# The State of the Art in Surface Current Estimation from Remote Sensing and In Situ Observations

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CLIVAR Surface Currents in the Coupled Ocean-Atmosphere System Workshop, 2020

# Surface Currents: the challenge

- Surface currents are usually not measured directly:
  - Waves riding on currents and other waves
  - Scatterers in the water
- There is a current shear at and near the surface that must be considered when interpreting the signals
  - Air-sea interactions care about the “true”surface
  - Models and many oceanographic applications care about 10 m-15 m
- The mean current is O(10 cm/s)
- Surface waves have a velocity signal O(1 m/s)

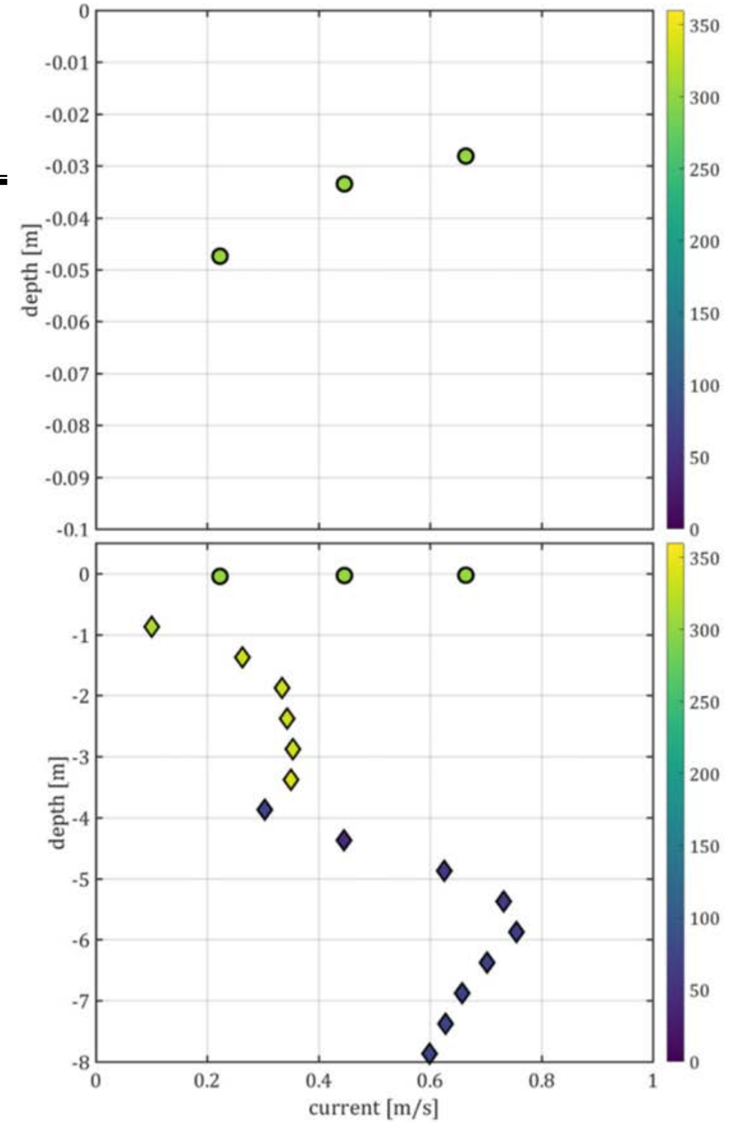


FIG. 11. The time-averaged current profile for MCR-1. (bottom) Full derived profile and (top) an expansion of the upper 0.1 m of the profile. Data presented include current observations from the polarimetric wave slope sensing method (●) and the moored ADCP (◆). Each symbol's fill color corresponds to its direction (deg) clockwise from true north in an oceanographic going-to convention. Wind velocity direction: 12.74°, wind velocity magnitude: 9.14 m $s^{-1}$; wind stress direction: 351.85°, wind stress magnitude: 0.0508 N $m^{-2}$.

**Passive Optical Sensing of the Near-Surface Wind-Driven Current Profile**

NATHAN J. M. LAXAGUE, BRIAN K. HAUS, DAVID G. ORTIZ-SUSLOW, CONOR J. SMITH, GUILLAUME NOVELLI, HANJING DAI, TAMAY ÖZGÖKMEN, AND HANS C. GRABER

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# In situ velocity measurements

- ‘Lagrangian’ measurements
  - Drifters
  - Lagrangian floats

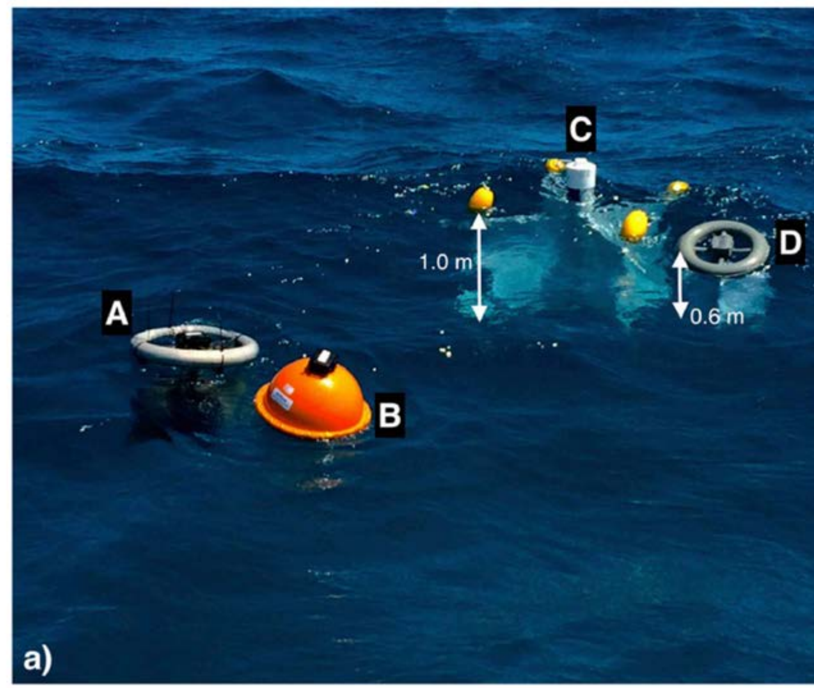
Stokes drifter (~5 cm)

Morey et al. (2018)

CARTHE drifter (~50 cm

Novelli et al. (2017)

FIG. 15. Field experiment: (a) Drifters deployed during the field drift comparison tests: (left)–(right) A, the rigid neck drifter with its silver torus float at the surface and a dark drogue underwater; B, the orange iSphere holding an extra GPS in a black box on top of the sphere; C, the CODE drifter with its four yellow buoys and white GPS housing visible at the surface, and its 1-m-deep underwater white drogue; D, the CARTHE drifter with its gray torus float at the surface and its 0.6-m-deep underwater white drogue. (b) Picture of the sea surface looking



