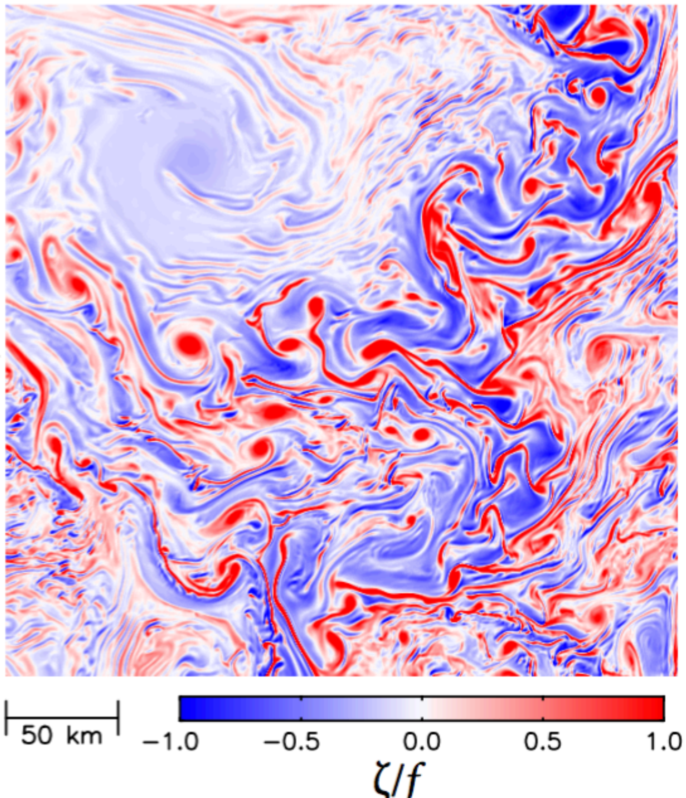
DopplerScatt Instrument Concept for Simultaneous Measurements of Ocean Surface Vector Winds and Currents

AMS2018

Dragana Perkovic-Martin,
Tamas Gal, Raquel R. Monje, Fabien Nicaise, Ernesto Rodriguez, Karthik Srinivasan, Bryan Stiles, Alexander Wineteer

Jet Propulsion Laboratory
California Institute of Technology

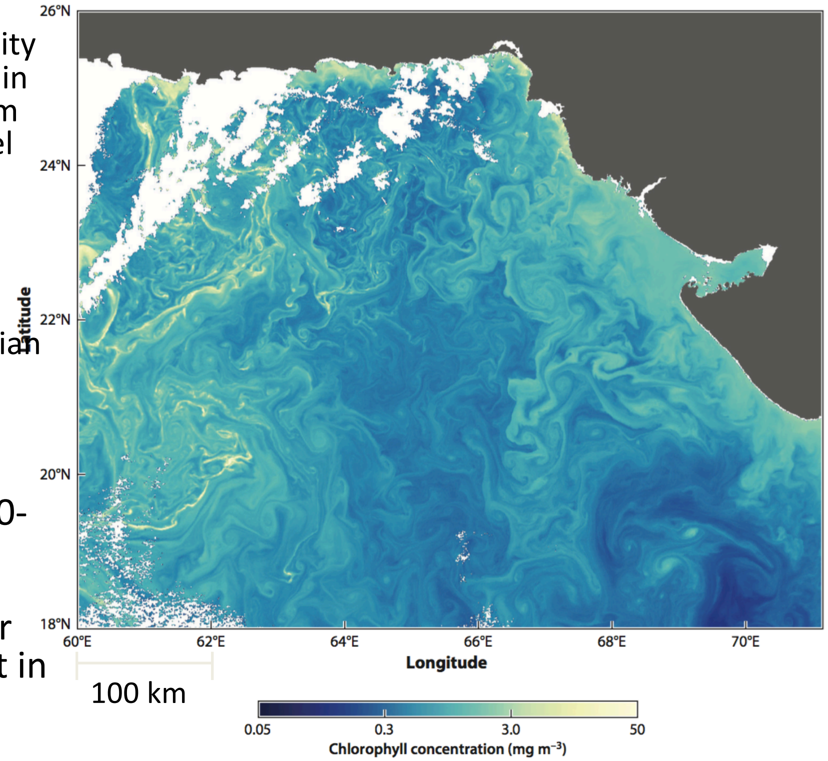
Why Measure Ocean Surface Currents and Winds?



Left: Ocean relative vorticity (~curl of surface velocity) in the California Current from ROMS 1 km spacing model (J. Molemaker, UCLA, D. Chelton OSU)

Right: Chlorophyll concentration in the Arabian sea as seen by MODIS, 02/22/2005

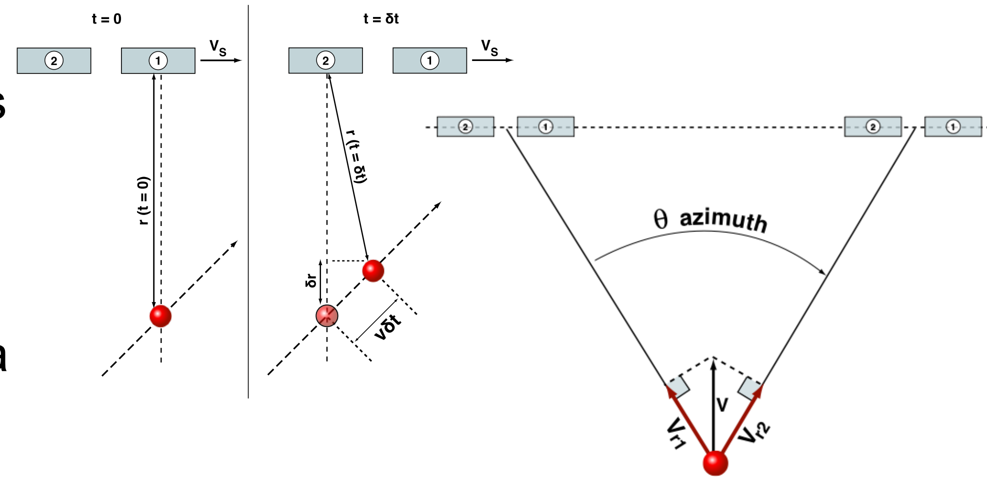
Small scales (1km to 20-30km) dominate vorticity/convergence and are responsible for most vertical transport in the ocean.

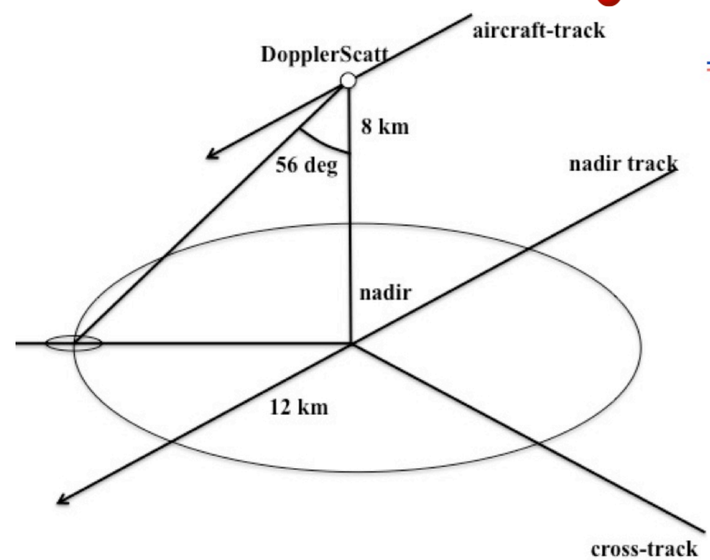


- Knowledge of ocean surface currents and winds will improve our knowledge of energy transfer between the atmosphere and the ocean and our understanding of the advection of heat, nutrients, and pollutants in the ocean
- The interaction between winds and currents has been identified as the next frontier by the US winds and currents communities

The DopplerScatt Concept

- Coherent radars can measure radial velocities by measuring Doppler shifts
- Rodríguez (2012, 2014) has outlined the spaceborne concept to be able to measure ***vector velocities*** by using a pencil-beam scanning scatterometer
  - A wide swath enables global coverage in one day
  - The same instrument also measures high resolution winds
- DopplerScatt IIP is a proof-of-concept airborne instrument demonstrating the feasibility and accuracy of this measurement technique with the results applicable to future spaceborne missions





Pencil-beam concept for the airborne DopplerScatt with wide-swath coverage

DopplerScatt IIP-13 Accomplishments

- **Data Products:**
  1. Vector ocean surface currents
  2. Vector ocean surface winds
  3. Radar brightness maps (sensitive to surfactants such as oil films)
- **Mapping capabilities**: 25 km swath; maps 200km x 100km area in about 4 hrs;
- Targeted (achieved) performance characteristics:

  Velocity: 1 m/s bias with 10 cm/s precision (5-15 cm/s)

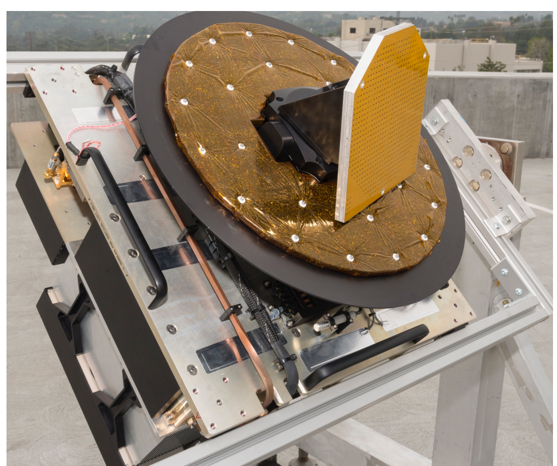
  Wind speed: 2 m/s accuracy (1m/s) for 3-20 m/s wind speed range

  10% accuracy in 20-30 m/s speed range

  Wind direction: 20 degrees accuracy (15 deg)

