Breaking Down the Effects of Current Feedback Coupling onto the Atmospheric Boundary Layer

Authors: Kamran Chowdhury[1,2] (kac24b@fsu.edu), Mark Bourassa[1,2], Marco Larrañaga[1], Jiahua Zhou[1]
Affiliations: [1]COAPS, Florida State University; [2]EOAS, Florida State University

Introduction & Motivation

Thermal feedback (TFB) is known to induce multiple atmospheric boundary layer (ABL) responses, via over a dozen hypothesized mechanisms. Especially important are:

- ABL stability-mediated adjustments (Wallace, et al. 1989); cause higher local winds to occur with higher local SSTs (Renault, et al. 2019; Seo, et al. 2023)
- Pressure gradient-mediated adjustments (Lindzen & Nigam 1987)

Current feedback (CFB) is also well characterized:

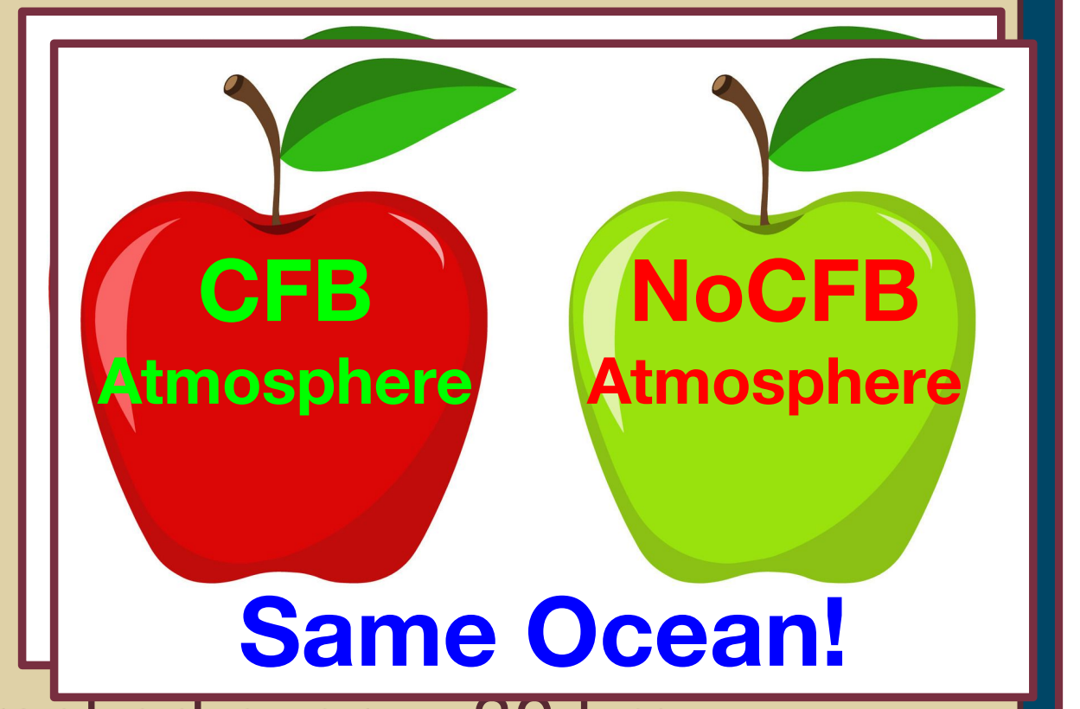
- Direct modulation of winds through wind stress (Dewar & Flierl 1987, Renault, et al. 2016)

CFB and TFB exist together in a dynamic atmosphere, resulting in complex interactions that need further exploration:

- Some 'disentanglement' of CFB and TFB can be done based on their dependences on wind direction (Renault, et al. 2019)
- CFB can influence secondary circulation (convergence and ascent), in addition to that seen from TFB – as seen in May & Bourassa 2023 – **setting the stage for this study**!

