DopplerScatt & SWOT CalVal

Ernesto Rodríguez[1], Tom Farrar[2]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Woods Hole Oceanographic Institution

In brief

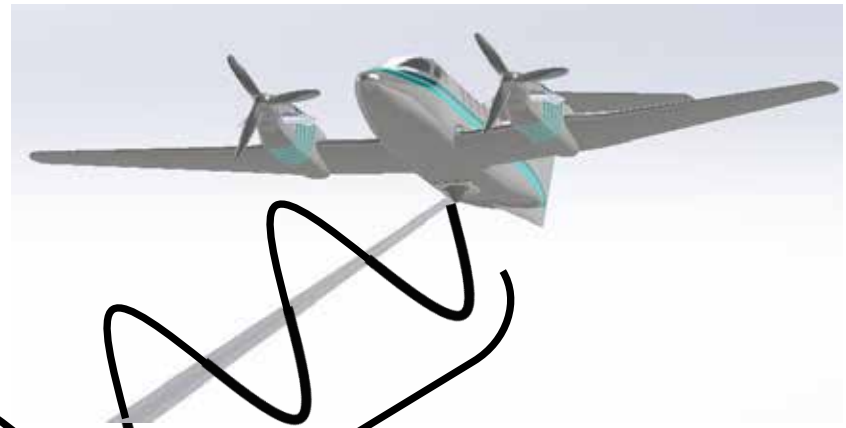
- DopplerScatt is a NASA airborne instrument that measures ***surface currents*** and ***winds*** at high spatial resolutions (200 m) that could help separate balanced and unbalanced current features during the SWOT 1-day CalVal.
- DopplerScatt can map the SWOT CalVal region several times during a 4.5 hour flight.
- DopplerScatt will become operational under the NASA Airborne Instrument Technology Transition program in 2019.
- The DopplerScatt current measurement has a wind/wave contamination that must be removed to get the true surface current. Current research is trying to validate and improve this correction (August 2018 experiment).
- There is a pending NASA Earth Ventures Suborbital (EVS) proposal (T. Farrar, PI), that would conduct an extensive campaign at the SWOT CalVal site. There is a chance that the SWOT and EVS schedules could line up.

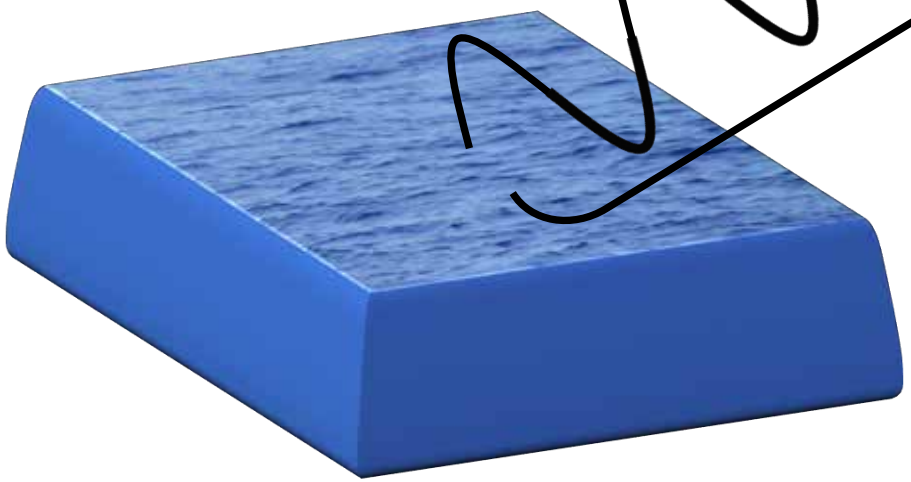
Doppler scatterometry

wavelengths for 2-way trip $= \frac{2r}{\lambda}$

complete phase cycles $= \frac{\Phi}{2\pi}$

$$\Rightarrow \quad r = \frac{\lambda\Phi}{4\pi}$$

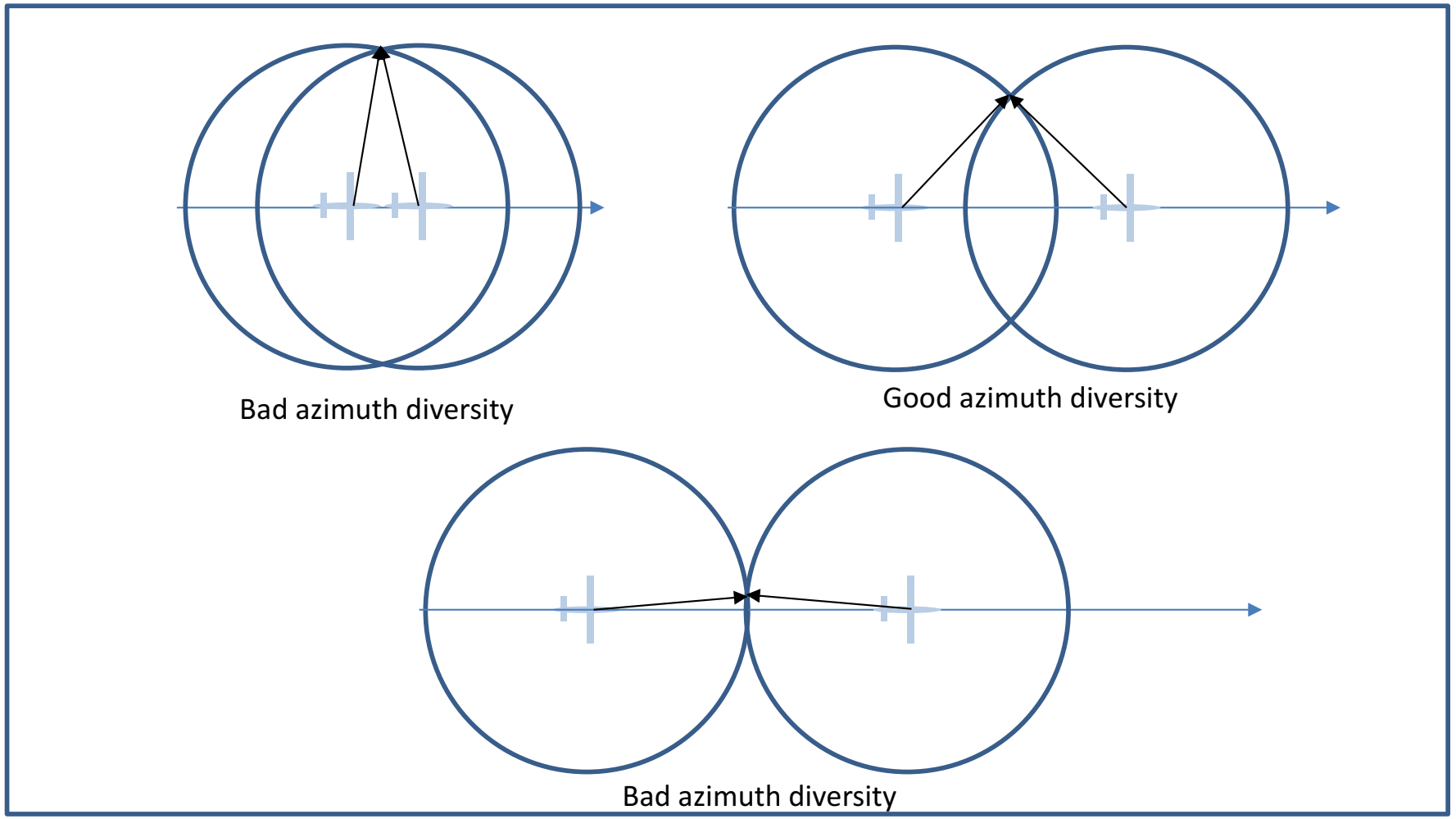




Radial velocity proportional to phase difference of successive pulses

$$v_{\text{radial}} = \frac{\Delta r}{\Delta t} = \frac{\lambda \Delta \Phi}{4\pi \Delta t}$$

