S-MODE Science Report: Oct 17-24, 2022

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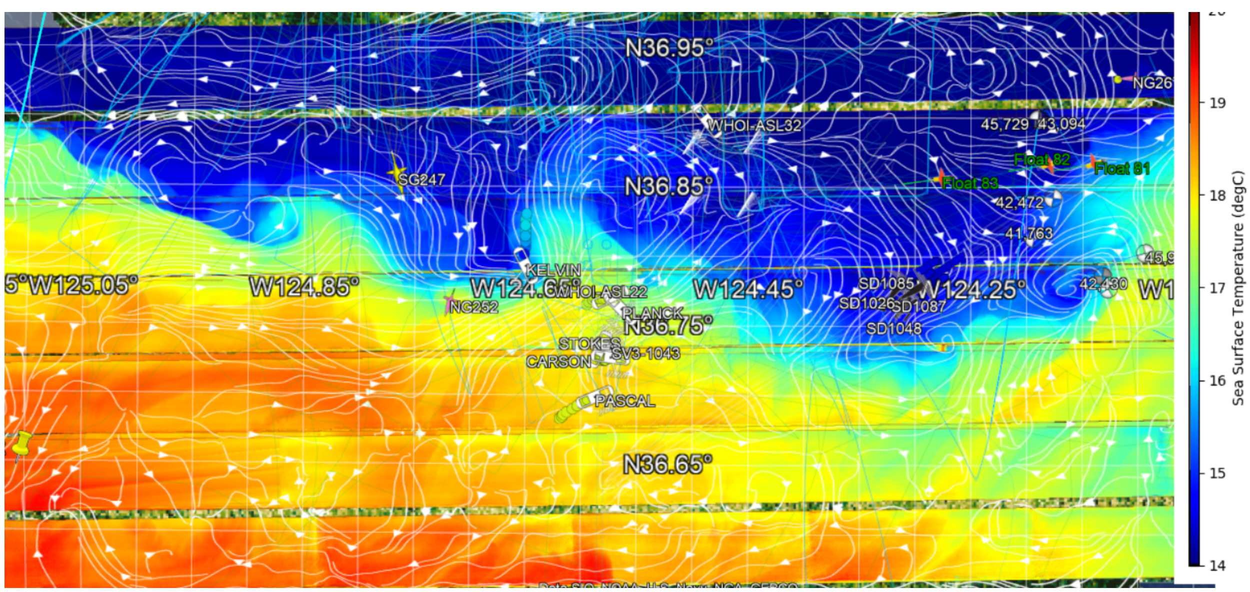
Science Highlights:

The science team has done a great job identifying and sampling a strong ocean front with developing submesoscale instabilities that have been well sampled by the ship, the Saildrones, the Wave Gliders, the Lagrangian Floats, the Twin Otter with MASS, the Armstrong B200 with DopplerScatt and MOSES, and the LaRC G-III with PRISM, all in a large-scale context set by the UW Seagliders and NAVO gliders. The data set from IOP-1 is extremely rich. The combination of early placement of in situ assets at a good site, clear skies, and skillful execution by the instrument and platform operators has allowed a data set that surpasses what we had hoped for when we envisioned S-MODE. It is difficult to choose a single image to summarize this situation, but the simultaneous imagery of sea surface temperature and ocean velocity streamlines (high-pass filtered) tells the story. The two "breaking waves'' seen in the left half of the image are about 20 km apart. Note also that the Wave Gliders, Saildrones, Seagliders, NAVO gliders, and the *M/V Bold Horizon* are collecting measurements in this field (though not all are visible in the image).



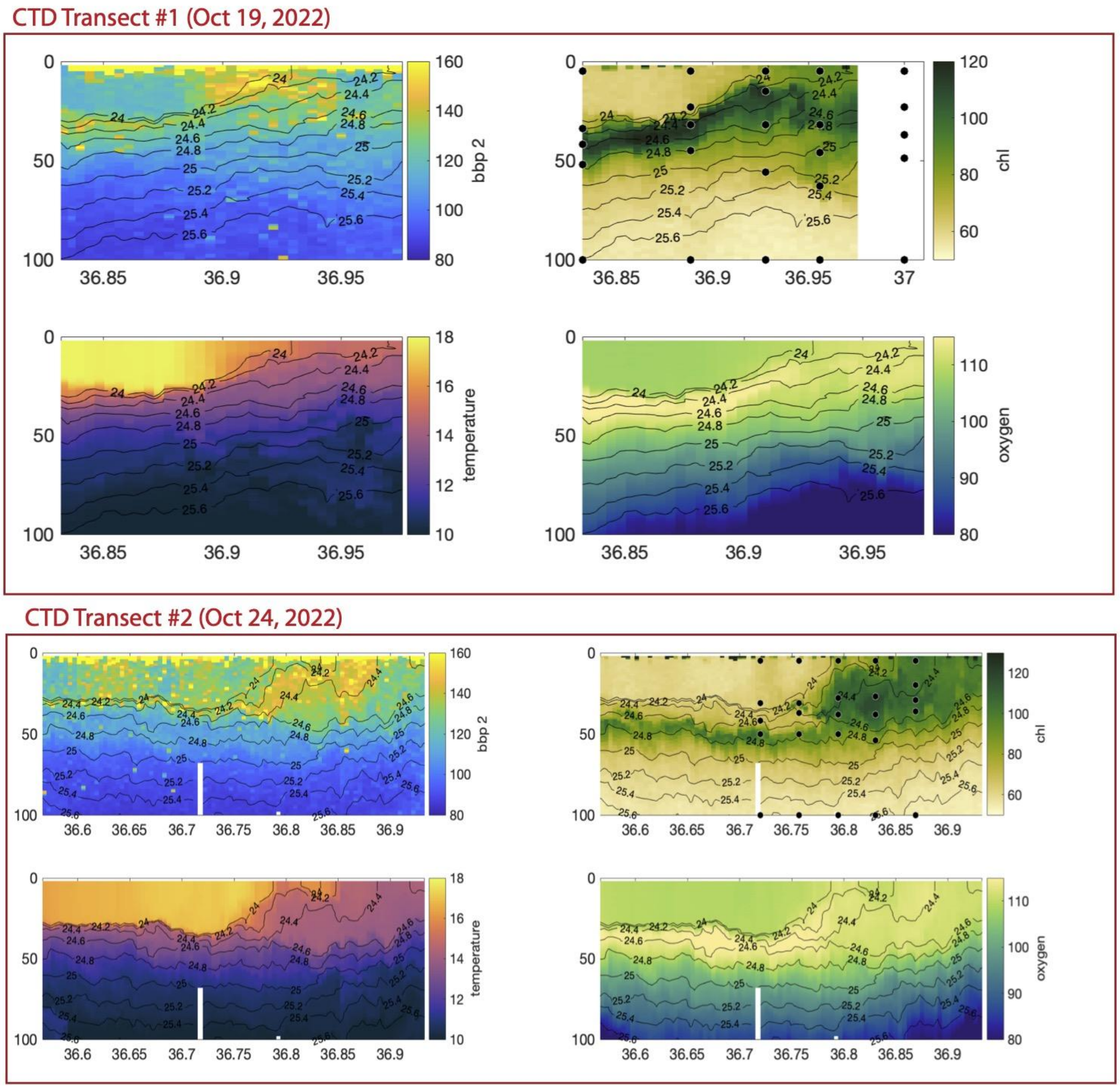
MOSES SST (colors) with coincident DopplerScatt streamlines, with several developing submesoscale eddies observed during a B200 flight on Oct 24, 2022.

