Sensitivity of Numerical Simulated Mesoscale Air-sea Coupling

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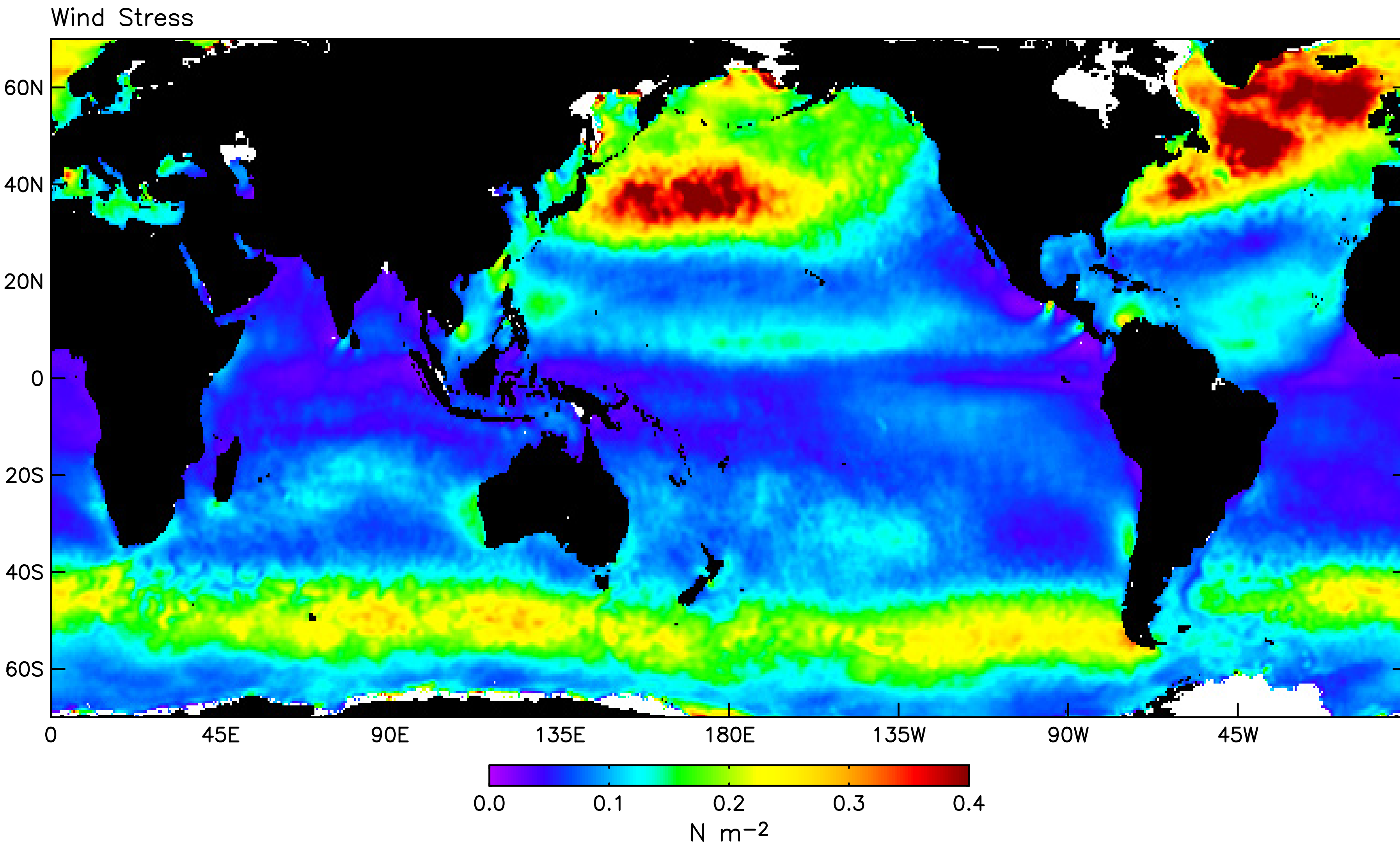
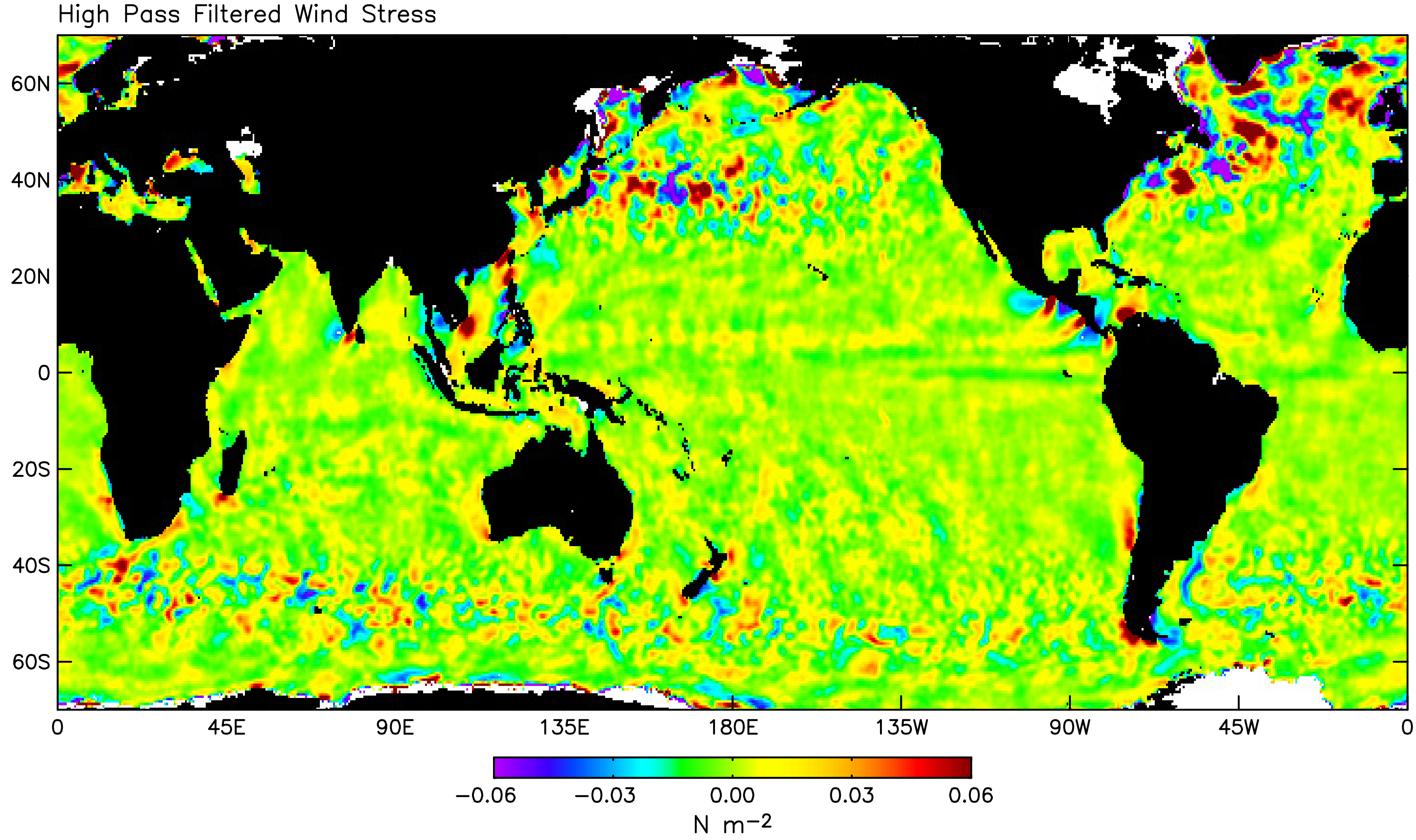
2-Month Average Wind Stress Magnitude

