The Impact of SST Specification on Surface Winds in Numerical Weather Prediction Models

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Overview:

- Overview of satellite observations of SST influence on surface wind stress:
  - QuikSCAT and Microwave SST (TMI and AMSR)
- ECMWF and NCEP simulations of the SST influence on surface wind stress before and after a May 9, 2001 change in the SST boundary condition in the ECMWF model.
- Ramifications of the observed SST influence on surface winds: strong small-scale perturbations of the surface divergence and vorticity fields.

References:

*Chelton, D. B., 2005: The impact of SST specification on ECMWF surface wind stress fields in the eastern tropical Pacific. J. Climate, **18**, 530-550.*

Chelton, D. B., and F. J. Wentz, 2005: Global microwave satellite observations of sea-surface temperature for numerical weather prediction and climate research. Bull. Amer. Meteor. Soc., in press.

Motivation

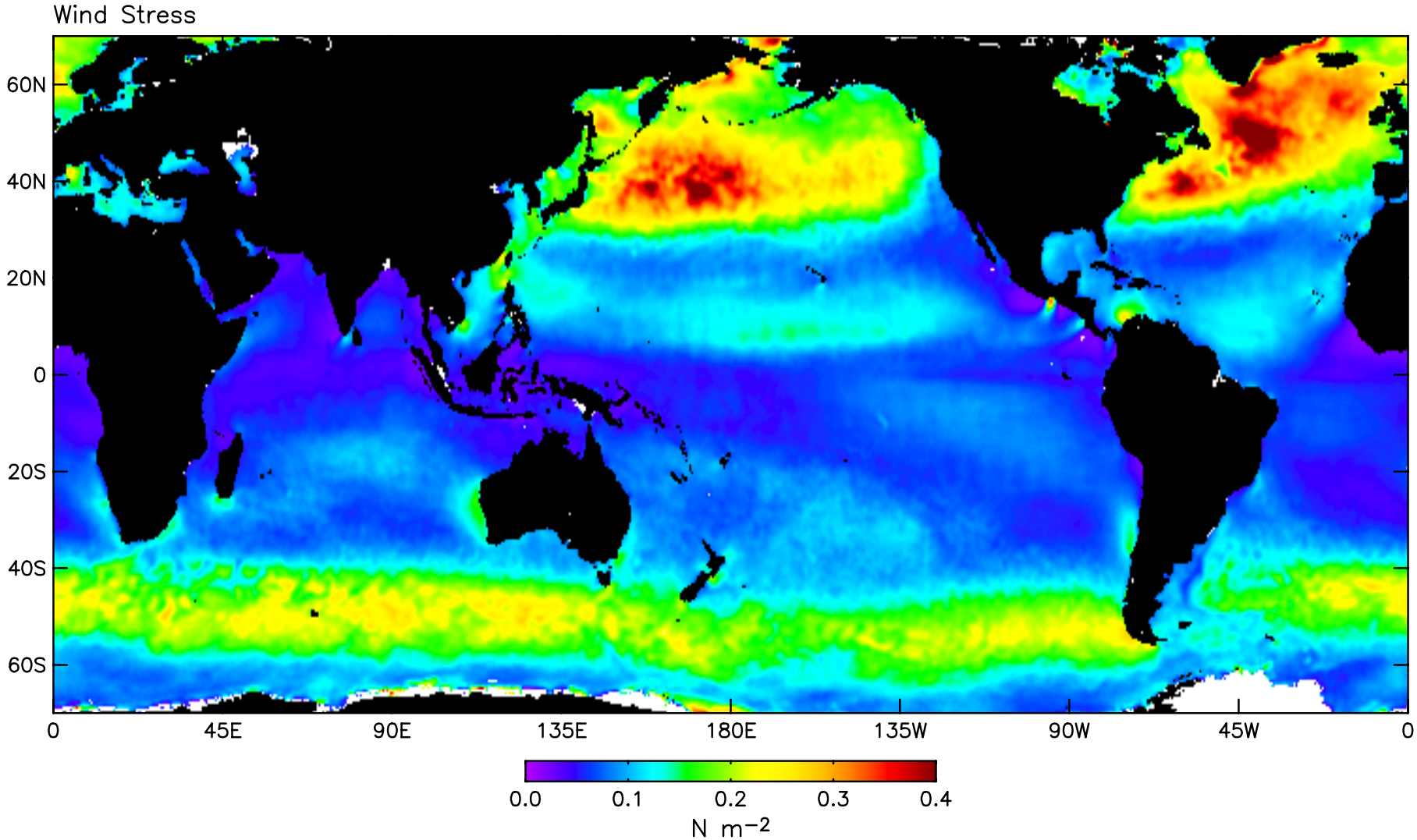
To assess the accuracy of NCEP and ECMWF surface wind fields for the purpose of forcing ocean circulation models.

$\Rightarrow$ The wind stress curl is of particular interest

Long-Term Interest

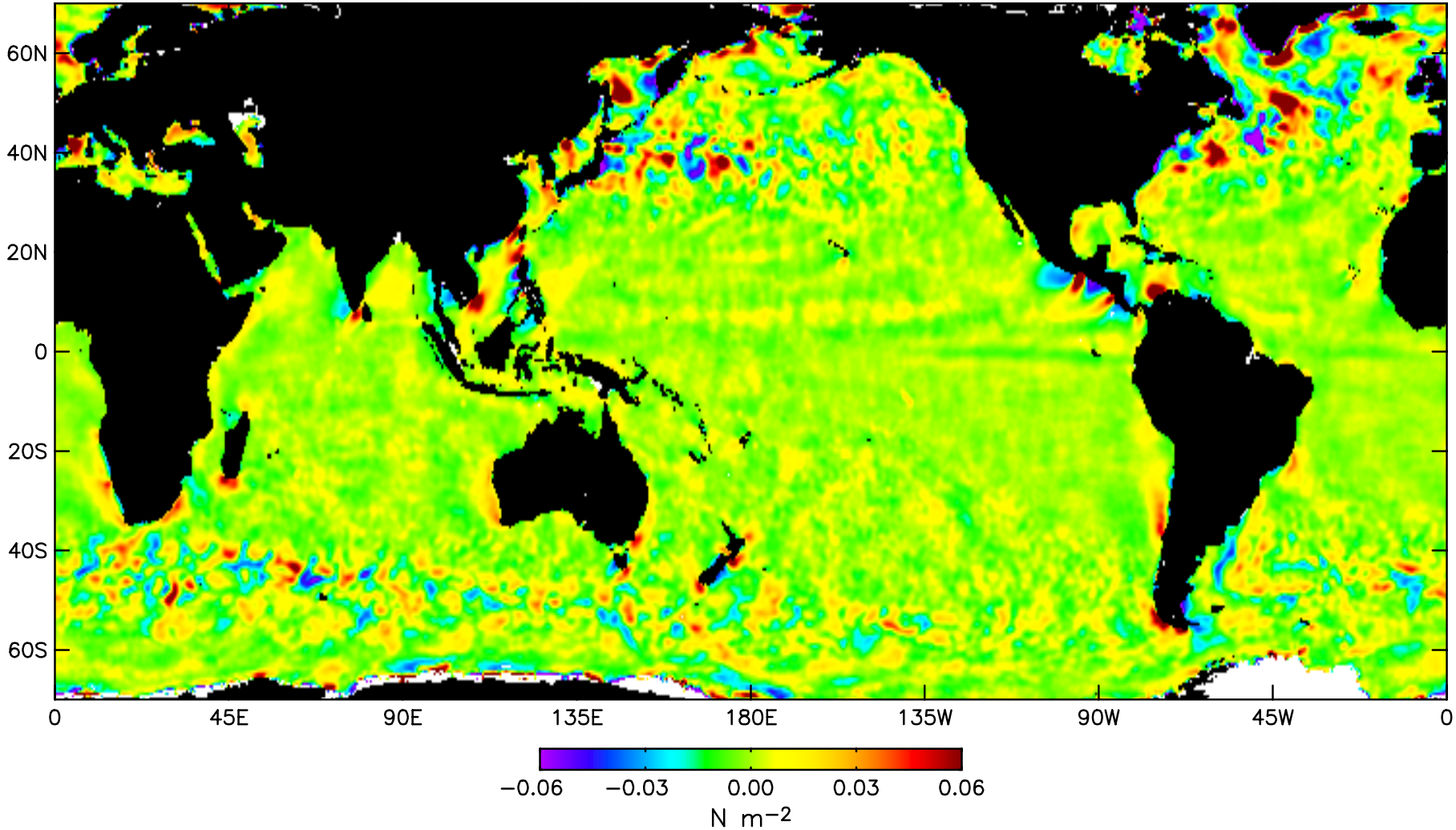
Does the observed strong influence of SST on low-level winds extend into the atmosphere above the boundary layer?

QuikSCAT, November 2002 – February 2003



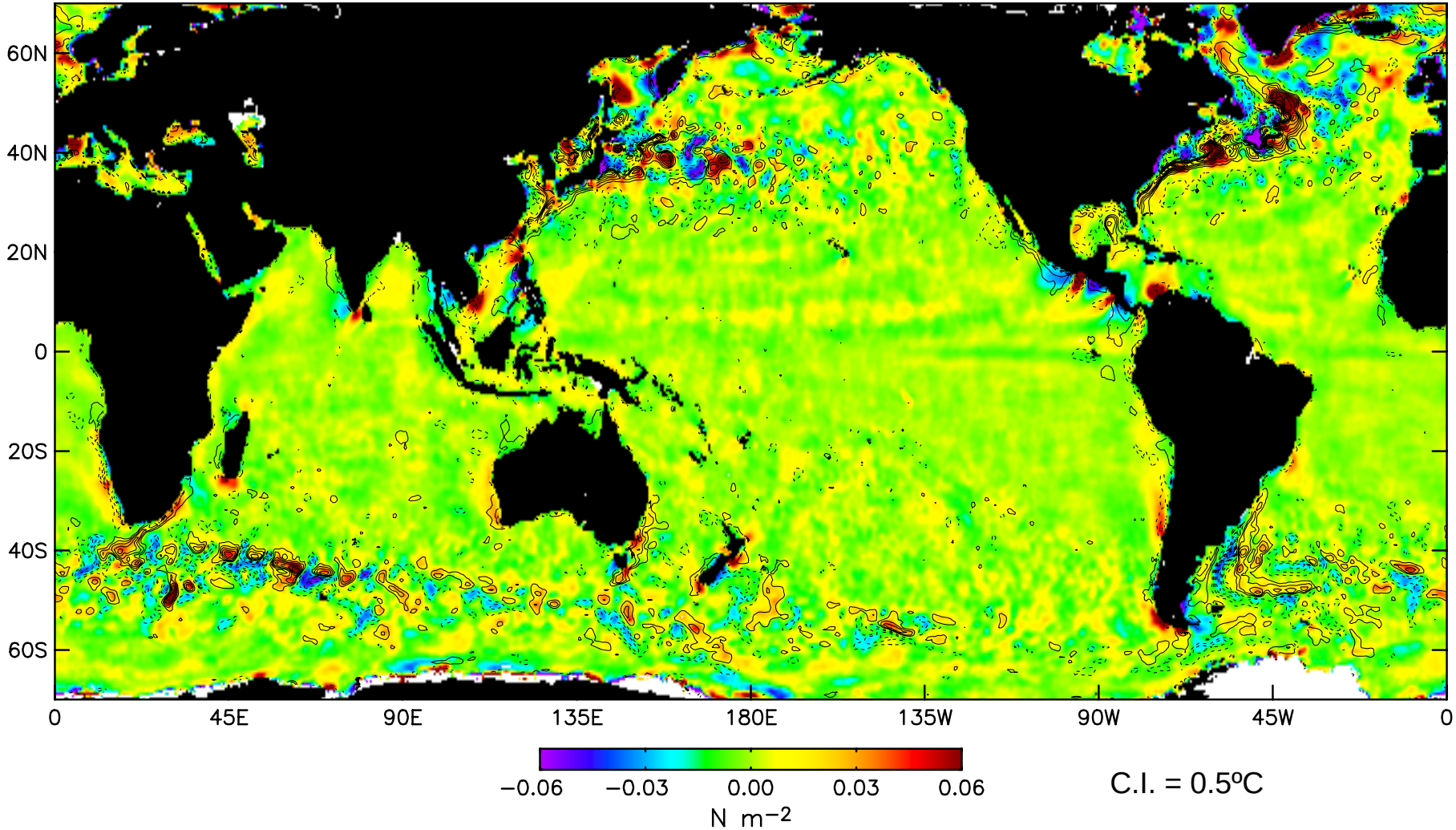
QuikSCAT, November 2002 – February 2003

High Pass Filtered Wind Stress and SST



QuikSCAT, November 2002 – February 2003

High Pass Filtered Wind Stress and SST



Past Studies of SST Influence on Surface Winds from Ship-Based and Aircraft Observations:

* Sweet et al., 1981: Air-sea interaction effects in the lower troposphere across the north wall of the Gulf Stream. *Mon. Wea. Rev.*, **109**, 1042-1052.

  Jury, M. R., and N. Walker, 1988: Marine boundary layer modification across the edge of the Agulhas Current. *J. Geophys. Res.*, **93**, 647-654.

  Wallace et al., 1989: The influence of sea surface temperature on surface wind in the eastern equatorial Pacific: Seasonal and interannual variability. *J. Clim.*, **2**, 1492-1499.

  Hays et al., 1989: The influence of sea surface temperature on surface wind in the eastern equatorial Pacific: Weekly to monthly variability. *J. Clim.*, **2**, 1500-1506.

  Jury, 1993: A thermal front within the marine atmospheric boundary layer over the Agulhas Current south of Africa: Composite aircraft observations. *J. Geophys. Res.*, **99**, 3297-3304.

  Rouault and Lutjeharms, 2000: Air-sea exchange over an Agulhas eddy at the subtropical convergence. *Global Atmos. Ocean Syst.*, **7**, 125-150.