# In situ velocity measurements

- 'Lagrangian' measurements
  - Drifters
  - Lagrangian floats
- 'Eulerian' measurements:
  - Acoustic Doppler Current Profilers (~75-2000 kHz sound, coherent and incoherent)
  - Current meters (either acoustic or mechanical)

Source: teledyne.com

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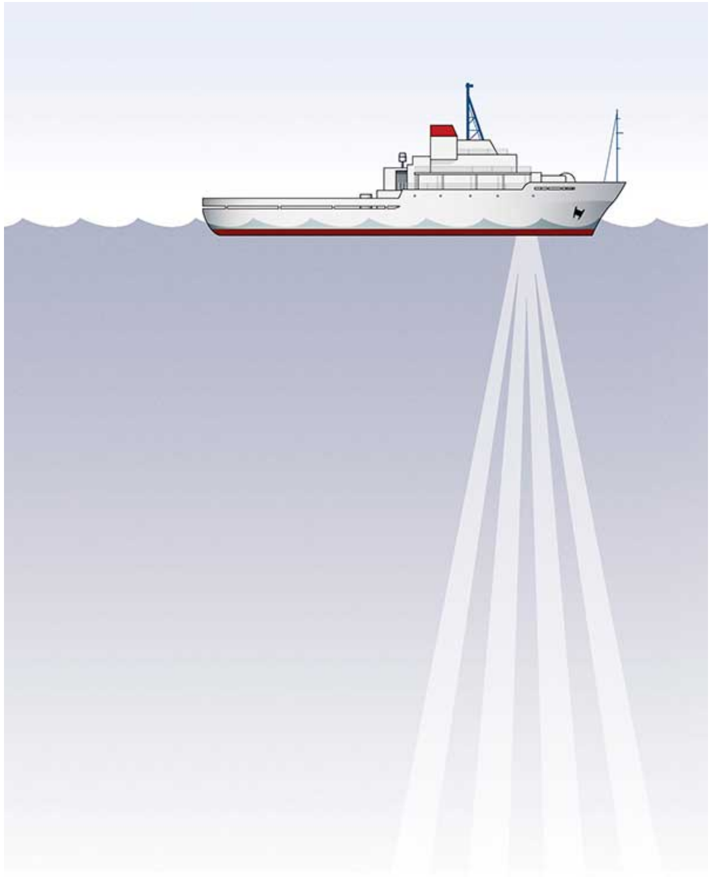
  - Acoustic Doppler Current Profilers (~75-2000 kHz sound, coherent and incoherent)
  - Current meters (either acoustic or mechanical)
- Measurements from ships or autonomous vehicles (typically using ADCPs)
  - Alignment of ADCP and vessel speed information are critical for vessel-based measurements (small error in removing 5 m/s ship speed is a large error in cm/s currents)



Source: teledyne.com

# Surface Current Remote Sensing Overview

- Measure wave dispersion relation Doppler shifts surface wave space-time spectrum using optical/radar image sequences (Young et al., 1985)
  - From airplanes (e.g., ROCIS from FUGRO) ( > 10m waves)
  - X-band ship radars (e.g., HZG radar)
  - From drones (e.g. Copter currents from HZG)
  - Using optical polarimetry (Zappa et al., 2008, etc.) (cm to meters)
- Measure surface wave radial Doppler shift
  - Coastal HF radar ( > 10 m waves)
  - Doppler Scatterometry (including SARs)
    - Bragg scattering from O(cm) waves (e.g. DopplerScatt)
    - Specular scattering (many wavelengths contribute) at near nadir incidence (e.g., SKIM)

# What current is being measured?

$$\mathbf{U}_E = 2k_B \mathbf{e}_{\theta_B} \cdot \int_{-\infty}^{0} \hat{\mathbf{u}} \exp(2k_B z)\, dz.$$

Stewart, R. H., & Joy, J. W. (1974). HF radio measurements of surface currents, *21*(12), 1039–1049. https://doi.org/10.1016/0011-7471(74)90066-7

12.1 m wavelength (12.4 MHz HF-radar): ~0.66 m depth ½ power
5 m wavelength (30 MHz HF-radar): ~0.28 m depth ½ power

$$\begin{aligned} U_R(\theta_B) &= C(\theta_B) - \mathbf{C}_{\text{lin}} \cdot \mathbf{e}_{\theta_B}, \\ &= \boxed{U_{Sf}(\theta_B)} + \mathbf{U}_E \cdot \mathbf{e}_{\theta_B}, \end{aligned}$$

Ardhuin, F., Marié, L., Rascle, N., Forget, P., & Roland, A. (2009). Observation and Estimation of Lagrangian, Stokes, and Eulerian Currents Induced by Wind and Waves at the Sea Surface, *39*(11), 2820–2838. https://doi.org/10.1175/2009jpo4169.1

