# DopplerScatt Results: What we have learned and implications for a Winds and Currents Mission

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California Institute of Technology

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# DopplerScatt Overview

## DopplerScatt Programmtic Overview

Scanning Doppler radar developed under NASA's IIP program
Becoming operational under NASA AITT program by 2019

## Data Products:

1. Vector ocean surface currents
2. Vector ocean surface winds
3. Radar brightness maps (sensitive to surfactants such as oil films)

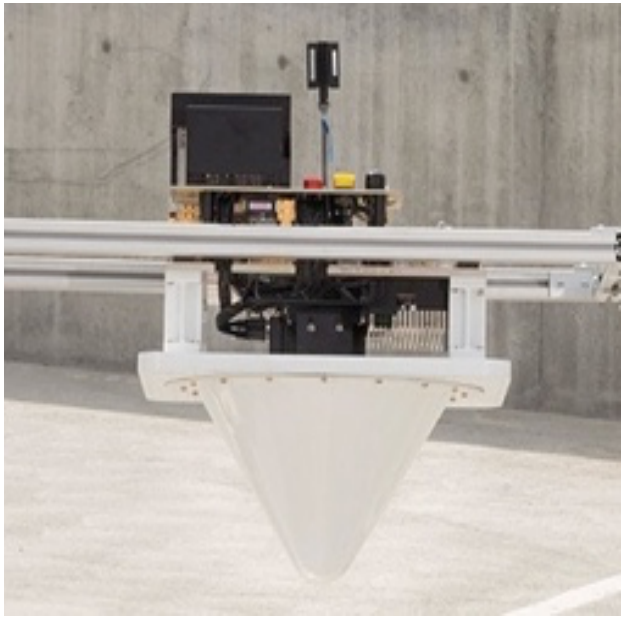
Data products are still being refined under AITT. Will be posted in NASA PODAAC when finished.

## Mapping capabilities:

- 25 km swath
- maps 200km x 100km area in about 4 hrs
- 200m data product posting
- Mapping within ~600 m of coast
- ~5-10 cm/s radial velocity precision.
- ~ 1 m/s wind speed, <20° wind direction.

## Campaigns flown/planned:

- Oregon coast (2016)
- SPLASH (Submesoscale Processes and Lagrangian Analysis on the Shelf) in Mississippi River Plume
- (CARTHE) & Taylor Oil Platform Plume (NOAA), April 18-28, 2017.
- KISS-CANON in Monterey Bay May 1-4, 2017.
- California current (September, 2018)



DopplerScatt instrument. It has been deployed on a DOE King Air and will transition to an operational instrument in the NASA King Air B200.



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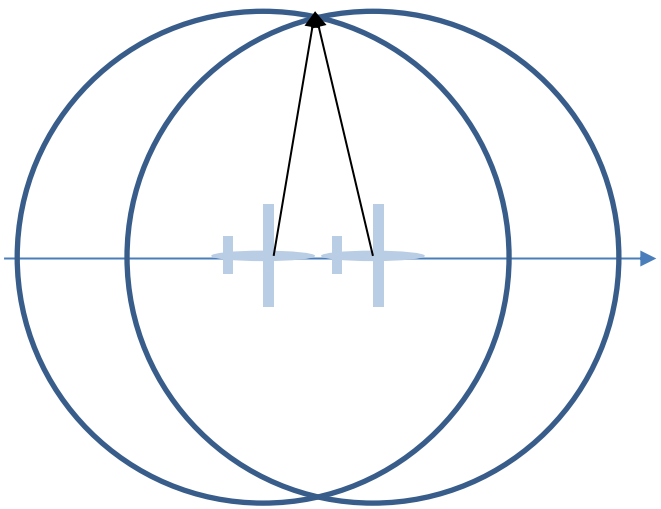
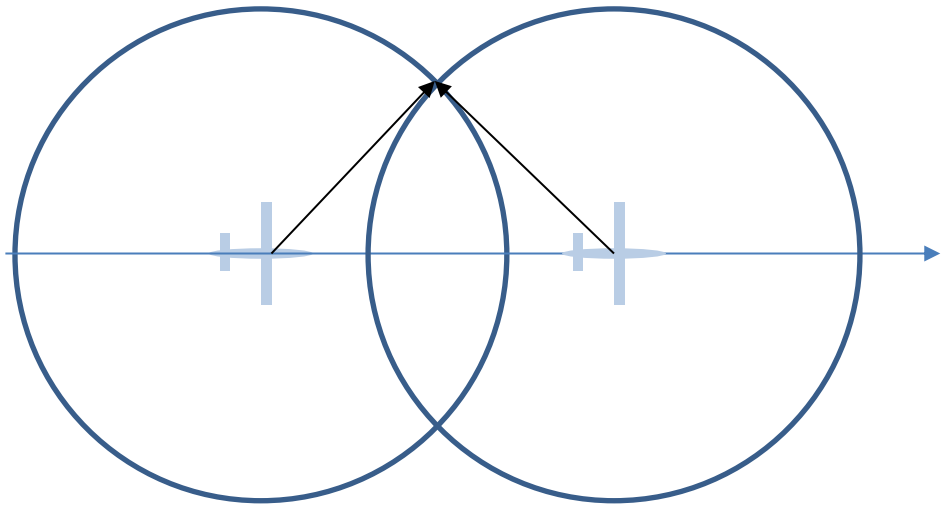
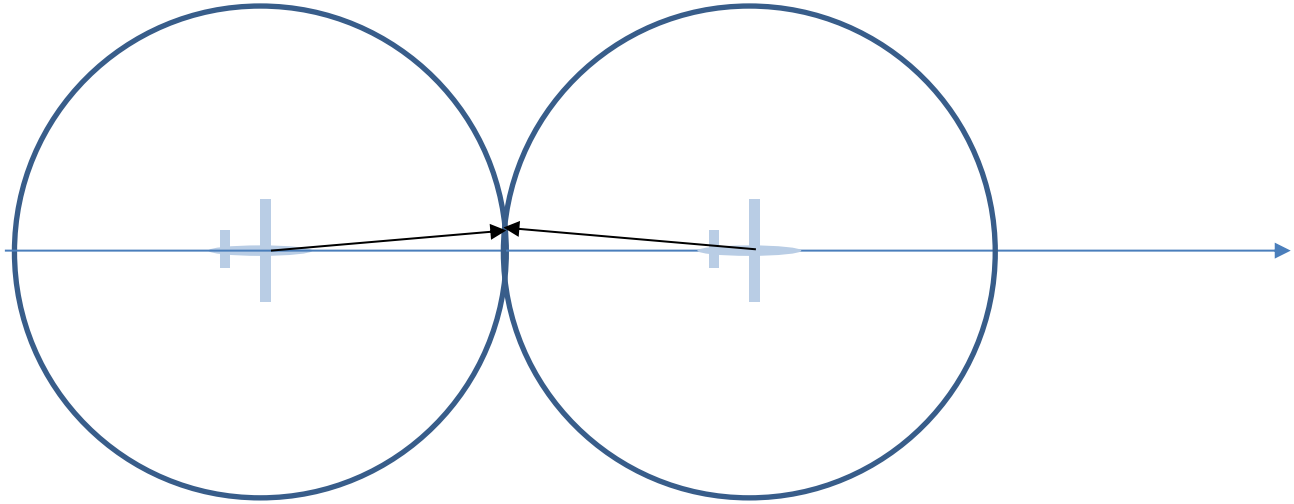
# DopplerScatt Vector Estimation



Bad azimuth diversity



Good azimuth diversity



Bad azimuth diversity

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# SCIENCE

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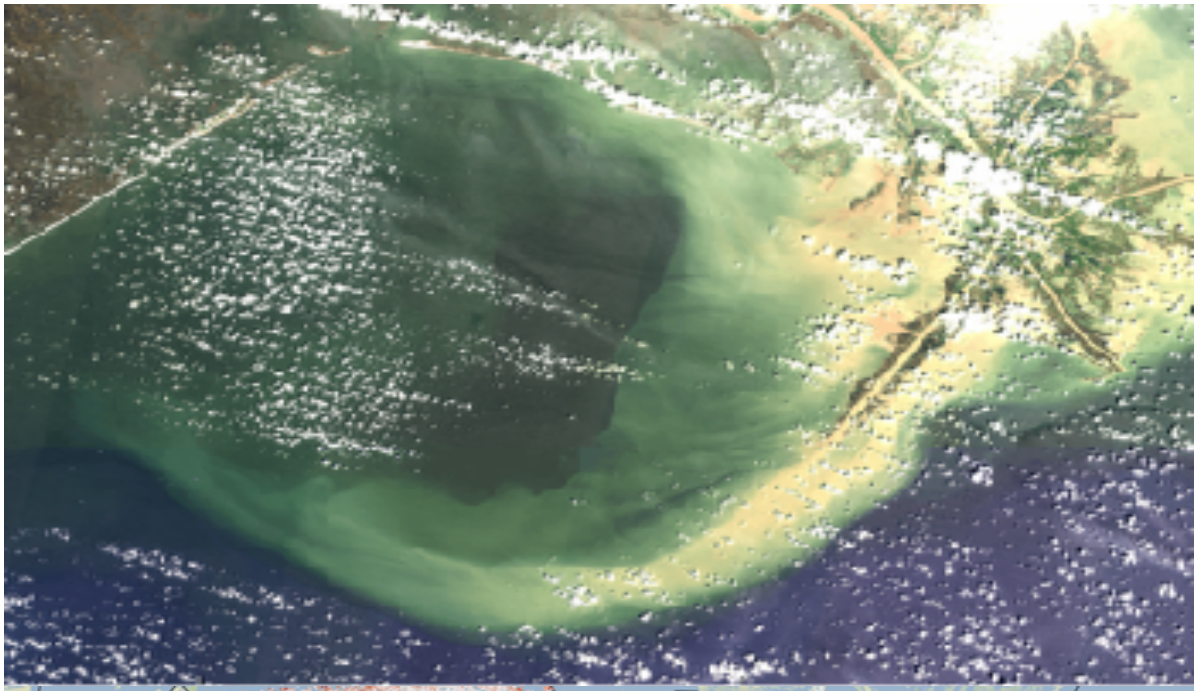
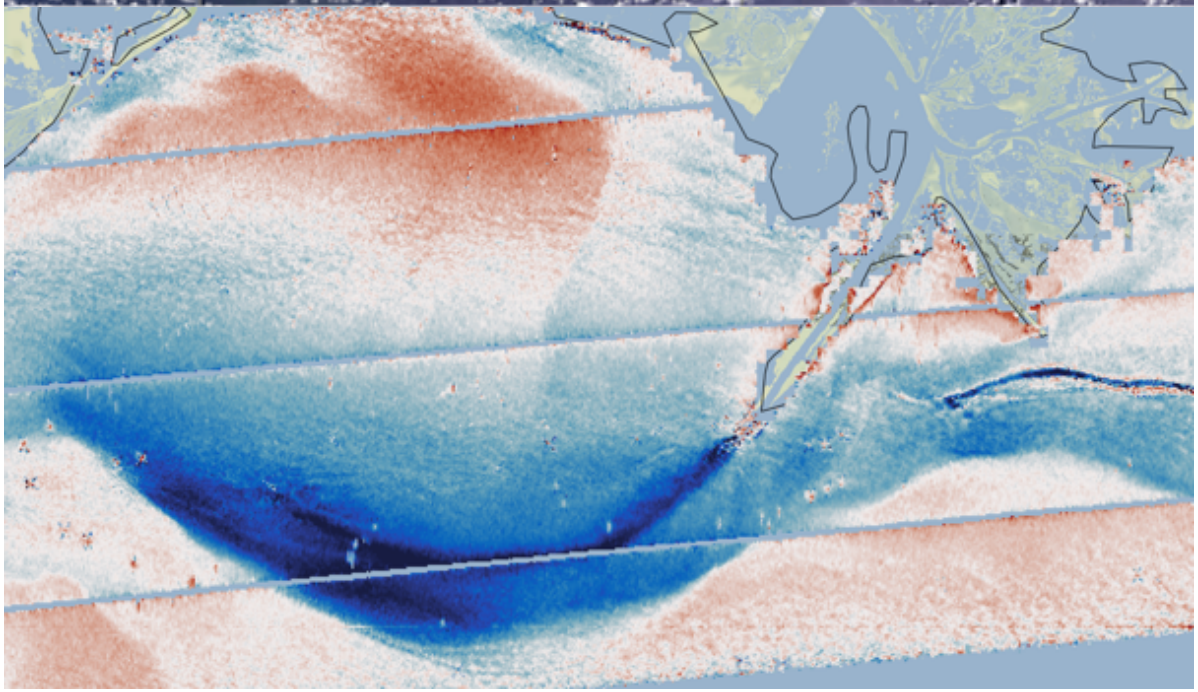


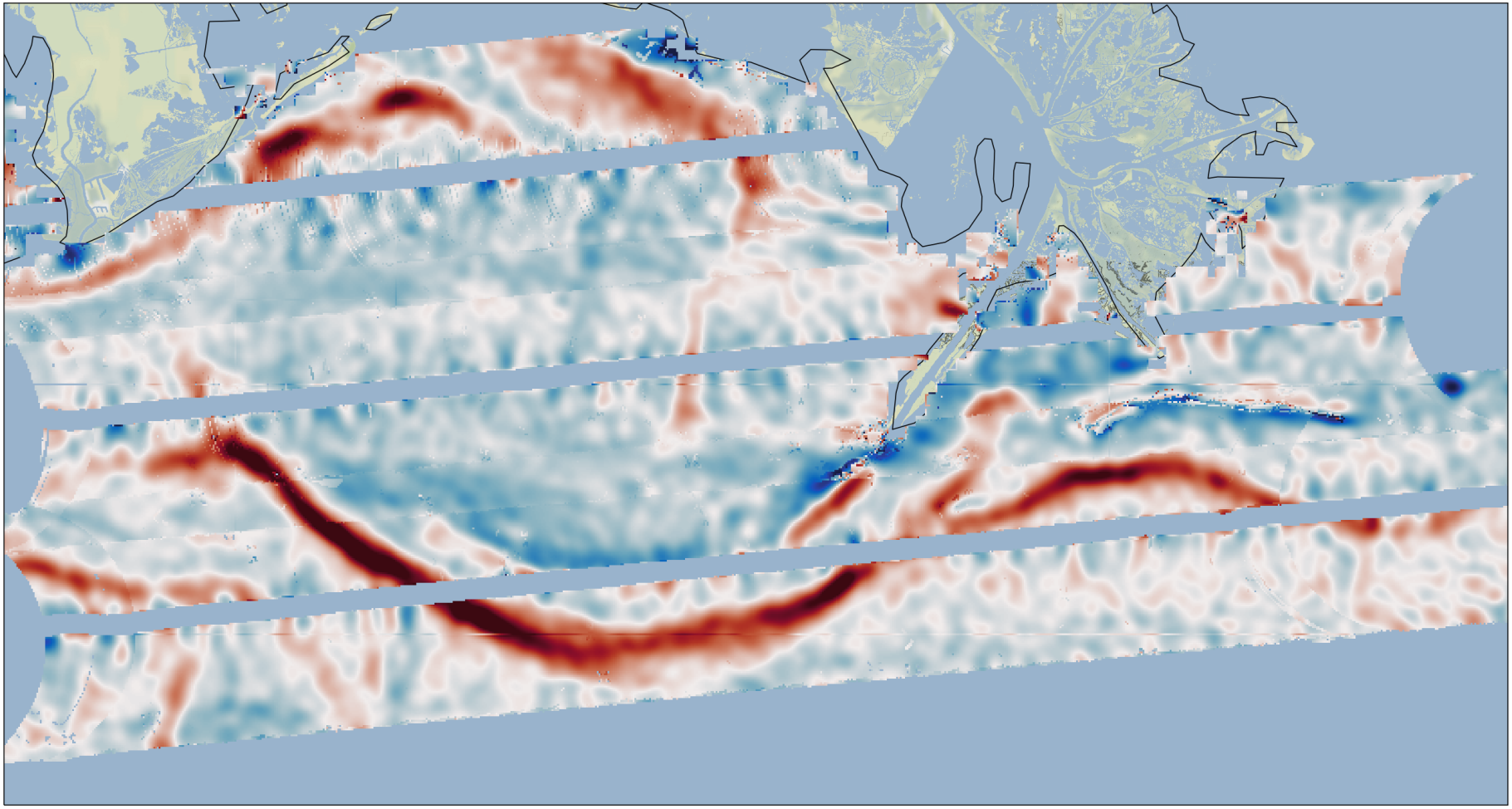
Sentinel 3 2017-04-18
Courtesy of Copernicus Sentinel, processed by ESA



