

Coupling ocean currents and waves with wind stress over the Gulf Stream

Mark A. Bourassa and Qi Shi

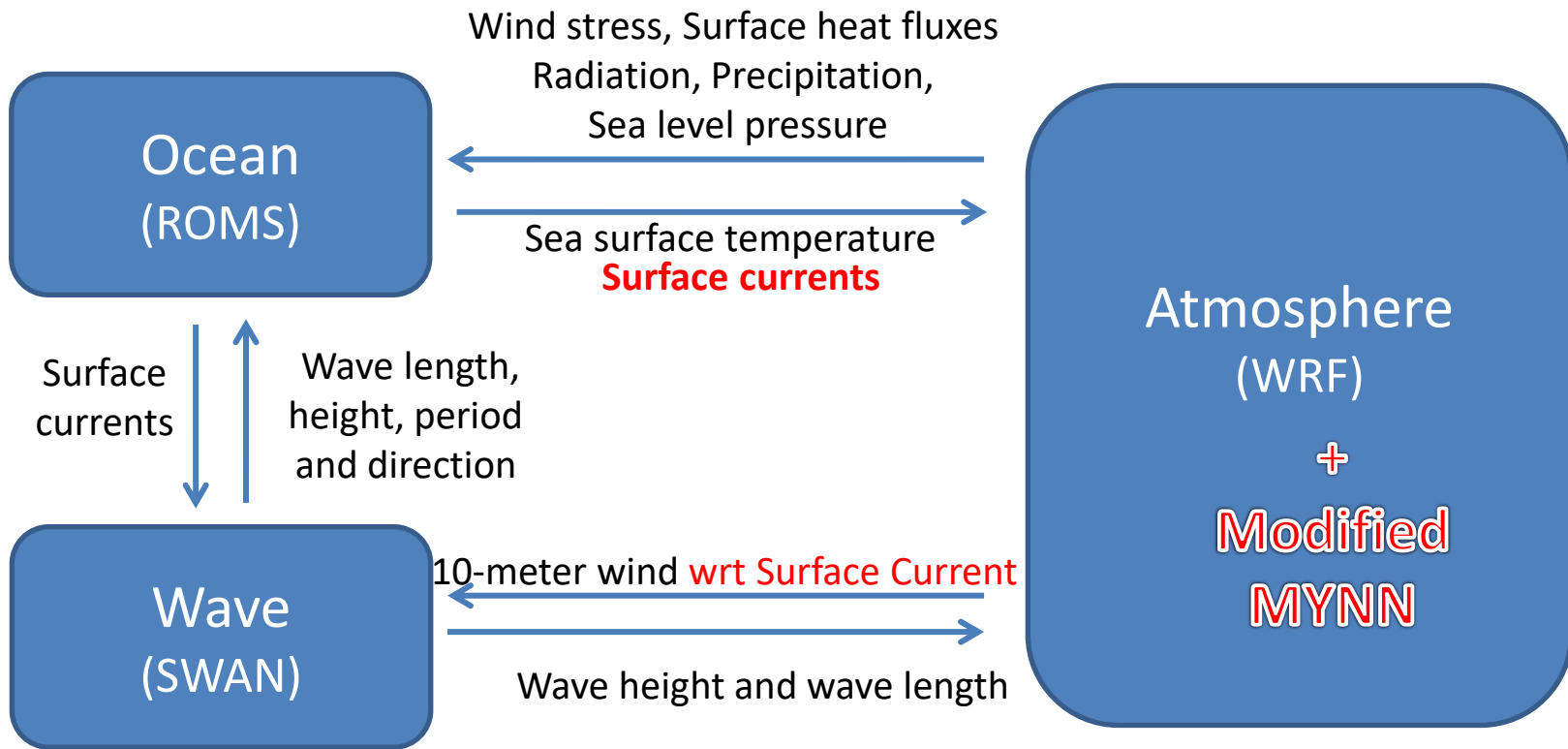
Center for Ocean-Atmospheric Prediction Studies
and Department of Earth, Ocean and Atmospheric Science, Florida
State University



Why Do We Want Two-Way Coupling?

