Measuring Winds and Currents with DopplerScatt

E. Rodríguez, D. Perkovic-Martin,
T. Gal, N. Niamsuwan, B. Stiles, A. Wineteer
Jet Propulsion Laboratory
California Institute of Technology

Why Winds and Surface Currents?

- Both are essential climate variables that have a tight two-way coupling
  - Stress and stress derivatives drive both horizontal and vertical circulation
  - Currents provide a moving reference frame for stress and also modulate winds through heat transport/SST
- A case was made to the ongoing US NRC Decadal Survey by multiple RFI 1 and 2 responses with broad support from the winds community
  - Decadal survey recommendations for future measurements expected by the end of 2017
- Concepts for simultaneous measurements of winds and currents using small modifications of available technology have been put forward in China (Dong et al, OVWST2106), Europe (Stoffelen et al, Ardhuin et al, SKIM), and the US (WaCM team).
- DopplerScatt (NASA IIP) is a proof of concept instrument to validate measurement physics, algorithms, technology readiness.

DopplerScatt Overview

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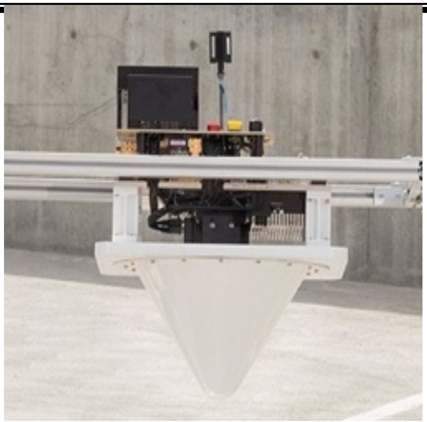
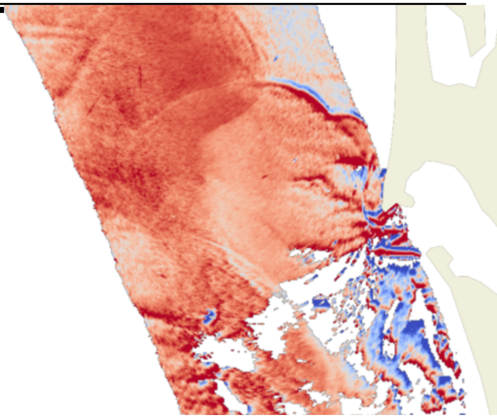
- Scanning Doppler radar developed under NASA's IIP program
- Becoming operational under NASA AITT program
- **Data Products:**
1. Vector ocean surface currents
2. Vector ocean surface winds
3. Radar brightness maps (sensitive to surfactants such as oil films)
- **Mapping capabilities**: 25 km swath; maps 200km x 100km area in about 4 hrs; 200m data product resolution; ~5-10cm/s radial velocity precision.
- **Current status**:
  - Instrument hardware completed
  - Instrument currently undergoing final calibration and validation
  - CalVal campaigns: SPLASH (Submesoscale Processes and Lagrangian Analysis on the Shelf) in Mississippi River Plume (CARTHE) & Taylor Oil Platform Plume (NOAA), April 18-28; KISS-CANON in Monterey Bay May 1-4.



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



DopplerScatt radial surface currents and biological surfactants (white) at Columbia River mouth.

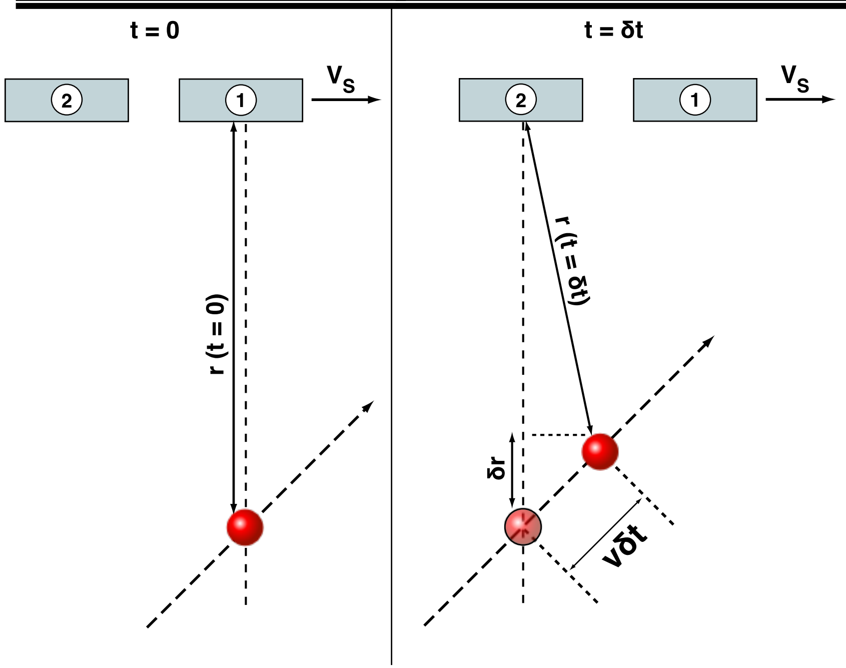
Potential Uses for Scientific Use

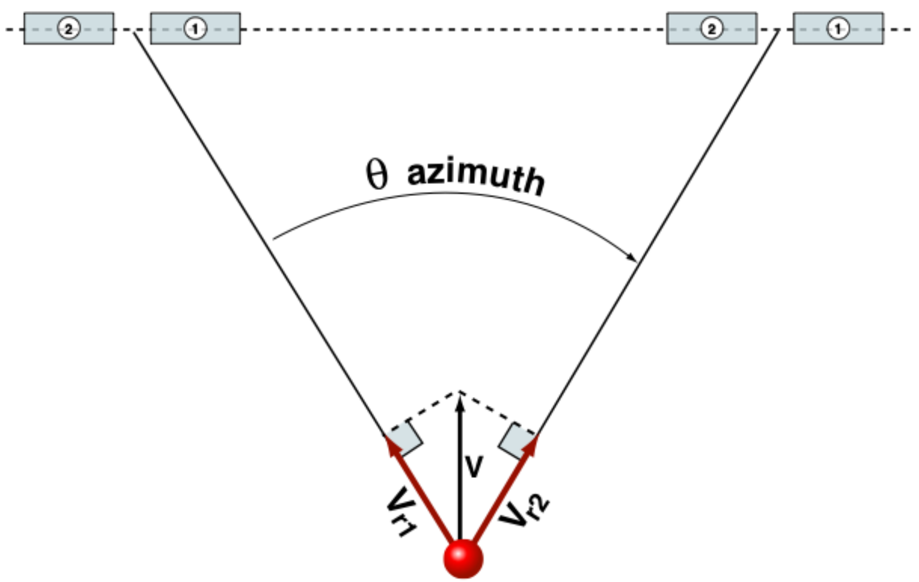
- Observation of mesoscale to submesoscale transition in surface current circulation with associated wind drivers.
- Observation of internal waves and evolution over synoptic scales
- Improved understanding of air-sea interaction by simultaneous measurements of surface currents, wind stress, and SST (separate sensor that can be accommodated in NASA King Air platform).
- Improved understanding of mechanisms leading to upwelling
- Understanding of interactions of river plumes and ocean circulation, including mixing

Potential for Operational Use

- High resolution characterization of circulation in coastal shipping areas
- Tracking of surface surfactants (e.g., oil) with simultaneous measurements of surface currents and winds to aid models in prediction of dispersal
- Understanding beach erosion
- Planning for oil platform siting and safety

Doppler Current Measurement Concept





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

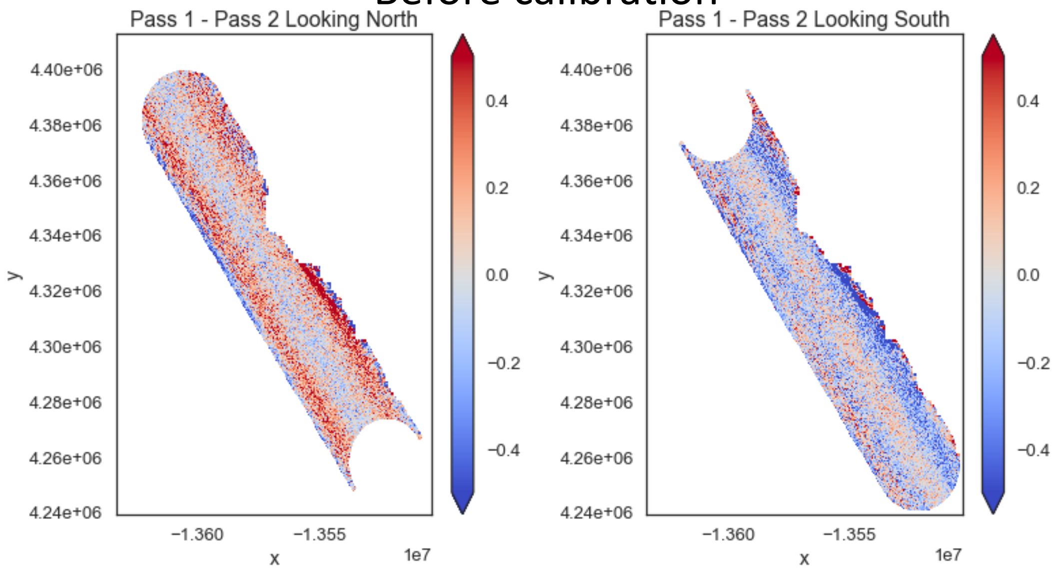
Radial velocity component: $v_r = \Delta r/\delta t = \Delta\Phi/(2k\delta t)$

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

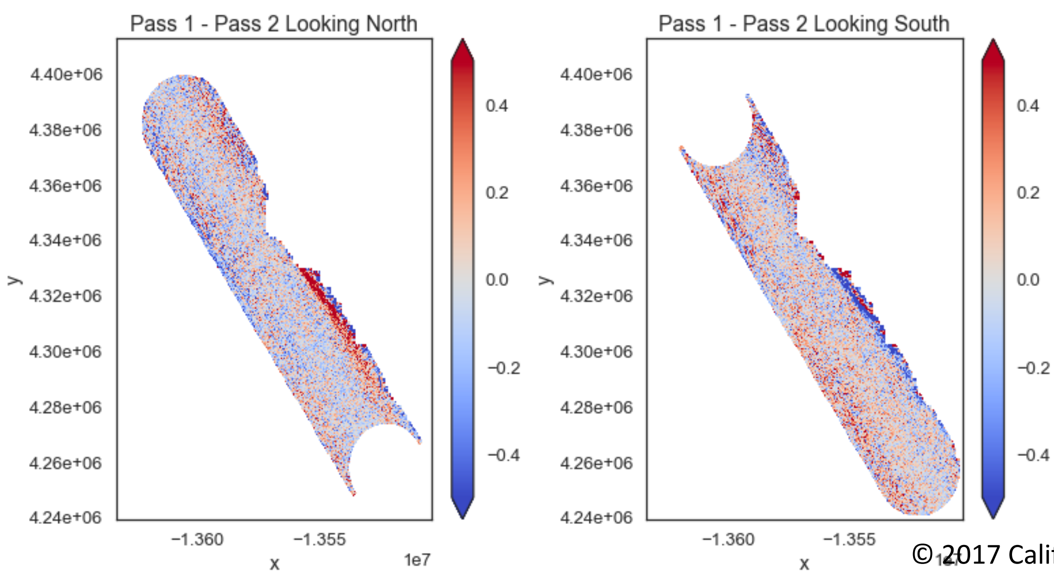
- Radars provide coherent measurements: both the phase and the amplitude of a scattered signal are measured.
- The phase is proportional to the 2-way travel time (or range)
- The amplitude is proportional to the scattering strength of the traget
- Doppler measurements, f_D, are obtained by measuring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

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.