Methods

- COAWST: ROMS (Ocean) and WRF (Atmosphere) coupled using MCT
  - ~4 km resolution, 32 vertical levels, over Gulf Stream extension, for winter 2015-16 (~6 months)
- **CFB**: *Fully-coupled* ocean & atmosphere
- **NoCFB**: Ocean state saved from **CFB** run and used to rerun WRF *without CFB* (i.e., no ocean current in stress calcs)
  - Straightforward comparison of **CFB** and **NoCFB** atmospheric states



- Max vorticity on left side of Gulf Stream tracked every ~30 km

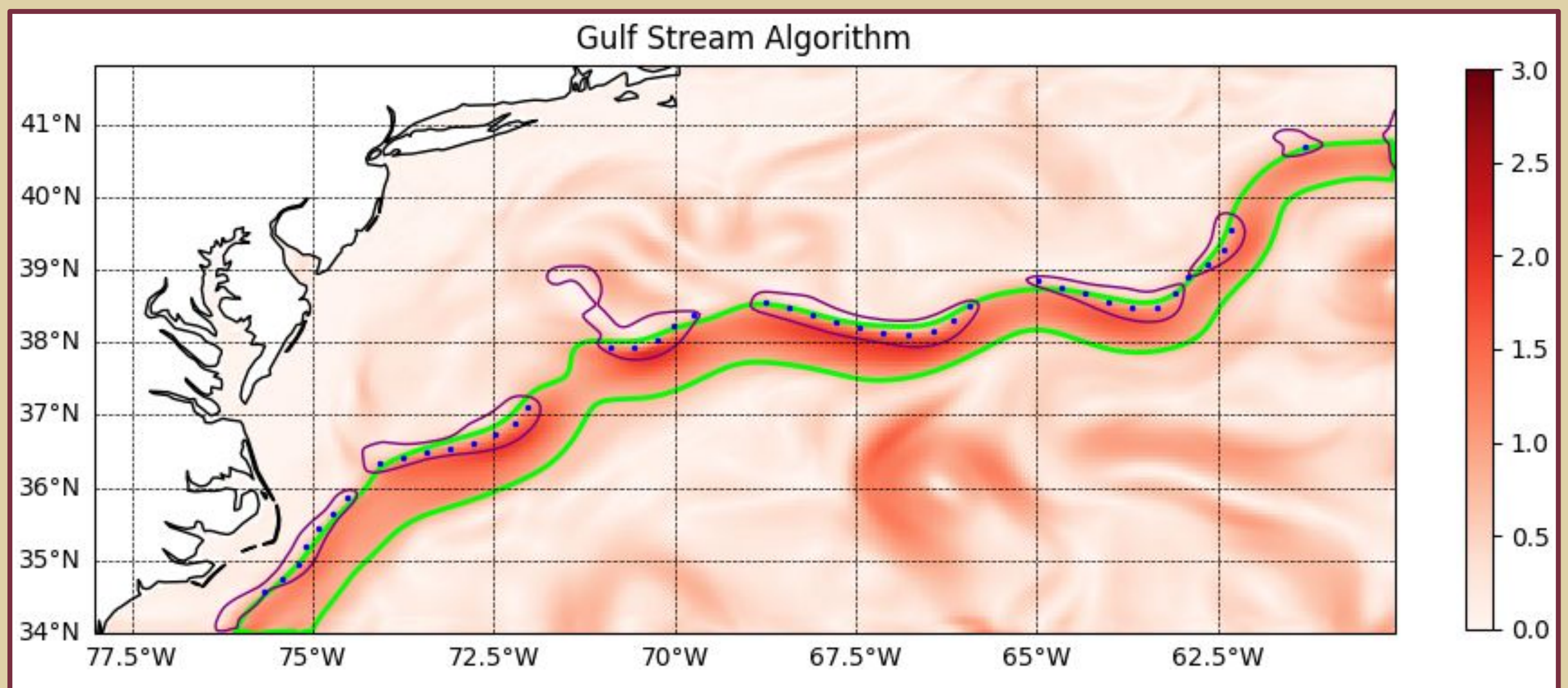


Figure 1: Demonstration of the current-tracking algorithm for a single time step. Blue dots are points selected by the algorithm, red shading is the geostrophic ocean current (m/s), lime contour is the Gulf Stream, and purple contours are vorticity maxima on the left side of the Gulf Stream.

