

S-MODE pilot campaign highlights

- Two aircraft, 9 robotic surface vehicles and one ship were coordinated by a Control Center to intercompare their measurements and measure the ocean submesoscale thereby validating the sampling approach.
 - The B200 completed 12 science flights over approximately 54 hours.
 - The Twin Otter completed 10 science flights over approximately 66 hours.
 - The B200 and Twin Otter coordinated their measurements on 5 flights with good overlap of measurements.
 - All aircraft instruments provided timely quick-look data that informed subsequent sampling plans. Delivery times for the quick-look data decreased from days to hours by the end of the campaign.
 - The team on the *Oceanus* measured 1396 profiles of upper-ocean temperature, salinity, oxygen, and chlorophyll fluorescence. They also collected 87 radiosonde profiles of atmospheric temperature and humidity, including unique over-ocean measurements during the major atmospheric river event.
 - The biology team on the ship collected 94 nutrient samples, 157 discrete chlorophyll samples, and 162 POC samples to enable calibration and proxy-development of the in situ bio-optics and airborne ocean color measurements.
 - Five Sairdrones operated in formation with each other, the Wave Gliders and *Oceanus*. The Sairdrones continued collecting data during the “double-bomb” cyclone and measured waves exceeding 10 m.
 - Three Wave Gliders operated in formation with each other and helped to conduct velocity surveys for site selection.
 - Nine NAVO underwater gliders collected data for two months (>2000 CTD profiles). Besides the direct utility of these data for scientific analysis, the data were assimilated into the NRL NCOM model, which provided skillful forecasts that were instrumental for targeting the measurements.
 - Data from all of these platforms and from operational models and satellite data were collected at a data server and used to plan and coordinate the operations.
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S-MODE Science Report - Oct 21, 2021

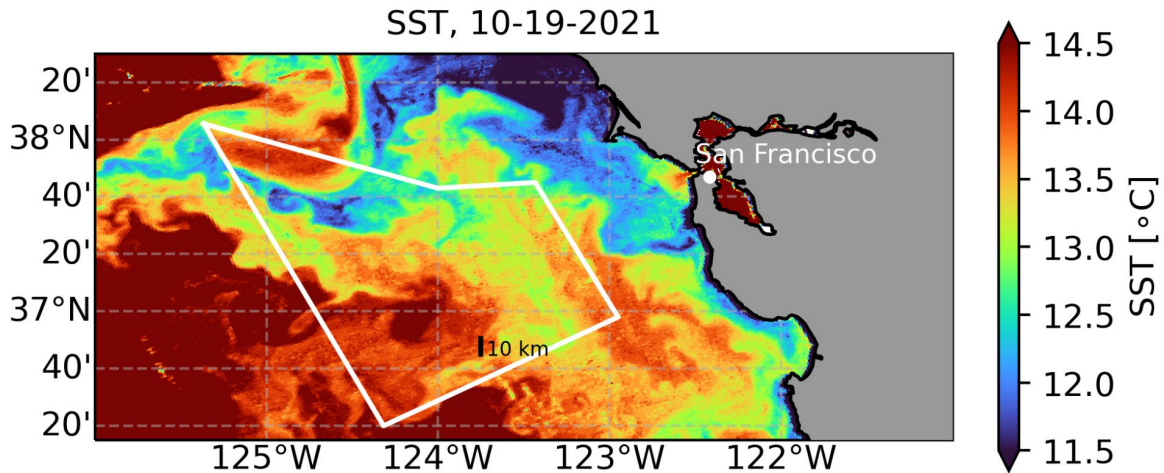
Overall weather conditions:

- The synoptic weather situation presents challenges for the first week of the three-week campaign.
- The region is experiencing a series of “atmospheric river” events, with an exceptionally strong event expected to arrive in the area on Sunday, 10/24
- Wave heights are expected to reach 9 m (30 feet) on Sunday evening.

Ocean conditions

- Ocean conditions are excellent! There are strong oceanic fronts in the region, and ocean model forecasts suggest that conditions will remain favorable for at least the next week.

- Using a combination of remote sensing and a suite of increasingly higher resolution models, we have honed in on the cold filament seen in the NW corner of the S-MODE domain in the satellite SST image below. This is a region of oceanic frontogenesis and strong submesoscale features.
- After identifying this feature as a primary target, we have begun to characterize it in more detail using aircraft remote sensing, robotic surface vehicles and a research vessel.