- Ocean and atmospheric models are advancing to the resolutions where two-way coupling is critical.
 - They are doing so to improve model accuracy.
 - Small scale processes greatly enhance the vertical transport of energy, materials in the ocean (salt, nutrients, gasses) and the atmosphere (water vapor)
 - These changes should impact
 - The global and regional energy and water cycles (weather)
 - Ocean mixed layer temperature and depth
 - CO₂ budgets of the ocean and atmosphere
 - Nutrient content for marine organisms

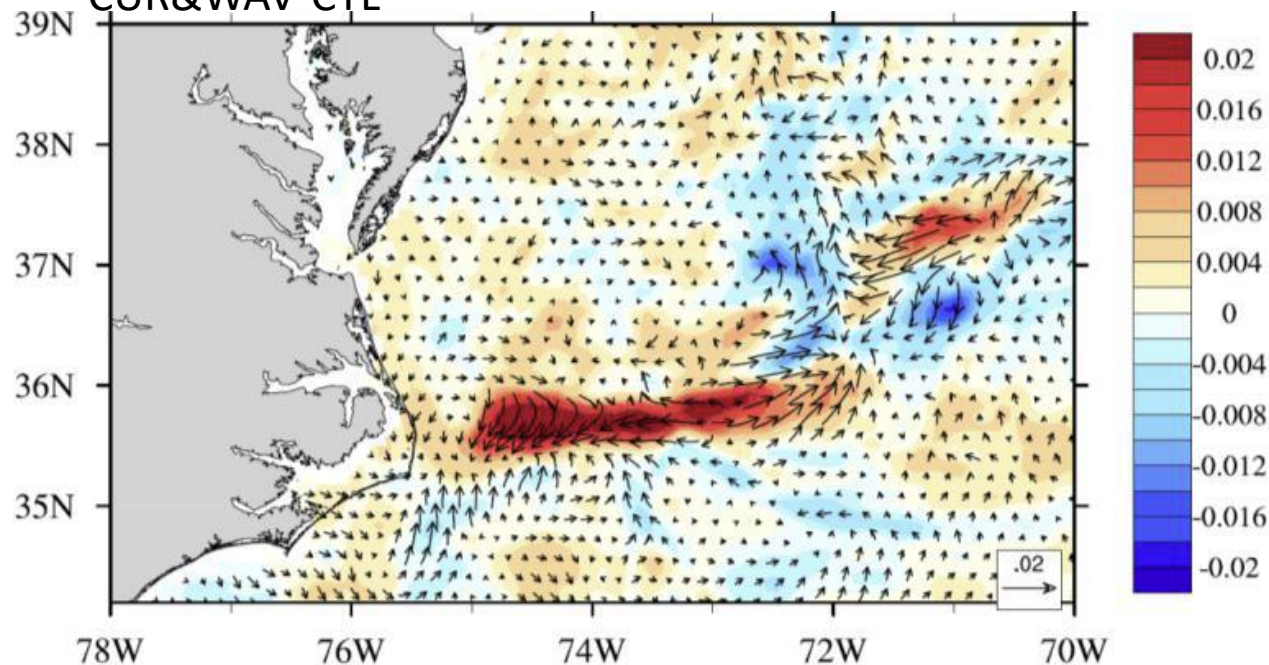
Ocean-Atmosphere-Wave Modeling



- Stress is based on wind shear (wind relative to the current)
- Stress is dependent on sea state via COARE's option for Taylor and Yelland's roughness length PLUS the roughness of a smooth surface

Changes in October Wind Stress Magnitude Relative to model with stress independent of waves and currents

