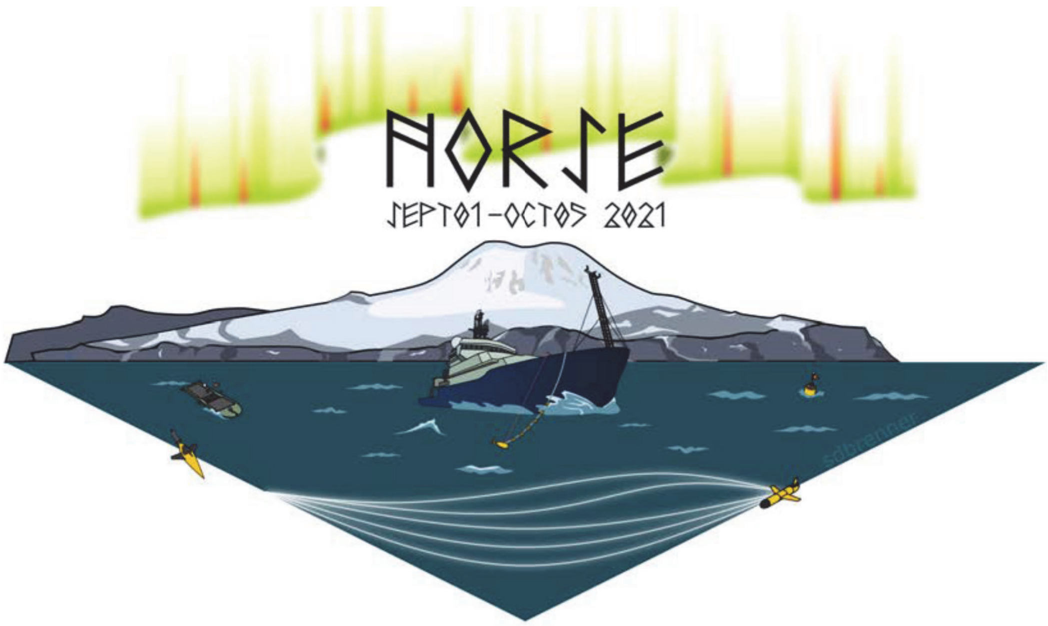


Northern Ocean Rapid Surface Evolution (NORSE) 2021 Cruise AR60-02

Luc Rainville, Leah Johnson, Laura Crews, Sam Brenner, Justin Burnett, Craig Lee, Jim Thomson, Kristin Zeiden, Justin Shapiro (APL-UW); Anna Savage, Alejandra Sanchez-Rios, Kerstin Bergentz, Jennifer Mackinnon, Luca Centurioni, Verena Hormann, Allison Ho, Raymond Young, Sophia Merrifield (SIO) Dave Morton, Phil Abbot, Vince Premus (OASIS); Harper Simmons (UAF), Laur Ferris (VIMS) Steven Jayne (WHOI); Angel Ruiz-Angulo (University of Iceland)

5 October 2021

1. Science Motivations

The NORSE DRI effort focuses on characterizing the key physical parameters and processes that govern the predictability of "upper-ocean rapid evolution events" occurring in the ice-free high latitudes. The faster time scales associated with oceanic processes (fronts, eddies, …) at higher latitudes and shallow acoustic ducting created by the vertical temperature structure of the Nordic Seas make acoustic propagation paths and transmission losses in regions north of Iceland particularly sensitive to upper ocean forcing events. The ship will support autonomous observations using an array of surface drifters, buoyancy-driven gliders, and floats, to make advances towards the general NORSE objectives:

1. Provide a better understanding of the coupled processes that drive rapid changes in the upper ocean at high latitudes, leveraging the adaptability and persistence of autonomous platforms.
2. Improve predictive capability for sound propagation, transmission loss, and surface duct formation, particularly by using distributed autonomous systems.

Artwork by Sam Brenner, APL-UW

Specific cruise objectives included

- Conduct several realizations of an acoustic transmission experiment, where a Slocum glider records the signal transmitted by a J-9 source deployed from the ship through an upper ocean environment characterized by autonomous platforms.
- Sample upper ocean fronts with autonomous platforms, including Seagliders and a Wave Glider.
- Characterize sound speed and sound speed variability near Jan Mayen, a region likely targeted during the NORSE field program for year-long mooring deployments.
- Sample several frontal zones with the ship, using the underway CTD system and bow chain.
- Occupy a several sections with full ocean CTD / LADCP.
- Use SWIFT buoys to conduct deployments of opportunity
- Deploy 3 Alamo floats, and several surface drifters.

Despite several days with adverse weather conditions, all these objectives and more were met during the cruise.

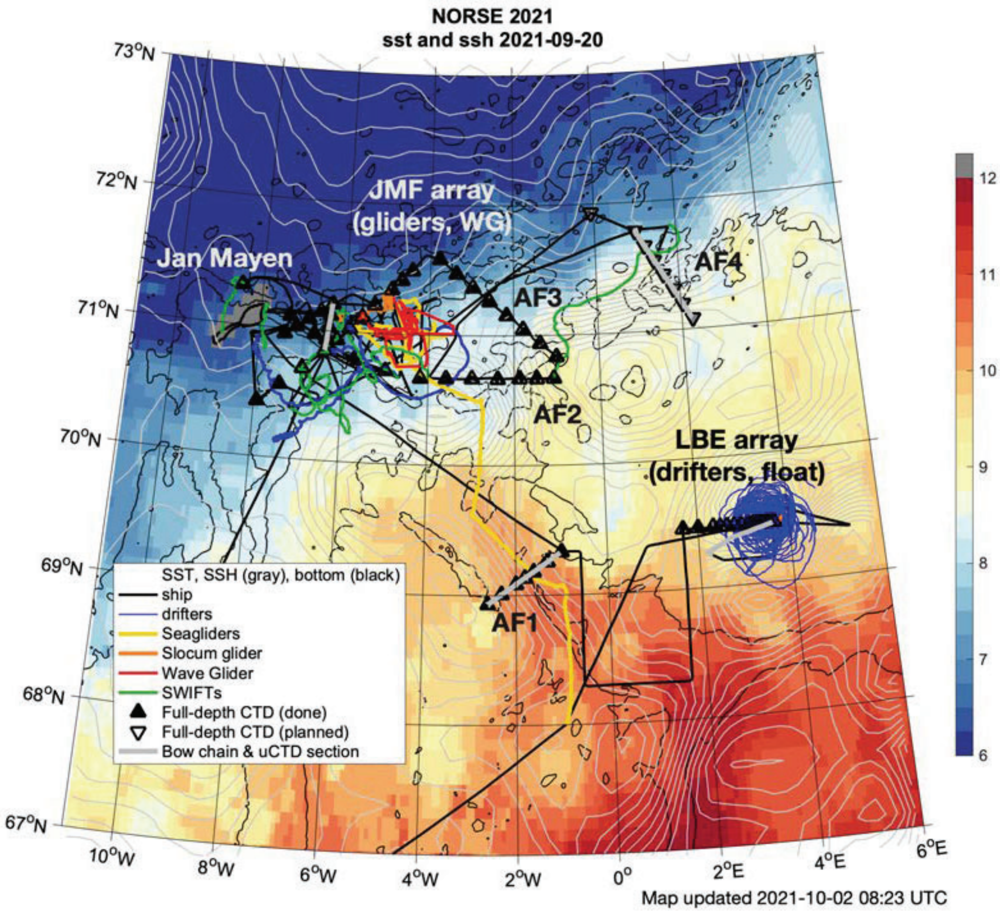


Figure 2.1. Map of sea-surface temperature (color) and height (contours) with the tracks of the ship (black) and the various instruments deployed during the NORSE 2021 cruise. Main modules (Lofoten Basin Eddy [LBE], Atlantic Front Current sections [AF1-4], Jan Mayen, and Jan Mayen Front [JMF]) are labeled. Thin black are isobaths (1000-m contours).

