S-MODE IOP-1 Field Report #1: Oct 6-16, 2022

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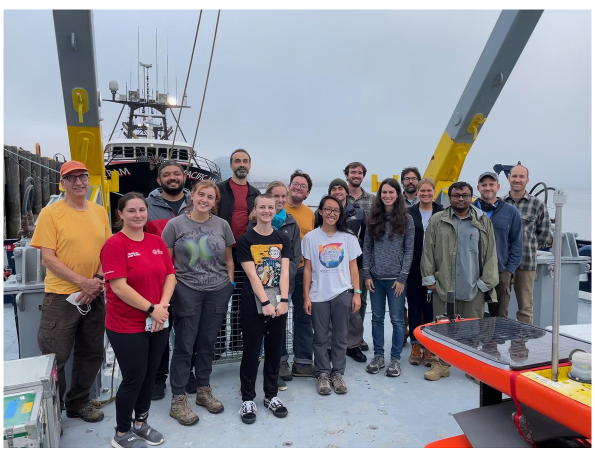
Science Highlights:

The study region has been beset by dense, low stratus cloud cover since the start of the experiment, limiting the amount of high resolution satellite sea surface temperature (SST) and ocean color data available to guide site selection. The science team used ocean model forecasts and lower resolution measurements of sea surface height (SSH) and microwave SST measurements to identify regions favorable to oceanic frontogenesis, and they conducted surveys with the autonomous platforms (gliders, Wave Gliders, and Saildrones) to identify specific fronts before the ship and B200 arrived to the study region around October 9.

We found some really nice fronts and set up the autonomous surface vehicles (ASVs, Wave Gliders and Saildrones) in formations to measure submesoscale gradients near and across the front.

M/V Bold Horizon (Chief Scientist: Andrey Shcherbina, UW)



