The Sub-Mesoscale Ocean Dynamics Experiment (S-MODE)

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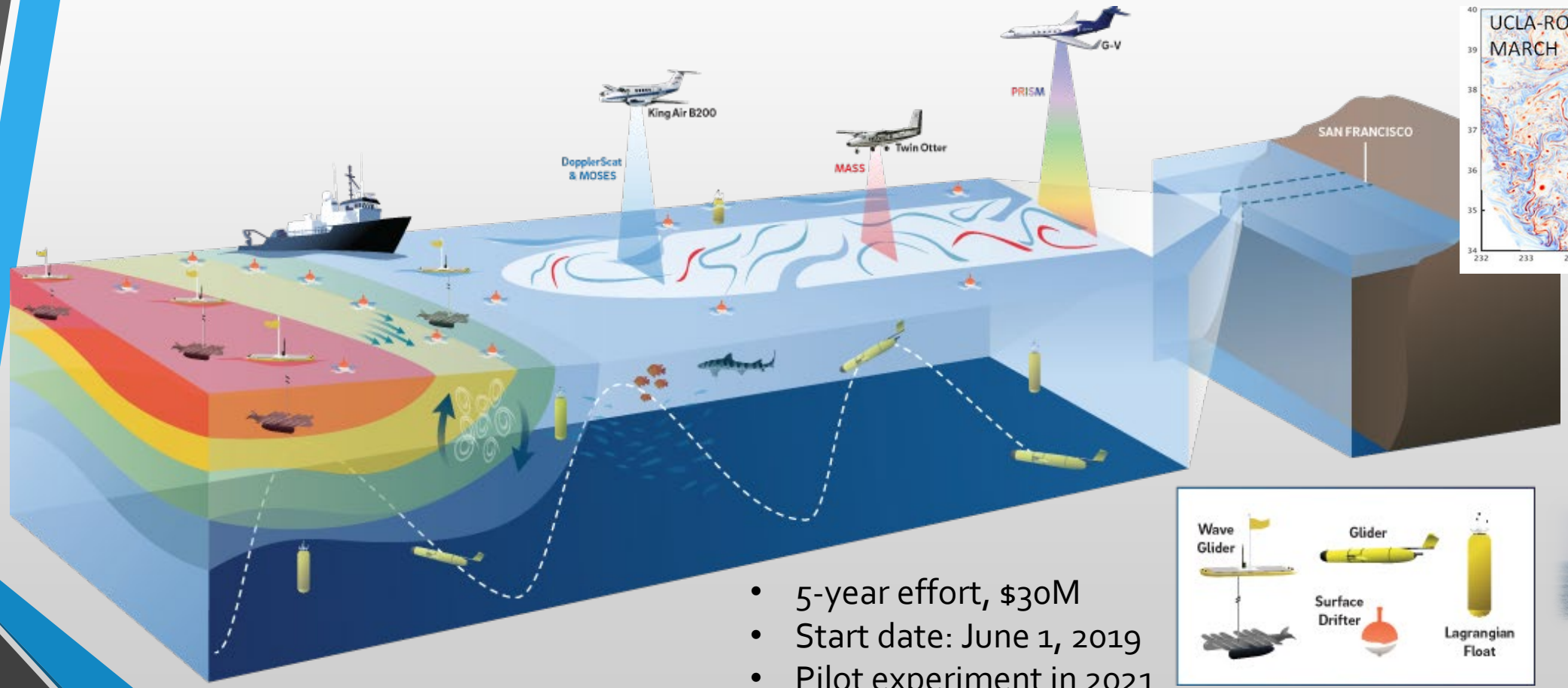
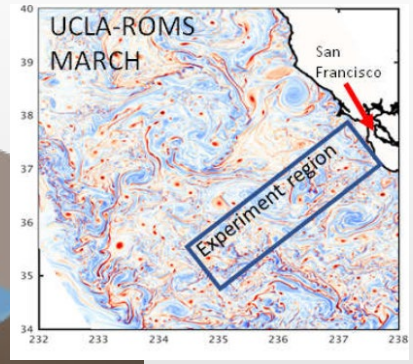
S-MODE Open Data Workshop,
1 December, 2022

The Sub-Mesoscale Ocean Dynamics Experiment (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.

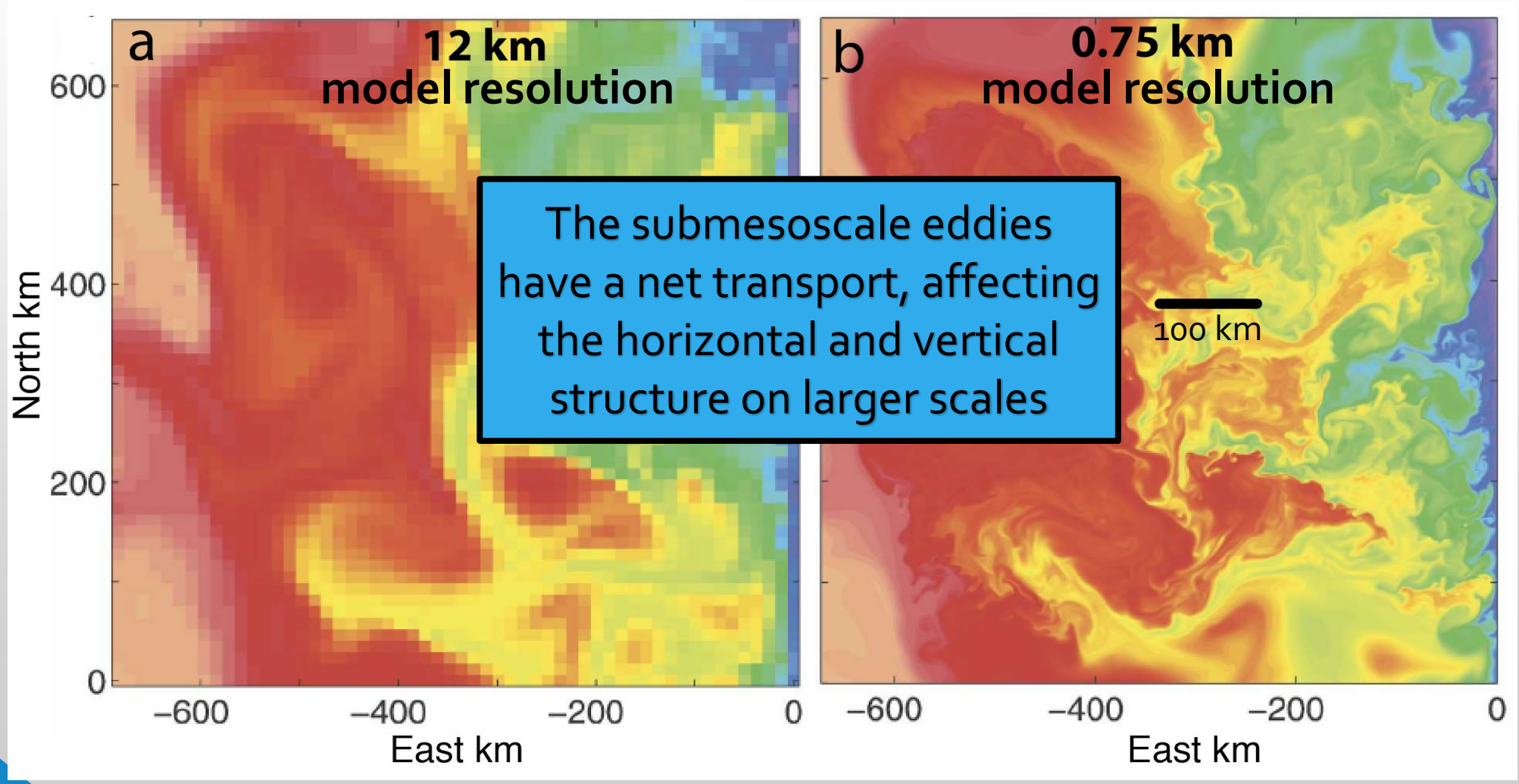




- 5-year effort, $30M
- Start date: June 1, 2019
- Pilot experiment in 2021
- Intense operations fall 2022/spring 2023

