AR35-03 cruise report

Near-Inertial Shear and Kinetic Energy in the North Atlantic experiment (NISKINe) 2019 process cruise.

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20 June 2019

1. Science Motivations

Near-inertial internal waves are generated by the wind in many places and times across the ocean. While they are an important component of the global energy balance of oceanic circulation, it is still unclear how inertial waves propagate through and interact with other oceanic dynamical structures. This cruise provided direct observations from ship-based and autonomous platforms. These observations will be used to develop our understanding of the mechanisms that govern the near-inertial response to wind forcing, with a specific focus on how do meso- and submesoscale variability impact generation and propagation of near-inertial internal waves. Science goals focused on the generation of near-inertial motions in the surface mixed layer, and propagation of these motions in the ocean interior as near-inertial internal waves in regions with strong vorticity gradients.

To investigate these questions, *R/V Neil Armstrong* supported autonomous observations using an array of **EM-APEX floats**, **Wave Gliders, surface drifters, wave buoys, Slocum gliders, Spray gliders, Seagliders**, and **Wirewalker**, augmented by intensive ship-based synoptic surveys using the **Triaxus towed, undulating profiler.** The **WAMOS Marine Radar** was used to map surface currents and wave conditions near the ship.

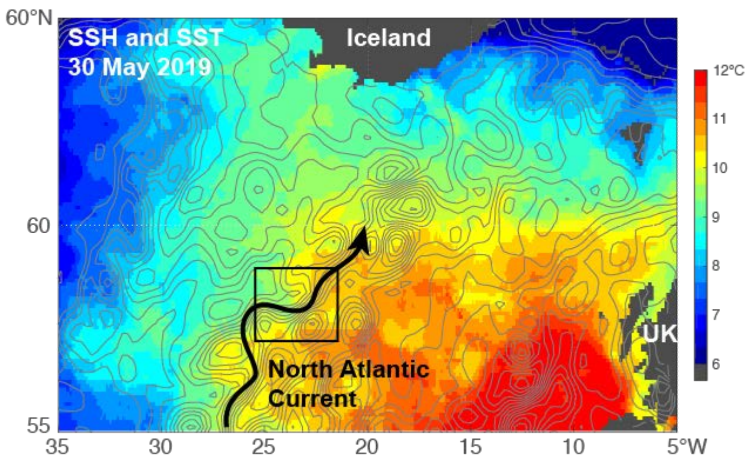


Figure 1-1. Map of sea surface temperature from passive microwave and sea surface height (Aviso, near-real-time) at the end of May. The black box shows the region where the cruise took place. Figure from L. Rainville.

2. Cruise Summary

2.1. Schedule

25 May	Begin mob
27 May	Depart Reykjavik
20 Jun	Return Reykjavik
22 Jun	End demob

2.2. Summary of process cruise sampling

Following the successful mooring deployment cruise, we left Reykjavik on R/V Armstrong and raced to the operational area ahead of a wind event. We were able to augment the existing observational array with 3 more Seagliders, a Wave Glider, 4 EM-APEX floats, and many drifters (including a few wave buoys, sea level pressure drifters, etc.). During the first wind event (18 m/s [35 kts] sustained winds, gusts to 22 m/s [40 kts]), we watched the initial evolution of inertial oscillations in a region of confluence and high vorticity gradients. First we surveyed a region straddling the center of the jet where the vorticity gradient is largest (*jet* survey), then an anticyclonic vorticity and confluence region (*confluence* survey), where we looked for phase variations, evolution of the horizontal wavenumber, and initial wave downward propagation. It looks like we might have captured beautiful examples of wave-mean flow interactions. Between the two surveys, a drifting array composed of EM-APEX floats, Wirewalker, S-ADOS, and drifters was deployed in the anticyclonic eddy south of the jet.

The intense sampling of the jet was followed by a survey around a drifting array (*sheepdog* survey), resolving small horizontal and vertical gradients of inertial waves in a quieter region. We observed tons of small-scale variability and expect that we can put all this data together to paint a great picture of the 4-D evolution of near-inertial waves.

We shifted our attention to the large anticyclone south of the moorings, first doing a full-depth hydrographic section with microstructure across the jet and towards the center of the eddy (again in what looks like a confluence region), then deploying another drifting array —and following it with the ship and Triaxus— in a submesoscale front-like structure on the edge of the anticyclone (*fence* survey). This region has amazing TS-variability, with large, but mostly density compensated, vertical and lateral gradients, yet the array stayed remarkably coherent. As the mesoscale circulation evolved, we shifted our survey (and the Wirewalker and some floats) a bit north, to where the jet and anticyclone's northern edge are squeezed against each other (*greyhound* survey). The preliminary ADCP and hydrography survey suggested the presence of an "inverted critical layer" at this location, arresting waves propagating upwards due to the subsurface velocity and vorticity maximum).

Several gliders, meanwhile, have been sampling in the cyclonic circulation near the moorings (Freya, SG527), in the jet (SG526, SG141, DG004, and a Wave Glider), and in the anticyclone (Spray 007 and SG151), providing great context for these measurements. And we have the moorings. Drifters continue to provide a larger scale picture of the circulation and inertial oscillations, guiding our observations.

After a few relatively calm days, winds picked up again. After looking at weather forecasts and staring at the sea, and we decided to keep sampling through this wind event. Strong winds, peaking at 17 m/s (39 kts) generated a nice inertial signal. The ship left the Wirewalker and floats after 60 hours, to go recover gliders and other instruments, before coming back for recovery. The last several days recovering many of the gliders, EM-APEX floats, Wave Gliders, and S-ADOSs, that have been deployed in the last few weeks.

The last operation of the cruise was the recovery of an OOI Slocum Glider, #363. In late April/ early May, glider 363 operated by the WHOI OOI glider group (Peter Brickley, Collin Dobson, Diana Wickman) starting showing signs of early battery depletion. They requested recovery during our cruise if possible, and started flying their glider towards our operation box. On the first week of June, however, 363 ran out of power and started drifting on the surface near 60°N 30°W. Luckily the drift carried it mostly north, and it was “only” a 100 nm detour to go pick it up at the end of our cruise. Timing worked out well and weather cooperated, so glider 636 was recovered at 61°N 57’ 29° 38’ W.

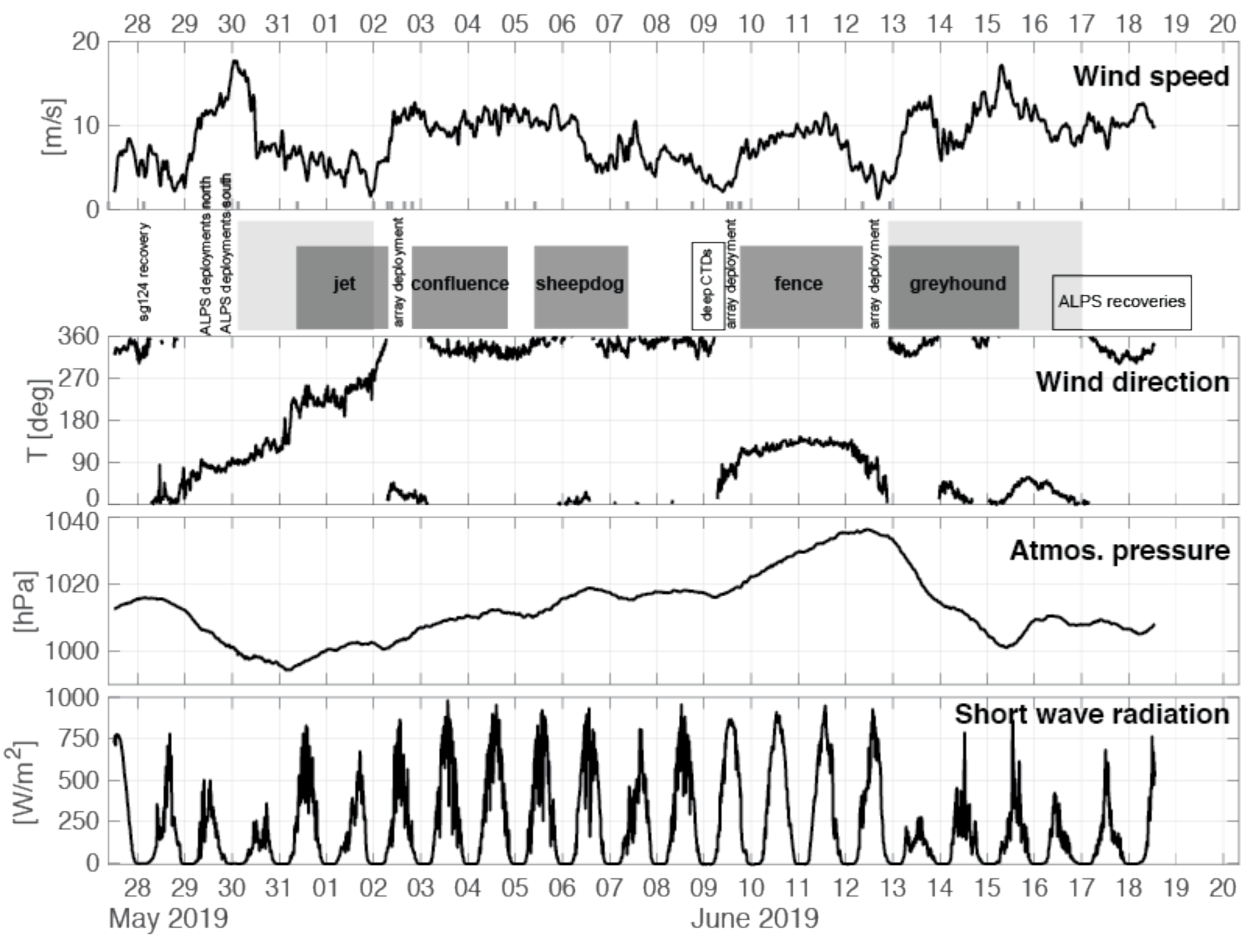


Figure 2-1. Overview of weather conditions during the cruise, with general time line of the operations. Figure from L. Rainville.

3. Cruise narrative (by instrument).

3.1. 3.1 SHIP-BASED SAMPLING

Ship Track

The cruise track, colored by sea surface salinity, is shown in Fig. 3.1-1.

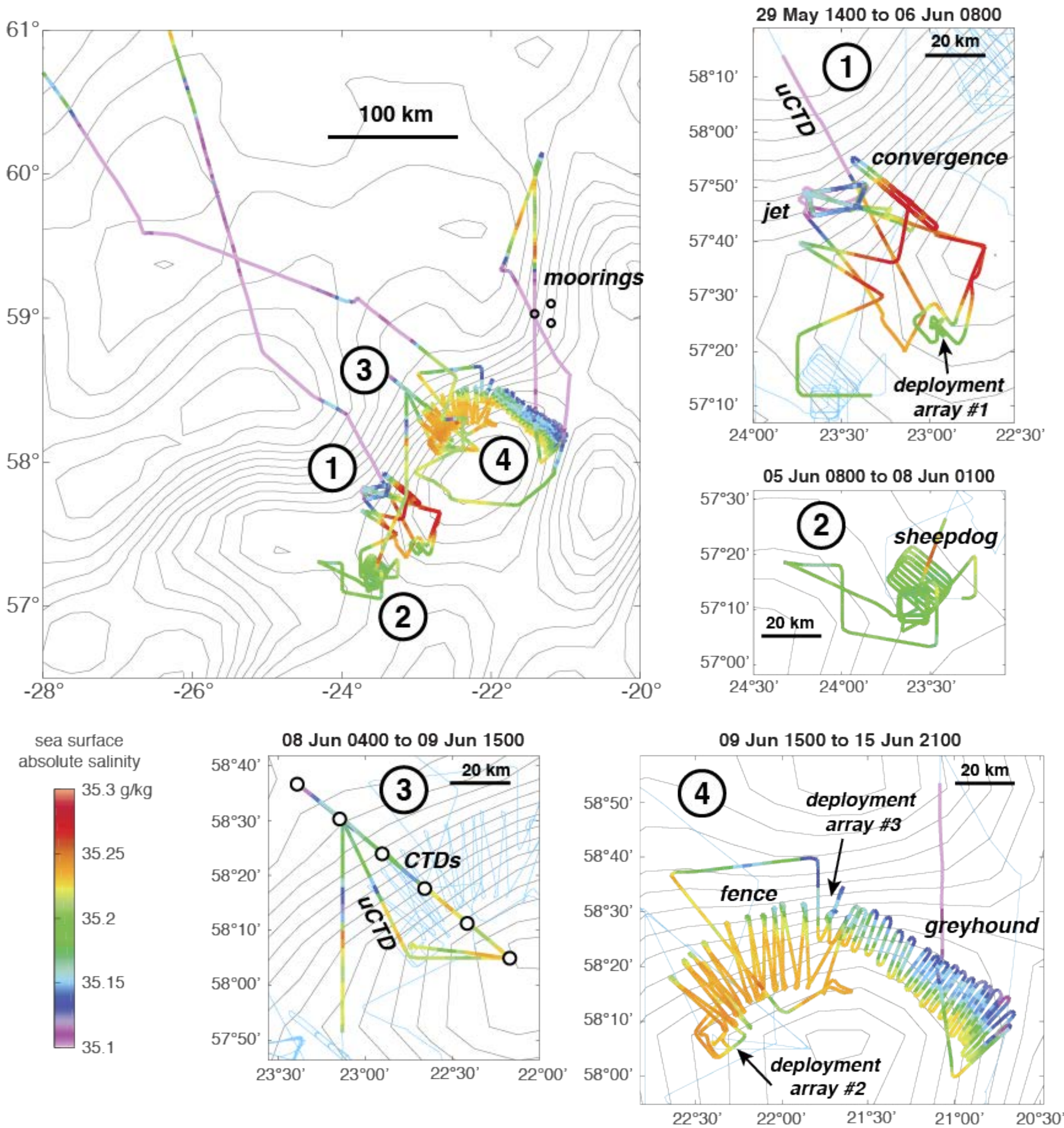


Figure 3.1-1: Ship track, with 4 inserts showing specific parts of the cruises for specific time intervals (thin blue lines show entire cruise track). Survey names and major activities are labeled. Scale of all the subplots is the same, and color scale for surface absolute salinity is the same for all plots. Figure from L. Rainville.

Triaxus

Triaxus is a towed, undulating profiler that can sample from the sea surface to 300-m depth while being towed at speeds ranging from 4 to 8 knots (slower speeds provide finer horizontal resolution at a cost to synopticity). The profiler carries dual SBE T-C sensors, up- and down-looking ADCPs, and a suite of bio-optical sensors. A **GustT** system from OSU (microtemperature and velocity sensors) was mounted on Triaxus to measure turbulence as the vehicle profiles.

Including the 2h test tow, Triaxus operated for 263 hours total, doing 5052 profiles over 3311 km in 6 surveys. We redid the termination only once, at the end of the *confluence* survey when the outside armor of the cable showed weaknesses (one strand broke when flexing the cable).

test: 3 hours
jet: 45 hours
confluence: 48 hours
sheepdog: 40 hours
fence: 62 hours
greyhound: 65 hours

Action Item: Triaxus ADCP data to processed

Action Item: GustT processing (Jim Moum).

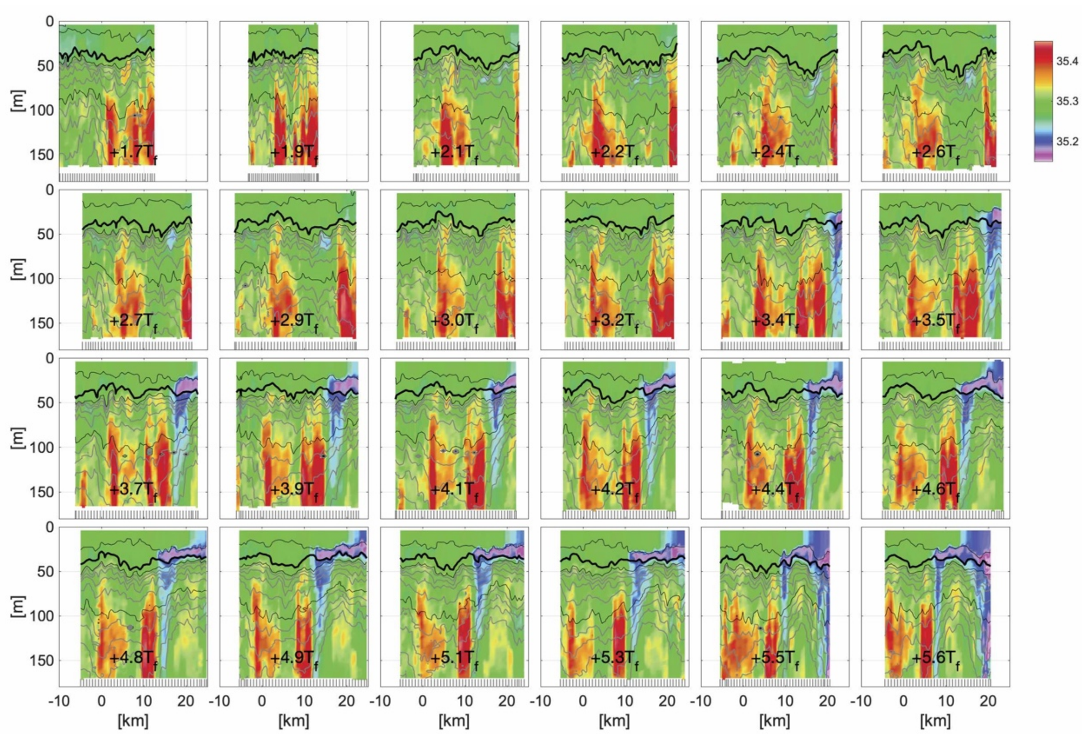


Figure 3.1-2: Absolute salinity sections from the Triaxus during the *fence* survey, as a function of cross-stream distance (0 km is the postion of the Wirewalker, positive moving north). Each section is labeled with time in inertial period since 09 June 2019 00:00. Gray ticks at the bottom of each panel indicate center of each profile. Figure from L. Rainville.

Ship ADCP

The ship ADCP system performed well during the cruise. We noticed an offset in the 150nb, with velocity consistently forward (and maybe starboard) of the ship. After discussions with Jules Hummon (thanks for being so responsive!), and playing with corrections (minimizing differences before and after turns), we concluded that we needed to correct the 150nb and bb data by applying a correction based on ship speed:

u_corrected = U+scale_factor *Uship.*exp(-1i*angle_correction/180*pi);

where U is the complex adcp velocity produced by the ship processing routines (contour files), scale_factor = 0.0055, Uship is the complex ship speed through the water, and angle_correction = 180. In general, the ship does not log the speed through the water (it interferes with the ADCPs!), so in this case we estimate it as the velocity over ground minus the first estimate of upper ocean velocity from uncorrected ADCP data. Corrected velocities look good (Fig. 3.1-3).

The OS38 and WH300 do not seem to need a scale factor correction.

Data in the ADCP file structure of the science share have not been corrected. There is a corrected field in the underway.mat structure, a Matlab compilation of the ship's underway data.

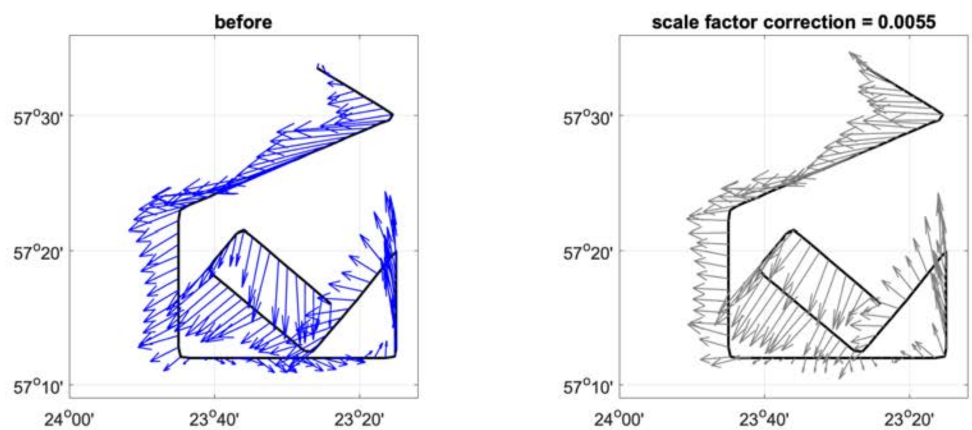


Figure 3.1-3: Averaged currents from 30 to 100m from the os150nb before and after the correction, for a period of 10 hours on 6 June (0300 to 1300), before and after applying a scale factor of 0.0055. Figure from L. Rainville.

