The S-MODE campaign near the SWOT California crossover

Tom Farrar and Iury Simoes-Souza

…and SWOT ST members Ernesto Rodriguez, Luc Rainville, Patrice Klein, Luc Lenain, Audrey Delpech, Bia Villas Boas…

…and Eric D’Asaro, Andrey Shcherbina, Alex Wineteer, Jeroen Molemaker, Mara Freilich, Delphine Hypolite, Hector Torres, Cesar Rocha, Amala Mahadevan, Hugo Peyrière, Luke Colosi, Dudley Chelton, Michelle Gierach, Craig Lee, Jim McWilliams, Dimitris Menemenlis, Melissa Omand, Larry O'Neill, Dragana Perkovic-Martin, Roger Samelson, David Thompson, Jacob Wenegrat, Andy Thompson and many others

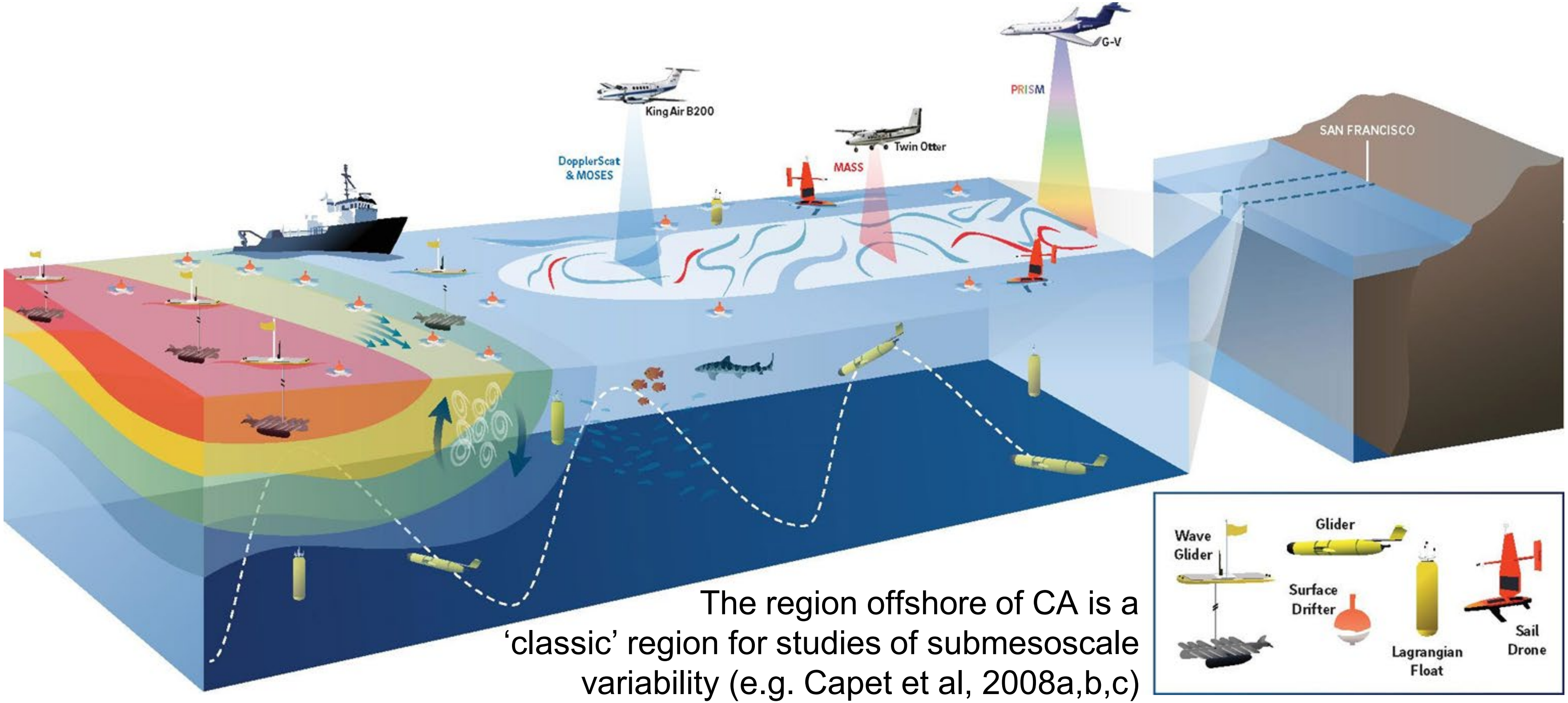
SWOT ST meeting, 19 Sept 2023

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

- NASA Earth Venture Suborbital Investigation, $30M
- Large multi-institutional field campaign studying the role of “submesoscale” (~1-10 km scale) ocean dynamics in vertical exchange in the upper ocean
- 3 campaigns:
  - Three ~25-day field campaigns (Oct 2021, Oct 2022 and April 2023)
  - Study region near California crossover
  - 3 aircraft with remote sensing measurements, Saildrones, Wave Gliders, drifters, and subsurface ocean gliders

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

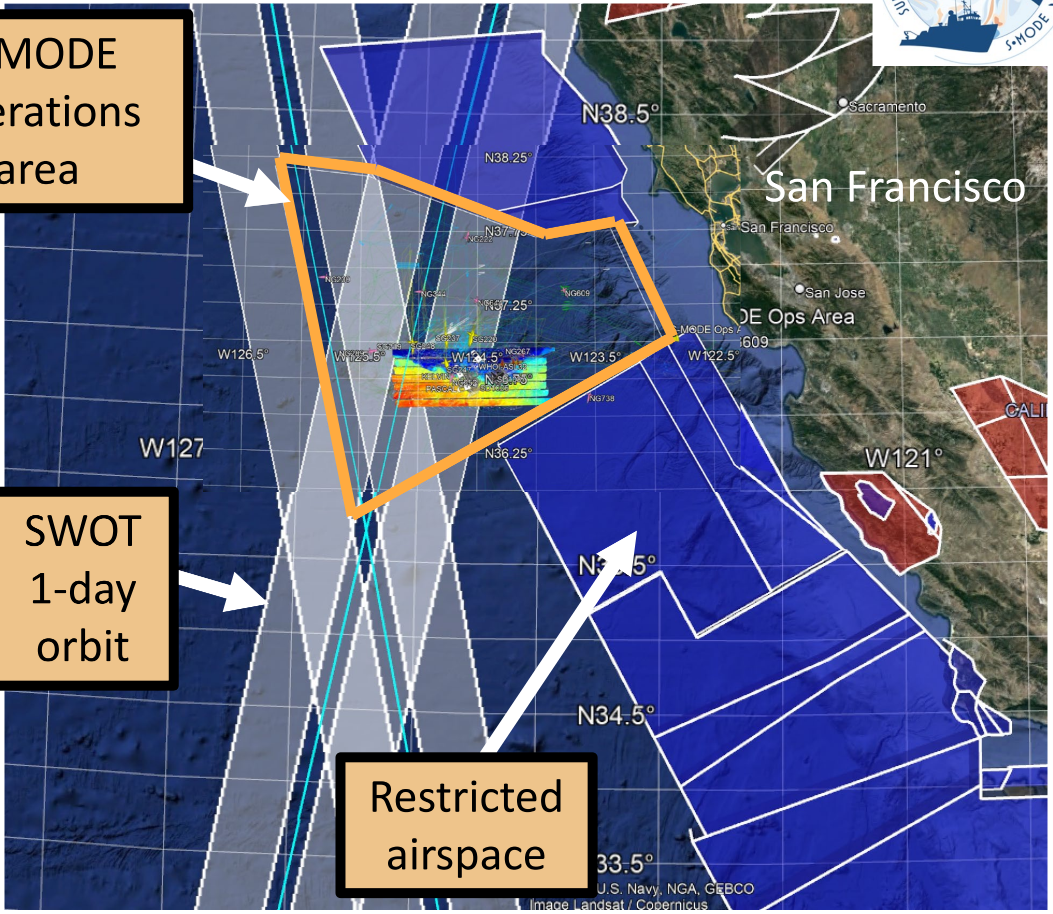
<u>Science:</u> Test the hypothesis that kilometer-scale ("submesoscale") ocean eddies make important contributions to vertical exchange of climate and biological variables in the upper ocean.



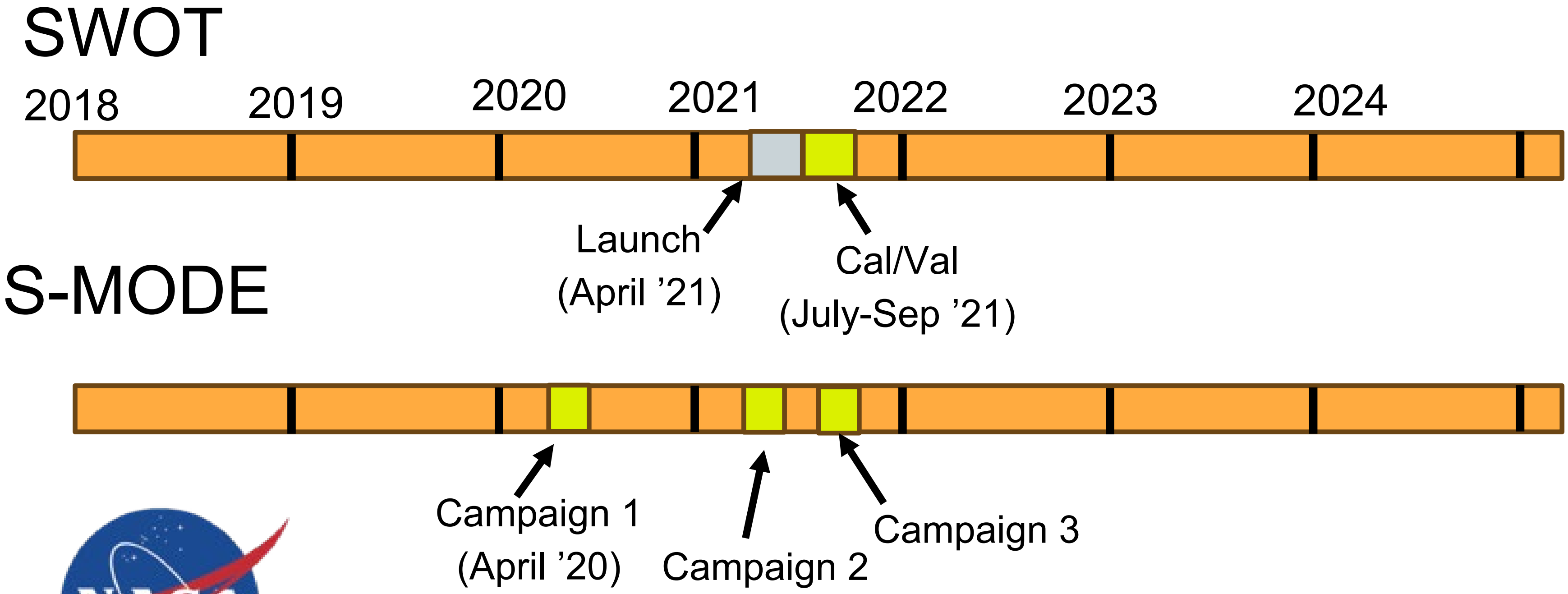
The region offshore of CA is a 'classic' region for studies of submesoscale variability (e.g. Capet et al, 2008a,b,c)

S-MODE and SWOT are independent projects, but…

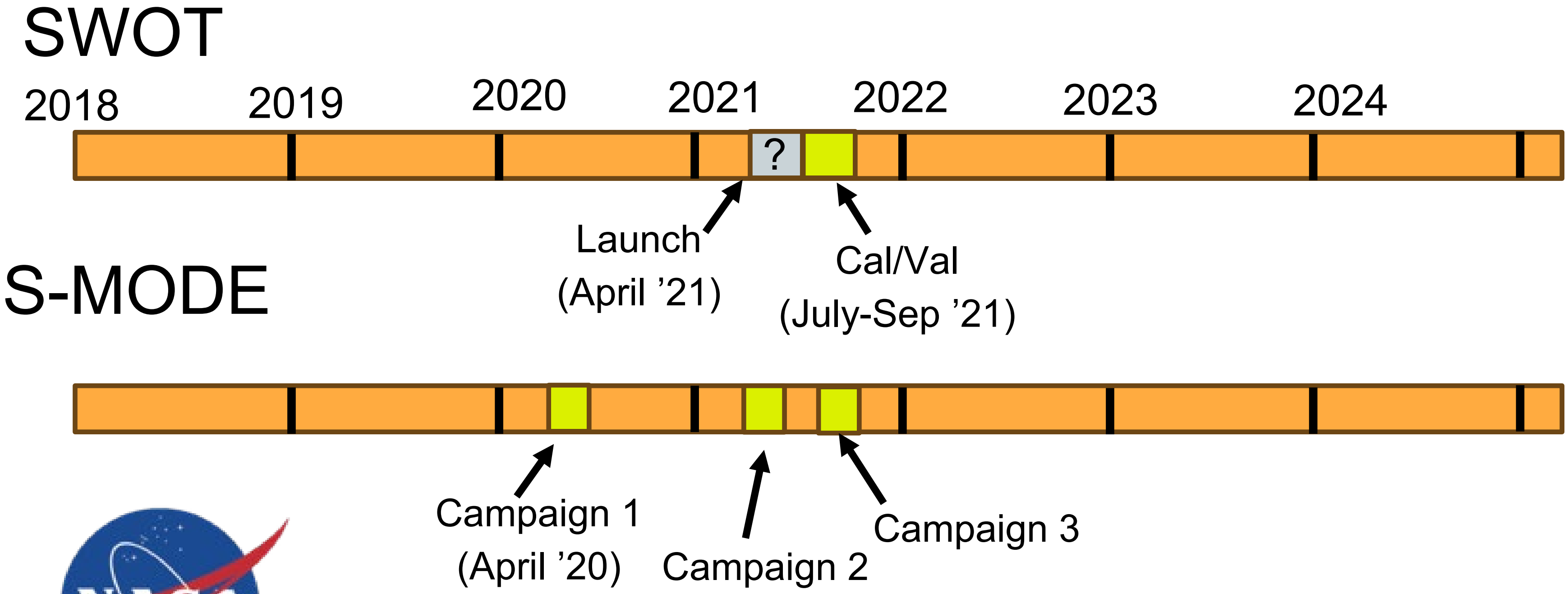
We always hoped to conduct one S-MODE campaign during SWOT cal/val



