Quantifying Air-Sea Interactions with Ka-band Doppler Scatterometry

Ocean Vector Winds Science Team Meeting, 2019
Portland, Maine

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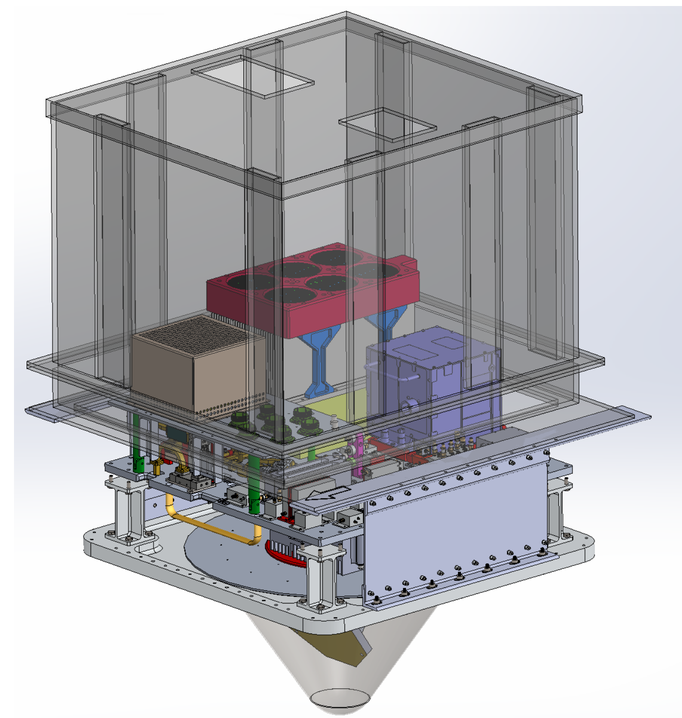
DopplerScatt: A Ka Band Doppler Scatterometer

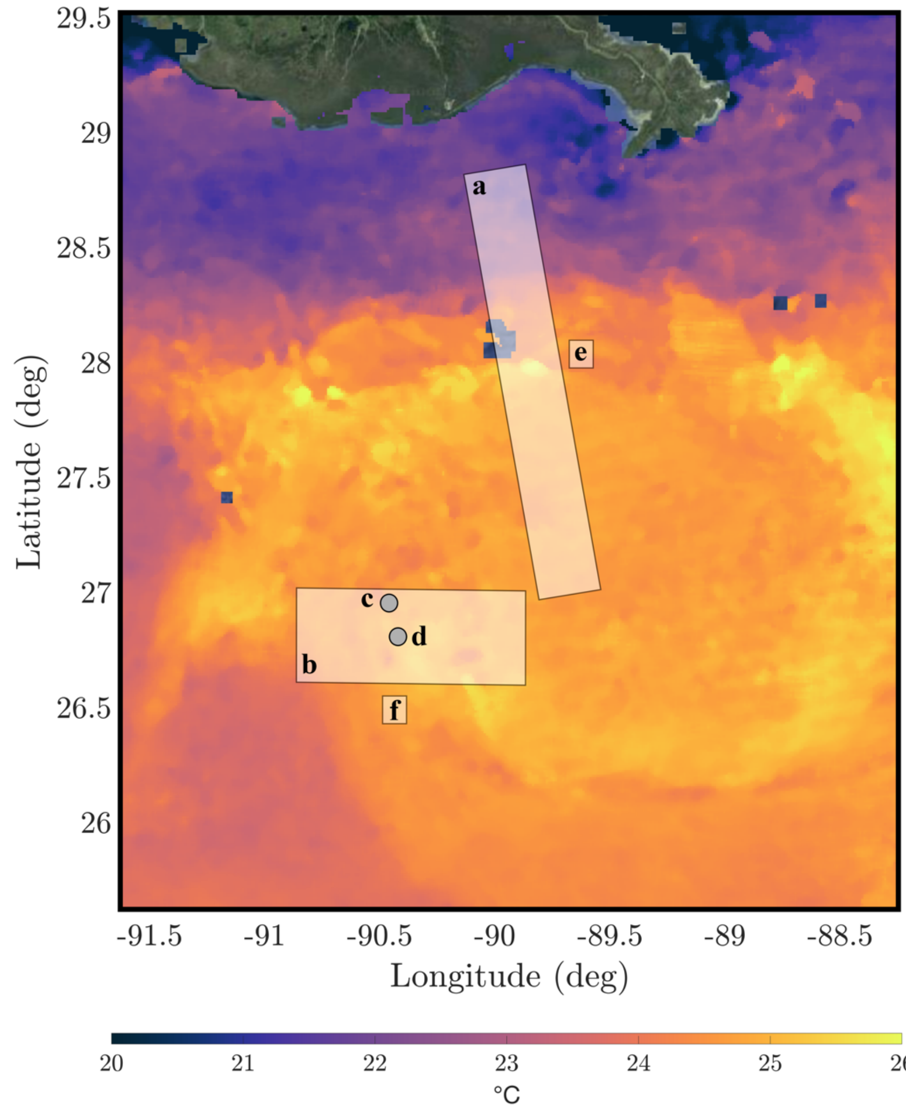
DopplerScatt is a Ka-band coherent scatterometer, designed to measure ocean vector winds and currents over a wide swath.

- **Data Products:**
  - Vector ocean surface currents
  - Vector ocean surface winds
  - Radar backscatter maps (sensitive to surfactants such as oil films)
- **Mapping capabilities**:
  - 25 km swath
  - maps 200km x 100km area in about 4 hours
- **Performance characteristics:**
  - Velocity: 5-15 cm/s component precision
  - Wind speed: 1 m/s accuracy for 3-20 m/s wind
  - Wind direction: 15 deg
  - Spatial resolution: 200m currents, 1km winds

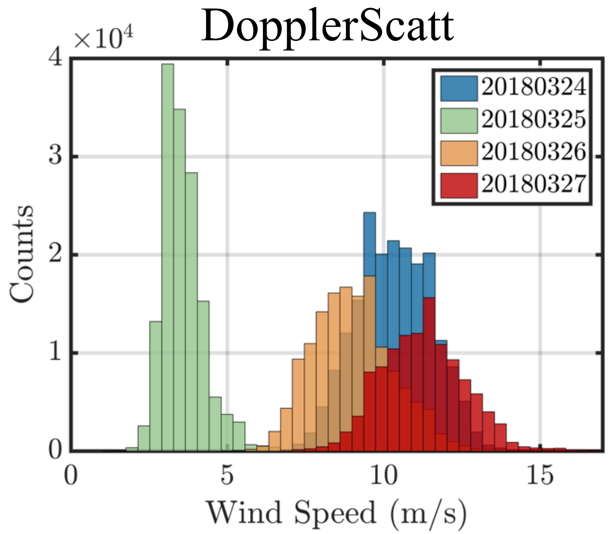


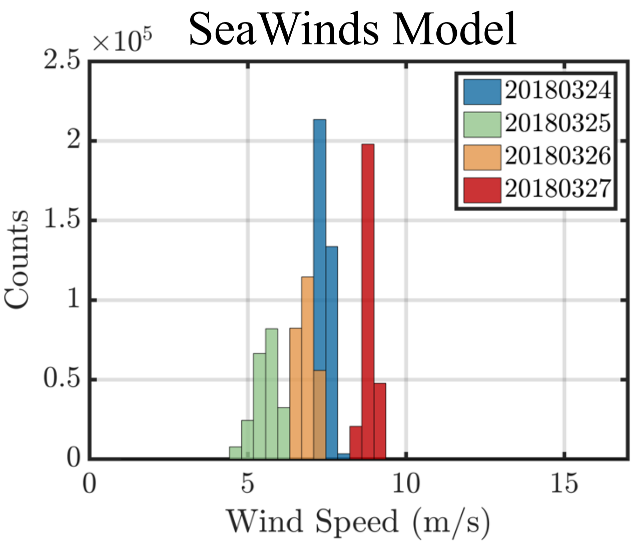
GoM – Chevron Flight Campaign

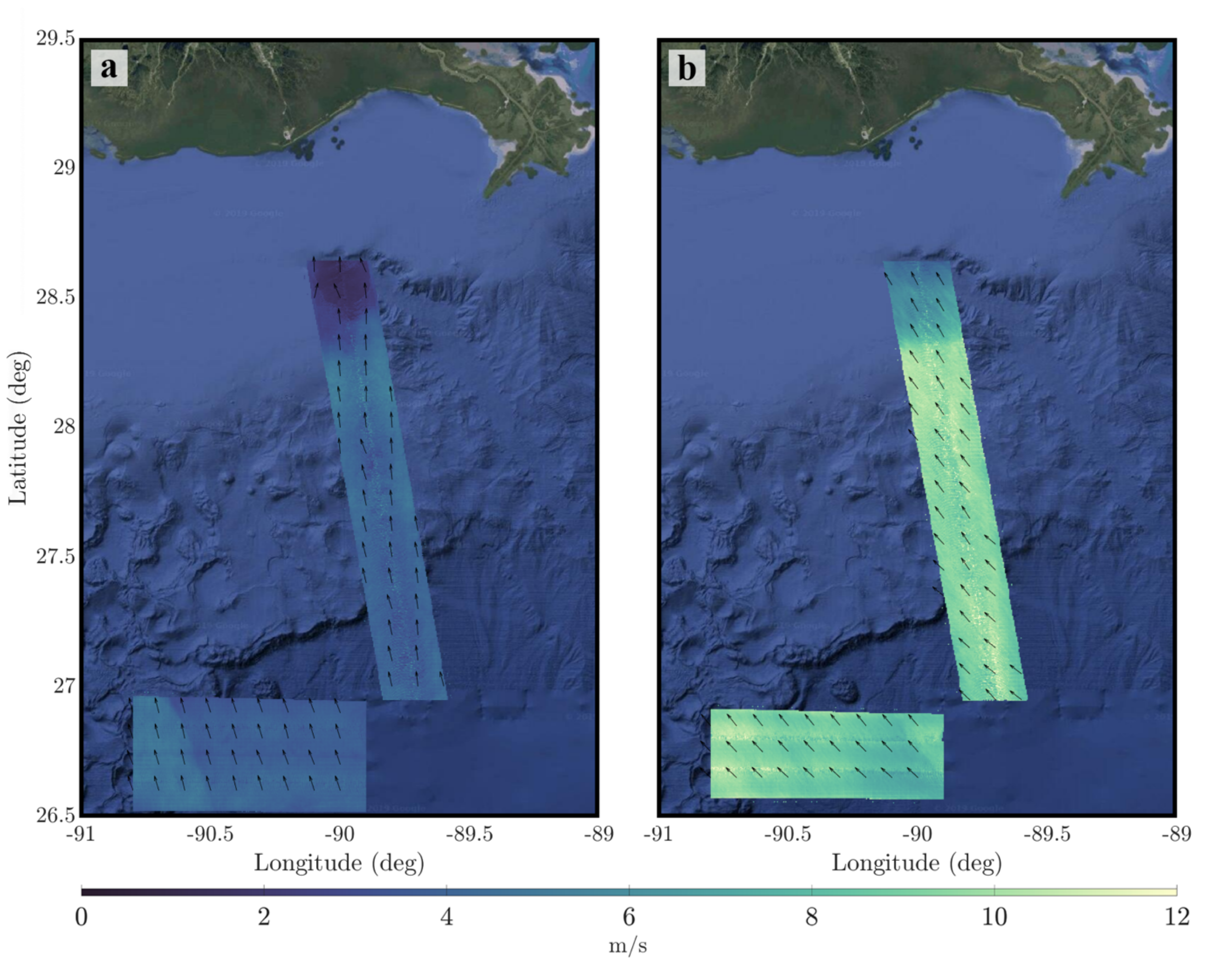
- Strong, warm core eddy "Eddy Quantum" was the target.
- Four flight dates during the week of April 24, 2018.
- Line (a) out
- About 4 hours of 30 minute repeat passes in box (b)
- Line (a) back.
- Buoys at (c) and (d).
- VIIRS 1 km interpolated SST underlay.
- Flights funded by the Chevron Corporation.