MONTHLY WEATHER REVIEW

MAY 1981

Air-Sea Interaction Effects in the Lower Troposphere Across the North Wall of the Gulf Stream

WAYNE SWEET, ROBERT FETT, JEFFREY KERLING AND PAUL LAVIOLETTE

Aerial Photos Near the Gulf Stream SST Front, 6 December 1979

Cold Slope Water, 5 m/s Wind Speed

Warm Waters of the Gulf Stream, 15 m/s Wind Speed

Aircraft Measurements of Boundary Layer Winds Across the Gulf Stream

(Sweet et al., 1981}

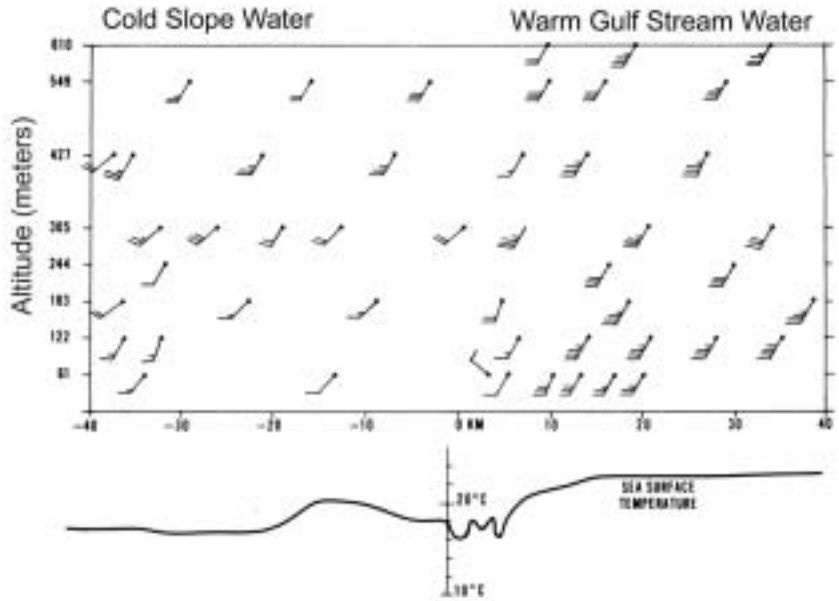
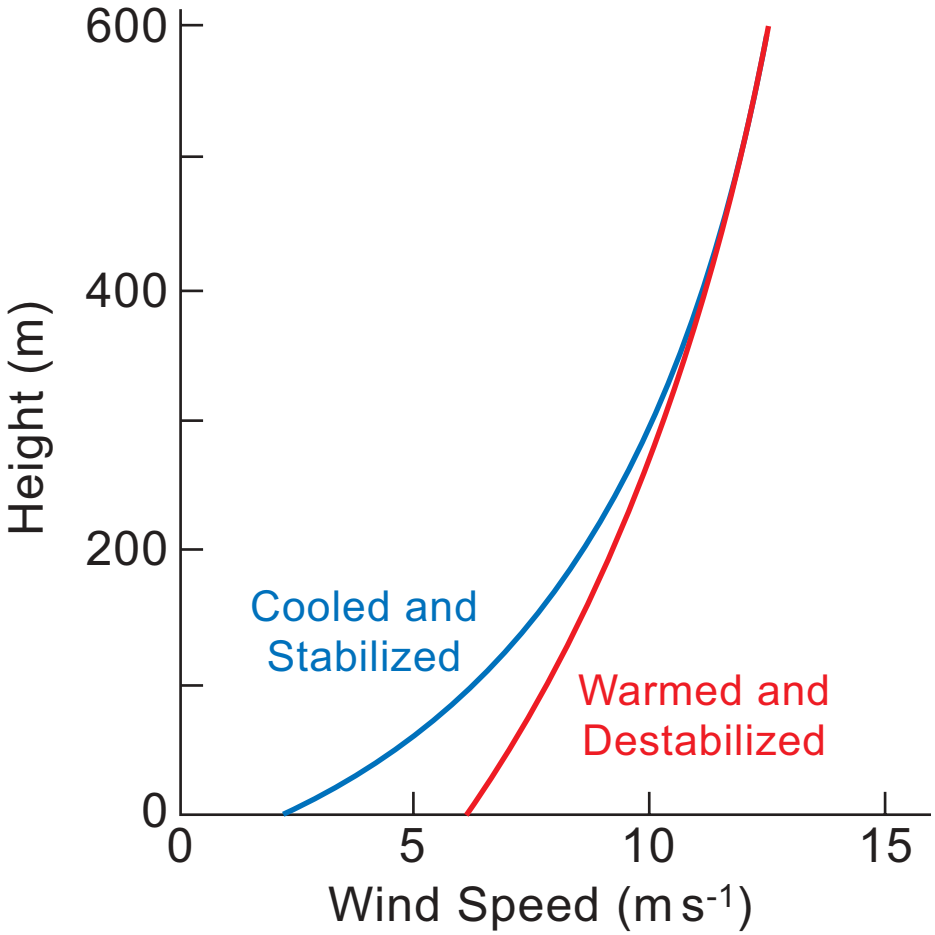


FIG. 9. Winds as determined from the inertial navigation system for the eight flight altitudes, 6 December 1979. One full barb ~ 5 m s^{-1} (10 kt).

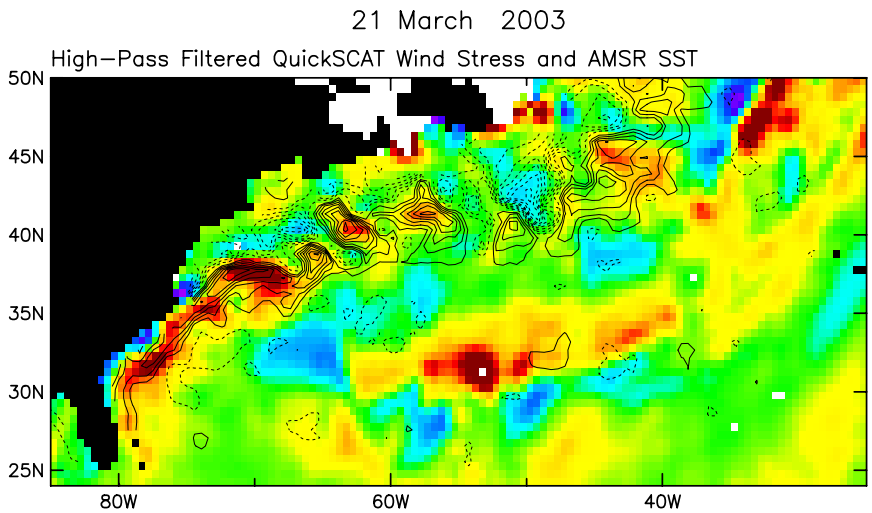
"A very rough sea state was observed as the aircraft proceeded toward the north wall from over the Gulf Stream. The north wall was detected both visually and by aircraft radar as a line separating agitated rough seas from much more placid conditions over the cold Slope Water.

... In flying from the Gulf Stream toward the Slope Water, the aircraft left a region of very turbulent flight conditions and good visibility. Once over the Slope Water, flight conditions immediately became smooth.

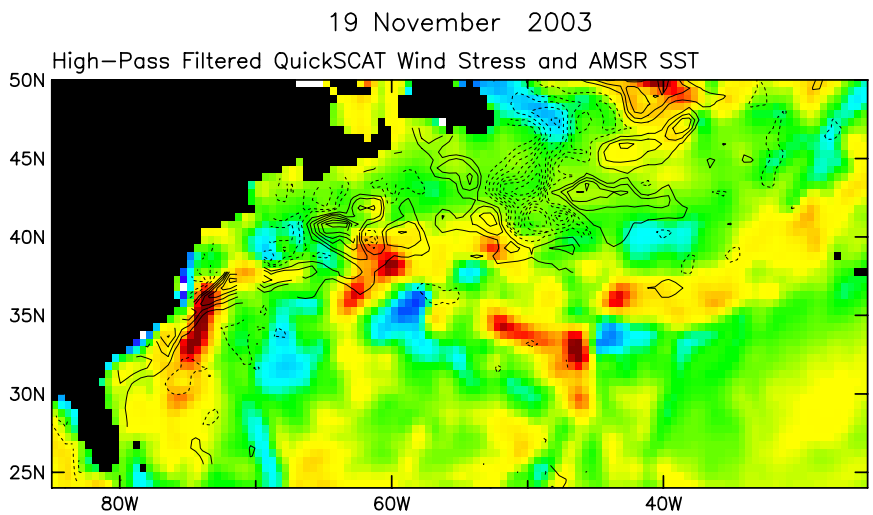
... The cold water apparently acted to stabilize the air moving over its surface and inhibited the development of stronger winds through vertical transfer of momentum."


600
400
200
0
Height (m)
Cooled and
Stabilized
Warmed and
Destabilized
0
5
10
15
Wind Speed (m s-1)

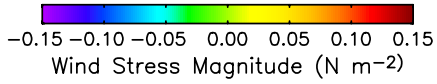
Example 3-Day Averages of High-Pass Filtered Wind Stress Magnitude and SST



