Dynamics and variability of surface wind speed and divergence over mid-latitude ocean fronts

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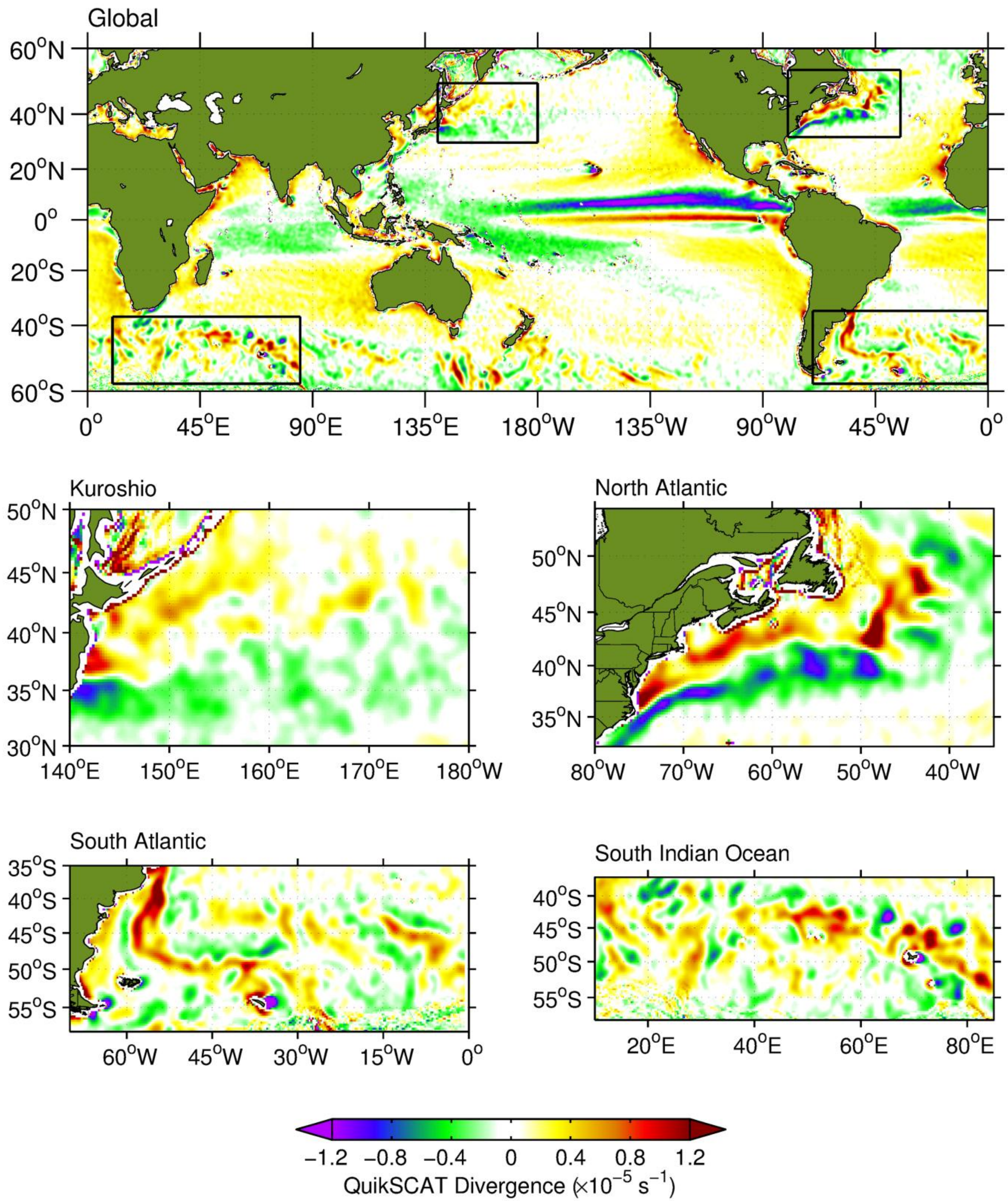
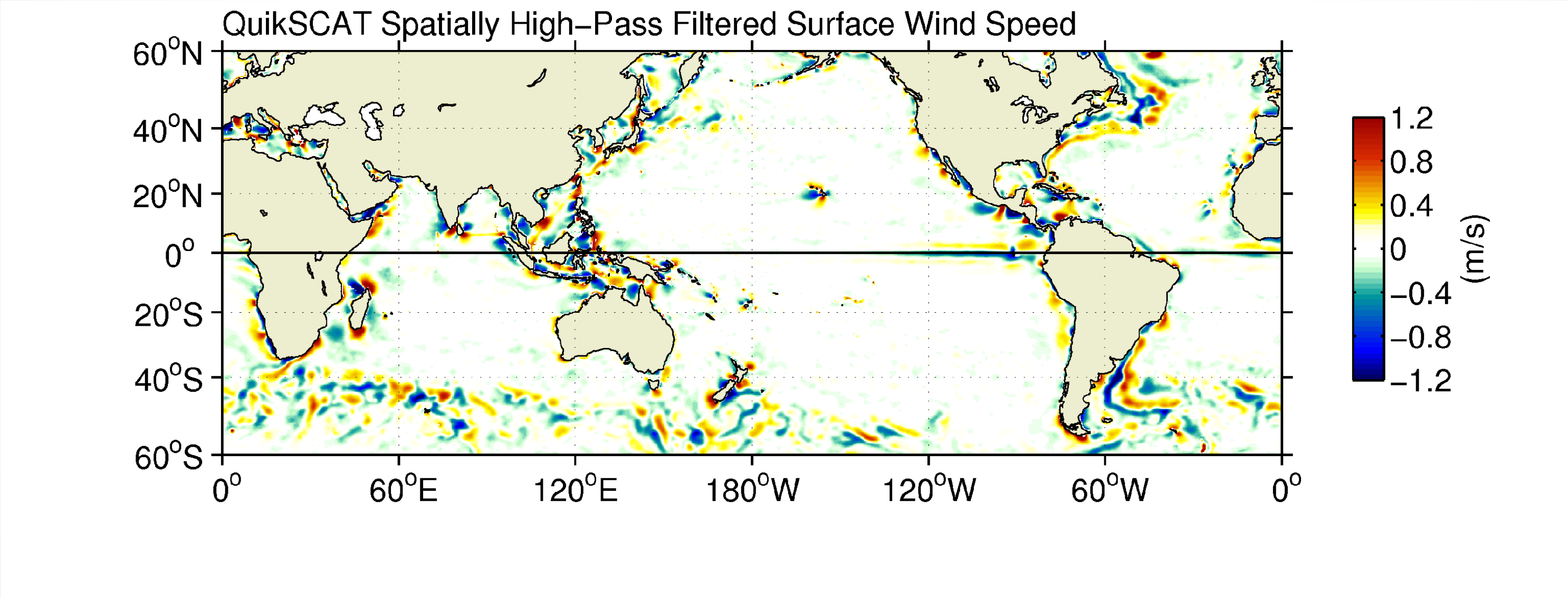
Overview:

1) Spatial and temporal variability of surface divergence estimated from QuikSCAT
2) Influence of mesoscale SST variability and large-scale surface wind speed on surface divergence variability
3) Dynamics associated with surface wind response from atmospheric numerical simulations of flow over the Northwestern Atlantic and Southern Oceans

QuikSCAT Surface Divergence 7-yr Average (June 2002-May 2009)

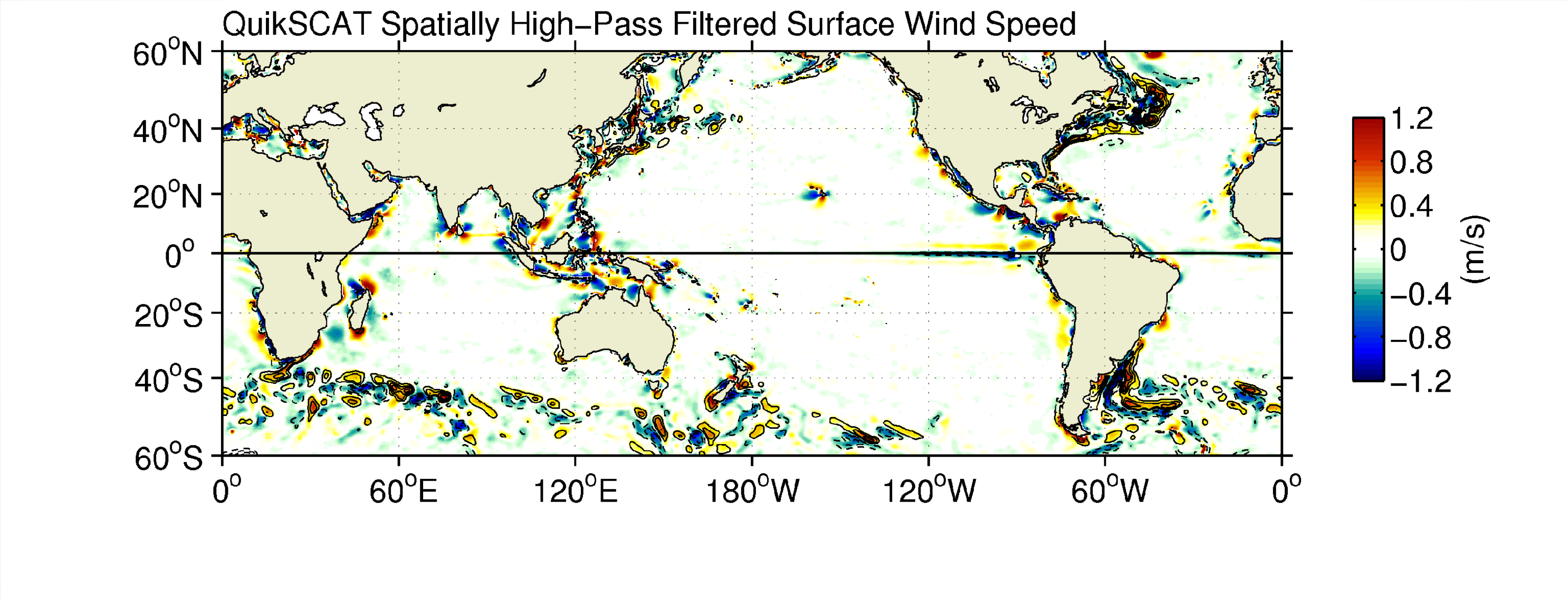


Small-scale surface wind speed contributes strongly to the divergence variability in mid-latitudes