- From algorithm points, transects perpendicular to the current were taken, sampling the ocean and both **CFB** and **NoCFB** atmospheres
- Transects filtered to emphasize mesoscale, reduce large- and small-scale noise, and 'disentangle' CFB effects from TFB effects
  - Wind ~90° to current, away from land and synoptic systems

References
Dewar, W. K., and G. R. Flierl, 1987: Some Effects of the Wind on Rings. J. Phys. Oceanogr., 17, 1653–1667, https://doi.org/10.1175/1520-0485(1987)017<1653:SEOTWO>2.0.CO;2.
Lindzen, R. S., and S. Nigam, 1987: On the Role of Sea Surface Temperature Gradients in Forcing Low-Level Winds and Convergence in the Tropics. J. Atmos. Sci., 44, 2418–2436, https://doi.org/10.1175/1520-0469(1987)044<2418:OTROSS>2.0.CO;2.
May, J.C., and M. A. Bourassa, 2023: Atmospheric dynamic response to coupling currents to wind stress over the Gulf Stream. *Atmosphere*, **14**(8), https://doi.org/10.3390/atmos14081216.
Renault, L., S. Masson, V. Oerder, S. Jullien, and F. Colas, 2019: Disentangling the mesoscale ocean-atmosphere interactions. *Journal of Geophysical Research: Oceans*, **124**, 2164–2178. https://doi.org/10.1029/2018JC014628.
Renault, L., M. J. Molemaker, J. C. McWilliams, A. F. Shchepetkin, F. Lemarié, D. Chelton, S. Illig, and A. Hall, 2016: Modulation of Wind Work by Oceanic Current Interaction with the Atmosphere. J. Phys. Oceanogr., 46, 1685–1704, https://doi.org/10.1175/JPO-D-15-0232.1.
Seo, H., and Coathours, 2023: Ocean mesoscale and frontal-scale ocean–atmosphere interactions and influence on large-scale climate: A review. *J. Climate*, **36**(7), 1981-2013, https://doi.org/10.1175/JCLI-D-21-0982.1.
Wallace, J. M., T. P. Mitchell, and C. Deser, 1989: The Influence of Sea-Surface Temperature on Surface Wind in the Eastern Equatorial Pacific: Seasonal and Interannual Variability. J. Climate, 2, 1492–1499, https://doi.org/10.1175/1520-0442(1989)002<1492:TIOSST>2.0.CO;2.

Guiding Question

What mesoscale atmospheric boundary layer responses occur due to ocean currents in quiet synoptic regimes over a western boundary current?