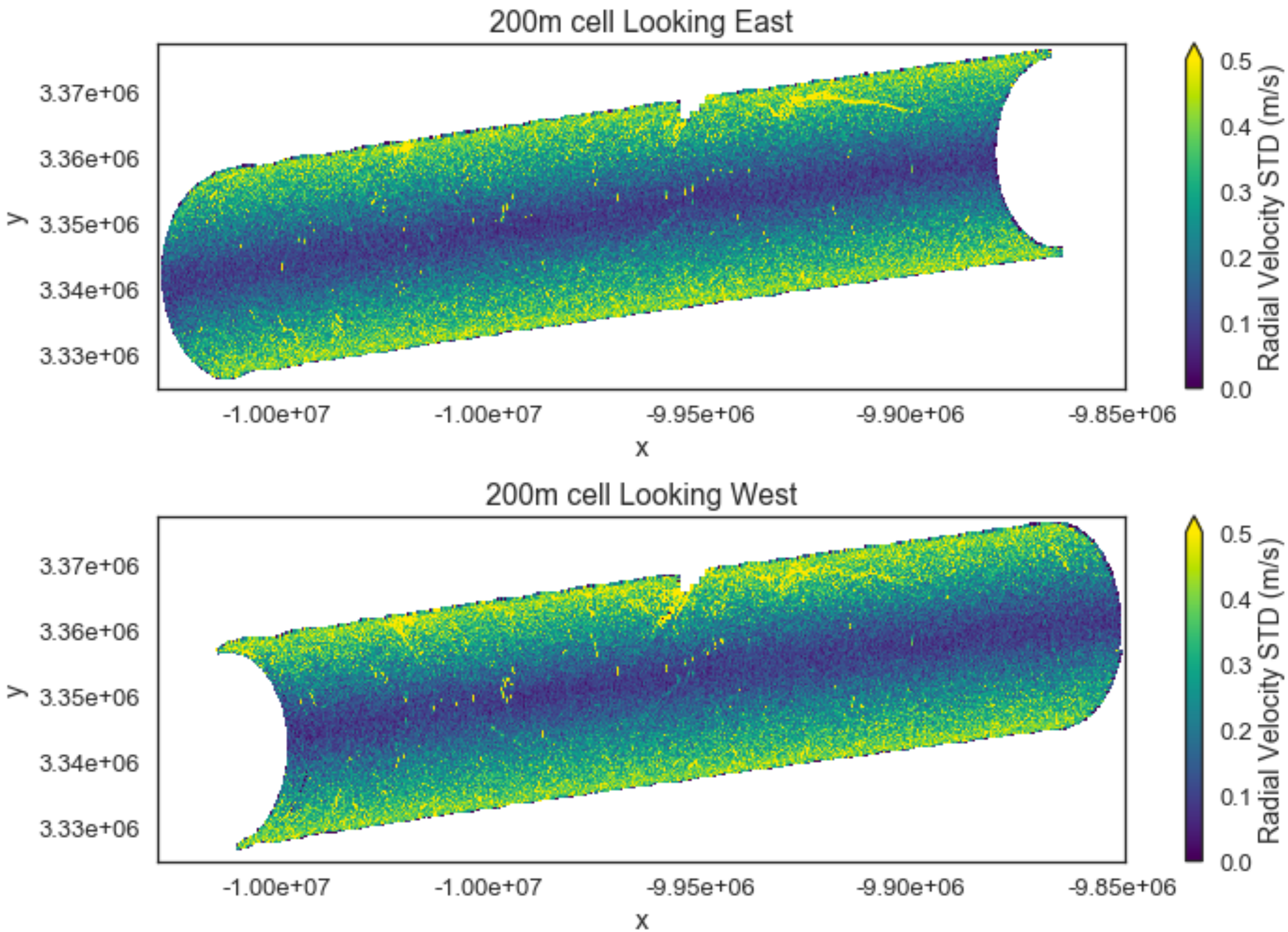
Airplane velocity from IMU is O(cm/s)

Calibration model

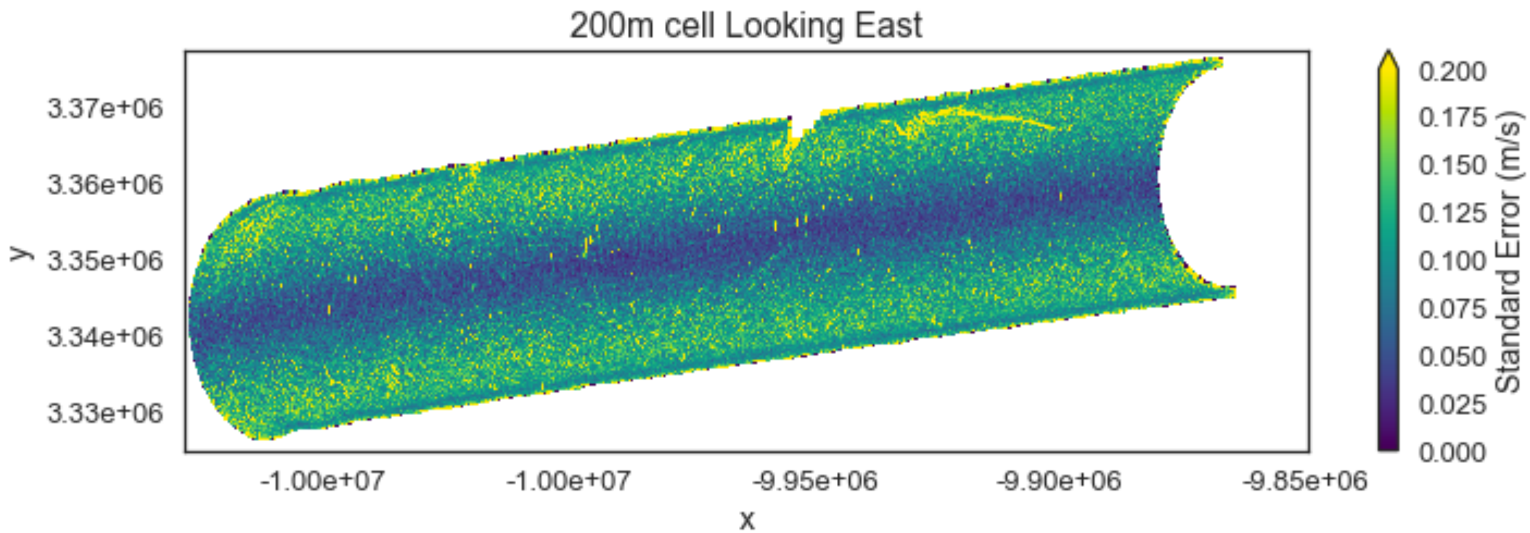
α is antenna rotation angle from encoder

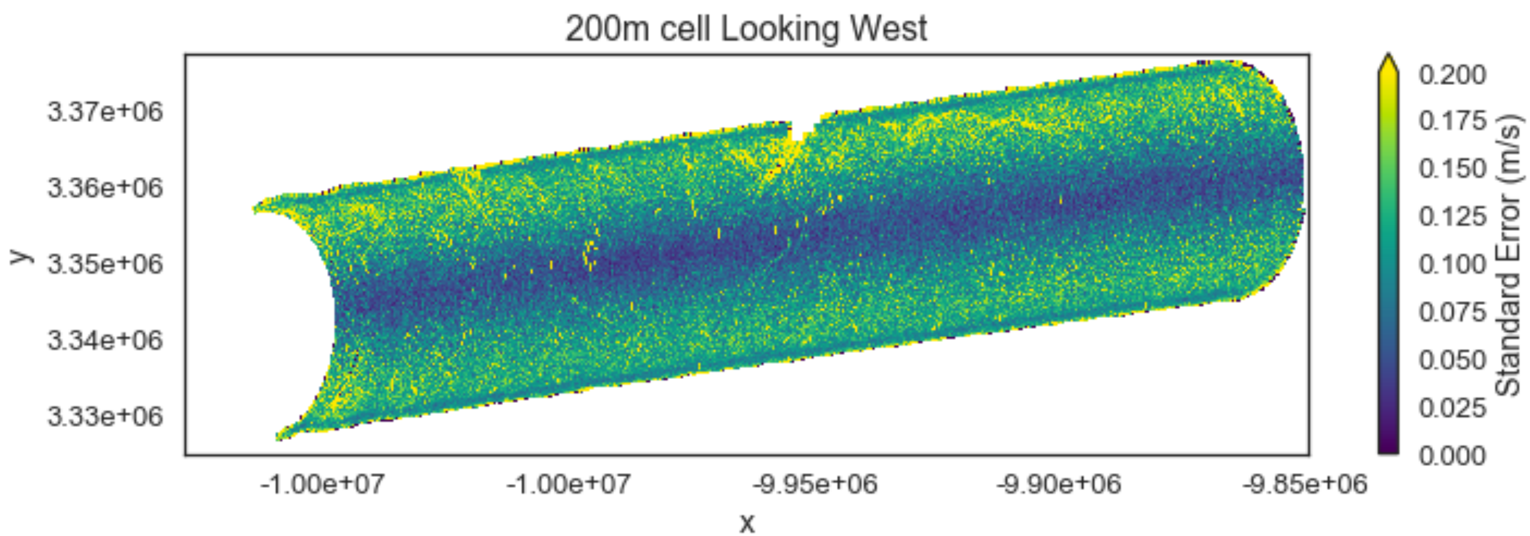
$$\delta\phi(\alpha) = a_0 + \sum_n a_n \cos(n\alpha) + b_n \sin(n\alpha)$$

Radial Velocity STD Per Measurement

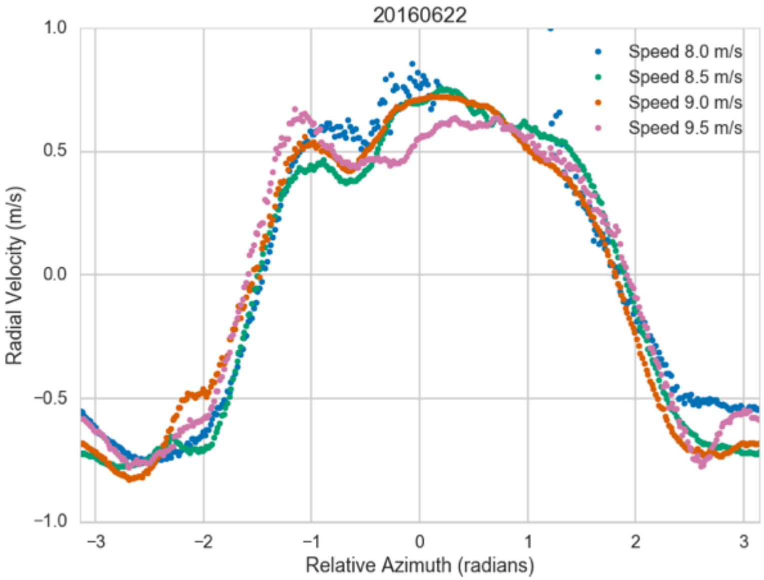


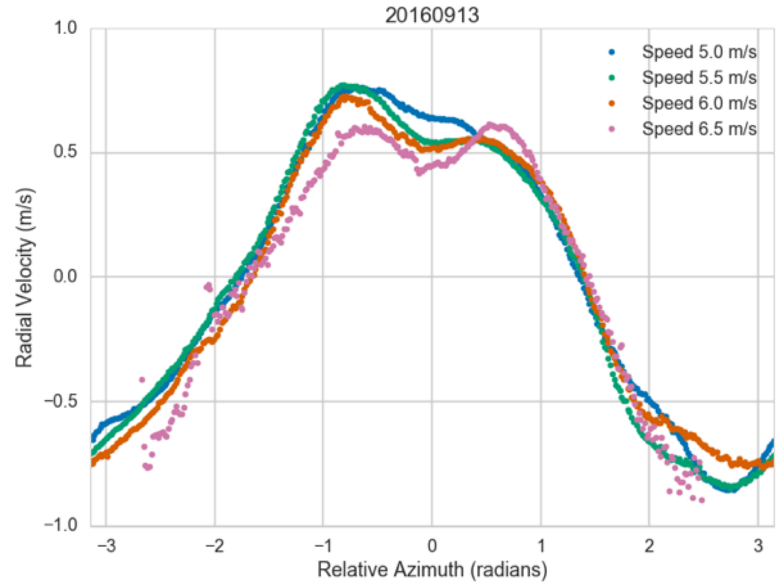
Radial Velocity Standard Error
200m Cell