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 and SST
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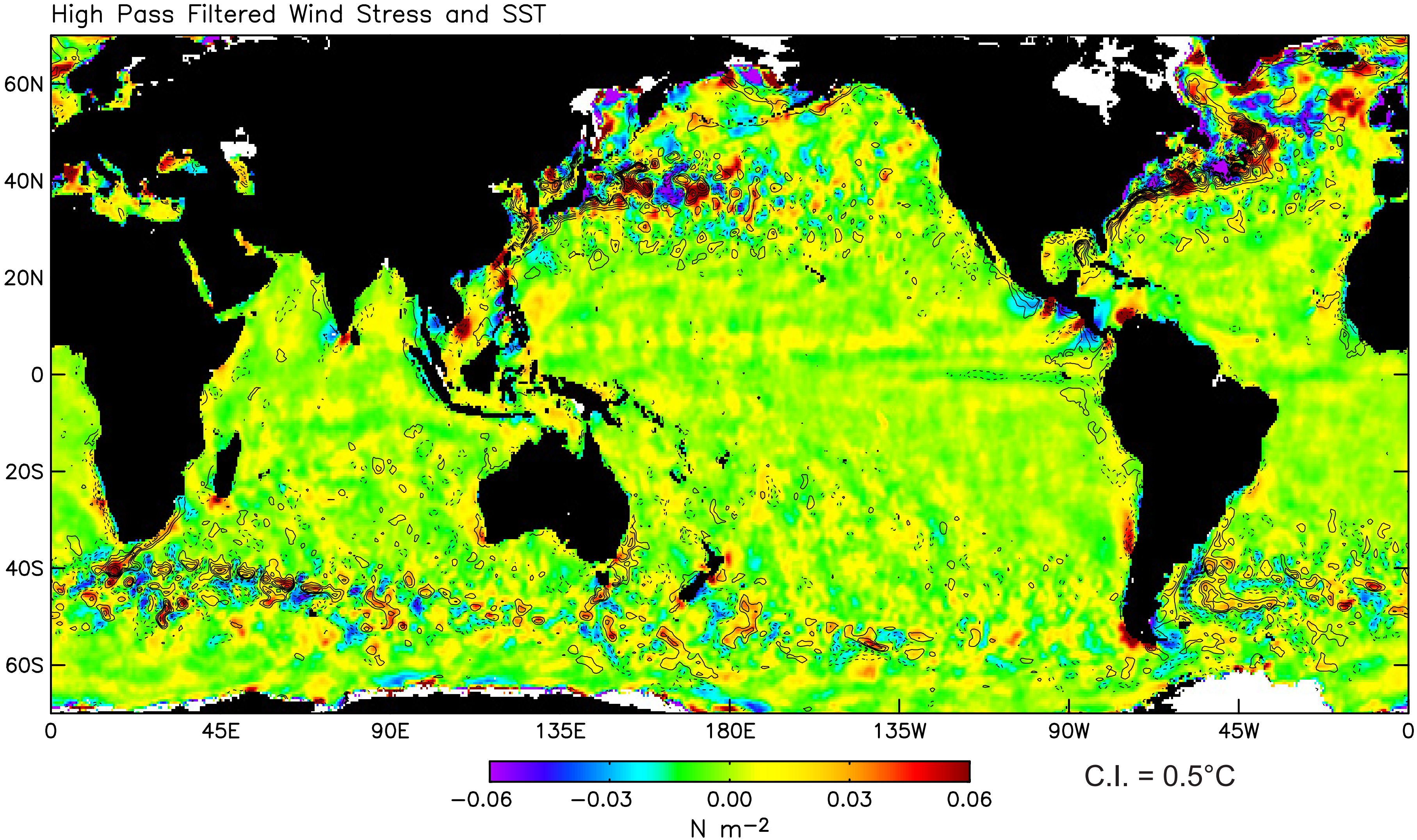
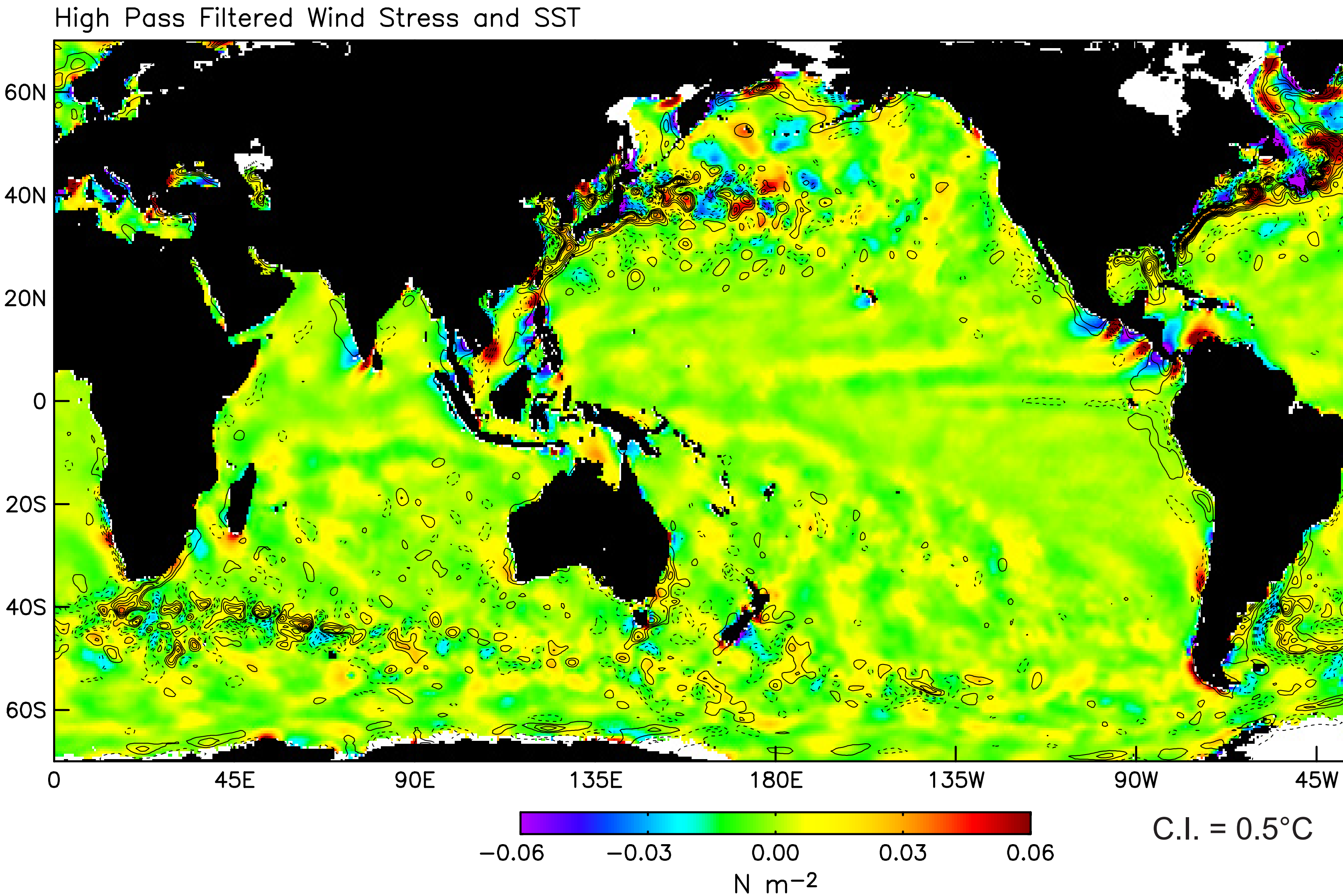
QuikSCAT, January–February 2003