"Submesoscale" ocean eddies

Sea surface temperature in numerical ocean simulation

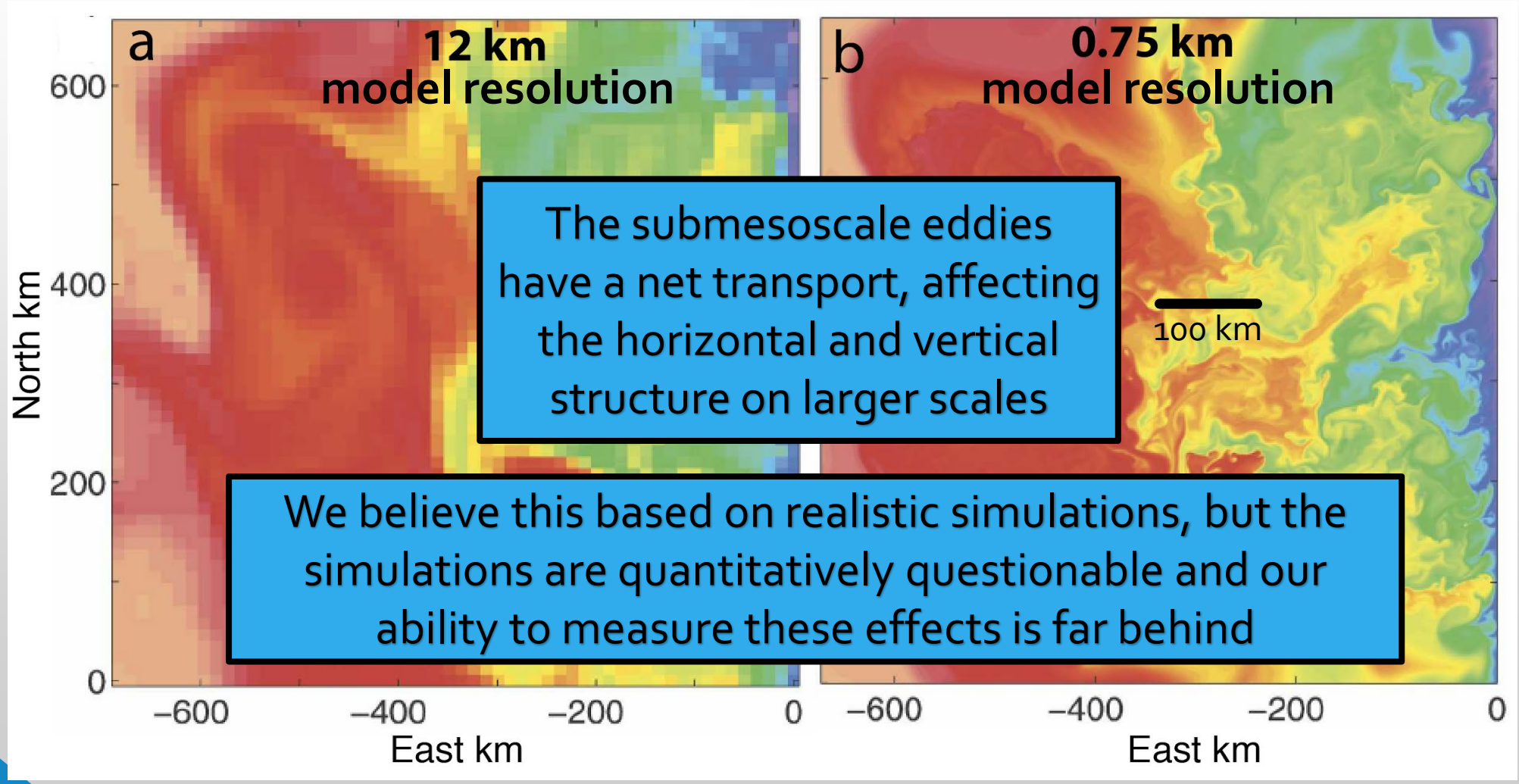


The submesoscale eddies have a net transport, affecting the horizontal and vertical structure on larger scales

Capet et al. (2008)

"Submesoscale" ocean eddies

Sea surface temperature in numerical ocean simulation

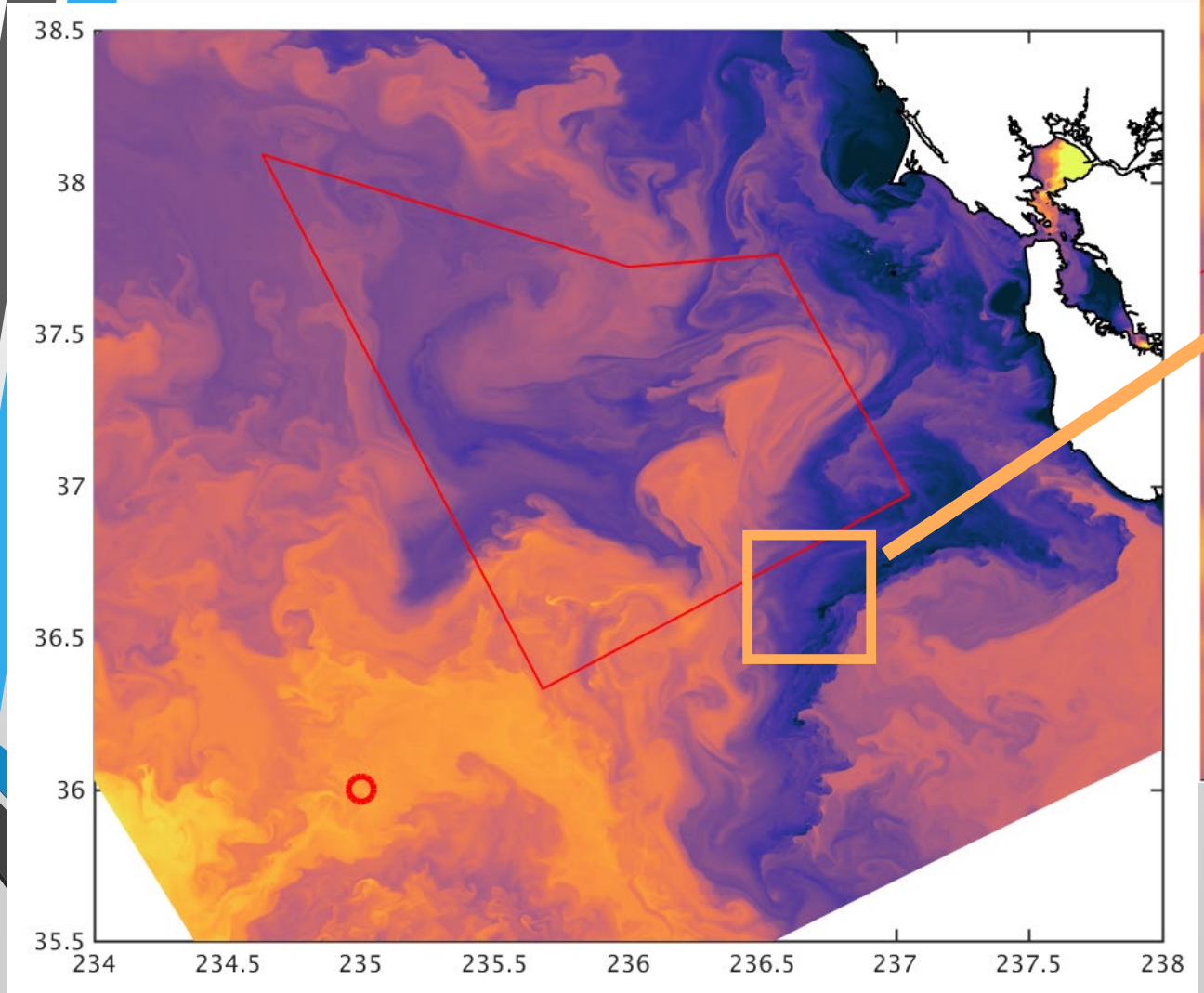


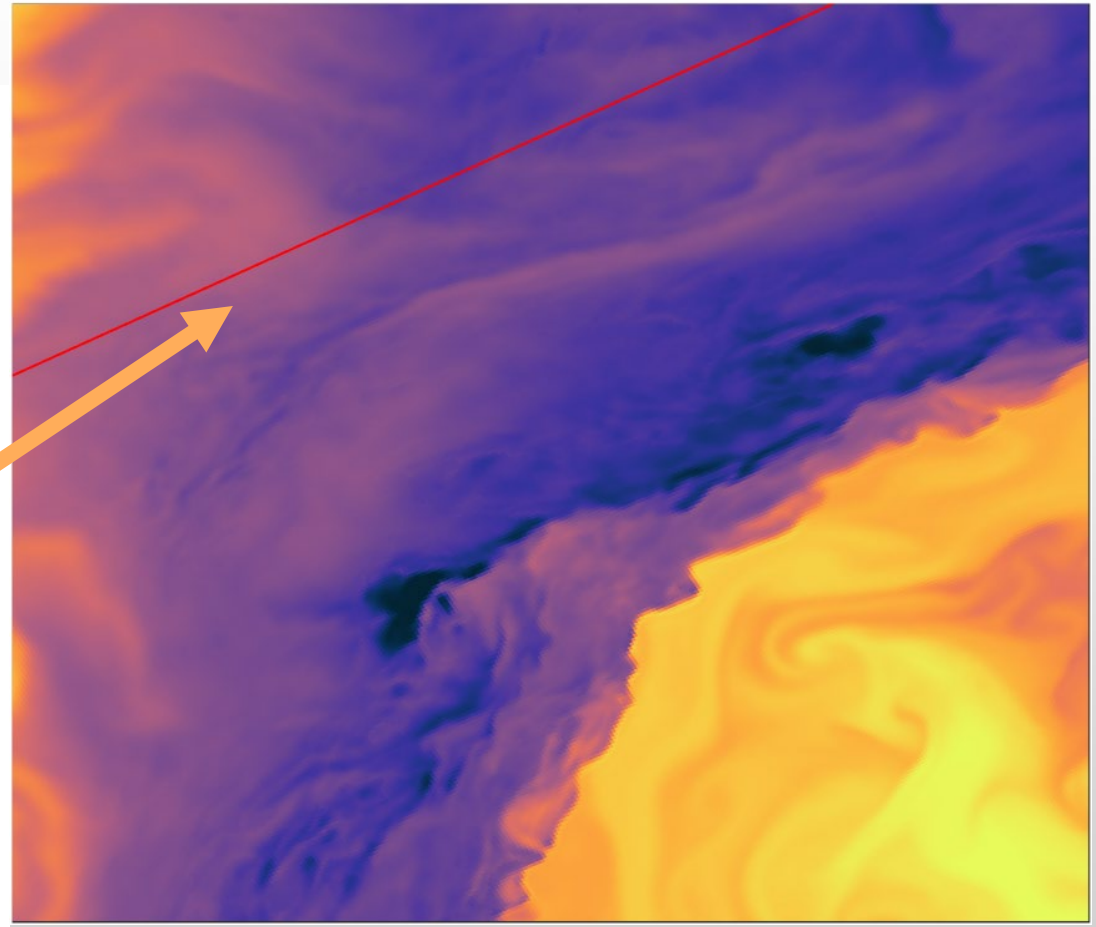
The submesoscale eddies have a net transport, affecting the horizontal and vertical structure on larger scales

We believe this based on realistic simulations, but the simulations are quantitatively questionable and our ability to measure these effects is far behind

Capet et al. (2008)