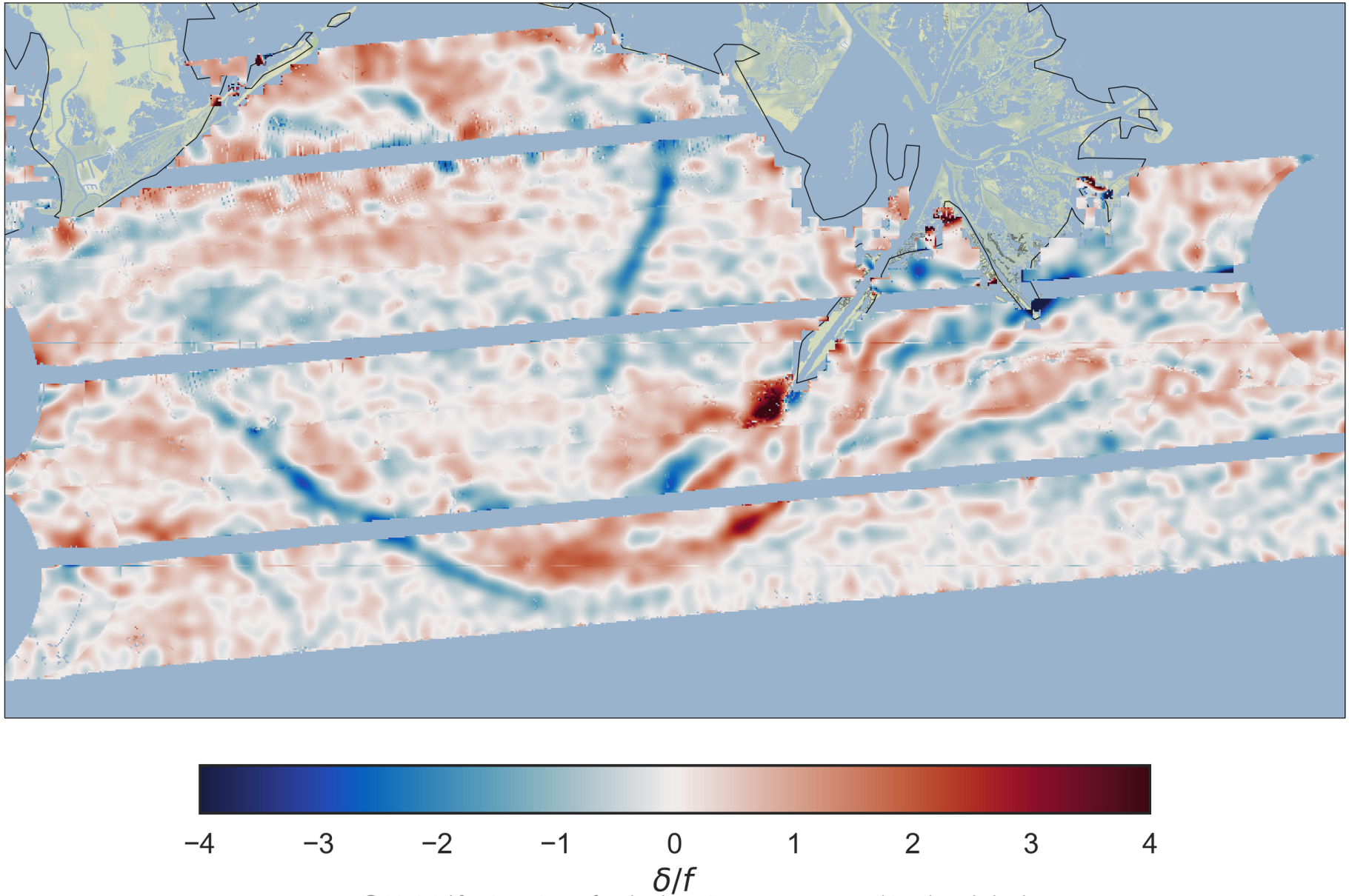
DopplerScatt surface current U component.

Circulation pattern matches Sentinel 3 color pattern very closely.

# Relative Vorticity

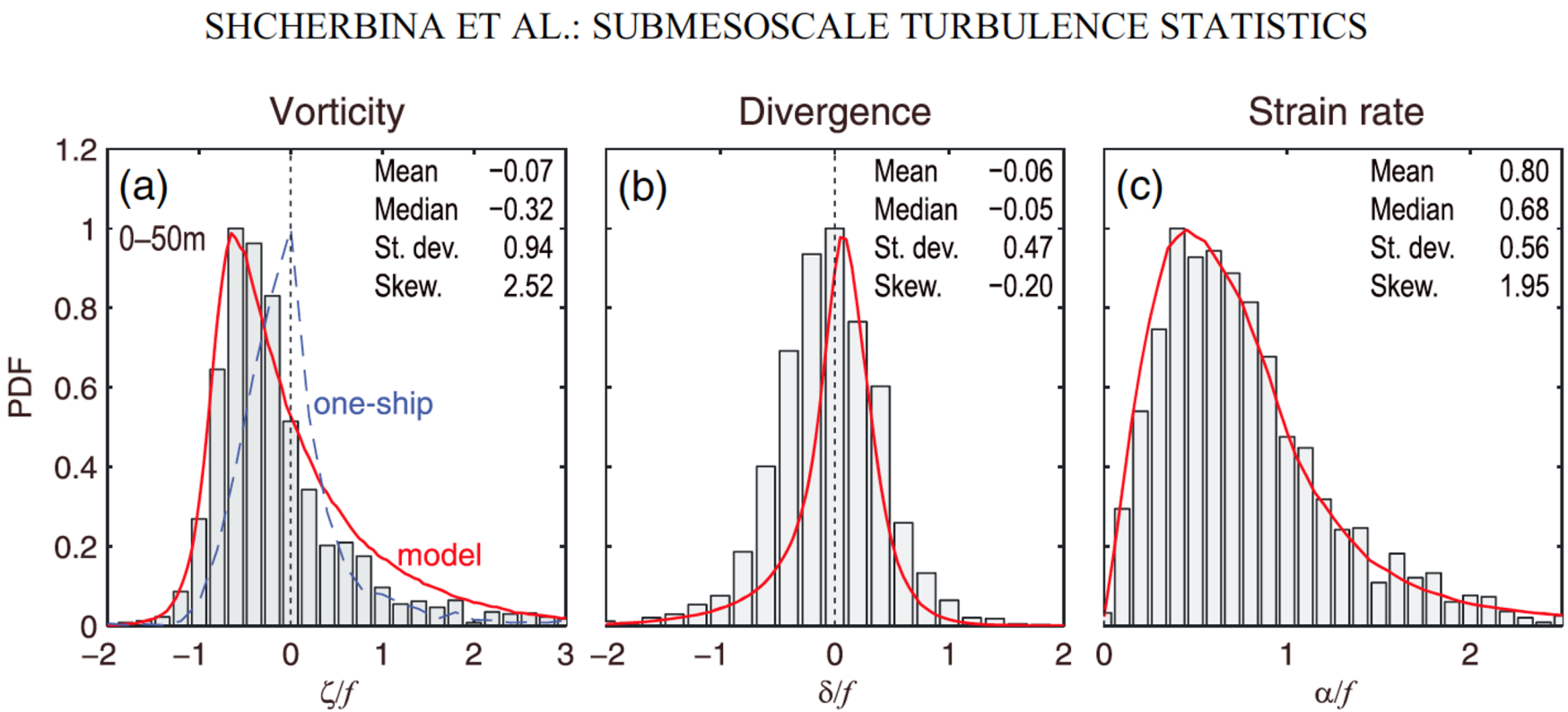


# Divergence



# Derivative PDFs from Shcherbina et al., GRL, 2013

Data collected by two ships traveling 1 km apart in parallel for 500 km and using ADCPs




Skewness > 0 expected as ζ>0 structures have greater stability

Divergence range smaller than vorticity. Slightly skewed towards convergence.

Strain rate approximately chi-squared distributed.

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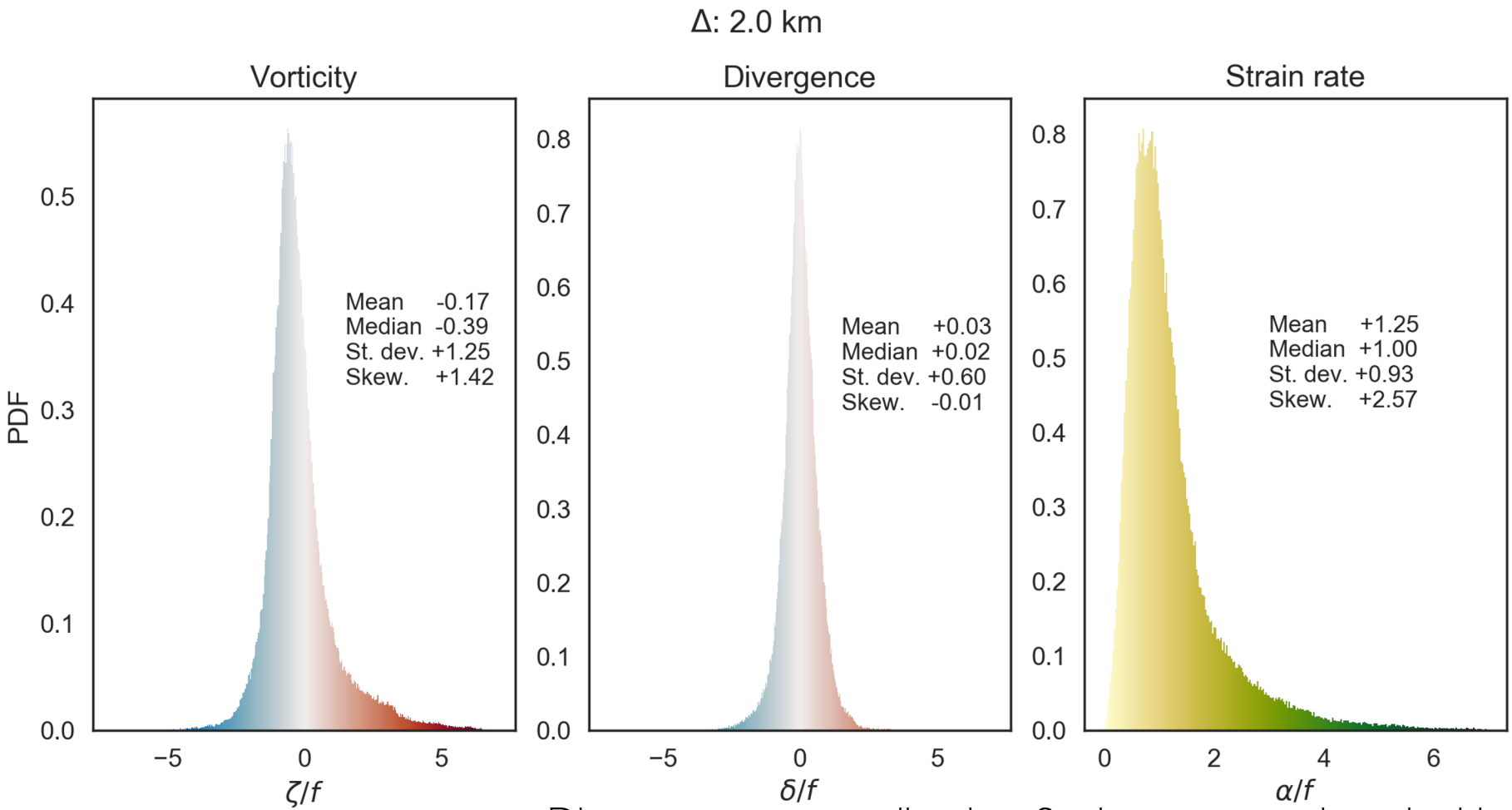
# DopplerScatt Derivative PDFs

Derivatives show similar statistics to Shcherbina et al. 2013




Skewness > 0 expected as ζ>0 structures have greater stability

Divergence range smaller than vorticity. Slightly skewed towards convergence.

Strain rate approximately chi-squared distributed.

