Coupled Ocean-Atmosphere Interaction on the Oceanic Mesoscale

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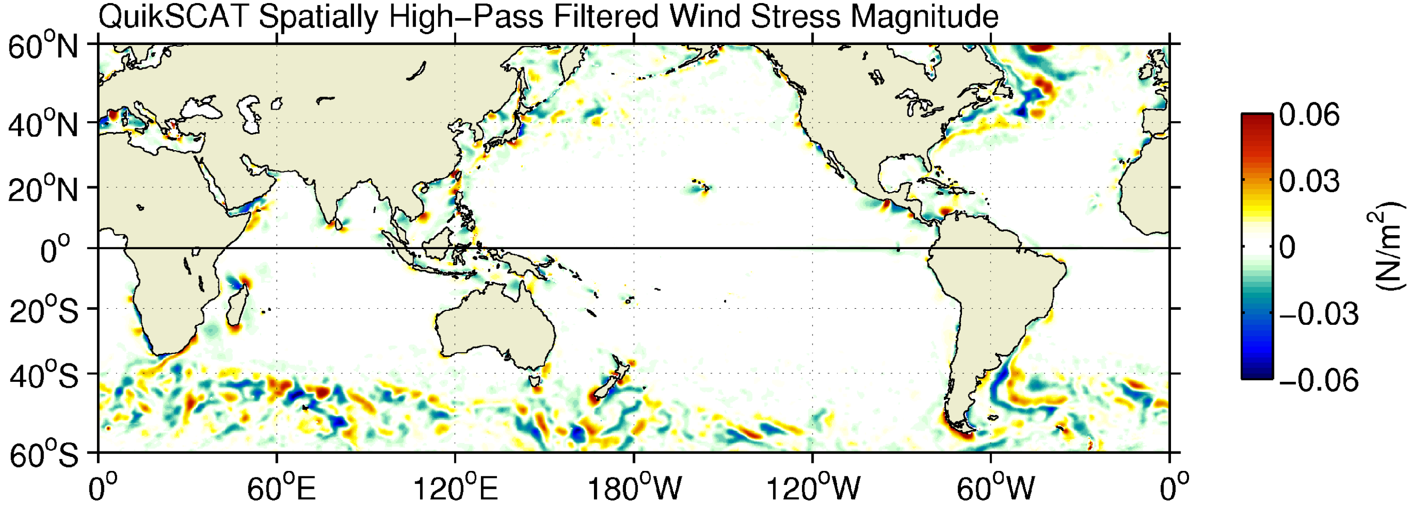
- Overview of surface wind-SST coupling near SST frontal zones as observed by satellites on spatial scales of ~50-1000 km
- Wind-SST interaction over ocean eddies using eddy-tracking procedure based on merged SSH fields
- Example of feedbacks of wind-SST coupling onto the ocean

Average June-2002 to May-2009



- QuikSCAT scatterometer
  - Surface wind stress magnitude

Filtered to remove variability with wavelengths longer than 20° long. x 10° lat.

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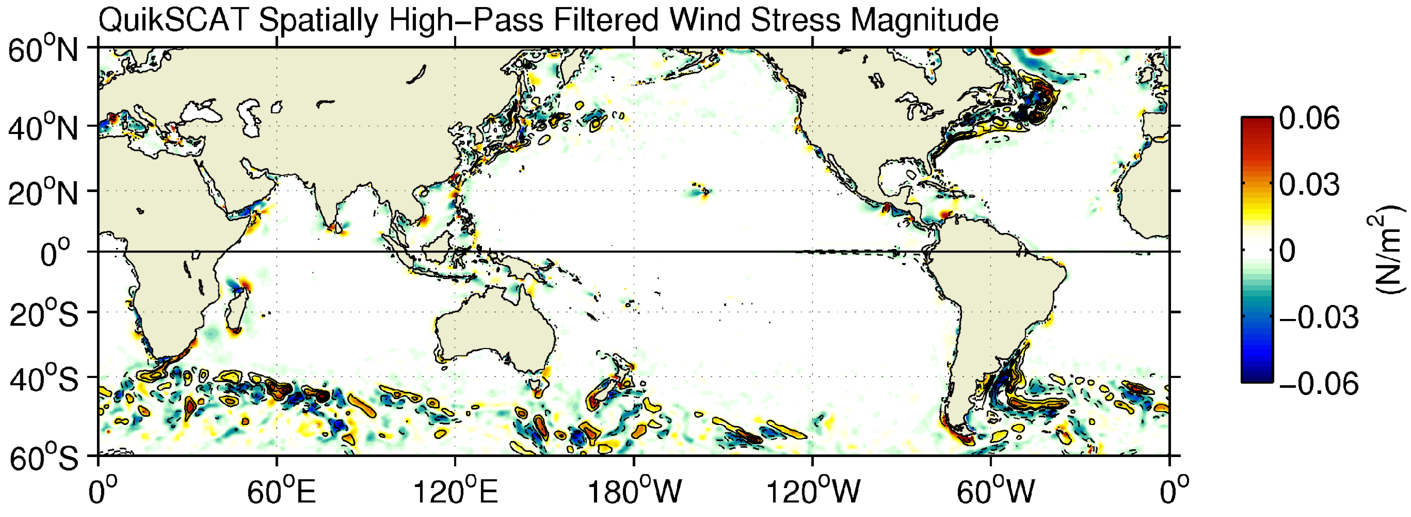

- QuikSCAT scatterometer
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- Advanced Microwave Scanning Radiometer on EOS-Aqua (AMSR-E) (June 1, 2002-present)
  - Sea-surface temperature (SST)

Contours of filtered AMSR-E SST with c.i.=0.5°C (solid=warm, dashed=cool)

Filtered to remove variability with wavelengths longer than 20° long. x 10° lat.

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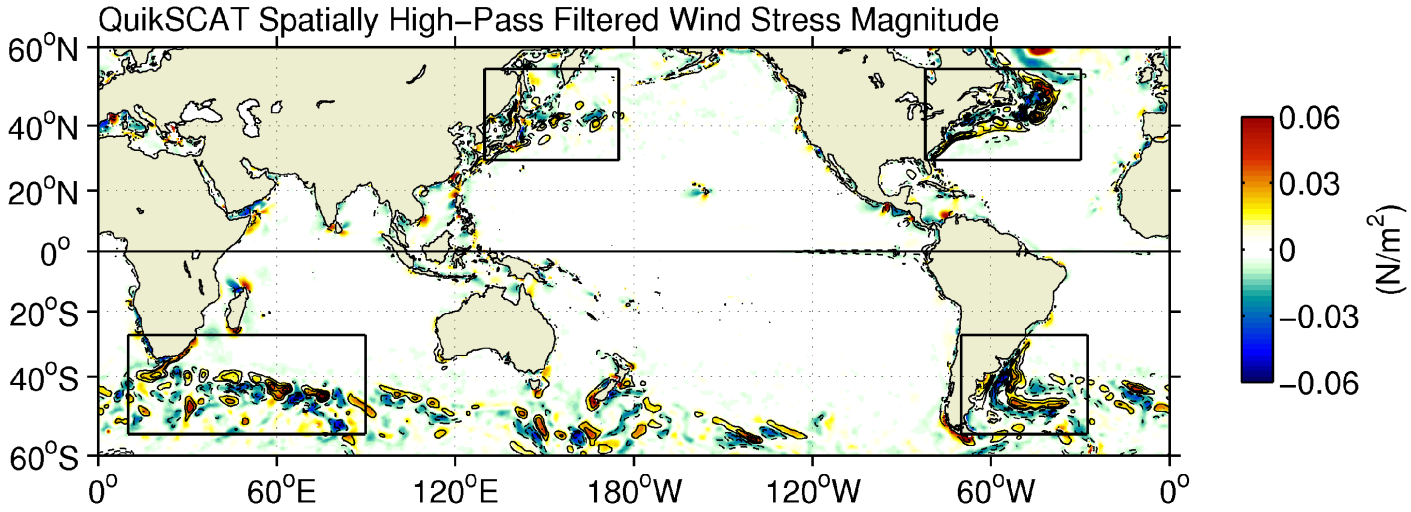

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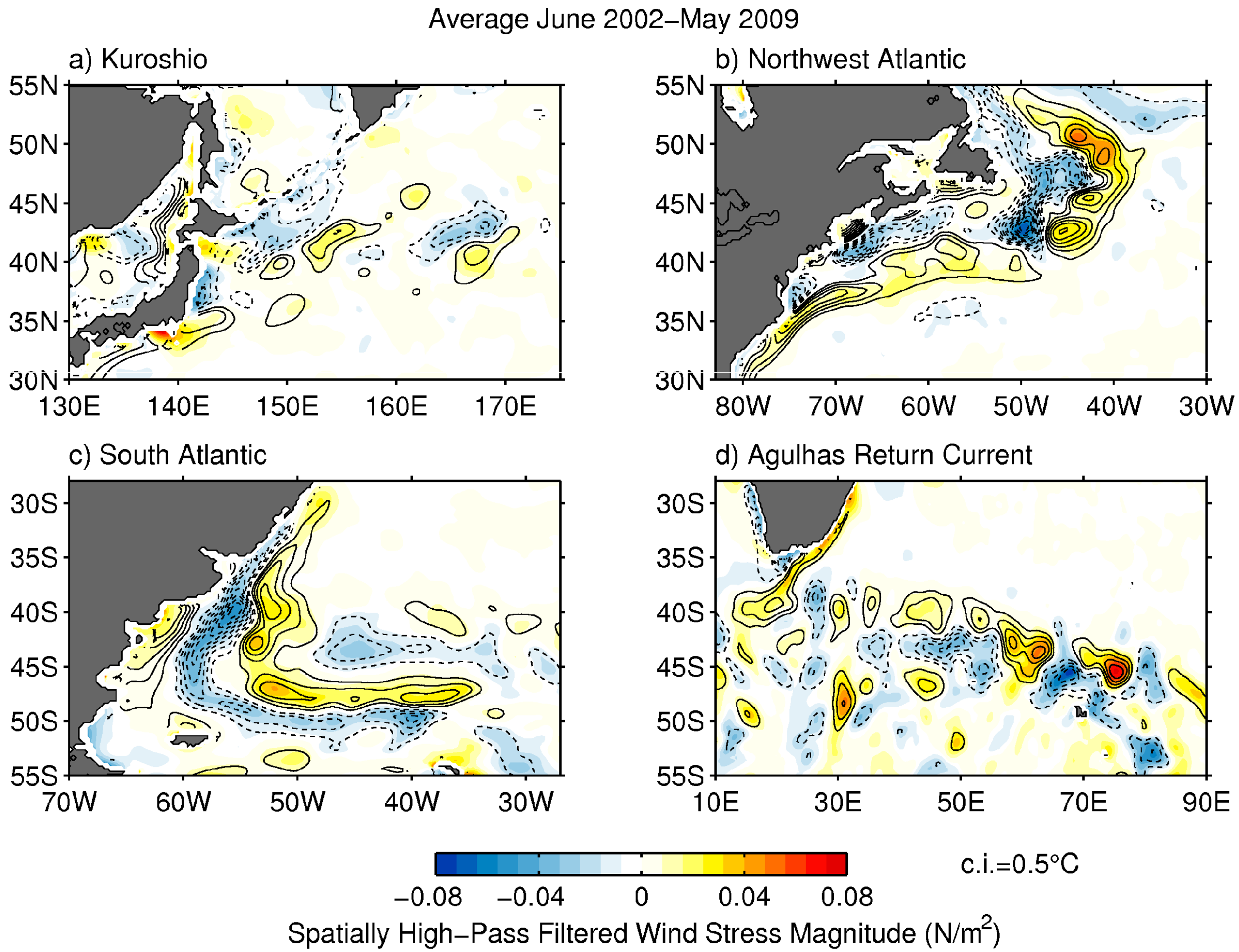
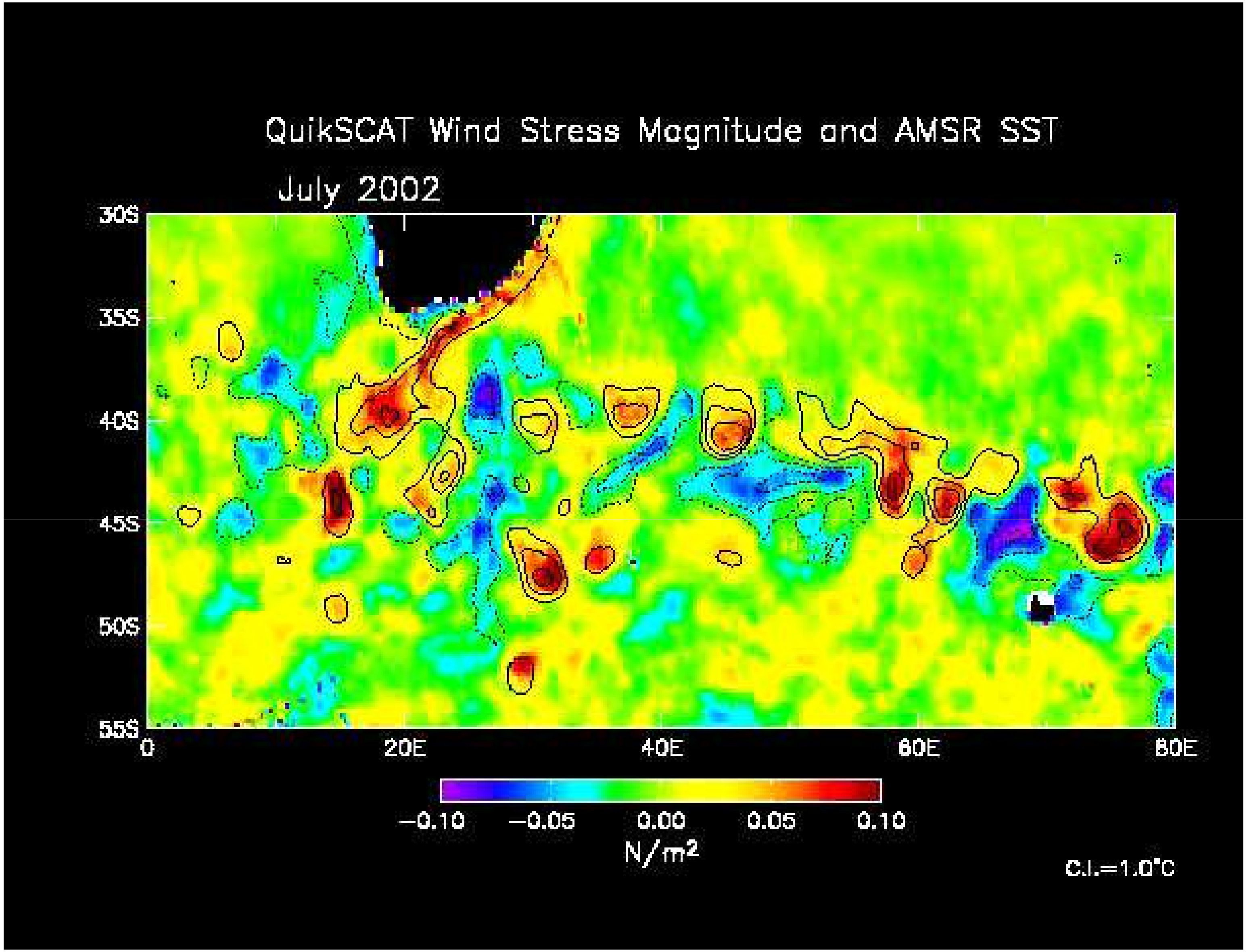
Spatially-filtered QuikSCAT wind stress magnitude (colors) and AMSR-E SST (contours) averaged for 6/2002 to 5/2009