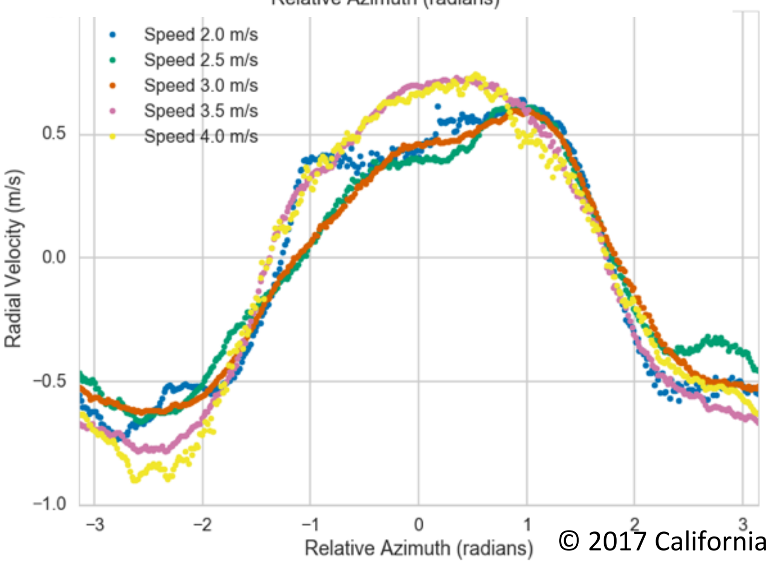




Correction for Wind-Driven Component

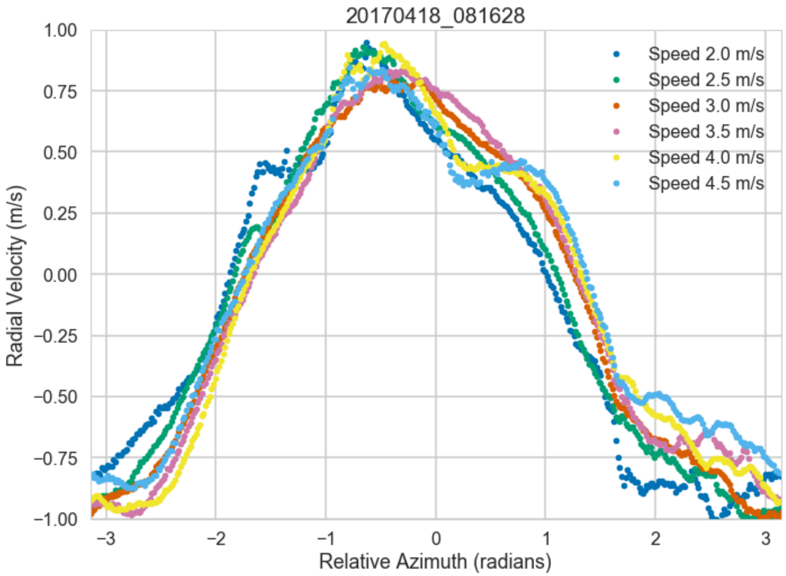


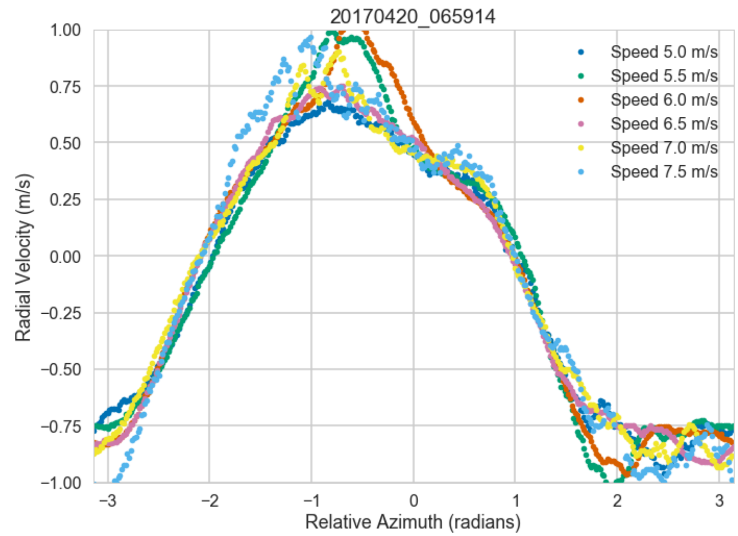


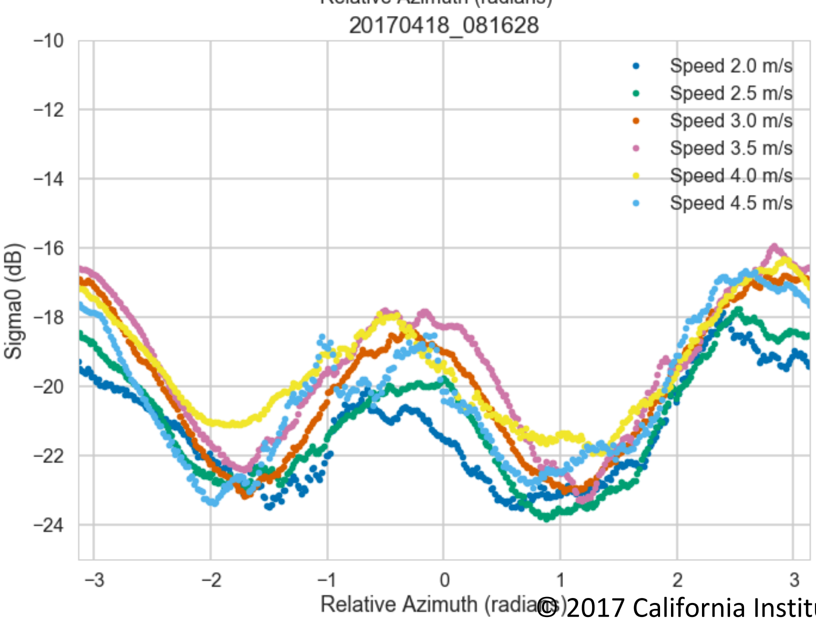


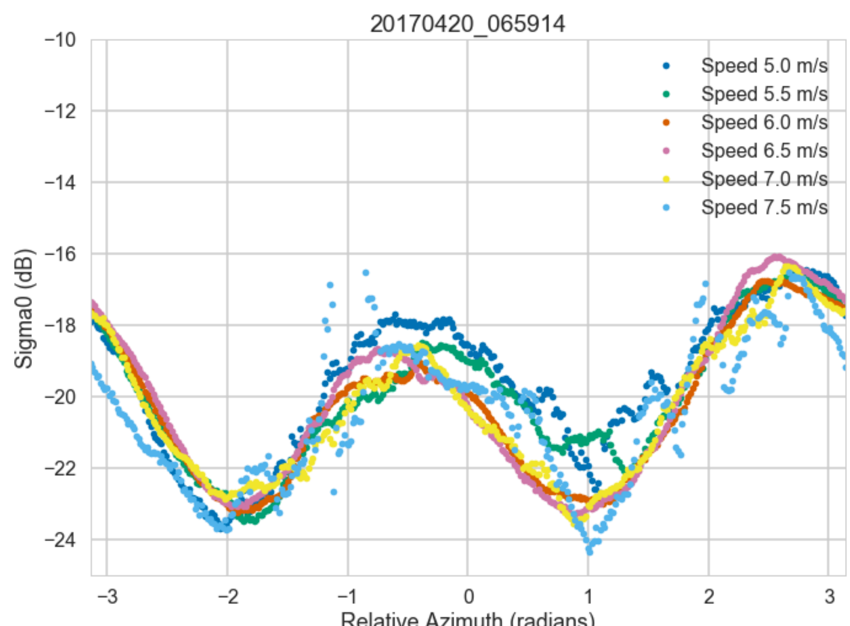
A wind driven component is estimated by binning Doppler velocities relative to wind direction to make a wind driven current GMF. The current estimates of the GMF are still being refined but preliminary estimates over a large range of wind speeds shows near universal behavior independent of waves and wind speed.

GMF Challenges
Model Resolution and Direction
Non-Wind Driven Surface Currents



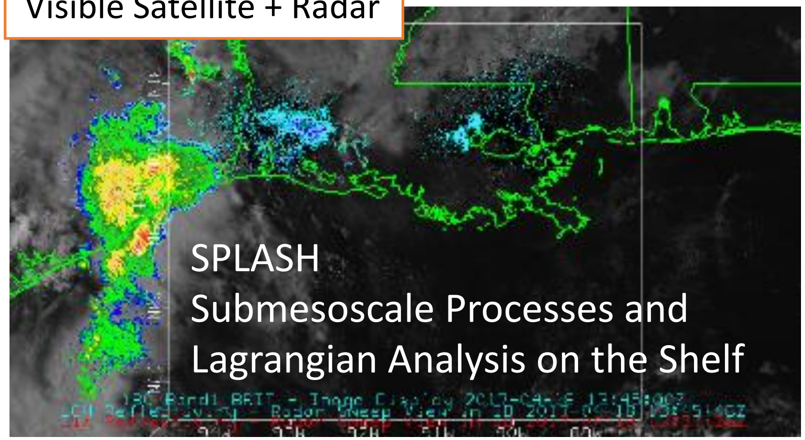


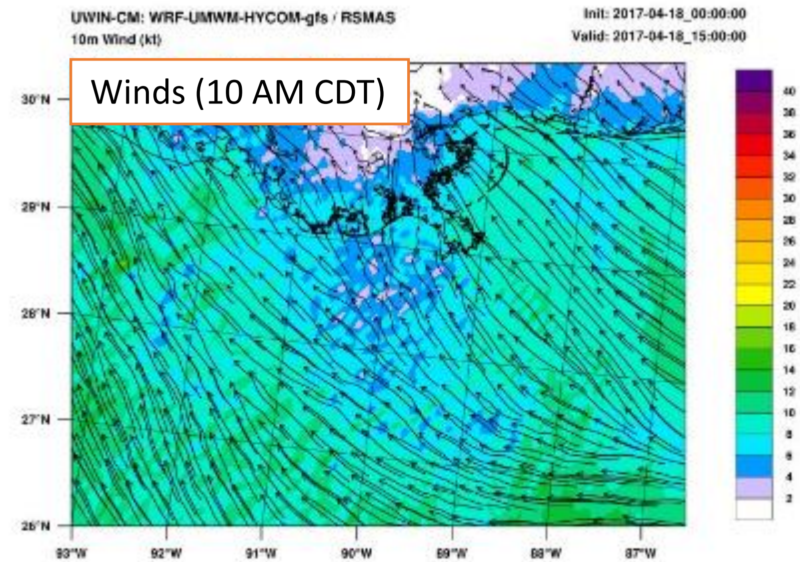




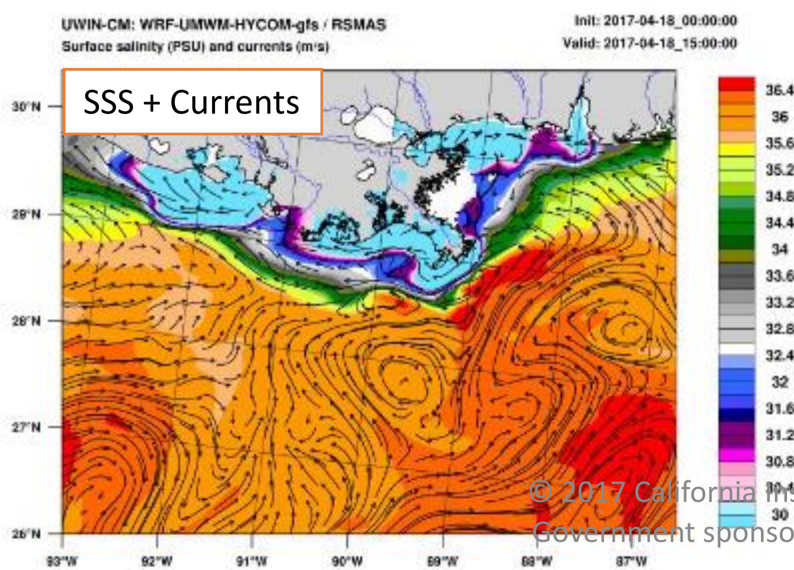
Today and tonight (Tuesday 18 April)