High Correlation



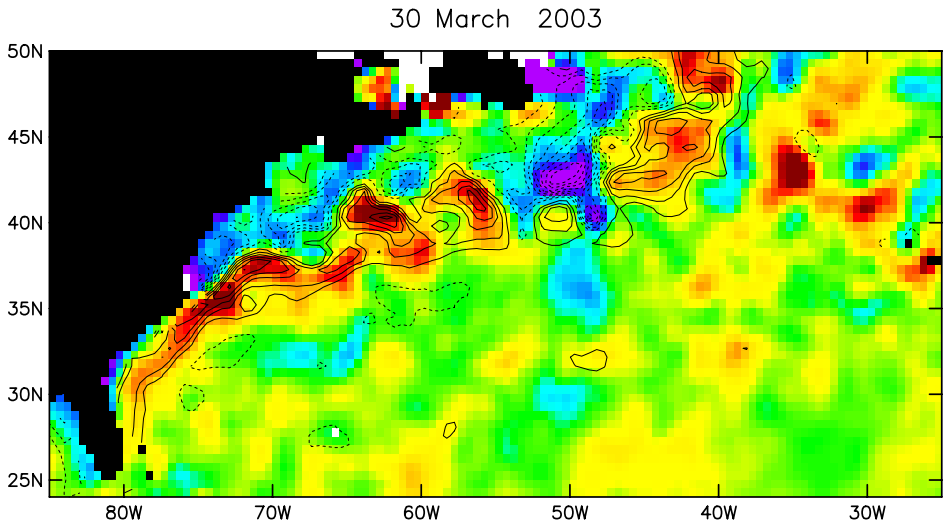
Low Correlation



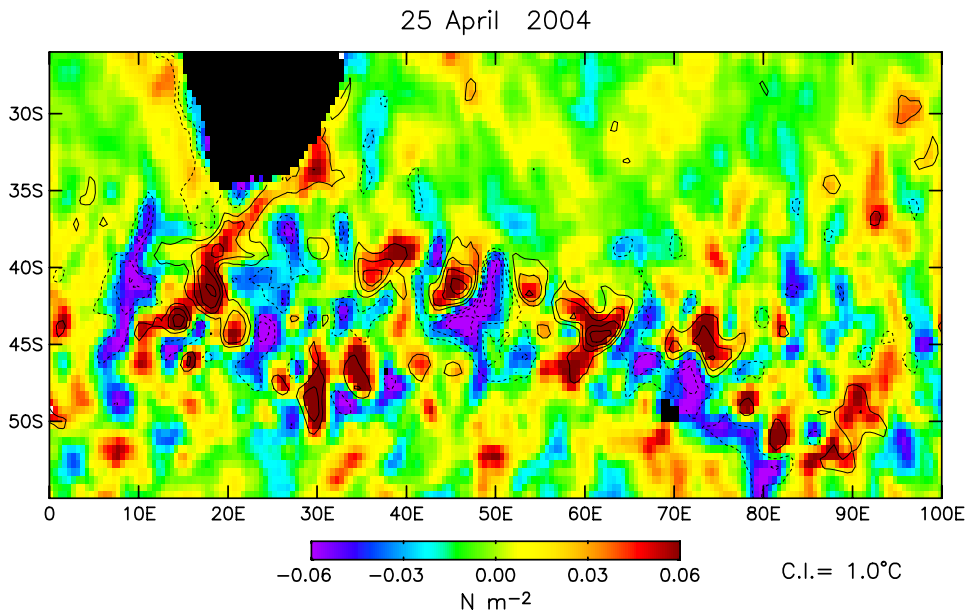
C.I. = 1ºC

Example 28-Day Averages of High-Pass Filtered Wind Stress Magnitude and SST

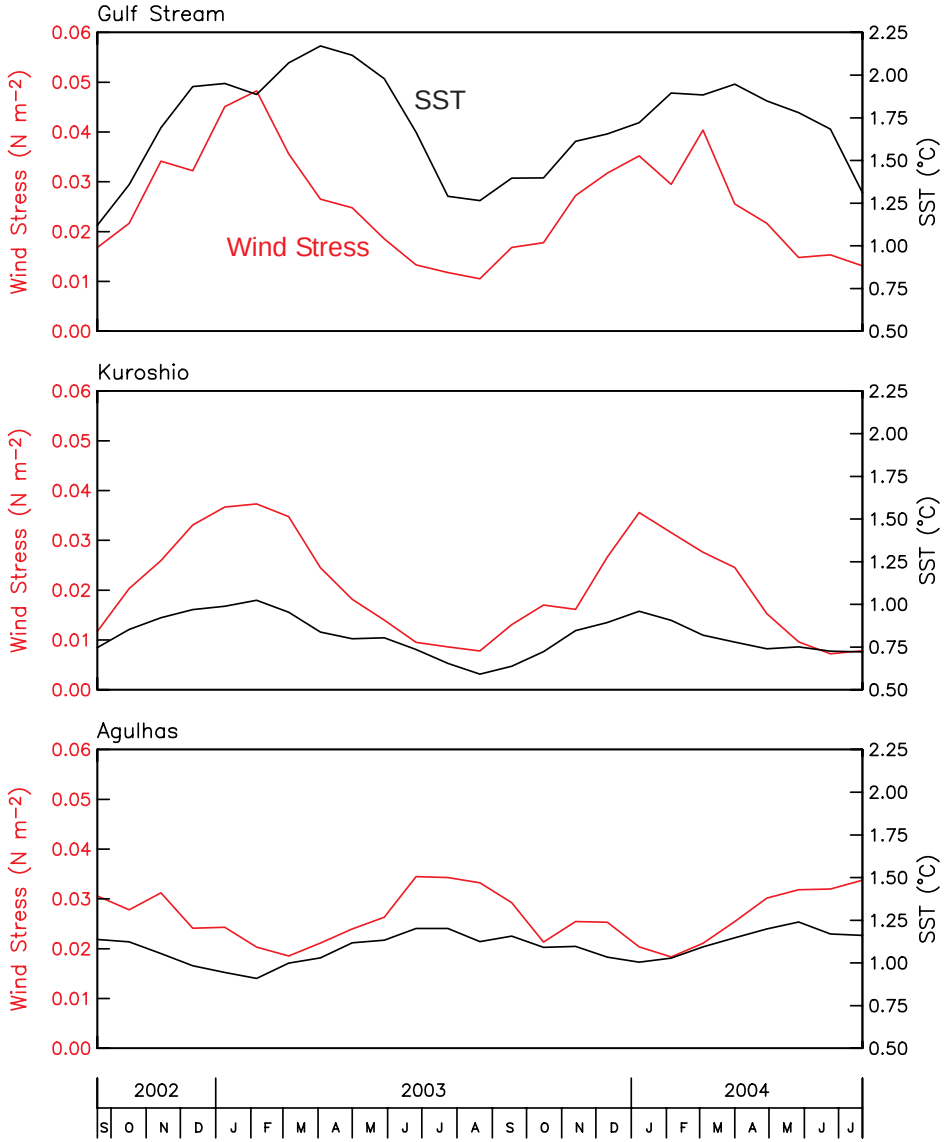
Gulf Stream Region

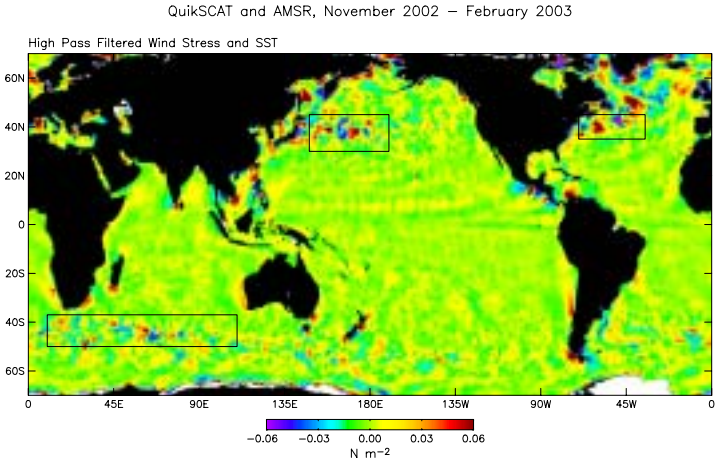


Agulhas Return Current Region

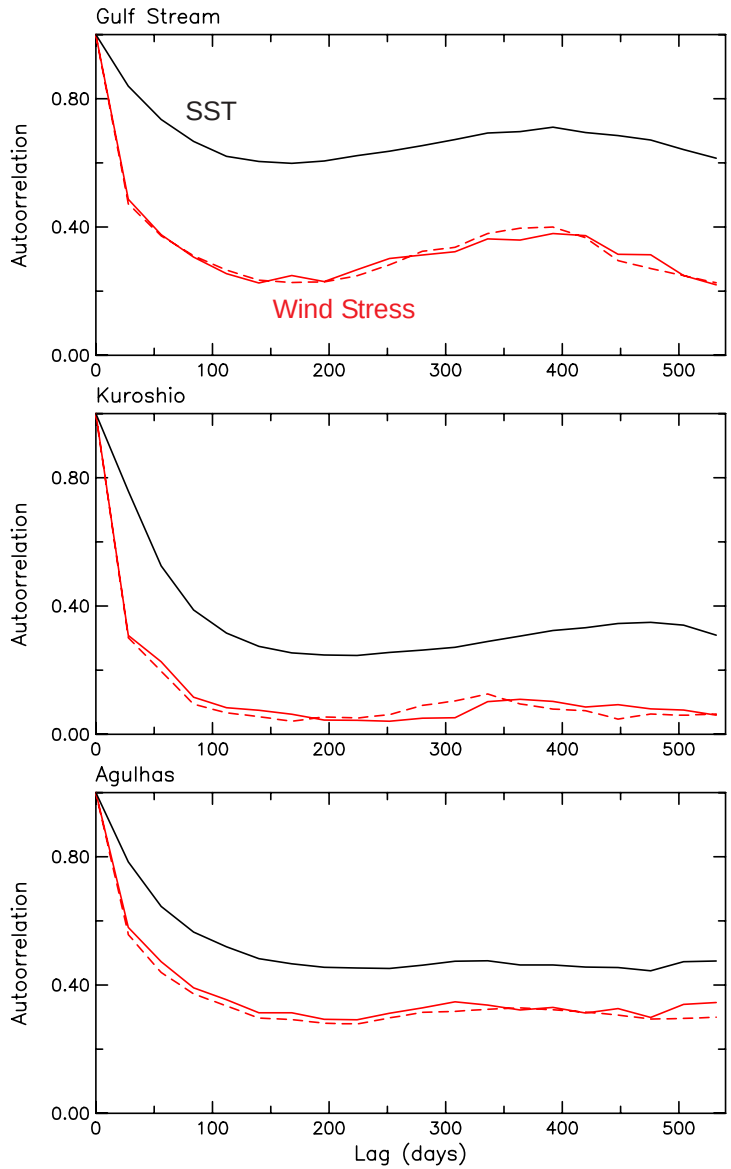


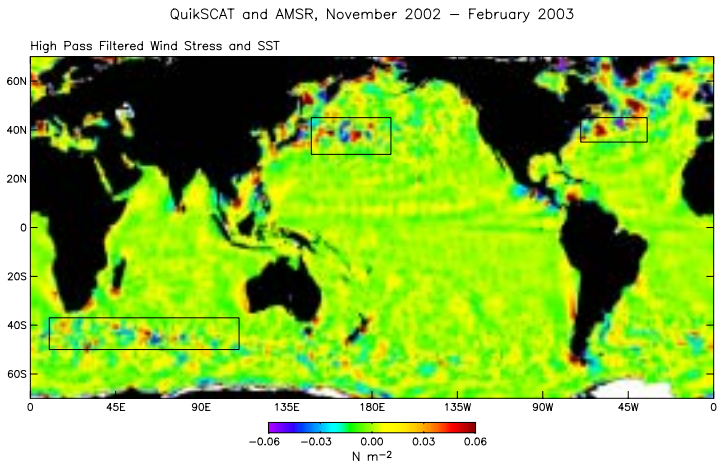
Spatial Standard Deviations of High-Pass Filtered Wind Stress Magnitude and SST





Temporal Autocorrelations of High-Pass Filtered Wind Stress Magnitude and SST



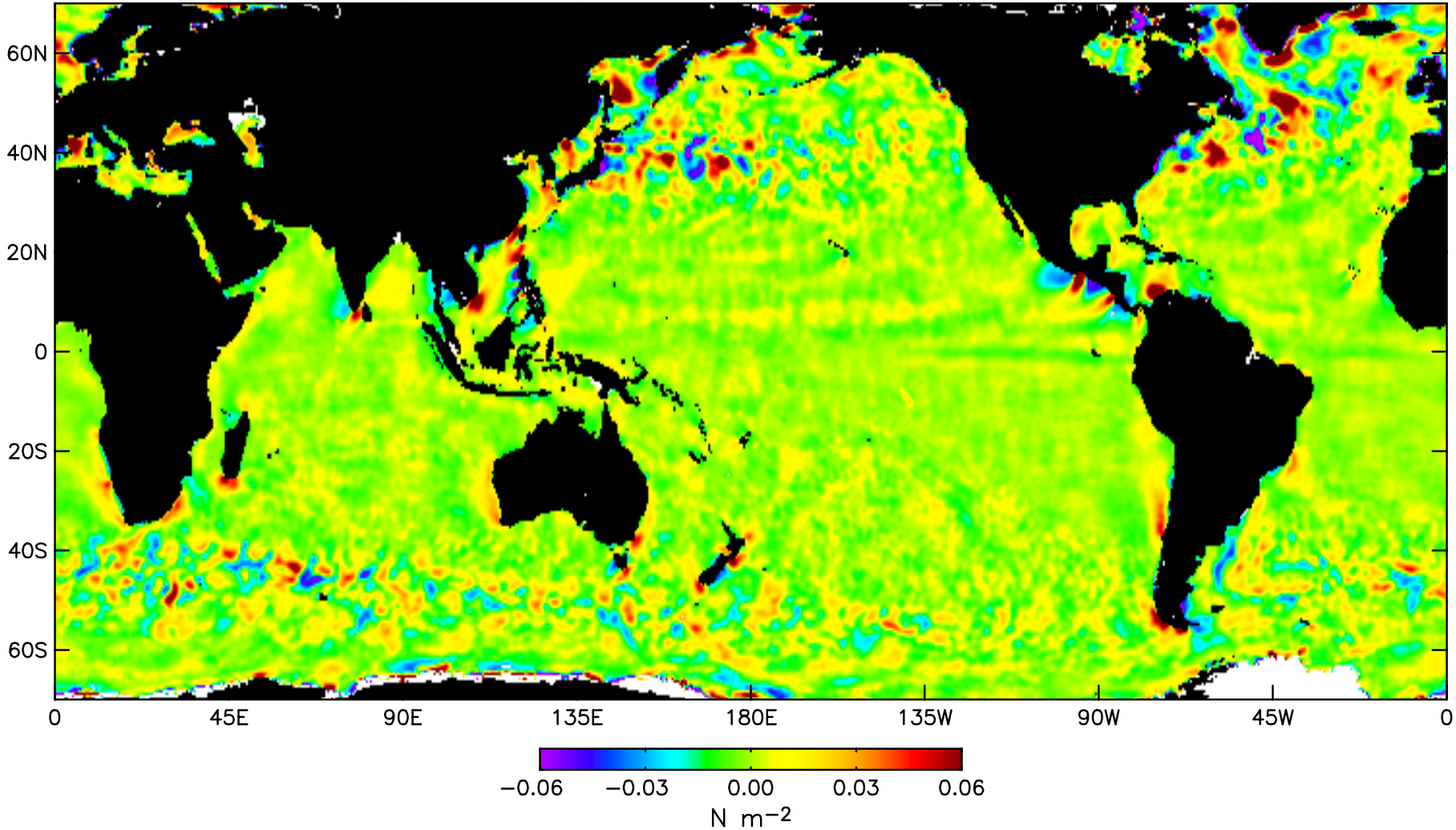


Red and Black solid lines: September 2002 - August 2004 (AMSR-E data record)

Red dashed line: August 1999 - August 2004 (QuikSCAT data record)

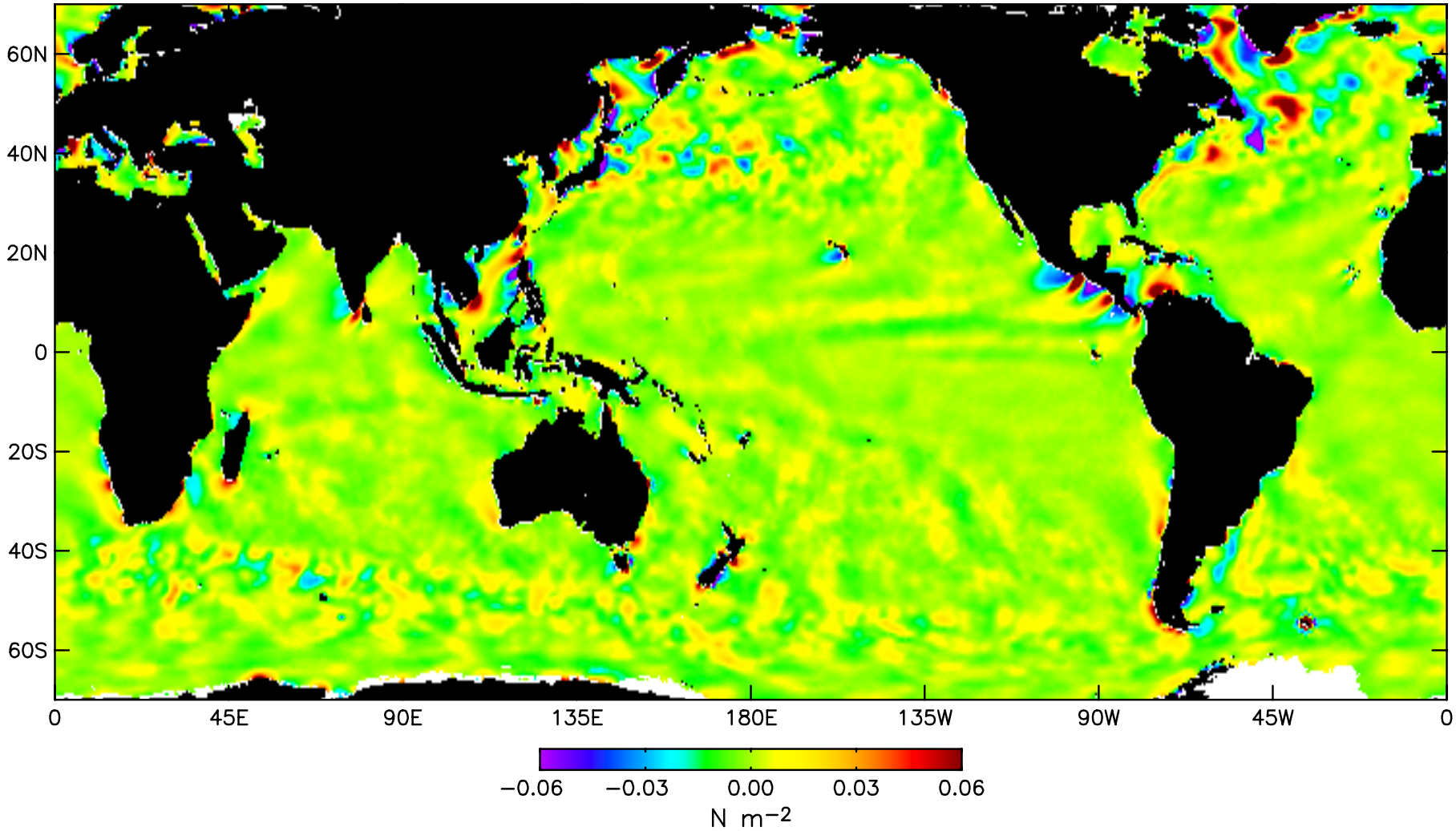
QuikSCAT, November 2002 – February 2003

High Pass Filtered Wind Stress and SST



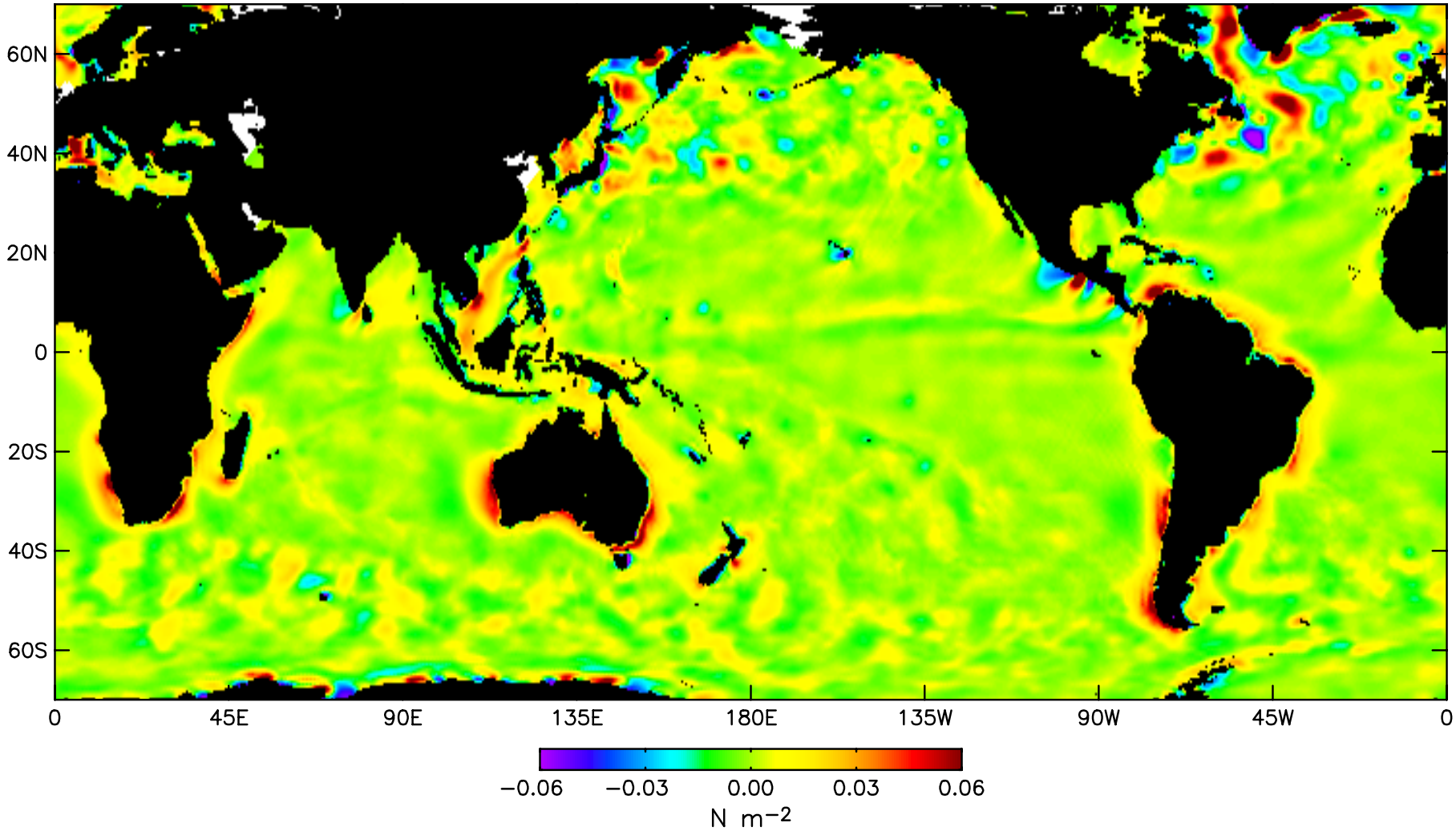
ECMWF and Reynolds, November 2002 – February 2003

High Pass Filtered Wind Stress and SST



NCEP and Reynolds, November 2002 – February 2003

High Pass Filtered Wind Stress and SST



Hypothesis:

The differences between contemporary ECMWF and NCEP surface wind fields are attributable primarily to the different specifications of the SST boundary condition in the two models.