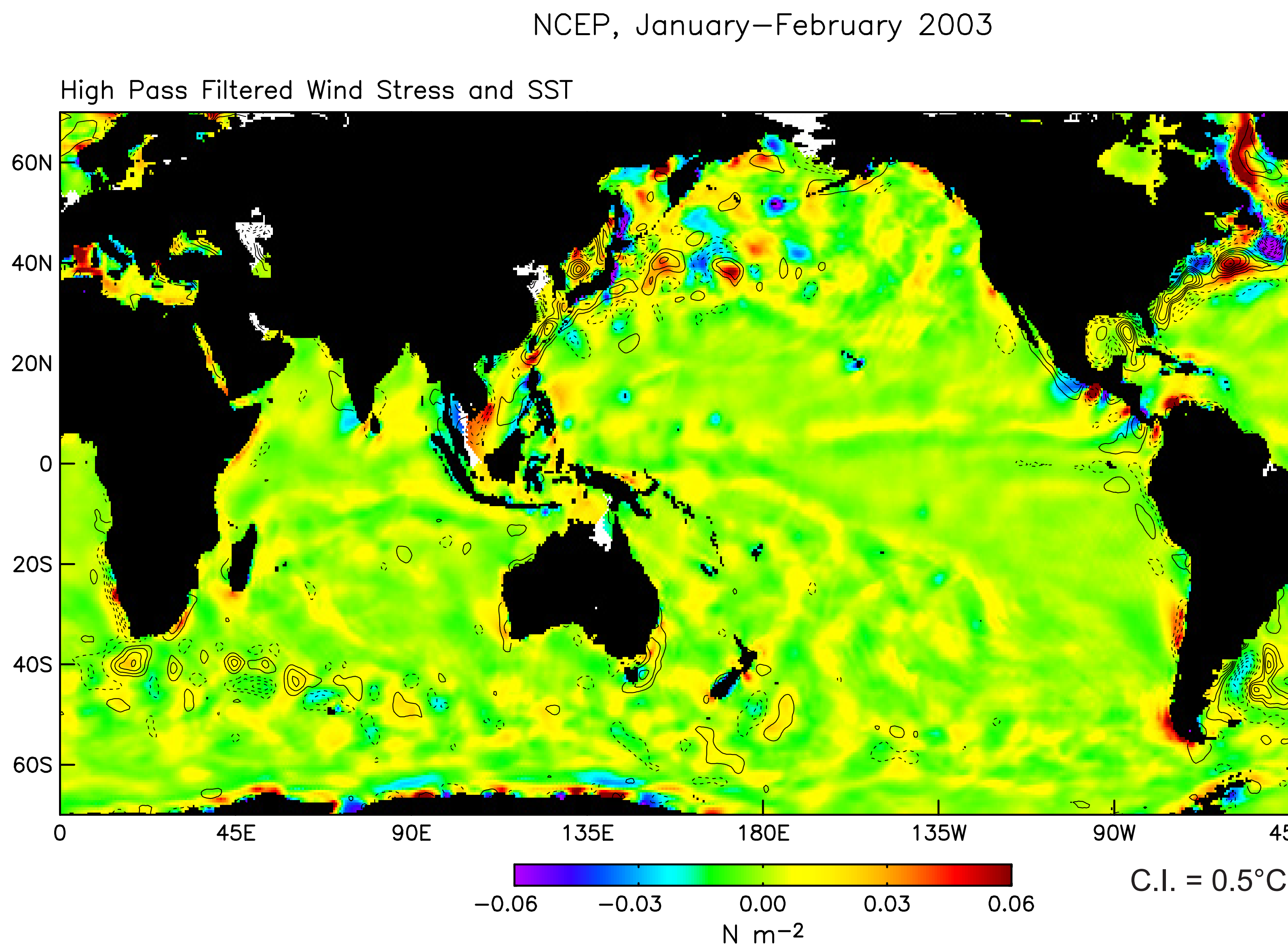


2-Month Average Wind Stress Magnitude and SST
(Spatially High-Pass Filtered)