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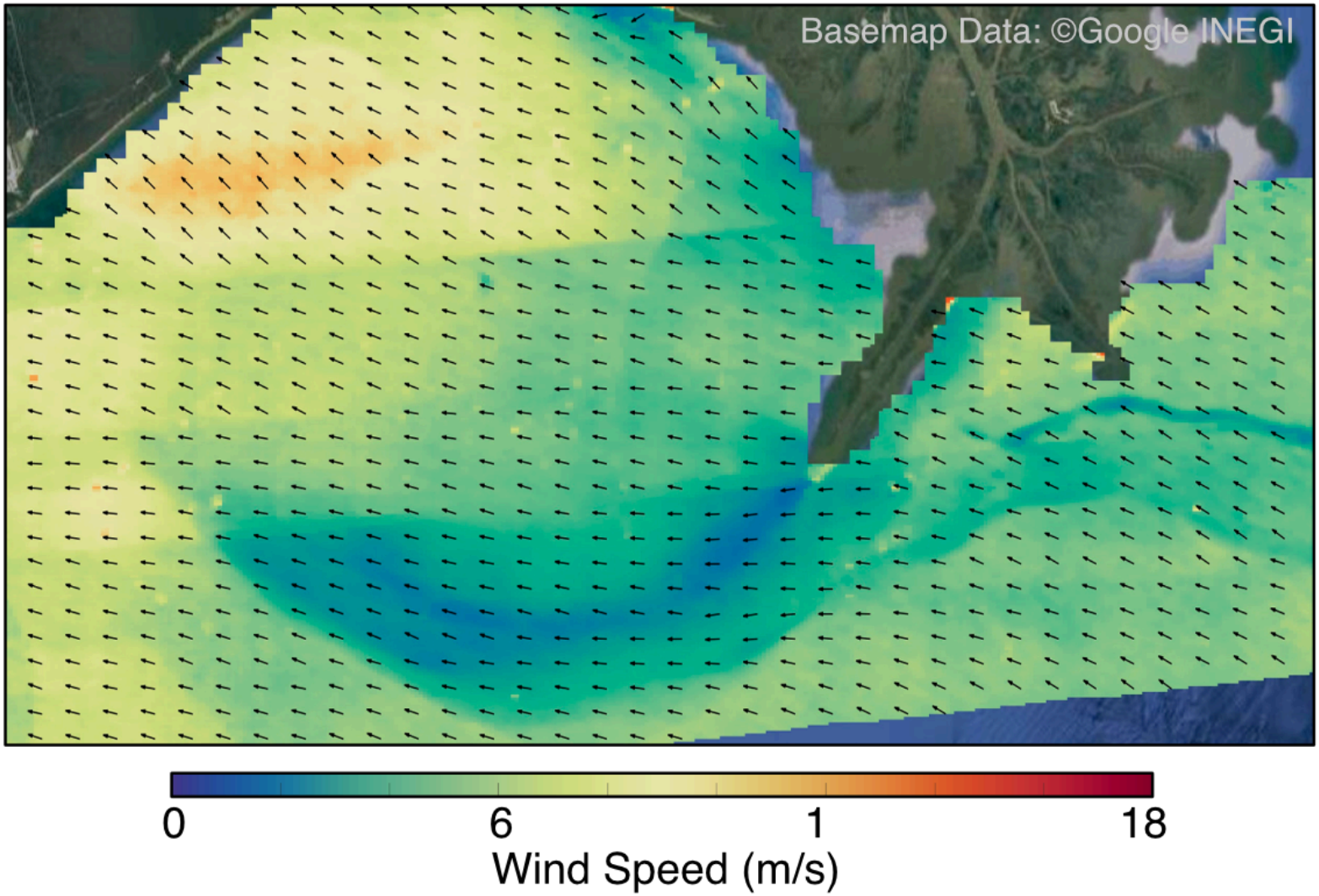
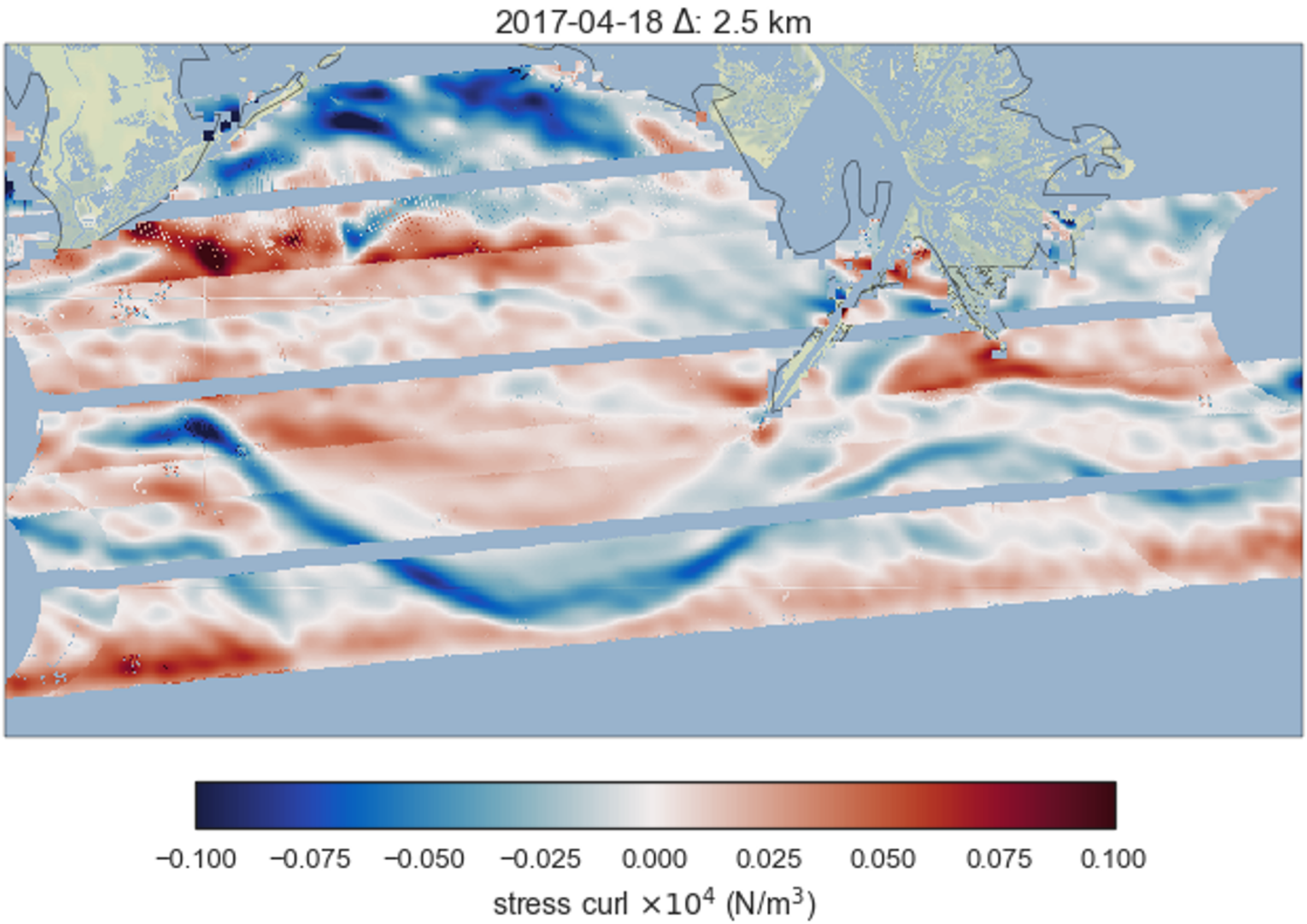
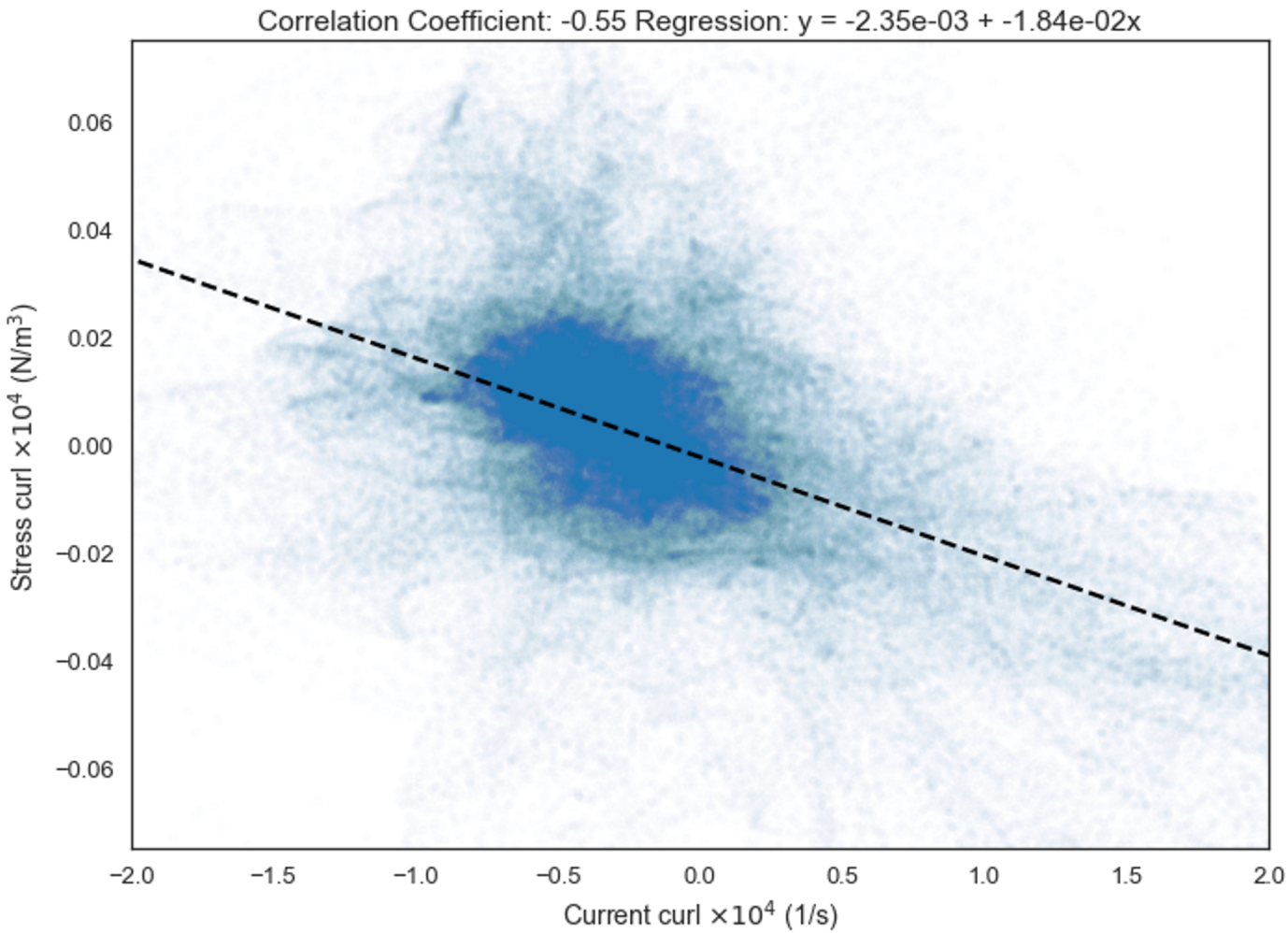
# Winds



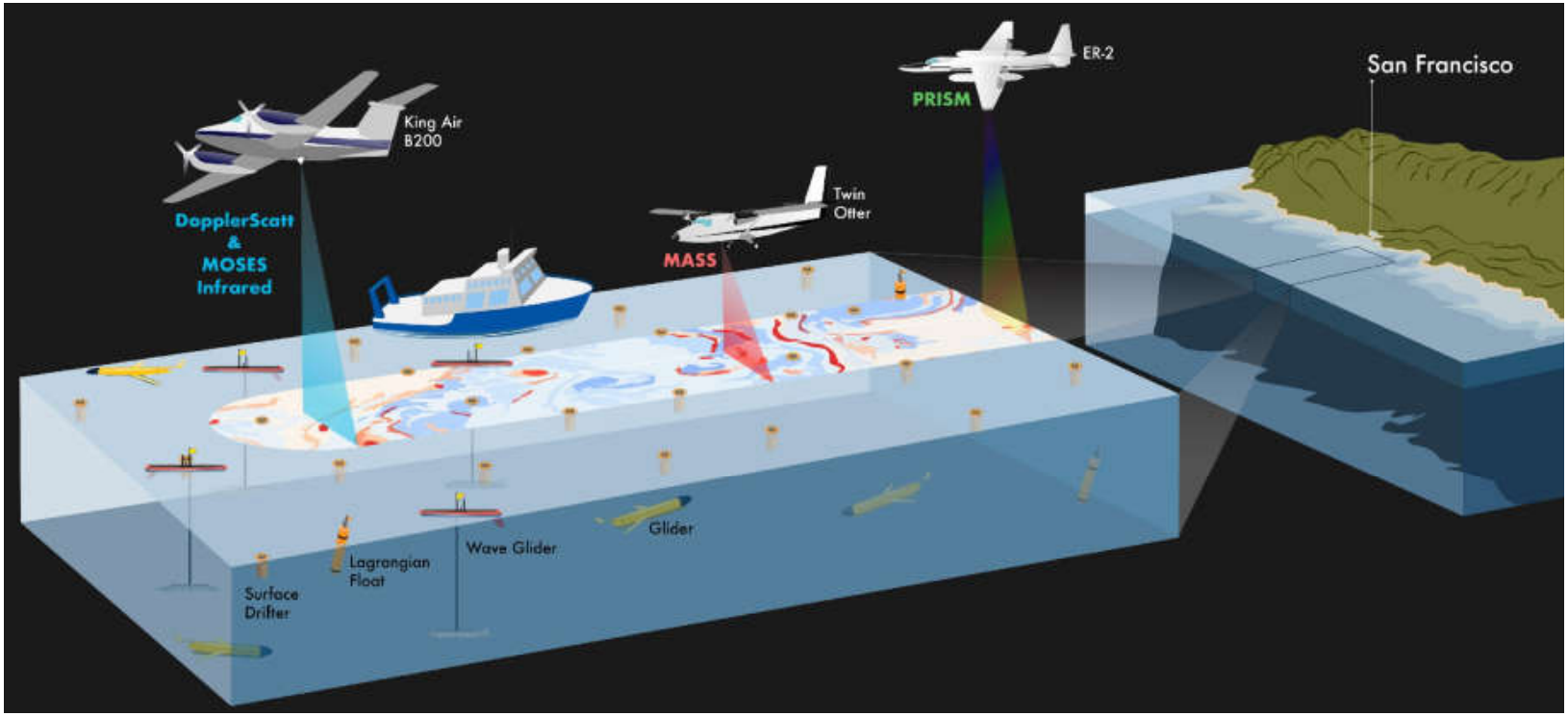
# Wind Stress Curl



# Wind Stress Curl vs Relative Vorticity



# Coming up




- SMODE: Sub-Mesoscale Ocean Dynamics Experiment
- NASA Earth Ventures Suborbital-3: 2019-2023
- PI Tom Farrar (WHOI)

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# PHENOMENOLOGY

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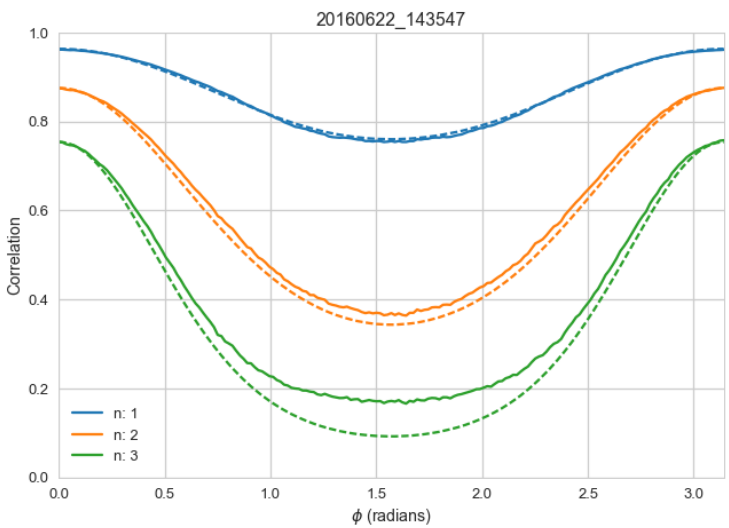
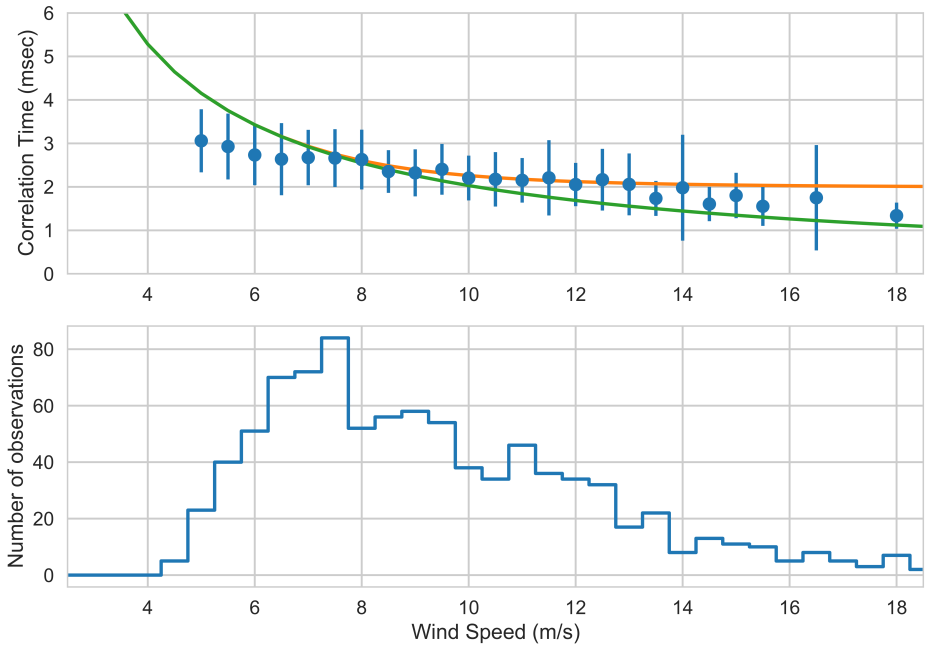
# Correlation

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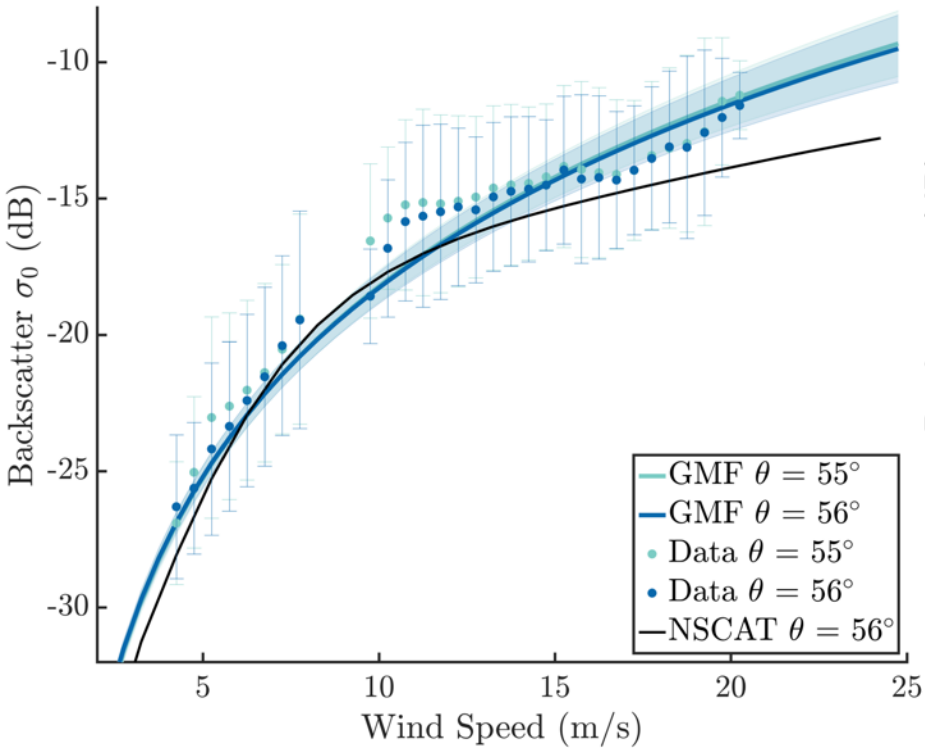
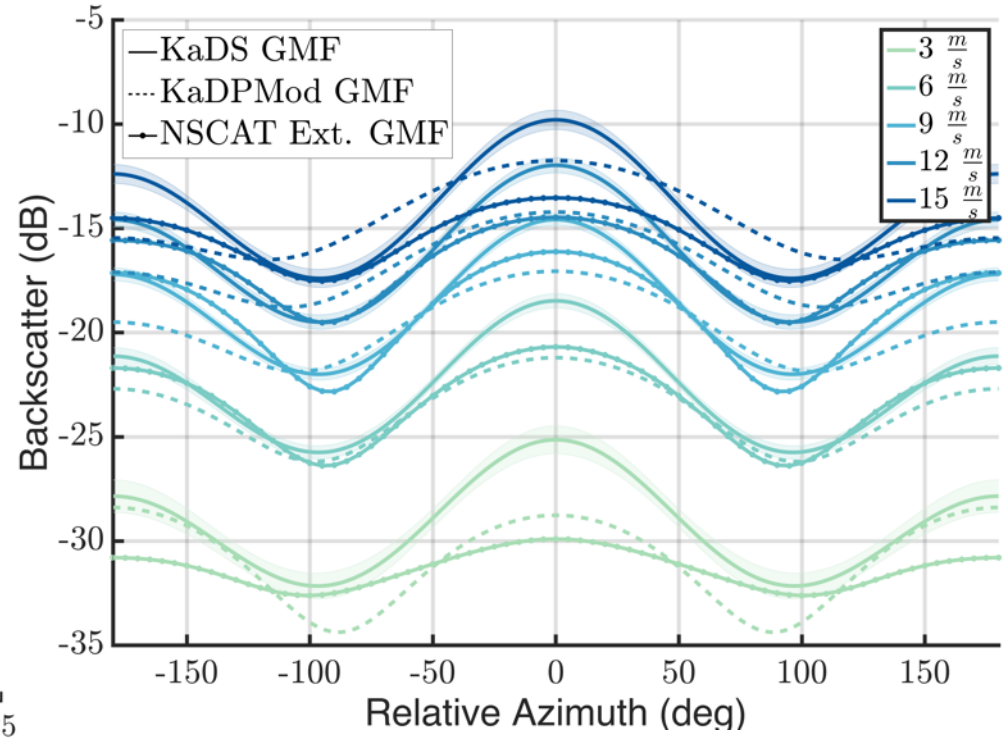
# Scatterometer Wind GMF




***The mean radar backscatter increases with wind speed.***




***The backscatter intensity is modulated as a function of azimuth angle relative to wind direction.***

- By combining measurements from multiple azimuth angles, wind speed and direction can be estimated. Ku & Ka backscatter have similar characteristics, so both are suitable for wind estimation.
- Experiments have shown that backscatter is proportional to wind stress (although normally parametrized as neutral wind).