Vector velocity estimation from radial velocity



DopplerScatt Overview (also see Rodriguez et al., 2018)

DopplerScatt Programmatic Overview

- Scanning Doppler radar developed under NASA's Instrument Incubator Program
- Becoming operational under NASA Airborne Instrument Technology Transition program by 2019

Data Products:

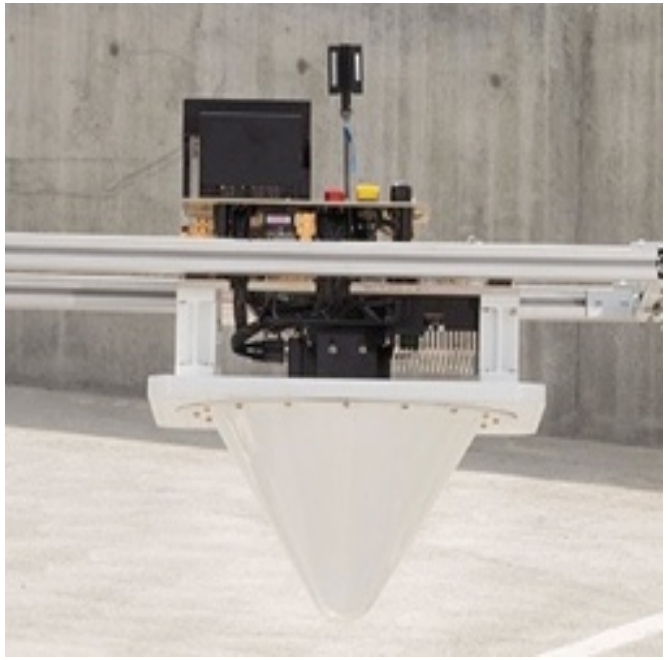
1. Vector ocean surface currents
2. Vector ocean surface winds
3. Radar brightness maps (sensitive to surfactants such as oil films)
4. Surface wave spectra (experimental)

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 (1-2 cm/s at 1km resolution)
- ~ 1 m/s wind speed, <20^{o} wind direction.

Campaigns flown or about to be flown:

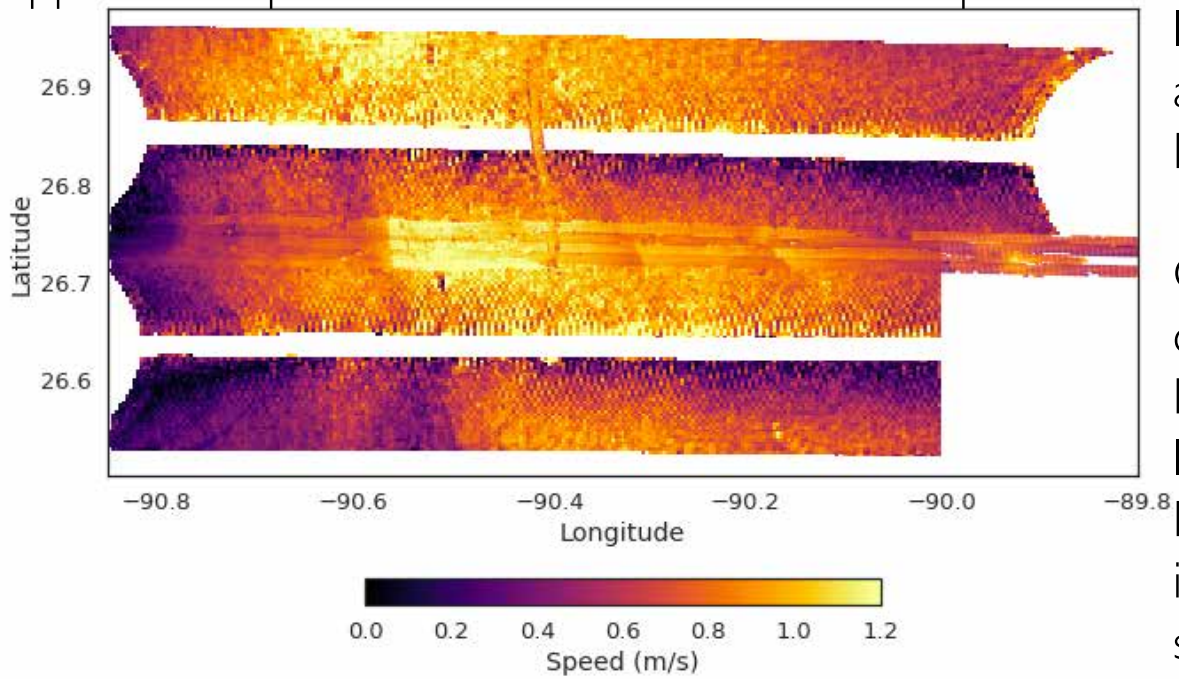
- Oregon coast (2016)
- SPLASH (Submesoscale Processes and Lagrangian Analysis on the Shelf) in Mississippi River Plume
- (CARTHE) & Taylor Oil Platform Plume (NOAA), April 18-28, 2017.
- KISS-CANON in Monterey Bay May 1-4, 2017.
- Gulf of Mexico Eddy (Chevron) March 24-27, 2018
- California current (August, 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.

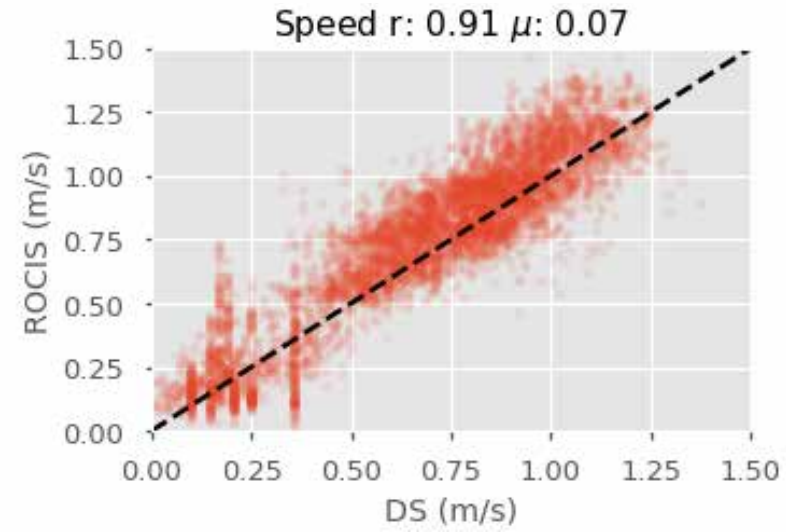
DopplerScatt Validation

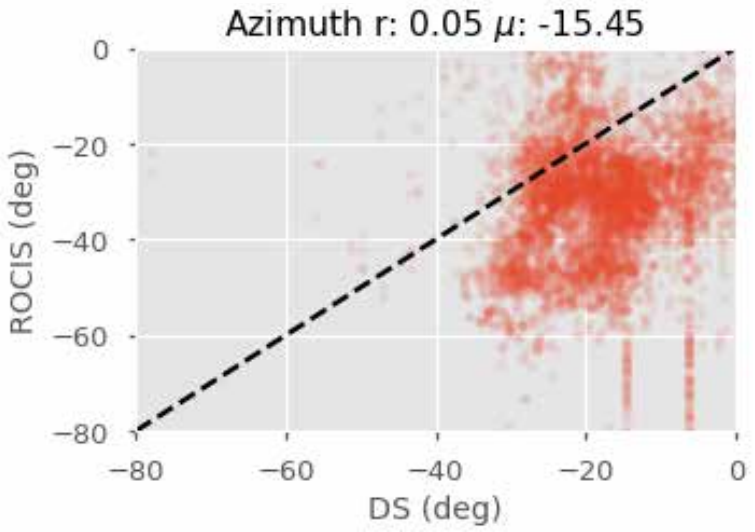
DopplerScatt Speed Data Overlaid with ROCIS Speed Data