ECMWF, January–February 2003

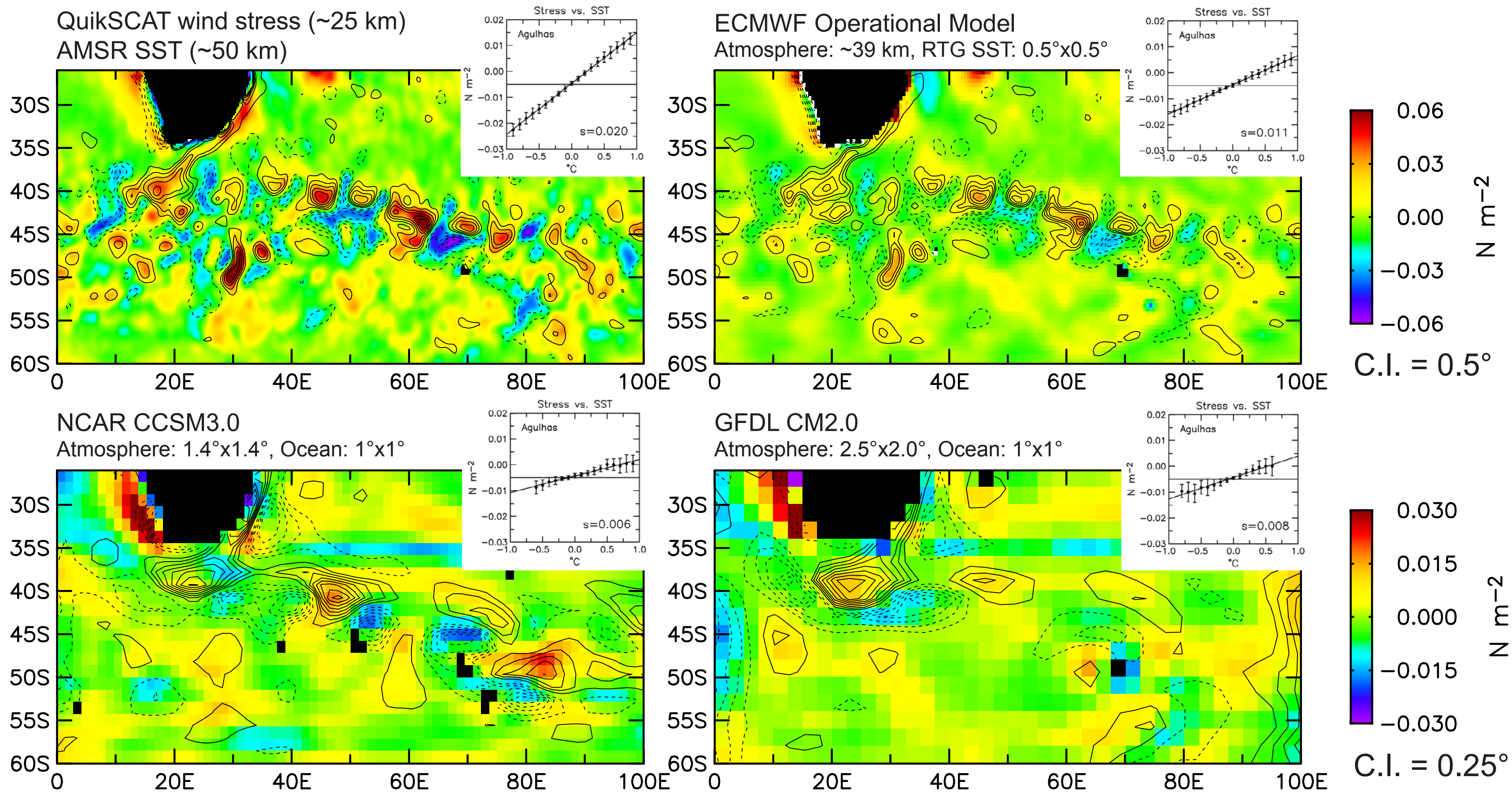


2-Month Average Wind Stress Magnitude and SST
(Spatially High-Pass Filtered)



Agulhas Return Current (Southwest Indian Ocean)

High Pass Filtered Wind Stress and SST



Note that the "feature resolution" of atmospheric models is generally about 5 times coarser than the model grid spacing.

Note also that all of the models underestimate the surface wind response to SST by about a factor of 2–3 compared with QuikSCAT.

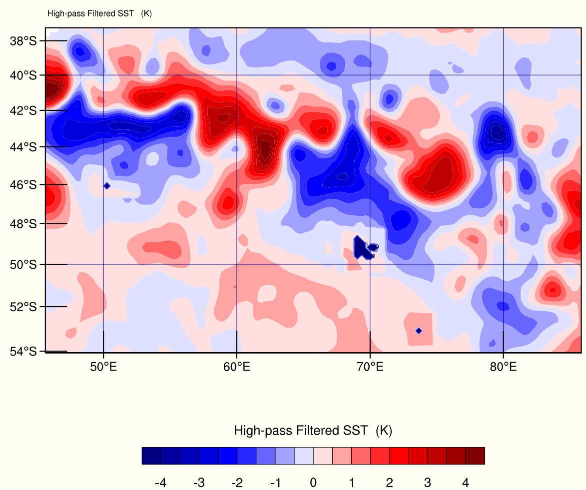
Maloney and Chelton (2006, J. Clim.)

Sensitivity studies with the Weather Research & Forecasting (WRF) mesoscale model to investigate the underestimation of surface wind response to SST in the ECMWF model.

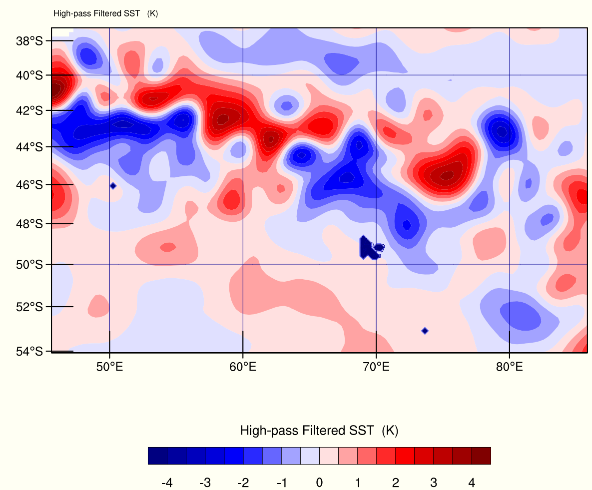
- Resolution of the SST boundary condition
- Model grid resolution
- Parameterization of horizontal mixing
- Parameterization of vertical mixing