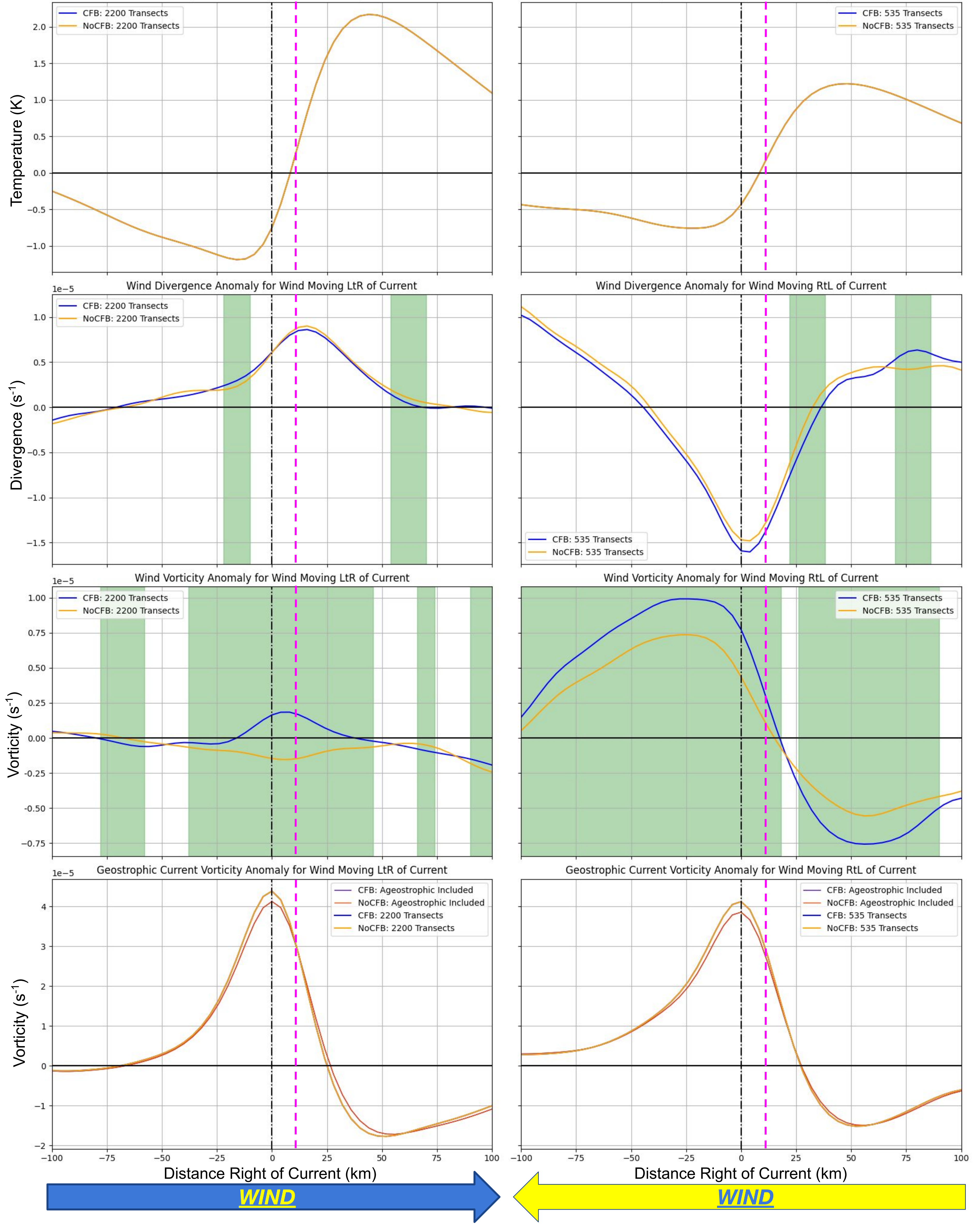
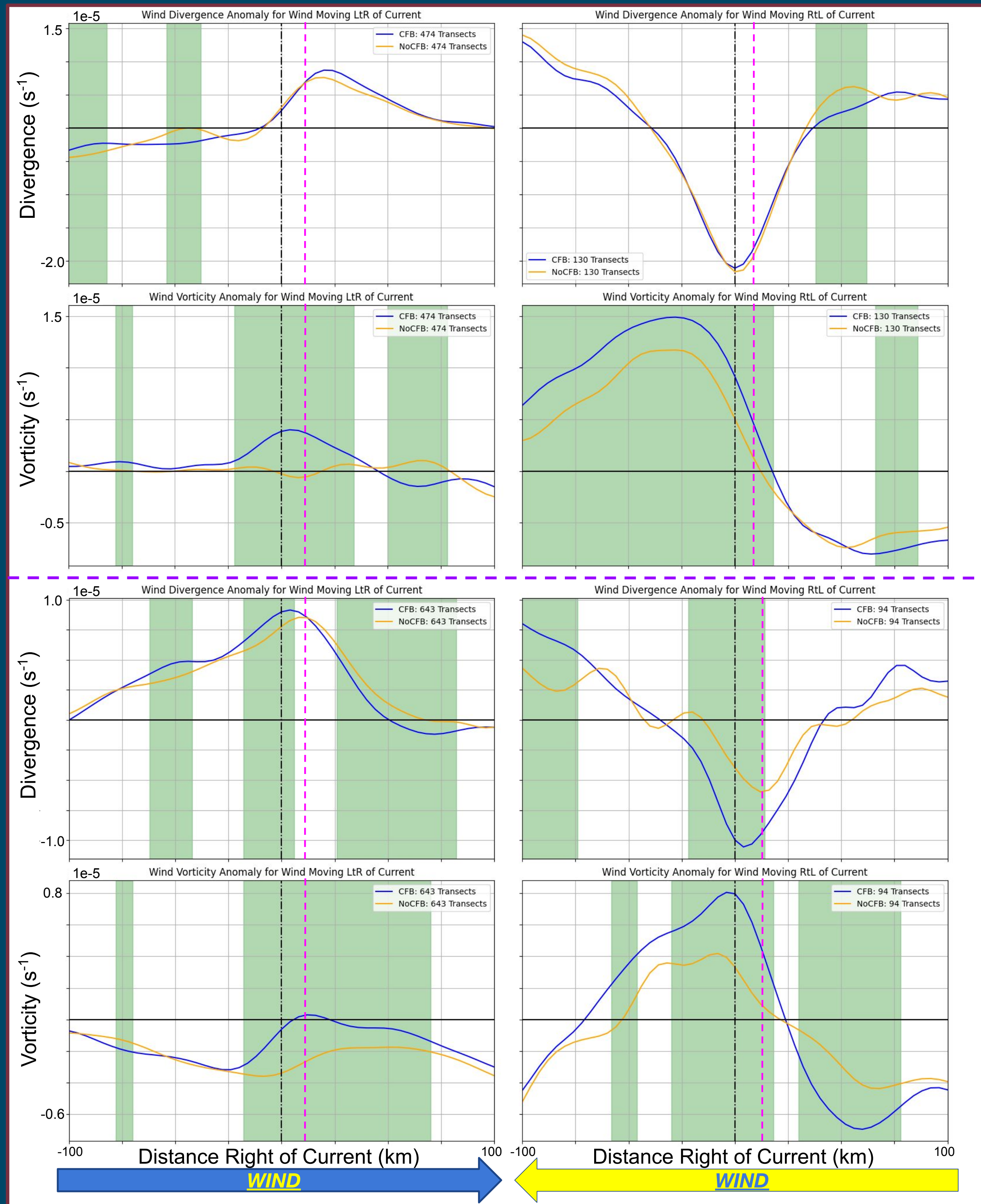