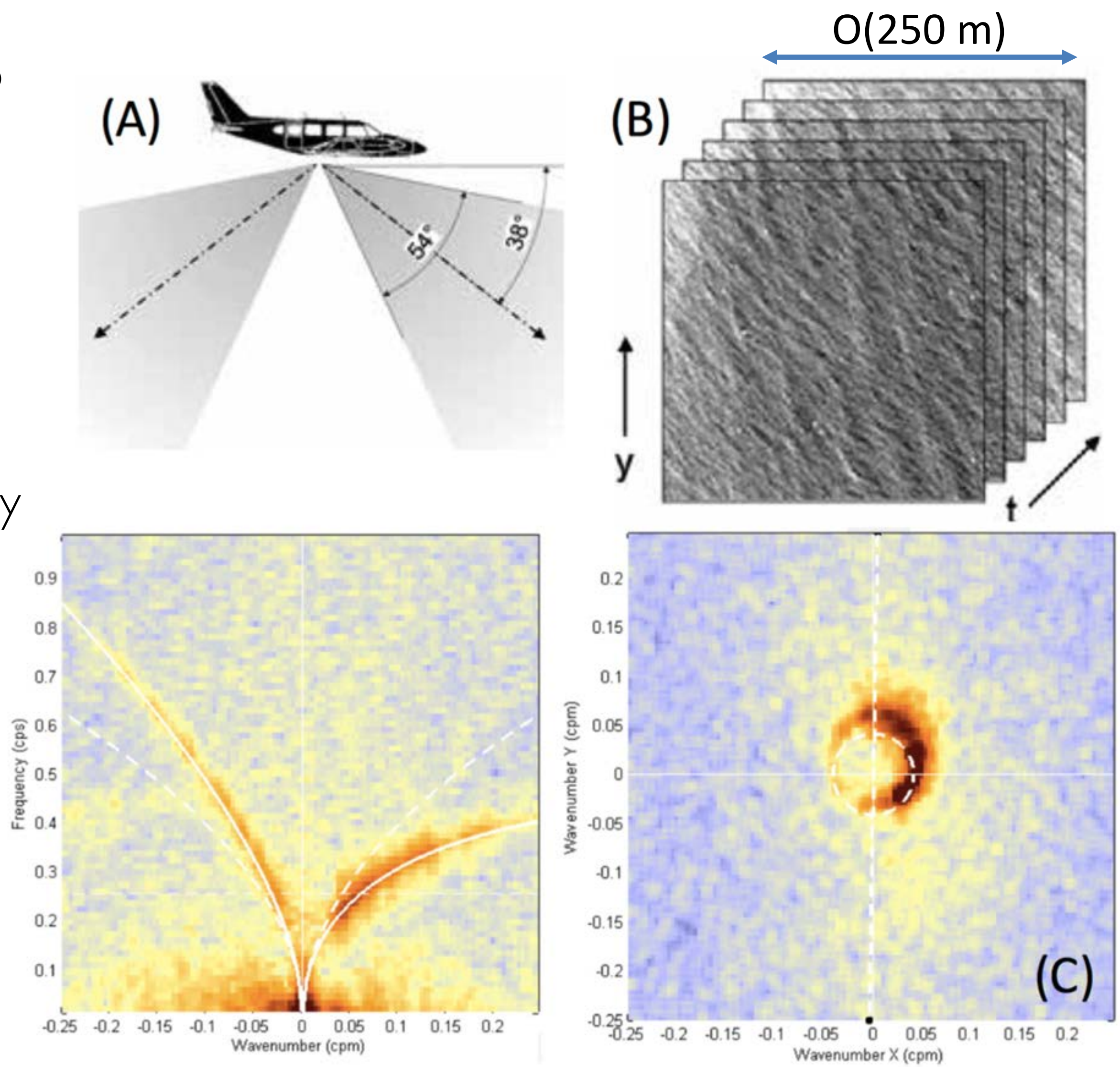
Additional Stokes drift-like correction

# REMOTE OCEAN CURRENT IMAGING SYSTEM (ROCIS)

Uses current induced shifts in the gravity wave dispersion relation to estimate surface currents from intensity imagery.

**Operational implementation:**
**ROCIS** - the Remote Ocean Current Imaging System- is an aerial survey payload developed by Fugro and Areté Associates to measure surface ocean currents.

This type of capability will be implemented by SIO MASS system during S-MODE




Anderson, S., Zuckerman, S., Smirren, J., and Smith, R. (2015). Airborne ocean surface current measurements for offshore applications. In Offshore Technology Conference Proceedings.

# X-band Marine Radar

Uses X-band radar brightness imagery

O(500 m) imaged area

O(1-3m) effective depth for current.

Comparison against CARTHE drifters gives relative differences O(4 cm/s)

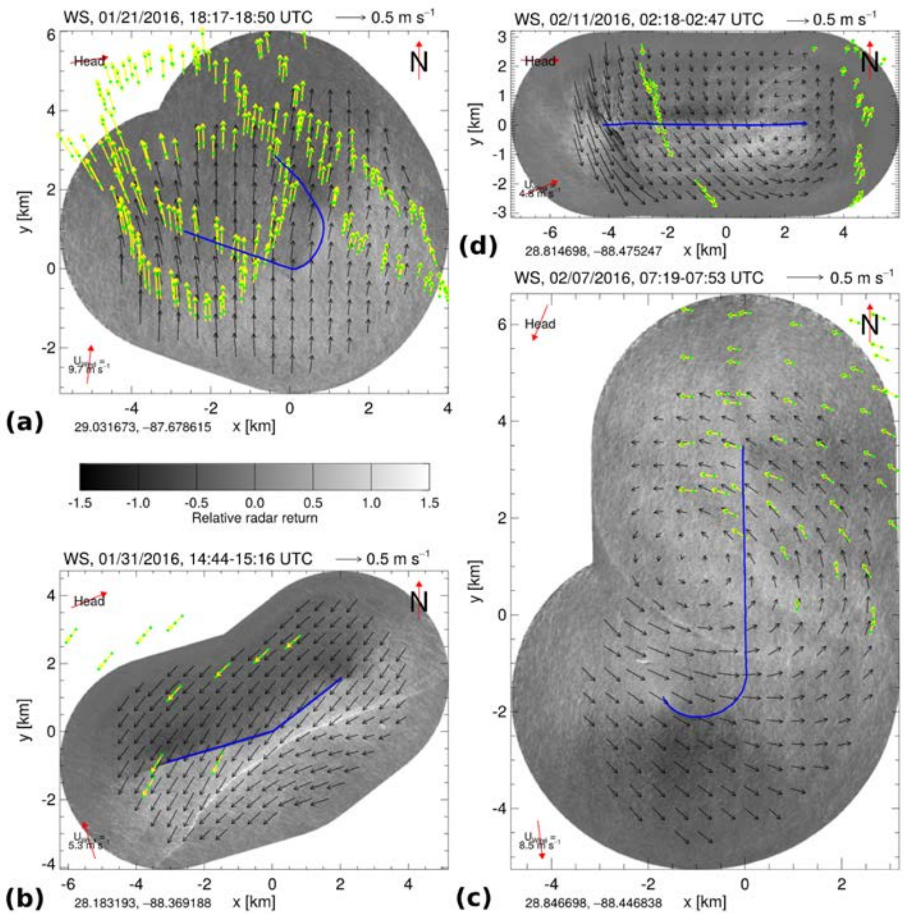



FIG. 6. Examples of MR near-surface current vectors (black) and corresponding drifter coordinates (green dots) and vectors (yellow) from (a) 1817–1850 UTC 21 Jan 2016, (b) 1444–1516 UTC 31 Jan 2016, (c) 0719–0753 UTC 7 Feb 2016, and (d) 0218–0247 UTC 11 Feb 2016. The backscatter intensity has been logarithmically transformed. The grayscale ranges from black (low backscatter) to white (high backscatter). The corresponding R/V *F. G. Walton Smith* cruise tracks are marked (blue lines).

Near-Surface Current Mapping by Shipboard Marine X-Band Radar: A Validation, Lund et al, JAOT, 2018