M/V Bold Horizon (Chief Scientist: Andrey Shcherbina, UW; Biology Lead: Melissa Omand, URI)

- *M/V Bold Horizon* spent the week surveying on long transects in the vicinity of the front, which sharpened dramatically during the week.
- The BH team also deployed and recovered the Lagrangian floats multiple times and completed three drift surveys over the week, helping to meet one of the Level-1 requirements.
- The biology team on the BH has continued doing intensive underway sampling during days with either PRISM or MASS flights, in addition to opportunistic intercalibration samples near

autonomous assets. They have completed two high resolution CTD transects across the front, with water depths targeted by the EcoCTD.

- Coordinated radiometric and bottle sampling were conducted during fly-overs, with a longer BH transect beneath the MASS flight path on Oct 19th.



EcoCTD transects of bio-optical properties (backscatter, Chl-F, upper panels) with temperature and oxygen (lower panels) during the two high-resolution CTD transects. Black dots indicate the targeted locations of water samples).

Left: Chief Scientist Andrew Shcherbina (UW) leads the daily science meeting on the Bold Horizon. Right: Bold Horizon science party preparing a Lagrangian Float deployment.

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

- The AFRC King Air B200 had another busy week completing six flights since last Sunday and an additional 20 hrs of science data collection. The DopplerScatt team performed an operator swap and continues to operate nominally.

Left: Delphine Hypolite (UCLA) and Federica Polverari (JPL/UCLA) ready for joint MOSES and DopplerScatt data collection. Right: B200 air and ground crew post-flight October 23rd.

- One of the main purposes of the DopplerScatt instrument is to provide synoptic information regarding the ocean circulation to aid the deployment of in situ targets and to provide the oceanographic context for other smaller scale observations. The daily DopplerScatt maps have served this purpose very well.
- The strategy of DopplerScatt and MOSES working together on the AFRC B200 was to provide complementary observations of the ocean circulation at synoptic scales. A few days of good weather allowed this to happen and coincided with the development of a spectacular feature: an ocean front forming and then breaking up into submesoscale instabilities. This is one of the processes targeted by the S-MODE science goals. A view of this instability development integrating data from both instruments is shown in the first figure below.

- The ability of DopplerScatt to collect high resolution synoptic measurements allows for ways of characterizing the ocean circulation not possible from point measurements; e.g., characterizing streamlines, separating large and submesoscale circulation and examining the impact of dynamical variables, such as the relative vorticity and strain, both of which involve calculating spatial derivatives, in generating submesoscale circulation. The following three figures illustrate this potential in mapping the instability feature observed on October 23 and 24.

