Climate Applications of Ocean Surface Vector Winds

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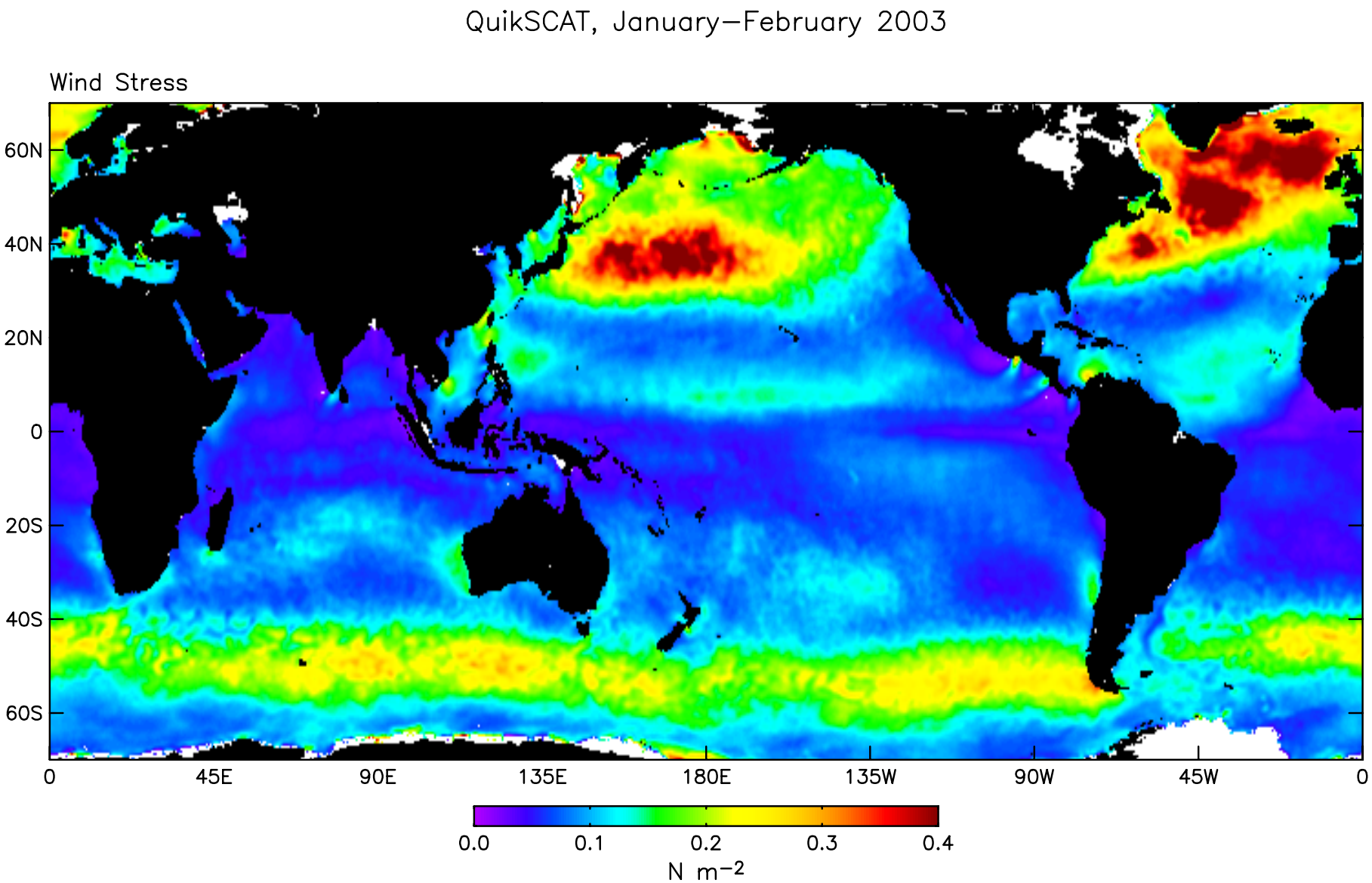
Issues:

- *Accuracy*
- *Spatial Resolution*
- *Global Coverage*
- *Continuity of Data Record*
- *Length of Data Record*

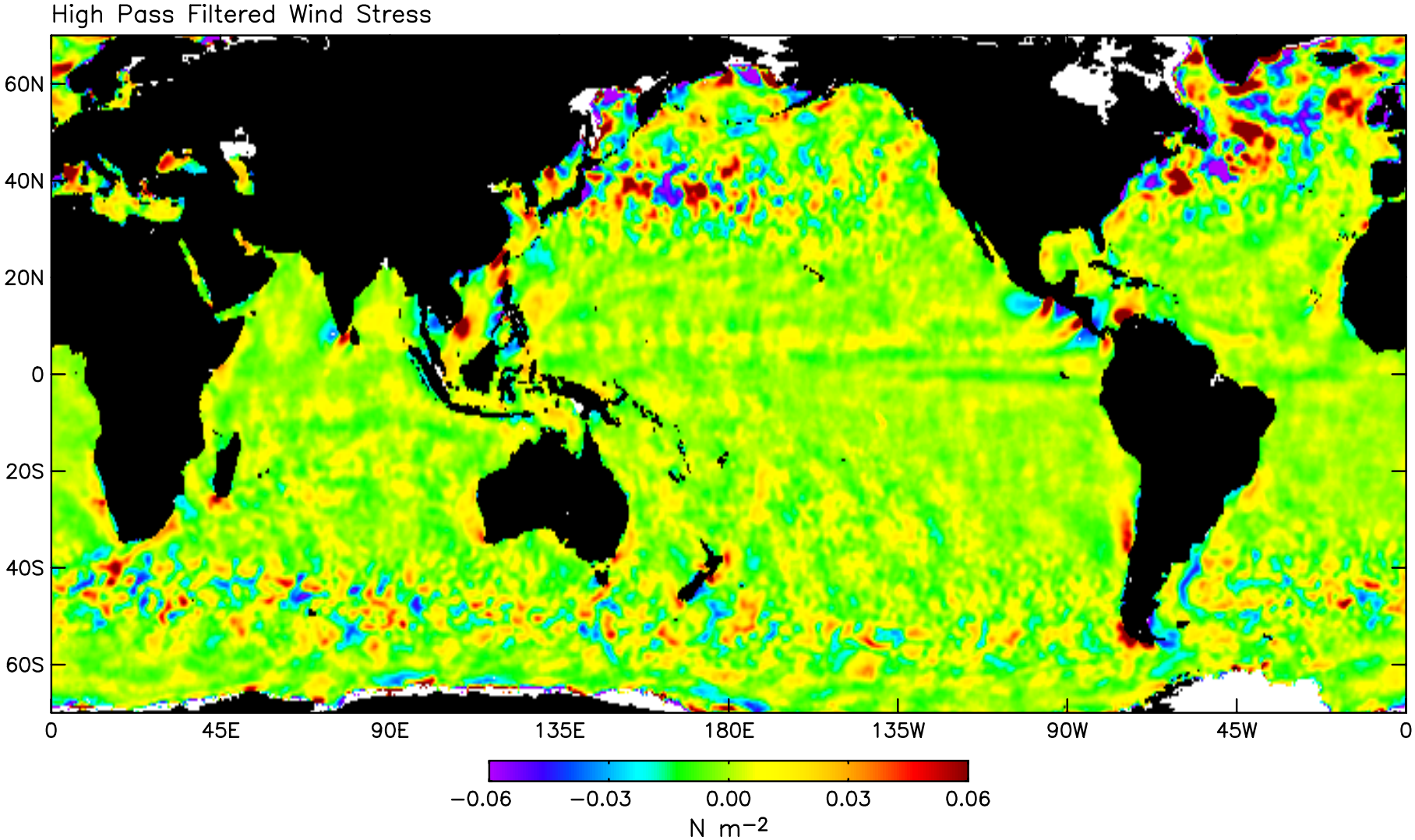
2-Month Average Wind Stress Magnitude



2-Month Average Wind Stress Magnitude

(Spatially High-Pass Filtered)

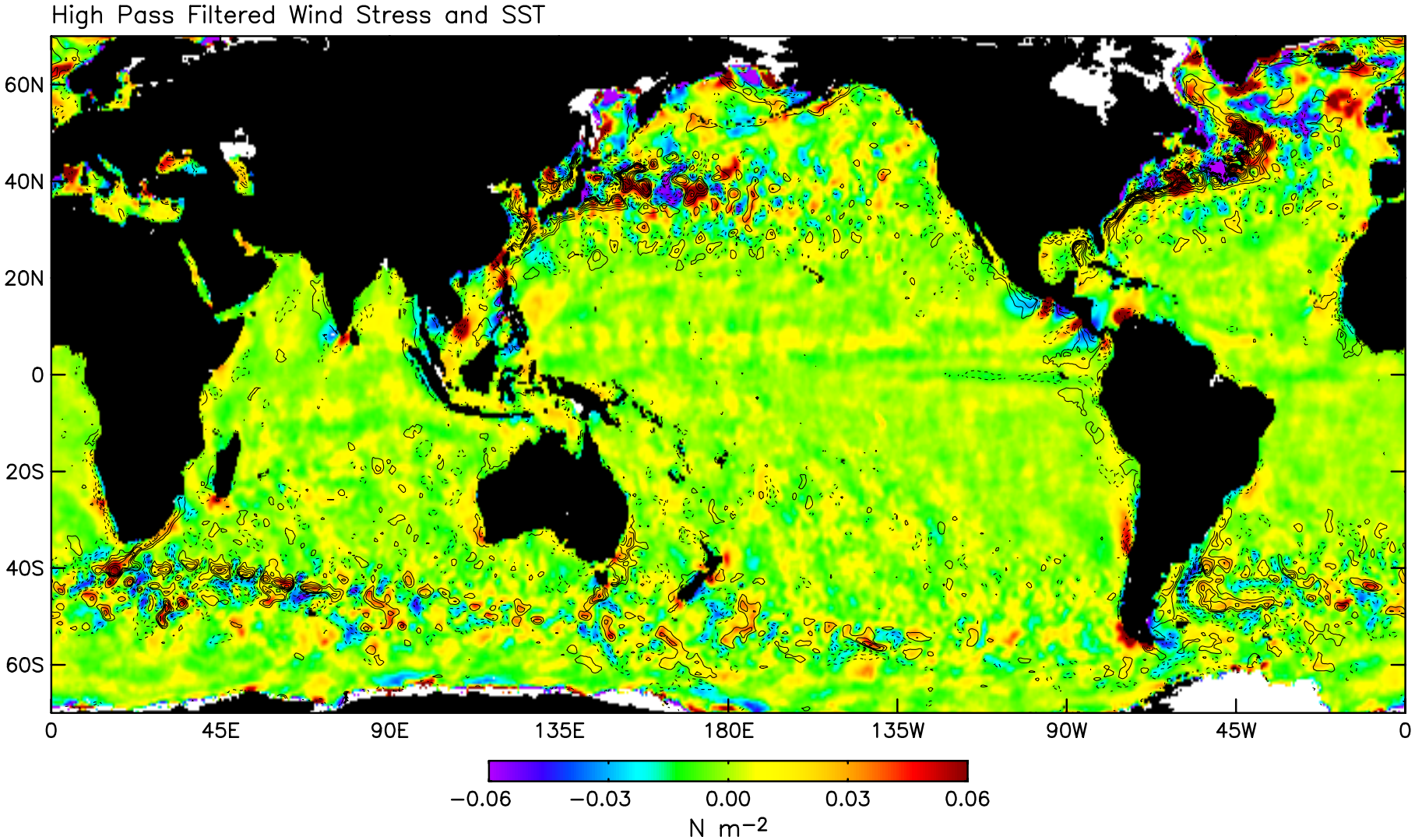
QuikSCAT, January–February 2003



2-Month Average Wind Stress Magnitude and SST

(Spatially High-Pass Filtered)

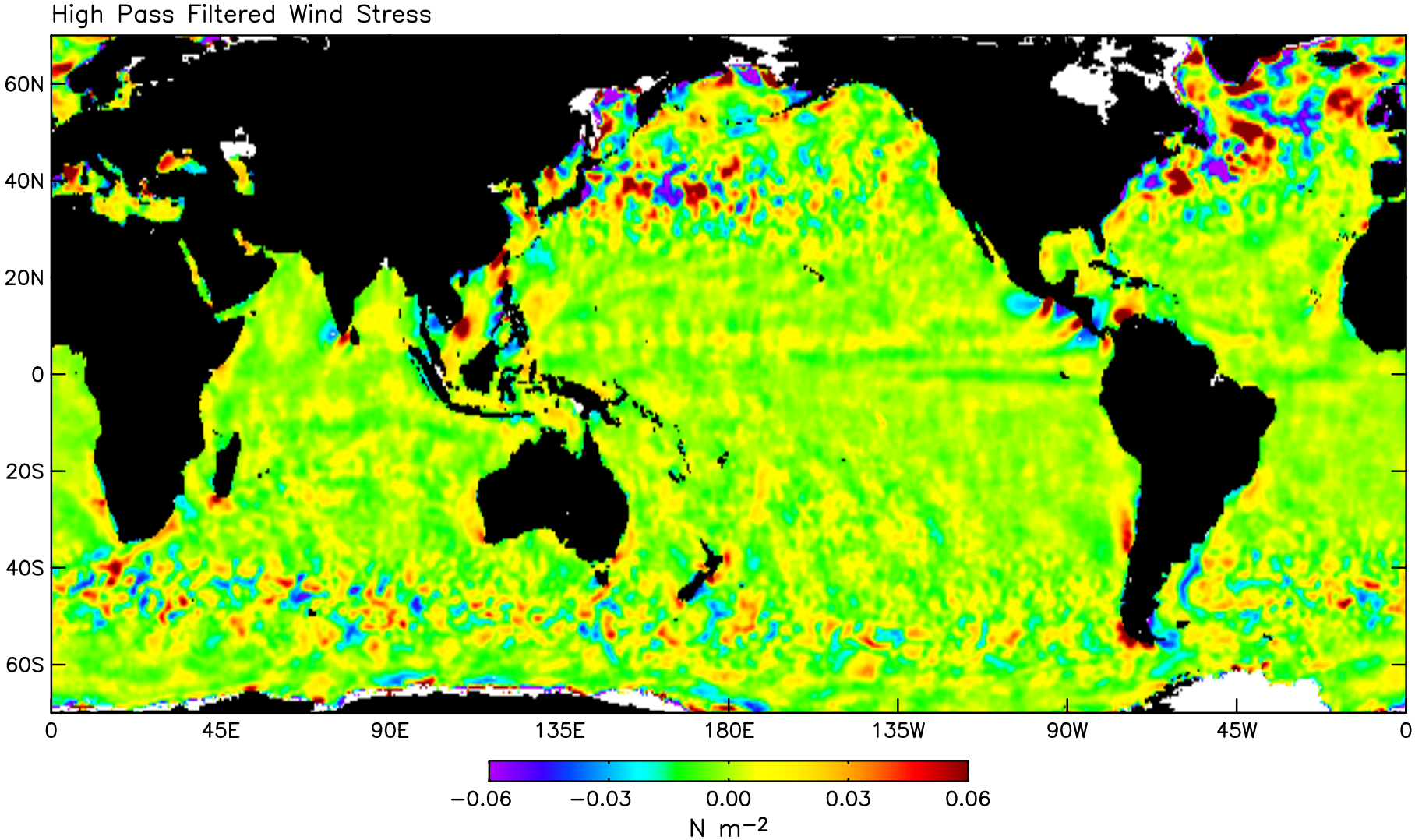
QuikSCAT, January–February 2003



2-Month Average Wind Stress Magnitude

(Spatially High-Pass Filtered)

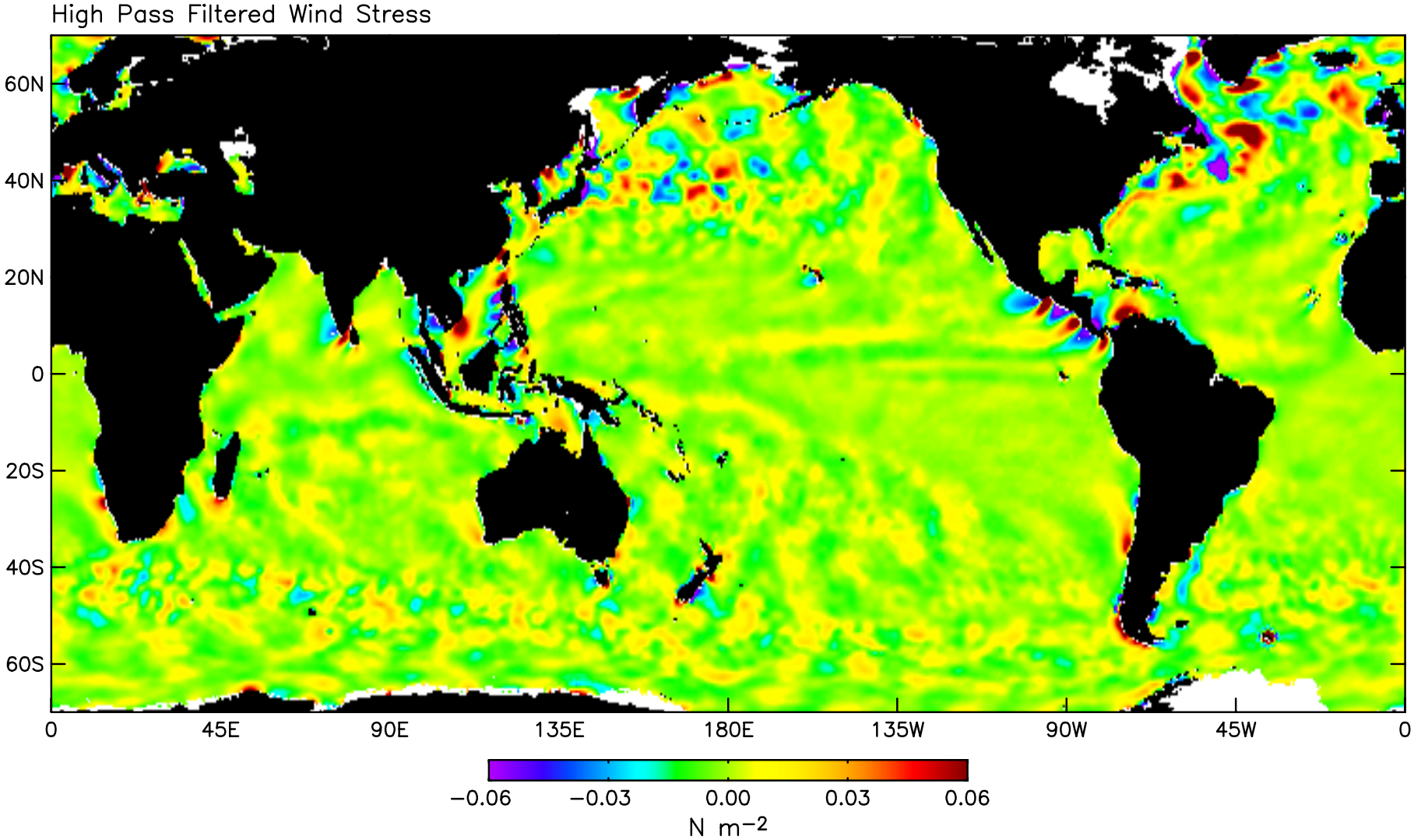
QuikSCAT, January–February 2003



2-Month Average Wind Stress Magnitude

(Spatially High-Pass Filtered)