Underway CTD

The Oceanscience Underway CTD (uCTD) system was used in 4 different occasions. An initial survey across the jet was done ahead of the storm, in our initial transit on 29 May (Fig. 3.1-4). A few profiles were collected during the *jet* survey on 30 May, before we put Triaxus in the water, to measure mixed layer depth. The initial sampling around the first drifting array, on 5 June, was done with the uCTD system, while Ben was finishing Triaxus' termination. Another section was collected across the jet on 8 June, just before the deep hydrographic section. Data are processed using a T-C correction that depends on fall rate. Details are in the document "UCTD processing.pdf".

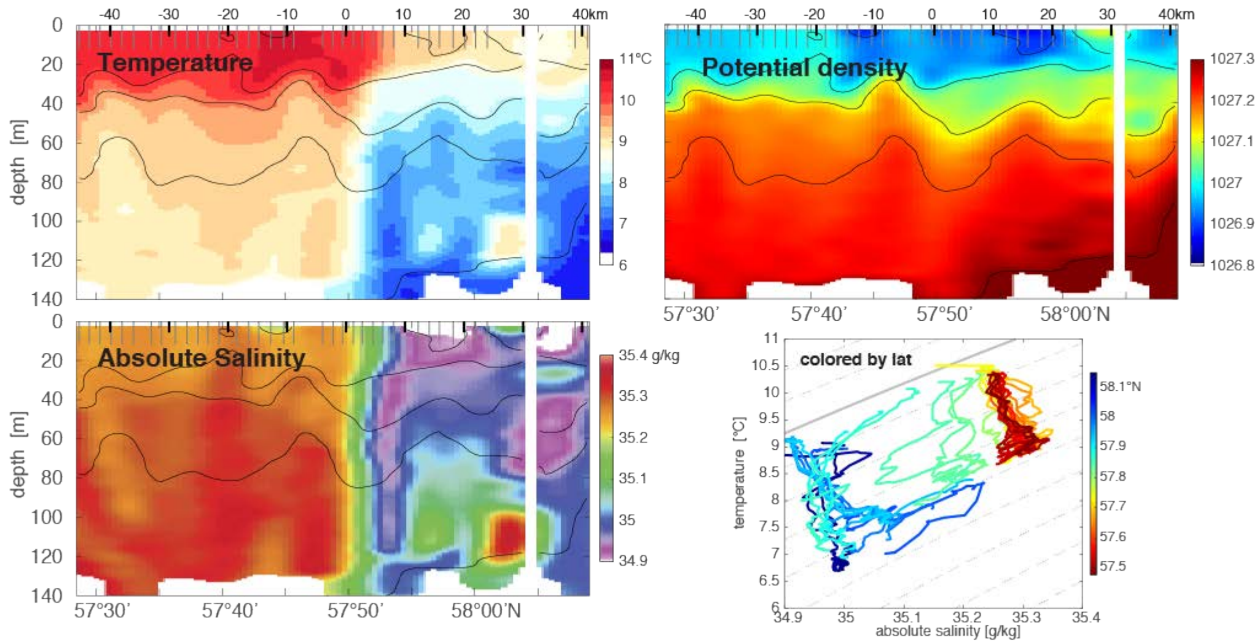


Figure 3.1-4: Section across the jet on 29 May. Temperature and absolute salinity show a large front associated with the velocity maximum (not shown), but they are almost completely compensated. Figure from L. Rainville.

Ship's CTD

7 deep hydrographic casts were done using the ship's CTD system without any Niskin bottles attached. A χ-pod with one upward and one downward looking fast sampling thermistor was attached to the rosette to estimate turbulent dissipation rate from thermal variance. A series of 6 stations to the bottom, separated by 10nm, were done on 8-9 June (Fig 3.1-5).

The level wind was not behaving very well on the way up from deep casts. We did a 7th CTD station on June 17th to allow the ship's engineers to observe and film the system, so that they can fix the problem for future cruises. This cast was done at the location of CTD004 (57°17 N; 36 km).

A CTD χ-pod, provided by Jim Moum, was attached on the rosette on the six full depth CTD casts along the transect into the anticyclone, sampling on June 8-9. Two χ-pod thermistors were mounted at the top and bottom of the rosette cage, clear of turbulence associated with the rosette. The downward facing thermistor provided consistent data on the downcasts of the first 5 CTD casts, but the upward facing thermistor reports higher values for χ on all casts. Elevated dissipation can be seen along the bottom edge of the anticyclonic eddy at approximately 700 m depth, deepening to nearly 1000 m depth (Fig. 3.1-6).

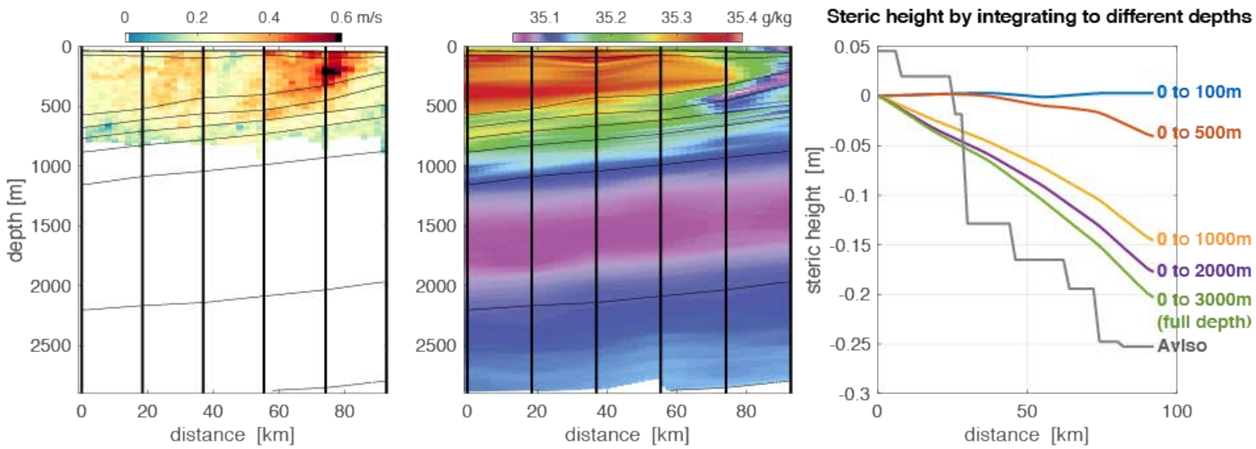


Figure 3.1-5: (Left) Magnitude of currents from the OS36nb ADPC, and (middle) absolute salinity versus depth and distance (from the station closest to the center of anticyclone, here positive moving north) for the hydrographic section. Station locations are indicated by the thick black lines. Potential density contours are plotted (0.1 kg m-3 intervals). (Right) Steric height as a function of distance, integrating the specific volume anomalies over different depth range. Most of the pressure gradient comes from signals deeper than 500m. Aviso SSH from near-real time is plotted in gray. Figure from L. Rainville.

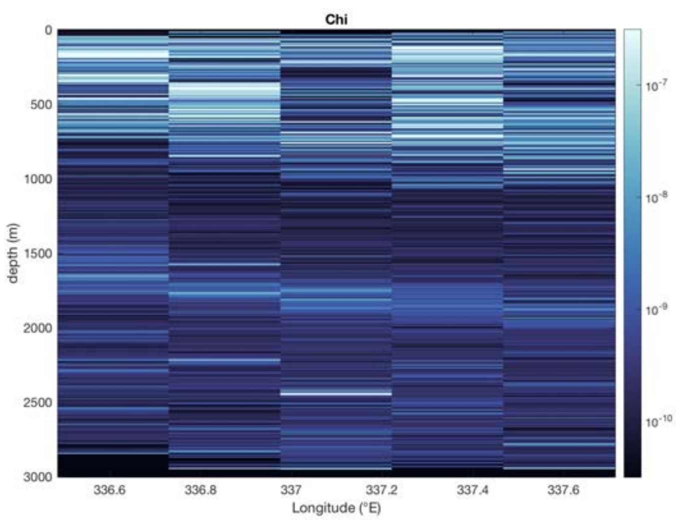


Figure 3.1-6: Rate of dissipation of thermal variance as a function of depth for 5 of the deep CTD stations (001 to 005). Figure from A. Savage.

3.2. EM-APEX floats

EM-APEX (ElectroMagnetic Autonomous Profiling EXplorer) profiling floats measured temperature, salinity, temperature microstructure (on selected floats only), and horizontal currents in clusters of up to 8 floats at a time. These devices are similar to the profiling floats in the global Argo array, with the addition of the velocity and microstructure. Relative velocity is measured to ±0.5 cm s^{-1} with a vertical resolution of 5 m. Velocities made absolute using GPS fixes between consecutive float surfacings have un- certainties of ±2 cm s^{-1}. The electromagnetic velocity sensor for the EM-APEX uses horizontally-separated seawater electrodes to sense the motionally-induced electric currents produced by the horizontal motion of the water in the vertical component of the earth's magnetic field. The velocity sensor and EM-APEX internal firmware were developed at APL-UW and are now commercially available from Teledyne Webb Research (TWR). A total of 15 EM-APEX were used in NISKINE (making a total of over 3200 one-way profiles), of which 6 floats were left behind for a long-duration mission following the cruise.

EM-APEX deployments were conducted using an air tugger routed to a block on the stern A-frame and a "grease-stick" quick release. Recoveries used a science-provided snap-hook on a pole and another air tugger for lifting over a block held by the ship's aft starboard hydro boom. A total of 30 launches and 24 recoveries (mostly in 3 targeted clusters, or Arrays along with the Wirewalker profiler and multiple surface drifters) were conducted over the course of the experiment. Fig. 3.2-1 shows the trajectories of each of the EM-APEX floats, as well as the 3 Wirewalker drifts.

The EM-APEX are capable of a variety of profiling behaviors, including constant-speed vertical profiling to a pre-set depth, holding at a particular pressure level, or yo-yoing between two depths. During NISKINE, a synchronized profiling mode was used which kept all floats on a pre-set schedule—often indexed to the inertial period of 14.1 hours and sampling at a rate of 4 or 6 round-trip profiles per inertial period. This led to a certain amount of variation in the maximum depth of each profile, depending on ambient conditions including vertical motions and sea state (affecting profiling speed and the time taken to send data at the surface). Additionally, a 'yo-yo' mode was used to increase temporal resolution around a particular depth range—for example to examine near-inertial waves in a critical layer at the base of an anticyclonic eddy. Figure 3.2-2 illustrates typical profile behavior for 2 floats making continuous synchronized profiles and yo-yos.

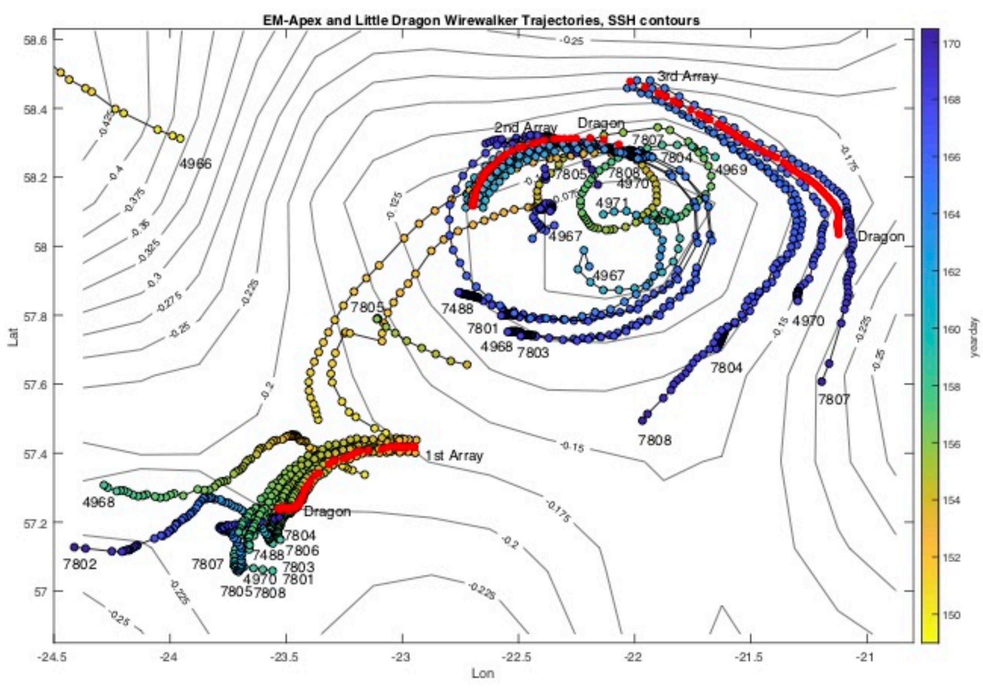


Figure 3.2-1: Map of EM-Apex float and Wirewalker trajectories. EM-Apex float locations are colored according to yearday, and the Wirewalker 'Little Dragon' trajectory is in red. The first four floats deployed include 4966 (northwest, trajectory off the page, shown in Figure 3.2-3 d), and the 'First Triangle' array, centered around Lat 57.4 and Lon -23.2. Arrays 1-3 include the Wirewalker. Sea Surface Height from altimetry is contoured in gray. Figure from C. Whalen.

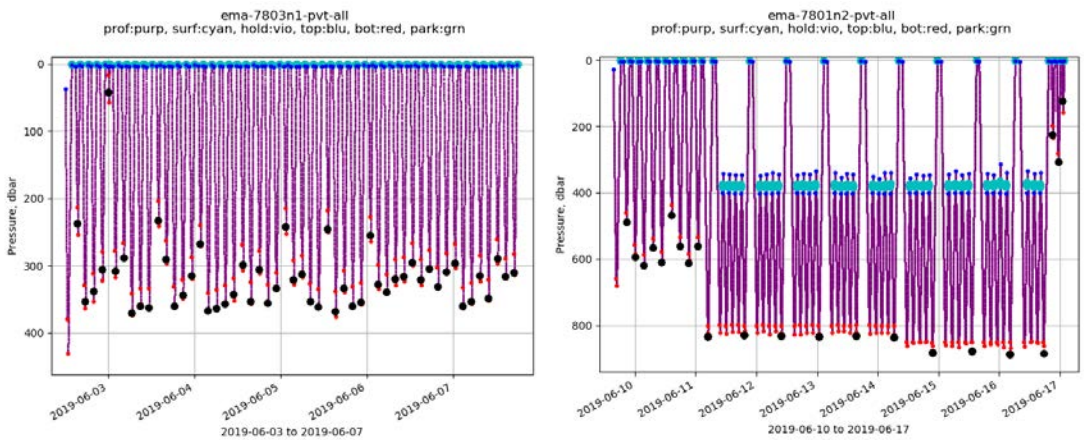


Figure 3.2-2: Typical EM-APEX profiling behaviors, including cycling at 6 round-trip profiles to ~350 m per inertial period (left panel), cycling at 4 round-trips to ~600 m per inertial period, and yo-yos between 400 and 800 m, surfacing approximately once per inertial period. Figure from J. Girton.

Several specific groupings or clusters of EM-APEX floats are likely to be useful for coordinated analysis. These include the 3 Lagrangian arrays (with Wirewalker and multiple surface drifters) as well as a few other subsets:

1) First triangle of 3 floats at 15 km spacing which split apart rapidly while Triaxus ran the initial cyclonic *jet* survey (seeing significant de-phasing of the inertial motions over the 20 km line). The phase of the strong inertial motions following the storm should initially be coherent, and the rate of phase divergence among these three can be compared to that in the jet.

2) Array #1 with Wirewalker, S-ADOS, 8 drifters; and later Triaxus *sheepdog* survey. Initially ship went up north for *confluence* survey while array operated to south.

3) Array #2 with Wirewalker, S-ADOS, 8 drifters, and Triaxus *fence* (back and forth) survey in vorticity divit (cyclonic feature) at edge of anticyclone.

4) Array #3 with Wirewalker, 7 drifters, and Triaxus *greyhound* (back and forth) survey in salinity front further out from anticyclone, possibly in confluent jet.

5) Deep yoyos with 4967 and other floats, including remainder of Array #2 (after 4 floats removed) to look at base of winter mixed layer. Possible coherent response to wind event.

6) Shallow cycling with remainder of Arrays 2 and 3, as well as further floats, to look for coherent response to 6/15 wind event.

7) Initial array of "left-behind" EM-APEX floats is spaced by 40-150 km and includes 3 floats (4971,7807,7808) loosely in the same anticyclonic eddy and 2 floats in a "between eddies" region to the southwest. Synchronized half-inertial pairs of profiles to 1000 m once per day could be a good test whether phase relationships can be seen over this scale. Likely coherent during large-scale storm forcing and incoherent shortly after, but perhaps the sign, direction, and rate of the phase changes over the first 2-6 inertial cycles will be informative and can be connected to mesoscale vorticity (or smaller-scale vorticity inferred

from path curvature). This mode will be used for the first few days following the cruise, then these floats will be slowed to a longer drift-profile interval to conserve battery power.

Throughout the study the EM-Apex floats revealed many signatures of internal wave activity under different submesoscale and mesoscale conditions. An example time series from Float 4966, the first float deployed, is shown in Figure 3.2-3. The float began by traveling north, and then transitioned to warmer water with anticyclonic vorticity around yearday 155. Immediately after transitioning the float sees downward propagating high-mode internal waves 300m and deeper, below the layer of warm, low-stratification water (Figure 3.2-3 a). The velocity also shows that low-mode waves become more prominent after the float enters the region of anticyclonic vorticity (Figure 3.2-3 b). Isopycnal displacements seem to roughly align with the low-mode velocity variations. The slope of the phase lines of these low-mode waves becomes less vertical as they leave the region of low stratification, suggesting that their speed changes by the changing background stratification and/or vorticity. Data from other floats also reveal a complex internal wave structure throughout the study region.

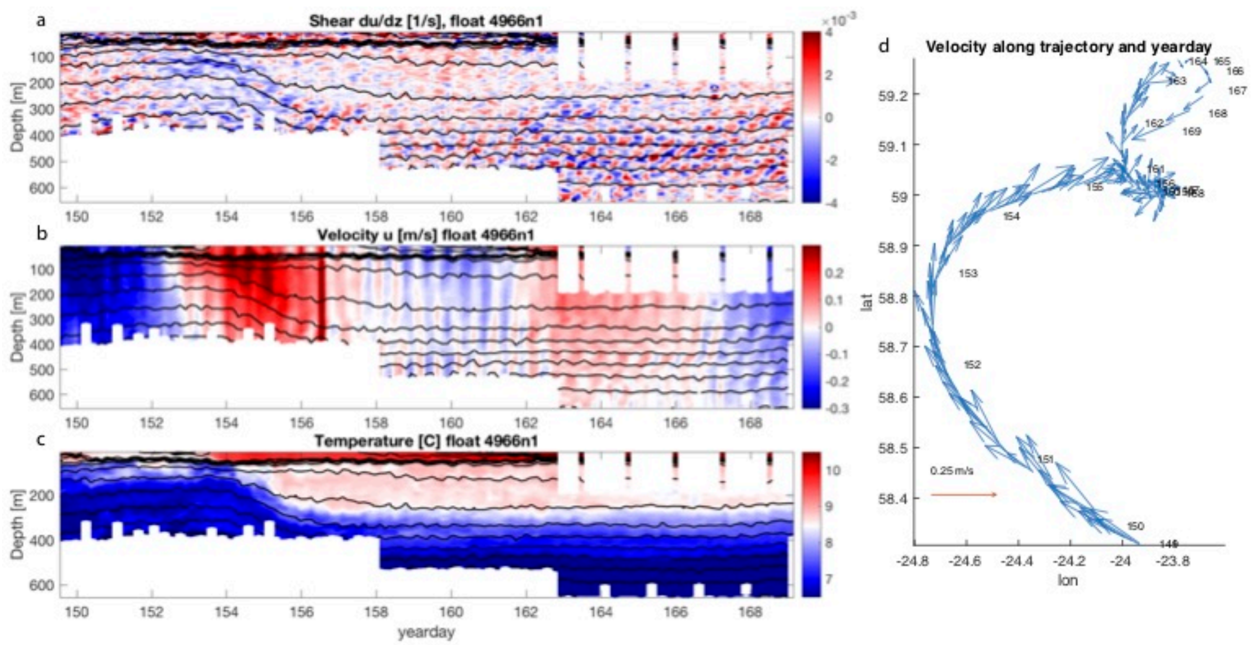


Figure 3.2-3: An example of data collected from the EM-Apex floats, including (a) meridional shear, (b) meridional velocity, and (c) temperature from float 4966. Black lines are isopycnals. (d) The trajectory of the float, including the water velocity and the position at each yearday. Figure from C. Whalen.