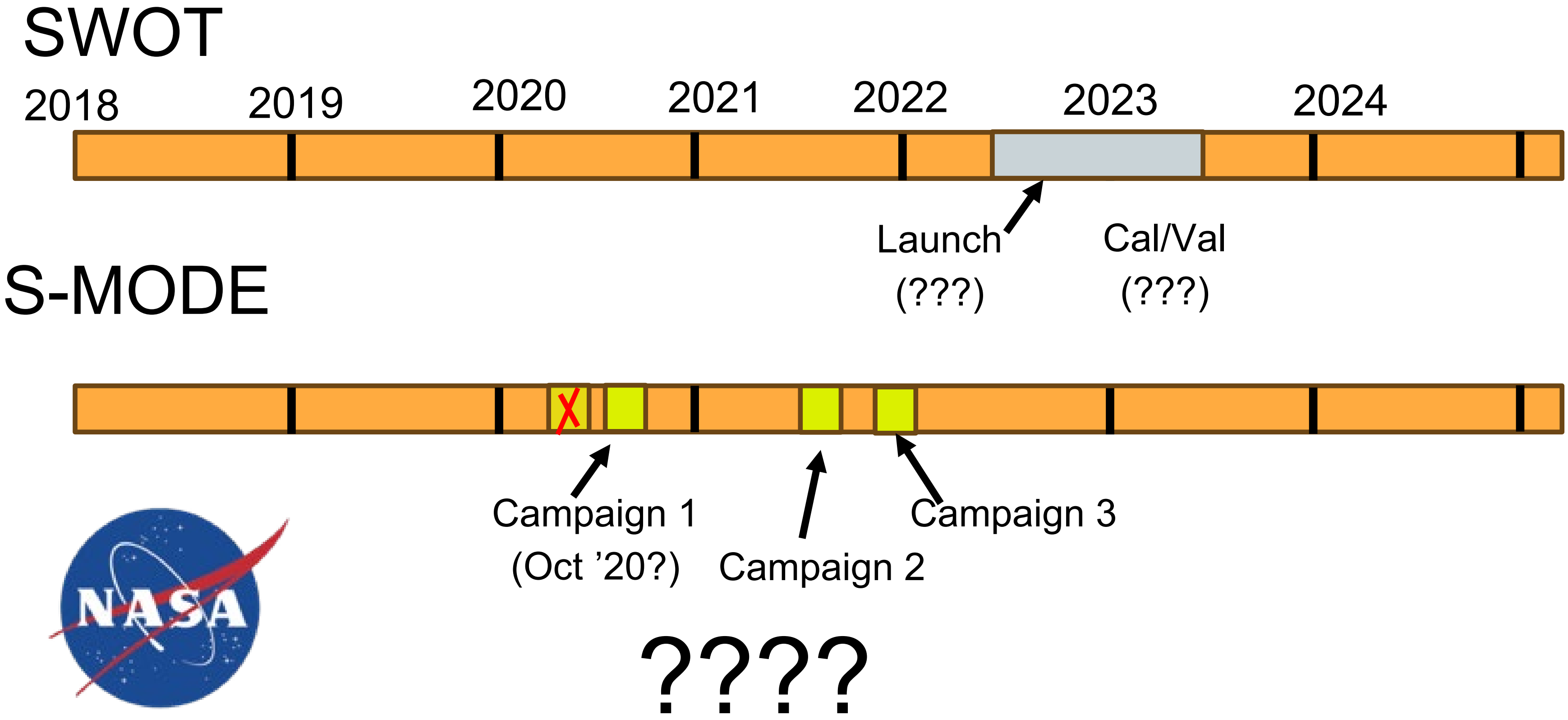
S-MODE and SWOT– our plans in April 2018



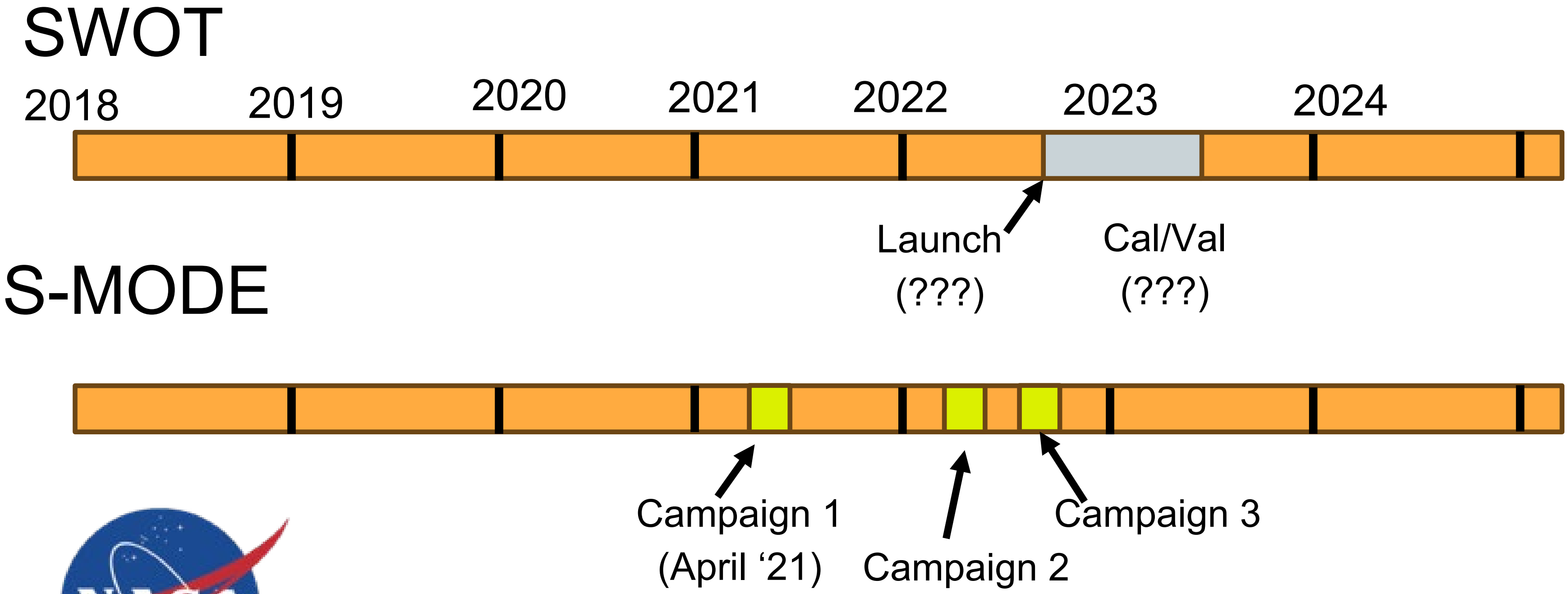
S-MODE and SWOT– our plans in April 2018



S-MODE and SWOT– our reality in April 2020



S-MODE and SWOT– our reality in April 2021



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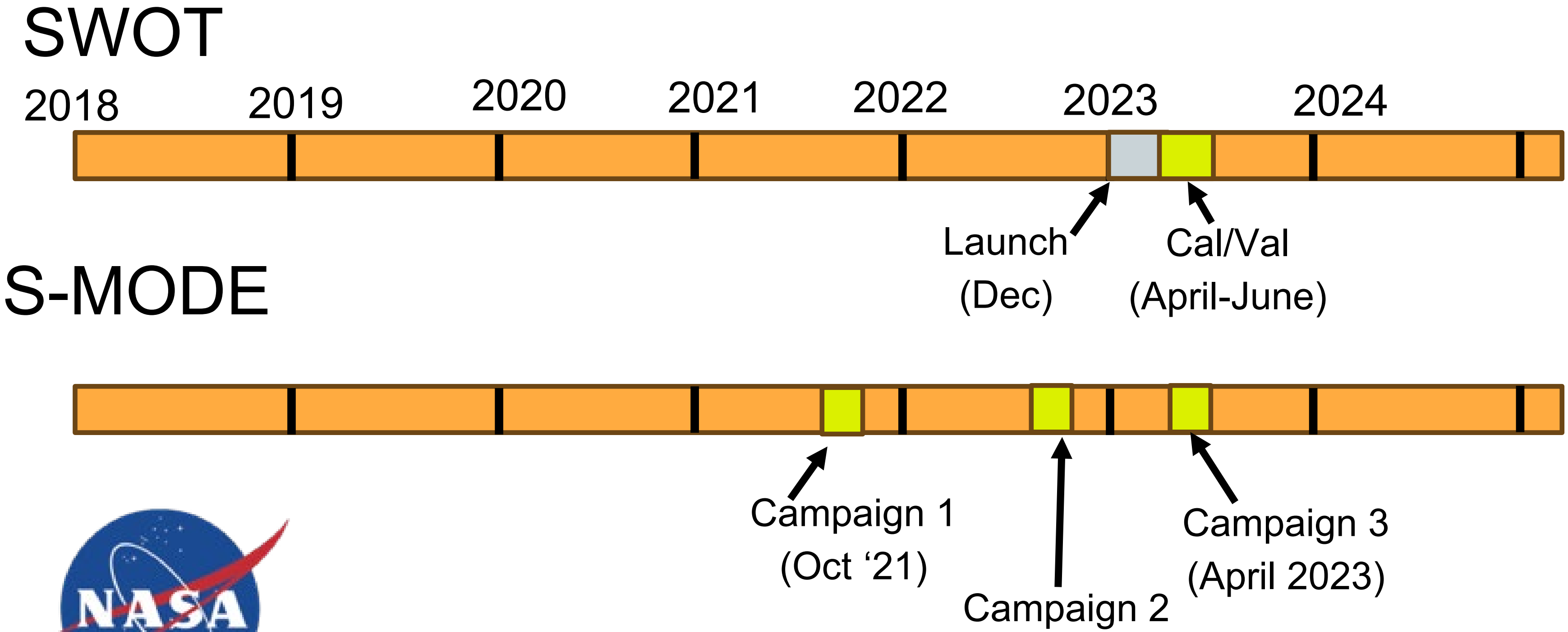
S-MODE and SWOT– plans stabilized in Oct 2021



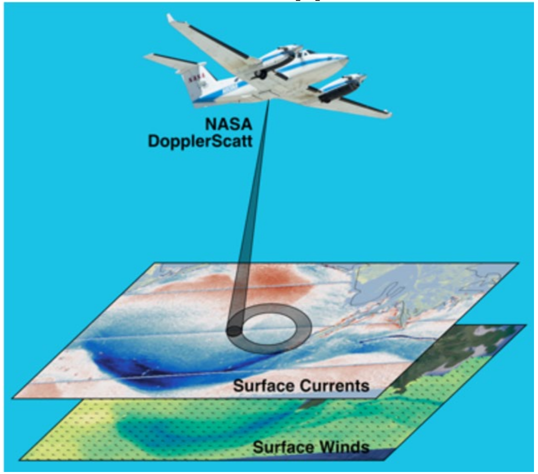
Observations coincident with SWOT ca/val

>30 platforms + 75 surface drifters

Aircraft observations:
- DopplerScatt (km-resolution surface currents, winds)
- MASS (lidar SSH, detailed wave measurements, surface currents, SST)
- PRISM hyperspectral (~10m resolution chlorophyll and more)
- Infrared imagery (~50m resolution SST)

In-water measurements:
- 9 underwater gliders (CTD, some with velocity)
- 8 Wave Gliders (velocity, directional wave spectra, meteorology)
- 10 Argo-style floats (CTD profiles, rapid repeat)
- 2 Lagrangian floats (CTD, 3D velocity)
- 1 Research vessel (velocity, rapid-profiling CTD, meteorology)
- 75 surface drifters