CUR&WAV-CTL

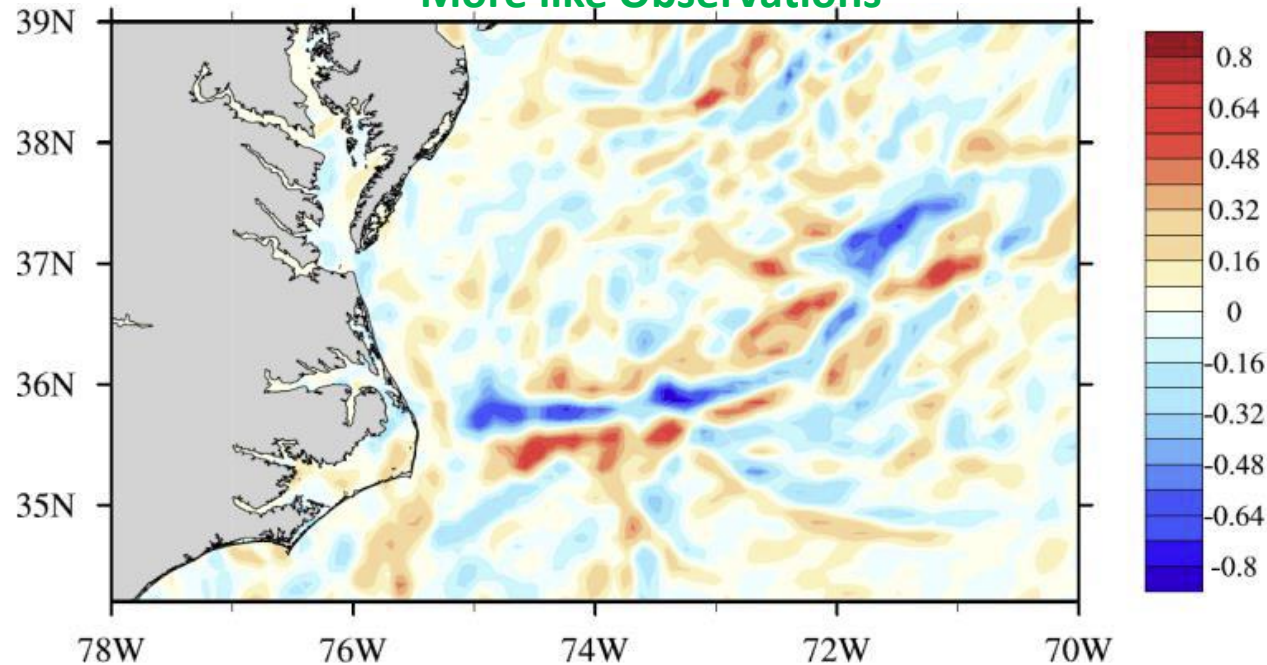


- The sea state and current dependent model has stronger stress gradients over the Gulf Stream
- Making the stress dependent on currents and sea state greatly strengthens these gradients, and currents are a much more important consideration
- These stress magnitudes seem to be consistent with ASCAT observations

Changes in October Ocean Ekman Pumping

CUR&WAV-CTL

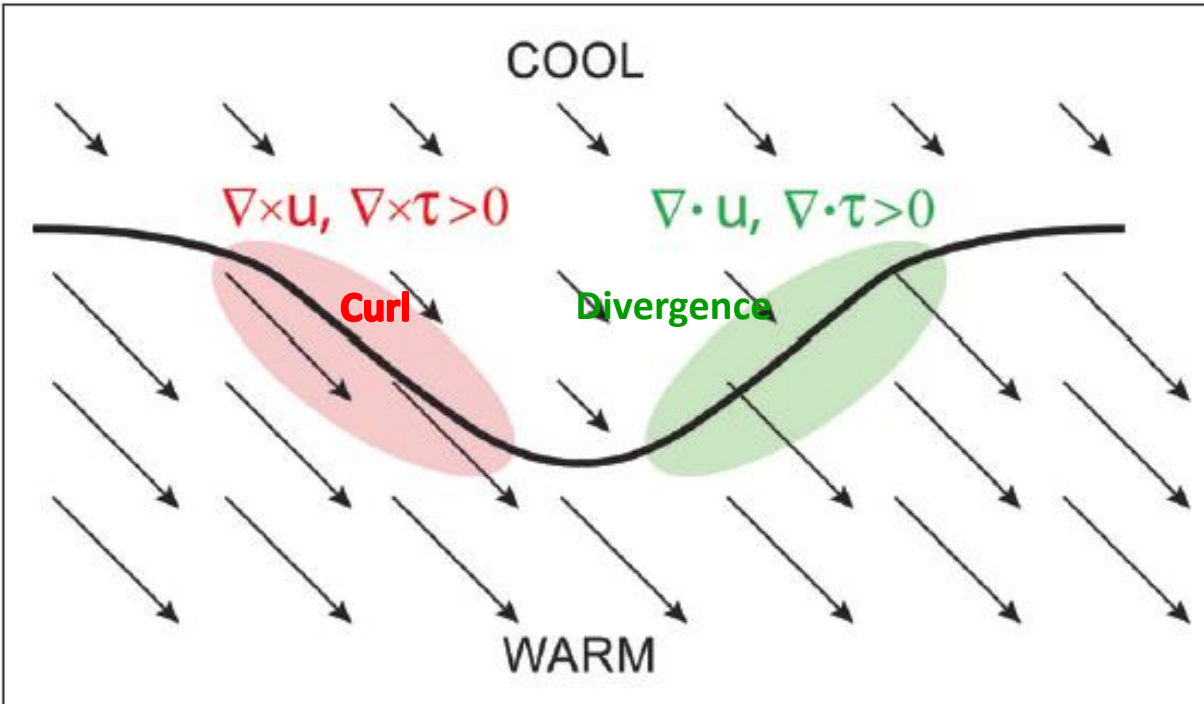
More like Observations



The influence of currents, in a two-way coupled model, were needed to greatly strengthen the positive and negative current seen on the sides of a major current.

- When both waves and currents are considered, the heat budget is dominated by vertical motion and entrainment at the bottom of the mixed layer.
 - Curl of stress is greater (more like observations) over SST gradients and current gradients

Sensitivity of the wind stress curl to the crosswind SST gradient



- Currents have already been shown to have a large impact on the pattern of stresses
- They also influence the pattern of SSTs (not shown in this version of the presentation)
- The coupling coefficient will be shown to be highly dependent on the physics considered in the parameterization of stress.