2. Cruise Overview

Schedule

30 Aug Begin mob
01 Sep Depart Reykjavik
05 Oct Return Reykjavik
17 Oct Demob in Woods Hole

Summary of cruise sampling

The general area of operation is located north-east of Iceland, in international waters and within the Norwegian and Icelandic EEZ (Fig. 2.1). The cruise targeted specific regions with large surface temperature and salinity gradients, specifically the region near the Lofoten Basin Eddy, the Atlantic Front Current (Fig. 2.1)., and near the island of Jan Mayen (Figs. 2.1, 2.2).

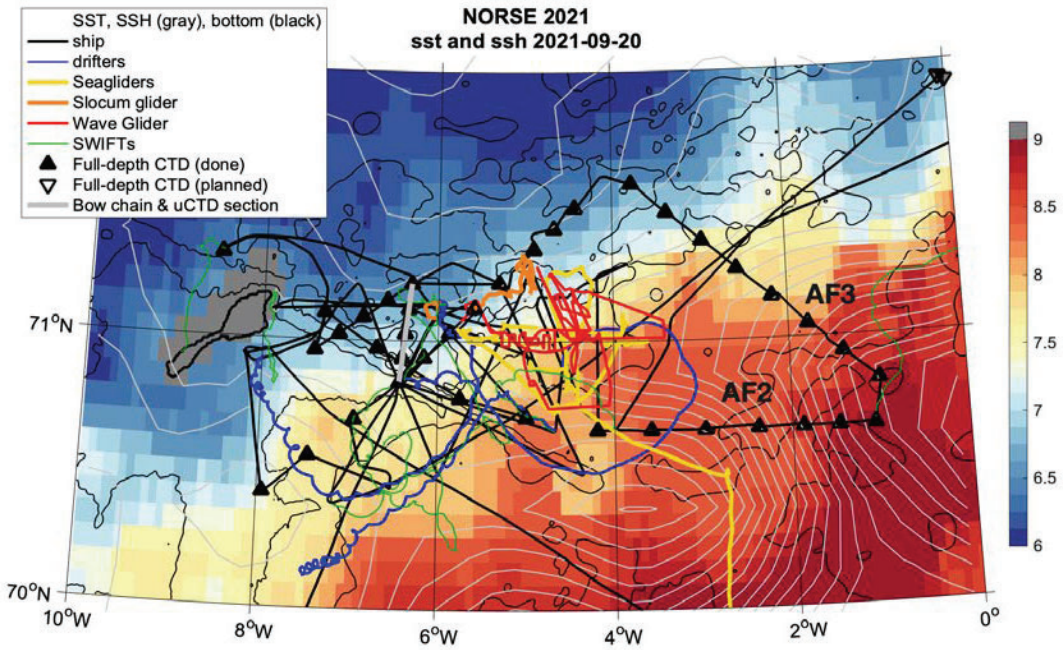


Figure 2.2 Map of sea-surface temperature (color) and height (contours) with the tracks of the ship (black) and the various instruments deployed during the NORSE 2021 cruise. Main modules (Lofoten Basin Eddy [LBE], Atlantic Front Current sections [AF1-4], Jan Mayen, and Jan Mayen Front [JMF]) are labeled. Thin black are isobaths (1000-m contours).

Met and Surface conditions

The operating area was a 3-day transit from Reykjavik. Overall, atmospheric conditions during the cruise were favorable but not calm, with a cruise average wind speed of 8.5 m/s and significant wave height always over 2 m. Two large low-pressure systems came over the region while we were sampling, with sustained winds exceeding 20 m/s in both occasions. All ship-based sampling stopped during these storms, and we sheltered in the lee of Jan Mayen (3-4 nm from its southern coast) to avoid the largest wind and waves. In total **3.5 days were lost due to weather.**

