



# **Roadmap to Space: Measuring Ocean Vector Winds and Currents with a Ka-Band Doppler Scatterometer**

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# Why Winds and Surface Currents? Why Submesoscale?

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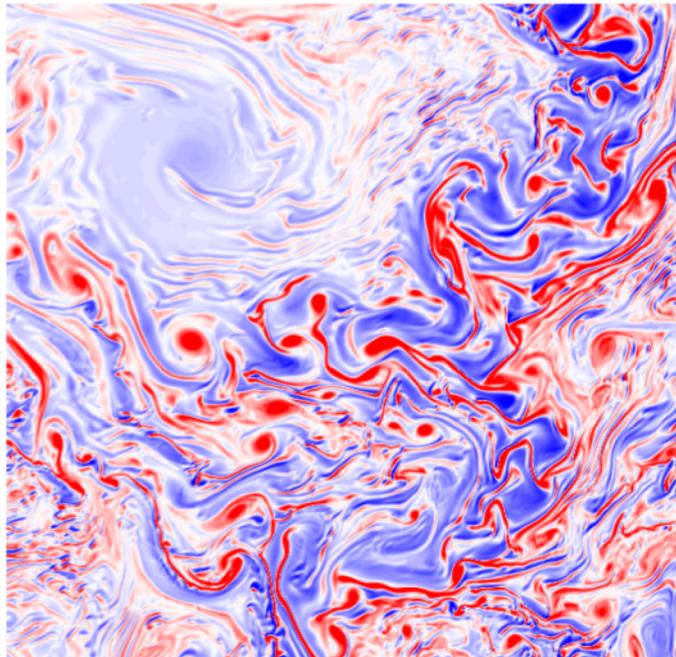
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- Winds and currents are essential climate variables that have a tight two-way coupling
  - Winds drive both horizontal and vertical circulation in the ocean.
  - Currents provide a moving reference frame for winds and also modulate winds through heat transport/SST.
- The 2017 NRC Decadal Review has identified “*Coincident high-accuracy currents and vector winds to assess air-sea momentum exchange and to infer upwelling, upper ocean mixing, and sea-ice drift*” as a targeted observable for a potential Earth System Explorer mission.
  - Doppler scatterometry identified as a measurement technique.
- ***Submesoscale ocean circulation*** (spatial scales 200m – 25 km) is suspected to be responsible for significant vertical air-sea fluxes that can be larger than the global radiation imbalance associated with the greenhouse effect (Su et al., 2018) and cannot be measured yet from space.

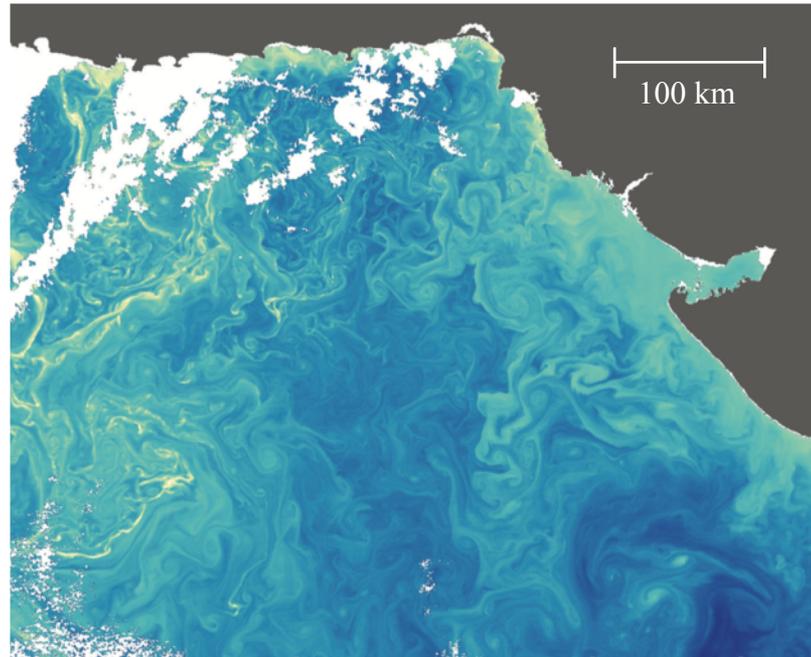


# Why Measure Ocean Surface Currents and Winds?

- Small scales (1 km to 25 km) 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.



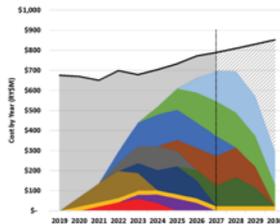
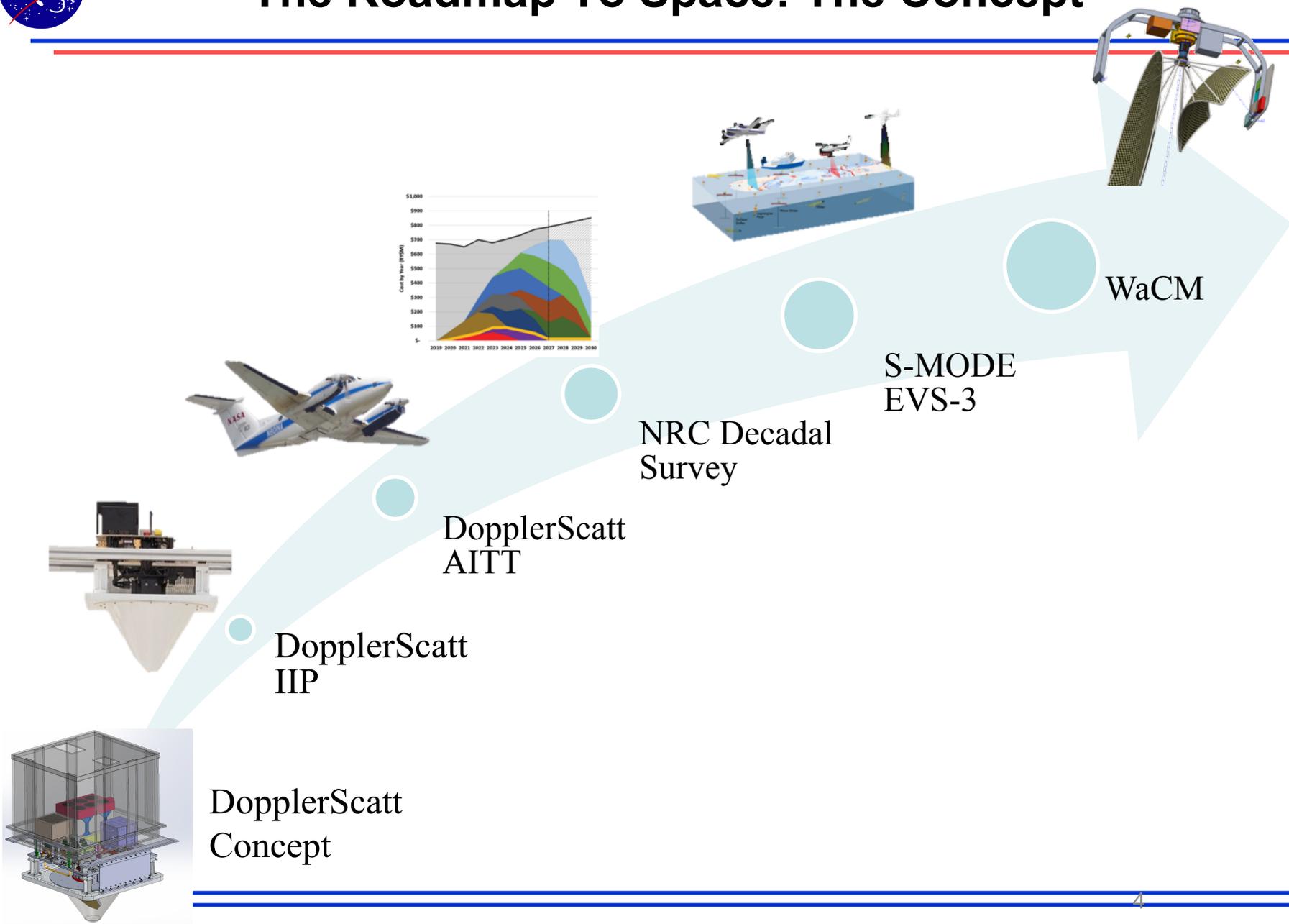
Left: Ocean relative vorticity in the California Current from ROMS 1 km spacing model (J. Molemaker, UCLA, D. Chelton OSU)



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



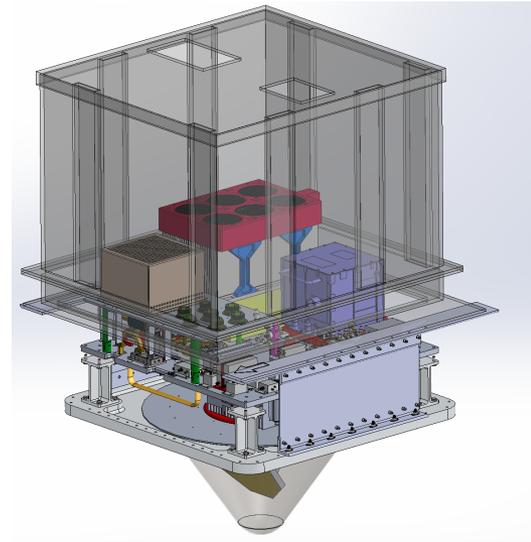
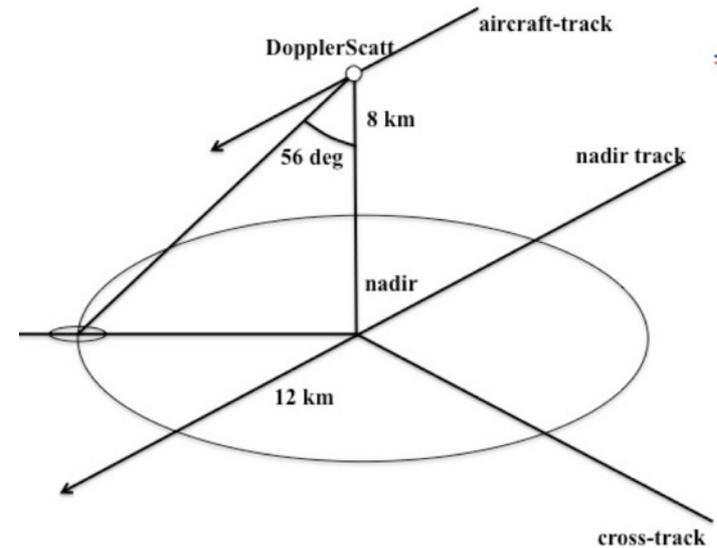
# The Roadmap To Space: The Concept