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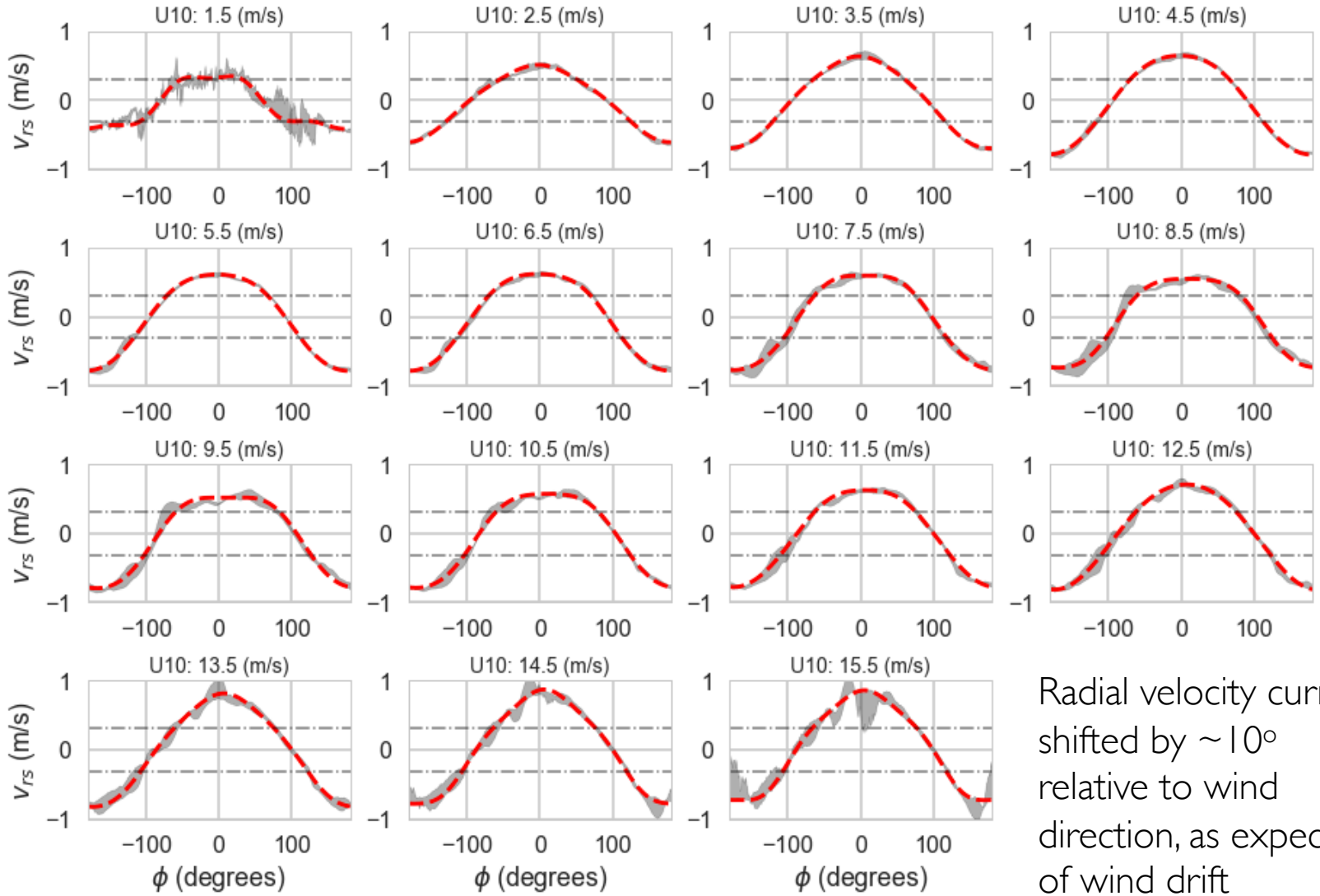
# Radial Velocities Binned by Wind Direction




Radial velocity currents shifted by ~10° relative to wind direction, as expected of wind drift

Dot-dash lines indicate Bragg phase velocities

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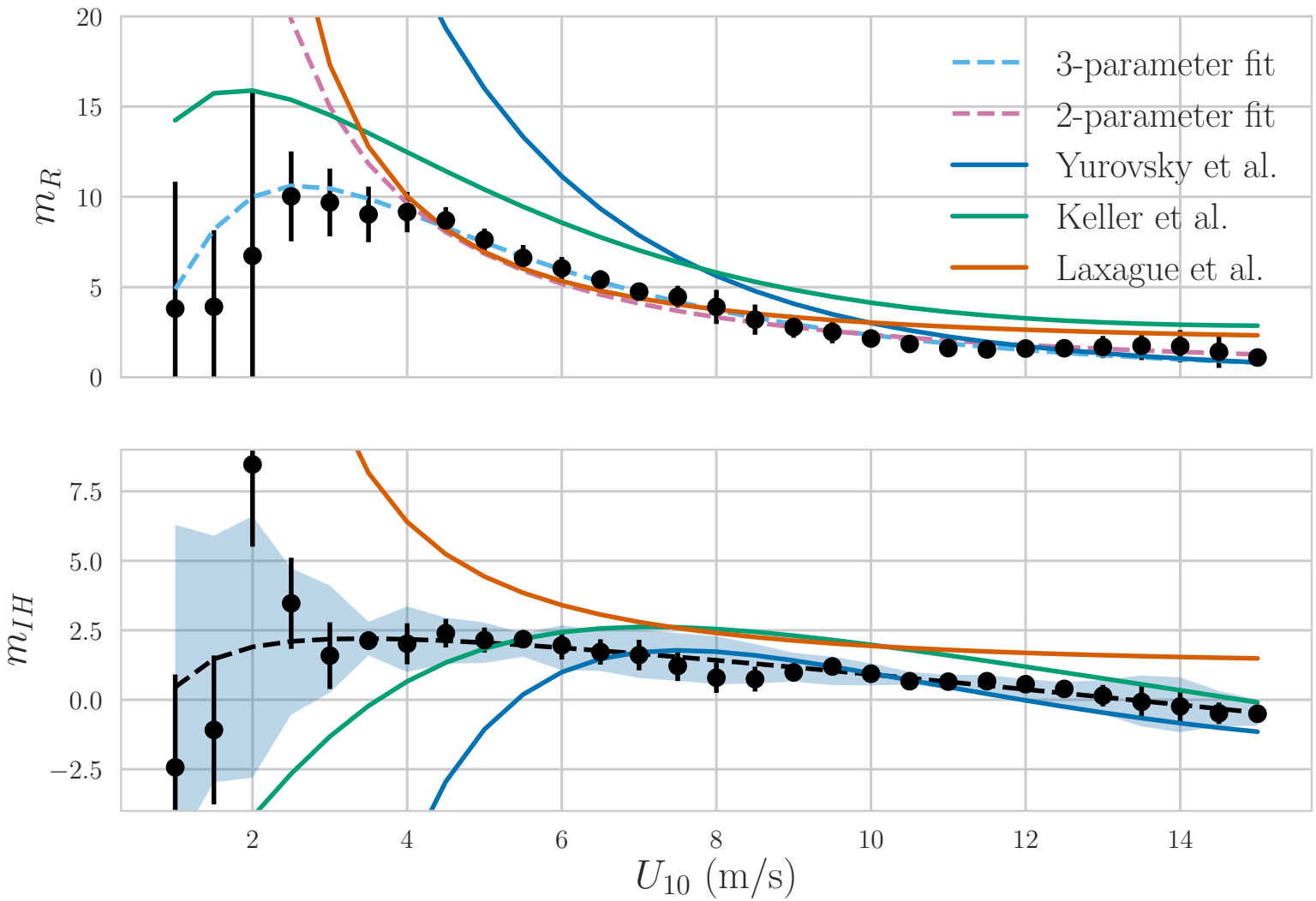
# Hydrodynamic Modulation

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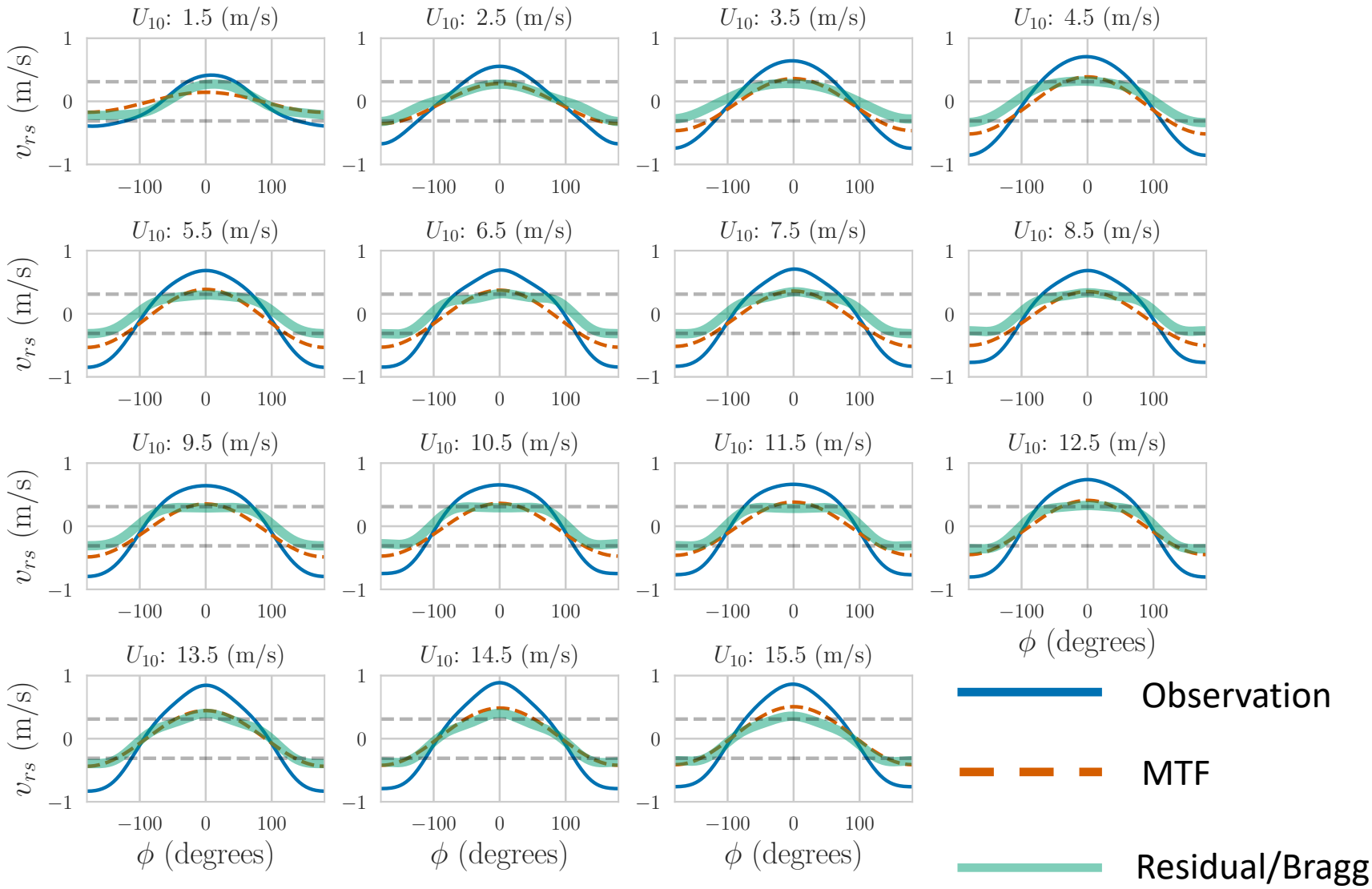
# Radial Velocity Decomposition

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# CALIBRATION

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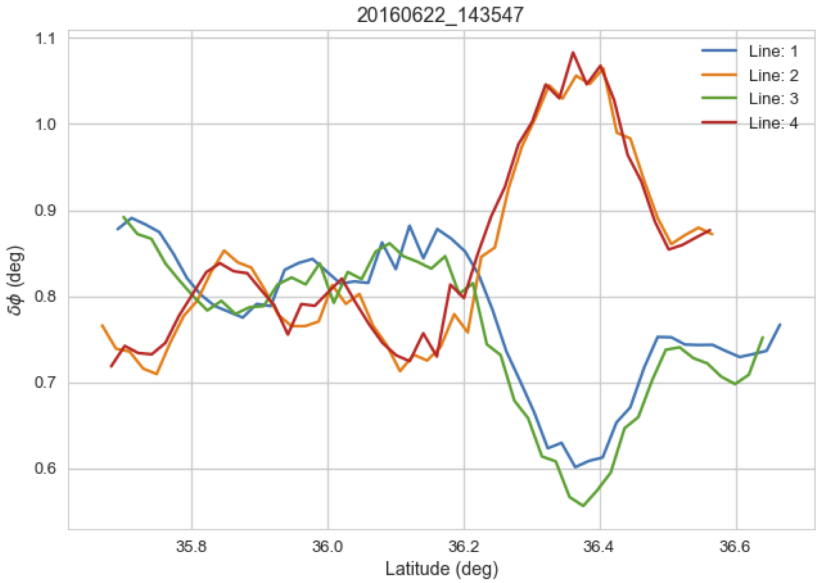
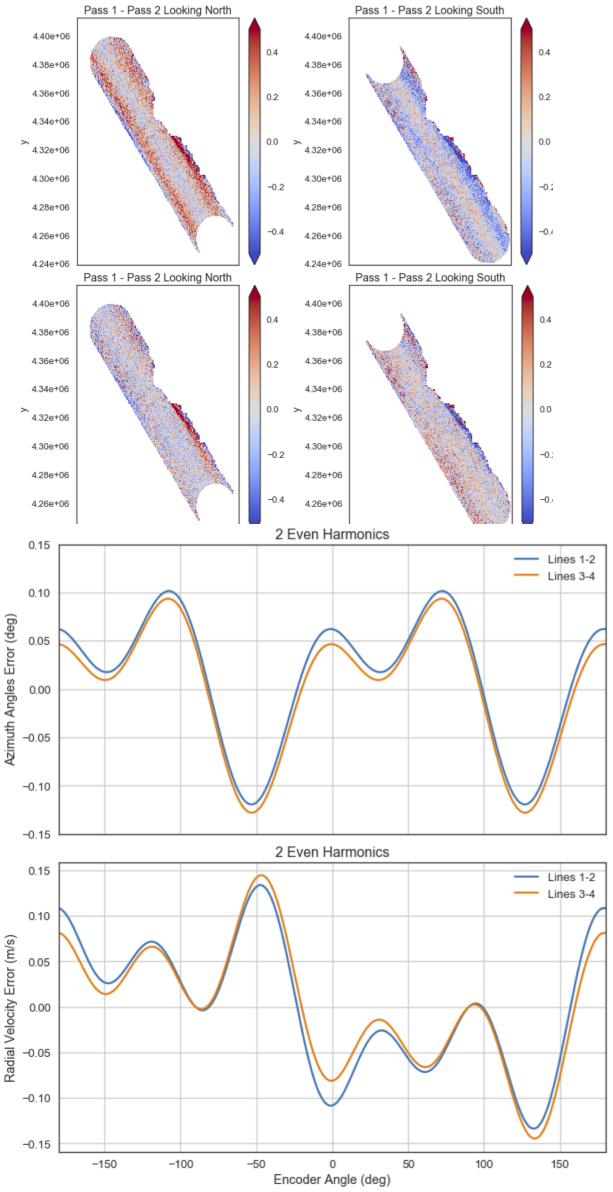
# Calibration Effects