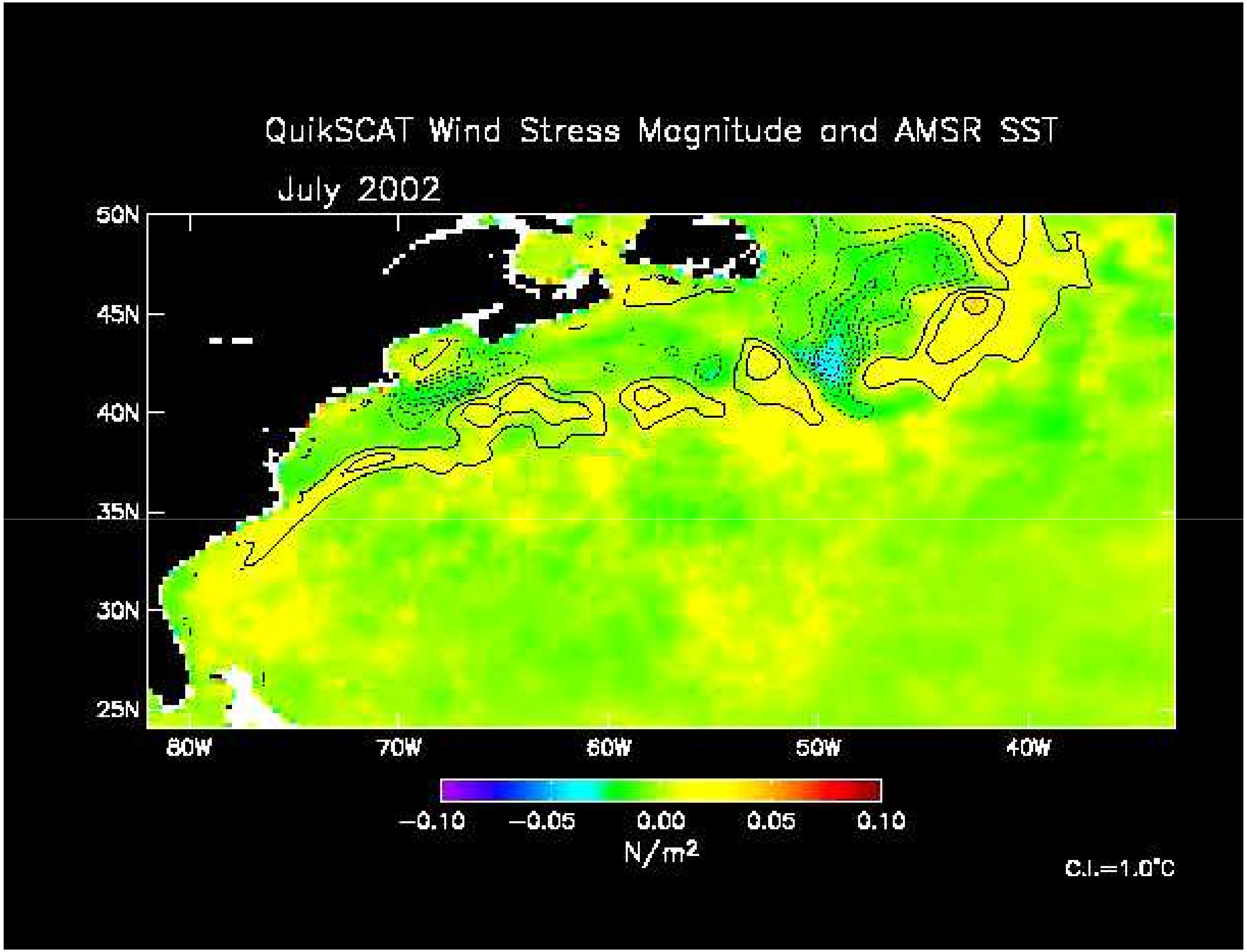
Enhanced stress over warmer water and reduced stress over cooler water

Stress varies greatly between seasons, however…

Contours are spatially high-pass filtered AMSR-E SST with a contour interval of 0.5℃ (solid=warm, dashed=cool)



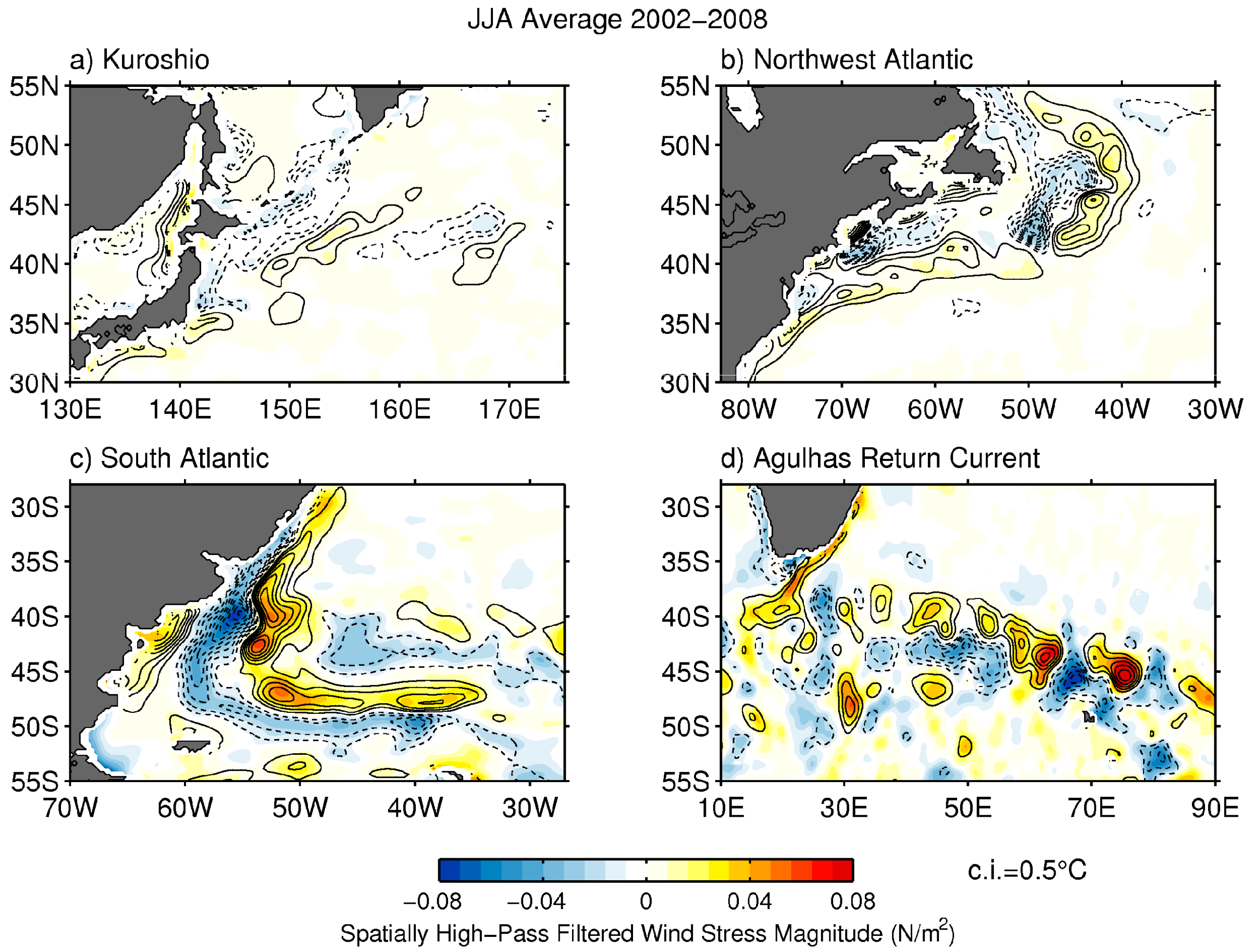
colors => Filtered QuikSCAT wind stress magnitude
contours => Filtered AMSR-E SST with c.i.=1℃ (solid=warm, dashed=cool)



colors => Filtered QuikSCAT wind stress magnitude

contours => Filtered AMSR-E SST with c.i.=1℃ (solid=warm, dashed=cool)

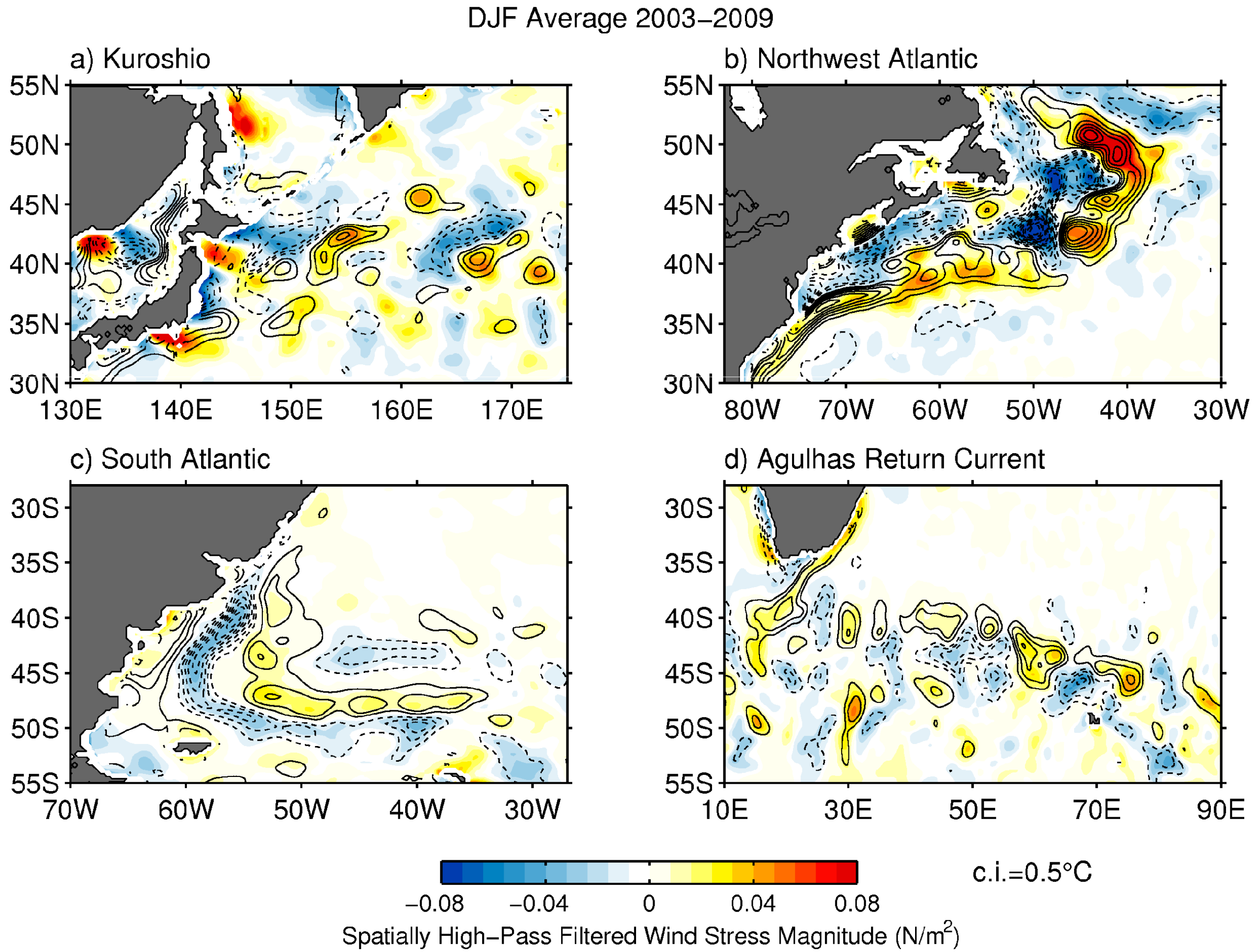
Spatially filtered wind stress magnitude and SST averaged for JJA (2002-2008)