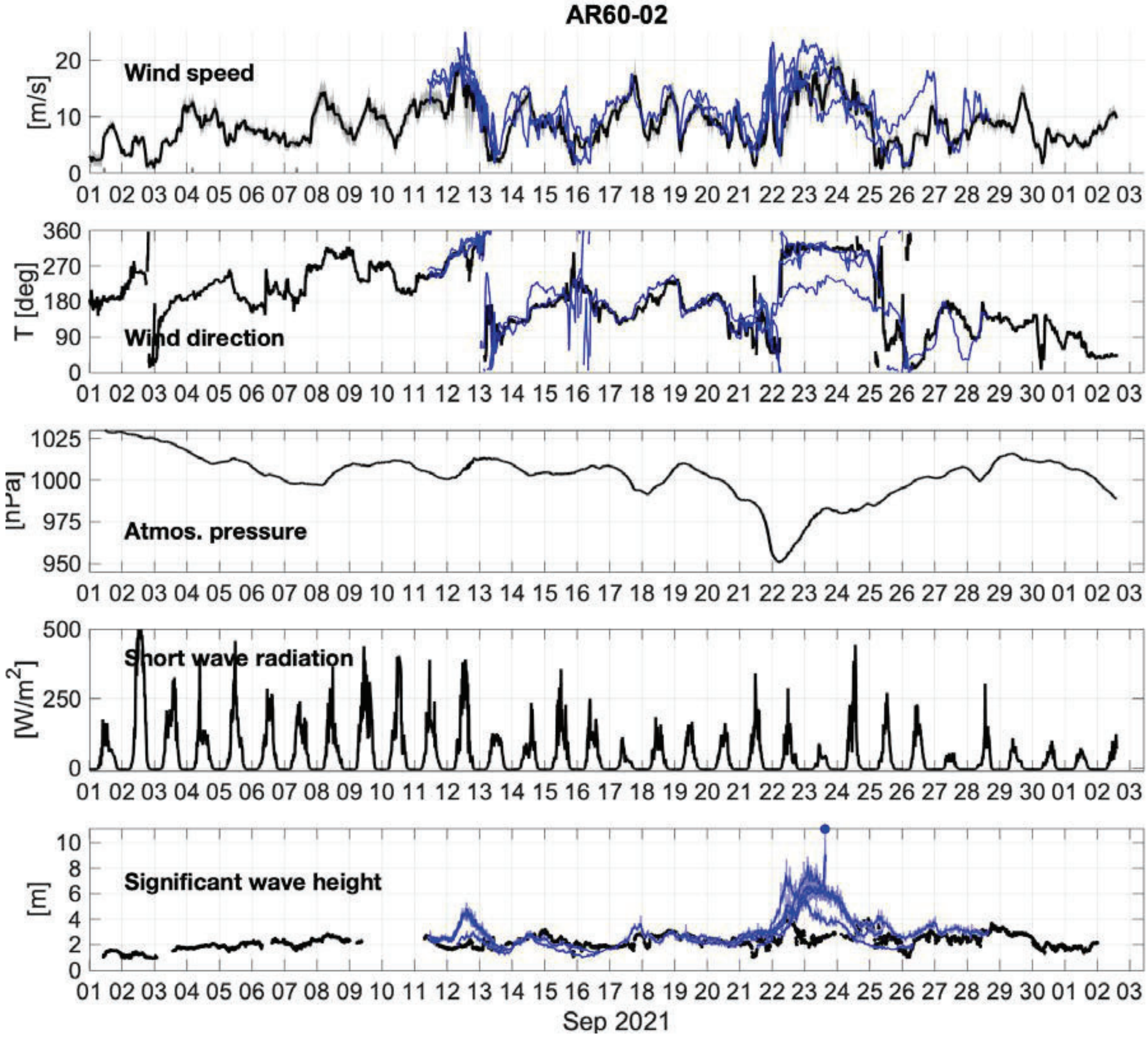


Figure 2.3. Wind speed and direction, atmospheric pressure, shortwave radiation, and significant wave height at the ship (black) and as recorded by the SWIFTs (blue lines) during the cruise.

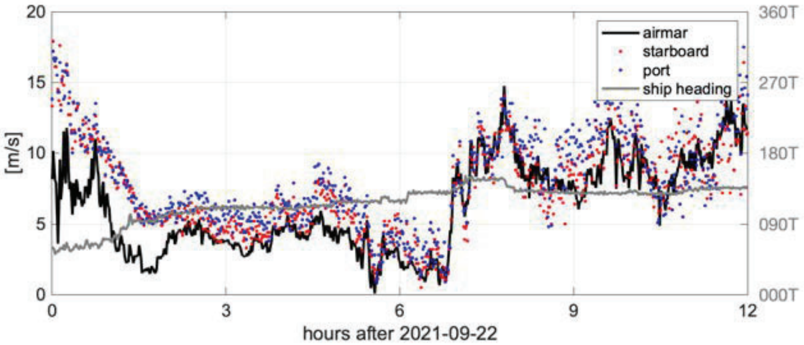


Figure 3.1. Example of 12-h of data comparing the Airmar (black) with the port and starboard Vaisala wind sensors on 22 Sept 2021. The ship was not moving during this time, and was changing heading to mostly point into changing seas, with variable winds coming mostly from the stern.

3. Cruise summary (by instruments)

3.1. Ship instruments.

The TSG and ADCP systems did perform quite well during the cruise. There might be a small offset in the 150 kHz ADCP, but analysis to find a “scale factor correction”, like we implemented during the NISKINe 2028 cruise, was inconclusive.

An Airmar WX220 was mounted on the stern A-frame recorded wind speed from a different angle, to make sure that we would always have wind speed uncontaminated by the ship structures. Preliminary analysis seems to indicate that it performed well (Fig 3.1).

3.2 Underway CTD System.

Laura Crews, Samuel Brenner

Probe setup, downloading, and data issues

The uCTD was deployed from the port fantail in the wake of the ship. Probe sn0316 had a high salinity bias that was detected shortly after its first deployment and the probe was then removed from service. Recalling that this probe showed similarly biased salinity on the 2019 Healy cruise (which we suspected was caused by a cracked conductivity cell), we inquired about the probe’s calibration history. Ben reported that all three uCTD probes went back to Teledyne/SBE in winter 2019 (presumably for calibration?) and were received back end of February 2020, and sn0316 had the conductivity cell replaced. Craig reported that during Exports sn135 struck the stern, but subsequent tests did not show any evidence of damage. Additionally, sn316 had what appeared to be a *low* salinity bias on the first Exports deployment which disappeared afterwards.

We noticed that the first cast after probe swaps showed anomalously high salinity which we guessed could be caused by thermal lag after bringing the probe out from the warm lab; once we realized that the first cast of each deployment was contaminated, we began holding the probe at the surface for 30 seconds to soak it before starting the first cast which seemed to eliminate this issue. These contaminated first casts (six contaminated casts on transect2, four contaminated casts on transect3) were removed from the transect data structures.

We did not use the usual uCTD Toughbook because the BlueSoleil software license had expired, prohibiting transfer of files larger than 2 MB. We instead downloaded all data using uCast on the IOP Windows #2 Lenovo ThinkPad (tape-labeled “spare laptop for uCTD ops”). Raw data were stored on that computer on `/Desktop/NORSE2021/` as well as on the science_share server at `/uCTD/data/transect{number}/`

There were several instances in which probes failed to record data. This may have been caused by failure to disconnect from uCast, but we are not certain that we did indeed forget to disconnect. Missing (unrecorded) data resulted in a ~10 km data gap on transect2, two adjacent data gaps of ~5 km each with one successful profile in the middle of the gaps on transect3, and a ~5 km data gap on transect7.

Sampling strategy

The uCTD was typically operated in a yoyo mode at ship speed of 4 kts (with the bow chain), with a 60 sec timed down profile to 150m, resulting in a 3.5 min complete cycle and horizontal spacing of about 400m. Higher resolution sections were obtained in AF4, with 40 sec down profiles to 100m (2 min complete cycle) at 3 kts, with horizontal spacing between profiles around 150m. Two operators from the science party were on deck all times during operations with communication to the bridge)

A total of 13 uCTD transects were completed, for a total of 1162 individual casts. After the sn316 salinity bias was discovered, we alternated between sn135 and sn136, swapping probes every 30-45 minutes. The first transect crossed the Atlantic Front Current downstream of the Vøring Spur junction and consisted of one uCTD profile every hour, resulting in approximately 20 km horizontal resolution. Transects 2-7 consisted of 60-second probe drops while the ship was travelling at roughly 4 kts, resulting in approximately 500 m horizontal resolution and depth coverage to around 150 m. Transect 8, whose objective was to resample wave-like features observed on transect 7, consisted of 40-second probe drops to around 100 m, with the ship moving at 3-5 kts depending on how close we were to the features of interest.

After transect4, the conductivity correction accounting for the variable fall rate was calculated and saved as `uCTD_lag_variable_fall_rate_NORSE.mat`. Profiles on previous transects were reprocessed using this fall rate. Data structures containing all profiles on each transect were saved as `uCTD_NORSE_transect{number}.mat`

Table 3.1: Name and details of all NORSE AR6002 uCTD transects and Corresponding Bow-Chain