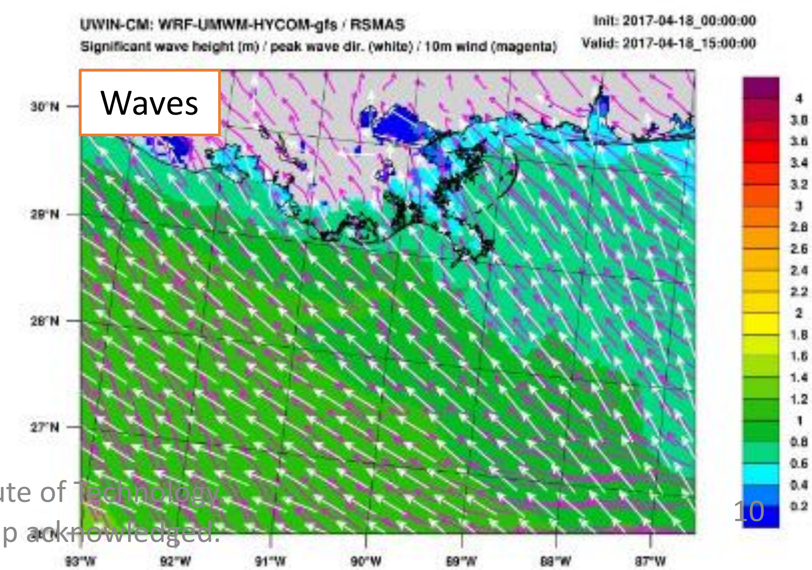
Winds from the SE 5-10 kts. Increasing to 10-15 knots tonight. Mostly clear.
Seas 2-3 feet, wave period 6-7 s. Nearshore fresh water with westward currents.