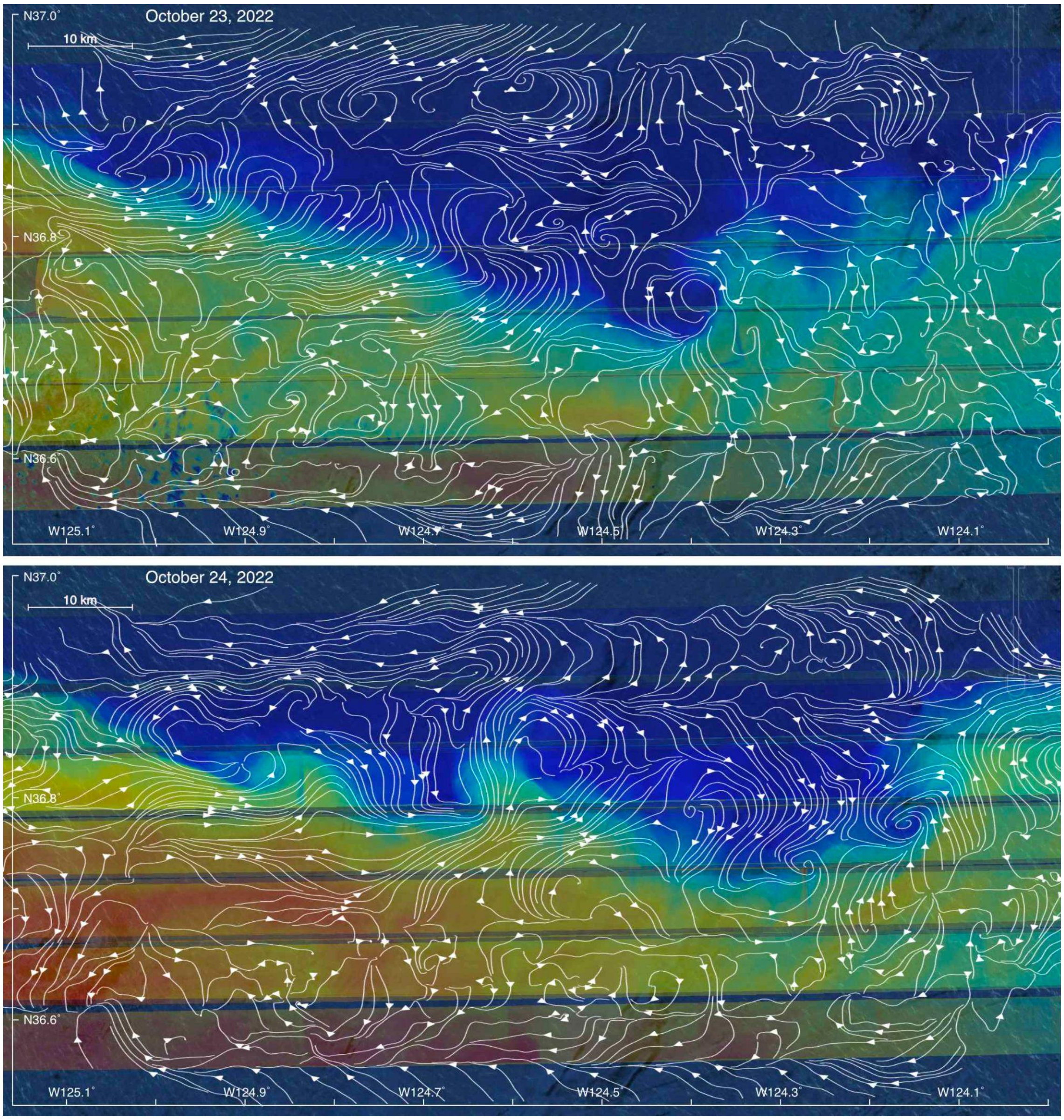


Image of MOSES sea-surface temperature (SST) overlaid with DopplerScatt submesoscale current streamlines. Warmer/cooler colors indicate warmer/cooler SST (still uncalibrated). Note that two frontal instabilities develop (center-left, middle) in a very short time and the SST and submesoscale currents present a consistent scenario. The swath each day is approximately 100 km in the East-West direction and 50 km in the North-South direction.