GoM Vector Winds

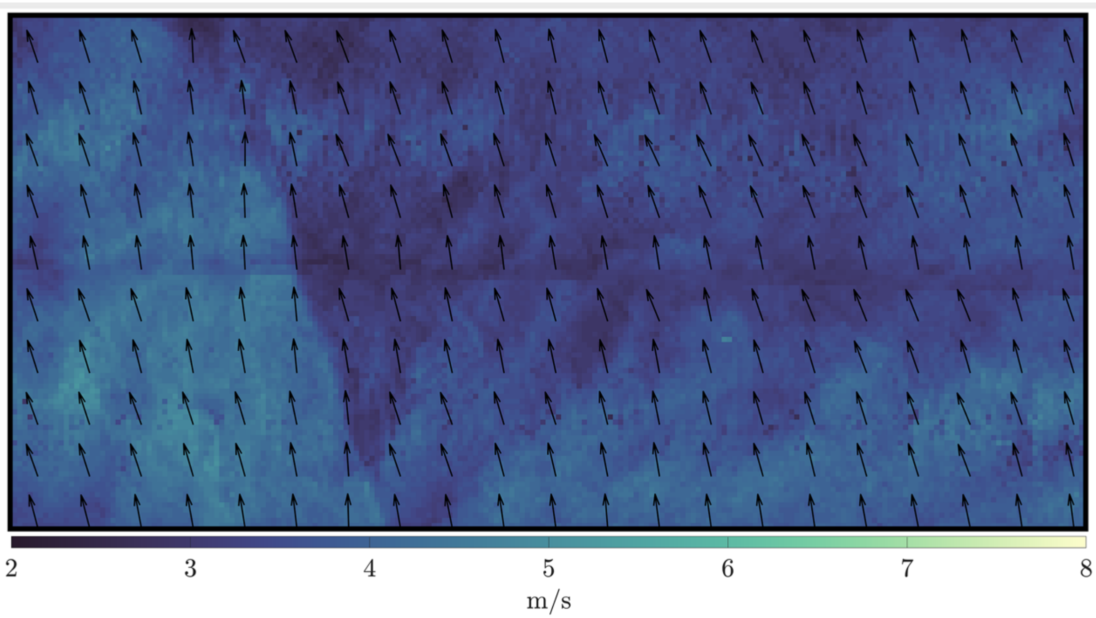




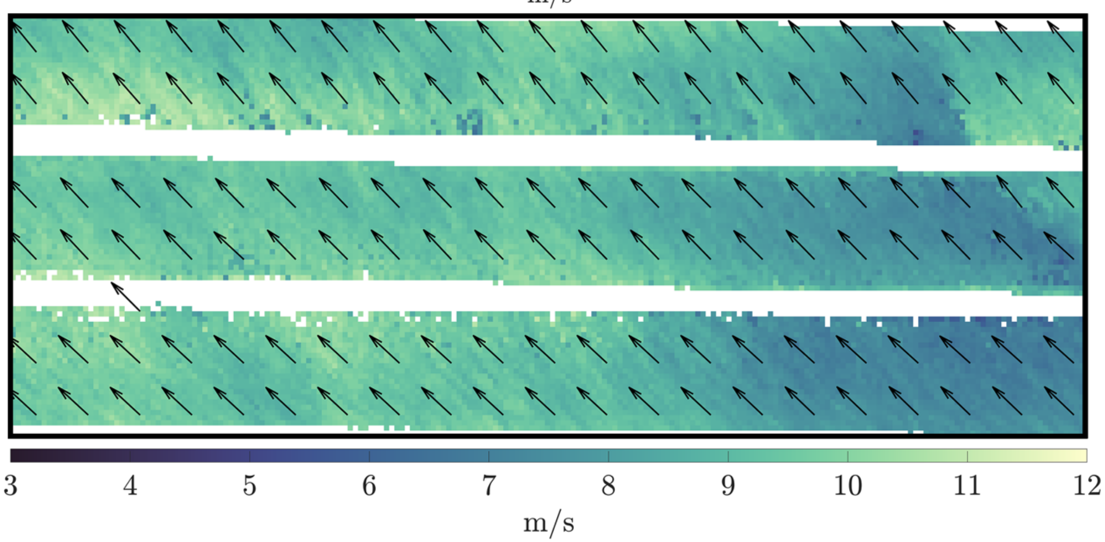


GoM Vector Winds (zoom)

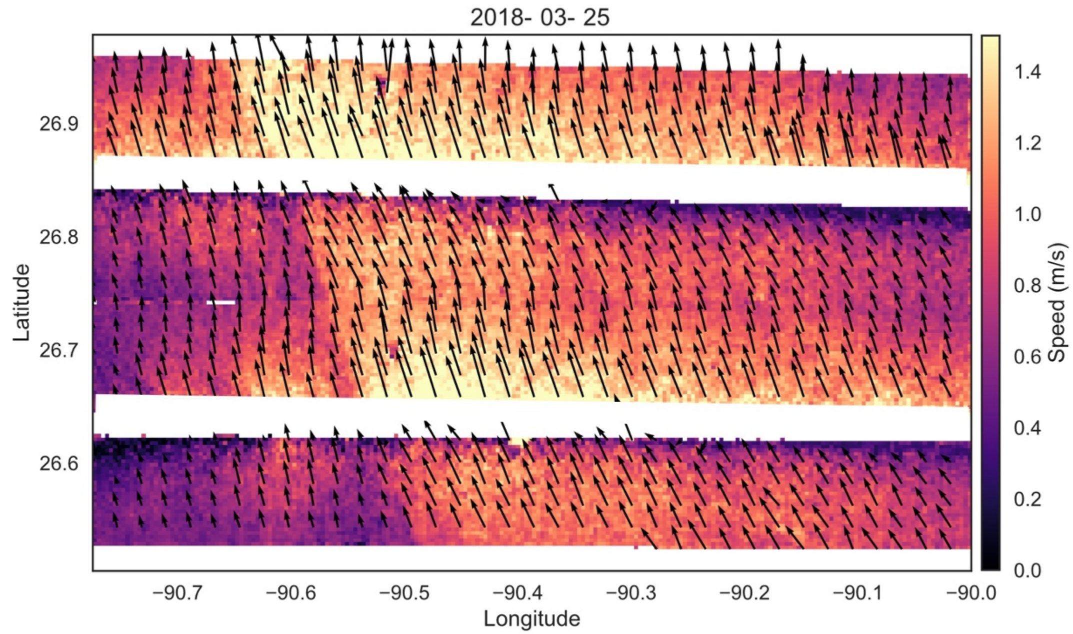
0325

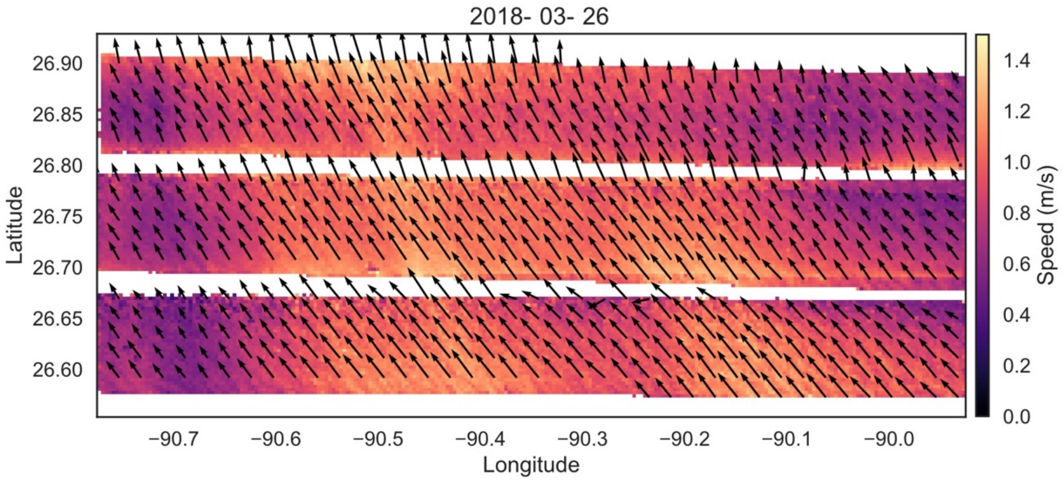


0326



GoM Vector Currents (zoom)





Eddy Quantum Wind Modulation

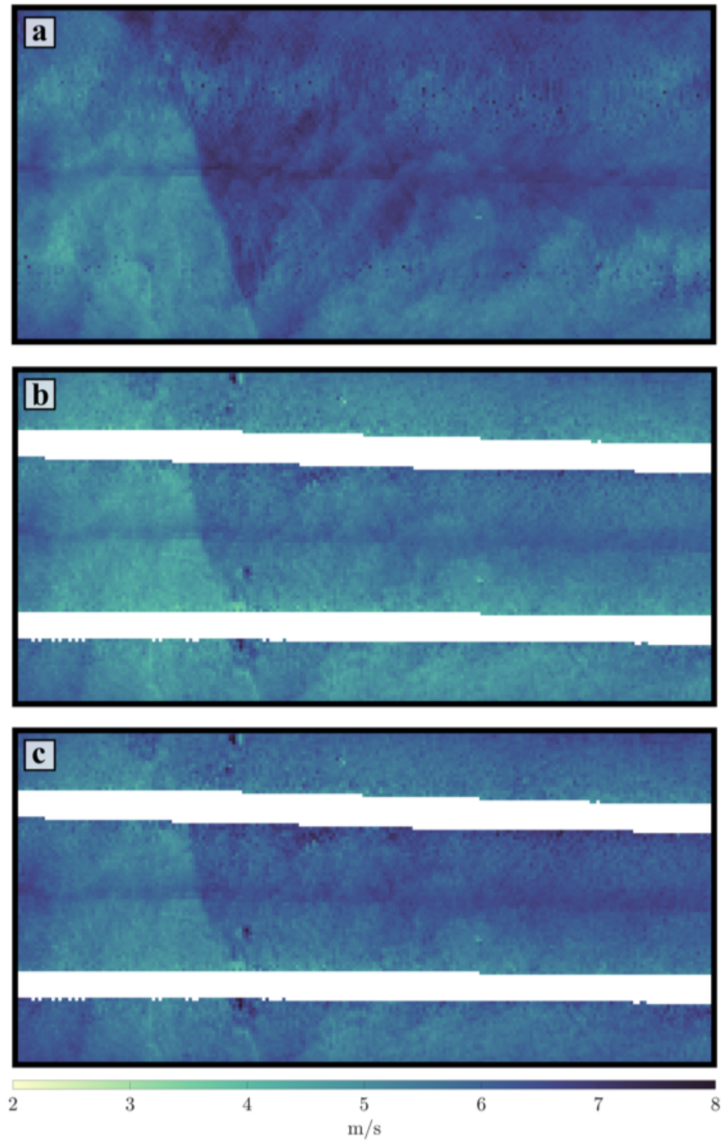
Scatterometer winds are measured:

- relative to surface currents.
- assuming neutral boundary layer stability.

These assumptions cause scatterometer winds to diverge from actual 10 meter winds in, for example, a warm core ocean eddy!

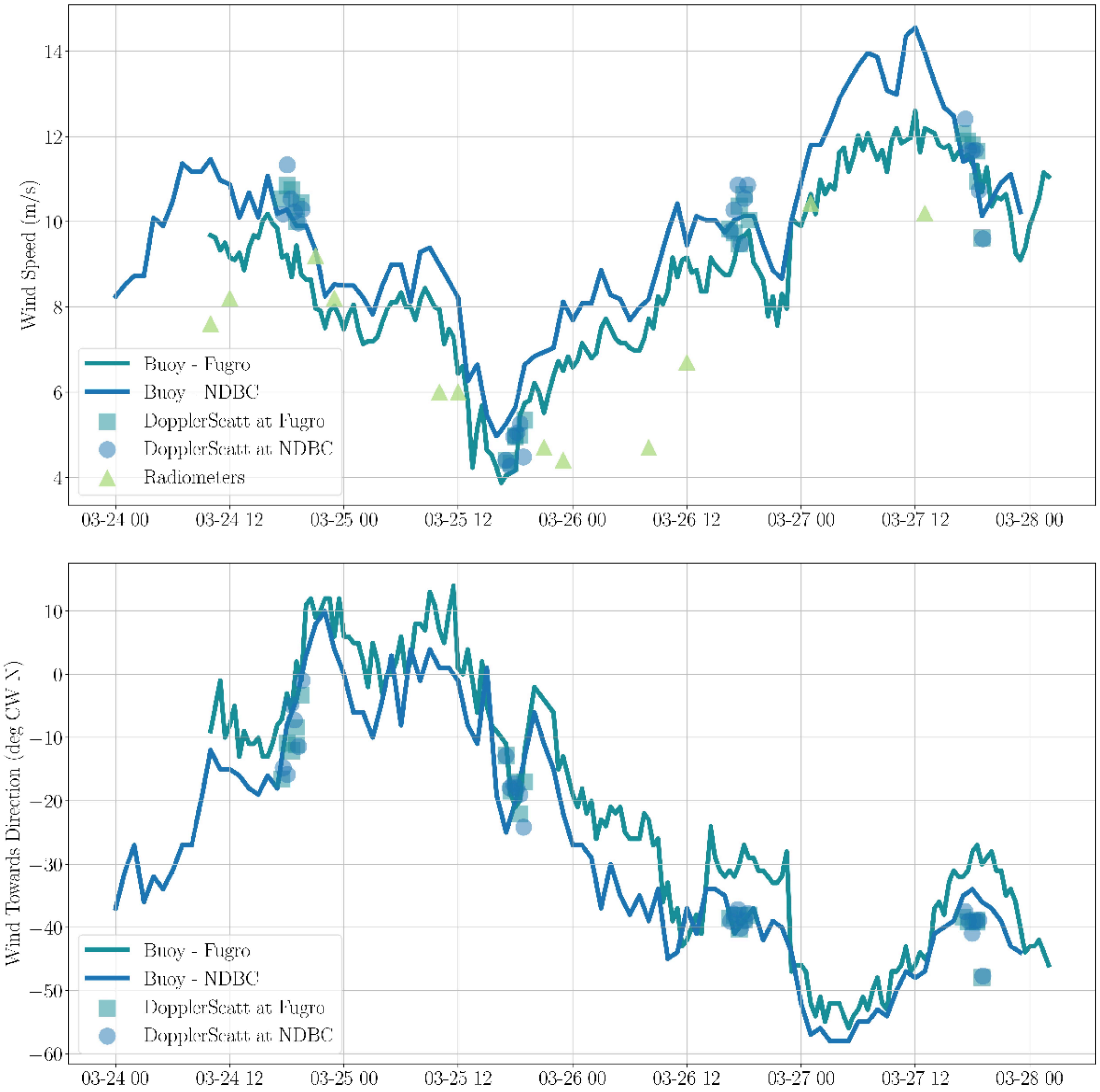
$$U(z) = U_s + \frac{u_*}{k}[ln(z/z_0) + \Phi(z, z_0, L)]$$

Right: The DopplerScatt measured wind field from March 25th.
(a) Original, scatterometer measured surface relative equivalent neutral wind field with no adjustments.
(b) Surface currents added back into (a) using DopplerScatt-measured currents.
(c) Atmospheric stratification adjustments made in addition to surface current.