  Spatial resolution: 5 km (200m currents, 1km winds)

- Demonstrated the concept and performance of DopplerScatt in three field deployments:
  - Engineering flights Monterey Bay June 2016,
  - Portland Oregon September 2016,
  - New Orleans and Monterey Bay April/May 2017
- Becoming operational under NASA AITT program

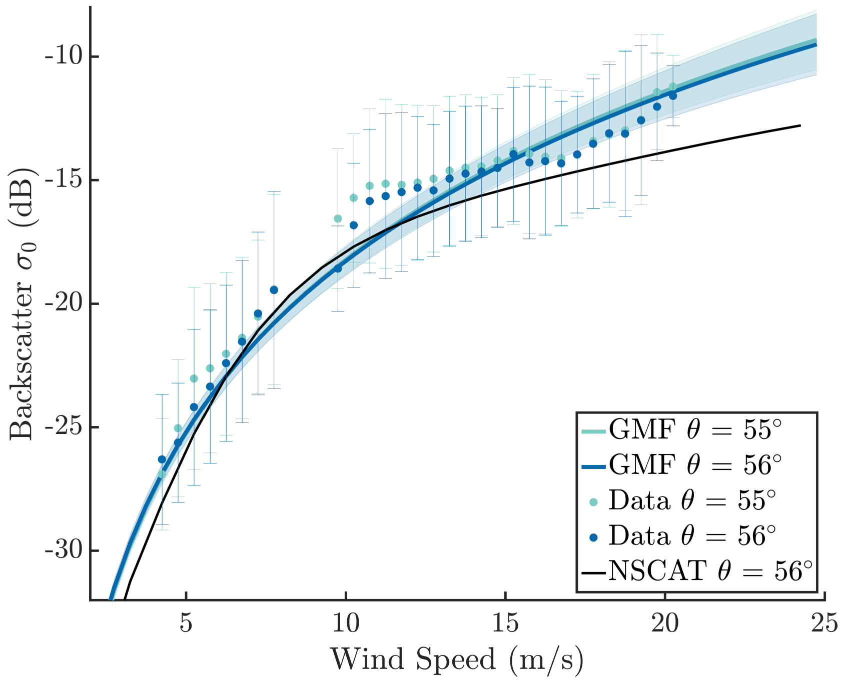


Top: DopplerScatt hardware and part of the team

Bottom: DopplerScatt aboard King Air B200

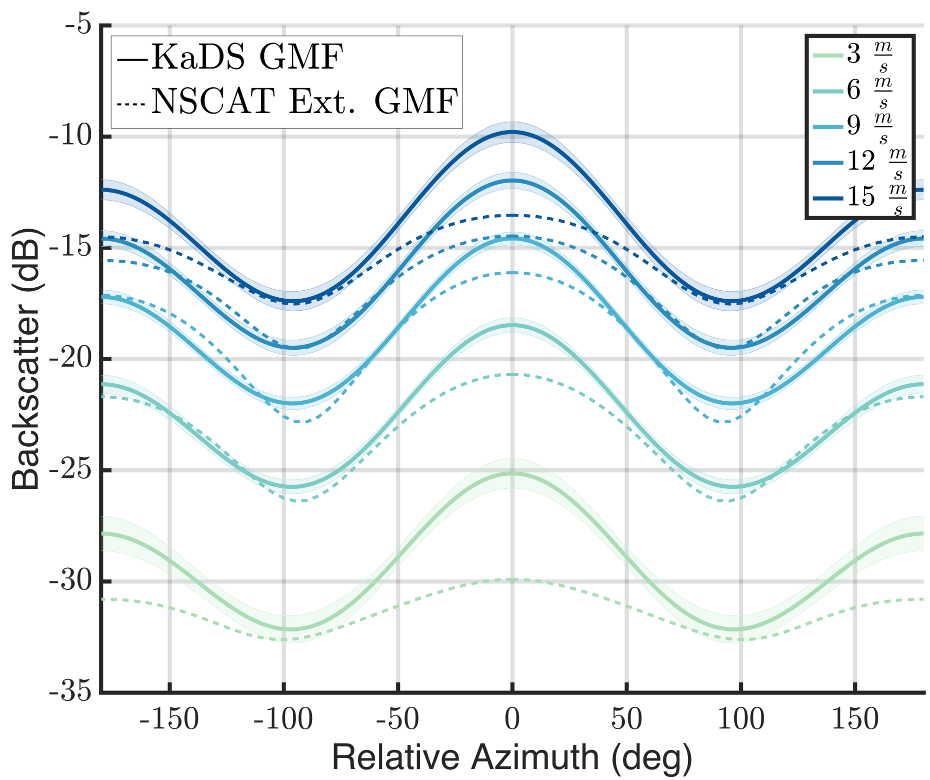
Left: DopplerScatt “under the hood”

DopplerScatt Wind GMF



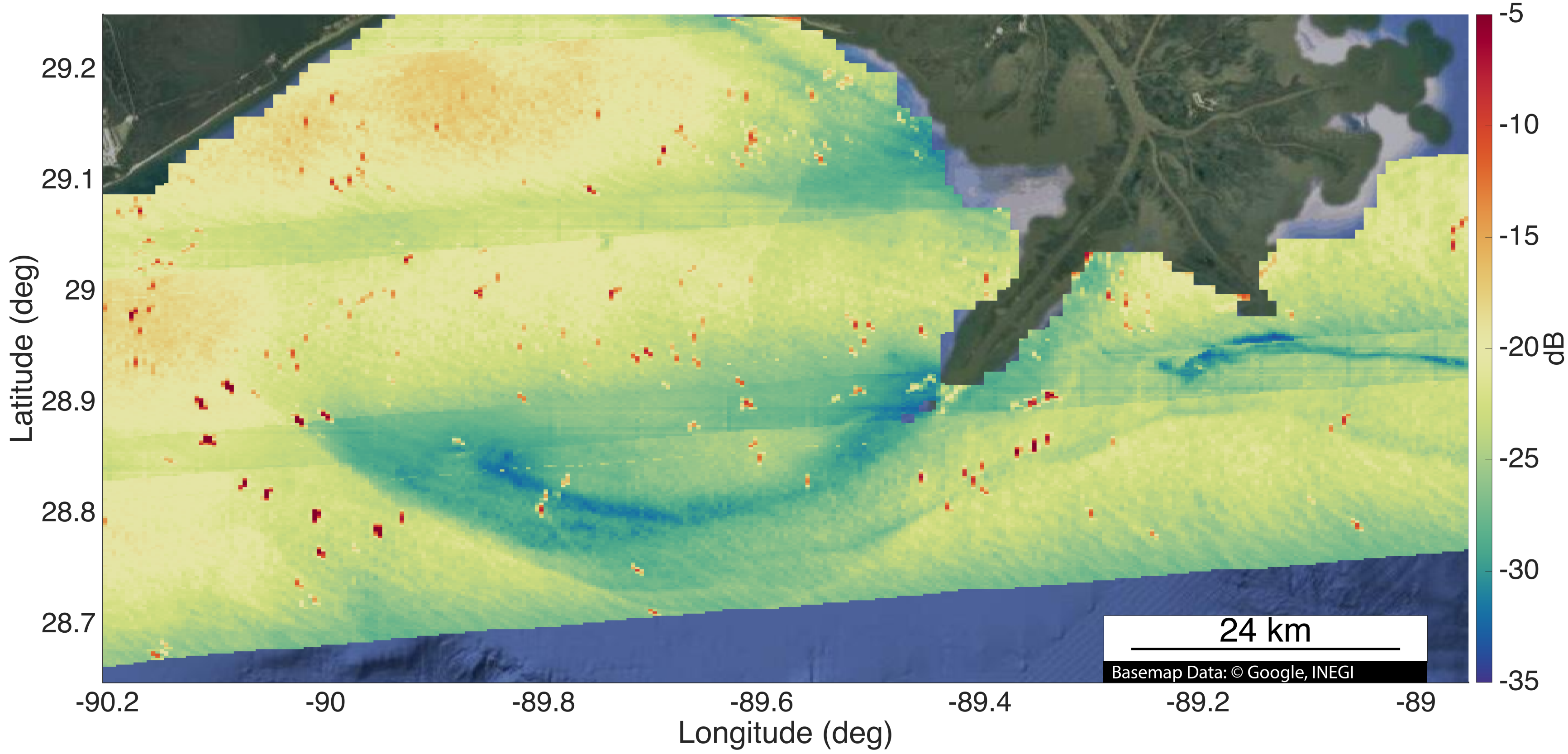
- DopplerScatt data and model indicate higher modulation at Ka-band than Ku-band between cross wind and up/down wind over a large range of wind speeds