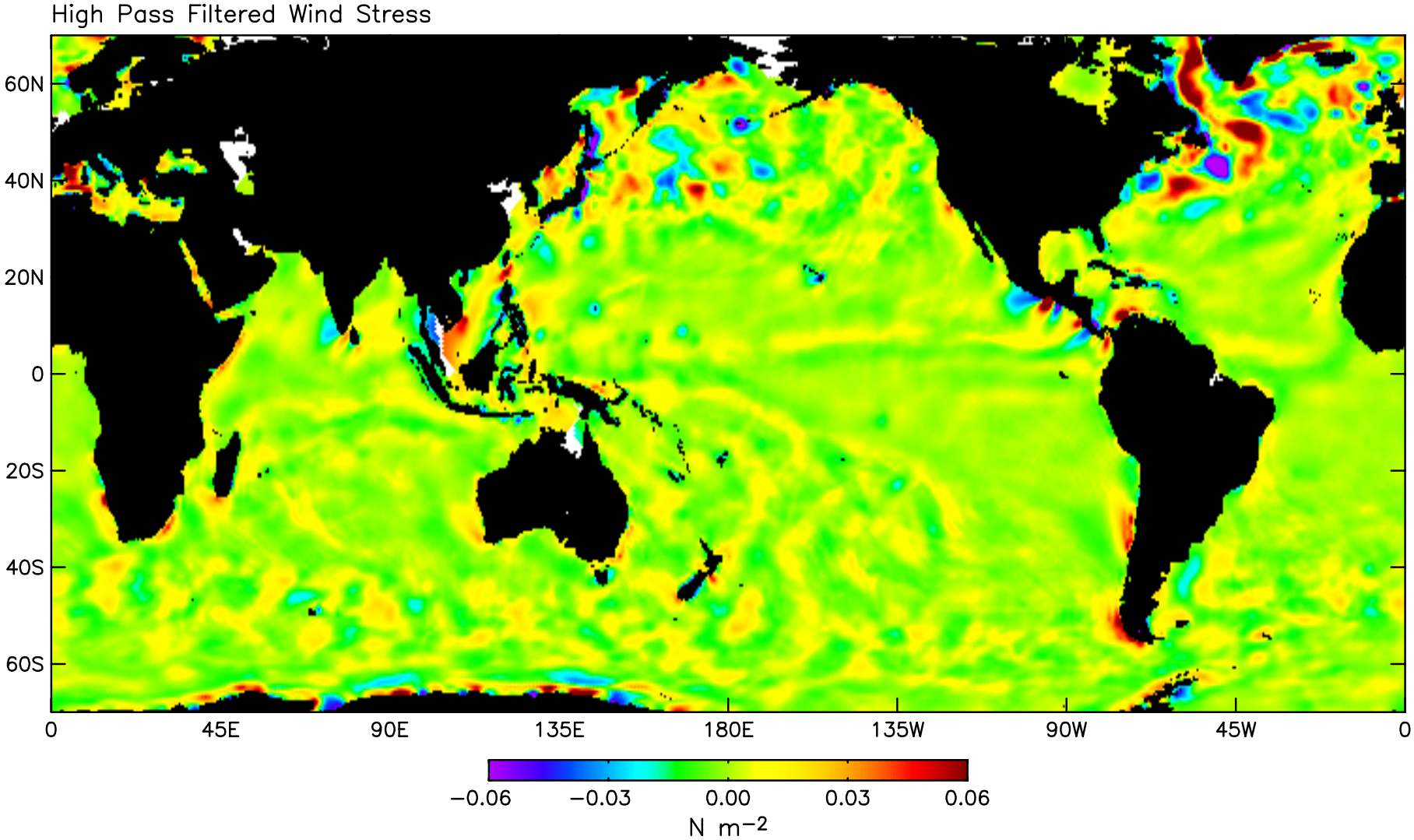
ECMWF, January–February 2003



2-Month Average Wind Stress Magnitude

(Spatially High-Pass Filtered)

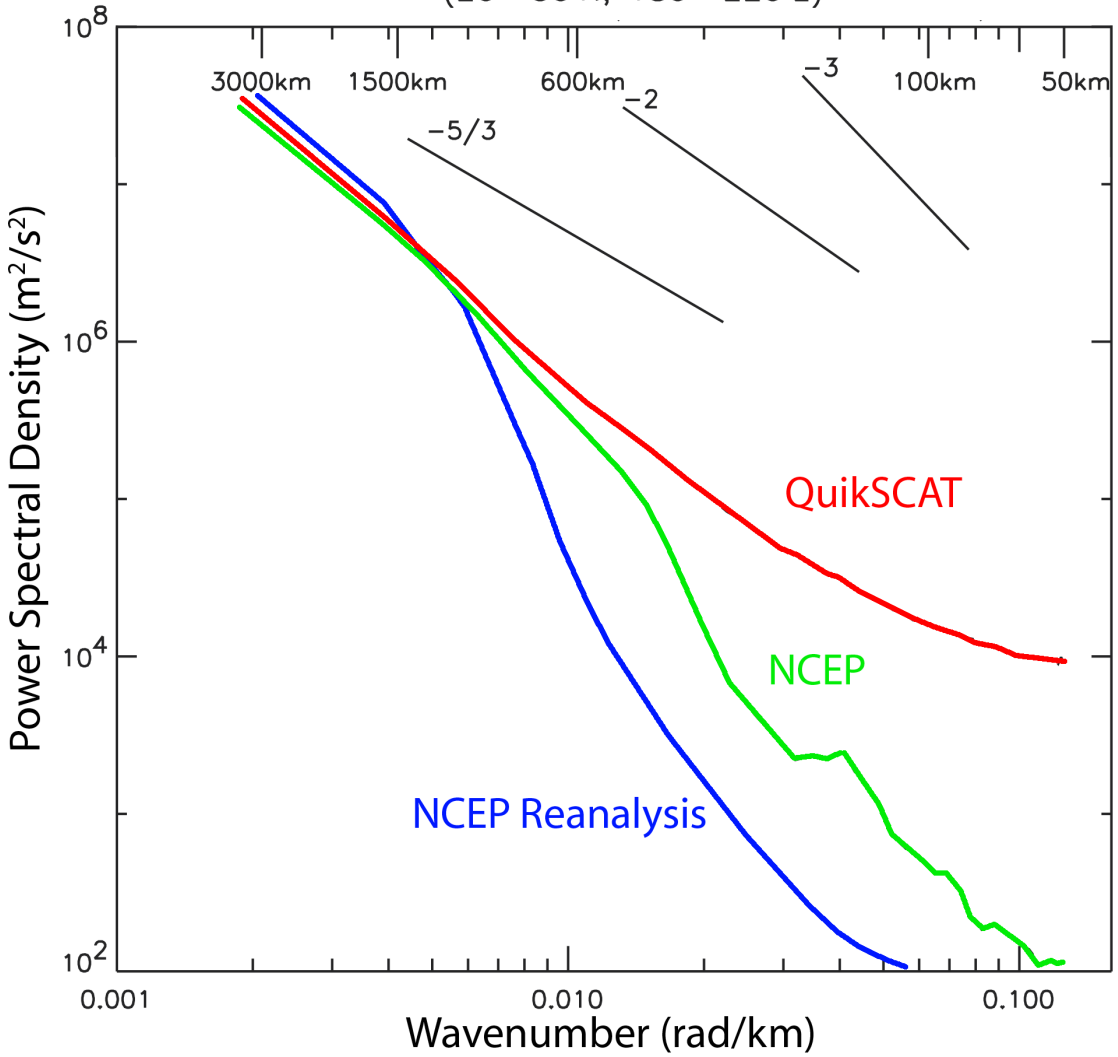
NCEP, January–February 2003



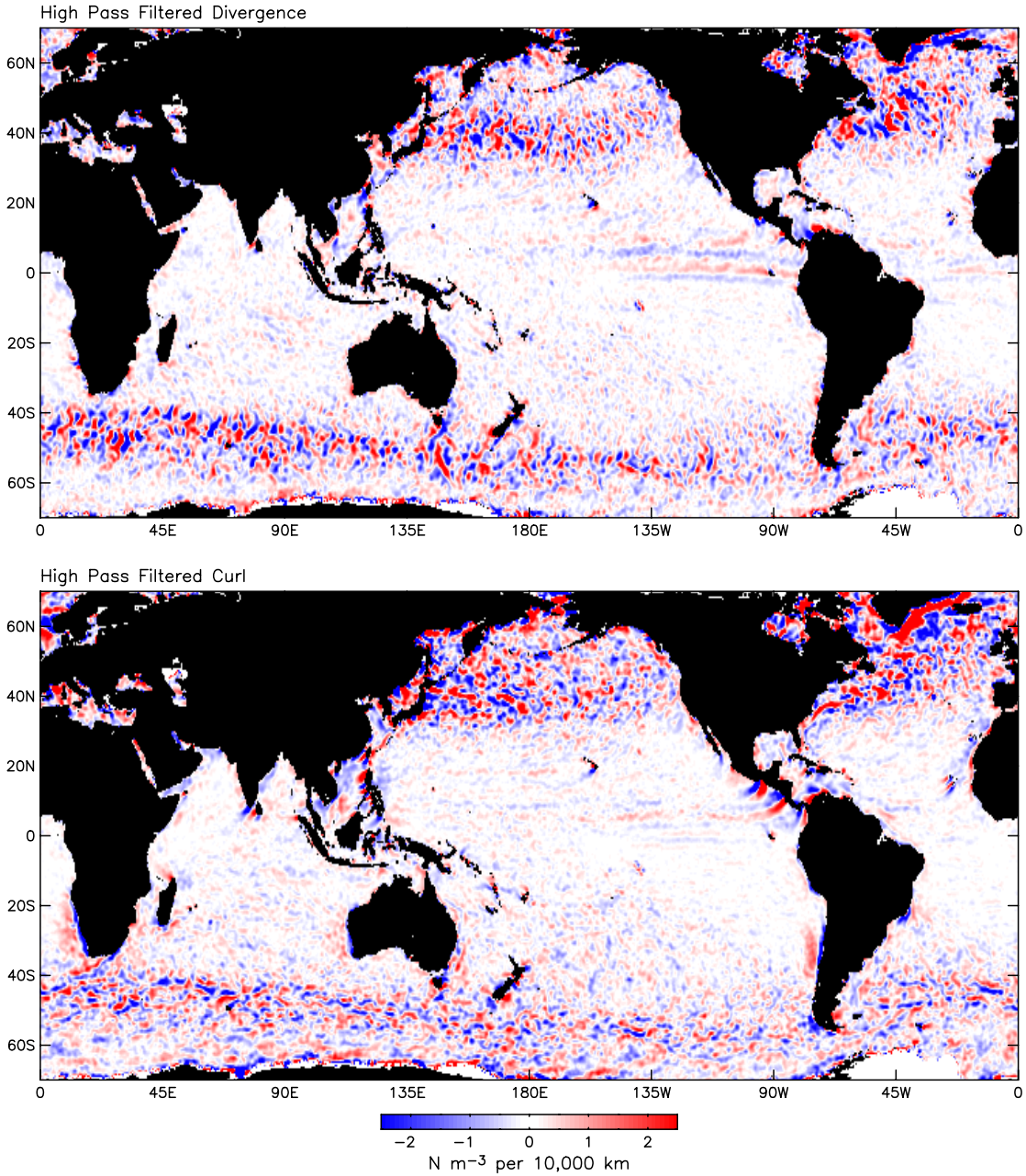
Wavenumber Spectra of Zonal Wind

January - December 2000

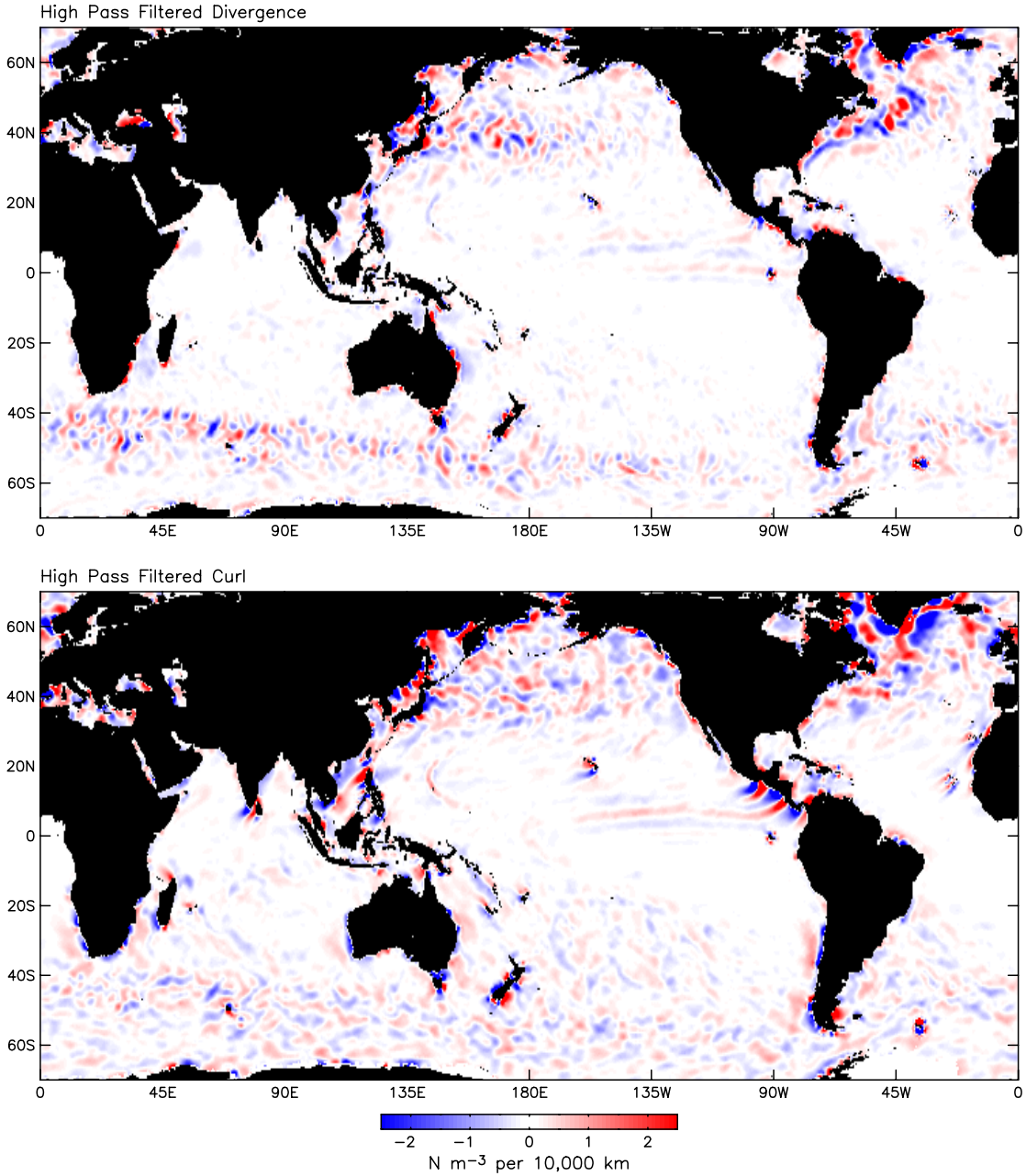
(20°–50°N, 180°–220°E)