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

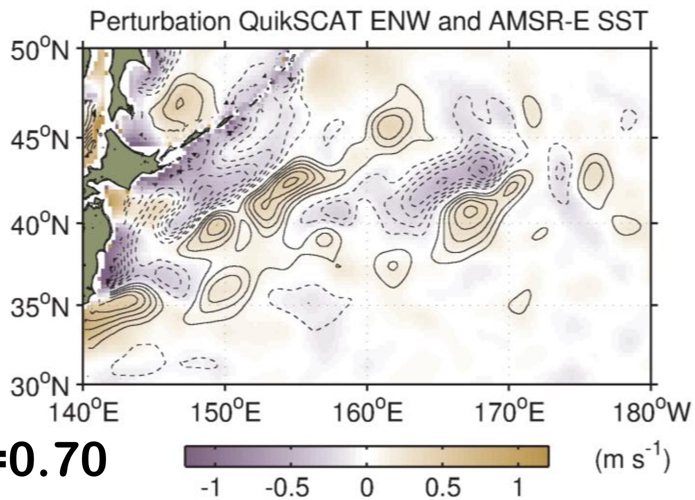
Small-scale surface wind speed contributes strongly to the divergence variability in mid-latitudes



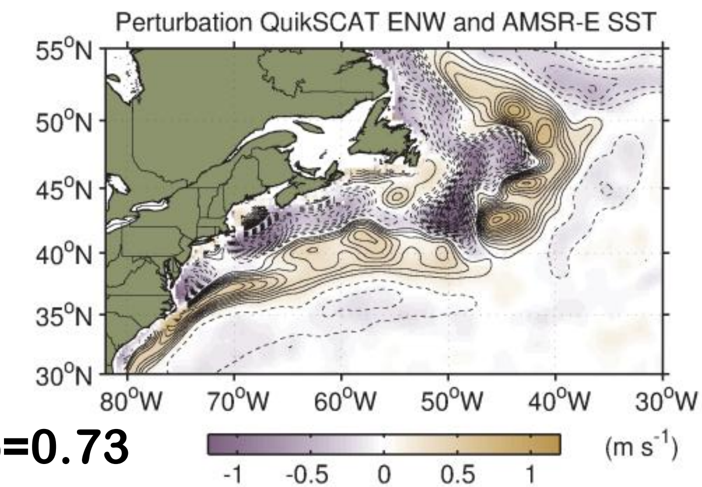
Filtered to remove variability with wavelengths longer than 20° long. x 10° lat.

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

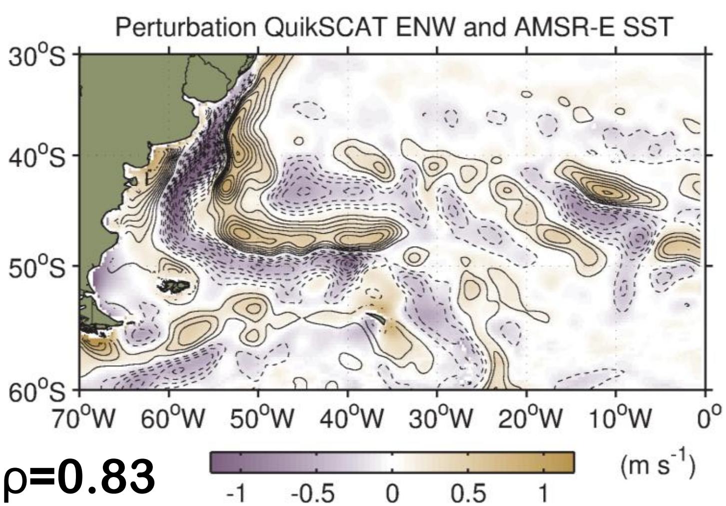
SST effects on the mesoscale wind speed measured from QuikSCAT and AMSR-E



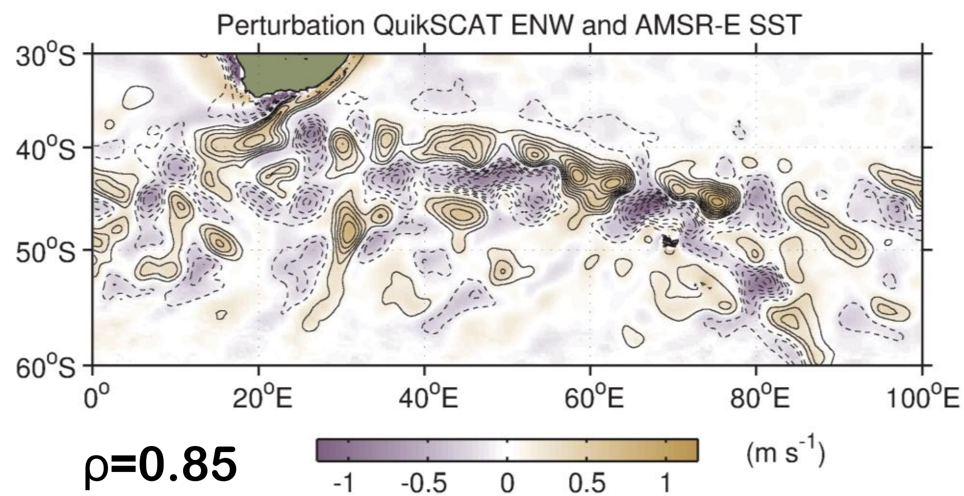
ρ=0.70



ρ=0.73



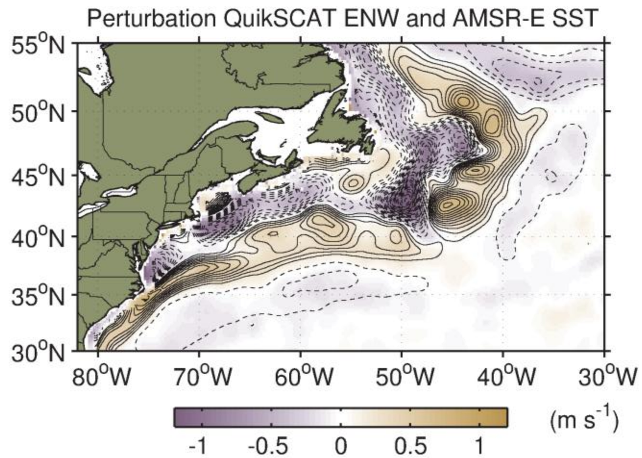
ρ=0.83

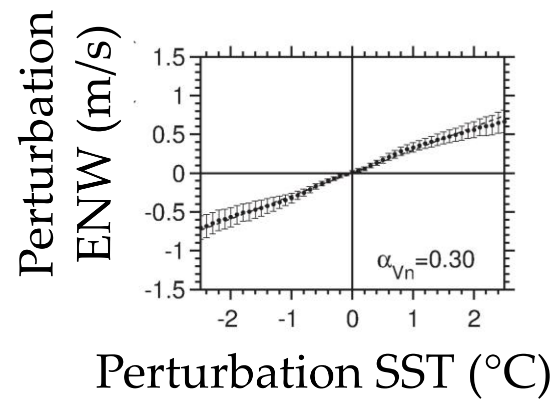


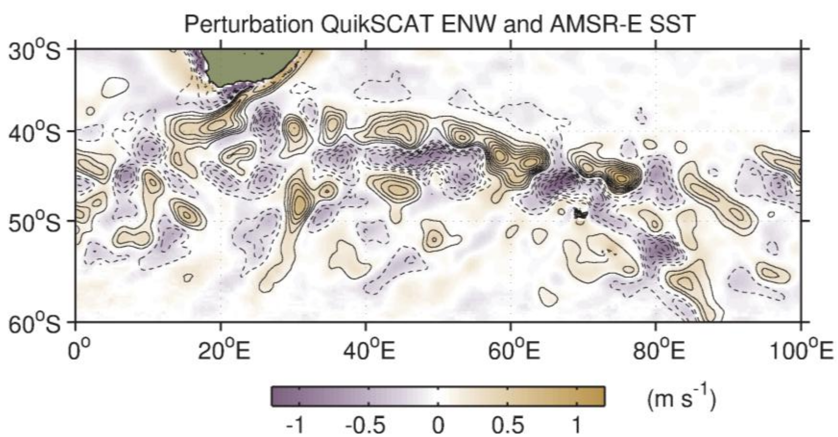
ρ=0.85

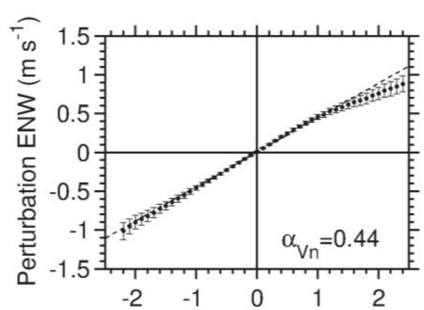
Satellite scalar wind speed response to SST

QuikSCAT 10-m neutral wind speed (colors); AMSR-E SST (contours)