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

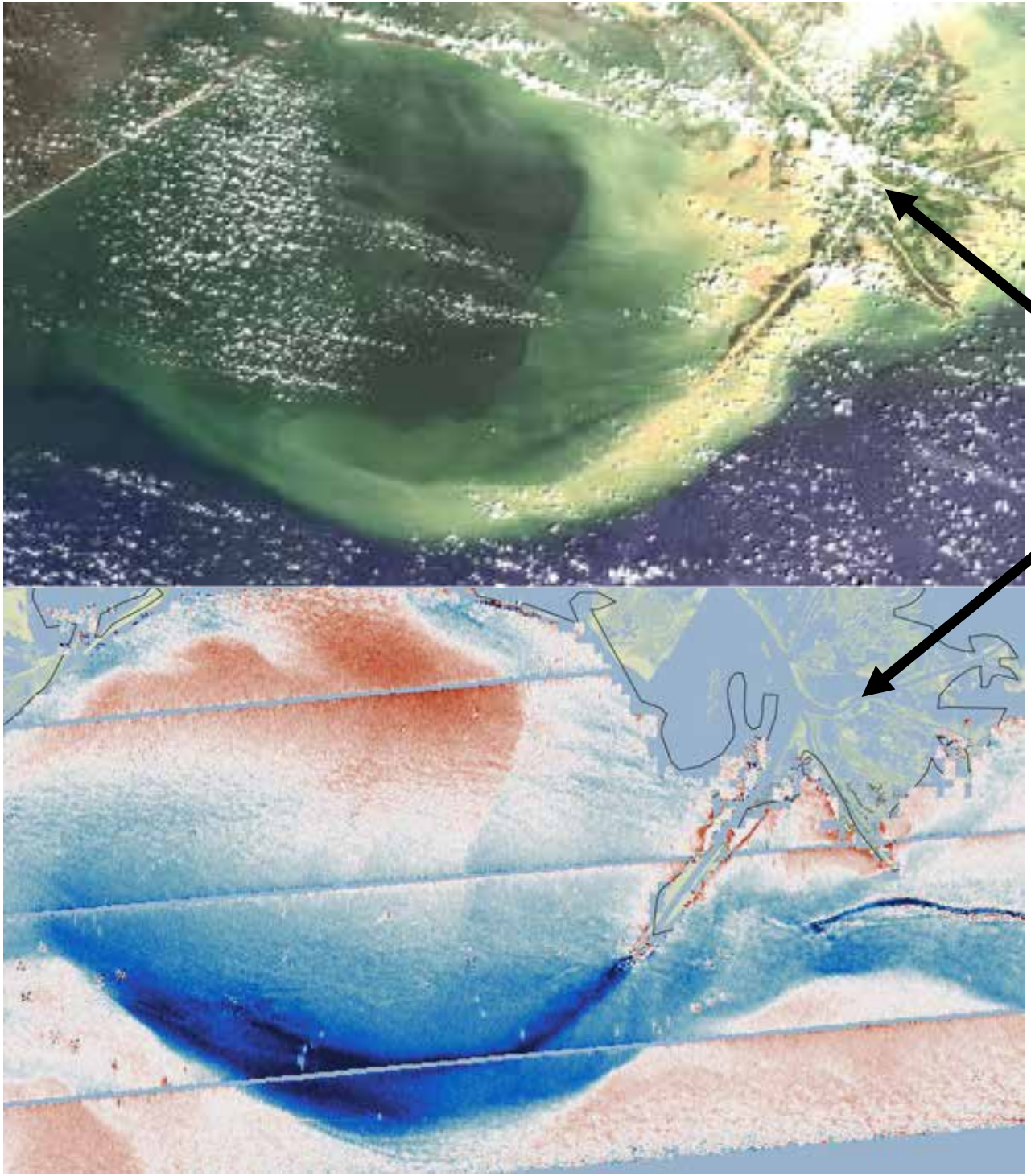
Ocean surface current data were collected at the same time with the Fugro's Remote Ocean Current Imaging System (ROCIS) which uses FFT's of space-time ocean wave imagery and the dispersion relation to solve for surface currents.





Preliminary results. Analysis on both sides still ongoing.

ROCIS data courtesy of Chevron and Fugro.



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

Mississippi River Delta

DopplerScatt surface current U component.

Circulation pattern matches Sentinel 3 color pattern very closely.