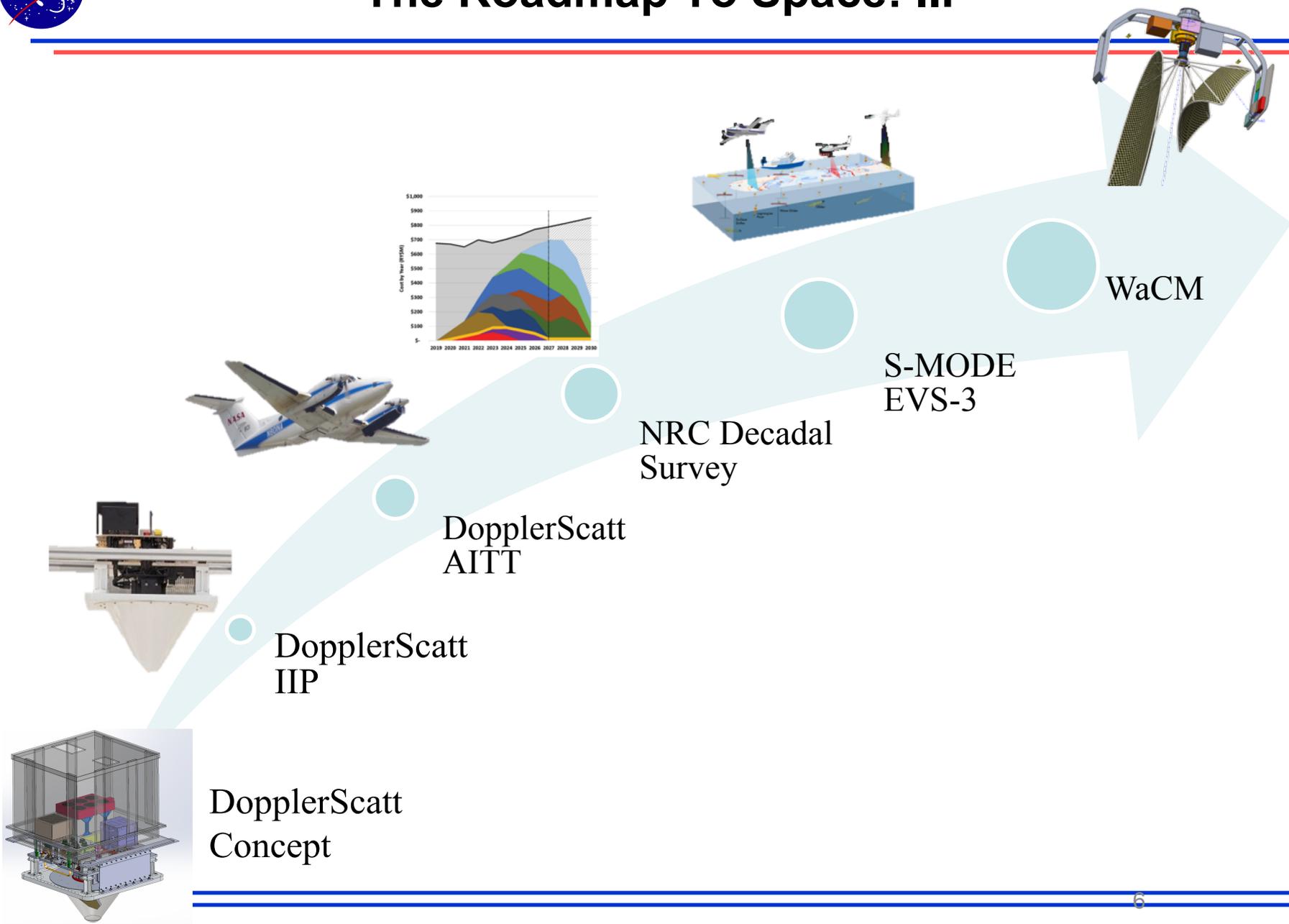
# The DopplerScatt Concept

- 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 is a proof-of-concept airborne instrument demonstrating the feasibility and accuracy of this measurement technique with the results applicable to future spaceborne missions.





# The Roadmap To Space: IIP





# DopplerScatt Instrument Incubator Program (IIP)

- **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 hours

- 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

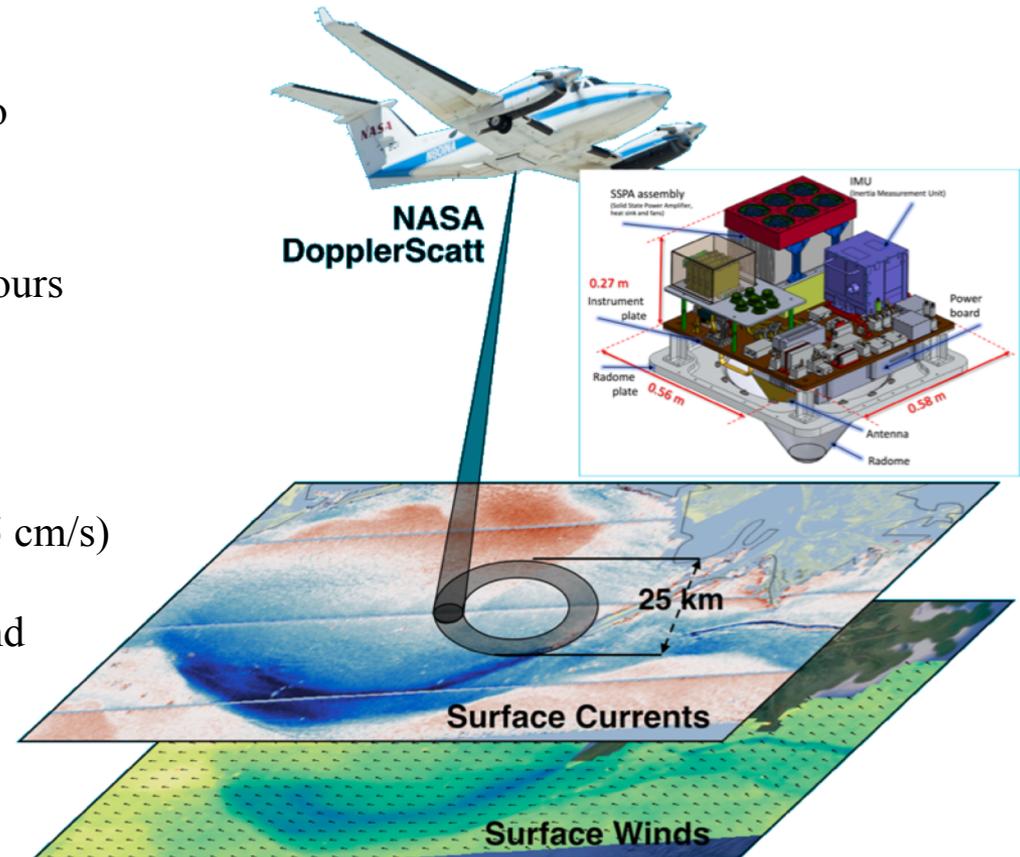
10% accuracy in 20-30 m/s speed

**Wind direction:**

20 degrees accuracy (15 deg)

**Spatial resolution:**

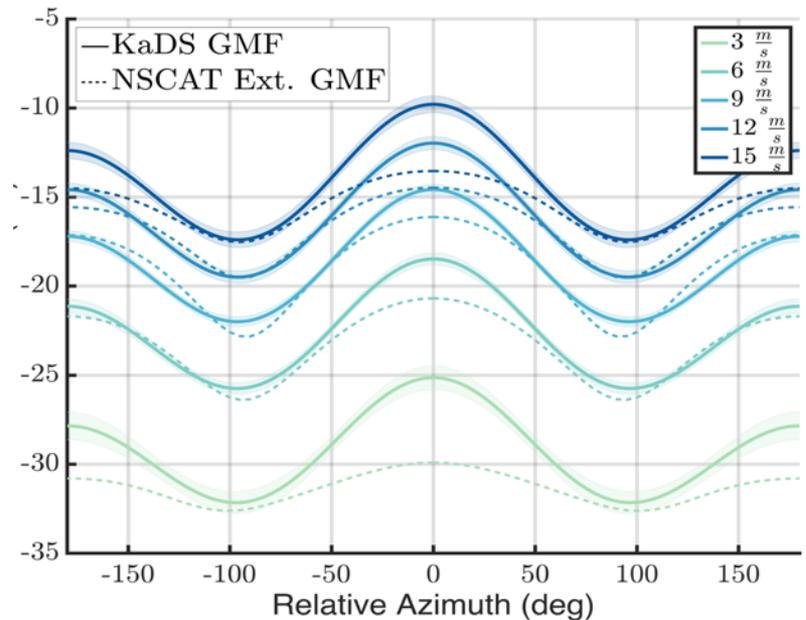
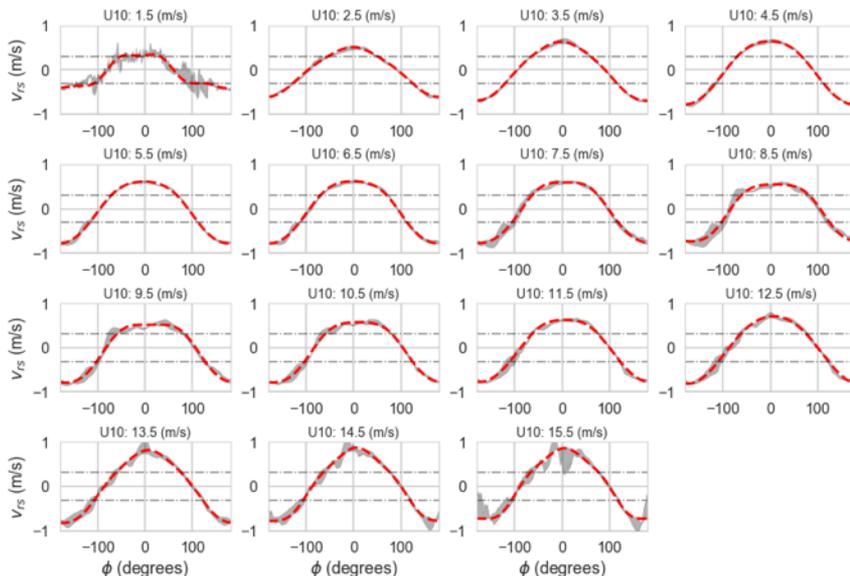
5 km (200m currents, 1km winds)





# IIP Results

- Designed and built the DopplerScatt instrument.
- 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
- Developed model functions and algorithms for estimating vector winds and currents.
- Began to dive into the phenomenology of Doppler Scatterometry and the applications of it.