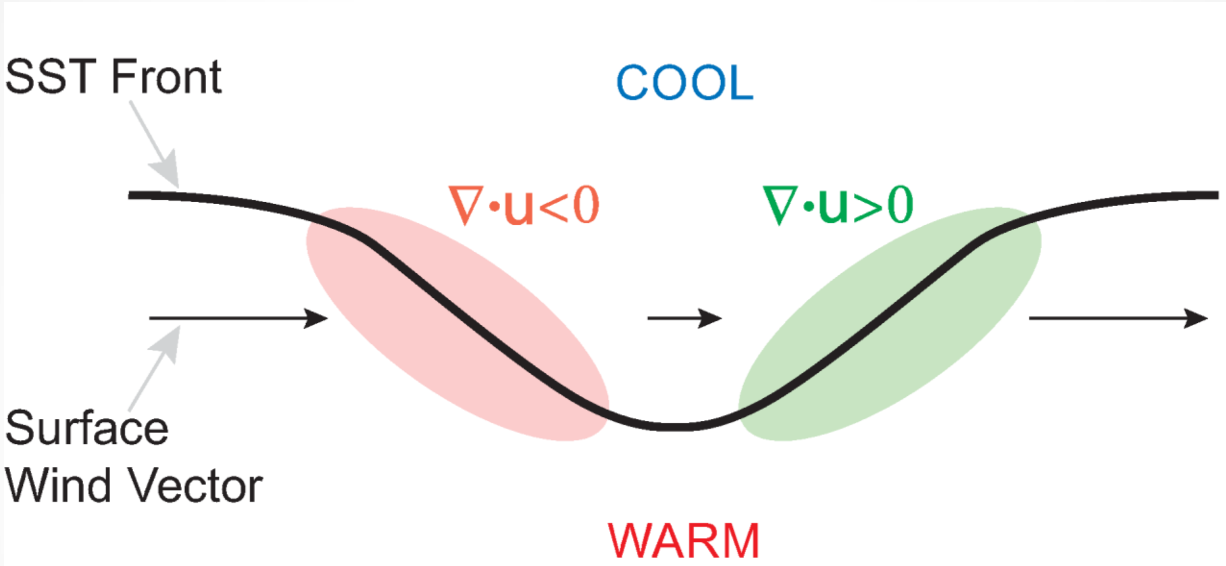




- 7-yr period June 2002-May 2009
- Surface winds and SST highly correlated on the oceanic mesoscale
- Surface wind speed is approximately related linearly with SST perturbations
- The slope of this approximate linear relationship is used to quantify the surface wind response to SST

Spatially high-pass filtered to remove variability with wavelengths longer than 12° longitude and 10° latitude

Surface divergence response to SST fronts

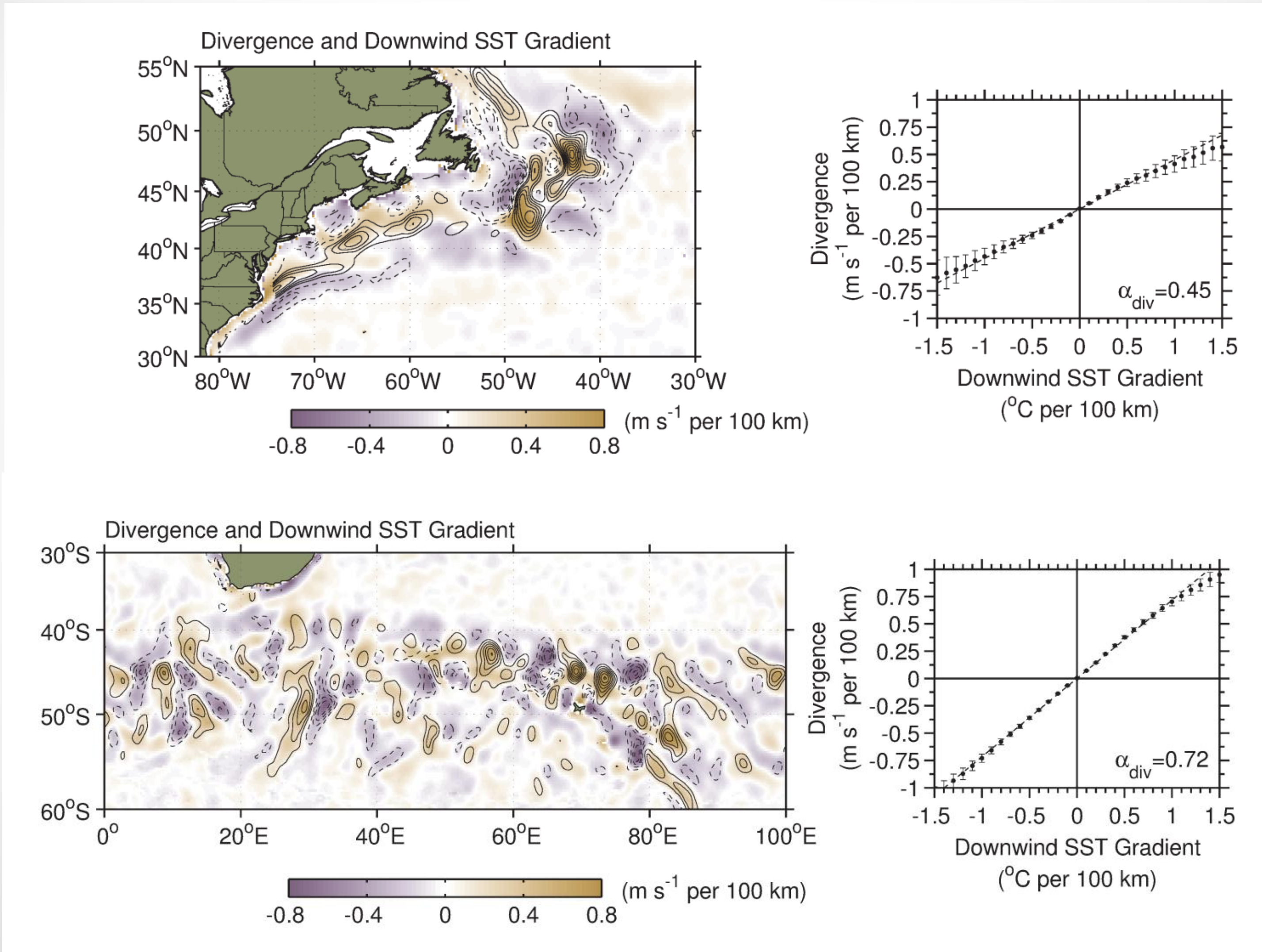


- Based just on the wind speed response to SST, the downwind speed gradient – and hence the divergence – should vary with the downwind SST gradient

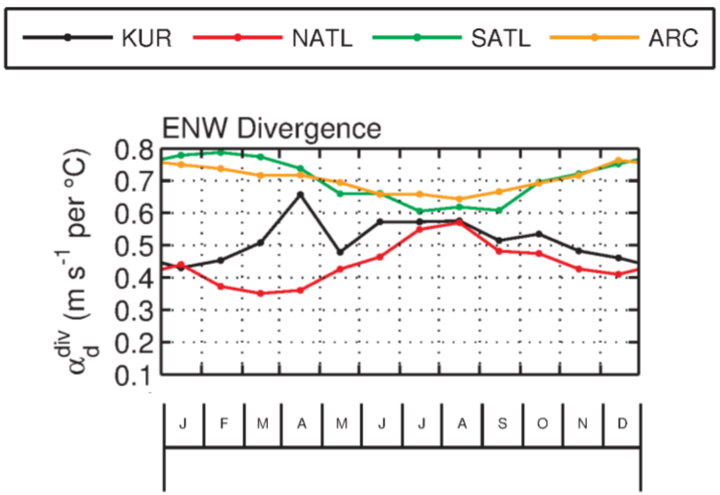
$$\underbrace{\nabla \cdot \boldsymbol{u}}_{\text{Divergence}} = \underbrace{\frac{\partial V}{\partial s}}_{\substack{\text{Downwind} \\ \text{Speed Gradient}}} + \underbrace{V\frac{\partial \psi}{\partial n}}_{\text{Diffluence}}$$

Divergence in the natural coordinate system

Divergence Response to Downwind SST Gradient



Temporal variability of divergence response to the downwind SST gradient



Summertime maximum divergence response to SST is a feature common over several mid-latitude regions

What is the momentum balance for near-surface flow adjustment to an SST front? Idealized 2-D LES simulations

Tom Kilpatrick et al., manuscript submitted to JCLI

Flow from cold to warm SST

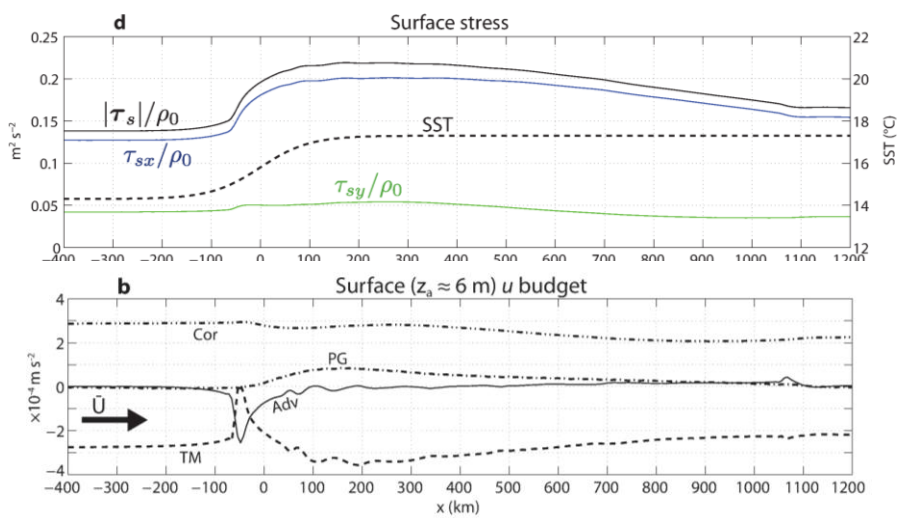


FIG. 8. Zonal momentum budget terms for the cold-to-warm case ($\overline{U}$=15 m s^{-1}) at two model levels: (a) upper MABL ($z \approx 450$ m); (b) surface ($z_a \approx 6$ m). The budget terms are labeled as in Eq. (11).