NASA JPL DopplerScatt

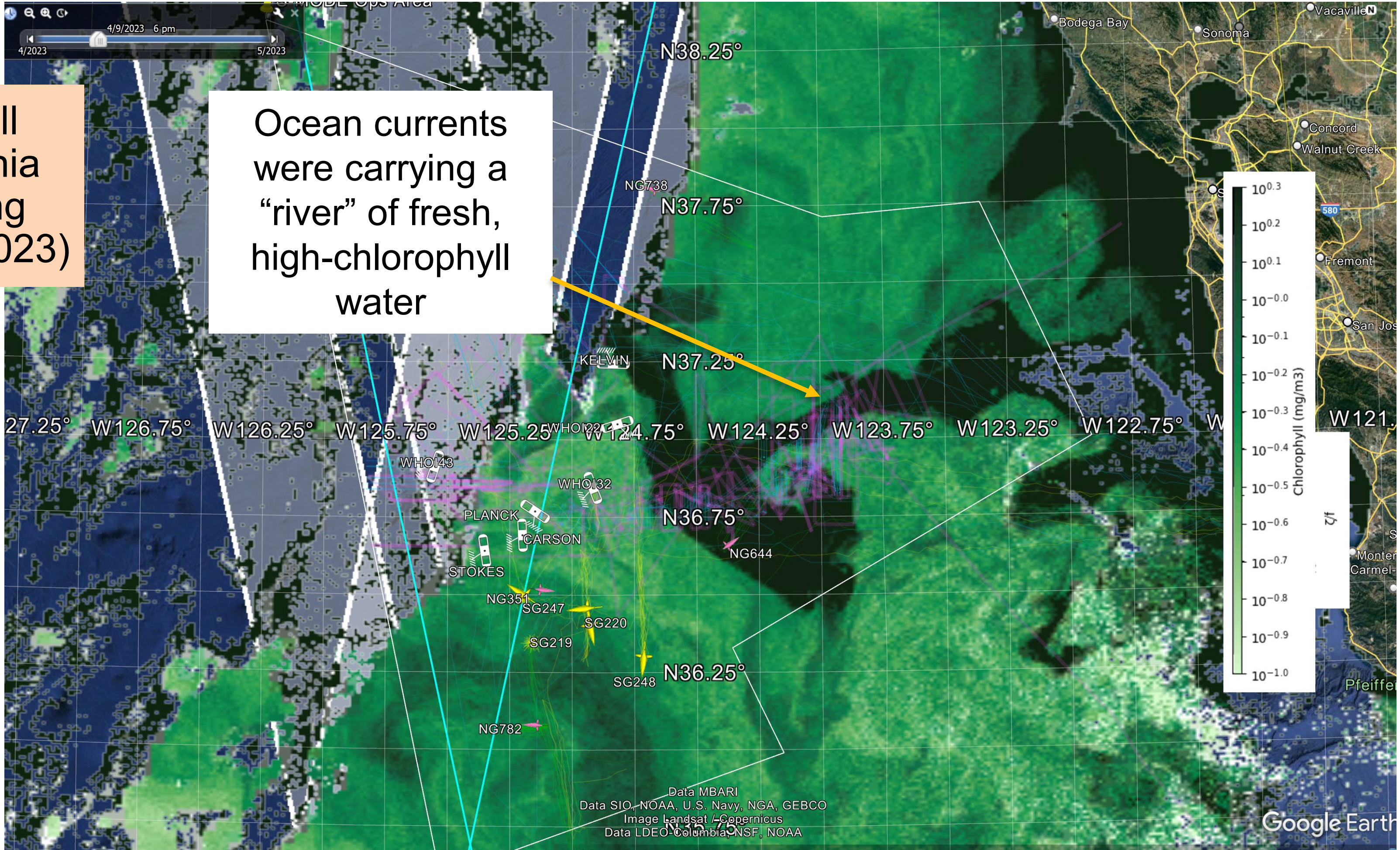


SIO Modular Aerial Sensing System (MASS)

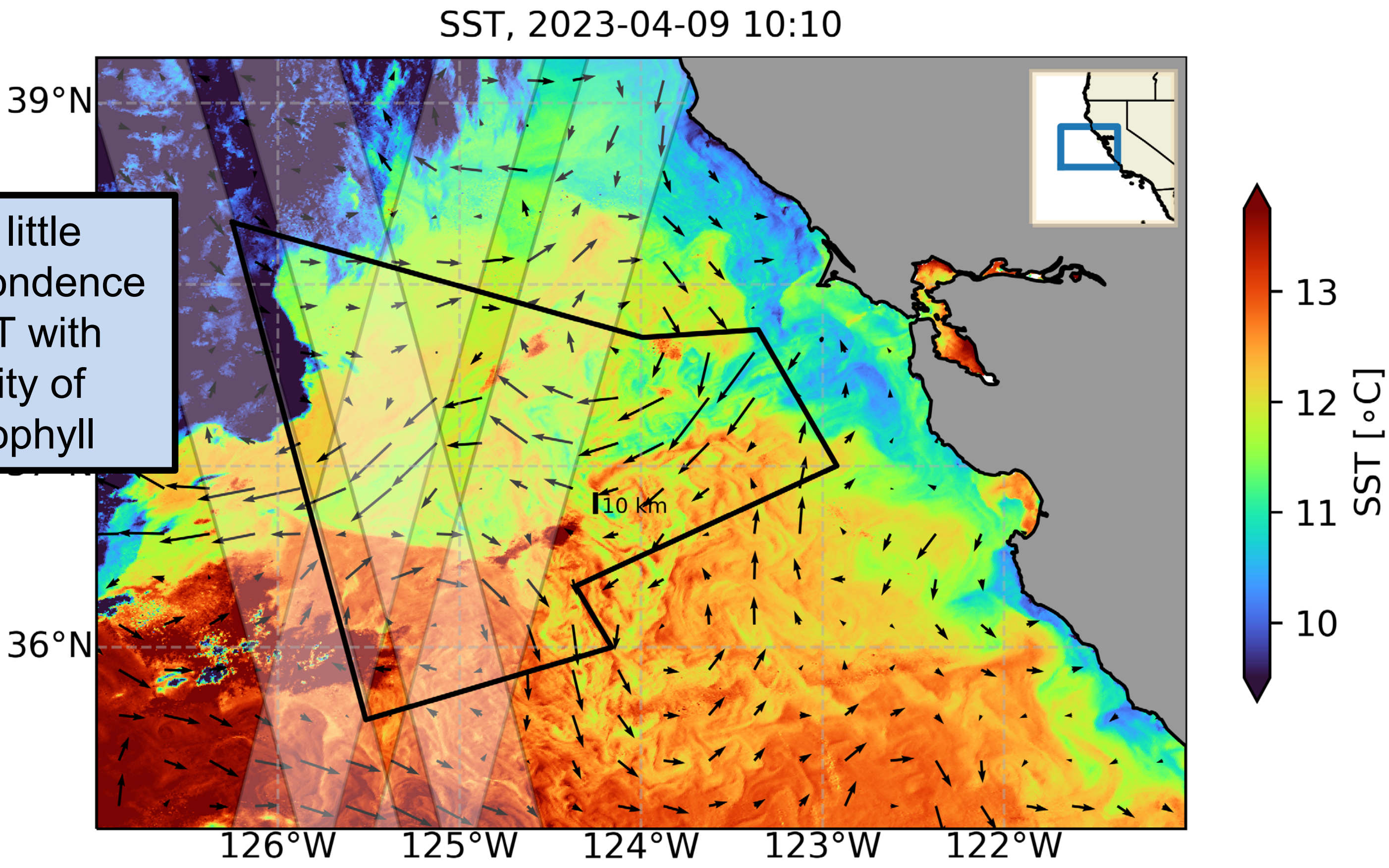
Chlorophyll, 4/9/2023 (first day of cruise)

(Recall California flooding Spring 2023)

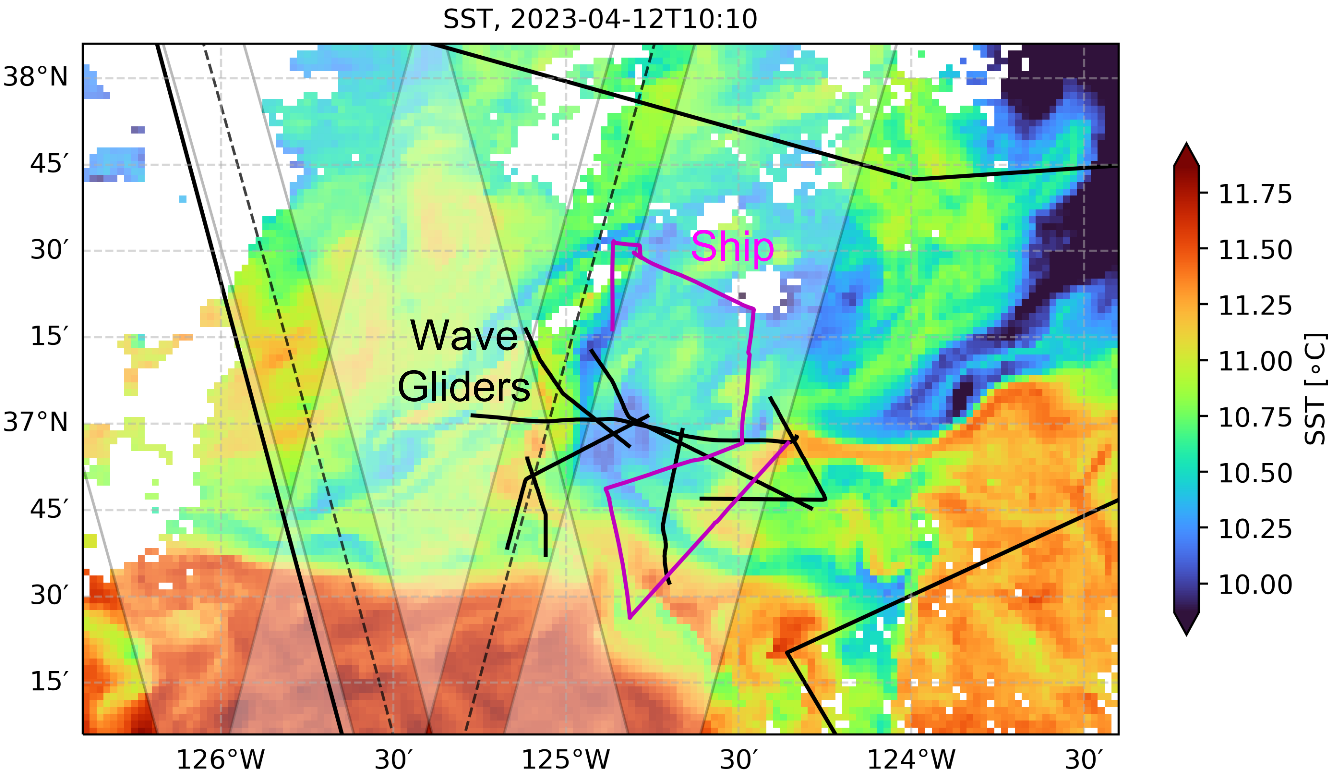
Ocean currents were carrying a “river” of fresh, high-chlorophyll water