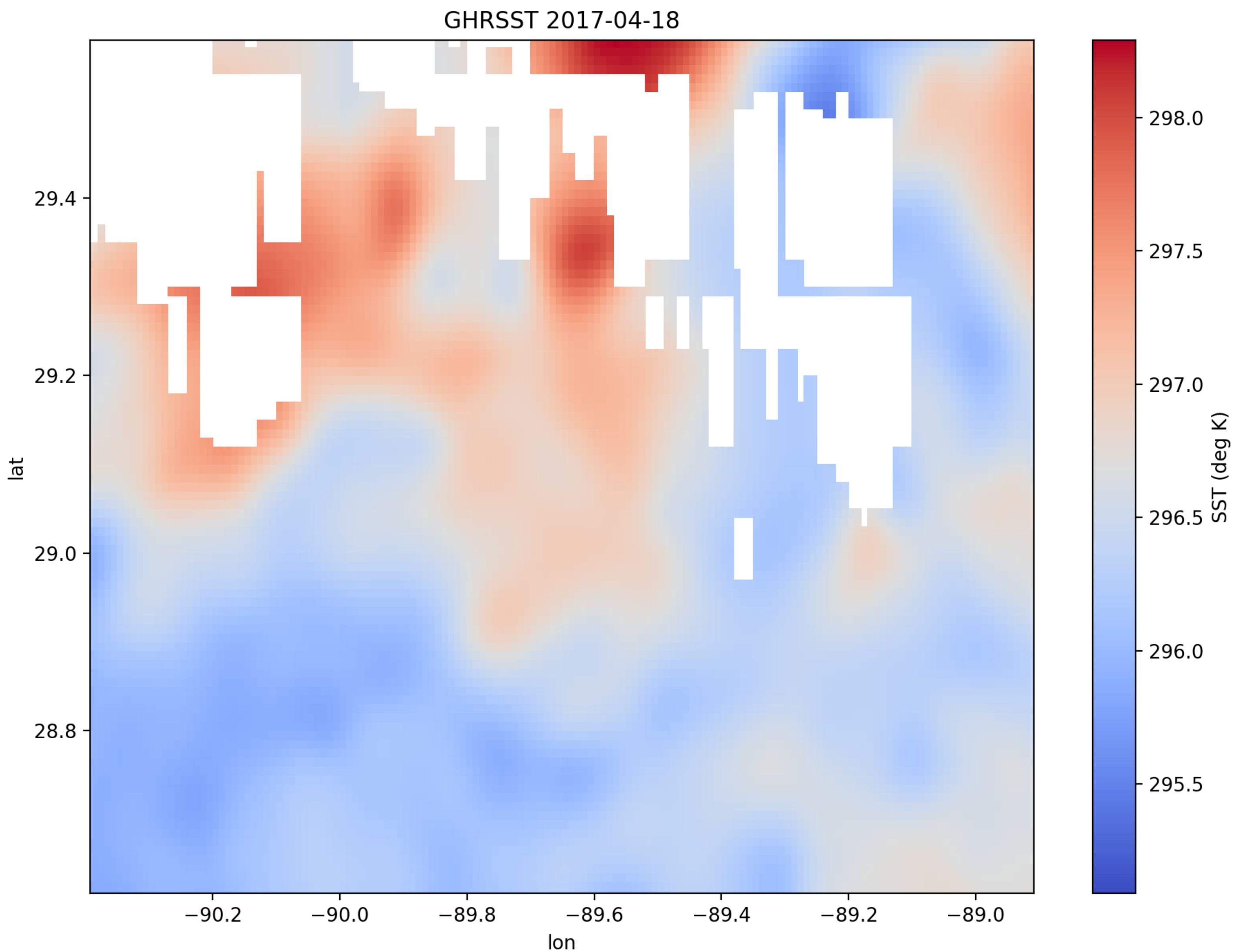


Model was run in real time by M. Curcic,
data were provided by B. Kerns, RSMAS

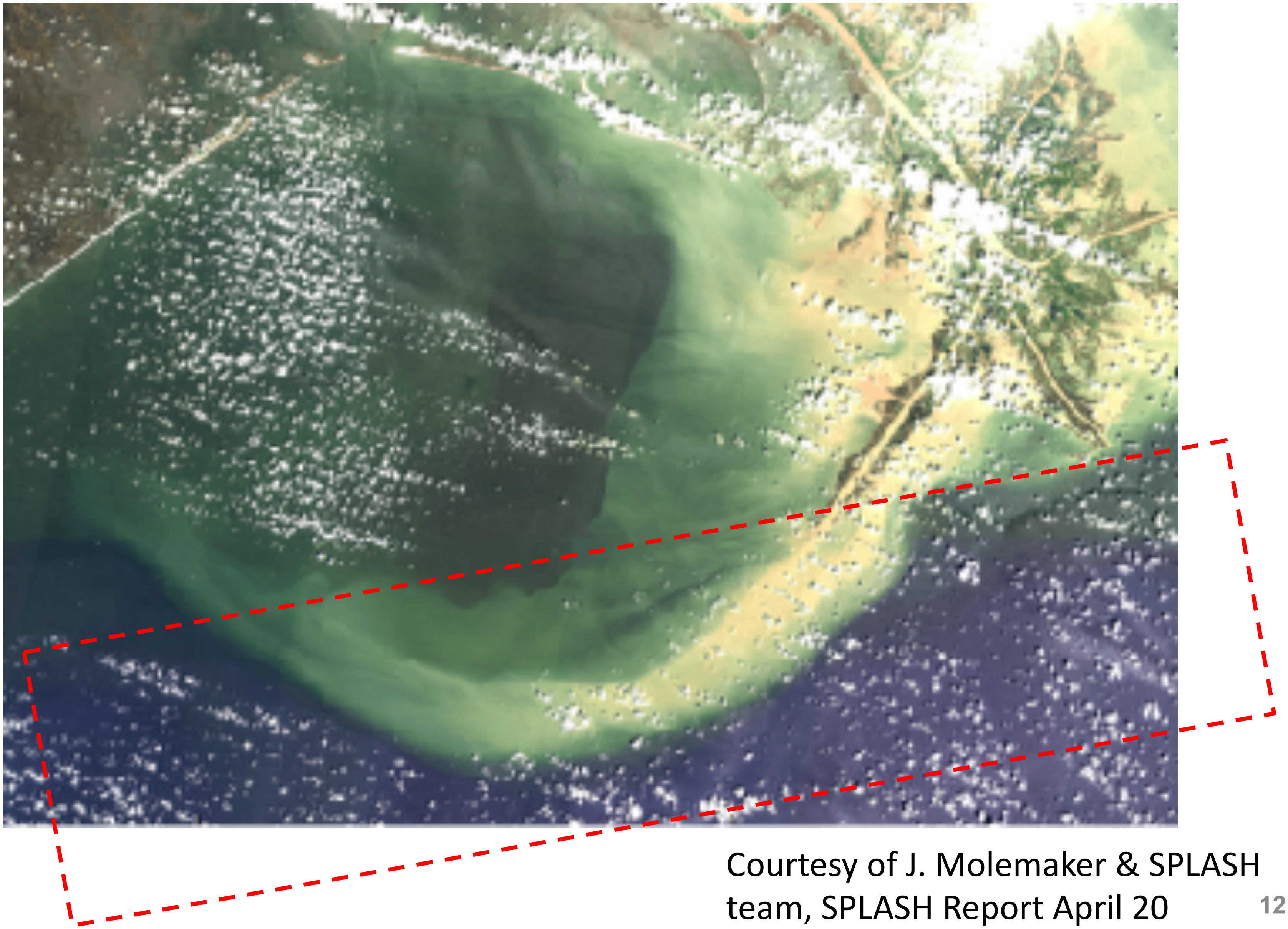




GHRSST 2017-04-18

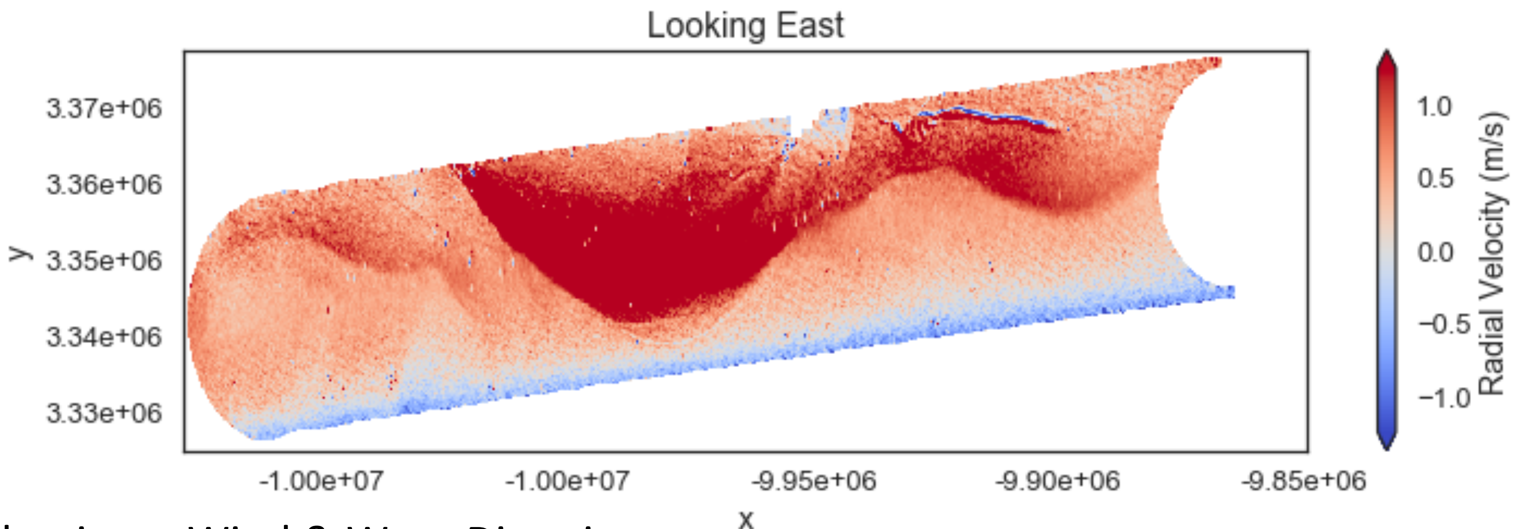


Sentinel 3 Image on 2017-04-18

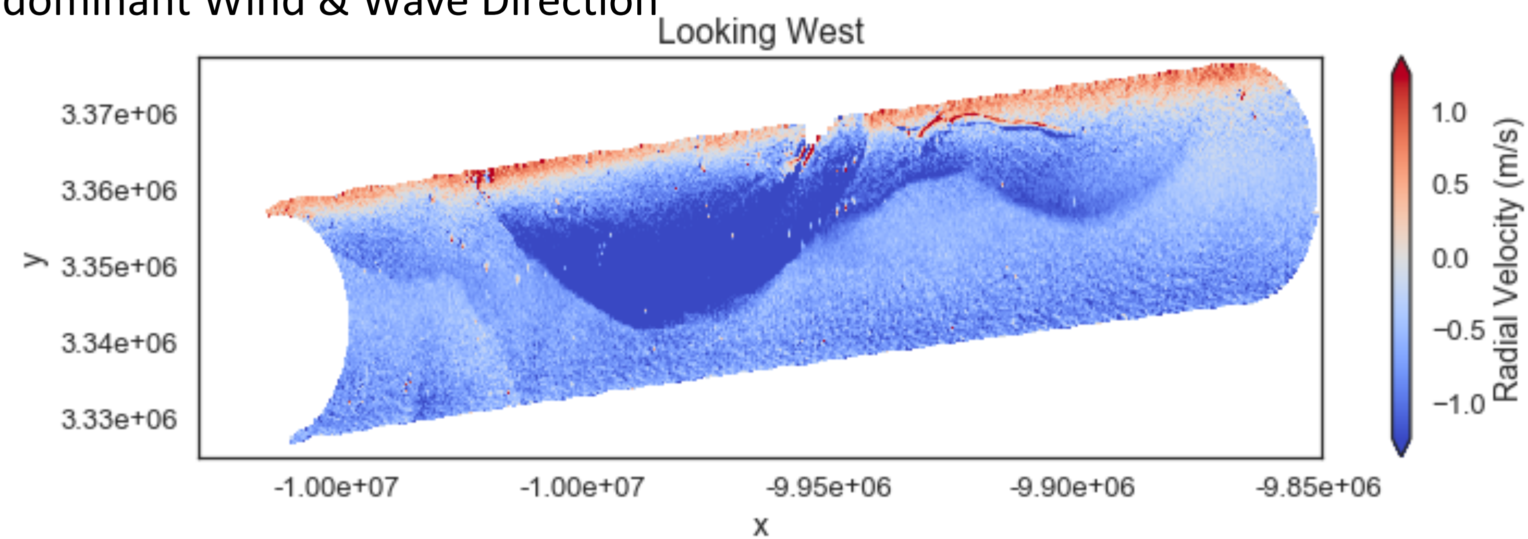


Courtesy of J. Molemaker & SPLASH team, SPLASH Report April 20

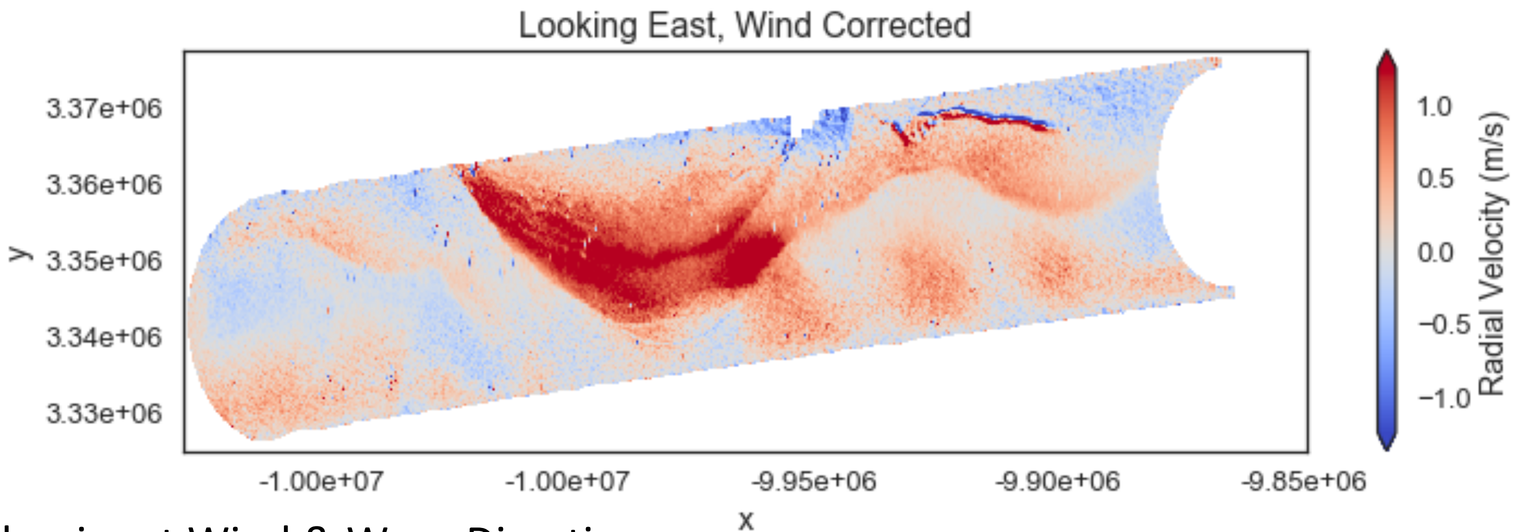
Radial Velocities
No Wind Correction



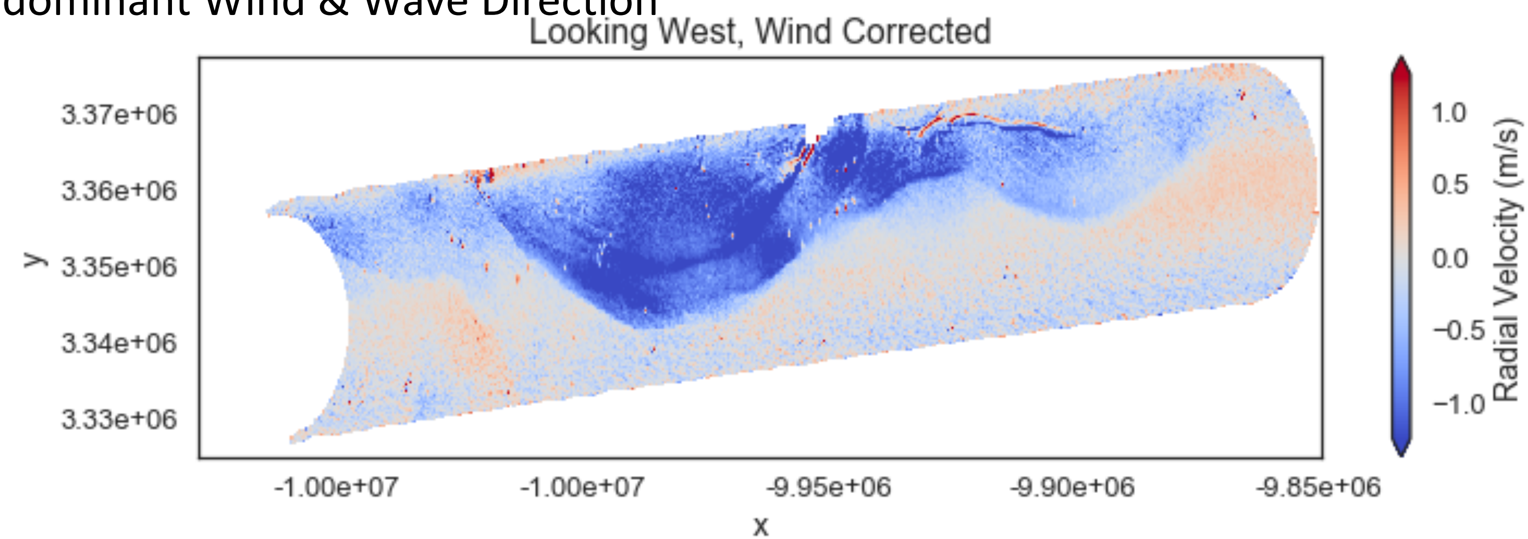