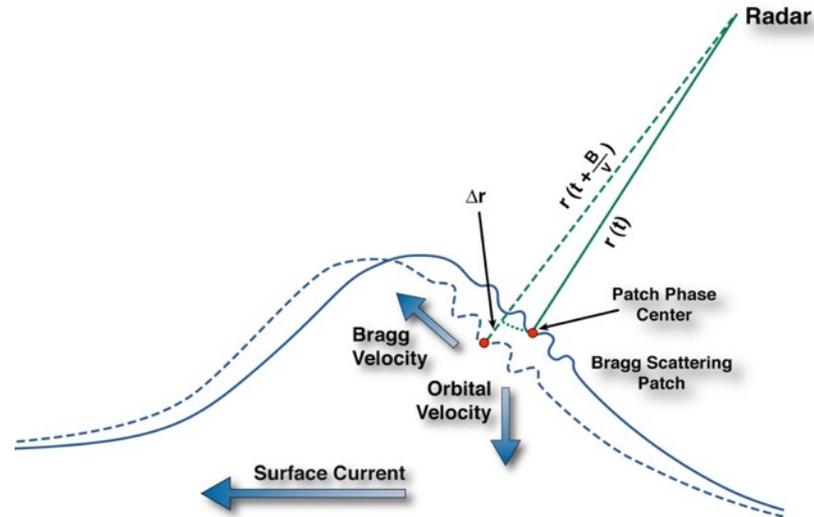




# What velocity are we measuring?

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

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

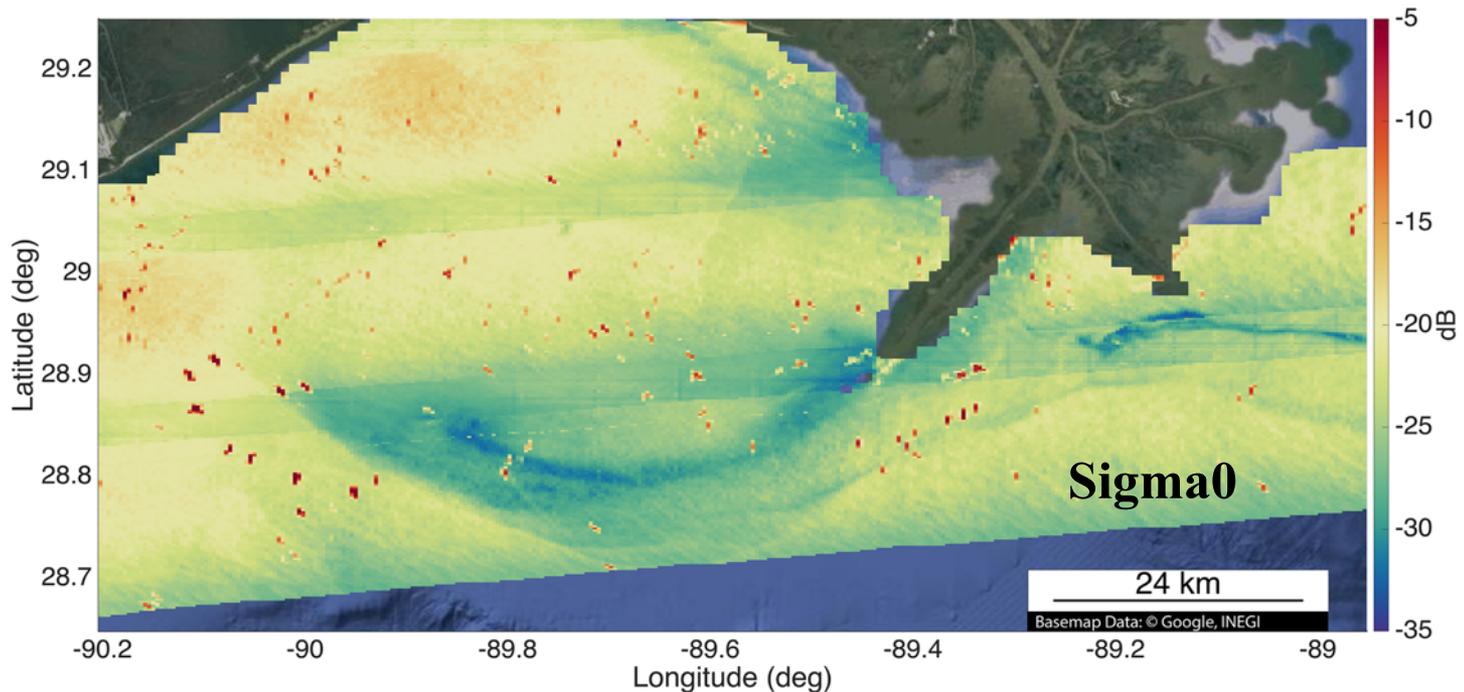


- Radar sensitive to phase speed  $\sim 0.5$  cm capillary waves (off-nadir) or tilts and small scale slope variations (near nadir)
- Free wave phase speed:  $\sim 31$  cm/s. Capillary waves can also be generated as bound waves due to straining: will travel at straining wave phase speed (low wind speeds).
- 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



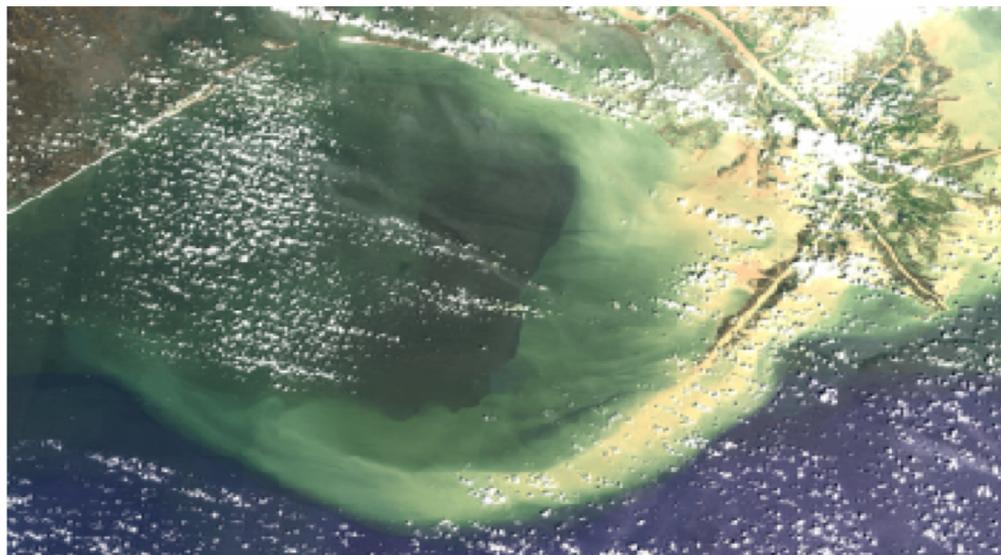
# What does backscatter tell us?

- Backscatter is a measurement of the normalized return power of the ocean surface.
  - At Ka-band, we are primarily measuring the scattering due to capillary waves driven by the wind. Capillary waves are measured relative to surface currents.
  - Affected by surface characteristics (SST, viscosity, dissolved solids)
- In the areas that DopplerScatt flies, there are typically river outflows and internal waves that will appear in backscatter.
- At the resolution DopplerScatt operates, many non-wind small scale processes will appear in the retrieved wind fields.

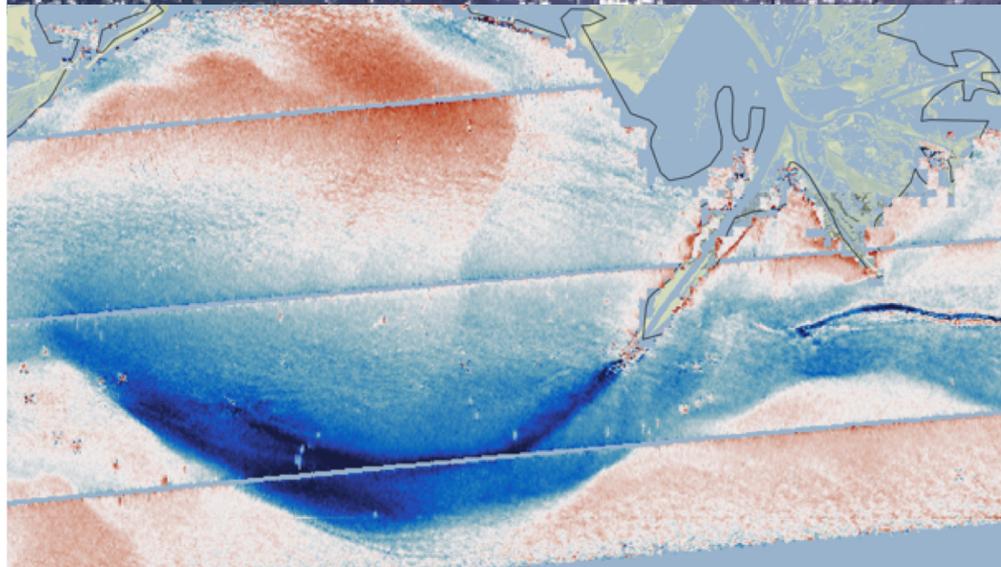




# Currents



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

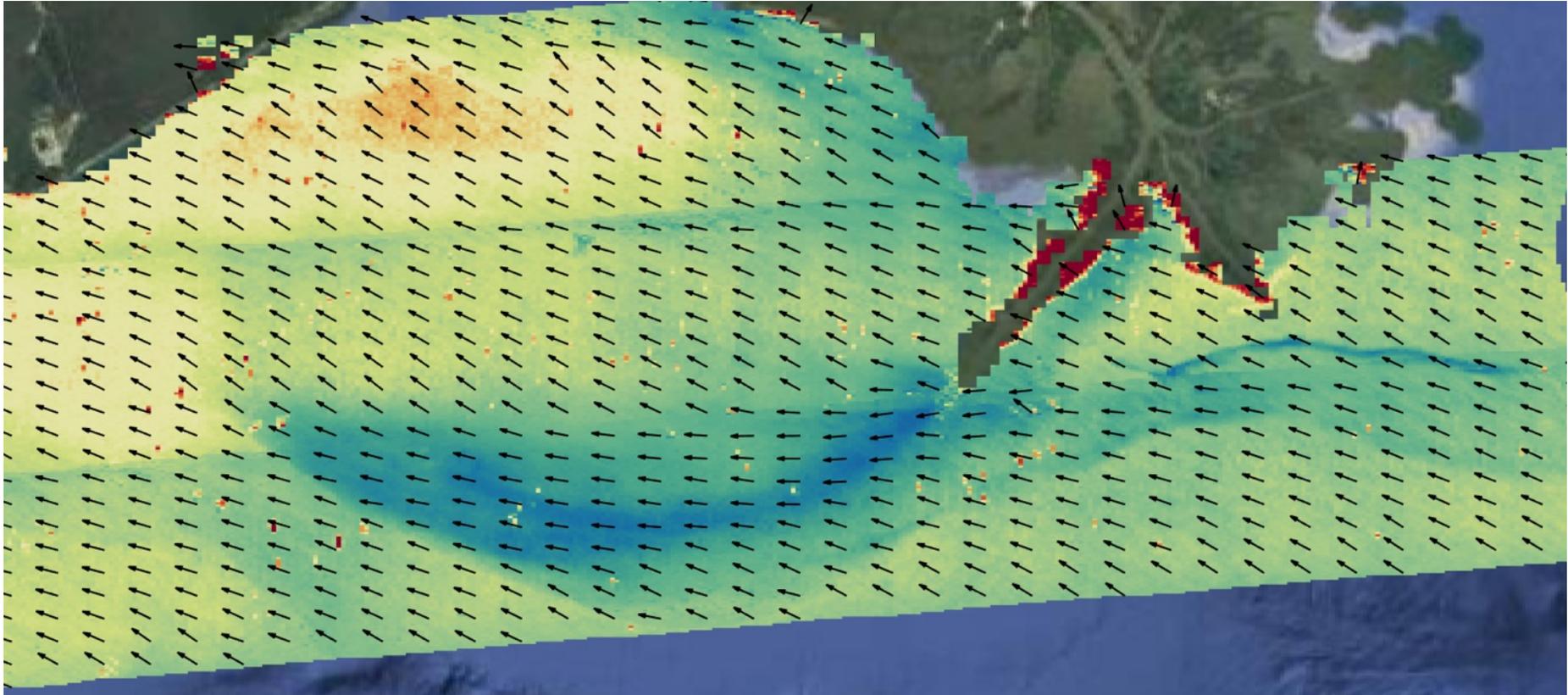


DopplerScatt surface current  
U component.