3.3. SURFACE DRIFTERS

32 SVP drifters drogued at 15-m depth and with sea surface temperature (SST) sensors were deployed during the cruise. In addition, we also deployed 10 surface drifters equipped with a barometer (SVP-B) and 5 Minimet drifters, surface drifters equipped with barometers, a high-quality sonic anemometers and an internal compass, measuring the wind velocity.

We initially deployed a line of 10 drifters spanning the entire width of the jet (29 May), followed by 8 more released as part of the *jet* survey to quantify confluence (30 May). 8 drifters were deployed on 2 Jun as part of the first drifting array, in a 10x10 km box centered around the Wirewalker. 8 drifters were deployed on 9 Jun as part of the second drifting array (*fence*), in a similar configuration. Finally, 7 driters, including 2 Minimet separated by 10 km, were deployed on 12 Jun as part of the last survey (*Greyhound*).

We note that several of the drifters from the first wave across the jet went around the cyclonic eddy north of the jet, to return to the northern tip of the *Greyhound* survey as we were starting this last drift. Together with the drifters from the *fence* survey (9 Jun) and those deployed on 12 Jun, these drifters were almost perfectly lined up and mapped the confluence and diffluence (jet and anticyclone) of the large-scale flow around the survey region.

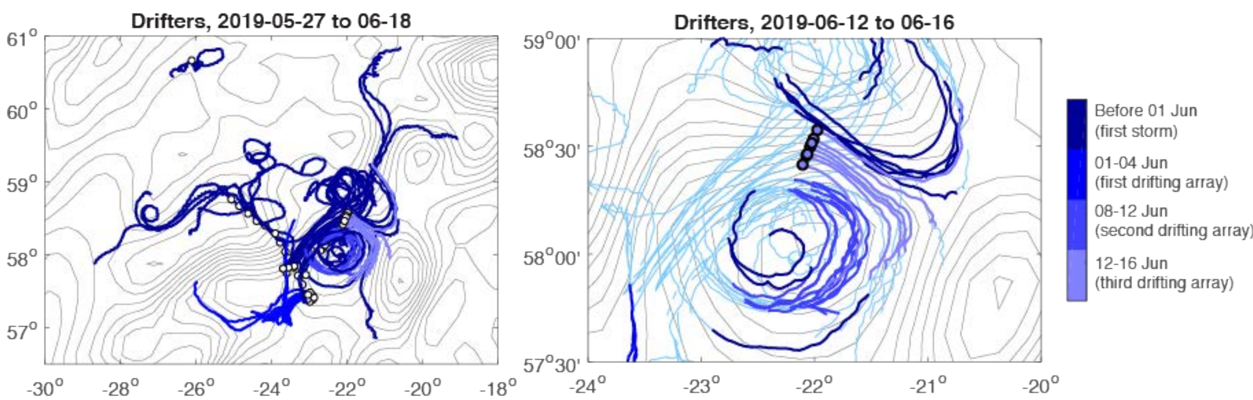


Figure 3.3-1: (Left) Map of all the drifter trajectories during the cruise period, for drifters that were deployed from the ship in 4 different time periods, color coded. (Right) Details of the drifter sampling around the time of the anticyclone surveys (*fence* and *greyhound*). Figure from L. Rainville.

3.4. GLIDERS and WAVE GLIDERS

Buoyancy gliders fly using their buoyancy relative to the oceanic stratification and the aerodynamic lift generated by their body and wings. Three glider classes were be used for our 2019 study: Seagliders operated by UW/APL (Rainville / Lee), Teledyne-Webb Slocum models operated by WHOI and UAF (St. Laurent / Shapiro / Simmons), and Spray gliders operated by WHOI (Todd).

- 1 Slocum turbulence glider and 1 Spray glider were deployed in April 2019 from a charter boat.
- 1 Slocum turbulence glider and 1 Seaglider was be deployed during the mooring deployment cruise.
- 3 Seagliders were deployed during the process cruise
- 1 Deep Glider was deployed during the process cruise
- 2 Slocum gliders, 1 Deep Glider, and 4 Seagliders were recovered during the process cruise, including a Seaglider that had been deployed in the Pilot in May 2018.
- The Spray glider and one Seaglider remain on site, and will be recovered from a charter vessel in August.

One SV3 Wave Glider was also deployed with the Spray and the Slocum in April 2019 and followed Slocum Apollo until recovery on 18 June 2019.

One SV2 Wave Glider was deployed on 29 May 2019 and recovered on 15 June 2019. This Wave Glider conducted surveys in the cyclonic side of the jet during the *jet* and *confluence* surveys (from 58°N to the top of the ship's survey patterns), and similar patterns a bit downstream, extending the *fence* survey. Science systems failed in the last few days, and it's unclear how much data was recorded when the Wave Glider was in the region of the *Greyhound* survey.

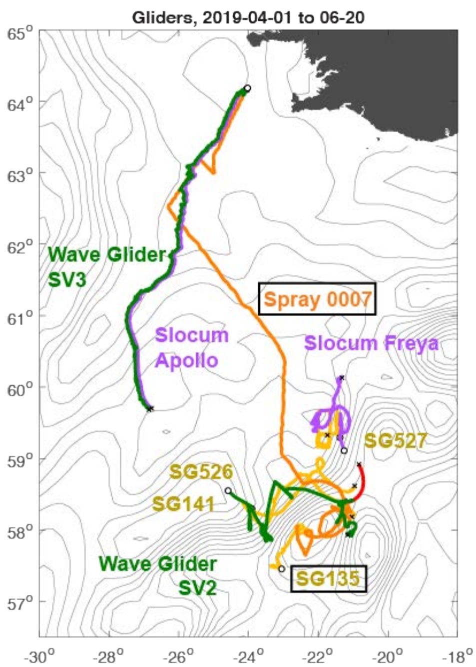


Figure 3.4-1: Map of 2019 NISKINe glider and Wave Glider operations since April 2019. All instruments were recovered during the cruise, except for Spray 0007 and SG131 (highlighted with black boxes), which will continue sampling until August 2019. Figure from L. Rainville.

3.5. WAMOS

R/V Neil Armstrong is equipped with a permanent Wave Monitoring System (WaMoS), which connects to the ship's JRC marine X-band (9.4 GHz) radar that is also used for navigation. It is a noncoherent radar made by JRC with 25 kW output power, a 2.7 long HH-polarized antenna, a 1.25 s antenna rotation period, a range resolution of 7.5 m, and a maximum range of 5.6 km. Due to its dual purpose, the radar is not always operated in short pulse mode, as is required for oceanographic applications.

To complement the WaMoS system, the CSTARS–University of Miami group installed a temporary Doppler marine X-band radar (MR) on a mast on top of the wheelhouse of R/V Neil Armstrong in Woods Hole, MS, on 24 and 25 April 2019. The radar was provided to CSTARS by Helmholtz Zentrum Geesthacht (HZG), Germany, on a 1-year loan. It consists of a commercial GEM elettronica marine X-band radar with a 2.3 m long VV-polarized antenna and a rotation period of 2 s. The antenna was situated at a height of 17.5 m above the sea surface. The radar transceiver operates with 12 kW output power and a pulse repetition frequency of 2 kHz in short pulse mode (i.e., a pulse length of 50 ns). The corresponding range and azimuthal resolutions are 7.5 m and 0.8°, respectively, the maximum range is 3.1 km. The radar was modified by HZG to measure both intensity and phase of the radar backscatter signal from the sea surface. The raw, uncalibrated radar measurements are linearly amplified and digitized at 20 MHz with 13-bit precision per channel. The A/D converter and amplifier are located inside the radar transceiver. The advantages of the HZG radar compared with the ship's WaMoS system are threefold: the phase information can be analyzed to yield the radar scatterers' speed along the antenna look direction, its VV-polarized antenna is more sensitive to sea clutter, and, since it is a dedicated science radar, it can always be operated in the optimal mode for oceanographic measurements. On the other hand, WaMoS has the advantages of a shorter antenna rotation period and greater maximum range.

During the mooring cruise (AR35-02), the HZG radar's bearing encoder (which measures the antenna heading mechanically and digitizes it) broke on 15 May 2019. With help from Jochen Horstmann and Jan Boedewadt (both from HZG), we replaced the defunct bearing encoder with a brand new one prior to this cruise (AR35-03). Unfortunately, the newly replaced bearing encoder broke as well on 1 June 2019. The cause of these repeated failures is still unknown but will be investigated further.

The CSTARS goal for this cruise was to support the adaptive sampling scheme by providing radar-derived sea-surface roughness imagery, near-surface current maps, and surface wave spectra in near-real time. To ensure accurate measurements, the HZG and WaMoS radar systems were carefully calibrated to account for heading, range, time, and GPS antenna offsets. (The HZG radar's calibration had to be repeated after the bearing encoder replacement.) The analysis is based on Python and IDL code developed at CSTARS. It was based on both the HZG (while available) and WaMoS (after the bearing encoder failure) radar raw data, which were also recorded for further analysis after the cruise. After improvements to the processing code's parallelization, the objective of producing results in near-real time was met.

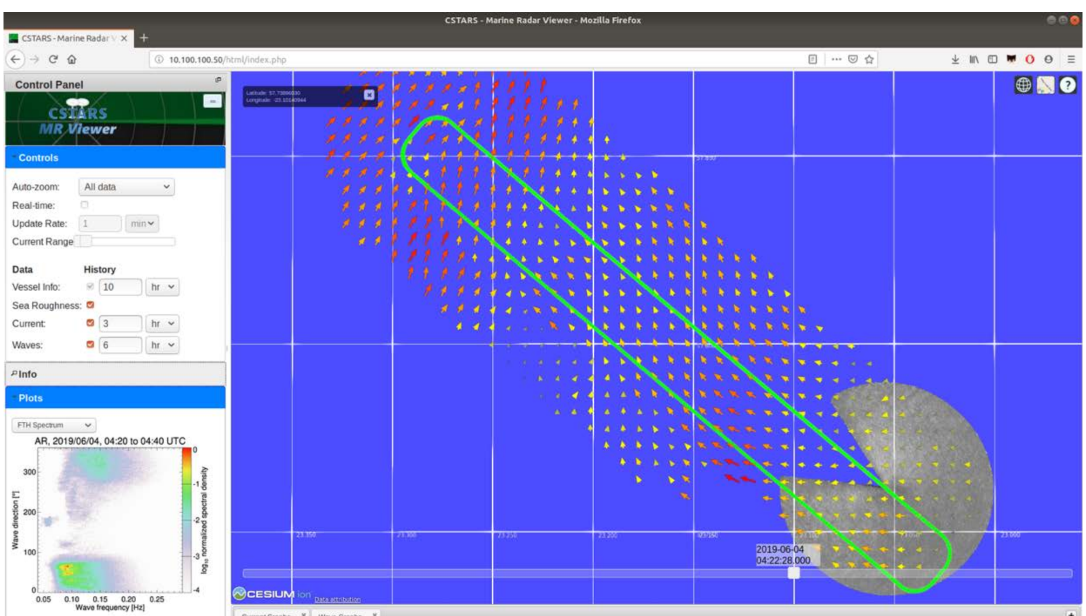


Figure 3.5-1: Screenshot of the CSTARS Marine Radar Viewer showing a frequency direction wave energy spectrum, a temporally averaged radar image, and near-surface current measurements from 4 June 2019, 01:22 to 04:22 UTC. Figure from B. Lund.

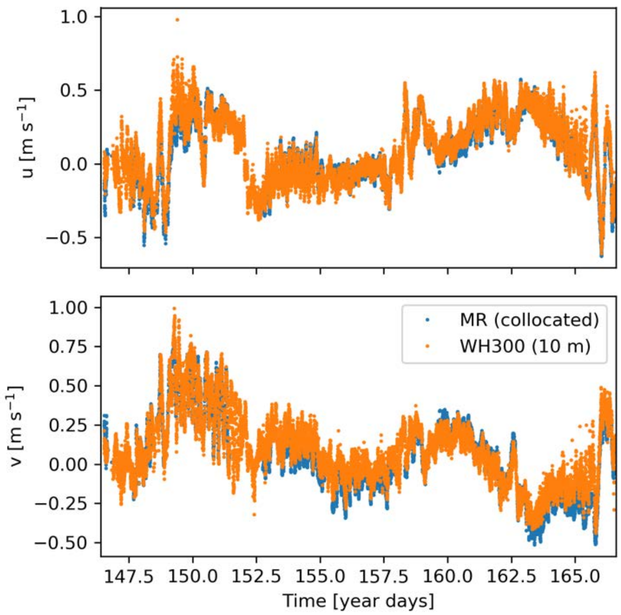
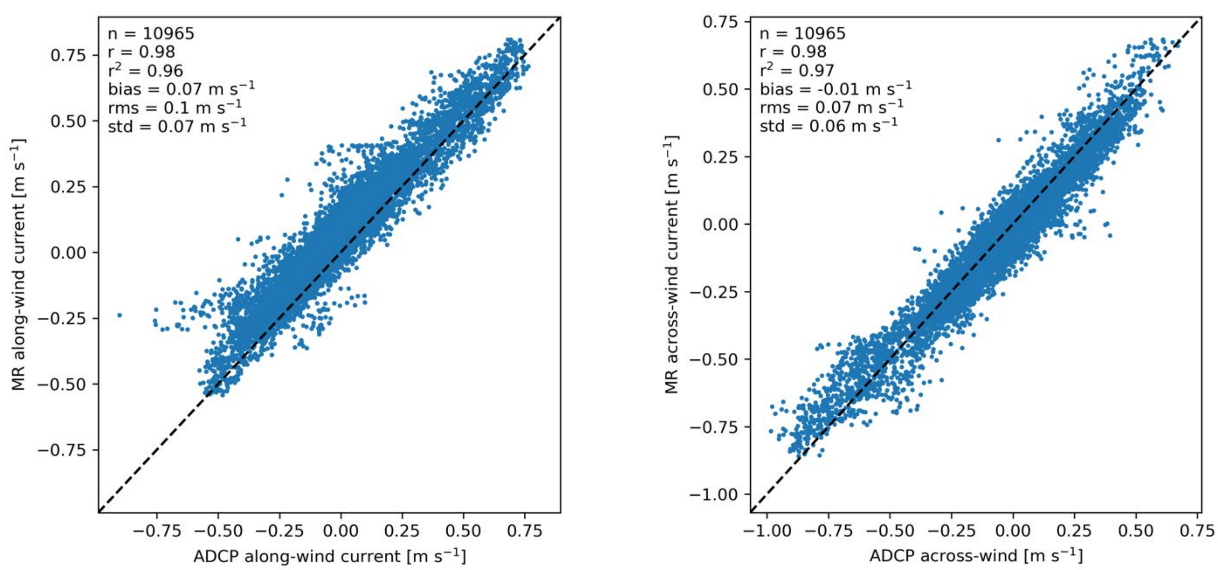


Figure 3.5-2: (left) Time series of shipboard WH300 ADCP measurements (10 m) in orange and collocated MR near-surface current measurements (1-4 m) in blue.

(below): Scatter plots of the shipboard WH300 ADCP measurements (10 m) and the collocated MR near-surface current measurements (1-4 m) with comparison statistics. The current measurements were rotated into an along- (left) and across-wind (right) coordinate frame using the 10-min smoothed wind from the ship's starboard Vaisala anemometer. Figure from B. Lund.



Results were shared with the science party and crew through the CSTARS MR Viewer web application (beta version) as well as in the form of KML, CSV, and NetCDF data files. Fig. 3.5-1 shows a screenshot of the CSTARS MR Viewer with a frequency direction spectrum of relative wave energy density from 4 June 2019, 04:20 to 04:40 UTC, the preceding 3 hours of near-surface current measurements, and a 1-min averaged image of radar backscatter intensity.

Fig. 3.5-2 shows a time series comparing the shipboard WH300 ADCP measurements at 10 m with MR near-surface currents at an effective depth of 1-4 m for the entire cruise. The radar current measurements are based on 6-12 min of data from geographically fixed circular analysis windows with ~600 m radius. They were interpolated spatially to match the location of the ship. The same data but mapped into an along- and across-wind reference frame as scatter plot (bottom panels of Fig. 3.5-2). As could be expected based on the different sampling depths, the MR data have a positive bias in the along-wind direction.

A strong current front observed near Iceland's southern peninsula on 13 May 2019, 14:00 to 15:00 UTC (during the previous cruise), is shown in Fig. 3.5-3.

Fig. 3.5-4 shows a time series of the MR peak and mean wave parameters, which are based on 20 min of measurements across the whole radar footprint. The square root of the signal-to-noise ratio (SNR) is linearly related to the significant wave height, a calibration is still pending. The strength of MR wave measurements lies in the system's ability to derive fully directional wave spectra without the use of model assumptions (e.g., maximum entropy method). The right panel of Fig. 3.5-4 gives an example of a MR-derived frequency direction spectrum acquired on 14 June 2019, 11:40 to 12:00 UTC. The wave radar's weakness lies in the significant wave height retrieval, which we expect has an accuracy of only ~0.5 m. The HZG radar's Doppler measurements have the potential to improve the significant wave height accuracy considerably.

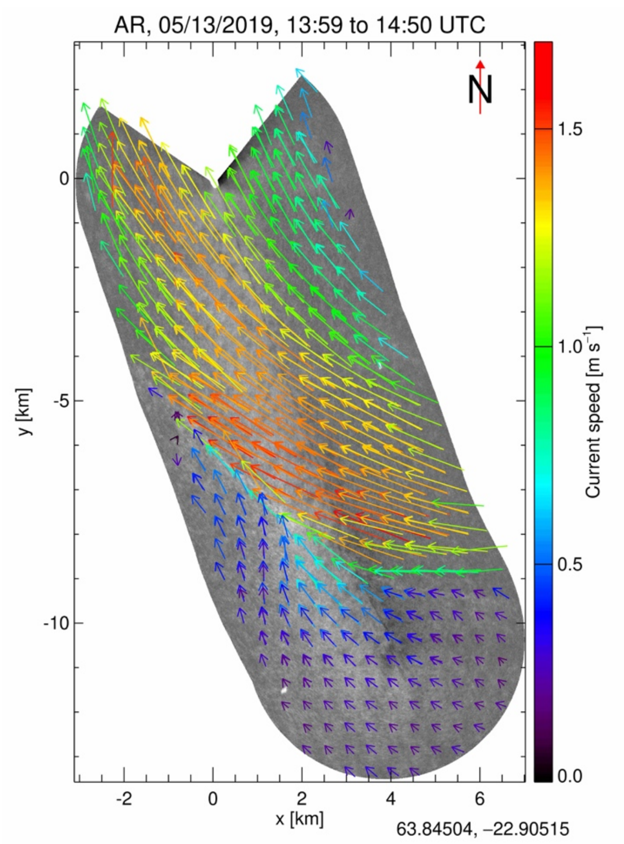


Figure 3.5-3: Radar near-surface current map acquired around Iceland's southern peninsula on 13 May 2019, 14:00 to 15:00 UTC. The radar image in the background shows a band of enhanced backscatter along the convergence zone separating the two flow regimes. Figure from B. Lund.