Predominant Wind & Wave Direction



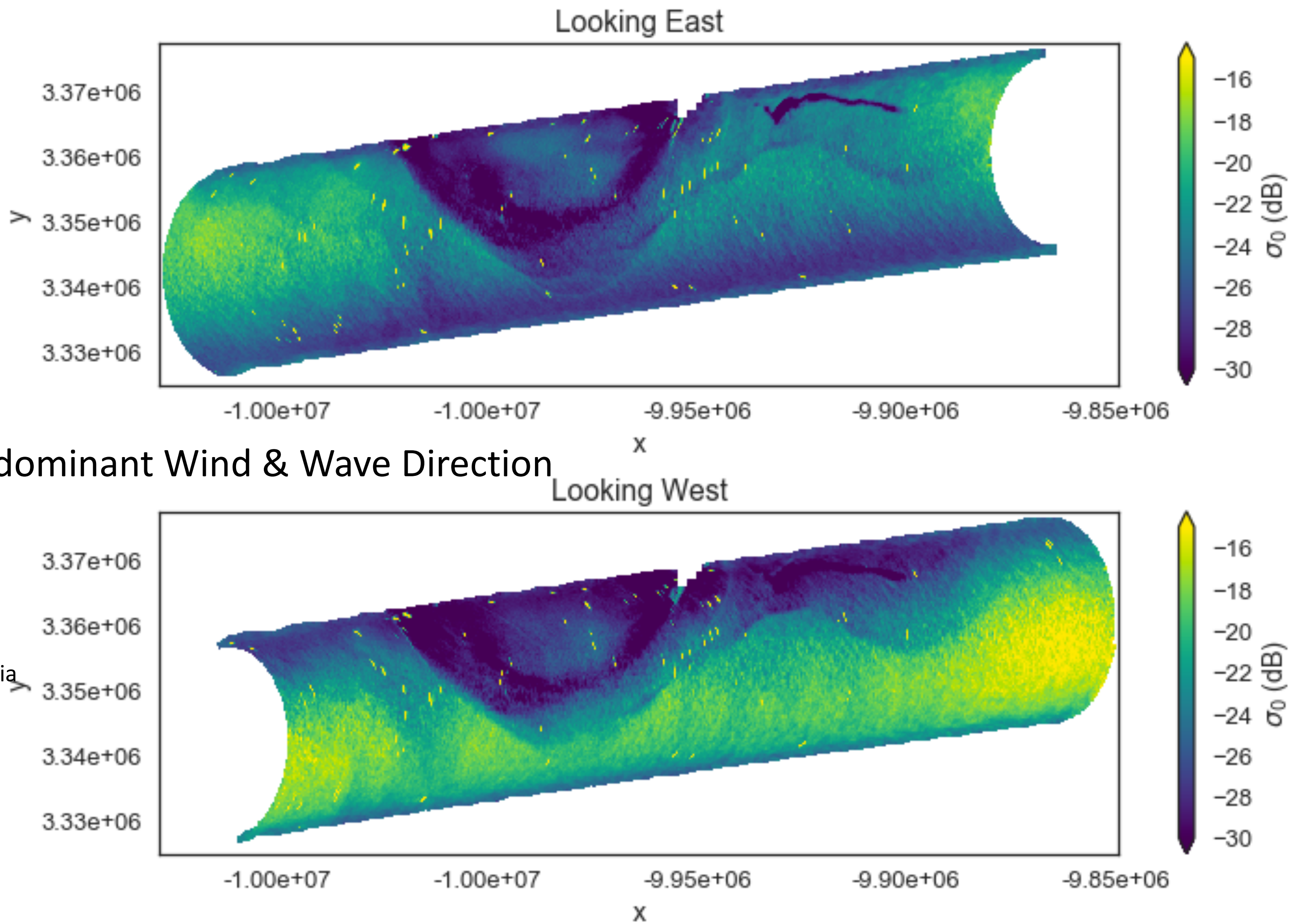
Wind Corrected Radial Velocities



Predominant Wind & Wave Direction

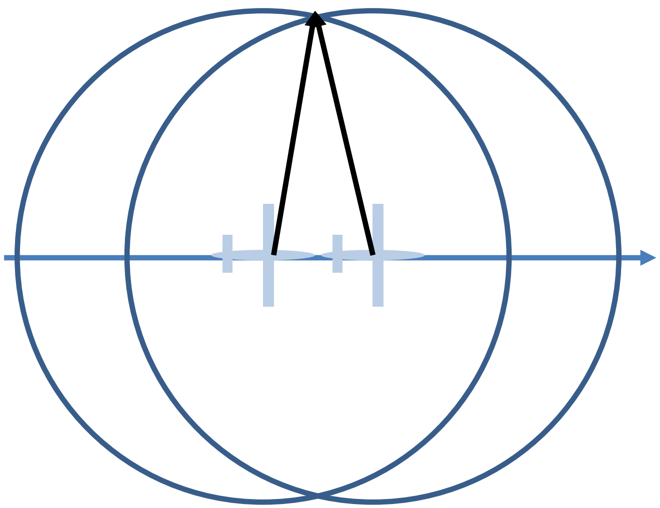


Modulation of σ_0

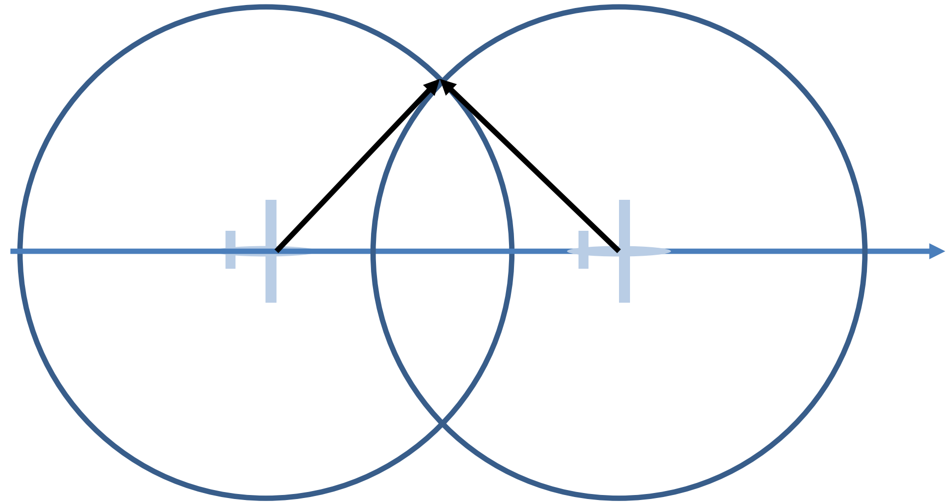


σ_0 shows significant “instantaneous” modulation by surface velocity and at oil spill plume.
Potential effects due to surfactants, kinematic moving frame effects of stress, or SST need further investigation.