NH Summer

SH Winter

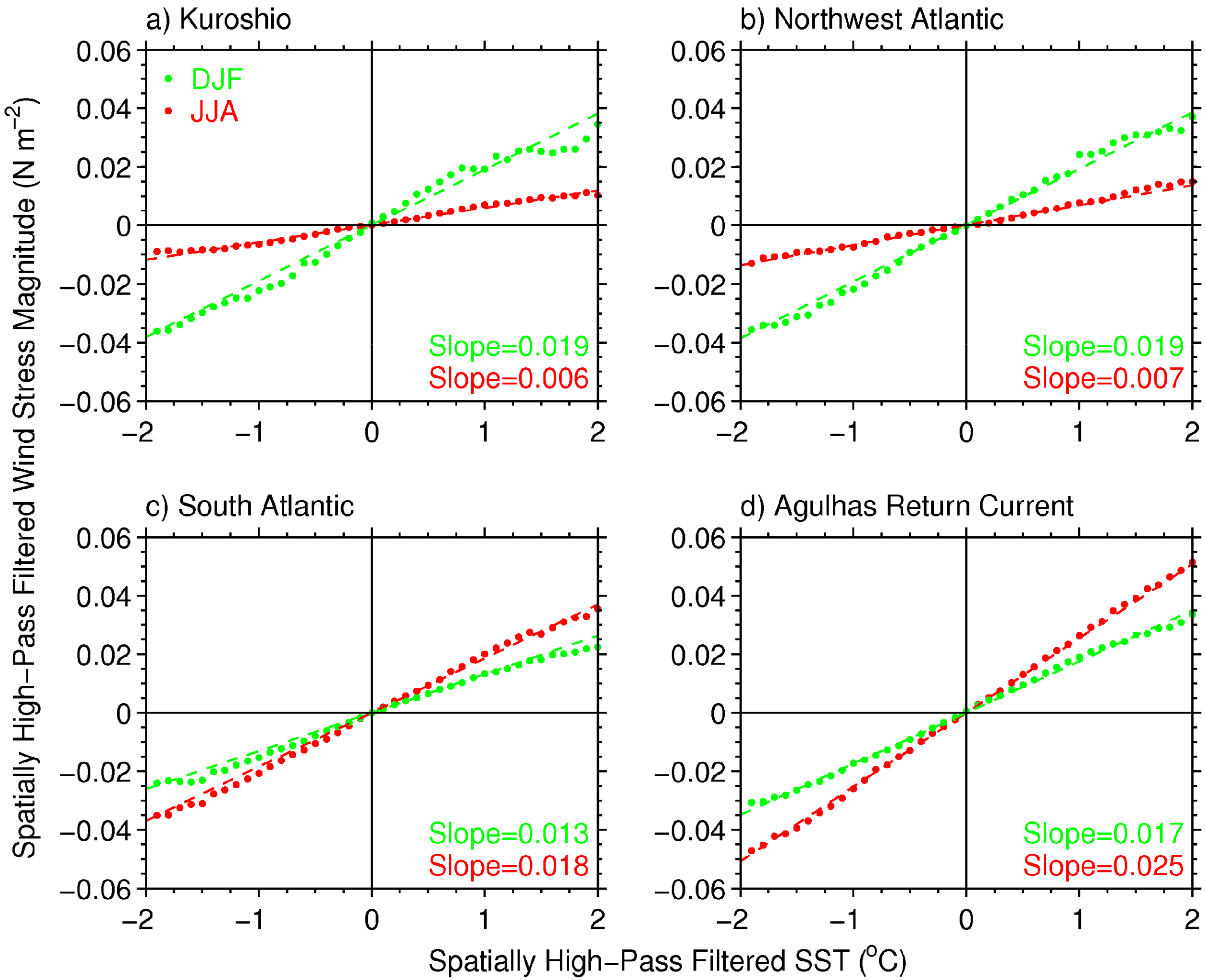
Spatially filtered QuikSCAT wind stress magnitude and SST averaged for DJF (2002-2009)



NH Winter

SH Summer

QuikSCAT wind stress magnitude vs. SST



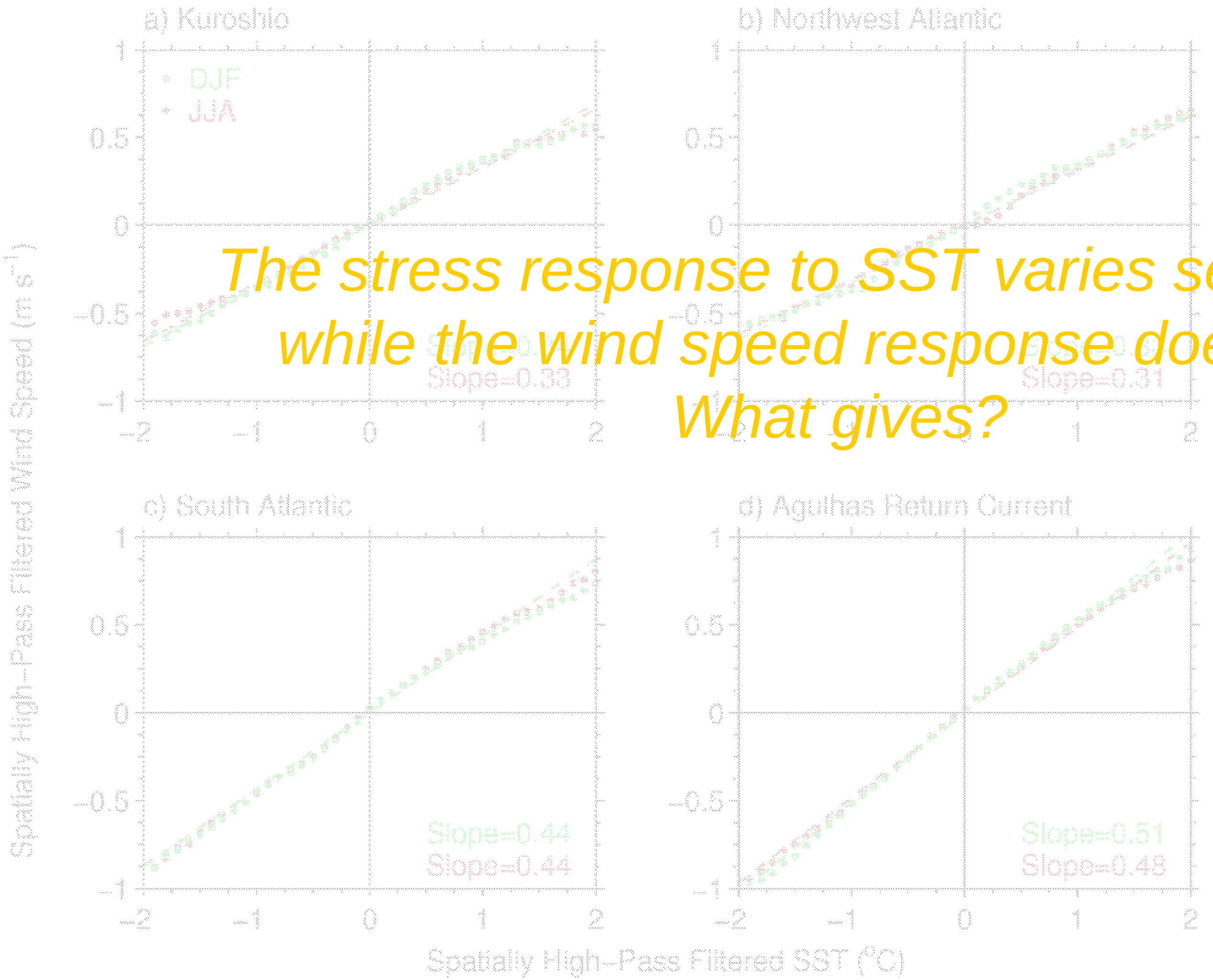
DJF, JJA

Wind stress response to SST varies significantly between summer and winter

Differences in slopes between summer and winter indicate that seasonal stress differences not due to seasonal mesoscale SST variability

$$\overline{|\boldsymbol{\tau}|}' = \alpha_{\boldsymbol{\tau}} \overline{T}'$$

QuikSCAT wind speed vs. SST



The stress response to SST varies seasonally while the wind speed response does not? What gives?

DJF, JJA

Whereas the SST-induced wind stress response varies by a large amount seasonally, the wind speed response to SST varies little.

$$V' = \alpha_v T'$$

Why is there a seasonal cycle in SST-induced wind stress perturbations but not wind speed?

$$|\tau| = \rho_0 C_{d10n} V_n^2 \qquad C_{d10n} = \frac{a_0}{V_n} + b_0 + c_0 V_n \quad \longrightarrow \quad \frac{|\tau|}{\rho_0} = a_0 V_n + b_0 V_n^2 + c_0 V_n^3$$

Wind stress response to SST is relatively stronger when the background winds are stronger during the winter.

Seasonal cycle in SST-induced wind stress may be a significant source of seasonal variability in the ocean near large-scale SST frontal zones.

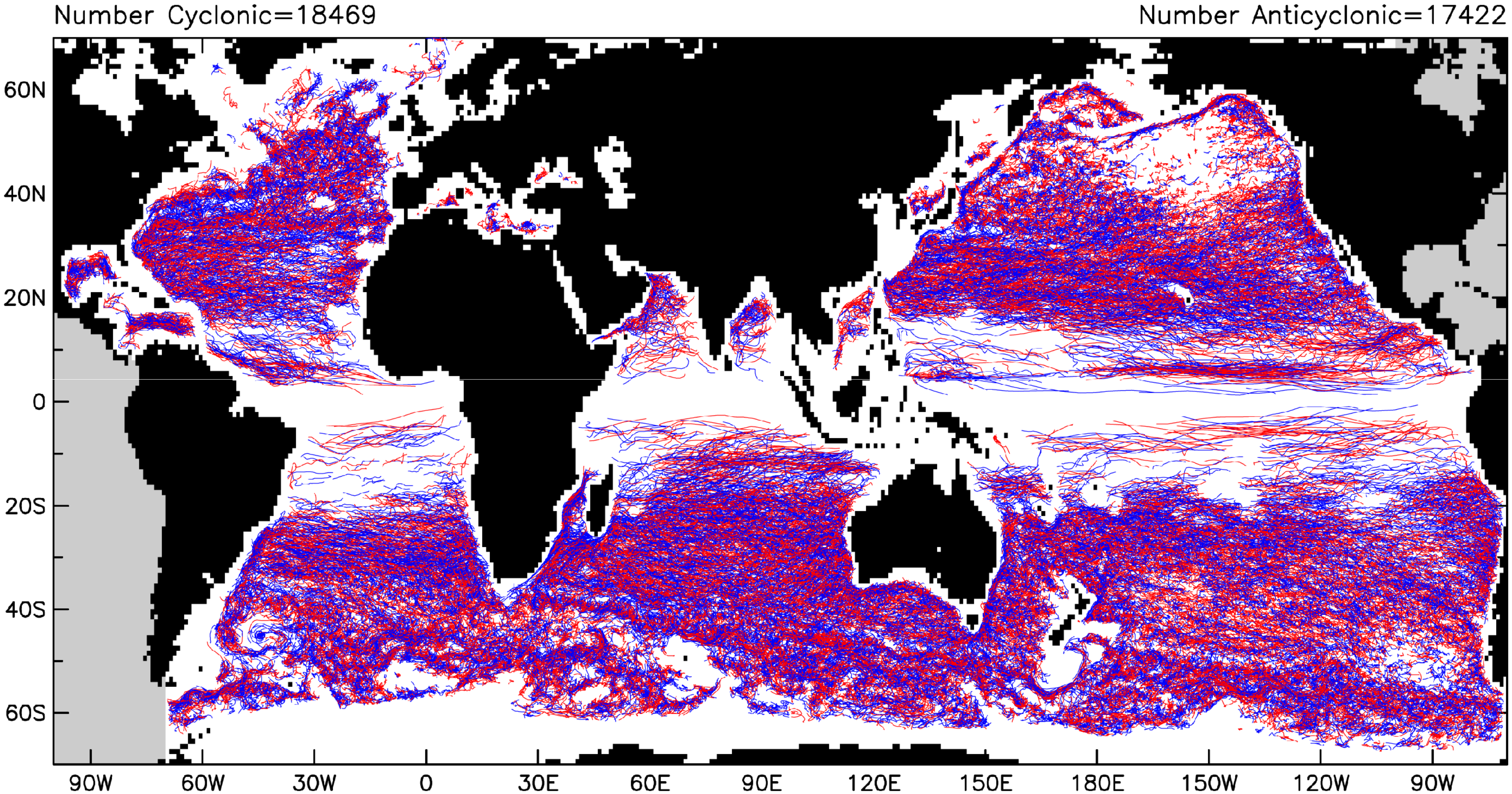
(O'Neill et al., 2010, *J. Climate*, submitted)

Wind-SST interaction over propagating ocean eddies using a global eddy-tracking procedure

- Census of ocean eddies using a new global eddy tracking procedure based on merged anomaly SSH fields using 2 simultaneous altimeters (from the so-called AVISO Reference Series)
- 16 year period Oct 1992-Dec 2008 at 7 day intervals
- Tracking algorithm used here (Chelton et al. 2010, *submitted to Prog. Oceano*.) differs substantially from Chelton et al. (2007; *GRL*)

Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 16 Weeks

(35,891 total)



Average lifetime: 32 weeks

Average propagation distance: 550 km

Average amplitude: 8 cm

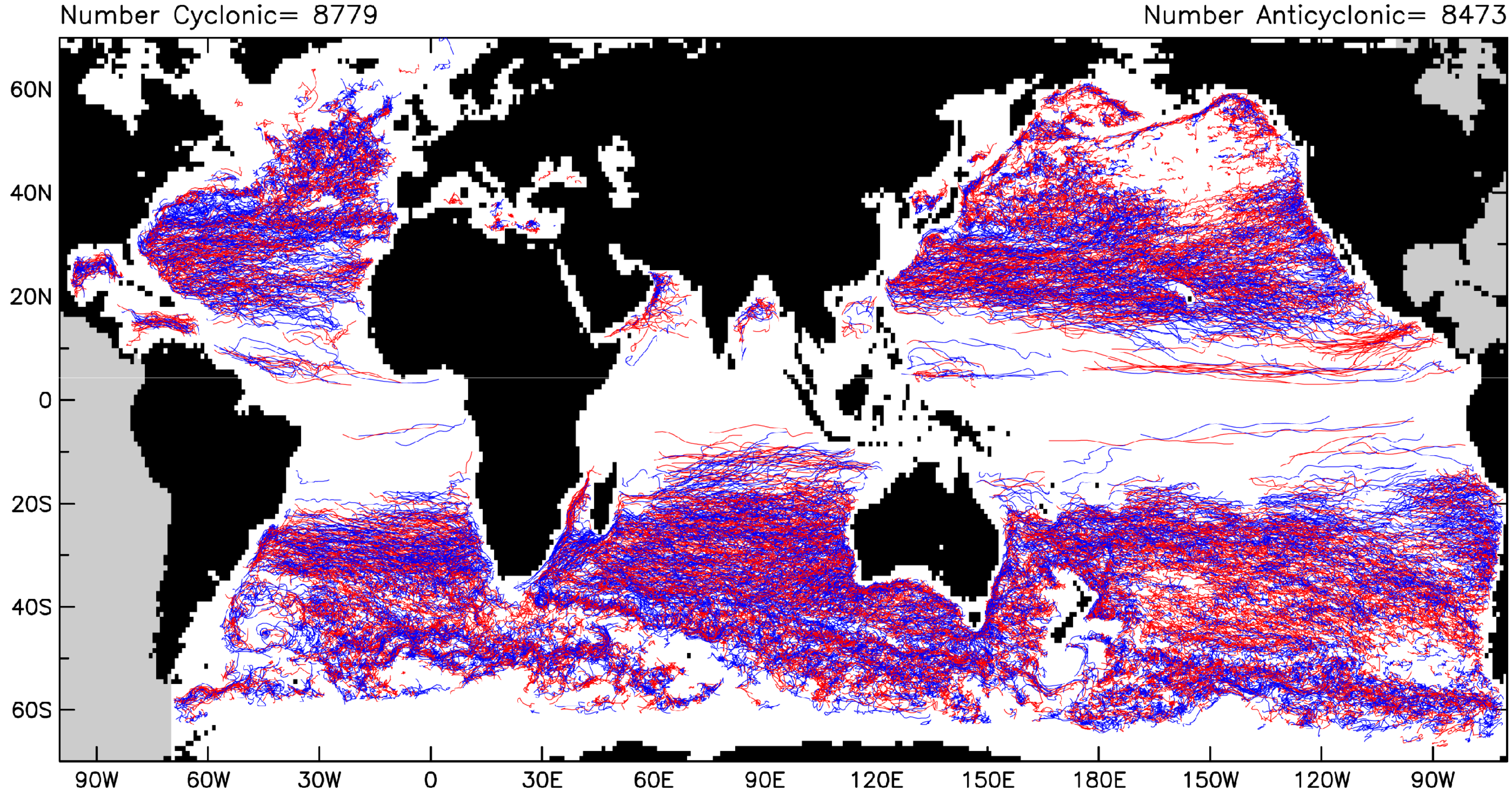
Average horizontal radius scale: 90 km

Total number of observations: ~1.15 million

Chelton et al. (2010; Submitted to Prog. Oceano.)