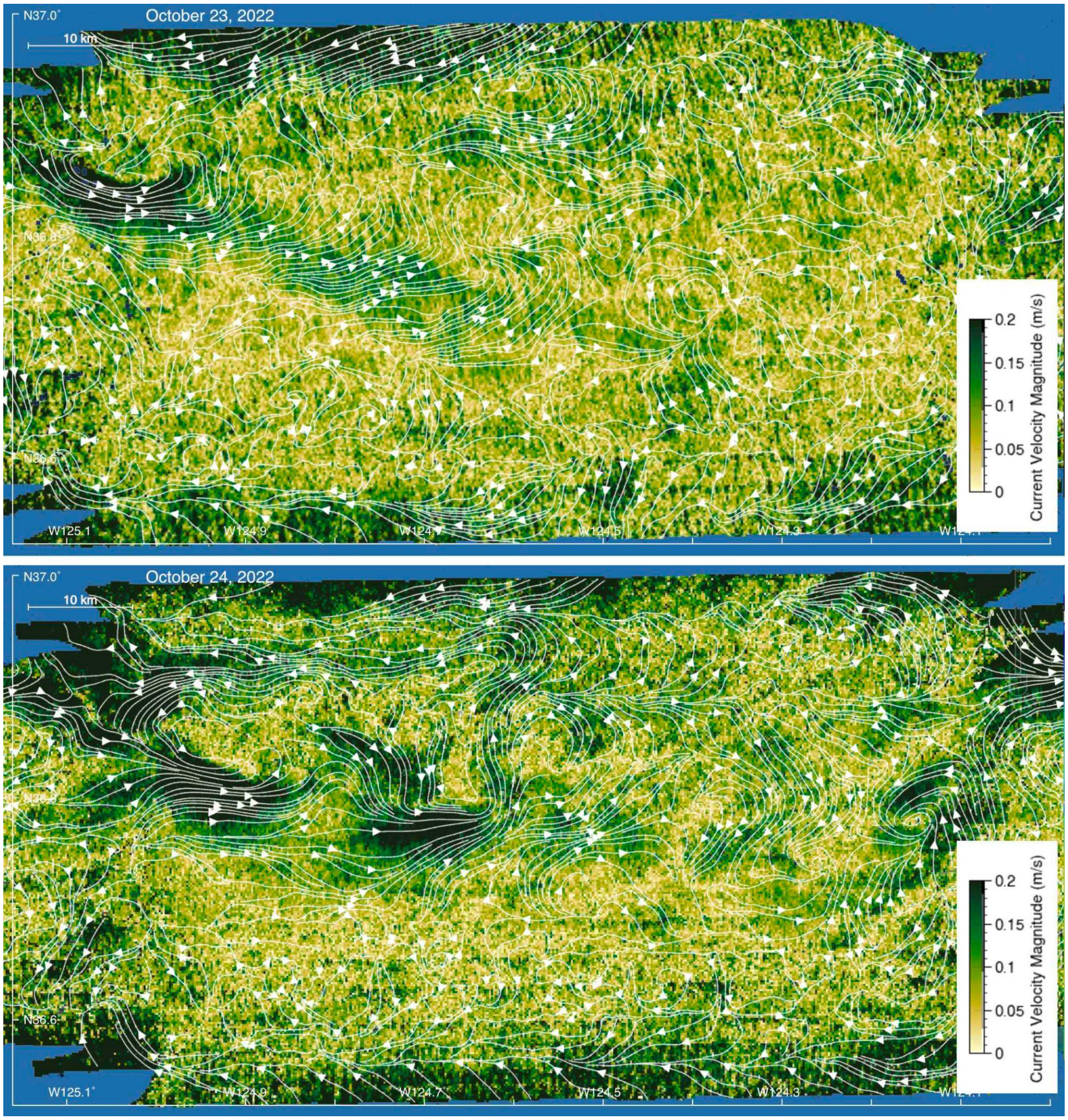


Image of the DopplerScatt submesoscale (scales < 15km) speed and streamlines on October 23 and 24. Notice the rapid increase in the surface current speed at the evolving instabilities. (The image has the same extent as the previous one.)

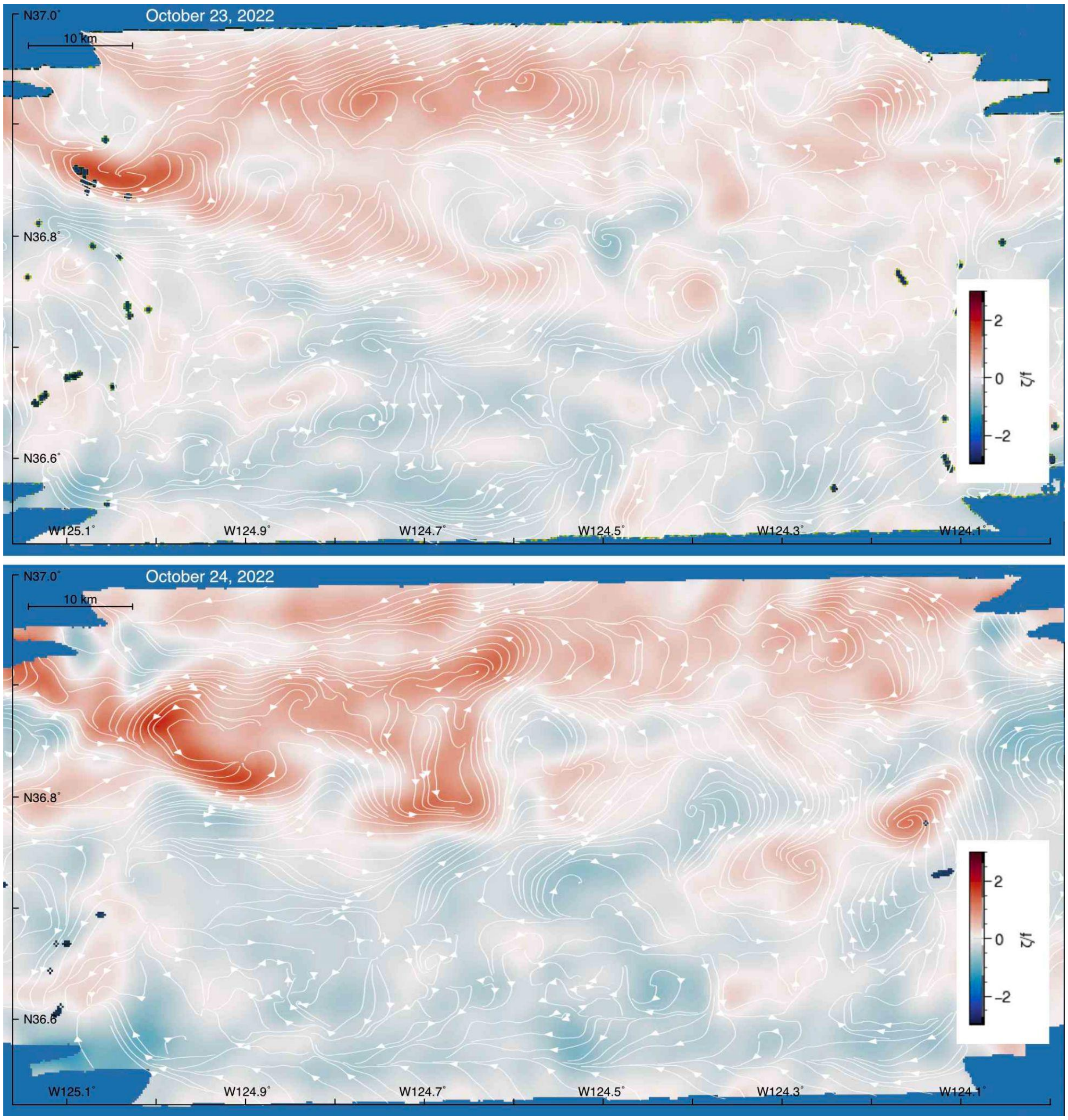


Image of the DopplerScatt total relative vorticity (water parcel rotation magnitude and direction) divided by f, the Coriolis parameter (~1/20hrs), on October 23 and 24. Values of f near or greater than 1 indicate strong submesoscale activity. Notice the significant increase in vorticity at the instabilities between the two days. Also notice the correlation between total relative vorticity and the submesoscale circulation, indicating the dominant influence of submesoscale processes in generating these events. (The image has the same extent as the previous one.)