GoM Buoy Wind Comparisons

- RMS:
  - .98 m/s
  - 8.2 deg
- Good time-tracking.
- Winds were corrected for surface currents (with DS measurements) and for boundary layer stability.



Wind Stress Power Spectral Density

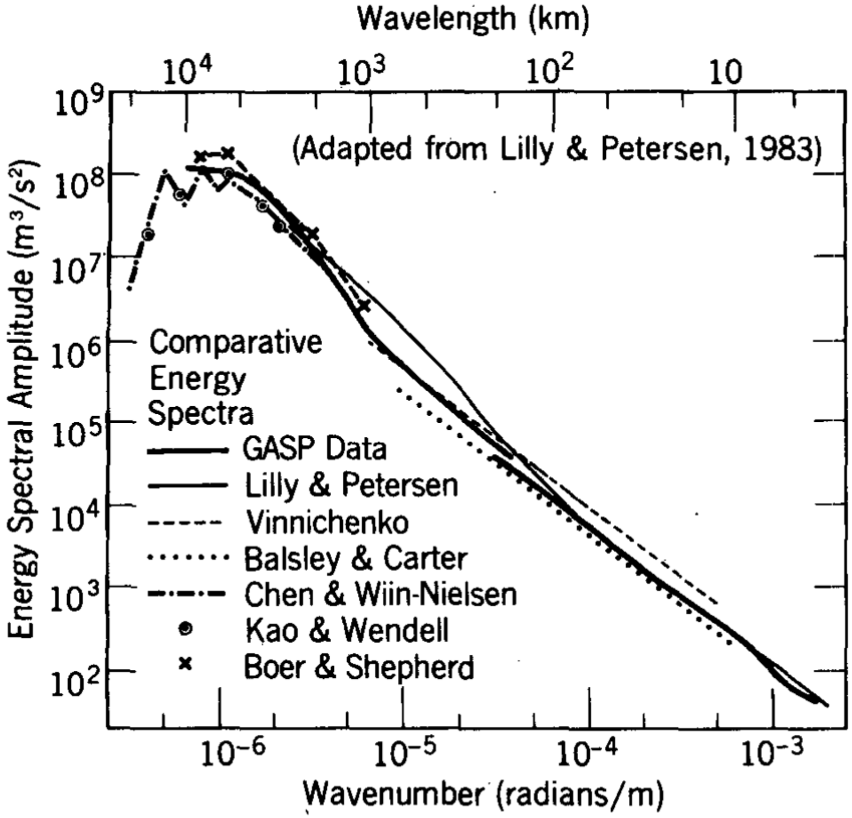


FIG. 4. Composite horizontal energy spectra with comparative results from Vinnichenko (1970), Balsley and Carter (1982), Chen and Wiin-Nielsen (1978), Kao and Wendell (1970), and Boer and Shepherd (1983) (adapted from Lilly and Petersen, 1983).

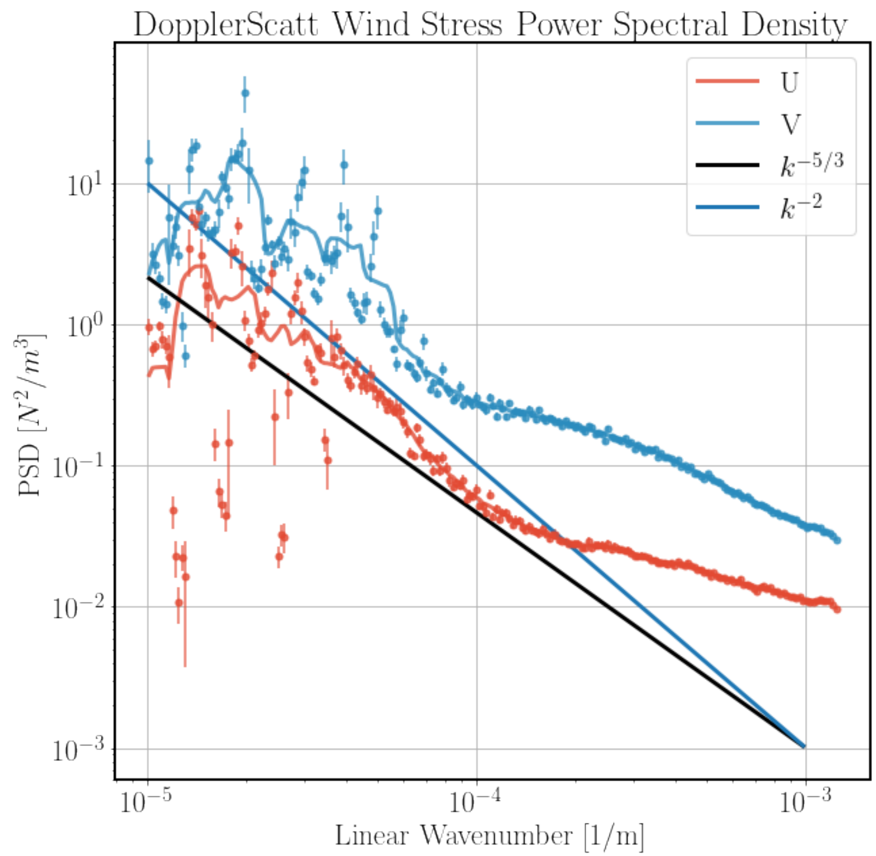
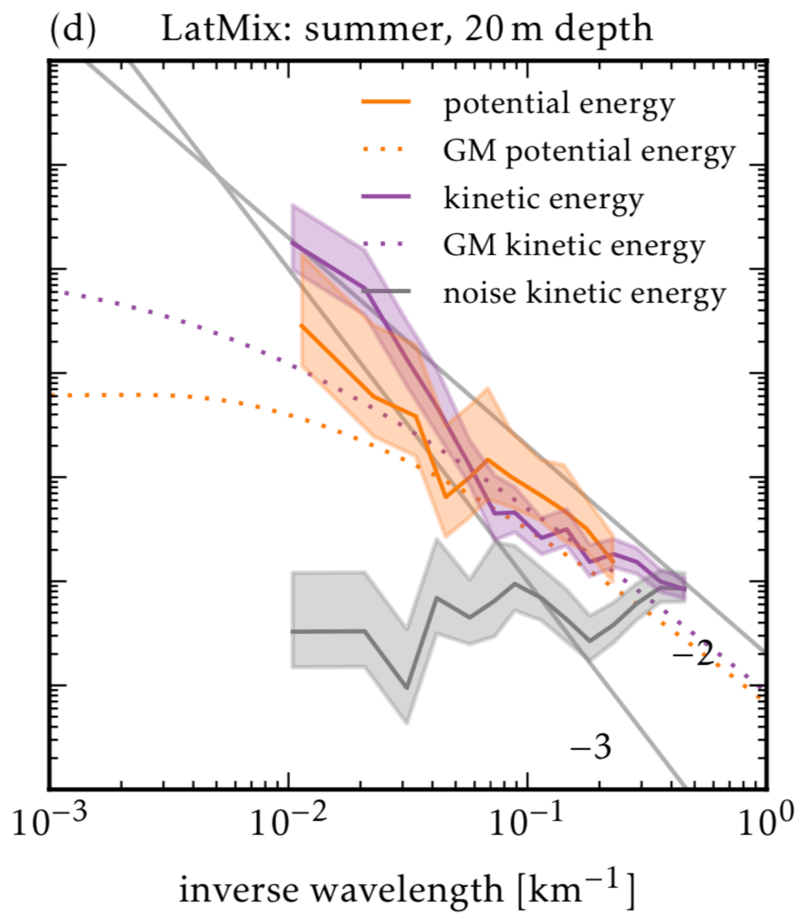


Figure: Nastrom and Gage, 1984: *A Climatology of Atmospheric Wavenumber Spectra of Wind and Temperature Observed by Commercial Aircraft*

Current Power Spectral Density



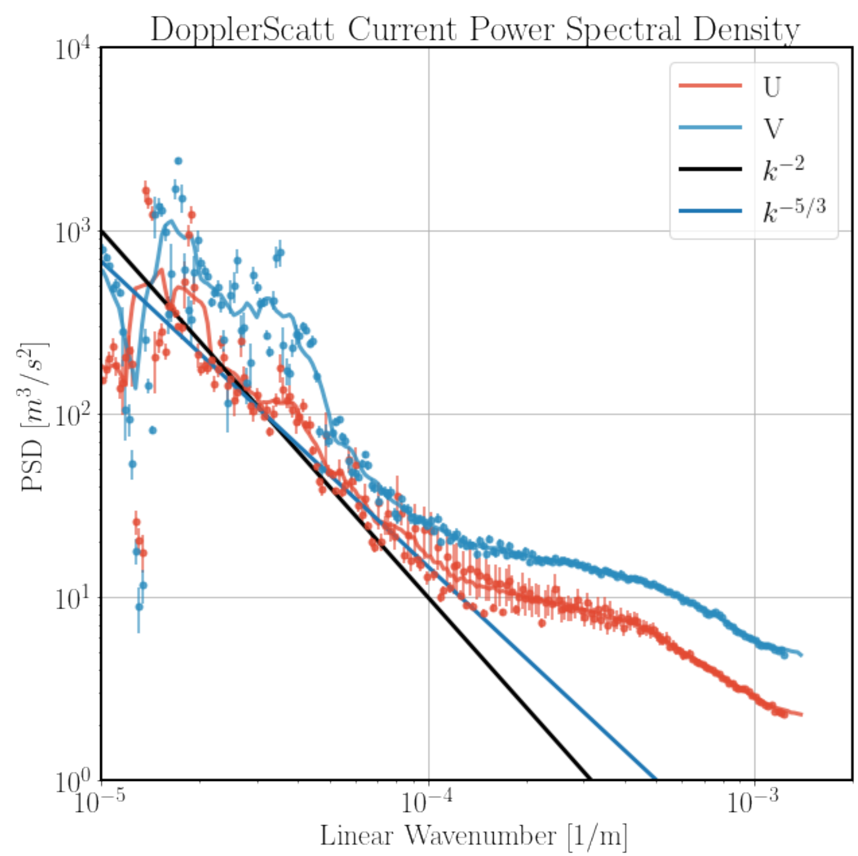
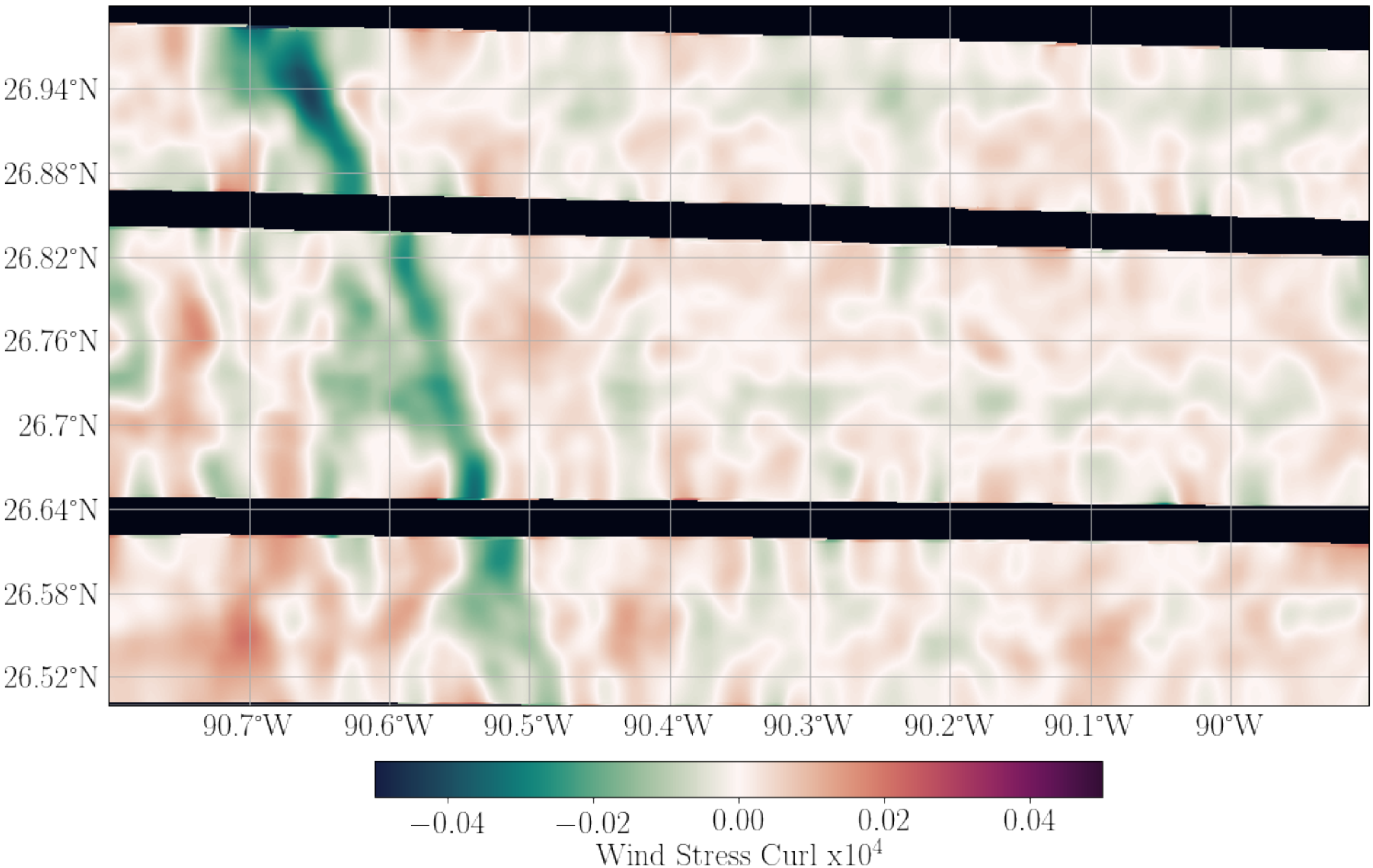