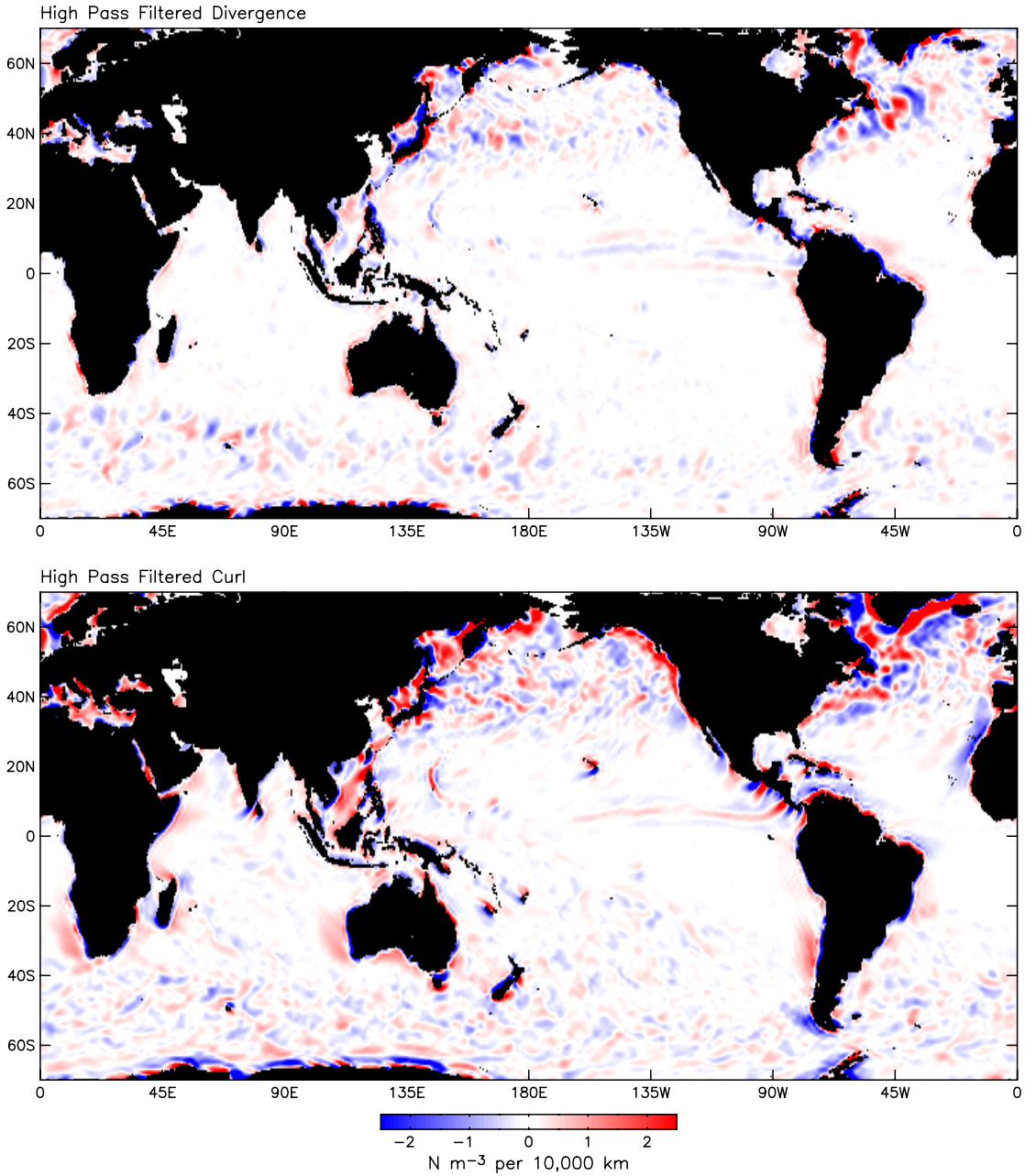
QuikSCAT, November 2002 – February 2003



ECMWF, November 2002 – February 2003



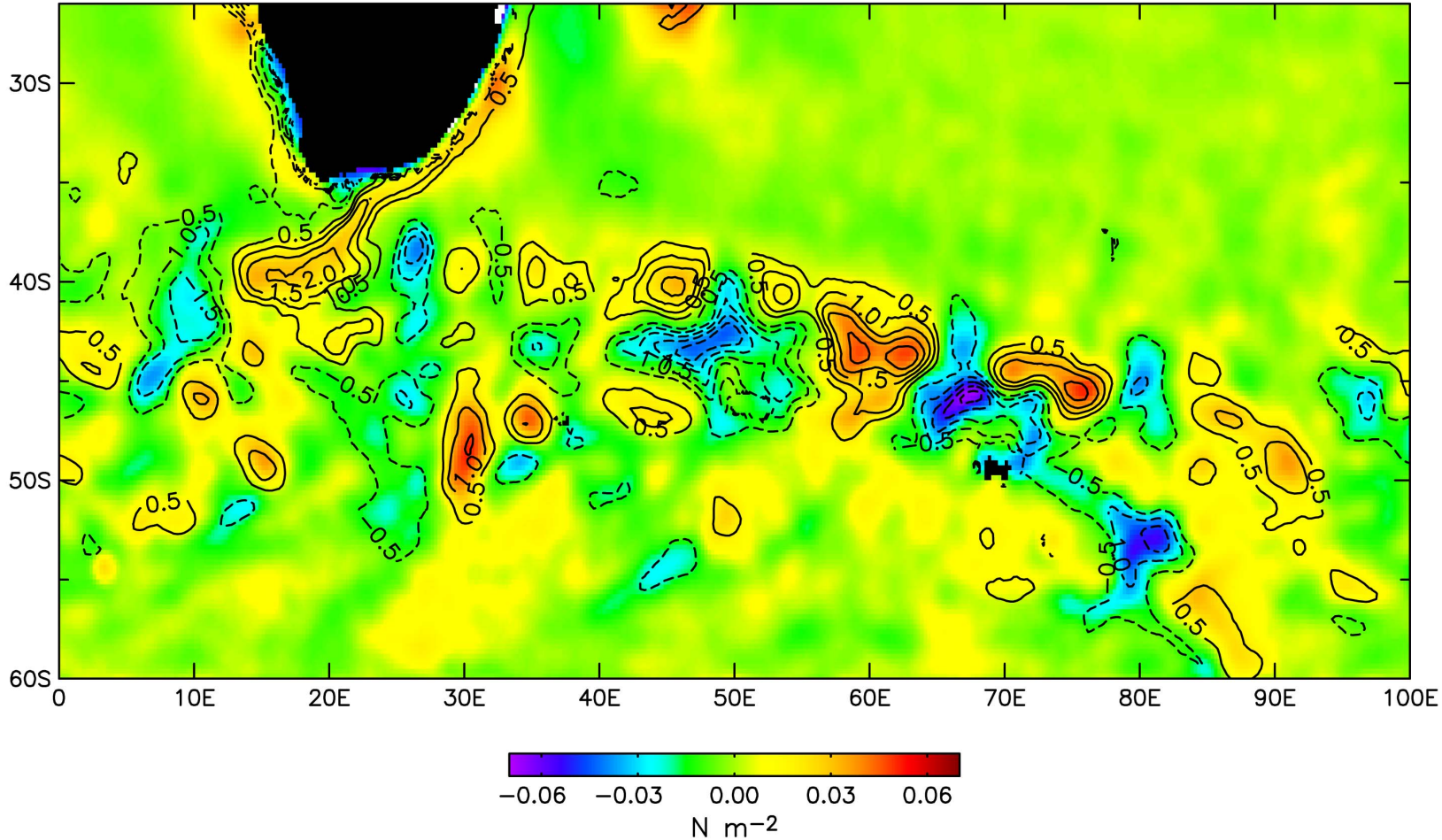
NCEP, November 2002 – February 2003



South Indian Ocean Region

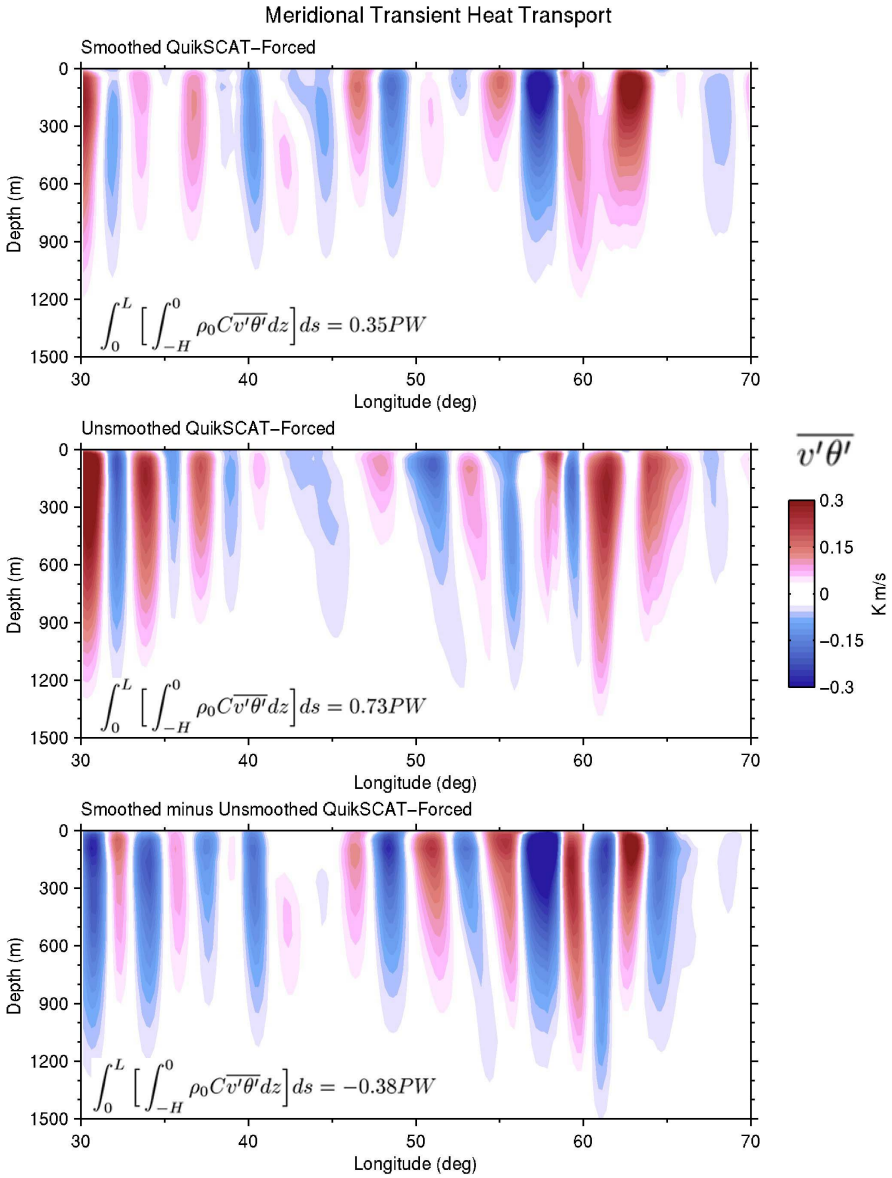
Filtered 2-Year Average QuikSCAT Wind Stress Magnitude and AMSR Sea Surface Temperature Contours

August 2002 - July 2004



Meridional Eddy Heat Transport in the South Indian Ocean

(O'Neill et al., 2006)

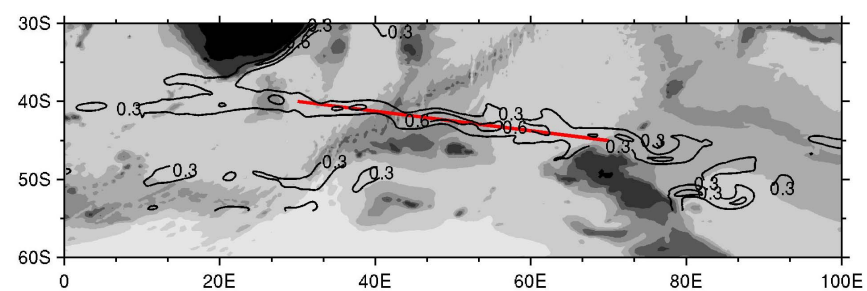


The MOM2 model was forced with 4-year average QuikSCAT winds in two ways:

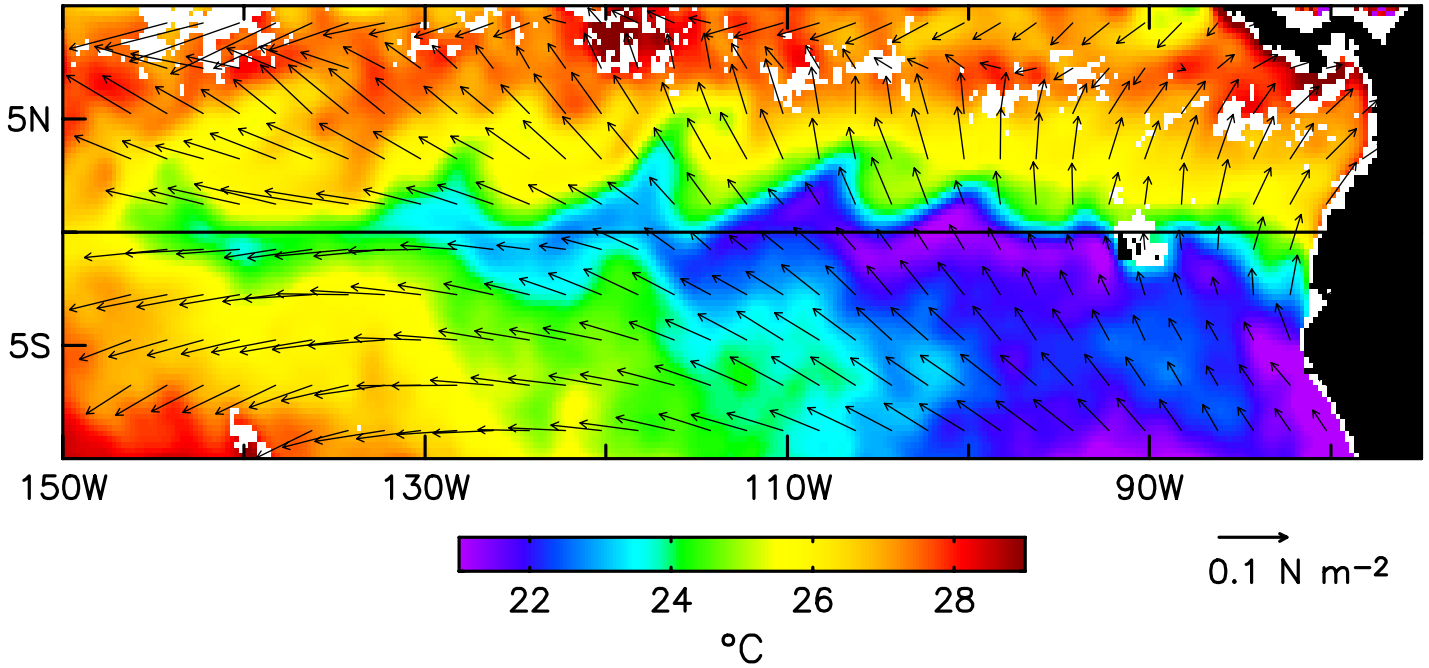
- *Raw 25-km QuikSCAT wind stress*
- *QuikSCAT wind stress spatially smoothed to retain only the large scales that are resolved by the NCEP global forecast model.*

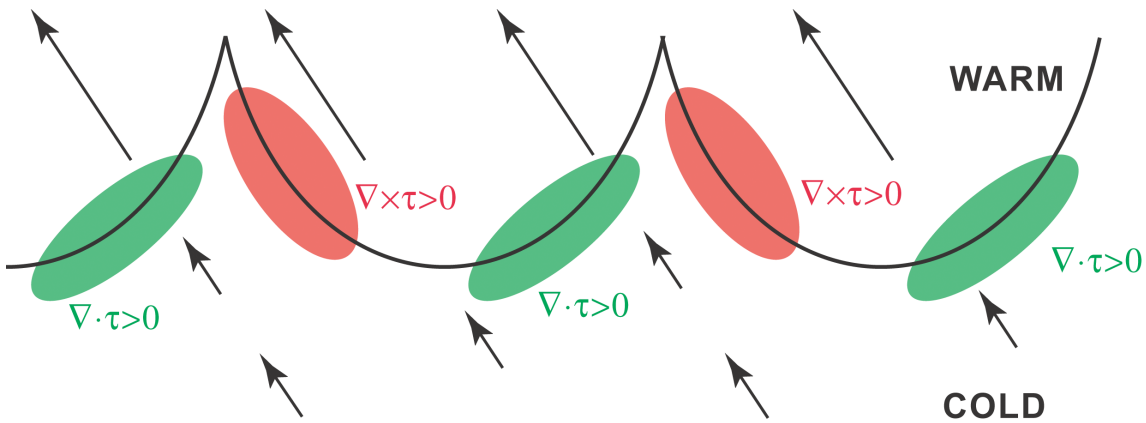
Result:

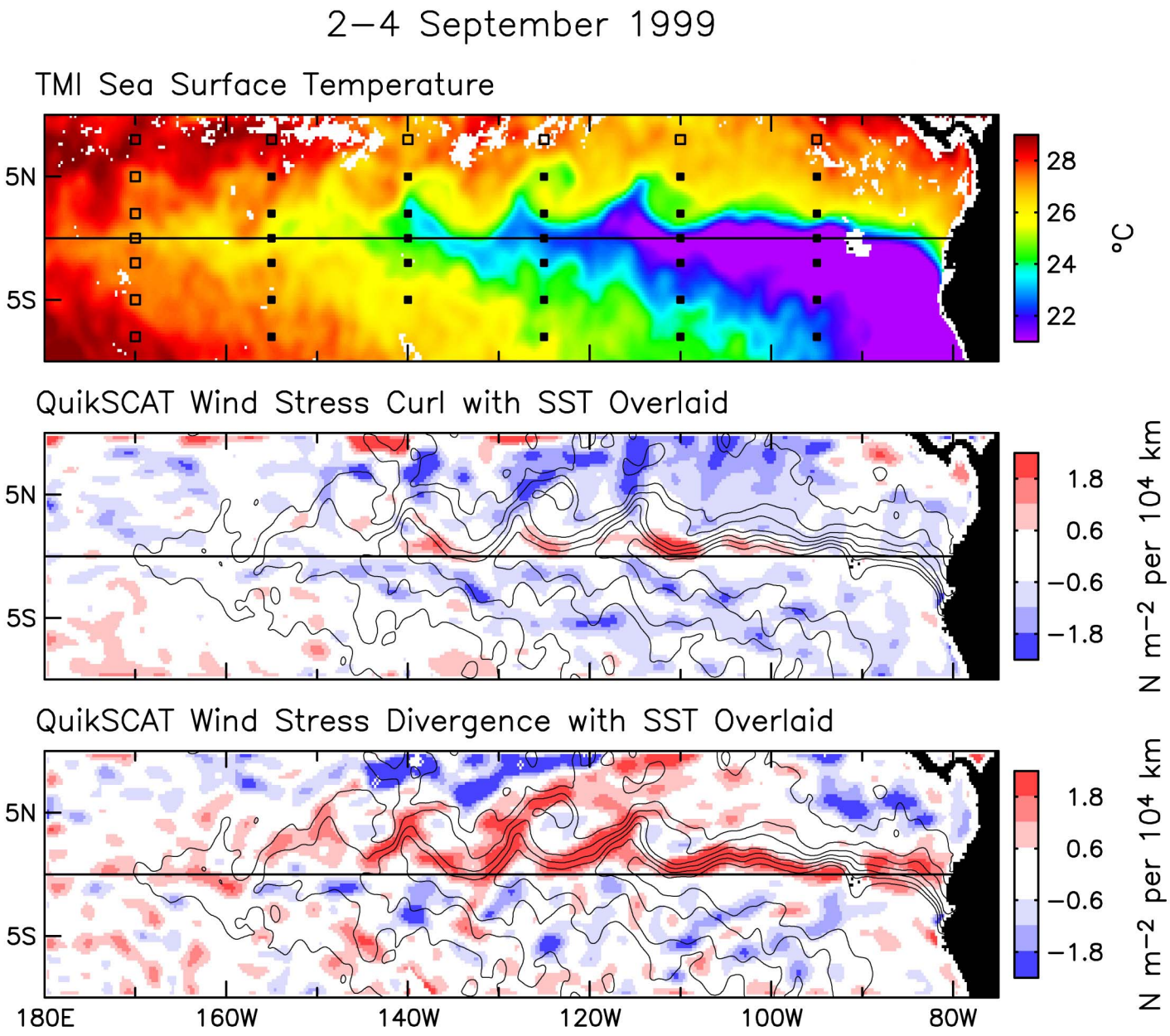
The meridional heat transport is twice as strong in the model forced by the smoothed wind stress field.

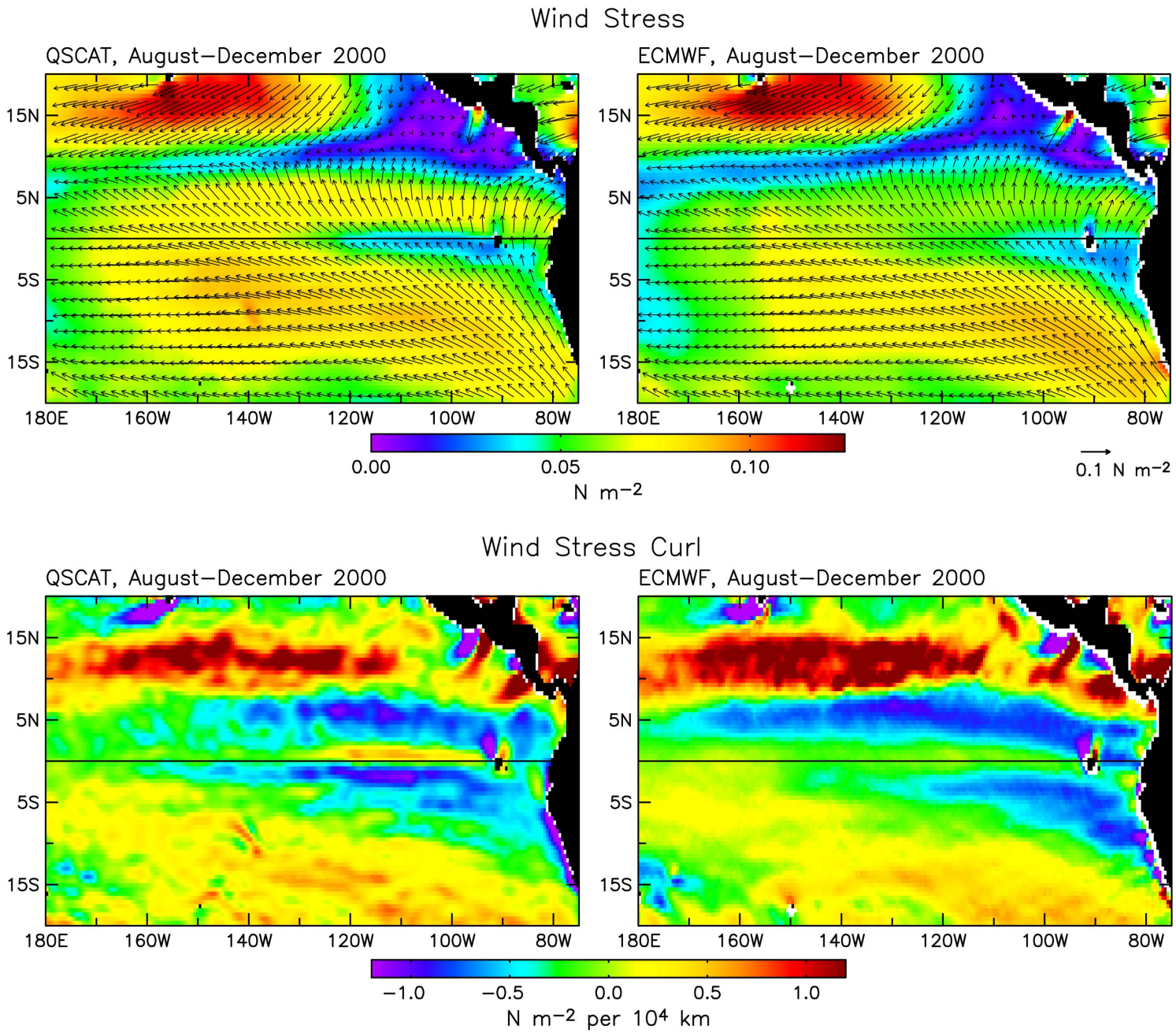


Wind Stress Vectors and SST, 12 December 2001






2–4 September 1999
TMI Sea Surface Temperature
5N
5S
28
26
24
22
°C
QuikSCAT Wind Stress Curl with SST Overlaid
5N
5S
1.8
0.6
−0.6
−1.8
N m−2 per 104 km
QuikSCAT Wind Stress Divergence with SST Overlaid
5N
5S
1.8
0.6
−0.6
−1.8
N m−2 per 104 km
180E
160W
140W
120W
100W
80W