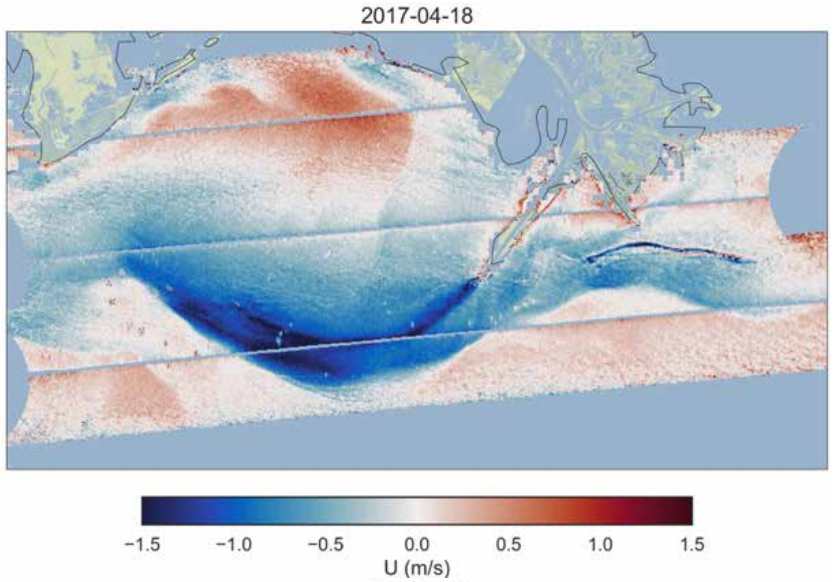
SPLASH 2017-04-18

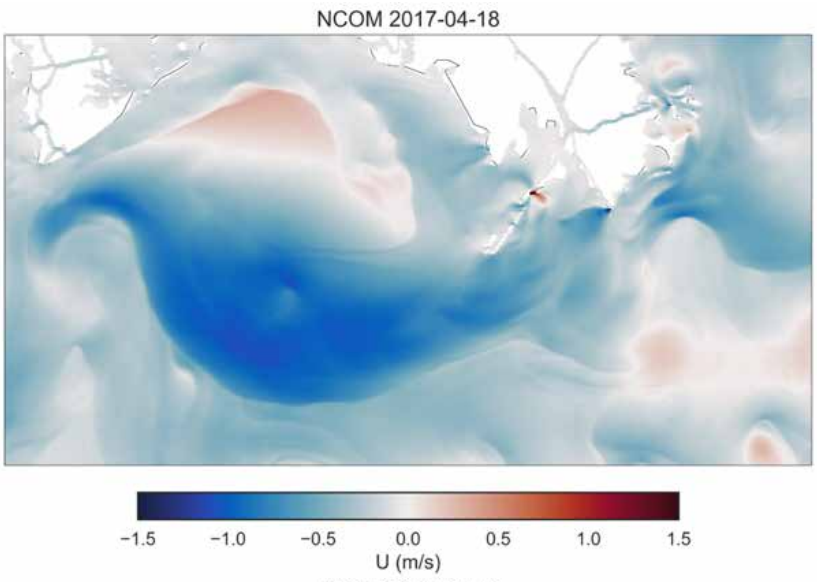
NCOM Data courtesy G. Jacobs & NRL NCOM Team