Transect	Location	Date	Bow_chain	Label	Notes
transect1	Southern AFC	Sept 4	-		One cast every hour
transect2	Lofoten Basin Eddy	Sept 5	Yes	**A**	Removed first cast of the first 6 probe deployments due to salinity bias
transect3	Southern AFC	Sept 10	Yes	**B**	Removed first cast of the first 4 probe deployments due to salinity bias
transect4	Jan Mayen	Sept 15	Yes	**C**	Along the JMA CTD/LADCP station line
transect5	Jan Mayen	Sept 15	Yes	**D**	
-	Jan Mayen	Sept 16	Yes	**E**	Along the JMA CTD/LADCP station line, No uCTD deployed during this transect
transect6	Jan Mayen	Sept 21	No		Along the JMA CTD/LADCP station line, No Bow-Chain deployed during this transect due to weather limitations
transect7	Northern AFC	Sept 26	Yes	**F**	
transect8	Northern AFC	Sept 27	No		Repeated a portion of transect7 at 3 kts with 40 s drops to resample the wave-like features at 40-60 m
transect9	Northern AFC	Sept 27	No		Repeated transect8 in the opposite direction
transect10	Northern AFC	Sept 27	No		Repeated transect9 in the opposite direction (same direction as transect8)
transect 11	Jan Mayen	Sept 29	No		Along the JMA CTD/LADCP station line
transect 12	Jan Mayen	Sept 30	Yes	**G**	Along the JMA CTD/LADCP station line
transect 13	Jan Mayen	Oct 1	Yes	**H**	Along the JMA CTD/LADCP station line

Repeated Transects

Jan Mayen A

The Jan Mayen A transect (CTD/LADCP stations JM5–9) was sampled six times by uCTD. The first two occupations (uCTD transect4 and uCTD transect5) were completed back-to-back on 15 September with the bow chain deployed the entire time. This transect was then sampled with bowchain only on 16 Sept; the uCTD was not used on this occupation because the uCTD power supply was not working. After the uCTD power supply was repaired, the Jan Mayen A transect was again sampled by uCTD on 21 Sept (Fig. 3.2) and 29 Sept without bow chain. Both the uCTD and Bow Chain were in the water for the final two realizations, on 30 Sept and 1 Oct.

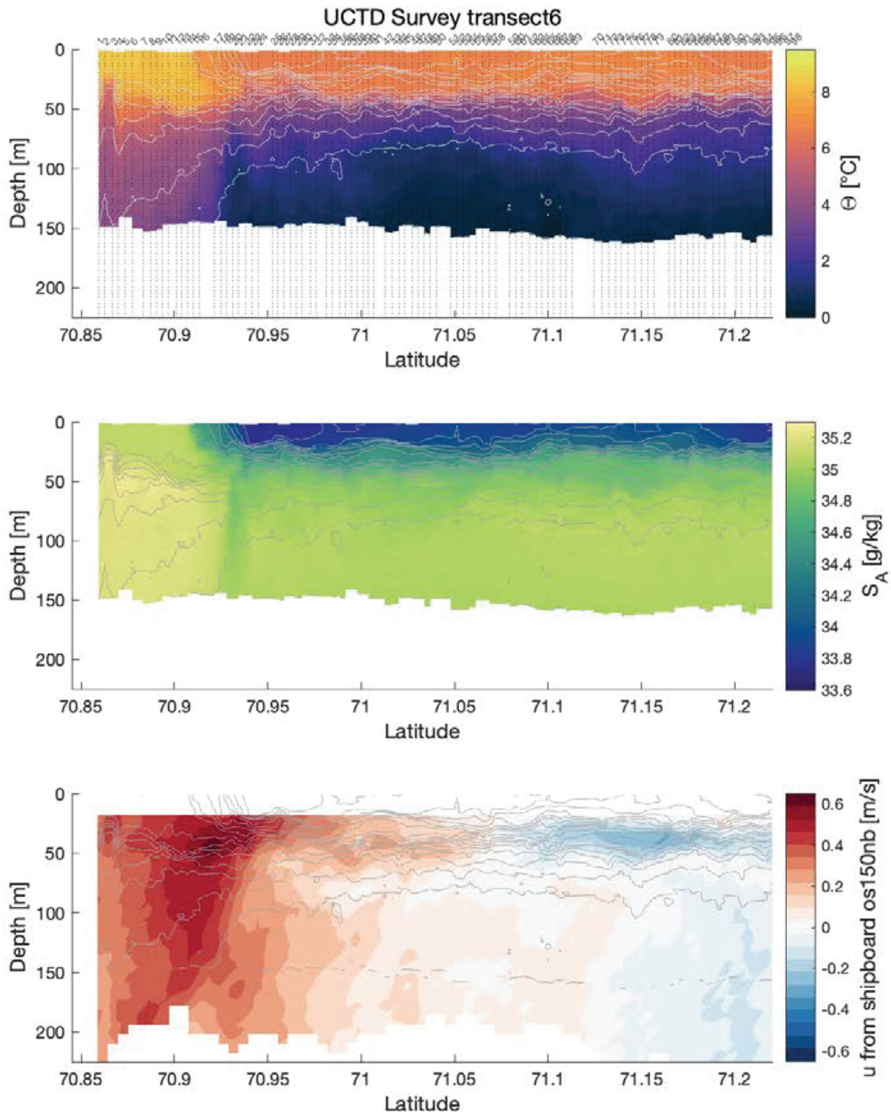


Figure 3.2. Temperature, Absolute salinity, and east velocity during the Jan Mayen transect 6.

Northern AFC (AF4 section).

Small oscillations of the base of the mixed layer just north of the main temperature front were observed in transect 7. After completing the deep CTD stations on the AF4 sections, this portion of transect 7 was repeated at 3 kts with 40 s drops (150m horizontal resolutions). This short transect was repeated 3 times (8,9,10) and captured what might be 20-m amplitude (peak-to-peak) non-linear waves propagating in the main thermocline (around 60-80 m)..

3.3 Bow Chain

Alejandra Sanchez-Rios, Anna Savage

To capture lateral high-resolution temperature and salinity variability near the surface across the ocean fronts. We deployed a 30-meter chain of temperature sensors (RBR solo, Table A1) off the bow, starboard side of the vessel. The chain included four CTD sensors (RBR Concertto) which were used to fit the shape of the line with depth. In the first deployment there were a total of 29 instruments, attached every 1 meter. Afterwards, we decided to include 8 RBR solos more in the surface to increase the resolution (every 0.5 meters). The final distribution of sensor along the line is detailed in Table 3.1.

The Bow-Chain was deployed and recovered at the bow of the RV Armstrong using a winch. We attached a 200 pound weight at the end of the bow-chain line to help maintain the array close to vertical in the water. During the survey, the bow-chain hang on the starboard side of the ship. With this set up and ship speed up to 4 knots, the deepest depth reached was 22 meters. While in transit we removed the weight and store the bow-chain inside in the dry lab.

