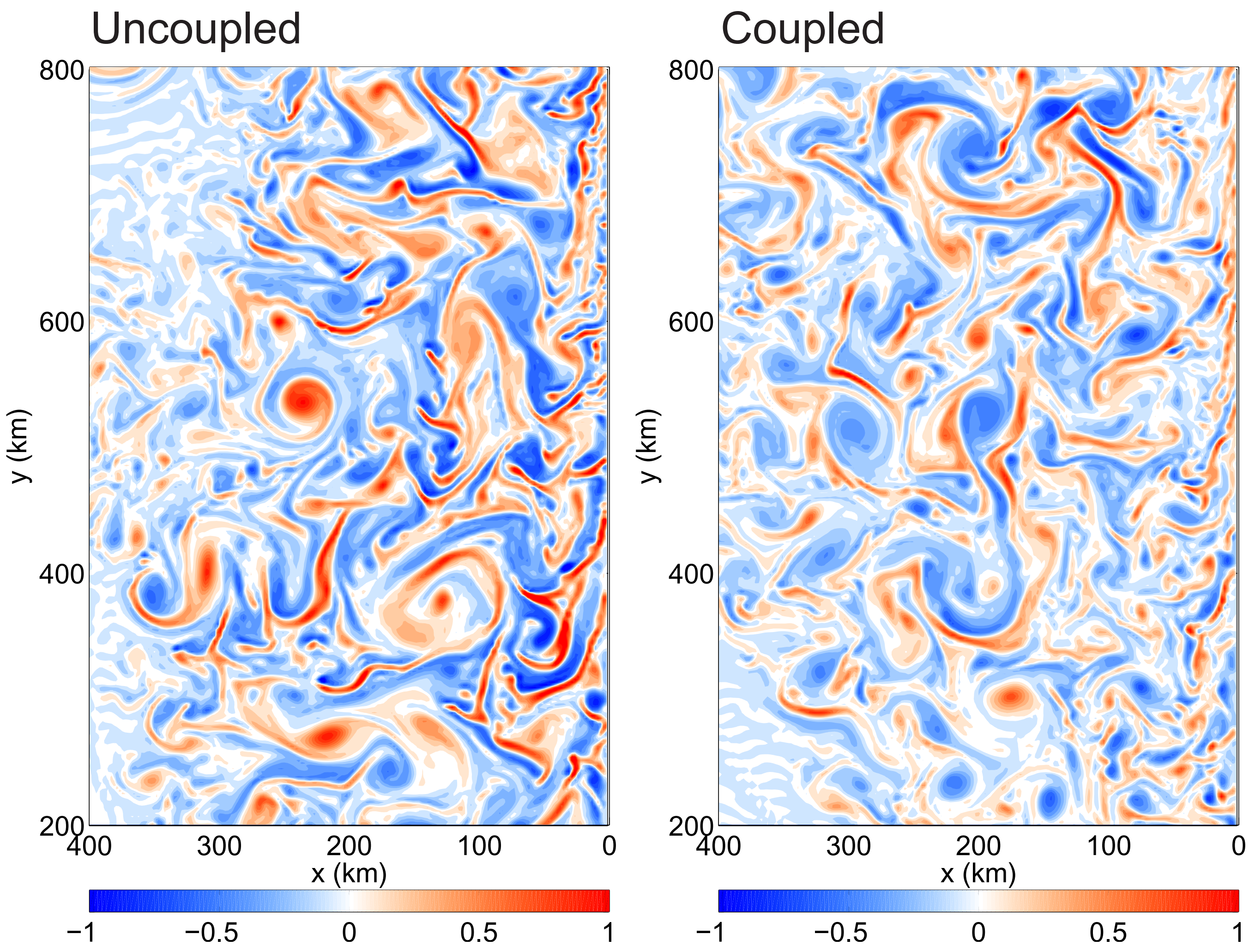


Sea-Surface Temperature, Day 60



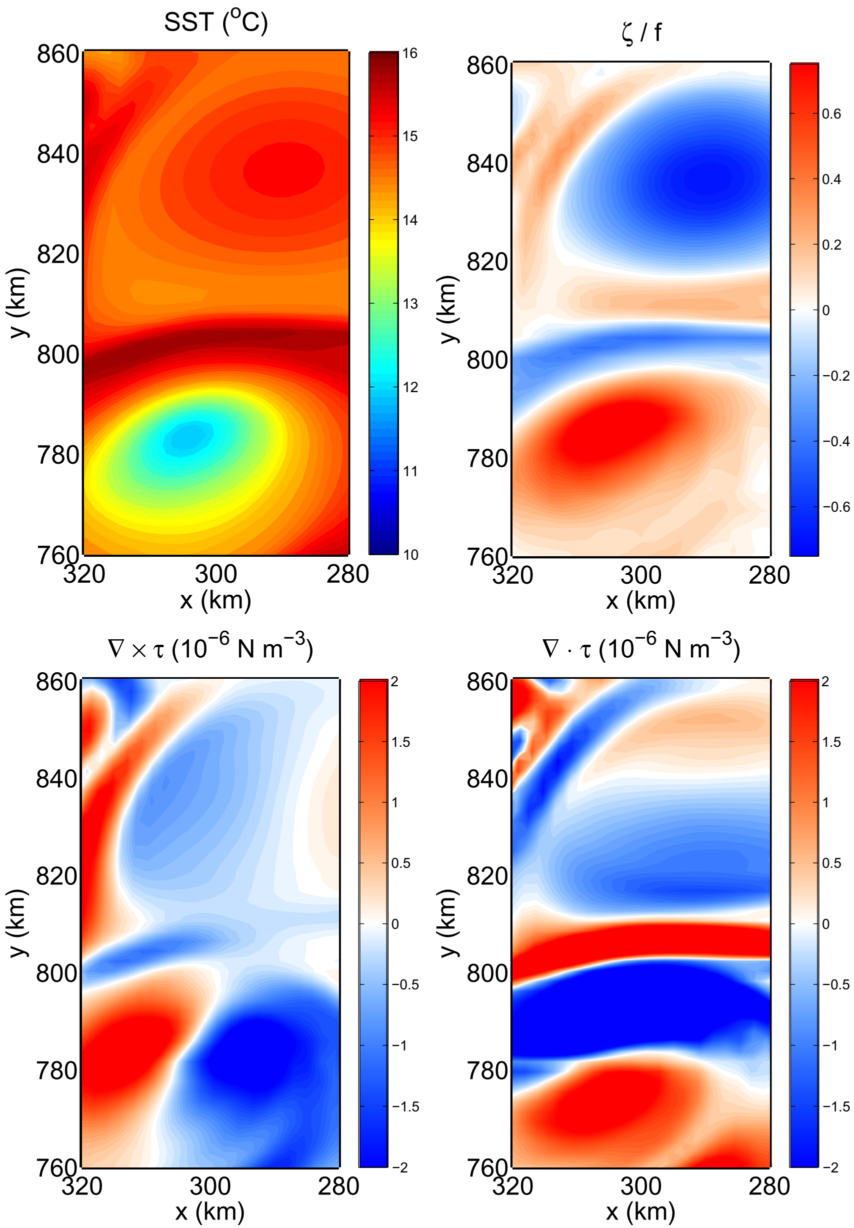
Note the weaker cross-shore gradient of SST and the weaker eddy kinetic energy in the coupled model run.

Surface Vorticity (Normalized by f) on Day 150



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

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 as a consequence of hydrostatic thermal wind balance:*

  => cyclonic vortices have larger SST and SSH extrema and smaller radial scale

- *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 that generates open-ocean upwelling.
- This ocean influence on the atmosphere is well represented in the COAMPS model run in an uncoupled configuration.
- Results from a “25-cent” fully coupled model of an idealized eastern boundary current upwelling regime conclude that:
  - *The cold upwelled water at the coast causes the nearshore winds to diminish, generating a nearshore positive wind stress curl that:*
    1) *weakens the equatorward surface current*
    2) *strengthens the poleward undercurrent*
    3) *weakens the alongshore SST front*
    4) *slows the development of baroclinic instability and weakens the mesocale eddy field*
  - *The coupling over oceanic eddies preferentially weakens cyclonic eddies, thus increasing the abundance of anticyclonic eddies.*