➢ **Makes wind direction estimation easier at Ka-band for high wind speeds.**



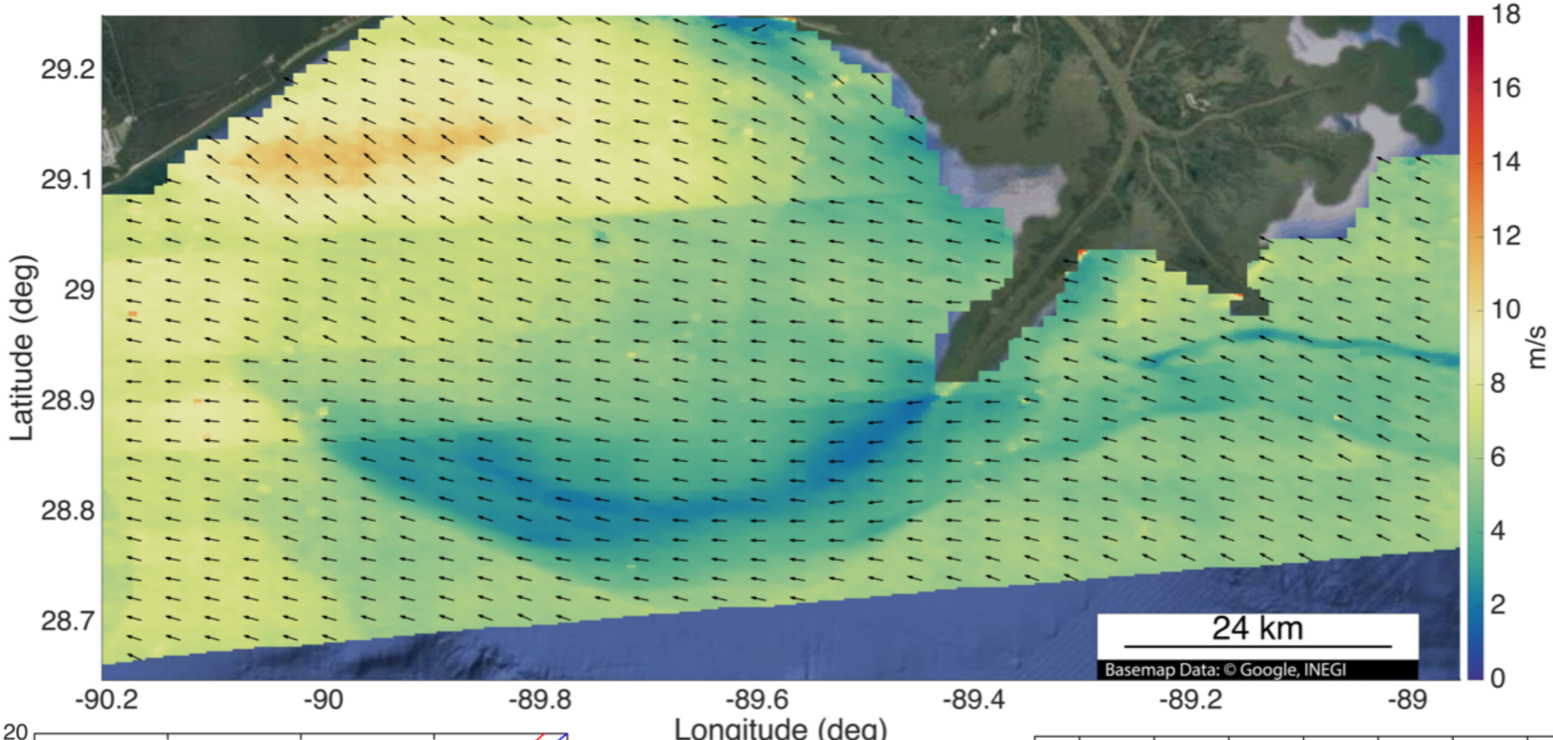
- Ka-band sensitivity to wind speed is very similar to Ku-band (NSCAT, QuikSCAT, RapidScat)
- Surprisingly, Ka-band seems to show less saturation at high winds than Ku-band, perhaps due to the higher impact of wave breaking (TBC with more data)
- **Ka-band scatterometers offer a feasible continuation of the Ku-band scatterometer climate data record**

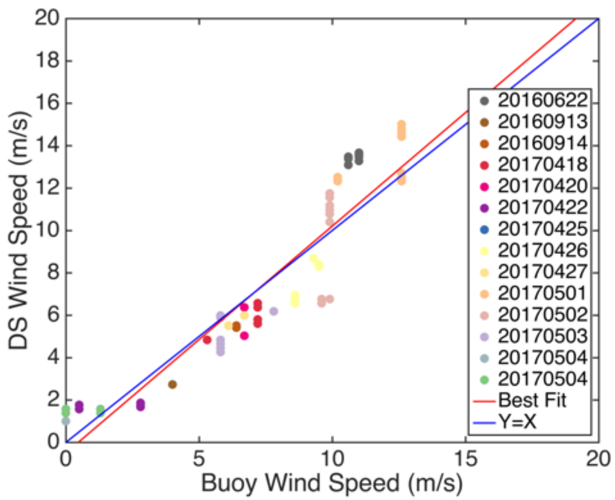
From Sigma0 to Winds

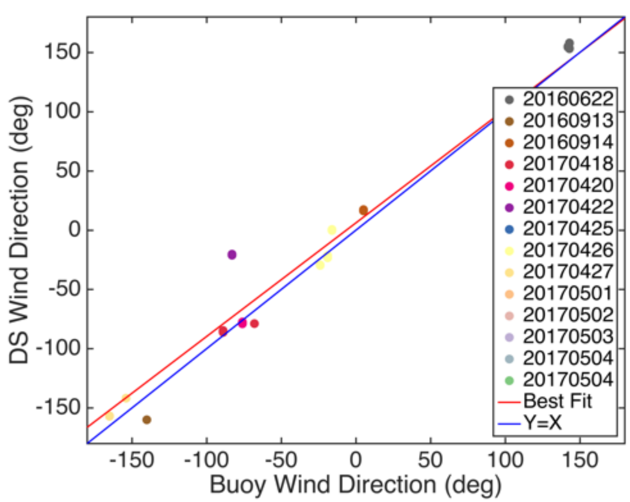


- Aft looking measured backscatter on April 18, 2017, near the outlet of the Mississippi river, at 200m resolution
- Small scale features are apparent and will affect wind retrieval
- Strong point sources are due to a large number of ships and oil platforms in the area

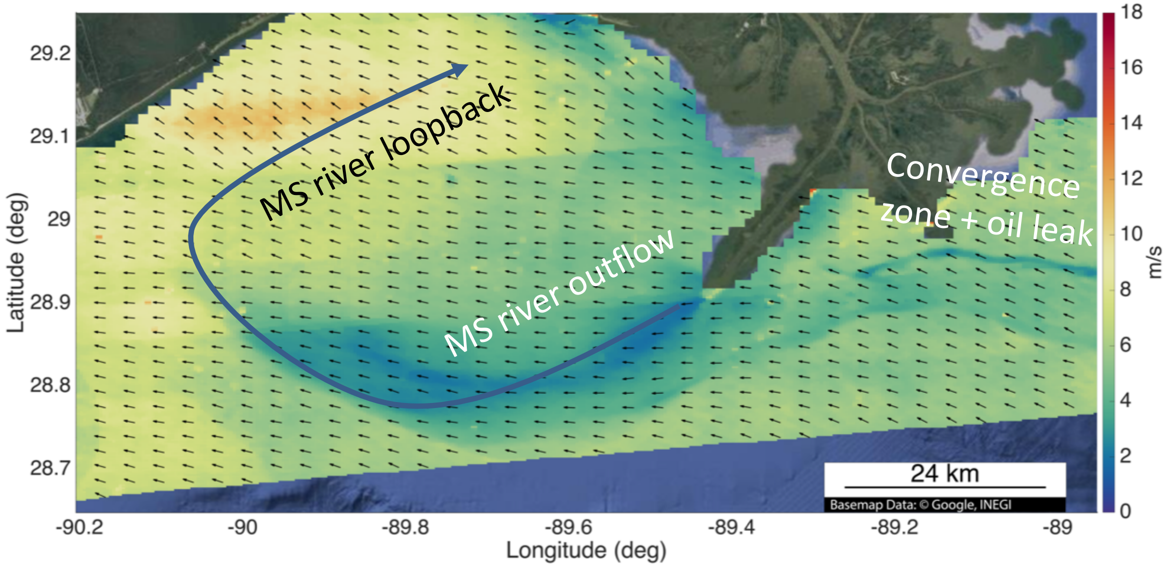
Retrieved Vector Winds 04-18-2017

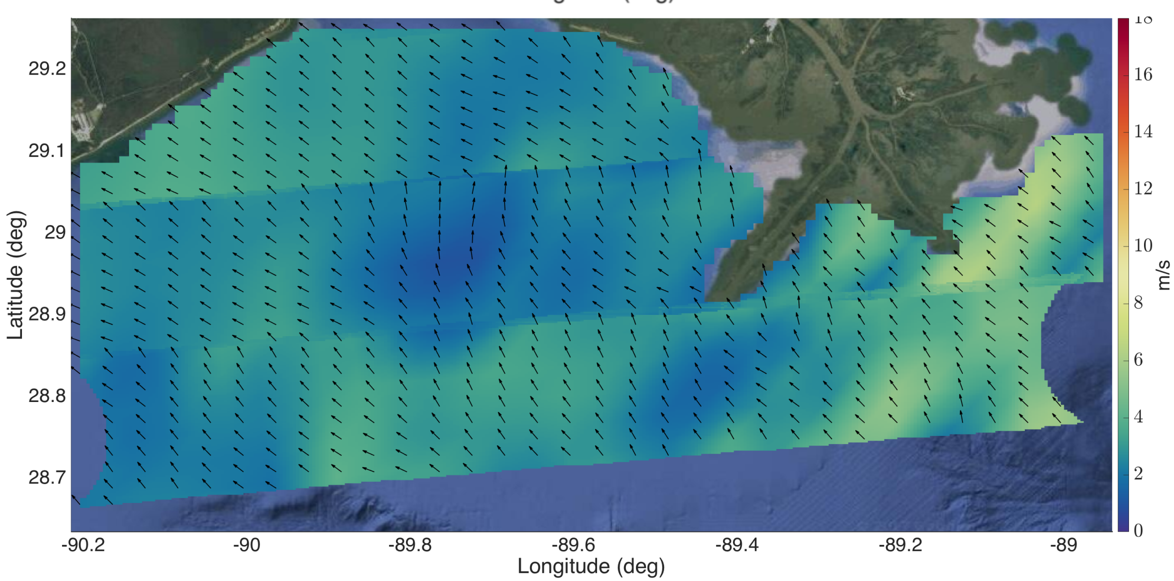






Comparison to RSMAS Model Winds





- Scatterometters measure 10-m neutral winds, which are closely related to wind stress and include surface interaction effects (currents and SST modulation)
- For this case, model winds are lower speed and miss the modulation of the wind stress by the Mississippi river outflow, a leaking oil rig, and ocean temperature changes.
- Buoys in the area measured ~7m/s wind speeds.