Wind Stress
QSCAT, August–December 2000
ECMWF, August–December 2000
15N
5N
5S
15S
180E
160W
140W
120W
100W
80W
0.00
0.05
0.10
N m−2
0.1 N m−2
Wind Stress Curl
QSCAT, August–December 2000
ECMWF, August–December 2000
−1.0
−0.5
0.0
0.5
1.0
N m−2 per 10⁴ km

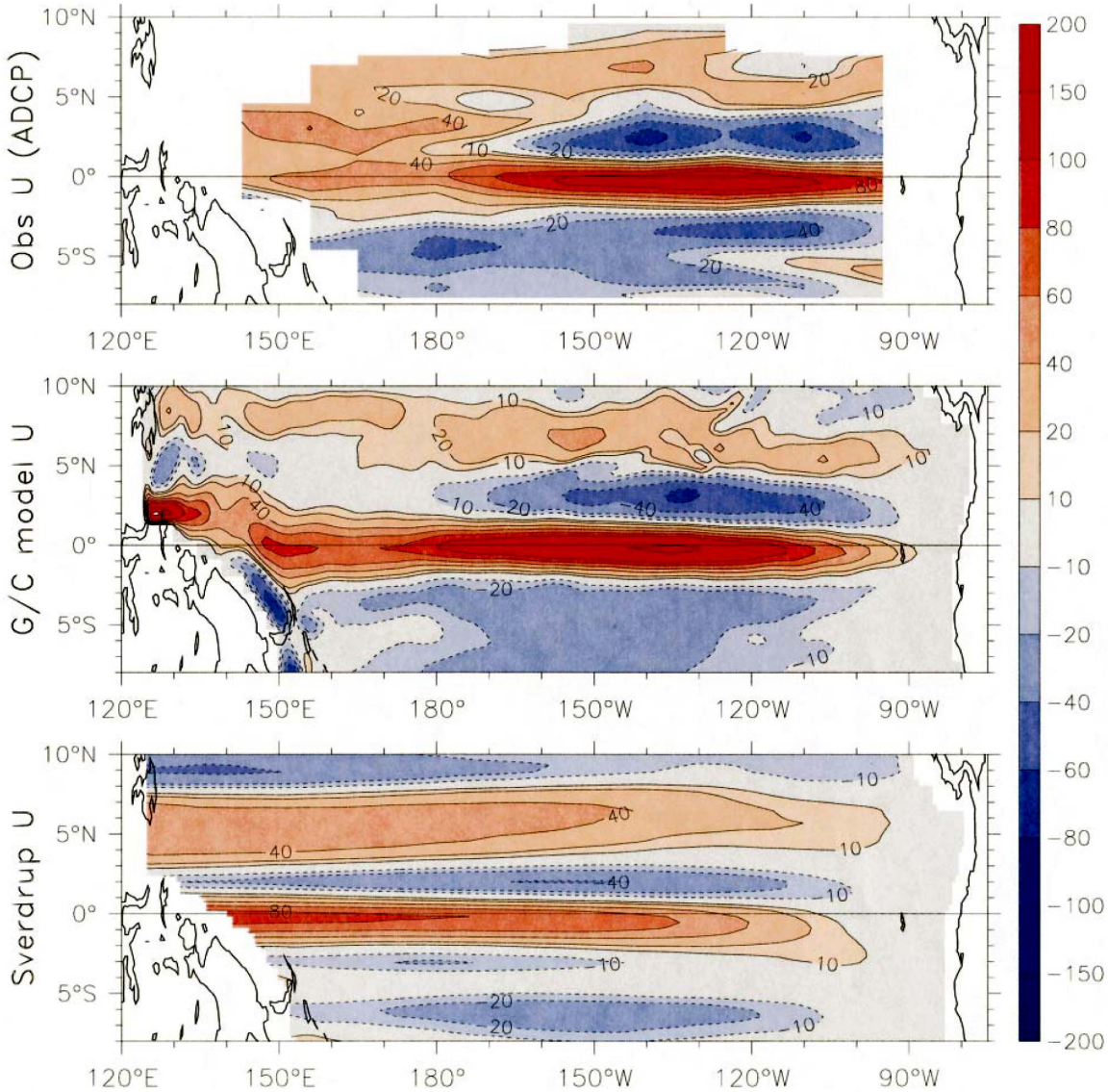
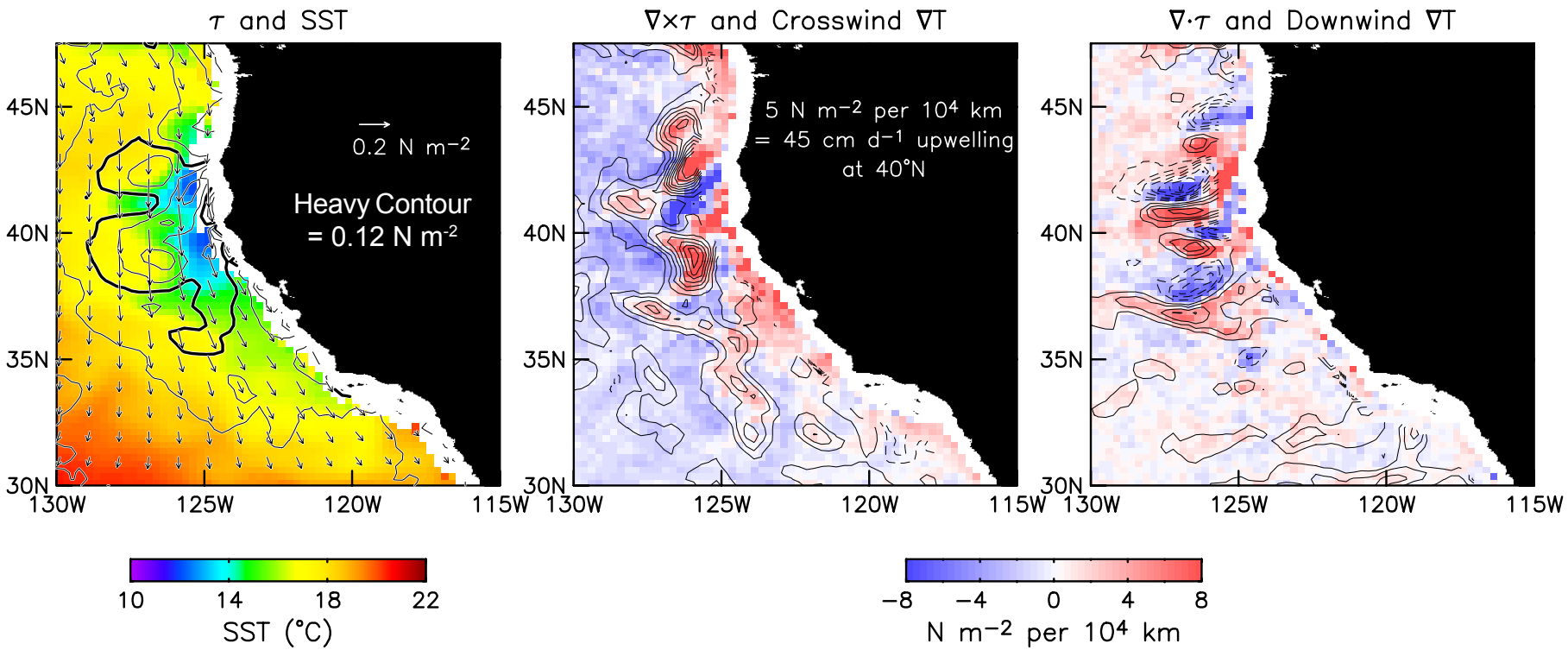
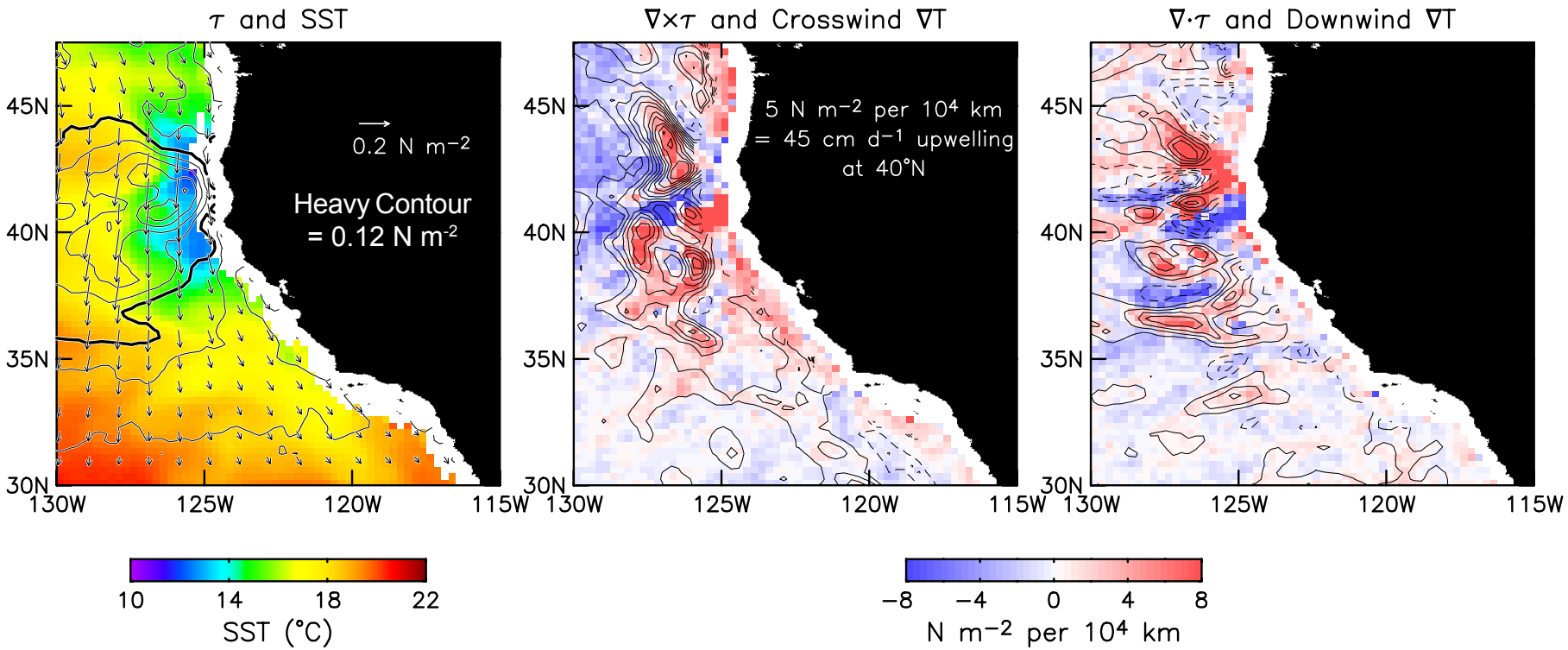


FIG. 3. Vertically integrated zonal transport/unit width ($m^2\ s^{-1}$) from (top) ADCP observations, (middle) model, and (bottom) the Sverdrup balance [Eq. (5)]. Red colors indicate eastward transport, blue colors westward. The colored area in the top panel shows areas sampled by ADCP observations. Observed and model transports are integrated from the bottom of the ADCP sampling and the model, respectively; about 400 m in each case.

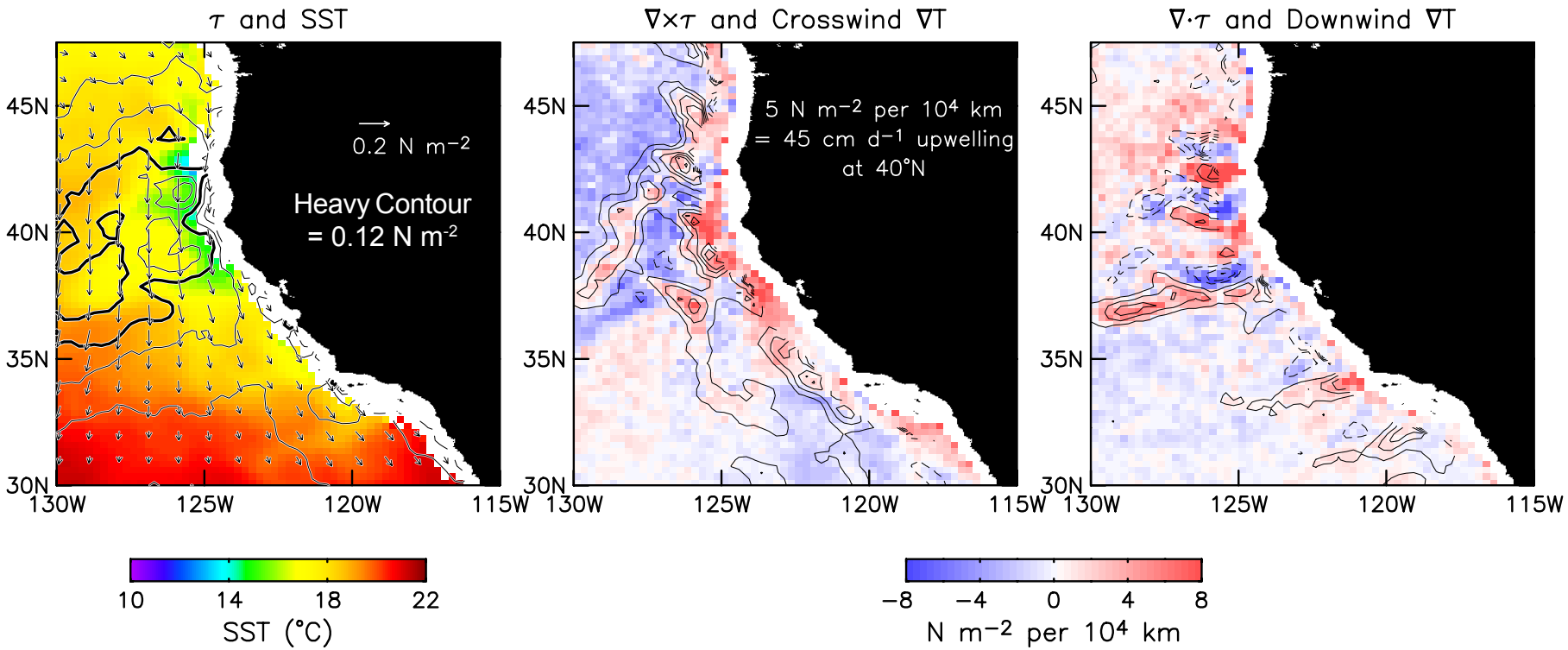
29-Day Average QuikSCAT Wind Stress Field Centered on 18 August 2002



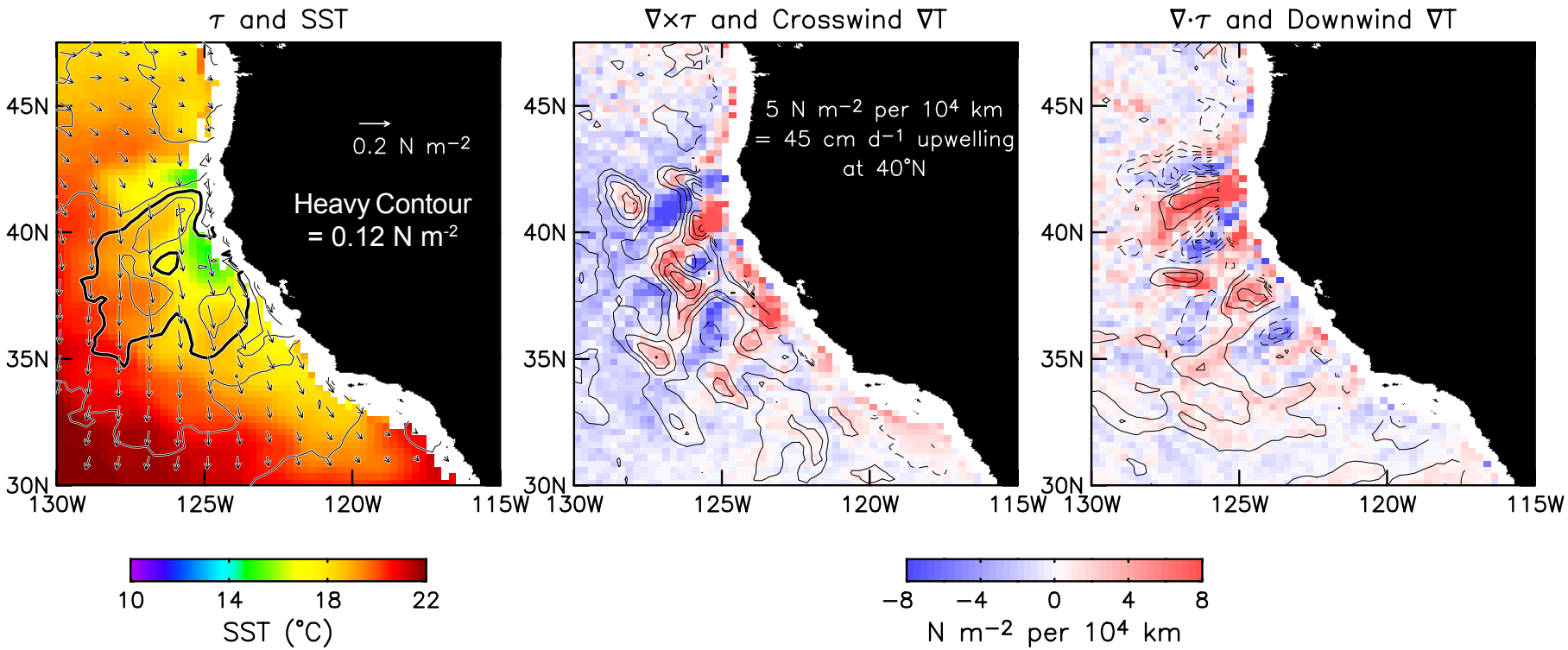
29-Day Average QuikSCAT Wind Stress Field Centered on 29 September 2002



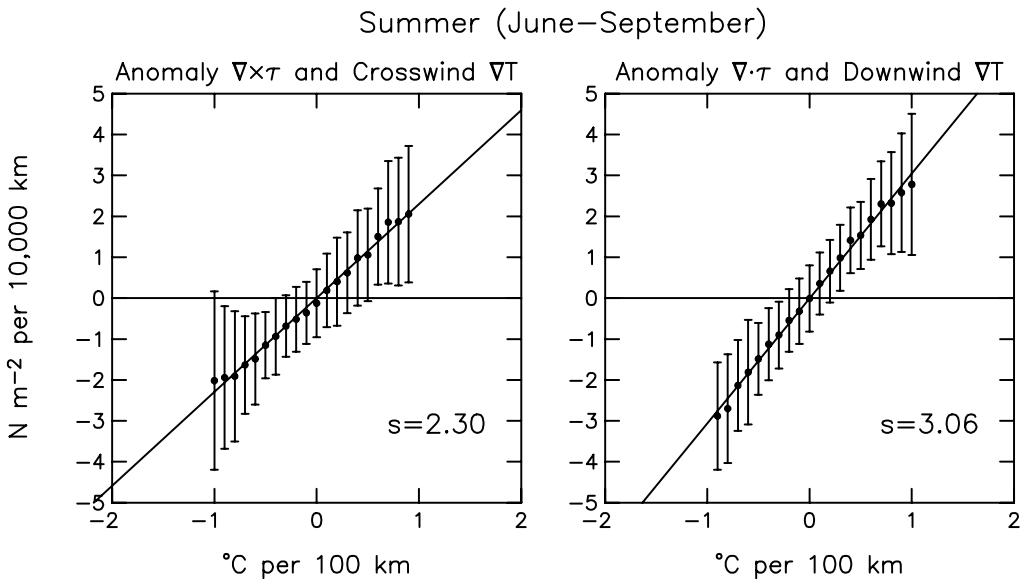
29-Day Average QuikSCAT Wind Stress Field Centered on 14 September 2003