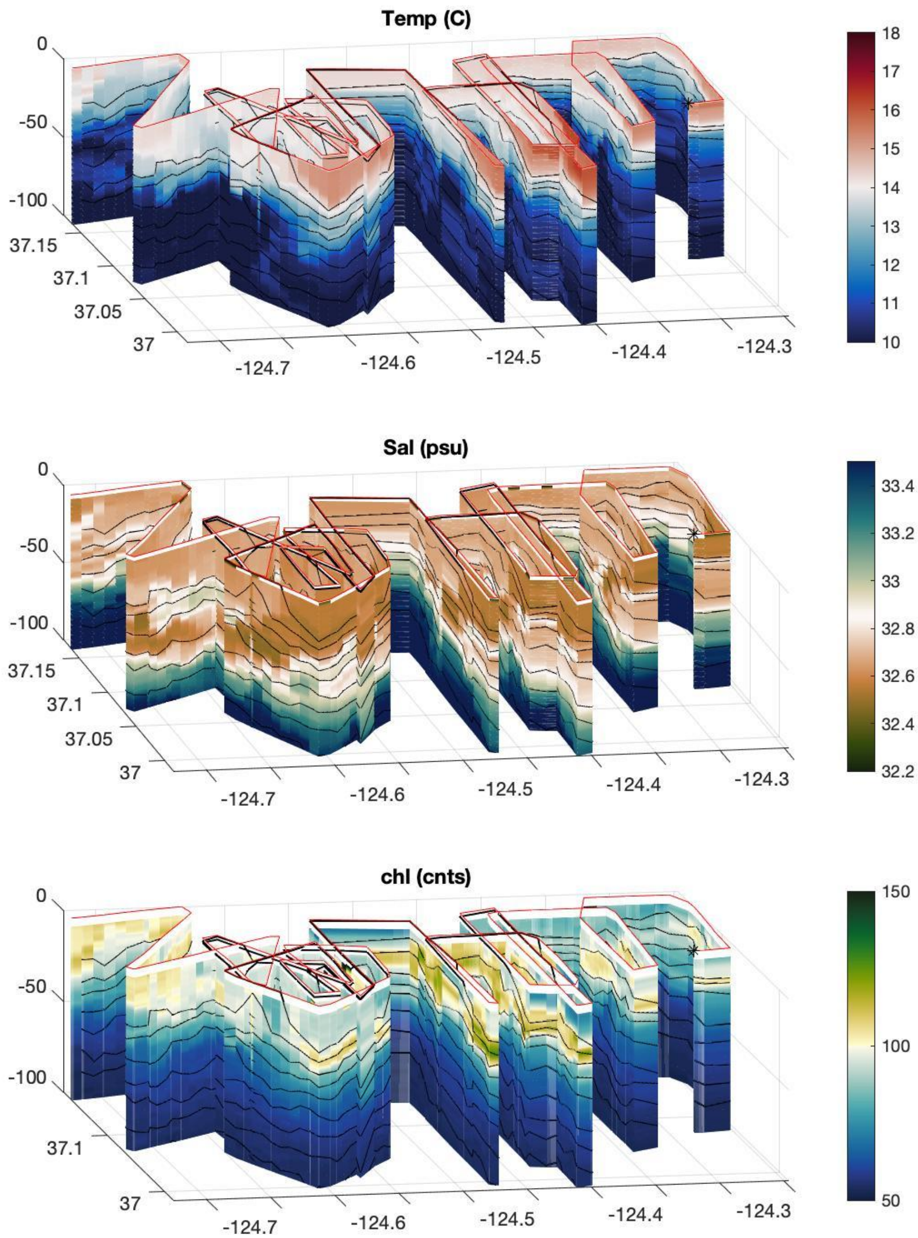
M/V Bold Horizon Science Party

EcoCTD night operations on the deck of the Bold Horizon

Mobilization for the M/V Bold Horizon began on Monday, October 3 in Newport, OR. In addition to the loading of cargo onto the deck and setting up lab spaces below deck, a large assembly housing an Acoustic Doppler Current Profiler (ADCP) and a Trackpoint was installed in the ship's moon pool in order to collect underway data. The science party set sail on October 7 and began science operations in the experimental region on October 9.

- The 16 people in the S-MODE science party on the Bold Horizon run 24/7 science operations with half of the people on the day shift and half on the night shift. In addition to performing along track surveys of the ocean, the ship has recovered and deployed gliders, and deployed and recovered Lagrangian floats.
- A flow-through system with hyperspectral optical properties, a phytoplankton camera and other bio-optical sensors was installed during ship mobilization and has been operating continuously. A

hyperspectral radiometer was installed on the bow. The biology team has collected over 300 samples (for Chl, POC, community and pigments) from the underway system, in addition to four Conductivity, Temperature, and Depth (CTD) casts, so far. The in-situ sampling and flow-through system has been working extremely well. The team is well-trained and in good spirits. All we need are clear skies!



EcoCTD surveys conducted on Oct 14 and 15 from the Bold Horizon - mapping a strong density front.