SST in 200-m UCLA ROMS simulation



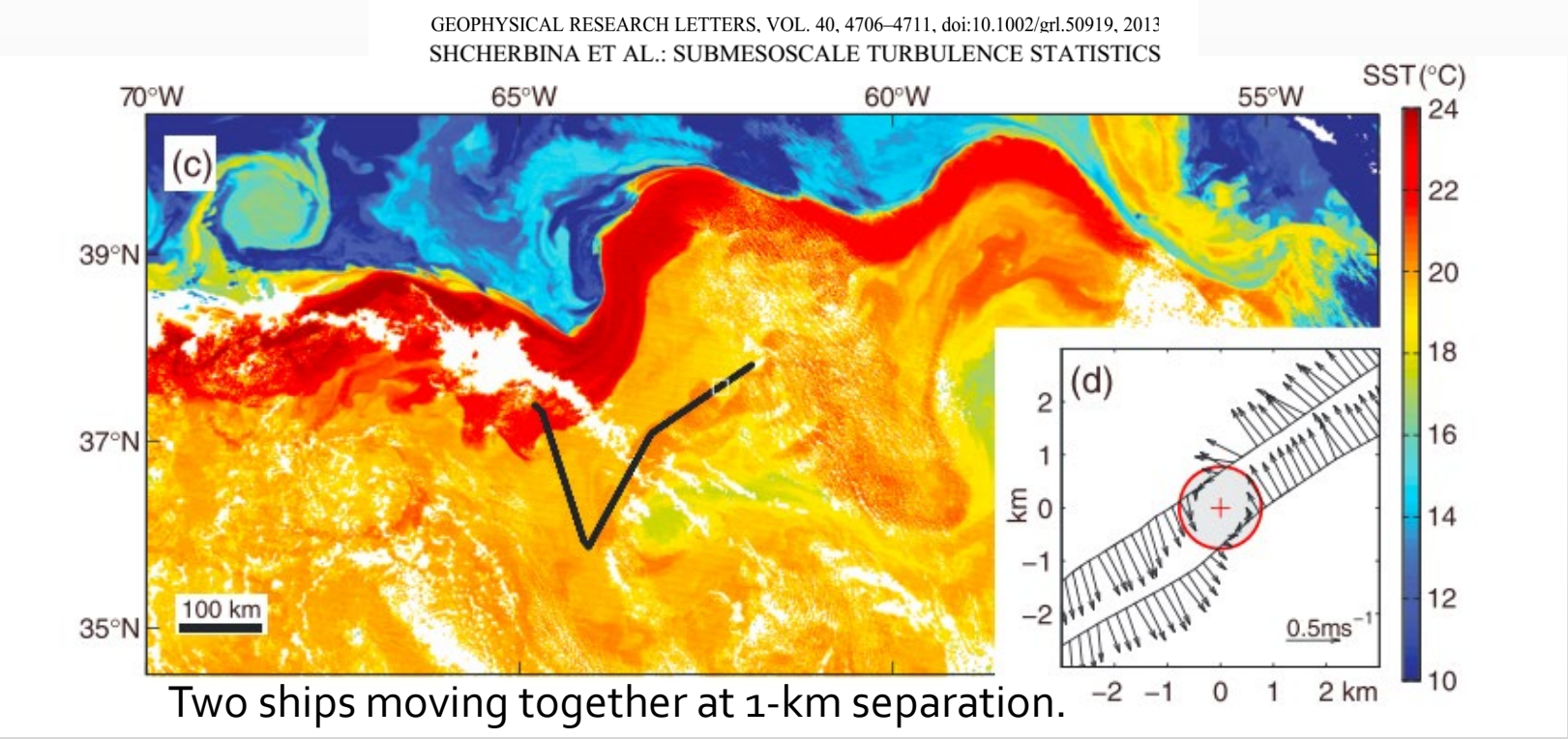


SST gradients as sharp as the grid allows…

(Figure: Jeroen Molemaker)

Observational state of the art for submesoscale velocity

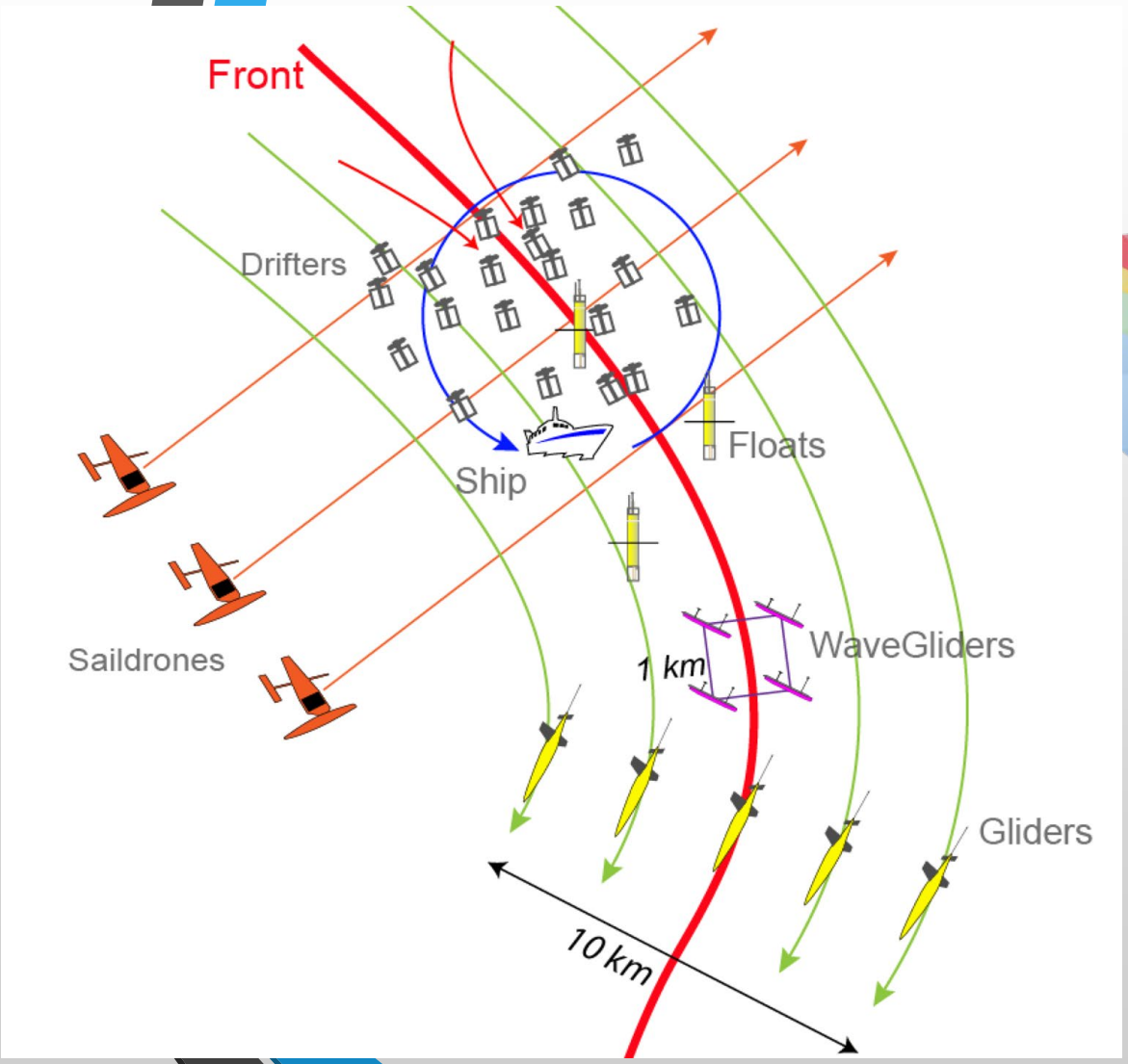
One of the benchmark studies of submesoscale variability was this 2-ship survey in the LatMix experiment, with two ships moving together at 1-km separation.

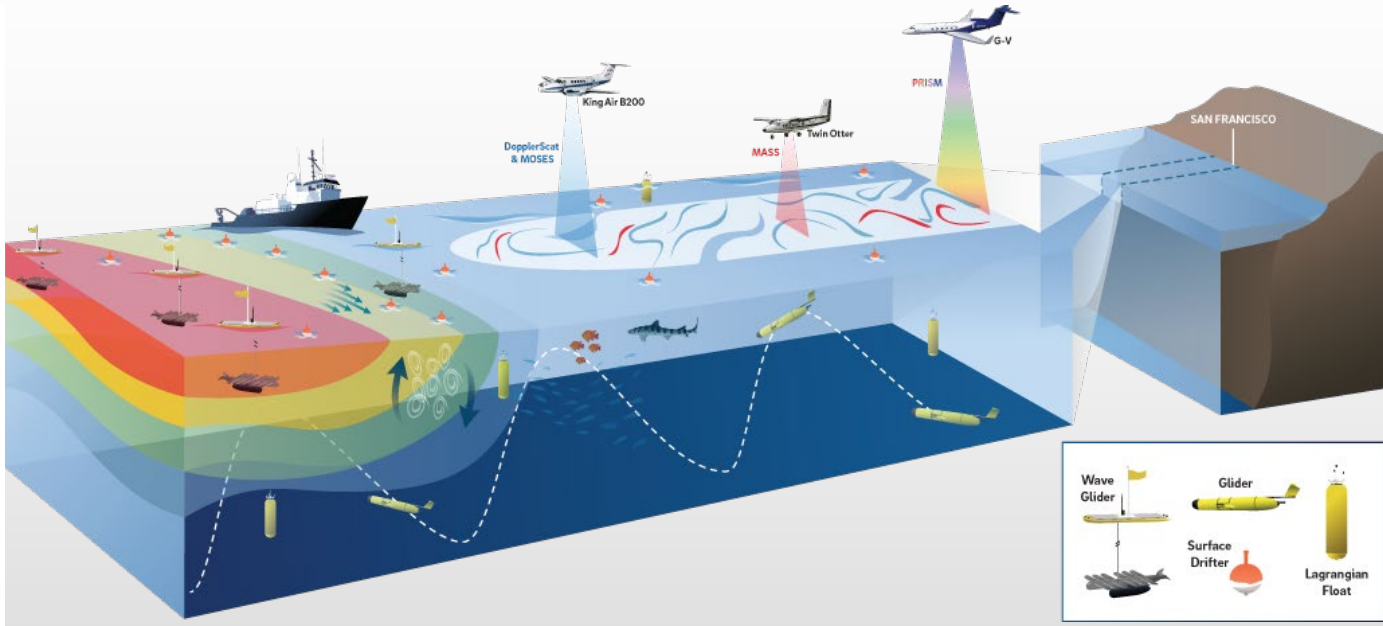


Two ships moving together at 1-km separation.