Circulation pattern, including  
submesoscale front, matches  
Sentinel 3 color pattern very  
closely.



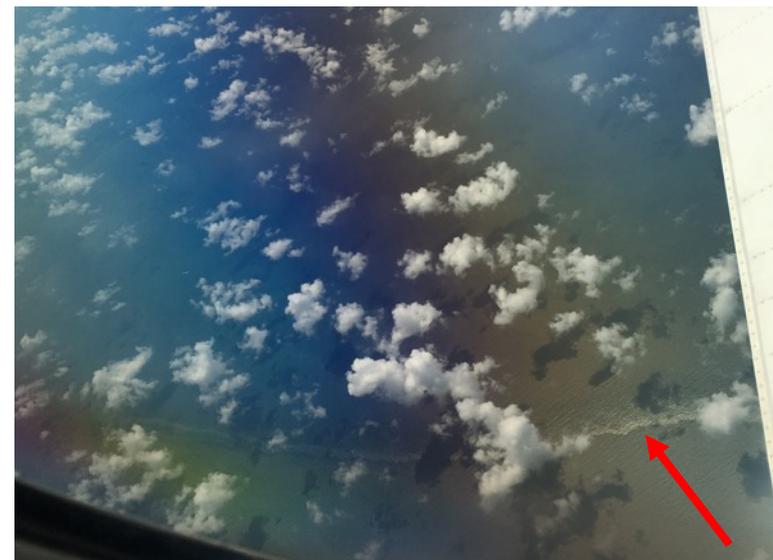
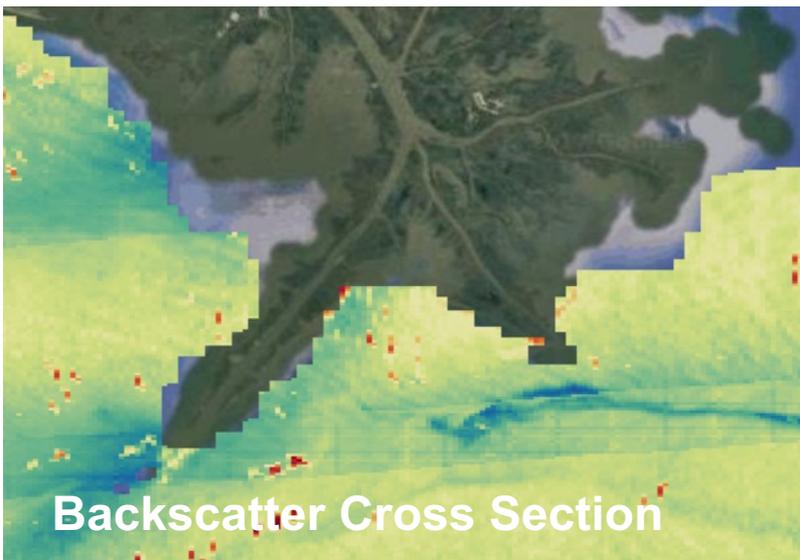
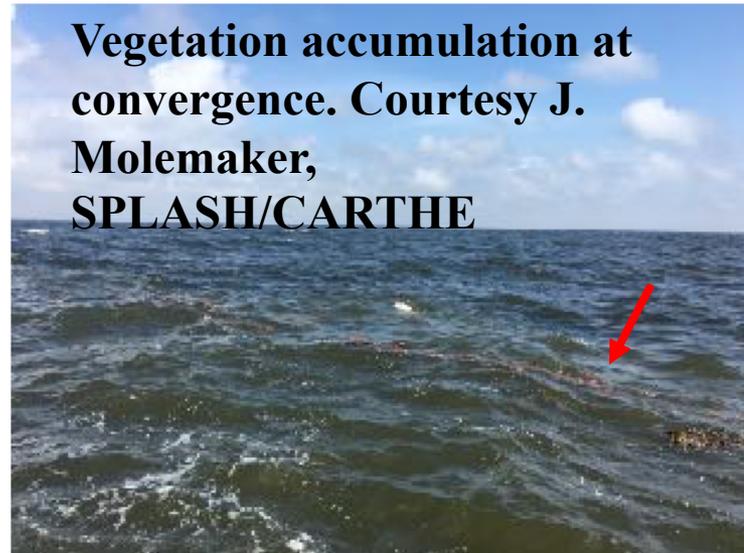
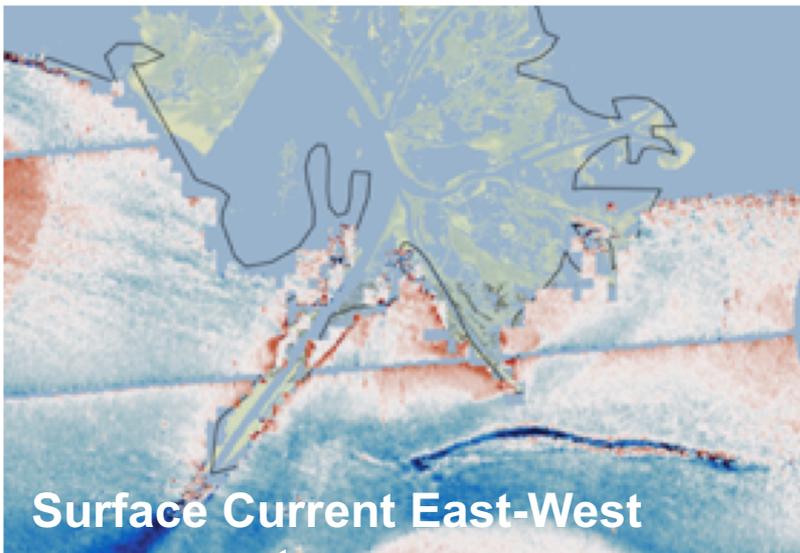
# Vector Winds



Ocean vector winds as retrieved by DopplerScatt near the outlet of the Mississippi river. Since scatterometers are sensitive to wind stress (which depends on the relative winds and currents), we see the Mississippi river current prominent in the winds.