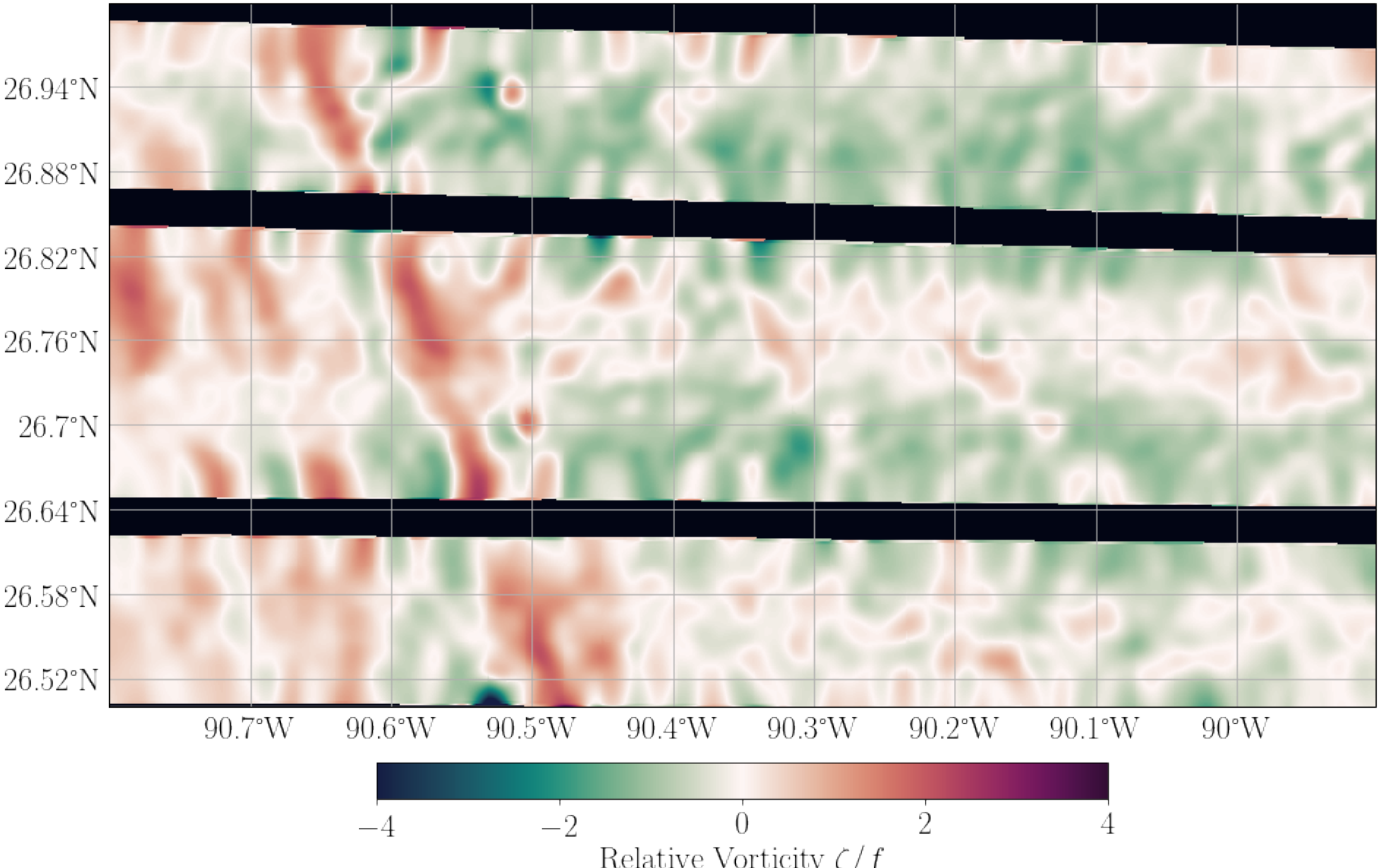
Figure: Callies et al. 2015 *Seasonality in submesoscale turbulence*

Derivatives

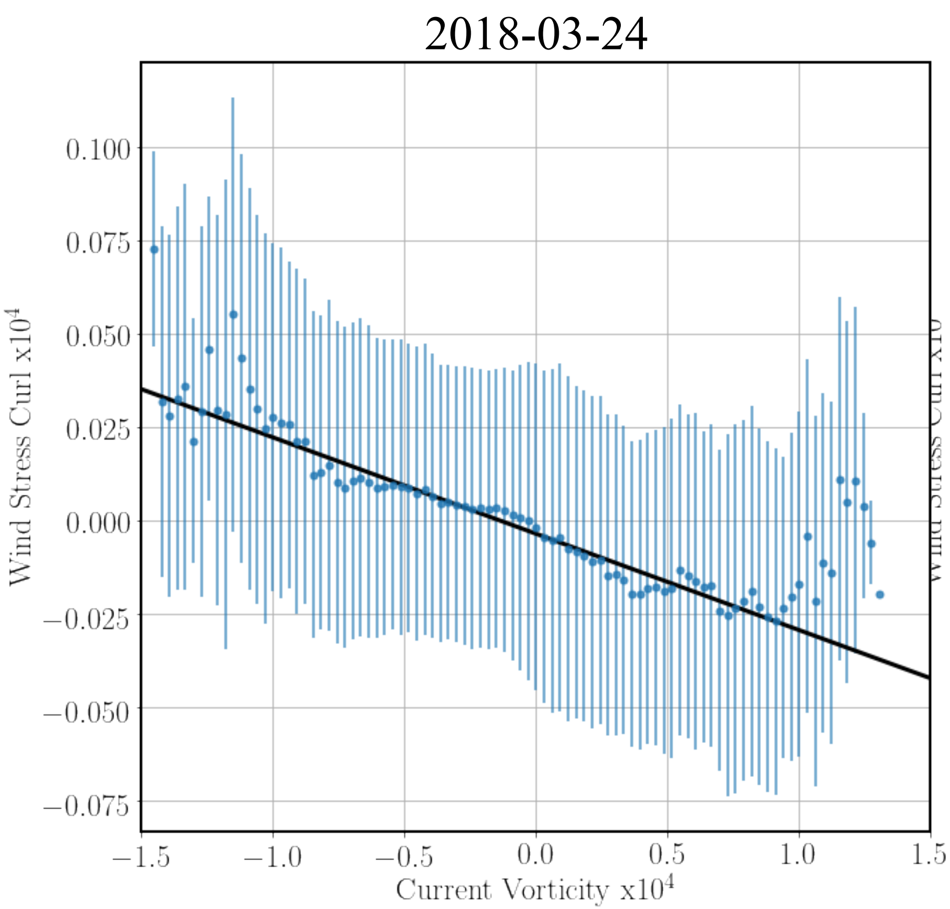
Wind Stress Curl – 0325 (low winds)



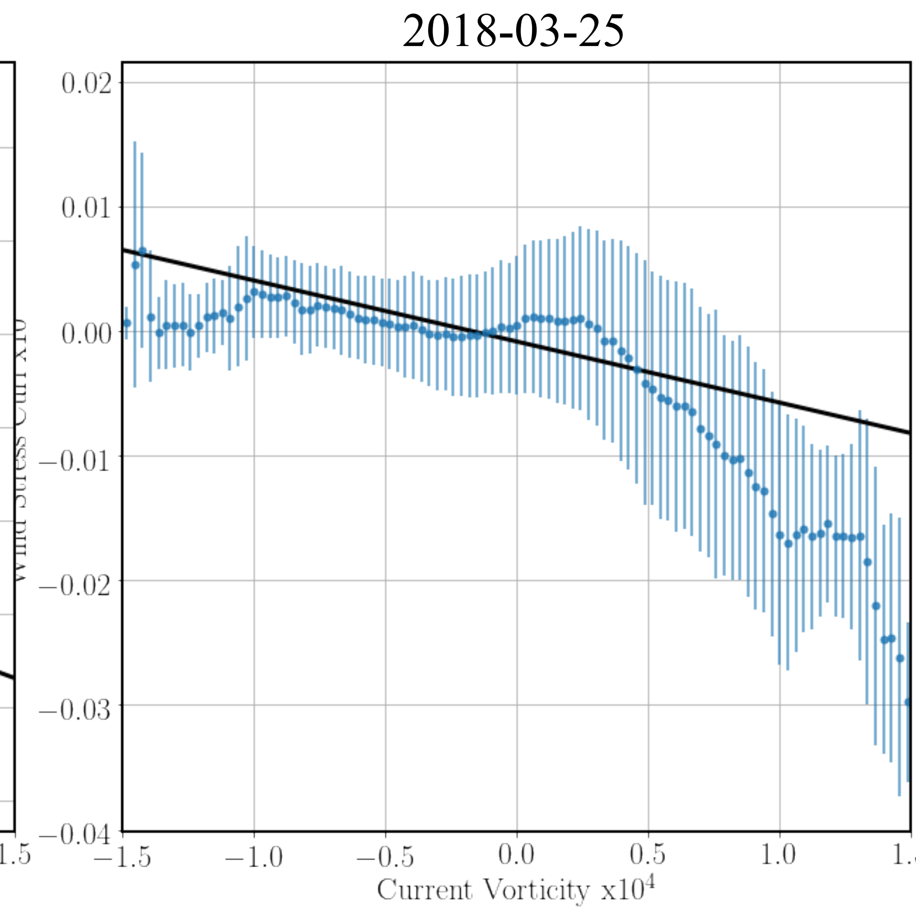
Current Relative Vorticity – 0325 (low winds)