Currents influence calibration results




A simple harmonic calibration is mot sufficient

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# ERROR MODEL VALIDATION

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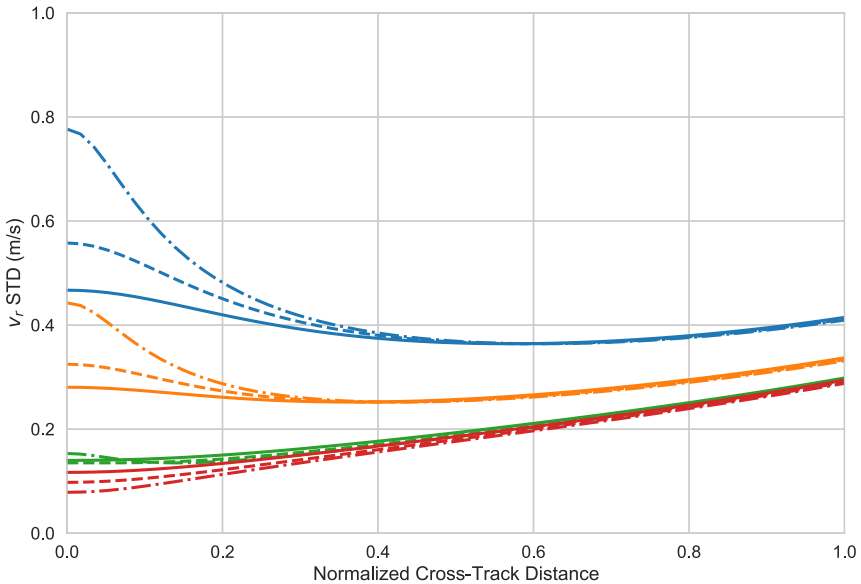
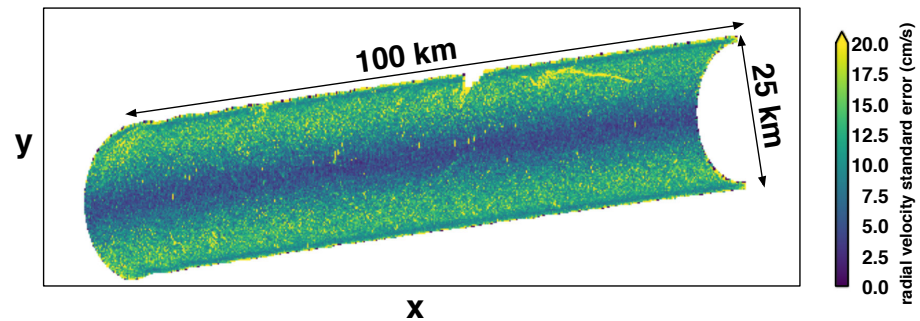
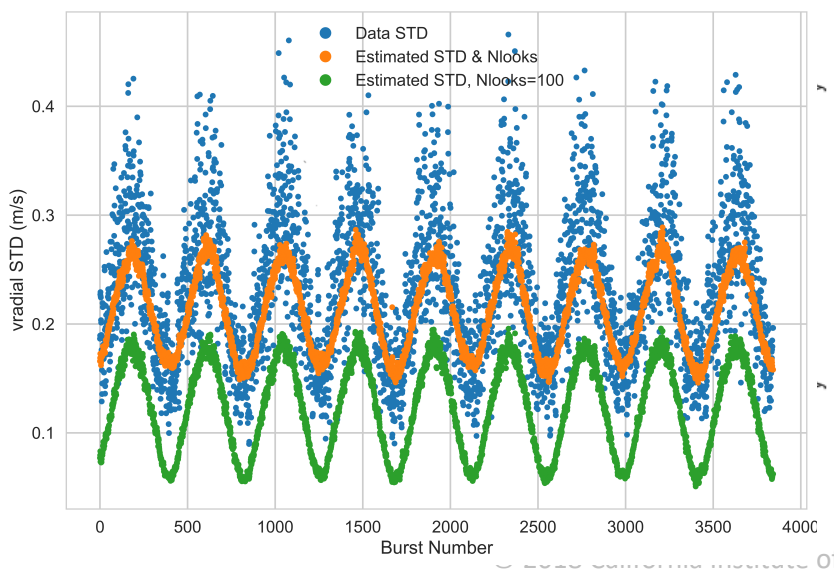
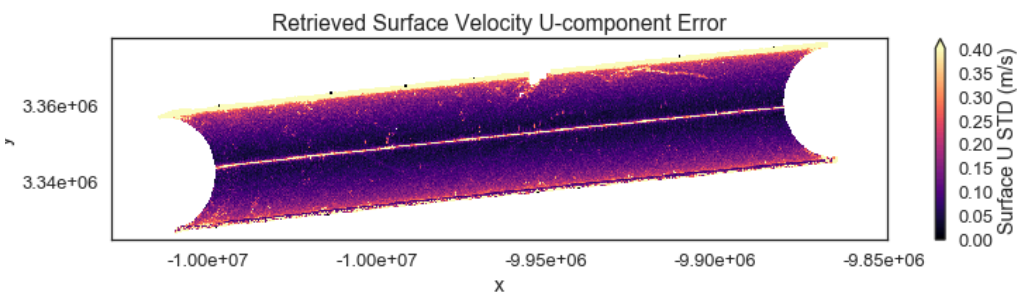
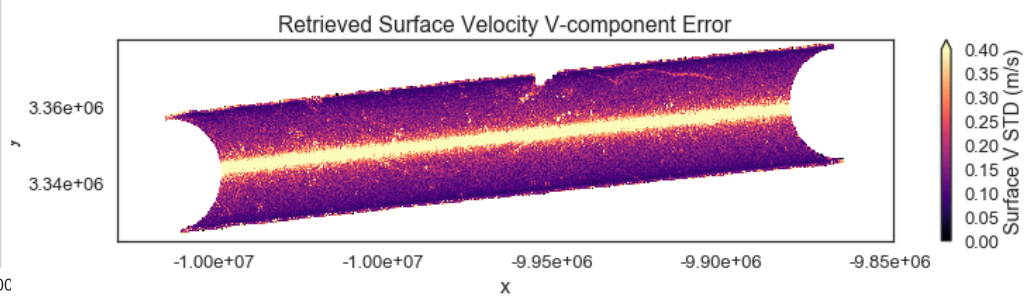
# Surface Velocity Random Errors

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# SPACEBORNE SYSTEM DESIGN

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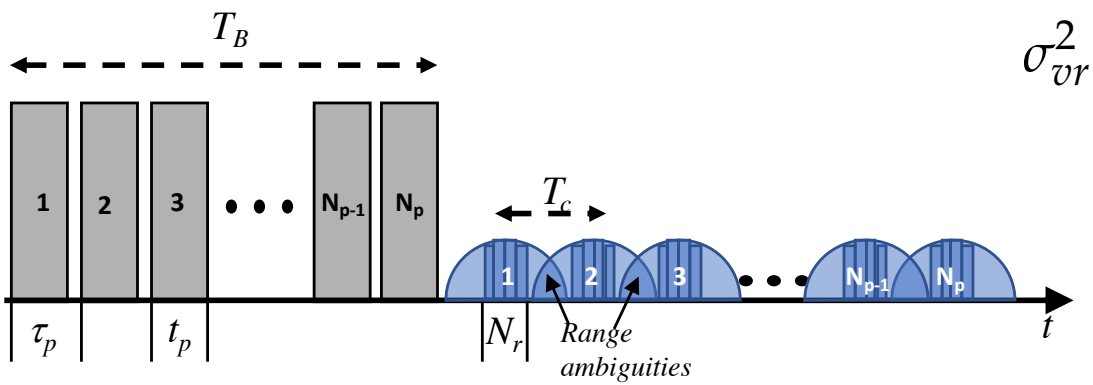
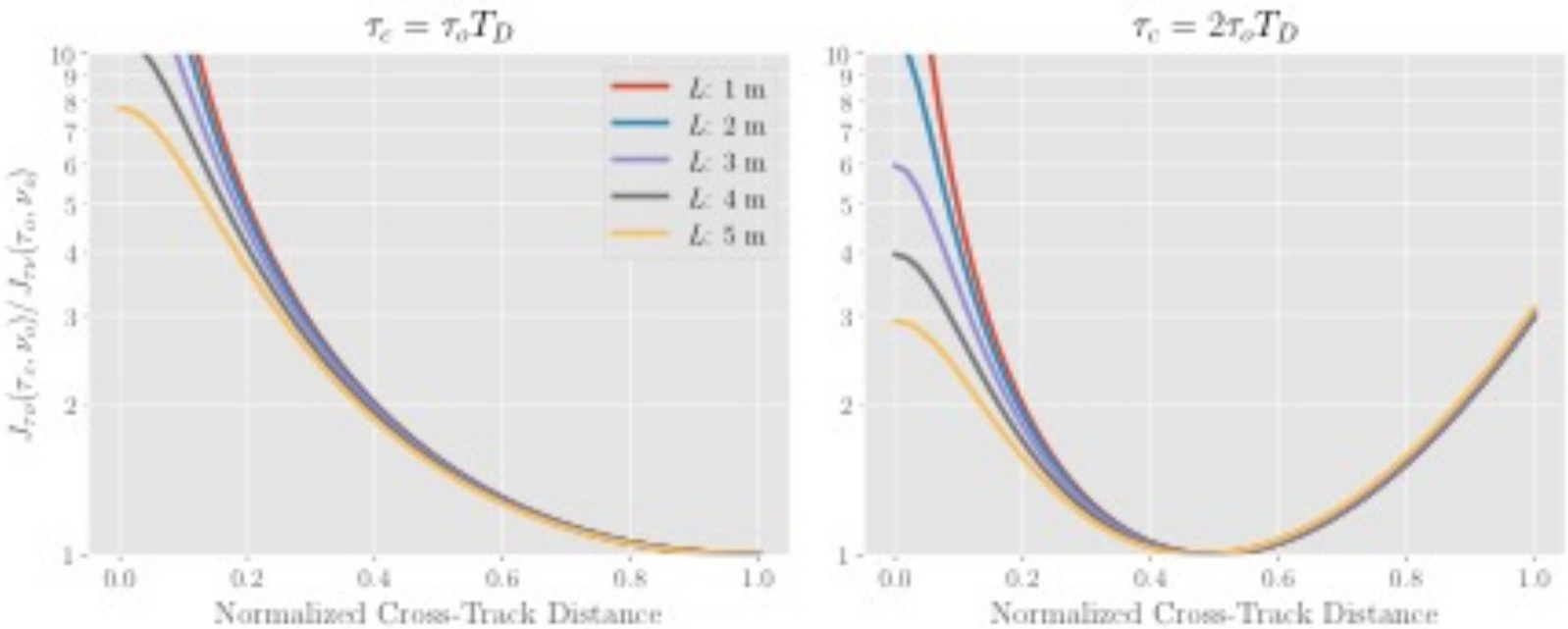
# Lesson 1: Optimize Pulse Separation by Keeping Pulse Correlation Constant




$$\sigma_{vr}^2 = \left(\frac{1}{2k\tau_p}\right)^2 \frac{1}{2N_r N_b} \frac{1-\gamma^2}{\gamma^2}$$

Pulse separation as long as possible

Pulses as correlated as possible

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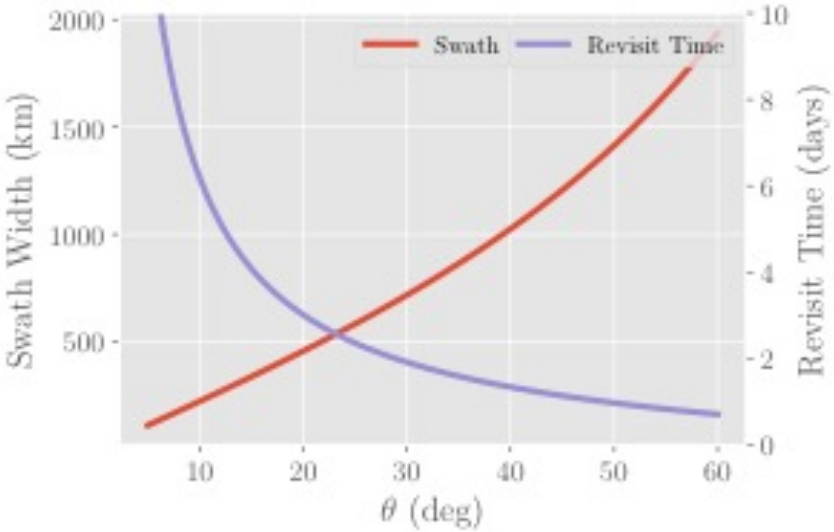
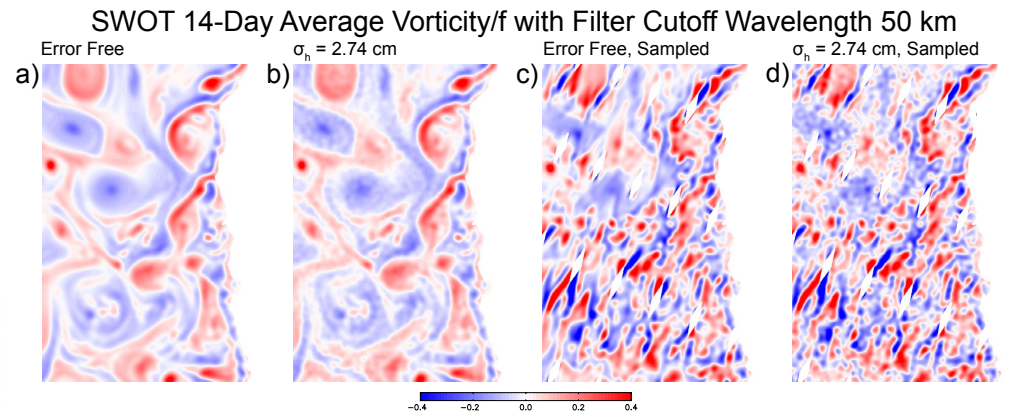
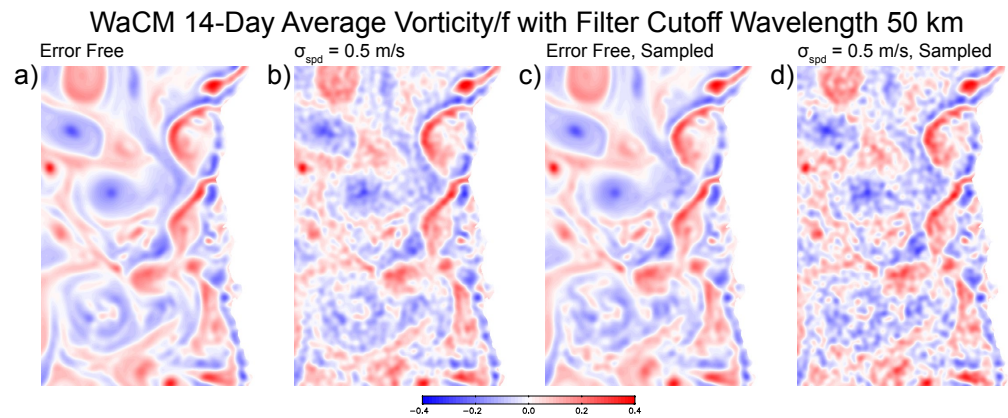
# Lesson 2: Minimize Temporal Aliasing by Achieving the Widest Swath Possible