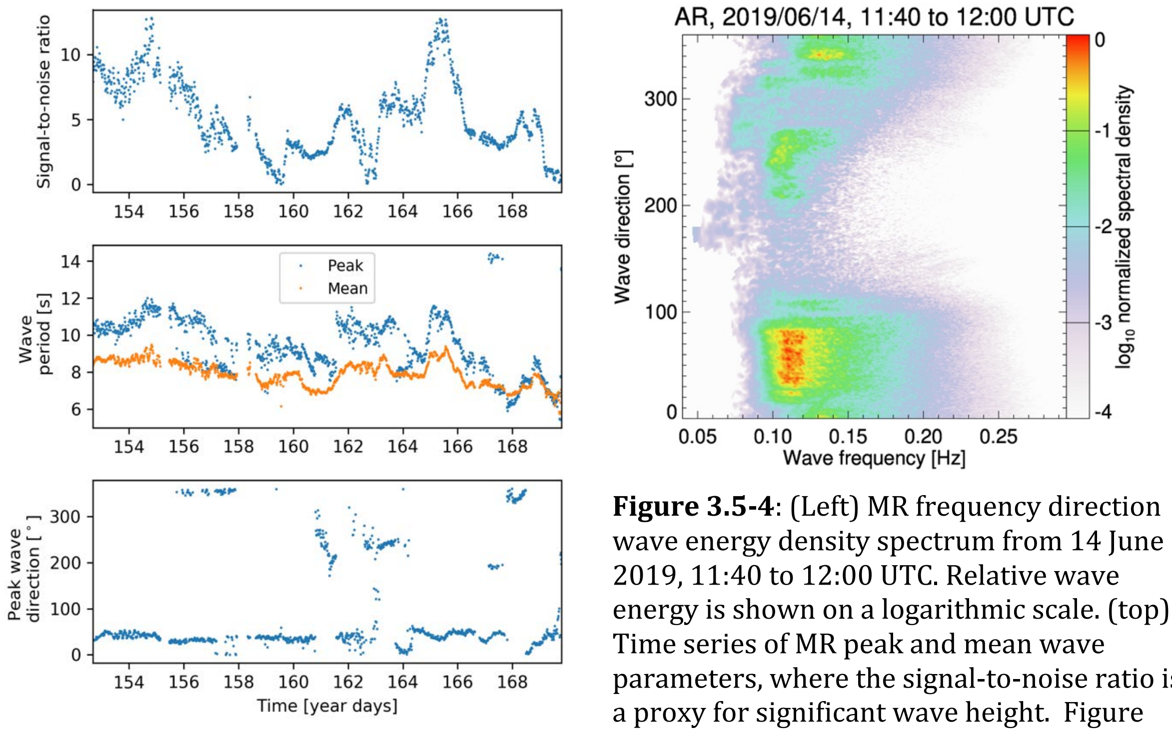


Figure 3.5-4: (Left) MR frequency direction wave energy density spectrum from 14 June 2019, 11:40 to 12:00 UTC. Relative wave energy is shown on a logarithmic scale. (top) Time series of MR peak and mean wave parameters, where the signal-to-noise ratio is a proxy for significant wave height. Figure from B. Lund.

3.6. WIREWALKER

A Wirewalker wave-powered profiling drifter was deployed 3 times during the cruise, doing profiles to 500m. The vehicle is equipped with CTD (RBR Concerto), velocity (Nortek Aquadopp), optics (WETLabs chlorophyll and CDOM fluorescence, 532 nm backscatter), dissolved oxygen, and a shear/temperature microstructure sensor (Epsi).

For the first drift, the Wirewalker was deployed with 8 EM-APEX floats and 8 SVP drifters as an array in a region of low cyclonic vorticity. The Wirewalker collected CTD and velocity data down to 500 m every 30 minutes. The microstructure instrument broke several hours after deployment, and therefore no microstructure data is available for this drift. Additionally, due to an external battery connection problem, the RBR Concerto only collected data for the first two days of the five day drift, lasting 2 June through 7 June. However, temperature and pressure data from the ADCP is available for the entire drift (Fig. 3.6-1). A compensated subsurface warm blob, which was also sampled by the S-ADOS and the EM-APEX floats, can be seen in the first day of the record. The shipboard ADCP and Triaxus *sheepdog* survey circled this array to provide some spatial context.

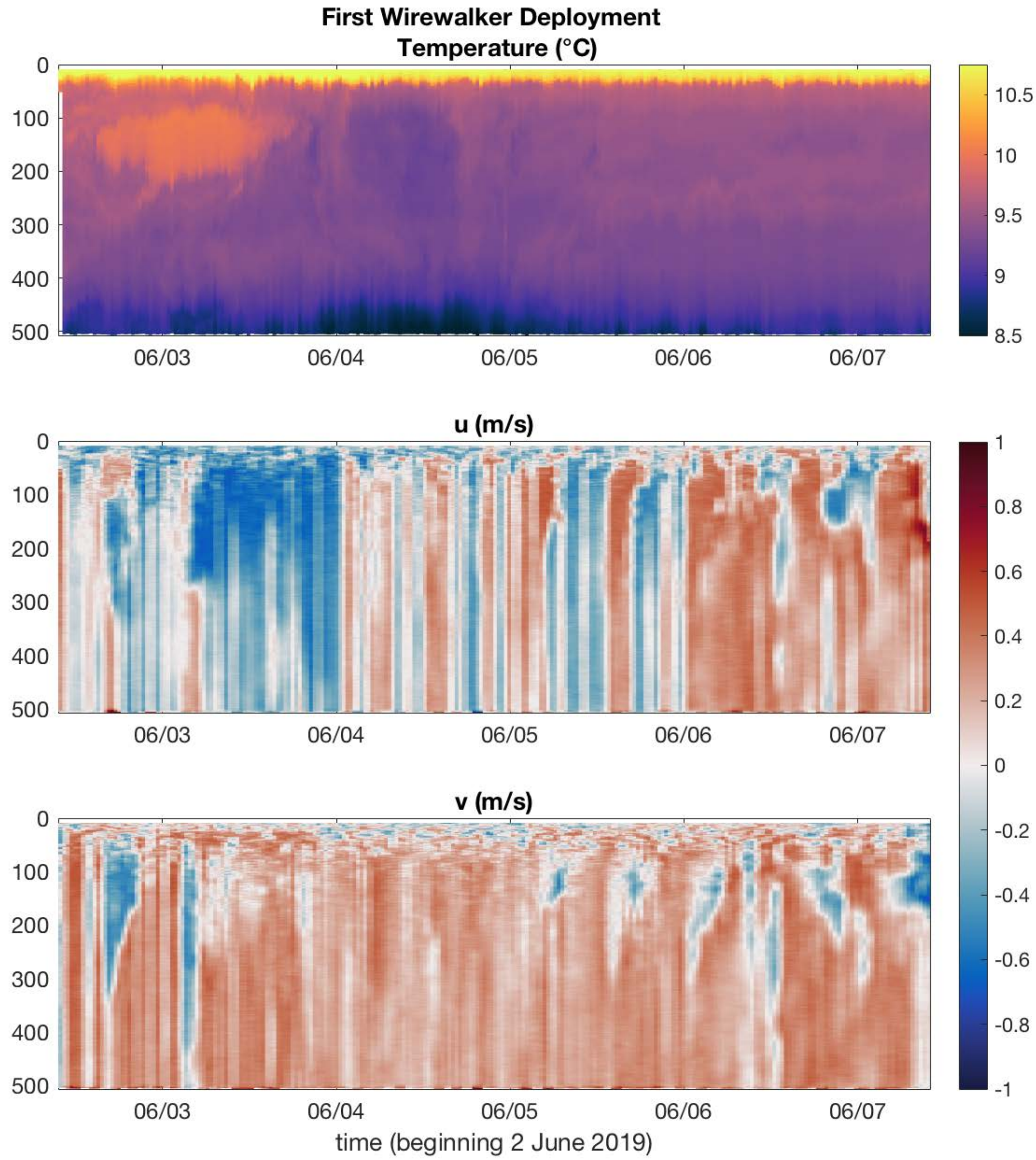


Figure 3.6-1: Temperature (top), east ocean velocity (middle) and north velocity (bottom) as function of depth and time for the first Wirewalker deployment. Velocity has been corrected for motion of the Wirewalker. Figure from A. Savage.

We then collected the Wirewalker and the EM-APEX floats and redeployed the array at the inner side of an anticyclone for a 2.5 day drift, from 9 June through 12 June. To address the battery life issue on the RBR, the sampling frequency of the RBR was lowered. Temperature and velocity data from the ADCP is shown in Fig. 3.6-2. The array curled around the northern side of the anticyclone, as the shipboard *fence* survey followed behind the drifting array.

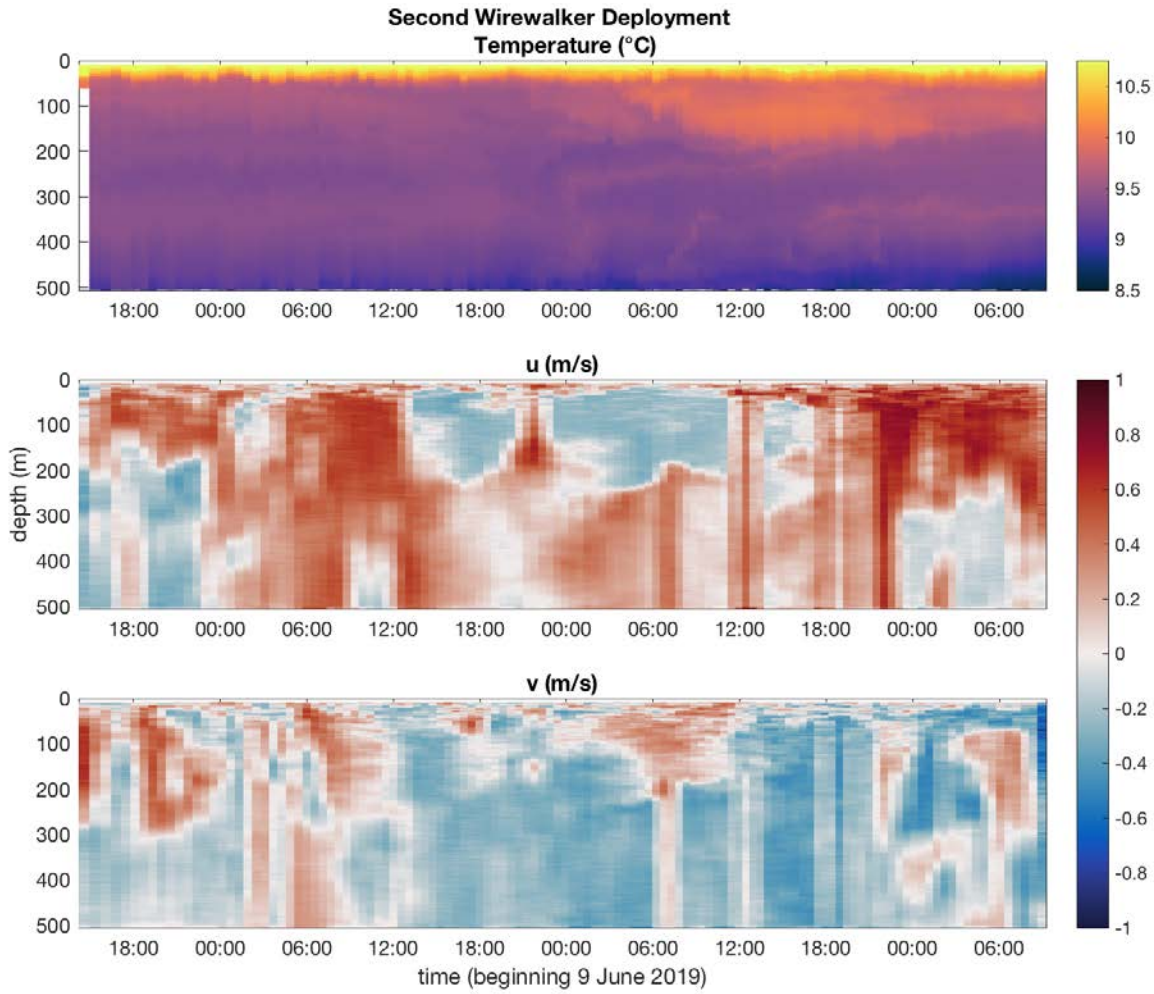


Figure 3.6-2: Temperature (top), east ocean velocity (middle) and north velocity (bottom) as function of depth and time for the second Wirewalker deployment. Figure from A. Savage.

The third Wirewalker drift occurred from late on 12 June to early on 18 June on the outer edge of the anticyclonic eddy. To address the battery life issue on the RBR, the ECO puck and dissolved oxygen sensors were removed for this drift. Fig. 3.6-3 shows velocity data from the ADCP as well as temperature data from the RBR concerto. Four of the eight EM-APEX floats deployed in the second drift were recovered and redeployed with the Wirewalker on the outer edge of the anticyclone, while the remaining four were left on the inner edge of the eddy. The ship followed behind the Wirewalker in the *greyhound* survey.

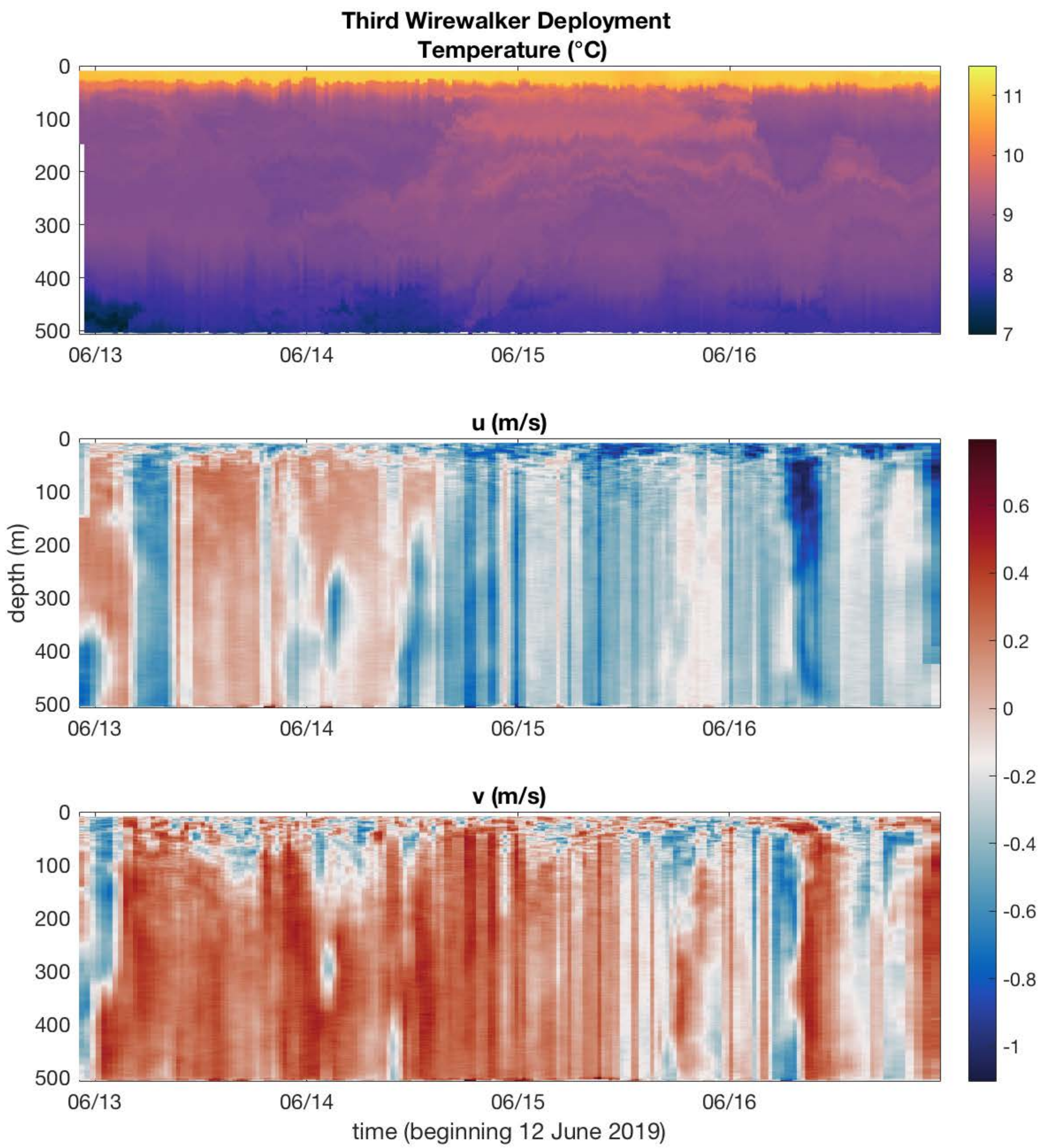


Figure 3.6-3: Temperature (top), east ocean velocity (middle) and north velocity (bottom) as function of depth and time for the third Wirewalker deployment. Figure from A. Savage.

3.7. SADOS (Super Autonomous Drifting Ocean Station)

Super Autonomous Drifting Ocean Station (ADOS) buoys are designed to measure the deepening of the mixed layer and concurrently make measurements of three-dimensional current profiles, horizontal wind and sea-level atmospheric pressure (see http://gdp.ucsd.edu/ldl_drifter/instruments/ados.html). The Super ADOS carries two 400 KHz Aquadopp Acoustic Doppler Current Profilers by Nortek, and ten inductive temperature and pressure pods (inductive pod accuracy: Pressure ±1 dbar, Temperature ±0.05 °C).

Both S-ADOS were deployed, one with the cluster of 3 EM-APEX floats deployed in the anticyclone ahead of the first storm, and the other as part of the first drifting array. This second S-ADOS was recovered after the *sheepdog* survey, to be redeployed in the second drifting array. It continued to sample in the anticyclone until the end of the cruise.

Action item: S-ADOS ADCP data to processed and shared.

3.8. WAVE MEASUREMENTS

In addition to the measurements of the wave spectrum near the ship from WAMOS, we deployed 9 wave buoys (from E. Terrill and S. Merrifield's group) and 10 Directional Wave Spectra Drifters (Centurioni's group). Since these drifters are undrogued, they will not be used to measure ocean currents.

Comparisons between direct measurements and WAMOS will be interesting.

We might have observed interactions between surface waves and the mean flow as well.

4. Initial summary of surveys and science results / questions

4.1. Jet Survey (cyclonic side of the jet, during wind event).

The objective of this survey was to study the generation of inertial oscillations in the mixed layer and their dephasing in space due to variations in the mean flow. To this end we used satellite altimetry to identify a region where the surface geostrophic flow had vorticity gradients and strain, where a simple ray tracing calculation suggested that horizontal variations in the NIWs would grow the fastest. The survey straddled a jet, sampling both its cyclonic and anticyclonic flanks. The jet was also in a region of confluent strain and had a mesoscale anticyclone to its east (see Fig. 4.1-1). Lateral variations in temperature and salinity were large but mostly compensated, with weak lateral density gradients (Fig. 3.1-2). As a consequence, the background flow was quite barotropic in the upper 400-500 m.

The survey was started on May 30 0600, around six hours after the peak winds during the wind event. The winds subsequently weakened in magnitude and rotated in the clockwise direction as an atmospheric front passed through (e.g. Fig 2.1-1), leading to ideal conditions for generating inertial oscillations. Indeed, a forecast made using Sam Kelly's slab mixed layer model forced by NOAA GDAS and GFS winds, predicted a very clean inertial signal and did a surprisingly good job at capturing both the phasing and amplitude of the observed inertial motions in the upper 50 m (Fig. 4.1-2).