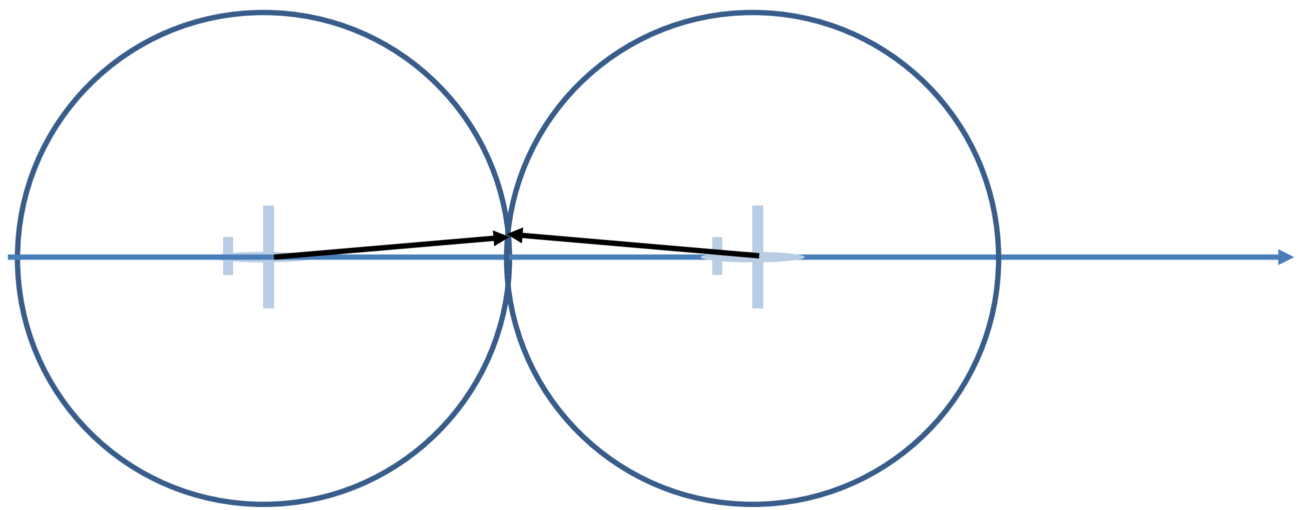
DopplerScatt Vector Velocity Estimation



Bad azimuth diversity

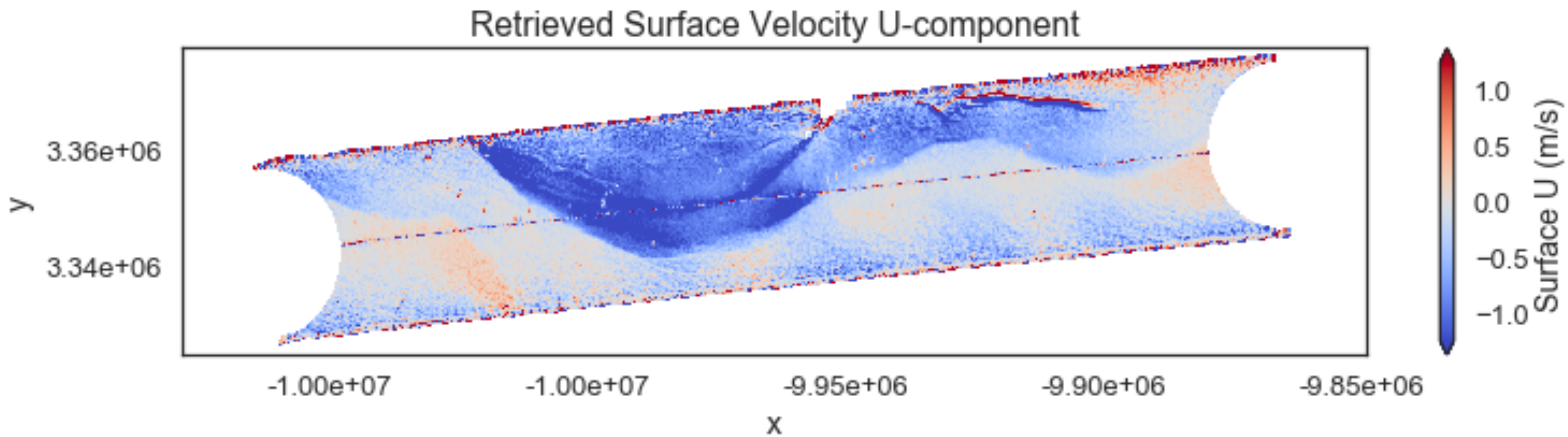


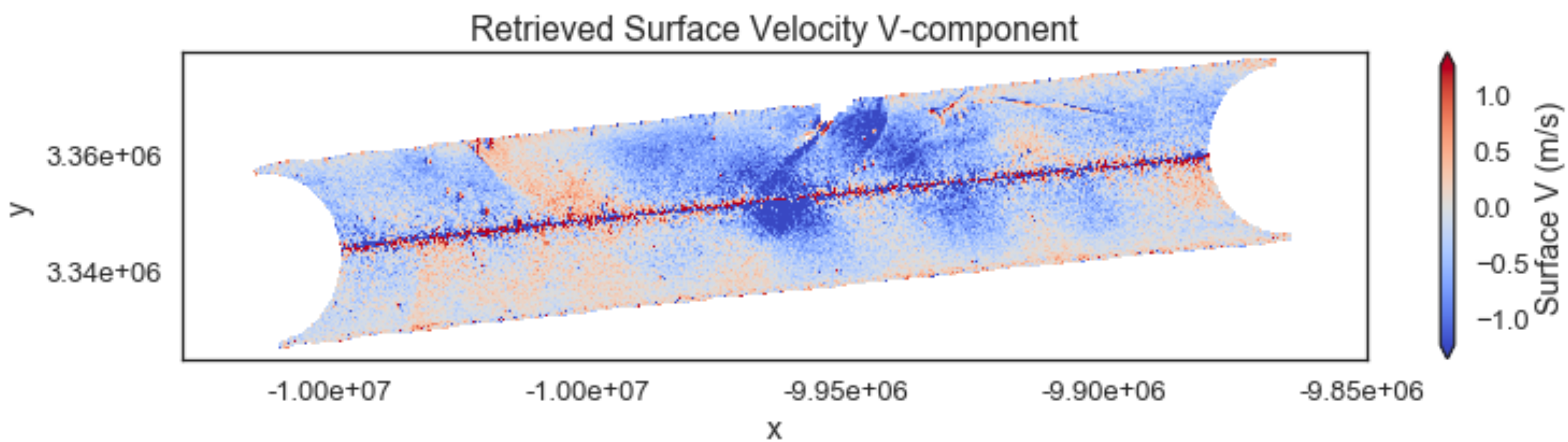
Good azimuth diversity



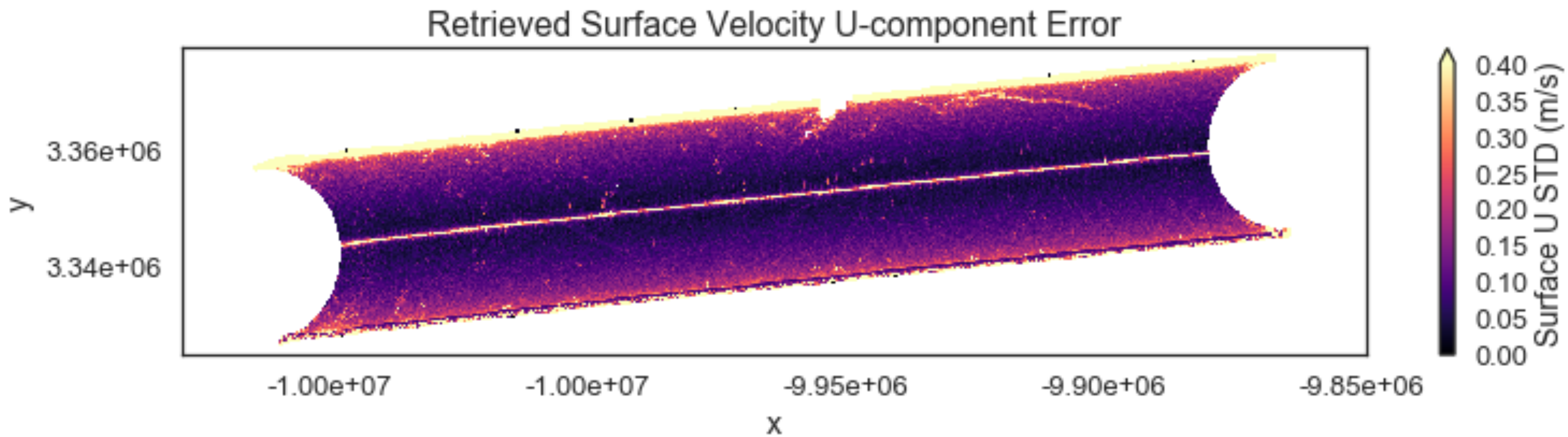
Bad azimuth diversity

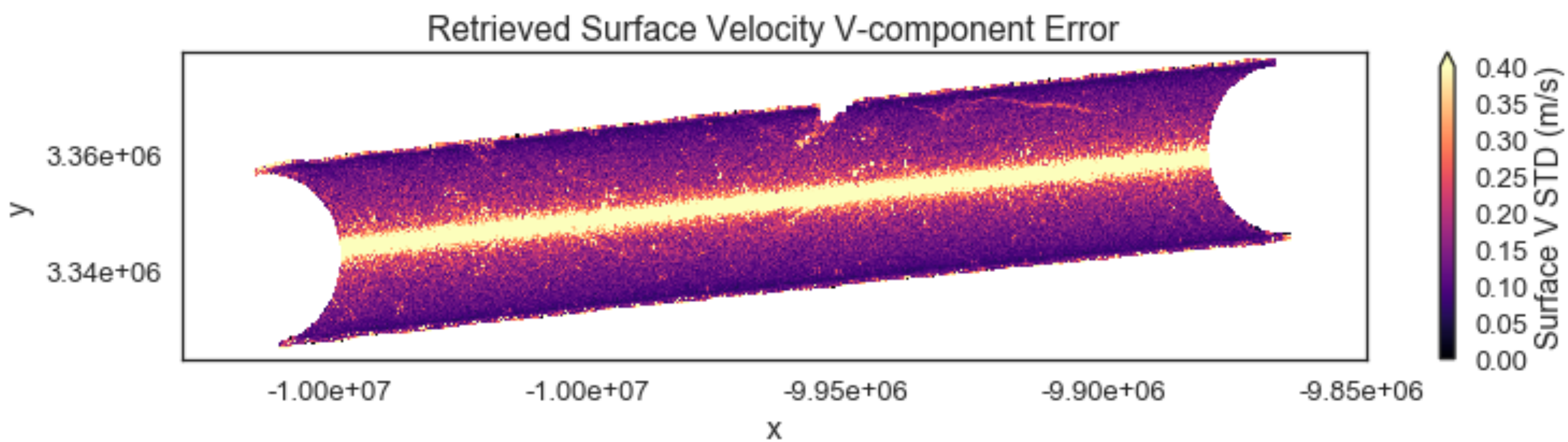
Retrieved Surface Velocity Components



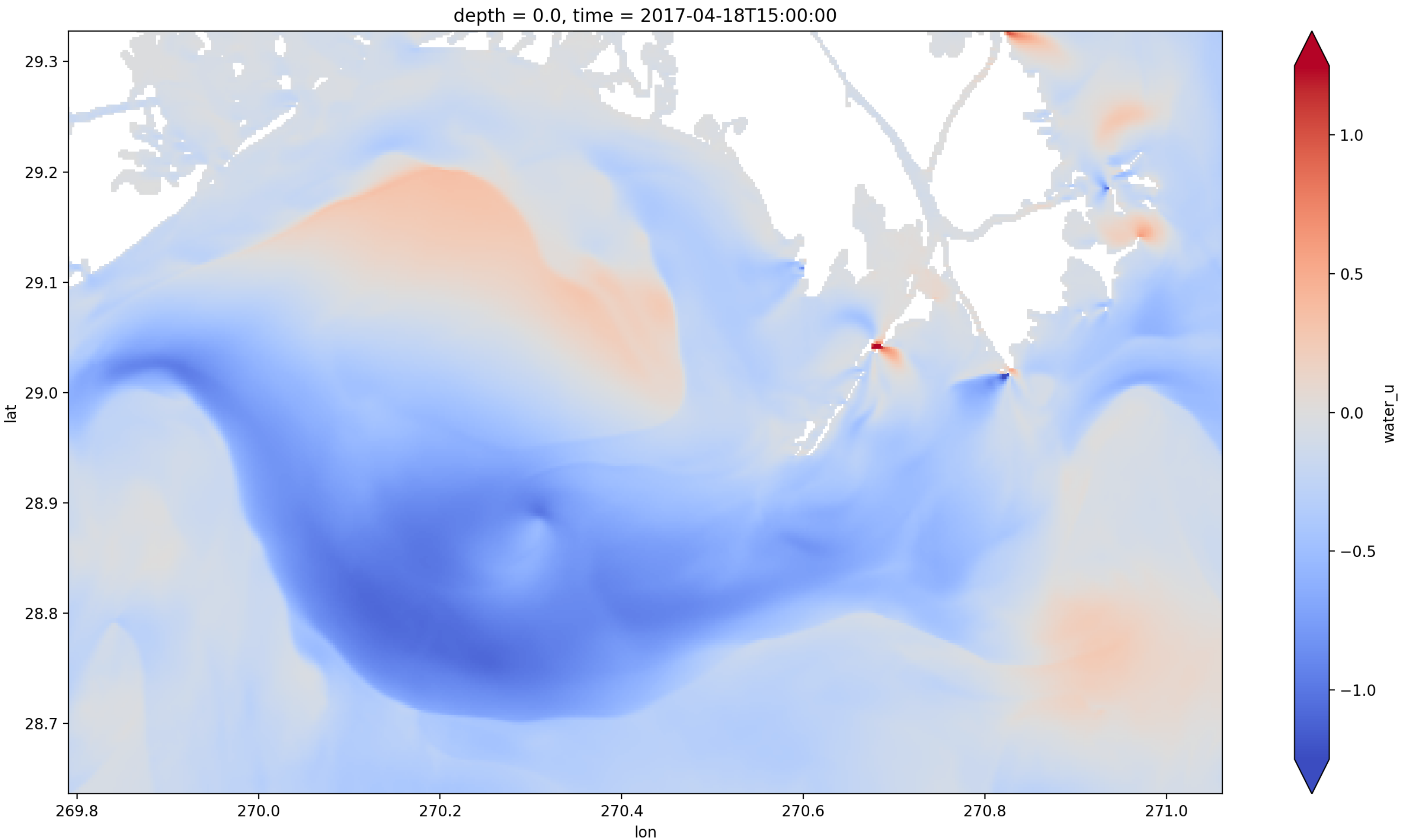


Retrieved Surface Velocity Errors



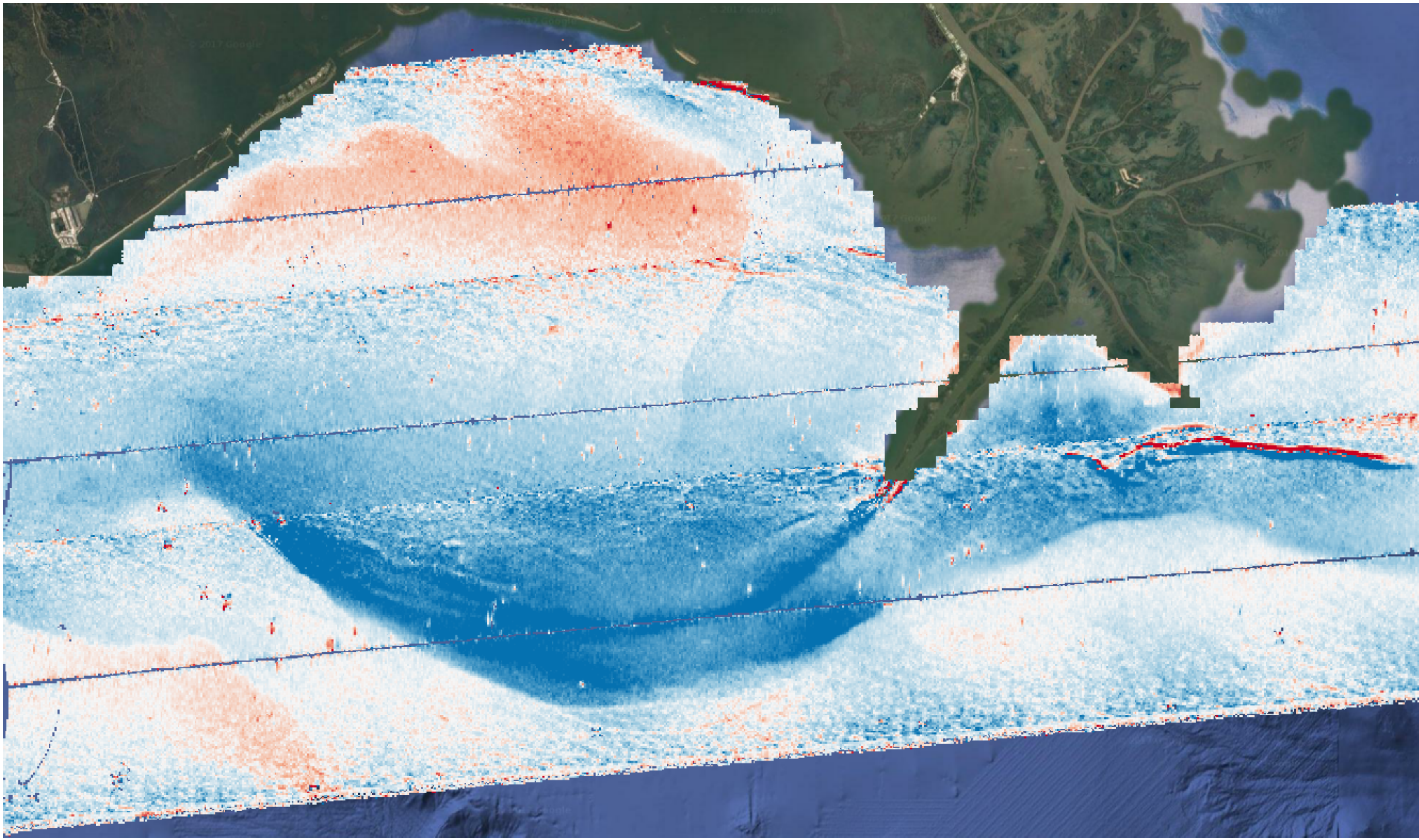


NCOM U Surface Velocity

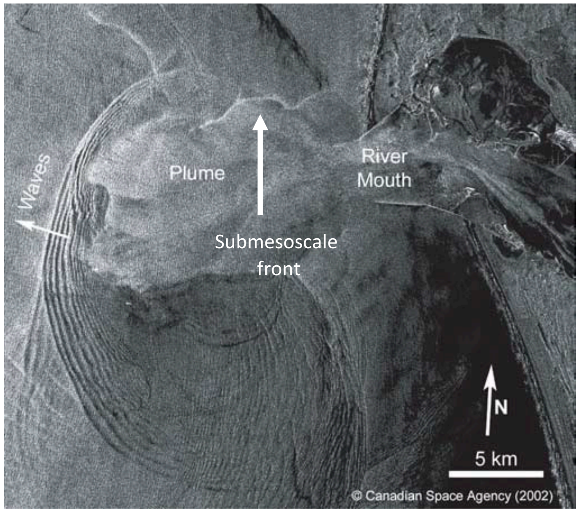


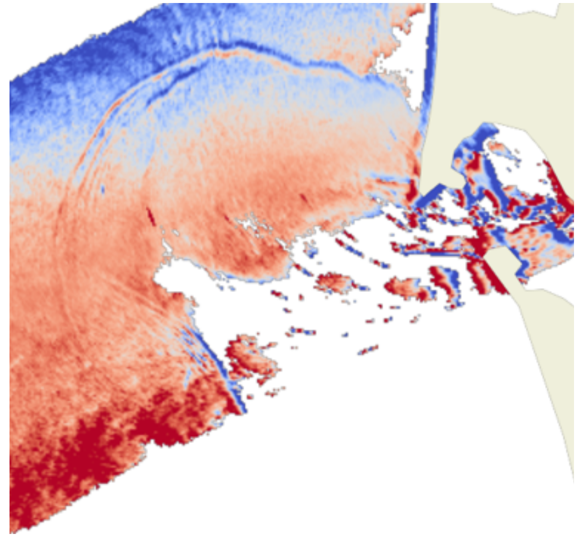
NCOM run at 250m resolution with special tuning for river inputs.
Data courtesy of G. Jacobs & NRL NCOM team