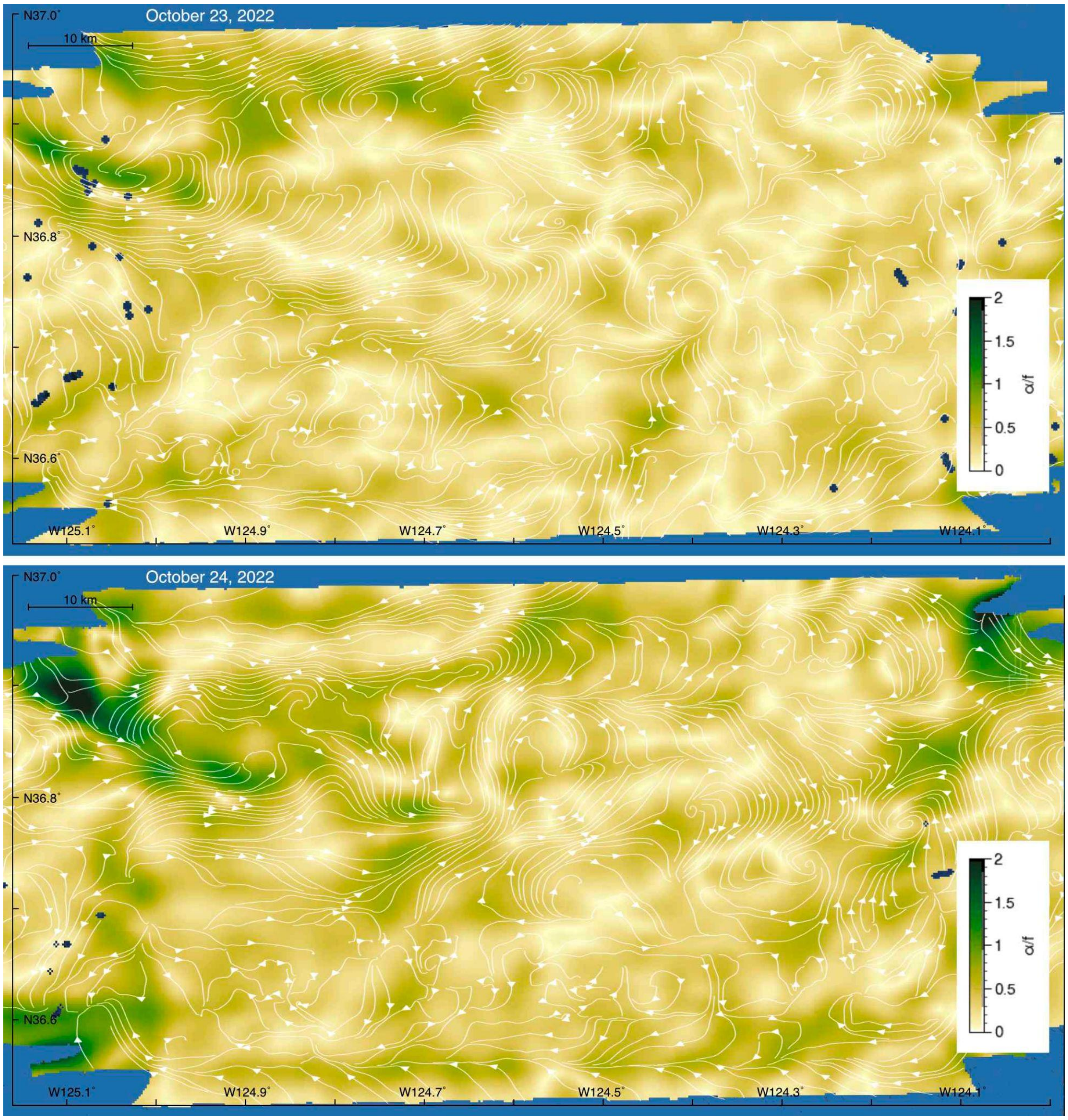
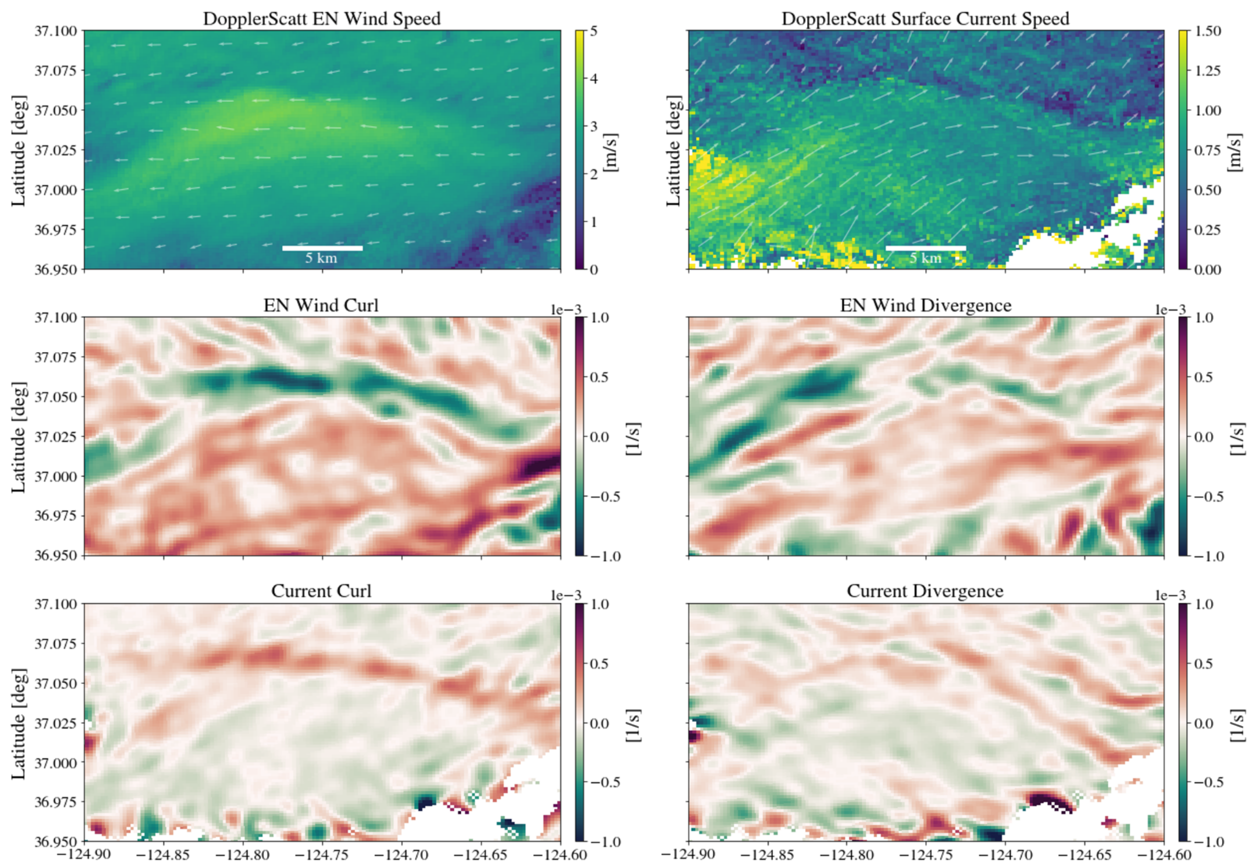