Inspecting the time series of the inertial motions more closely at two locations straddling the axis of the jet (indicated by the blue and red stars in Fig. 4.1-3) reveals the development of a phase difference in the oscillations between the two locations over time. More specifically, as time progresses, the inertial oscillations on the cyclonic side of the jet (blue) appear to lead the oscillation on the anticyclonic side of the jet (red), Fig. 4.1-3. The phase difference can be quantified by calculating the angle of the velocity perturbation $\phi_u = \text{atan}\left(\frac{v}{u}\right)$ at the two locations. The angle decreases more rapidly on the cyclonic side of the jet, leading to a phase difference of around 1.8 radians after 5 inertial periods. Given the 9 km spacing between the two locations, this implies that waves had a ~30 km wavelength that was continuing to shrink in size with time. This increase in wavevector, with waves propagating towards the anticyclonic side of the jet, is consistent with NIW refraction by vorticity gradients. Given the rate of increase in phase difference, the theory for wave refraction would require a vorticity gradient β_{eff} of $8\text{x}10^{-10}$ m^{-1} s^{-1}, which is comparable to the observed vorticity gradients around the jet (namely changes in vorticity of order 0.1 f over 10 km). What is puzzling, however, is the apparent lack of influence of the confluent strain on the evolution of the NIW wavevector. The strain rates near the jet were of order 0.1f, and presumably should have led to an exponential rather than linear increase in the wavenumber with time after the initial stage of refraction by vorticity gradients. However there was no evidence of this rapid growth in phase difference as measured using ϕ_u. One possible explanation for this is that the depth averaged velocity perturbation used to calculate ϕ_u is dominated by the low modes, and that these low modes are highly dispersive given the observed stratification (10^{-5} s^{-2}< N^2< 10^{-4} s^{-2}) and thus are only minimally affected by advection and straining by the background flow (e.g. Rocha et al 2018). This hypothesis should be explored more fully.

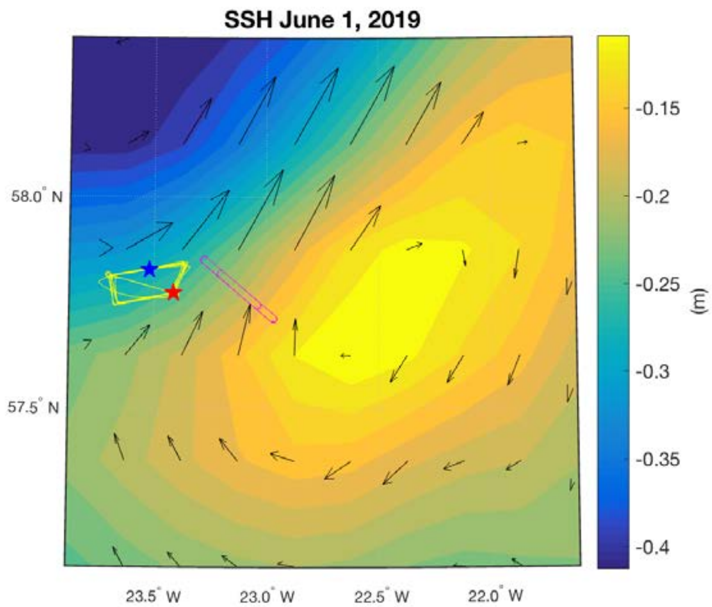


Figure 4.1-1. SSH (color) and surface geostrophic velocity (vectors) from satellite altimetry and the shiptracks of the Jet (yellow) and the Confluence (magenta) surveys. The red and blue stars indicate the positions where the time series in Fig. 4.1-2 were made. Figure from L. Thomas.

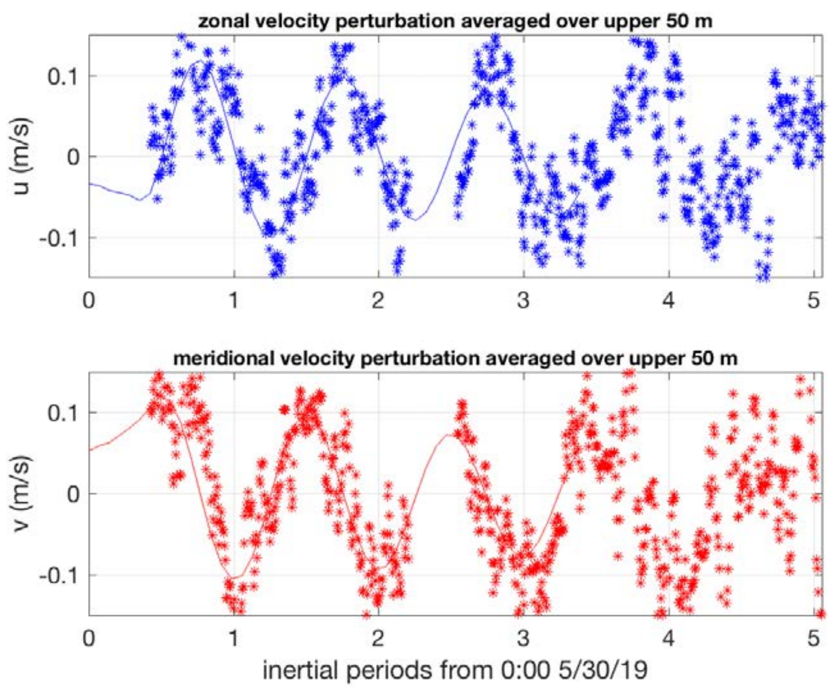


Figure 4.1-2: Prediction for the currents in the mixed layer from a slab model forced by NOAA GDAS and GFS forecast winds from 5/29/19 at 58 N 24 W, thin lines, compared to the observed velocity perturbation averaged over the upper 50 m (stars) at all locations and times during the Jet survey. The velocity perturbation is defined as the deviation of the total velocity from the velocity averaged between 50-200 m, which essentially removes the nearly-barotropic background flow and highlights the surface-intensified inertial motions. Time is in units of an inertial period which is 14.18 hours at the latitude of the survey. Figure from L. Thomas.

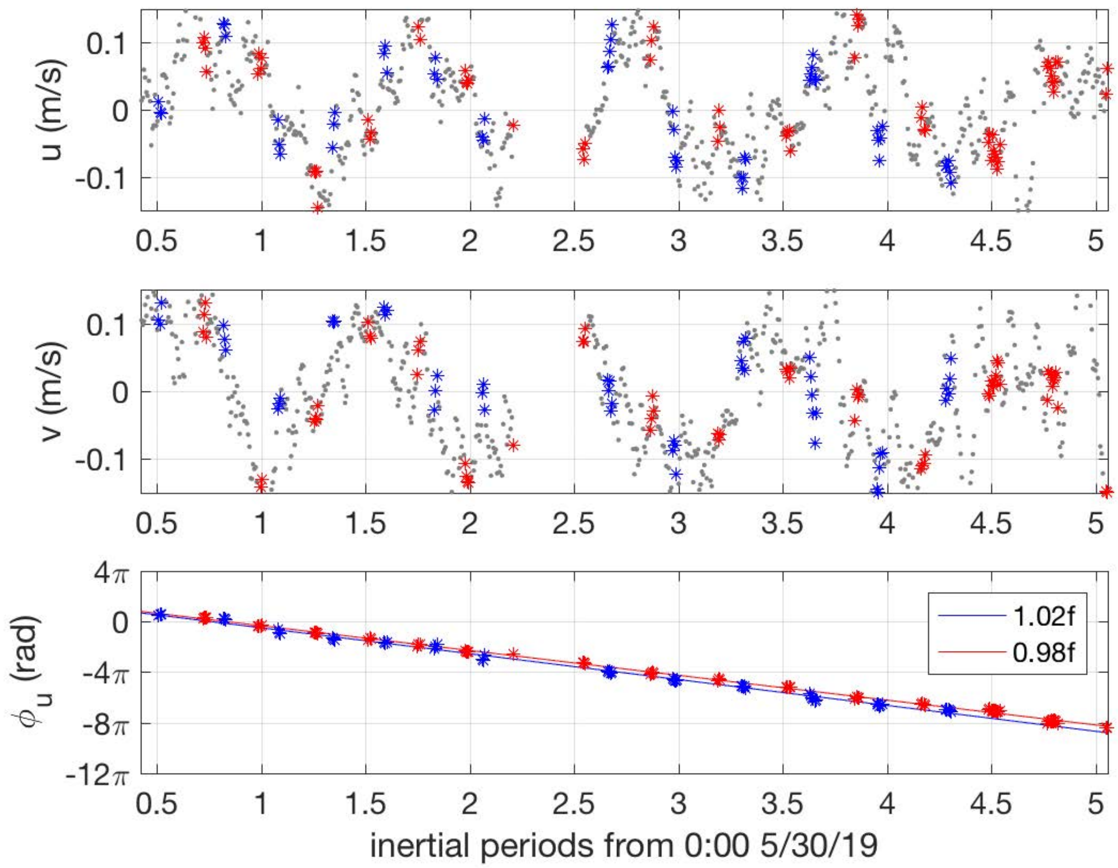


Figure 4.1-3: Time series of the zonal (top) and meridional (middle) velocity perturbation averaged over the upper 50 m at two locations in the Jet survey (see Fig. XX), one on the anticyclonic side of the Jet (red) and the other on the cyclonic side of the jet (blue). The velocity perturbation from all the locations in the Jet survey is shown in gray. The inertial oscillations on either side of the jet develop phase differences which can be quantified using the angle of the velocity perturbation vector $\phi_u = \text{atan}(v/u)$ (bottom panel) which decreases with time at slightly different rates. Fitting a line to this angle (solid lines) yields a frequency of 1.02f and 0.98f on the cyclonic and anticyclonic side of the jet, respectively. Figure from L. Thomas.

4.2. Confluence Survey (anticyclonic side of the jet, after wind event).

The objective of this survey was to observe the evolution of the horizontal wavenumber of the NIWs and their radiation following the wind event. The survey was located on the anticyclonic side of the jet and into the anticyclone (Fig. 4.1-1). The background flow (estimated as the velocity averaged between 50-350 m, using the corrected velocities; see section 3.1) was projected into along-stream and cross-stream components for each section of the survey. The along-stream direction is defined as the speed-weighted average direction of the background flow on the section. The cross-stream coordinate is defined to be perpendicular to the along-stream direction, increasing towards the anticyclone. The cross-stream velocity was confluent with a strain rate of order 0.1f that did not vary much over the duration of the survey. The vorticity, as estimated from the cross-stream derivative of the along-stream velocity, did vary considerably during the survey, starting out anticyclonic with values of order -0.1 f, then decreasing by nearly an order of magnitude. There do appear to be modulations of the vorticity and strain on inertial time scales and this could be due to contamination of the estimate of the background flow by NIWs.

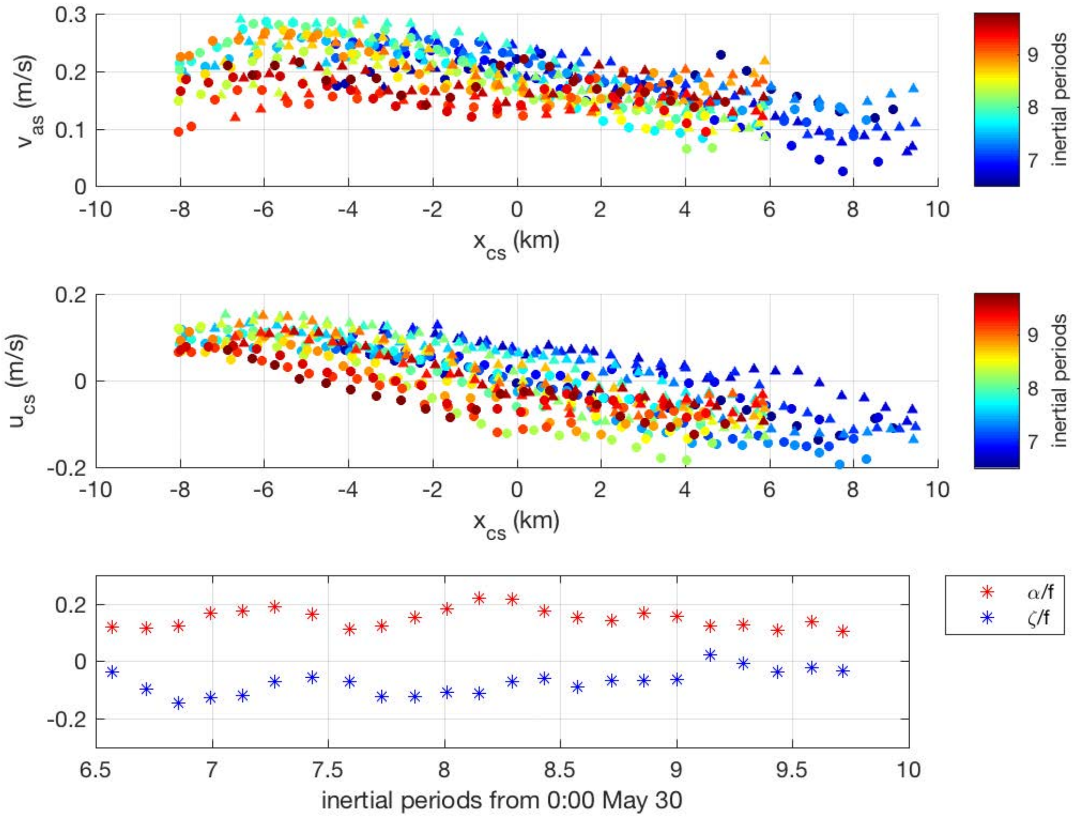


Figure 4.2-1: The along-stream v_{as} (top) and across-stream u_{cs} (middle) components of the background flow (estimated as the velocity averaged between 50-350 m) as a function of the cross-stream coordinate, x_cs, and time (color) for all sections of the Confluence survey, Bottom panel: time series of the vorticity $\zeta = \partial v_{as}/\partial x$ (blue) and confluence $\alpha = -\partial u_{cs}/\partial x$ (red) averaged over each section of Confluence survey and normalized by f. Figure from L. Thomas.

The lateral and vertical variability of the NIWs was clearly evident on the sections. In particular, near-inertial wave beams with downward tilting phase lines appeared to be propagating down and towards the anticyclone (Figure 4.2-2). The NIWs early on in the survey had vertical wavelengths of ~300 m and lateral wavelengths of ~30 km. Later on in the survey these scales appeared to shrink, however a more careful analysis needs to be performed to determine if this is the case, as the wave field is more complex and seems less monochromatic at this stage. The Triaxus surveys revealed undulations in isopycnals on the spatial scales of the NIWs suggesting that the waves were generating buoyancy and pressure anomalies and thus could flux energy and have potential energy. A ray tracing calculation performed using a background flow with uniform vorticity (i.e. the average value on the section) and a stratification profile taken from station 2 of the deep CTD casts, suggests that the NIW beam has an intrinsic frequency very near f.

Many questions, still remain, however. In particular, what sets the ~300 m vertical wavelength of the fastest propagating, low mode NIWs? Based on the Jet survey it appeared that most of the NIW energy injected by the wind event was confined to the upper ~50 m of the water column, above the shallow pycnocline. Therefore, it is somewhat puzzling that the fastest propagating, low mode NIWs have a vertical wavelength nearly six times this scale. In addition, if the intrinsic frequency of these low mode waves is very close to f, their vertical propagation speed is order 10s of meters per day. If they were generated by the wind-event on May 30, then they should have propagated only a few tens of meters not hundreds of meters into the interior by the time the section shown in Figure 4.2-2 was made. Finally, it is unclear what caused the apparent increase in vorticity over the duration of the survey. Was it simply QG dynamics (i.e. advection of vorticity by the balanced flow, vortex stretching/squashing) or were wave-mean flow interactions, which tend to skew vorticity distributions positive, at play (e.g., Rocha et al 2018).

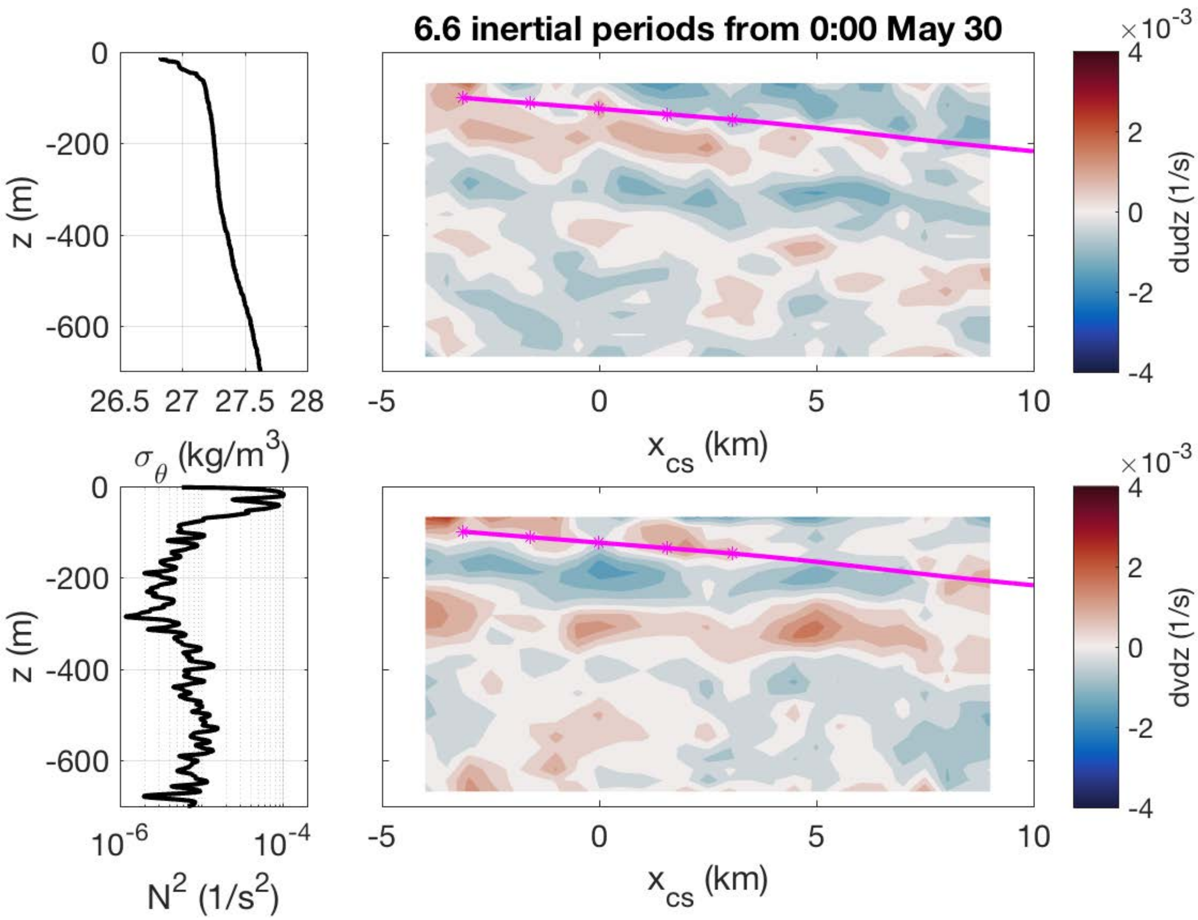


Figure 4.2-2: Sections of the vertical shear of the zonal and meridional velocity (left panels) during the first transect of the Confluence survey which was taken 6.6 inertial periods/3.9 days after the peak winds. The section has been projected into an across-stream coordinate system where increasing x_cs moves from the jet toward the anticyclone and the along-stream direction is into the

page. A beam of NIW energy is clearly evident and is directed towards the anticyclone. A ray corresponding to a NIW with frequency f and a vertical wavelength of 300 m is shown in magenta. The ray tracing calculation assumes a background flow with uniform vorticity equal to the average vorticity over the section (-0.02f) and a stratification profile corresponding to that observed at station 2 of the deep CTD casts (profiles shown on the left). The stars on the ray correspond to the position of a wavepacket for each day of travel time, up to 4 days. Figure from L. Thomas.

4.3. Sheepdog Survey (drifting array #1).

This densely sampled 10x10 km patch of ocean should allow us to capture the 3D structure of near-inertial motions, and how the evolve. Marine radar should be really valuable here.