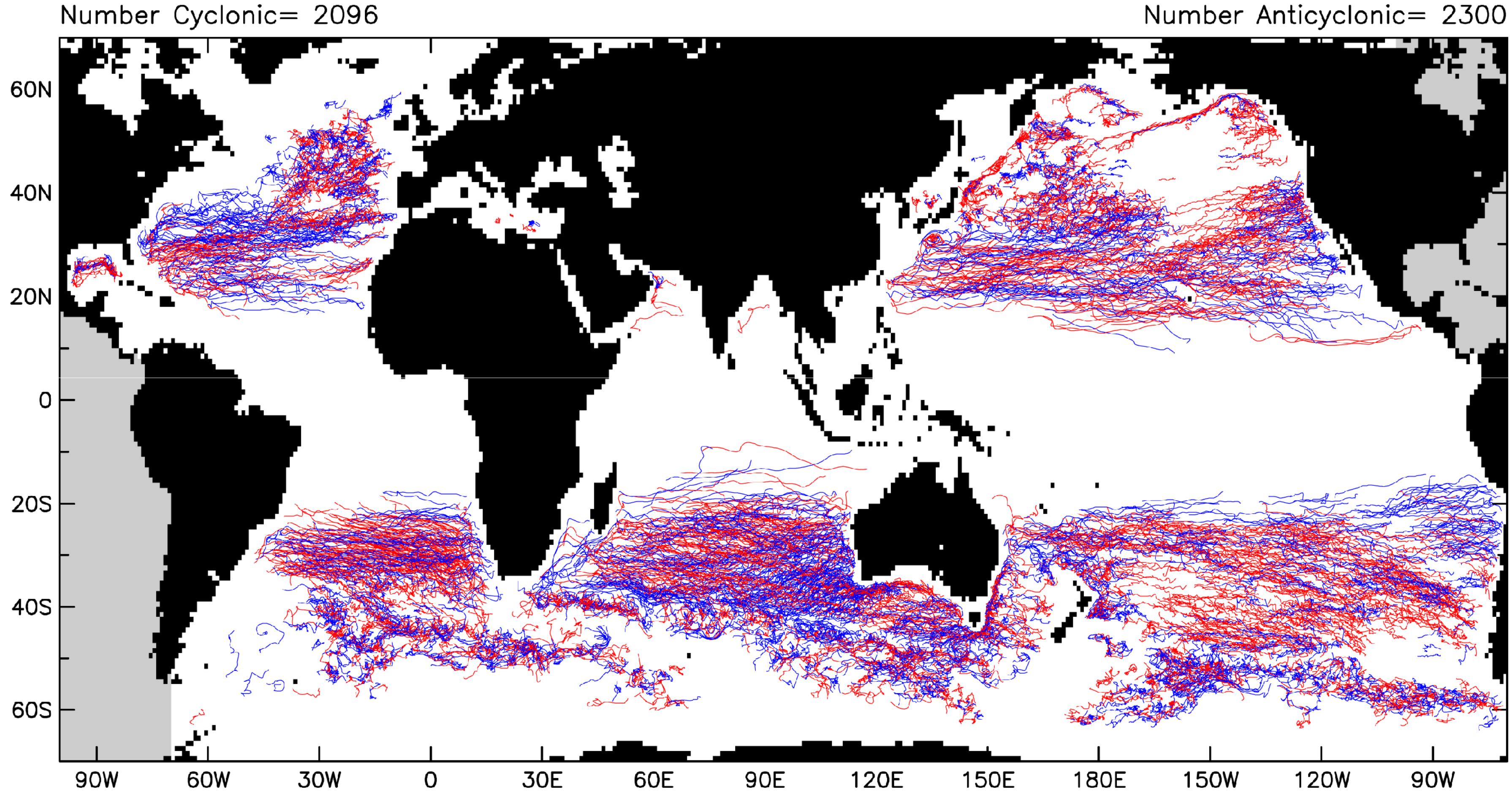
Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 6 Months

(17,252 total)



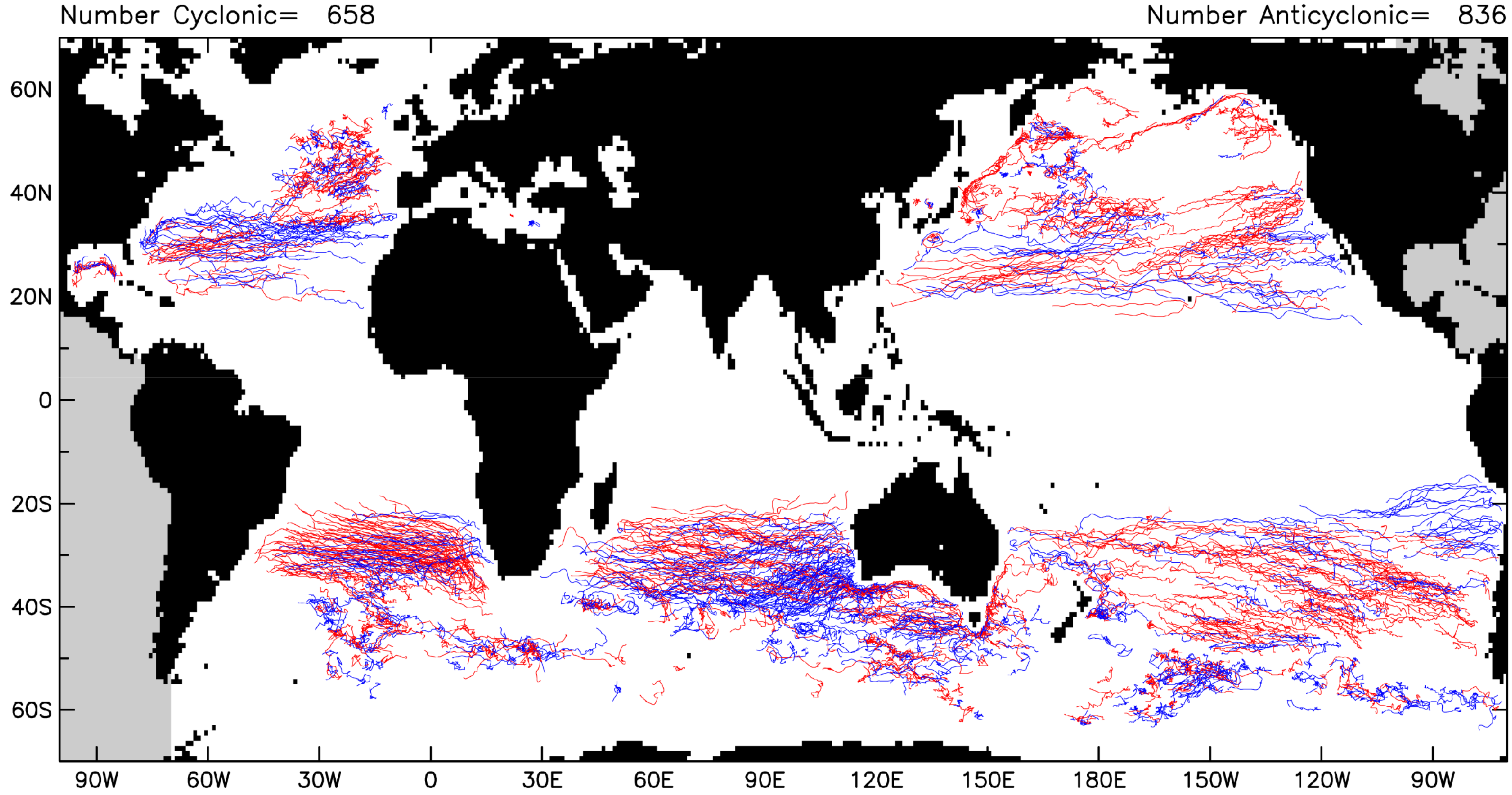
Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 12 Months

(4396 total)

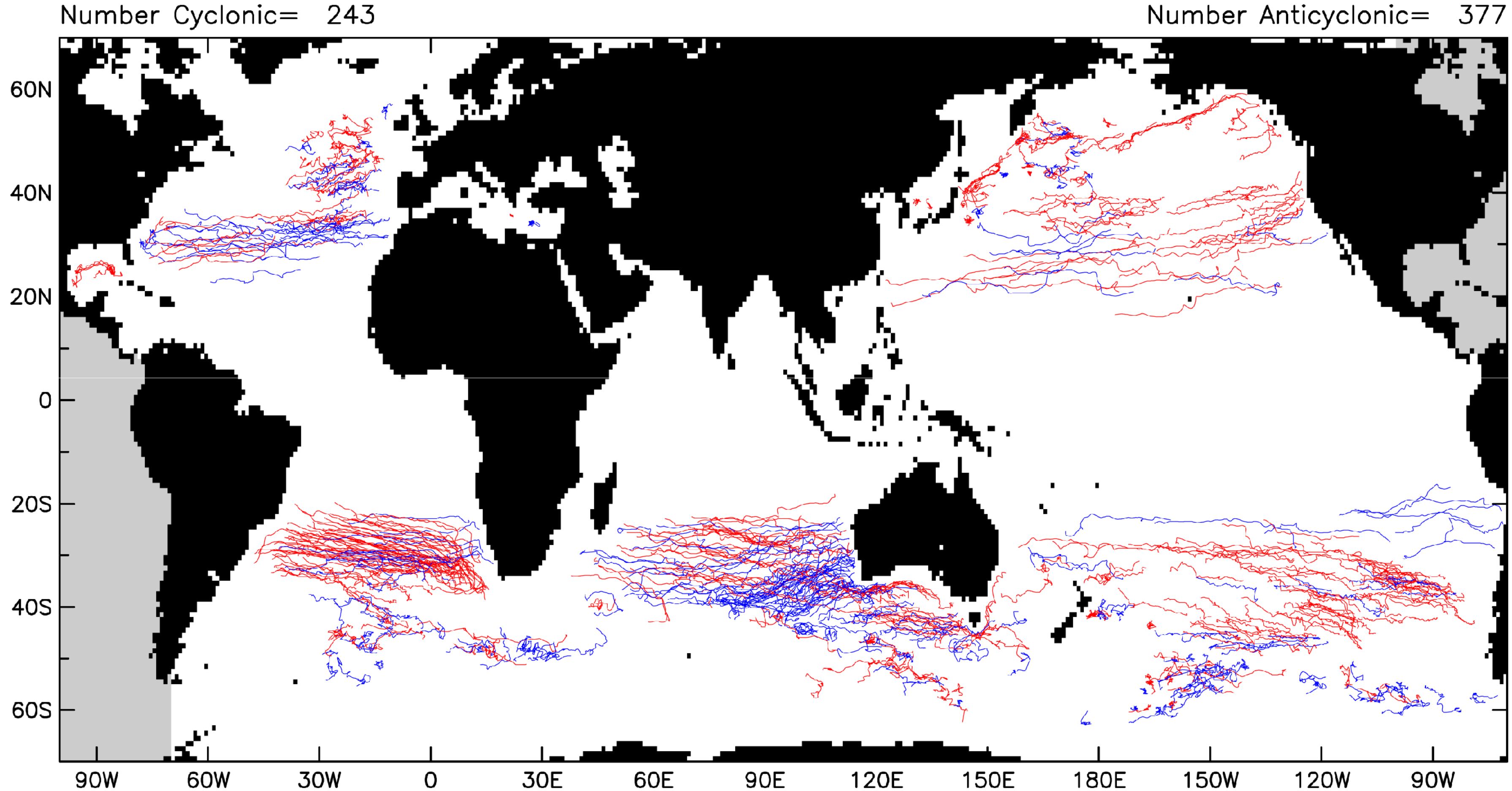


Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 18 Months

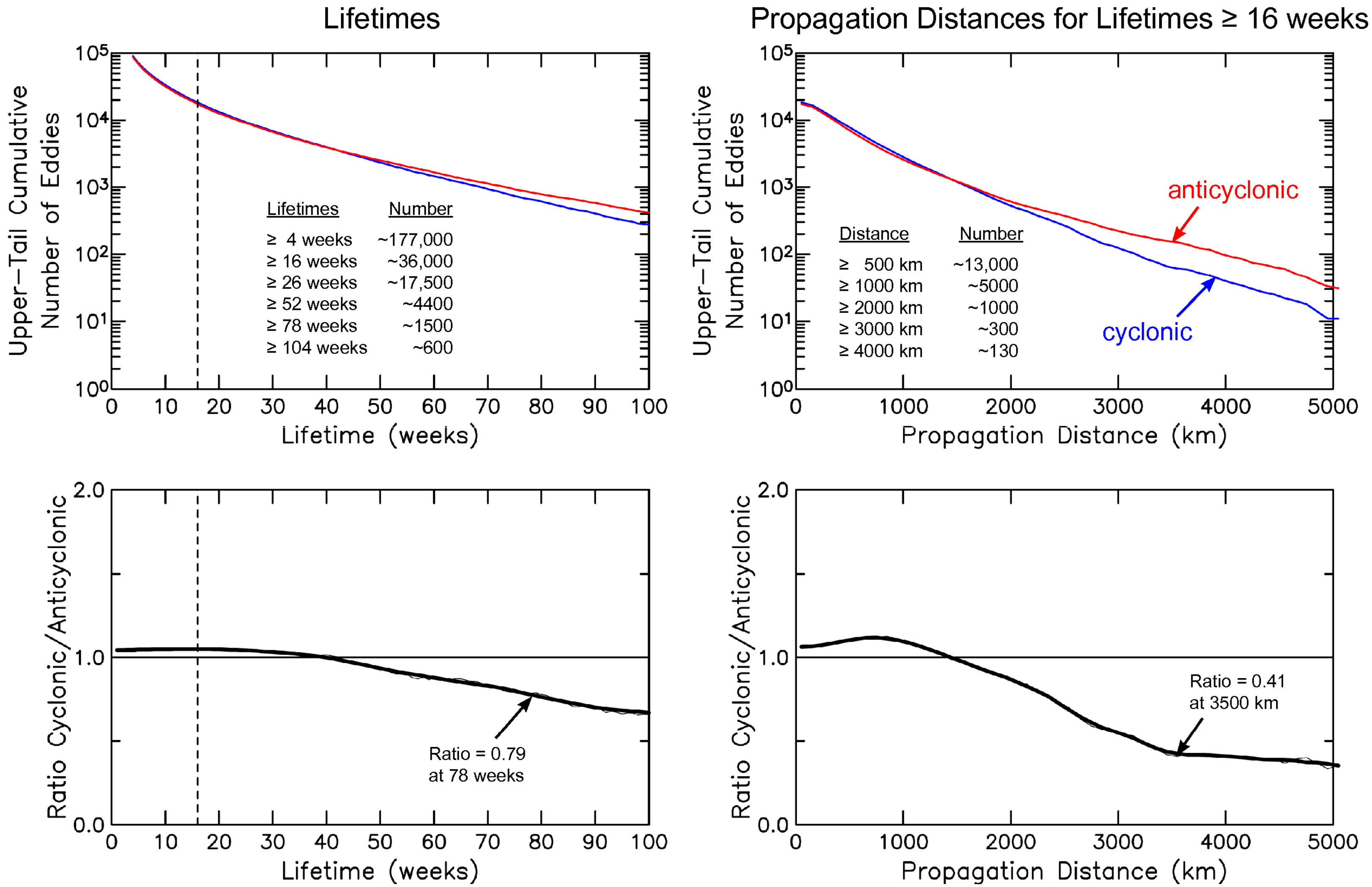
(1494 total)