DopplerScatt

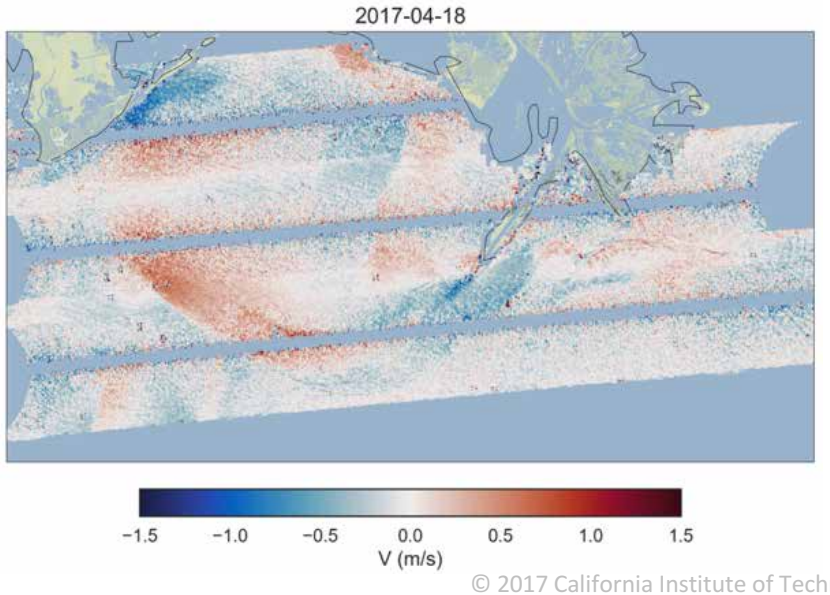
NCOM

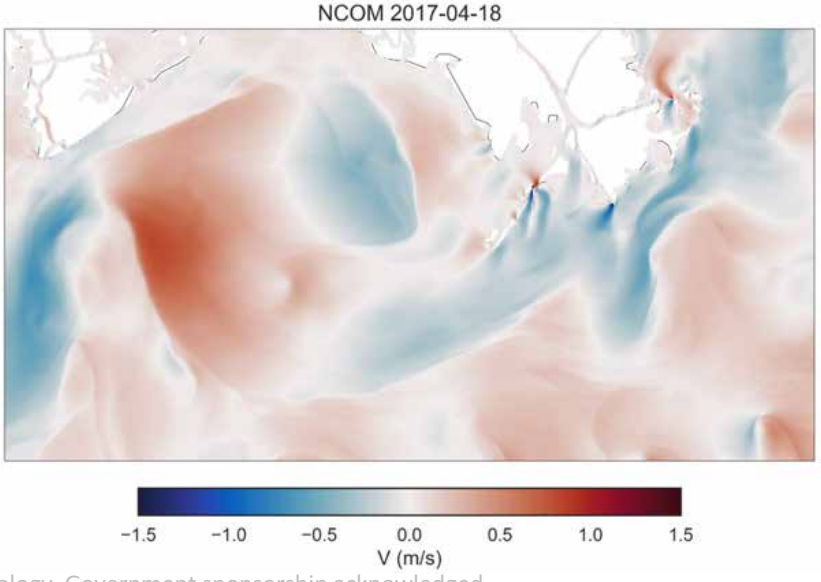
U



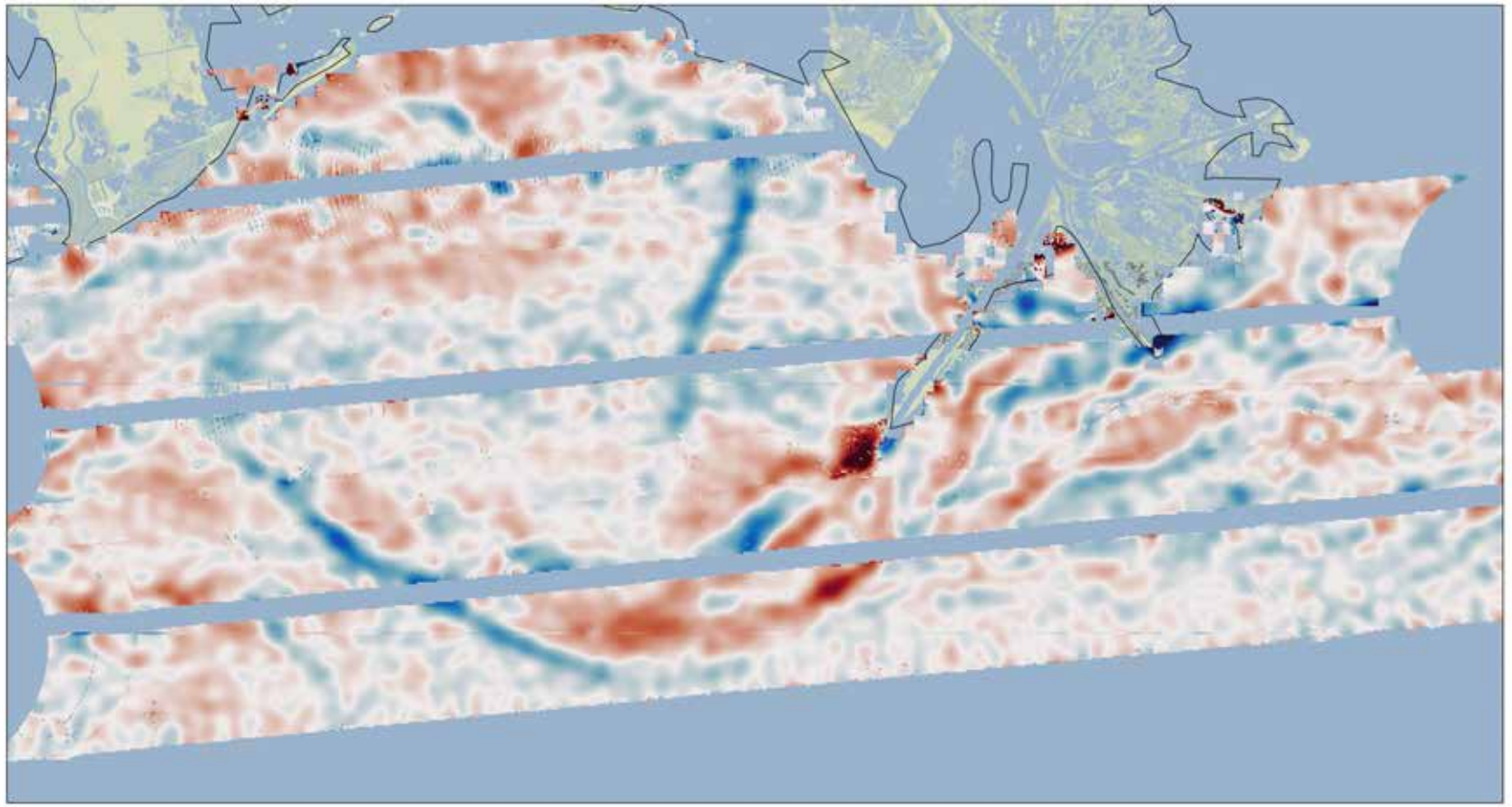


V

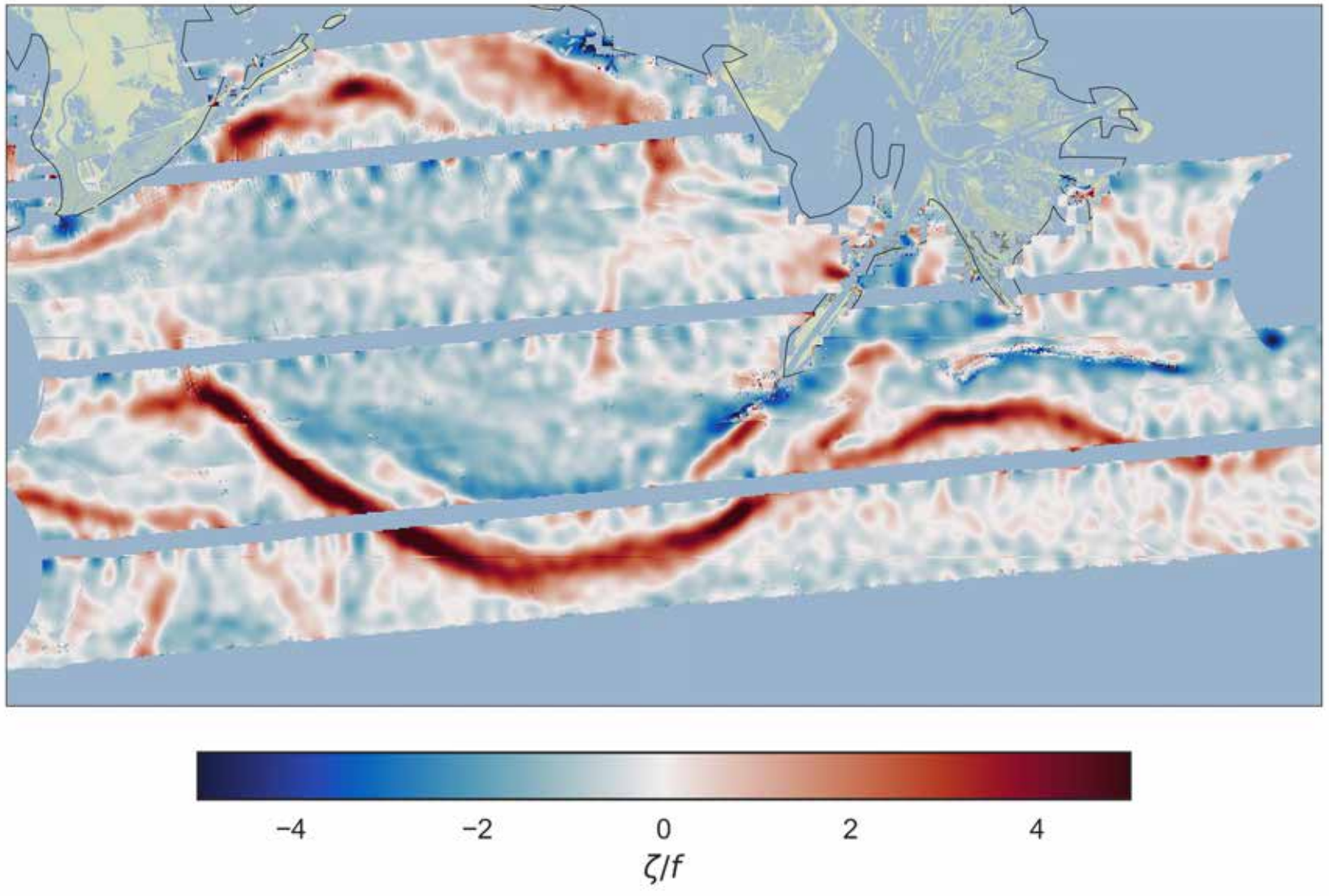


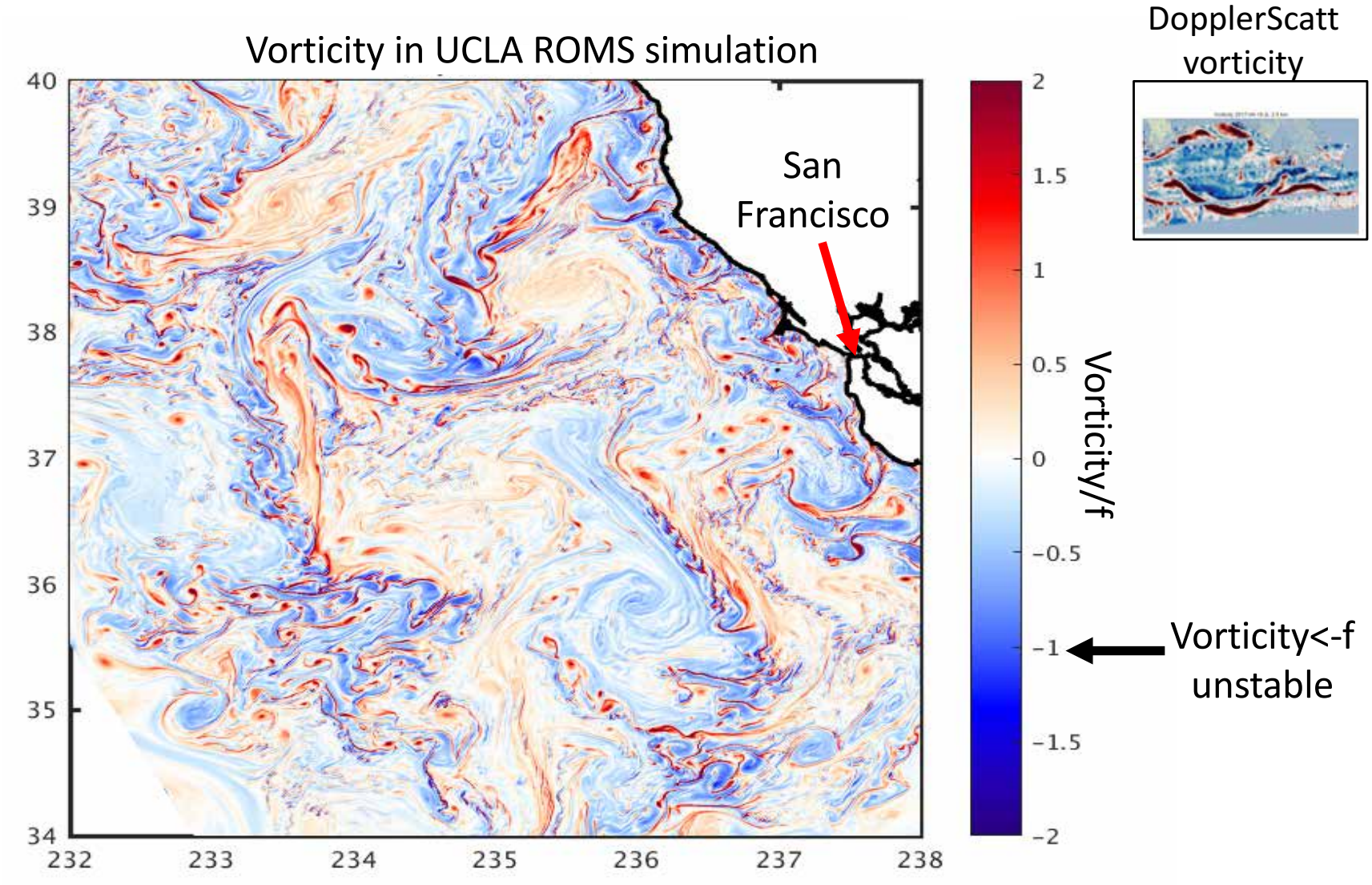


DopplerScatt
Normalized Surface Current Divergence

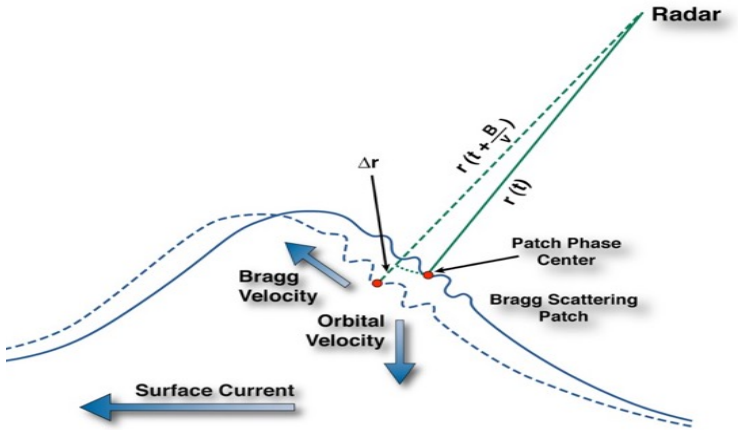


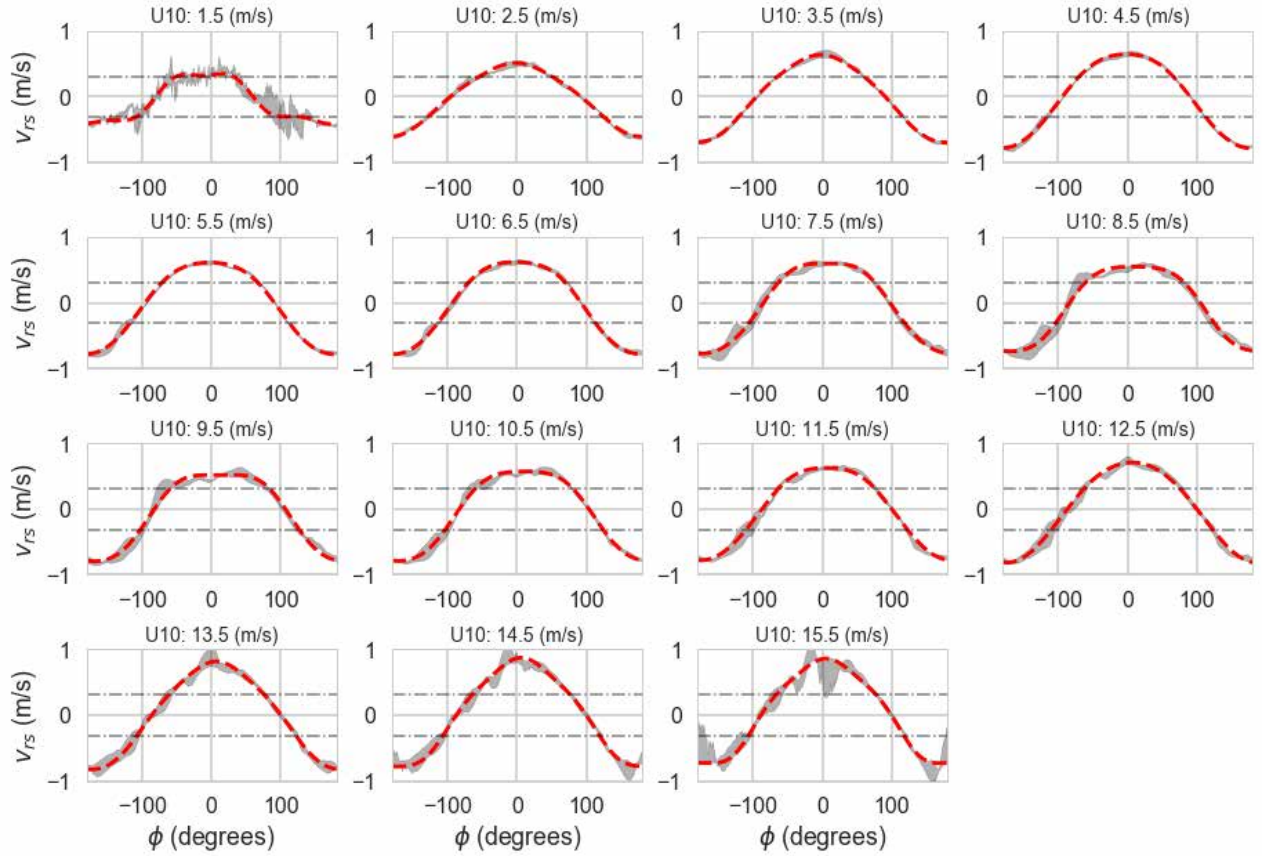
DopplerScatt
Normalized Relative Vorticity




Vorticity in UCLA ROMS simulation
San Francisco
40
39
38
37
36
35
34
232
233
234
235
236
237
238
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
Vorticity/f
DopplerScatt vorticity
Vorticity<-f unstable

Wind/Wave Contamination





DopplerScatt measures the velocity o capillary (1.5 cm wavelength) waves modulated by gravity wave radial velocity.

Differential brightness between peaks and troughs introduces a bias similar to the EM bias in altimetry.

- At this time, wind/wave biases are removed via an empirical function.
- Unfortunately, this also removes some desirable components (e.g. Stokes drift)
- The next set of experiments (August 2018) will concentrate on improving this current correction.