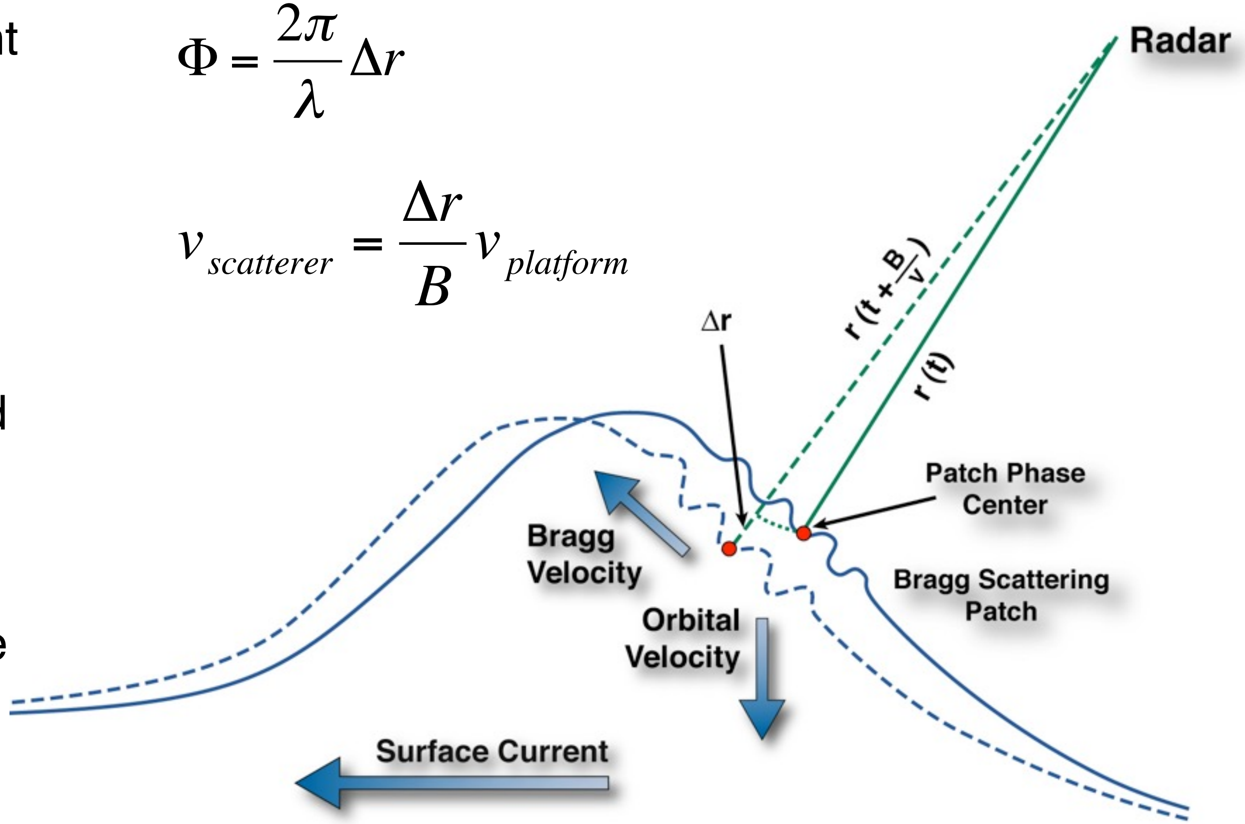
What Velocity are we Measuring?

Surface scatterers (resonant gravity/gravity-capillary waves satisfying the Bragg condition) motion is due to several effects:

1) group velocity of resonant patch (free and bound Bragg scatterers)
2) orbital wave velocity
3) advection due to surface currents (including wind & Stokes drift)

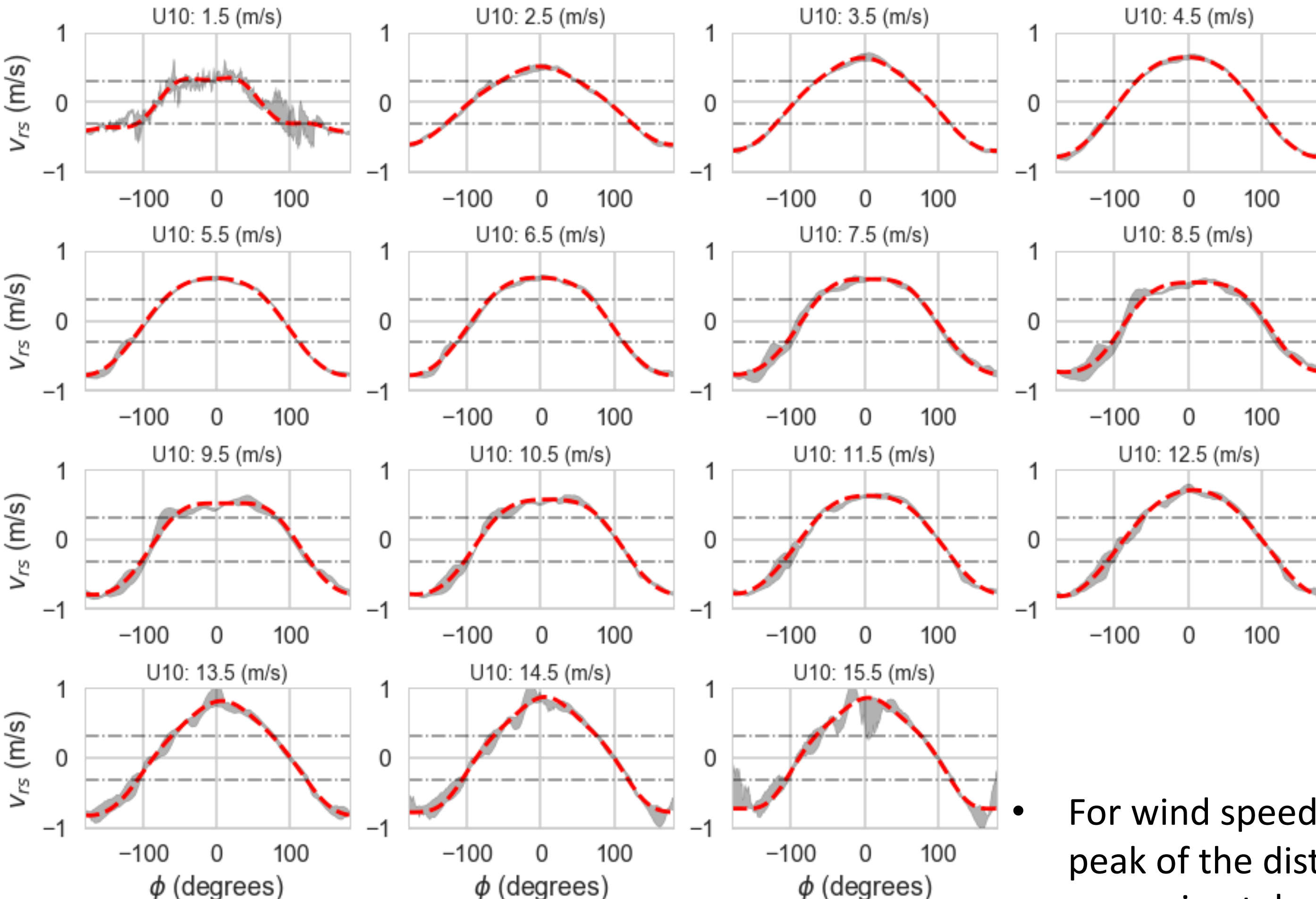
$$\Phi = \frac{2\pi}{\lambda}\Delta r$$

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



- Free Bragg wave group velocity can be estimated using the dispersion relation and knowledge of the wind direction
- Orbital wave velocity would average out if Bragg waves were uniformly bright over the long waves (but we expect some hydrodynamic and tilt modulation, so residual wind dependent effects will be present)

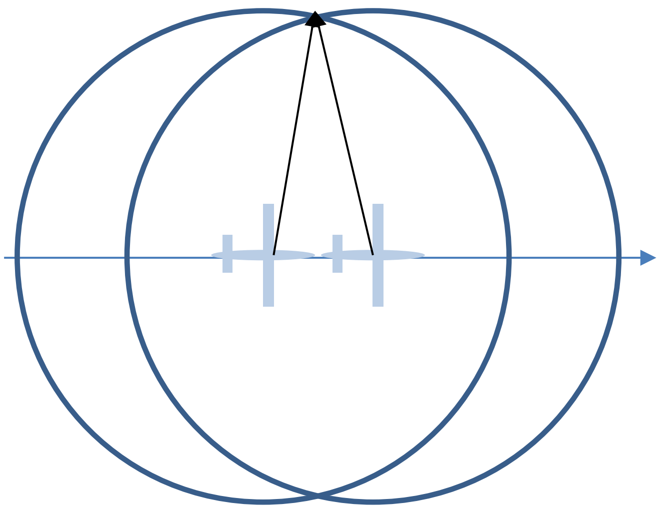
Current GMF



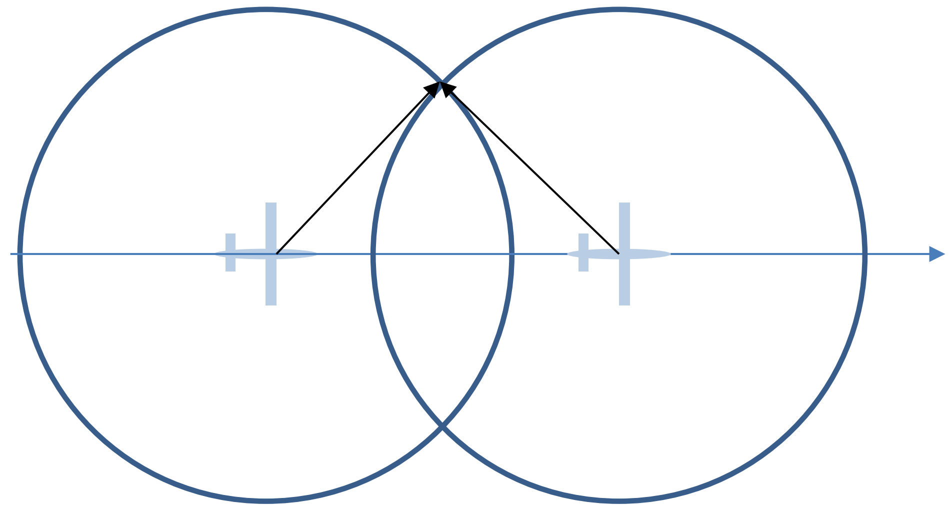
Dot-dash lines indicate Bragg phase velocities
x-axis origin is in downwind direction