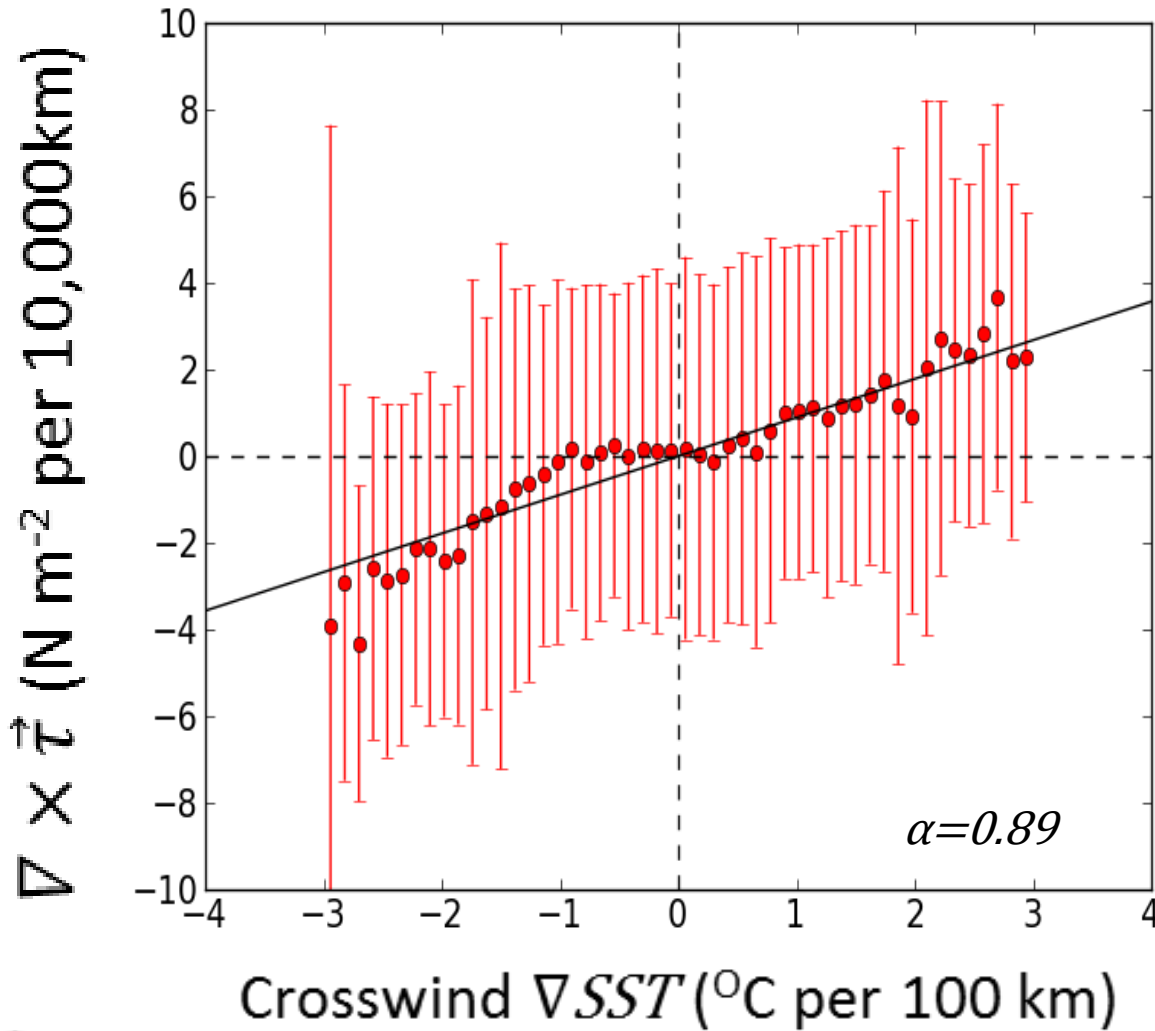
(Chelton et al., 2007)