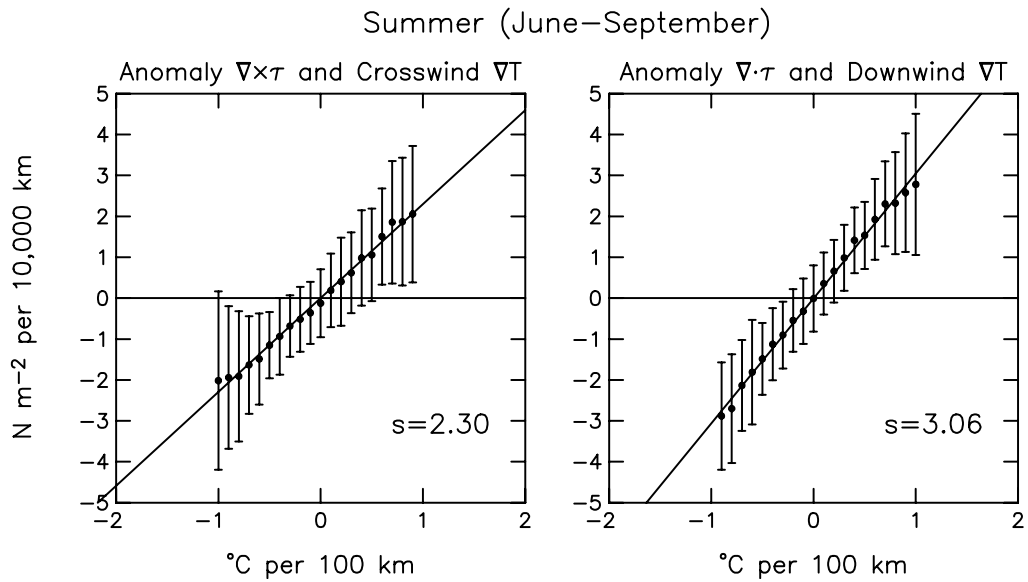
29-Day Average QuikSCAT Wind Stress Field Centered on 5 September 2004



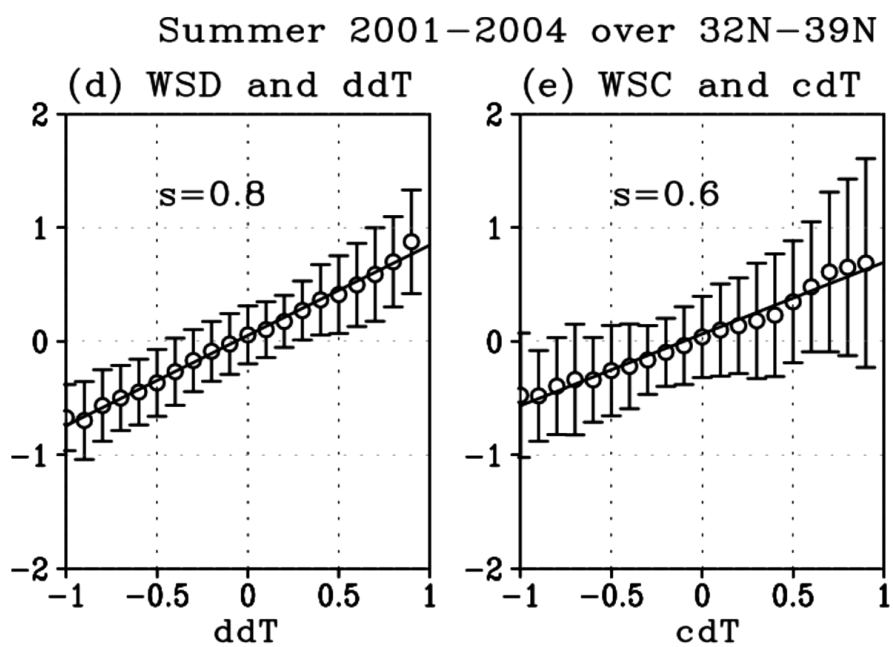
QuikSCAT and AMSR



QuikSCAT and AMSR

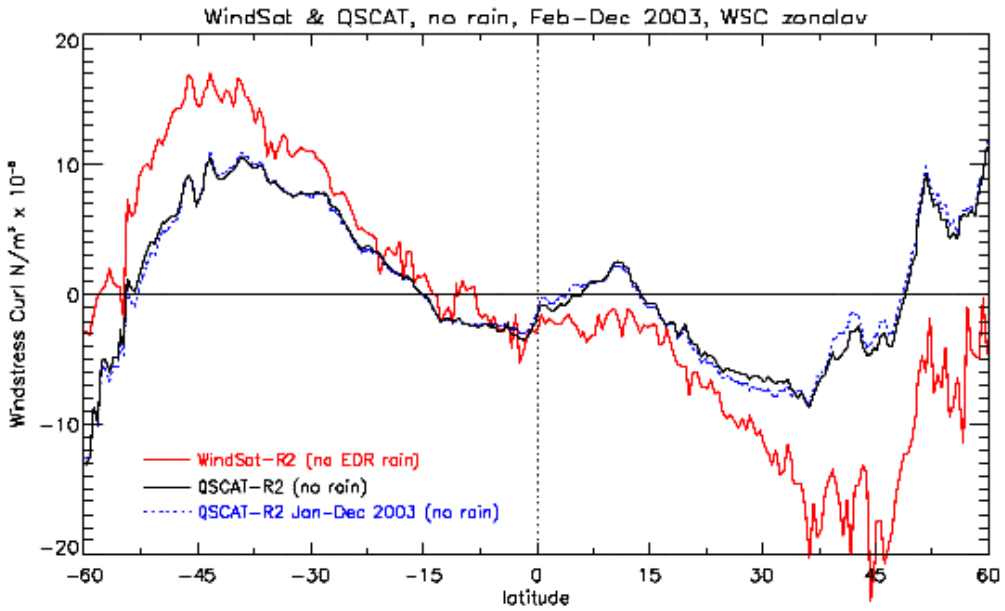


Scripps Coupled Ocean-Atmosphere Regional Model
(Seo et al., 2006)



QuikSCAT vs. WindSat Global Zonally Averaged Wind Stress Curl

(11-month average, February - December 2003)



Conclusions

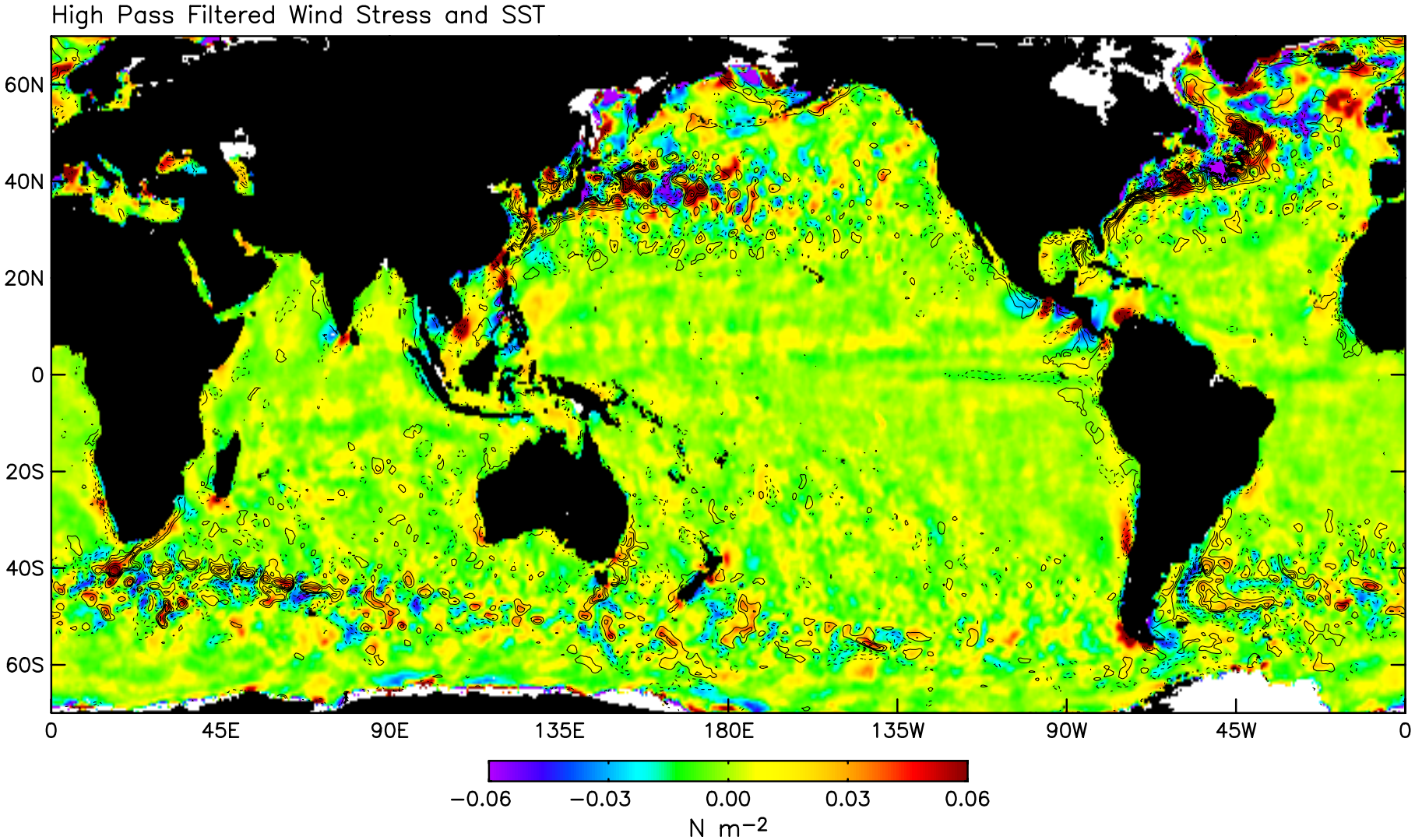
- QuikSCAT has established a 7-year data record that reveals previously unknown persistent and pervasive SST-induced small-scale structure in the surface wind field.
  - *This small-scale structure is poorly represented in all other wind datasets.*
- The QuikSCAT data record is only now approaching a length that is useful for climate research applications.
  - *How can the continuity of this data record be maintained?*
- QuikSCAT data are nonetheless proving to be extremely useful for assessing the accuracy and resolution limitations of operational forecast models, climate models, and coupled ocean-atmosphere models.
- QuikSCAT data are beginning to be analyzed to investigate climate variability in both the atmosphere and the ocean:
  - *Is there a link between SST and atmospheric variability above the boundary layer?*
  - *What are the feedback effects of SST-induced small-scale variability in the wind stress field on the ocean circulation?*
- Analyses conducted to date expose serious concerns about the utility of passive polarimetric measurements of surface winds for research applications.

Extra Figures

2-Month Average Wind Stress Magnitude

(Spatially High-Pass Filtered)

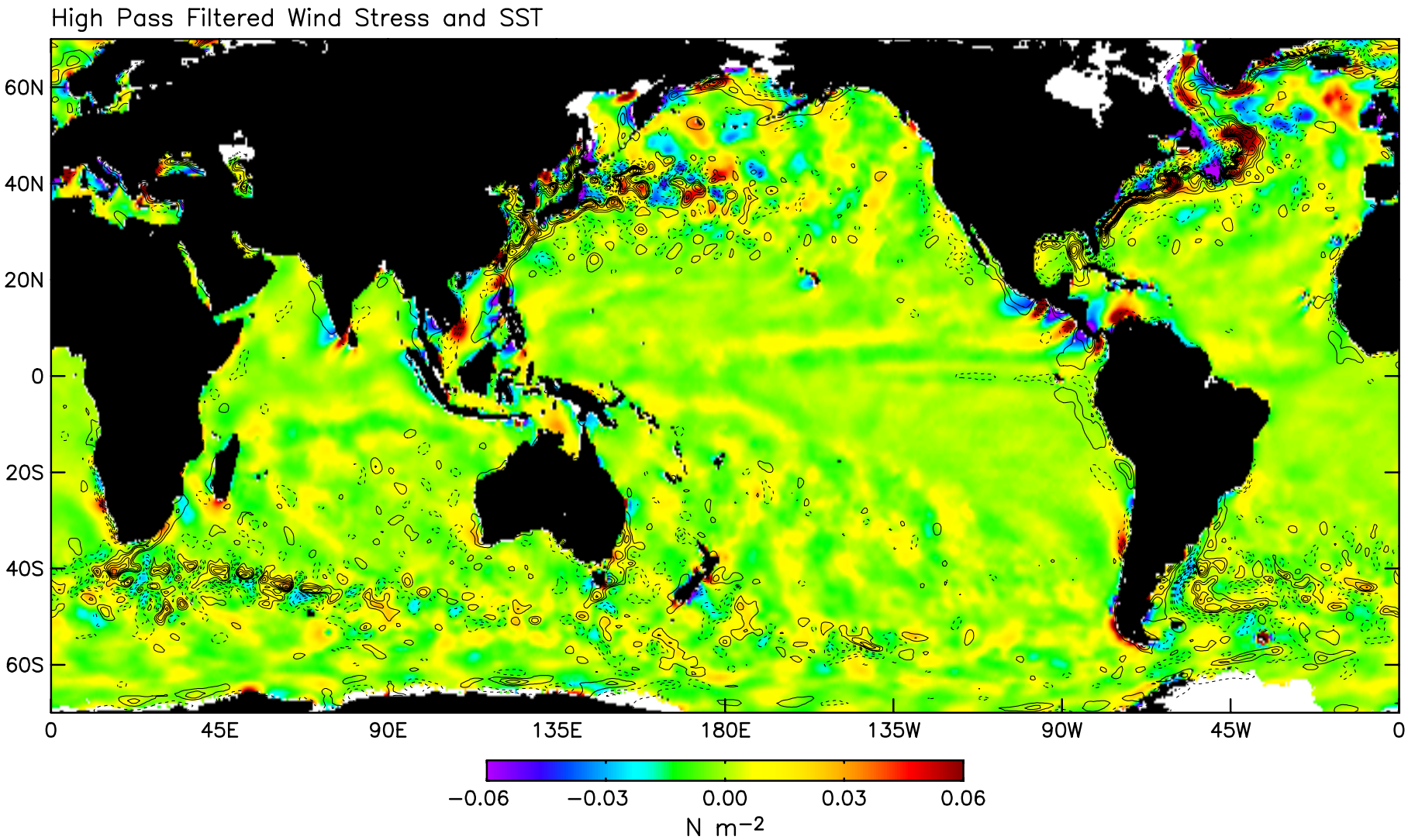
QuikSCAT, January–February 2003



2-Month Average Wind Stress Magnitude

(Spatially High-Pass Filtered)

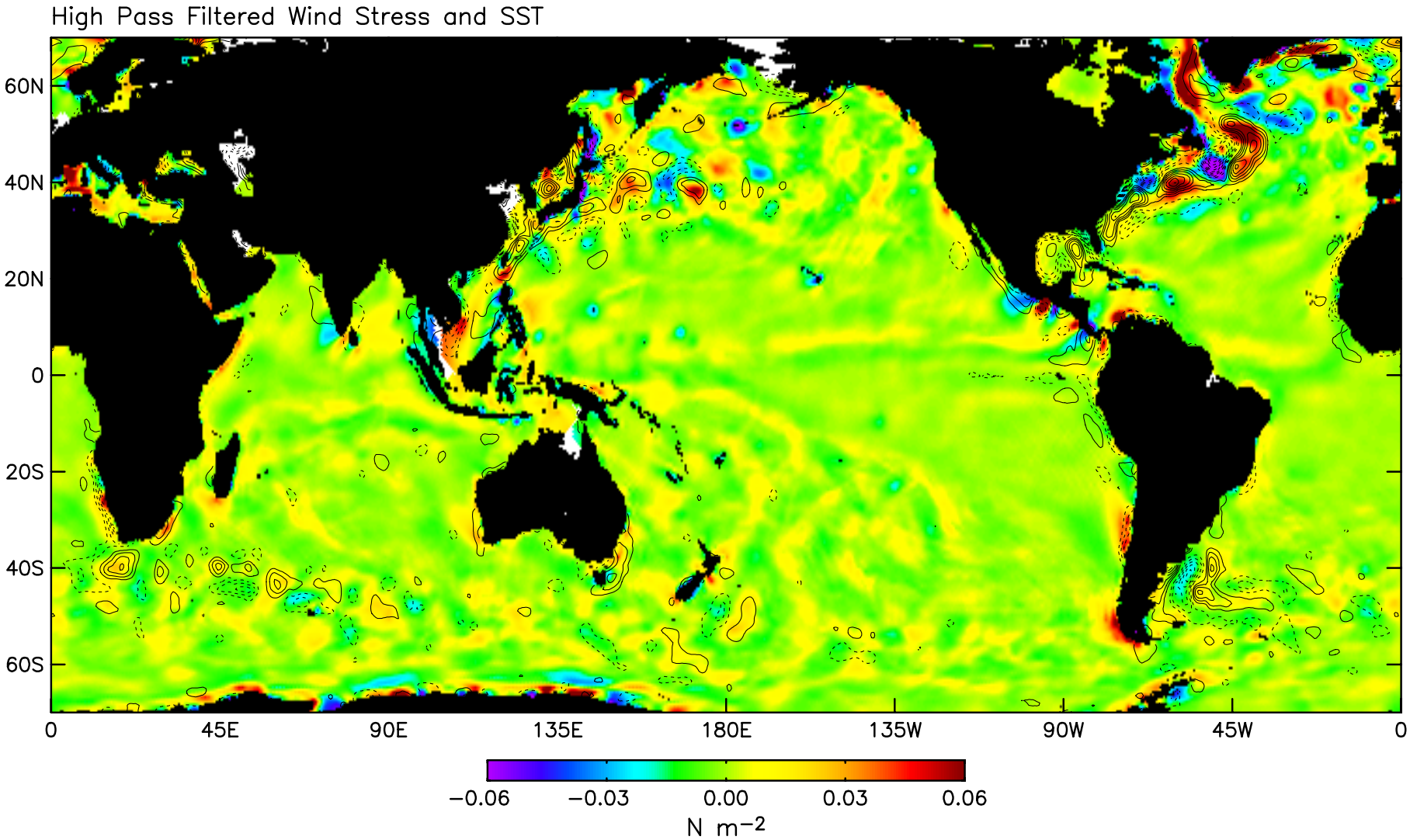
ECMWF, January–February 2003



2-Month Average Wind Stress Magnitude

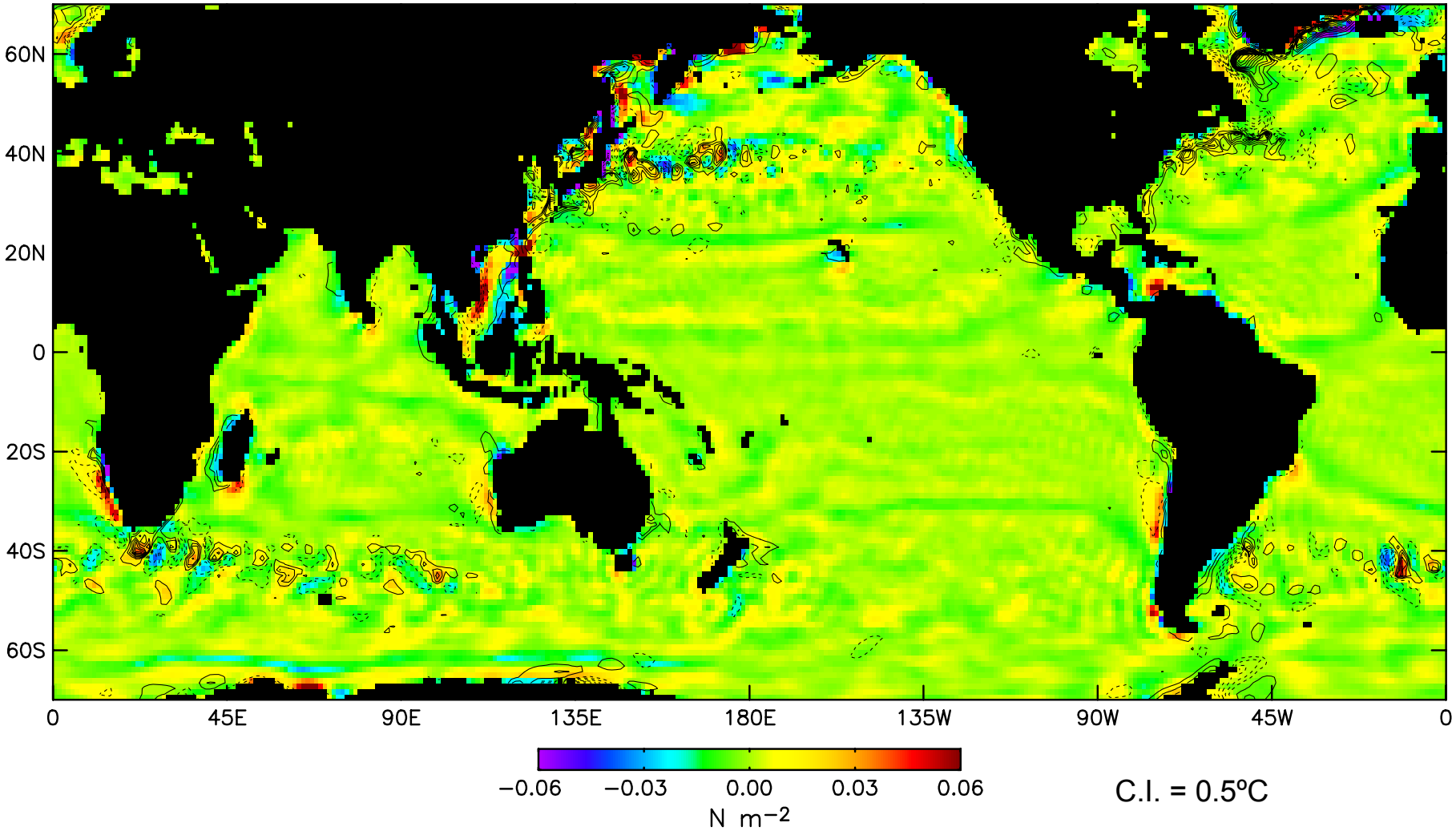
(Spatially High-Pass Filtered)