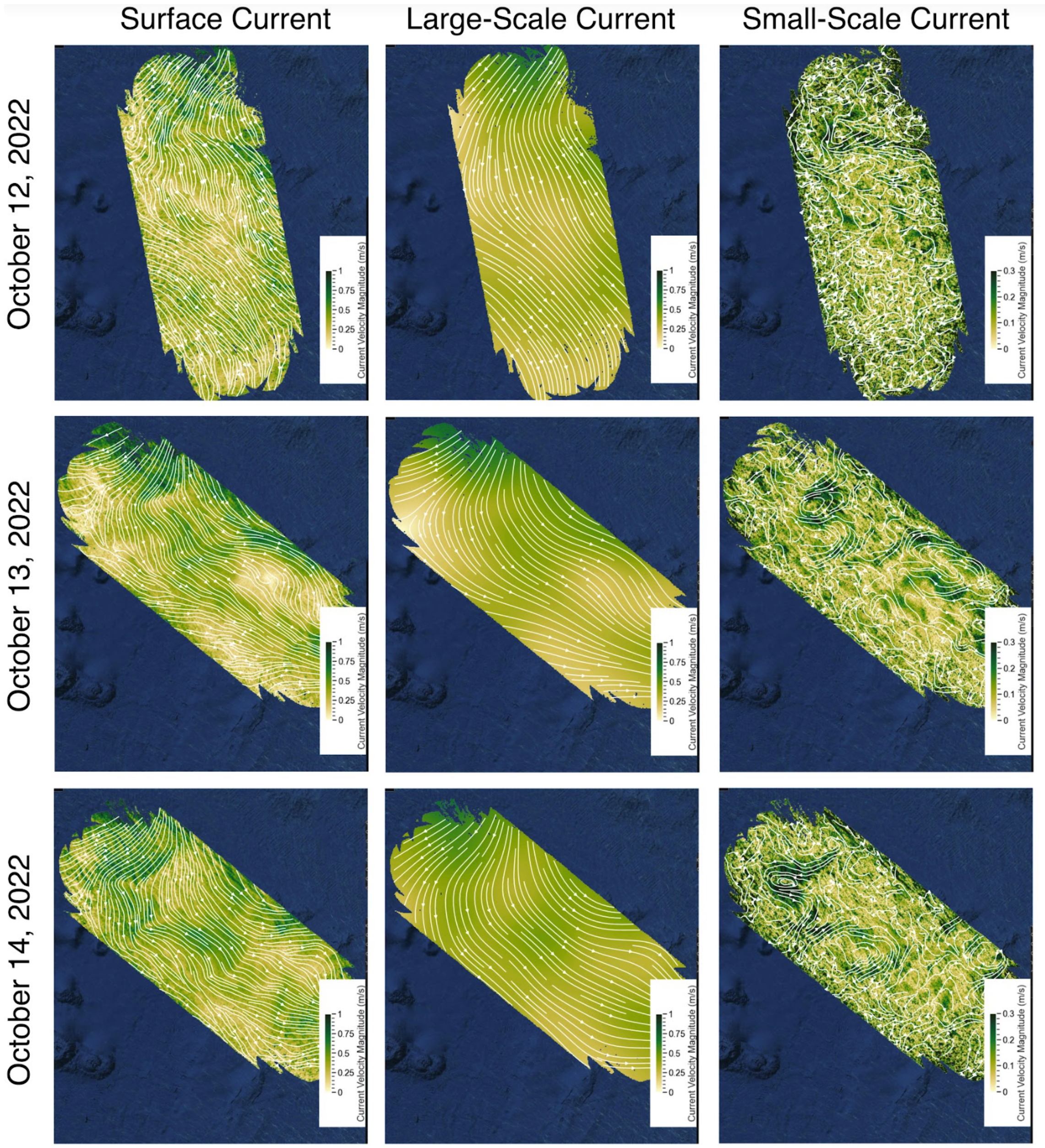
DopplerScatt (PI: Dragana Perkovic-Martin, JPL), MOSES (PI: Jeroen Molemaker, UCLA)