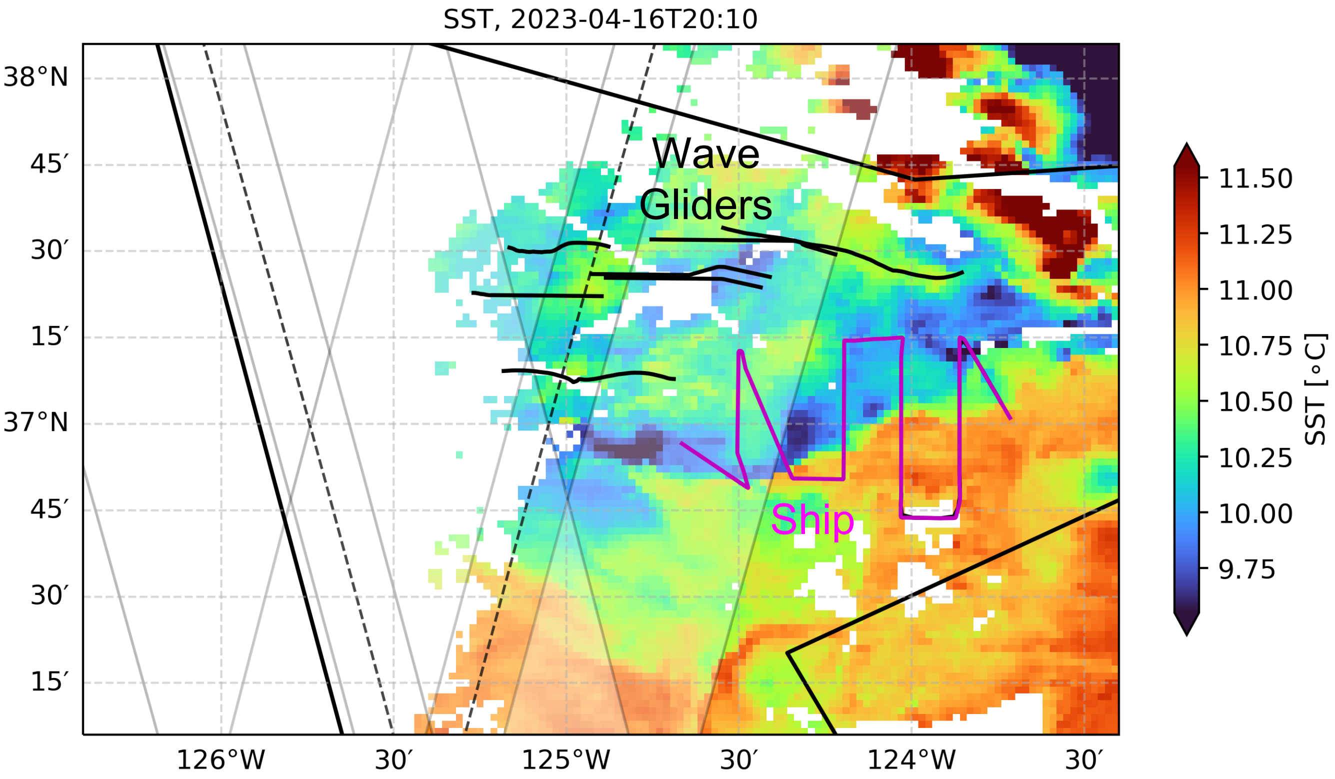


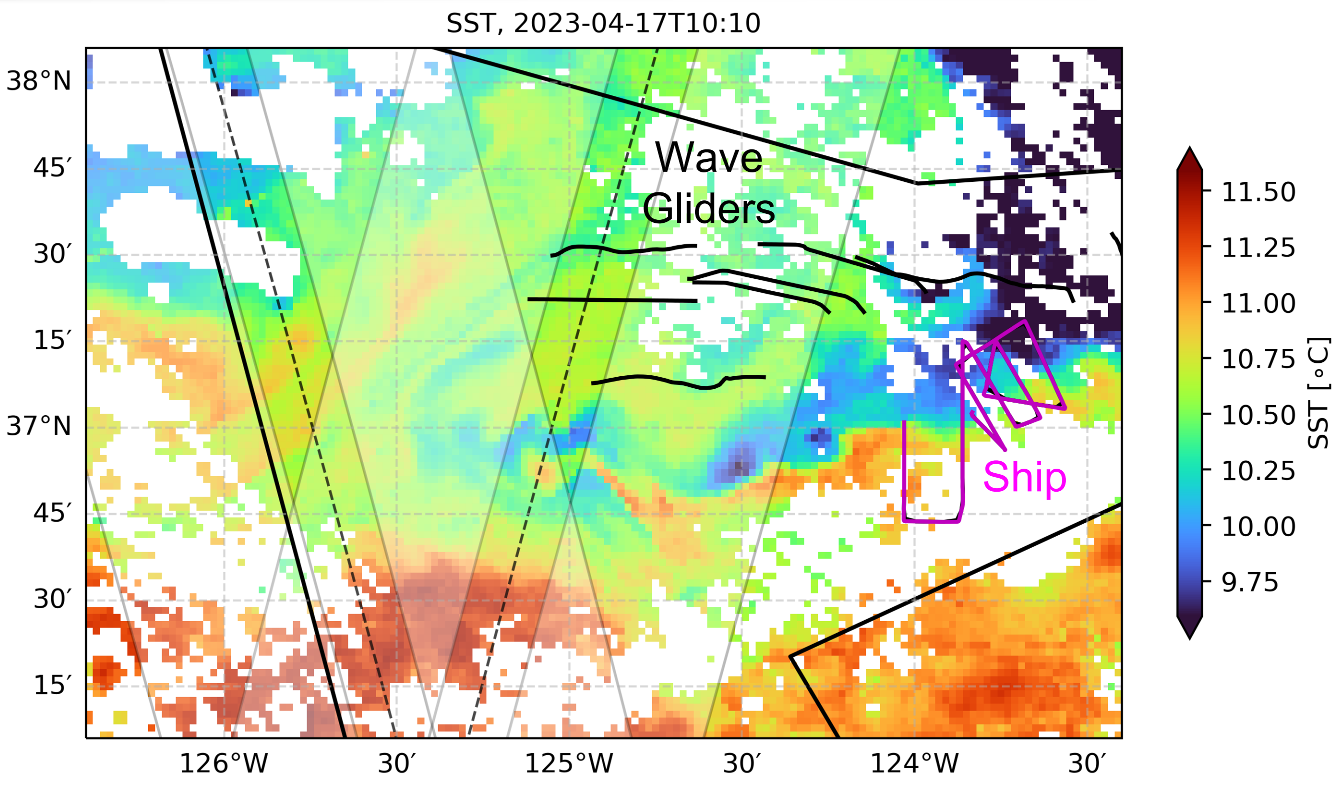
SST, same day (first day of cruise)



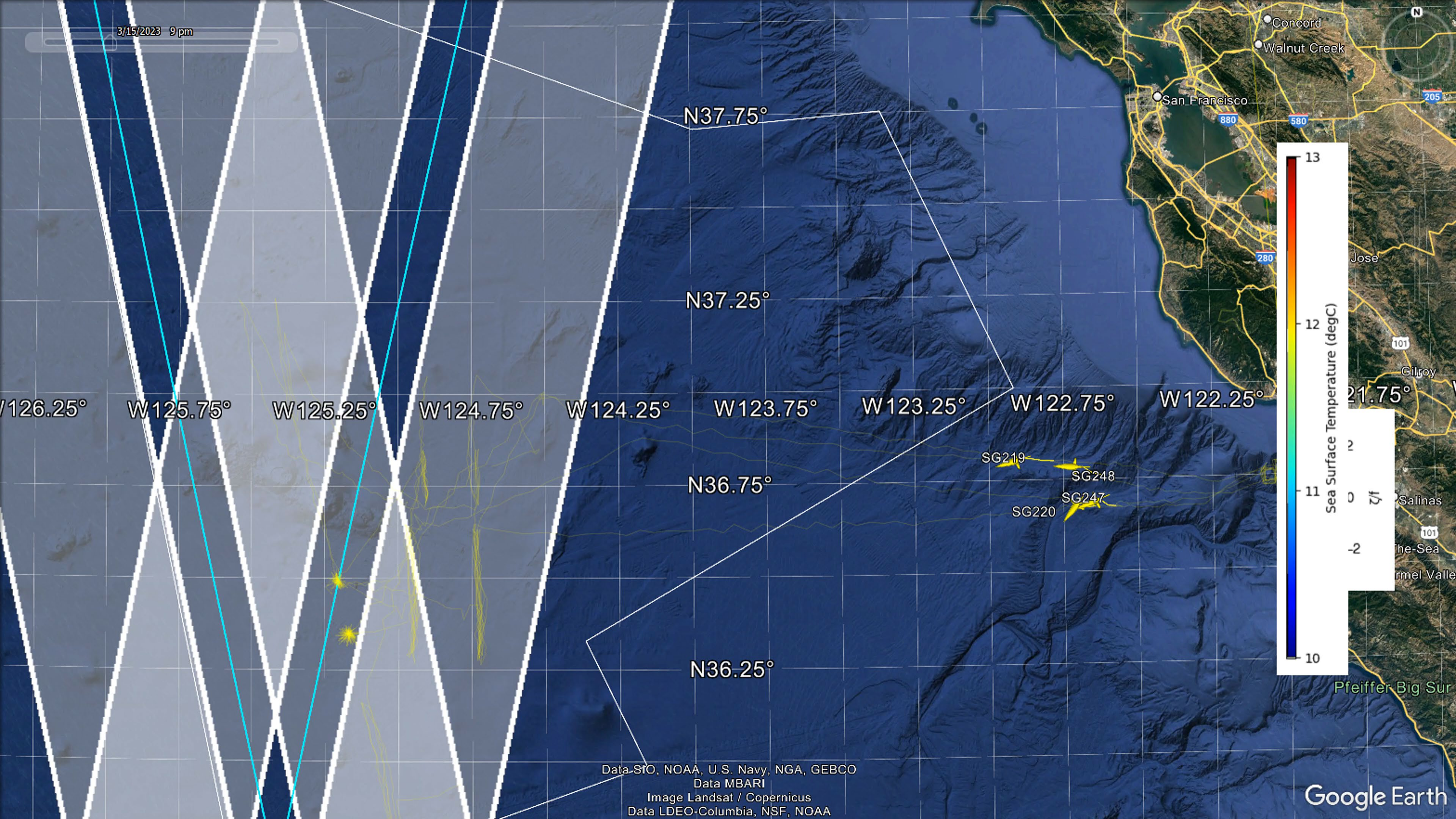
Very little correspondence of SST with density of chlorophyll

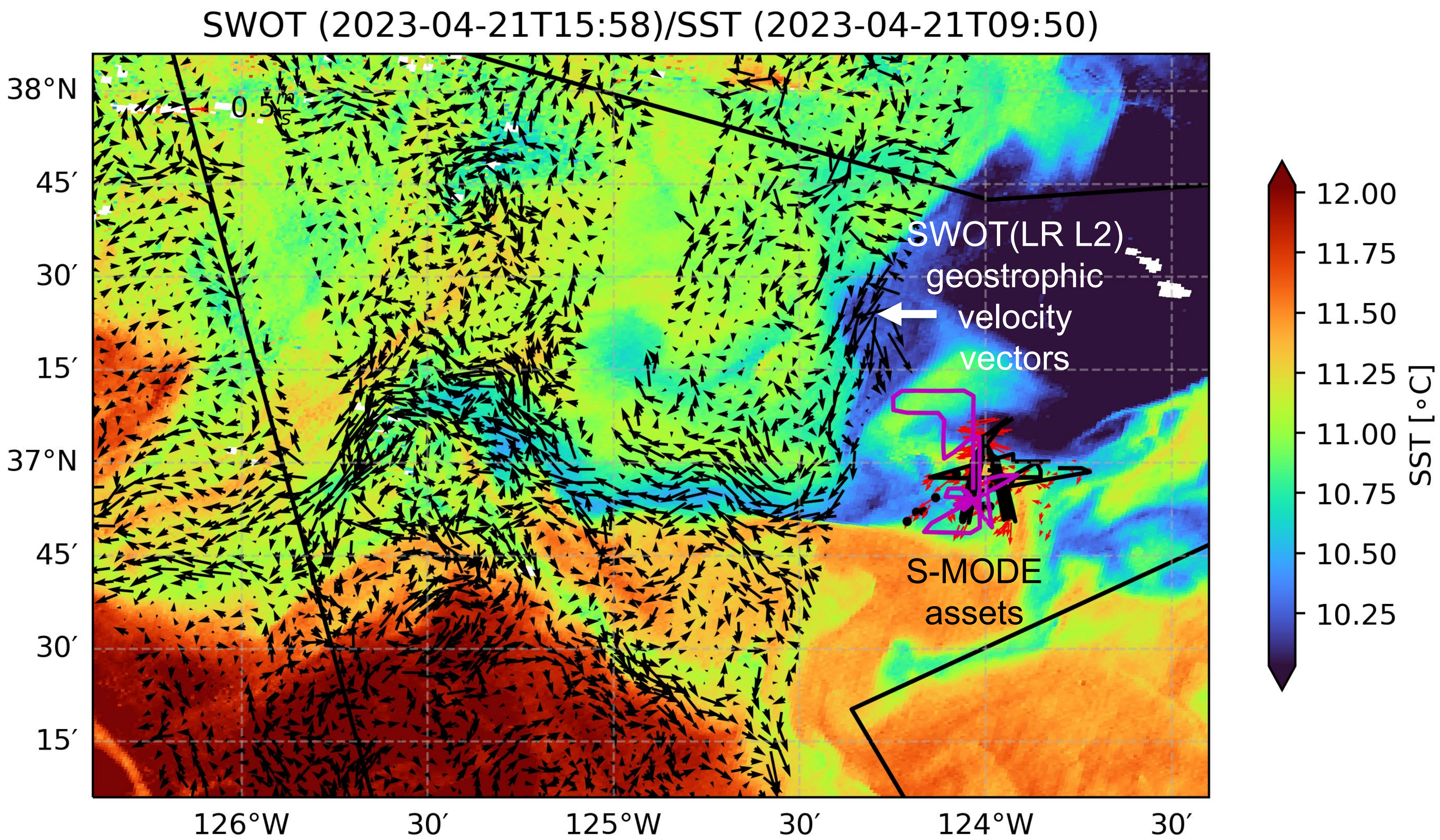

SST, 2023-04-12T10:10
38°N
45′
30′
15′
37°N
45′
30′
15′
126°W
30′
125°W
30′
124°W
30′
Ship
Wave
Gliders
11.75
11.50
11.25
11.00
10.75
10.50
10.25
10.00
SST [∘C]


SST, 2023-04-16T20:10
38°N
45′
30′
15′
37°N
45′
30′
15′
126°W
30′
125°W
30′
124°W
30′
Wave
Gliders
Ship
11.50
11.25
11.00
10.75
10.50
10.25
10.00
9.75
SST [°C]