***Wide swath & temporal sampling are key***



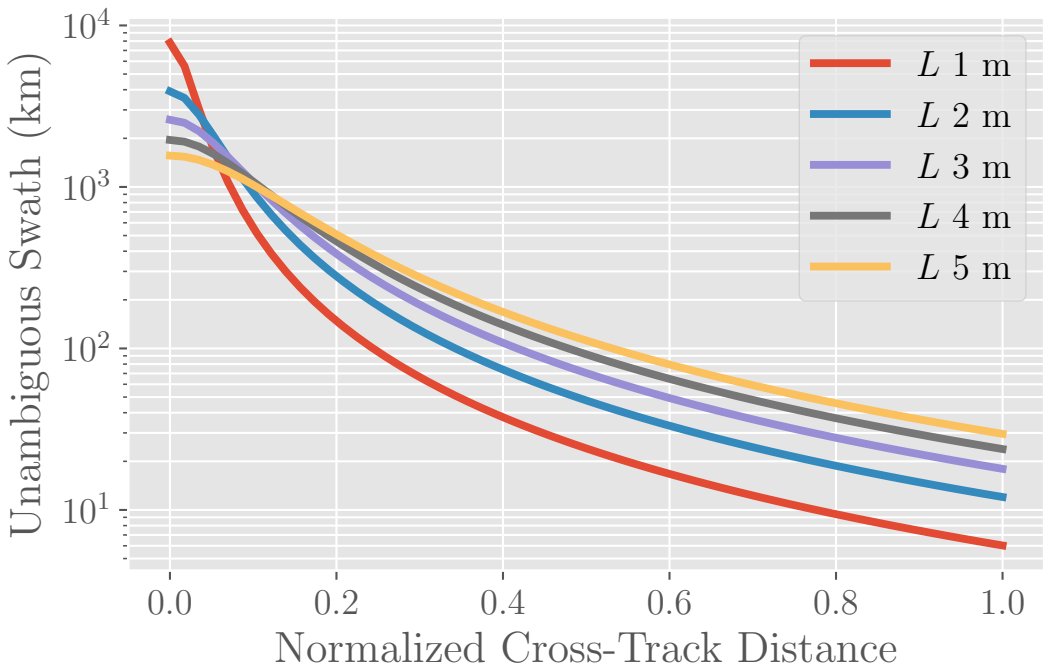



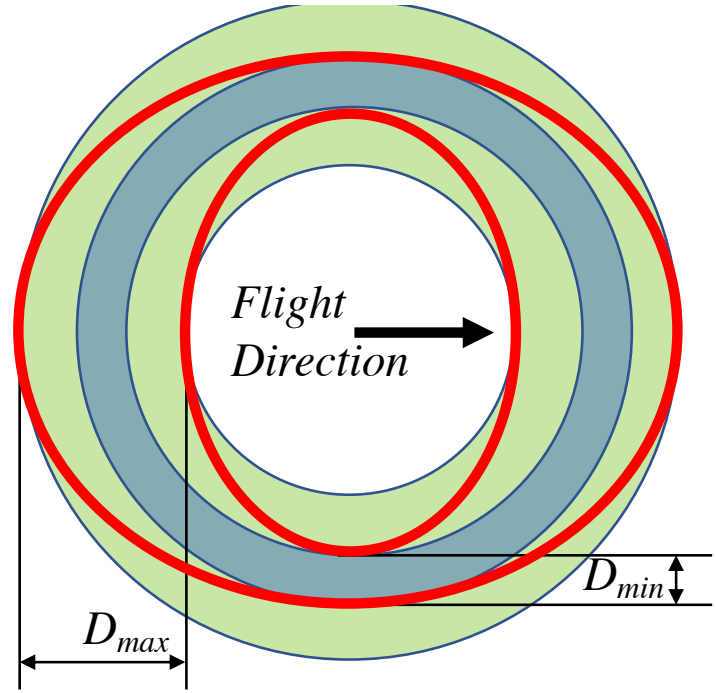




From Chelton et al, 2018
Prog. Ocean. In press

WaCM samples O(2x/day) so that inertial and tidal signal aliasing is minimized in temporal averages.

# Lesson 3: Minimize Mapping Error by Coverage Minimizing Gaps




By varying the PRF, its is easier to achieve swath continuity

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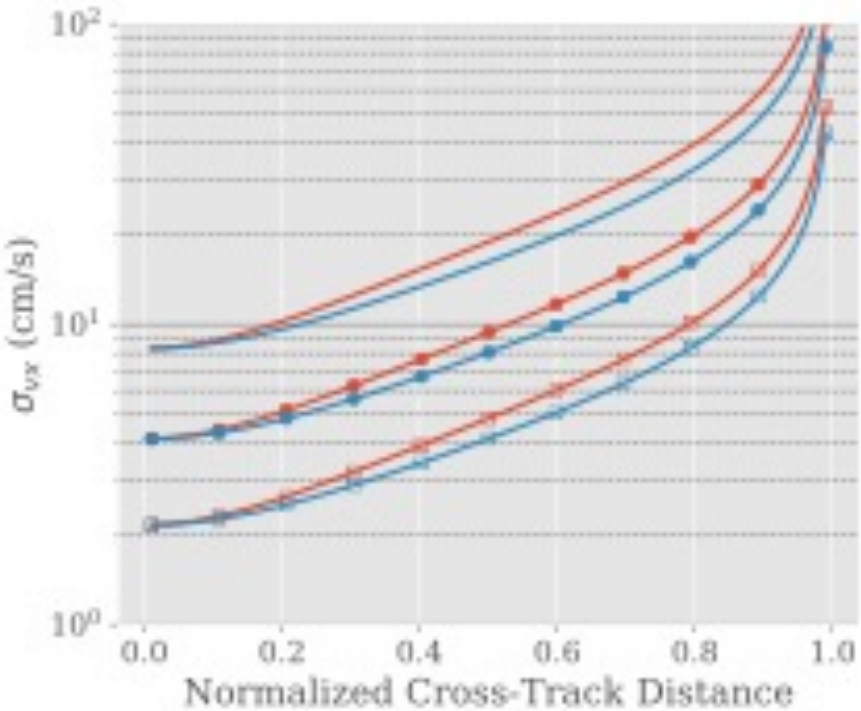
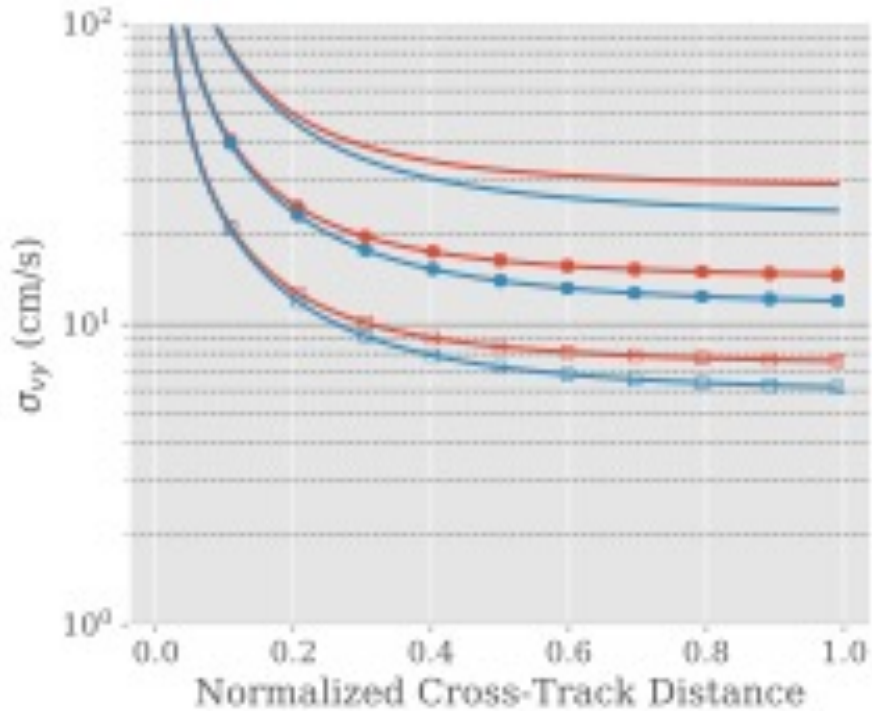
# WaCM Performance at 5km Sampling




Antenna length: 4m (blue), 5m (red)
Peak Transmit Power:
100 W: solid lines
400 W: circles
1.5 kW: empty squares

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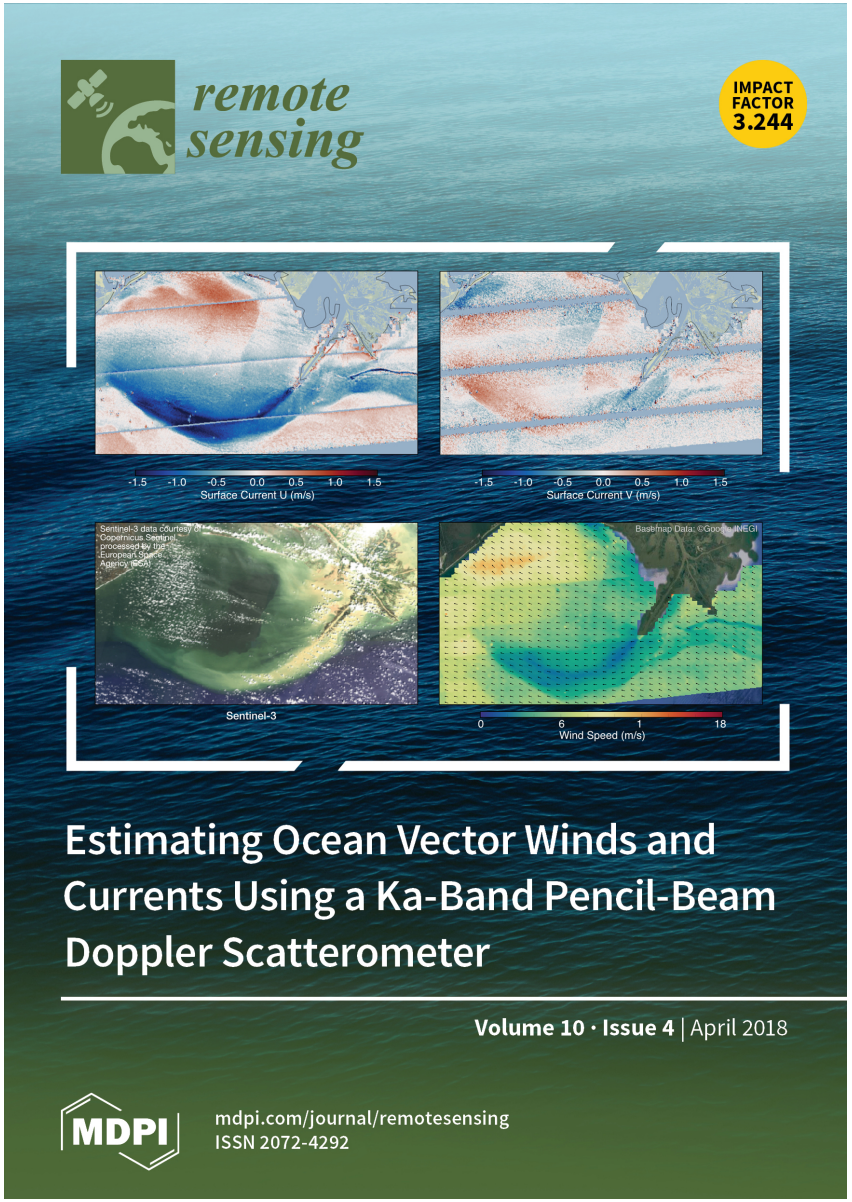
# References




*Article*

## On the Optimal Design of Doppler Scatterometers

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https://www.preprints.org/manuscript/201810.0106/v1

# BACKUPS

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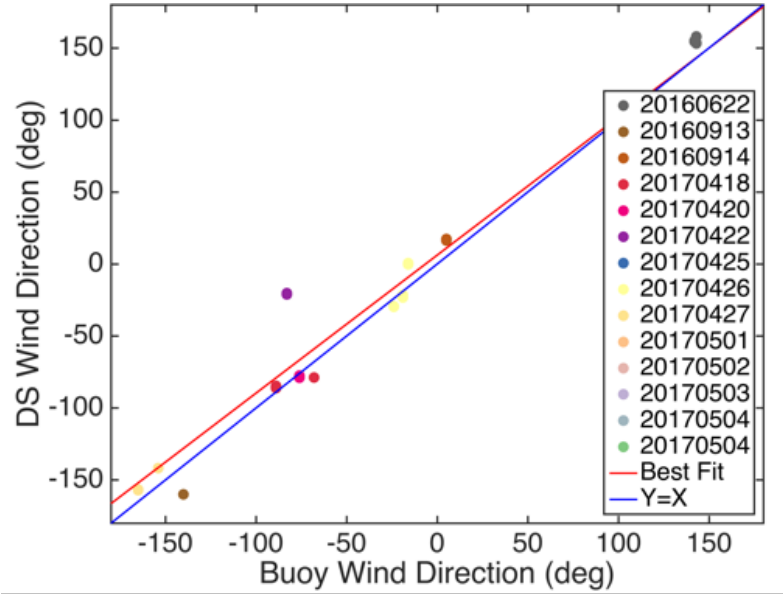
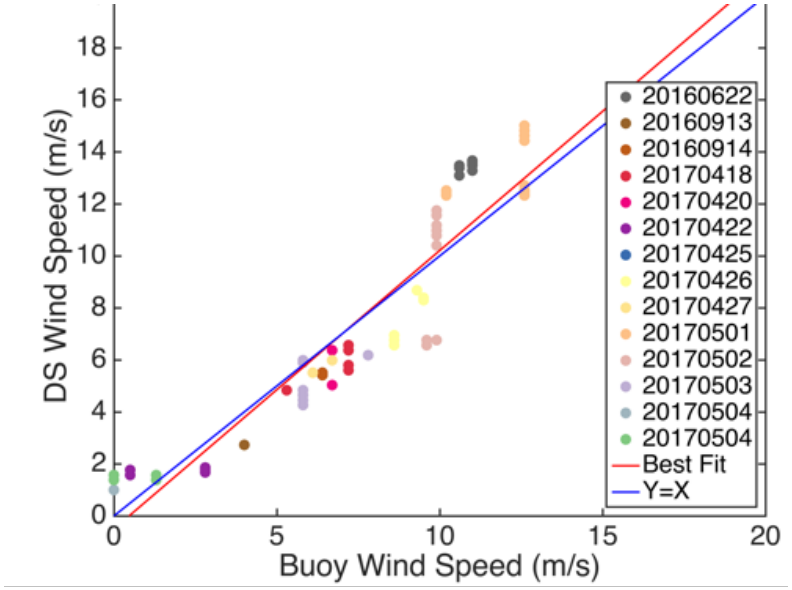
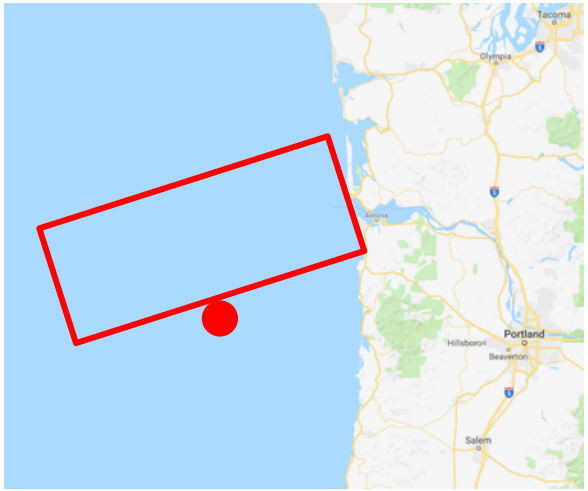
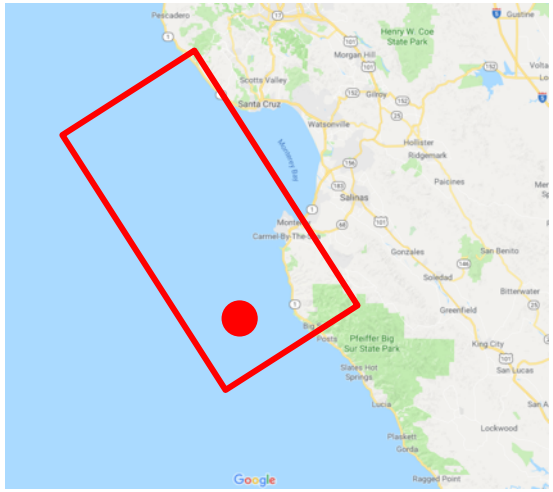
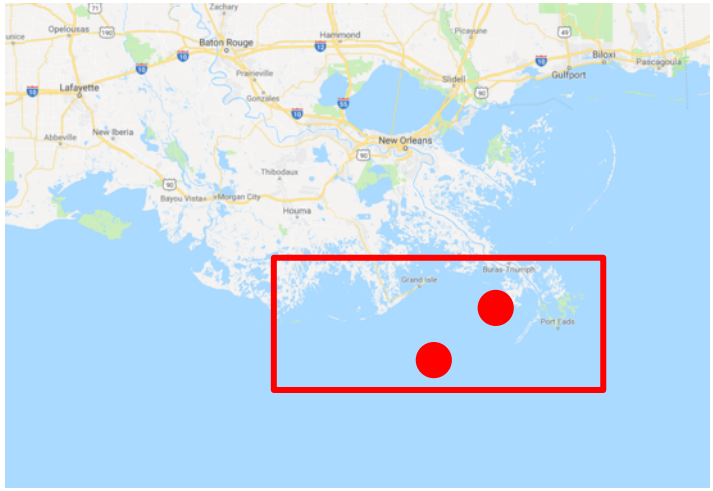
# DopplerScatt Wind Validation