Sensitivity to Specification of the SST Boundary Condition

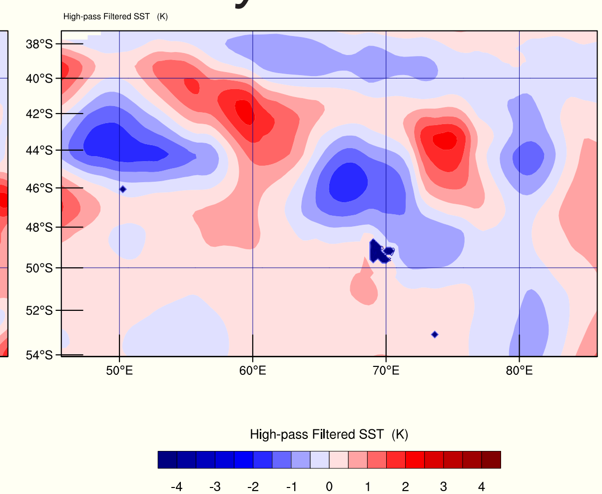
AMSR SST

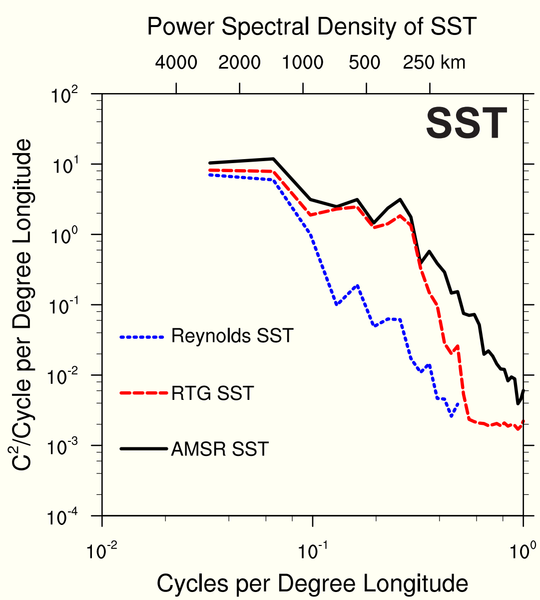


RTG SST



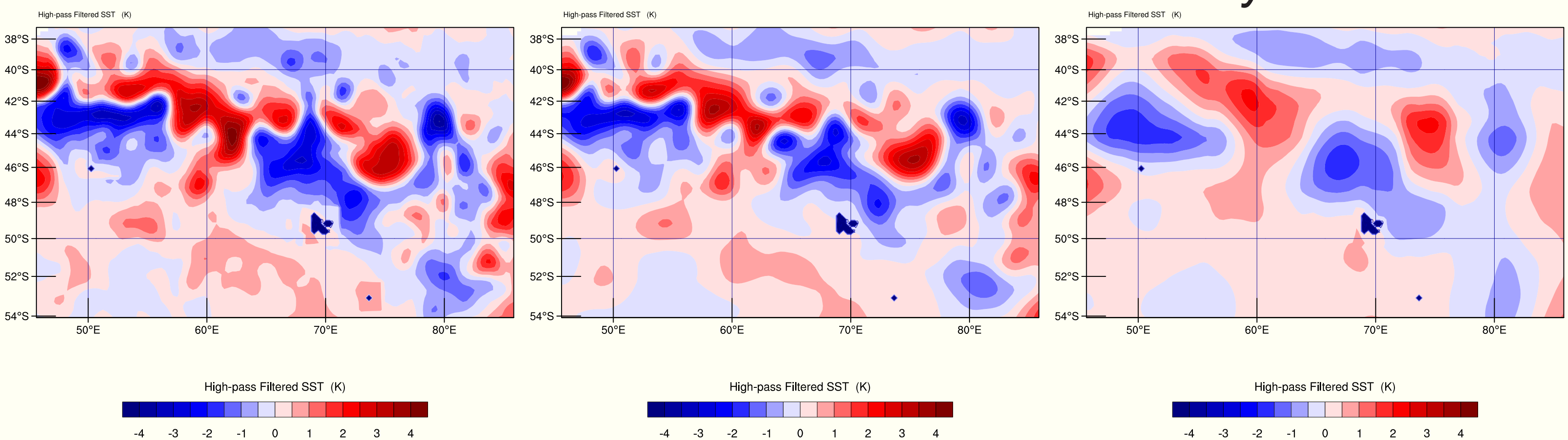
Reynolds SST

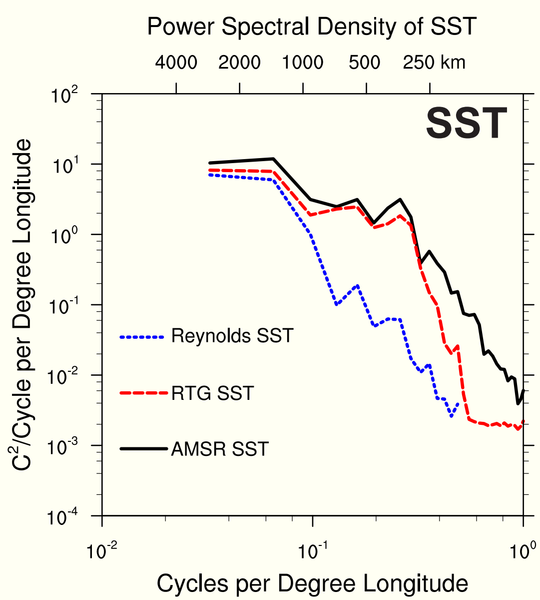


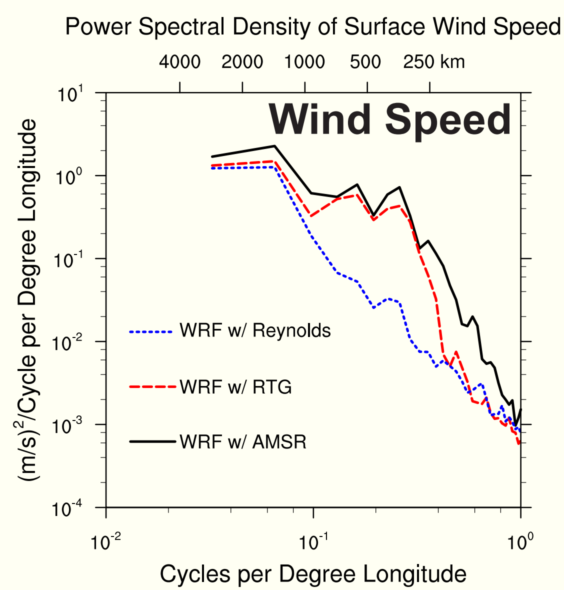


Sensitivity to Specification of the SST Boundary Condition

AMSR SST *RTG SST* *Reynolds SST*



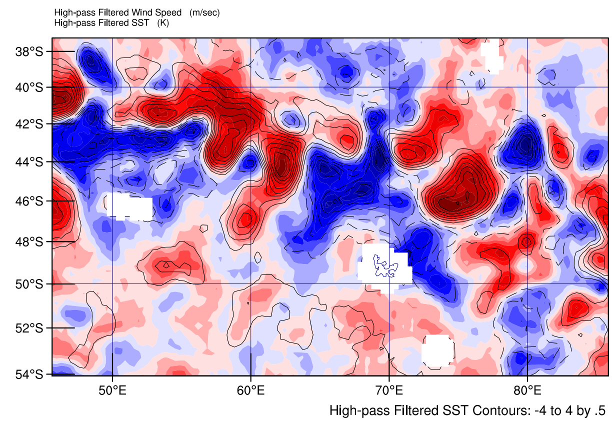


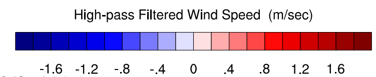


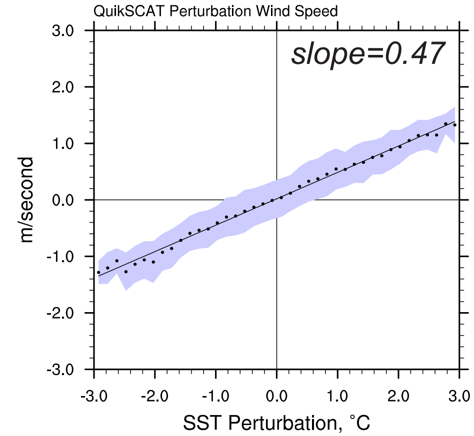
- *Forcing by Reynolds SST underestimates the energy on all scales shorter than ~1000 km.*
- ***Forcing by RTG SST underestimates the energy only on scales shorter than ~250 km***

Coupling Coefficients for Equivalent Neutral Stability 10-m Wind Speed from QuikSCAT and WRF