Coupling coefficient

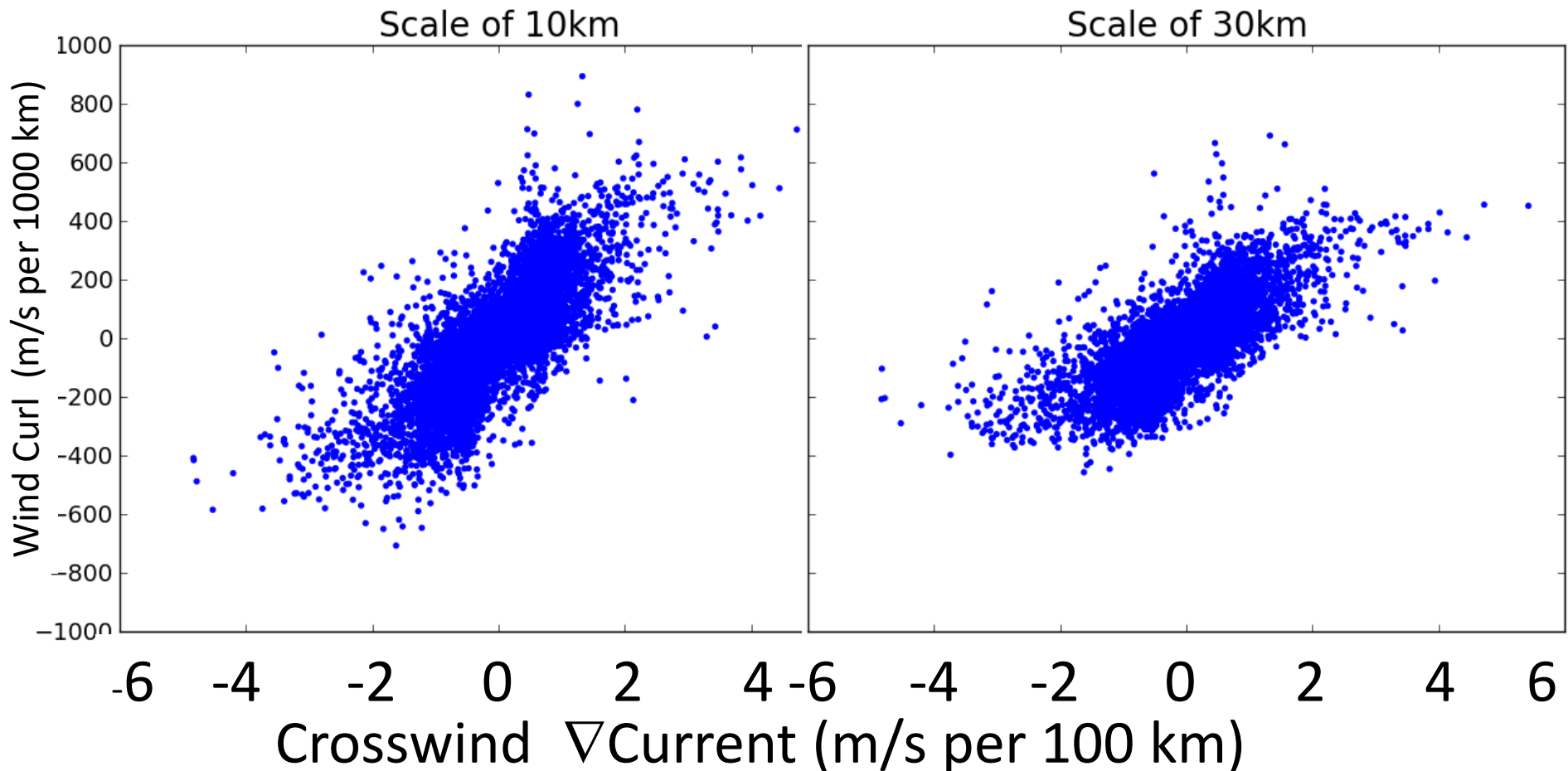
$$\alpha = \frac{\nabla \times \vec{\tau}}{\nabla SST \times \frac{\vec{\tau}}{|\vec{\tau}|}}$$

Coupling Coefficient

The coupling coefficient for model data is highly dependent on the stress parameterization.



Modeled Wind Curl vs Current Gradient (as a function of spatial scale)



- Wind Curl (y) vs. Gradient of current in the direction perpendicular the wind vector (x)

Summary

- The modeled curl of wind (and curl of stress) are sensitive gradients of SST and current, in the direction perpendicular to the wind.
 - This curl is a key player in coupling the ocean and atmosphere
 - Impacting vertical and horizontal motions
 - Impacting the local heat budget
- This sensitivity of the curl of wind stress is much greater to gradients of currents than to gradients of SST