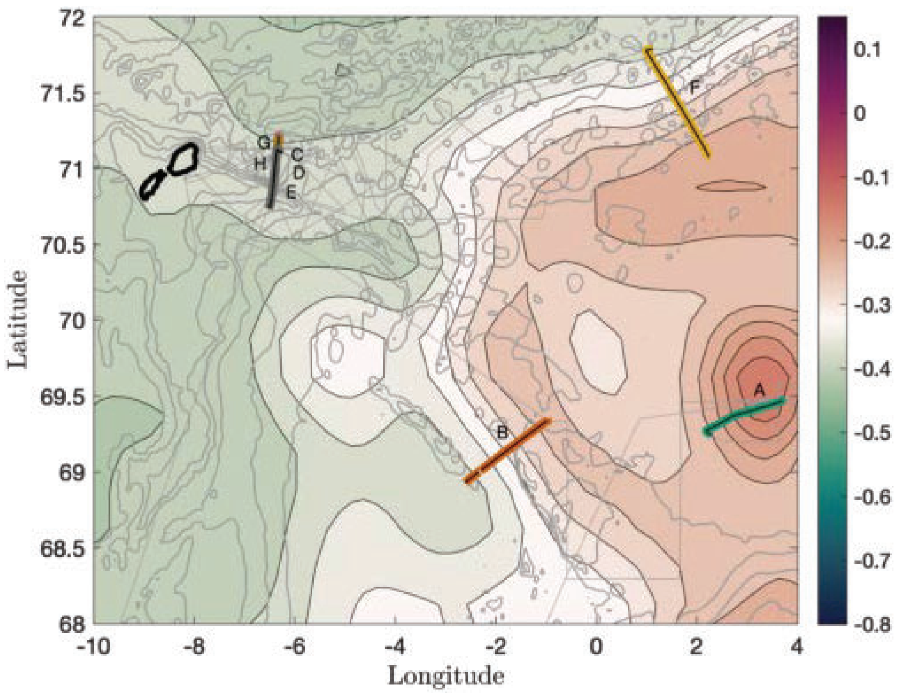


Figure 3.3 Location of all bow-chain cross-sections. (A) We did one section across the Lofoten Eddy, (B and E) two sections across the Atlantic current front, and (C, D, E, G, H) sections across the Jan Mayer A. Data shown in Figure 3.5.

We completed a total of 8 section with the Bow-chain (Fig 3.3). When possible, we deployed the bow-chain at the same time during uCTD profiles (Table 3.1).

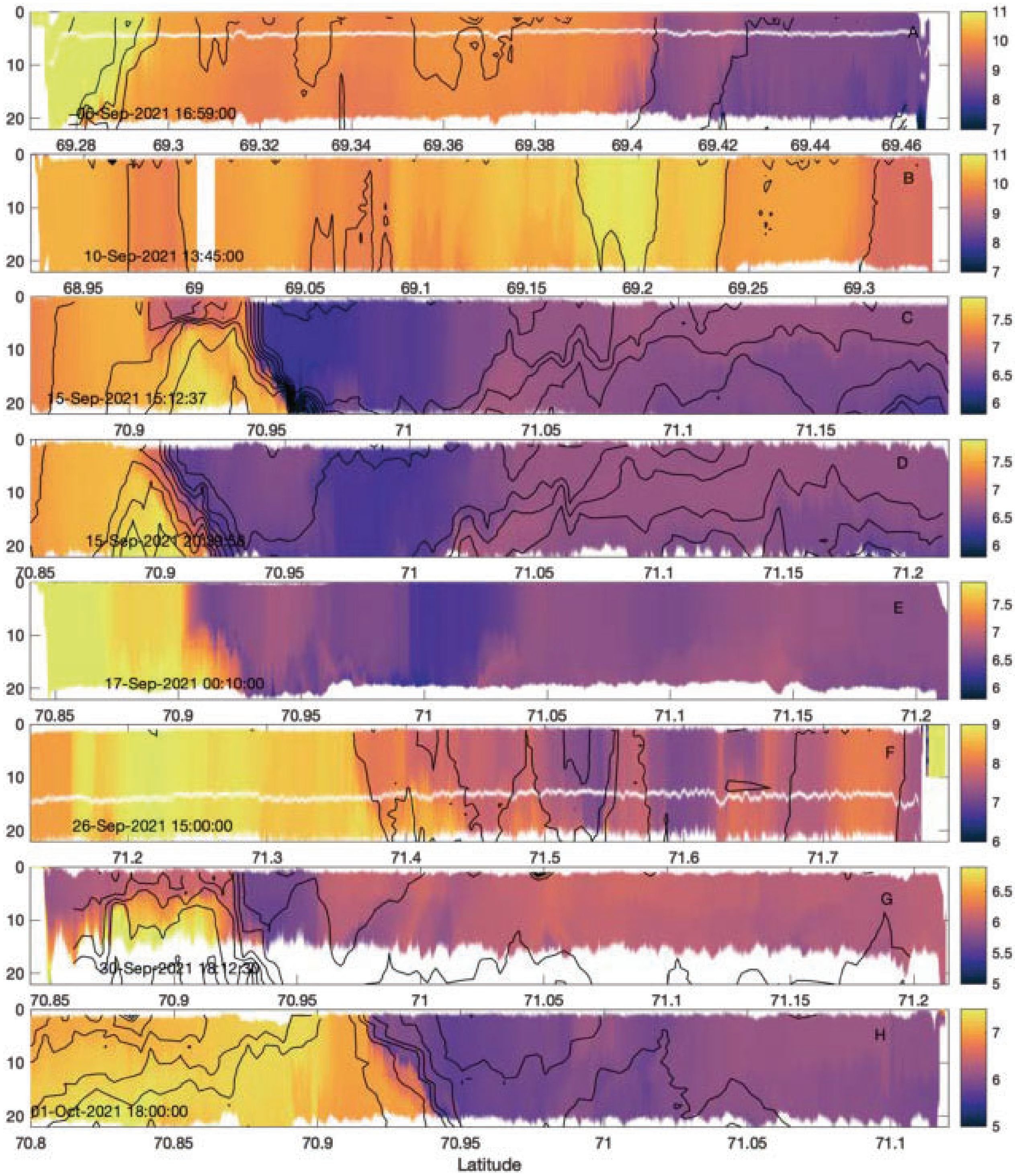


Figure 3.4: Temperature cross-section from all bow-chain deployments during NORSE 2021. The black contour lines are isopycnals obtained from the uCTD cross sections when available. (A) We did one section across the Lofoten Eddy, (B and E) two sections across the Atlantic current front, and (C, D, E, G, H) sections across the Jan Mayer A. For position refer to Fig 3.3.

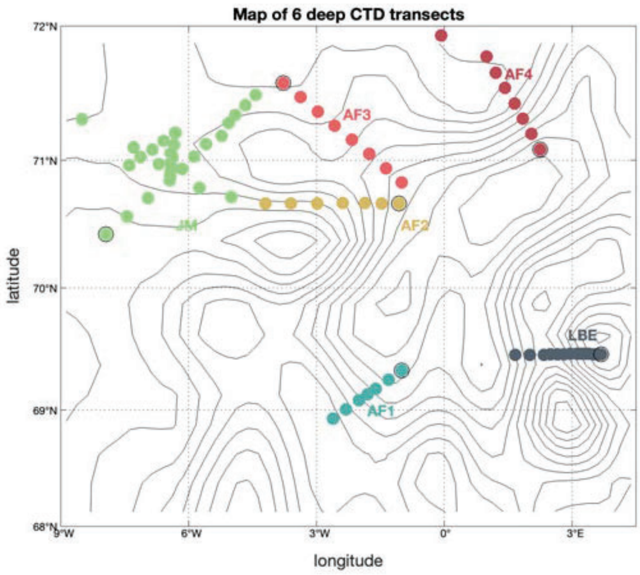


Figure 3.5: Map of six full depth CTD transects completed. Black contours are mean sea level anomaly over the duration of the pilot experiment.