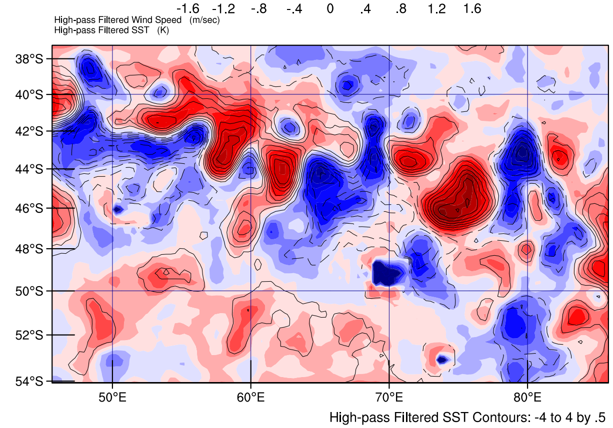
QuikSCAT

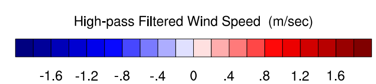


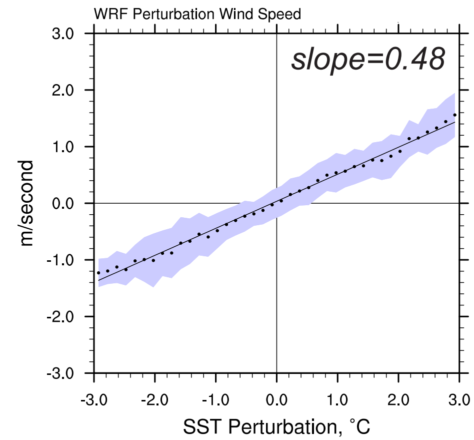




WRF



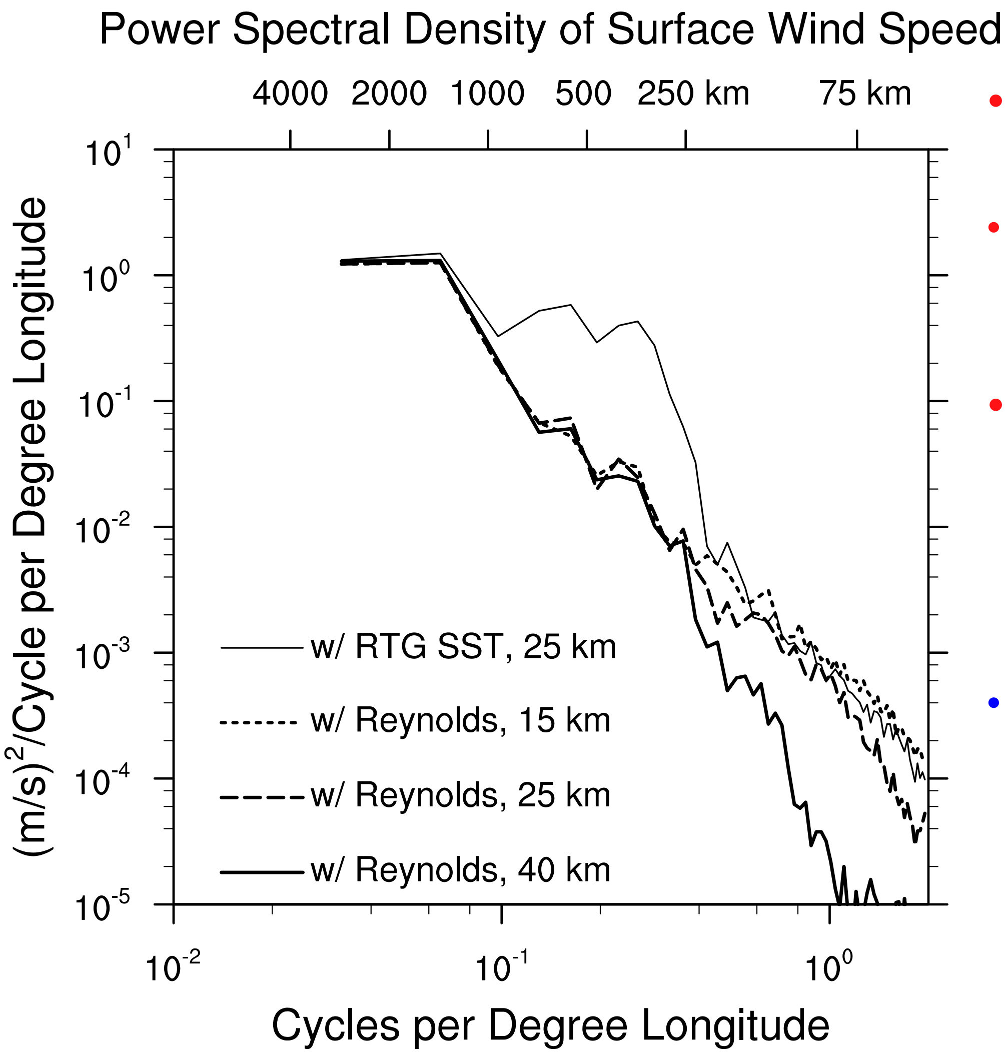




The agreement between QuikSCAT and the WRF simulation forced by AMSR SST is remarkably good.

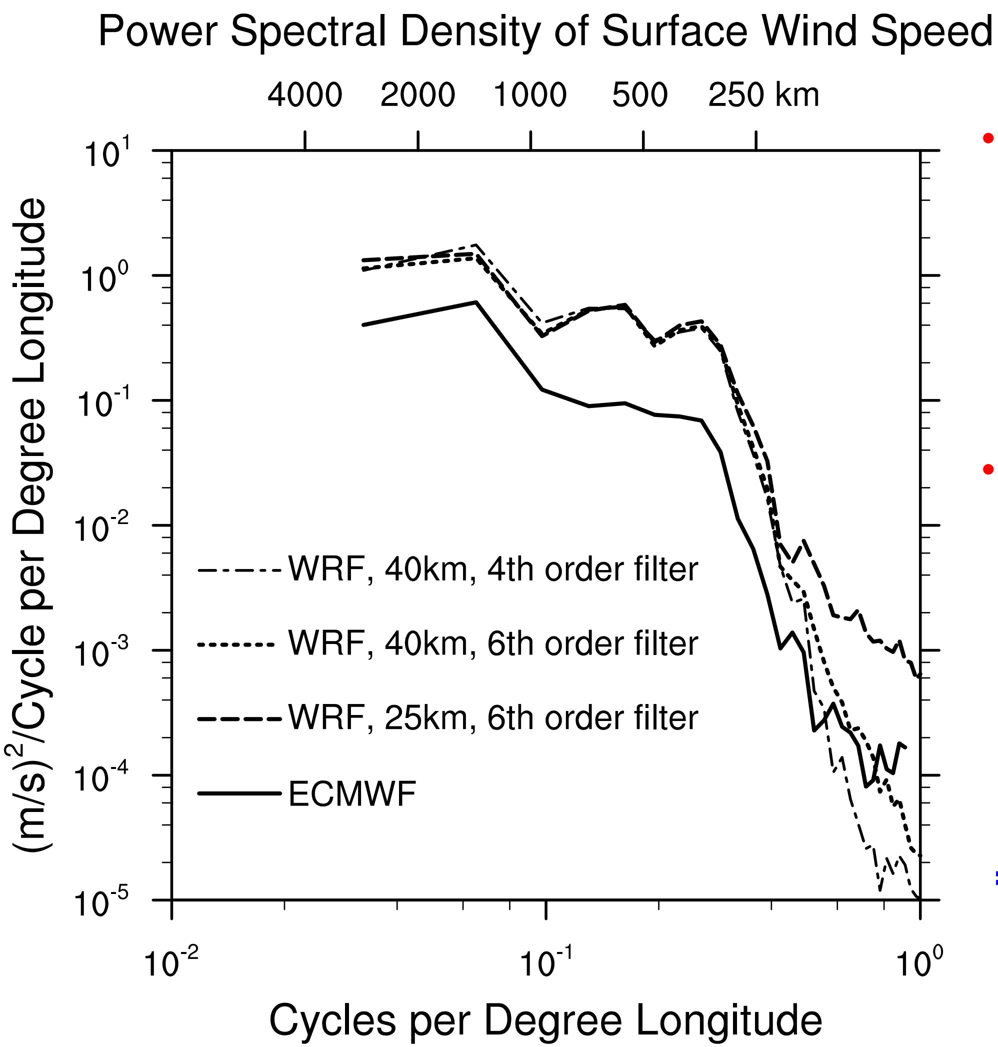
- *Note that the slope is 0.42 for 10-m winds in the WRF model forced by AMSR SST.*

Sensitivity to Grid Resolution



- ***The nominal grid spacing for our WRF experiments is 25 km.***
- *Increasing the grid spacing to 15 km had a minor effect only on scales shorter than ~100 km.*
- ***Decreasing the grid spacing to 40 km degraded the surface wind fields on scales shorter than ~250 km.***
  - *Note that the ECMWF grid spacing was 39 km during the time considered here.*
- *Replacing the Reynolds SST boundary condition with RTG SST had no discernable effect on scales shorter than ~250 km, but increased the energy of the surface winds on scales longer than ~250 km.*
  - *This is because there is little energy in the RTG SST fields on scales shorter than ~250 km, as shown previously.*

Sensitivity to Horizontal Mixing



- *To control small-scale noise and to avoid numerical instabilities, the WRF model uses implicit horizontal diffusion (filtering) in its integration and advection schemes, in addition to explicit horizontal diffusion.*
- *Changing the nominal 6th-order horizontal filter to 4th-order degraded the surface wind fields moderately on scales shorter than ~250 km.*
  - *This degradation was less than that from decreasing the grid spacing from 25 km to 40 km.*

=> The underestimation of wind speed response to SST in the ECMWF model on scales longer than ~250 km is evidently NOT due to <u>horizontal mixing</u>.