August 2018 Experiment

Map surface currents at:

- "True Surface" using 10 ultra thin drifters (Morey)
- Integrated current to ~20 cm using 10 self righting drifters (***Morey, FSU***)
- "Meter" depth currents using hourly 2km HF-radar (back-up, 6km HF-radar) (***Rodríguez, JPL***)

Ship survey (Shana Rae RV) (***Drushka & Gaube, UW/APL***):

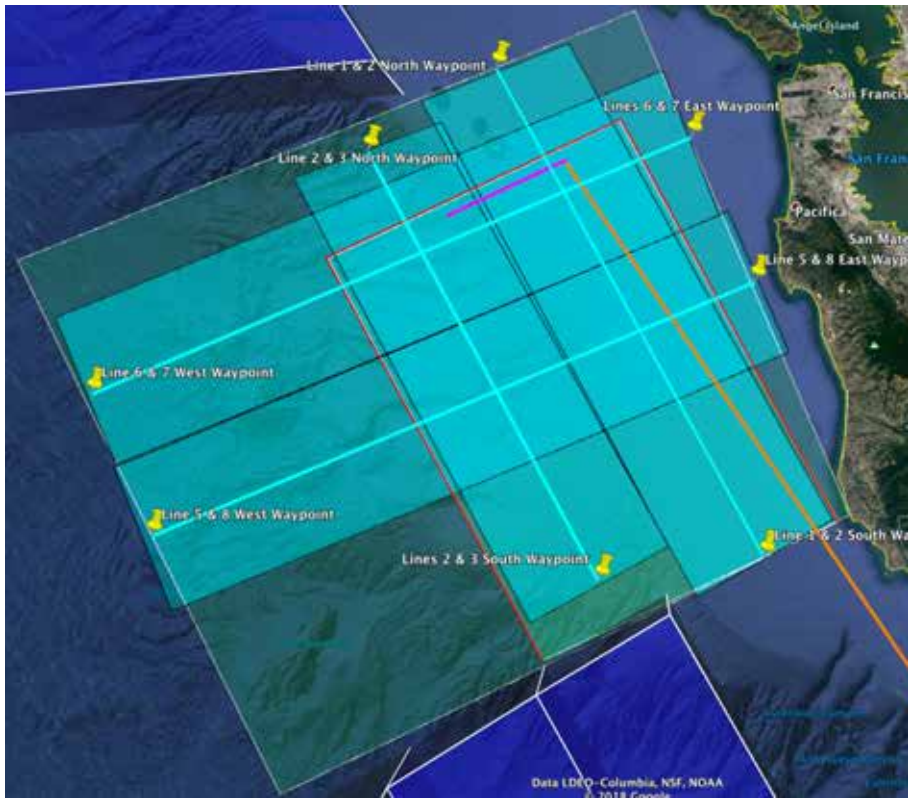
- Underway CTD (T,S,backscatter)
- SST,SSS
- ADCP currents (2–100 m)
- Acoustic backscatter
- Meteorology (winds, etc.)

DopplerScatt 50 km x 50 km surveys: Estimate that will be able to cover the area using checkerboard pattern between 10-20 times over ~4.5 hours (***Rodríguez & DopplerScatt team, JPL***)

- "Surface currents"
- Surface winds and backscatter
- Surface wave spectra

Scripps MASS (Melville & Lenain)

- Lidar for waves and SSH
- NIR Camera for SST
- Multispectral for ocean color
- Surface currents from image correlation



This experiment will occur near the SWOT CalVal site on the California Current.

The instrumentation and site are preliminary version of the proposed EVS-3 campaign.

Using DopplerScatt for interpreting SSH Variability

x-component of horizontal momentum equation

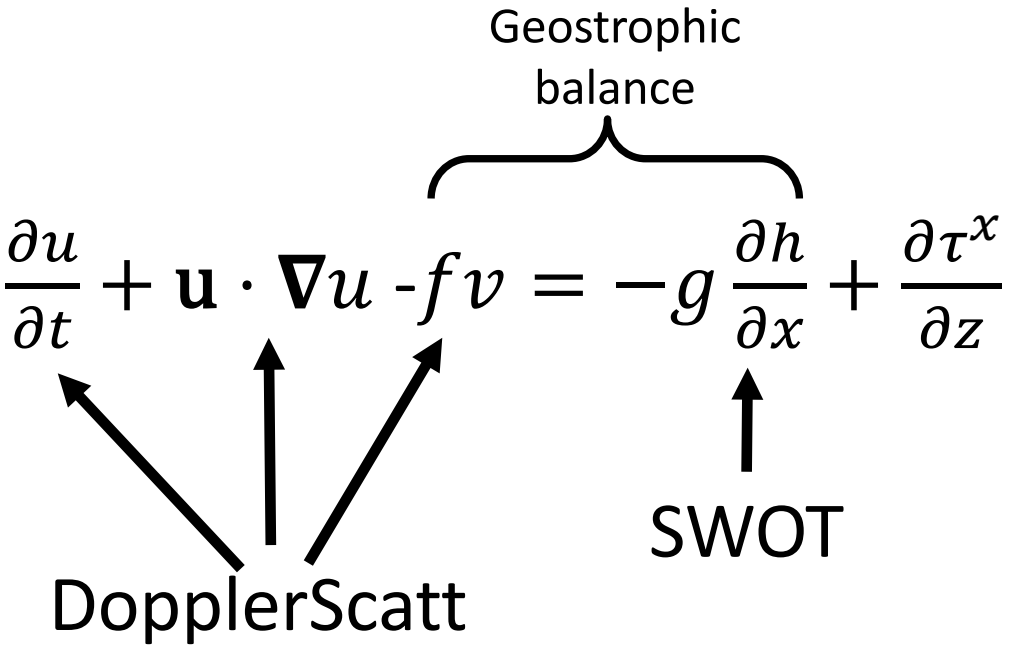
$$\frac{\partial u}{\partial t} + \mathbf{u} \cdot \nabla u - fv = -g\frac{\partial h}{\partial x} + \frac{\partial \tau^x}{\partial z}$$

Geostrophic balance

SWOT

Using DopplerScatt for interpreting SSH Variability

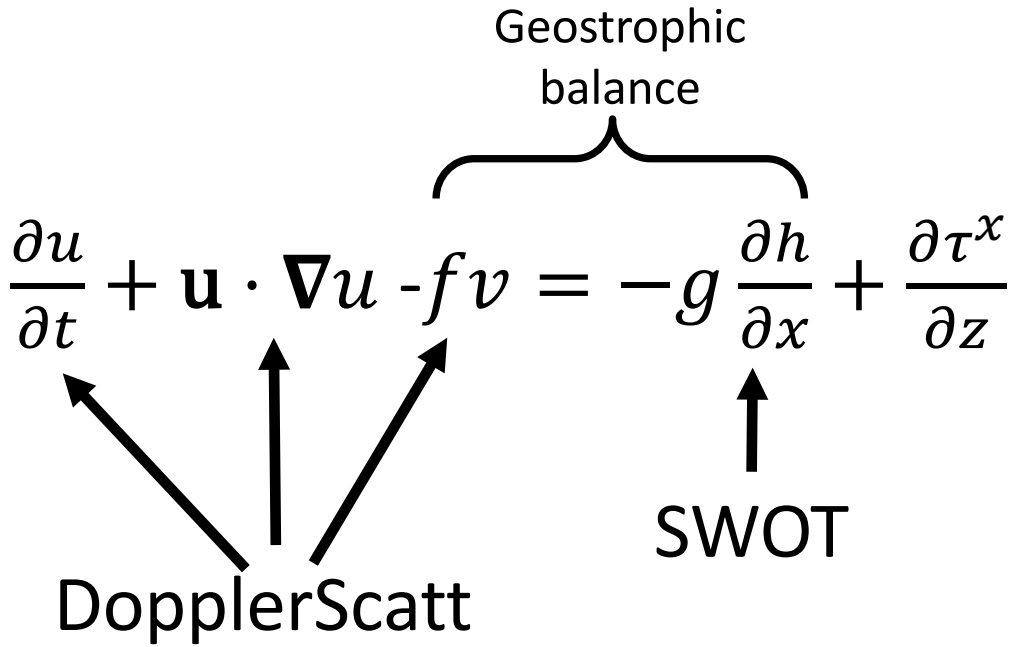
x-component of horizontal momentum equation