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

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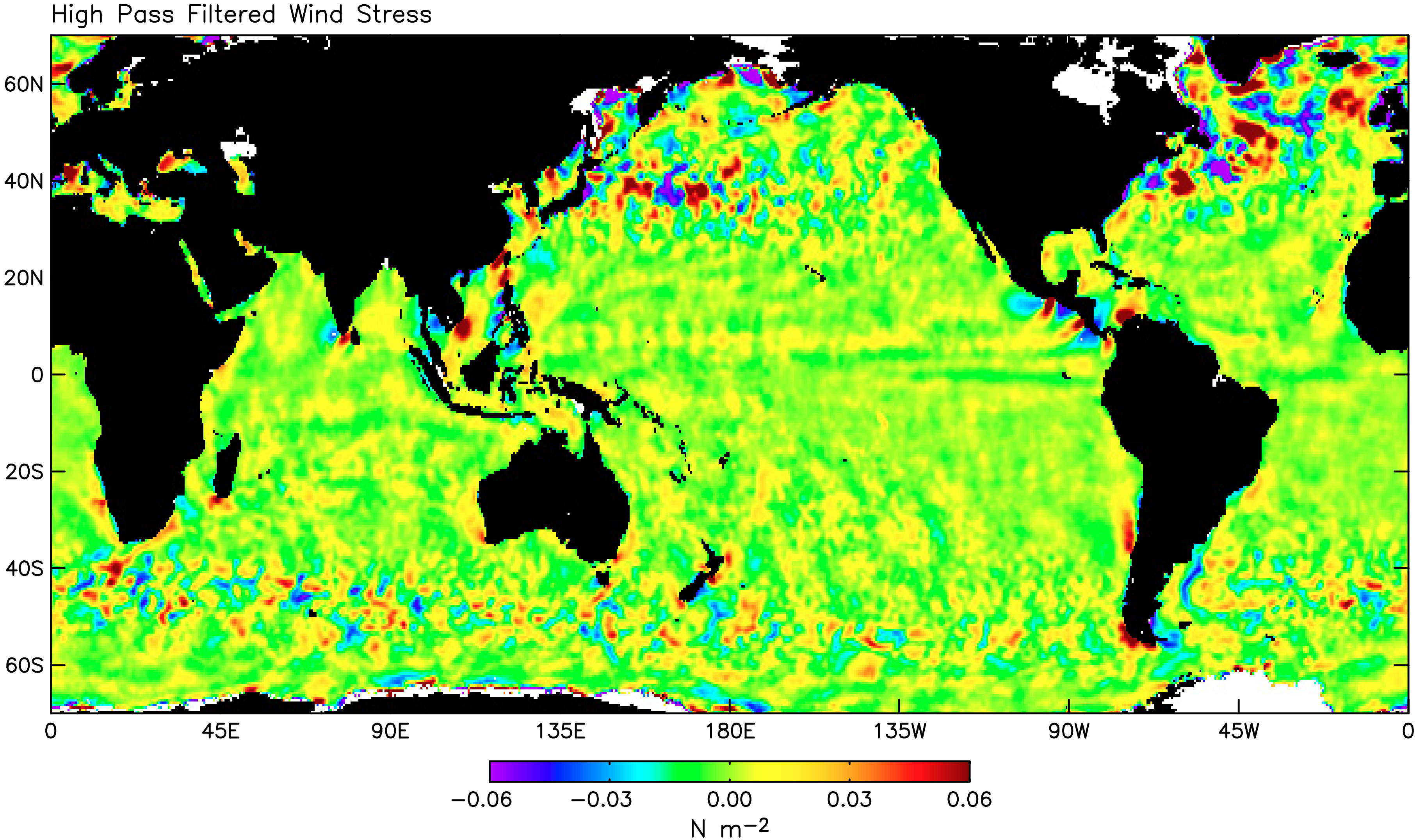
2-Month Average Wind Stress Magnitude

(Spatially High-Pass Filtered)