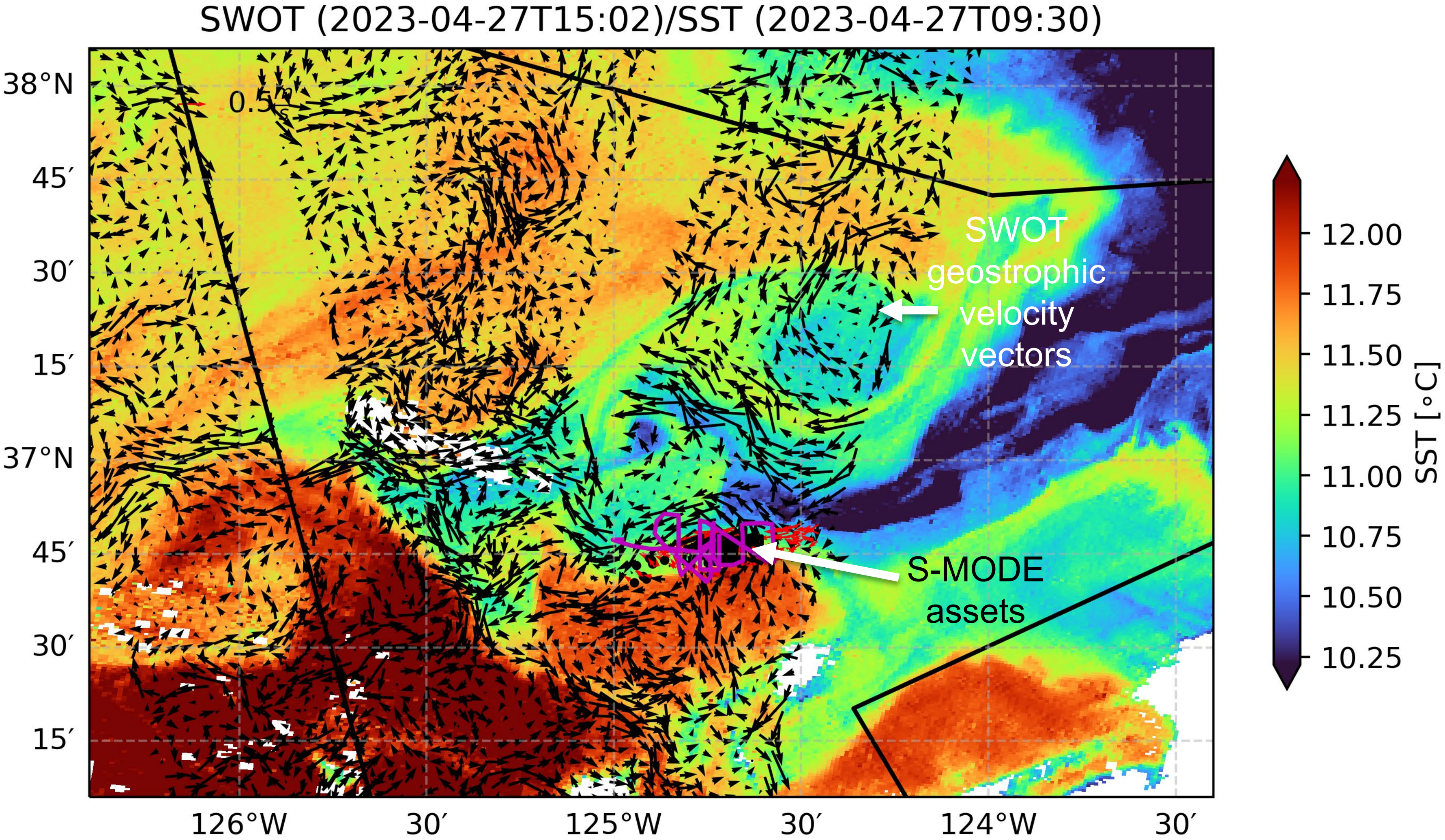


SST, 2023-04-17T10:10
38°N
45′
30′
15′
37°N
45′
30′
15′
126°W
30′
125°W
30′
124°W
30′
Wave
Gliders
Ship
11.50
11.25
11.00
10.75
10.50
10.25
10.00
9.75
SST [°C]


3/15/2023 9 pm
N37.75°
N37.25°
N36.75°
N36.25°
W126.25°
W125.75°
W125.25°
W124.75°
W124.25°
W123.75°
W123.25°
W122.75°
W122.25°
SG219
SG248
SG247
SG220
Concord
Walnut Creek
San Francisco
Salinas
Gilroy
Pfeiffer Big Sur
13
12
11
10
Sea Surface Temperature (degC)
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data MBARI
Image Landsat / Copernicus
Data LDEO-Columbia, NSF, NOAA
Google Earth

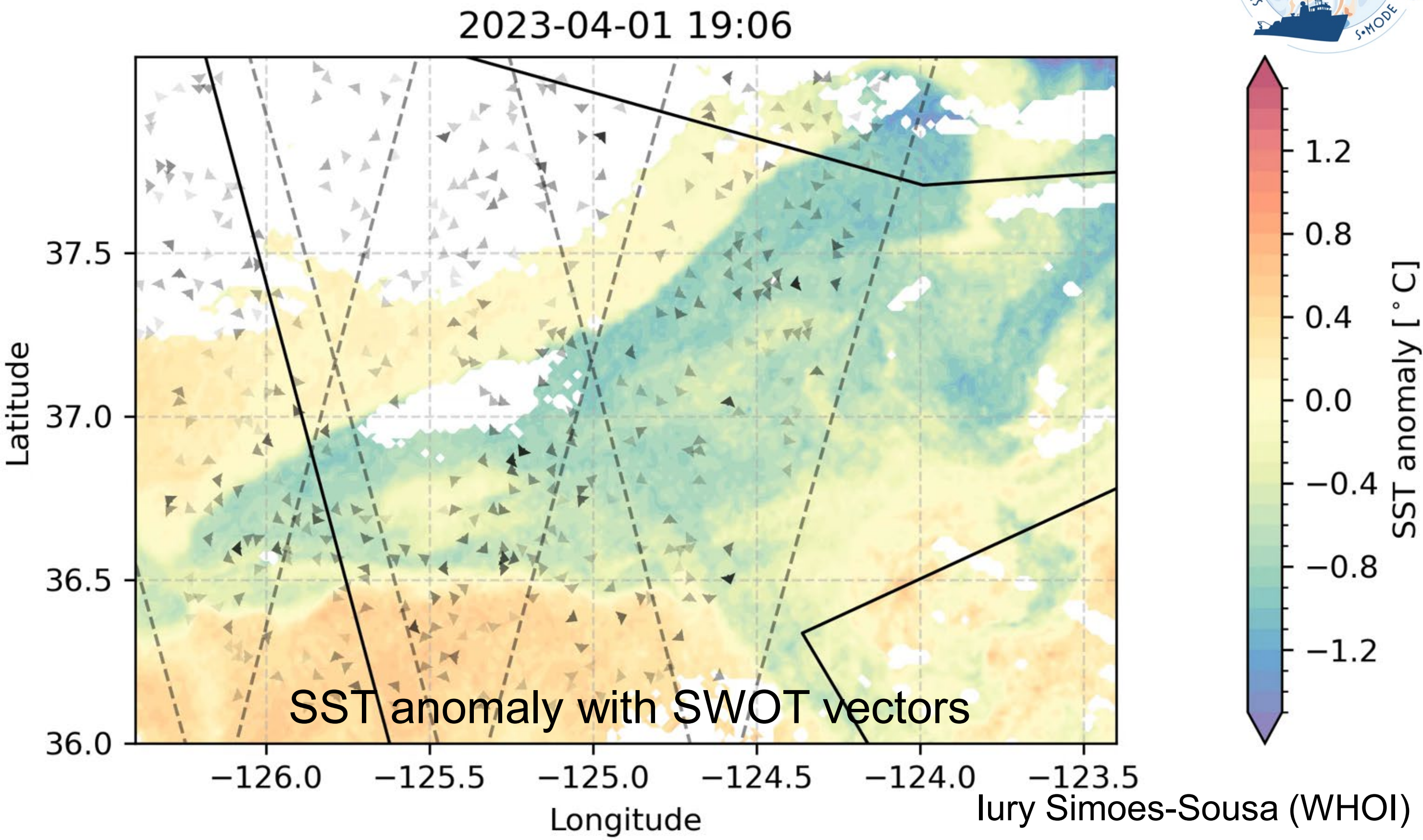


SWOT (2023-04-21T15:58)/SST (2023-04-21T09:50)
0.5 m/s
SWOT(LR L2) geostrophic velocity vectors
S-MODE assets
38°N
45′
30′
15′
37°N
45′
30′
15′
126°W
30′
125°W
30′
124°W
30′
12.00
11.75
11.50
11.25
11.00
10.75
10.50
10.25
SST [°C]


SWOT (2023-04-27T15:02)/SST (2023-04-27T09:30)
38°N
45′
30′
15′
37°N
45′
30′
15′
126°W
30′
125°W
30′
124°W
30′
SWOT geostrophic velocity vectors
S-MODE assets
SST [°C]
12.00
11.75
11.50
11.25
11.00
10.75
10.50
10.25

Conclusions

(1) There is a wealth of S-MODE data coincident with SWOT
(2) The data are freely available
(3) Initial comparison to SWOT is very encouraging



Iury Simoes-Sousa (WHOI)

Conclusions

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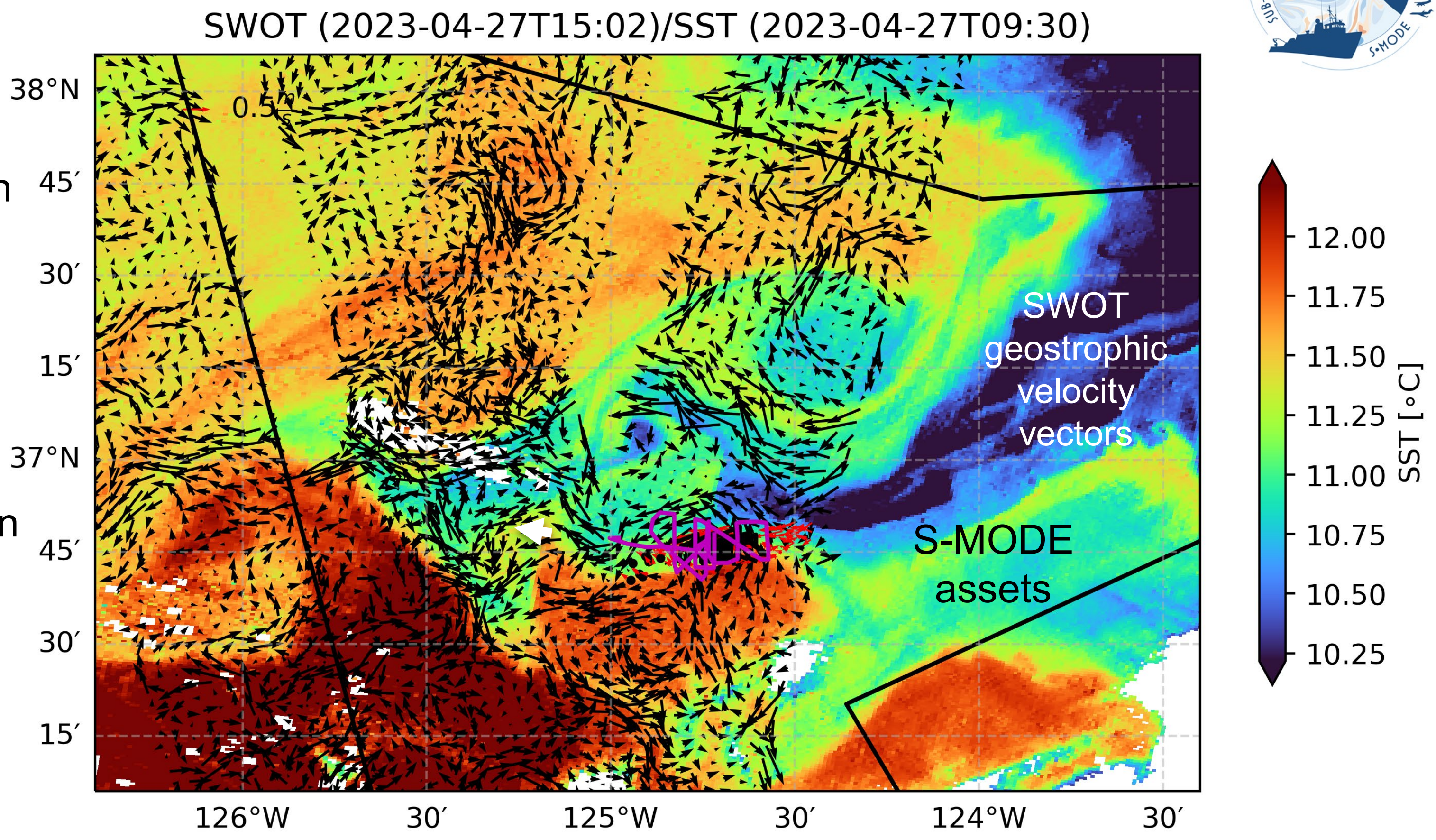
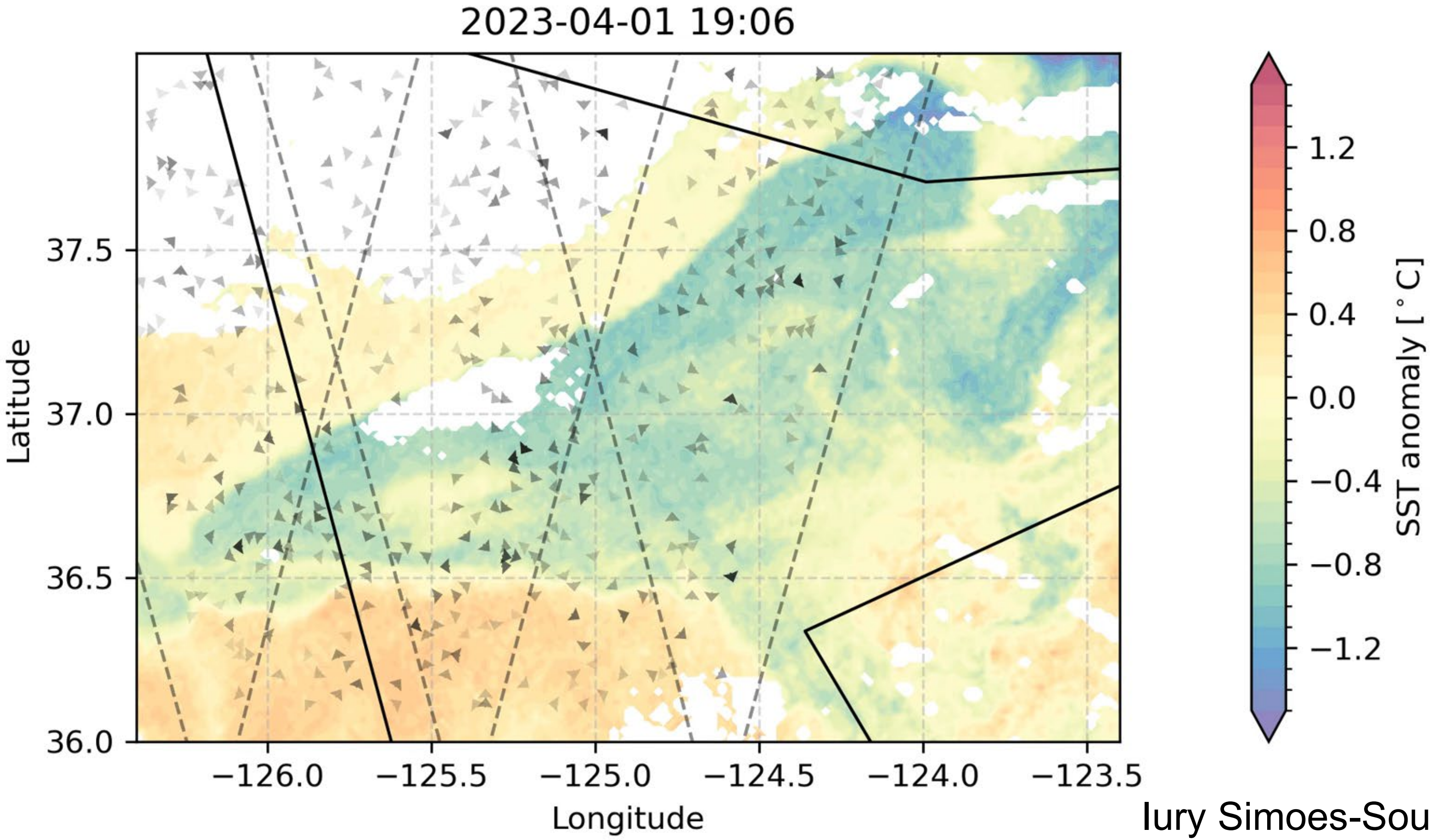
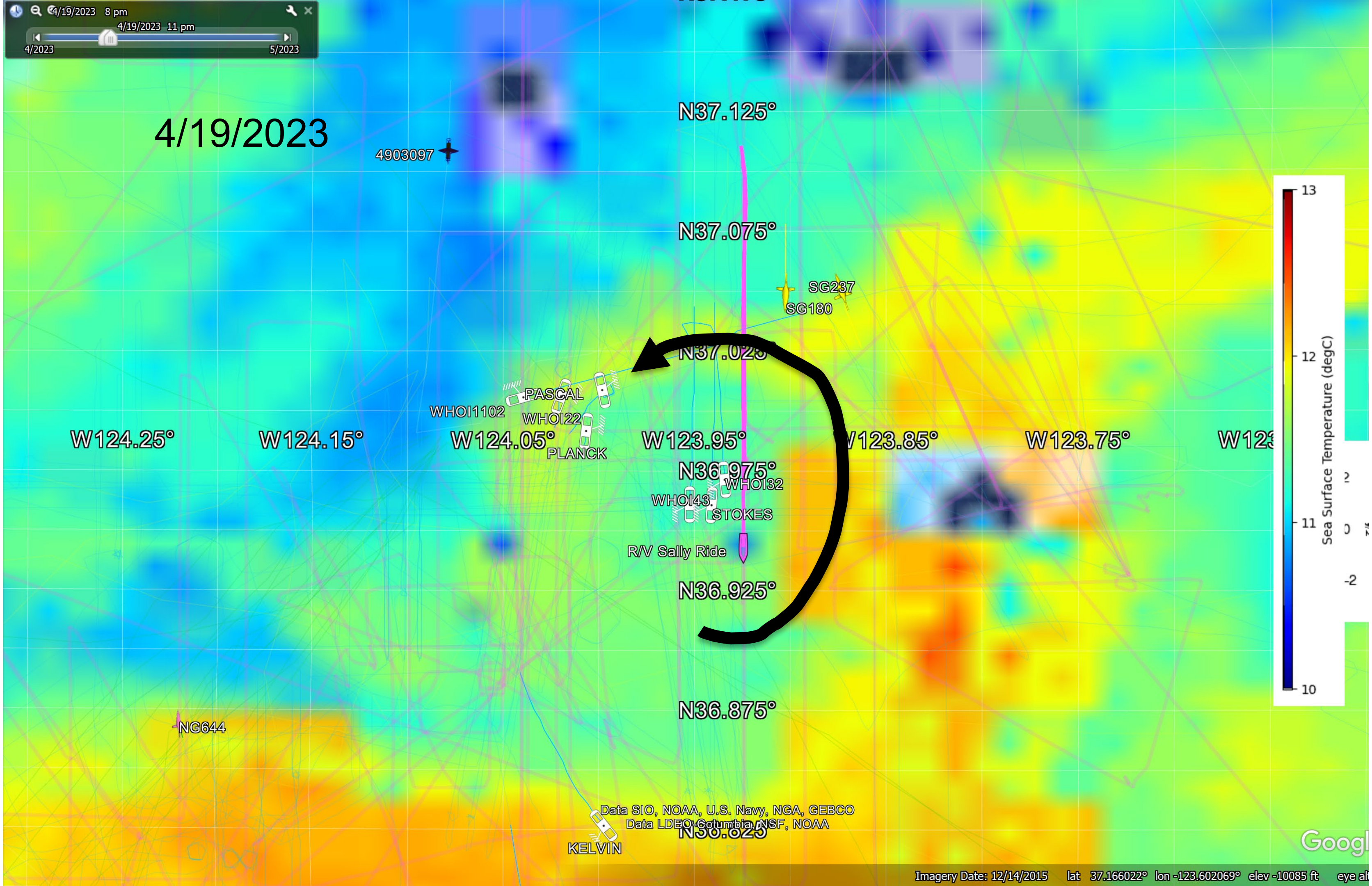