Figure 2: Transect-aggregate means displaying the immediate surface impacts of TFB and CFB on the atmosphere, separated by wind direction. Both **CFB** and **NoCFB** atmospheres had to meet filtering criteria to be included. For each variable, daily-averaged band-pass values are shown. The band-pass is defined by a Gaussian filter with 50- and 500- km cutoffs. Transects are centered around maximized current vorticity, while maximum SST gradient is a little bit to the right, as approximated by the magenta dashed line. Top to bottom plotted are SSTs, wind divergence, wind vorticity, and current vorticity. Regions where the **CFB** atmosphere (blue) is significantly-different (paired t-test p<0.05) from the **NoCFB** atmosphere (orange) are shaded in green.

Implications

Better knowledge of the processes and responses studied in this research will inspire improved, more-targeted remote sensing methods, enabling yet further improvements in the understanding of the atmosphere-ocean system.



High Wind (> 10 m/s) ONLY

Note changed y-axes!

Low Wind (< 6 m/s) ONLY

Note changed y-axes!

Figure 3: Middle 4 panels of Fig. 2, but binned by large-scale wind as it crosses the current vorticity maximum (high wind in top 4 panels; low wind in bottom 4 panels). Transects are included only if both **CFB** and **NoCFB** atmospheres meet wind criteria.

Discussion

Results & conclusions from Fig. 2:

- TFB induces wind divergence with along-wind SST gradient and wind convergence with against-wind SST gradient
  - This occurs at and just downwind of maximized SST gradient
- Wind vorticity response occurs with TFB; anticyclonic near along-wind SST gradient, cyclonic downwind of against-wind SST gradient
- CFB produces wind vorticity response over and slightly downwind of corresponding ocean vorticity
- Relative magnitudes and shapes of TFB and CFB responses are wind direction-dependent

Results & conclusions from Fig. 3:

- There is a wind speed dependence on wind direction
- There is a wind speed dependence of TFB and CFB responses
  - Very nonlinear system; different processes at different wind speeds

Next Steps

Results shown here are promising; further work is motivated:

- Additional statistical tests and binning by different atmospheric & oceanic conditions
- Consider other wind directions, wave & wind stress parameterizations, time lag analysis, etc.
- **Visualization of surface fluxes and 2D vertical ABL cross-sections to gauge response aloft!**

Acknowledgements
This work was funded in part by NSF grant #2307335 and in part by NASA HQ's funding for the Ocean Vector Winds Science Team.
A thanks goes out to Jackie May at the NRL and Xu Chen at NOAA CO-OPS for additional insight for my work.