S-MODE should take us far beyond this, using a combination of aerial and autonomous in situ measurements.

Sampling Strategy





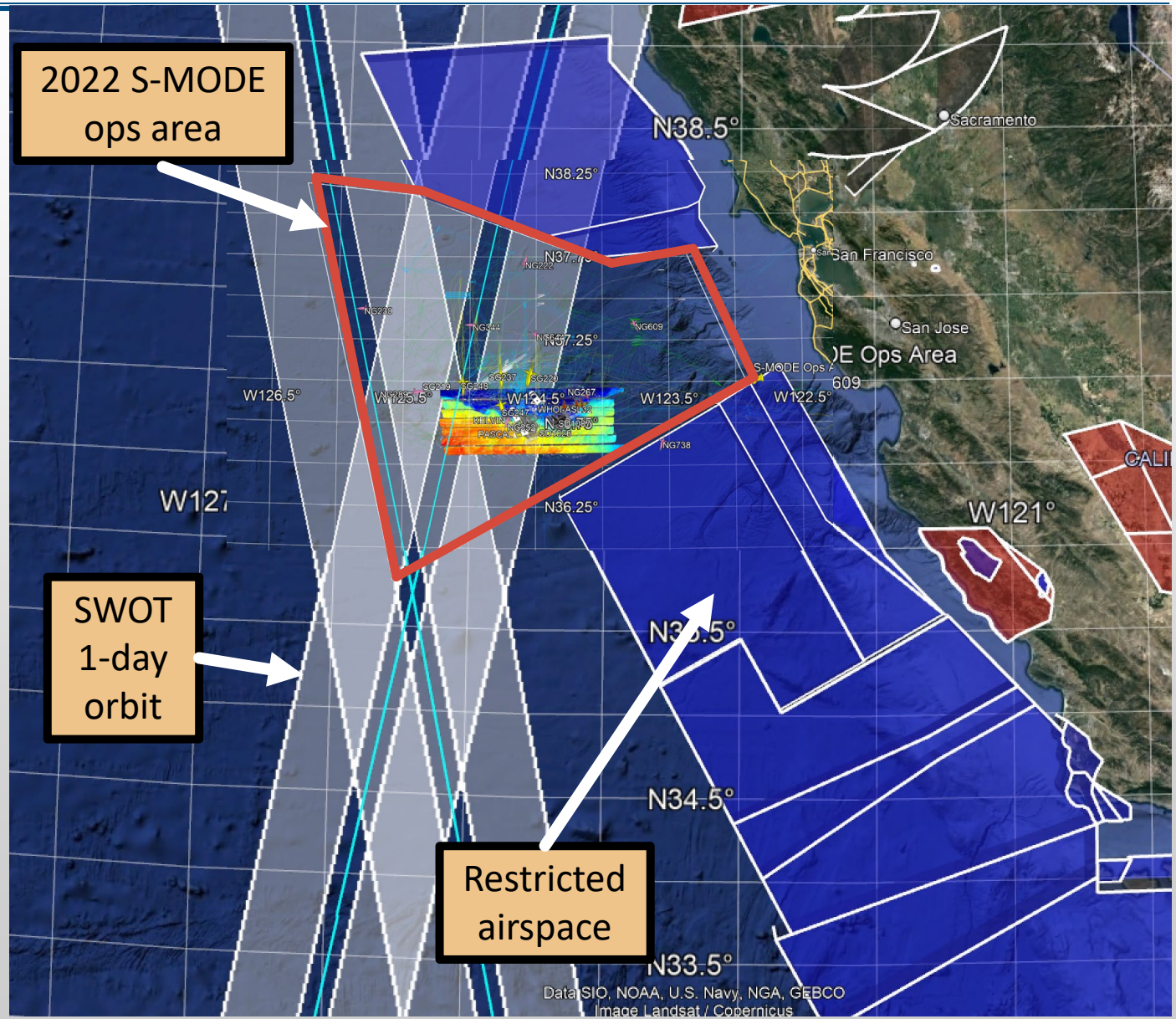
Focus on vertical velocity and gradients of horizontal velocity (vorticity and divergence)

Three campaigns:

- A smaller scale pilot campaign (done)
- Intensive operations period 1 (Fall 2022)
- Intensive operations period 2 (Spring 2023)

S-MODE: What, Where, When

- <u>What:</u> S-MODE involves many measurement platforms: 3 aircraft with remote sensing, ~30 autonomous platforms, ~100 drifters, research vessel
- <u>Where:</u> Area offshore of San Francisco, near SWOT cal/val crossover, constrained by:
  - restricted airspace
  - distance from shore
  - Need to be near ocean fronts
- <u>When:</u> 3 campaigns, "Pilot campaign" in Oct 2021, "Intensive Operations Periods" in Oct 2022 and April 2023



Why now?

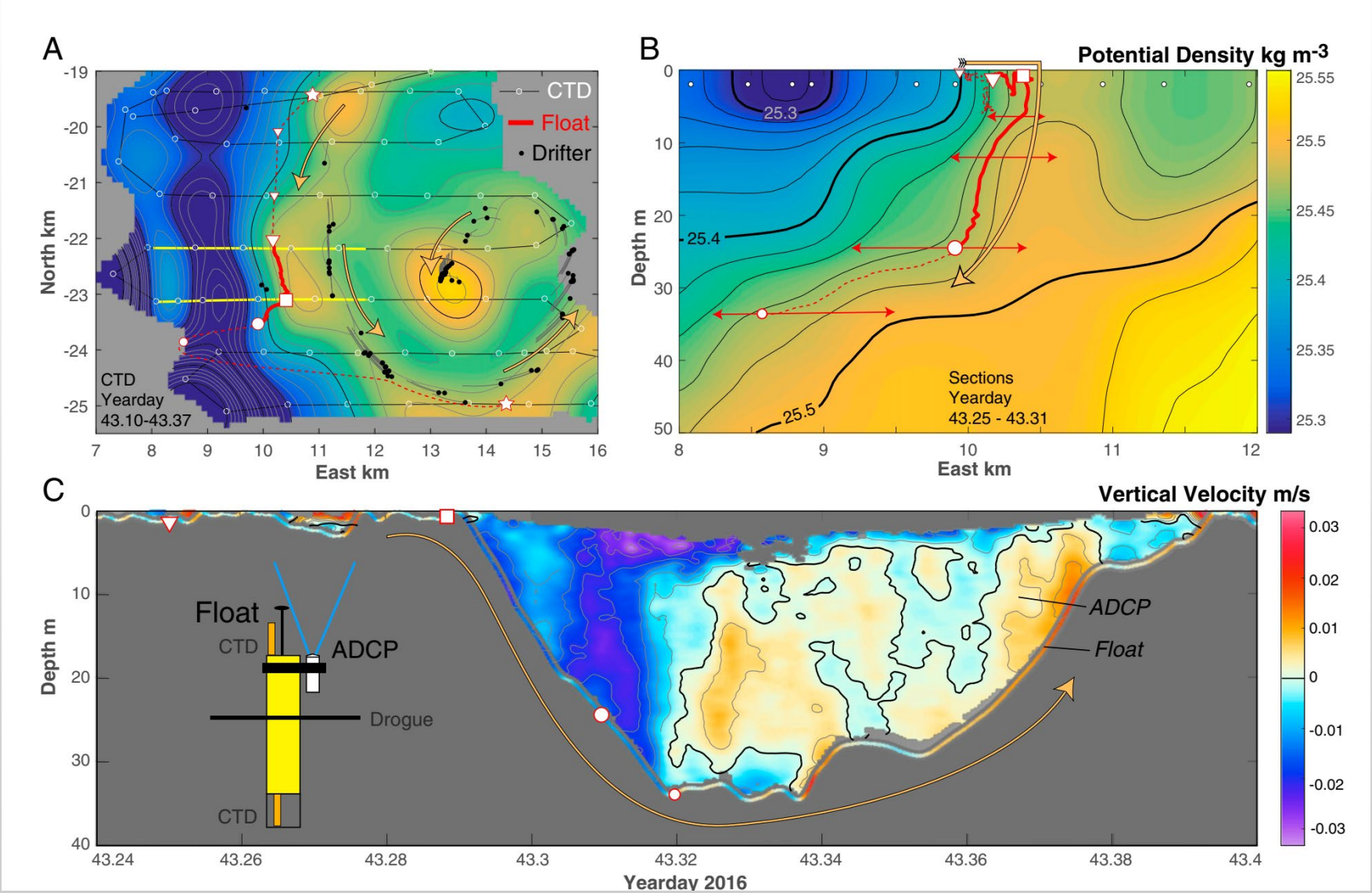
A combination of factors make this a good time to push ahead:

(1) Recent advances with ADCPs and in situ platforms allow measurement of vertical velocity

(2) Aircraft remote sensing measurements of surface currents

Direct measurements of vertical velocity

Lagrangian floats with modern ADCPs (D'Asaro et al., 2018).