Flow from warm to cold SST

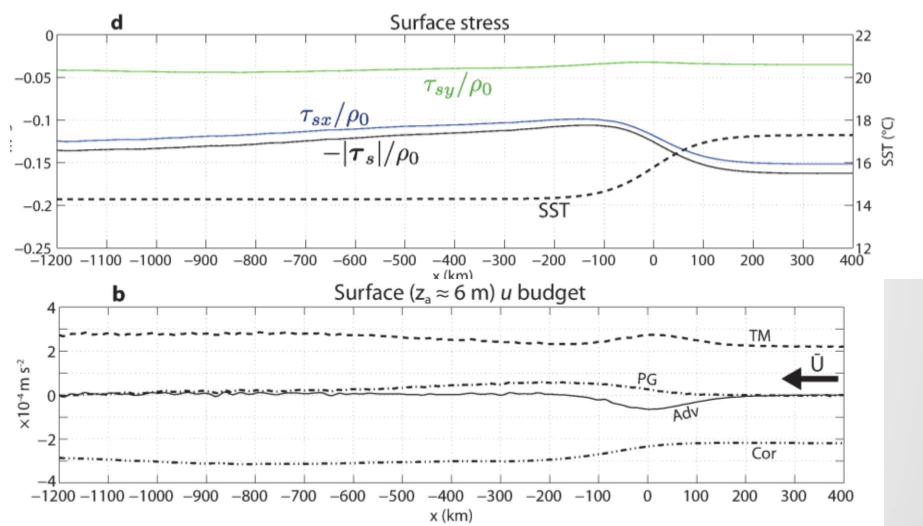
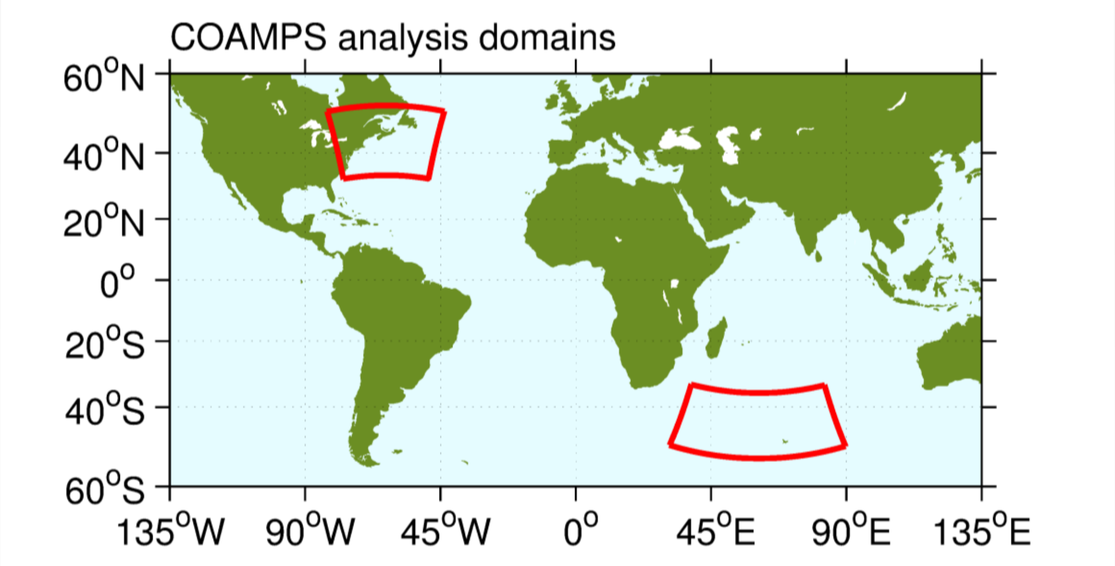


FIG. 11. As in Fig. 8, but for the warm-to-cold case ($\overline{U}$=−15 m s^{-1}).

- Upwind of front, surface flow is in an Ekman balance.
- Over front, turbulent stress divergence and horizontal advection are influenced strongly
- Downstream of front, SST-induced pressure gradients form; flow adjusts to a modified Ekman balance

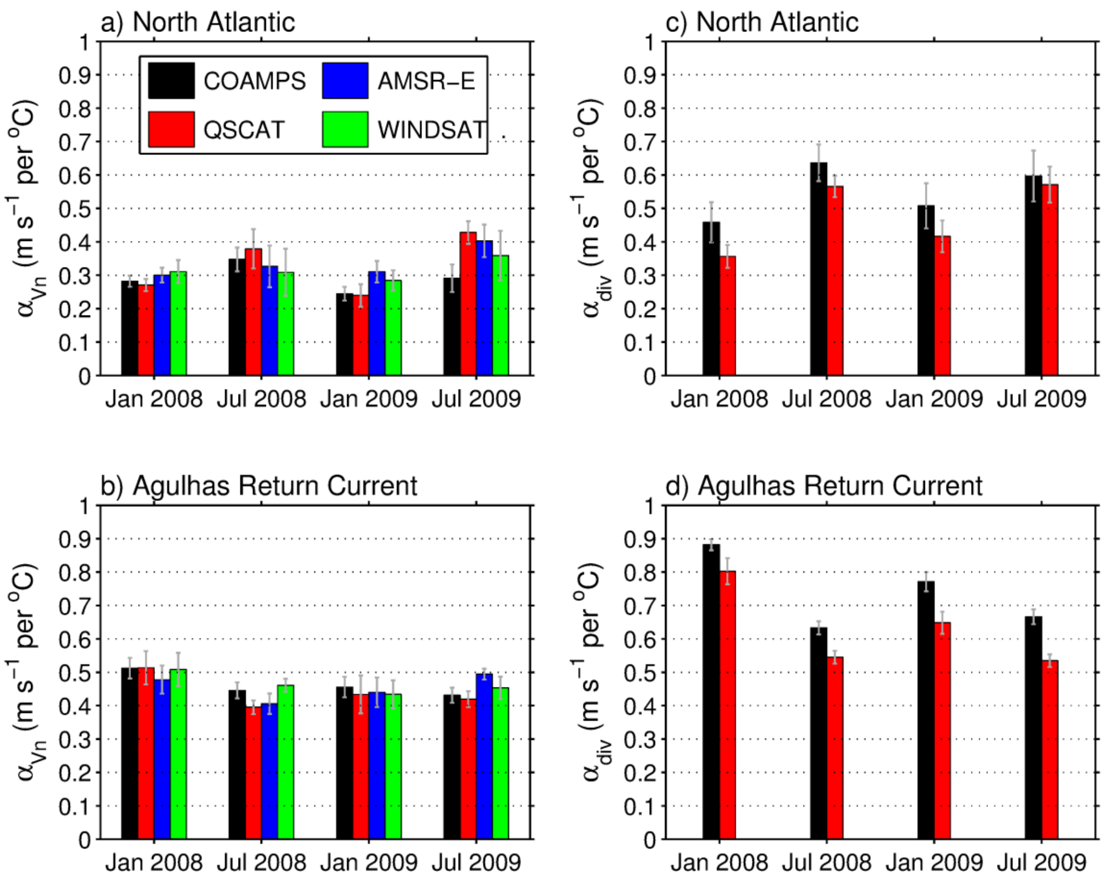
COAMPS atmospheric model simulations



Results are shown here from several month-long simulations of the COAMPS model

- Months of January and July, 2008 and 2009 shown here
- Atmosphere only simulation with prescribed SSTs (NCODA analyses)
- 50 vertical levels, with 20 below 1000-m
- Lowest grid point at 10 meter height above surface analyzed
- Doubly nested domain; inner nest analyzed; grid spacing of 9-km
- Non-hydrostatic
- 24 hour forecasts initialized every 12 hours; analyze forecast hours 7-18
- Lateral boundaries forced with operational NOGAPS global analyses