Cyclonic and Anticyclonic Eddies with Lifetimes ≥ 24 Months
(620 total)



Distributions of Eddy Lifetimes and Propagation Distances from 16 Years of SSH Fields in the AVISO "Reference Series"

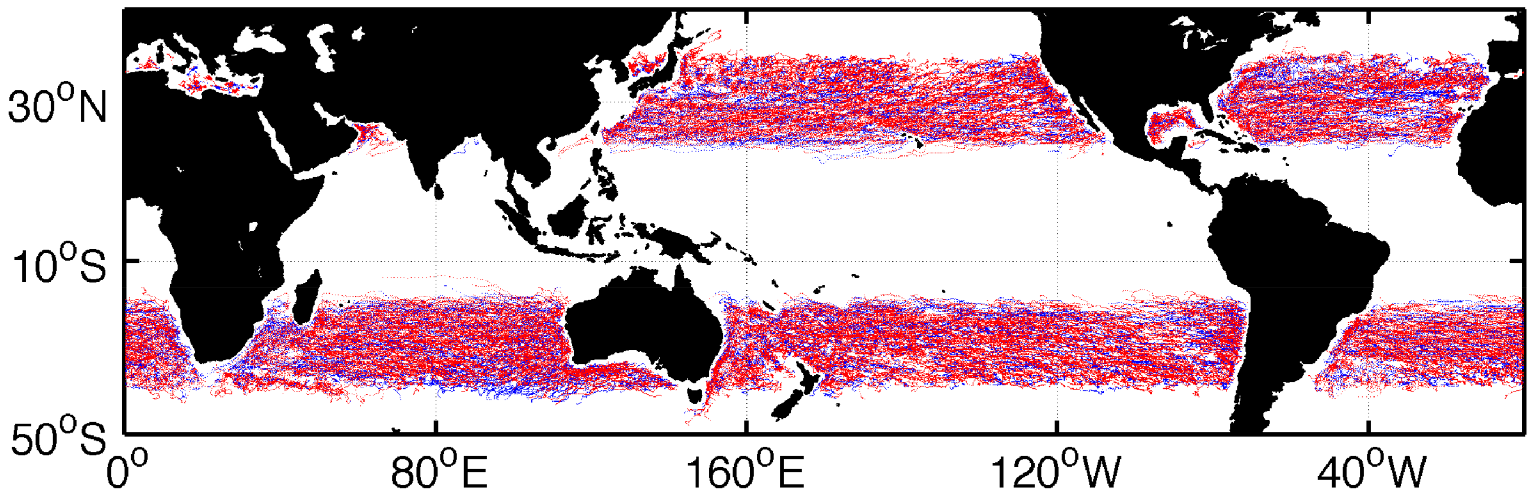


Overall, there is a slight preference for cyclonic eddies, and a significant preference for anticyclonic eddies with long lifetimes and long propagation distances.

Eddy Tracks

Midlatitude Eddies Selected for this Study

July 1999 - December 2008

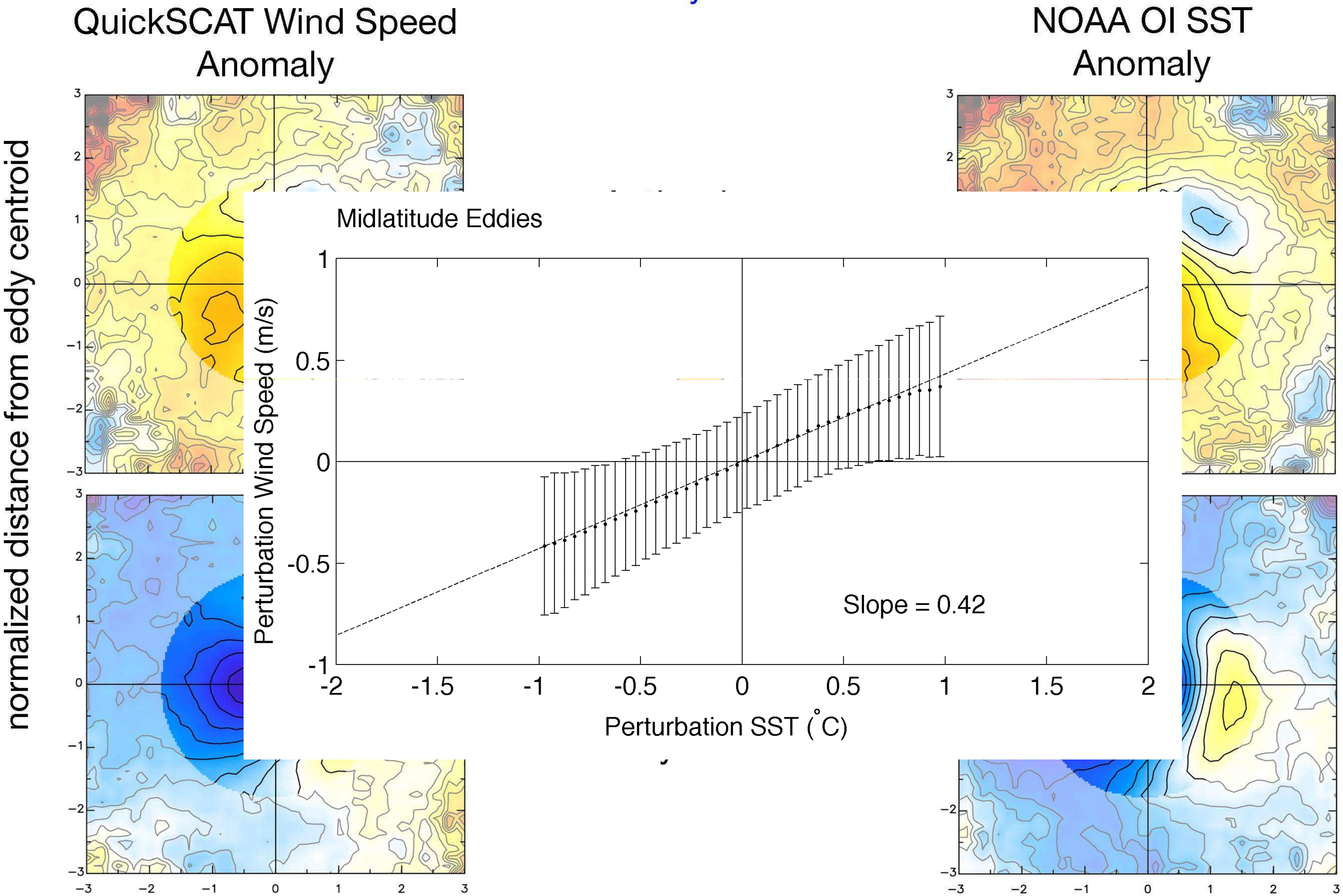


- Eddies that originating between +/- 20° and 40° with lifetimes ≥ 12 weeks
- A total of ~400,000 eddy observations were used to create composite averages

SST-induced Wind Speed Perturbations Over Eddies

Midlatitude Eddies

Horizontally Normalized



SST–Wind Interaction in Coastal Upwelling: Oceanic Simulation with Empirical Coupling

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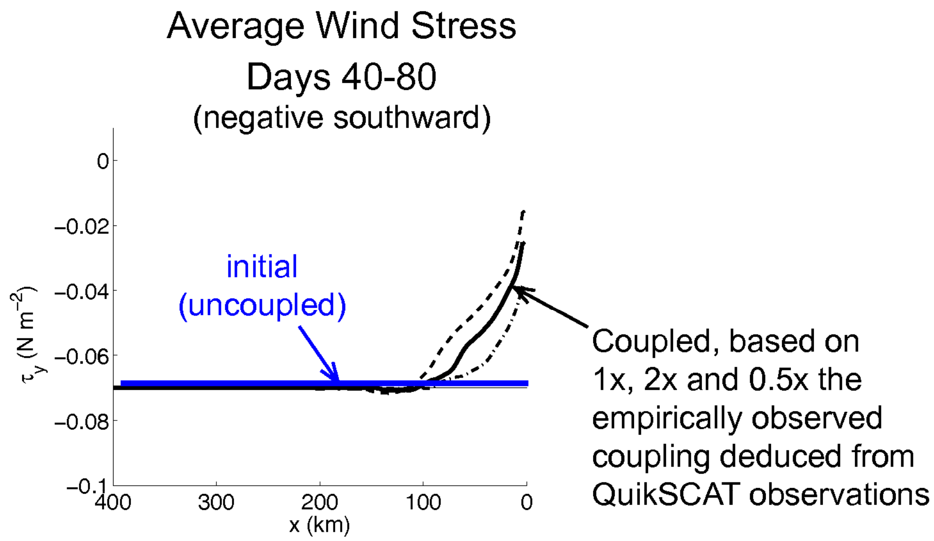
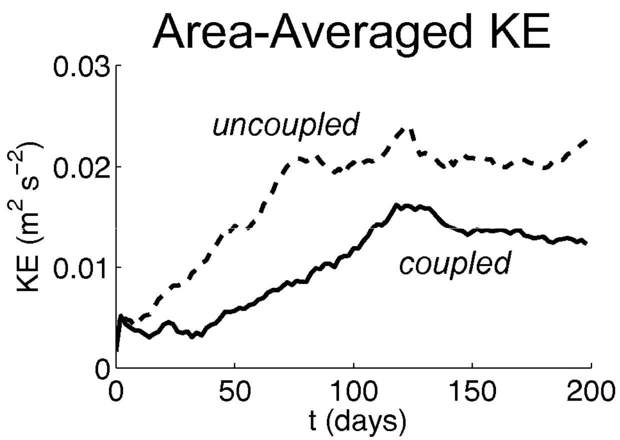
NASA Jet Propulsion Laboratory, Pasadena, California

A "25-Cent" Empirical Coupled Model:

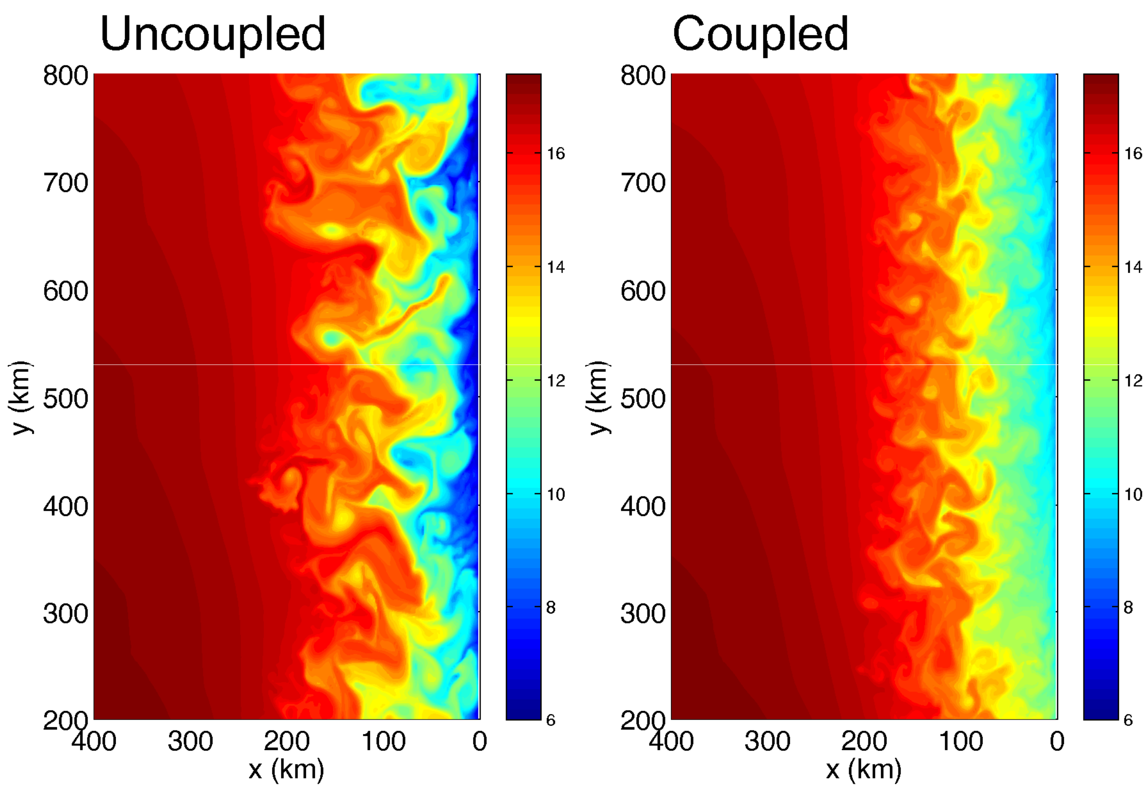
- *Based on:*
  - *the ROMS model of an idealized eastern boundary current system with a straight coastline.*
  - *QuikSCAT-based empirical coupling coefficients for the feedback on the ocean.*
- *The winds are modified at each time step to conform to the empirical coupled relations among SST gradients, wind direction, and the local curl and divergence of the wind stress.*
- *This leads to an evolving modified wind obtained by inverting the diagnosed curl and divergence fields, while maintaining the original wind values on the open-ocean boundary.*