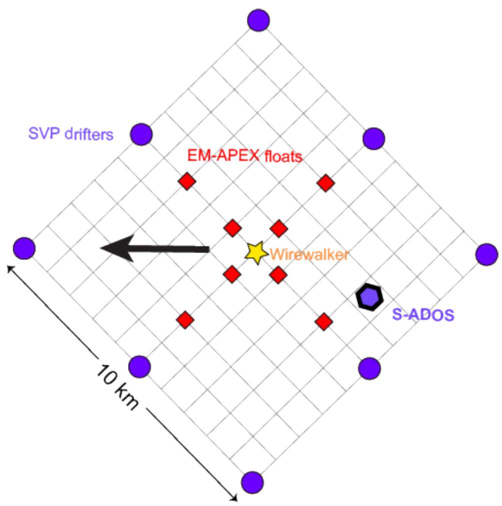


Figure 4.3-1. Drifting array deployment configuration. Figure from L. Rainville.

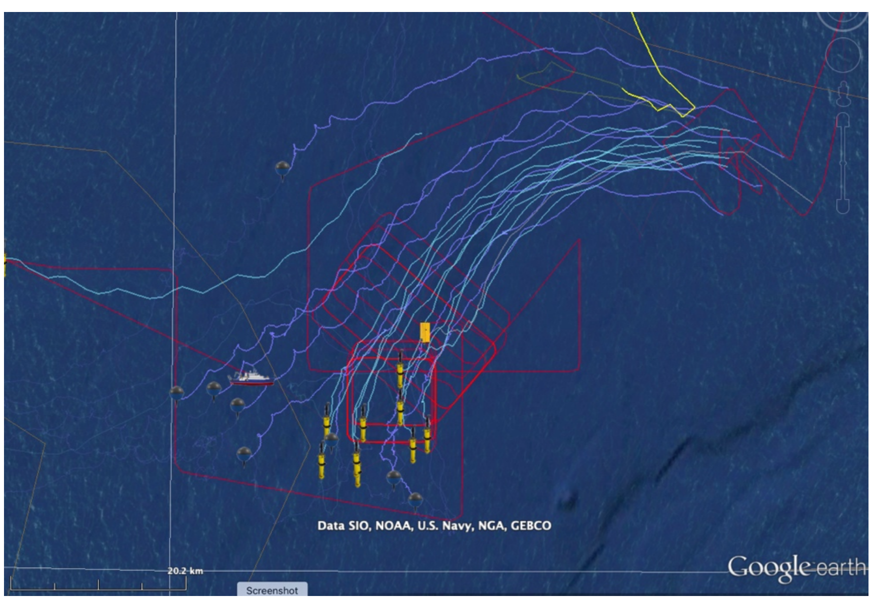


Figure 4.3-2: Snapshot of the trajectories of NISKINe instruments around the drift array #1, from 6 June 0600 to 7 June 1800. Figure from L. Rainville.

4.4. Transect of Anticyclone (ADCP, uCTD, and deep CTD with chi-pods)

Prior to redeploying the Wirewalker and array of floats we made a couple of transects through the anticyclone from the jet towards the eddy center, to determine where we should deploy the drifting array (see panel 3 in Figure 3.1-1). On the first transect only shipboard underway data was collected, while on the second transect five deep CTD casts with chi-pod microstructure measurements were also made. On both transects, NIW shear bands were evident (Figure 4.4-1). These may have been associated with critical layers or turning points because they were found in the proximity of the locations where $f_{eff} = f$ and where subinertial NIWs could be trapped, and amplified.

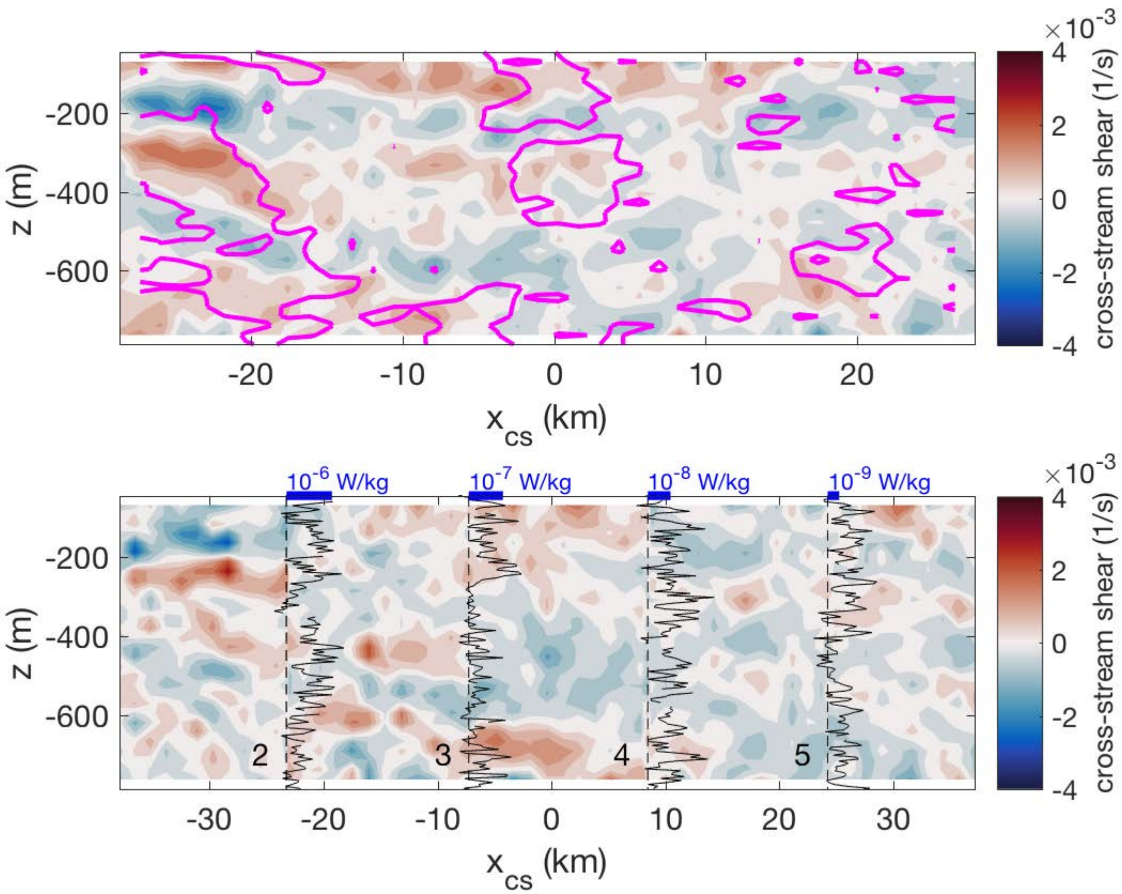


Figure 4.4-1: Two sections of the vertical shear of the cross-stream component of the velocity (color) transecting the anticyclone. The sections are plotted as a function of the cross-stream coordinate, x_cs, which increases moving from the eddy edge towards its center. The transect in the upper panel was made between 0800-1200 on June 8, while the transect in the bottom panel was made from June 8 2000 to June 9 1000 and also included deep CTD stations. The magenta contours in the upper panel indicate the locations where $f_{eff} = f$. Within or near these regions there tends to be enhanced shear which might be associated with a critical layer. Profiles of $\log(\epsilon)$ inferred from the chi-pods at CTD stations 2-5 are plotted in the bottom panel at the positions of each station. Scalings for $\log \epsilon$ are indicated by the blue bars at the top of the panel and the CTD station numbers are indicated in black. Figure from L. Thomas.

Estimates of dissipation from the chi-pods suggests that there is enhanced turbulence in these shear bands (e.g. station 2 between 100-300 m and 400-600m). However, there are other stations where the dissipation is enhanced yet the shear rather featureless and is not particularly strong such as station 4 where the inferred dissipation reached values of O(10^{-6} W/kg). At this station, the depths where the inferred dissipation was enhanced coincided with thermohaline intrusions (Figure 4.4-2). Thus it is possible that part of the enhanced χ at this station could be generated by lateral fluxes of temperature and therefore the assumptions used to infer ϵ from χ may have to be reevaluated. Apart from exploring this issue more fully, the physics of critical reflection in these sections of the anticyclone should also be studied more carefully.

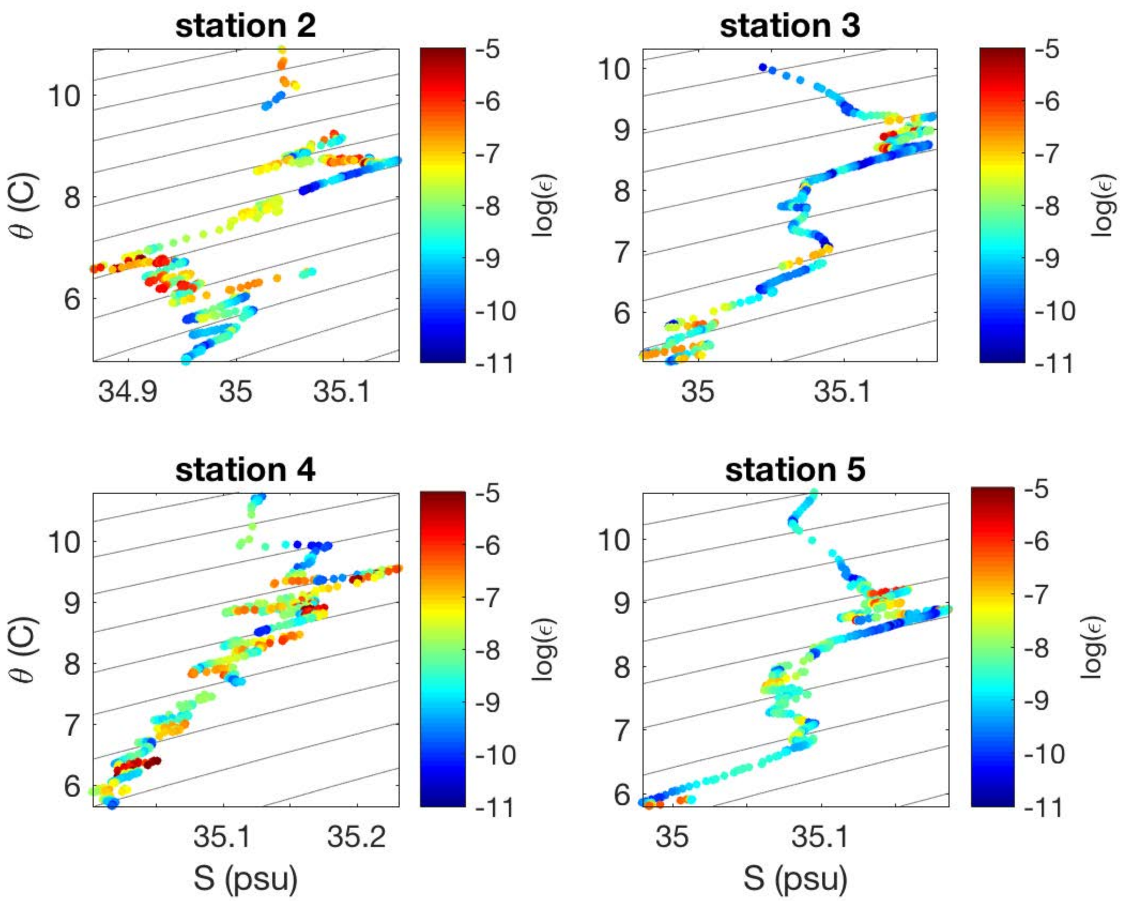


Figure 4.4-2: T-S relation and log of dissipation as inferred from the chi-pod for the four deep CTD stations within the anticyclone. Only the upper 800 m of the profiles is shown and isopycnals are contoured every 0.1 kg/m^3. Figure from L. Thomas.

4.5. Fence Survey (drifting array #2; inner side of anticyclonic eddy).

On a few sections of the Fence survey (Fig. 4.5-1) there were pronounced shear bands on the ends of the sections away from the eddy center (see Figure 4.5-2, x_{cs}<-5 km). These shear bands were located in a region where the strength of the anticyclonic vorticity actually *increased* with depth, as isopycnals domed upwards. This characteristic of the background flow could lead to the trapping and amplification of upward propagating NIWs in an "inverted critical layer" near the surface. Indeed, the shear bands appear to be associated with upward propagating NIWs as the angle that the shear makes with the horizontal $\phi_{shear} = \text{atan}\left[\frac{\frac{\partial v}{\partial z}}{\frac{\partial u}{\partial z}}\right]$ rotates counterclockwise with depth (Figure 4.5-2, left panel). The structure of the vorticity field causes contours of constant f_{eff} to bend concave-downward, which focuses wave rays in the near-surface pycnocline, possibly leading to a critical layer and wave breaking. Exploring this physics more fully using theory and modeling, and looking for evidence of wave breaking in the dissipation estimates from the microstructure sensors on the Triaxus would be a worthwhile endeavor.

The sections also reveal fascinating T-S variability that seems to be correlated with the vorticity field. For example, below the near-surface pycnocline, there are filaments of fresher waters, which are mostly density compensated, that appear to coincide with filaments of cyclonic vorticity where $f_{eff} > f$. The freshest waters on the section are found in a thin layer within the pycnocline, near the inverted critical layer, and appear to be streaming towards the eddy center from a source at the edge of the eddy. The pycnocline was also interrupted by a lenticular-shaped pycnostad in the center of the section. This feature was observed on other sections and could have been associated with an intrathermocline eddy or a baroclinic filament with low PV.

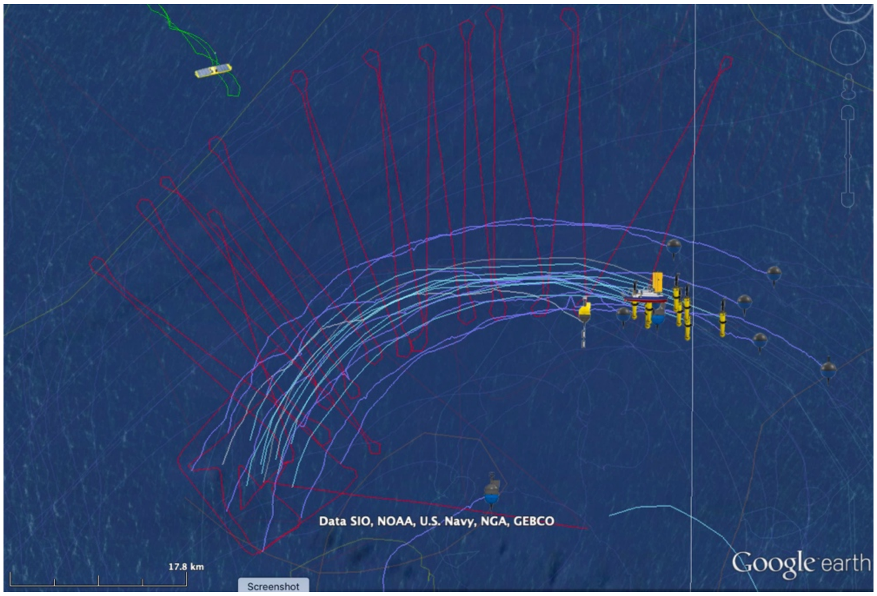


Figure 4.5-1: Snapshot of the trajectories of NISKINe instruments around the drift array #2, from 9 June 1200 to 12 June 0800. Figure from L. Rainville.

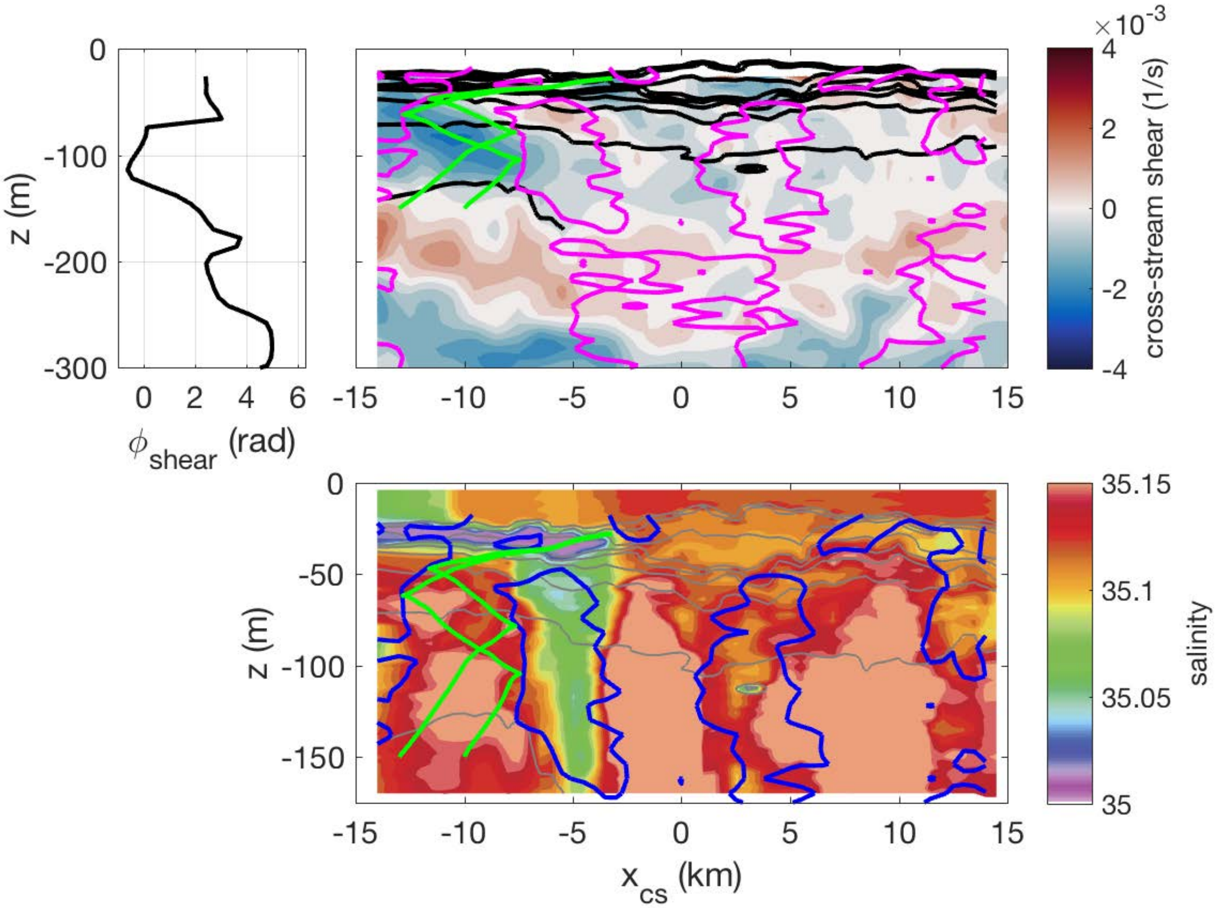


Figure 4.5-2 Sections of vertical shear of the cross-stream velocity (upper panel) and salinity (lower panel) taken between 1745-2010 June 11 during the Fence survey. Increasing values of x_cs are closer to the eddy center. Isopycnals are contoured in black and gray, in the upper and lower panels, respectively, every 0.05 kg/m3. The contour where $f_{eff} = 0.98f$ is indicated by the magenta and blue lines in the panels. The structure of the vorticity field can trap and focus upward propagating NIWs in an "inverted critical layer", as illustrated by rays for waves of frequency $0.98f$ shown in green. The shear appears to be enhanced in this trapping region, and the angle that the shear makes with the horizontal $\phi_{shear} = \text{atan}\left[\frac{\frac{\partial v}{\partial z}}{\frac{\partial u}{\partial z}}\right]$ evaluated at x_cs=-10 km (left panel) rotates counterclockwise with depth between 100-300 m, suggesting that the NIWs responsible for the shear are propagating upward. Figure from L. Thomas.