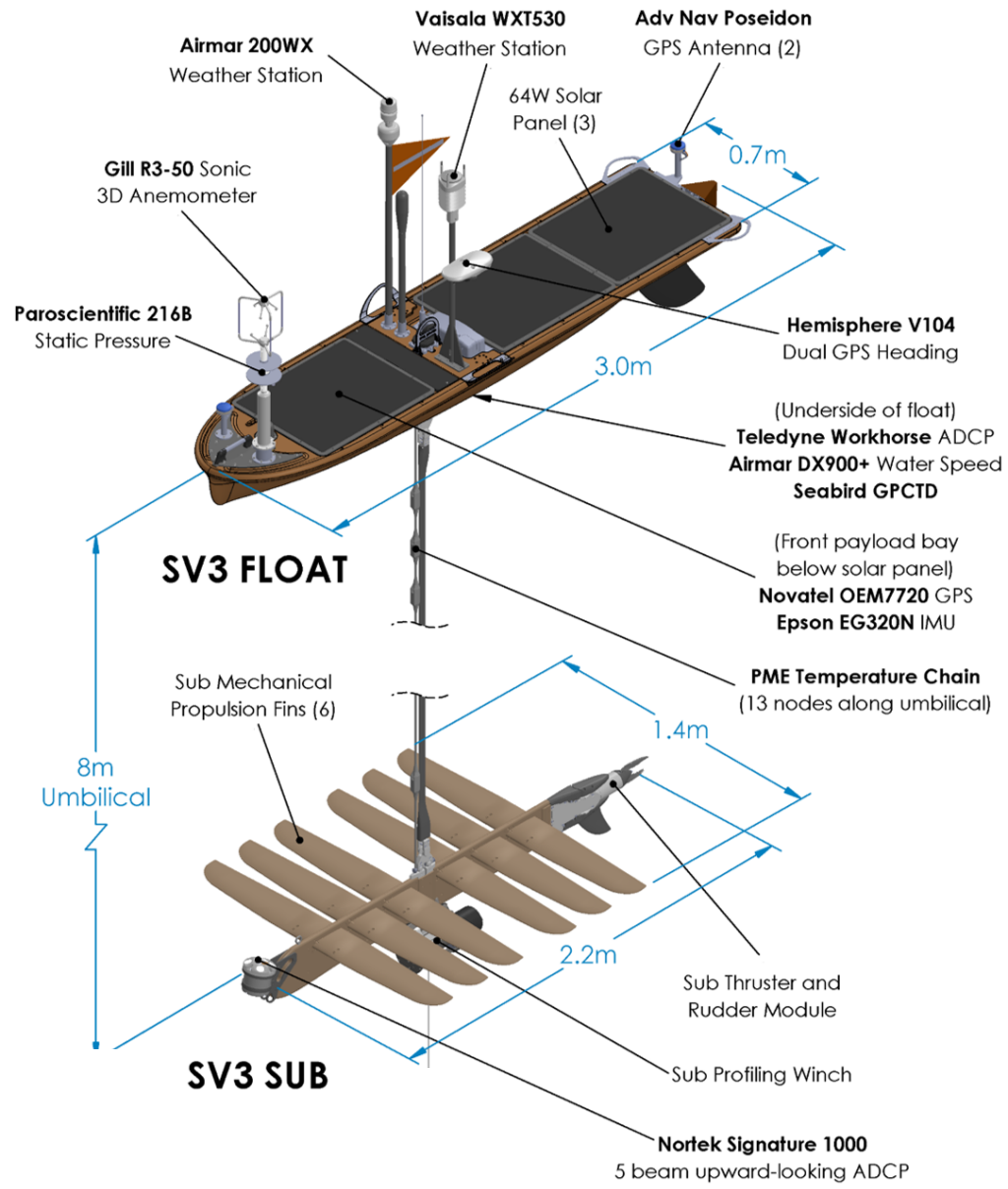


Autonomous platforms with ADCPs

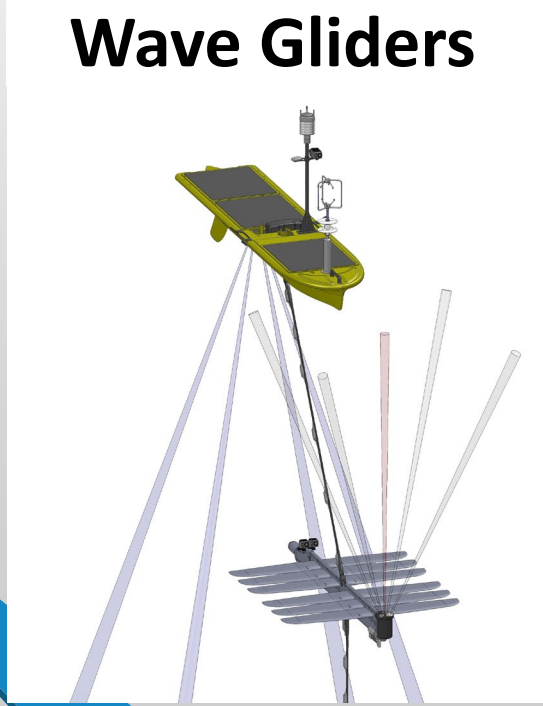
One example: Scripps Wave Gliders

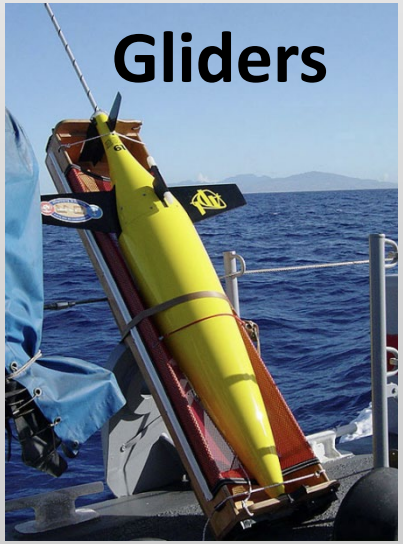
- Current profiles:
  - **Float downward ADCP**, *Teledyne Workhorse 300kHz*,
  - **Sub upward ADCP**, *Nortek Signature 1000*.
- Float position and movement: GPS/IMU, *Novatel OEM7720 + Epson EG320N*.
- Sub position, movement and pressure: IMU/pressure sensor, *Nortek Signature 1000*.

Grare et al., 2020; Hodges et al., in prep; Peyriere et al., in prep

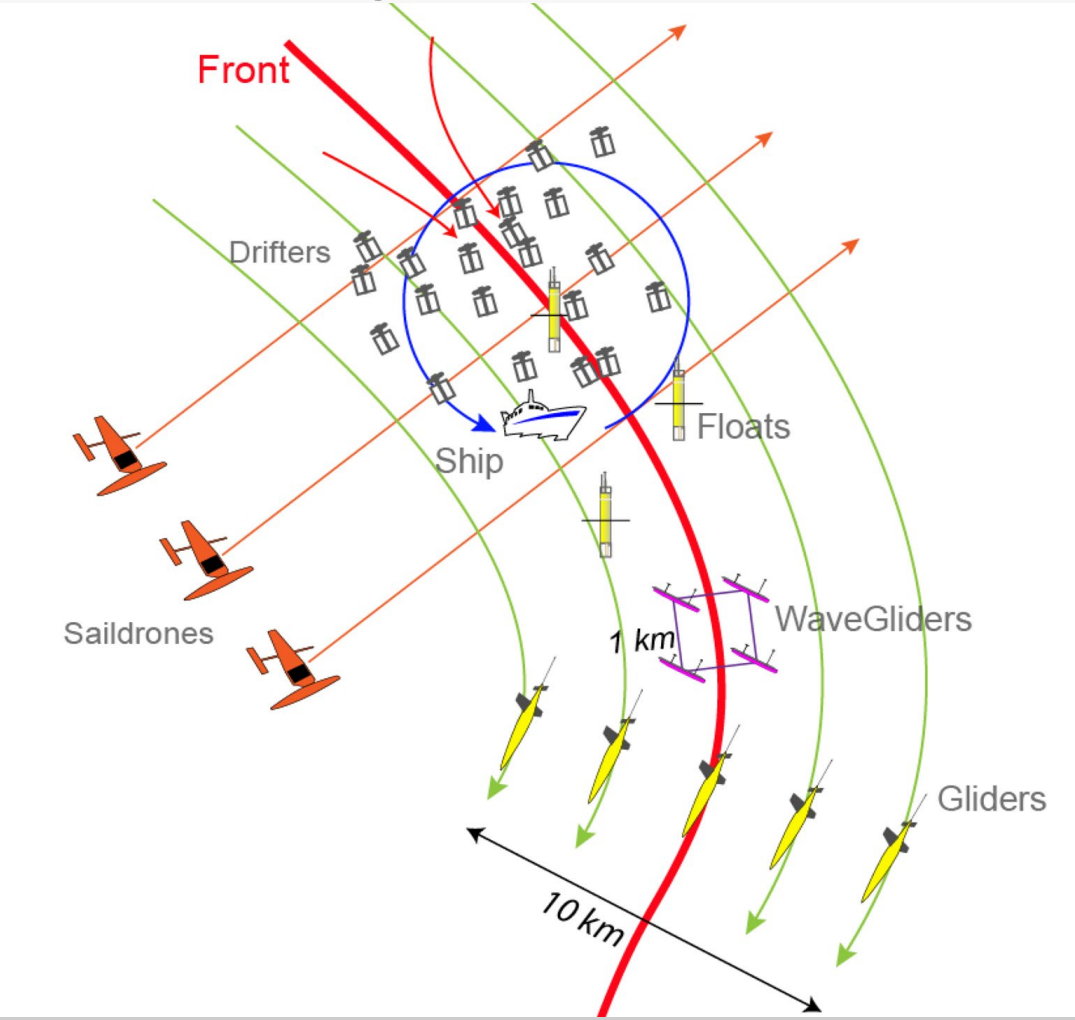


Autonomous platforms with ADCPs



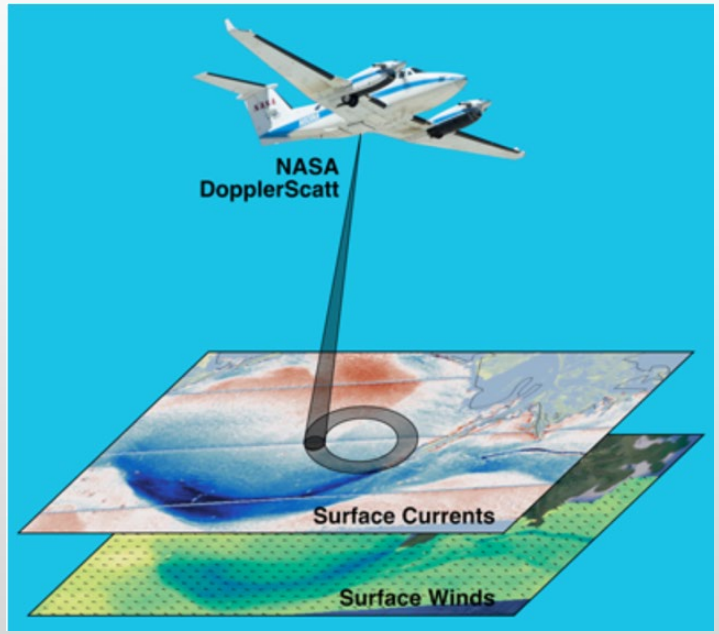


Operate in arrays to get horizontal divergence and infer *w*



Aircraft remote sensing measurements of surface currents, wind, SST, ocean color, waves