Wind-Current Curl Correlation

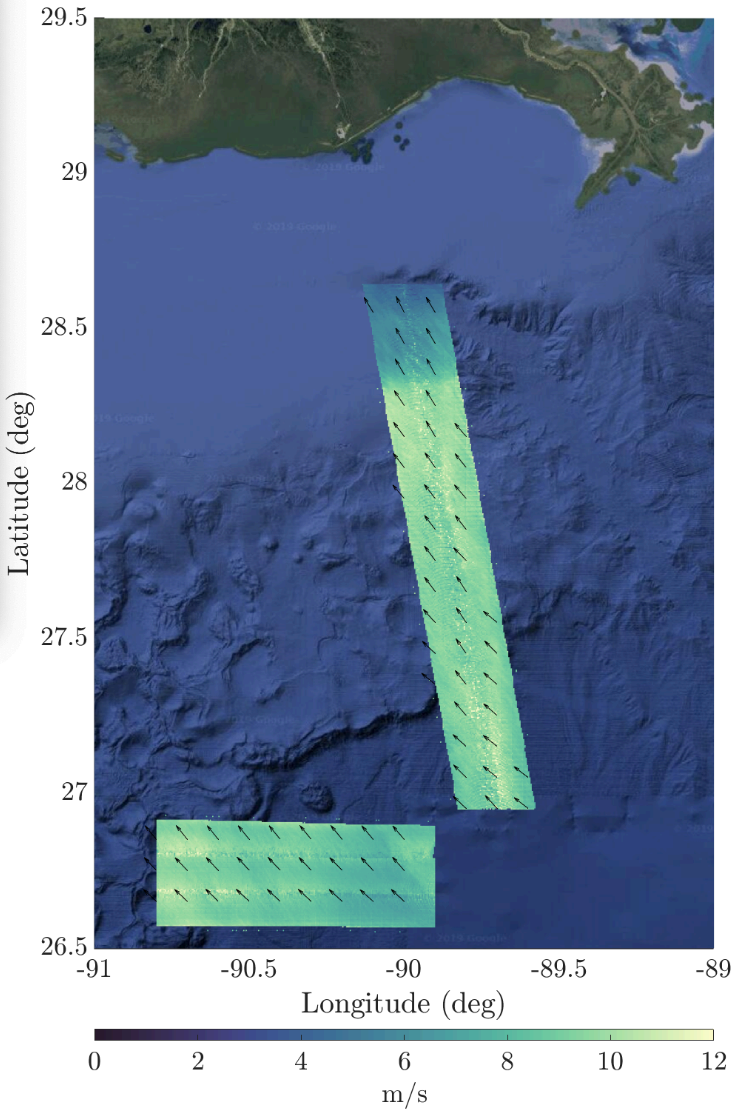


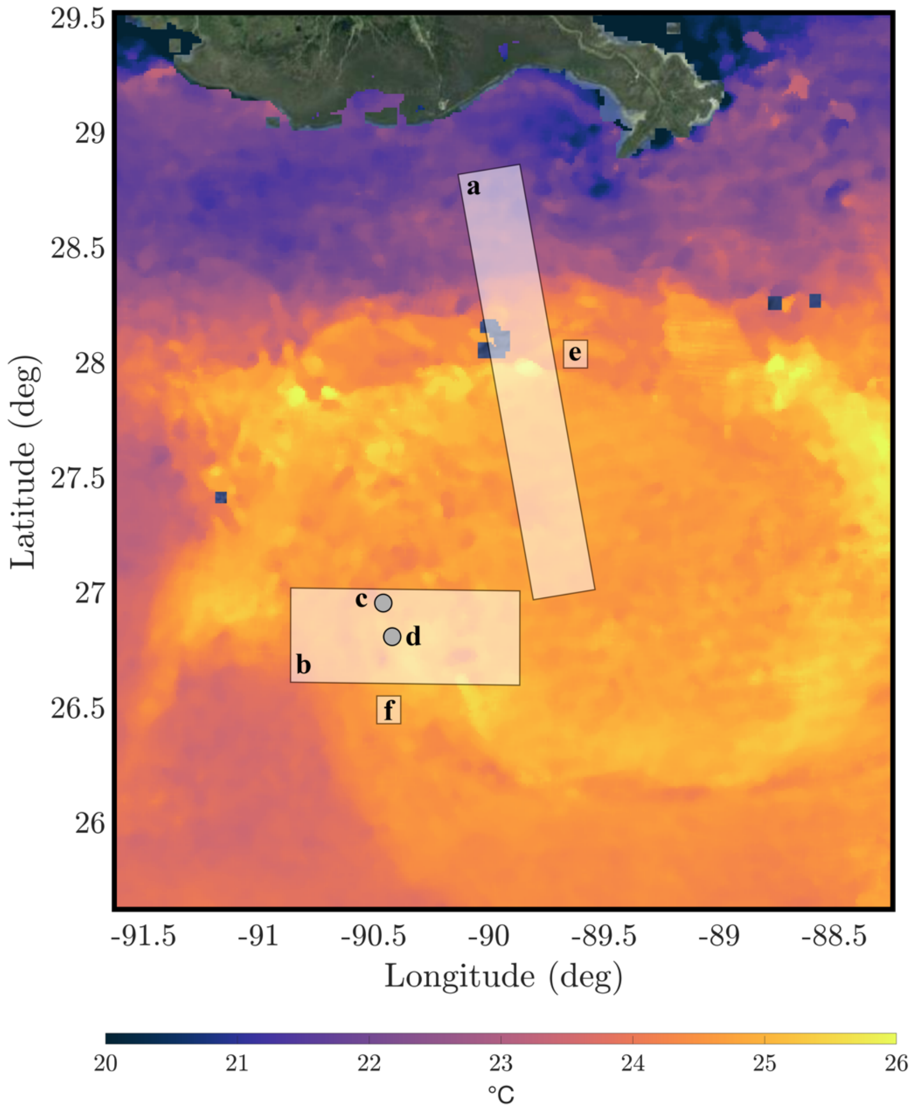
R = -.24
Slope = -.025



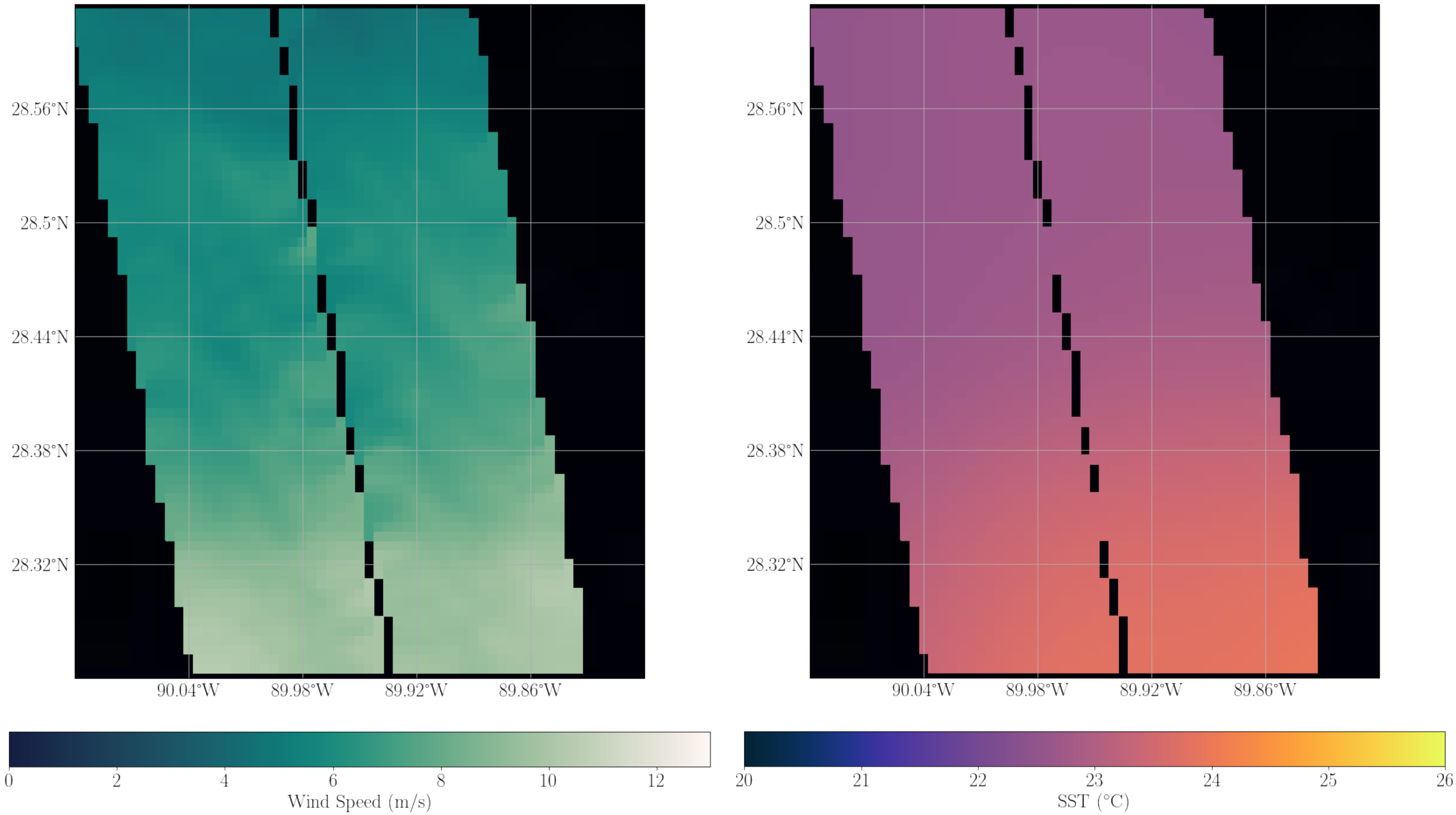
R = -.29
Slope = -.0048

Wind-SST Interactions

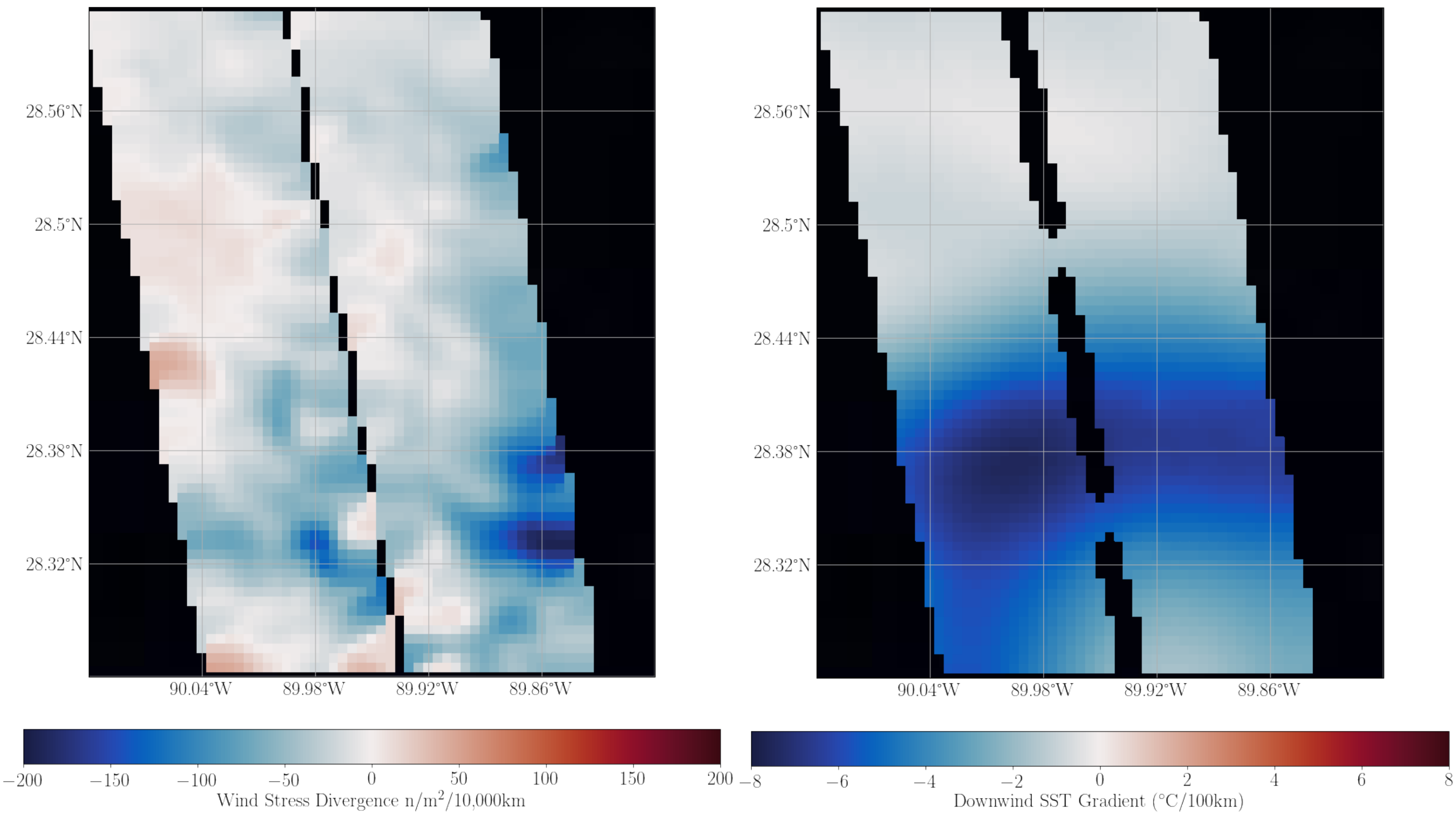




Wind-SST Interactions



Wind-SST Derivative Interactions



Wind-SST Interactions

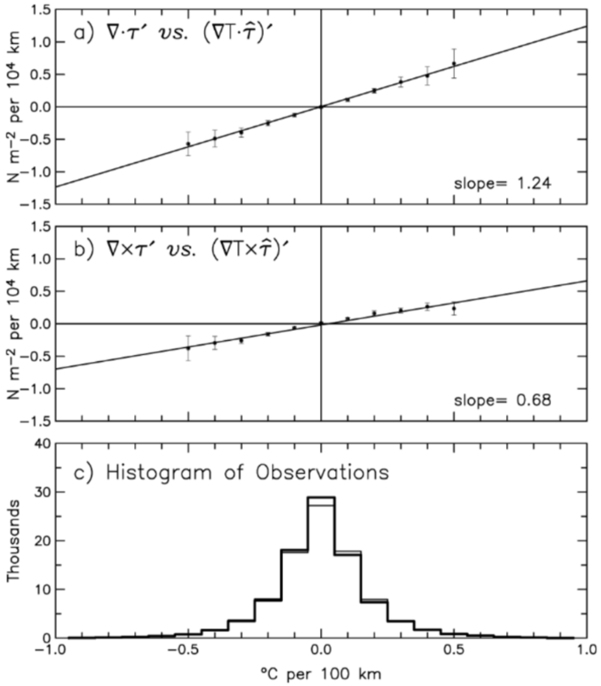
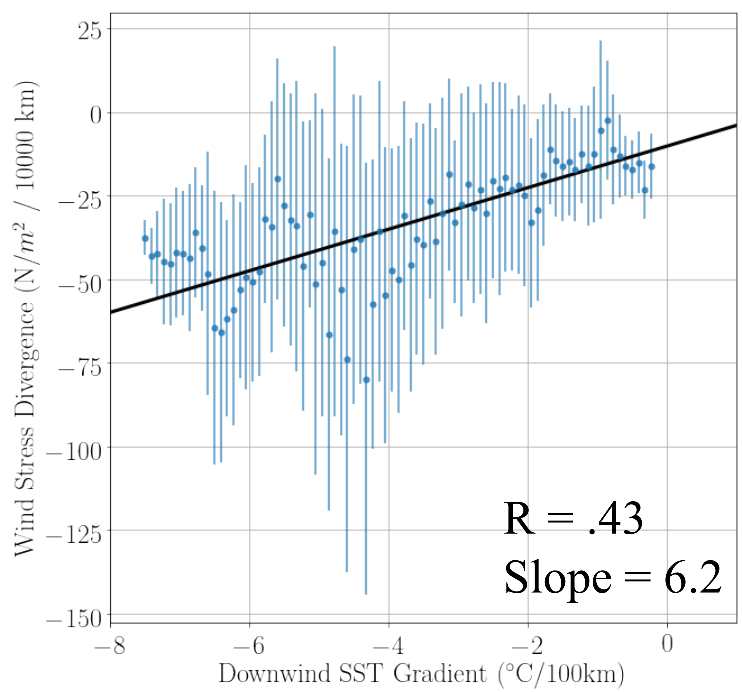


FIG. 7. Binned scatterplots of the relationships between the spatially high-pass-filtered SST and wind stress fields: (a) the perturbation wind stress divergence, $\nabla \cdot \hat{\tau}'$, plotted as a function of the perturbation downwind SST gradient, $(\nabla T \cdot \hat{\tau})'$; (b) the perturbation wind stress curl, $\nabla \times \hat{\tau}' \cdot \mathbf{k}$, plotted as a function of the perturbation crosswind SST gradient, $(\nabla T \times \hat{\tau})' \cdot \mathbf{k}$; and (c) histograms of the number of observations within each bin for (a) (thick line) and (b) (thin line). The points in (a) and (b) are the means within each bin computed from the 11 individual 3-month averages, and the error bars are ±1 std dev of the means within each bin. The lines through the points represent least squares fits of the binned overall means to straight lines.

Figure: O'Neill et al 2003: *Observations of SST-Induced Perturbations of the Wind Stress Field over the Southern Ocean on Seasonal Timescales*

- Wind stress divergence vs SST gradient projected in the wind direction.
- Bottom: DopplerScatt
- Left: O'Neill 2003 (QuikSCAT)
- Somewhat stronger coupling in the higher resolution DopplerScatt data.
  - 400m vs 12.5 km resolution



Summary

- Summary:
  - Scatterometer winds at Ka-band are consistent with buoy observations.
  - Winds, currents, SST, and their derivatives are coupled!
  - The submesoscale structure of winds and currents are likely interdependent on one another.
- To Do:
  - Look at more regions outside the GoM and mesoscale eddy to determine how the spectrum of winds/currents changes/