Satellite SST image (from the AVHRR instrument on EUMETSAT's Metop-A), showing the S-MODE Pilot campaign operations area (white polygon). We are currently focusing sampling on the cold filament in the NW corner of the operations area. (The shape of the operations area is constrained by aircraft warning areas.)

R/V Oceanus

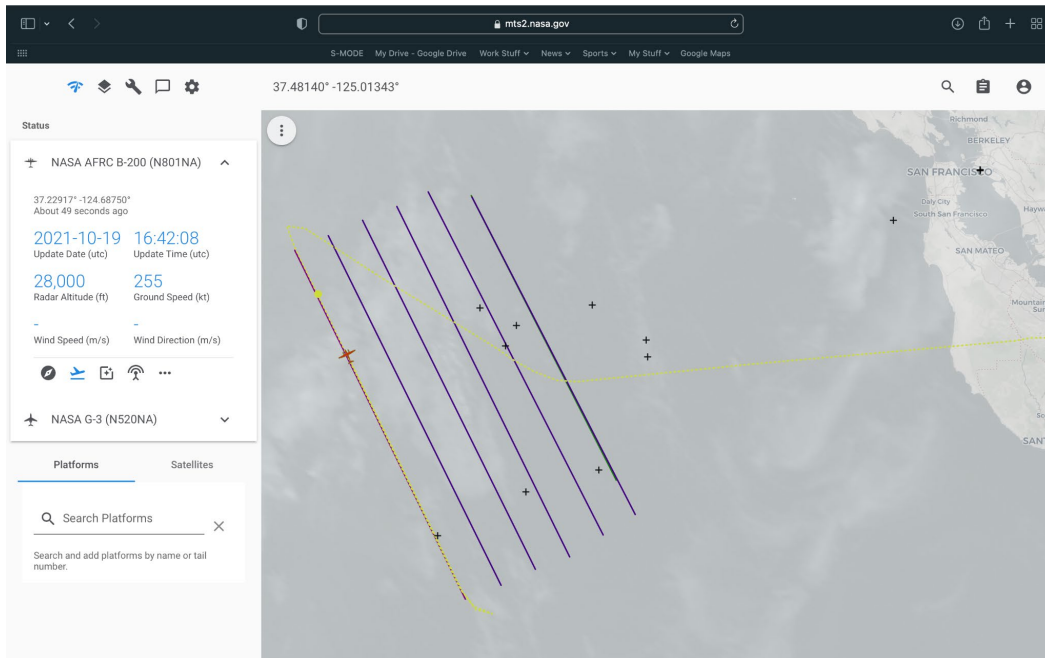
- Oceanus departed Newport, OR around noon local time on October 19. The ship is en route to the S-MODE operations area but is experiencing rough seas, which has slowed down the transit.
- Three of the four Wave Gliders (WGs) onboard the R/V Oceanus were damaged overnight on October 20 by a very large wave. One WG is undamaged, two are fixable, and one requires repairs on a timeline that will not work for this campaign. This is not a major setback, as aircraft operations are limited due to weather conditions.
- Oceanus is currently scheduled to arrive in the northwest corner of the operations area Friday morning. After collecting coincident data with the B200 and Twin Otter overflights, the ship will cruise to calmer waters in San Francisco Bay and dock at Pier 19 near Embarcadero, so the repairs can begin on the damaged WGs. This situation is fast evolving.



R/V Oceanus sailing south during the afternoon of October 19, 2021.