4.6. Greyhound Survey (drifting array #3; outer side of anticyclonic eddy).

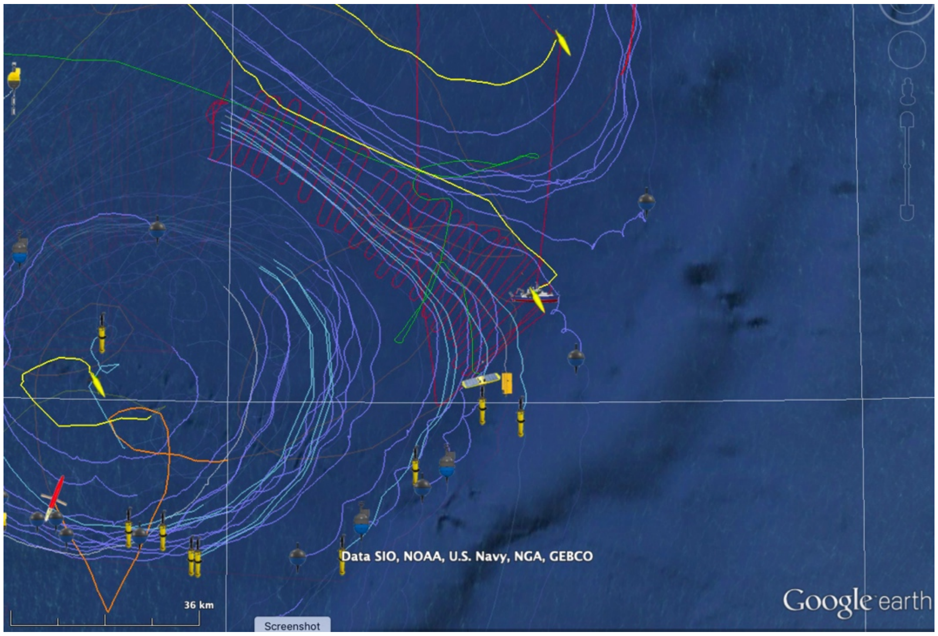


Figure 4.6-1: Snapshot of the trajectories of NISKINe instruments around the drift array #3, from 12 June 2100 to 16 June 2100. Figure from L. Rainville.

4.7. Science topics discussed during the cruise as possible subjects for later analysis:

Mixed-layer T-S properties

Mixed-layer T-S properties cover a smaller range than the T-S spread below the ML. So T-S plot converges on mixed layer. Why? Leif thinks maybe because of shear dispersion by inertial waves in the ML. To evaluate, need amplitude of shear (and indication that it's inertial) along with vertical diffusivity in ML. Shear dispersion theory (e.g., Young, Rhines, Garrett 1982) generates lateral diffusivity, which can be compared with time evolution of T-S front (where? how?) or somehow statistically combined with forcing scales to illustrate rate of collapse in ML relative to below (where compensated T-S variance can persist for long times).

Mixed layer depth

Base of ML jumps up and down over 30 m range on very short spatial scales (as short as from one Triaxus profile to the next — ~1 km). Overall, ML base has (a) slope across confluent jet, and likely (b) inertial heaving due to pumping by surface layer phase differences, but also (c) lots of embedded finescale structure or (d) high-frequency vertical motions due to super-inertial internal waves. Note that W inferred from EM-APEX rise-fall rate deviations is often +/- 1-2 cm/s or more.

Wave – mean flow interaction

Wave momentum flux could be damping anticyclonic vorticity. Symptom is that Leif noticed vorticity decrease (while strain stayed constant) during *confluence* survey (anticyclonic side of confluent jet). Theory by Young, Rocha, Wagner (and earlier Vanneste and Zhai?) suggests NIWs carry momentum flux toward AC side which acts as a force, then sets up perpendicular geostrophic response which generates cyclonic vorticity.

Mean flow maps

We started making estimate of the mean flow, by mapping the depth-average currents from 50 to 250m using an objective map with a non-divergence constraint. This is based on old programs from Luc's graduate student days in a class with Dan Rudnick (and some code originating from Andrey Shcherbina). Using both components of the velocity vector, we estimate the pressure field that best matches the observations. We did it for the (corrected) ship ADCP, averaged between 50 and 250m, and the map seem to work really well. Here we use 3 inertial periods, centered on each day.

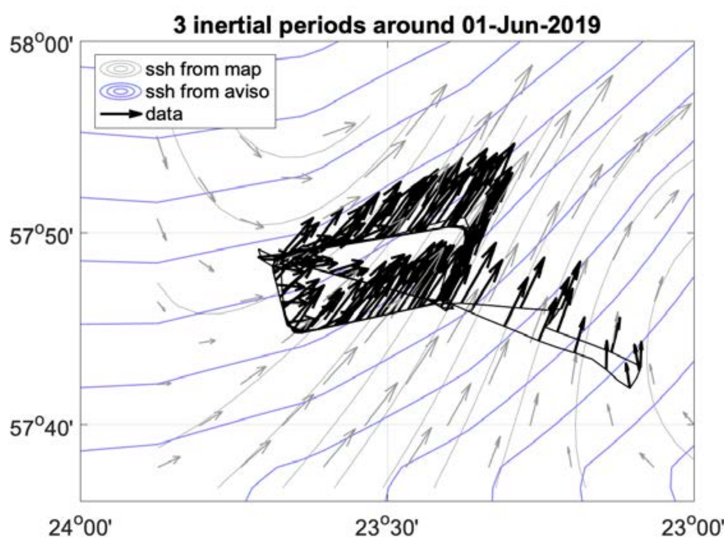


Figure 4.7-1: Map of the observed velocity vectors (black), and mapped ssh (or streamfunction; in gray). For reference, the Aviso SSH is shown in blue. Decorrelation scales of 30 km are used. Figure from L. Rainville.

Action item: We should include all velocity estimates for the surface drifters, EM-APEX float, and S-ADOS, glider's ADCPs, etc. in this!!!

Similar maps can be made on smaller scales.

This should be used to estimate the inertial velocities (residuals).

Filamentation

The sharp temperature and salinity structure, and the thin filaments of negative vorticity in the jet are reminiscent of some of the high-resolution simulations. These filaments can also be seen in ocean color (Fig. 4.7-2). It will be interesting to look at the evolution of these structures from careful examination of the Triaxus surveys and drifting arrays.

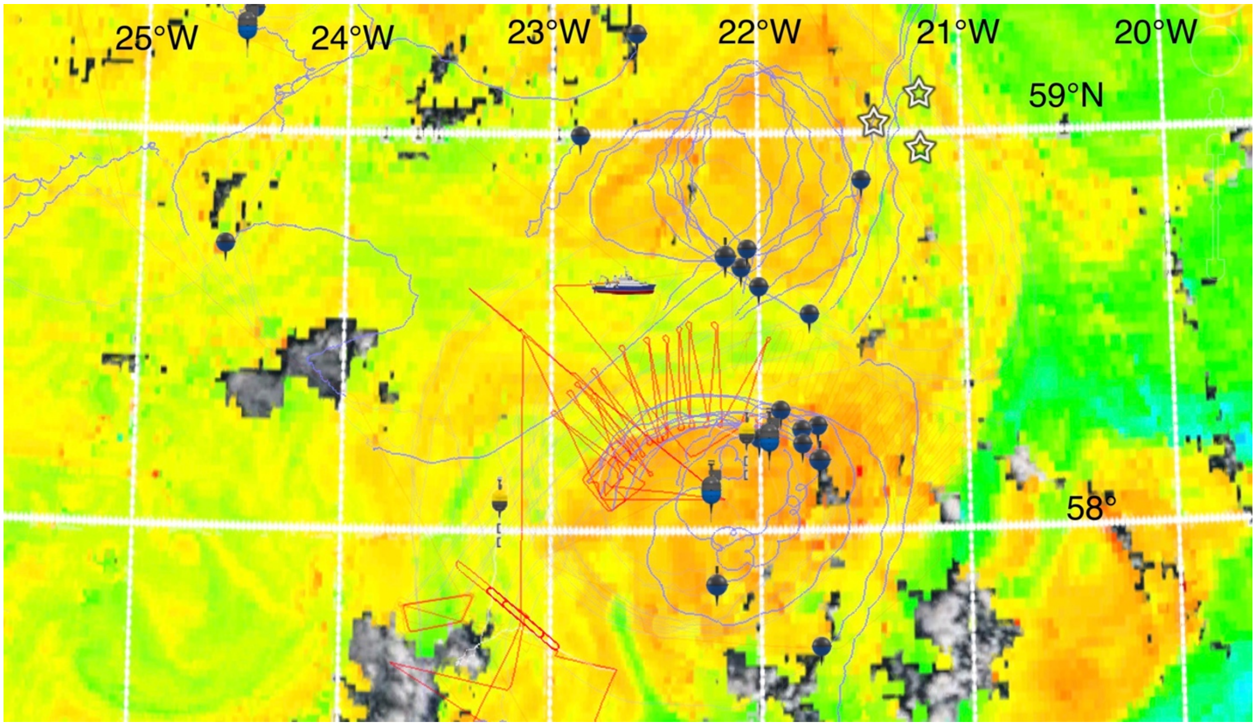


Figure 4.7-2: Chlorophyll-a concentration from MODIS Terra, on 9 June 2019. Ship track (red line) and drifter tracks (blue lines) are shown between 2 and 12 June. Figure from L. Rainville.

5. Event log

Monday, 27 May 2019

0900 Departure from Reykjavik, followed by science crew assembly and safety presentation by the first mate (Mike)

1530 Triaxus trial tow. 2h. 300-400m out. Profiling from 3-4 m to about 125m at the end.

Anna says something is strange with the GusT. They emailed Jim Moum. Update (5/28): One of them will be removed (bad data). The good one flooded (dirty o-ring) during the test, but had good data. Seems okay.

Tuesday, 28 May

0300 - Recovered sg124

1800 - Deployment of SVP-B 300234066312160

1800 - Deployment of Wave buoy 658

Wednesday, 29 May

Deployment of autonomous assets before arrival of first storm: Plan is to launch a line of drifters along an ADCP+UCTD transect across a SSH dipole between a cyclone (which did not persist) and an anticyclone (which eventually became the hub of much of the observations made during the cruise). Also deploy a few instruments (2 gliders, waveglider SV2, 1 EM-APEX, and 1 minimet drifter) at the midpoint of the line, which appears to be a small cyclone or "cyclonic filament." Then launch 3 EM-APEX in the anticyclone at the southeast end of the transect.

0530 - Deployment of SVP-B 300234066312120 and of Wave buoy 660

Winds are ~20 kts.

0630 - Deployment of SVP 300234066218770

0730 - Deployment of SVP 300234066218830

0830 - Deployment of SVP 300234066218820

0930 - Deployment of SVP 300234066218840

1115: Deployment of sg526

1117: Deployment of EM-APEX 4966 (approx. 58 17.55 N, 23 53.72 W)

1120: Deployment of minimet and DWS drifter

1130: Deployment of sg141

1136: Deployment of Wave Glider

1430 - Deployment of SVP

1530 - Deployment of SVP

1630 - Deployment of SVP

1730 - Deployment of SVP

1830 - Deployment of SVP

1930 - Deployment of SVP

Some time during the section, the bungee cord holding EM-APEX 7808 to its wooden rack worked loose, and the float fell over. Two fins were broken but there was no other visible damage, and float self-tests didn't find any problems. Greatest concern was that the conductivity cell may have been damaged, but subsequent data quality indicated that this did not occur.

1400 - 2030: uCTD. Section. The file NISKINe_01.asc contains bad data because tape was left on the probe. There might be a bad ground on the winch. The ship sees something strange when we run the winch. They are checking it. We plugged the winch inside the lab, instead of using the outlet on deck.

Deployment of Lagrangian mini-array (3 EM-APEX, 2 drifters) in a 15 km triangle at the presumed outer edge of the anticyclone's core.

2121: Deployment of EM-APEX 4967 (57 27.129'N, 23 01.676'W). Microstructure guards left on accidentally.

2121: Deployment of minimet and DWS drifter simultaneous with float.

2309: EM-APEX 4968 deployed (57 19.93 N, 23 08.34 W)

Thursday, 30 May. Storm day.

0008: EM-APEX 4969 deployed (57 26.31 N, 23 16.18 W), making the third point in the triangle.

Going around in the jet as a bowtie (doesn't work), and box pattern.

Releasing 3 drifters on the top of the box line, every loop. 1 Wave buoy, 3 SVPs.

1900: uCTD for 45 min along the northern side of the box.(Mixed layer characterization).

Friday, 31 May

0730: leaving the box to go recover EM-APEX 4967 at its closest approach to the timeseries survey (to remove microstructure guards).

0845: Recovery of EM-APEX 49670945: Triaxus deployment. *Jet*. Doing a section across the jet, then resuming the counter-clockwise box pattern.

1200: back to the Box at B2. Doing the box survey. Timeseries continued after roughly a 4.5 hour gap.

West end of survey box is cold, but there is a warm+salty+dense filament in the middle, which may have a submesoscale vorticity signature. This is really just related to uplifted isopycnals in the upper 40m, with depressed isopycnals at 150m or so (i.e., lower stratification in filament). This is on cyclonic edge of jet, but similar to another filament seen on the anticyclonic side. Center of the jet is a sharp compensated T-S front (warm+salty to cold+fresh) with most of geostrophic shear and corresponding density structure deep below (400m or more). T-S front must be a signature of frontogenetic secondary circulation and/or confluence/strain.

Saturday, 1 June.

Triaxus…

Trouble with the graphic card on the data server. Keeps freezing every 2.5 hours… Power cycle every 2h? Sometimes fix the problem. Jason is working on it.

Continuing Triaxus/ADCP survey while 4 EM-APEX floats are profiling (and seeing NIW signals propagating to ~300m depth rapidly after the storm—unless they were there already). In evening, switched from box survey to back-and-forth line to get a few more widely-spaced timeseries points near end of pattern.

Sunday 2 June

Leaving the box at midnight, heading to the anticyclone south of us. Long Triaxus section across the eddy, then back out. First line nearly due east to center of eddy, then to south-southwest for spatial structure to decide where to deploy the Wire Walker. Second line ended around 7am; Triaxus recovered and site selected for Wirewalker.

7:00 Recovering Triaxus.

0900 to 1530 Deployment of the drifting array.

9:45: Deployment of Wirewalker.

Deployments of 8 EM-APEX floats over 2 hours to form 3km box with 1kmi nner box (Array #1). Used Caitlin's algorithm to advect planned deployment points with mean ADCP velocity seen at Wirewalker deployment:

1) 1012: EM-APEX 4970 at 57 25.682'N, 22 57.486'W

2) ~1025: EM-APEX 7807 at 57 26.535'N, 22 58.772'W

(set to profile at 1/4 inertial period to ~650m)

3) 1053: EM-APEX 7808 at 57 24.033'N, 22 59.461'W

(also set to profile at 1/4 IP to ~650m)

4) 1108: EM-APEX 7801 at 57 24.852'N, 22 57.881'W

5) 1121: EM-APEX 7488 at 57 25.538'N, 22 56.415'W (only float with shear probe)

6) 1134: EM-APEX 7802 at 57 26.241'N, 22 55.008'W

Note: float twisted immediately on contacting the water (and before release line pulled). Chi sensor(s) may have touched the release line as it rolled over. Probably just missed, but check data.

7) 1154: EM-APEX 7803 at 57 24.586'N, 22 57.026'W

8) 1208: EM-APEX 7804 at 57 23.843'N, 22 55.448'W

Following last EM-APEX, began to launch 8 drifter array in large (10 km x 10 km) box around the Wire Walker. But after first buoy, WW was not sending GPS positions, so ship went to pick it up. WW buoy brought on board, GPS turned off and on, and another Xeos tracker was added (from APL-IOP collection) as backup. Now both seem to be working.

Also, Super-ADOS (T-chain+ADCPs) drifter launched near Wirewalker.

Between 1 and 4pm, remainder of drifters were launched in surrounding box. .

~1220: Deployment of 1 SVP

1300: recovery of top float of WW and redeployment with APL beacon.

1315: s-ADOS deployment.

1400: start deploying SVPs again.

1530: last one off.

Then steam to "center" of anticyclonic eddy (though uniform velocity structure suggests center is elongated and further north) to launch EM-APEX with another S-ADOS and a wave buoy.

1800: Deployment of S-ADOS #2, and wave buoy at A3 (center of anticyclone).

1824: EM-APEX 7805 launched at 57 39.099'N, 22 40.921'W

(set to profile deep--to ~1400m at 1/2 inertial period repeats)

Next, steaming back to confluence for a timeseries survey (mostly a back-and-forth racetrack for ~4 hourly repeats with a tiny bit of along-flow spacing to estimate confluence) on anticyclonic side of jet. The hope is that the drifter/EM-APEX/Wirewalker array will turn and flow through the confluence past our timeseries.

Triaxus: graphics card is not doing well. Jason made several changes, tested for many hours. Upon deployment, display was now working. We have a work around (using Jason's laptop, and Jason is working on a more permanent solution).

2000: Triaxus is in the water.

EM-APEX status: 3 floats (4968, 4969, 4970) are ballasted light (unable to reach 12 cm/s on descent at minimum piston position)

EM-APEX 4968 has bad E2 velocity channel

EM-APEX 4969 E2 velocity channel went bad after HPID 32 (and came back again in HPID 108 and after; must have been electrode equilibration)

EM-APEX 7801 has bad E2 velocity due to electrode offset jumps on up-profile; later develops jumps on down as well (both between 200 and 250 dbar, but slightly different pressure values)

EM-APEX 7808 clock in APF9 is set one day behind (GPS-RTC=~1day)

Monday 3 June

Continued same back-and-forth Triaxus survey on anticyclonic side of jet ("Confluence" survey) for full day. Drifting array moved slowly west, including inertial cusps, but not much hint of turning to north. In fact, seemed to be bending south by the end of the day. Initial dispersion showed middle 4 EM-APEX (1.4 km box) spread to same radius as outer 4, making ring ~7km in diameter.

Triaxus-ing, *confluence* survey.

Moved the A4-A5 line by 3 nm to the NW. A6 to A7.

Deployed at DWS drifter at 12:45

Tuesday 4 June

Lagrangian array has not spread very much and is definitely bending to south. No sign of entering confluent jet. Next phase of cruise plan has us taking Triaxus out of the water at 1900 and re-terminating the cable. We'll then head south to the array to make an ADCP survey around it with the ship, then begin UCTD work on a finescale survey around the array for 28-56 hours until we recover at least the Wire Walker (to replace batteries).

Triaxus-ing, *confluence* survey. A6 to A7.

1705: passed next to S-ADOS that was deployed in the anticyclone.

1945 stopped *confluence* survey

2015: Triaxus recovered

2115: Decided to pick up EM-APEX 7805 because of CTD errors which John Dunlap thinks might be related to saltwater sprays due to leaking electrode wire seals near CTD. Want to look for signs that this has actually occurred (and prevent float from dying).

EM-APEX 7805 surfaced around 2123 and sent a GPS position. Took a while (~40 min) to get a second fix, but then located and recovered fairly quickly (by 2215).

From there, began zigzag survey to the south to fill in mesoscale velocity field between the confluent jet and the Lagrangian array. Large scale survey, using only ship's systems.

Wednesday 5 June

Area ADCP survey around drifting array continued during the night for mesoscale velocity context. Then UCTD+ADCP box around array repeated every 3 hours for several (2-3?) passes.

1000: Sheep dog survey, uCTD. 10 kts.

1418: @ 57 14.898'N, 23 35.947'W. Deployed EM-APEX 7806 during UCTD survey on southwest edge of box. Set to profile deep at 1/2 inertial period intervals.

1700: Deployment of Triaxus, Sheepdog survey 7 kts. (~4 hour repeats)

Thursday 6 June

Continuing Sheepdog survey with Triaxus — angled box survey moving with EM-APEX array over night. Drifted generally to southwest.

0945: passing close to WW.

Around 11am switched to smaller square box to attempt to resolve small-scale gradients closer to timeseries points (floats and Wirewalker). Shear shows lots of upward and downward propagating features, but little coherence from one repeat of the line to the next (at ~4 hour intervals).

Significant T-S variability, including surface fronts and filaments (~0.1C), in the small box. Also shows diurnal warming in surface layer, so need to use surface fluxes to estimate restratification. Initially 40m deep mixed layer, but later stratification appears in upper 20m. Along with lower chlorophyll in upper 20m, remaining elevated below, to 40m. Why is this? Light quenching (adaptation of cells to high-light environment at surface)?