  - Wavelet and filtering analysis to see what sorts of processes drive the energy spectrum at different scales.

Thank you!

For more, see:

Rodríguez, E.; Wineteer, A.; Perkovic-Martin, D.; Gál, T.; Stiles, B.W.; Niamsuwan, N.; Rodriguez Monje, R. Estimating Ocean Vector Winds and Currents Using a Ka-Band Pencil-Beam Doppler Scatterometer. *Remote Sens.* **2018**, *10*, 576.

References:

O'Neill, L. W., Chelton, D. B., & Esbensen, S. K. (2012). Covariability of surface wind and stress responses to sea surface temperature fronts. *Journal of Climate*, *25*(17), 5916-5942.

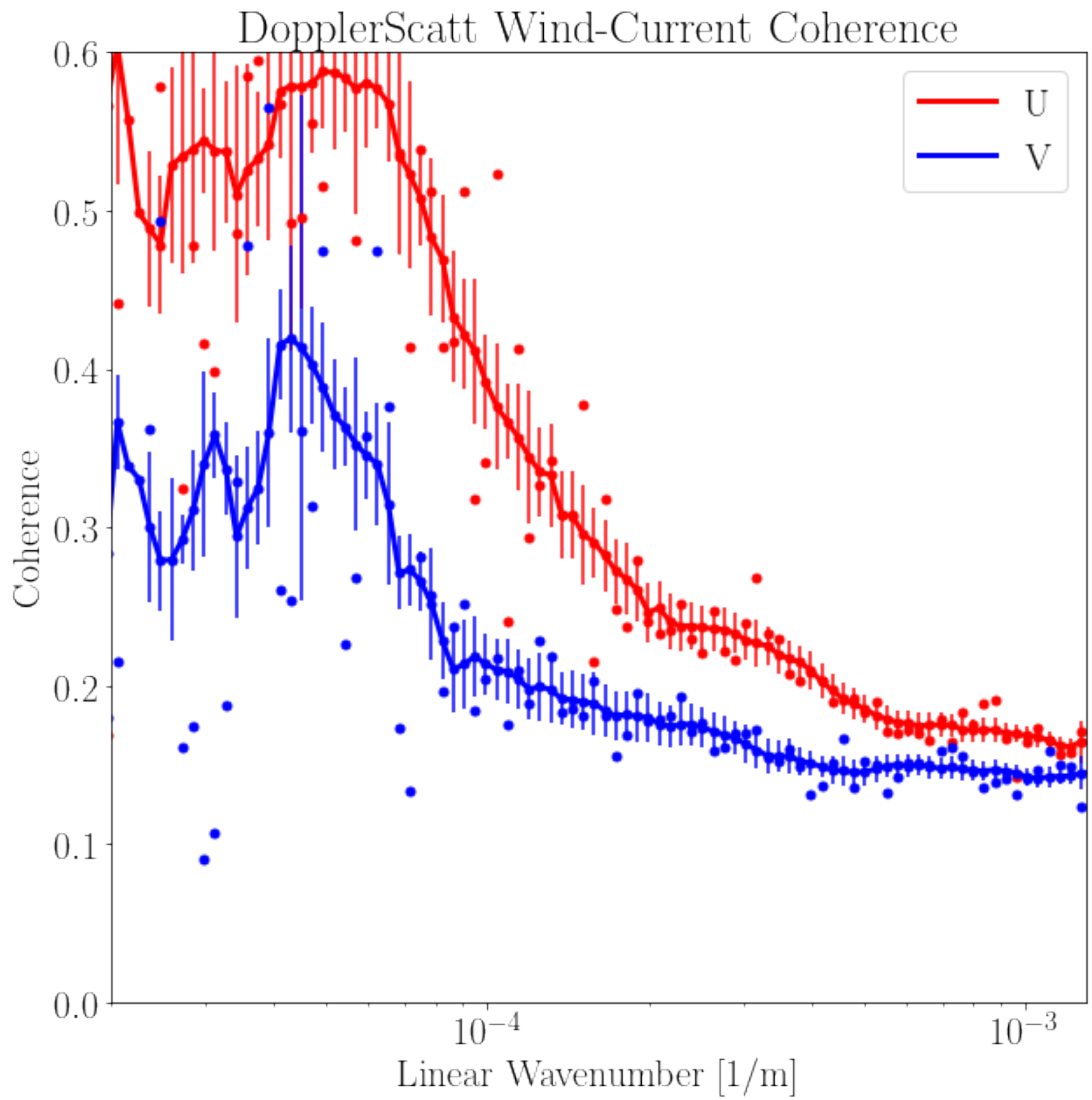
Plagge, A.M., D. Vandemark, and B. Chapron, 2012: Examining the Impact of Surface Currents on Satellite Scatterometer and Altimeter Ocean Winds. J. Atmos. Oceanic Technol., 29, 1776–1793, https://doi.org/10.1175/JTECH-D-12-00017.1

O'Neill, L.W., D.B. Chelton, and S.K. Esbensen, 2010: The Effects of SST-Induced Surface Wind Speed and Direction Gradients on Midlatitude Surface Vorticity and Divergence. J. Climate, 23, 255–281, https://doi.org/10.1175/2009JCLI2613.1

Callies, J. et al. Seasonality in submesoscale turbulence. Nat. Commun. 6:6862 doi: 10.1038/ncomms7862 (2015)

Nastrom, G.D. and K.S. Gage, 1985: A Climatology of Atmospheric Wavenumber Spectra of Wind and Temperature Observed by Commercial Aircraft. J. Atmos. Sci., 42,950–960, https://doi.org/10.1175/1520-0469(1985)042<0950:ACOAWS>2.0.CO;2

Wind-Current Coherence



DopplerScatt/Buoy Wind and Surface Currents

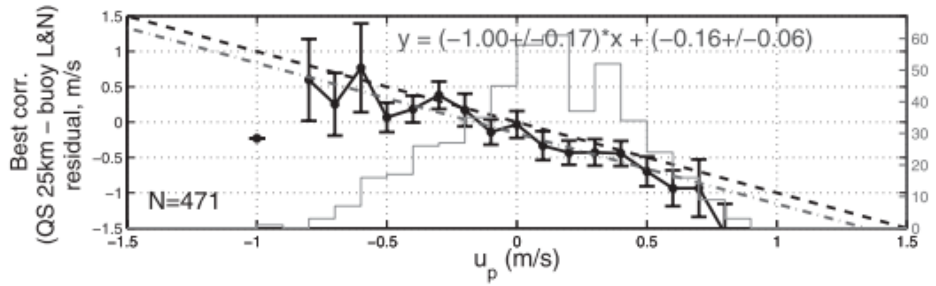
- The wind is *vectorally* sensitive to the moving surface currents.
- Project surface current speed along the wind direction to do analysis in speed space.

$$U_p = U_c \cos(\phi_{U_c} - \phi_{U_{10}})$$

- Buoy winds are not sensitive to the surface currents, so differences should appear.
- Expect slope of negative one for buoy-DS wind diff vs Up.

$$U(z) = U_s + \frac{u_*}{k}[ln(z/z_0) + \Phi(z, z_0, L)]$$

(Plagge 2012 for neutral stability)



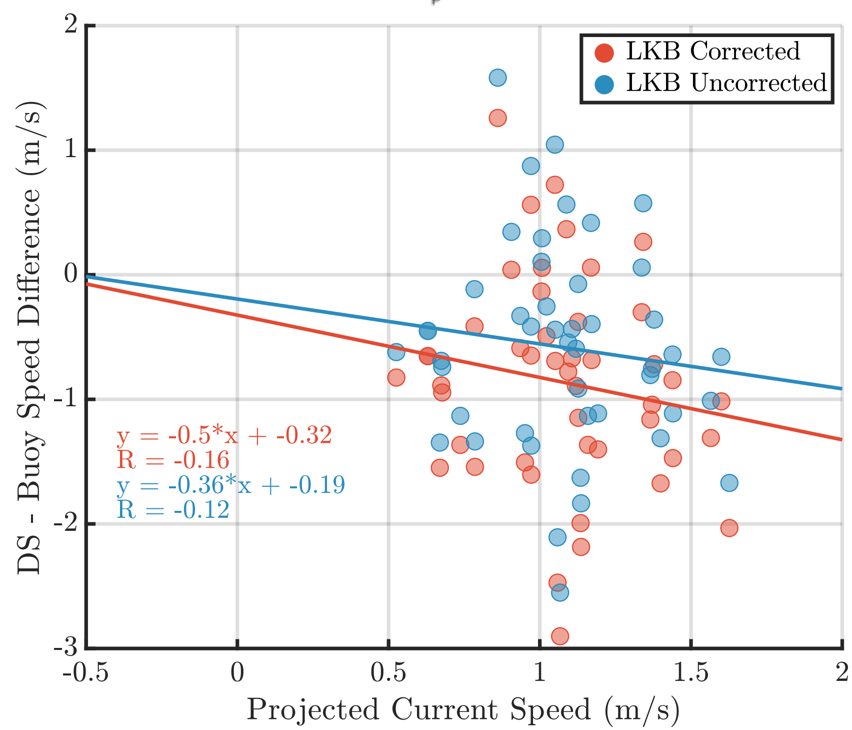


Figure: Plagge et al, 2012: *Examining the Impact of Surface Currents on Satellite Scatterometer and Altimeter Ocean Winds*