Image of the DopplerScatt total lateral strain rate (water parcel deformation) divided by f, the Coriolis parameter (~1/20hrs), on October 23 and 24. Notice the large increase in the strain at the growing instabilities, and the associated shear and normal strain rate deformation implied by the submesoscale current streamlines. (The image has the same extent as the previous one.)

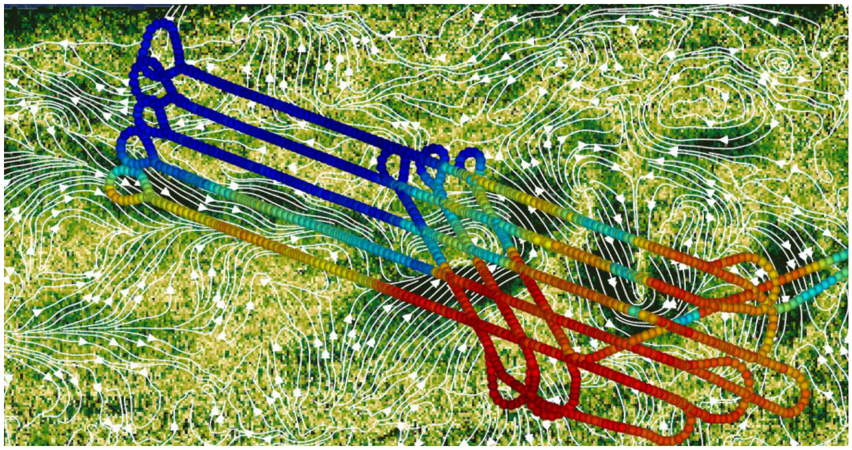
- DopplerScatt measurements of stress equivalent neutral wind speeds and directions, when combined with its simultaneous measurements of ocean vector currents allow for the observation of dynamic coupling between the wind and current. As shown in the below figure, negative EN wind curl is associated with positive surface current curl, at kilometer scales, with near instantaneous wind stress response to a sharp surface current front. A similar anti-correlation is visible in divergence fields. These very strong wind stress curl and divergence features O(f) also have implications for the strength of ocean and atmosphere vertical transport, which respond to the magnitude of these derivative fields.



Air-sea interactions observed from DopplerScatt measured equivalent neutral winds and currents. A strong anti-correlation is apparent between derivatives of EN winds and currents, indicating a dynamic coupling between the ocean and atmosphere.

MASS (PI: Luc Lenain, Scripps)

After a week of uncooperative weather conditions, which only saw two Twin Otter research flights, the Scripps MASS instrument flew 6 of the 7 days this week, with flight times averaging ~6.5 hours each. The MASS ties the S-MODE project together with its DoppVis instrument that provides surface velocity measurements, which complement DopplerScatt data, also capturing high-resolution of the modulation of surface wave properties and mean squared slope (MSS) across the submesoscale features we have been targeting, along with ocean color measurements that support PRISM and that supplement the ship’s biology data.



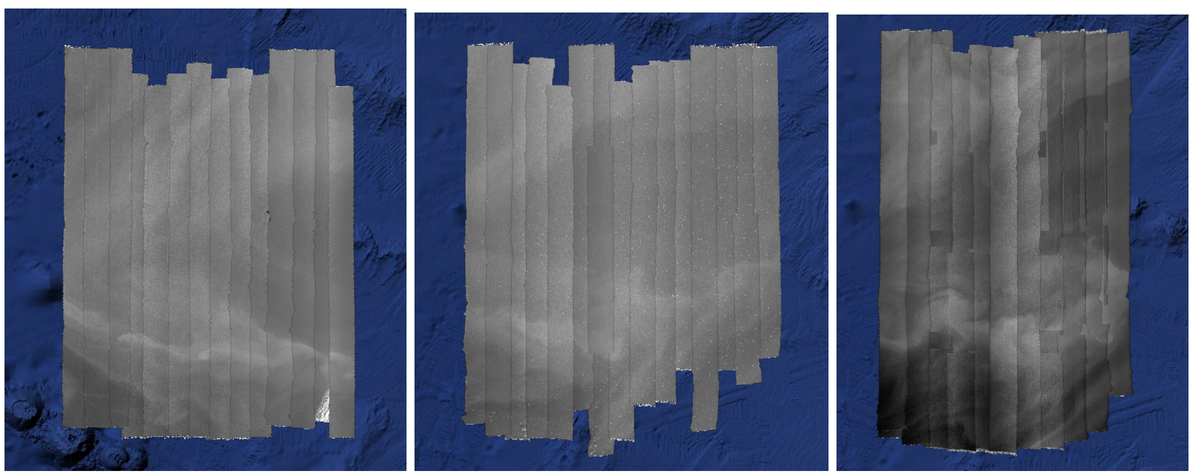
MASS SST data from the S-MODE flight on Oct 25 collocated with DopplerScatt surface currents. The sharp SST changes are at times collocated with strong modulation of MSS and surface wave properties as shown in photos below.