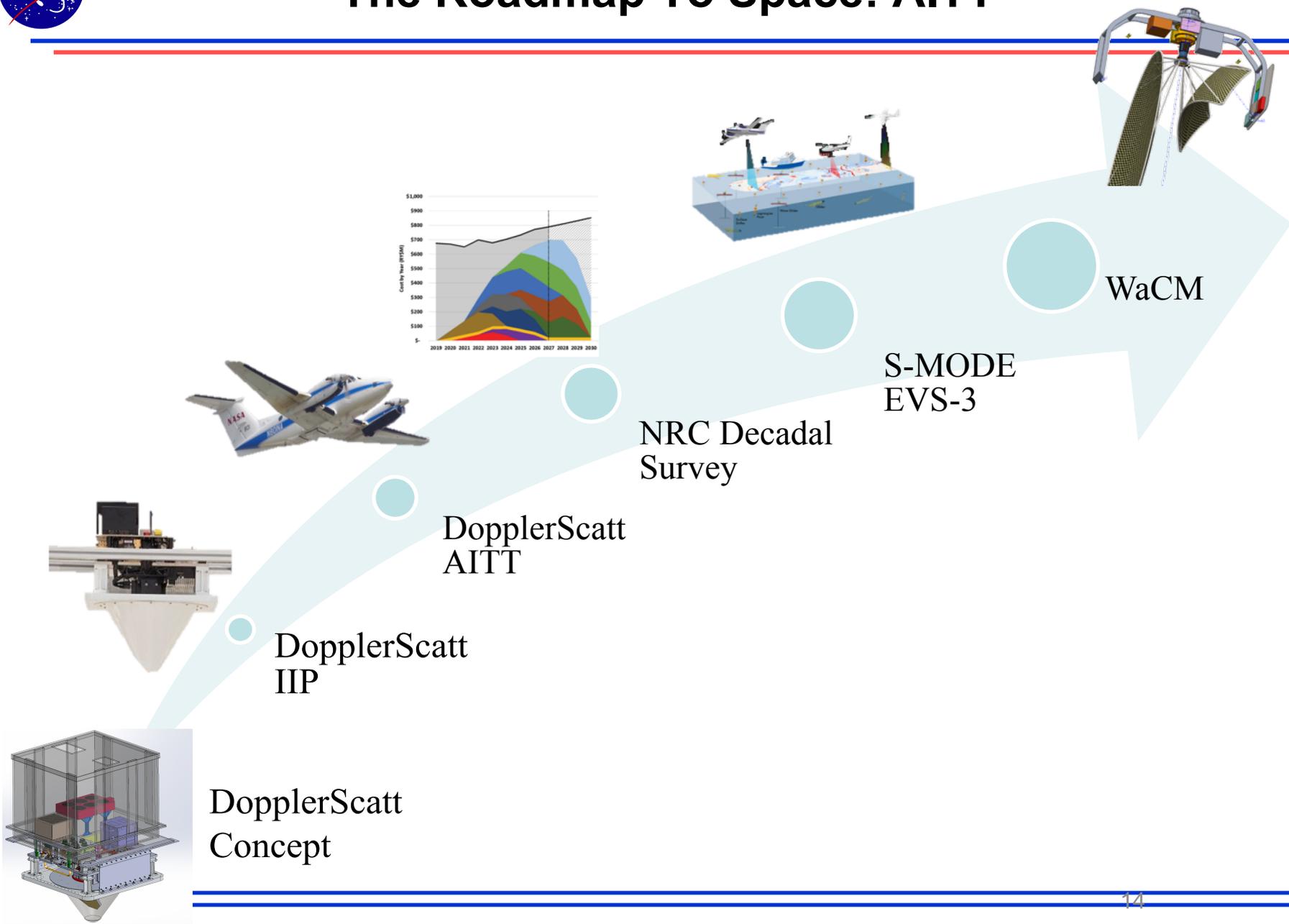


# Tracking Oil Dispersal from Taylor Oil Platform





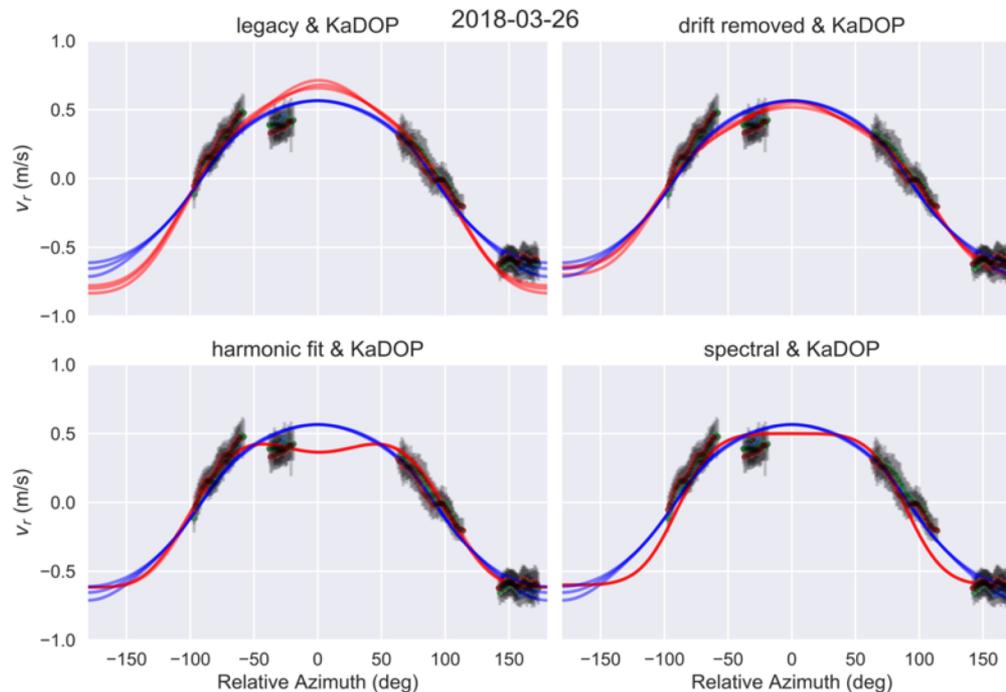
# The Roadmap To Space: AITT





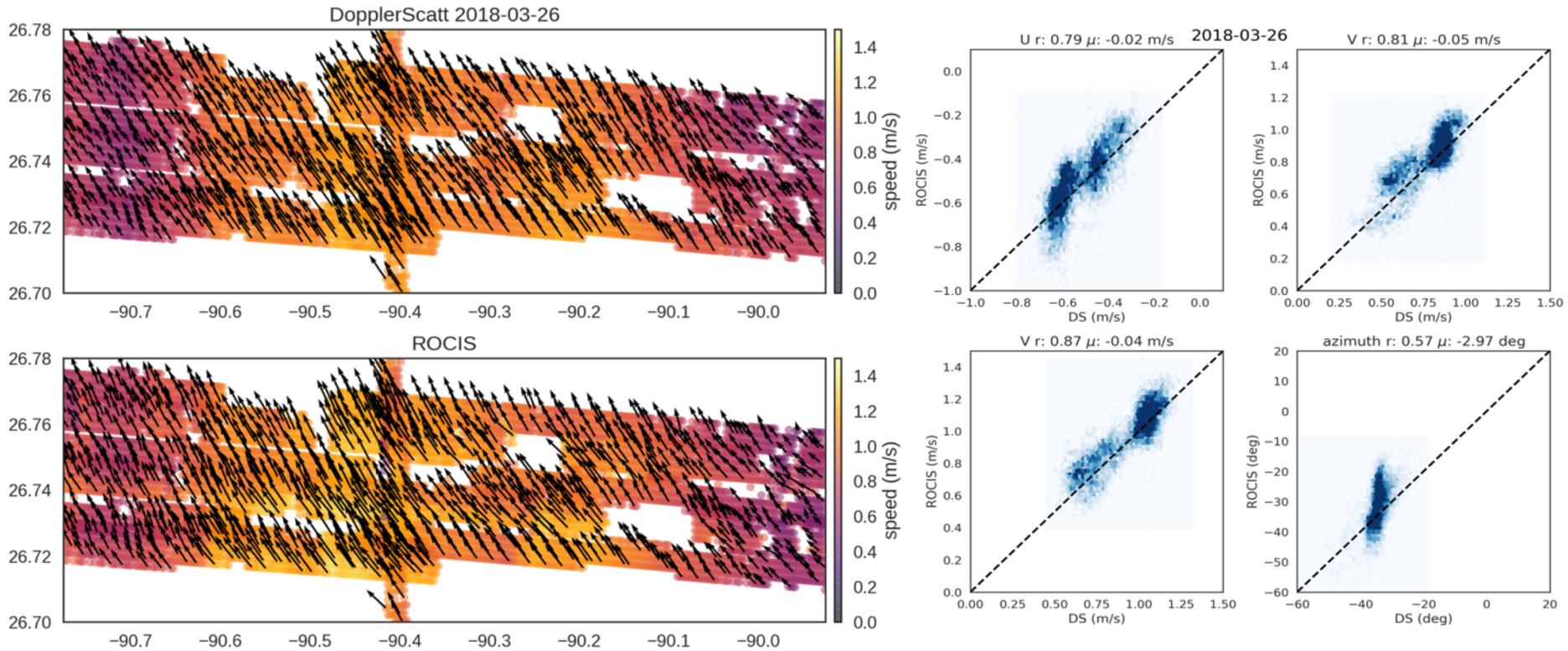
# Advanced Instrument Technology Transition (AITT)

- “Make the instrument and processing campaign ready”
- Refine algorithms, model functions.
- Speed up processing to near real time.
- Validate measurements
- Continue to further understand the phenomenology of these measurements.





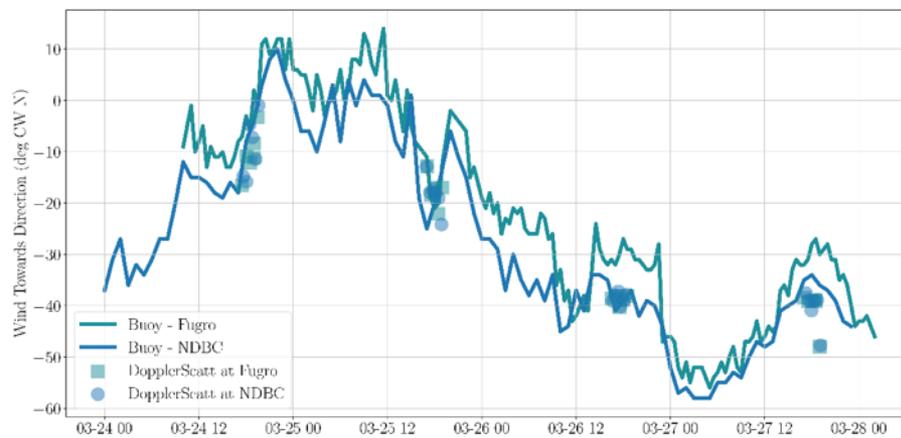
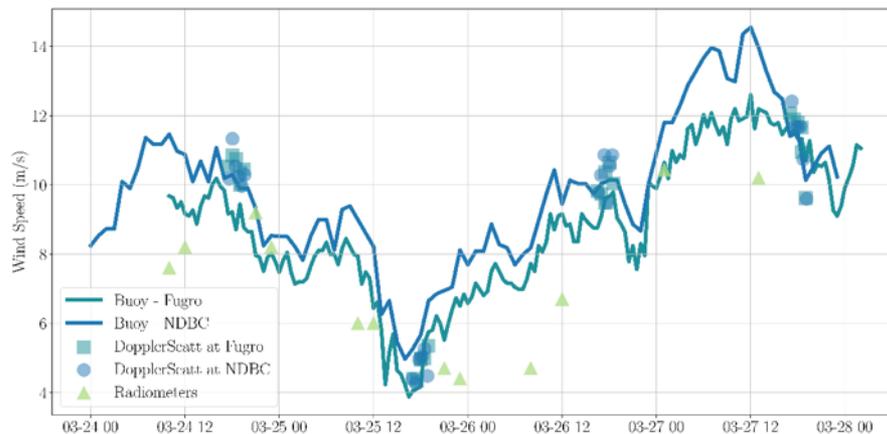
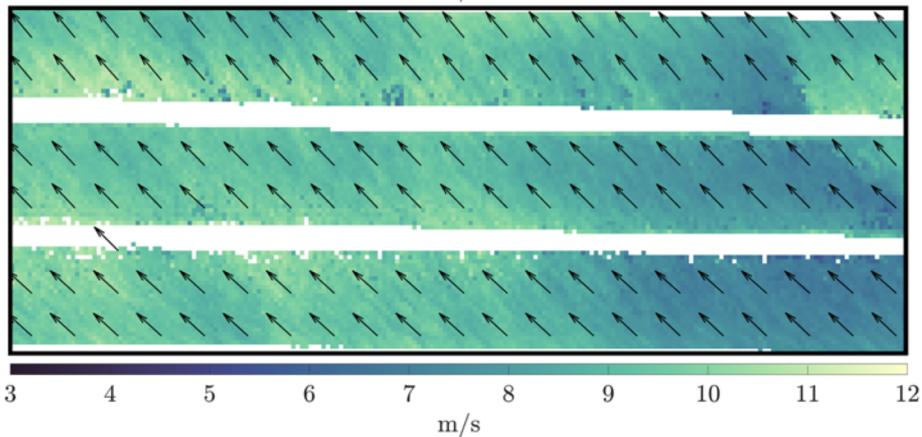
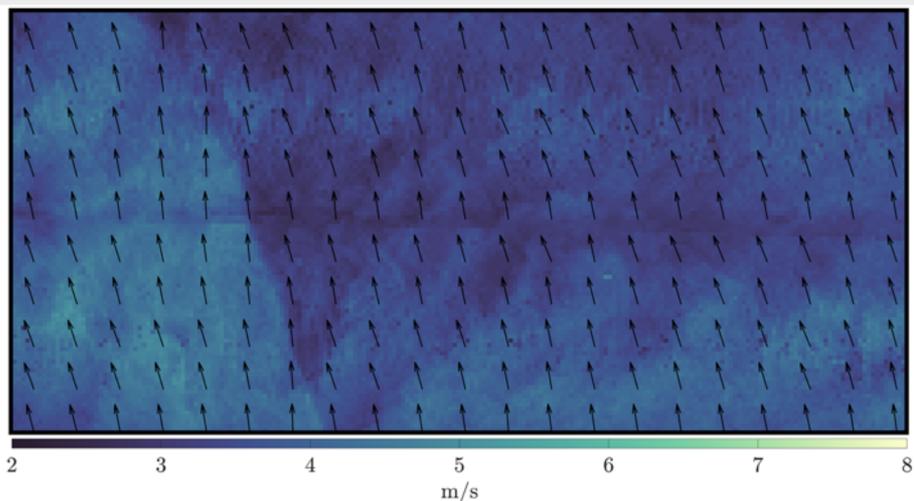
# AITT Results - Currents