3.4 CTD

In total, we collected full-water column CTD profiles at 77 stations. Most of the stations were part of selected sections across the Lofoten Basin Eddy (and a cyclonic eddy neighbor), the Atlantic Front current (4 separate sections), and in the regions around Jan Mayen (along 4 different sections across and along the Jan Mayen channel, one of which was repeated twice). Figure 3.5 depicts a map of the six separate transects: Lofoten Basin Eddy (LBE), Jan Mayen channel (JM), and four Atlantic Front current (AF1-4).

Figure 3.6 shows summary figures of the temperature and salinity data collected from the full-depth CTD transects shown in Fig. 3.5. Lateral temperature gradients can be seen in all 6 transects, primarily in the top 1300 m of the water column. Large, mostly compensated salinity intrusions are also measured in all CTD transects.

In general, the Atlantic Front current transects share similar qualities: the cross-front temperature gradients are on the order of several degrees Celsius, and occur in the top 800 m. The temperature profiles measured in the Lofoten Basin Eddy show a steady deepening of the thermocline within the eddy. Large near-surface temperature and salinity and salinity gradients are visible in the Jan Mayen region, occuring in the the top ~500 m of the water column.

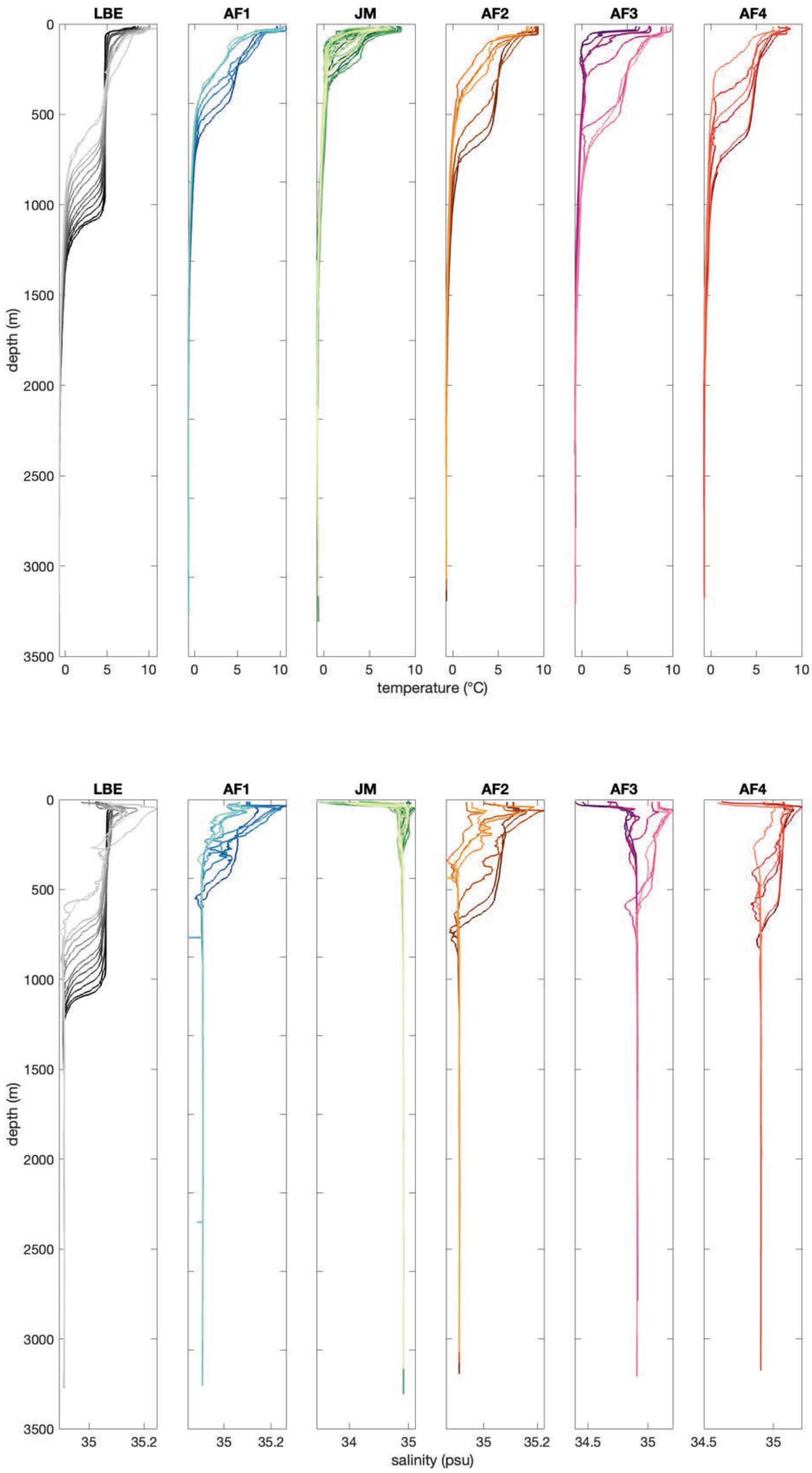


Figure 3.6: Temperature and salinity profiles from all CTD stations, separated by transect

Temperature-salinity diagrams from all full-depth CTD stations, separated by transects shown in the CTD map above demonstrate some of the general characteristics of the study region (Fig. 3.7). In the Atlantic Front and Jan Mayen transects, saltier and warmer water is observed on the westernmost part of the transects, and colder, fresher water is observed towards the west, closer to the Greenland Sea. The Lofoten Basin Eddy transect is the exception to this rule, where the core of the eddy is colder and fresher than the surrounding waters, which are primarily sourced by the North Atlantic Front current.

A freshwater intrusion is visible across all CTD sections, and can be identified as a local minimum in absolute salinity for temperatures below 2°C. This freshwater intrusion appears higher in the water column in westward CTD stations, closer to the inflow of cold, fresh near-surface water from the Greenland Sea.