Surface signatures of wave-current interaction at the edge of fronts on October 25 2022. Note the enhanced breaking on one side of the front

Twin Otter and MASS crew after the sixth MASS flight of the campaign on Oct 21.

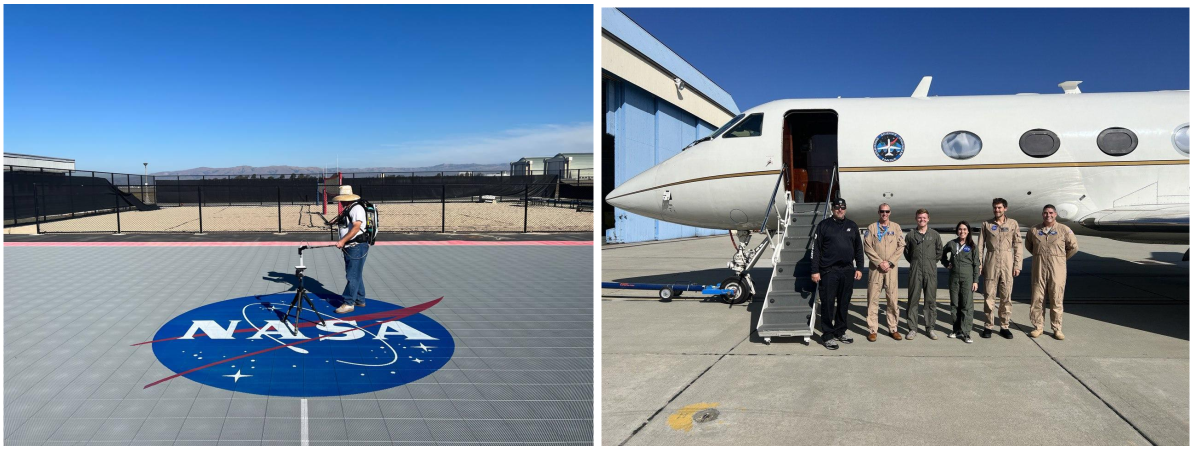
PRISM (PI: David Thompson, JPL):

PRISM flew on 19, 21, 23, and 24 October. Initial data quality looks cloudy for Oct 19, but good for Oct 21, 23 and 24. Example mosaics appear below. These three mosaics show a chlorophyll index, the ratio of 550 and 490 nm bands, as a "quick look" indicator of phytoplankton. Future versions of these products, which will include atmospheric correction, glint removal, and radiometric recalibration, will reduce the appearance of mosaic seams. Prominent submesoscale structures are visible. These filaments follow currents identified by DopplerScatt. The quicklook products were produced within 24 hours and used to inform next-day flight planning. A partly-overlapping mosaic image on Oct 23 shows similarly prominent structures. The image on Oct 24 revised the sampling strategy, with a narrower box that was overflown multiple times to track the temporal evolution of these features.



Left: Mosaic of PRISM Chl-A (unitless index produced as a "quicklook" product with no glint or atmospheric corrections yet), October 21. Center: PRISM Chl-A index on October 23. Right: PRISM overflight on Oct. 24. The final sortie included multiple passes over key flightlines, revealing the temporal evolution of these structures over short timescales.

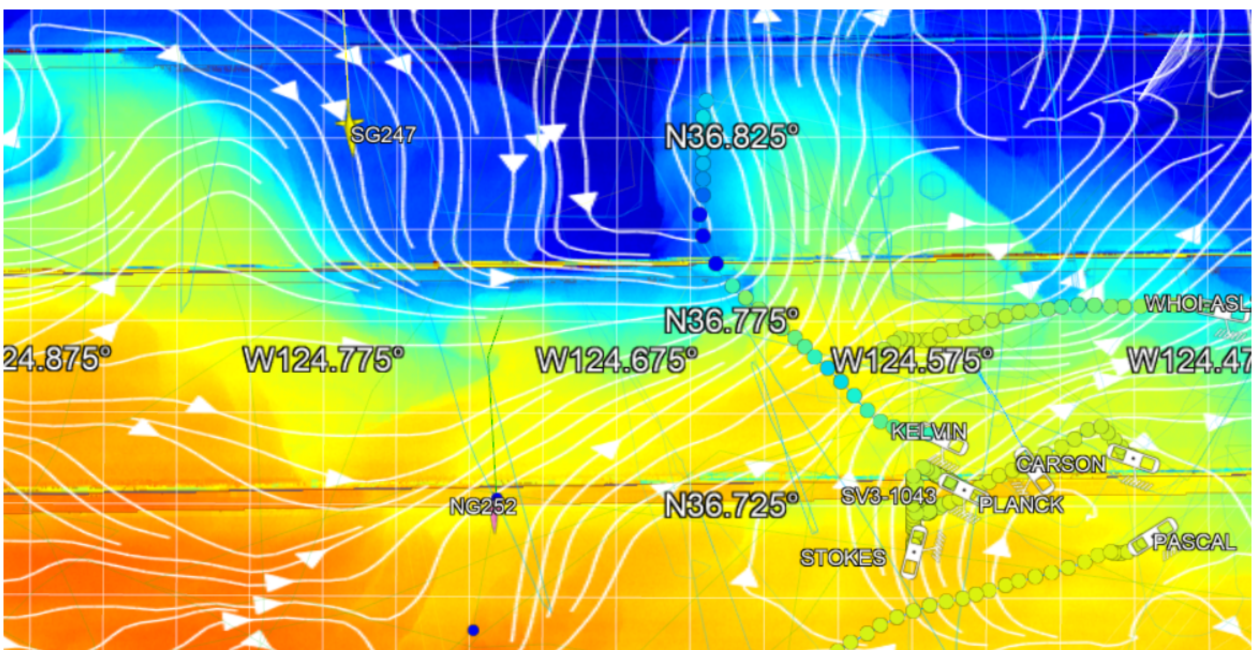
In addition to the science flights, the PRISM team conducted ground calibration experiments that will be used to calibrate the PRISM radiances. These included a "vicarious calibration" activity, in which PRISM team members acquired ground reference data from sites and then overflew them on a subsequent day. Reference surface reflectance data will be compared to the remote measurements and used to validate (and if needed, update) the PRISM radiometric calibration.