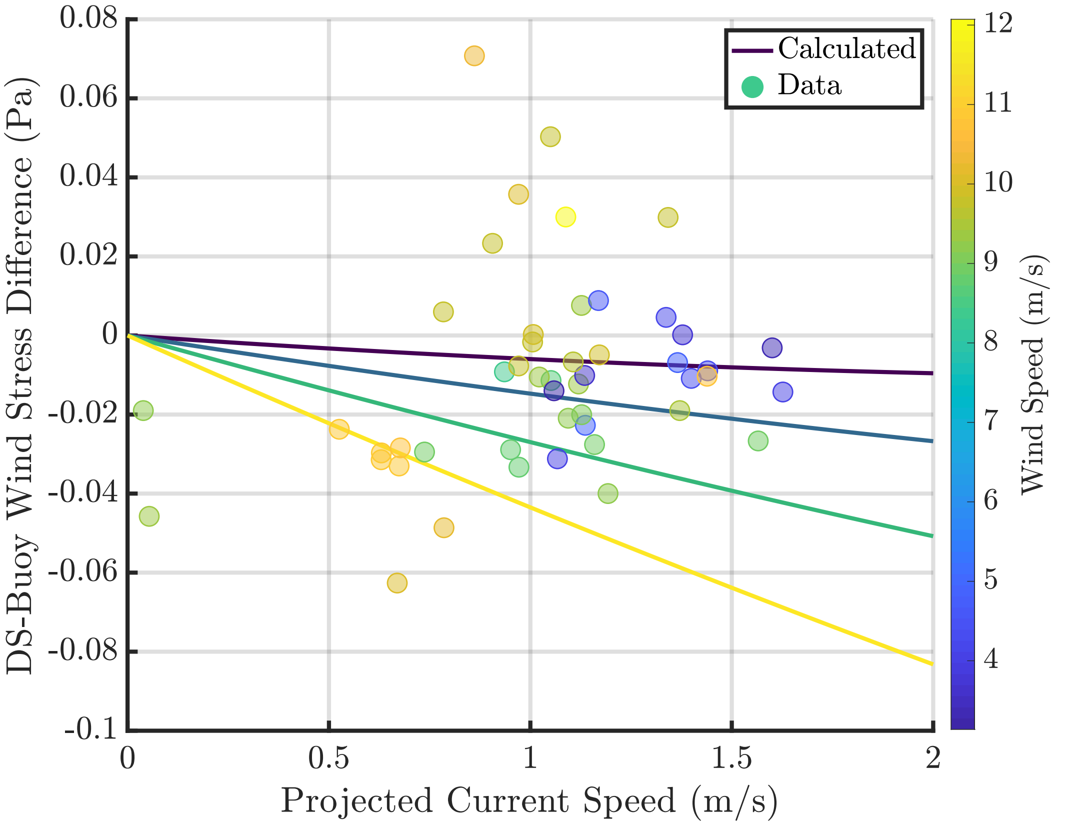
DopplerScatt/Buoy Wind *Stress* and Surface Currents

- The same analysis can be done for DopplerScatt stress and buoy stress, τ.

$$\vec{\tau} = \rho_{air} C_d |\vec{U}_{10} - \vec{U}_s| (\vec{U}_{10} - \vec{U}_s)$$

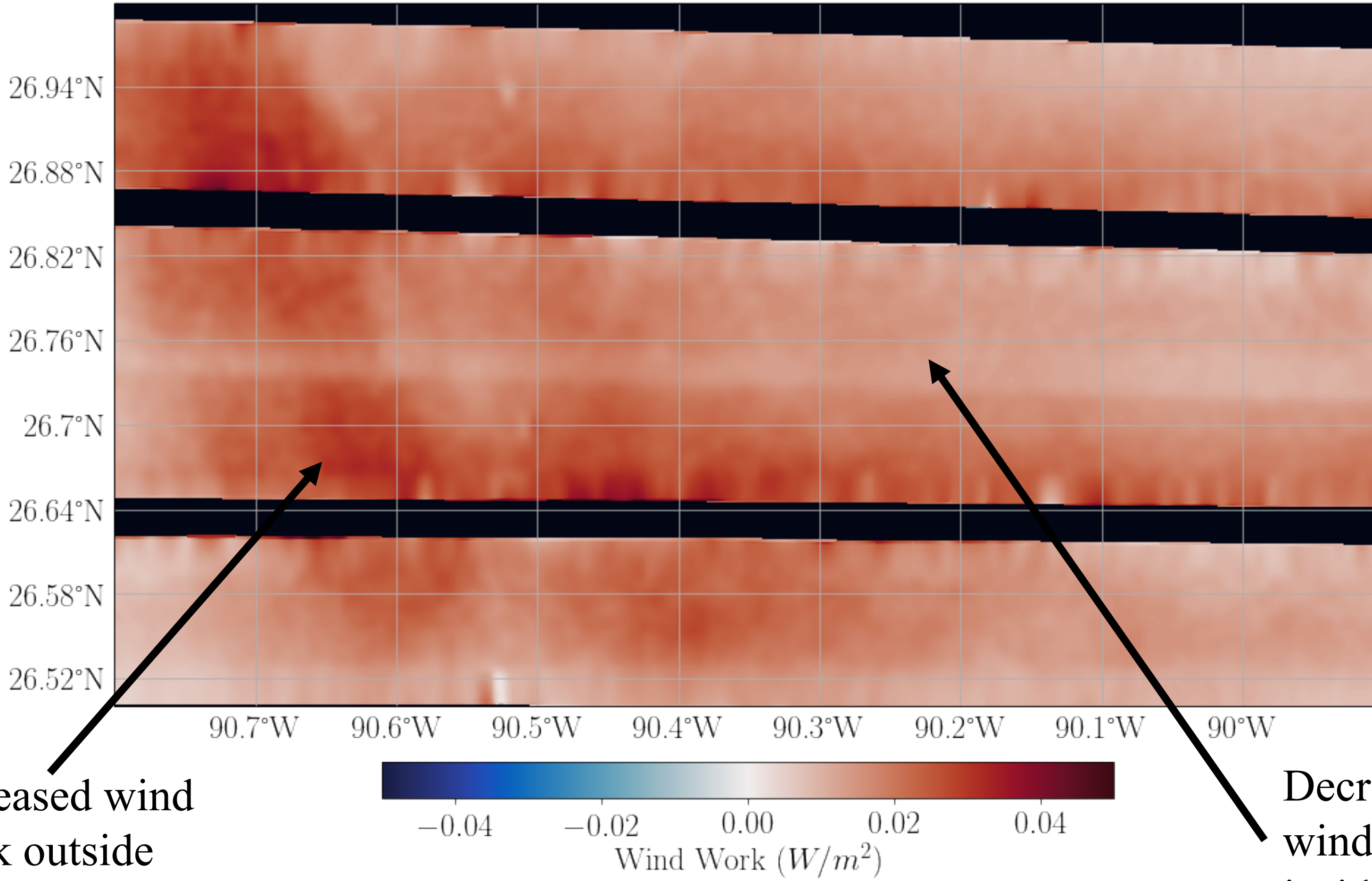
- If we assume Us is zero for the buoy, the expected stress difference between the buoy and DopplerScatt is:

$$\Delta\tau = \rho_a C_d (U_s^2 - 2U_{10} U_s)$$



Wind Work

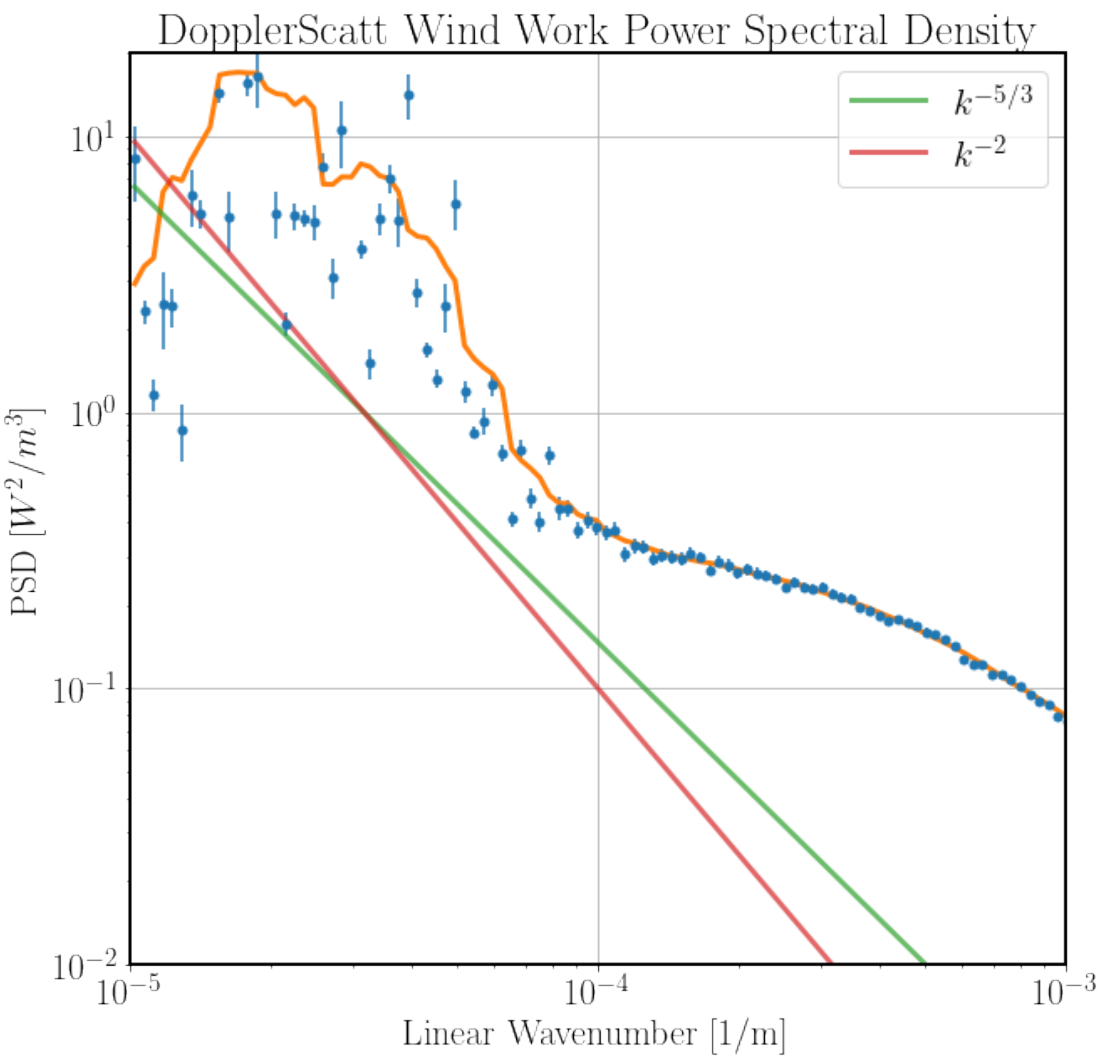
$$\dot{KE} = \vec{U} \cdot \vec{\tau} \qquad \vec{\tau} = \rho_{air} C_d |\vec{U}_{10} - \vec{U}_s| (\vec{U}_{10} - \vec{U}_s)$$