- For very low wind speeds the surface scatterers propagate near the phase velocity of the free Bragg-resonant capillary waves (~ 31 cm/s)
- For wind speeds less than 4.5 m/s, the peak velocity increases and the shape of the distribution begins to approximate a sinusoid
- For wind speeds greater than 4.5 m/s, the peak of the distribution remains approximately constant, up to higher wind speeds (~ 13 m/s), where a slight increase seems to occur, although there is significant scatter around the mean, making this trend less certain

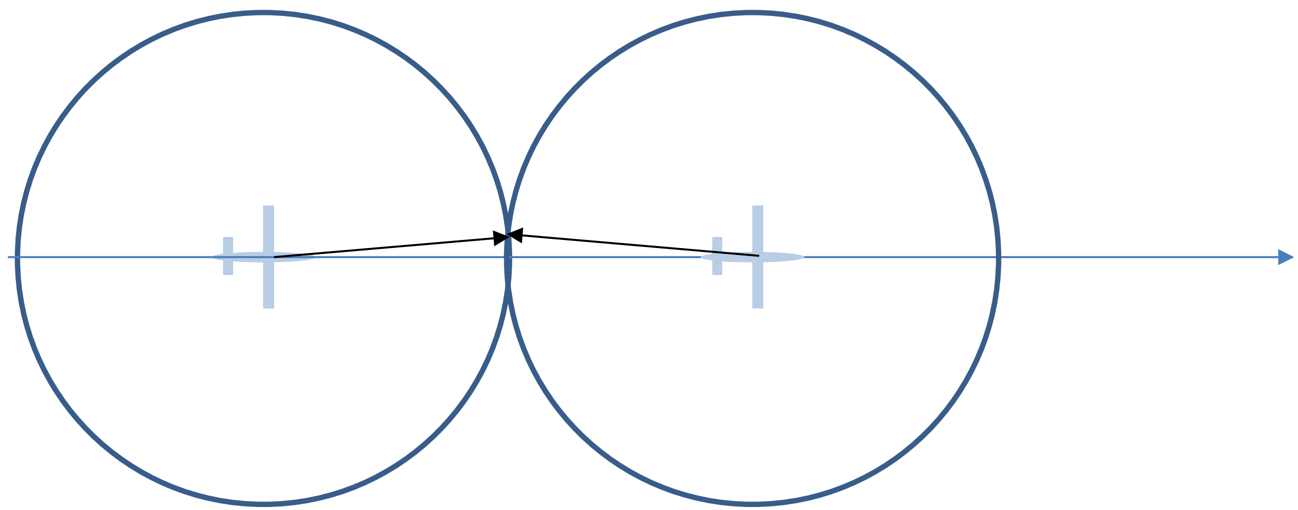
DopplerScatt Vector Velocity Estimation



Bad azimuth diversity

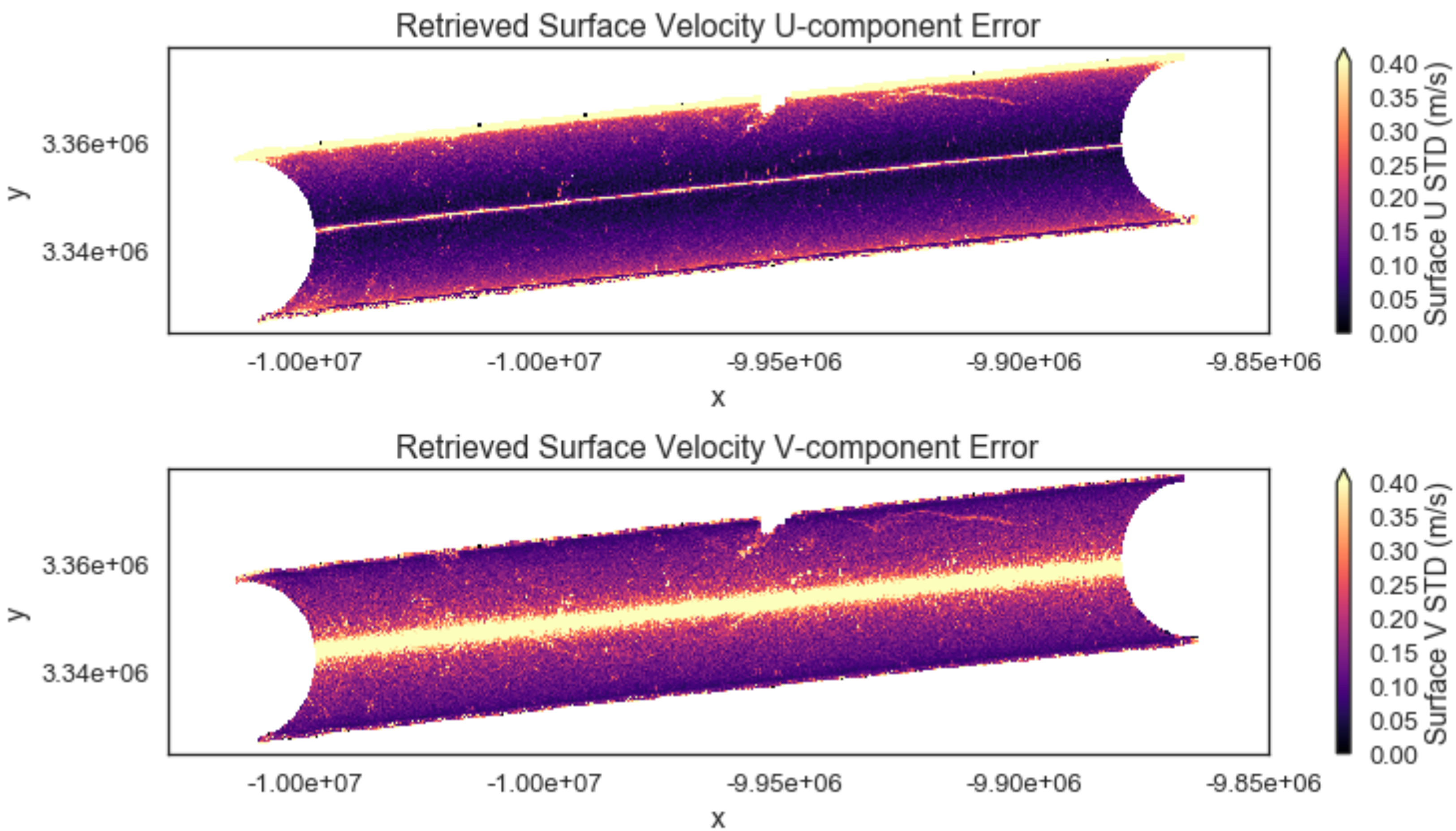


Good azimuth diversity



Bad azimuth diversity

Retrieved Surface Velocity Errors



- For most of the swath, the random errors at 200-m resolution are below 10cm/s (averaging to 800-m resolution would reduce the error by 4 times)
- The along-track component error is much smaller than the cross-track component error
- These errors are consistent with observation of submesoscale phenomena

2017-04-18

DopplerScatt | **NCOM**

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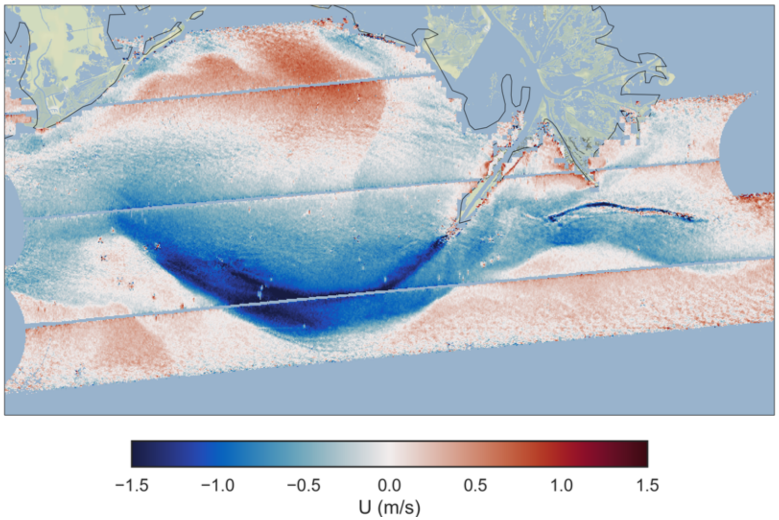
2017-04-18