The underestimation of wind speed response to SST in the ECMWF model on scales longer than ~250 km is evidently due to something besides the grid resolution, horizontal mixing or the use of the RTG SST boundary condition.

Sensitivity studies with the Weather Research & Forecasting (WRF) mesoscale model to investigate the underestimation of surface wind response to SST in the ECMWF model.

- Resolution of the SST boundary condition
- Model grid resolution
- Parameterization of horizontal mixing
- Parameterization of vertical mixing

WRF Model Sensitivity to Vertical Mixing

The WRF model uses the Mellor and Yamada (1982) stability-based parameterization of vertical turbulent mixing, with an option to use the Grenier and Bretherton (2001) enhancement of vertical mixing.

The Mellor and Yamada (1982) parameterization of vertical eddy diffusivity for horizontal velocity can be written as

$$K_m = S_m l \sqrt{e}\,,$$

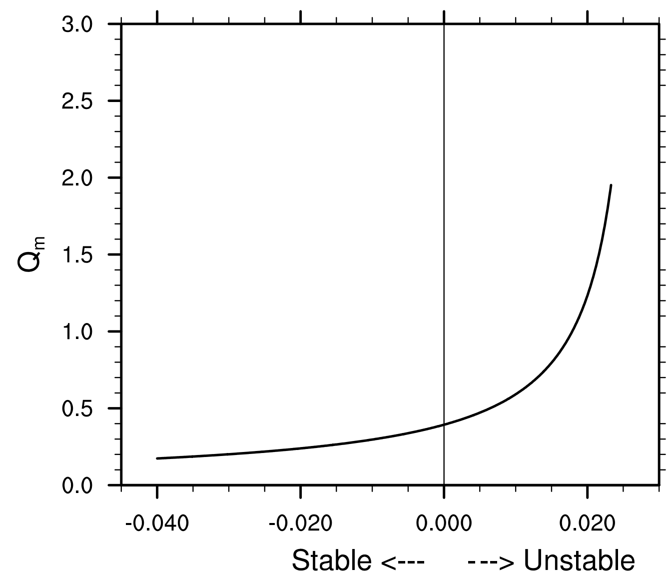
where e is the turbulent kinetic energy (TKE), l is a turbulent length scale and S_m is a stability function.

The Grenier and Bretherton (2001) parameterization enhances the vertical transport of TKE to match the TKE profile obtained from large-eddy simulations by formulating the vertical eddy diffusivity as

$$K_m = Q_m l \sqrt{e}\,,$$

where $Q_m = 5\,S_m$.

Grenier-Bretherton Dependence of Q_m on Stability



Song et al. (2008, J. Clim., in press)

Modification of the Grenier and Bretherton (2001) Parameterization of Vertical Mixing for these Sensitivity Studies

The stability dependence of the vertical mixing parameterization is modified here to have the same form

$$K_m = Q_m l \sqrt{e}\,,$$

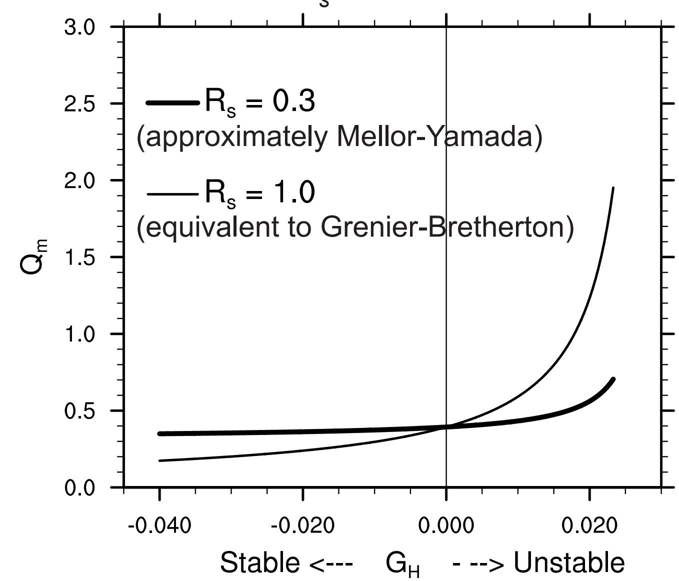
but with Q_m defined by

$$Q_m = S_m^N + R_s\left(5S_m - S_m^N\right)\,.$$

Here S_m is the Mellor-Yamada stability function and S_m^N is the value for neutrally static conditions. The stability response factor R_s modulates the dependence of vertical diffusion on stability.

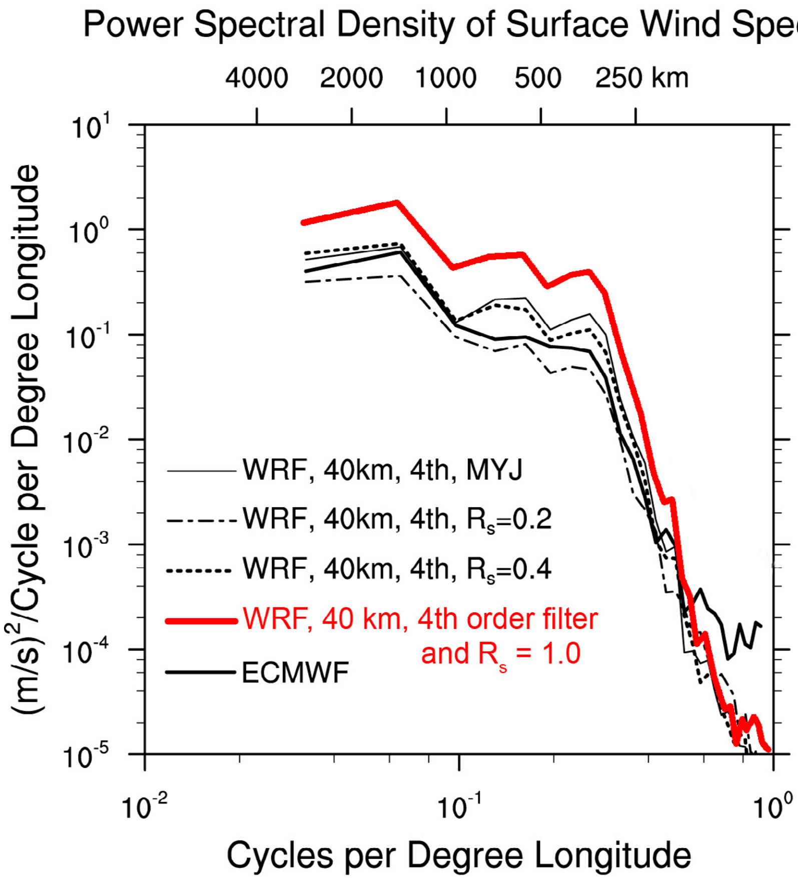
A value of $R_s = 1$ corresponds to the Grenier and Bretherton (2001) scheme with $Q_m = 5\,S_m$. Values of $R_s < 1$ correspond to reduced dependence of vertical mixing on stability.