AFRC B200 arriving at NASA Ames on Oct 6

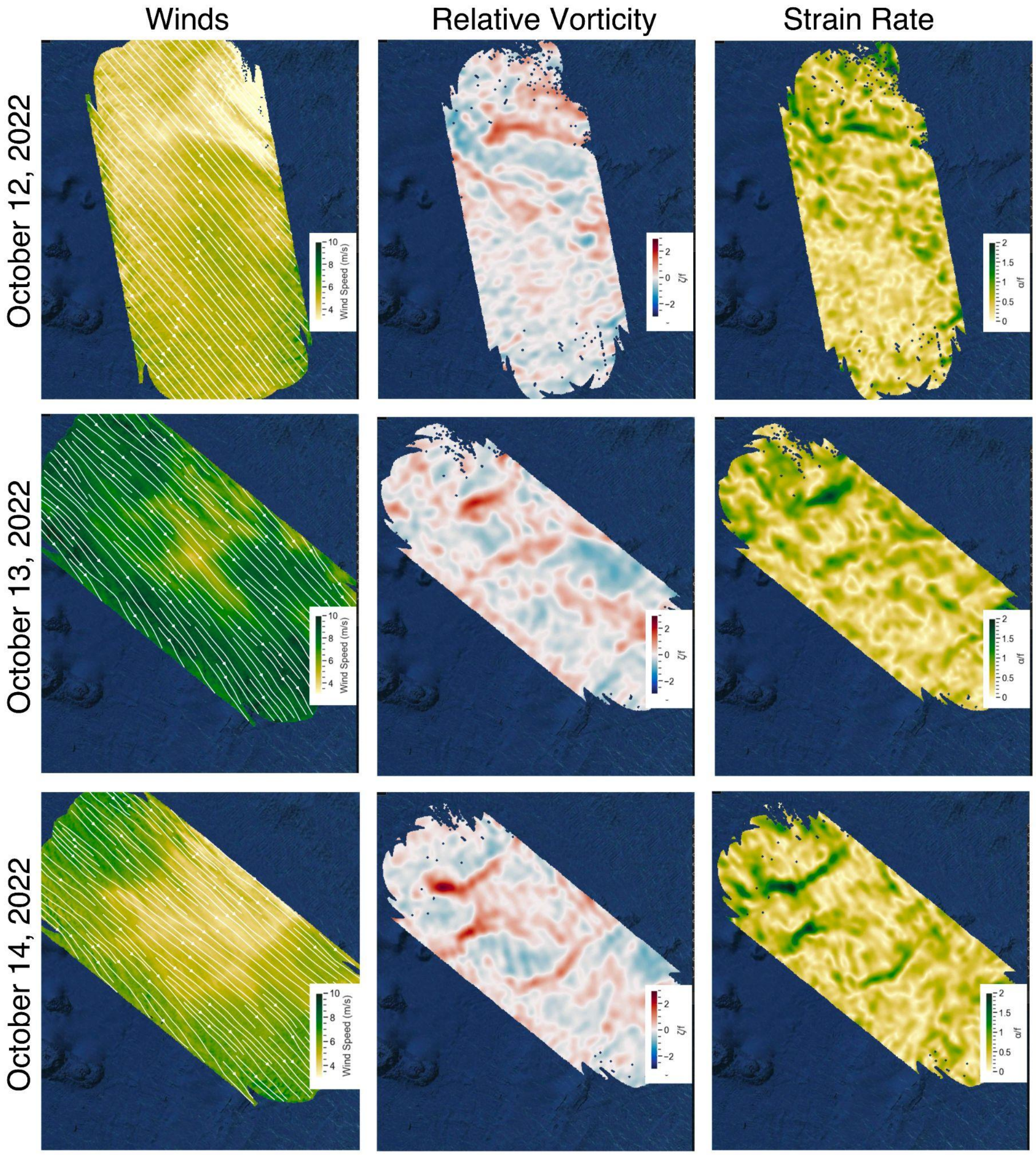
JPL, UCLA, AFRC, and ARC S-MODE team members

The Armstrong Flight Research Center (AFRC) B200 arrived at Moffett Field/NASA Ames Research Center on Thursday, October 6 and has completed eight science flights since arrival, including a two-flight day on Tuesday, October 11. This fulfills the mission-level requirement to collect at least 7 surface current datasets over an area greater than 50km. The UCLA Multiscale Observing System of the Ocean Surface (MOSES) instrument has been hindered by a persistent low cloud deck over the S-MODE operations area only collecting one ocean-viewing data set. The team is hoping for better weather conditions in the coming weeks.

- JPL DopplerScatt has already collected over 30 hours of data in the first 10 days of S-MODE. As demonstrated in the Pilot and now continuing in IOP-1, the DopplerScatt data processing team, led by Ernesto Rodriguez and Alex Wineteer, are producing surface velocity maps of the ops area. The quick-look images are being used by the broader science team to target features of interest for the ship and autonomous vehicles.
- DopplerScatt is able to collect synoptic snapshots of the ocean surface currents (125km x 50km) over a period of hours, a capability only possible with a wide swath Doppler scatterometer. By collecting the same tracks repeatedly over days, one can see the evolution of surface features, from large-scale to submesoscale. The image below shows the evolution of the flow field over a period of three days over our target region. The column to the left shows the total current stream lines during the DopplerScatt overflights. By low-passing (middle column) and high-passing (right column) the images, one gains an understanding of the contribution of the smooth large-scale flow, and of the evolution of the submesoscale features. For instance, in the left column, one can see the generation of a small (O(10km)) eddy, and its advection by the mean flow. These are the types of features S-MODE is designed to measure.