NCEP, January–February 2003



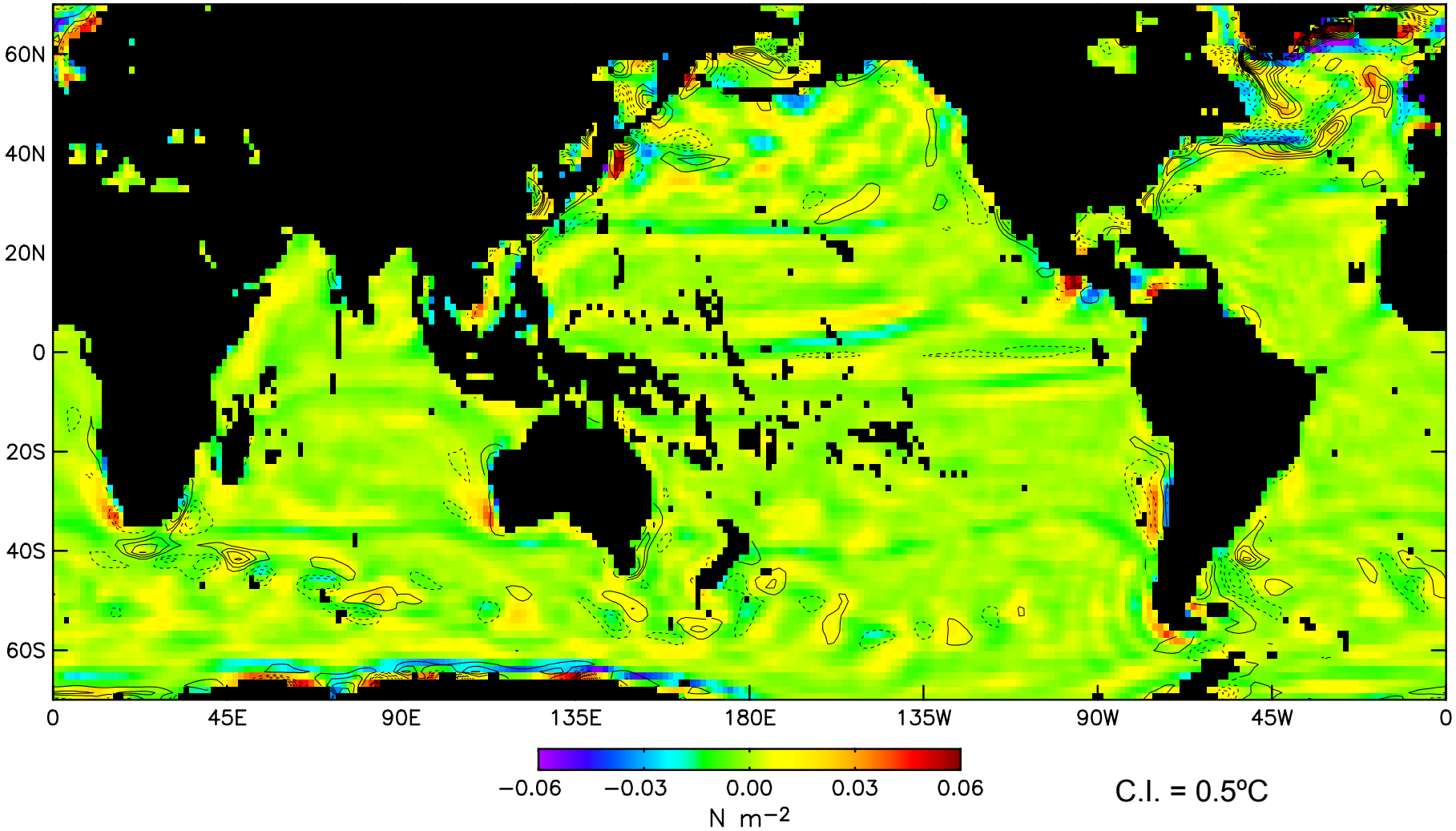
MIROC, November 1998 – February 1999

High Pass Filtered Wind Stress and SST



NCAR, November 1998 – February 1999

High Pass Filtered Wind Stress and SST



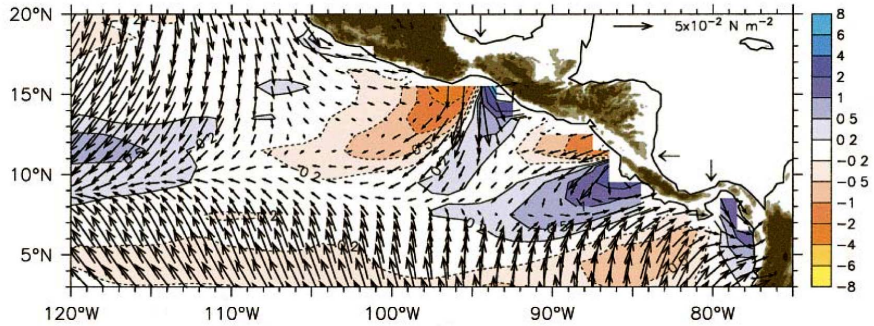


FIG. 5. Mean wind stress vectors and curl (colors) averaged over Aug 1999–Jul 2000. Red shading shows negative (downwelling) curl and blue positive (upwelling) curl, in units of 10^{-7} N m^{-3}, with (stretched) color key at right. The scale vector (5×10^{-2} N m^{-2}) is located in the Caribbean. The gray shading on land indicates altitudes greater than 250 m. The three mountain gaps referred to in the text are marked with arrows on the Caribbean side; from north to south these are denoted the Isthmus of Tehuantepec, the Gulf of Papagayo, and the Gulf of Panama.

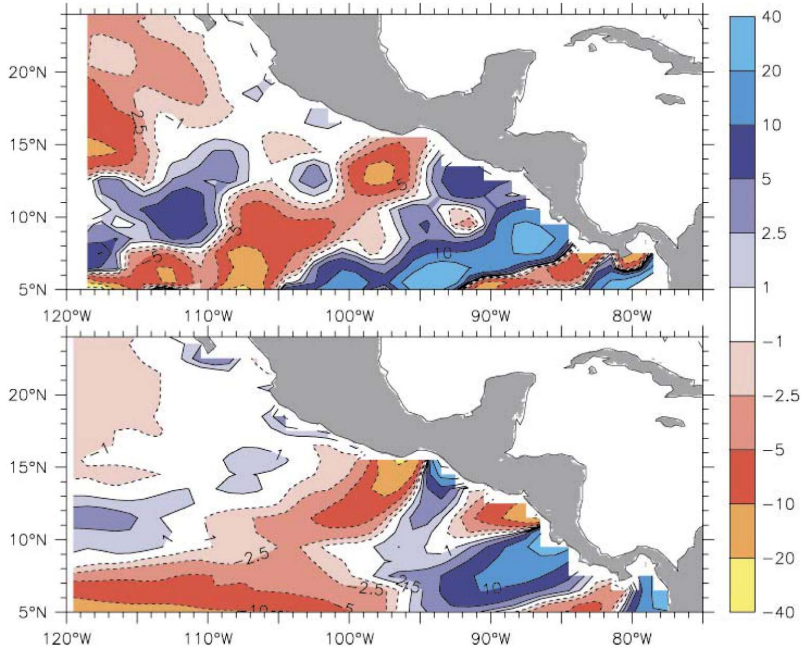
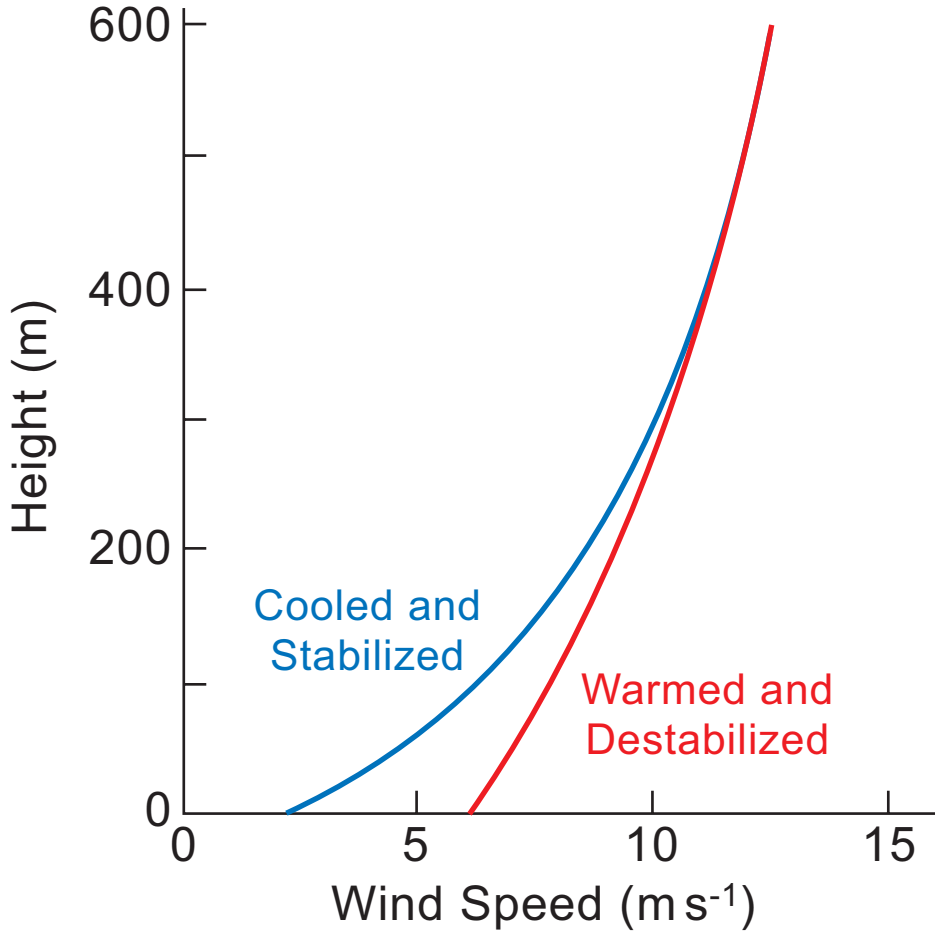
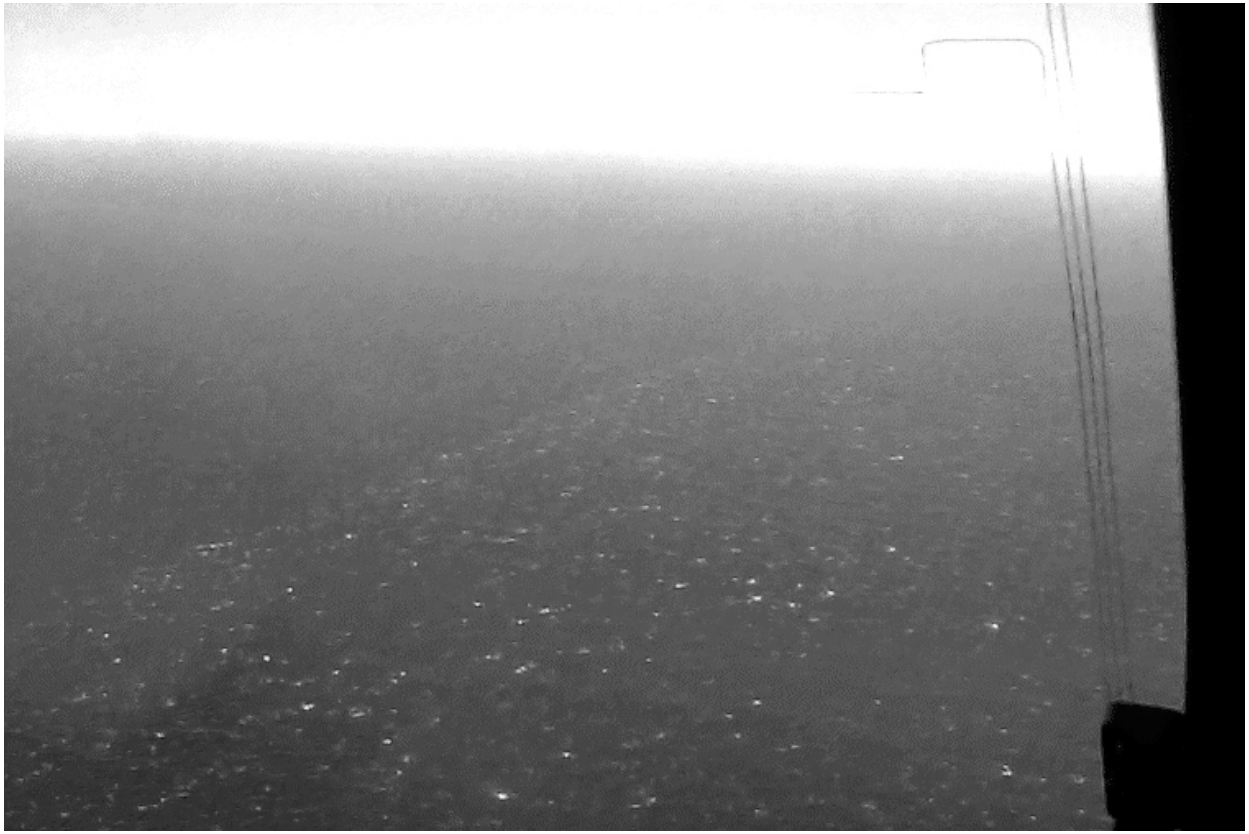


FIG. 6. Sverdrup balance comparison [lhs and rhs of Eq. (2)]: (top panel) the "ocean term" ($\beta/f \int v_g\, dz$) calculated from the XBT data; (bottom panel) the "wind term" (curl($\tau/\rho f$)) calculated from the wind data (both in units of m month^{-1}). Blue shading indicates poleward transport and upwelling curl in the top and bottom panels, respectively; red shading is equatorward transport and downwelling curl. The color key for both quantities is at right.



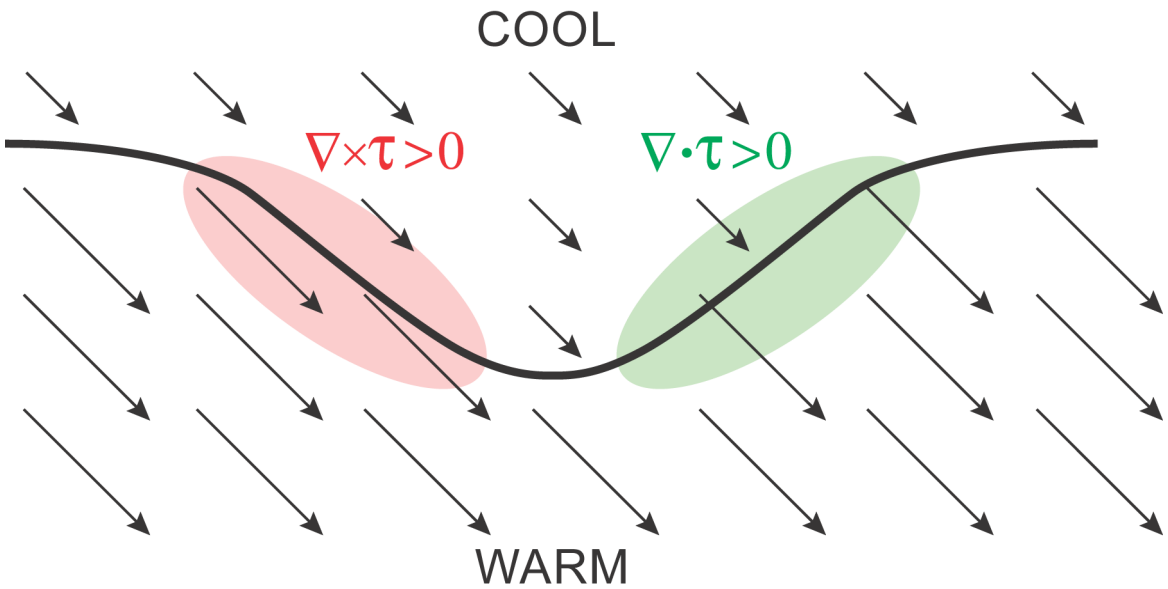
Similar to diurnal variation of the atmospheric boundary layer over land:

- *nocturnal stable boundary layer from radiative cooling*
- *daytime unstable boundary layer from solar heating of the land*



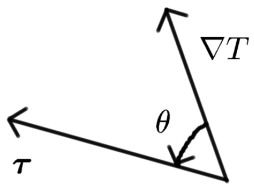
Photograph taken from the NOAA P-3 aircraft looking northeast across the North Wall of the Gulf Stream. The winds were blowing from the northeast at the time of the photograph. The seas were calm over the colder slope waters to the northwest of the Gulf Stream (the upper left area of the photo) and white caps covered the warmer water to the southeast. (Courtesy of Paul Chang, NOAA.)