# Copter Currents

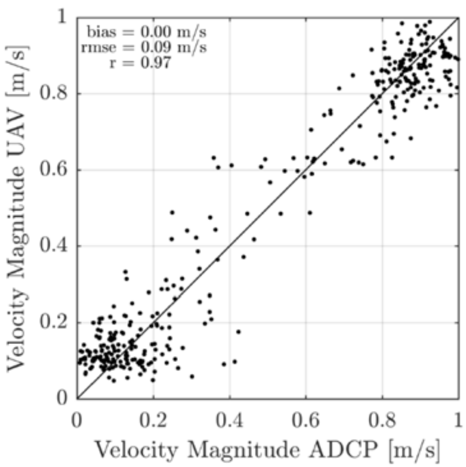
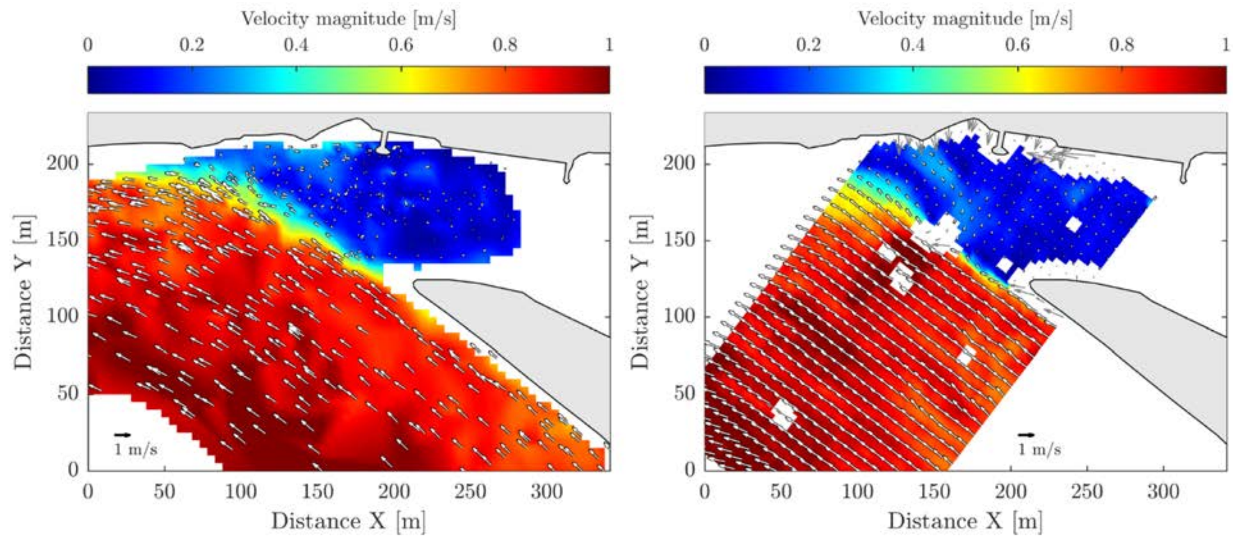



Fig. 3. Scatter diagram of ADCP and UAV-based velocity magnitudes. Only measurements are considered where the ADCP measurement is not more than 5 meters away from the UAV estimate.




(a) ADCP (b) UAV

Fig. 2. Current maps acquired from the Acoustic Doppler Current Profiler (ADCP) (a) and estimated from UAV (b) at the Elbe River in Lauenburg. For the ADCP map (a), the current vectors indicate the true locations of the ADCP ensembles and the color coded map is interpolated to a regular grid. The UAV-based current vectors in (b) show every second grid cell center. Low Signal-to-noise ratio areas ($SNR < 3$) are masked and current vectors in these areas are plotted in gray. The origin of the local coordinate system is at 603477 m East and 5914370 m North (UTM32).

## Video Based Estimation of Surface Currents Using a Low-Cost Quadcopter

Michael Streßer, Ruben Carrasco, and Jochen Horstmann *Member, IEEE*

Uses video from GPS equipped low-cost drone to estimate currents from space-time dispersion relations. Accuracy ~9 cm/s. Imaged area O(8 m).

# Polarimetric Slope Sensing

Uses the different polarization response of tilted surfaces to infer 2D surface slopes.

Velocities at different depths are estimated by fitting the Doppler shifted dispersion relations from space-time slope estimates at different frequencies.

O(1 m) imaged area.

Bound waves, which occur for smaller wavelengths, to be avoided.

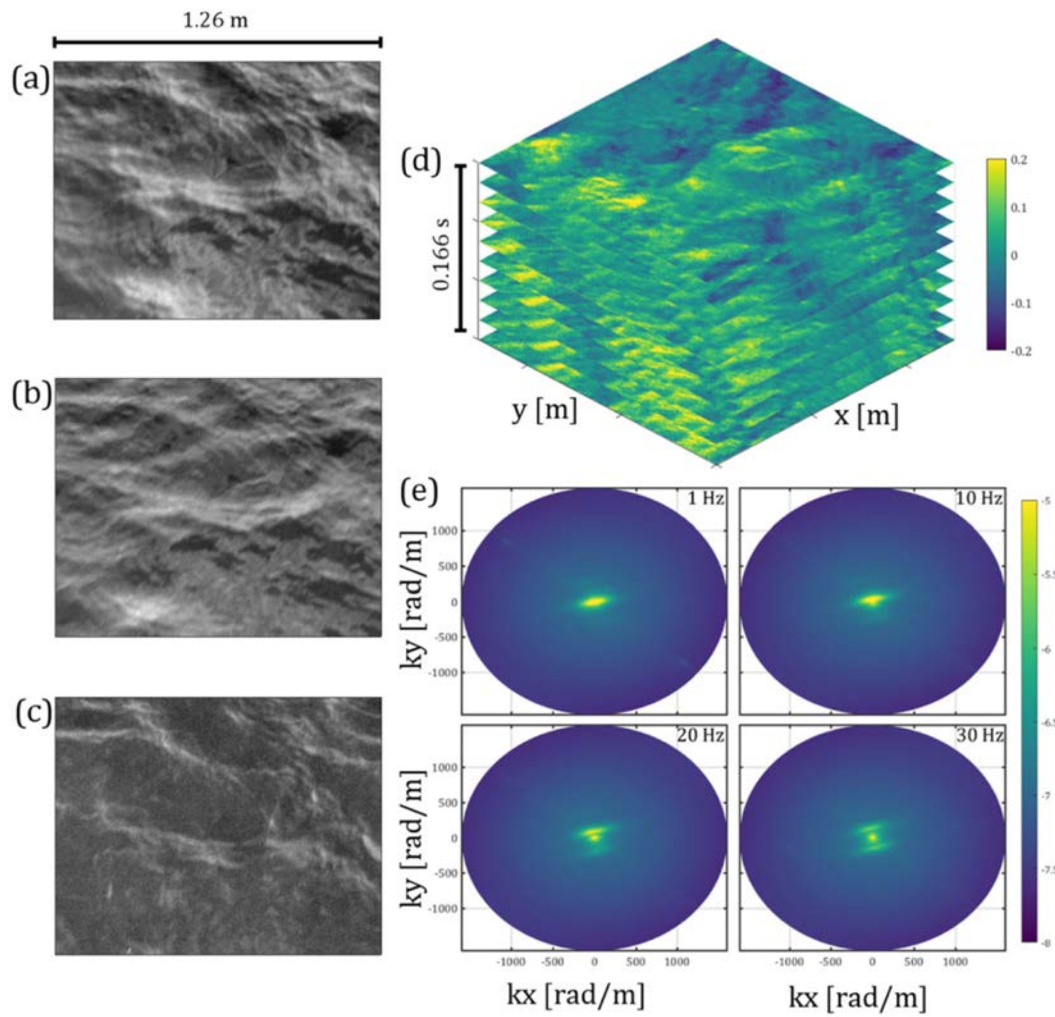



FIG. 2. Visual breakdown of the process from image triplet to $k-\omega$ spectrum. Raw image intensities in (a) 90°, (b) 45°, and (c) 0° polarizations. (d) Stack of slope fields forming $\mathbf{S}(x, y, t)$, colored by the wave slope magnitude in radians. (e) Four frequency slices from the resulting wavenumber–frequency spectrum $P(k_x, k_y, \omega)$, colored by the base-10 logarithm of directional wavenumber–frequency slope spectral density ($m^2\,Hz^{-1}\,rad^{-3}$).