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

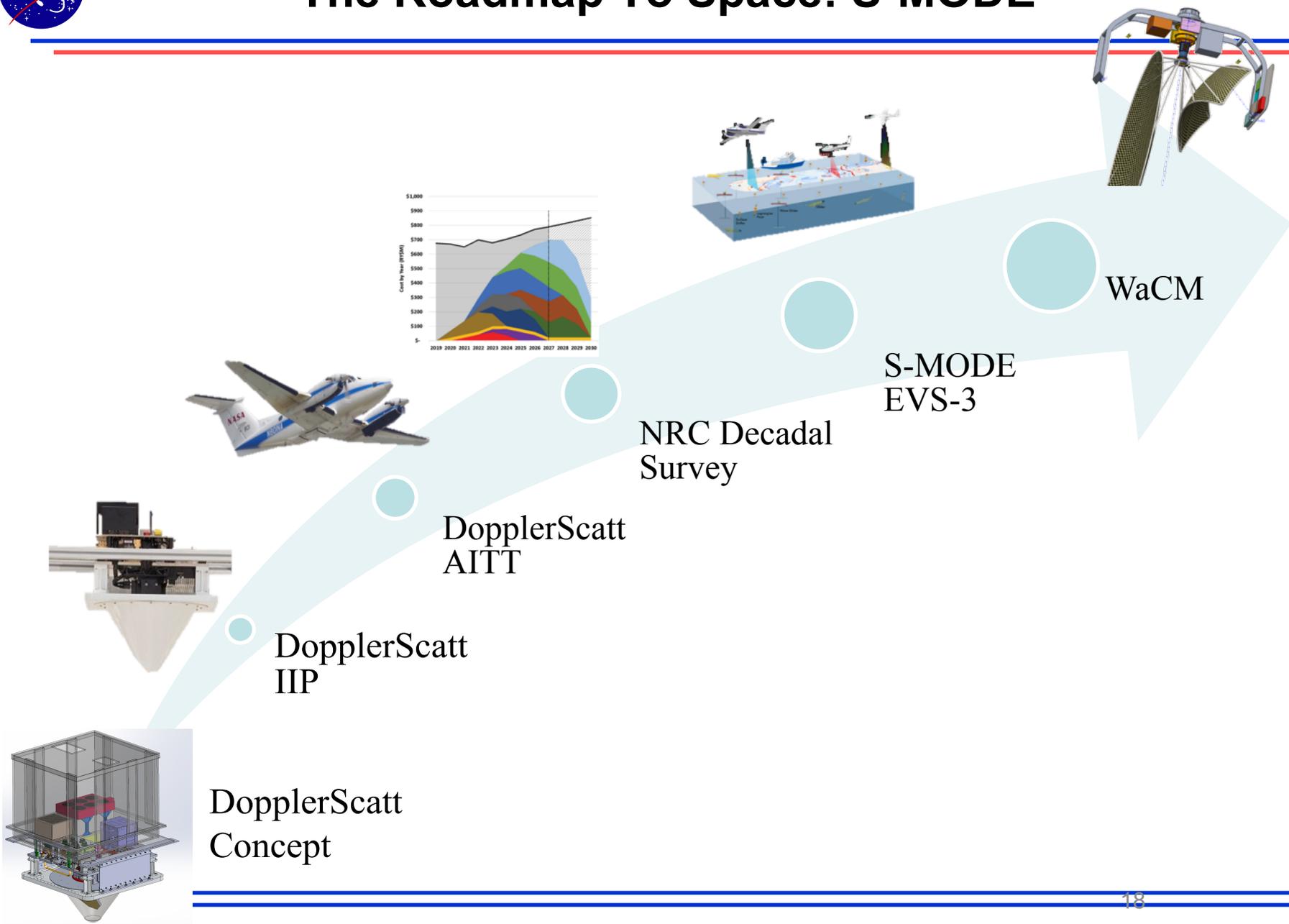


# AITT Results - Winds





# The Roadmap To Space: S-MODE

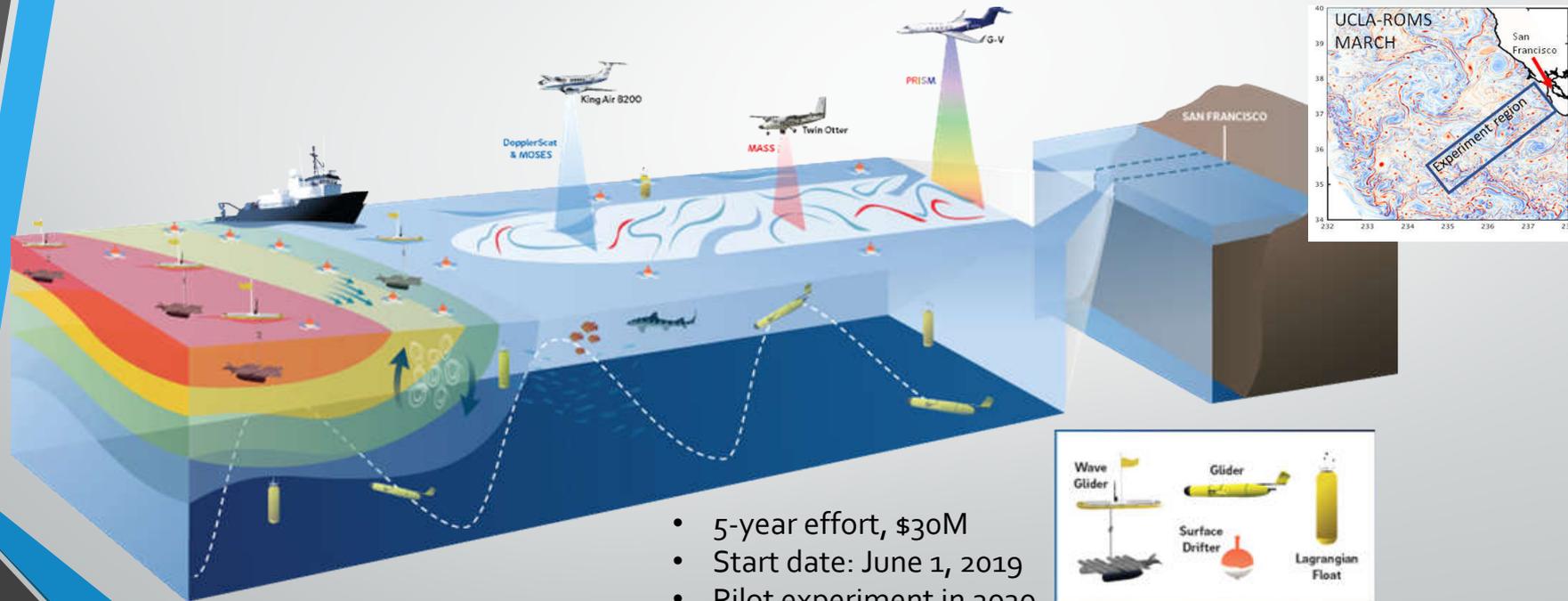




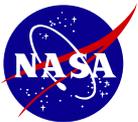
# S-MODE (PI: Tom Farrar, WHOI)

**S-MODE**

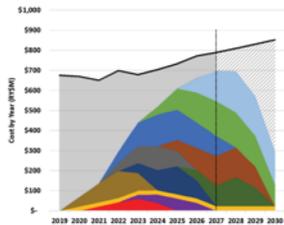
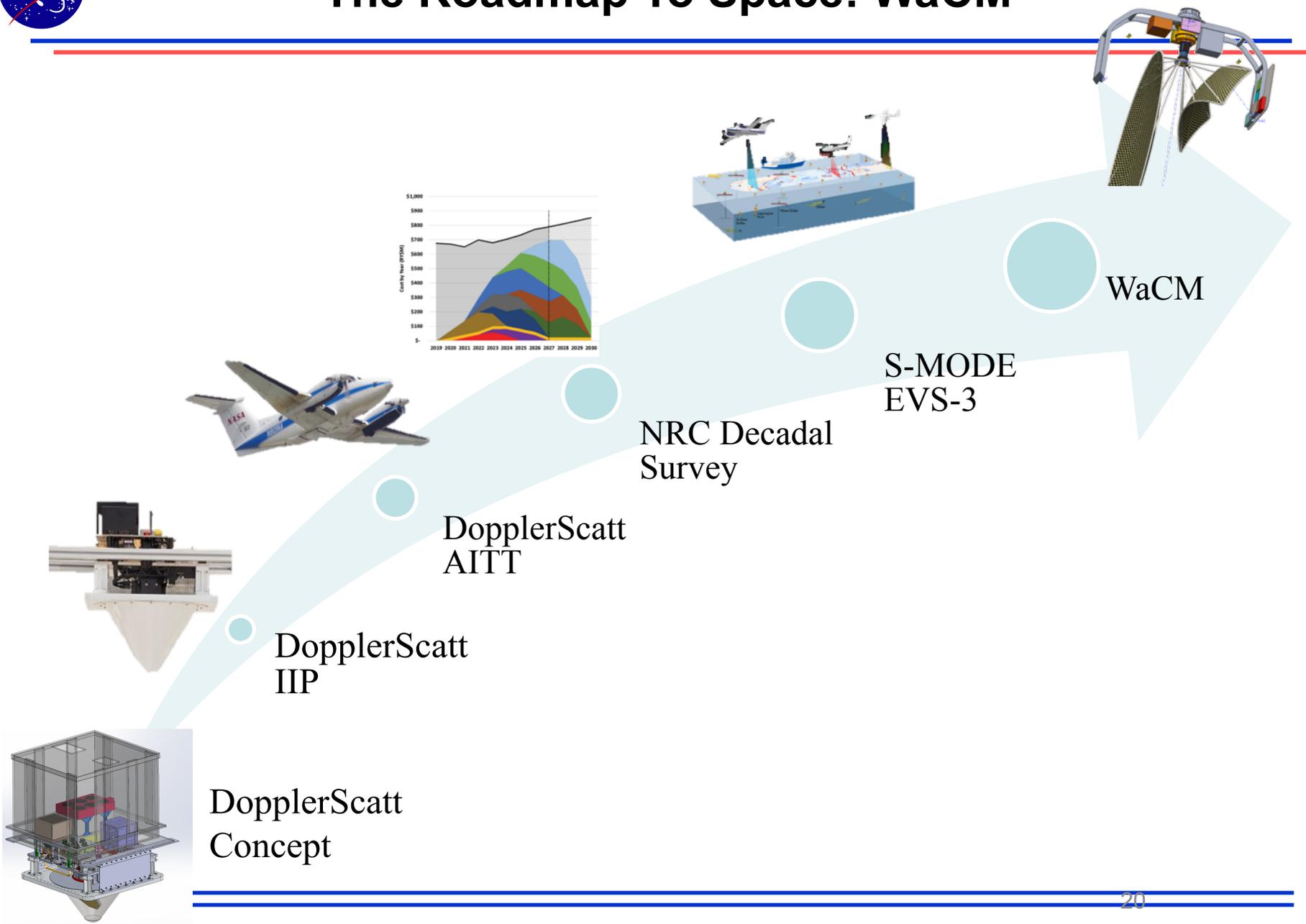
**Science:** Test the hypothesis that kilometer-scale (“submesoscale”) ocean eddies make important contributions to vertical exchange of climate and biological variables in the upper ocean.