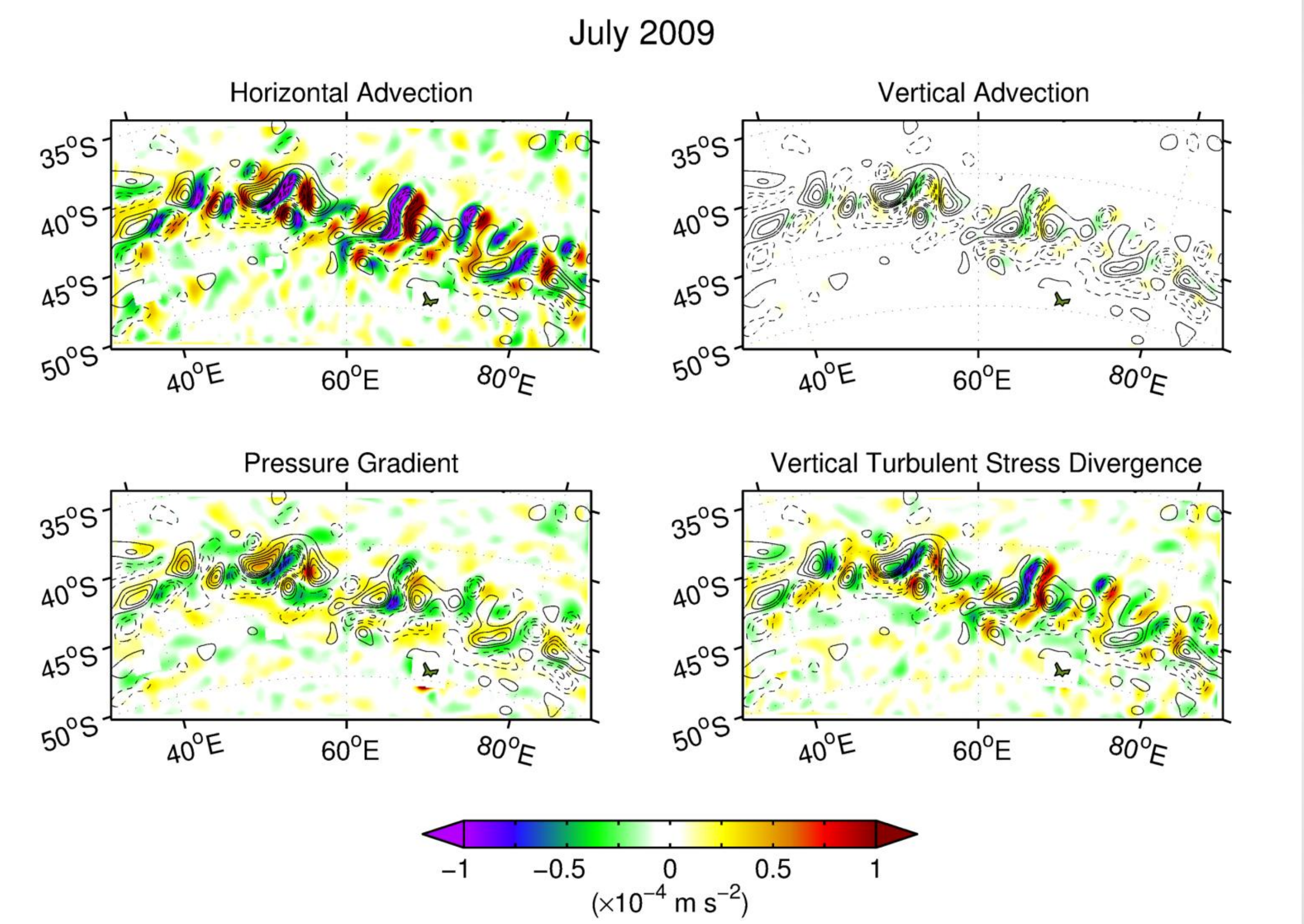
Model-satellite comparison of linear responses of 10-m neutral wind speed and divergence to SST



Model reproduces the wind response to SST reasonably well

Southern Ocean

Advection most important term in surface momentum balance over mid-latitudes

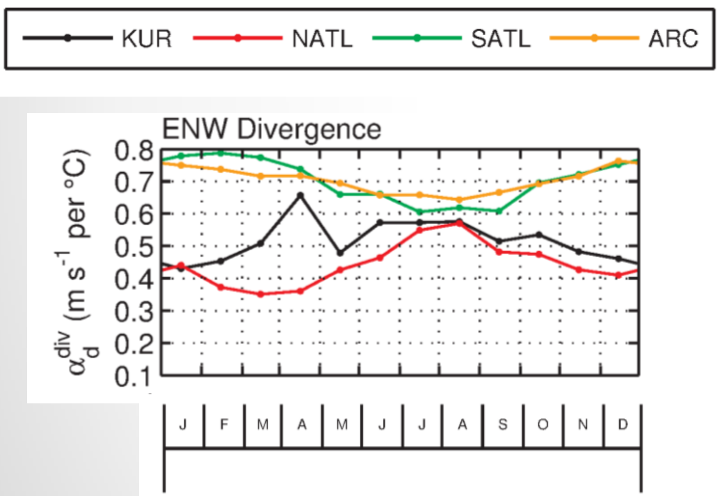


$$\left(V\frac{\partial V}{\partial s}\right)' = \left(-\frac{1}{\rho}\frac{\partial p}{\partial s}\right)' + (F\cdot\hat{s})'$$

Inverse relationship between divergence response to SST and surface wind speed

$$\left(\frac{\partial V}{\partial s}\right)' \approx \frac{1}{\widetilde{V}}\left[\left(-\frac{1}{\rho}\frac{\partial p}{\partial s}\right)' + (F\cdot\hat{s})'\right].$$

Model simulations indicate this balance holds for the small-scale surface wind speed

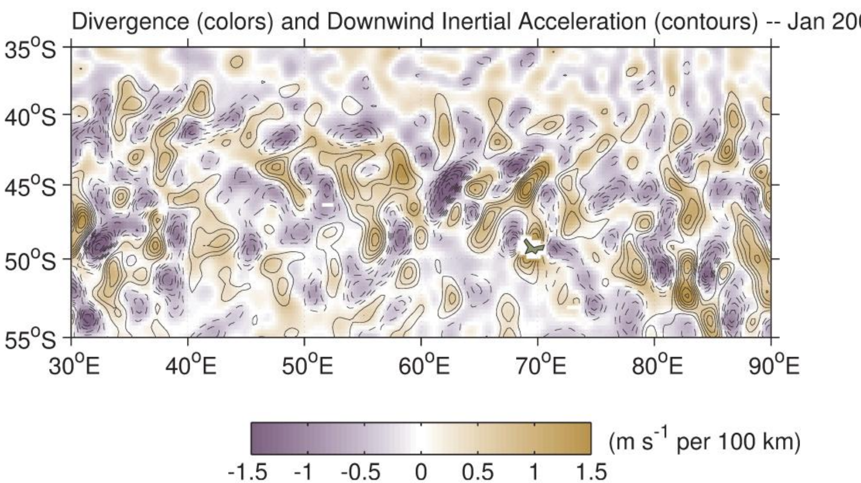


$$\underbrace{\nabla\cdot\boldsymbol{u}}_{\text{Divergence}} = \underbrace{\frac{\partial V}{\partial s}}_{\text{Downwind Speed Gradient}} + \underbrace{V\frac{\partial \psi}{\partial n}}_{\text{Diffluence}}$$

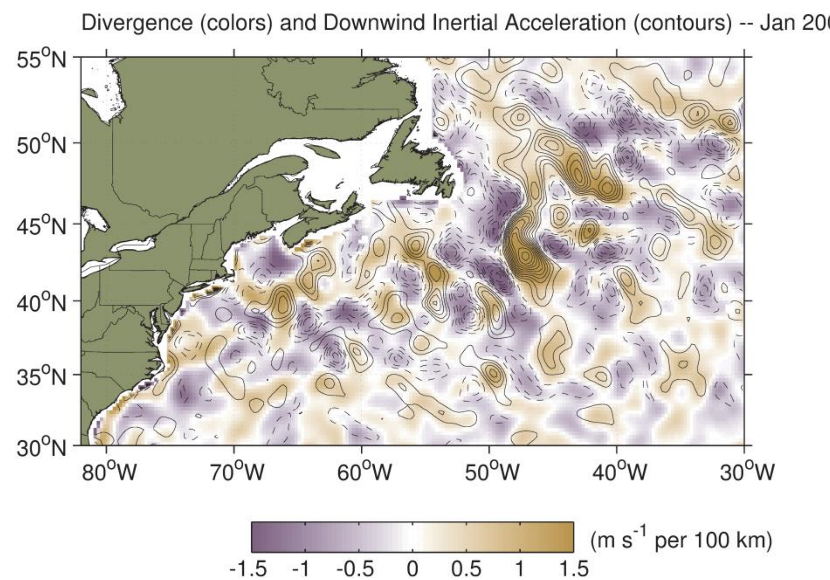
Summertime maximum in divergence response to the downwind SST gradient is due to summertime wind speed minimum

Divergence (colors) and downwind advective (contours) estimated from QuikSCAT during January 2008

Southern Ocean

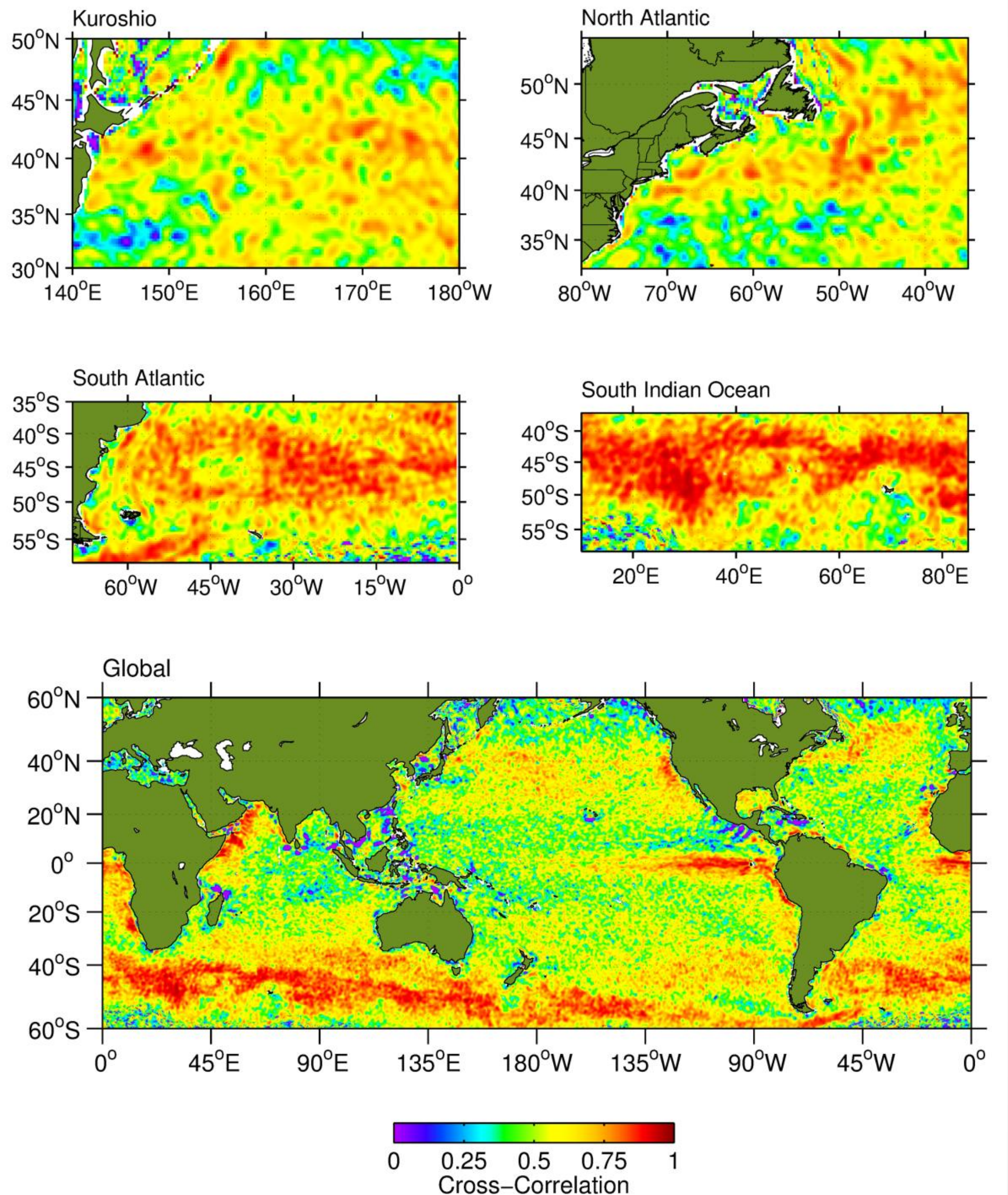


North Atlantic



- Divergence and downwind advection are highly correlated
- Different from previous explanations regarding divergence variability over mid-latitudes (i.e., Minobe et al., 2008)