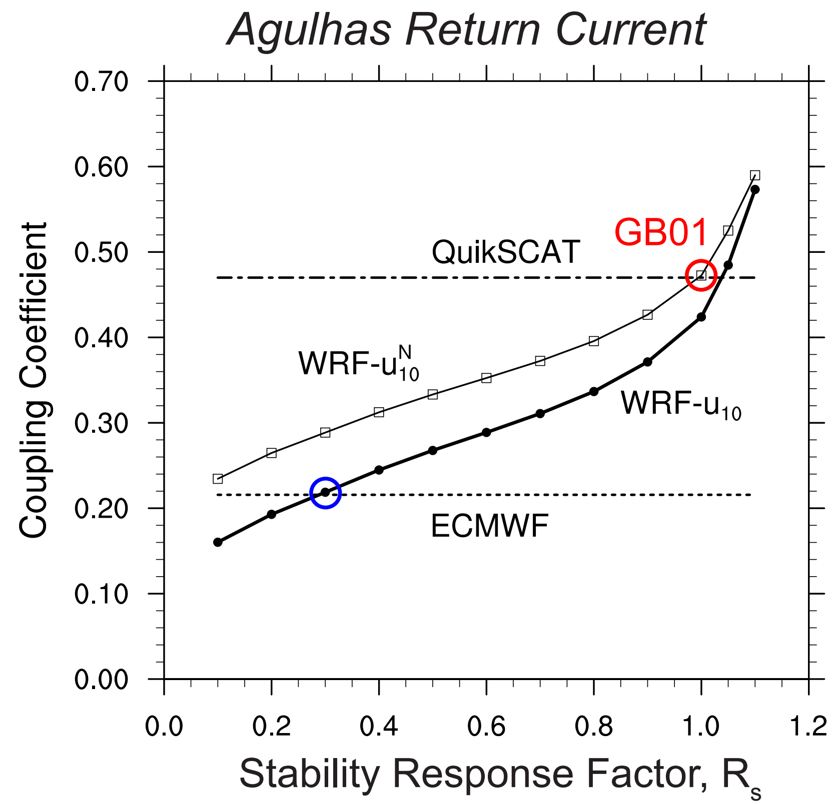
Dependence of Q_m on Stability for R_s = 0.3 and 1.0



Song et al. (2008, J. Clim., in press)

Sensitivity to Vertical Turbulent Mixing



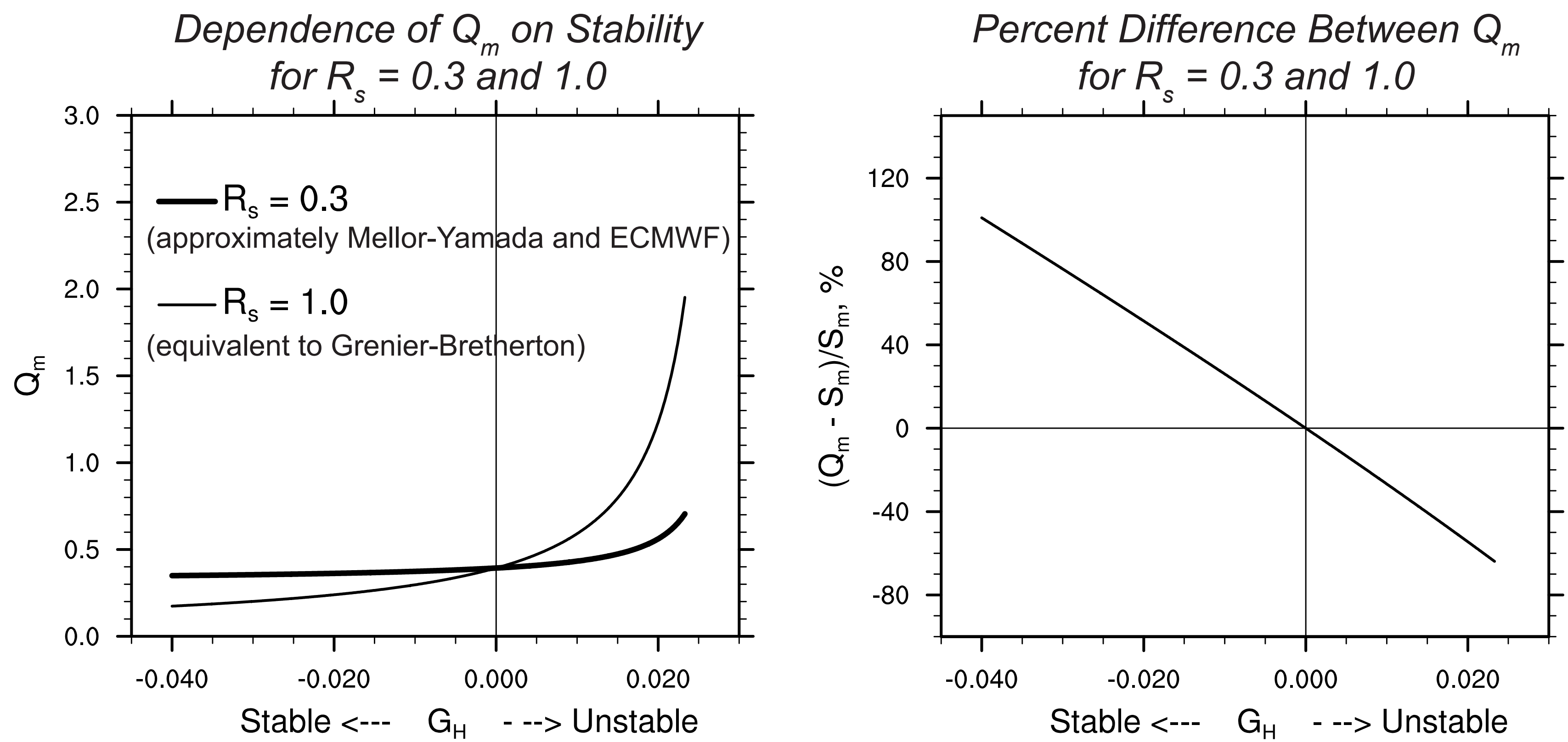


Spectral analysis and the coupling coefficient between surface wind speed and SST in the WRF experiments both suggest that vertical mixing in the ECMWF model is comparable to a value of $R_s \approx 0.3$ for the stability response coefficient.

A value of $R_s \approx 1.0$ yields a WRF response to SST almost identical to QuikSCAT observations, when converted to equivalent neutral stability 10-m winds.

Song et al. (2008, J. Clim., in press)

Relevance to NWP and Coupled Climate Models



The WRF sensitivity experiments suggest that NWP and coupled climate models:

- *overestimate vertical mixing in stable conditions*
- *underestimate vertical mixing in unstable conditions*

Song et al. (2008, J. Clim., in press)

Conclusions

- SST exerts a strong influence on surface winds over SST fronts associated with surface ocean currents.
- The model inadequacies are due to 3 primary factors:
  - Grid resolution of the atmospheric models
  - Accuracy and resolution of the SST fields.
  - Parameterization of vertical mixing sensitivity to atmospheric stability.
- The WRF experiments suggest that the NWP models:
  - overestimate vertical mixing in stable conditions
  - underestimate vertical mixing in unstable conditions (more typical of the ocean)