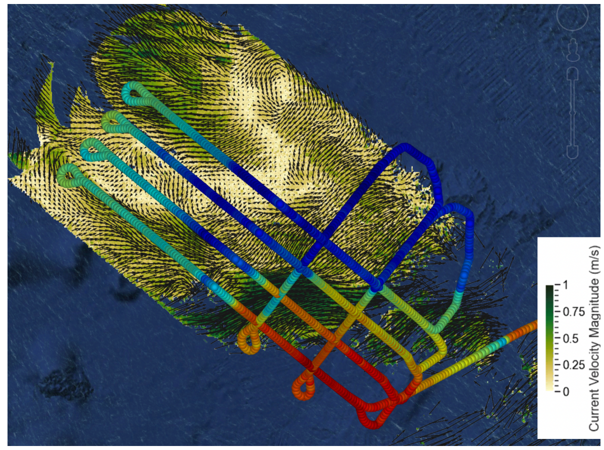
- In addition to surface currents, DopplerScatt measures surface winds, which aids in the study of air-sea interaction. At much larger scales, there have been model and satellite observations between the changes in the wind (or surface stress) and the circulation, but the scale at which these happen has not been possible to measure prior to Doppler scatterometry. One way to look at the effect on the circulation is to look at the relative vorticity (tendency of a water packet to rotate) and lateral strain rate (tendency of a water packet to deform). In the following picture, we show wind speed and direction (left column) together with the relative vorticity (middle column) and lateral strain rate (right column), both divided by the Coriolis frequency. Values O(1) are indicative of potential submesoscale activity. There is a clear relationship between areas where the wind magnitude changes significantly to areas of increased lateral strain rate and relative vorticity. These deformations are indicative of the potential formation of submesoscale features.



MASS (PI: Luc Lenain, Scripps)

The Scripps Modular Aerial Sensing System (MASS) instrument was installed on the Twin Otter in Grand Junction, CO and arrived in Watsonville, CA on Wednesday, October 5. Although the first week of campaign did not present conditions conducive to MASS data collection, the team has flown one calibration flight (over terrestrial target for boresight calibration of the optical sensors) and two science flights to date including one on Sunday, October 16 where coincident data was collected with DopplerScatt installed in the B200.

Twin Otter aircraft on the ramp in Watsonville, CA field

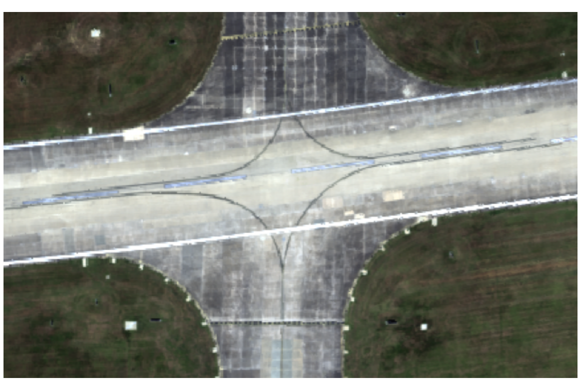


MASS quick SST data overlaid on a DopplerScatt surface velocity from coincident flights on Oct 16

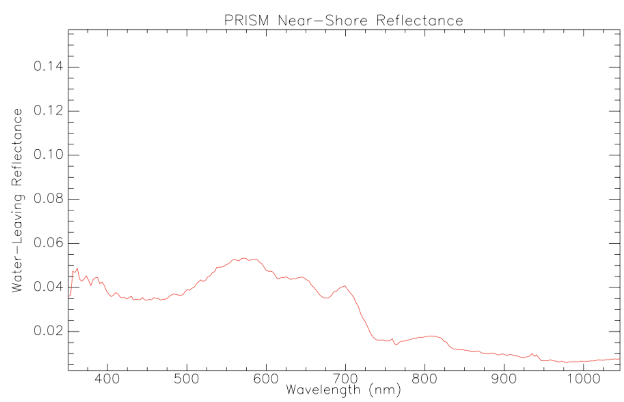
PRISM (PI: David Thompson, JPL)

After a brief weather hold, the LaRC G-III arrived at Moffett Field on Sunday, October 9. Before arrival, the team has tested out orthorectification, generation of quicklook chlorophyll data products, and the surface reflectance retrievals.