AFRC B200

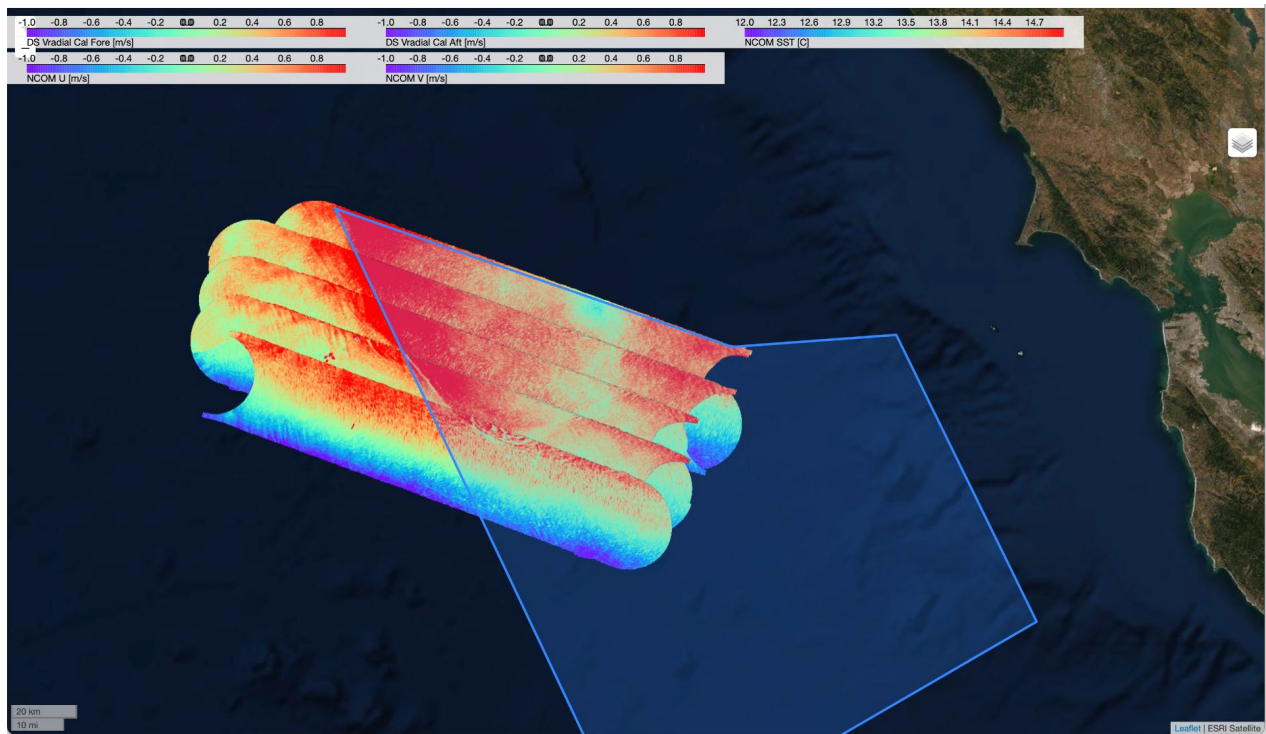
- The AFRC B200 has completed two 4.5-hour science flights with a third expected tomorrow. Both the DopplerScatt and MOSES instruments are delivering good data.
- The primary goal of the first two (and upcoming) B200 flights is to characterize a “cold filament” area, which is located in the northwest section of the S-MODE operations area. This area is also being transected by Saildrones.



NASA Mission Tools Suite display of B200 SF1. The small crosses in the picture are Saildrones and NAVO Gliders.



From L to R: Scott "Jelly" Howe (NASA AFRC), Federica Polverari (NASA JPL), Delphine Hypolite (UCLA), and Mike Stewart (NASA ARC) during B200 Science Flight (SF) #2 on October 20, 2021.



Quick look DopplerScatt current radial velocity from Doppler data from B200 SF2. The signature of the cold front on the radial velocities can be seen clearly as a diagonal feature in the image. The S-MODE operations area is illustrated by the blue polygon.

Twin Otter

- The Twin Otter transited to Monterey Regional Airport midday on Wednesday. The team is planning its first science flight tomorrow with the MASS instrument, overflying Oceanus and coinciding with the B200.

Saildrones

- Saildrones SD-1072 and SD-1073 continue to collect data near the “cold filament” in the northwestern corner of the operations area.
- Three additional Saildrones will be coming online early next week.

S-MODE Science Report: Oct 22-Oct 31, 2021

Science Highlights:

There have been two oceanographic target regions:

1. A strong SST front 37N, 125W (Figure 1). This front was sampled by DopplerScatt, MOSES, MASS, the RV *Oceanus*, and 5 Saildrones (black dots in Figure 1). During the S-MODE campaign,

we observed a rapid sharpening of the front and its collapse. An example of data from the MOSES infrared imager is shown in Figure 2.

2. A region with strong and weak velocity gradients in close proximity, being used for velocity intercomparisons (Figure 3). This feature is still developing, and satellite imagery has been obscured by clouds.