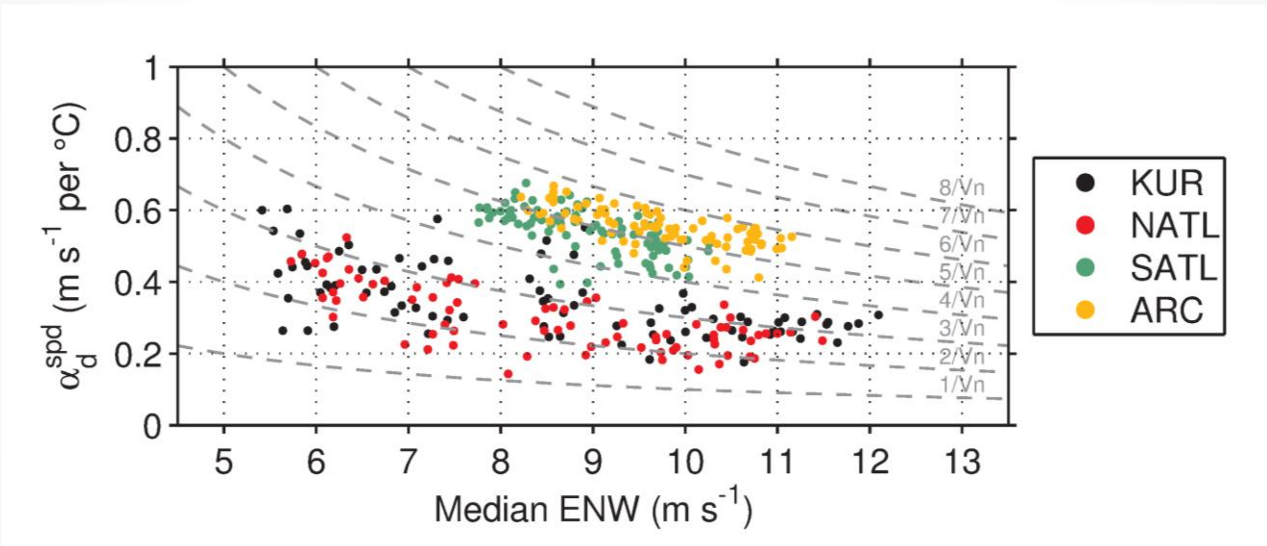
Correlation between downwind advection and divergence from QuikSCAT



- Correlations are highest in strong SST frontal regions
- This indicates that the pressure gradient and turbulent stress divergence responses to SST are unbalanced in these regions

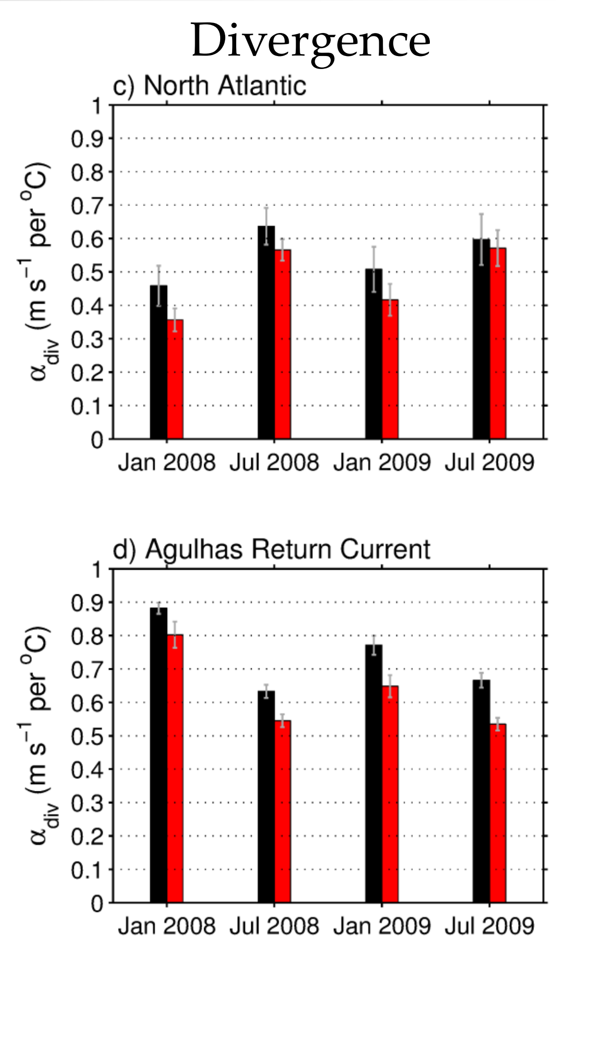
Inverse relationship between divergence response to SST and large-scale surface wind speed from satellite wind and SST fields

Coupling coefficient between divergence and downwind SST gradient (m/s per deg C)

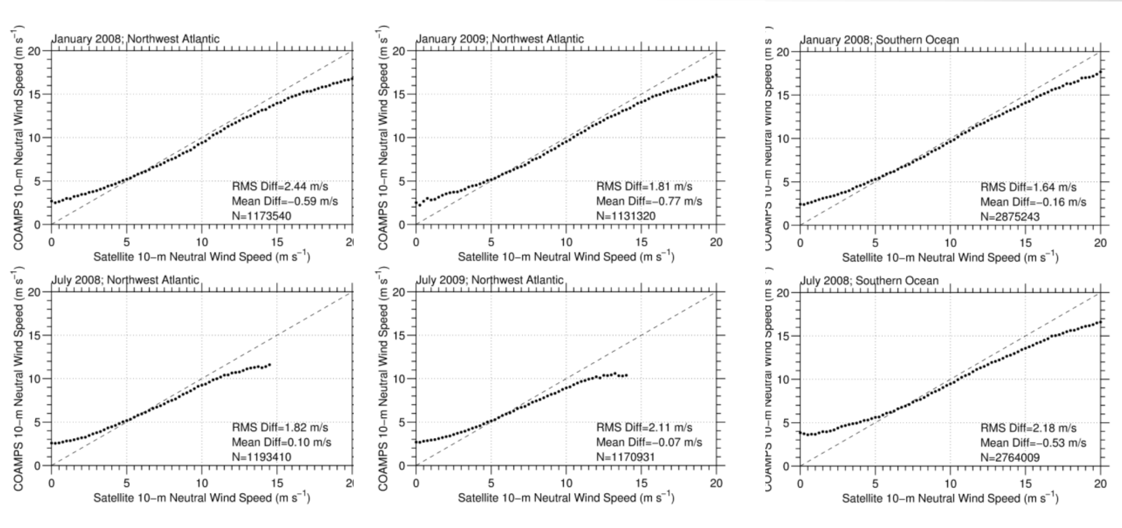


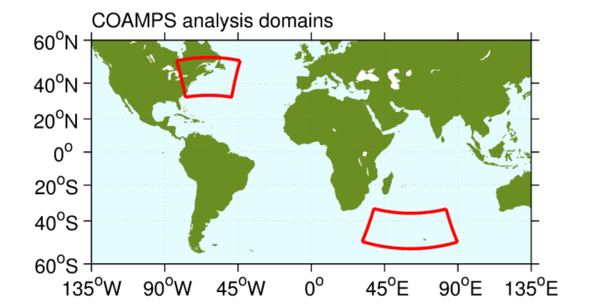
Divergence response to SST strongest when the large-scale wind speed is weakest and vice versa

COAMPS-satellite comparison of linear responses of 10-m neutral wind speed and divergence to SST



Overestimate of COAMPS divergence response to SST compared to satellite may be partly related to the low wind speed bias (relative to satellite)