Temporal Evolution of the Eddy Field



Sea-Surface Temperature, Day 60



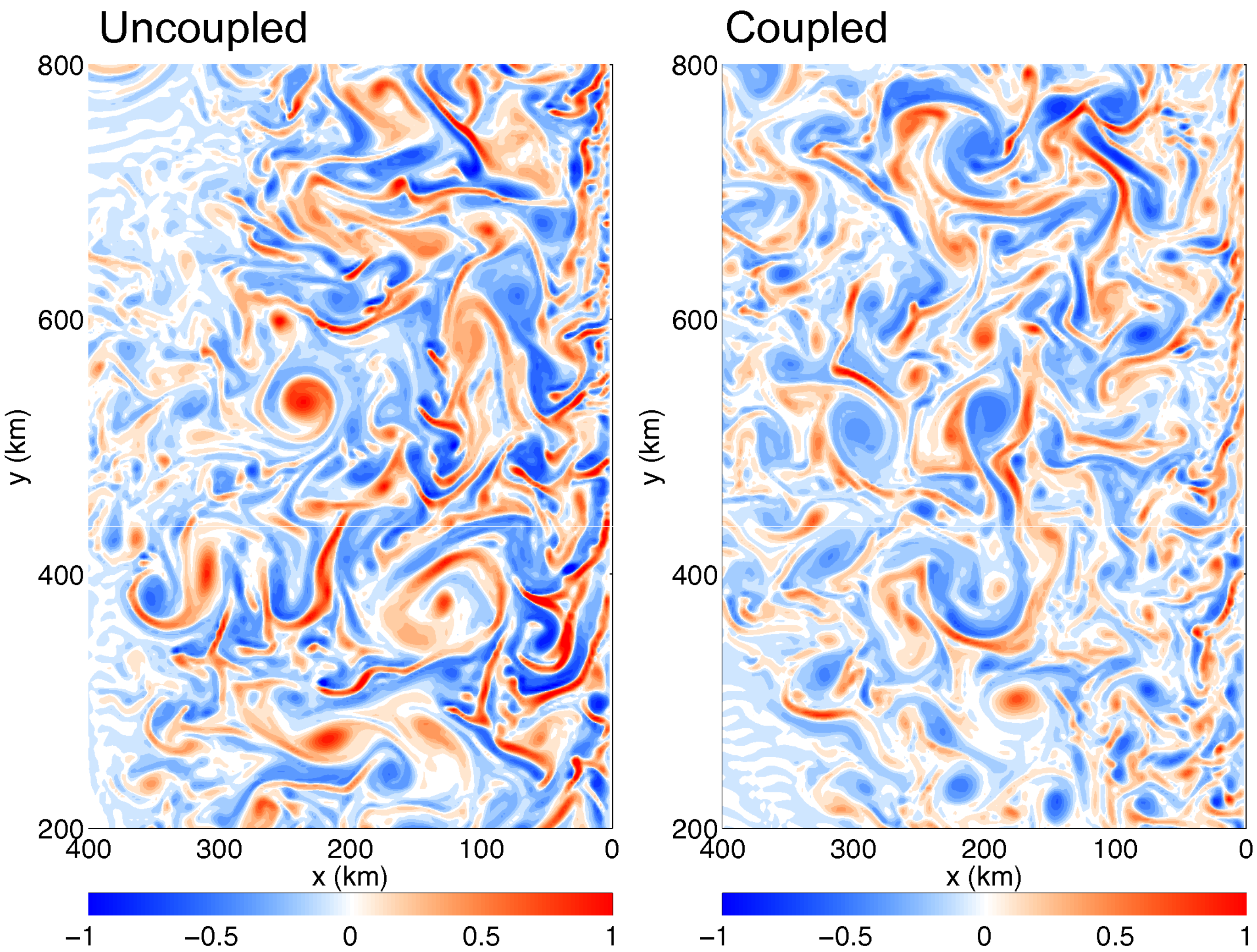
Note the weaker cross-shore gradient of SST and the weaker eddy kinetic energy in the coupled model run.

Jin et al. (2009, J. Phys. Oceanogr.)

Conclusions

- Near SST frontal zones and ocean eddies, surface winds are stronger are warmer water compared to nearby cooler water.
- Evidence is quickly emerging that these wind-SST interactions feedback onto the ocean, which influence large-scale basin circulations, coastal upwelling zones, Ekman pumping, and the eddy field.

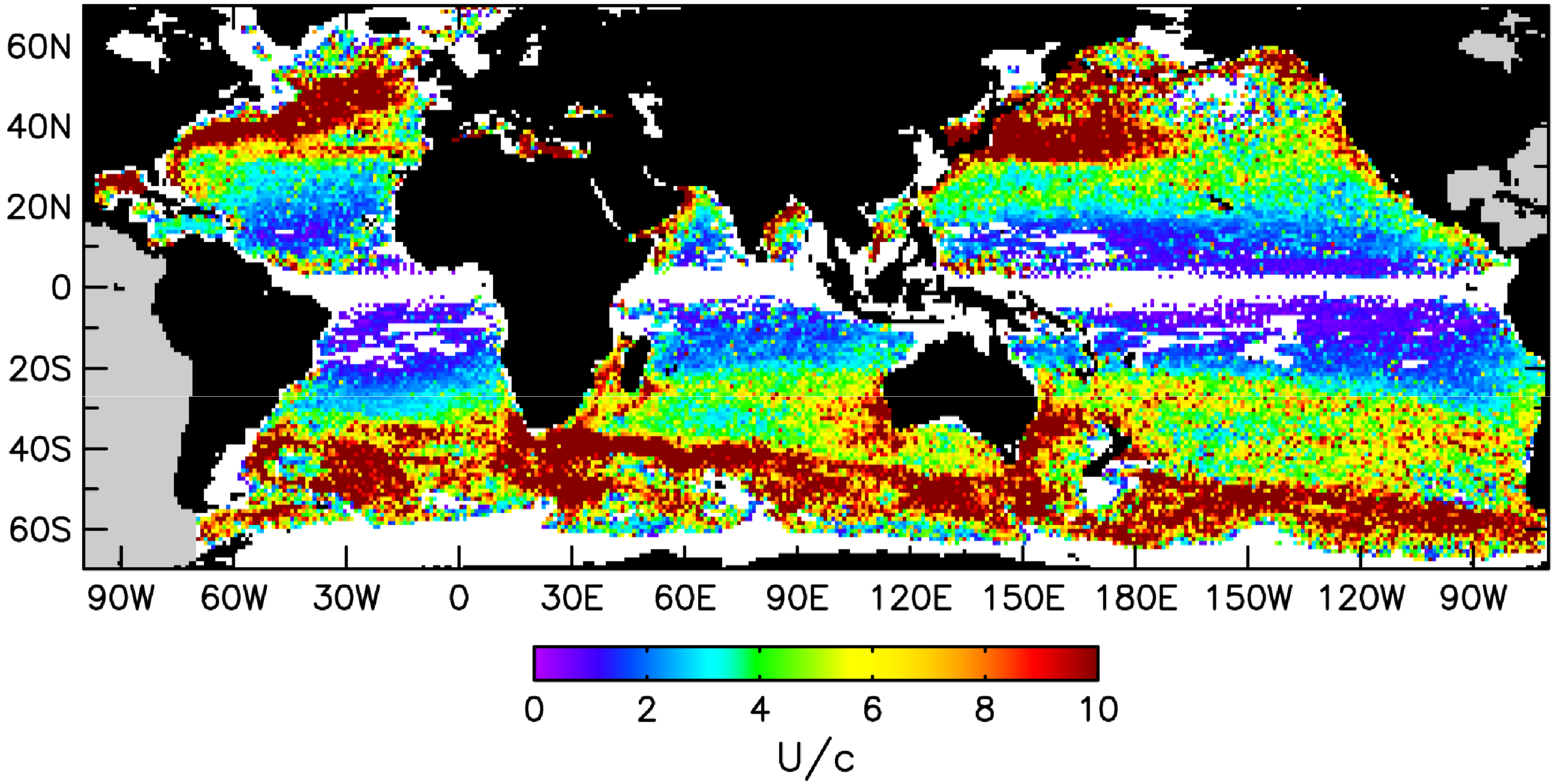
Surface Vorticity (Normalized by f) on Day 160



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

Jin et al. (2009, J. Phys. Oceanogr.)

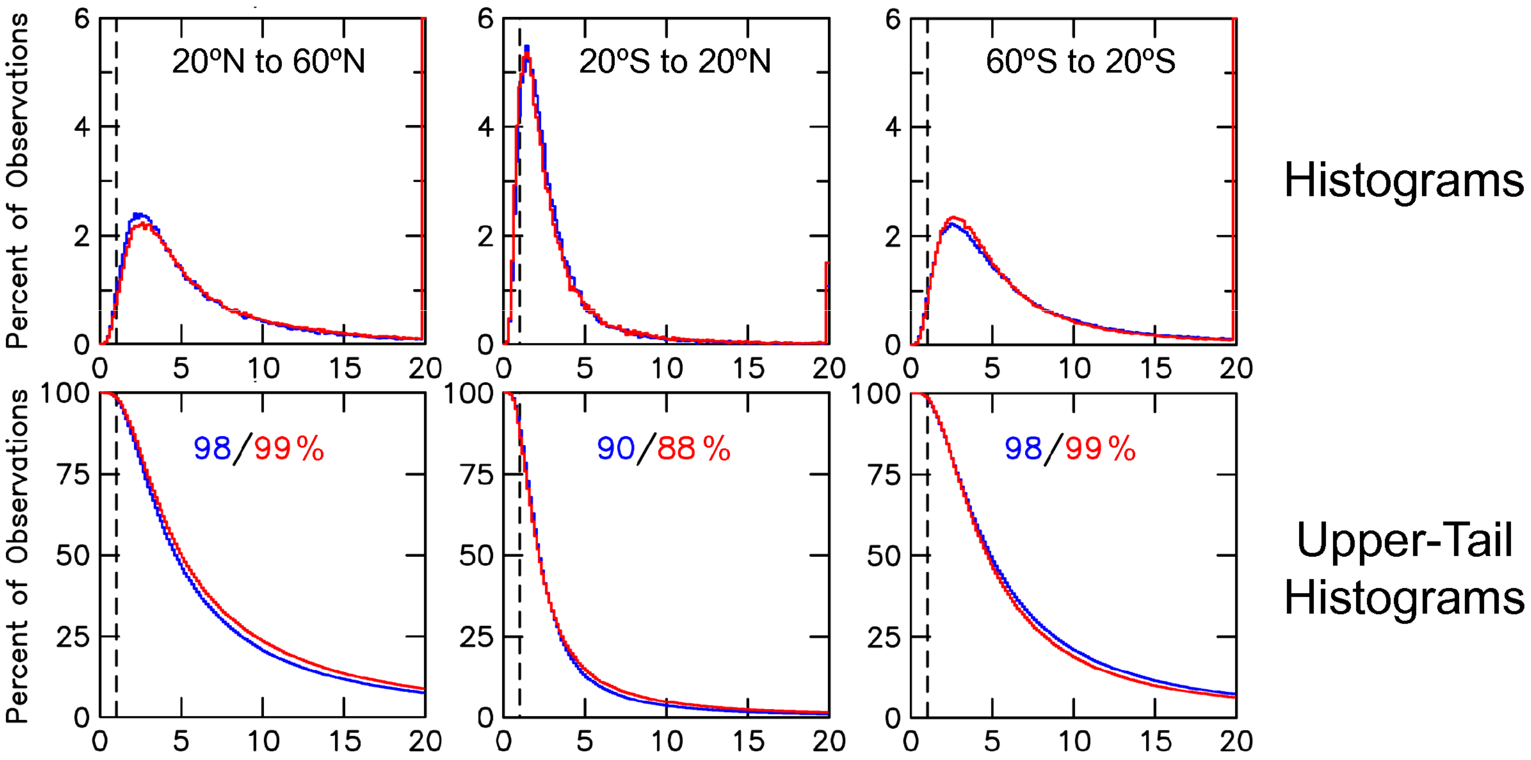
The Average Nonlinearity Parameter *U/c* in 1°x1° Bins



The importance of nonlinearity can be assessed from the ratio of nonlinear advection to acceleration, which scales as $\frac{u \cdot \nabla u}{\partial u/\partial t} \sim \frac{kU}{\omega} = \frac{U}{c}$

Distributions of Nonlinearity Parameter *U/c* in 3 Latitude Bands for Cyclonic and Anticyclonic Eddies

The characteristic fluid velocity U within the eddy interior is based on the average geostrophic speed around the SSH contour with maximum average geostrophic speed, and the translation speed c is computed from the eddy tracking.