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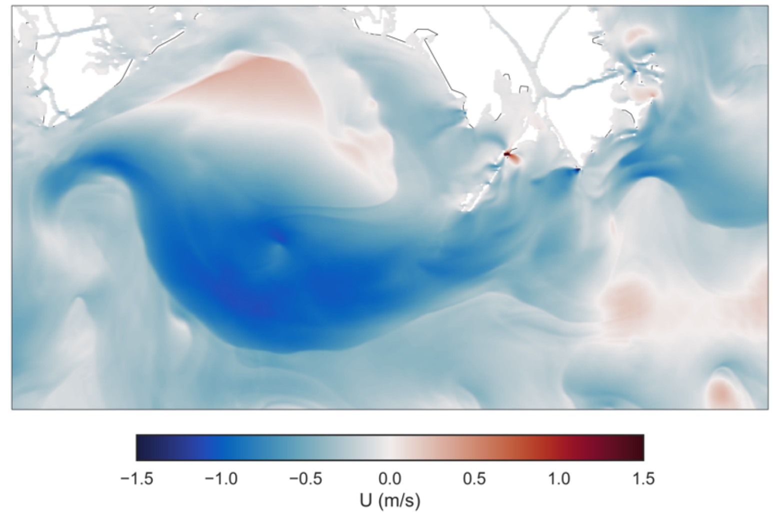

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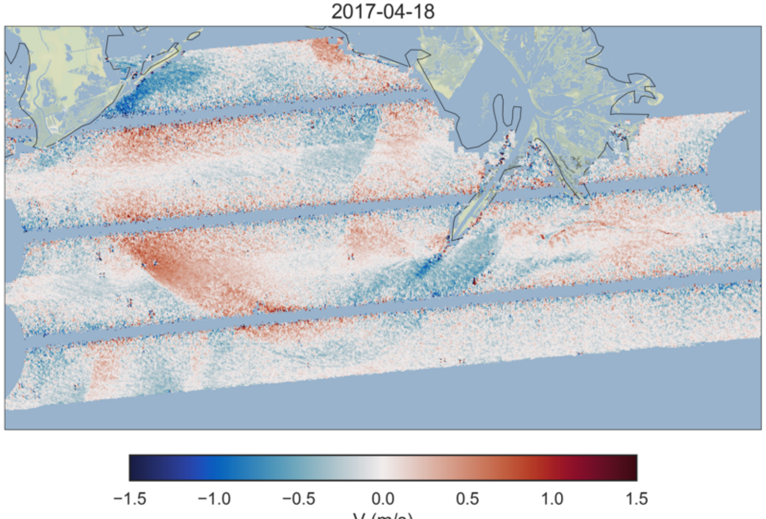

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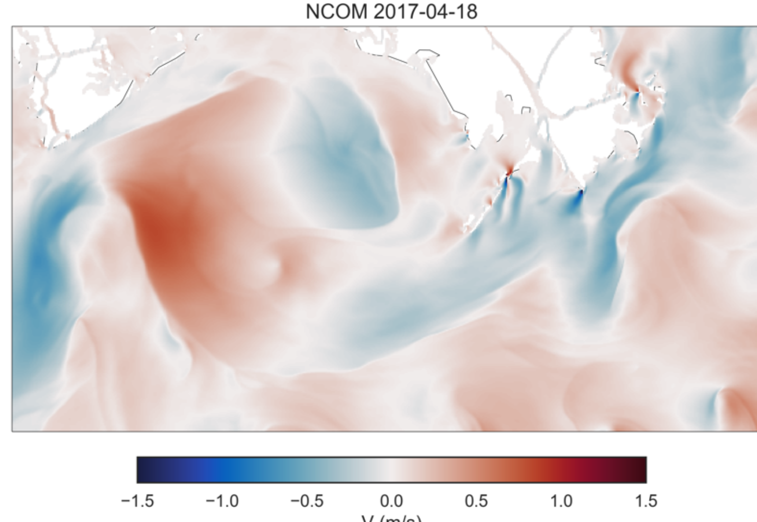
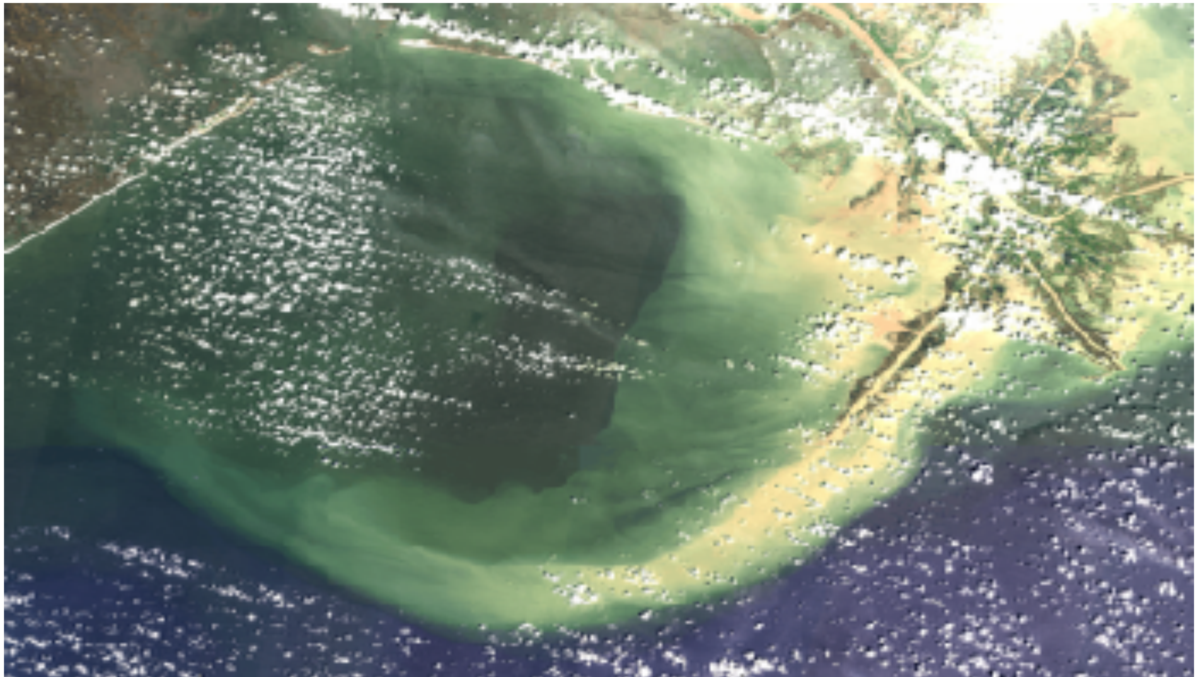
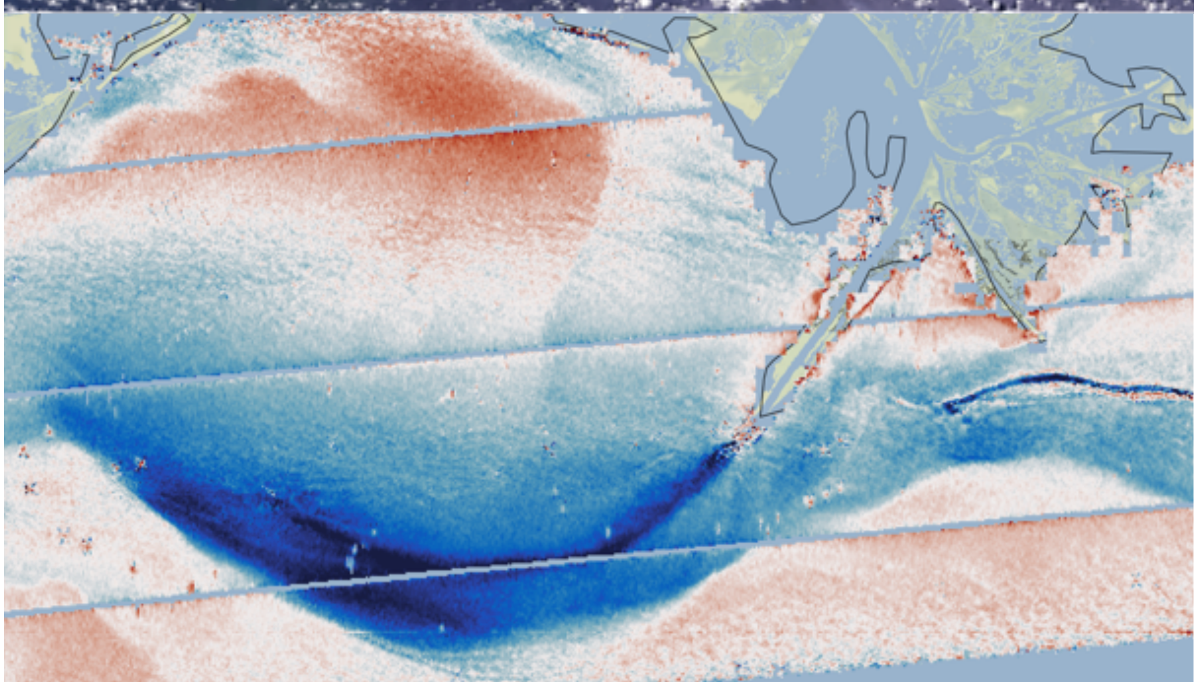




Sentinel 3 2017-04-18
Courtesy of Copernicus Sentinel, processed by ESA



DopplerScatt surface current U component.

Circulation pattern matches Sentinel 3 color pattern very closely.