- 5-year effort, \$30M
- Start date: June 1, 2019
- Pilot experiment in 2020
- Intense operations spring/fall 2021



# The Roadmap To Space: WaCM



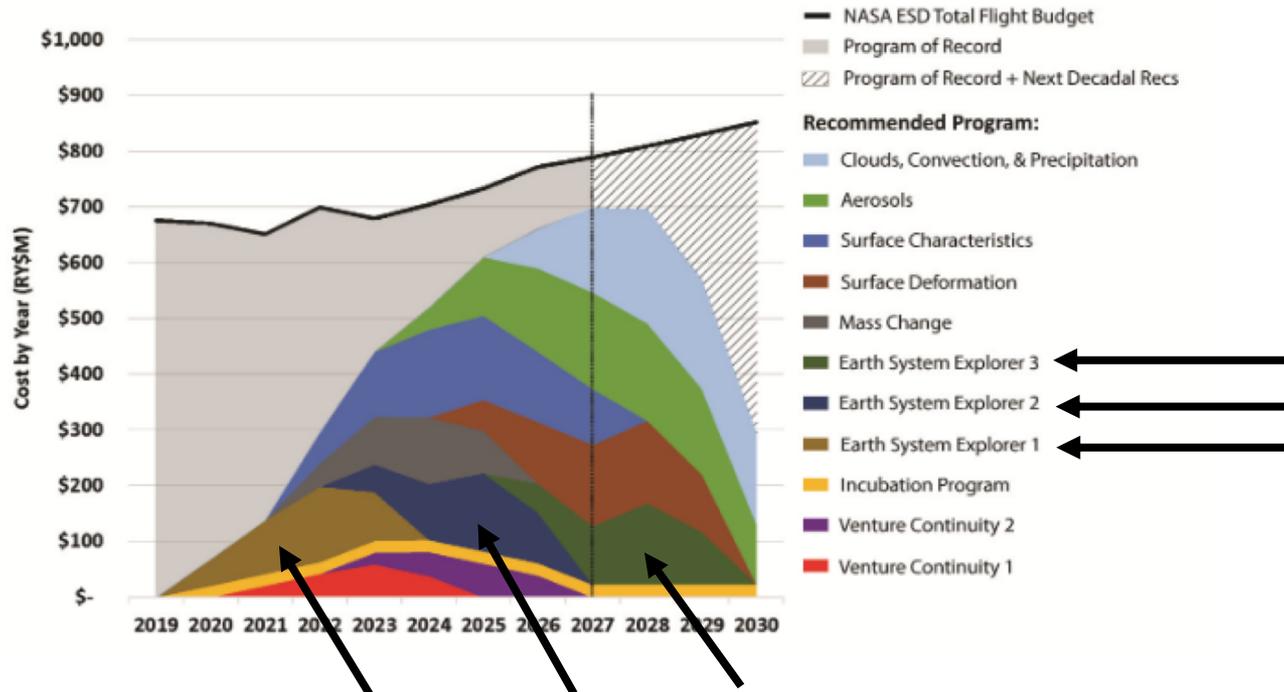


# The Winds and Currents Mission (WaCM)

Model design:

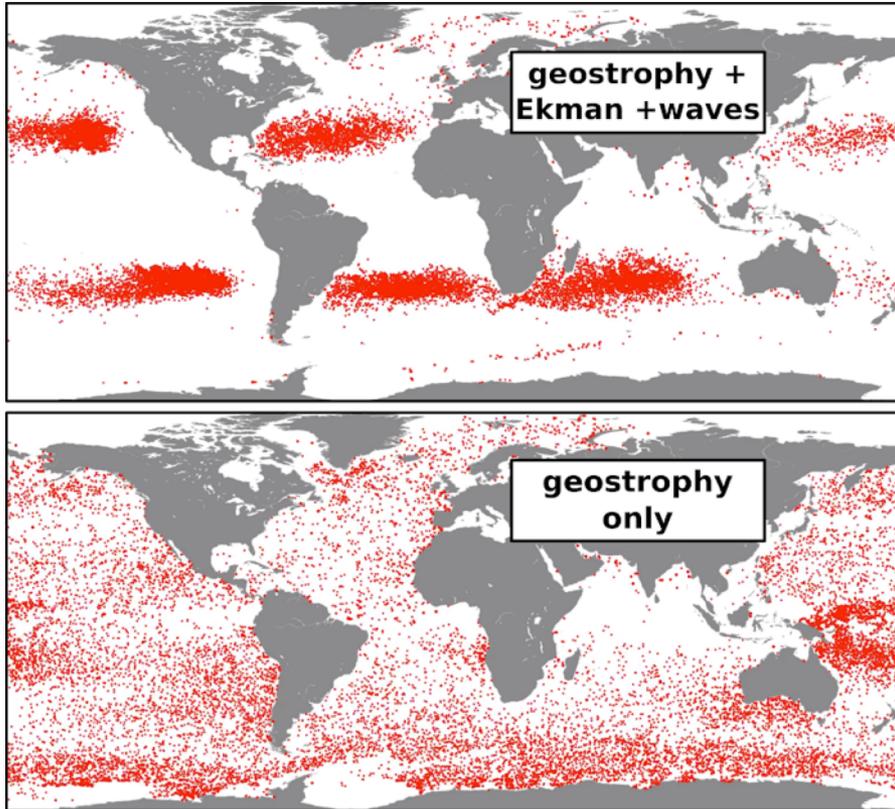
- 5 km resolution, coincident vector winds and currents
- True currents– not just geostrophic (e.g. SWOT and altimeters)
- 1800 km swath
- 90% ocean coverage every day with 4 day repeat cycle

Winds and currents + Doppler Scatterometry recommended by NRC for competed slots.

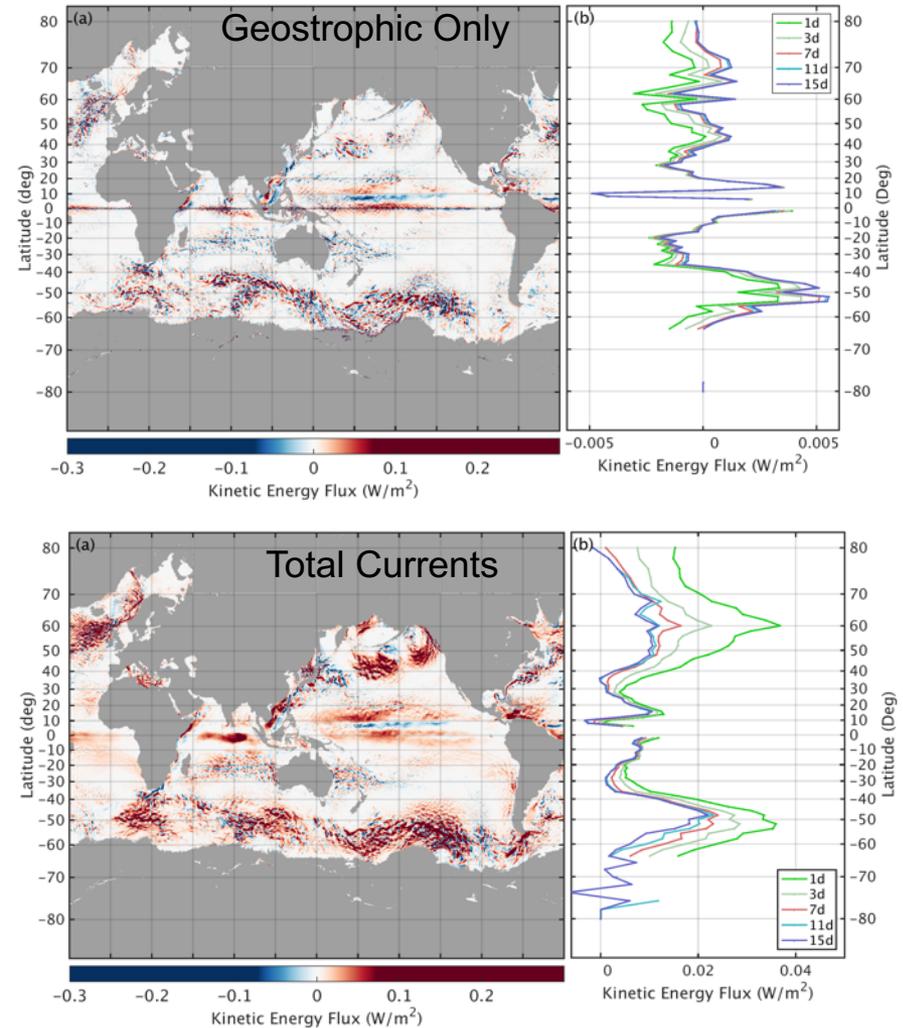




# Why Total Currents?



Distributions of virtual surface particles, after 10 years starting from a uniform distribution. The four panels show the effect of three components of the surface current combined or their effect taken separately (Adapted from Onink et al., 2019)



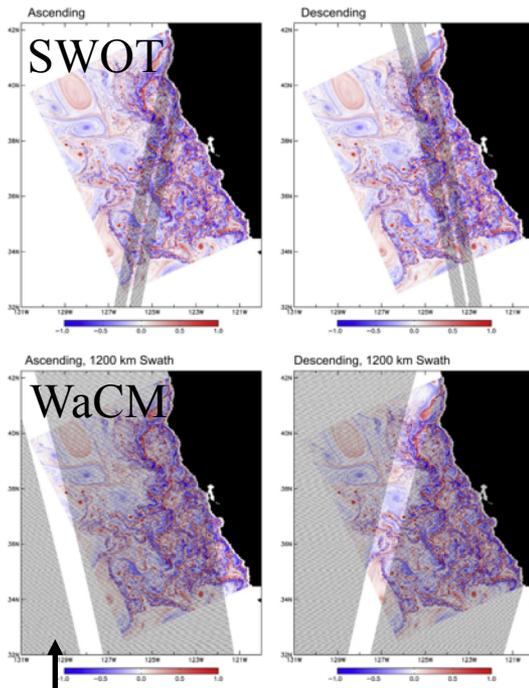
Wind-work done on the ocean.