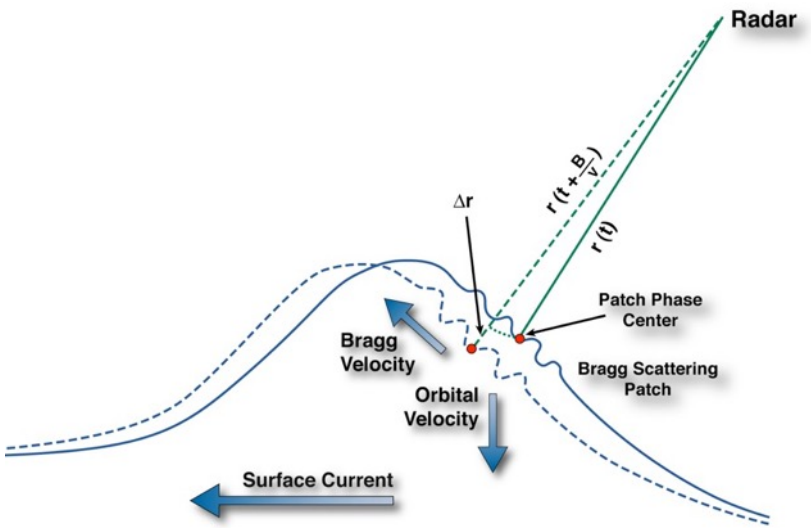



# What velocity are we measuring?

$$\Phi = \frac{2\pi}{\lambda}\Delta r$$

$$v_{scatterer} = \frac{\Delta r}{B} v_{platform}$$




- Radar sensitive to phase speed ~0.5 cm capillary waves
- Free wave phase speed: ~31 cm/s. Capillary waves can also be generated as bound waves due to straining: will travel at straining wave phase speed (low wind speeds).
- Phase speed modulated by surface currents. Winds will add Stokes drift & surface drift.
- Gravity wave orbital velocity is added to capillary wave velocity. When averaging over surface waves, velocity is weighted (by radar brightness) spatial average.
- Brightness not homogeneous over long wave:
    - Hydrodynamic modulation due to 1) capillary amplitude modulation by spatially varying orbital velocity;; 2) wave breaking; 3) bound waves

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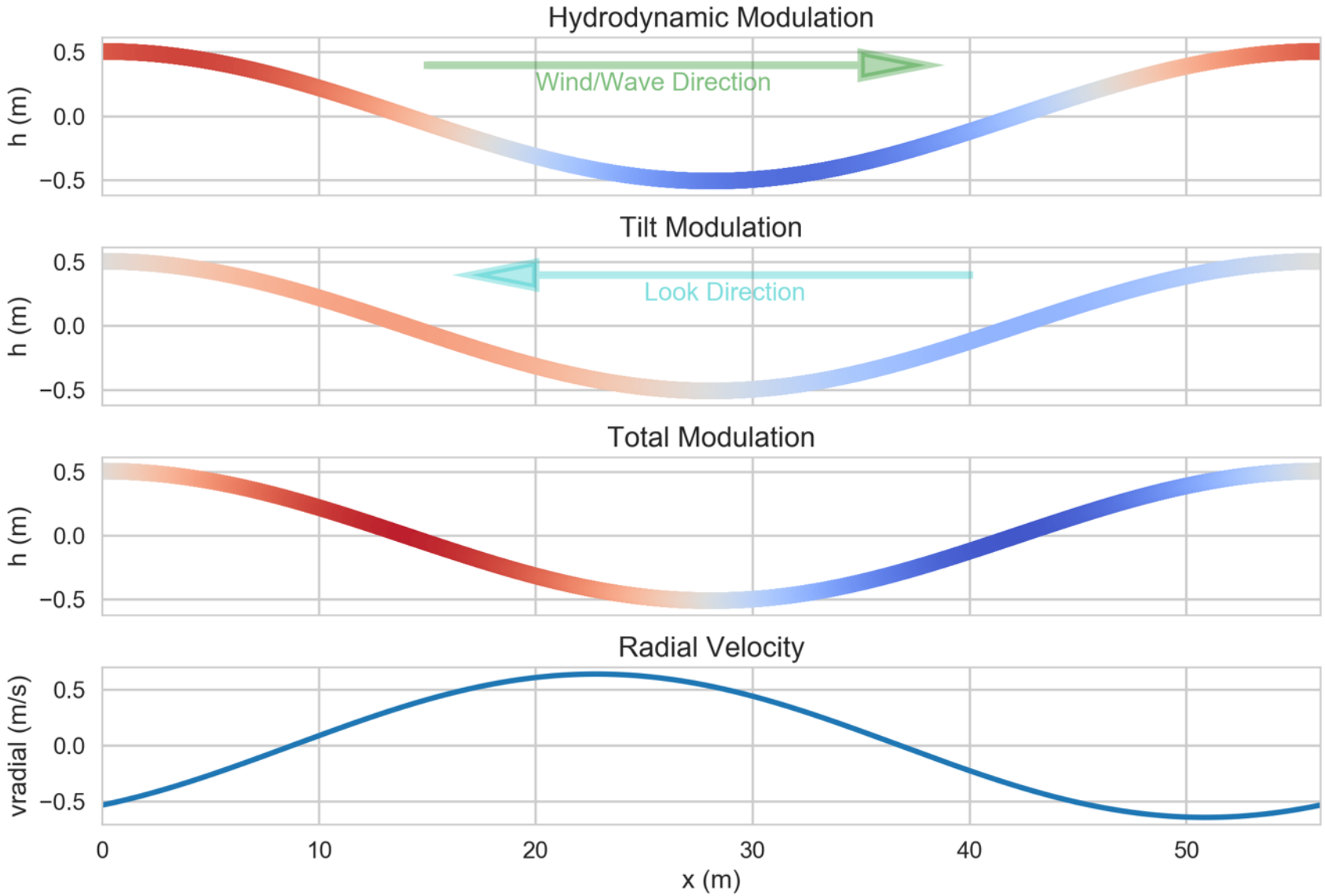
# Radar Brightness Modulation

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# Observation Model

$$\eta = \sum_n a_n \cos\Theta_n \eta_x$$

**Gravity wave height**

In phase with *u* In phase with *w*

$$\left.\frac{\delta\sigma_0}{\sigma_0}\right|_{\text{Hydro}} = m_r \sum_n a_n k_{xn} \cos\Theta_n - m_i \sum_n a_n k_{xn} \sin\Theta_n$$

**Hydrodynamic modulation**

In phase with *w*

$$\left.\frac{\delta\sigma_0}{\sigma_0}\right|_{\text{Tilt}} = -m_T \cos\phi_r \sum_n a_n k_{xn} \sin\Theta_n = \frac{\partial \log\sigma_0}{\partial\theta} \cos\phi_r \eta_x$$

**Tilt modulation**

$$\delta v_S = U_S \left[\cos\phi_r m_r + \cot\theta \left(m_i + \cos\phi_r m_T\right)\right]$$

**Net gravity wave contribution**

$$U_S = \int dk\ k_x \omega F(k_x)$$

**Stokes drift**

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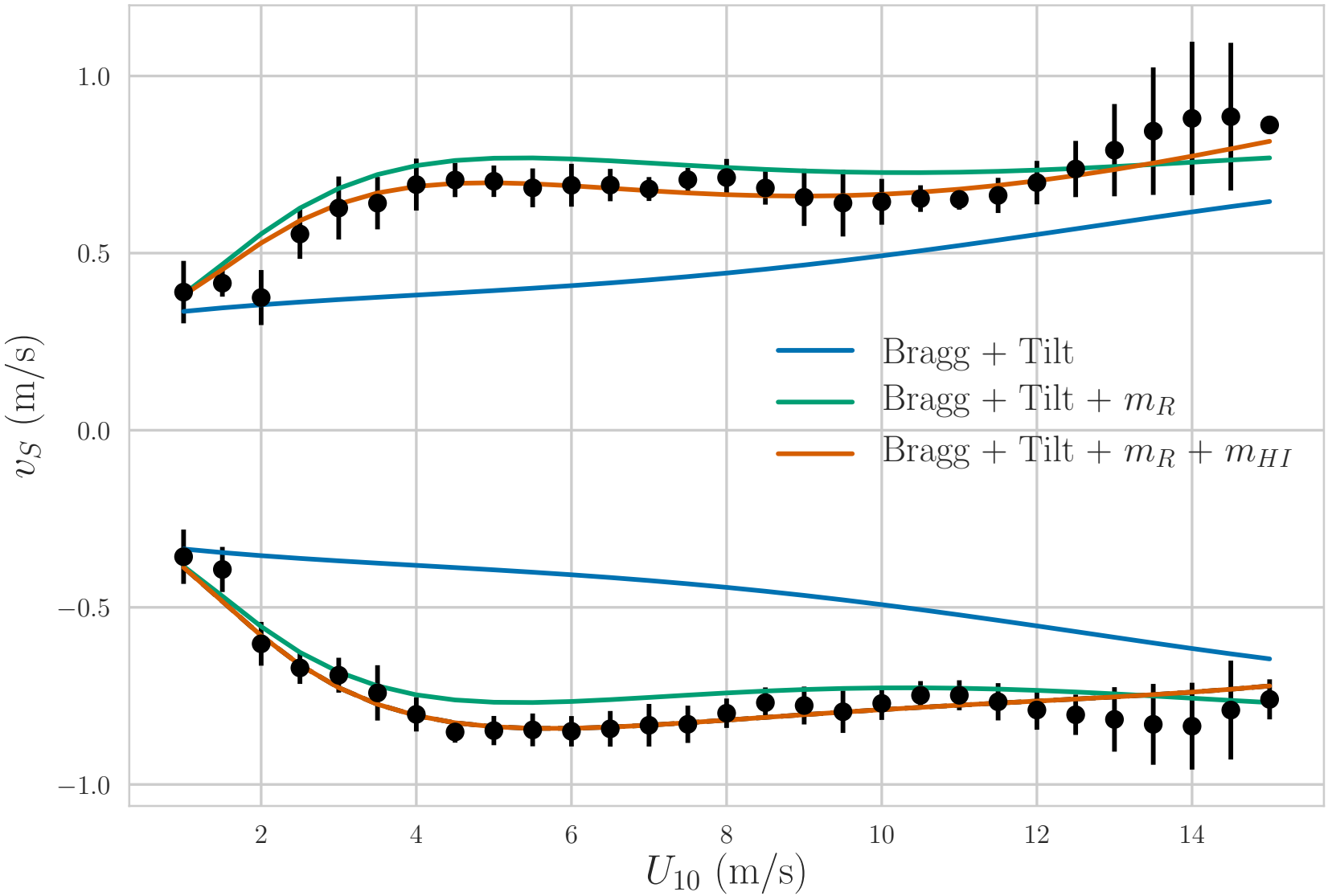
# Upwind/Downwind Velocities vs Theory

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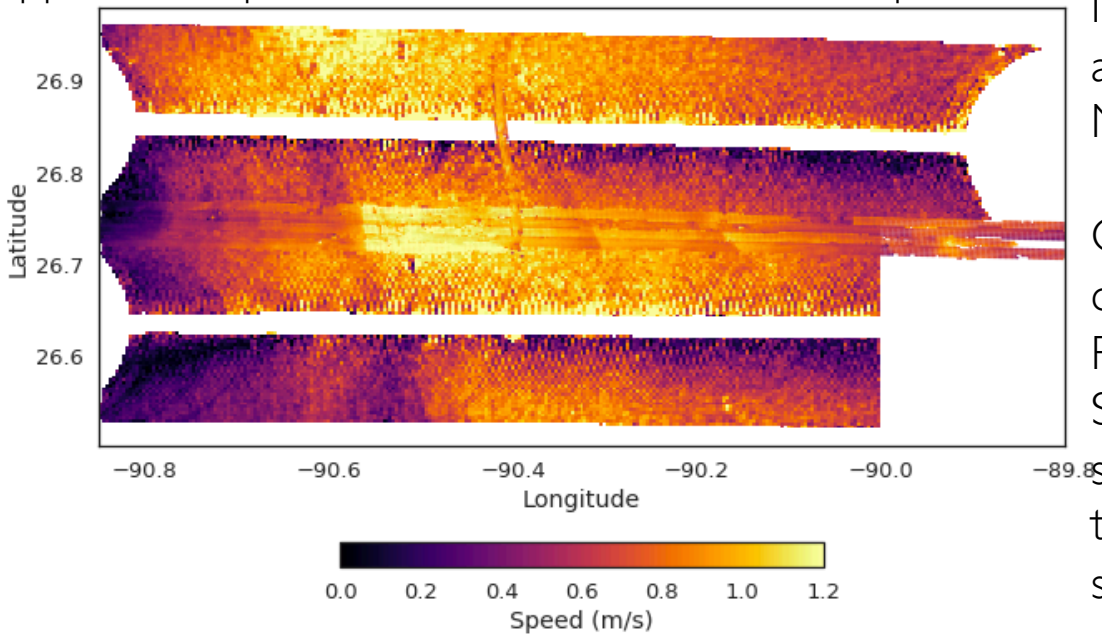
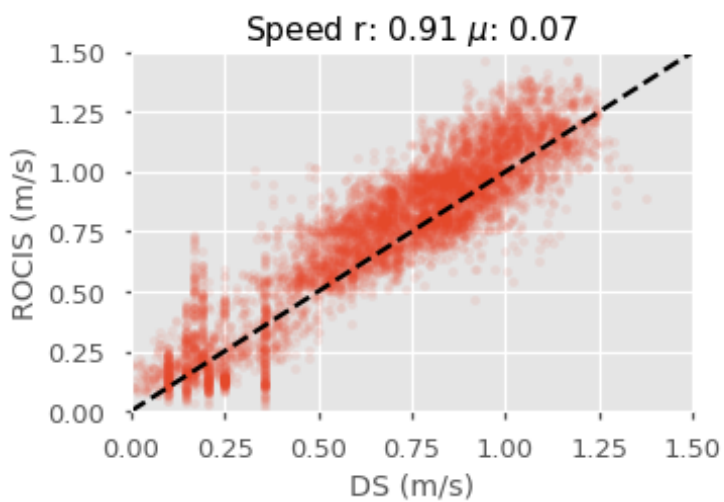
# DopplerScatt GoM Eddy Validation

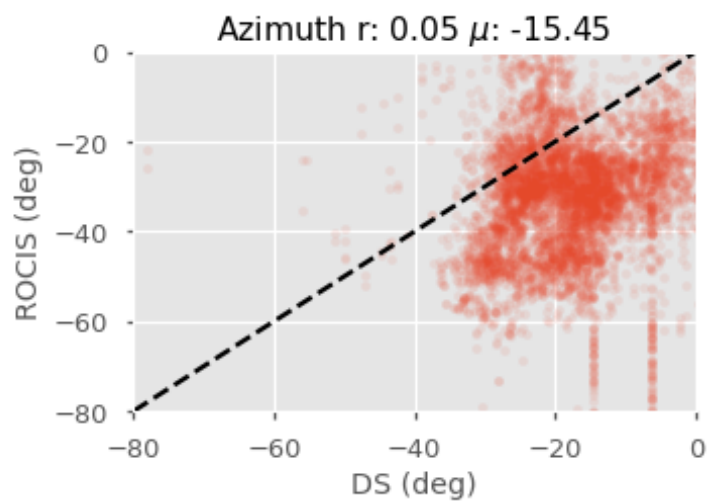
DopplerScatt Speed Data Overlaid with ROCIS Speed Data




In March 2018, DopplerScatt flew over a large Gulf of Mexico Eddy south of New Orleans.

Ocean surface current data were collected at the same time with Fugro's Remote Ocean Current Imaging System (ROCIS) which uses FFT's of space-time ocean wave imagery and the dispersion relation to solve for surface currents.




Preliminary results. Analysis on both sides still ongoing.

ROCIS data courtesy of Chevron and Fugro.