2017-04-20

DopplerScatt

NCOM

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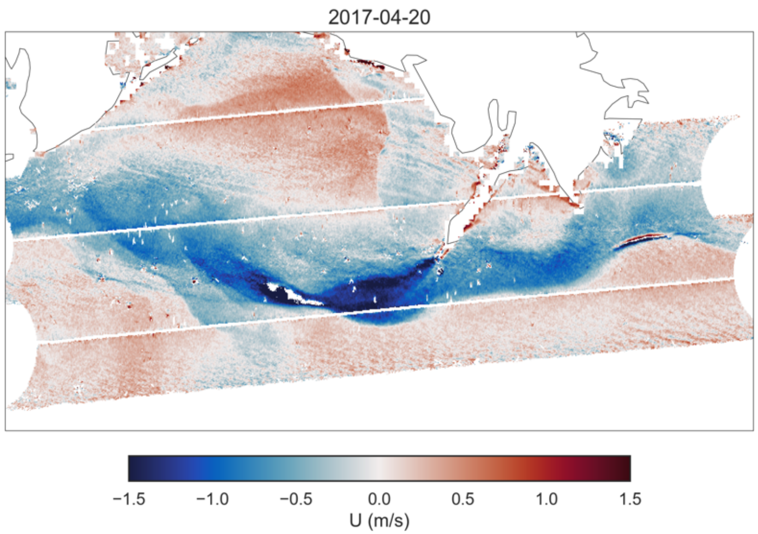

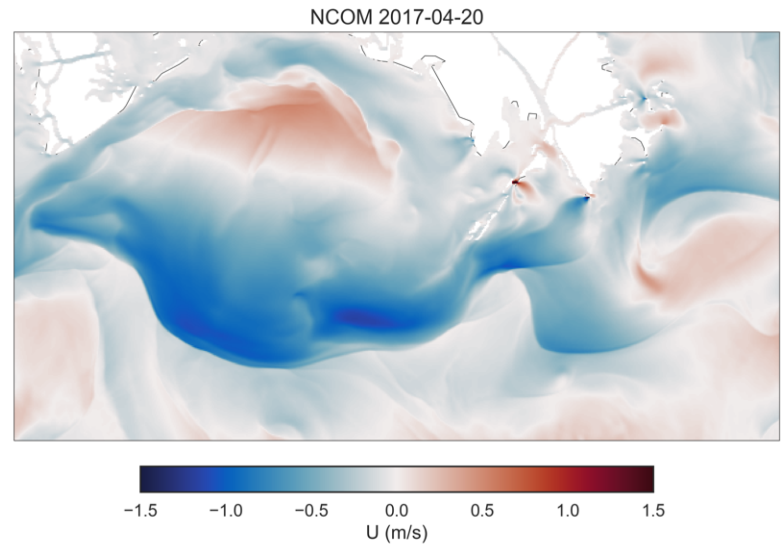

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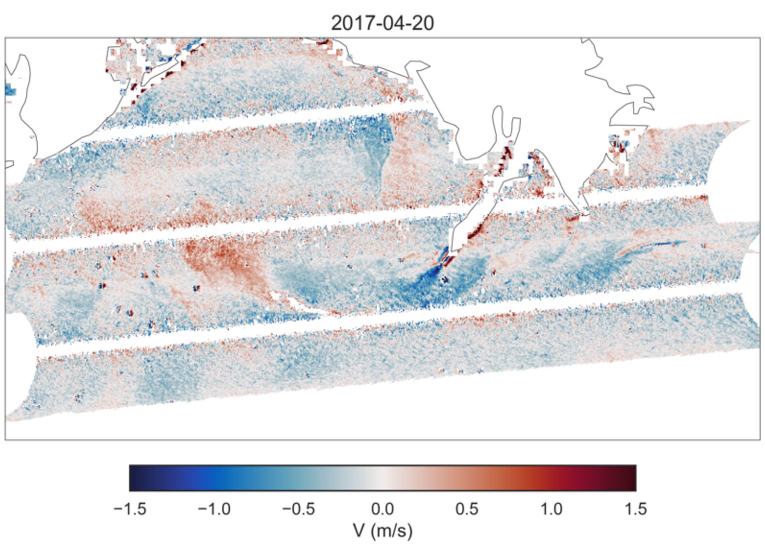
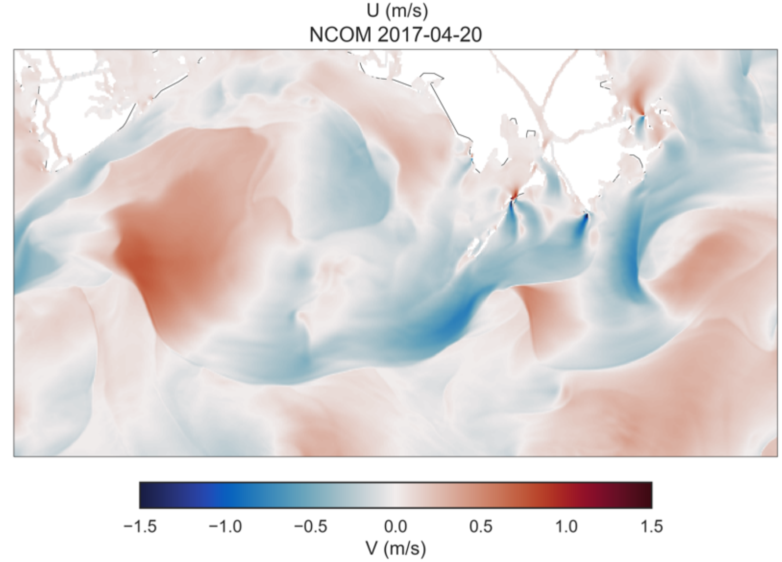
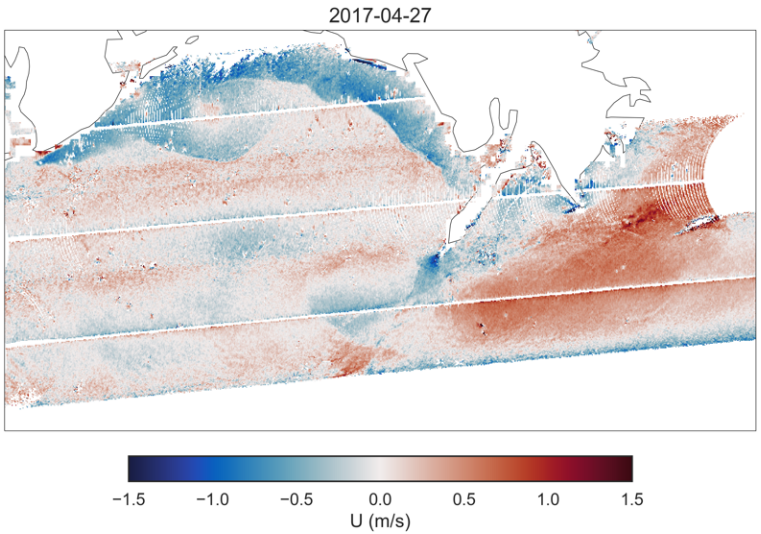
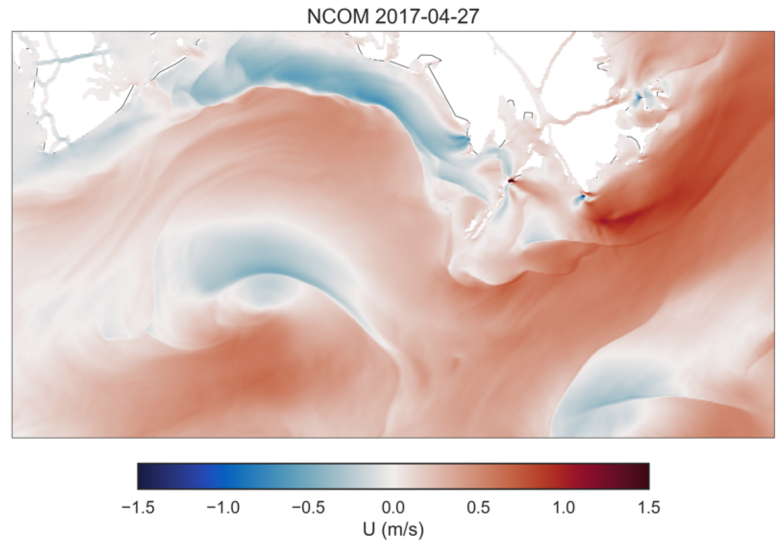
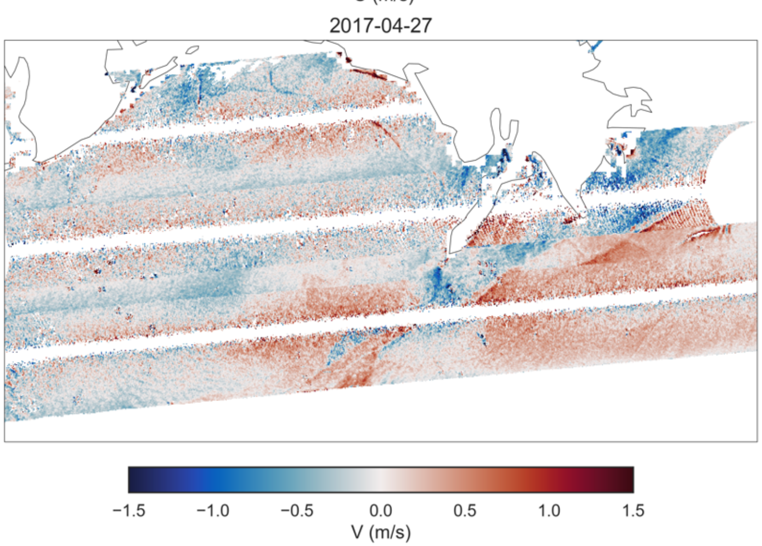
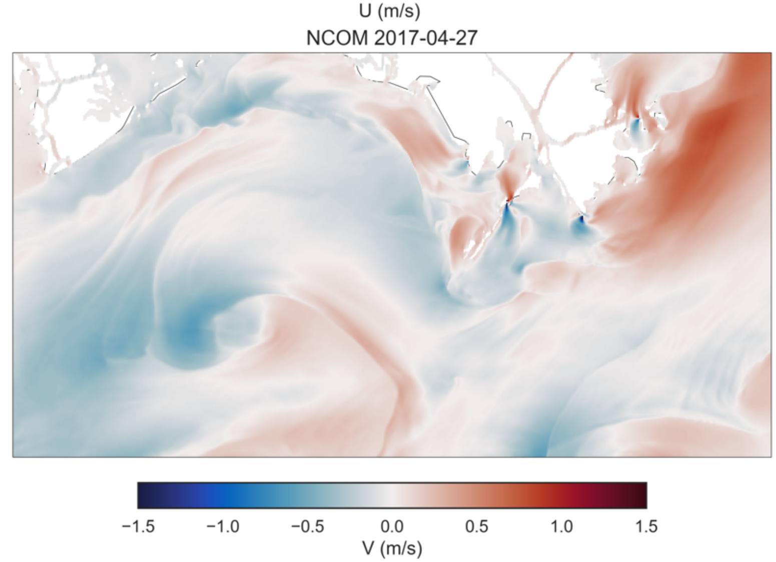