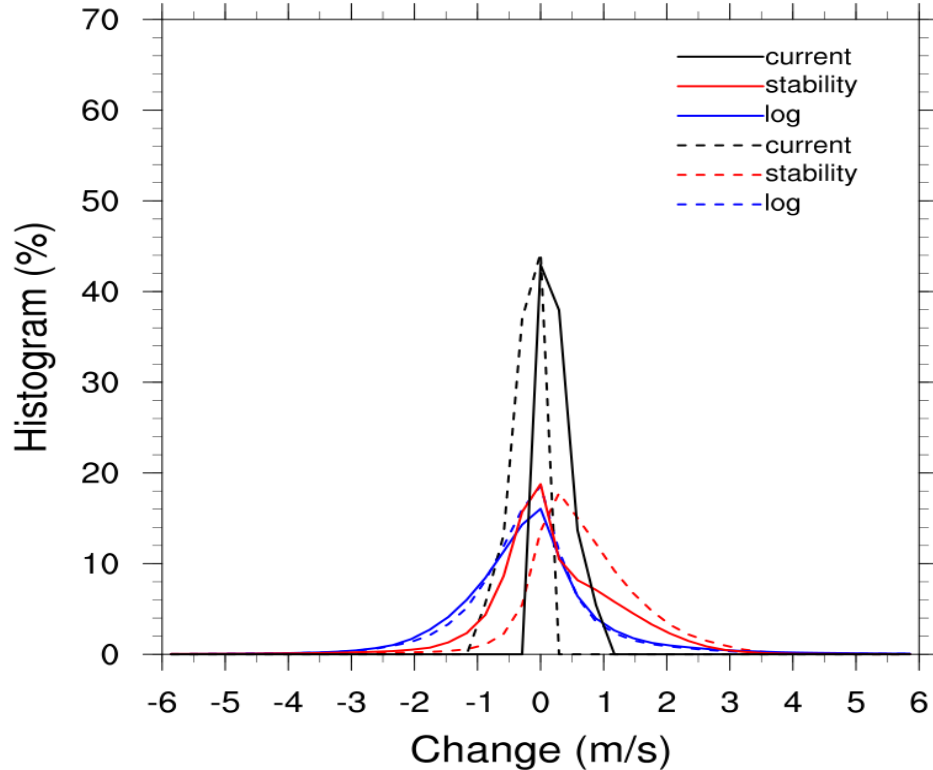
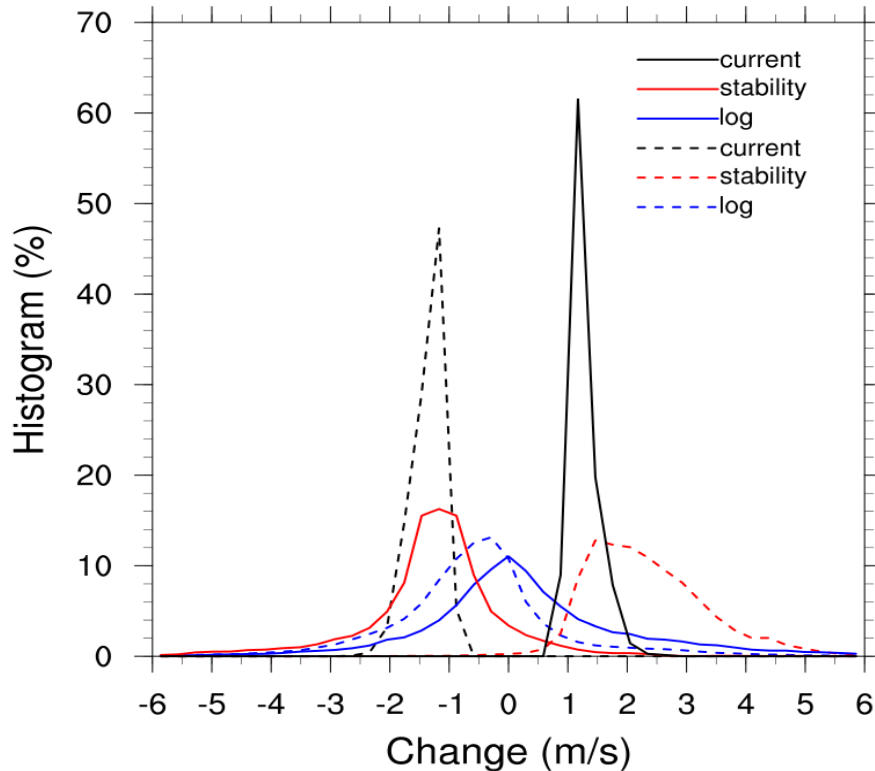
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