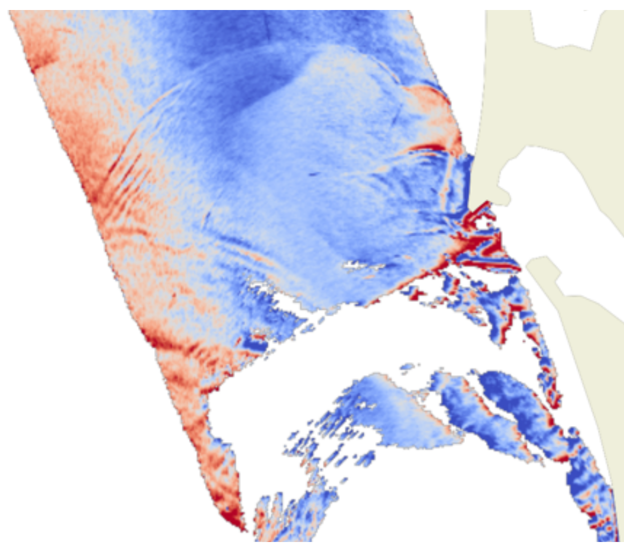
DopplerScatt U Surface Velocity

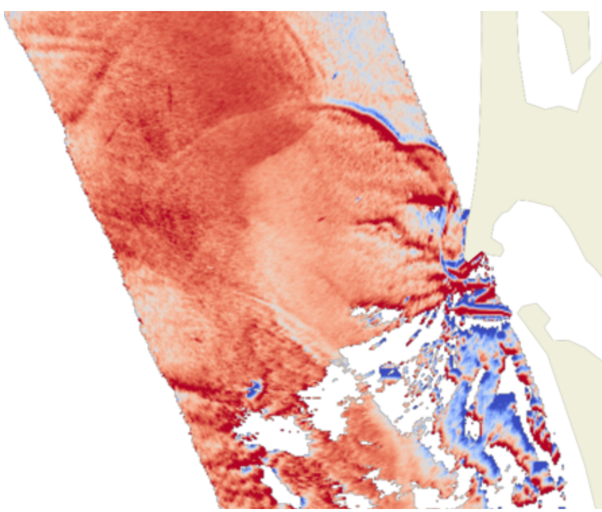


Columbia River Internal Wave Tidal Bore









Clockwise from top left:

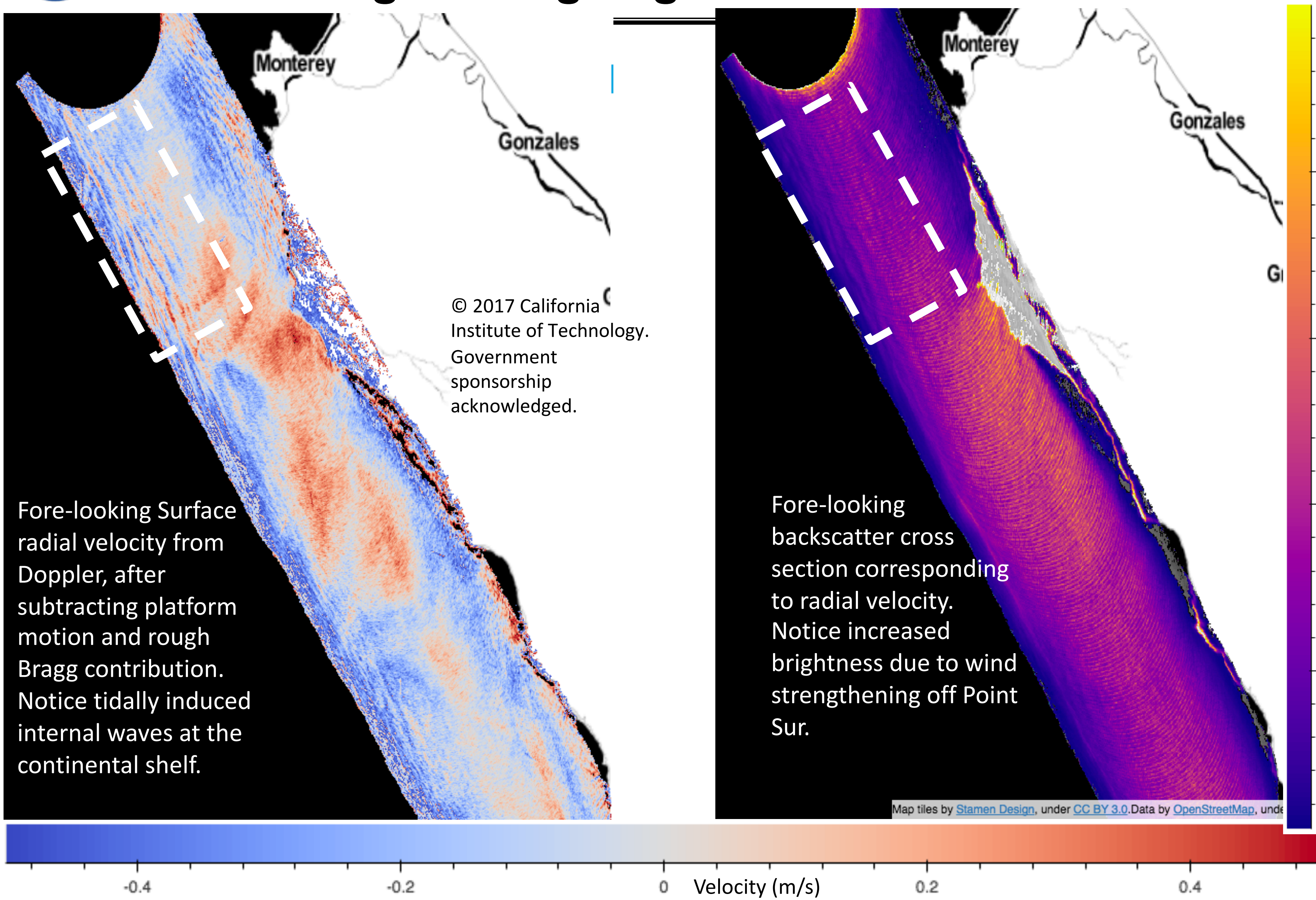
1. Satellite SAR image of the Columbia river plume from Aug 9th 2002, Nash & Moum, Nature, 2005 showing internal waves generated by the plume. Another feature has been conjectured to be a submesoscale front (Akan et al, JGR submitted. J. McWilliams, personal communication)

2. DopplerScatt September 13th Track 1 fore-looking radial velocity

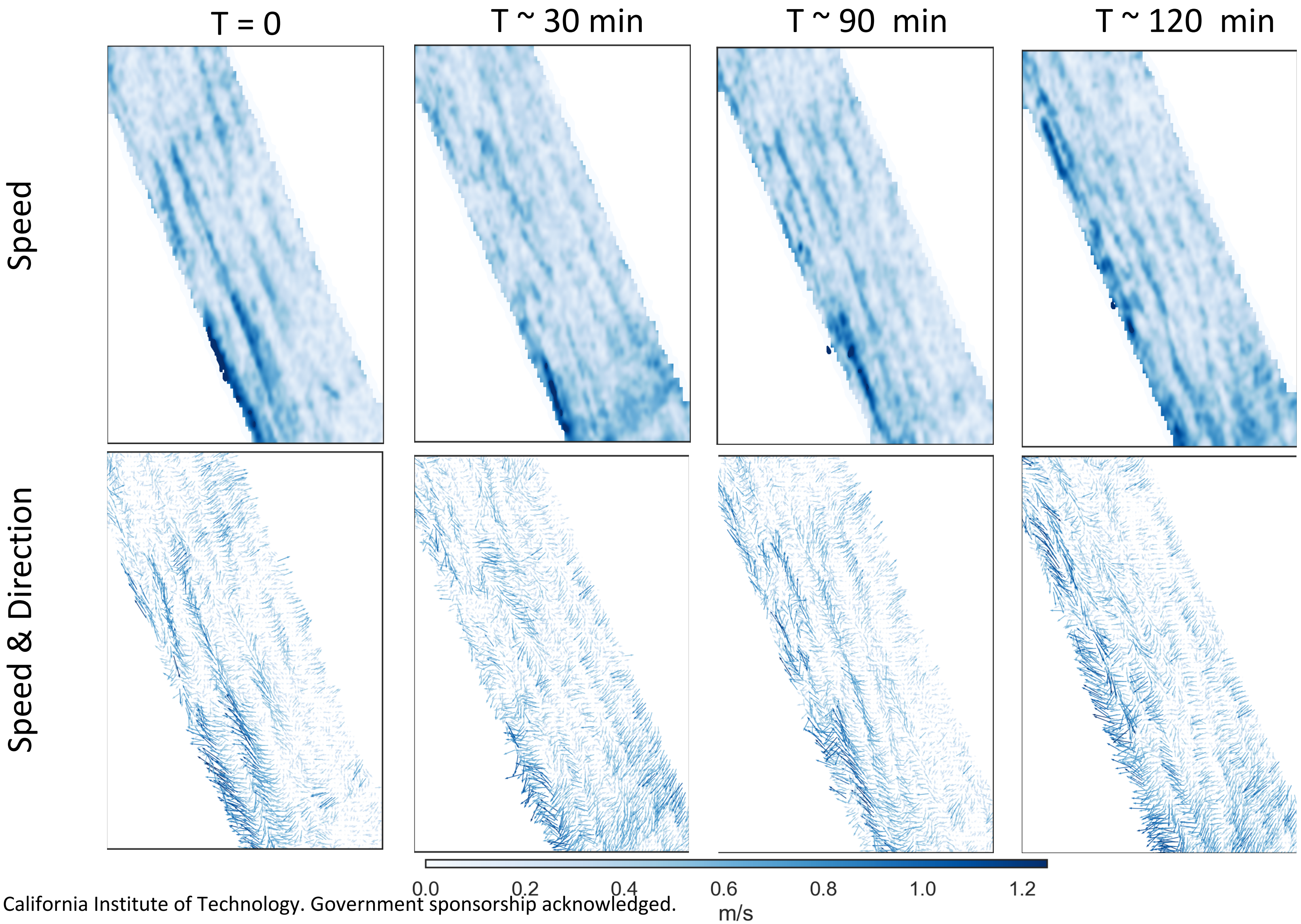
3. DopplerScatt September 13th Plume track fore-looking radial velocity

4. DopplerScatt September 13th Plume track aft-looking radial velocity

DopplerScatt physical measurements– Engineering Flight June 22nd 2016



Preliminary Retrievals with Wind Correction
Internal Wave Changes



Candidate Statement

Surface ocean vector winds and surface currents are tightly coupled essential climate variables and must be measured simultaneously to improve our present understanding of the coupled ocean-atmosphere system. These measurements will allow significant advances in understanding of topics ranging from large-scale circulation in the tropics, air-sea interaction along western boundary currents, to basic physical processes such as the vertical circulation of the ocean and its role in the upwelling of nutrients that governs the ocean's biological productivity. Measurements with a resolution of 5 km or better would also improve significantly our understanding of ocean-atmosphere variability from 10km to 200km, which is not yet well observed. These measurements will also have significant impact for applications ranging from fisheries, coastal shipping, and disaster management, especially if they can be made at high resolution (5km or better) near the coasts. The international ocean vector wind community endorses the pursuit of such simultaneous measurements , including the first global observation of surface currents, which are being advocated by teams from the United States, Europe, and China.