Box continued through night. Plan for tomorrow is to recover Wire Walker and replace batteries. Decide whether to recover rest of array and move to anticyclone (to NE where

EM-APEX 4967 and 4969 are) or redeploy and maintain array as is—because remaining coherent.

Friday 7 June

0900: Recover Triaxus, End of Sheepdog survey

1000: Recover Wirewalker

RBR seems to have a clock problem. Record might be short.
Epsi stopped after 4 days.
ADCP looks good.

Ship survey around the drifting array (with ADCP) for regional flow structure, to try to understand how to relate local flow to AVISO map. Could be a confluence and stagnation point in an eddy quadrupole, but need to clarify with measurements, since AVISO streamlines and float/drifter array are moving opposite directions!

We decide that the drifting array was falling apart. We should recover. Plan is to recover

array, then head northeast to anticyclone where 4967 and 4969 are currently looping. Likely to have bigger NIW and vorticity signals to work with, as well as not too rapid array dispersal (although small-scale coherence may still be tough). Leave 7806 and 7804 at SW and NE corners; recover 7807,S-ADOS,7803,7801,4970,7808,7488,7802 in single loop. Note: After recovery, reset 7808 clock (set 1 day late); check 7801 E2 channel (big electrode jumps/offsets); add weight to 4968 and 4970 (30g in external washers? to make descend better).

1615: Recovered EM-APEX 4968

1840: Recovered EM-APEX 7807

1930: Recovered S-ADOS (hauled in by hand)

2000: Recovered EM-APEX 7803

2020: Recovered EM-APEX 7801

2059: Recovered EM-APEX 4970

2100: Launching a wave buoy.

2119: Recovered EM-APEX 7808

2147 Recovered EM-APEX 7488….. 7802, our next target, was prematurely sent down.

2315: Recovered EM-APEX 7804 (after waiting for a few minutes for it to surface and then locating in the dark)

Next, steaming to northeast for ADCP survey of jet and anticyclone (where 2 other floats, 4967 and 4969 are residing). Once adequately sampled, we'll release the flotilla (including S-ADOS and Wire Walker) once again.

Leaving 2 behind. (EM-APEX 7802 and 7806).

Saturday 8 June

Survey back to the anticyclone with ADCP. Added UCTD starting at 1130 on a second line across the jet/eddy edge. Deciding where to deploy Lagrangian array.

uCTD on the line coming north, 1400 to 1730. Then started deep CTD line back across jet/eddy. 6 stations at 10 nm spacing.

We forgot to put the caps on probe 316 last time. Justin replace the pin connector, but in the process the magnetic switch was damaged. Probe 316 out of commission.

Probe 136 has trouble downloading large files in binary modes again.

Probe 135 worked very well, except that it didn't turn on the last cast. Voltage was fine (4.0V). It was put into sleep mode at the end of the last cast (QS in UCTDTerm). I'm at a loss.

We did the DG self test.

1800: First full ocean CTD cast, using the ship system. It took about 2 hours, with bad raps.

2100: arrive at Station #2

Sunday 9 June

Continuing ship CTDs. (#3, #4, #5)

Started deep CTD #6 at ~10am. All 6 stations have been to 2800 or 2900m. Gradual deepening of deep thermocline shows progress toward center of eddy, but still ~200m shallower than at floats 4967+4969.

Thoughts on EM-APEX 7801 electrode channel 2 issues: No smoking gun, but problem has to be in electrode, agar, wire, seal, solder joint, or ADC, and seems to be pressure-dependent. E2 offset has a fairly (but not exactly) repeated pattern on all profiles (down and up), with a rapid jump around 200m which interferes with velocity demodulation processing. Some of the slowly varying features of the E2 offset also show up in the E1 offset but at lower amplitude. Maybe related to flexing of the hull at particular pressures, but why does it impact E2 primarily? Related to wire routing or motion of hull or other components flexing solder joint? Regardless, plan is to deploy 7801 again in the second array, because all systems other than E2 are working and E2 doesn't seem to threaten the life of the float.

As of 1130z today, float 4969 has not called in for ~30 hours so there may be a problem. It had been going to 750m and slowing down to 8 cm/s on the way (below 10 cm/s below 500-600m).

1156: Deployment of EM-APEX 7805 at the last station, center of eddy (just after rosette came out of the water). 58 05.036'N, 22 09.773'W

We picked a spot for the drifting array near the edge of the eddy (and corner of UCTD line from yesterday). 58 07 N 22 42 W.

13:45: Wirewalker deployment, making center of Array #2. 58 06.780'N, 22 42.072'W.

Then 8 EM-APEX floats in 2 boxes around the Wirewalker: 4 floats 1 km away and 4 floats 3 km away, making a cross:

1435: #7488 ; 58 07.027'N, 22 42.831'W

1448: #4968 ; 58 07.910'N, 22 44.358'W

1510: #4970 ; 58 05.532'N, 22 44.173'W

1522: #7801 ; 58 06.506'N, 22 42.557'W

1533: #7803 ; 58 07.299'N, 22 41.154'W

1544: #7804 ; 58 08.132'N, 22 39.663'W

1545: launched DG.

1601: #7807 ; 58 06.462'N, 22 41.274'W

1613: #7808 ; 58 05.839'N, 22 39.692'W

Then 8 Scripps drifters (including 2 SVP-B w/ pressure and 1 minimet

w/ winds).

Deployed S-ADOS

Deployed 6 SVPs, 1 Minimet, 1 SVP-B

1800: Deploying Triaxus for the Fence survey.

Notes on EM-APEX performance now (after Array #2 is in water):

- 4968 and 4970 are descending at a good speed (12 cm/s at 600m) after adding two stainless steel nuts to each (28g water weight).

- 4970 has electrode and velocity noise on both channels at depth (mainly around 500-600m). Restrict to above 450m. Also, later on (hpid 26 and later) 4970 Chi channel 1 looks bad

- 7801 has depth-dependent electrode offset drifts on E2, showing up as "pings" in velocity at 100m on descent and 300m on ascent. Could be a bubble in an electrode after all. E1 looks ok.

- All floats have large electrode offsets at top of first profile, so there must be an initial equilibration time.

- 7803 looks good

- 7804 looks good; from hpid 14 and onwards Chi ch1 looks bad.

- 7805 has large electrode offset in E1 so sometimes gets no velocity from E1; but E2 looks good. The offset is similar to what was seen before the recovery and redeployment. At first, ADC channel spikes at depth seemed to be gone (fixed by tape between compass board and chassis) but they came back after the first few profiles. Only below 800m, so shallower cycling may help. Try restricting to below 1000m for starters.

- 7807 looks good

- 7808 has bad Chi sensor on channel 1 (from beginning). Some E1/E2 difference, especially in U on upcasts.

Monday 10 June

Triaxus survey ("Fence" survey; could also be a sunburst or dragon tail) is proceeding with lines simultaneously across the current and through the array (at the edge of the current. Looks like array is in a cyclonic (raised mixed-layer base, highT/lowS water below) patch with a persistent anticyclonic (depressed ML base at 50m, domed shallow thermocline at 20m) filament or feature to the northwest. T-S variability in array looks interesting.

Likely near-miss this afternoon. EM-APEX 4970 crossed ship path at 22.6411 W, 58.2149 N at 12:50pm moving at ~0.5 km/h. Ship crossed 22.6411 W at 12:38; 58.2149 N at 12:40 (matlab plot estimates using projected float drift and measured ship trajectory). Maybe 100m separation when ship went by? Float was definitely on the surface sending data from 12:25 to 12:45 (plus GPS before and after). No adverse affects noticed in later data. But this should at least be a good place/time to compare ADCP and EM velocity profiles.

UAF glider developed a leak. It’s drifting at the surface.

Tuesday 11 June

Continuing Fence survey. Triaxus tow continuing with a radial (relative to eddy) line that moves along with the array. Mostly aiming line at wire walker, which is now lagging behind EM-APEX group a bit. S-ADOS is lagging even further behind.

After successfully testing 'yo-yo' mode (subsurface cycling between two depths without coming to the surface) with EM-APEX 4967 (and seeing strong near-inertial variability in the stratified layer around 500-600m depth), sent 4 floats from the array (4968,7488,7801,7803) into yoyo mode at the 400-800m layer, surfacing once per inertial period.

Plan is to recover 4 floats (4970, 7804, 7807, 7808; the ones not yoyoing) along with Wirewalker tomorrow morning and redeploy in the jet to the north. Note: replace FP07 on 4970 (ch1), 7804 (ch1), and 7808 (ch1). And add another stainless nut to 4970. If time, could take antenna relay out of 4970 and use to make 4971 into a working float (not yet deployed because of inability to make Iridium calls). But probably not necessary since we'll be running faster shallow cycles this time.

Wednesday 12 June

End of *fence* survey

0830. Recovered Triaxus:

0900. Recovered Wirewalker

Recovery of floats:

0950: #7807

1019: #7804

1045: #7808

1119: #4970

EM-APEX 7804 showed visible damage on Ch2 chi sensor, as well as a clear offset in the "mean" value seen on the terminal when talking to the float. None of the other floats show visible damage on FPO7s, even though 4970, 7804, and 7808 all showed elevated noise on those channels. So replacing *both* FP07s on 7804 and CH1 only on 4970 and 7808. Some suggestions from terminal TM results in lab that CH1 does have problems, even though not visible. After replacing CH1 on 4970, "mean" seen on terminal matched better between ch1 and ch2.

Survey to pick the spot.

Came right back up to the tip of *fence* survey

Array #3:

First 7 surface (15m drogued) drifters launched in a 20 km line across the jet--centered on the salinity front. Then Wirewalker launched around 2200 in the middle of an 0.09 psu salinity front (salty to south toward anticyclonic eddy; fresh to north). Front is very close to maximum vorticity gradient at center of jet velocity max. Jet core descends to the south (subsurface velocity max) so there could be an "inverted critical layer" above the core where anticyclonic vorticity decreases toward the surface.

2200: deployed Wirewalker.

2229: EM-APEX 7804 launched at 58 27.858'N, 22 03.817'W

2242: EM-APEX 7808 launched at 58 28.805'N, 22 04.866'W

2257: EM-APEX 4970 launched at 58 29.962'N, 22 03.532'W

2313: EM-APEX 7807 launched at 58 30.009'N, 22 00.649'W

2320: Triaxus out

Thursday 13 June

Greyhound survey. Triaxus survey following WW+EM-APEX+drifter array is moving at about 1 kt and survey lines of 8 nm are being repeated—essentially following the same water—a bit quicker than every 1.5 hours.

After 24 hours, WW+EMA array has more-or-less kept the same shape and dimensions, with only a minor amount of rotation and deformation.

Friday 15 June

Greyhound survey. Triaxus survey continues, with floats still in pretty good box formation. Winds are picking up.

Current EM-APEX sampling status:

4966 looping anticyclonically off to the northwest (first float launched)

7802,7806 left to south in area between eddies (remainder of Array #1)

4967,7805 are near center of current eddy (anticyclone which most of assets are circling around). 4967 was launched in eddy early on (before Array #1) and stayed in. 7805 was launched near center of eddy later (after Array #1).

4968,7488,7801,7803 (remainder of Array #2) are making yoyos at deep pycnocline (400-800m) at 30-40 km radius from eddy center. Soon to switch 3 of these back to upper-ocean timeseries to look at NIW generation and de-phasing in wind events of 6/13 and 6/15 (anticipated).

4970,7804,7807,7808 (Array #3) passing or orbiting eddy at 60km radius (with Wirewalker, Wave Glider, and Triaxus survey). Appear to be just starting to diverge after confluence between cyclone and anticyclone, with possibility for staying near the eddy or peeling away to the northeast.

4969 was near center of eddy but hasn't called in since 6/8 at 5:45am (over 6 days) and is presumed lost.

4971 has a bad antenna relay (or some other reason for being unable to make Iridium calls) and has been sitting in the lab. Plan is to swap in the relay from another float to be recovered tomorrow to take advantage of the full load of batteries (and, presumably, working sensors) on board and relaunch for long-term phase of experiment.

Current list of known EM-APEX sensor issues:

4966 CTD,V1,V2,TM2 good; TMicro CH1 has slightly higher noise level than CH2

4967 CTD,V1,V2,TM1 good; TMicro CH2 has slightly higher noise level than CH1. [Previously, TMicro probe guards left on for first few profiles: hpid 1-30]

4968 CTD,V1,TM1,TM2 good; high E2 offset [present from the beginning] which occasionally hits -3400 uV and makes velocity go bad

4969 gone [and previously had off-scale E2 offset for some profiles: hpid 33-107]

4970 CTD,V1,V2,TM2 good; substantial V1/V2 difference in velocities; TMicro CH1 has higher noise than CH2 [present in first array deployments too and not fixed by FP07 replacement after Array #2]; also elevated electrode noise (both channels) appears when profiling below 500-600m [very prevalent during Array #2]; occasional piston noise too.

4971 not in operation yet

7488 CTD,V1,V2,TM2 good; TMicro CH1 (shear) looks like it has low signals and little correlation with CH1 (chi); CH1 spectral levels go up when run fast (consistently 25 cm/s on up-profile for most of Array #1) but noise features seem to increase as well. Noise on TM CH2 (chi) may also increase at faster speeds.

7801 CTD,V1,TM1,TM2 good; E2 electrode jumps around 400-500m give velocity pings [present in some form in previous Array deployment, too]; suggests possible bubble in electrode which grows and sinks with pressure; also substantial V1/V2 difference even when apparently good.

7802 CTD,V1,V2,TM1,TM2 all good! From hpid 200 seems to have developed TMicro problems in both channels. Ch2 clears up somewhat later and may be usable.

7803 CTD,TM2 good; E1,E2 have occasional electrode noise which shows up in velocity (especially in 600-800m range) but mostly ok; TMicro CH1 broken (from mid-profile hpid 28 onwards)

7804 CTD,V1,V2,TM1,TM2 all look good; sizeable V1/V2 difference (2-3 cm/s); occasional noise in piston values [Note that TMicro CH1 had slightly higher noise level than CH2 in the first two Arrays , but this stopped when probes were replaced between deployments]

7805 CTD,V1,V2,TM1,TM2 all look good; E1 offset very large (around -3000 uV) indicating risk of maxing out; sometimes V1/V2 differences (possibly larger above 600m); when operating below 800m (or 7 deg C) problems were appearing on all EM board channels (EF, compass, accel) but these went away when profiles were kept shallower than 800m (or warmer than 7 C). EM problems were present from the beginning of Array #1. Unsure whether pressure or temperature related. Electrical tape placed between compass board and chassis after Array #2 recovery did not fix the problem.

7806 CTD,V1,V2,TM1,TM2 all good!

7807 CTD,V1,V2,TM1,TM2 all look good; sizeable V1/V2 difference (2-3 cm/s) at times

7808 CTD,V1,V2,TM1,TM2 all look good; sizeable V1/V2 difference (2-3 cm/s) at times. [Note 7808 had clock set 1 day behind during first Array. Also elevated noise on TM1 during Array #1, but fixed after FP07 replacement forllowing Array #2.]

Plan is to continue Triaxus through a small storm that's coming up and expected to peak tomorrow (Sat) morning at 9am, then recover in the afternoon/evening. Steam north to recover UAF glider (Freya), then come back Sun/Mon to pick up all instruments.

For storm forcing and inertial wave dephasing across N wall of anticyclone, took 3 of Array#2 floats (7803,4968,7488) and 4967 out of yoyoing mode and returned to upper-ocean timeseries cycling. This should give 3 distributed locations, including 2 clusters (3 and 4 floats) to get NIW wave phase gradients from.

Deciding on which 6 EM-APEX to leave behind. Selected 4971 (after repair), 7802, 7806, 7807, 7808 (plus missing 4969).

Saturday 15 June

Triaxus Greyhound survey continues following Wirewalker and 4 floats, which are finally spreading out. Weather has picked up in the morning, with 3+ m waves and 25+ knot winds.

1200: we decide to leave the Wirewalker and floats and Wave Glider out here for recovery tomorrow or Monday. Doing one line back across the survey pattern to evaluate temporal changes (large).

1600 Triaxus Recovery.

Sunday 15 June

Sweep-up phase.

0630: Freya recovered. She twisted after Pete hooked her, edging into the boat. One FPO7 damaged.

1210: DG044 recovered. Probe guard cracked as we lowered the glider into the cradle.

1245: SG527 recovered. Ding from picking it up over the rail.

1830: SG526 recovered.

2130: SG141 recovered.

2315: Wave Glider SV2 (Centurioni) recovered.

2359: Wirewalker recovered.

Monday 16 June

EM-APEX recoveries:

0130: #4970 recovered

0255: #7804 recovered

0600: #7803 recovered

0625: #4968 recovered

0710: #7801 recovered

Wave buoy deployed.

0805: #7488 recovered

S-ADOS recovered

1206: #4967 recovered

Triaxus wire cleaning.

Swapping relay from EM-APEX 4970 to 4971 didn't improve Iridium connection problems seen with 4971. Next tried swapping full APF9+modem+gps board assembly (to take advantage of full load of batteries in 4971). This was successful, and 4971 with a new brain passed all checkout tests.

1500: #7805 recovered

Longest EM-APEX recovery yet. Initial snap hook fell off twice (maybe gate didn't close or hook failed to come out of pole); then tried with boathook but didn't quite manage to catch recovery loops. During this process, float was forced down (possibly by a push from boat hook while ship rocked and swell moved up and down ~6' or so, or possibly sucked under by wash from ship's propulsion). Float disappeared for ~30s and appeared far forward, almost under bridge. Then disappeared again and appeared far forward of bow (probably because captain cut propulsion when float disappeared and ship drifted backwards in wind). On next approach, snap hook worked fine and recovery went quickly. Seas 2m, wind

19kts. Nothing too extreme. Reminder to be careful of pushing float down too hard during recovery!

1617: EM-APEX #4971 deployed at 58 17.628'N, 22 39.278'W (after verifying that Iridium calls work, running GPS for at least one 20 min interval and many 5 min intervals, and updating parameters to give cycling to 100 m). Called back in after just under an hour (while ship still at CTD station) and allowed verification of correct operations. With help from John Dunlap and Ren-chieh Lien on shore, confirmed that all systems on 4971 are working.

DEEP CTD begun immediately after float launch (for the ship to examine bad wire wraps near 1600m of wire out) near previous CTD #3 site. Sampled to 100m off the bottom (~2900m).

2100: Super-ADOS recovery

Tuesday 19 June

0330: Recovery of float #4966

1530: Recovery of Slocum Apollo. Rudder seems stuck, but no external damage.

1600: Recovery of SV3.

Wednesday 19 June

0700: Recovery of OOI glider 363.

6. Science Personnel

		Primary Role	Institution	Email
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	Joe McCabe	SSSG	WHOI	

7. Crew

1	Kent Sheasley	Master
2	Mike Singleton	Chief Mate
3	Joshua Woodrow	Second Mate
4	Chris Mannka	Third Mate
5	Pete Liarikos	Boatswain
6	Leo Fitz	Able-Bodied Seaman
7	Keenan Foley	Able-Bodied Seaman
8	Kevin Roth	Able-Bodied Seaman
9	Pete Marczak	Chief Engineer
10	Nickolas Alexander	First Assistant Engineer
11	Vasile Tudoran	Second Assistant Engineer
12	Isaac Cardosa	Third Assistant Engineer
13	Russ Adams	Electrician
14	Roger Fong	Oiler
15	John Estrela	Oiler
16	Pete Gimlewicz	Oiler
17	Harry Burnett	Steward
18	Matt Stein	Cook
19	Thomas Leong	Mess Attendant
20	Brooke Wagstaff	Cadet

8. Acknowledgements.

The captain and crew of R/V Armstrong have been fantastic, as always. Ship handling, lookouts, gear wrangling by Bosun Pete and others, food, and general can-do attitude throughout the ship have been excellent and made for a wonderful cruise. It's a pleasure to sail with this crew. We also acknowledge the support of many colleagues on shore, who provided guidance, piloted instruments, analyzed data, sent us simulations and predictions, and coordinated with those of us on the ship to make this cruise a success.