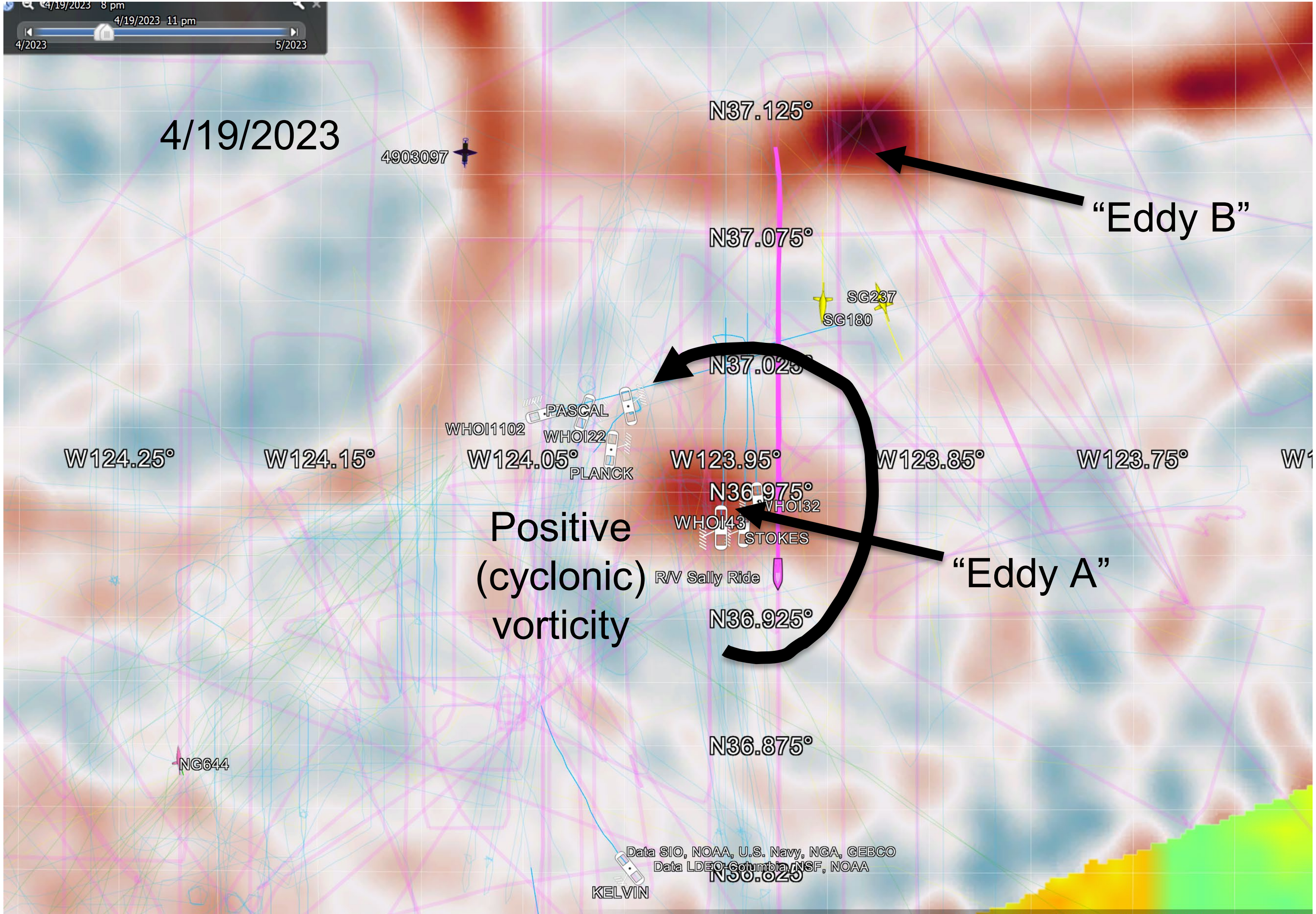
SST anomaly with SWOT vectors

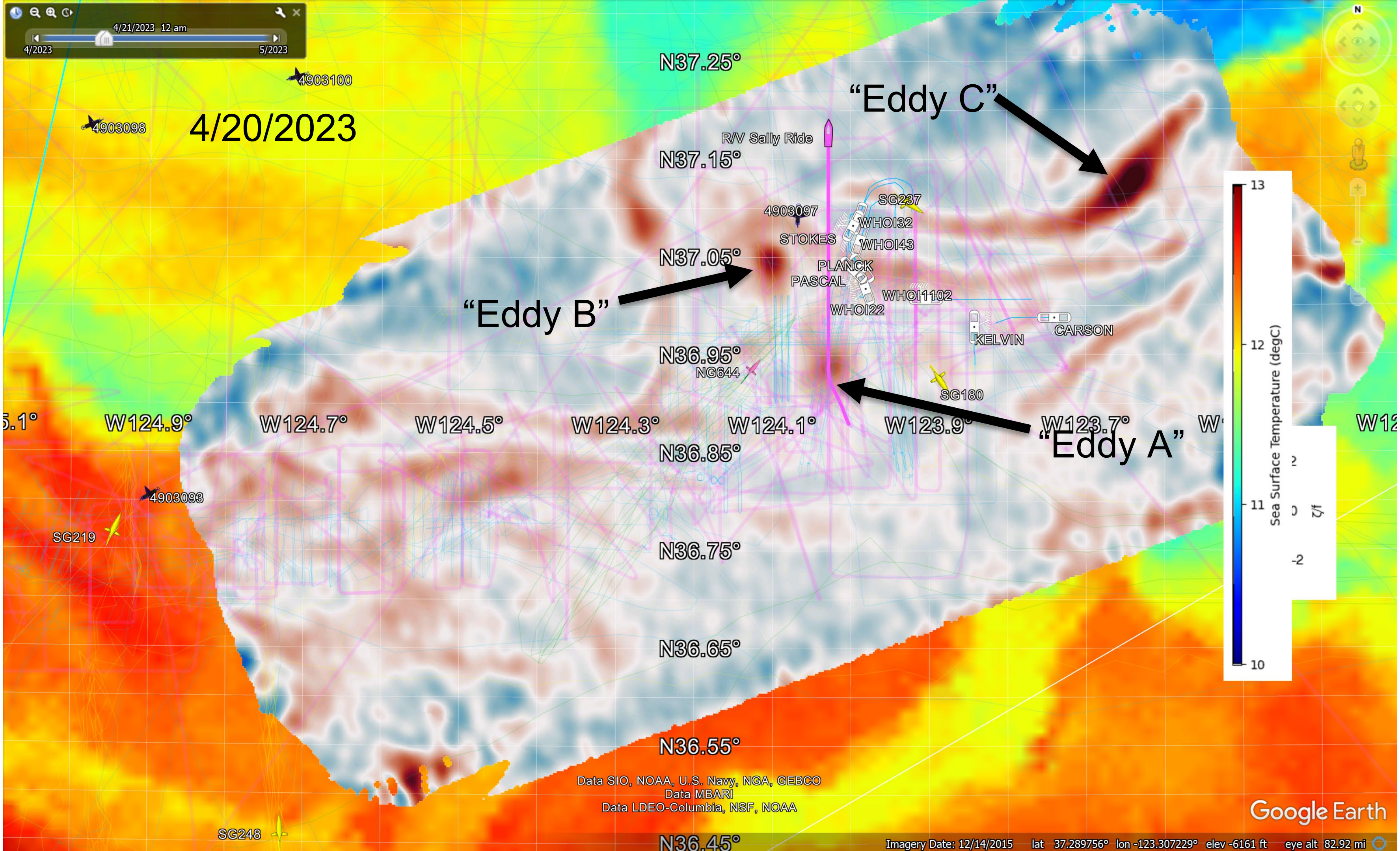


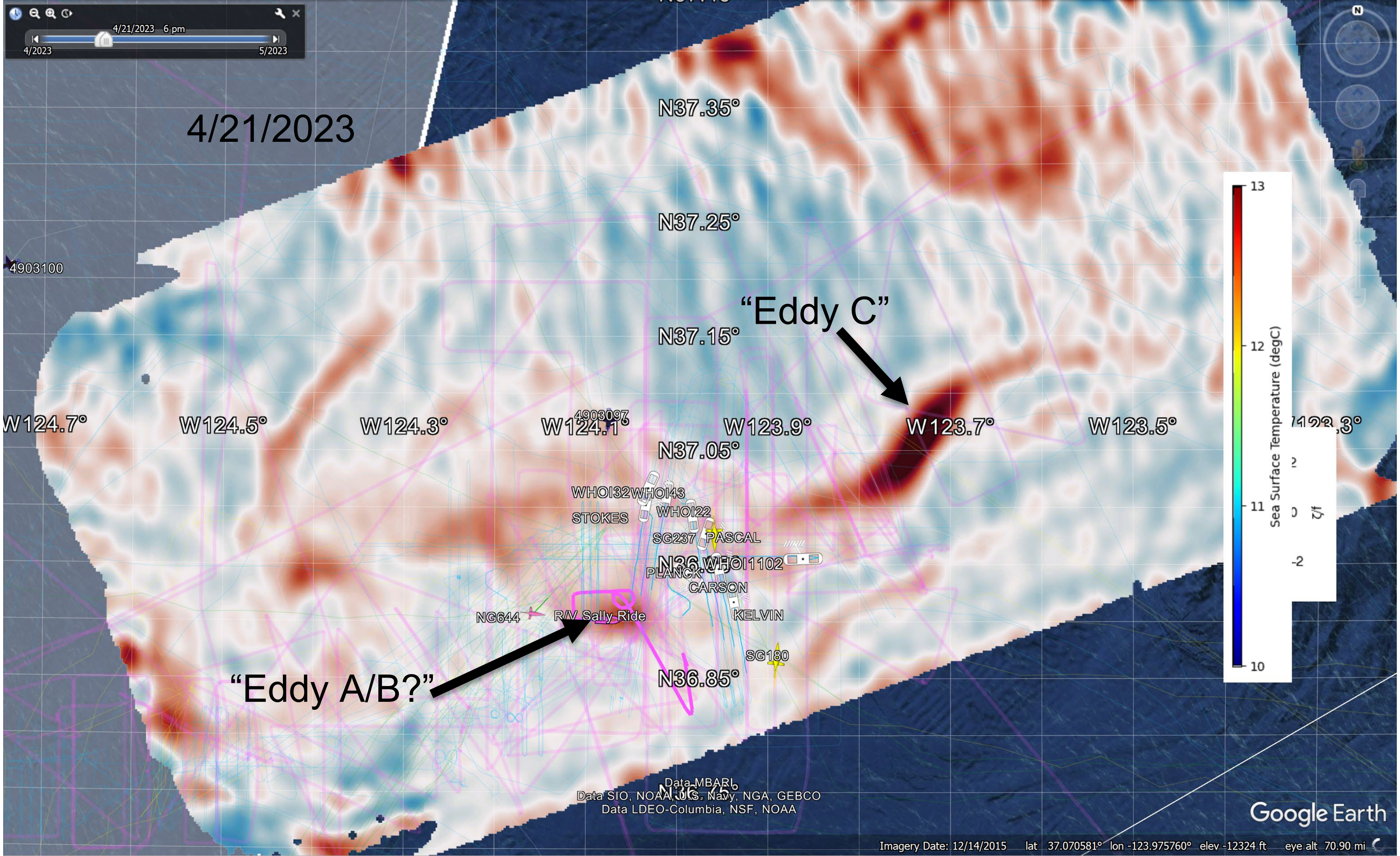
Iury Simoes-Sousa (WHOI)



4/19/2023 8 pm
4/19/2023 11 pm
4/2023
5/2023
4/19/2023
4903097
N37.125°
N37.075°
SG237
SG180
PASCAL
WHOI1102
WHOI22
W124.25°
W124.15°
W124.05°
W123.95°
W123.75°
PLANCK
N36.975°
WHOI32
WHOI43
STOKES
R/V Sally Ride
N36.925°
N36.875°
NG644
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
KELVIN
Sea Surface Temperature (degC)
13
12
11
10
Imagery Date: 12/14/2015 lat 37.166022° lon -123.602069° elev -10085 ft


4/19/2023 8 pm
4/19/2023 11 pm
4/2023
5/2023
4/19/2023
4903097
N37.125°
"Eddy B"
N37.075°
SG237
SG180
N37.025°
PASCAL
WHOI1102
WHOI22
W124.25°
W124.15°
W124.05°
PLANCK
W123.95°
W123.85°
W123.75°
N36.975°
WHOI32
WHOI43
STOKES
Positive
(cyclonic)
vorticity
R/V Sally Ride
"Eddy A"
N36.925°
N36.875°
NG644
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
KELVIN


4/21/2023 12 am
4/2023
5/2023
4903100
4903098
4/20/2023
N37.25°
"Eddy C"
R/V Sally Ride
N37.15°
SG237
4903097