NASA JPL DopplerScatt with UCLA MOSES infrared imager

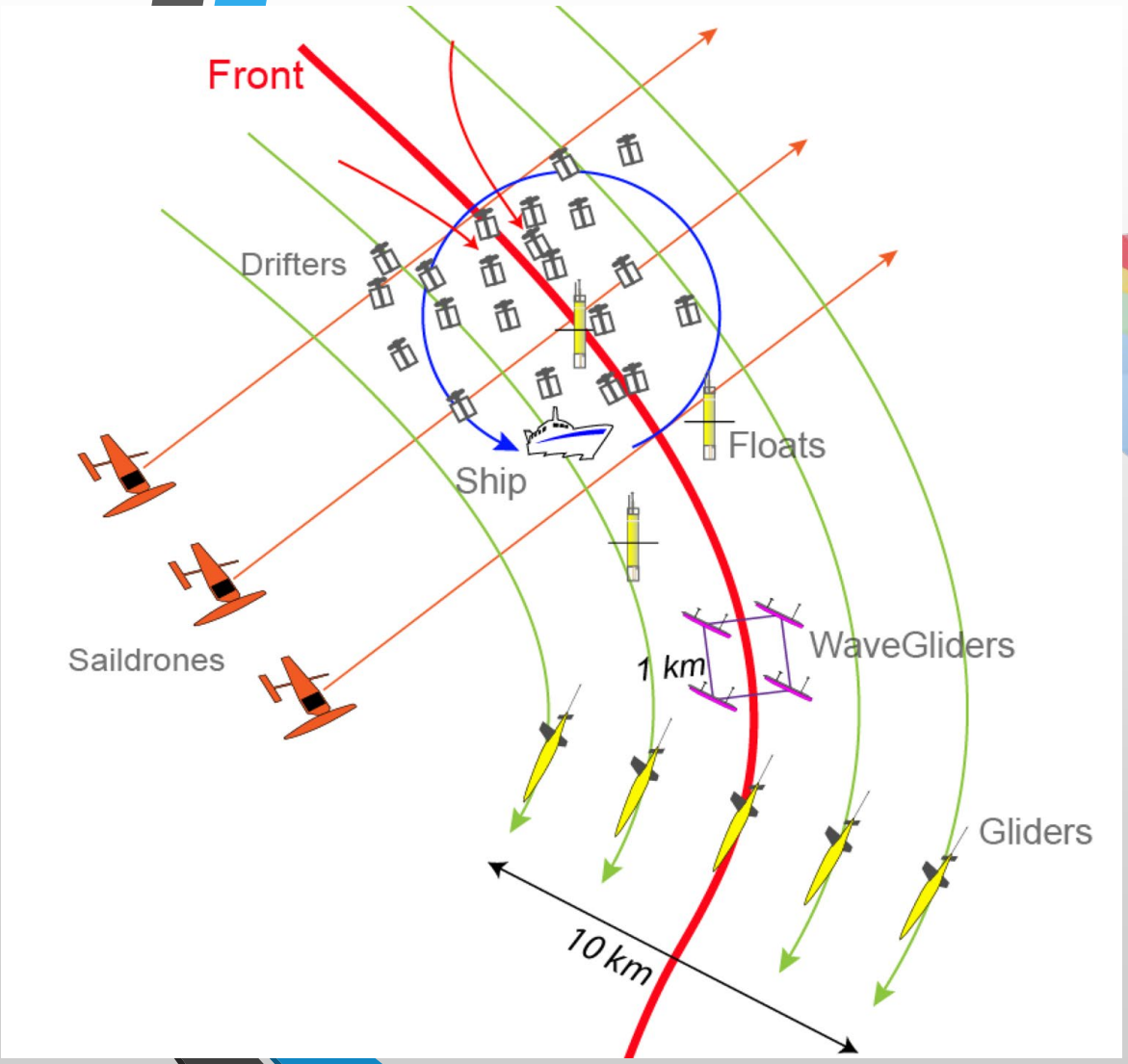


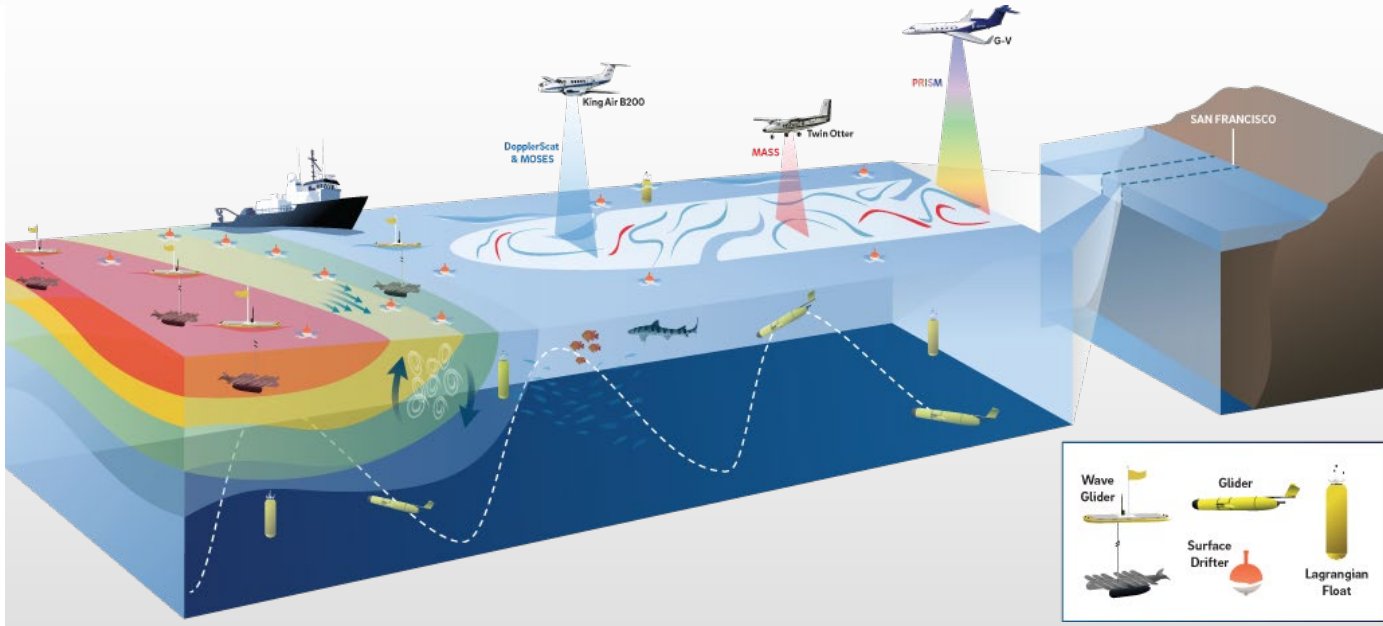
Scripps Modular Aerial Sensing System (MASS)

High-resolution instrumentation package built specifically for airborne remote sensing applications. Instrumentation includes an airborne topographic lidar integrated with video, infrared, and hyperspectral imaging systems.

NASA JPL Portable Remote Imaging Spectrometer (PRISM)