Left: Ground reference measurements of the NASA basketball court at Ames Research Center, by Mark Helmlinger. This and other locations around ARC will be used as opportunistic vicarious calibration sites. Right: PRISM team and pilots.

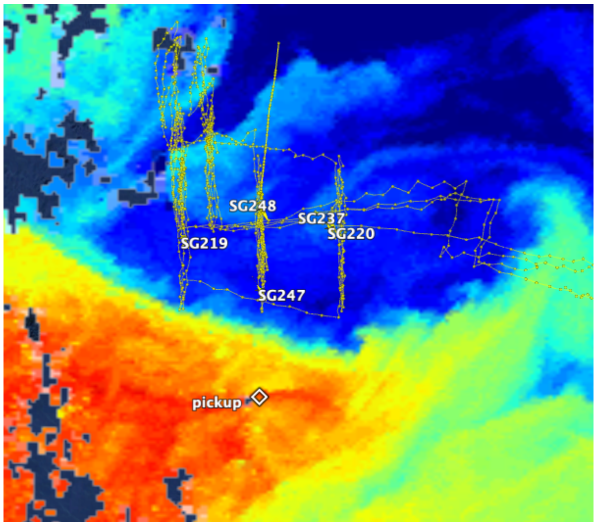
Wave Gliders (PIs: Tom Farrar, WHOI; Luc Lenain, Scripps)

The Wave Gliders have been measuring velocity and density gradients and have been helping to monitor and map the position of the front. The Wave Gliders maintained tight formations near the front to estimate vorticity and divergence as a function of depth, helping to meet one of the Level-1 requirements for S-MODE. The figure below shows their triangular ~1-km array pattern with SST and ocean velocity anomalies during a B200 overflight– a couple of hours later, the large meander to their west propagated by and blew them off of their position toward the northeast.



Seagliders (PI: Luc Rainville, UW)

For the last several days, Seagliders have been occupying 3 parallel lines, roughly spanning 50 by 50 km in the target region. As the front is moving south, the vehicles are now all extending their lines across the front. They will eventually gather in a point south of the main front to do a set of cross-calibration dives, and be recovered by the ship.



Tracks and positions of the 5 Seagliders (yellow dots) up to 24 October, overlaid on SST image from 2022-10-23 1750Z (METOPB).

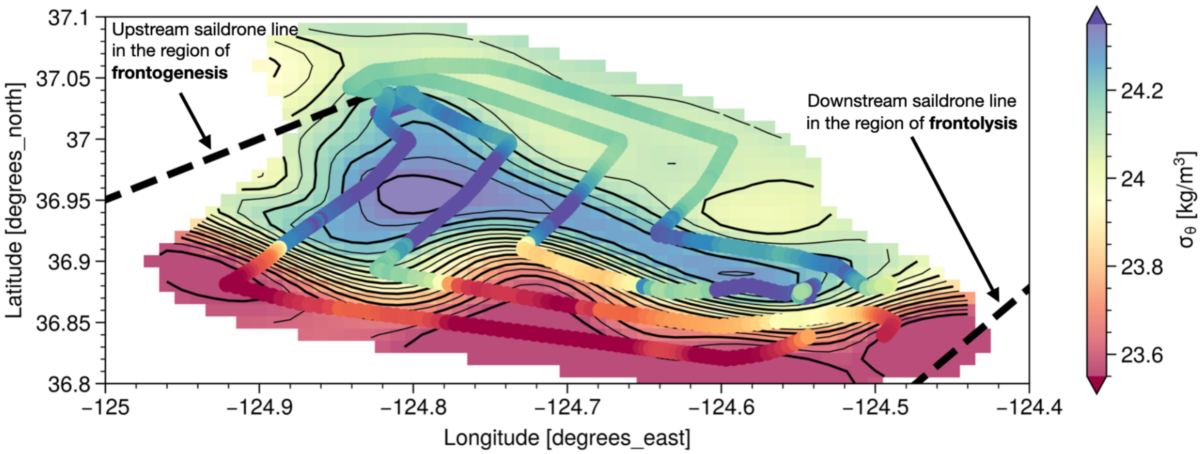
Lagrangian Floats (PI: Eric D'Asaro, UW)

The UW Lagrangian Floats completed three drift surveys this week fulfilling a major objective of the IOP-1 campaign to conduct submesoscale feature surveys and collect measurements of water-following (Lagrangian) trajectories.

Saildrones (PI: Cesar Rocha, UConn)

As reported previously, the Saildrones were sampling submesoscale velocity gradients west of the Wave Glider array, sailing back and forth across a front in a 1-km side quad formation. This upstream line was located in a frontogenetic region, where the background mesoscale strain field was sharpening the front. On October 19, we made a decision to move the Saildrones eastward to sample a region we suspected to be frontolytic. (SST images on October 23-24 further suggested that submesoscale instabilities were developing in that region.) While in transit, the Saildrones broke the formation to conduct a small mesoscale to submesoscale survey of the front. The survey was concluded in 12 hours and thus was efficient in producing a quasi-synoptic map of the front and of a dense filament north of it, as shown in the figure below.

After conducting the survey, the saildrones stayed on a 5-km holding pattern for two days and then moved to a new NE-SW line to continuously sample submesoscale velocity gradients across the front and instabilities.



Surface density survey conducted by four Saildrones while transiting from the "upstream region," where frontogenesis is taking place, to the "downstream region," where frontolysis is at work.