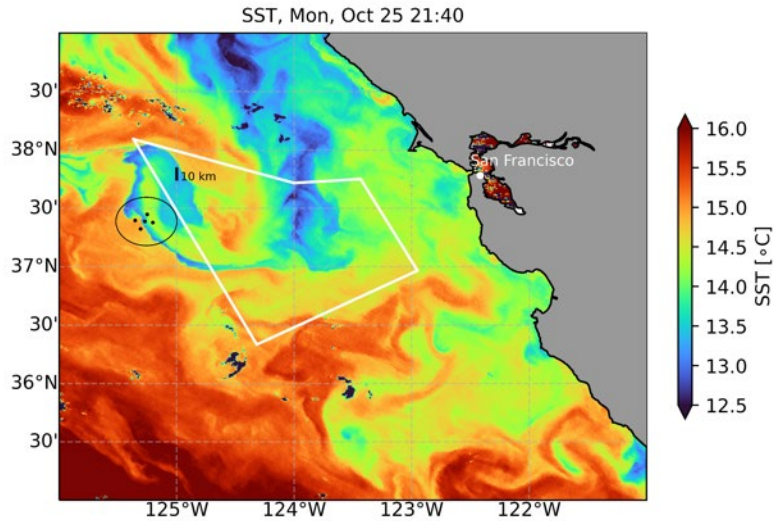


Figure 1: Sea surface temperature in S-MODE operations area on Oct 25. First oceanographic target area circled. The black dots are the position of the Saldrones around the time of the satellite overpass and the aircraft sampling.

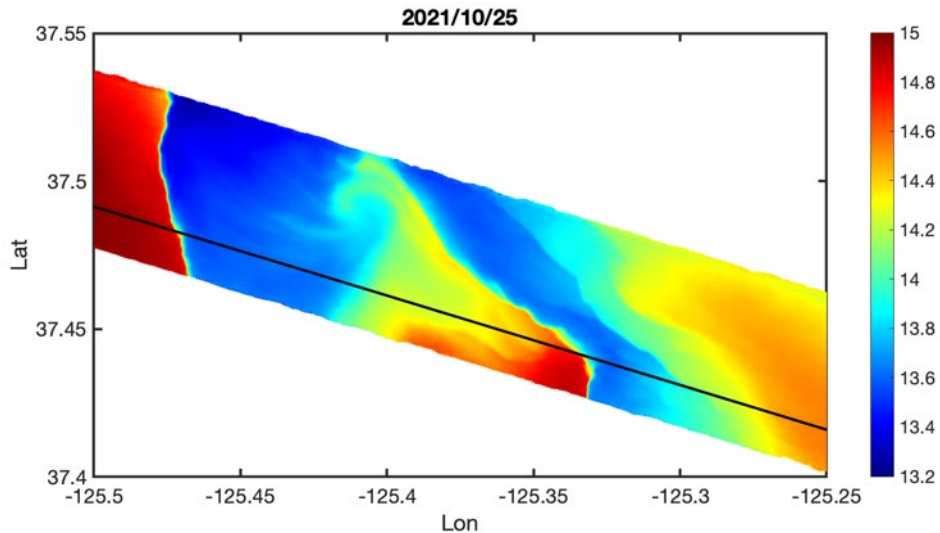


Figure 2: High-resolution measurements from the MOSES Infrared imager within focus area 1 showing: (1) a very sharp front near 125.47W, (2) development of a submesoscale eddy near 37.5N, 125.4W and (3) smaller-scale eddies developing near 37.45N, 125.35W.

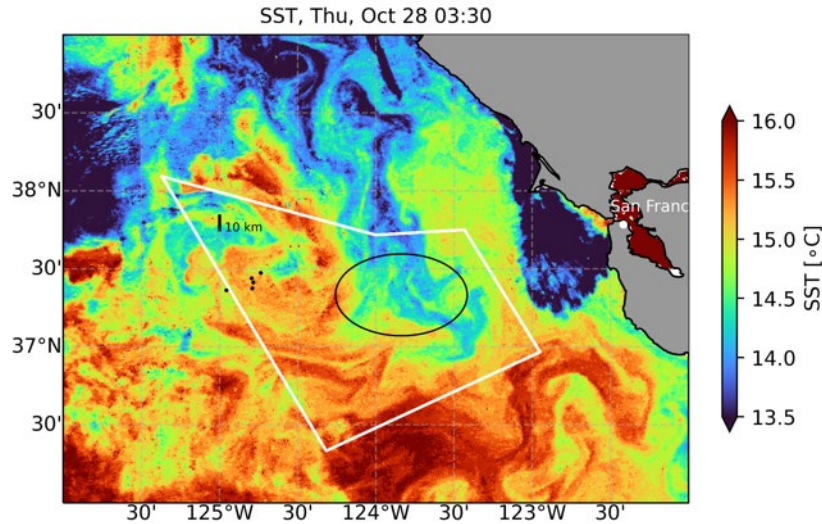


Figure 3: Sea surface temperature in S-MODE operations area on Oct 28. Second oceanographic target area circled.