Northern Hemisphere Winter

QuikSCAT, January–February 2003



2-Month Average Wind Stress Magnitude and SST Contours

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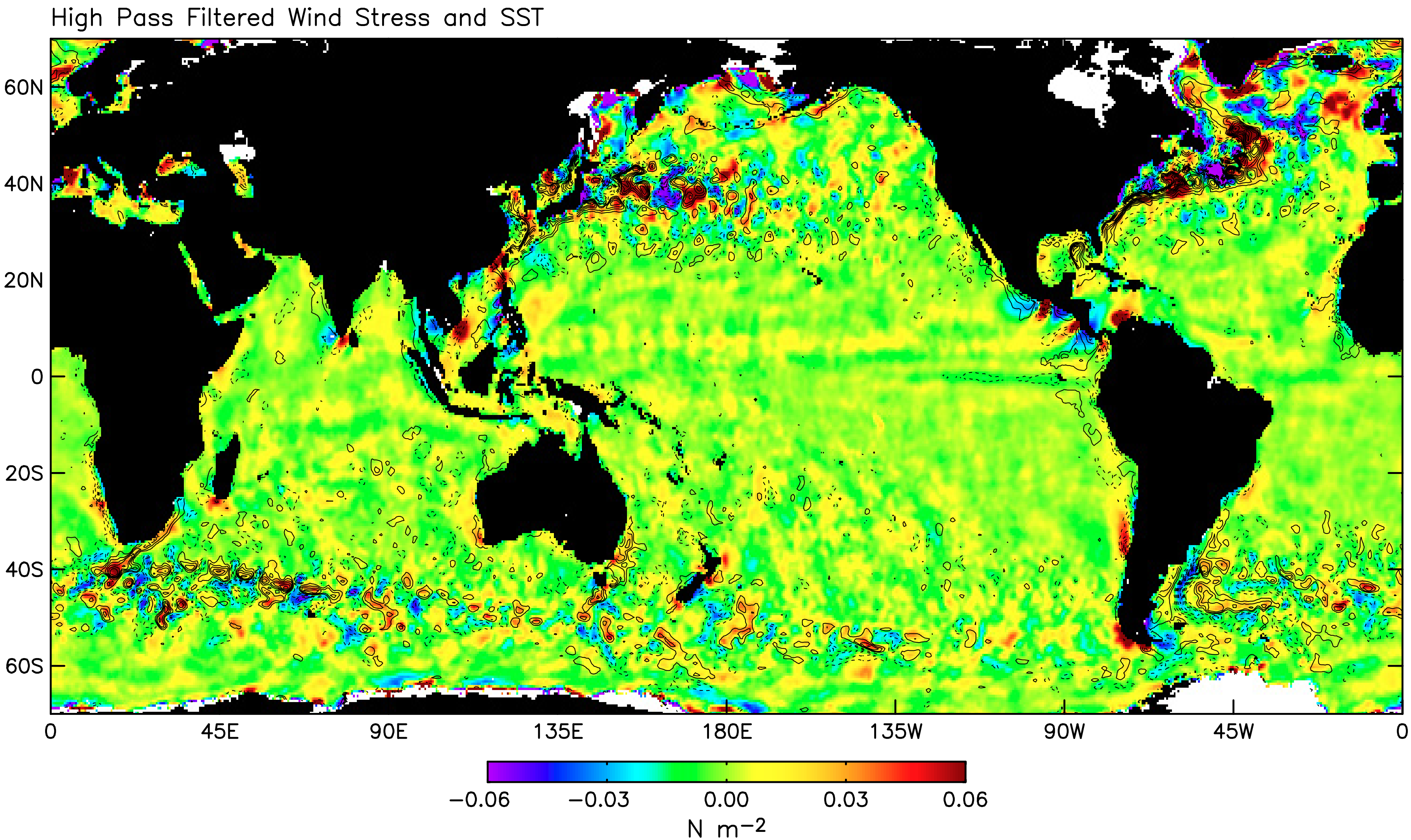