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# HF Radar

Measures Doppler centroid of Bragg resonant waves for frequencies 3-50 MHz (3 m to 50 m waves)

Widely available in coastal US and in selected other countries (growing coverage).

Maps <200 km of coast (6 km resolution) or < 50 km (2 km resolution) (Higher resolution sometimes available very near coast.

Data availability depends on the availability of Bragg resonant waves.

When available, space-time coverage can be very good.

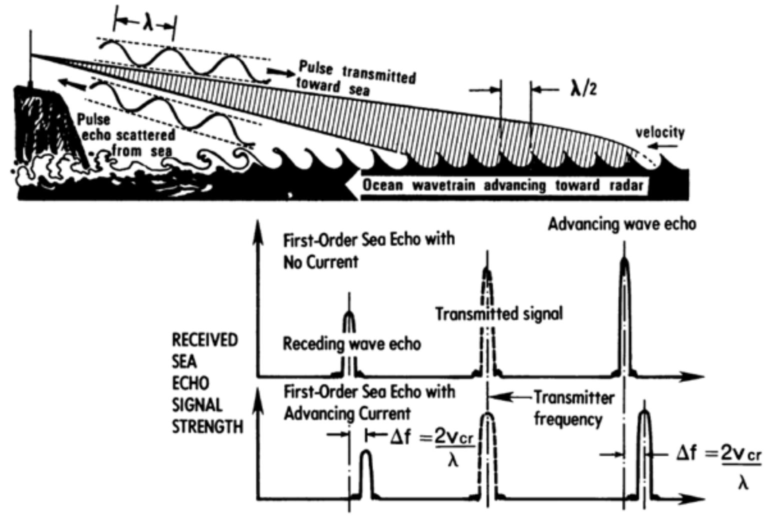
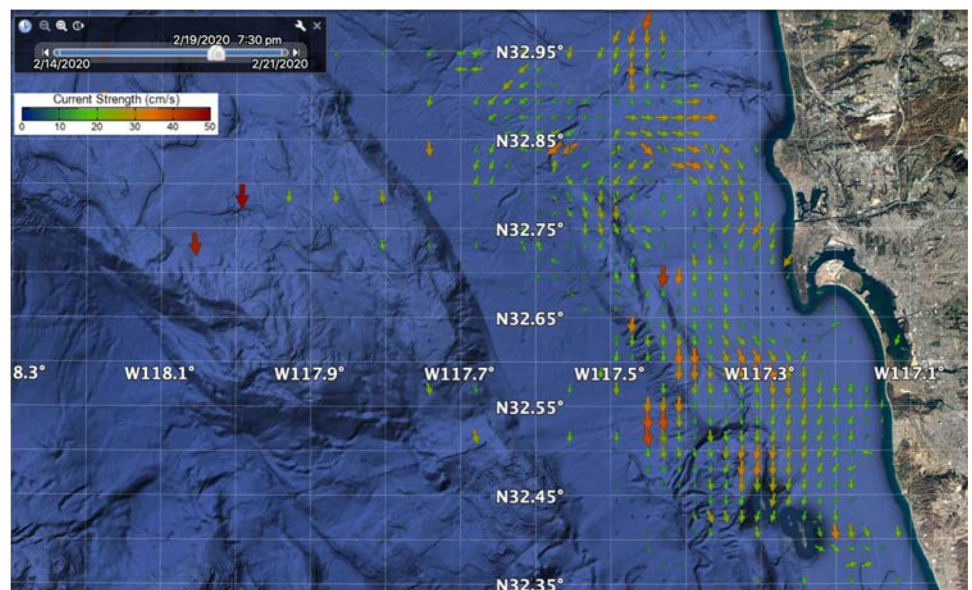
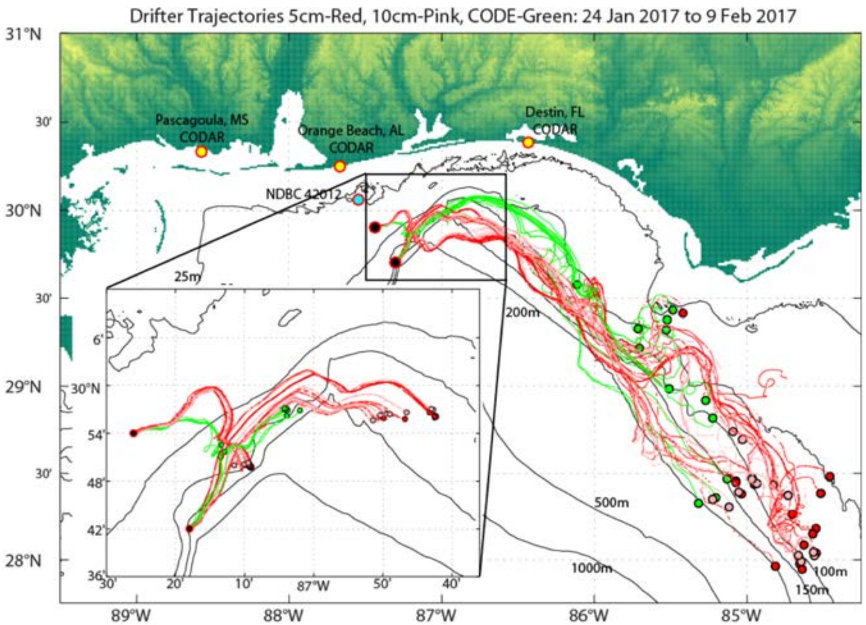



Fig. 1. Sketch showing the principles of first-order HF Bragg scatter from the sea, and resulting signal echo spectra without and with an underlying current.