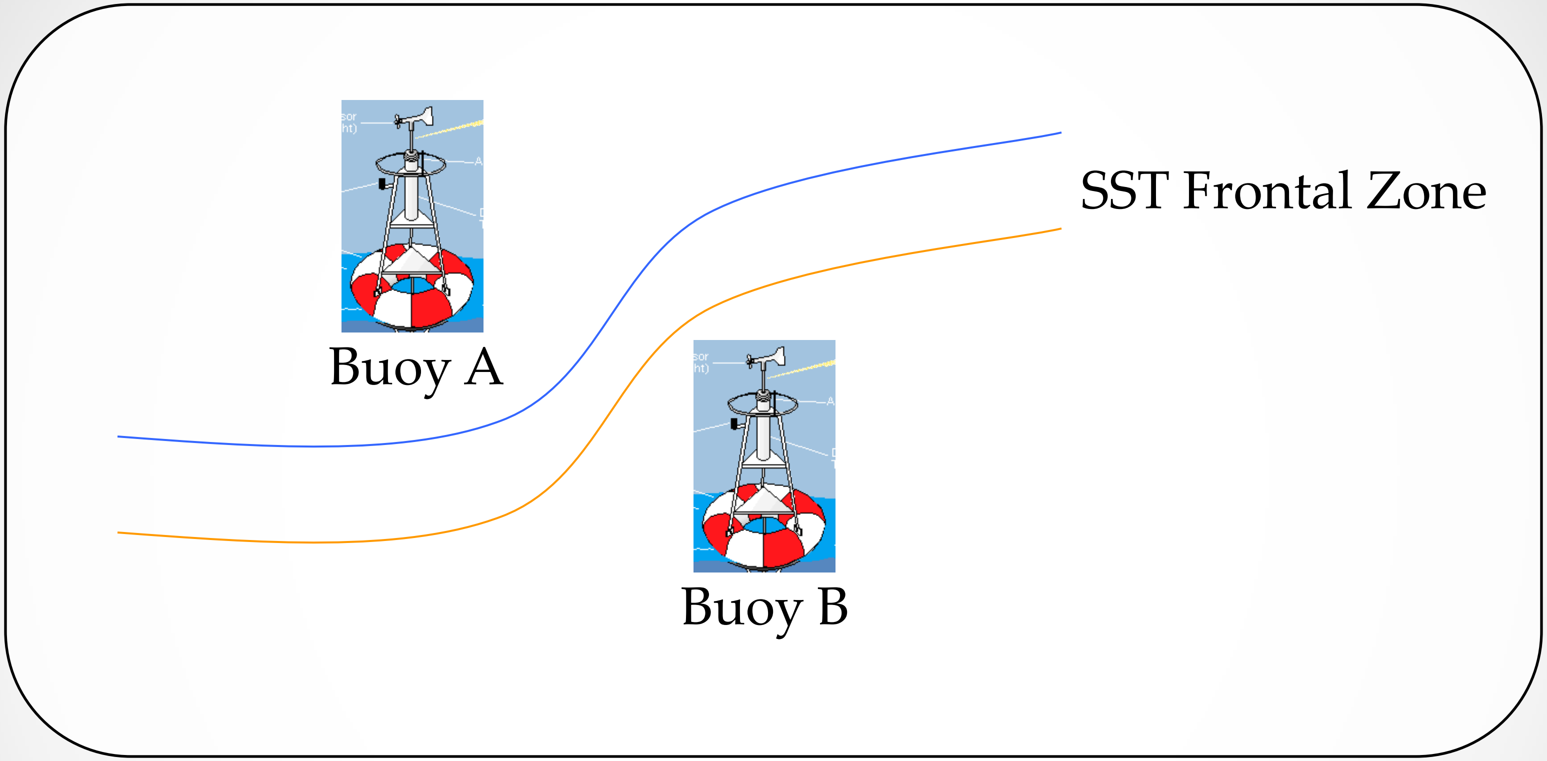




Summary

- *Horizontal advection is important* to accurately describe the surface wind speed and divergence responses to mesoscale SST perturbations over mid-latitude oceans
    - Ekman dynamics do not account for the surface divergence variability near mid-latitude SST fronts
- The downwind advective acceleration forms from an imbalance between the downwind pressure gradient and turbulent stress divergence
    - Significant regional differences in the behavior of the turbulent stress divergence:
        - Over much of the Gulf Stream region, the turbulent stress divergence opposes the pressure gradient;
        - Over the ACC, the turbulent stress divergence acts in concert with the pressure gradient to accelerate the flow
- Downwind speed gradient inversely proportional to the large-scale surface wind speed
    - Responsible for summertime maximum in downwind speed gradient and divergence responses to SST

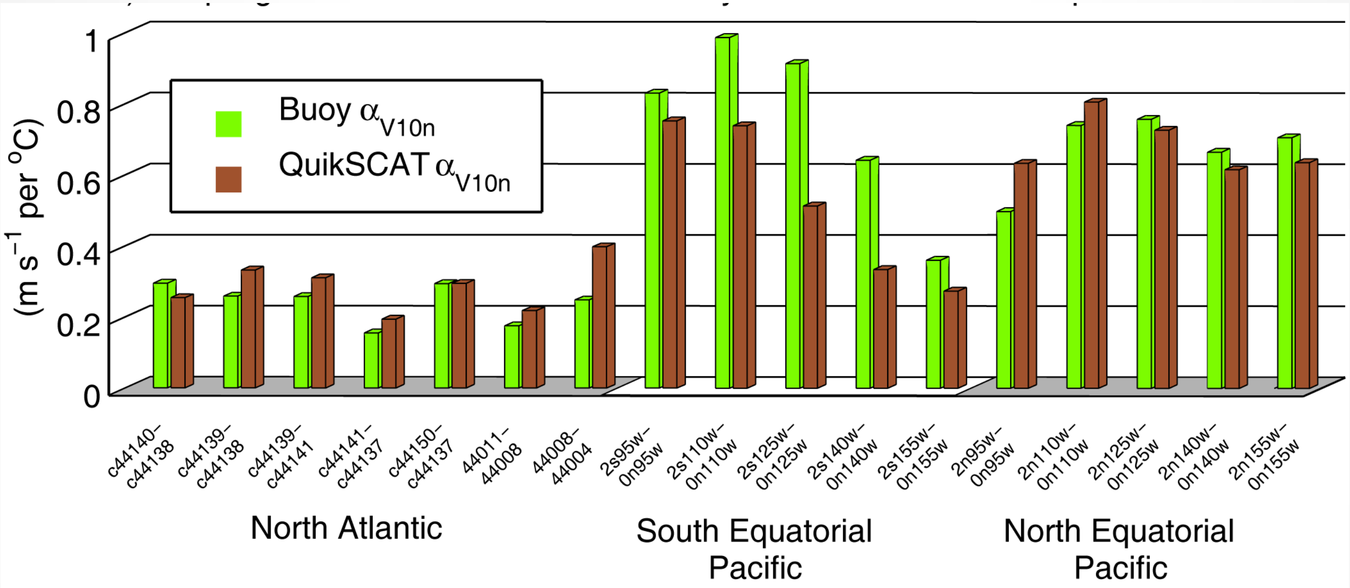
Evaluating ENW response to SST derived from QuikSCAT/AMSR-E



Test the hypothesis that the wind speed difference $V_{10B}-V_{10A}=\delta V_{10}$ depends on the SST difference $T_{SB}-T_{SA}=\delta T_S$

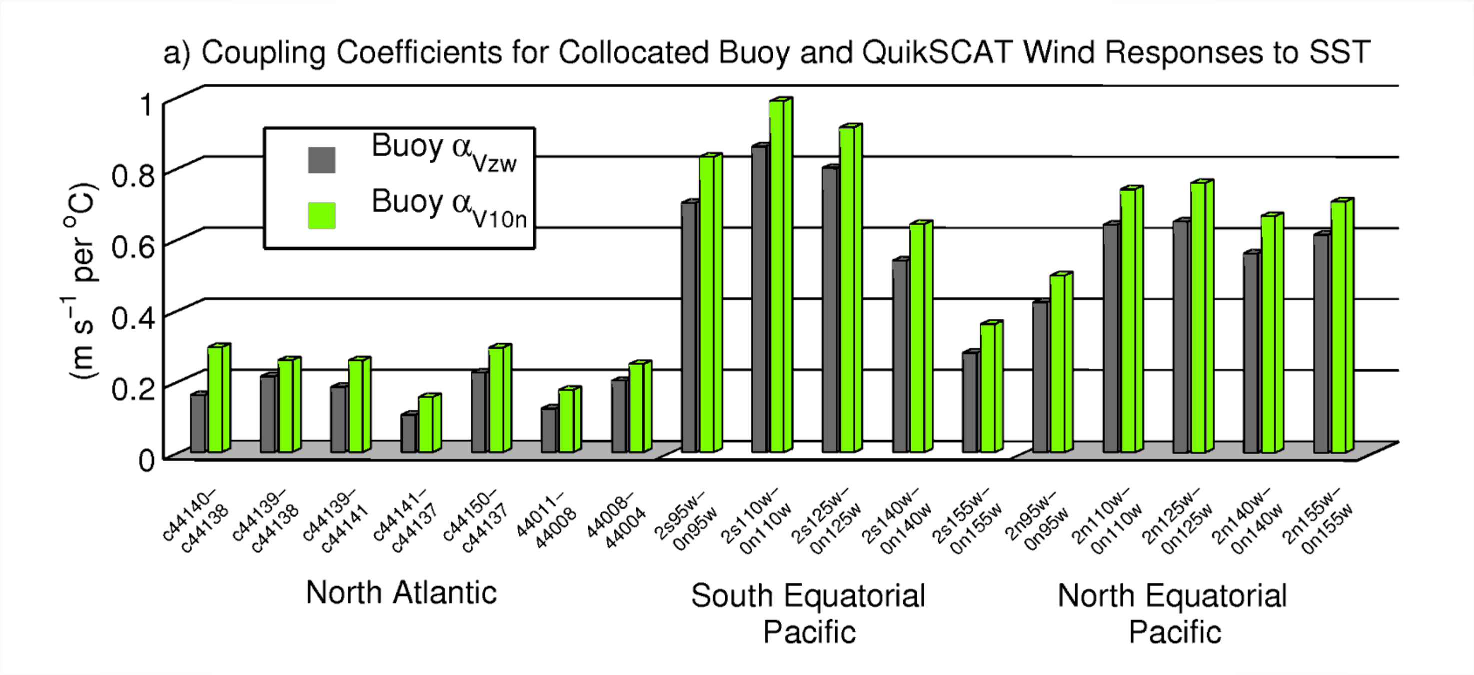
O'Neill, L., 2012: Wind Speed and Stability Effects on Coupling between Surface Wind Stress and SST Observed from Buoys and Satellite. *J. Climate*, **25**, 1544-1569