- Surface reflectances look good, and a more quantitative validation activity is underway. The team made an opportunistic overflight of Railroad Valley, NV during the transit. This site contains automated in situ instrumentation for calibration and validation of optical instruments. The resulting dataset can also validate the instrument radiometric calibration.
- The team assessed orthorectification over Langley airfield. This confirms that the resulting image is rectilinear (lines appear straight) and that the well-known coordinates of ground control points are correctly represented in the projected image. The team assessed geolocation accuracy to be 10 m or better.



PRISM Orthorectification test over Langley airfield



PRISM Water-leaving reflectance spectrum

- While deployed at Moffett Field, the G-III has attempted two science flights with the JPL Portable Remote Imaging Spectrometer (PRISM) instrument. However, conditions were cloudy and to date the instrument has only been able to find a few patches of clear sky in the S-MODE operations area.

LaRC G-III in hangar N248 at NASA Ames

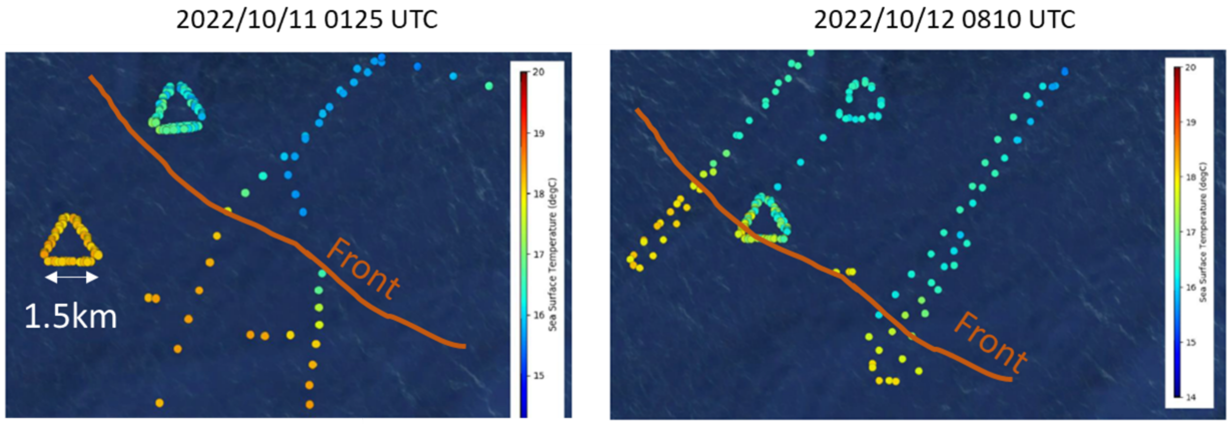
PRISM G-III postflight briefing on Oct 14

Wave Gliders (PIs: Tom Farrar, WHOI; Luc Lenain, Scripps)

A total of 8 Wave Gliders were deployed as part of the project. Seven Wave Gliders were deployed from the R/V Shana Rae off Santa Cruz at the end of September and made their way to the operation area, while the 8th one was deployed from the R/V Bold Horizon once it arrived at the site.

One of the “SV3” Wave Gliders being loaded on the R/V Shana Rae prior to deployment on September 21, 2022