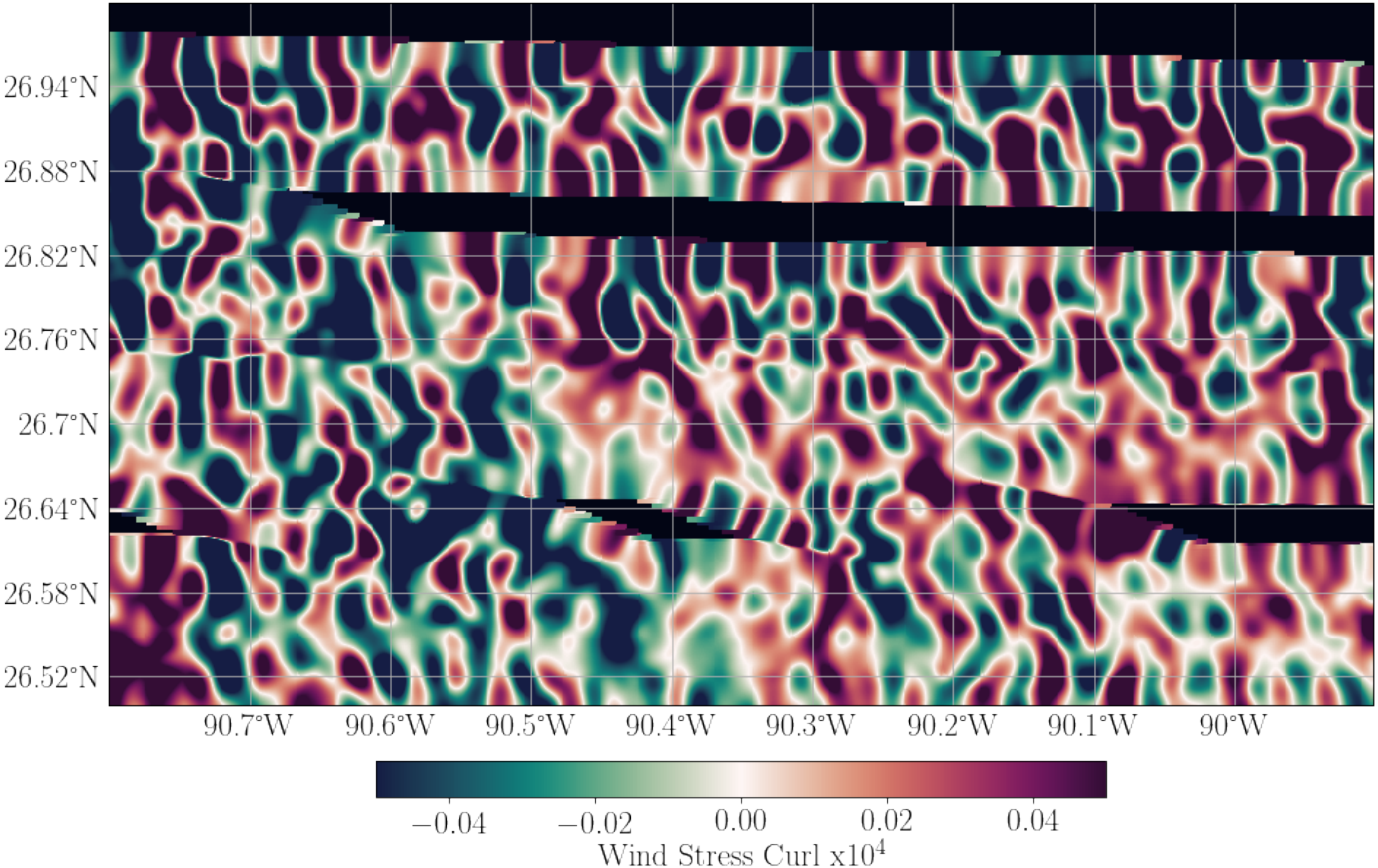
Increased wind work outside eddy.

Decreased wind work inside eddy.

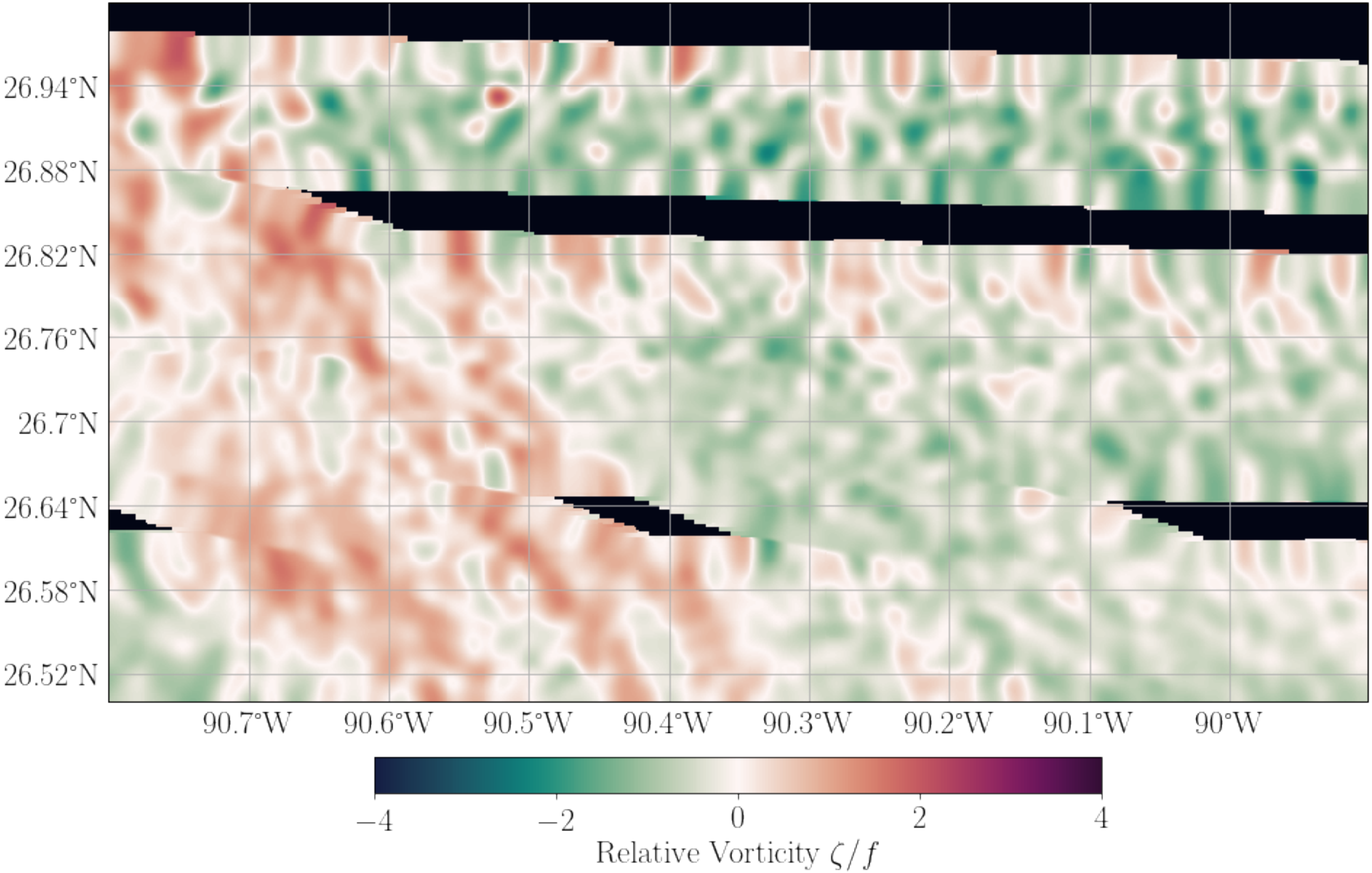
Wind-Work Power Spectral Density



Wind Stress Curl – 0324 (Moderate Winds)



Current Relative Vorticity – 0324



Wind-Current Curl Coherence

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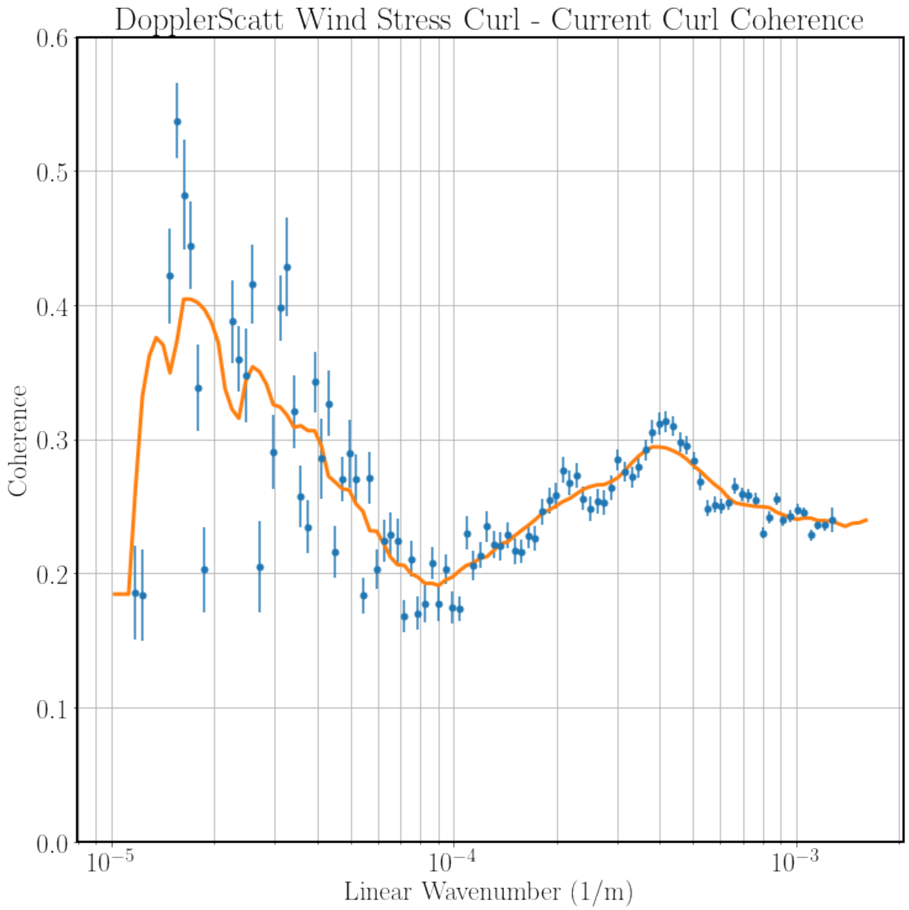

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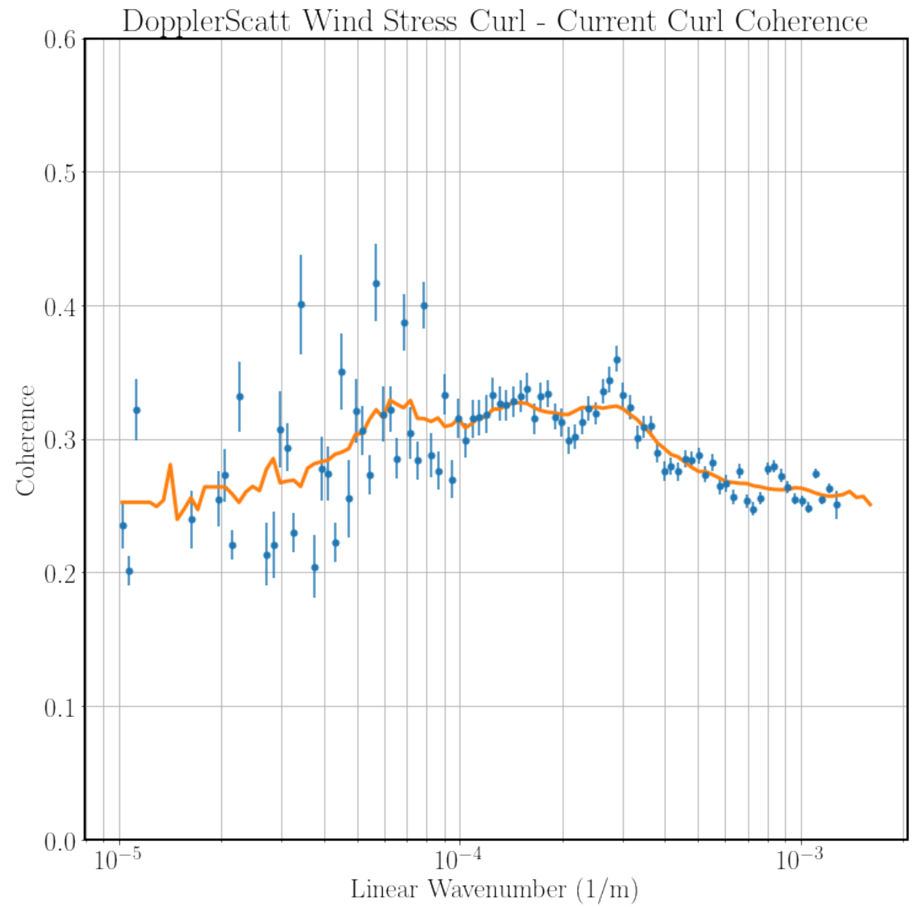

Spectra Methodology

- Grid winds/currents along track.
- Take spectrum along track for each cross-track bin.
- Multitaper windowing, detrended.
- Estimate mean and standard deviation of spectrum over all cross track spectrum realizations using jackknife sampling.
- Perform over either a single date or set of dates.
- Power spectral densities shown.
- Coherence is magnitude squared.

Derivative Fields Methodology

- Original wind/current fields taken in retrieved lat/lon coordinates at 400m resolution.
- Filtered to 1.5 km using a 2d gaussian filter.
- Curl and divergence taken for each flight line separately.
- Results are then gridded at 100m resolution (since flight lines overlap).
- Filtered back to 1 km and plotted.
- For spectra, the 1.5km filtered data are taken for each flight line.