Using DopplerScatt for interpreting SSH Variability

DopplerScatt can map the SWOT CalVal region several times during a 4.5 hour flight.

x-component of horizontal momentum equation



S-MODE EVS-3 Experiment

Sub-Mesoscale Ocean Dynamics Experiment (S-MODE)

Threshold Science Objectives	Quantitatively measure the three-dimensional structure of the submesoscale features responsible for vertical exchange in the upper ocean
	Understand the relation between the velocity (and other surface properties) measured by remote sensing at the surface and that within and just below the surface boundary layer
Baseline Science Objectives	Quantify the role of air-sea interaction and surface forcing in the dynamics and vertical velocity of submesoscale variability
	Examine vertical transport processes at submesoscales to mesoscales

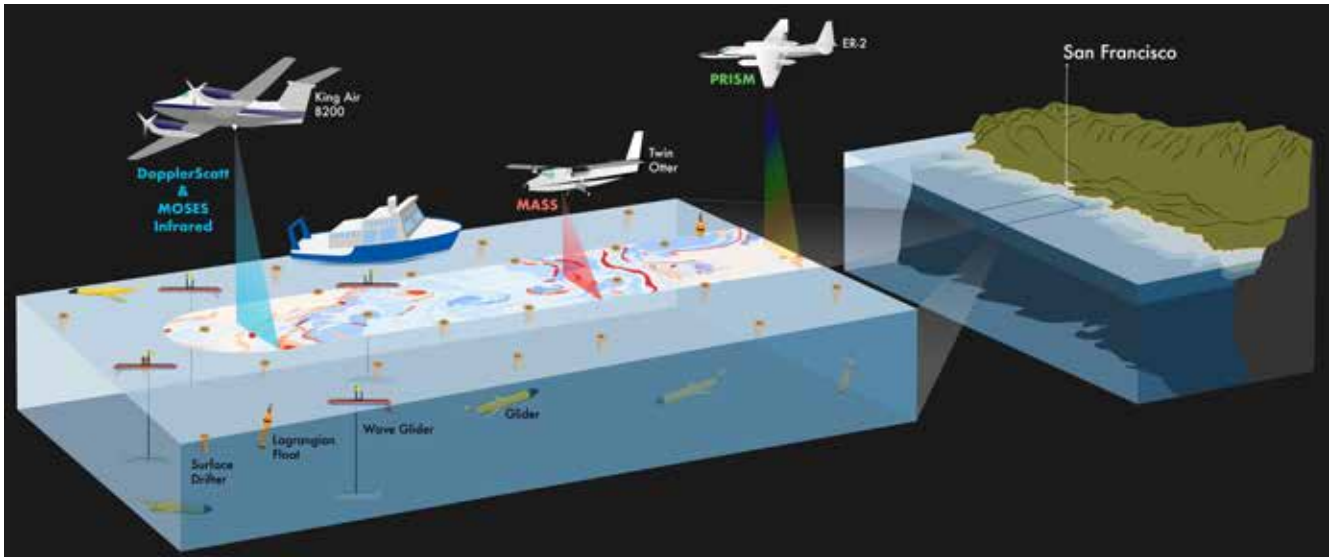
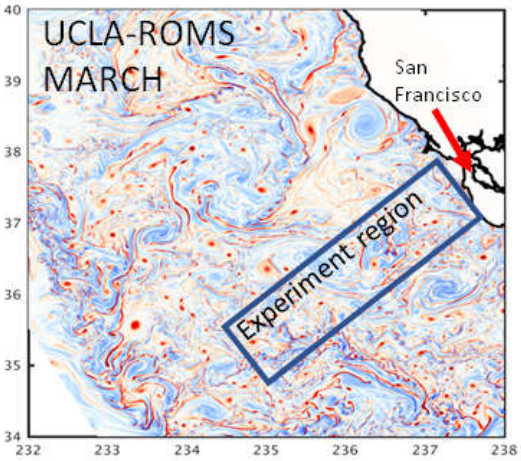


Figure 1.1: A sketch of the S-MODE investigation, depicting the experimental site offshore of California and the platforms and aircraft instruments that will be employed. The experimental plan involves a two-week pilot campaign and two, 25-day intensive operating periods during spring and fall of 2021, with 10-15 flights in each period. The nominal site is 300 km from San Francisco.



- PI: J.T. Farrar (WHOI) + large cross-disciplinary team (JPL, OSU, WHOI, UW/APL, SIO, UCLA, URI)
- 5-year effort
- Nominal start in 2019
- Intense operations spring/fall 2021

Conclusions

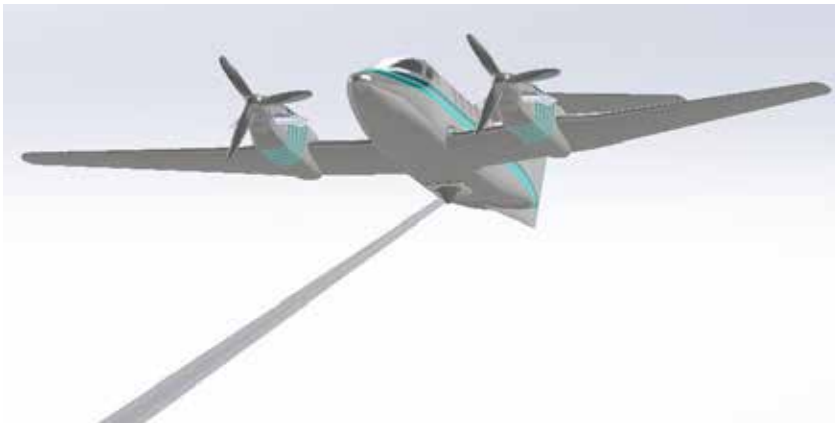
- DopplerScatt is a NASA airborne instrument that measures ***surface currents*** and ***winds*** at high spatial resolutions (200 m) that could help separate balanced and unbalanced current features during the SWOT 1-day CalVal.
- DopplerScatt can map the SWOT CalVal region several times during a 4.5 hour flight.
- DopplerScatt will become operational under the NASA Airborne Instrument Technology Transition program in 2019.
- The DopplerScatt current measurement has a wind/wave contamination that must be removed to get the true surface current. Current research is trying to validate and improve this correction (August 2018 experiment).
- There is a pending NASA Earth Ventures Suborbital (EVS) proposal (T. Farrar, PI), that will conduct an extensive campaign at the SWOT CalVal site. There is a chance that the SWOT and EVS schedules could line up.

Woods Hole Oceanographic Institution

Backup slides

DopplerScatt: Specifications

Parameter	Value (CBE)
Center Frequency	35.75 GHz
Peak Transmit Power	90 W (110W)
Burst Repetition	8 kHz (4.7 kHz)
System Noise Figure	10 dB (6 dB)
Antenna Rotation Rate	5-25 rpm (12.5 rpm)
Antenna Beamwidth	2.9 deg
Velocity Bias	1.0 cm/s
Velocity Precision	10 cm/s
Wind Speed Accuracy	2 m/s (3-20 m/s) 10 % (20-30 m/s)
Wind Direction Accuracy	20 deg
Resolution cell size	200 m



Retrieved Surface Velocity Errors

Noise at 200m resolution is 5-20 cm/s.

Averaging to 1km resolution would reduce noise to 1-4 cm/s.