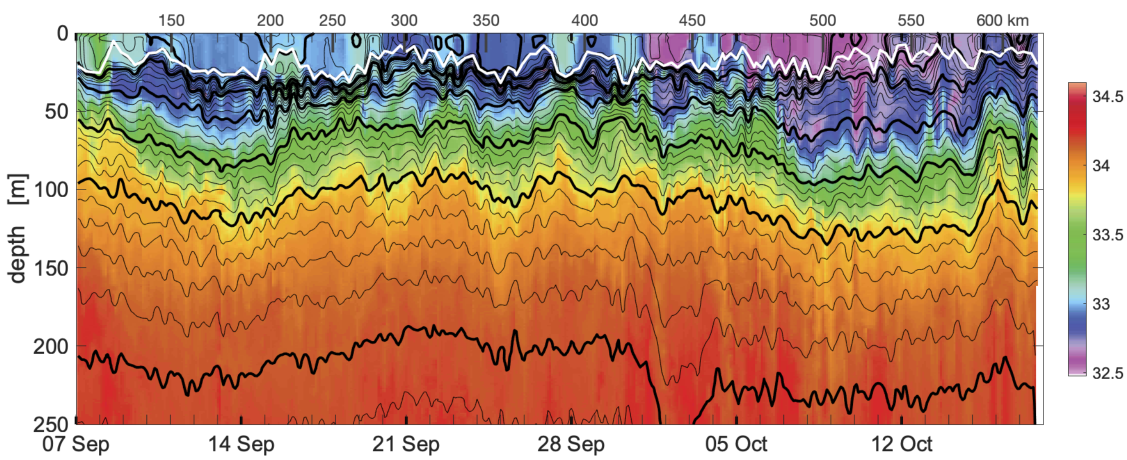
These instrumented autonomous vehicles are used to conduct both large-scale surveys (10-40km transects or racetracks) of the region to identify submesoscale features, along with tight formations (triangular array) at km scale to characterize upper ocean dynamics. Early on October 10, 2022, two of these arrays were placed on both sides of a submesoscale front, a few kms apart. The front was observed from these two arrays as it sloshed back and forth (see figure).



Example of SST collected from the Wave Gliders operating in both tight formation (fixed triangular arrays) and surveying (long transects) as the edge of a submesoscale front moves to the south of the domain on October 11.

Seagliders (PIs: Luc Rainville, Craig Lee, UW)

Six autonomous underwater Seagliders were deployed on 23 and 24 August 2022 from the charter Shana Rae, out of Santa Cruz. One of the gliders (SG248) was recovered promptly because of a bent rotor, making heading control difficult. The five S-MODE Seagliders transited offshore along two parallel lines, arriving in the operation area around 5 September.



Depth-time series of absolute salinity from SG247, since entering the S-MODE area. Isopycnals are contoured in black (0.1-intervals, 0.5 kg m^{-3} in bold), mixed layer depth is shown in white. Note that only the top 250m are shown (gliders sample to 1000m). Cumulative distance since deployment is labeled on top.

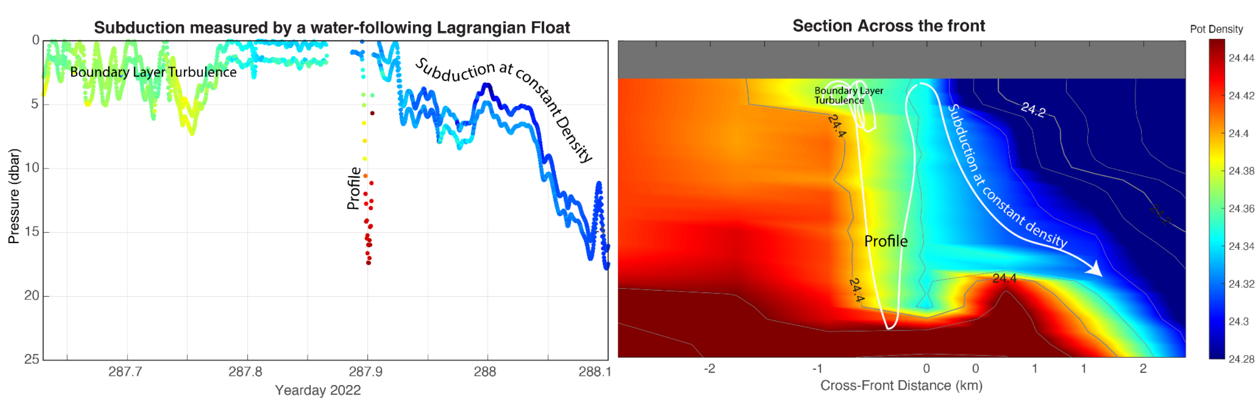
One of the gliders developed a problem with its buoyancy system, and was eventually recovered by R/V Bold Horizon on 9 Oct. The ship also redeployed SG248 on 9 Oct, maintaining the S-MODE Seaglider array to five vehicles.