# Comparing HF-radars and drifters




**Measurement Characteristics of Near-Surface Currents from Ultra-Thin Drifters, Drogued Drifters, and HF Radar**

Steven L. Morey [1,2,*], Nicolas Wienders [3], Dmitry S. Dukhovskoy [2] and Mark A. Bourassa [3]

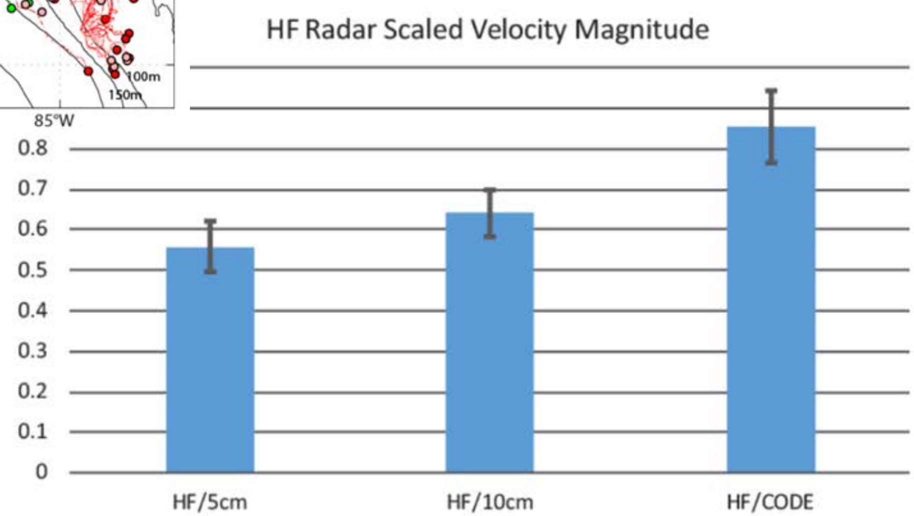
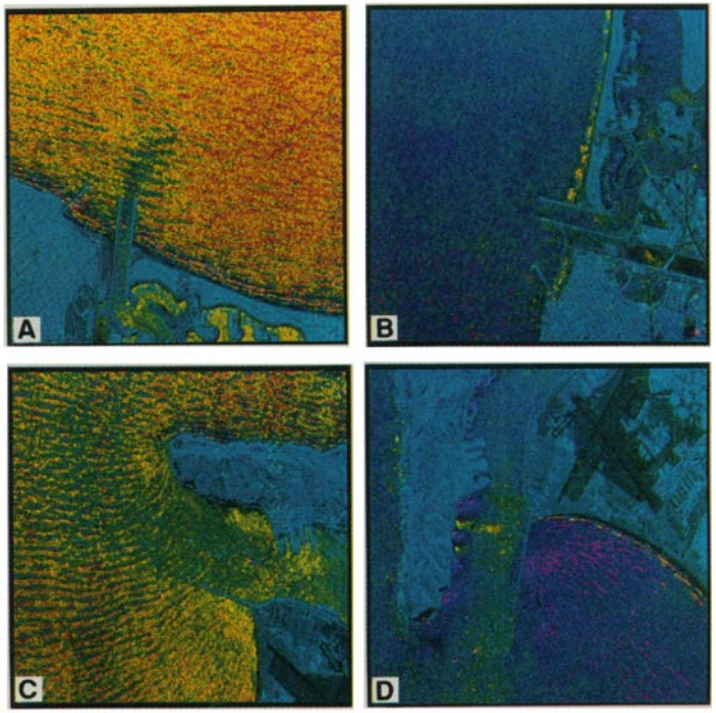



**Figure 8.** Mean magnitude of the HF radar velocity relative to binned 5-cm, 10-cm, and CODE-style drifter velocity as calculated by Equation (1). Error bars represent the 95% confidence interval of the estimate of the mean.

# Along-Track Interferometry




Goldstein et al, 1989

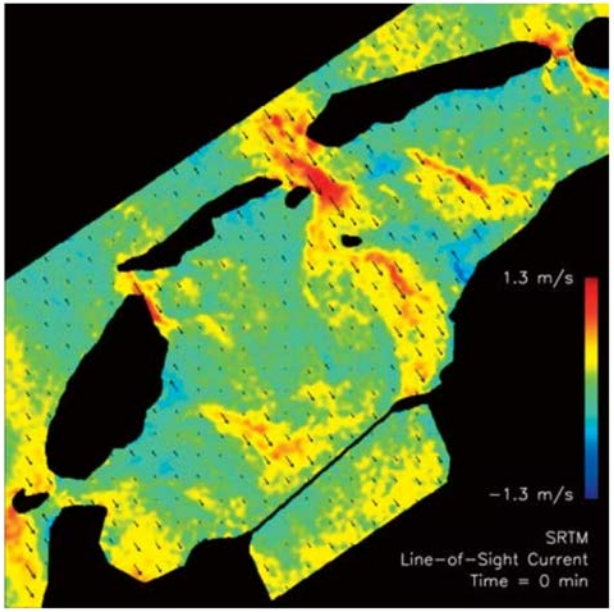



Fig. 3. Line-of-sight current field derived from the SRTM phase image of Fig. 2(b). Arrows indicate the orientation and strength of the current component parallel to the radar look direction.

Romeiser et al, 2005

Uses 2 antennas + SAR processing to obtain high accuracy Doppler centroid shifts along the look direction.
Multiple look directions to obtain vector velocities requires multi-beam antennas
High-resolution SAR processing makes global data acquisition challenging
SAR systems are typically high power, high mass, high data rate => expensive!

# Single Antenna Doppler

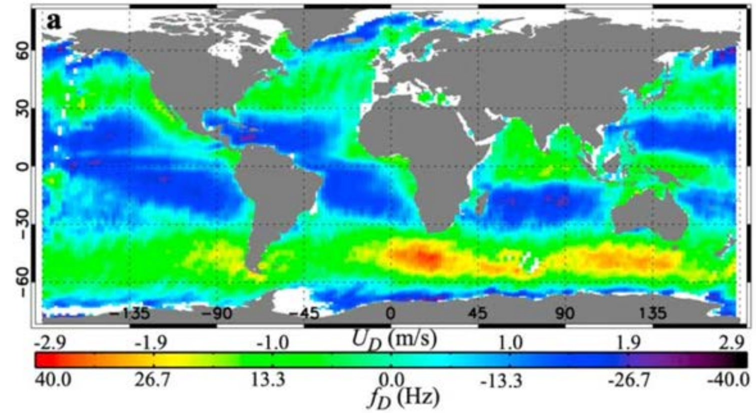
Chapron et al. (2005) showed that single antenna Doppler contained information about surface currents at lower spatial resolution than ATI (but significantly lower cost).

They also showed that there is a strong signal due to winds (or amplified Stokes currents) that must be removed.

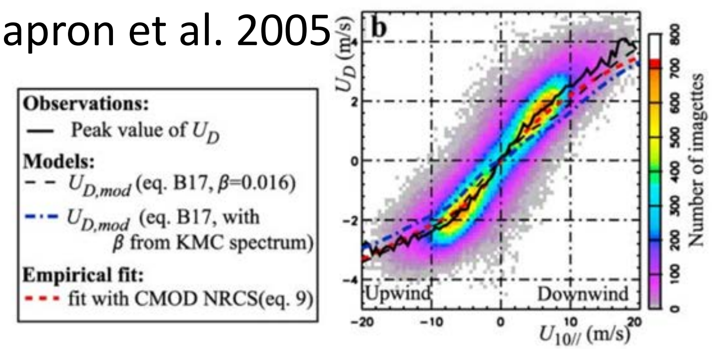
SARs still have the problem of single look direction, high data rate, small swaths (poor spatial coverage).