WHOI32
STOKES
WHOI43
N37.05°
PLANCK
PASCAL
WHOI1102
"Eddy B"
WHOI22
CARSON
KELVIN
N36.95°
NG644
SG180
W124.9°
W124.7°
W124.5°
W124.3°
W124.1°
W123.9°
W123.7°
"Eddy A"
N36.85°
4903093
SG219
N36.75°
N36.65°
N36.55°
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data MBARI
Data LDEO-Columbia, NSF, NOAA
SG248
N36.45°
Sea Surface Temperature (degC)
13
12
11
10
2
0
-2
Google Earth
Imagery Date: 12/14/2015 lat 37.289756° lon -123.307229° elev -6161 ft eye alt 82.92 mi



4/21/2023
4/21/2023 6 pm
4/2023
5/2023
N37.35°
N37.25°
N37.15°
N37.05°
N36.85°
W124.7°
W124.5°
W124.3°
W124.1°
W123.9°
W123.7°
W123.5°
"Eddy C"
"Eddy A/B?"
4903100
4903097
WHOI32
WHOI43
WHOI22
STOKES
SG237
PASCAL
WHOI1102
PLANCK
CARSON
KELVIN
NG644
R/V Sally Ride
SG180
Sea Surface Temperature (degC)
13
12
11
10
Data MBARI
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data LDEO-Columbia, NSF, NOAA
Google Earth
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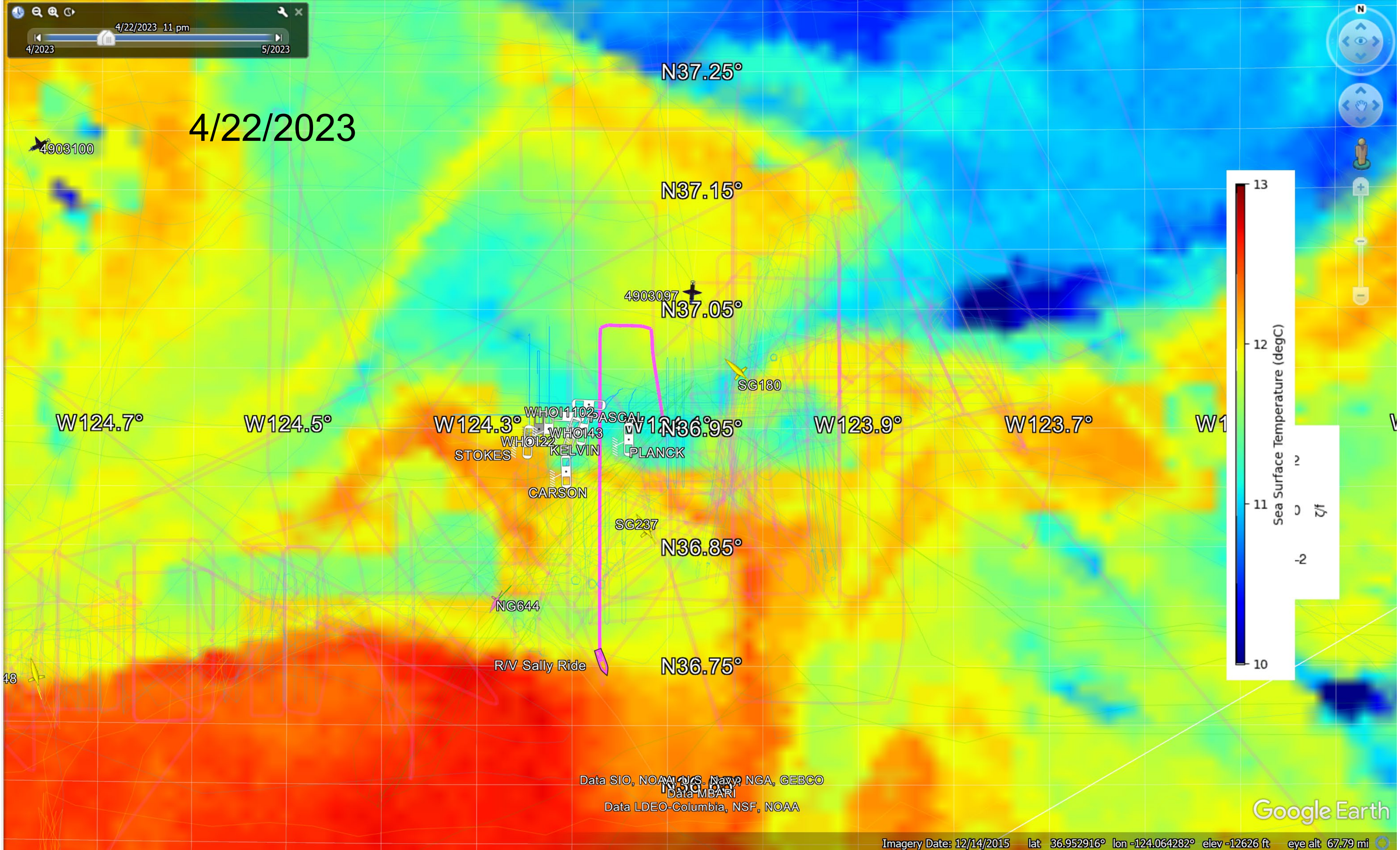
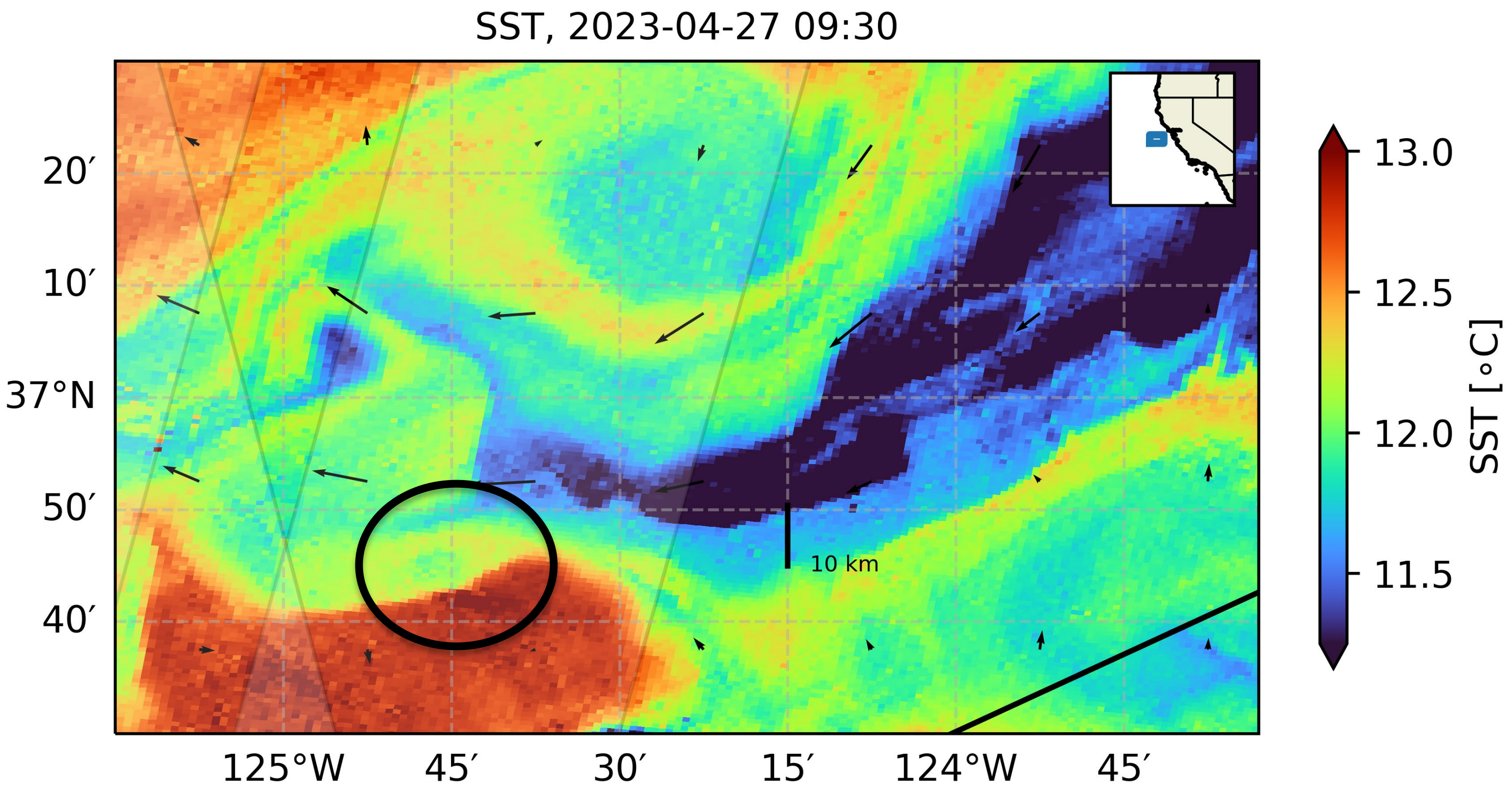
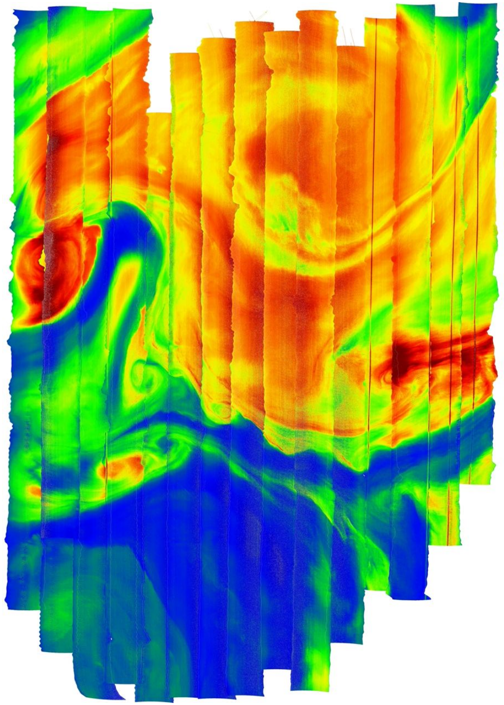
4/22/2023