Comparison between buoy and satellite ENW responses to SST from 7 years of data



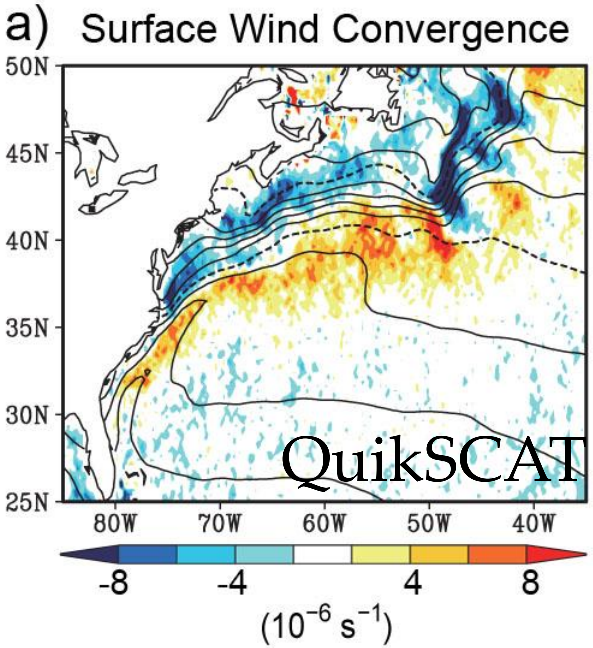
- QuikSCAT ENW and AMSR-E SST
- Buoys from NDBC, TAO, and CDFO
- Response of 10-m ENW from QuikSCAT similar for most buoy pairs, although biased low over the south equatorial Pacific.

Comparison of buoy actual wind speed and ENW responses to SST



- Response of ENW V10n to SST is only about 10-30% larger than the response of the actual wind speed Vzw to SST

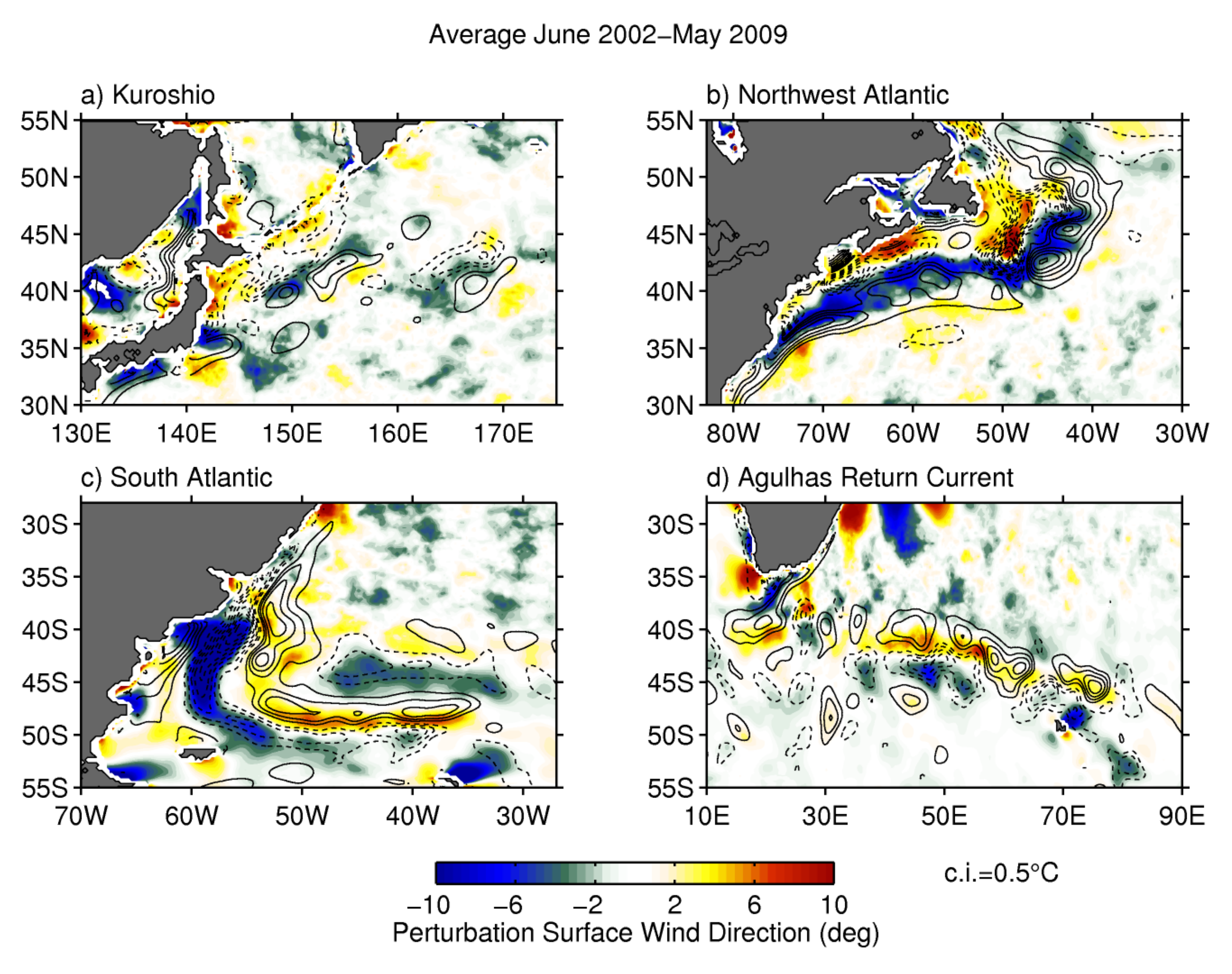
- Buoy ENW response to SST is caused mainly by the response of the actual near-surface wind speed to SST rather than near-surface stratification



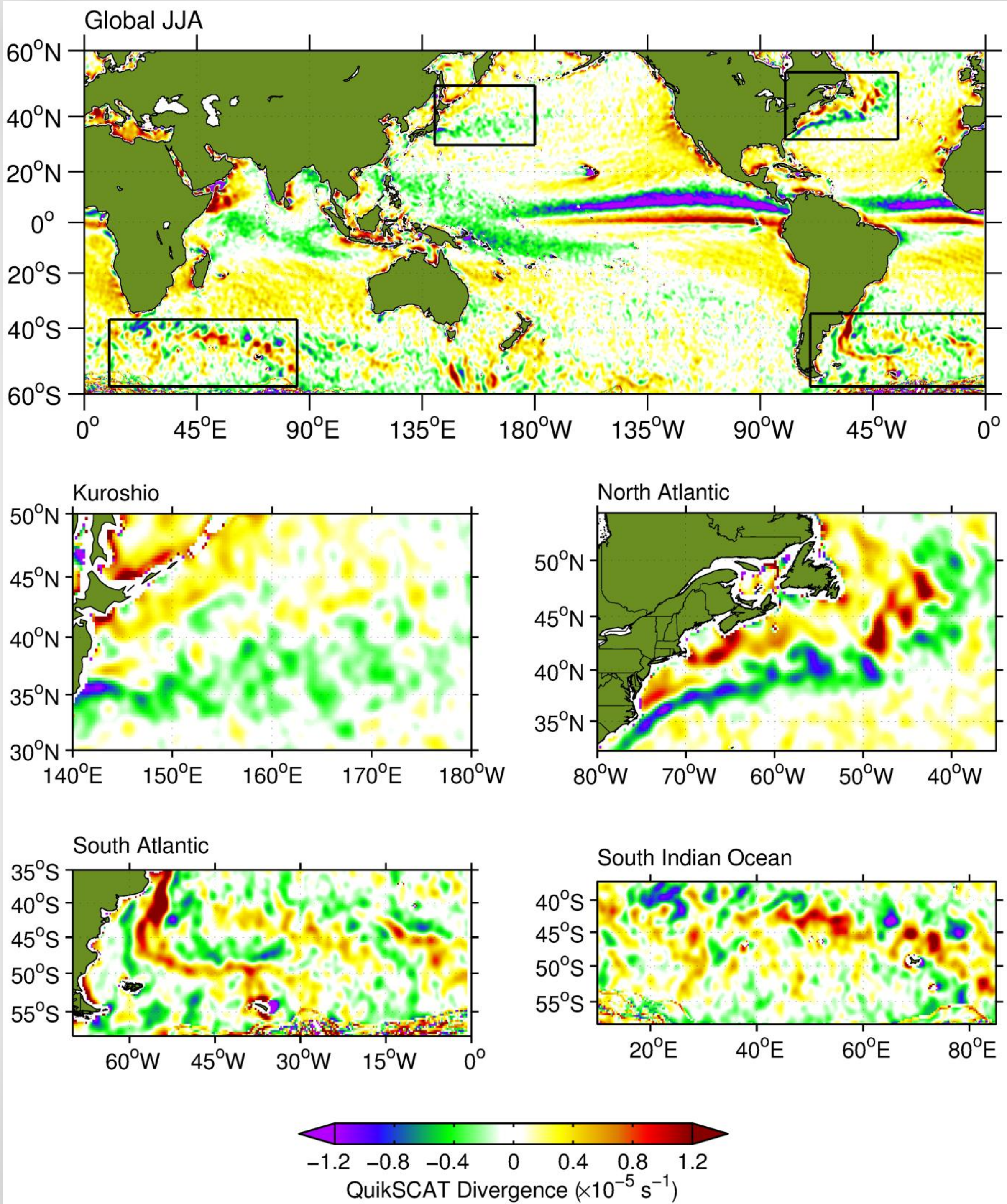
Minobe et al. (2008; Nature)

SST-induced surface convergence and divergence aloft influences clouds and precipitation

QuikSCAT wind direction



June-July-August 2002-2009



December-
January-
February
2002-2009