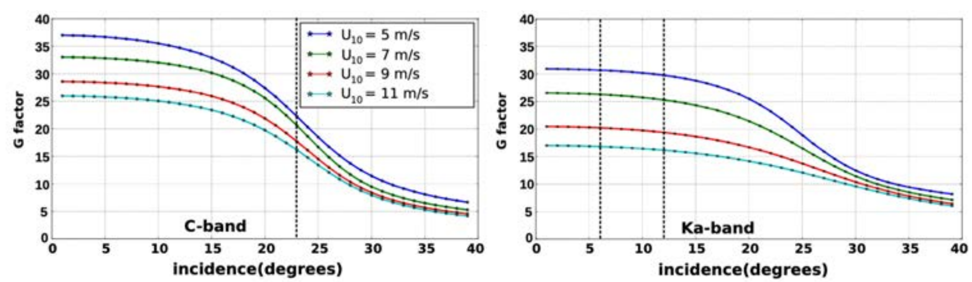
Removal of wind/Stokes signal is a common issue for high frequency radars

Multiplier factor for Stokes drift velocity multiplier (Ardhuin et al, 2018)



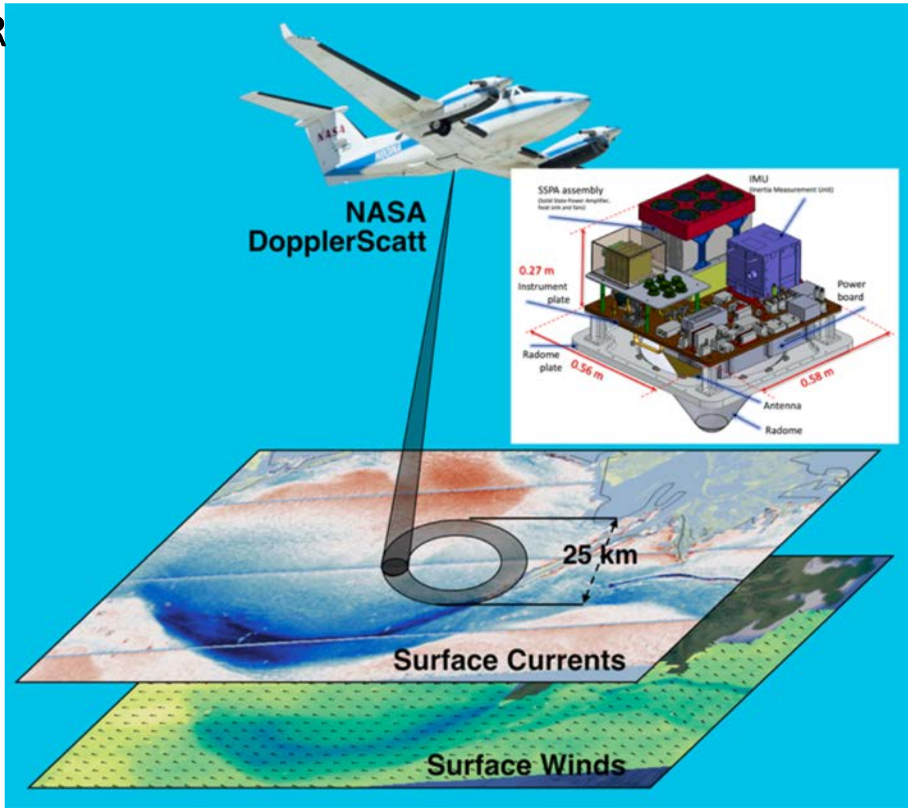

Chapron et al. 2005



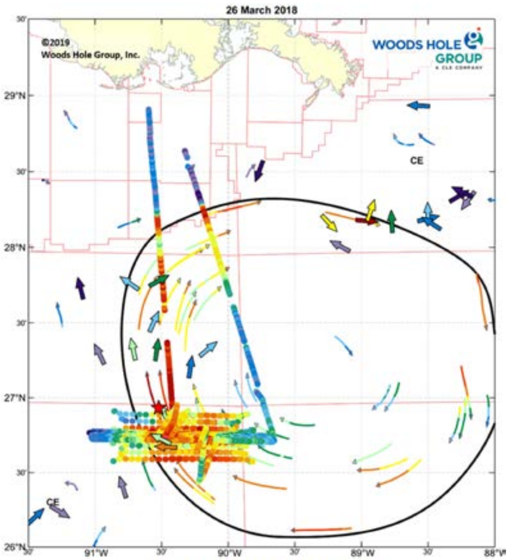



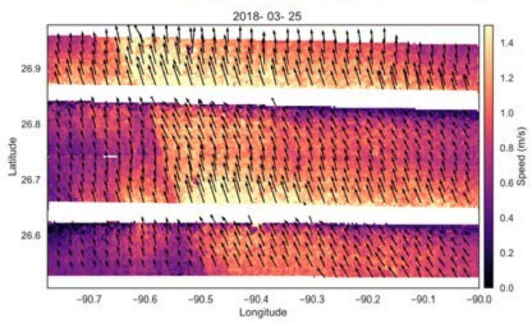
# Airborne Doppler Scatterometry with DopplerScatt

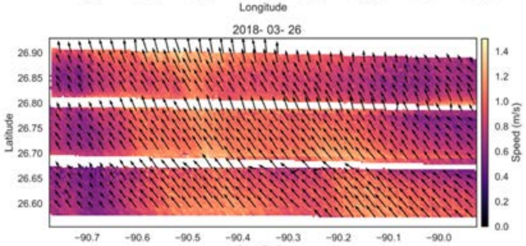
- Rodriguez (2012) showed that by using a small rotated antenna, many of the limitations of SAR Doppler could be avoided
  - Large swaths (~daily global coverage from space) and low data rate (easy onboard processing)
  - Ka-band minimizes wave contamination
  - NASA developed DopplerScatt as proof of concept airborne instrument
- Advantages:
  - Can be done from planes or from space
  - Much better spatial resolution
  - Can be used to measure winds (at incidence angles > 20 deg: WaCM) or gravity waves (SKIM)
- Disadvantages:
  - Longer gravity waves/winds contribute to total signal
  - This contribution must be removed using a mixture of theory and experiment to get at surface currents