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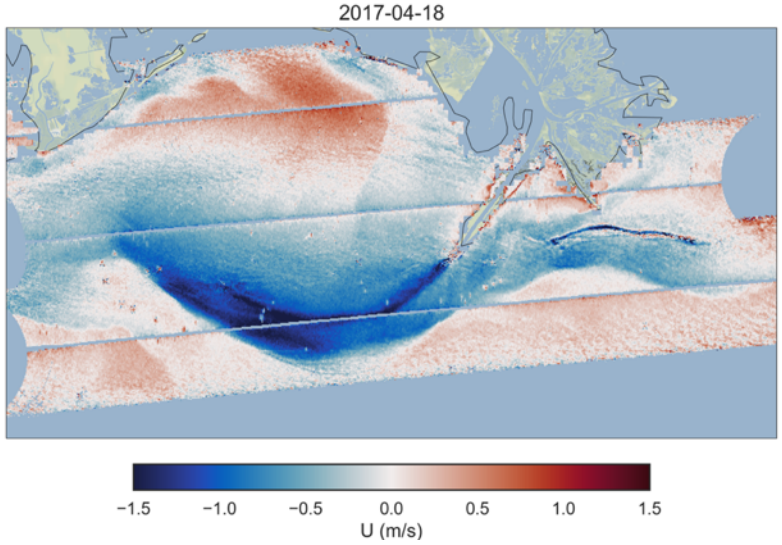
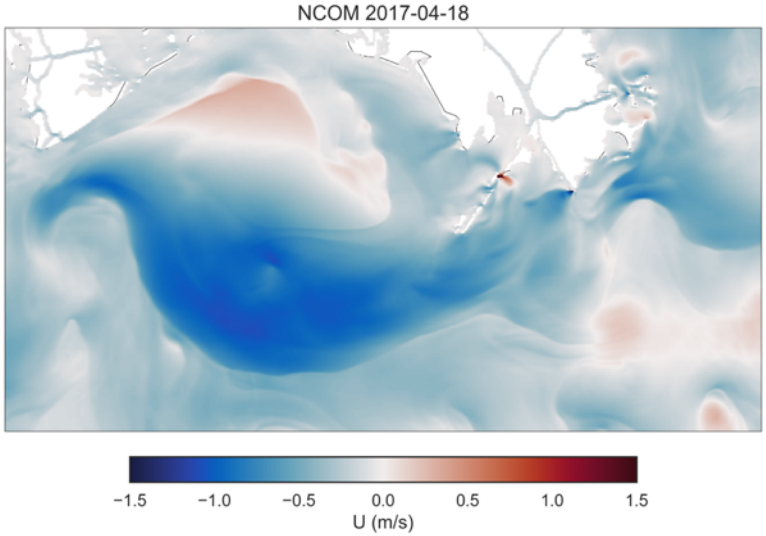
# SPLASH 2017-04-18

## DopplerScatt

## NCOM

**U**

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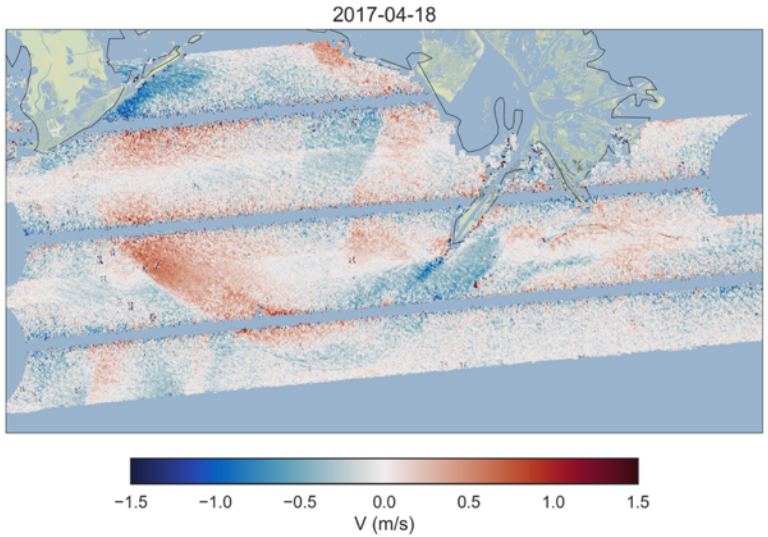


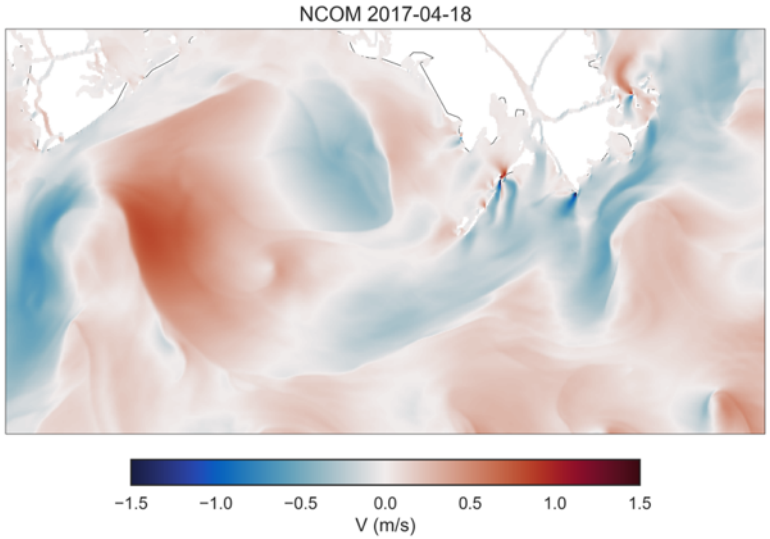


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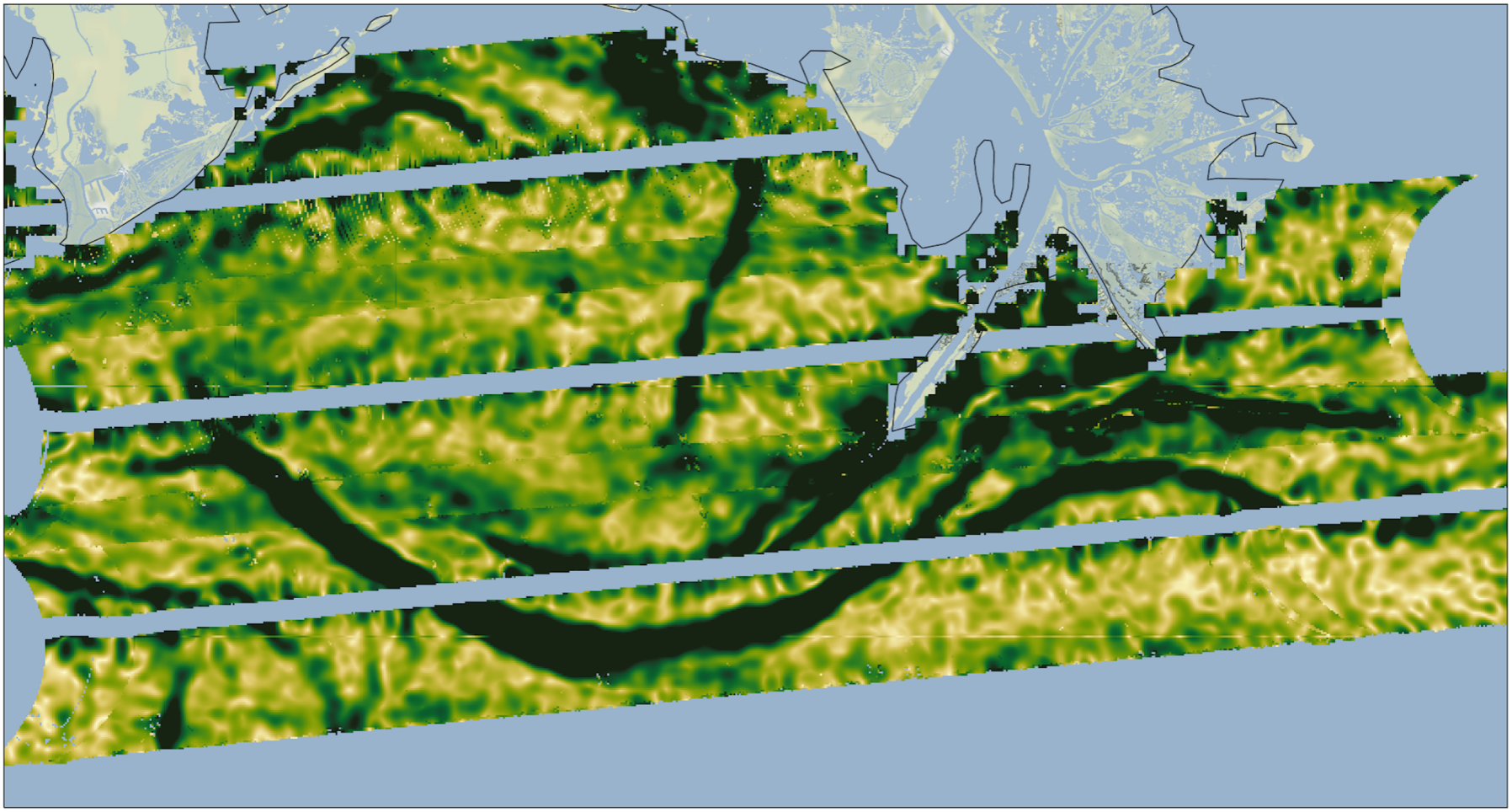
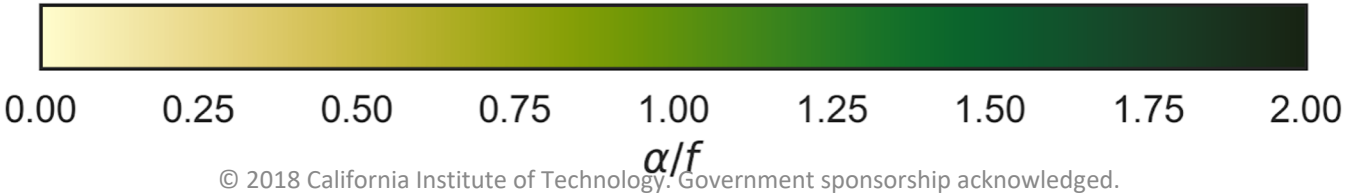
# Strain Rate



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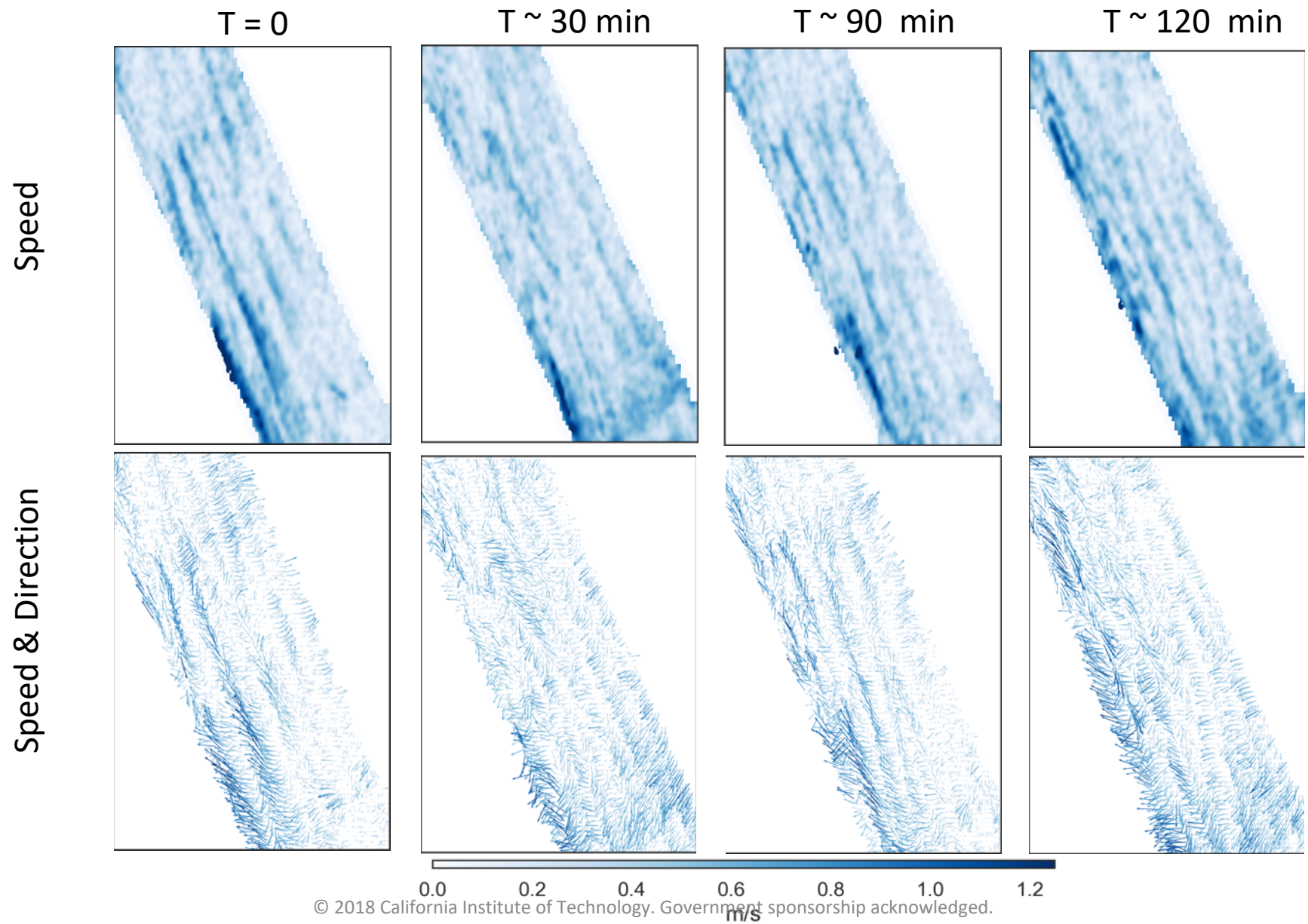
# Fast Internal Wave Changes

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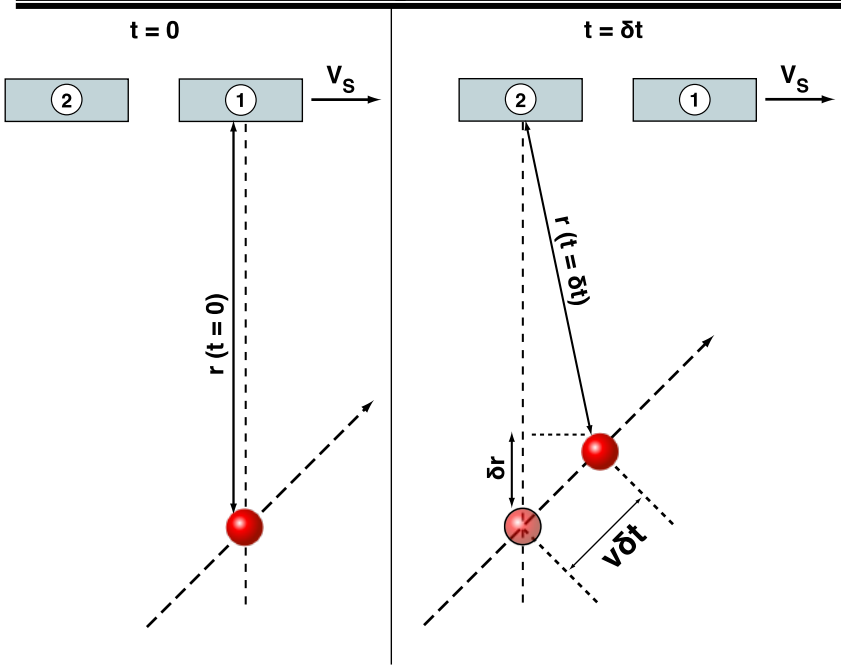
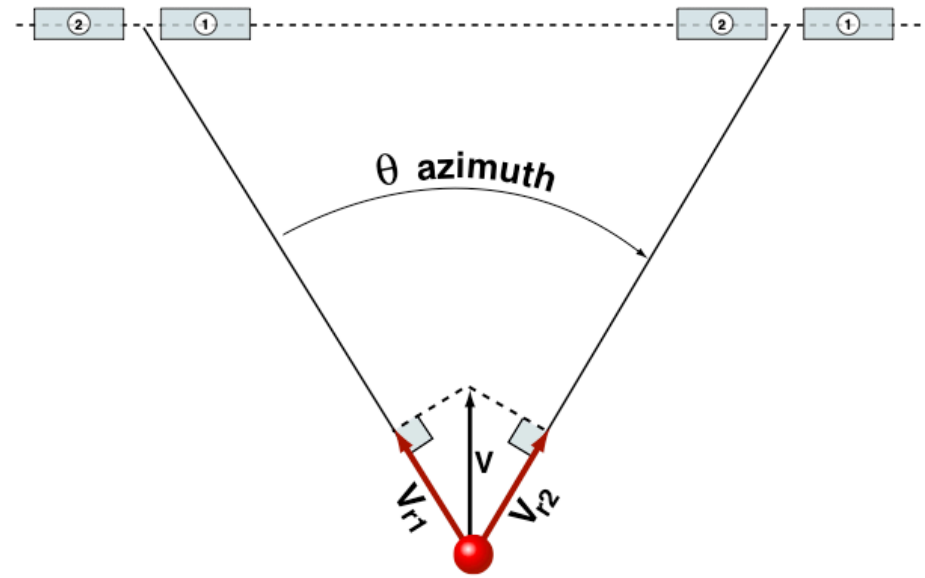
# Doppler Current Measurement Concept




Doppler Phase Difference: $\Delta\Phi = 2k\Delta r = f_D\delta t$

Radial velocity component: $v_r = \Delta r/\delta t = \Delta\Phi/(2k\delta t)$

Vector currents are estimated by combining multiple (≧2) azimuth observations and projecting vector to the ocean surface.

- Radars provide coherent measurements: both the phase and the amplitude of a scattered signal are measured.
- The phase is proportional to the 2-way travel time (or range)
- The amplitude is proportional to the scattering strength of the traget
- Doppler measurements, $f_D$, are obtained by measuring the phase difference between pulses, $\Delta\Phi$. Noise is reduced by combining multiple pulses.

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