This can be tested from comparison of ECMWF and NCEP surface wind stress fields before and after May 9, 2001:

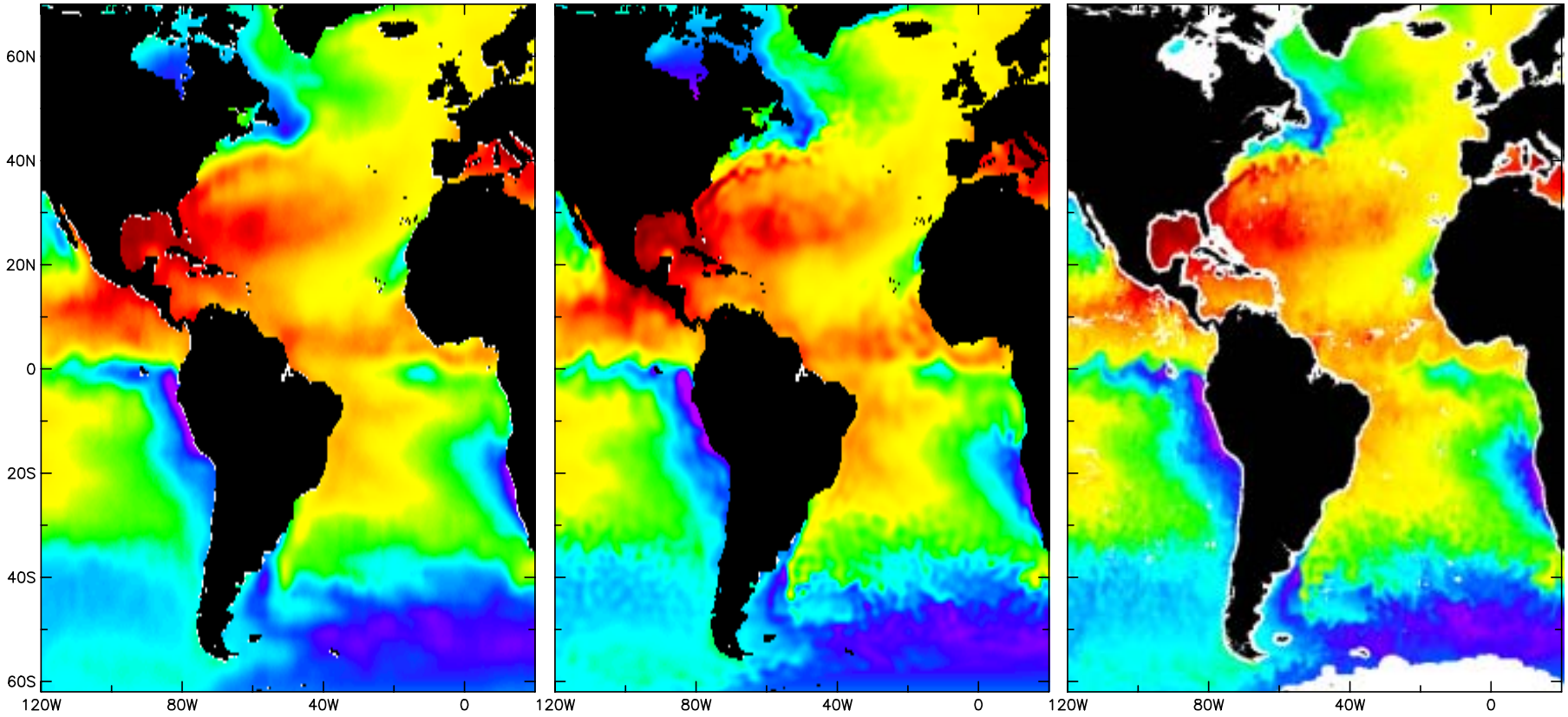
The ocean boundary condition in the ECMWF model was changed from the low-resolution Reynolds SST analyses to the much higher-resolution NOAA Real-Time Global (RTG) SST analyses.

The NCEP Global Forecast System (GFS) continues to use the Reynolds SST analyses as the ocean boundary condition.

Note that the NOAA North American Mesoscale model (NAM, formerly Eta) has used the RTG SST analyses as the ocean boundary condition since January 30, 2001.

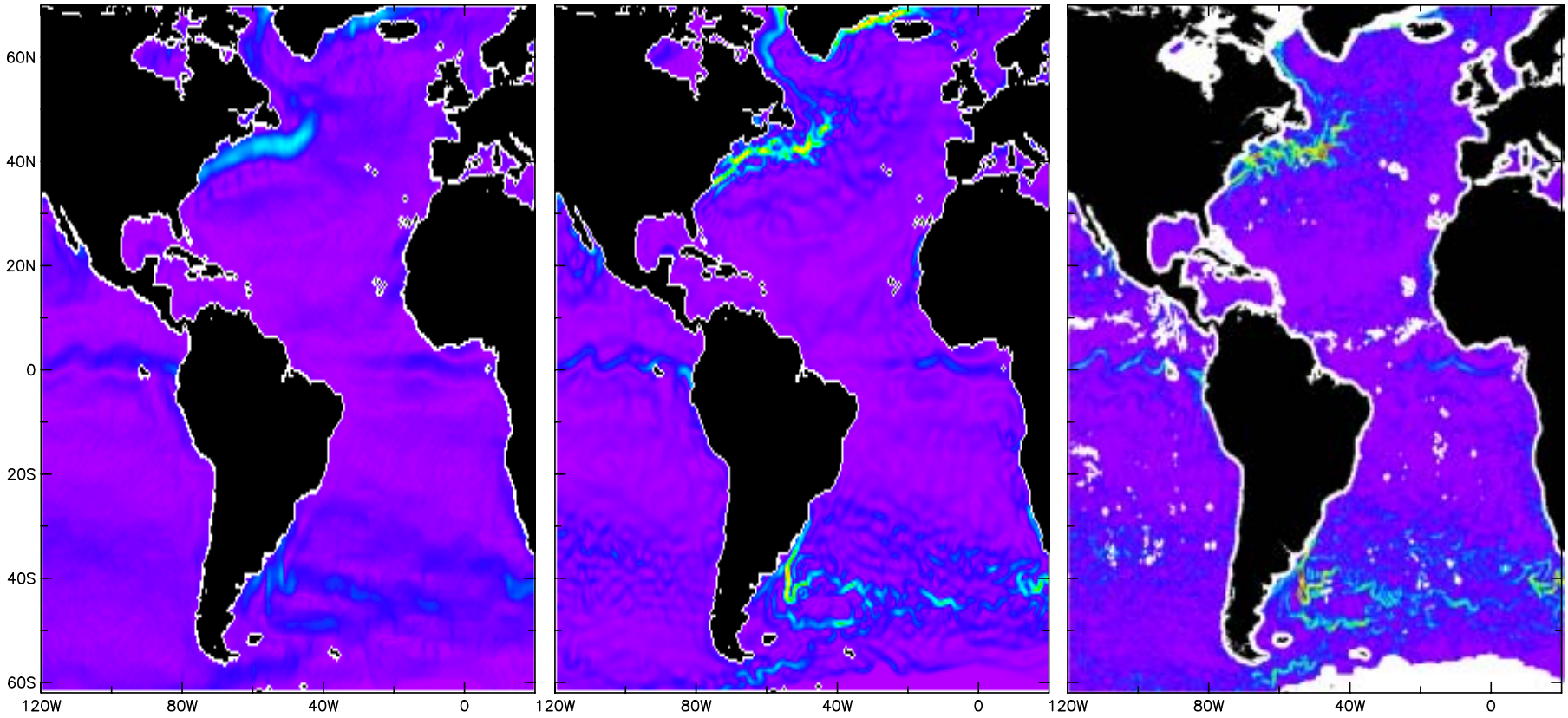
SST, June 23-25, 2003

Reynolds Analysis | RTG Analysis | AMSR



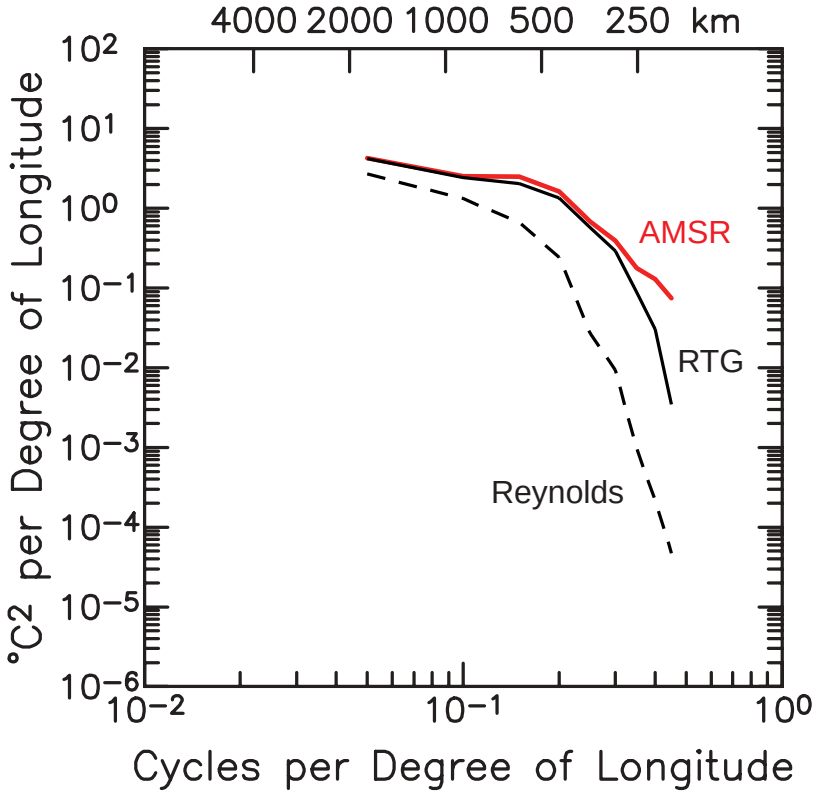
SST Gradient Magnitude, June 23-25, 2003