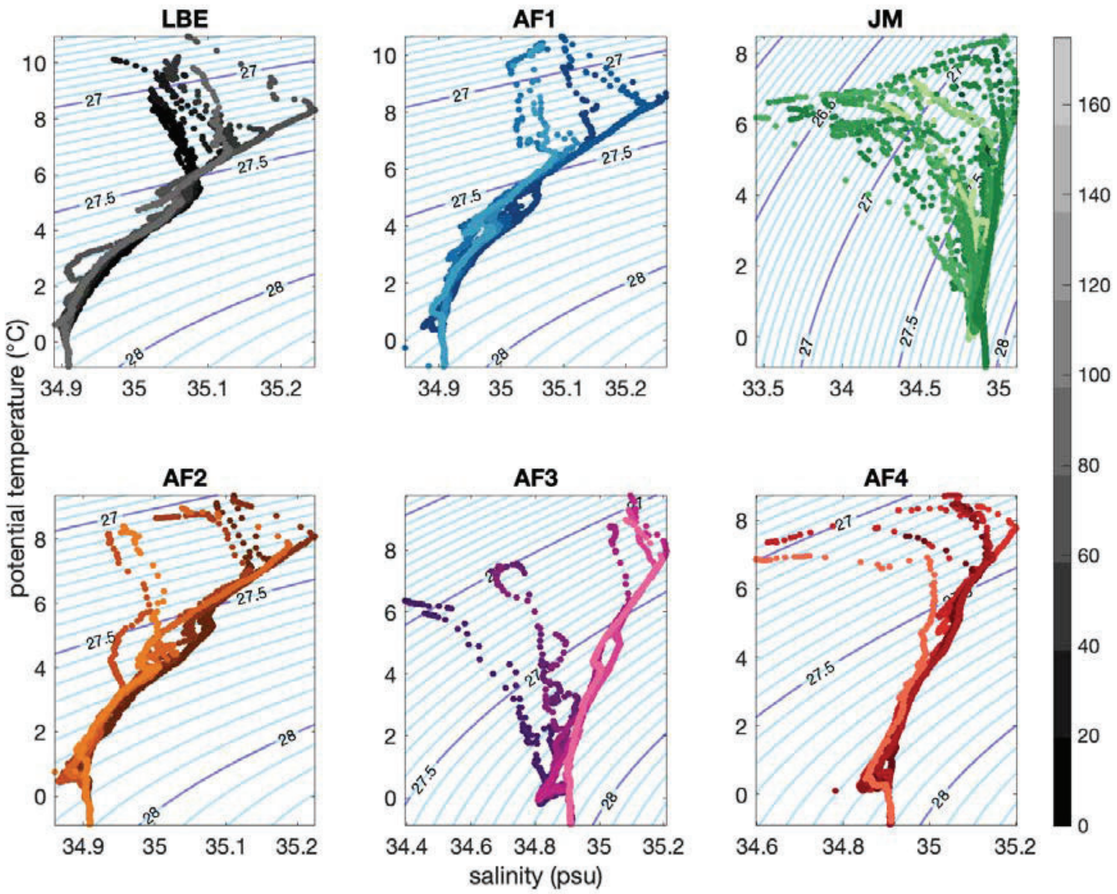


Figure 3.7: Temperature-salinity diagrams from full-depth CTD stations separated by transect. Darker colors indicate eastward stations and lighter colors indicate westward stations.

Examples of full-water column sections in the Lofoten Basin Eddy (Fig 3.8), and for one of the Atlantic Front current sections (Fig 3.9) show the different vertical structures of both currents and salinity. In these figures, velocity is a composite of the 300 kHz (above 50m), 150 kHz (50-250m), 38 kHz (from 250m to max range), and L-ADCP below this. We also show the dynamical height (SSH) obtained from Aviso (satellite) and an estimate of the non-divergent stream function from near-surface velocity, as well as the steric height obtained from integrating specific volume anomalies over different depths, as an indication of where in the water column the dynamical height comes from. It is interesting to see how different the vertical structure of the ocean processes responsible for the SSH signal can be across the NORSE domain.

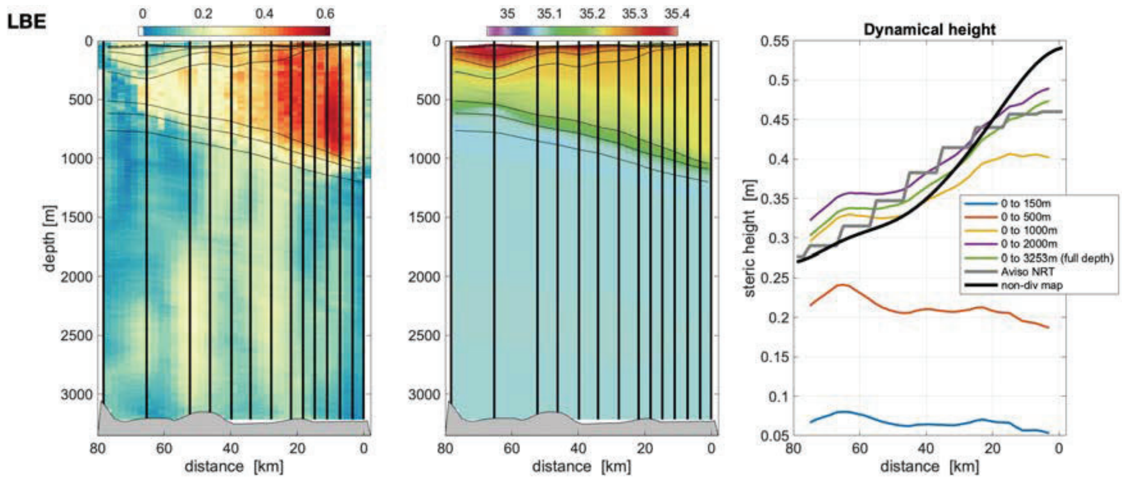


Figure 3.8: (Left) Magnitude of currents for a composite of ship ADCP and LADCP, and (middle) absolute salinity versus depth and distance for the LBE section. Station locations are indicated by the thick black lines. Potential density contours are plotted (0.1 kg m-3 intervals). (Right) Steric height as a function of distance, integrating the specific volume anomalies over different depth range. Most of the SSH signal comes from signals deeper than 500m. Aviso SSH from near-real time is plotted in gray. SSH from the non-divergent map is in black.

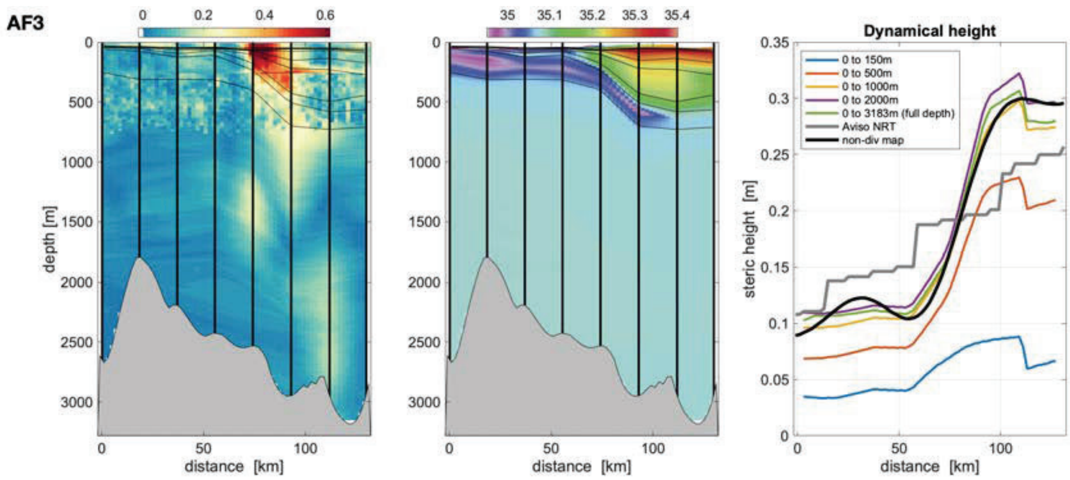


Figure 3.9: As in Fig. 3.8, but for the AF3 section. Steric height signal is from the upper ocean.

3.5 LADCP:

Laura Crews, Samuel Brenner, Angel Ruiz-Angulo

Instrument set up

LADCP equipment and instruction were provided by Dan Torres (WHOI). The LADCP was assembled on the *Armstrong* CTD rosette from 30 August to 1 September while in port in Reykjavik by Angel, Sam, and Laura.