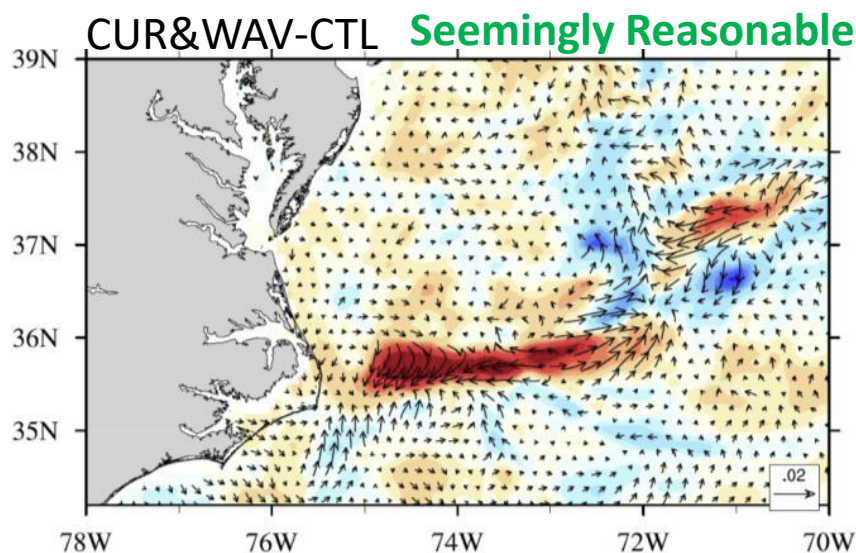
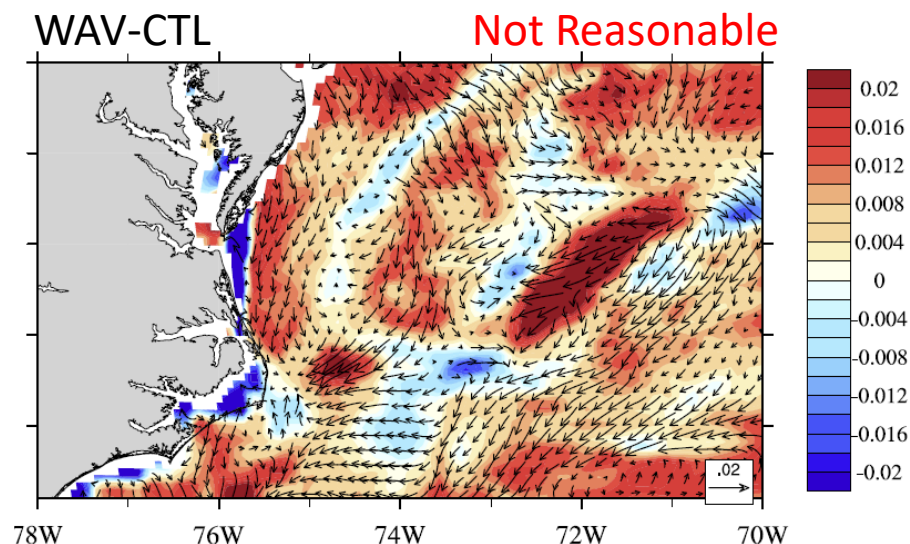
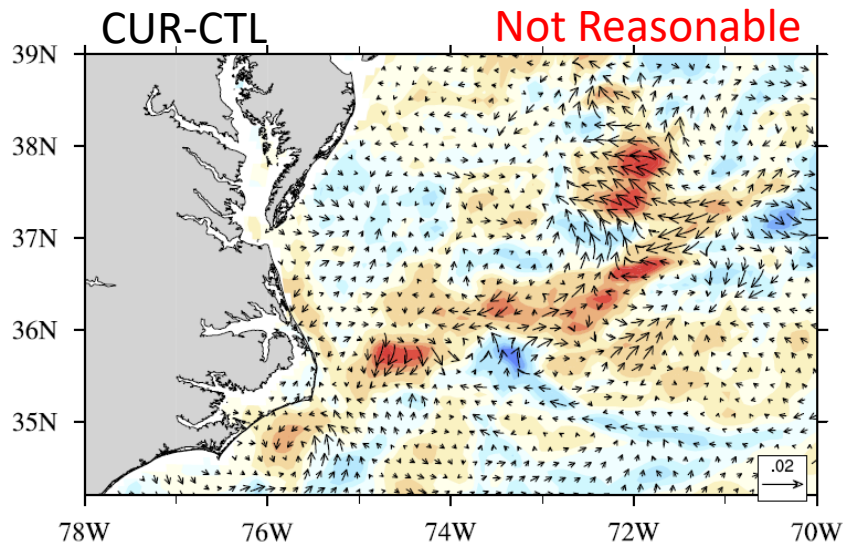