Reynolds Analysis RTG Analysis AMSR

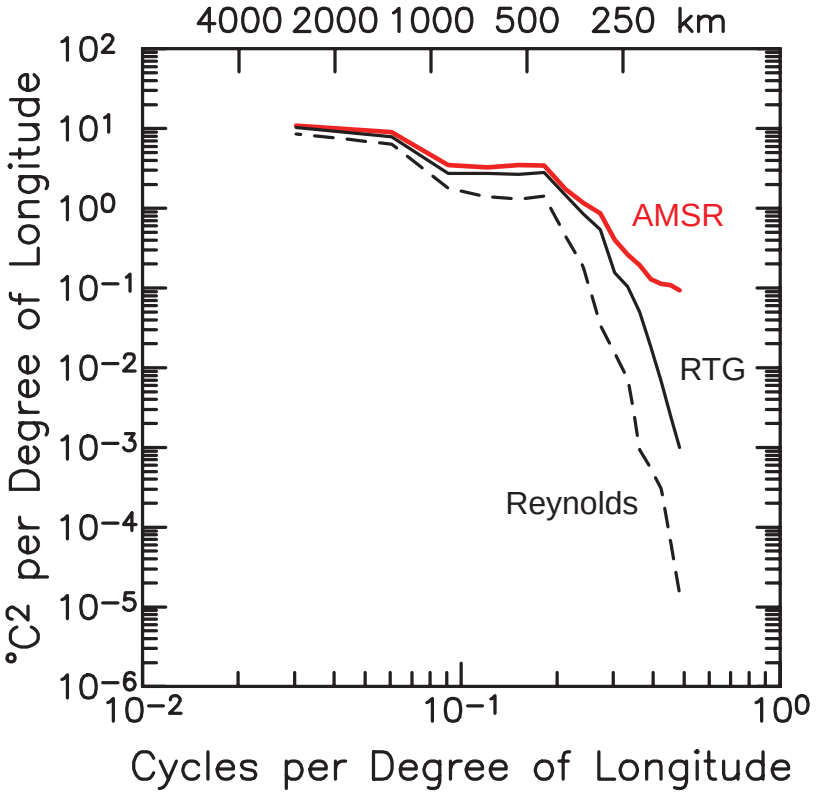


Zonal Wavenumber Spectra of SST

Kuroshio Extension



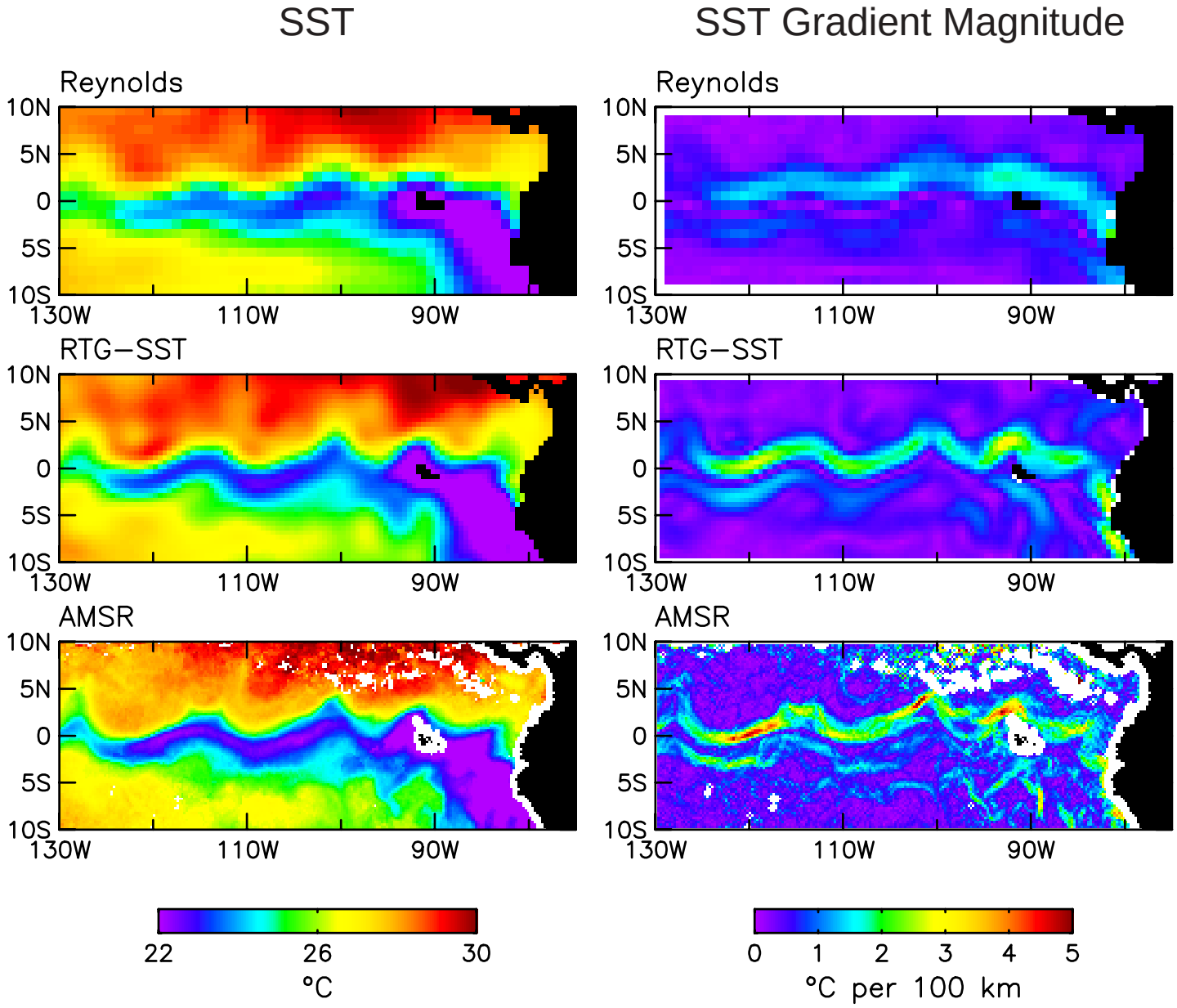
Agulhas Return Current



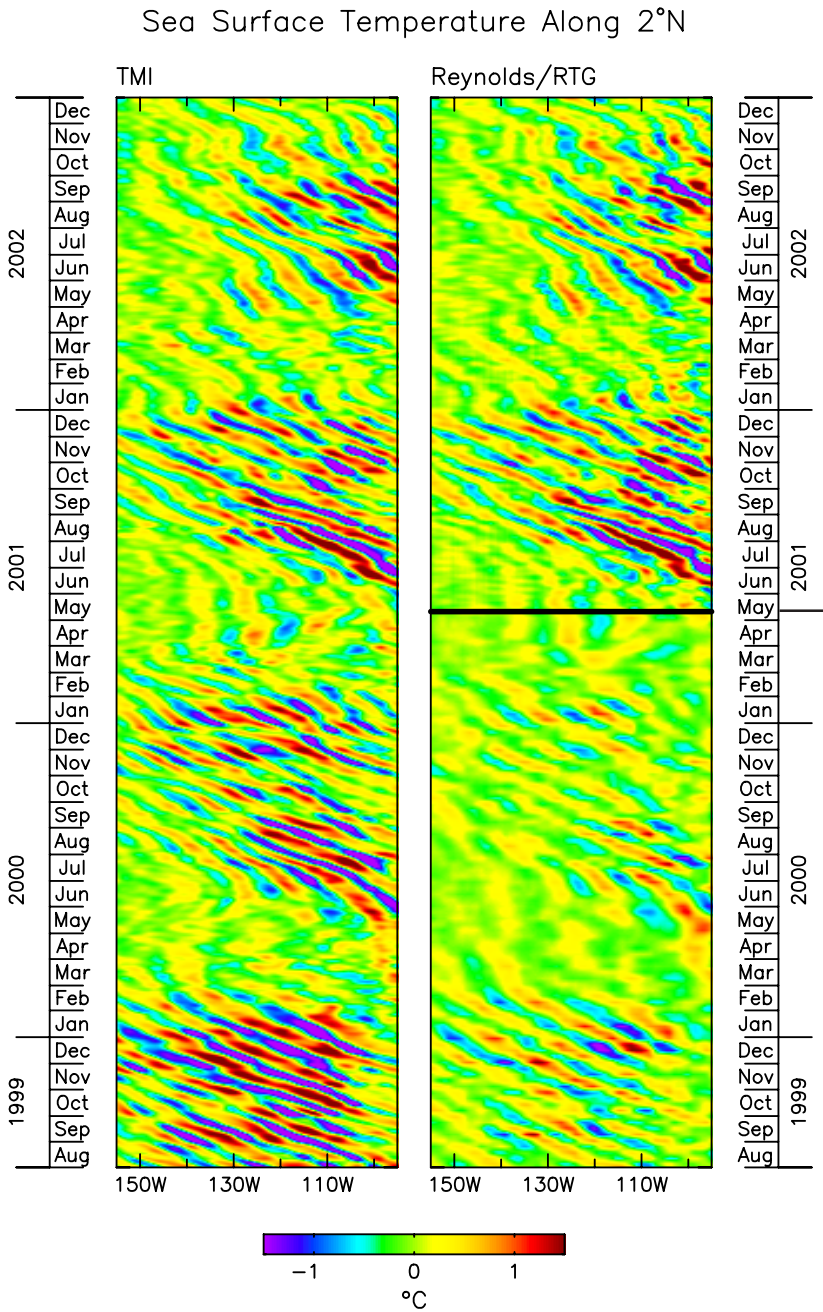
Regions Considered:

- *Eastern tropical Pacific*
- *Gulf Stream*
- *Agulhas Return Current*
- *Kuroshio Extension*

Example for the Eastern Tropical Pacific, May 27-29, 2003



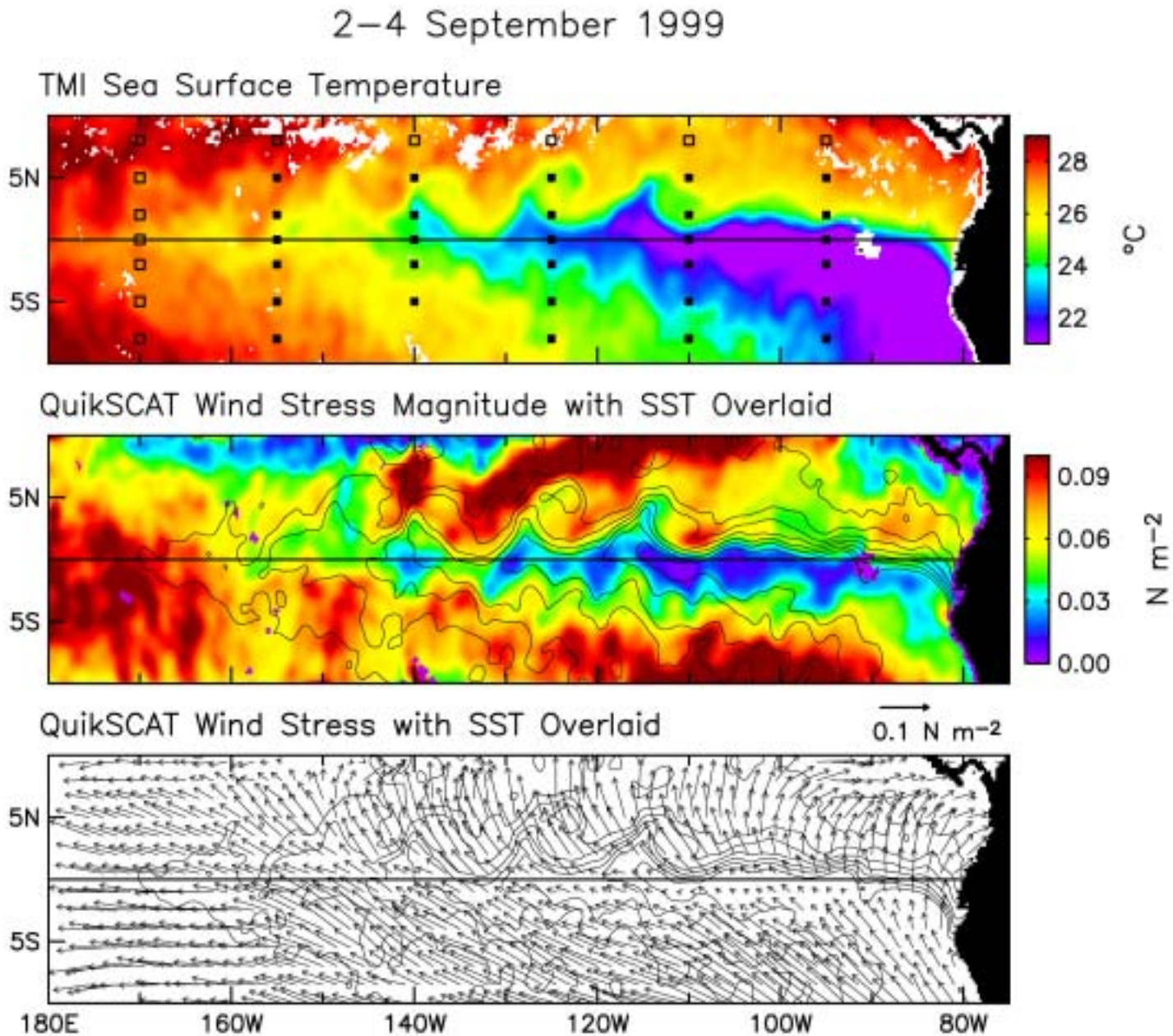
TMI Microwave SST



RTG SST Analyses

May 9, 2001

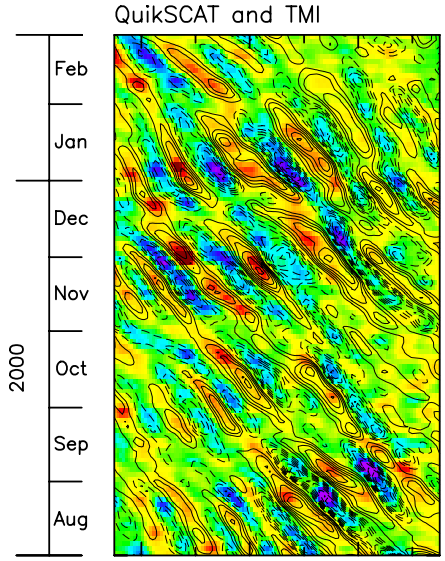
Reynolds SST Analyses

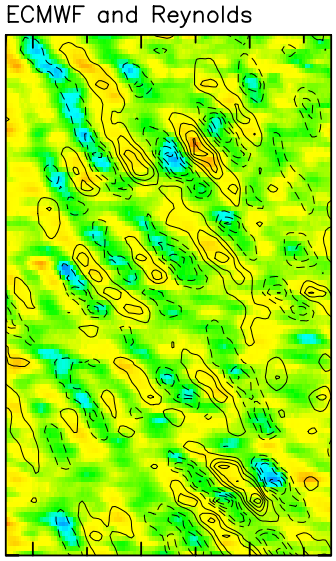

2–4 September 1999
TMI Sea Surface Temperature
5N
5S
28
26
24
22
°C
QuikSCAT Wind Stress Magnitude with SST Overlaid
5N
5S
0.09
0.06
0.03
0.00
N m⁻²
QuikSCAT Wind Stress with SST Overlaid
0.1 N m⁻²
5N
5S
180E
160W
140W
120W
100W
80W

SST and Wind Stress Magnitude Along 2ºN

Aug 2000 - Feb 2001

QuikSCAT Wind Stress & Contours of TMI SST



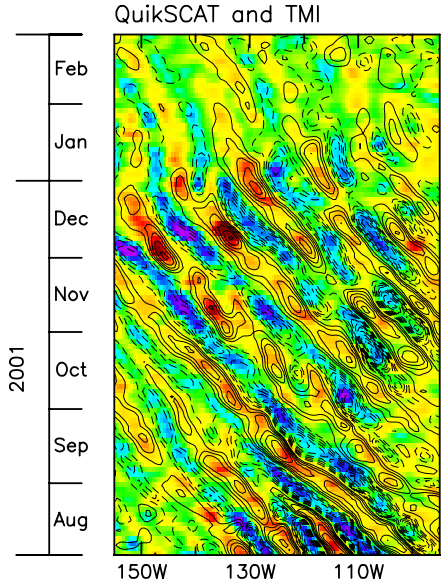


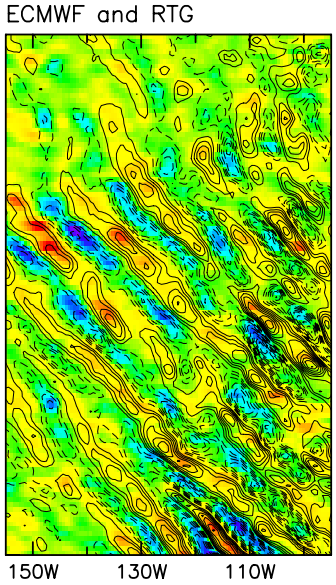
Aug 2000 - Feb 2001

ECMWF Wind Stress & Contours of Reynolds SST

Aug 2001 - Feb 2002

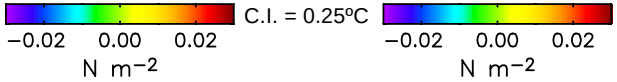
QuikSCAT Wind Stress & Contours of TMI SST