2-Month Average Wind Stress Magnitude and SST Contours

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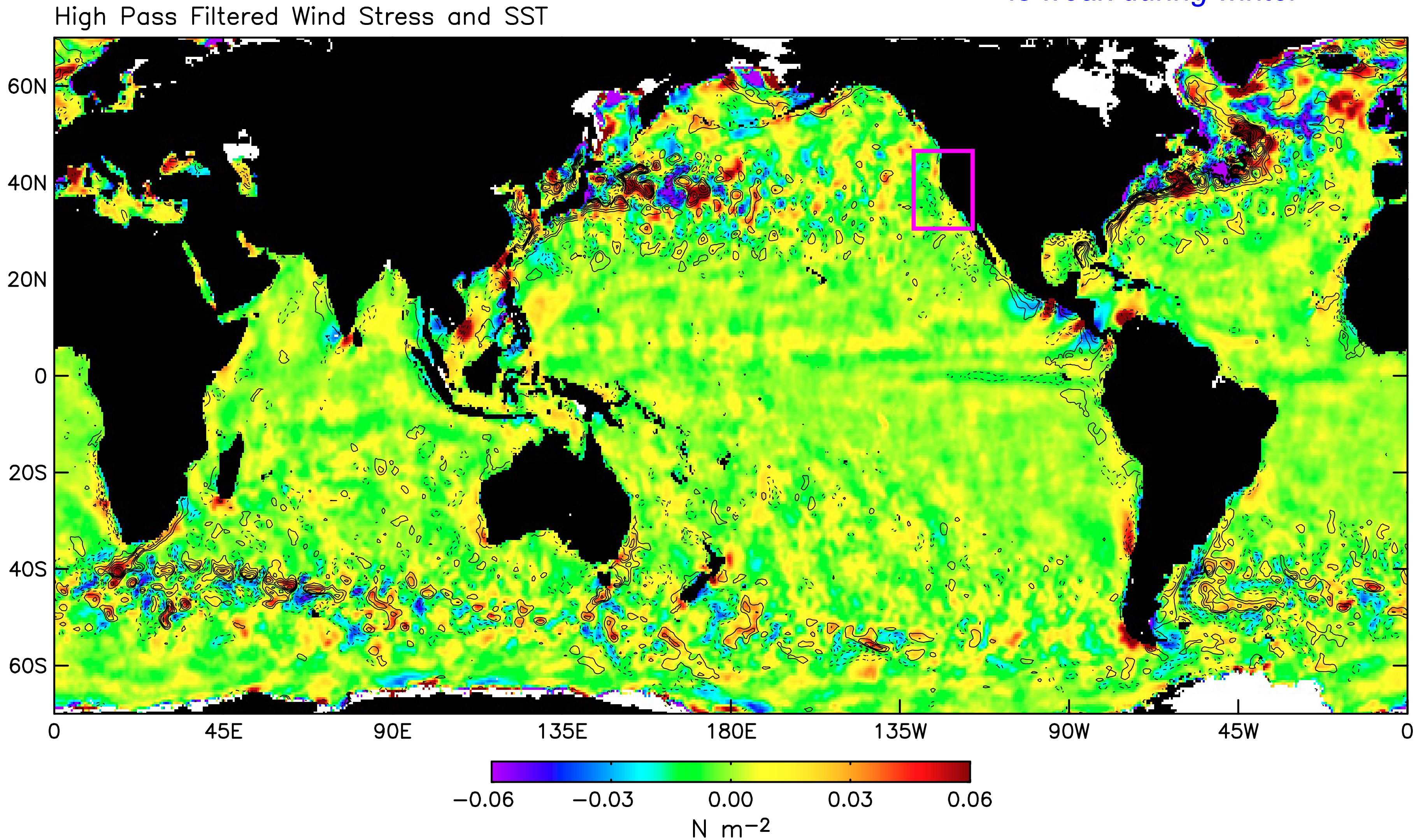
Northern Hemisphere Winter