Surface Wind Response



- Histograms of the difference of current, stability and log profile terms in the log-wind equation between CUR_WAV and WAVE experiments. The statistics are computed over strong-current ($U_s > 1$ m/s; left) and weak-current ($U_s < 1$ m/s; right) regions. Dashed lines are associated with negative changes in currents.

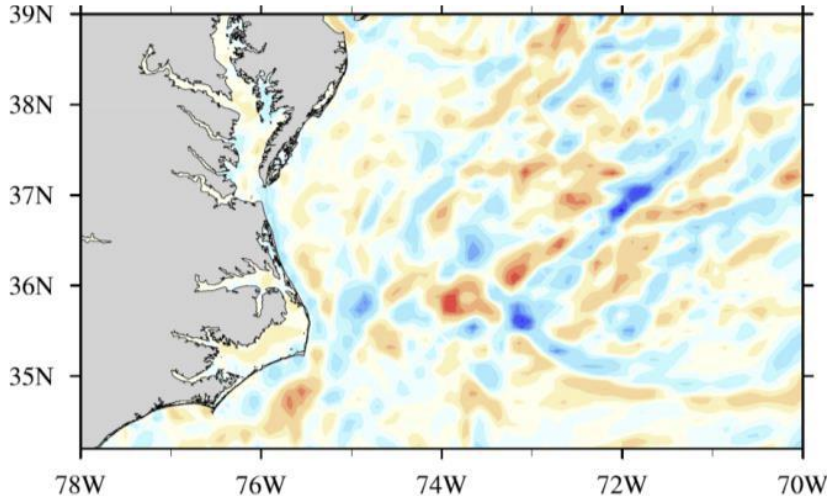
Changes in October Wind Stress Magnitude Relative to model with stress independent of waves and currents



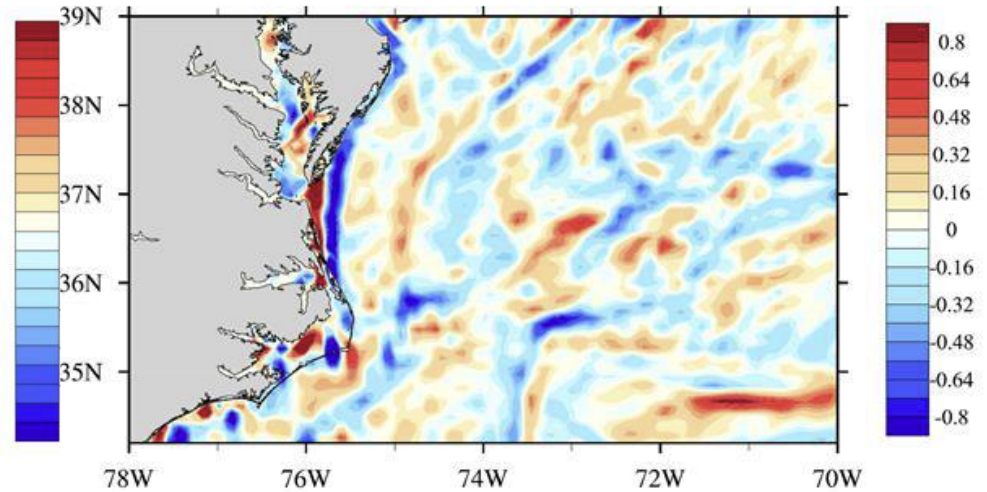
- Currents alone tend to reduce EKE production beyond reasonable values
- Waves alone tend to increase stress
 - But not as needed
- Waves together with currents are not a linear sum of the two
 - Good for ocean EKE
 - Surface currents are critically important

Changes in October Ocean Ekman Pumping

CUR-CTL

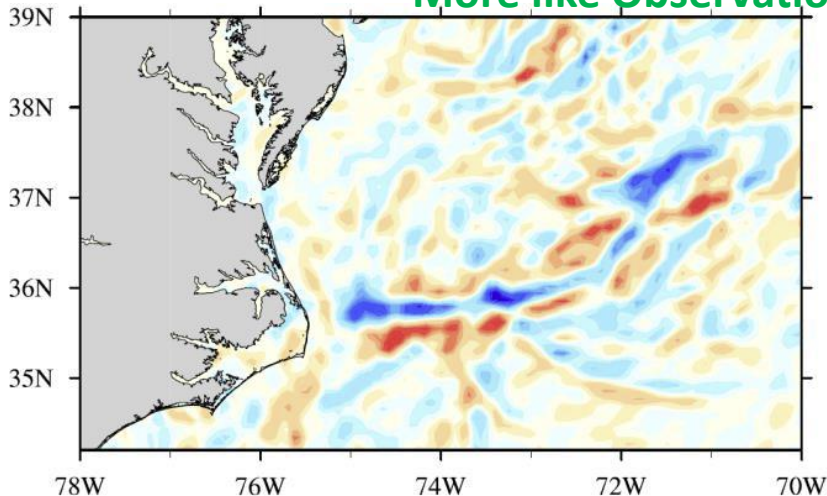


WAV-CTL



CUR&WAV-CTL

More like Observations



- In the upper two images the mixed layer heat budget is dominated by horizontal transport processes.
- In the bottom case, the heat budget is dominated by vertical motion
 - Curl of stress is greater over SST gradients (more like observations)