SST Effects on the Divergence and Vorticity of Surface Winds



Wind Stress Curl $\nabla \times \boldsymbol{\tau} \sim \underbrace{\nabla T \times \hat{\boldsymbol{\tau}} = |\nabla T| \sin\theta}_{\text{Crosswind SST Gradient}}$

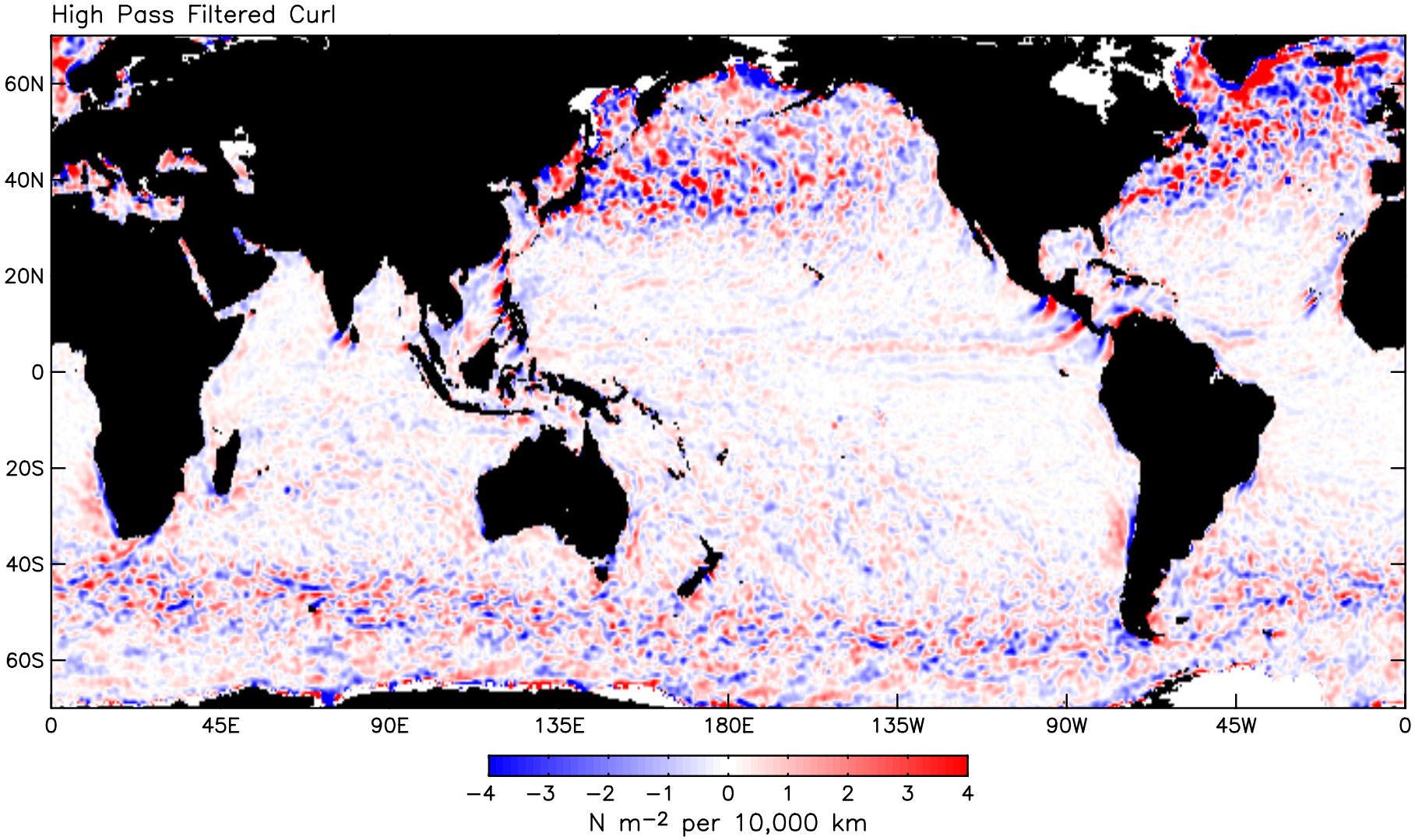
Wind Stress Divergence $\nabla \cdot \boldsymbol{\tau} \sim \underbrace{\nabla T \cdot \hat{\boldsymbol{\tau}} = |\nabla T| \cos\theta}_{\text{Downwind SST Gradient}}$



2-Month Average Wind Stress Curl

(Spatially High-Pass Filtered)

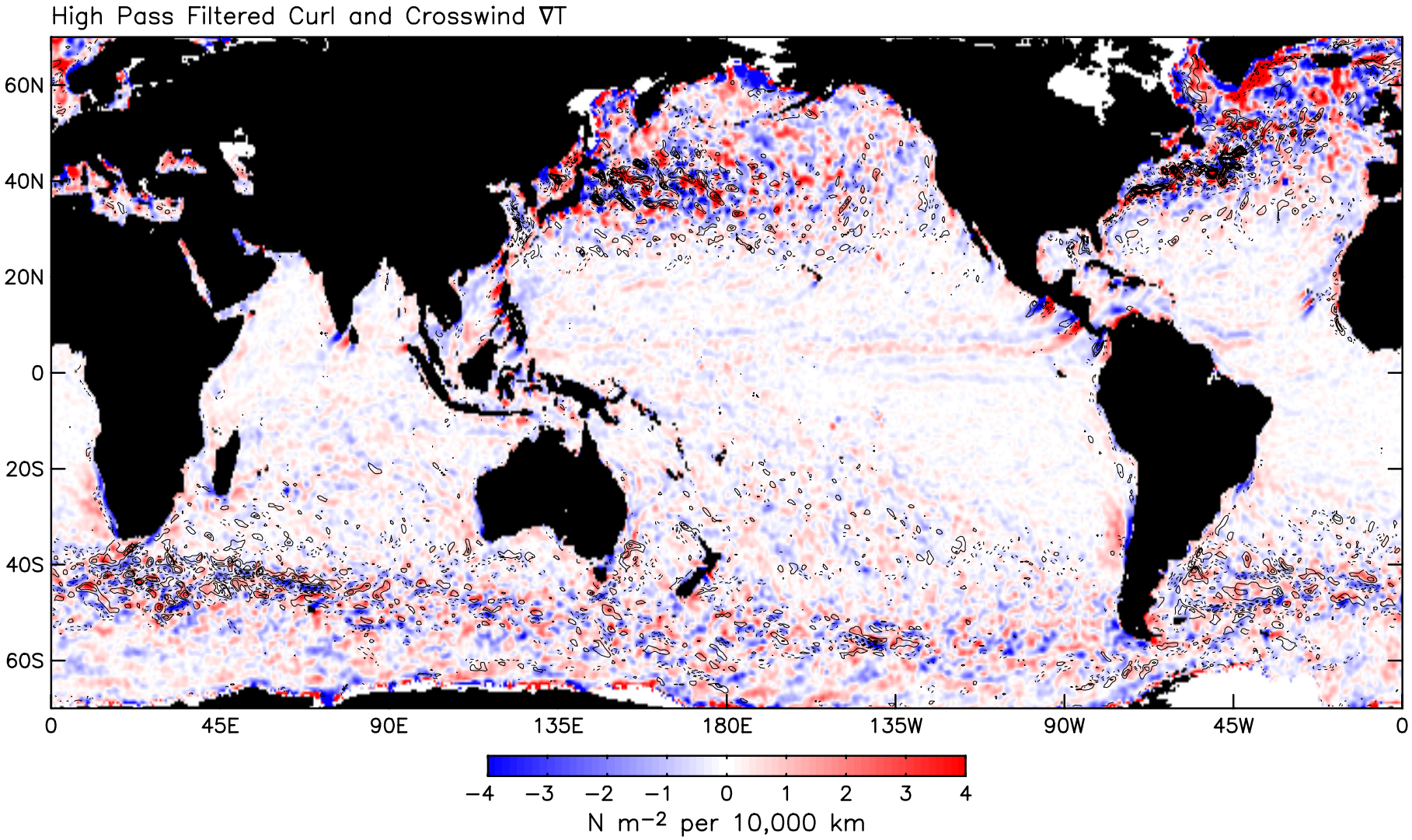
QuikSCAT, January–February 2003



2-Month Average Wind Stress Curl and Crosswind SST Gradient

(Spatially High-Pass Filtered)

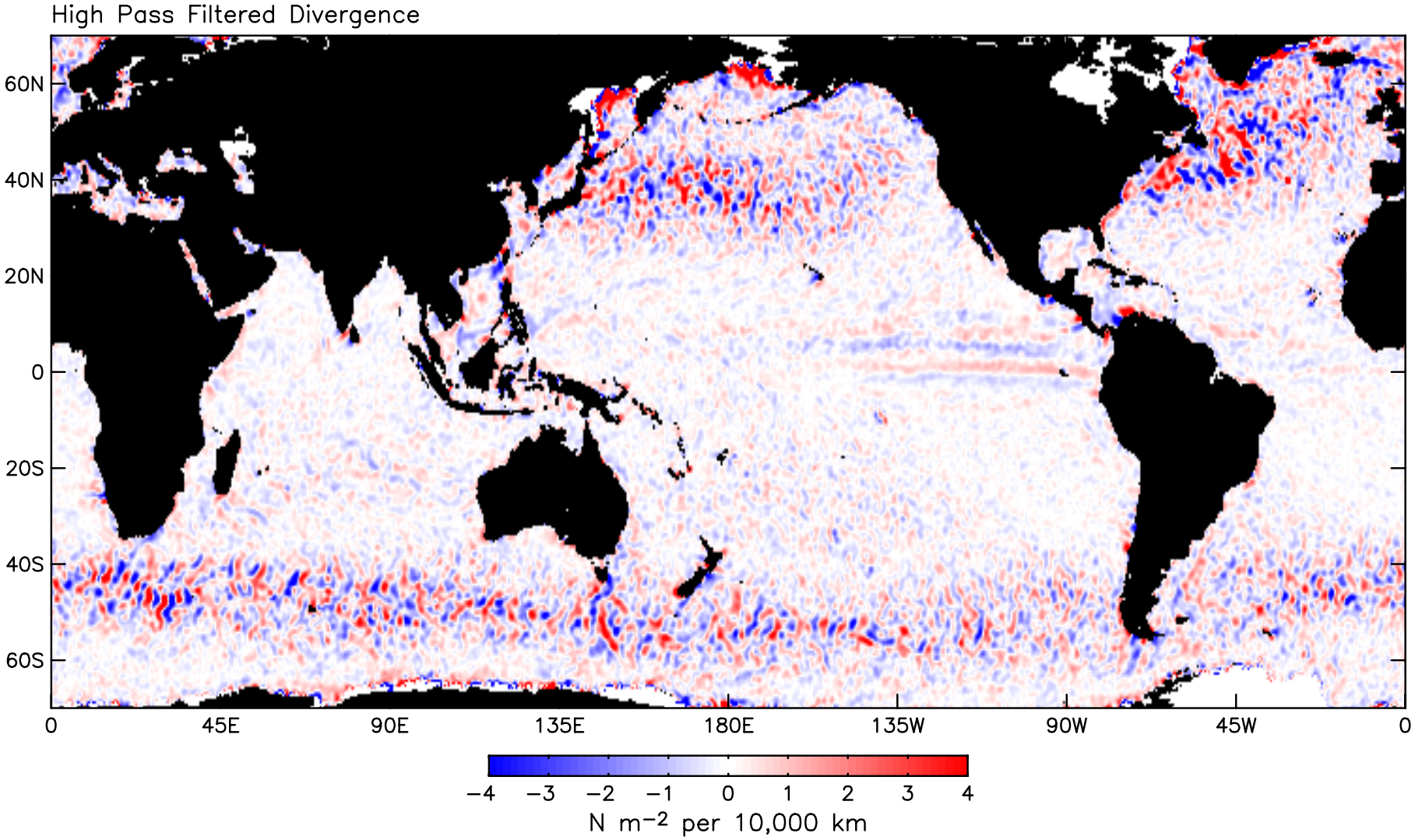
QuikSCAT, January–February 2003



2-Month Average Wind Stress Divergence

(Spatially High-Pass Filtered)

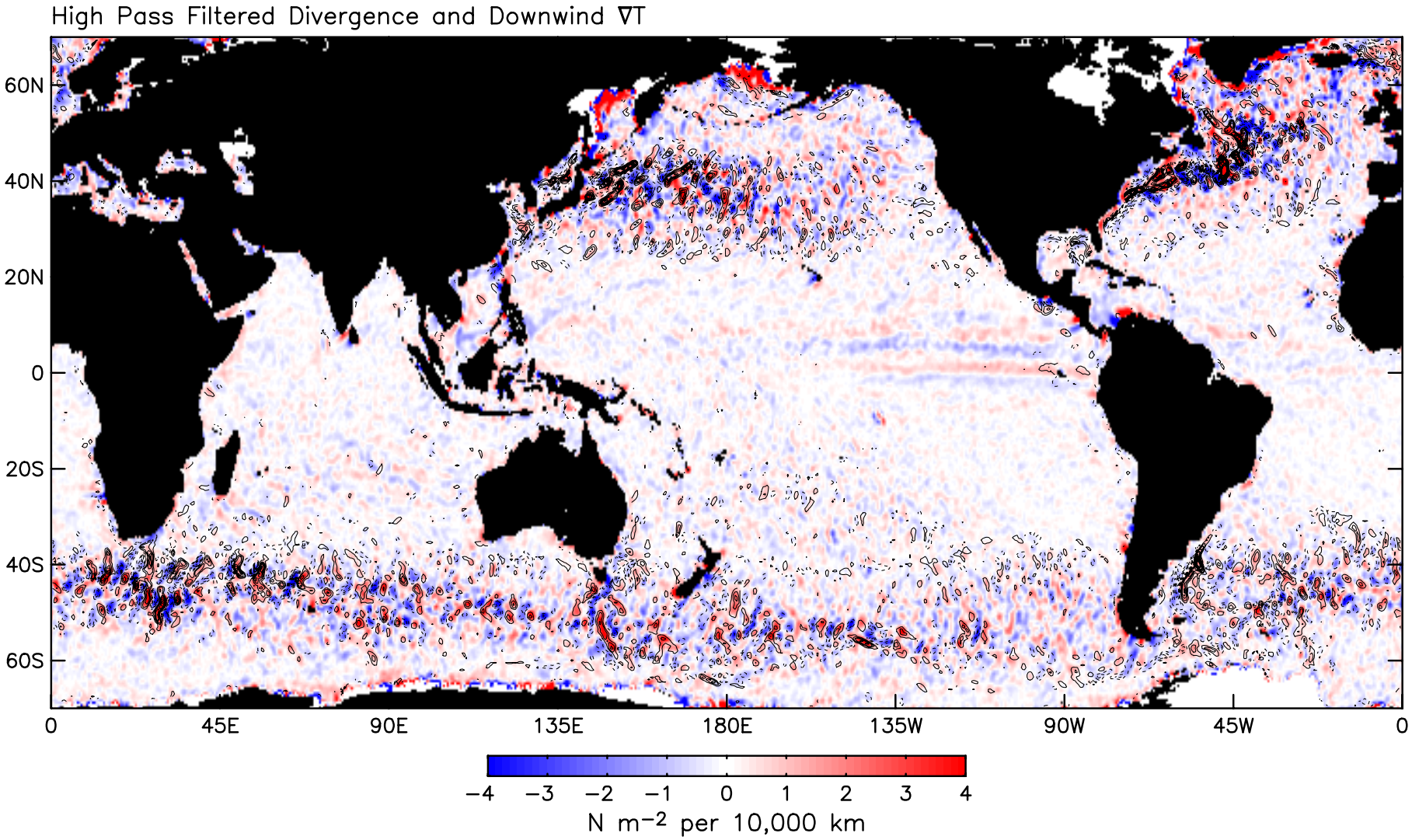
QuikSCAT, January–February 2003



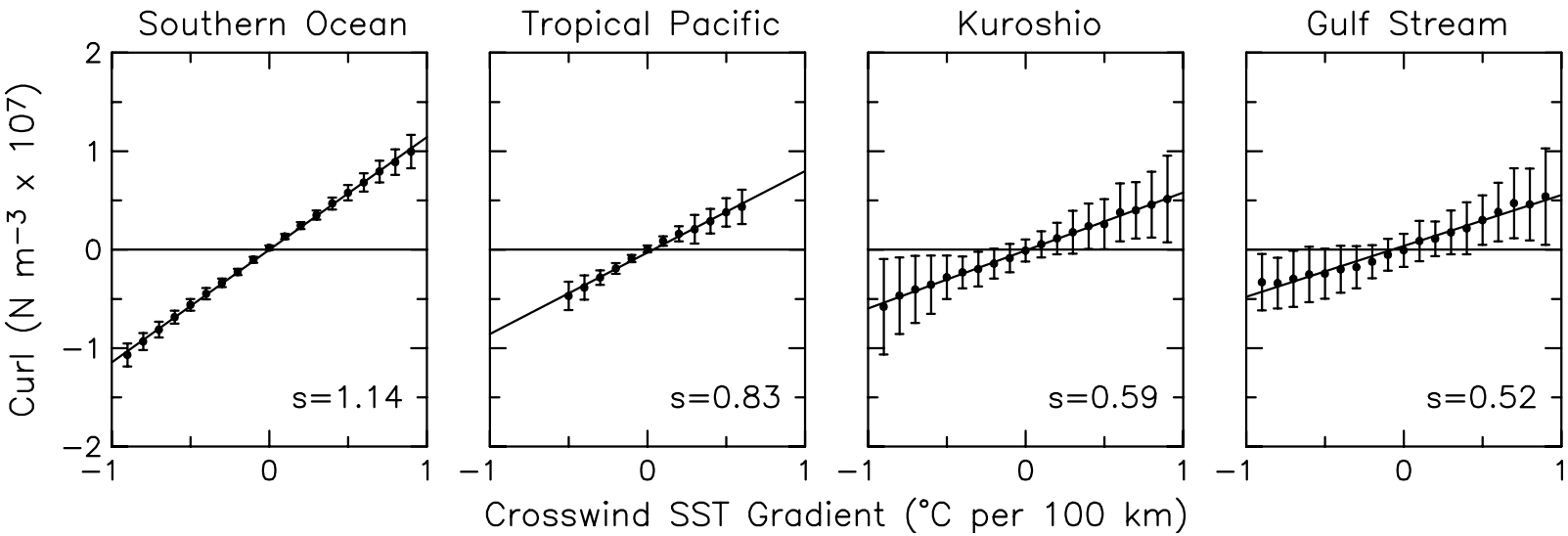
2-Month Average Wind Stress Divergence and Downwind SST Gradient

(Spatially High-Pass Filtered)