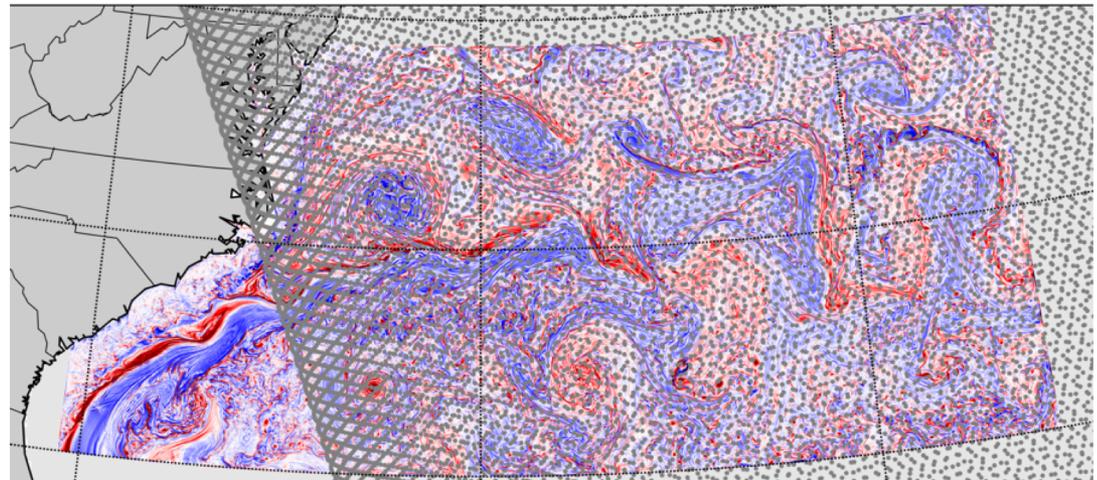
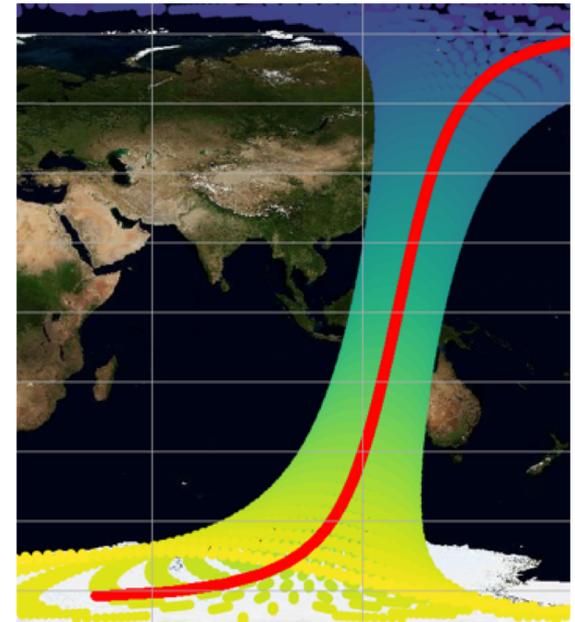
# WaCM Simulations

Now: Characterization of science potential and resolution:

- Much better sampling than SWOT or SKIM.
- WaCM is relatively noisy, but better sampling enables lower overall errors across filled regions.



Soon: High fidelity errors and realistic radar sampling.

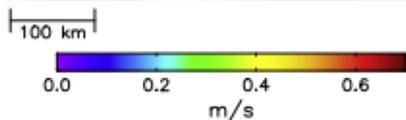
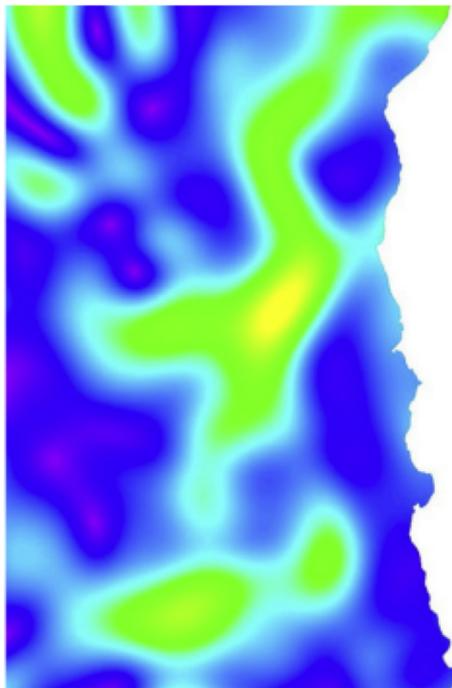




# WaCM Impact on Currents

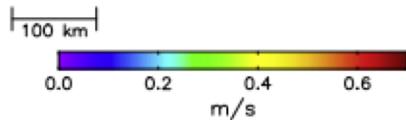
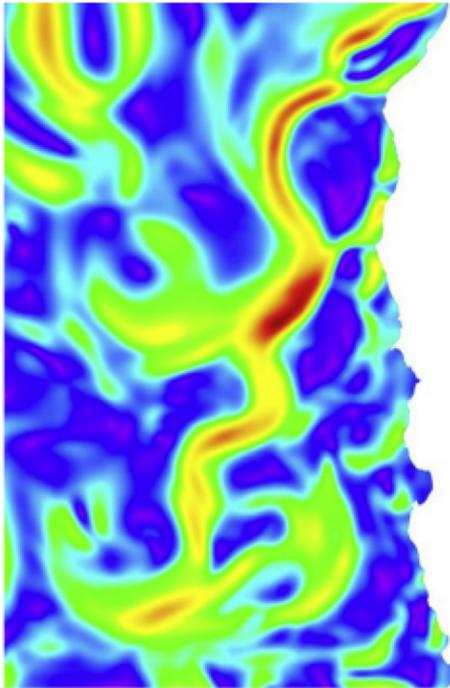
## SSH-Geostrophic

a) 30-Day Average  
with 200 km Filter Cutoff  
(AVISO)



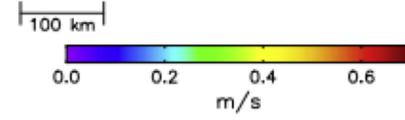
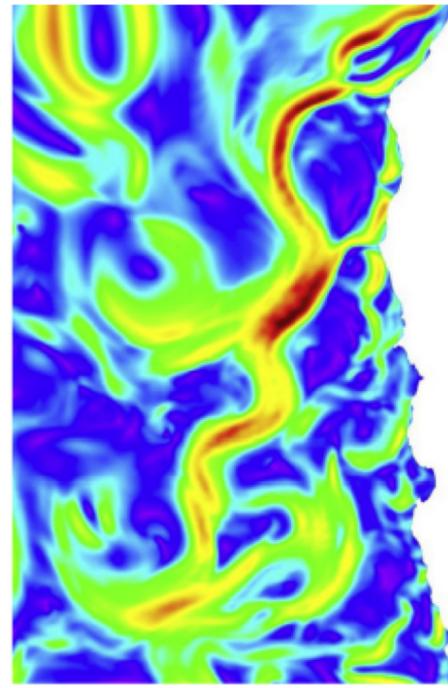
## WaCM

c) 4-Day Average  
with 45 km Filter Cutoff  
(1800 km swath, 0.50 m/s noise)



## WaCM

e) 4-Day Average  
with 20 km Filter Cutoff  
(1800 km swath, 0.25 m/s noise)

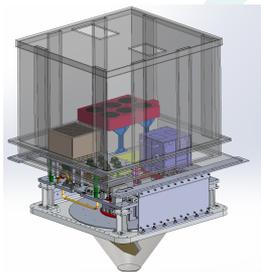
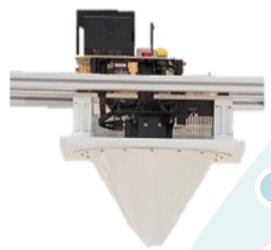
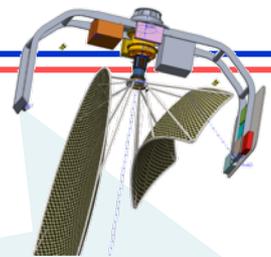
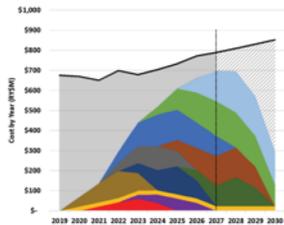
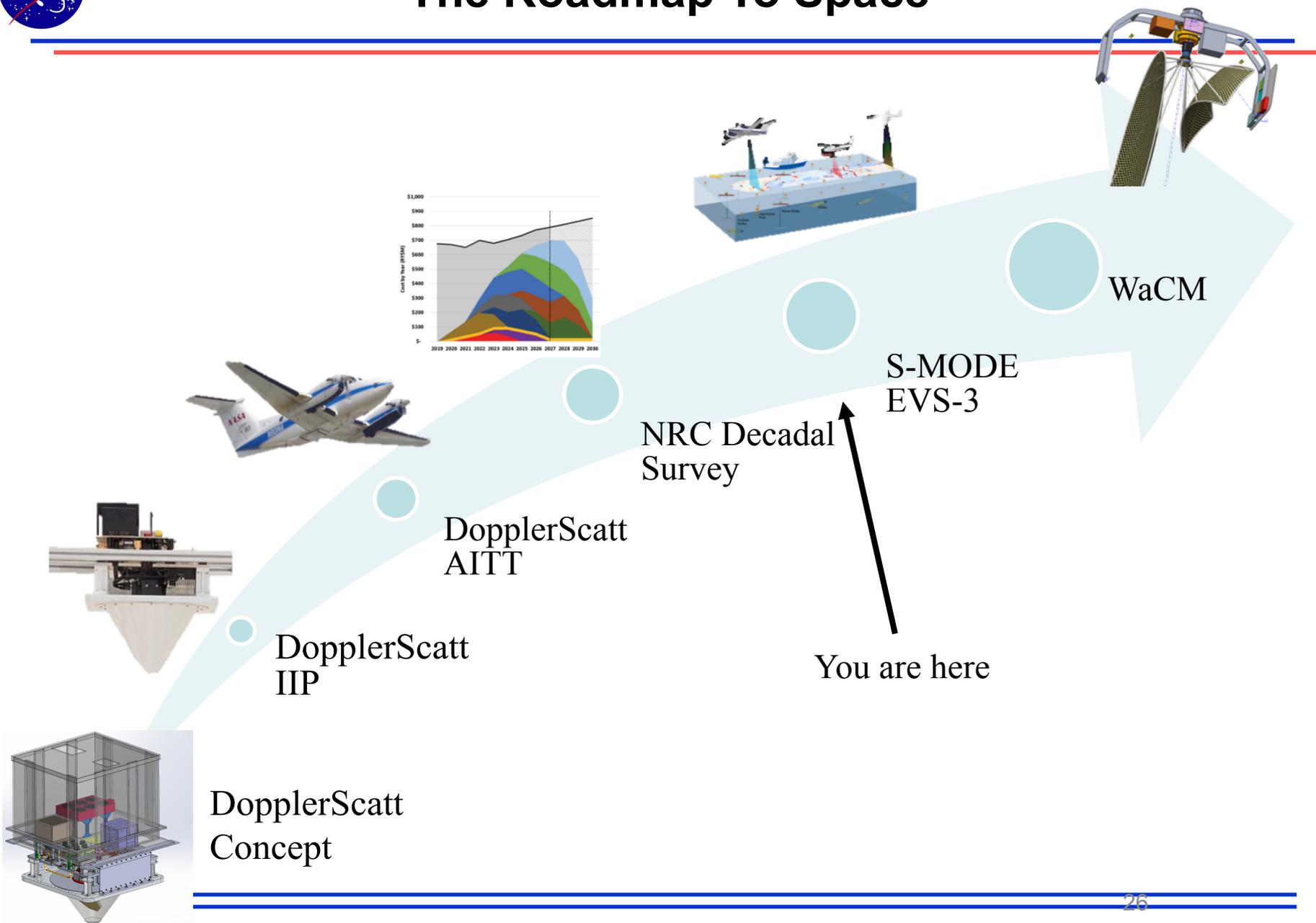


Chelton et. al. 2019, *Prospects for future satellite estimation of small-scale variability of ocean surface velocity and vorticity*





# The Roadmap To Space





# Thank you!

For more, see:

Rodríguez, E.; Wineteer, A.; Perkovic-Martin, D.; Gál, T.; Stiles, B.W.; Niamsuwan, N.; Rodriguez Monje, R. Estimating Ocean Vector Winds and Currents Using a Ka-Band Pencil-Beam Doppler Scatterometer. *Remote Sens.* **2018**, *10*, 576.