QuikSCAT, January–February 2003

SST influence in the California Current region is weak during winter



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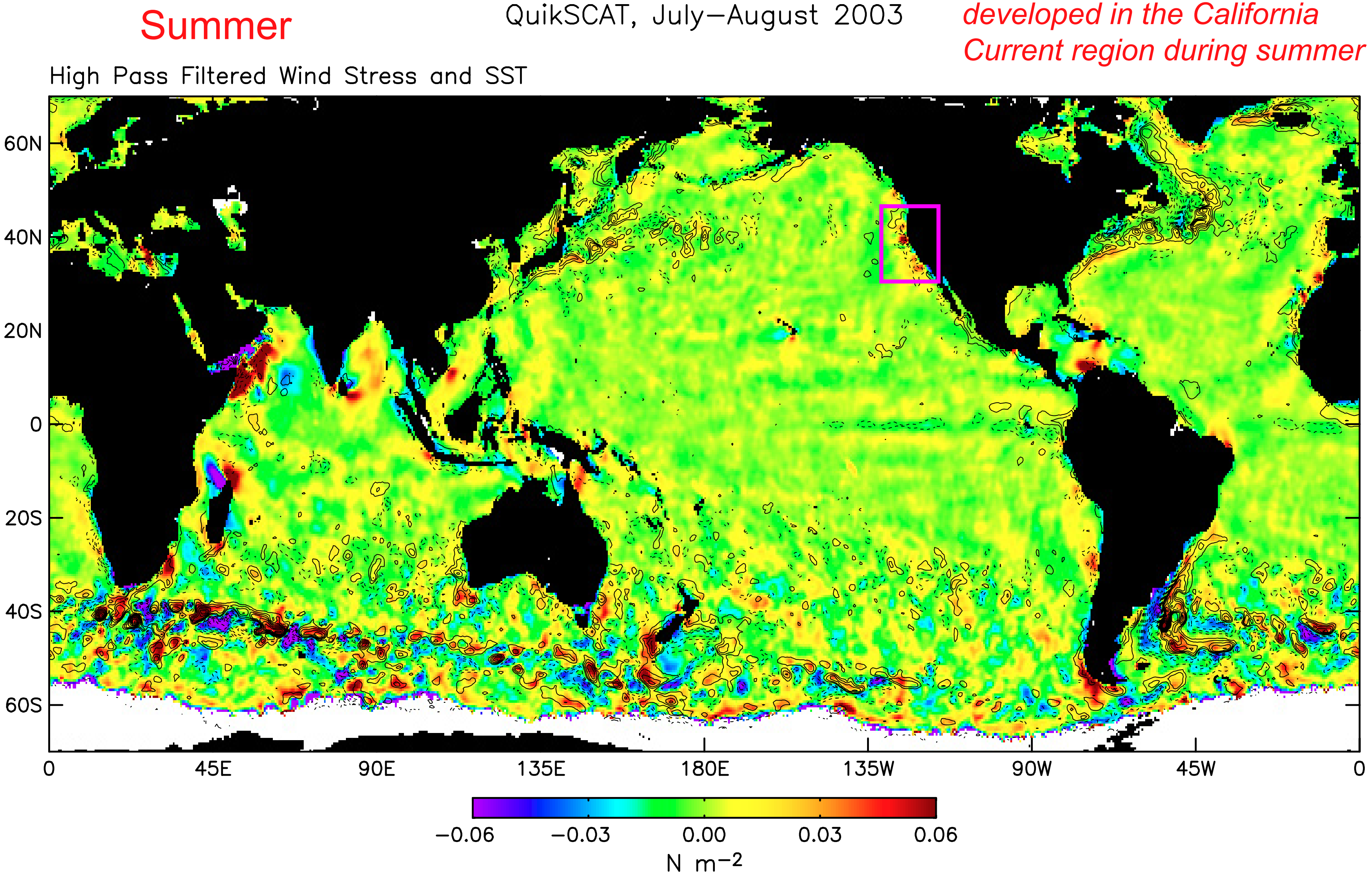
Small-scale structure is well developed in the California Current region during summer



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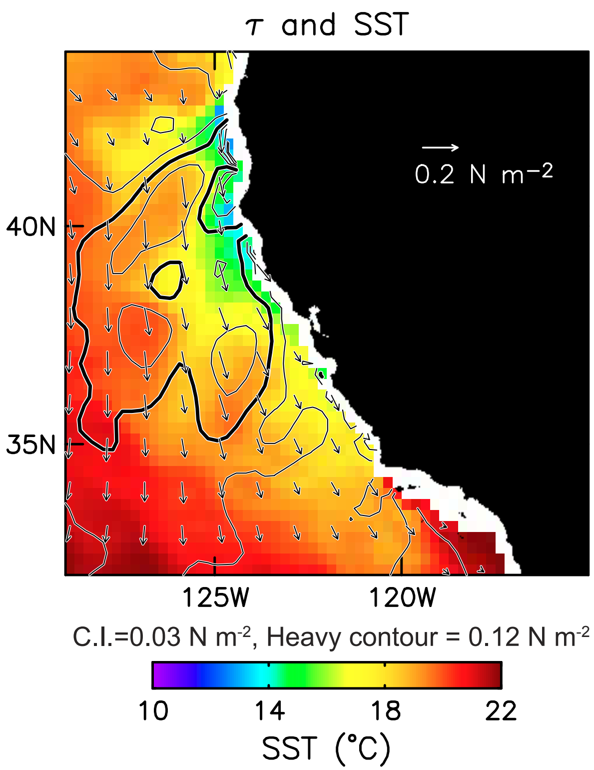
d) 5 September 2004, QuikSCAT and COAMPS SST