Sampling Strategy





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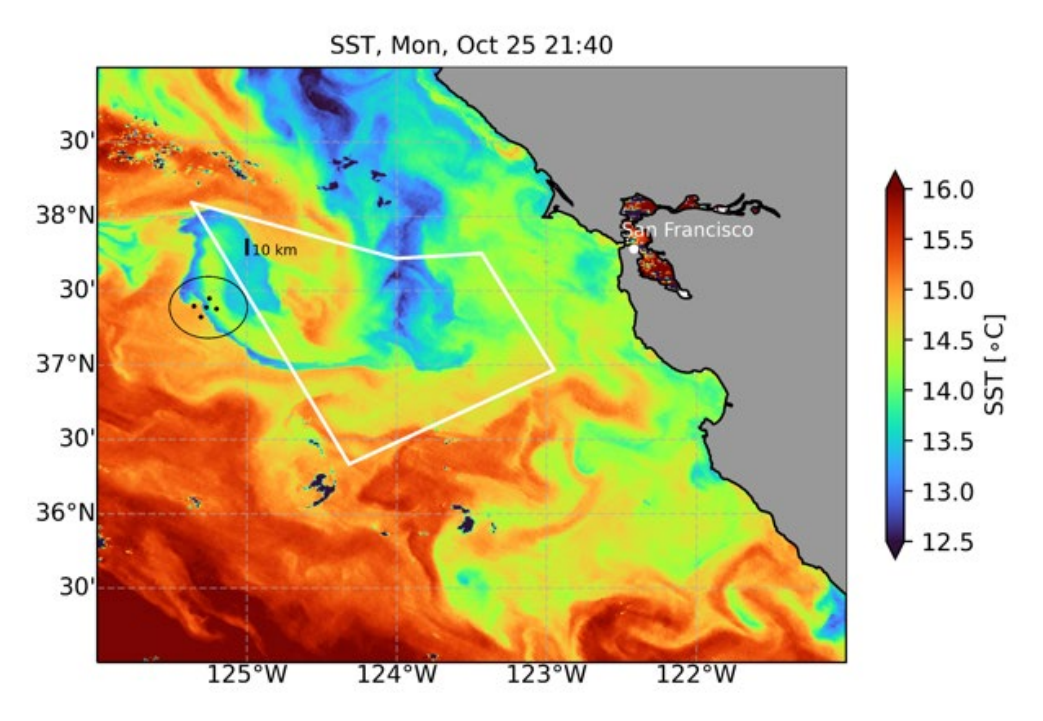
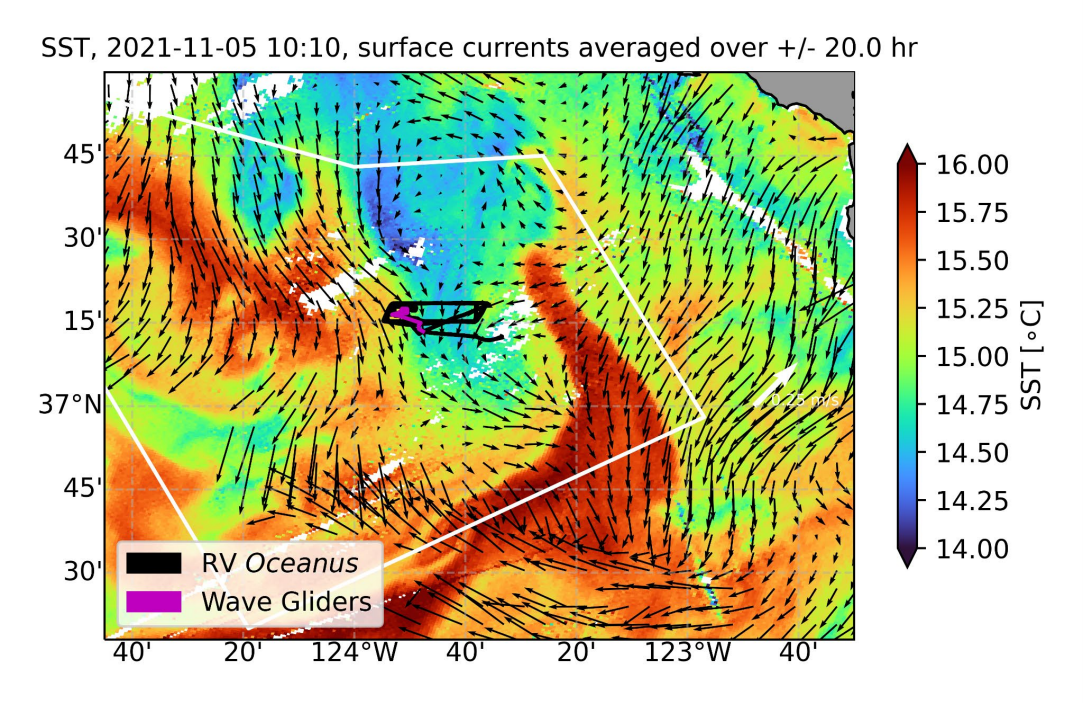
- Intensive operations period 1 (done Oct 2022)
- Intensive operations period 2 (Spring 2023)

Focal points in pilot campaign

Frontal survey



"Velocity extravaganza"



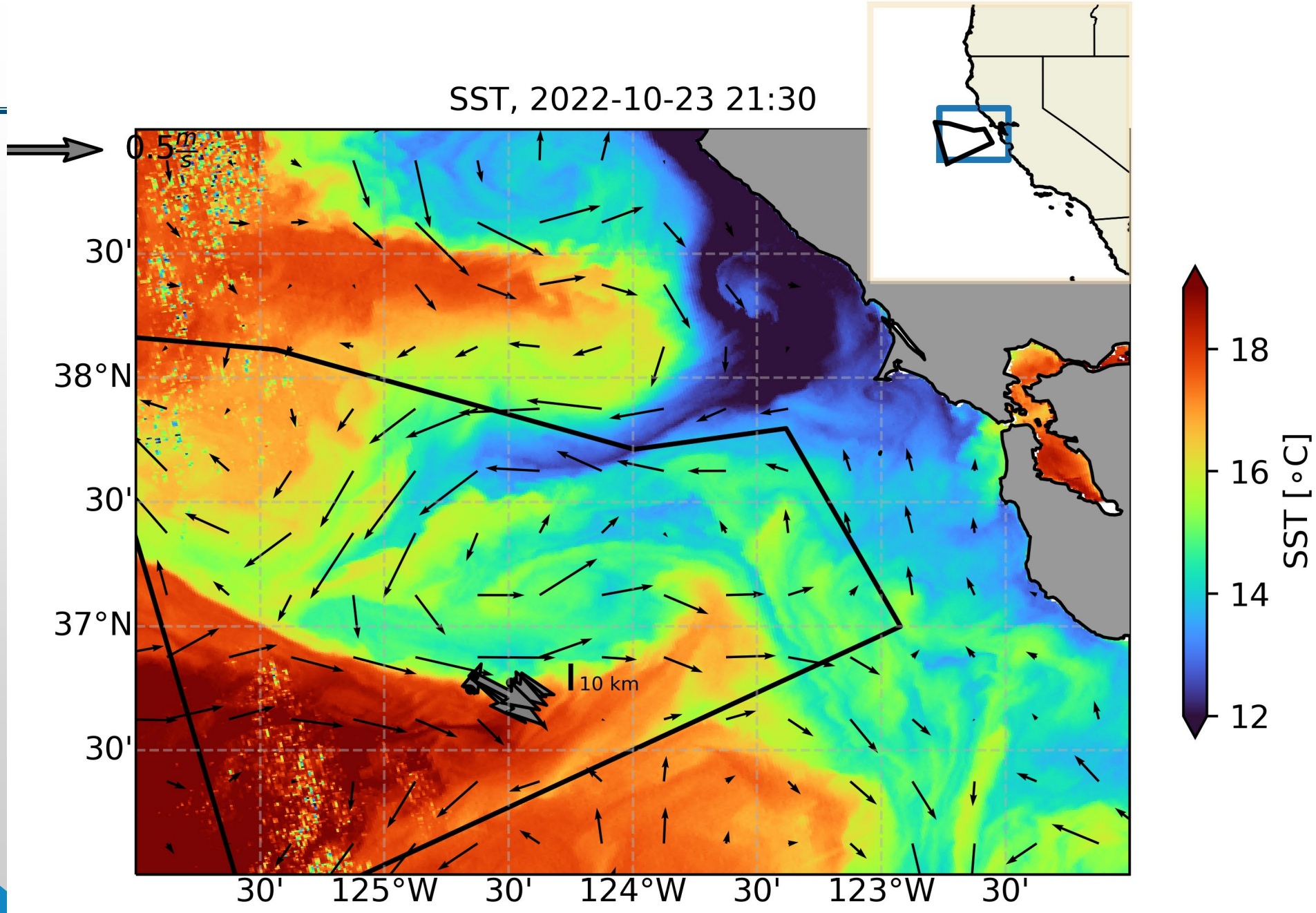
S-MODE Pilot Campaign Data

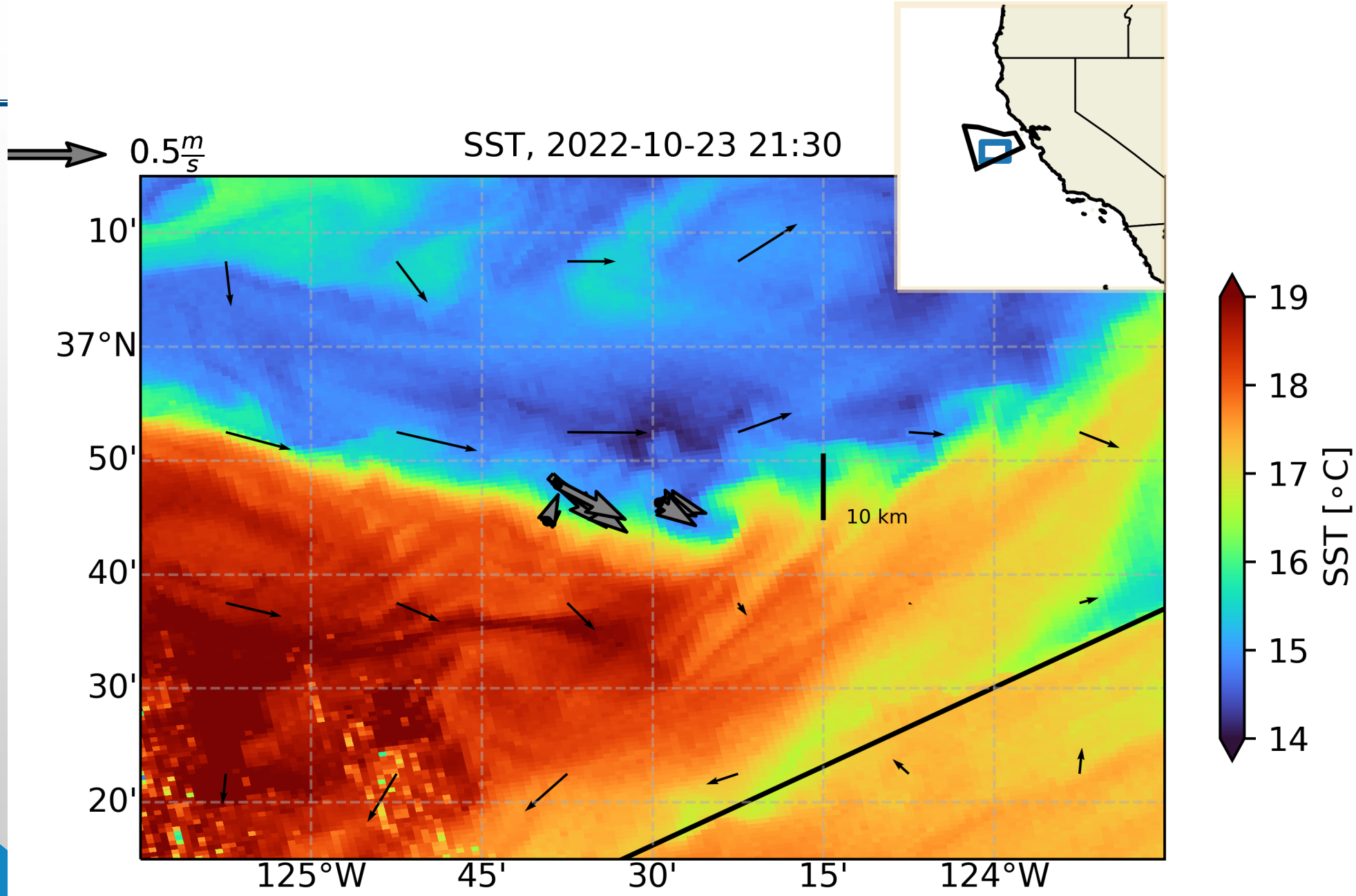
Shipboard Acoustic Doppler Current Profiler Measurements Version 1
Shipboard Bottle Data Version 1
Conductivity, Temperature, and Depth Measurements Version 1
Shipboard SUNA nitrate data Version 1
Shipboard Thermosalinograph and Meteorology Measurements Version 1
Meteorological Data from Rawinsondes Version 1
Shipboard Radiometer Measurements Version 1
Shipboard uCTD and EcoCTD Measurements Version 1
Position Data from Surface Drifters Version 1
Temperature and Salinity from Saildrones Version 1
Temperature and Salinity from Slocum Gliders Version 1
DopplerScatt Level 2 Ocean Winds and Currents Version 1