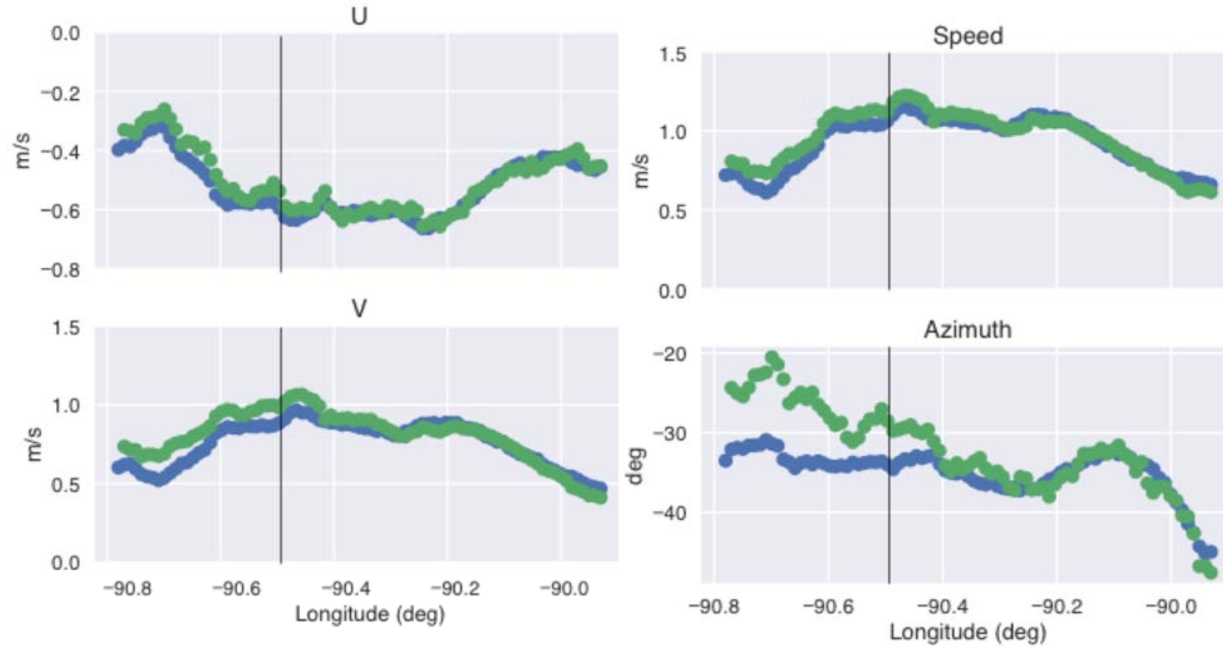


# DopplerScatt – ROCIS Comparison



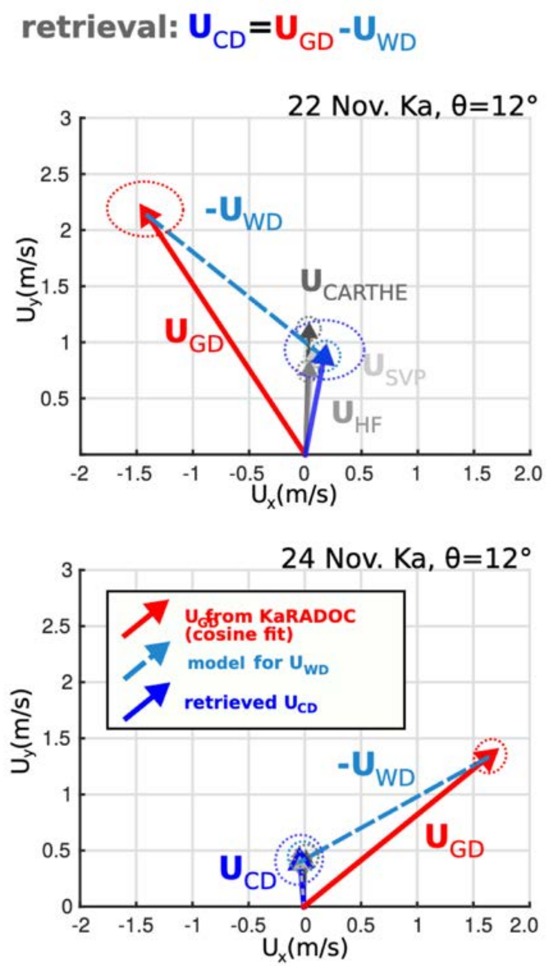



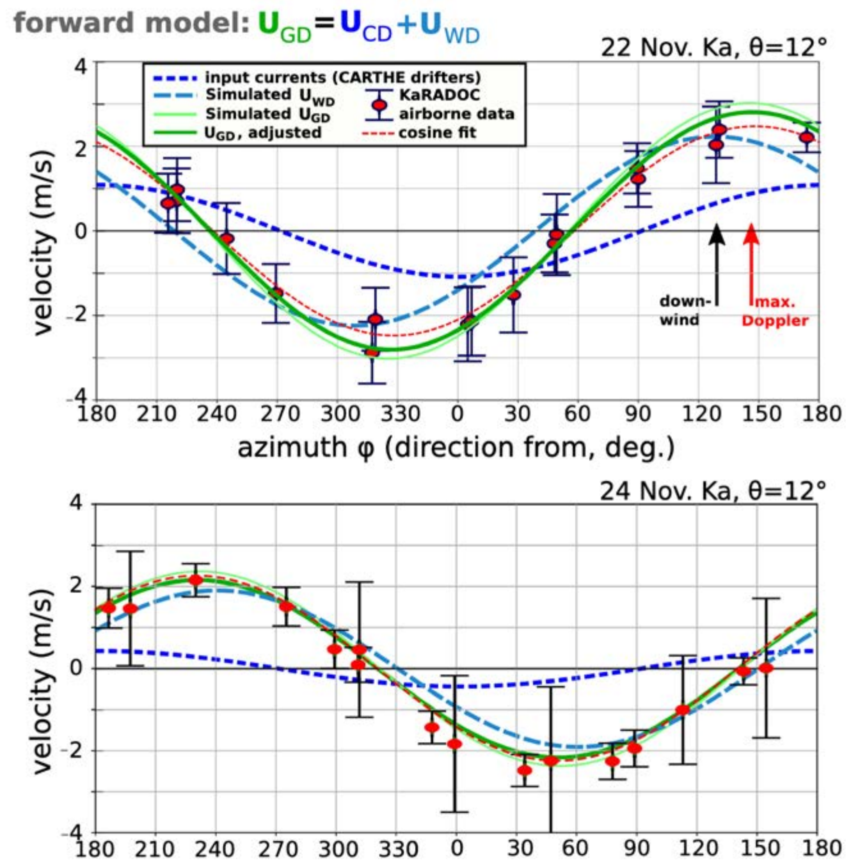




Data collection funded by Chevron.
ROCIS data courtesy of Areté Associates.

# Near-nadir Doppler Scatterometry
# SKIM




Le Marié et al, 2020. Demonstration of removal of near-nadir wave contamination component using wave spectra + model against UHF radar, drifters

# Some thoughts

- There is no standardized meaning of surface currents
  - Given surface shear this is problematic when comparing measurements
- The more localized the measurement, the better understood it is
  - This is a problem for obtaining synoptic measurements and derivatives
- Measurements capable of being extended into space will need maturation by comparisons against well established sources
  - There are tower experiments and airborne campaigns (e.g., S-MODE) that will improve the maturity of these measurements.
- Works needs to be done still, especially in collecting more data to characterize shear and compare measurement techniques.