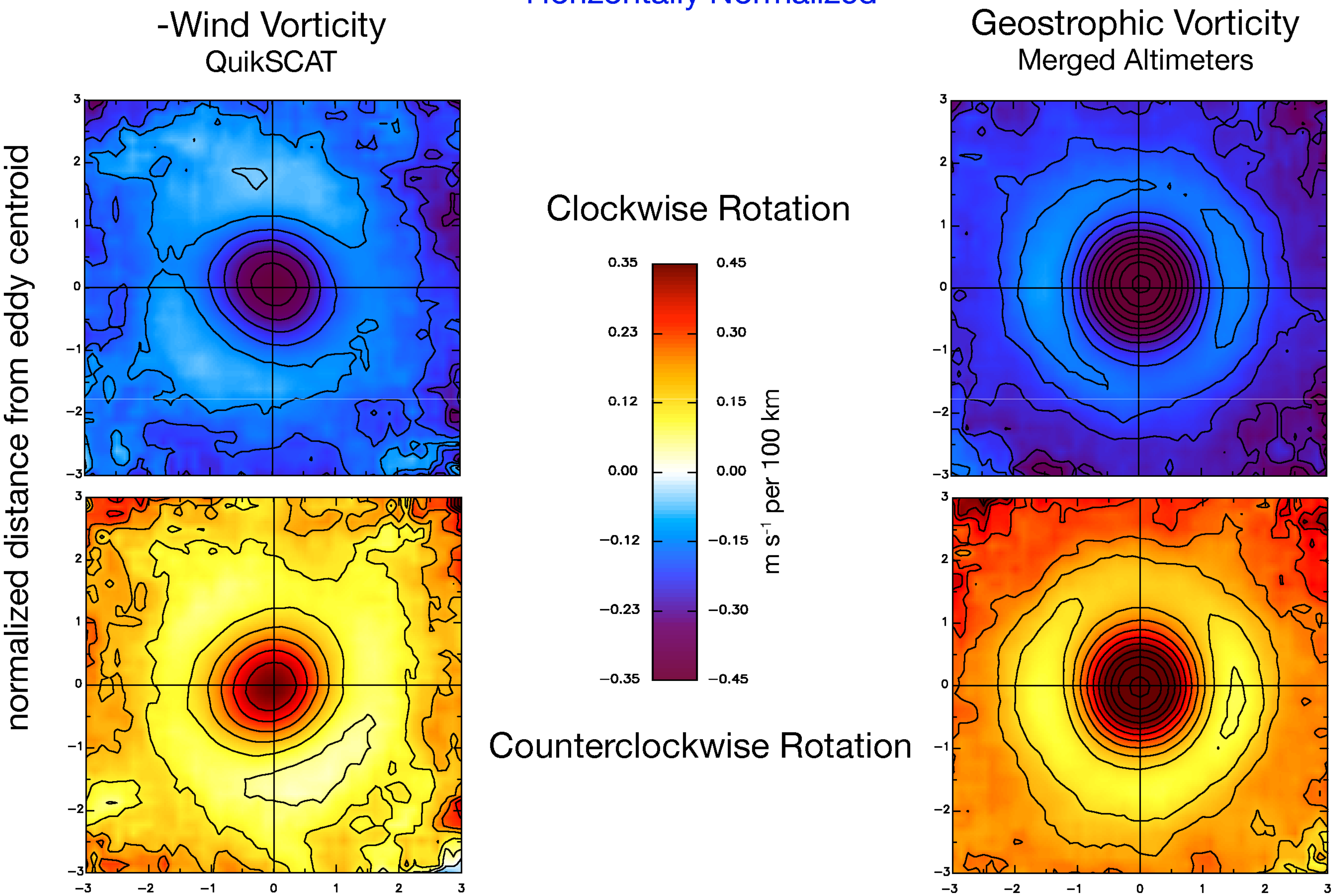


For the extratropical eddies:
98% had U/c > 1
48% had U/c > 5
21% had U/c > 10

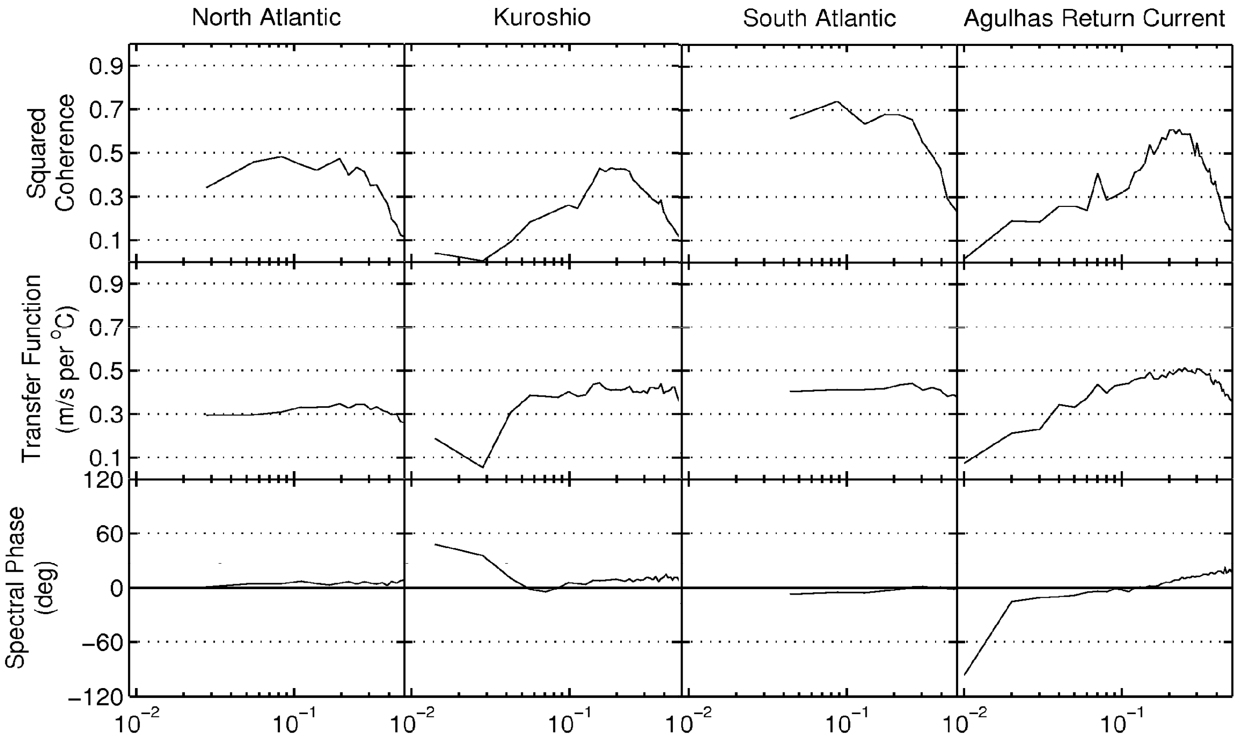
Composite Medians of Vorticity

30-day 2x2 and 6x6

Horizontally Normalized



Cross-spectral statistics in zonal wavenumber domain for wind speed and SST



Zonal Wavenumber (Cycles per degree Longitude)

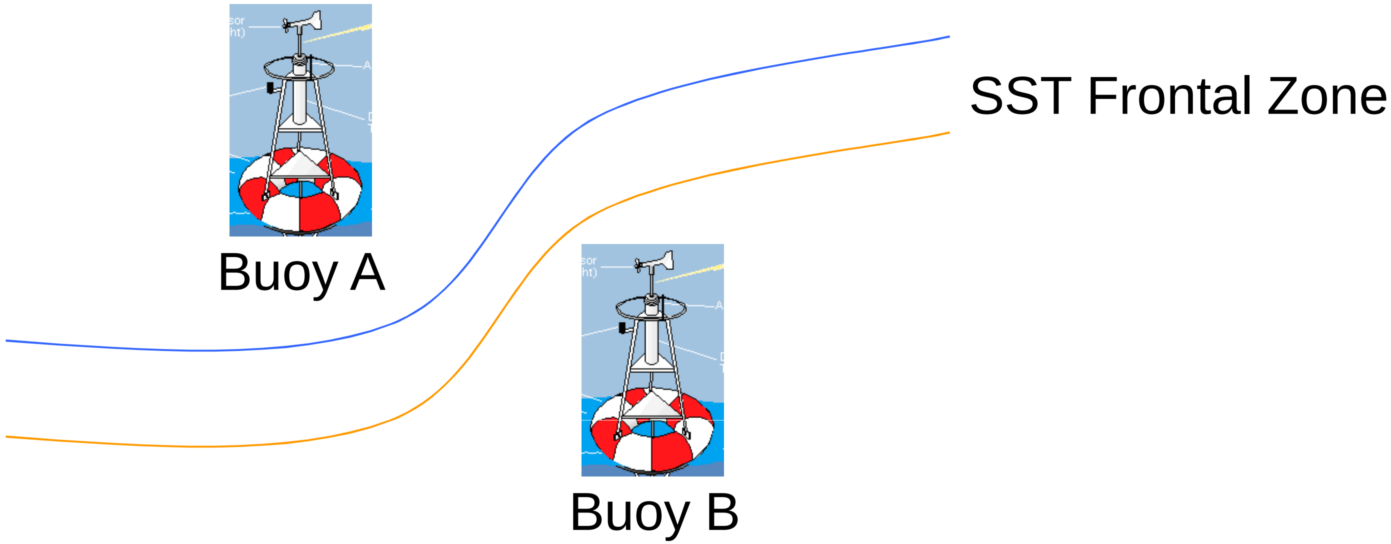
Computed from weekly-averaged QuikSCAT and AMSR-E wind and SST fields

-At zonal wavelengths of <20°, spectral phase shows SST leads wind speed

-Since winds are predominantly westerly in these regions, this indicates SST forces the surface wind speed

-At longer wavelengths, wind speed leads SST, indicating wind speed forces SST

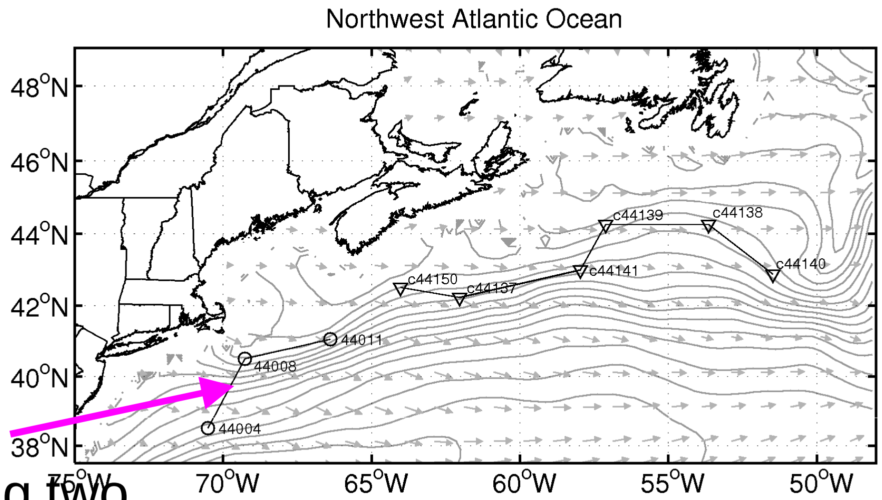
Satellite-moored buoy comparison methodology



Test the hypothesis that the *wind speed difference V_{10nB}-V_{10nA}=δV_{10n} depends on the SST difference T_{SB}-T_{SA}=δT_S*

This hypothesis is tested in a very simple way, first from moored buoys, to provide a means to compare the satellite wind response to SST with buoys.

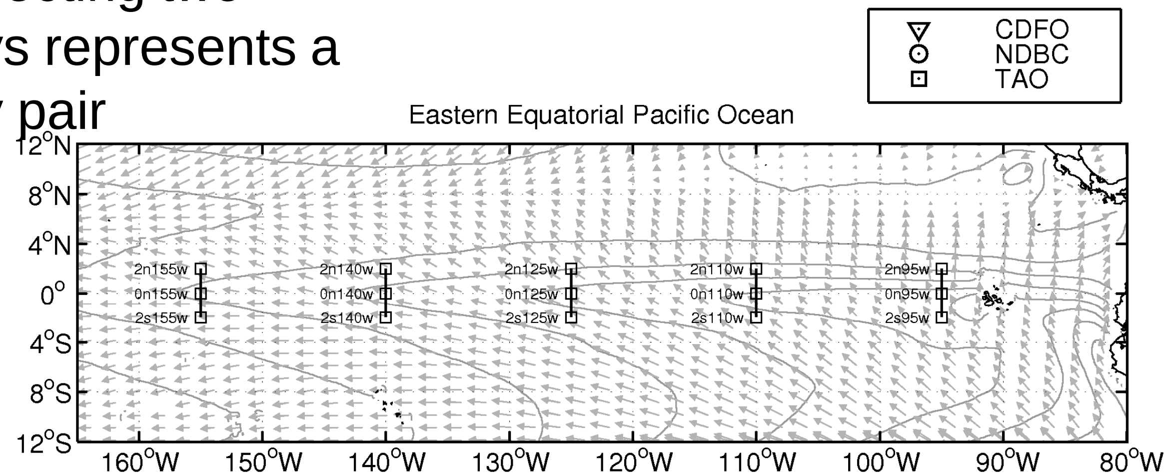
17 buoy pairs in the Gulf Stream and eastern equatorial Pacific



Broken into 3 regions:

1) Gulf Stream
2) Southern Equatorial Pacific
3) Northern Equatorial Pacific

Each line connecting two buoys represents a buoy pair



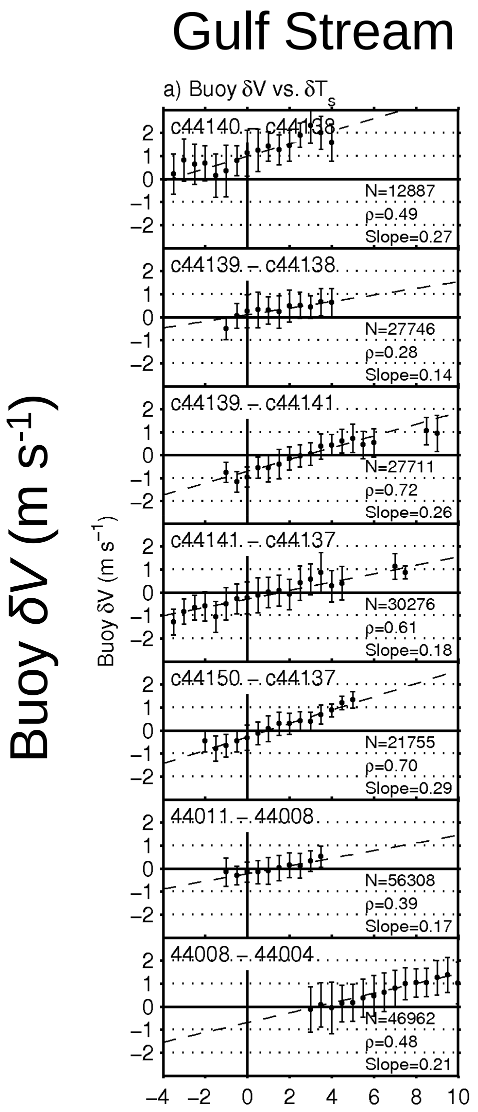
Contours: mean AMSR-E SST

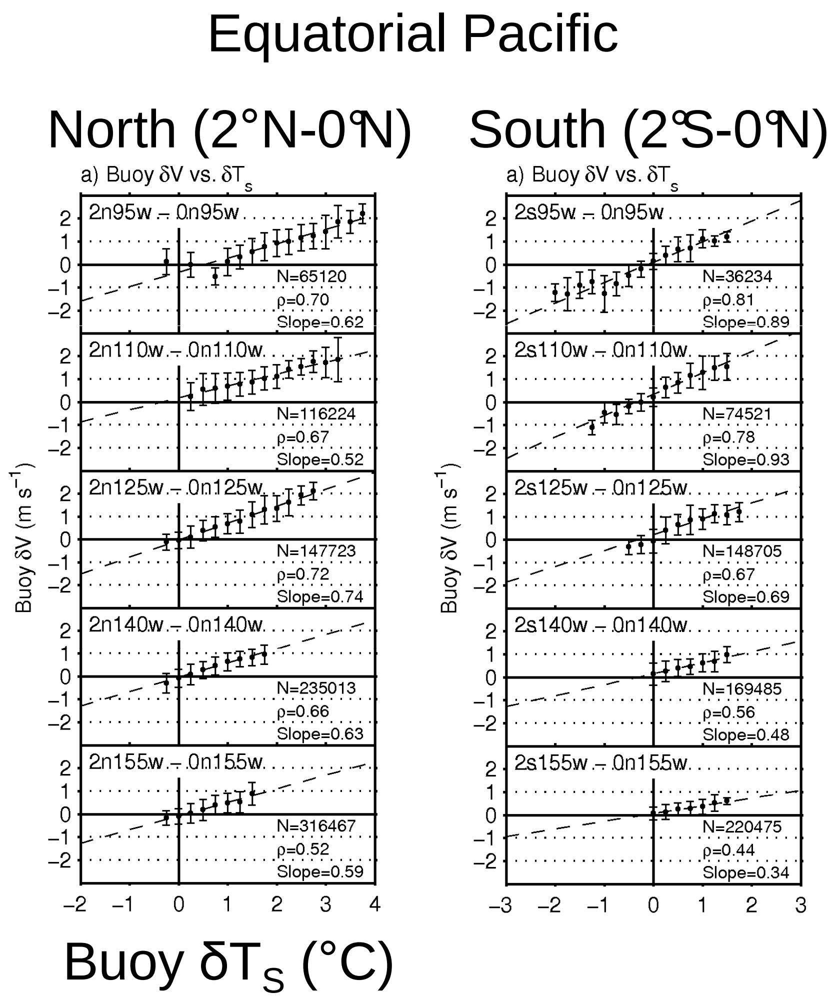
Vectors: QuikSCAT mean wind vector

Period: Jun-2002 to May-2009

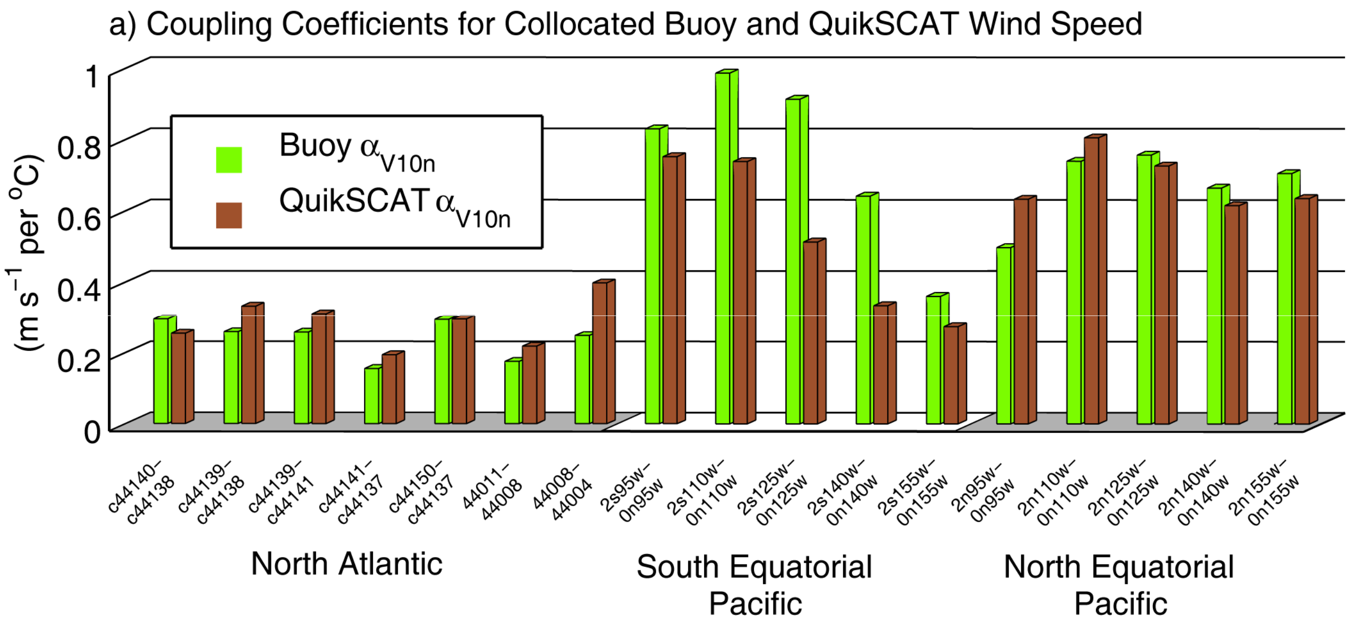
Buoy-measured wind speed differences are correlated positively with and related linearly to the SST differences.

No height or stability corrections applied to buoy wind measurements.





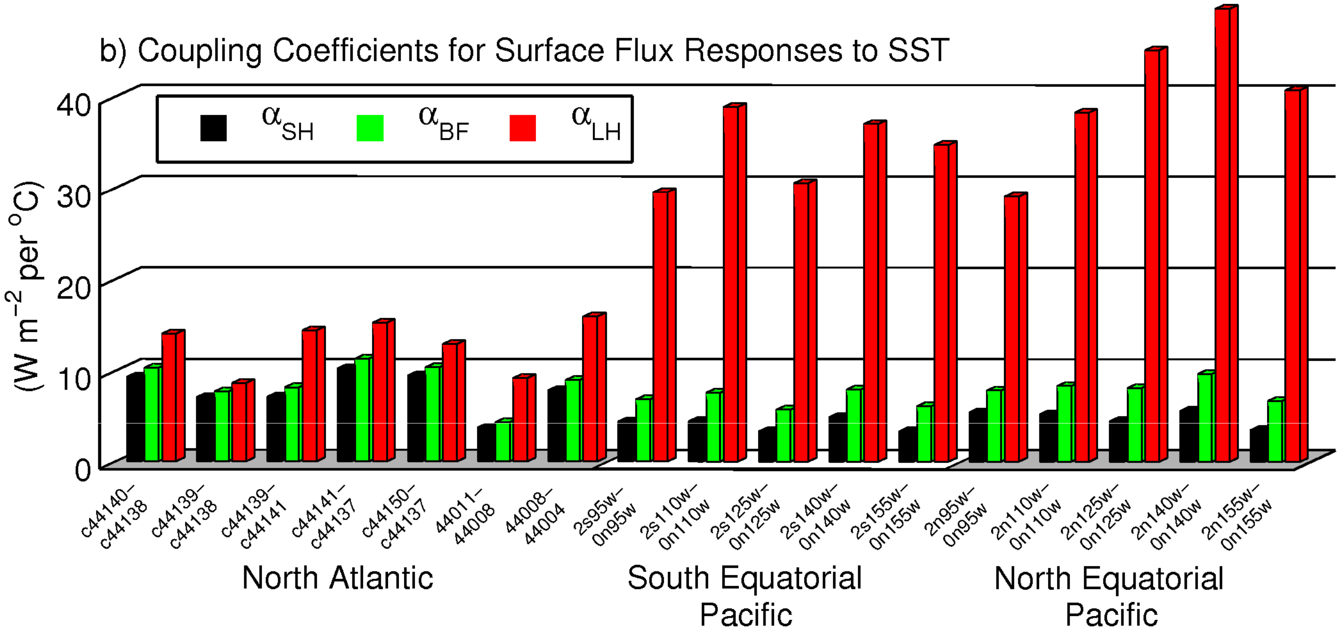
Comparison between buoy and satellite wind responses using the slopes of the linear δV_{10n} vs. δT_S relation



Response of 10-m ENWs from QuikSCAT similar to most buoy pairs, although biased low over the south equatorial Pacific.

A similar analysis with AMSR-E winds in place of the QuikSCAT winds show a nearly identical result.

Slopes of linear relationship of buoy heat and buoyancy fluxes to δT_S

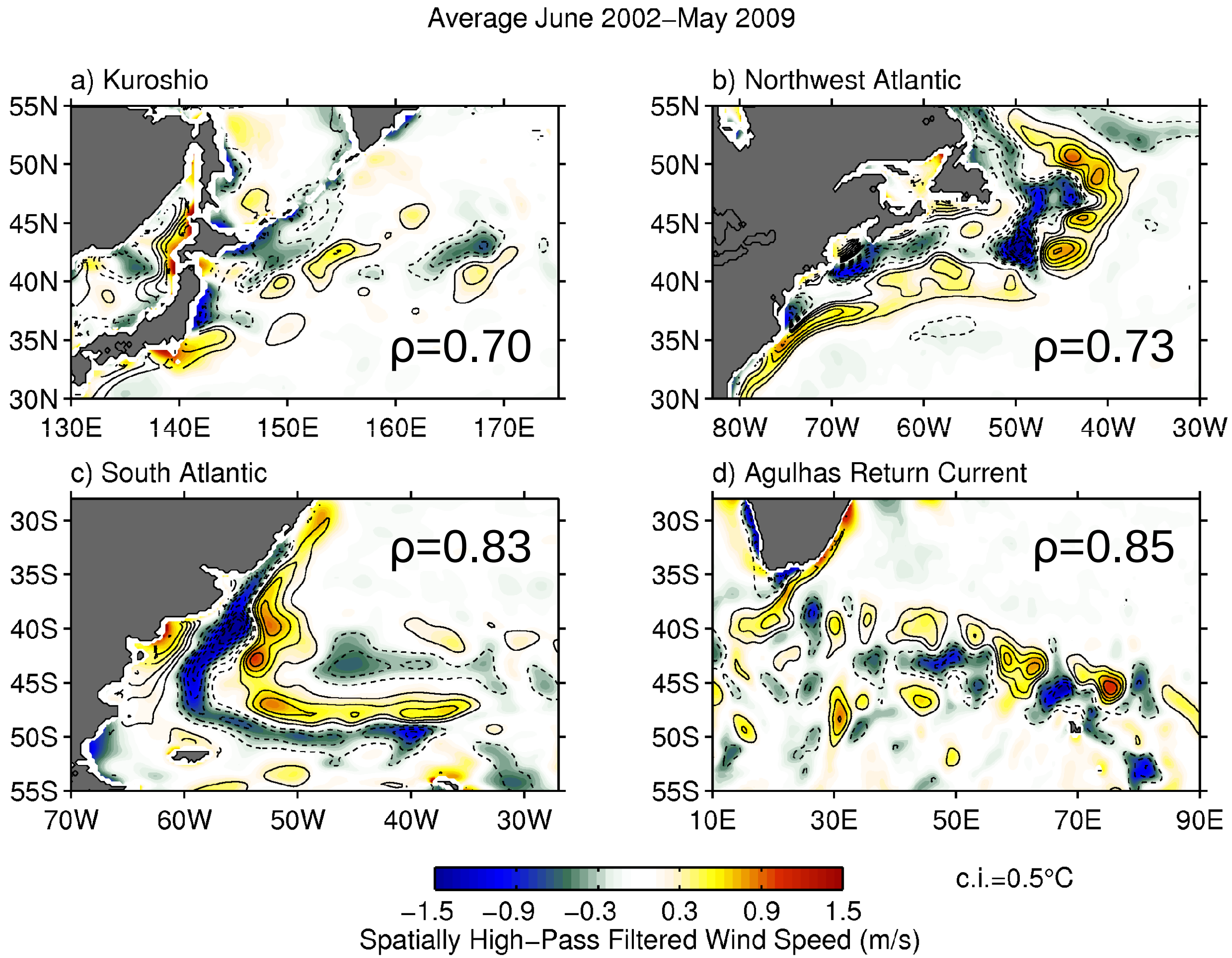


- Buoyancy flux response to SST slightly smaller over equatorial Pacific and Gulf Stream, although fractional contribution of latent and sensible heat fluxes much different

- Sensible heat flux response to SST about half as large over eq Pac compared to Gulf Stream

- Latent heat flux response to SST more than twice as large over equatorial Pacific than over the Gulf Stream

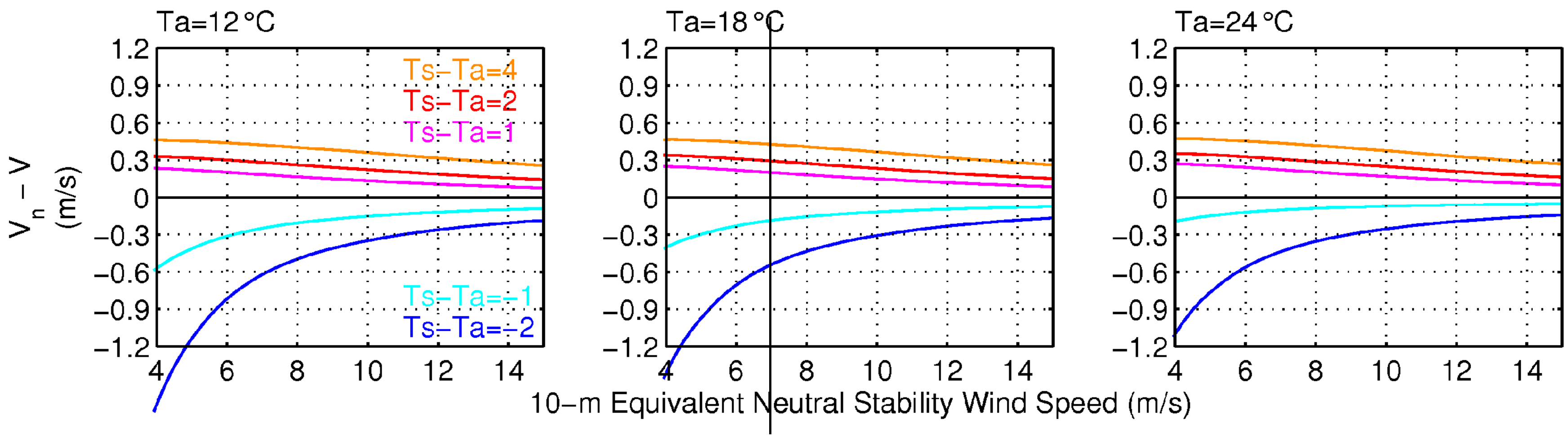
Spatially filtered QuikSCAT *wind speed* (colors) and AMSR-E SST (contours) averaged for June-2002 to May-2009



Colors = *spatially filtered QuikSCAT wind speed*

Contours = spatially filtered AMSR-E SST with a c.i. of 0.5℃ (solid=warm, dashed=cool)

Comparing 10-m Neutral and Actual Wind Speed Relative to Surface Ocean Currents



- Computed using similarity theory-based state-of-the-art COARE 3.0 bulk flux algorithm (Fairall et al. 2003) using methodology of Liu and Tang (1996)
- According to similarity theory, difference between 10-m neutral and actual wind speed:
  - Is very significant in extremely stable and low neutral wind speed conditions
  - Decreases very rapidly for increasing wind speed in both stable and unstable conditions
  - Is relatively small in unstable conditions for all neutral wind speeds
- This effect is not related to the turbulent mixing mechanism of Wallace et al. (1989) and Hayes et al. (1989)