Coming soon:
MASS: georeferenced visible, hyperspectral, infrared and lidar data (L1)
MOSES infrared imagery
Wave Gliders: surface wave directional spectra, surface meteorology, ADCP currents, surface CTD

2022 & 2023 Intensive Operations Periods (IOPs)

- 6 gliders with ADCPs (UW/APL)
- ~10 gliders with only CTDs (NAVO)
- 8 Wave Gliders with ADCPs
- ~4 Saildrones with ADCPs
- Research vessel with ADCP and underway CTD
- ~75 drifters
- MASS lidar, infrared, visible, hyperspectral (Twin Otter)
- DopplerScatt & MOSES infrared (B200)
- PRISM hyperspectral (Gulfstream III)
- Many other measurements (bio-optics, atmospheric)


SST, 2022-10-23 21:30
0.5 m/s
10 km
30'
38°N
30'
37°N
30'
30'
125°W
30'
124°W
30'
123°W
30'
18
16
14
12
SST [°C]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10'
37°N
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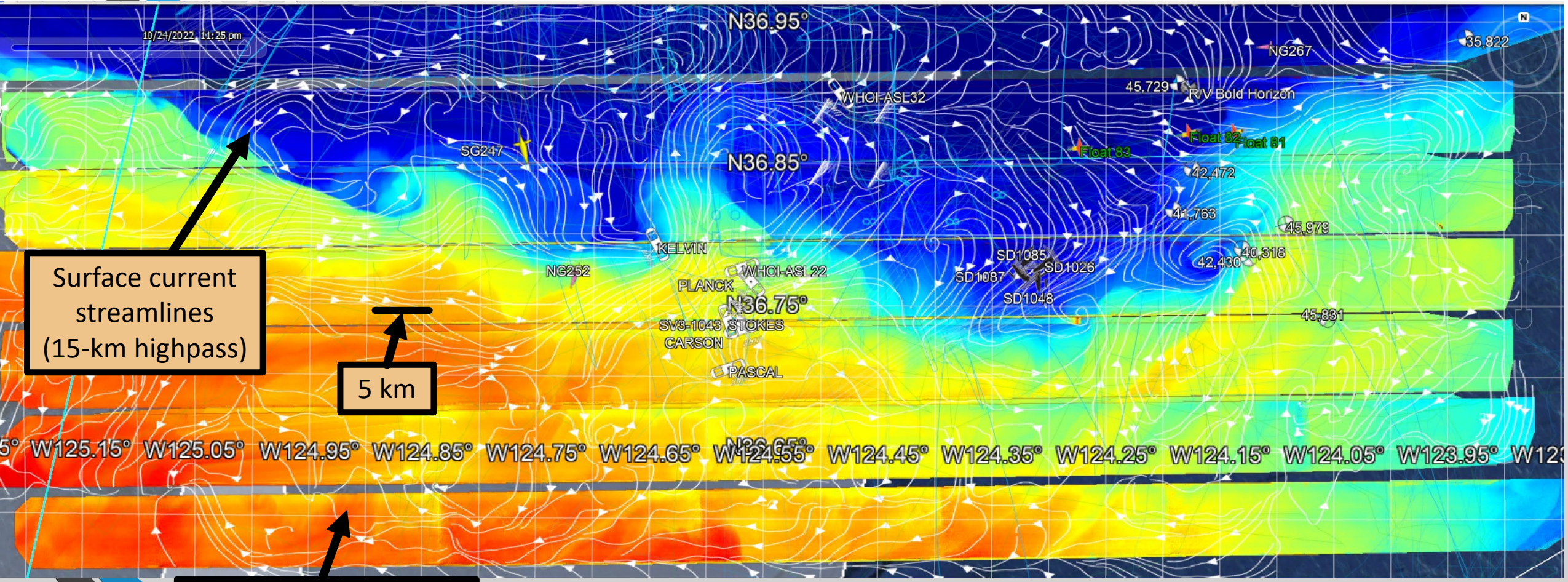
40'
30'
20'
125°W
45'
30'
15'
124°W
10 km
19
18
17
16
15
14
SST [°C]

SST with DopplerScatt surface current streamlines



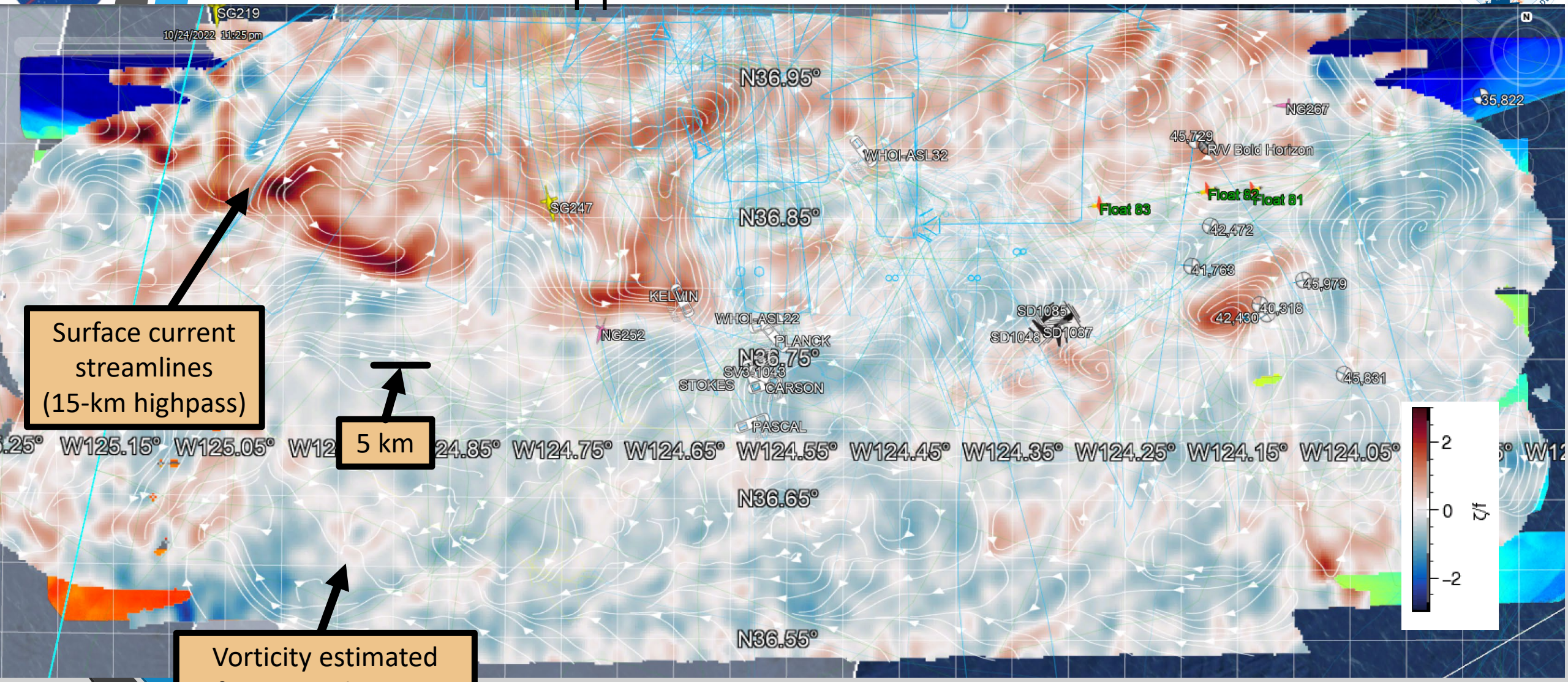
Surface current streamlines (15-km highpass)

5 km

SST from IR imager on aircraft

SST: Jeroen Molemaker (UCLA)
DopplerScatt: Ernesto Rodriguez (JPL)

SST with DopplerScatt surface current streamlines



Surface current streamlines (15-km highpass)

Vorticity estimated from DopplerScatt

DopplerScatt: Ernesto Rodriguez (JPL)

NASA/S-MODE Open Data Policy

- All of the data will be made freely available
- Data to be transferred to NASA data center (PO.DAAC) within 6 months of collection
- NASA and the S-MODE team want you to use the data!

- These state-of-the-art instruments have limitations, and all users are encouraged to interact with the data producers (contact info in data file metadata fields)

Conclusions

- Data from 2021 pilot campaign are on PO.DAAC now; all are welcome to use them
- Data from the 2022 campaign will be available soon
- The final campaign will be in April 2023

- Data users are encouraged to interact with data producers