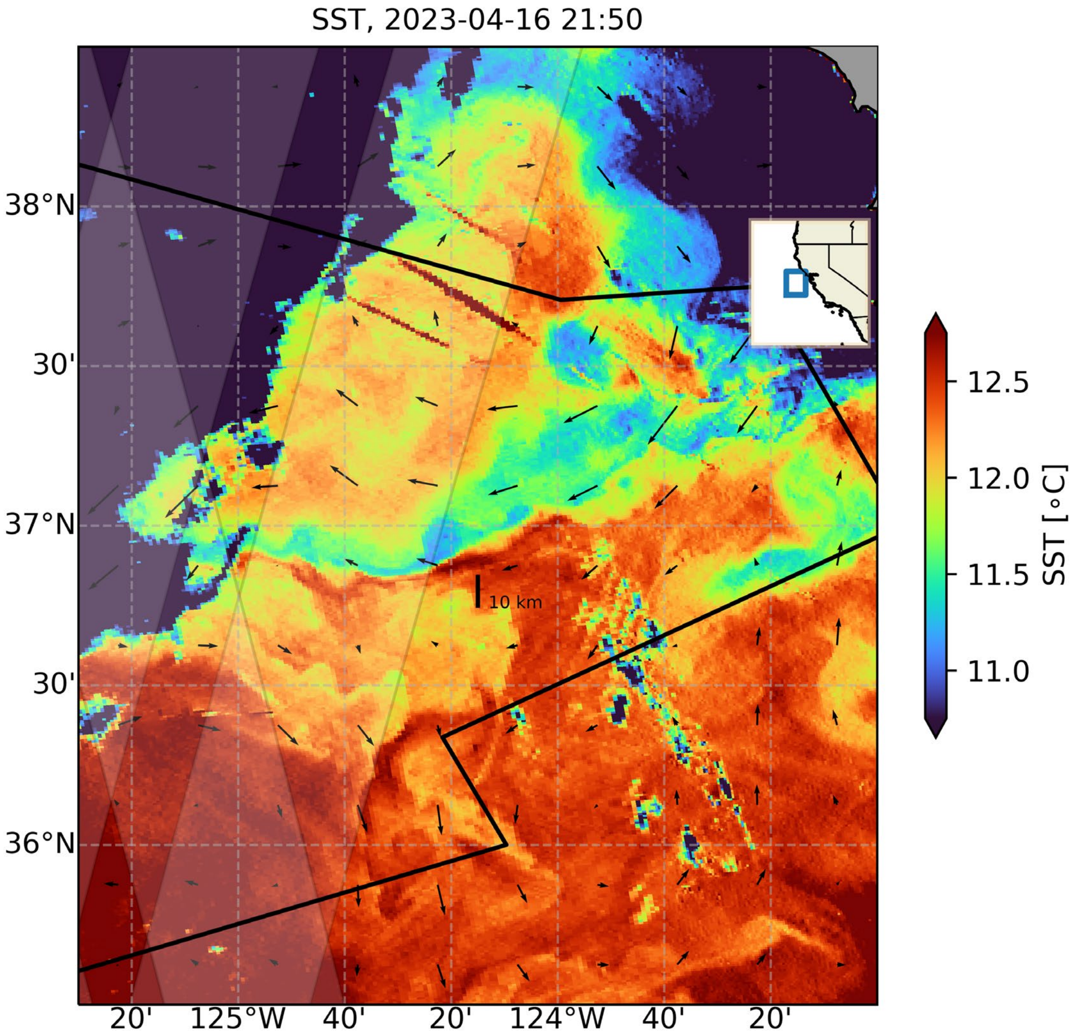


4/22/2023 11 pm
4/2023
5/2023
4903100
N37.25°
N37.15°
4903097
N37.05°
SG180
W124.7°
W124.5°
W124.3°
W123.9°
W123.7°
N36.95°
WHOI1102
PASCAL
WHOI43
WHOI22
STOKES
KELVIN
PLANCK
CARSON
SG237
N36.85°
NG644
R/V Sally Ride
N36.75°
Sea Surface Temperature (degC)
13
12
11
10
-2
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Data MBARI
Data LDEO-Columbia, NSF, NOAA
Google Earth
Imagery Date: 12/14/2015 lat 36.952916° lon -124.064282° elev -12626 ft eye alt 67.79 mi

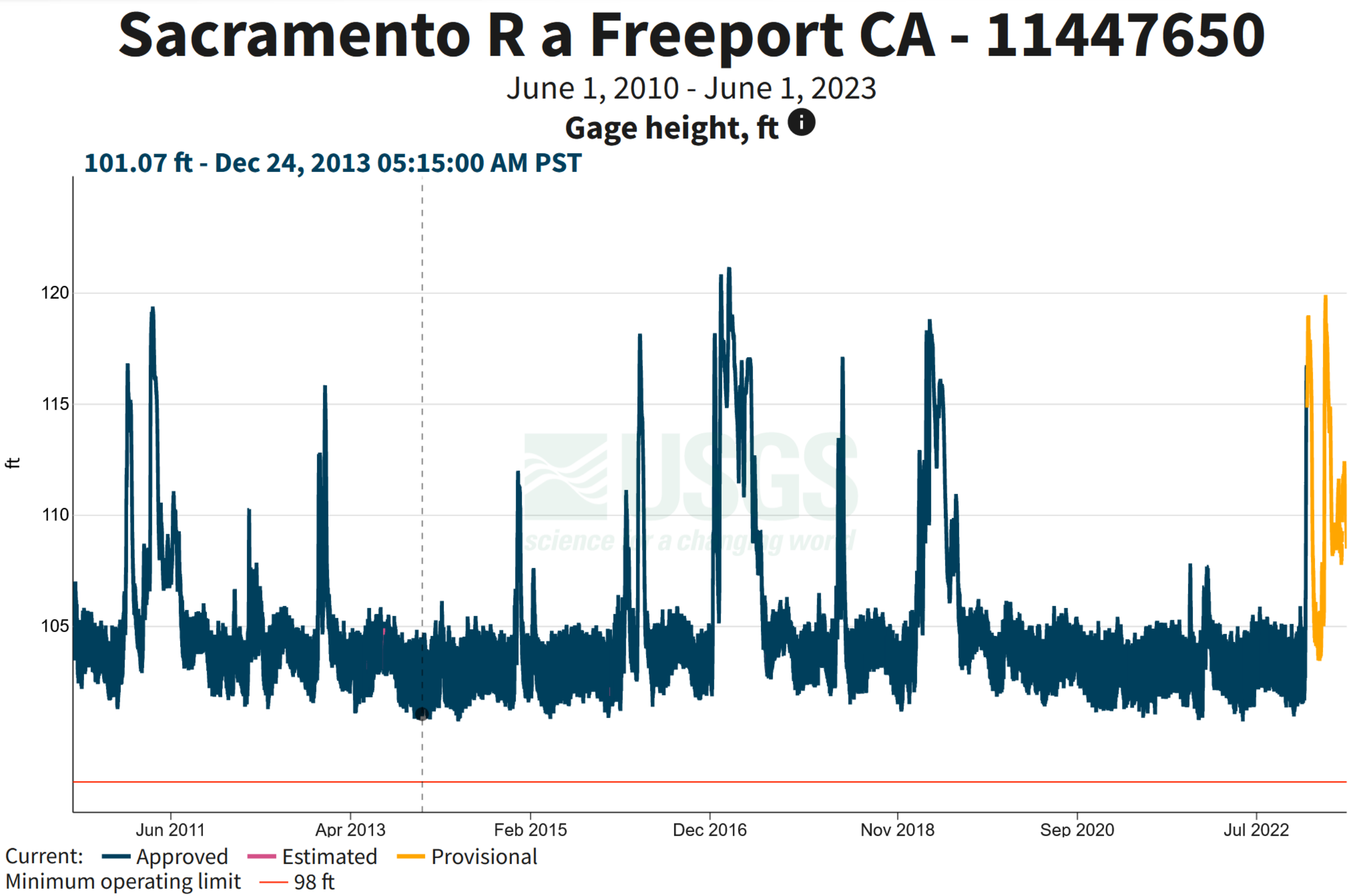

SST, 2023-04-27 09:30
20′
10′
37°N
50′
40′
125°W
45′
30′
15′
124°W
45′
10 km
13.0
12.5
12.0
11.5
SST [∘C]

4/27/2023 PRISM chlorophyll and POC




SST, 2023-04-16 21:50
38°N
30'
37°N
30'
36°N
20'
125°W
40'
20'
124°W
40'
20'
10 km
12.5
12.0
11.5
11.0
SST [∘C]

California flooding Spring 2023



High river discharge (happens once every few years)

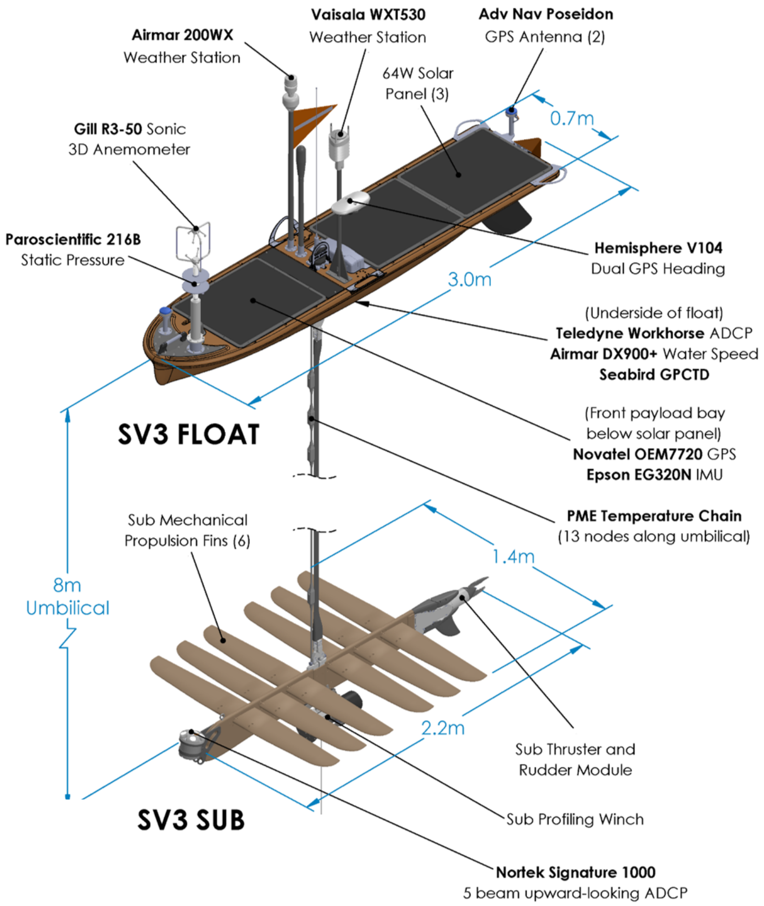
Autonomous platforms with ADCPs

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*.

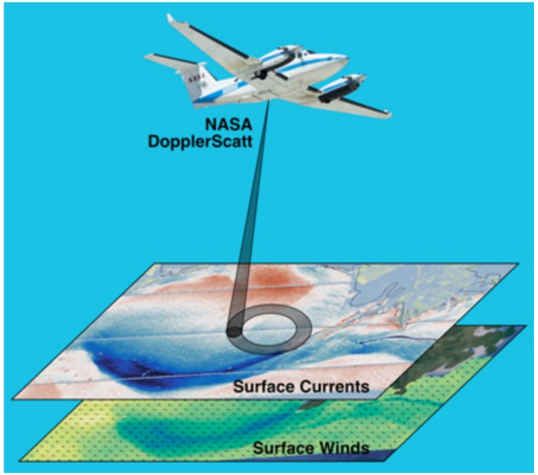
- Sub position, movement and pressure: IMU/pressure sensor, *Nortek Signature 1000*.



Grare et al., 2020; Hodges et al., 2023; Peyriere et al., in prep

Aircraft remote sensing measurements of surface currents

NASA JPL DopplerScatt



SIO 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.