Before the beginning of the IOP, gliders occupied a smaller pattern of three 40-km long parallel lines separated by 10km. Since the arrival of faster autonomous and ship assets sampling frontal regions with greater time resolution, gliders have been occupying ‘mesoscale’ sampling patterns in the S-MODE region, generally three parallel lines 50km long separated by 25 km. Gliders are reporting ocean properties (temperature, salinity, chlorophyll, oxygen, optics) in real-time, while ADCP and microstructure (on 3 of the gliders) are recorded onboard. Outputs for quality-controlled, real-time data for the latter are being developed.

Lagrangian Floats (PI: Eric D'Asaro, UW)

We have made two deployments of 3 Lagrangian floats. These floats are deployed and recovered from the ship with typical mission lengths of 2 to 4 days. The main goal of these deployments is to directly measure the vertical transport at submesoscale features and place this within the context of the feature structure as measured by other platforms.

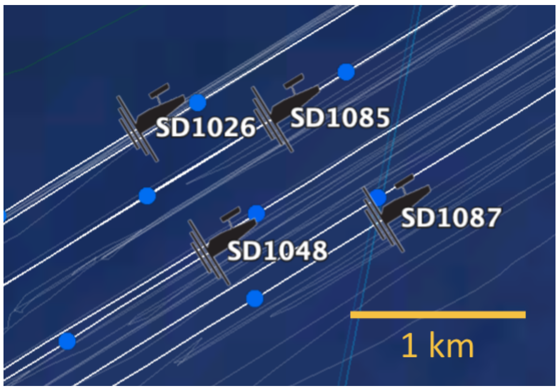
- The first deployment aimed to accurately calibrate the volume of the float using an equation of state that has been developed over the last few years. Due to a medical evacuation, this deployment was extended to 2.5 days and yielded an exceptionally good calibration; the volume of each float was estimated to an accuracy of better than 1 cc, and was stable over the entire deployment.
- In the second deployment 3 floats were deployed near a submesoscale density front mapped with a coordinated survey using the ship and autonomous platforms survey. As shown in the figure, the float drifts in the mixed layer carried vertically by the turbulence until the boundary layer dives under lighter water (bluer) on the other side of the front, reaching about 18m before it surfaces to communicate. This is a direct measurement of the submesoscale vertical transport.



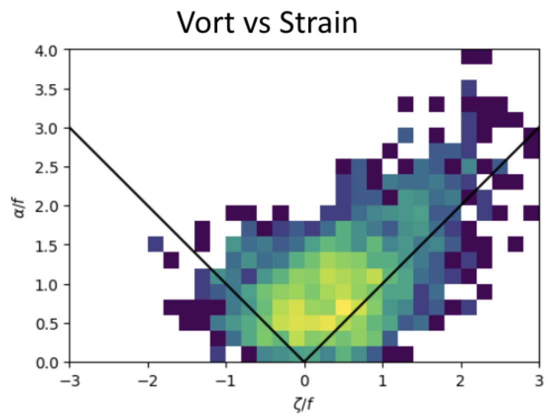
Saildrones (PI: Cesar Rocha, UConn)

- The campaign started with good wind conditions for sailing, and the four Saildrones spent the first 2.5 days performing a mesoscale survey to help pinpoint a strong frontal region for intensive submesoscale sampling.
- With a promising front identified, the Saildrones regrouped in quad formation, with 1 km spacing, and started occupying a 15-km transect, sailing back and forth across the front for about 3 days. This submesoscale sampling allowed us to continuously measure submesoscale velocity gradients as a function of depth in the upper 80 m.

- Preliminary statistics of submesoscale kinematic quantities (vertical vorticity, horizontal divergence and lateral strain rate) from Saildrones are encouraging. For example, the figure below shows a vorticity-strain joint-PDF, depicting positively skewed vorticity and a strong correlation between large vorticity and strain (1f to 3f), which are statistical footprints of a vigorous submesoscale field. Further analysis of horizontal divergence will lead to an indirect estimate of submesoscale vertical velocity.



The Saildrone quad submesoscale formation



A submesoscale vorticity-strain joint-PDF from Saildrone