R/V Oceanus and Wave Gliders

- On Oct 22, as the Oceanus first arrived at the S-MODE operations area to begin collecting data, a mechanical issue was discovered, and the team had to cut their survey short to go to port in San Francisco. Fortunately, the issue was repairable and after spending four days in port, the ship departed San Francisco midday on Oct 27.
- The Scripps team arrived in San Francisco on Oct 23 and began work on repairing the three damaged Wave Gliders (WGs). All were repaired prior to Oceanus departing from San Francisco.
- On Oct 27, the four WGs were deployed. One WG (Planck) had to be recovered shortly after the deployment due to communication issues. It will not return to the water this campaign. However, the other three WGs have been collecting good data.

S-MODE Science Report: Nov 1-5, 2021

Science Highlights:

- The S-MODE science team dubbed the final three days of the campaign the “*velocity extravaganza*”. The team had all of the platforms that measure surface and subsurface velocity collecting data in a small box inside the operations area, and the weather conditions were amenable to airborne data collection from all sensors.
- Both the B200 and the Twin Otter conducted 4 flights in 3 days, with optimal conditions for data collection from the various instruments.
- We operated the Wave Gliders and Saildrones in kilometer-scale arrays while the ship moved relatively quickly to survey a larger area around the uncrewed vehicles (Figure 1) and the B200 and Twin Otter surveyed the larger region.

- This successful demonstration is what the science team had envisioned before the campaign (Figure 2) as a method to: (1) make quantitative comparisons between velocity measurements from different platforms and (2) compare independent estimates of surface current vorticity and divergence.
- We expect that this mode of operations will be utilized many more times during the Intensive Operating Periods (IOPs) in Fall 2022 and Spring 2023.
- The Level 1 requirements for the Pilot campaign were unambiguously met.

SST, 2021-11-05 10:10, surface currents averaged over +/- 20.0 hr

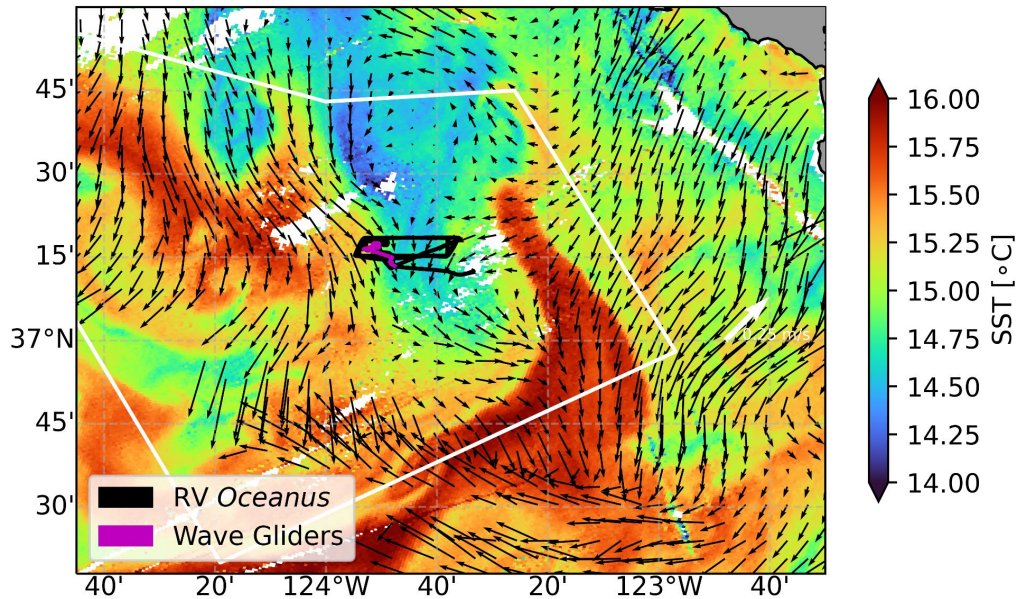


Figure 1: Sea surface temperature (background colors) on the morning of the last day of data collection. The black vectors show the 40-hour average surface currents from the US high-frequency coastal radar network, and the black and magenta lines show the locations of the RV Oceanus and the Wave Gliders during the same time period. DopplerScatt and MASS collected surface current measurements at much higher resolution than provided by the HF Radar data.