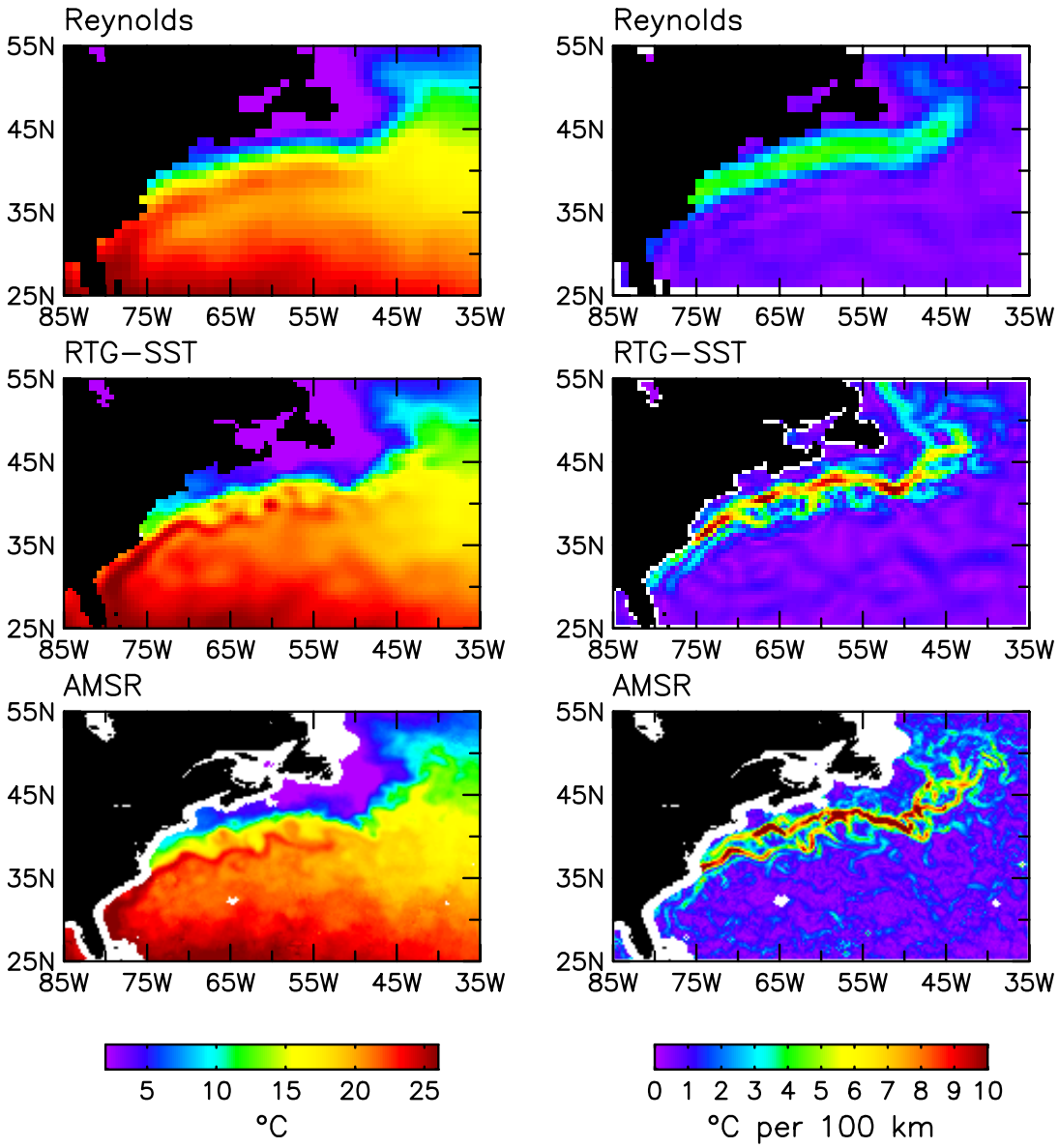


Aug 2001 - Feb 2002

ECMWF Wind Stress & Contours of RTG SST



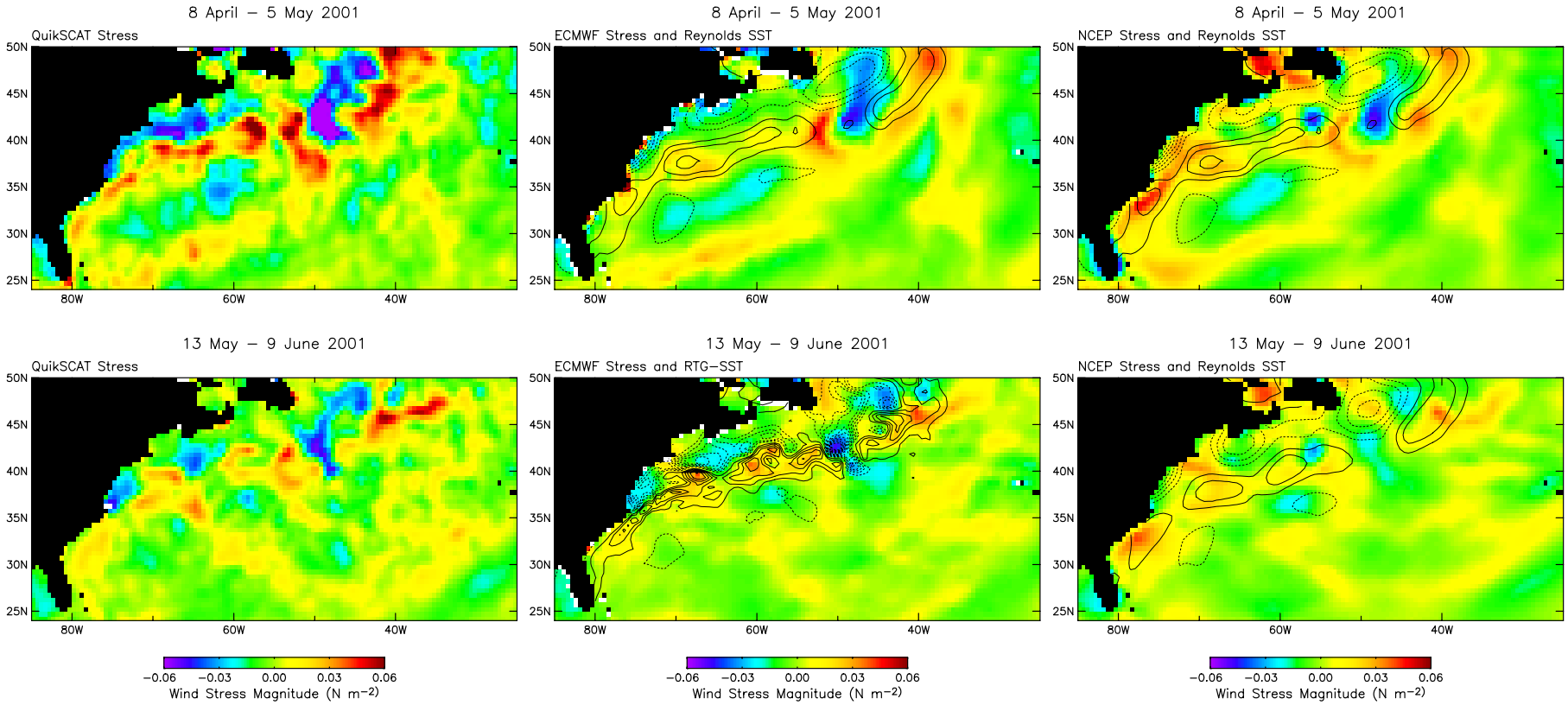
Example Maps of SST in the Gulf Stream Region, April 30 - May 2, 2002



The Gulf Stream Region

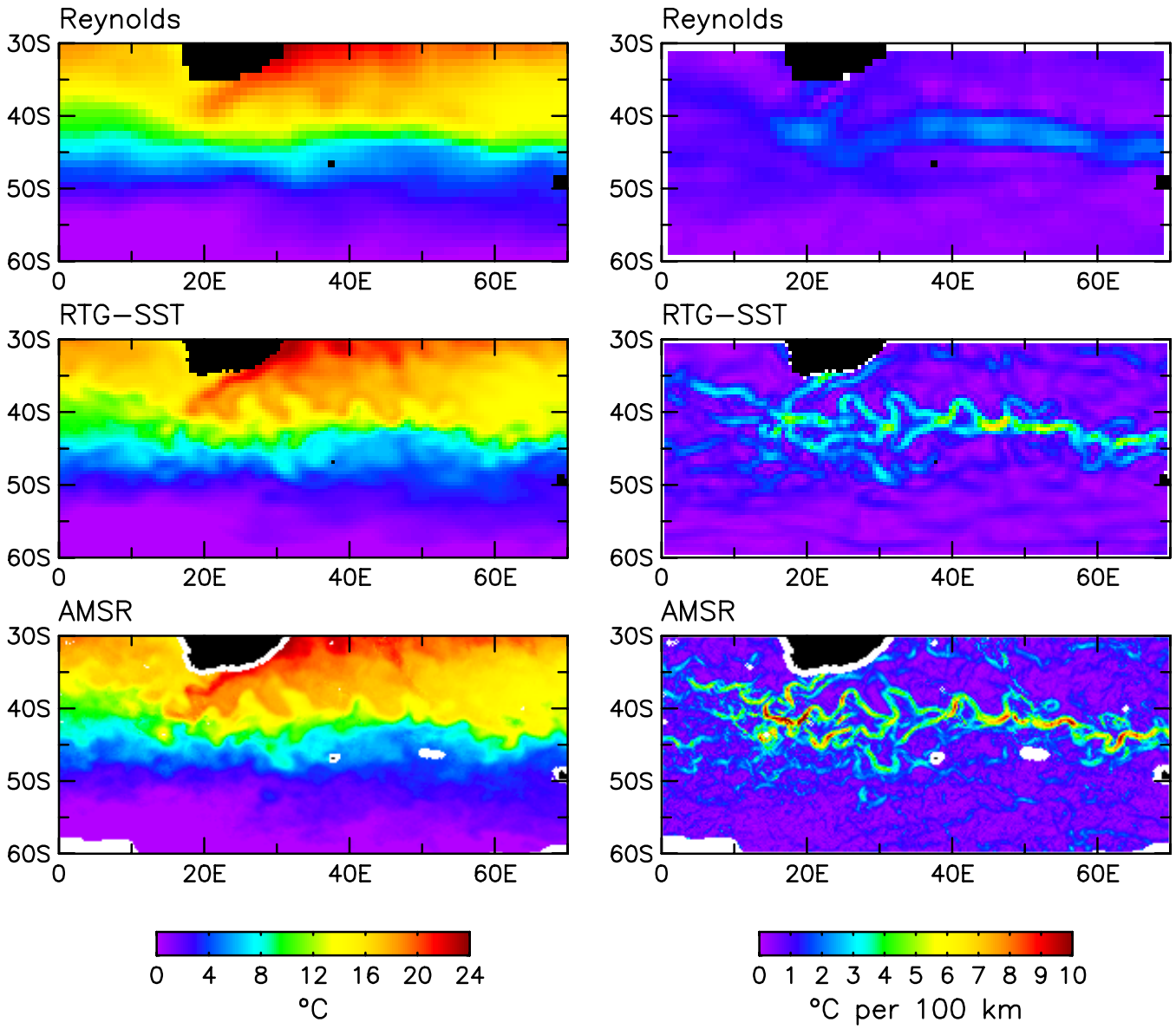
4-Week Averages Before/After May 9, 2001

QuikSCAT | ECMWF | NCEP



C.I. = 1ºC

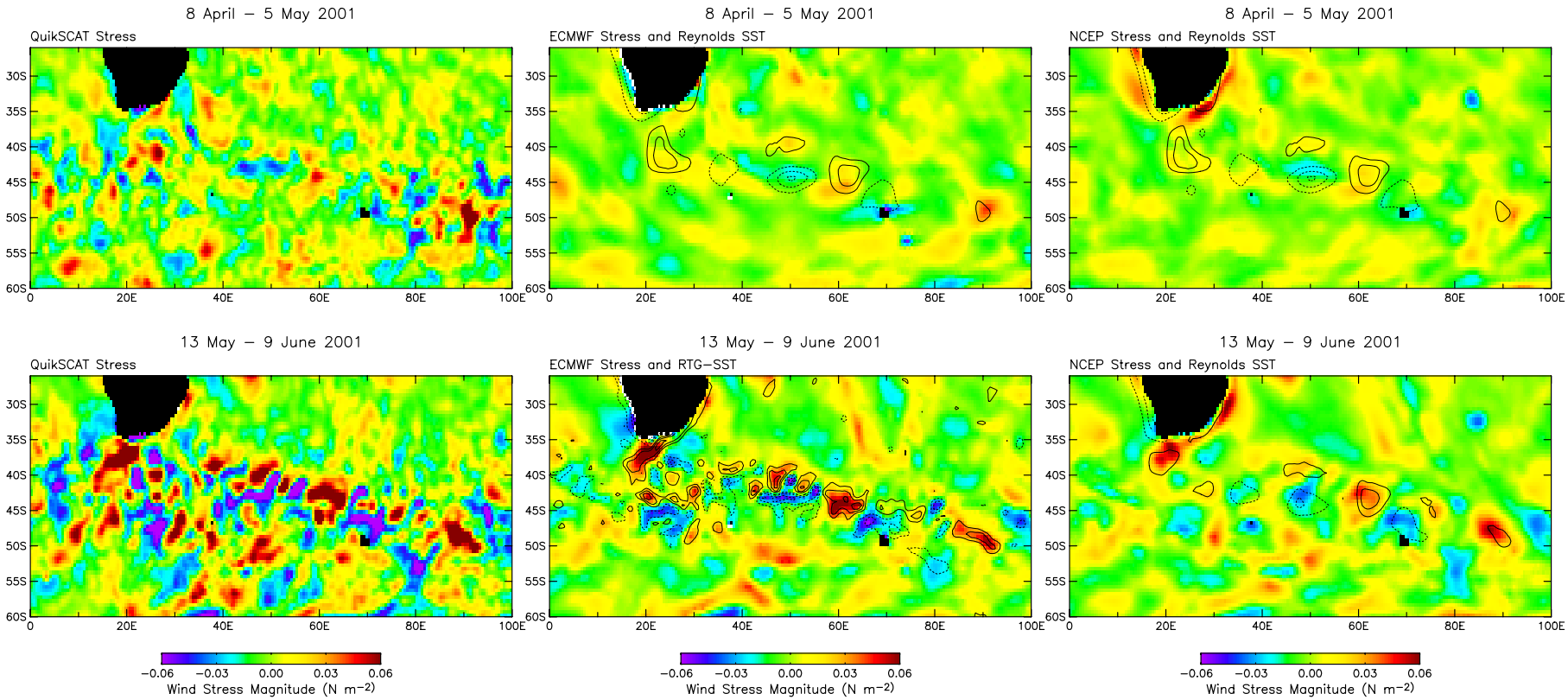
Example Maps of SST in the Agulhas Return Current Region, July 4-6, 2002



The Agulhas Return Current Region

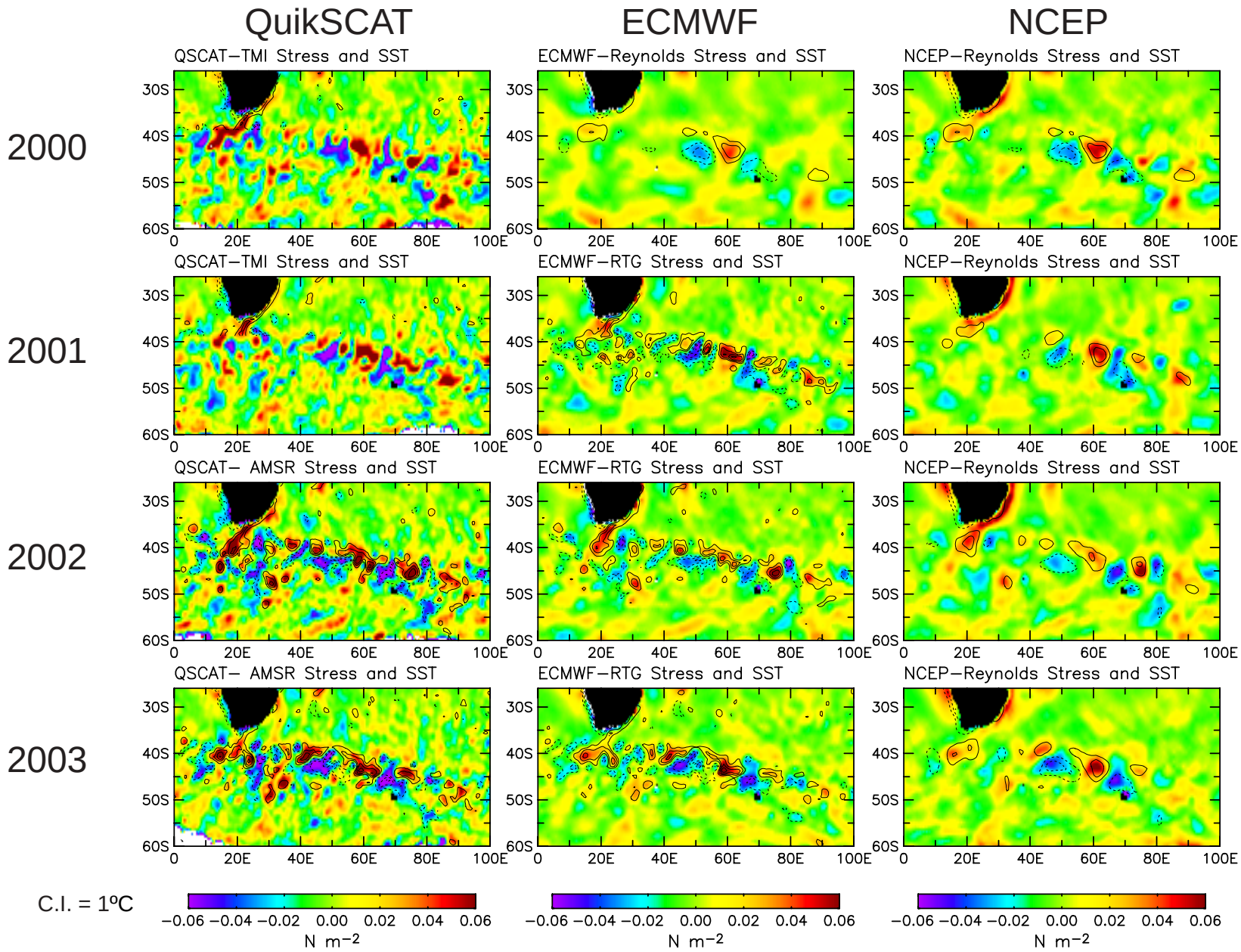
4-Week Averages Before/After May 9, 2001