COAMPS® Model Run with Two Different SST Boundary Conditions:
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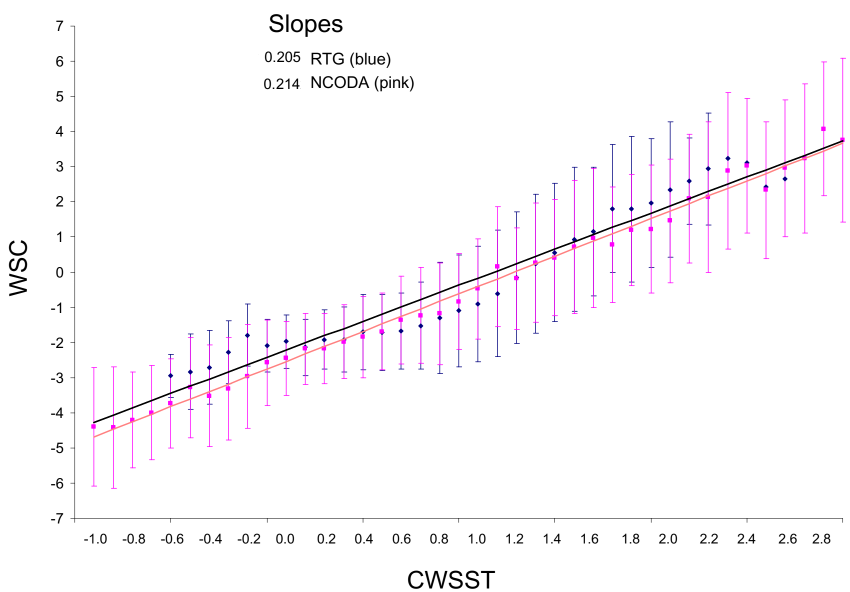
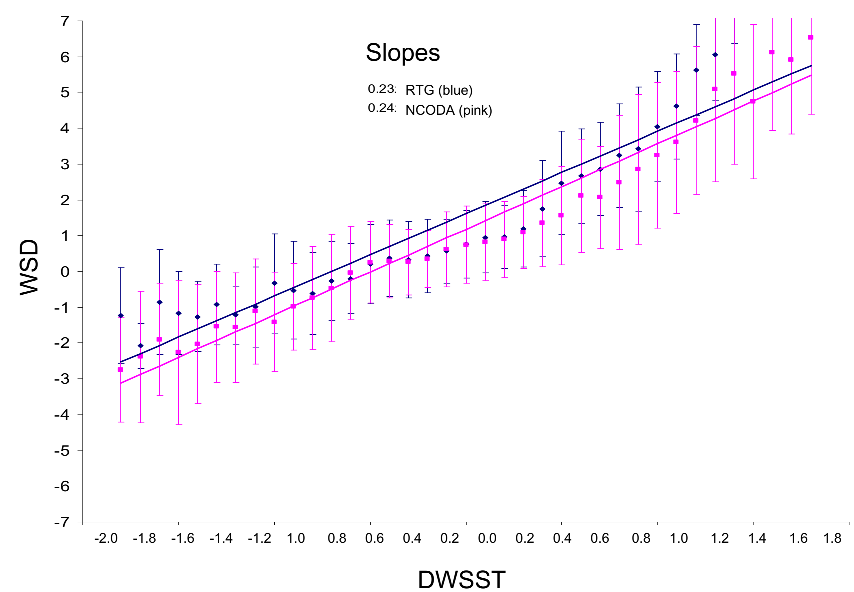
Coupling Coefficients

Wind Stress Curl



Wind Stress Divergence



The coupling coefficients are nearly identical for both model runs, indicating that they are an intrinsic measure of the boundary layer dynamics within the model.

- A given SST anomaly therefore generates a given wind stress response, regardless of the accuracy and resolution of that SST anomaly.