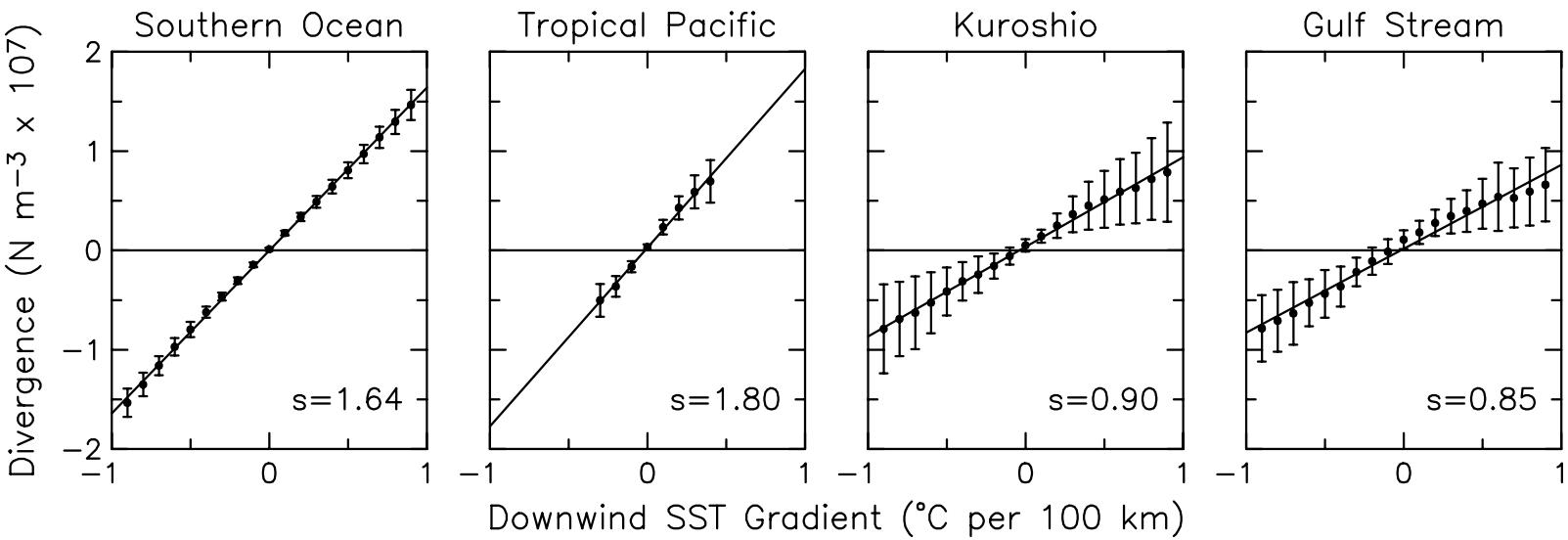
QuikSCAT, January–February 2003



Coupling Between Wind Stress Curl and Crosswind SST Gradient



Coupling Between Wind Stress Divergence and Downwind SST Gradient



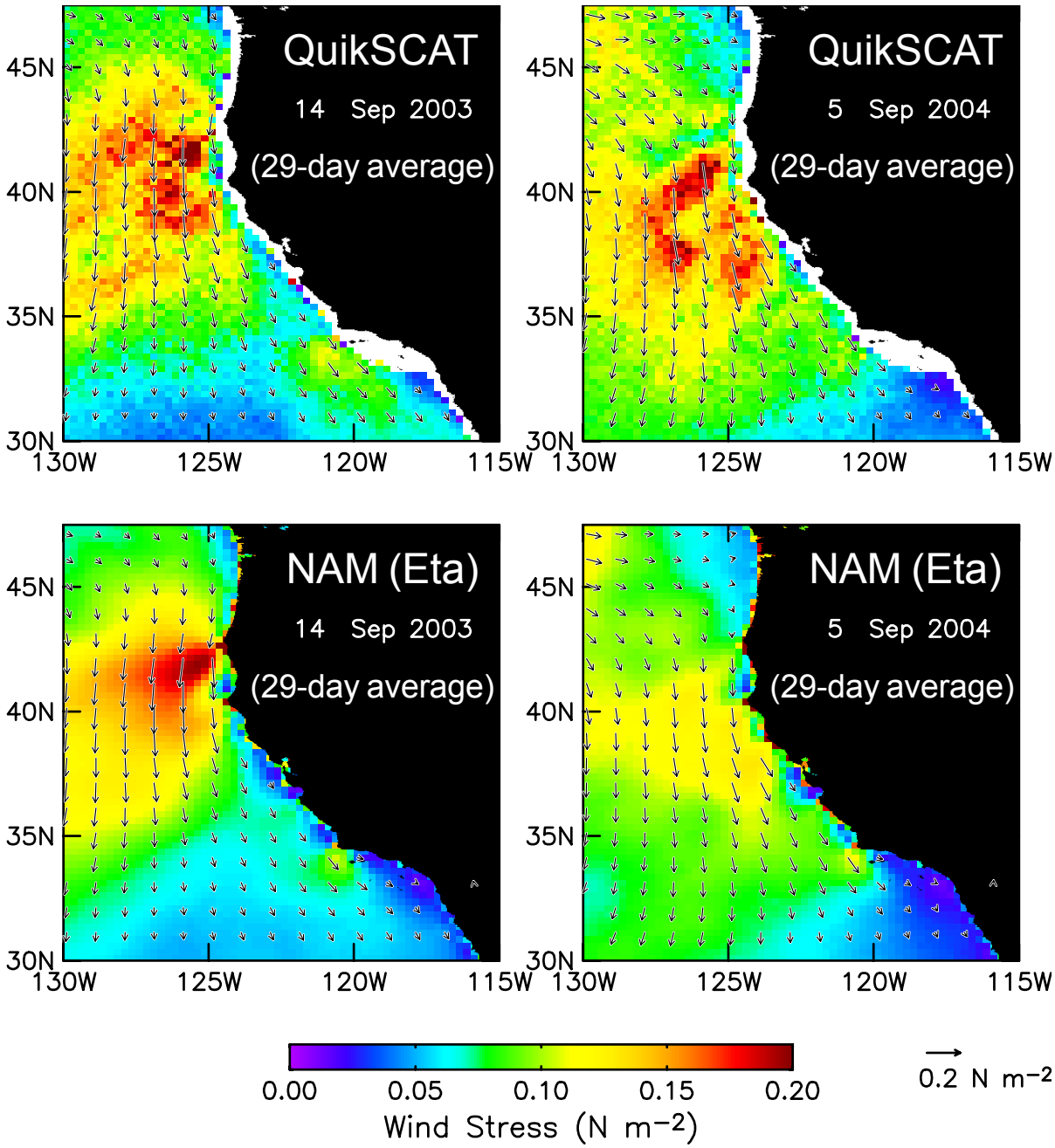
Question:

How well are the observed SST-induced perturbations of the wind stress field represented in mesoscale atmospheric models?

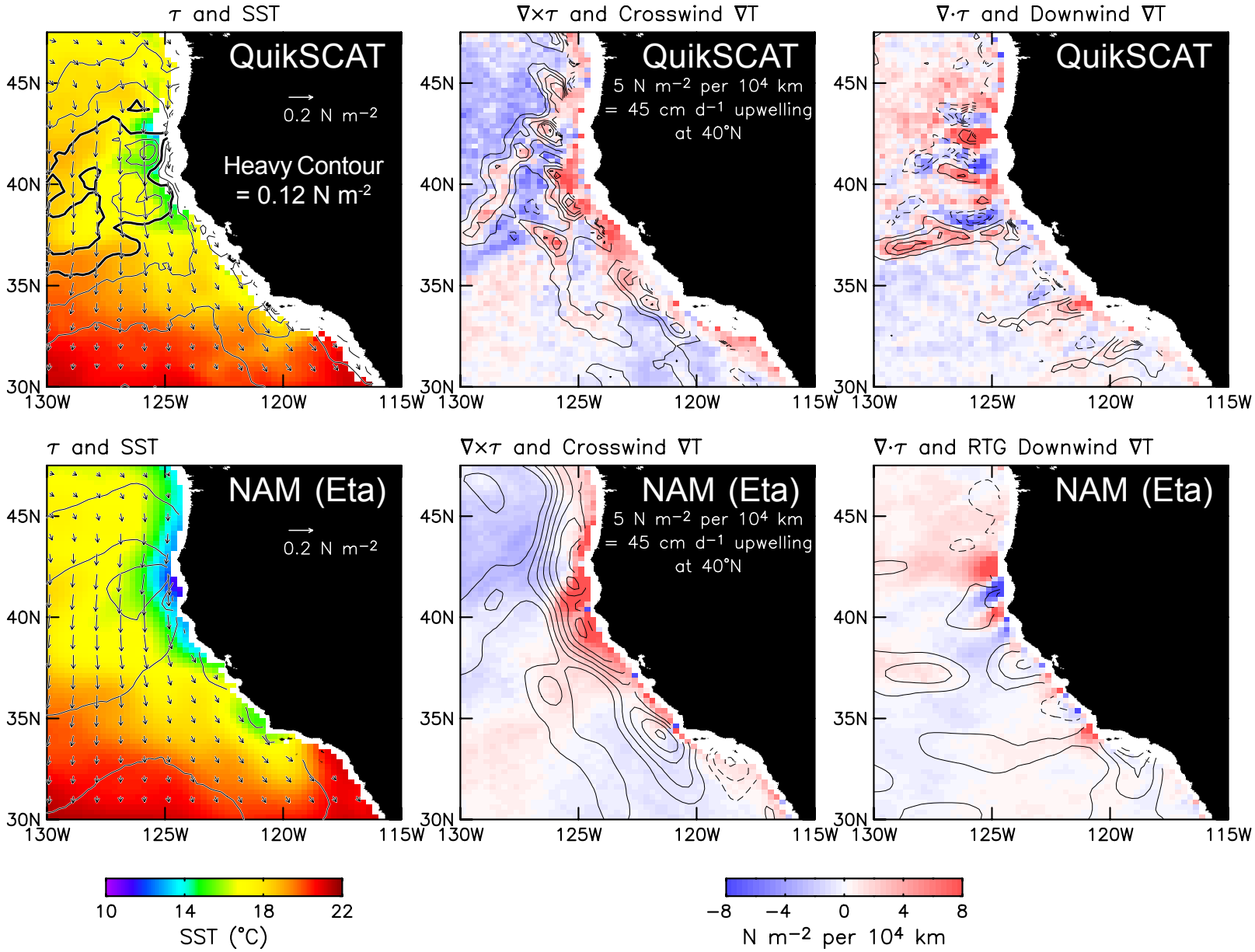
Consider the NOAA North American Mesoscale Model:

(NAM, formerly called the Eta Model)

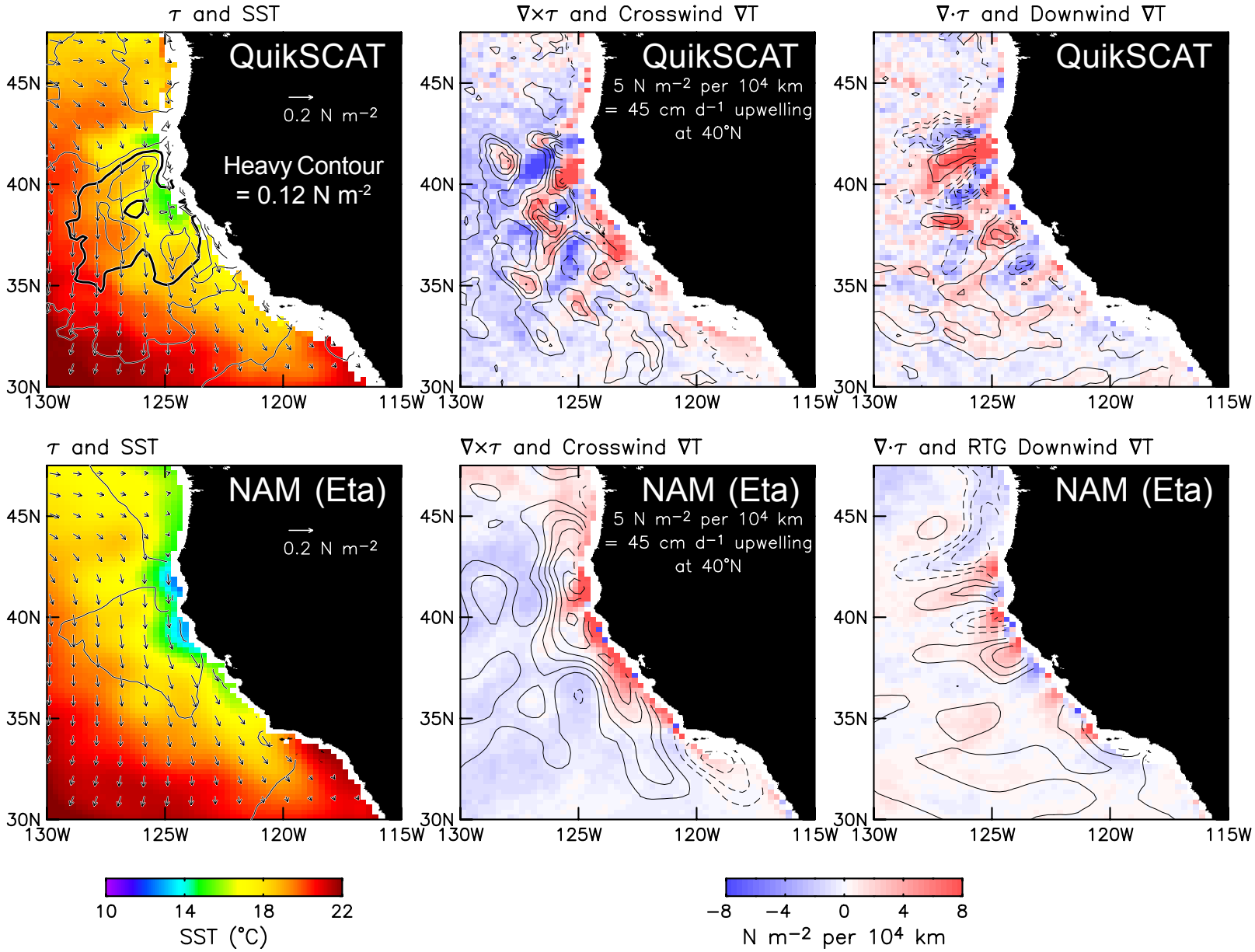
- *12-km grid over the domain outlined by the dashed line in the figure below.*
- *Twice-daily forecast wind stress winds at 0300 UTC and 1500 UTC, which correspond closely to the 0300 UTC and 1400 UTC QuikSCAT overpass times.*
- *Time period considered here: January 2003 - July 2005*


QuikSCAT
14 Sep 2003
(29-day average)
QuikSCAT
5 Sep 2004
(29-day average)
NAM (Eta)
14 Sep 2003
(29-day average)
NAM (Eta)
5 Sep 2004
(29-day average)
45N
40N
35N
30N
130W
125W
120W
115W
0.00
0.05
0.10
0.15
0.20
Wind Stress (N m^{-2})
0.2 N m^{-2}

29-Day Averages Centered on 14 September 2003



29-Day Averages Centered on 5 September 2004



Result:

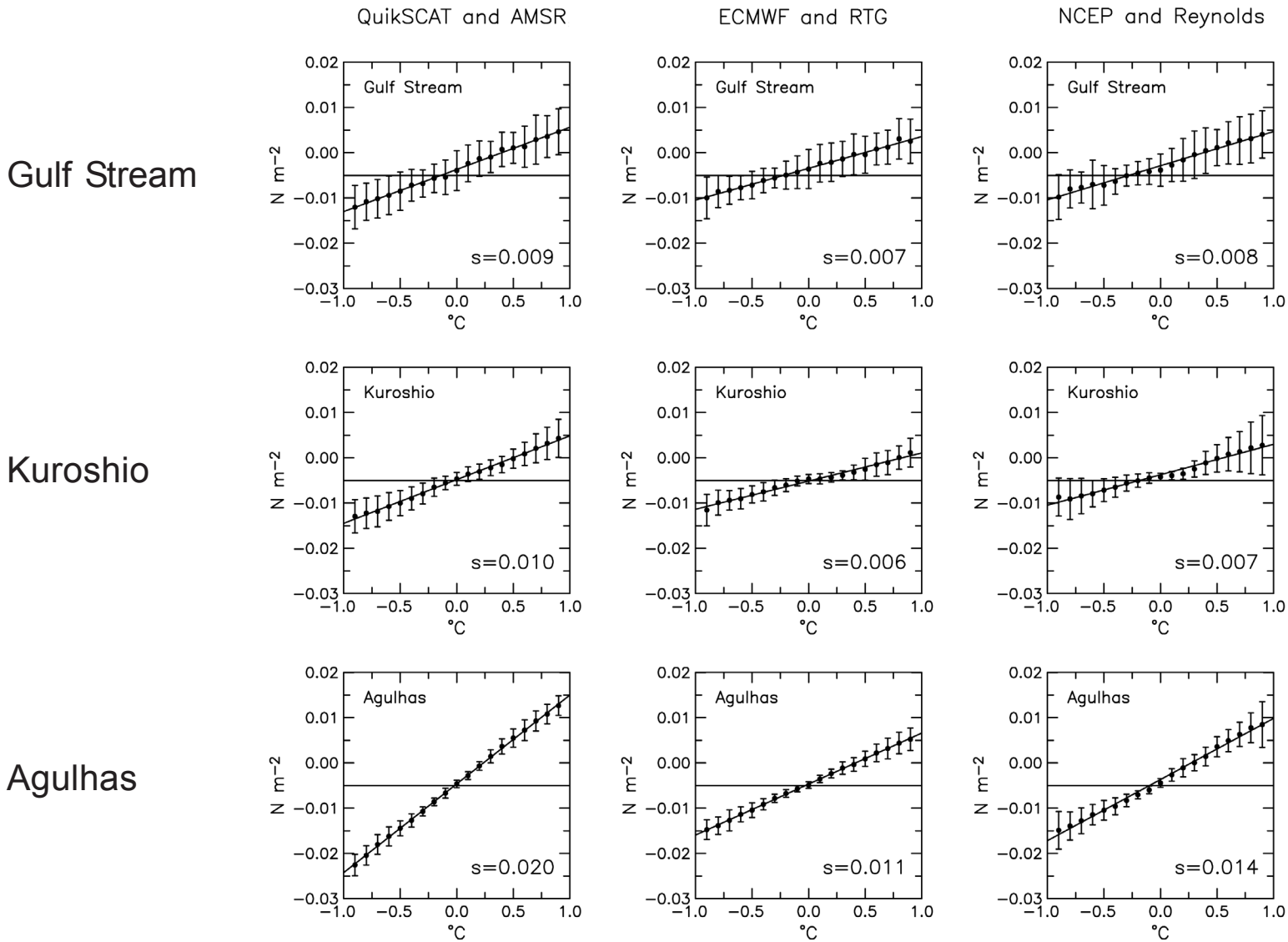
Improving the resolution and accuracy of SST improves the accuracy of surface winds in NWP models.

Question:

How well would the observed air-sea interaction be represented in the models if the SST boundary condition were “perfect” ?

In other words, how well does the coupling coefficient between wind stress and SST in the models compare with the coupling coefficient inferred from QuikSCAT and AMSR data?

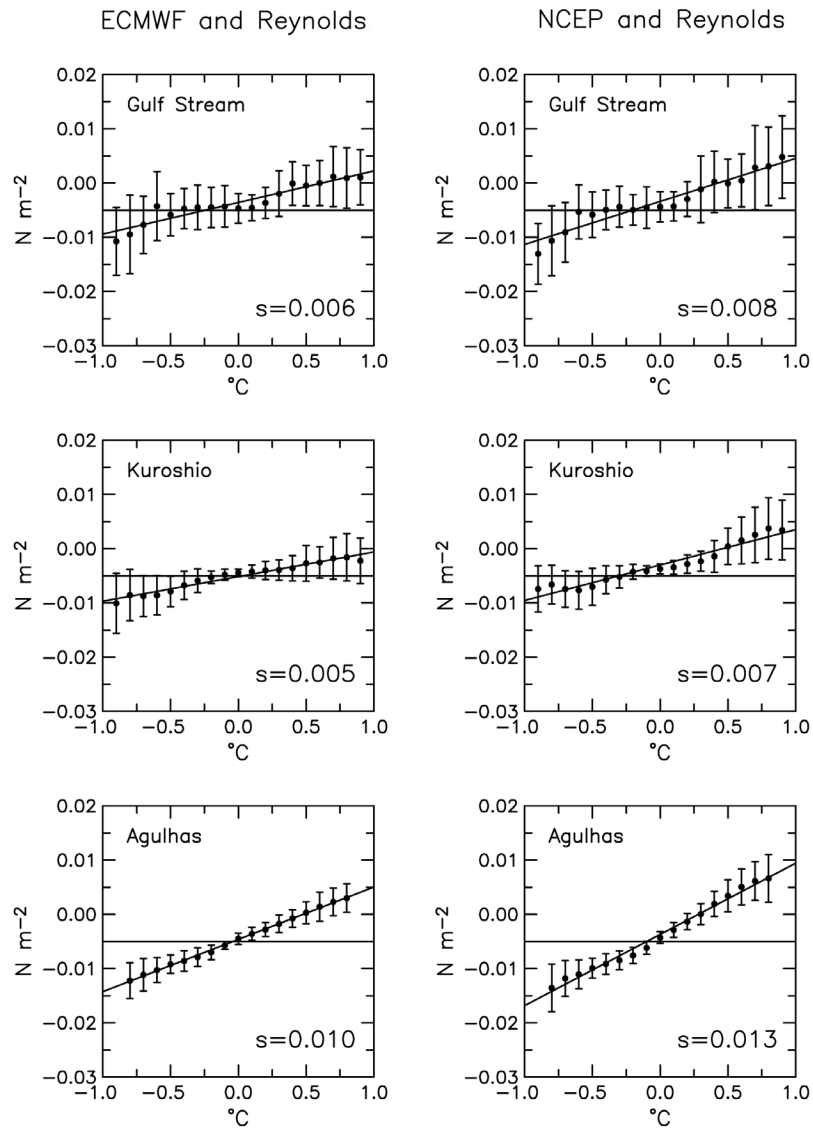
Spatially High-Pass Filtered Wind Stress Magnitude versus SST
September 2002 - August 2004



Spatially High-Pass Filtered Wind Stress Magnitude versus SST
August 1999 - April 2001

Gulf Stream

Kuroshio

Agulhas

No AMSR SST data available for QuikSCAT analysis prior to July 2002