QuikSCAT | ECMWF | NCEP



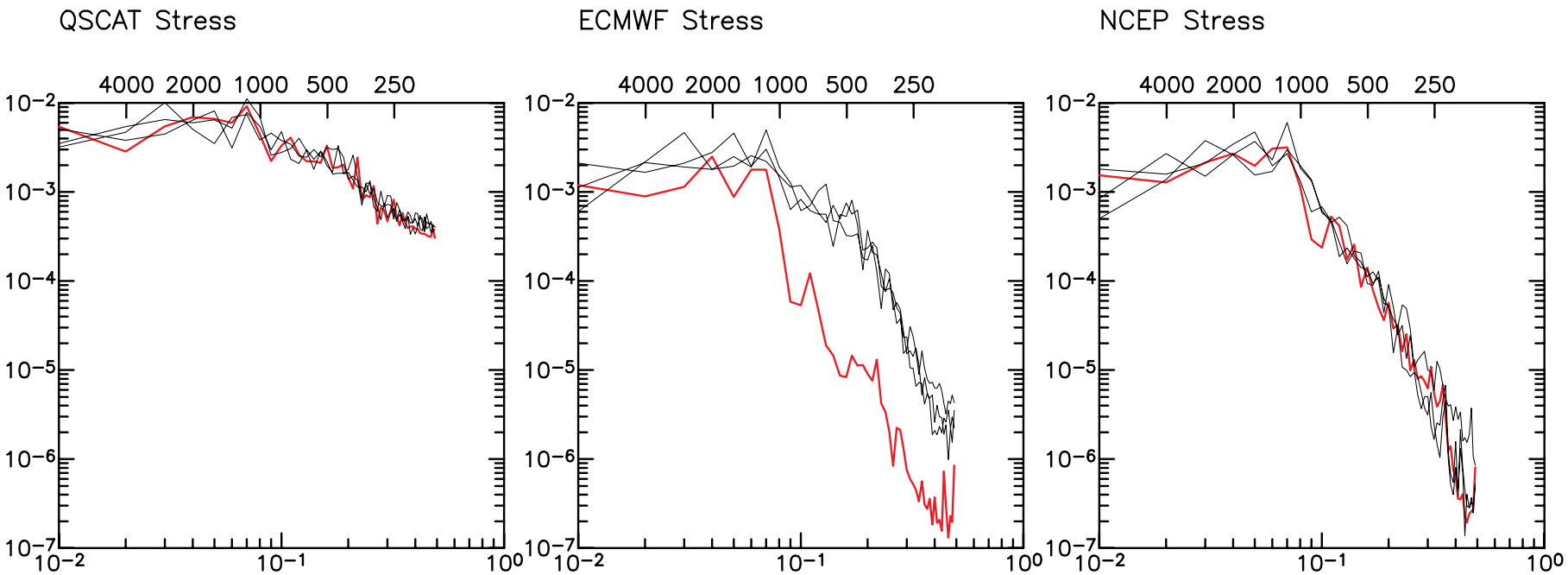
C.I. = 1ºC

Agulhas Return Current, June-July 2000, 2001, 2003 & 2003

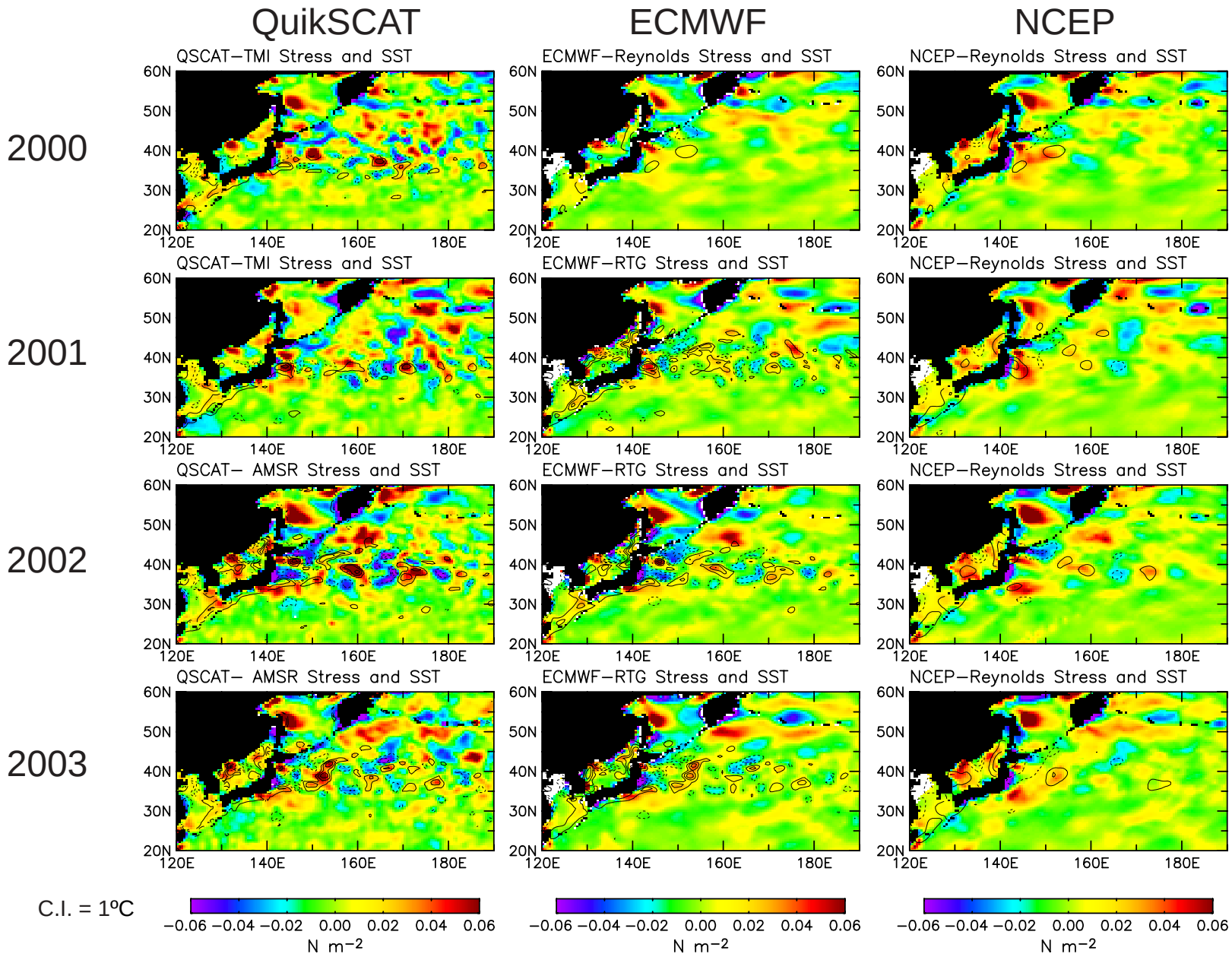


Agulhas Return Current

Zonal Wavenumber Spectra of Wind Stress Magnitude
June-July 2000, 2001, 2002 & 2003

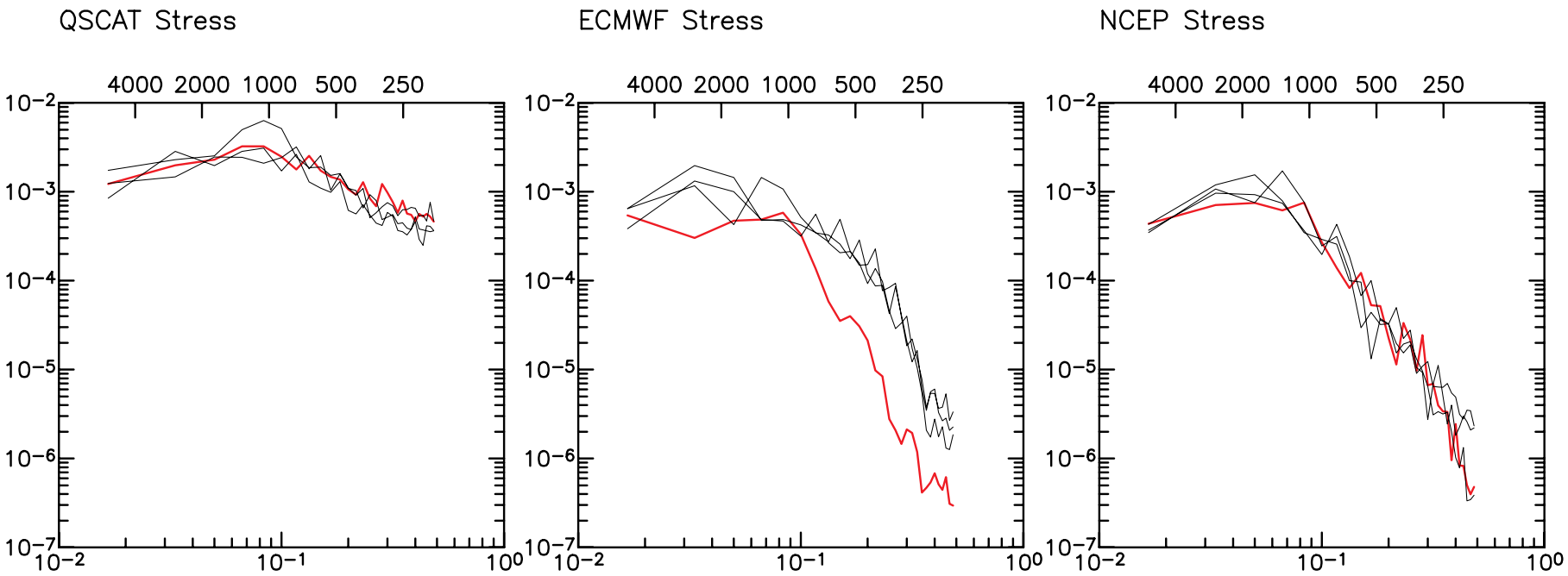


Kuroshio Extension, November-December 2000, 2001, 2003 & 2003

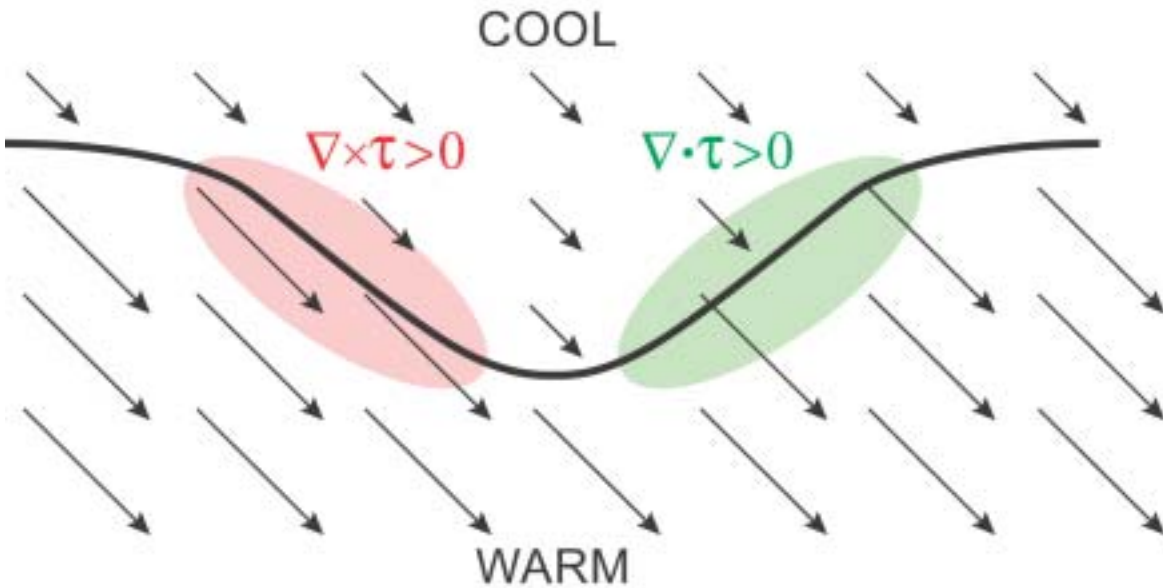


Kuroshio Extension

Zonal Wavenumber Spectra of Wind Stress Magnitude
November-December 2000, 2001, 2002 & 2003



SST Effects on the Divergence and Vorticity of Surface Winds

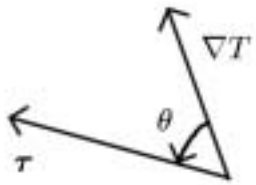


Wind Stress Curl

Wind Stress Divergence

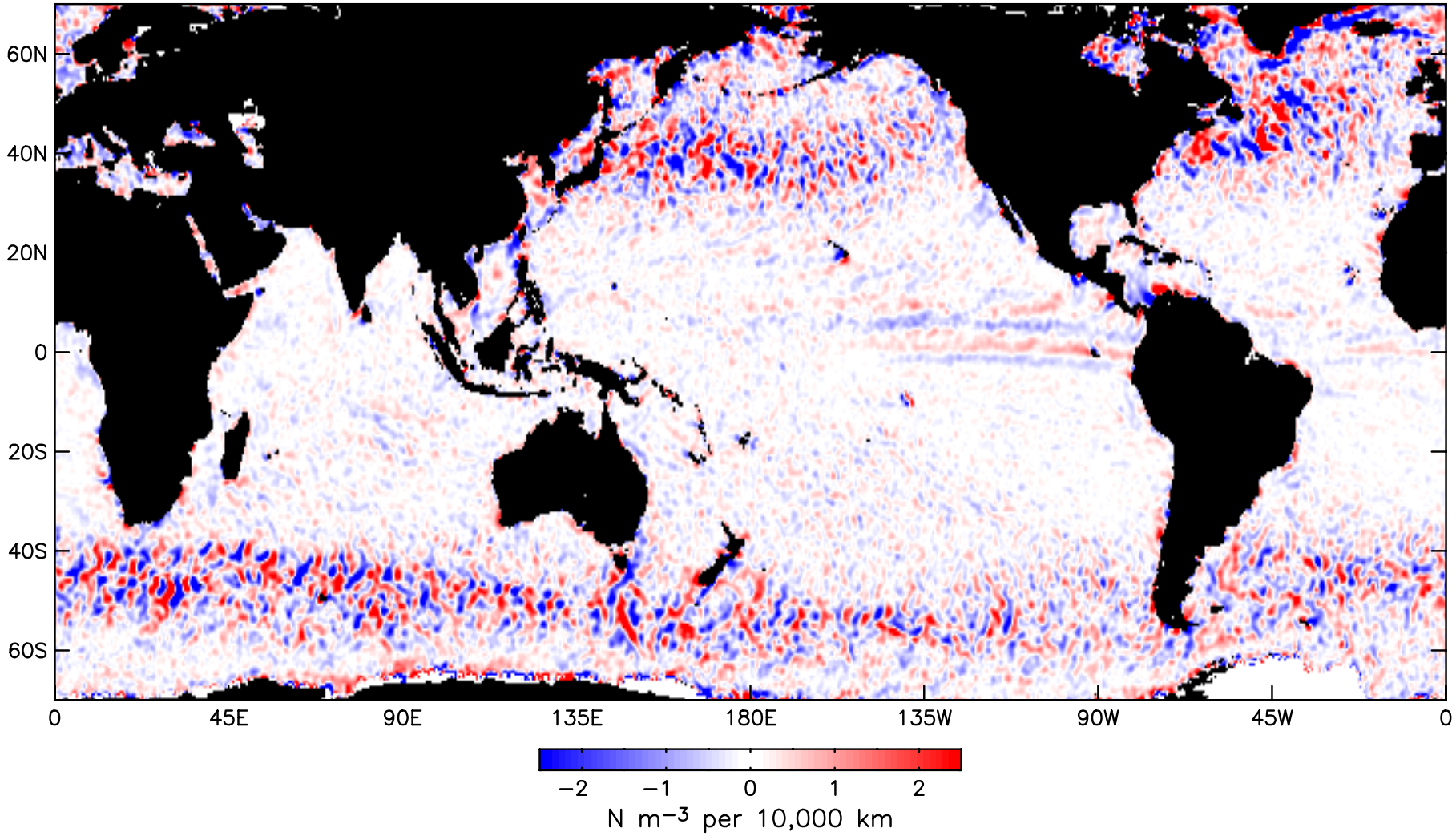
$$\nabla \times \boldsymbol{\tau} \sim \underbrace{\nabla T \times \hat{\boldsymbol{\tau}} = |\nabla T| \sin\theta}_{\text{Crosswind SST Gradient}}$$