2017-04-27

	DopplerScatt	NCOM
U		
V		

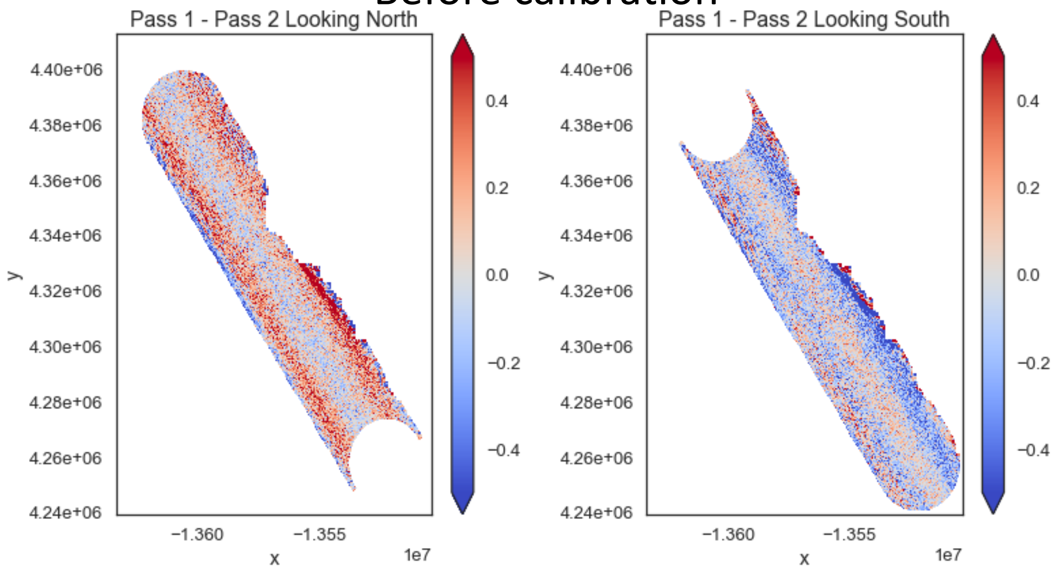
Summary and Prospects

- Ka-band scatterometry shows promise in measuring ocean vector winds with a sensitivity to wind speed similar to QuikSCAT, and better direction sensitivity
- DopplerScatt has demonstrated measurements of wide-swath surface currents
  - Surface current estimates show good qualitative agreement with the NCOM model (within the expected limitations of a forecast model)
  - Validation of surface currents against surface drifters and HF-radar data is ongoing
- Unlike C-band, wind driven surface current contamination does not depend strongly on wind speed, making wind driven component removal simpler than at C-band
  - A Doppler scatterometer has simultaneous wind measurements that enable more accurate removal than using models
- DopplerScatt calibration is proceeding satisfactorily (although not finished for all lines collected to date)
- NASA AITT work in progress to transition to a NASA King Air platform that has longer range than previously flown
  - Calibration flights planned for February 2018, with a field campaign towards the end of summer (California Current)

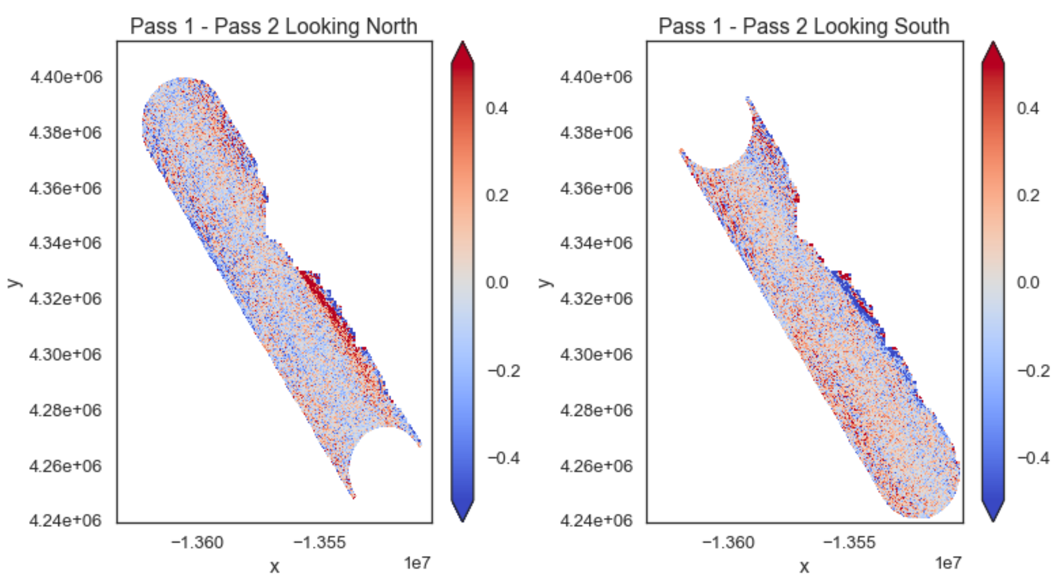
BACKUP

Radial Velocity Pointing Calibration

Before calibration



After calibration



Radial velocity sensitivities

$$
\begin{aligned}
v_r &= \hat{\ell} \cdot (v_p - v_s) \\
\hat{\ell} &= \sin\theta[\hat{x}\cos\phi + \hat{y}\sin\phi] - \cos\theta\hat{z} \\
\delta v_{r\phi} &= \frac{\partial \hat{\ell} \cdot v_p}{\partial \phi}\delta\phi
\end{aligned}
$$

Errors in look angle θ is from range and is very accurate.

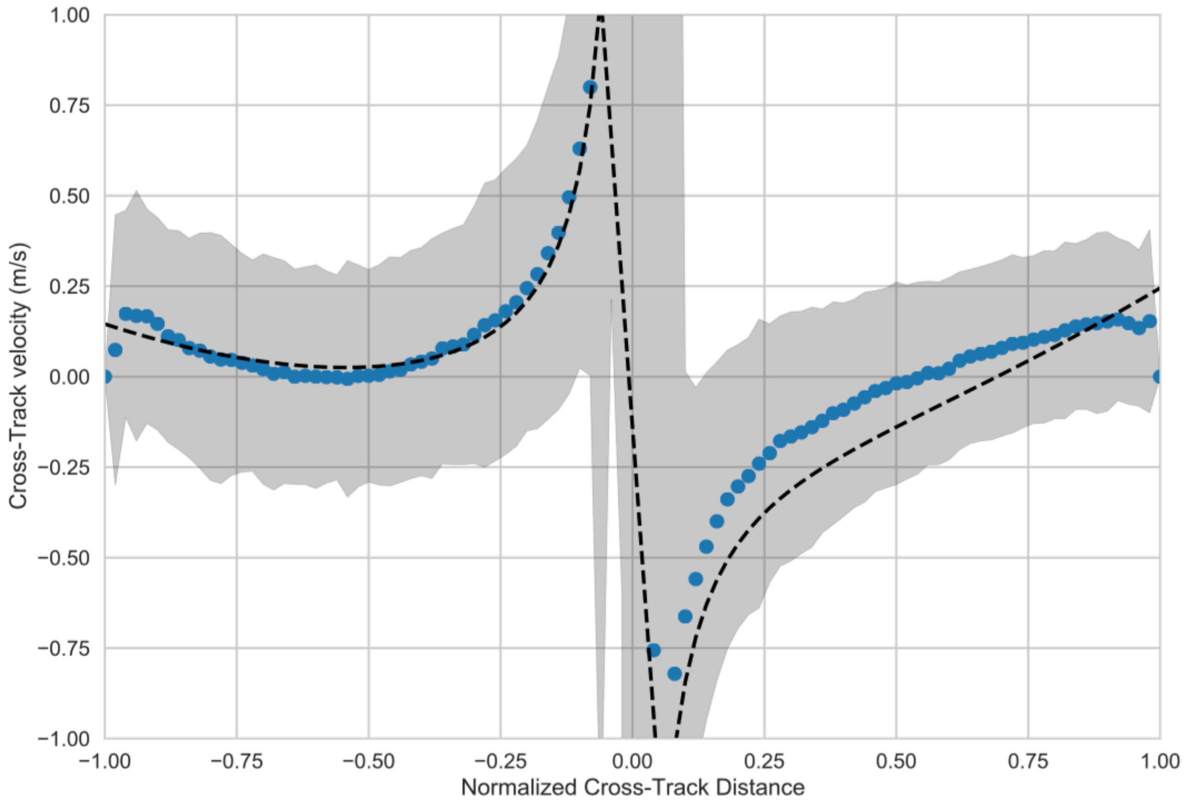
Airplane velocity from IMU is O(cm/s)

Calibration model

α is antenna rotation angle from encoder

$$\delta\phi(\alpha) = a_0 + \sum_n a_n \cos(n\alpha) + b_n \sin(n\alpha)$$

Cross-track velocity correction



- The opposite-direction, repeat pass technique is not sensitive to harmonics that have a periodicity such that the resulting error is identical for fore and aft viewing geometries
- These errors are estimated by averaging the cross-track velocity in the along-track direction and accumulating these results over multiple flight lines, to minimize effects of the actual surface velocity
- The trend is fitted by the low order polynomial and then removed for cross-track velocities
- No significant trend is found for along-track velocities