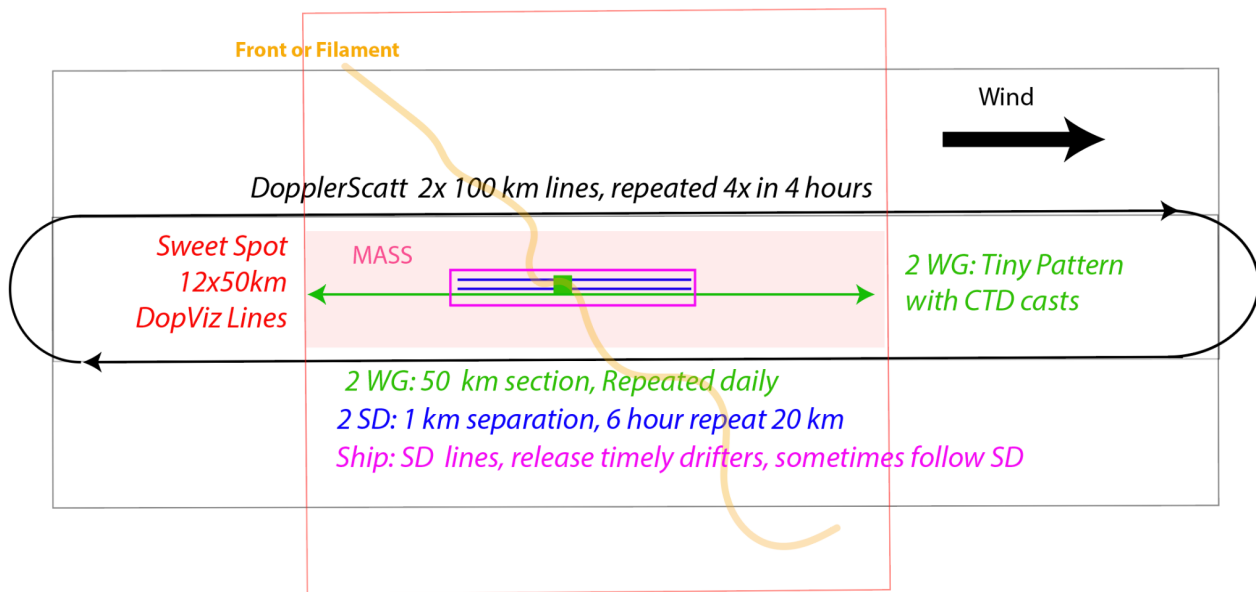


Figure 2: Mockup of multi-platform velocity intercomparison conceived prior to the experiment. The team was able to test this in reality with “velocity extravaganza” operations from Nov 3-5.

R/V Oceanus, Wave Gliders, and Saildrones

- As part of the “velocity extravaganza”, all five Saildrones and three Wave Gliders were formed into arrays while Oceanus circled them in a racetrack. This was the in situ data collection mode for practically all of the final five days of the campaign.
- In total during the campaign, the team on the *Oceanus* collected 1396 profiles of upper-ocean temperature, salinity, oxygen, and chlorophyll fluorescence. (That is a lot!)
- They also collected 87 radiosonde profiles of atmospheric temperature and humidity, including some during the large atmospheric river event.



R/V Oceanus Science Party conducting uCTD operations somewhere out in the Pacific Ocean

AFRC B200

- After a hard down day on Monday and bad weather on Tuesday, the B200 closed out the Pilot campaign with 4 flights in 3 days, during what was probably the most optimal weather conditions of the entire campaign.
- For the four flights, the B200 flew a tight lawnmower pattern back and forth over a compact in situ operations area.
- DopplerScatt continued to collect good data and the team produced surface velocity maps within a few hours of landing. The efficiency with which the team produced these quick look maps is commendable and will be quite valuable during the IOPs.
- MOSES got a few clear days to collect high resolution sea surface temperature data that showed good agreement with other sensors.
- The B200 finished the S-MODE Pilot campaign with 12 science flights over approximately 54 hours.

Twin Otter

- The Otter also completed 4 flights over 3 days and ended the campaign with 10 science flights over approximately 66 hours.



B200 crew from L to R: Sam Habbal (AFRC), Karthik Srinivasan (JPL), Alex Wineteer (JPL), Tracy Phelps (AFRC), Delphine Hypolite (UCLA), David Carbajal (AFRC), Leroy Marsh (AFRC), Tom Lynn (ARC)