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



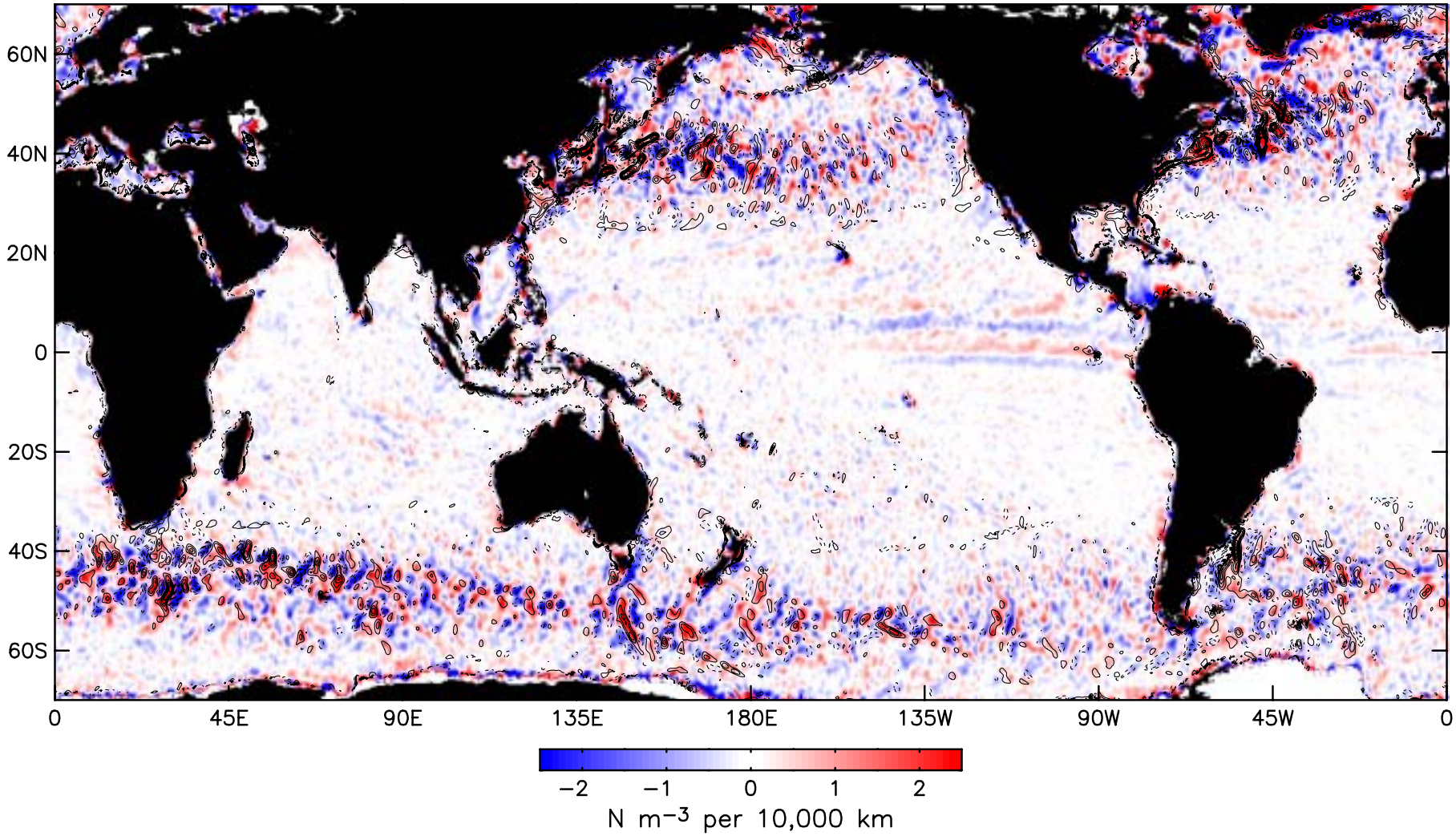
QuikSCAT, November 2002 – February 2003

High Pass Filtered Divergence



QuikSCAT and AMSR, November 2002 – February 2003

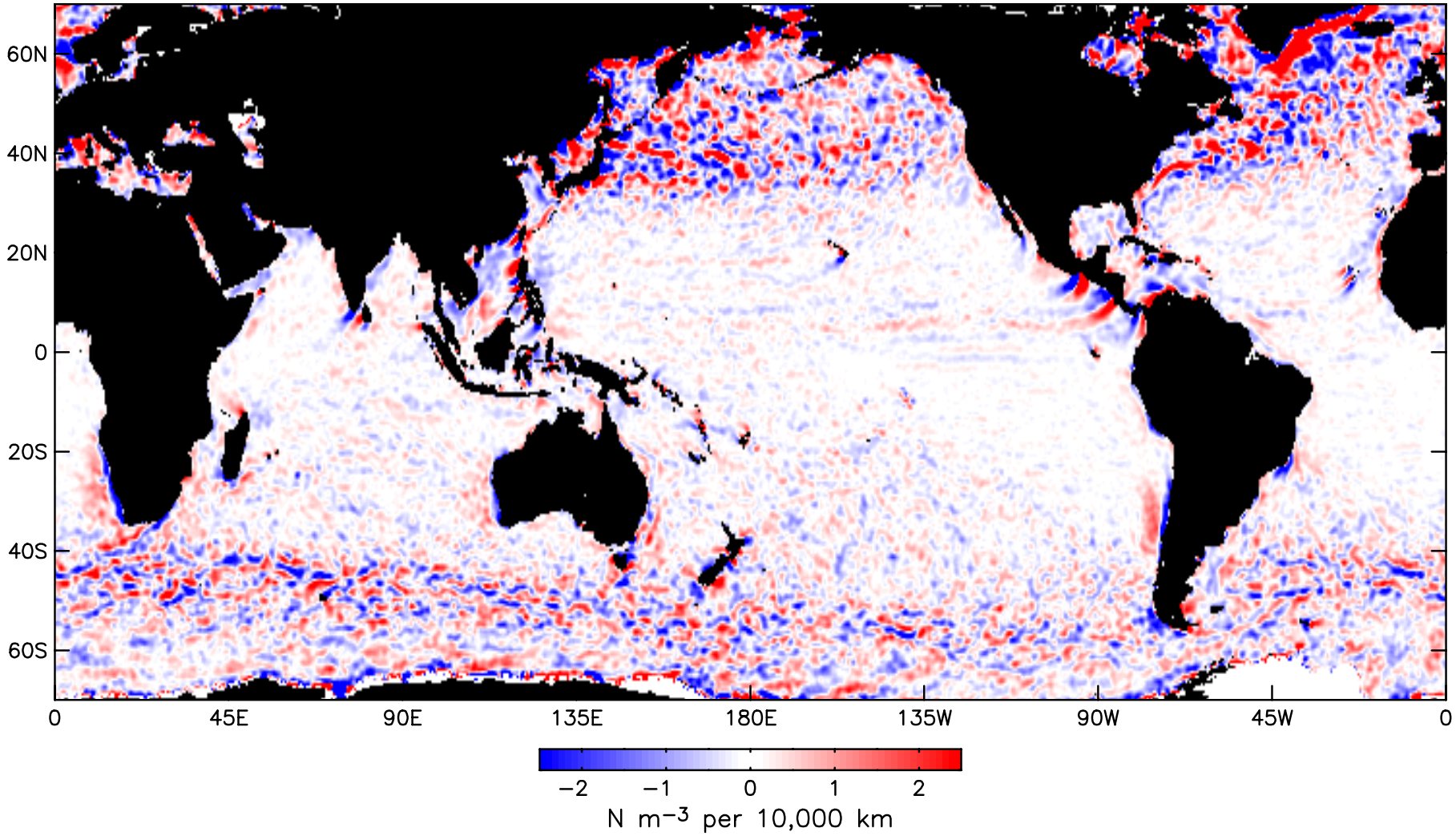
High Pass Filtered Divergence and Downwind ∇T



C.I. = 0.5ºC per 100 km

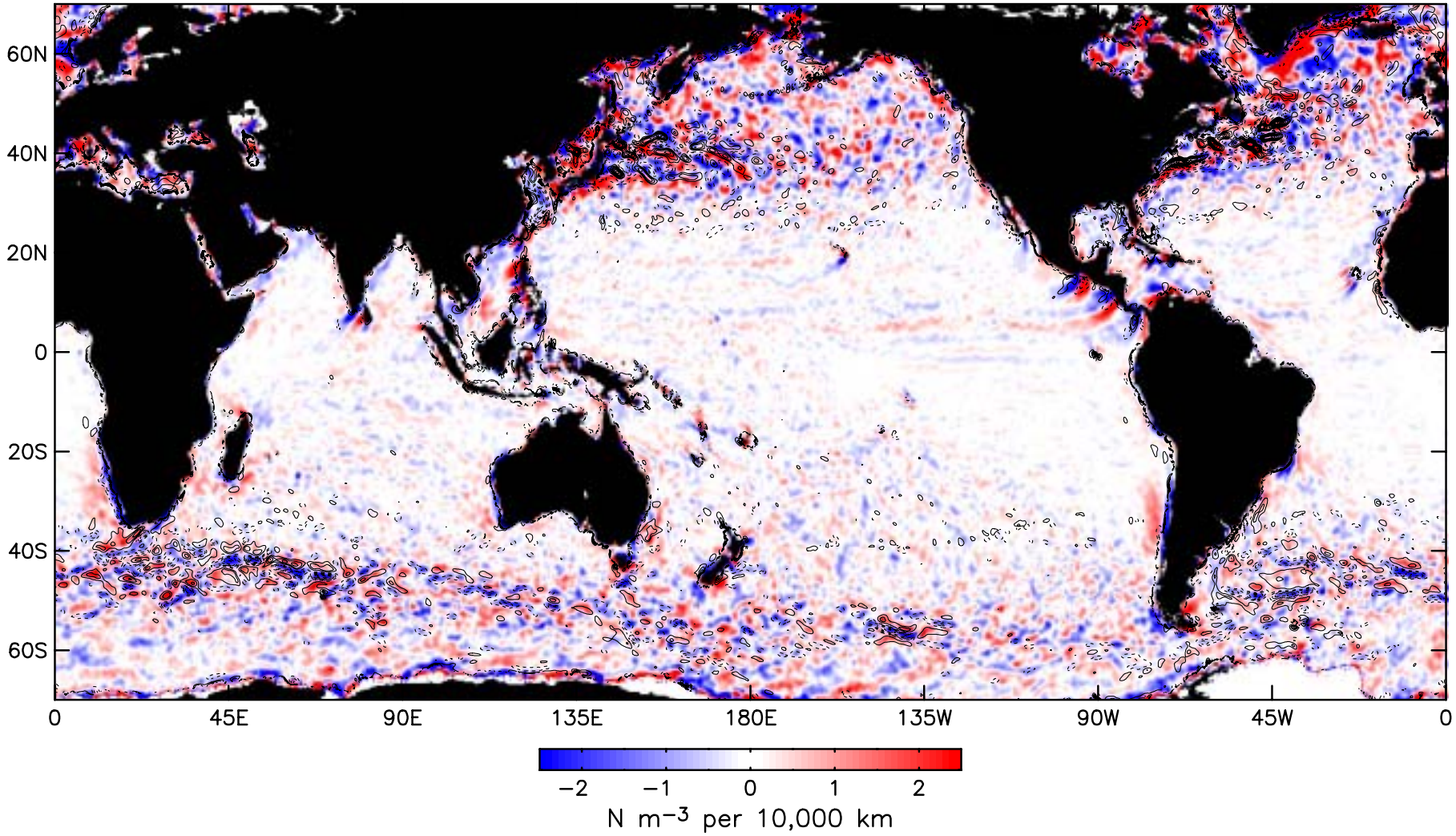
QuikSCAT, November 2002 – February 2003

High Pass Filtered Curl



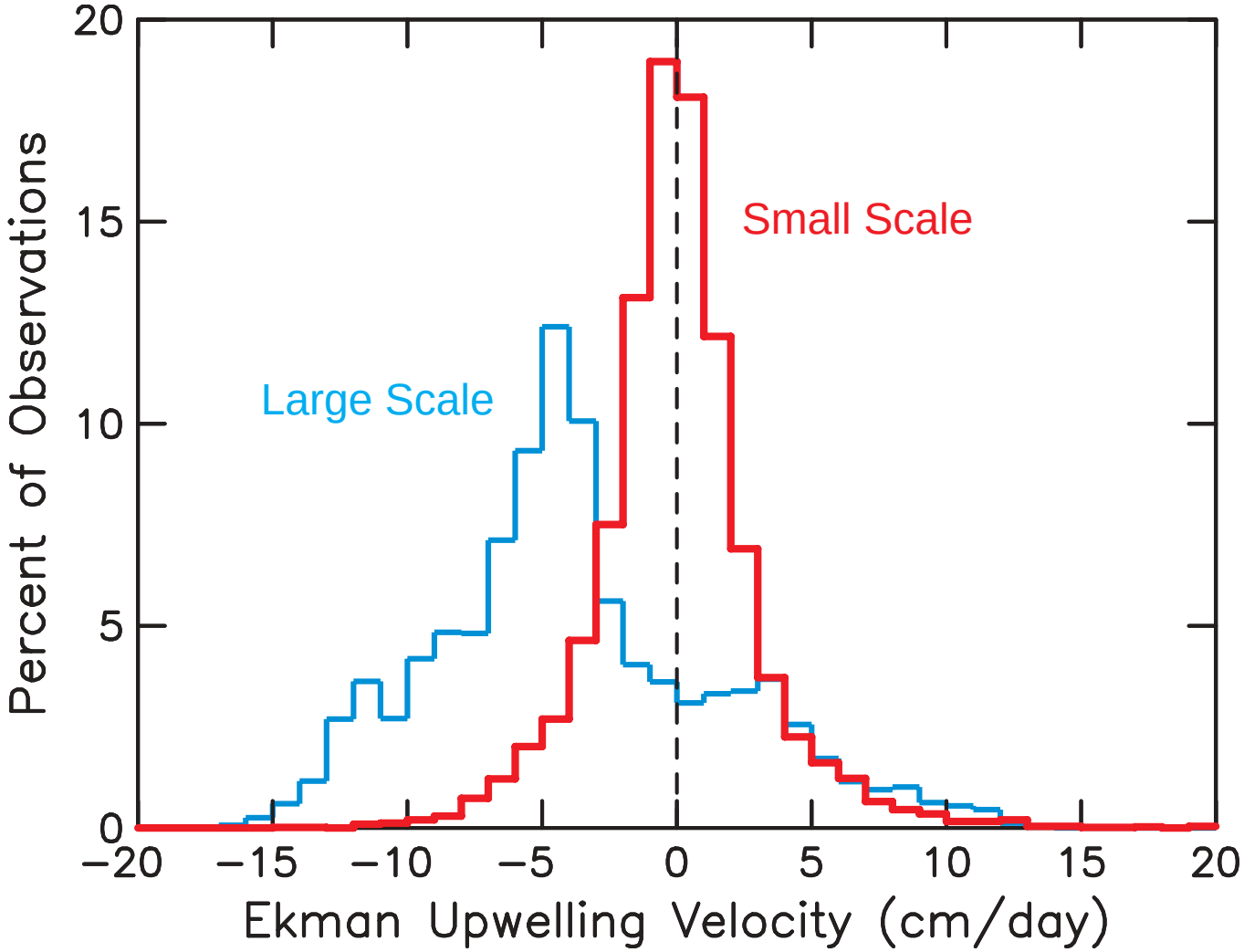
QuikSCAT and AMSR, November 2002 – February 2003

High Pass Filtered Curl and Crosswind ∇T



C.I. = 0.5ºC per 100 km

Histograms of Wind Stress Curl-Driven Ekman Upwelling Velocity in the Southern Ocean (30ºS to 60ºS)



Conclusions

- SST exerts a strong influence on surface winds over SST fronts associated with ocean currents.

- This observed air-sea interaction is stronger and more accurately represented in the ECMWF model than in the NCEP model.
  - *The difference is attributable to the higher resolution of the RTG SST boundary condition implemented in the ECMWF model on May 9, 2001.*

- Even with a "perfect" SST boundary condition, the wind stress response to SST in the NWP models would be underestimated by ~ 30-40%.
  - *This may be attributable to:*
    - *errors in the parameterization of boundary layer turbulence*
    - *coarse vertical resolution in the boundary layer*
    - *coarse horizontal resolution*

Question: Can these issues be ameliorated through more effective assimilation of satellite observations of ocean surface vector winds (QuikSCAT, WindSat, CMIS...) into the NWP models?