Initial testing revealed two star cables (which attach to the rosette and connect the ADCPs to the battery and, when on deck, to comms), the yellow-taped comms cable, and ADCP s/n 1412 were malfunctioning. These were replaced as follows. The third star cable (second spare) was taped and zip-tied to the rosette. The spare comms cable (which is slightly larger in diameter than the others) was installed and taped with yellow tape. The faulty ADCP was removed and replaced with the spare. After installation was complete, the upward looking ADCP was s/n 4896 and the downward looking ADCP was s/n 24468. The LADCP computer (labeled AR602 Primary) and American Reliance battery charger (labeled LADCP Charger #6, s/n 30501030018) were set up in the wet lab. Tests showed that the yellow comms cable (connected to the downlooking ADCP) must be in the upper computer serial port for the downlooking ADCP to appear in the bottom window of the python-created DualLADCP user interface. This plug arrangement is counterintuitive, i.e., the upward ADCP goes in the serial port *below* the serial port for the downward ADCP.

Subsequent tests revealed that the uplooking ADCP (which is the follower/slave) was not recording data. Dan hypothesizes that the uplooker was not receiving the synch pulse from the downlooker (master). This suggests the problem was the star cable, which transmits the synch pulse between ADCPs. As we had already found the initial star cable and the first spare star cable to be faulty, there were no remaining cables with which to replace the second, mostly-functioning (apart from the synch pulse) spare star cable. Instead, Dan sent new command files (`wh300_dn4X.cmd` and `wh300_up4X.cmd`) that eliminate the synch pulse. This means the ADCPs could interfere with each other – Dan thinks this risk is minimal but we have not tested it. With the new command files, both ADCPs recorded data.

Processing basics

LADCP processing was carried out with LDEO IX version 13 provided by Angel. Processing parameters were set in a `set_cast_params.m` script written for this cruise; the correct version of `set_cast_params.m` notes that it was written for the 2021 Norse cruise at the top of the script. There were some notable processing values set to differ from the LDEO IX defaults:

> `p.timoff = 1/24;` We were unable to set the LADCP computer to match the ship's clock despite trying multiple approaches. Instead **the LADCP time lagged the ship time (UTC) by one hour**. This parameter updates the LADCP to the correct time during processing.

`p.btrk_ts = 30;` This increases the target detection strength to improve bottom detection even with interference.

`p.drot = -1.71;` Sam was able to install the `magdev.m` program and calculate this magnetic deviation value for the general area. For final processing, **consider installing `magdev.m` and reprocessing with a more accurate value for each cast's location**.

`p.fix_compass = 3;` LDEO IX gives the warning "Large compass deviation". We think this is caused by differing compass calibrations between the two LADCPs. The heading differences between the instruments is shown in the upper panel of figure 6 (produced during processing); if this difference is too large, the "large compass deviation" error is triggered (see lines 125-145 of `prepinv.m`). This `p.fix_compass` setting will rotate up-looking velocities to the downlooker's heading. Note that it is also possible to rotate the down-looking velocities to the uplooker's heading by setting `p.fix_compass = 4` (see lines 209-217 of `default.m`). We don't know which (if either) ADCP's compass is reliable, and using this setting did not eliminate the "large compass deviation" error (though it's possible that the error is thrown before the correction is applied). **Additional effort investigating/fixing the compass deviation is recommended!**

Note that LDEO IX requires times in Julian dates and that all **dates are incorrectly converted by LDEO IX so that they are 12 hours ahead of the actual time**!! This seems to be fine as long as all products (CTD data, LADCP data, and SADCP data) have the same offset, which will happen by default within LDEO IX. However, it can lead to confusion during debugging as data will have a timestamp that is twelve hours too late at intermediate steps during processing.

Incorporating CTD data

The standard CTD files produced by Armstrong do not save the time-series of the ship's position throughout the cast (just one value at the beginning of the cast). SSSG implemented a separate routine to process the CTD files (named ar60-02_{CTD station number}_ladcp.cnv) for the LADCP processing, including the latitude/longitude time series as well as elapsed time throughout the cast. These CTD files were written directly to the LADCP data directory on the science_share server rather than to the data_on_memory server where most of the ship's routinely-collected data are cached. Partway through the cruise (around CTD45) Angel requested the CTD files contain additional variables so he could compute vertical velocities; LADCP data were not reprocessed with these new CTD files, but this should not affect the LADCP results. There are two files set_cast_params, however if new LADCP processing was to be performed the use of the plain "set_cast_params.m" should work as it is consistent with the latest versions of CTD files.

Incorporating Shipboard ADCP (SADCP) data

Armstrong has three shipboard ADCPs (or "SADCPs"; the 38 kHz 'os38nb', the 150 kHz 'os150nb', and the 300 kHz 'wh300'). 'nb' stands for narrow-band processing, though 'bb' broad-band SADCP data are also available for the 38 kHz and 150 kHz. The 150 kHz data had contaminated large velocities at around 70 m to 80 m, particularly while on station, and were not used. Our primary processing routine was to input only the 38 kHz SADCP data to LDEO IX. Additional trials were completed only the using the 300 kHz SADCP and using a composite product that combined the 300 kHz SADCP data in the upper ocean and the 38 kHz SADCP data at depth. These trials are described in the following section called *LADCP Results with Varied Processing*. When incorporating a single SADCP instrument, the LDEO IX function `mkSADCP.m` was used to make the properly-formatted SADCP data structure from the `contour_xy.mat` and `contour_uv.mat` files. The combined os38nb and wh300 product was made using `makeCompositeSADCP.m` (remember that LDEO IX requires times in Julian days!).

Table 3.2: Station numbers of casts on each of the CTD/LADCP transects.

Transect long name	Transect short name	CTD/LADCP cast numbers	Jan Mayen station numbers	Sampling period	Notes
Lofoten Basin Eddy 1	LBE1	2, 4–11, 13-17	N/A	6–8 Sept	
Atlantic Front Current 1	AF1	18–24	N/A	9–10 Sept	
Atlantic Front Current 2	AF2	59–69	N/A	19–20 Sept	
Atlantic Front Current 3	AF3	50–52, 54–58*	N/A	18–19 Sept	
Jan Mayen A	JMA	29–33	JM5–JM9	13–14 Sept	Repeated uCTD and Bow Chain
Jan Mayen B	JMB	29–33**	JM1–JM5	14 Sept	
Jan Mayen C	JMC	26–29, 42–49	JM23, JM22, JM21, JM9–16	13, 15–18 Sept	
Jan Mayen D	JMD	38, 36, 39, 30, 40–41***	JM17, JM2, JM18, JM8, JM 19–20	13–15 Sept	Jan Mayen Channel
Jan Mayen 24	JM24	66	JM24	21 Sept	Lone station on north side of Jan Mayen
Atlantic Front Current 4	AF4	74, 67–69, 73, 72, 71, 70***	N/A	25–27 Sept	Cast 74 failed to record LADCP data. Repeated uCTD and Bow Chain along part of this section for intrathermocline eddies
Jan Mayen A2	JMA2	75–81	JM5–6, JM 27, JM26, JM25, JM28, JM9***	29–30 Sept	Repeat of JMA line, but with some new station locations

*There is no CTD/LADCP cast 53

** CTD/LADCP casts 29, 33 are included on more than one transect when transects overlapped or shared corners

*** This is the order of the casts point-to-point on the transect

LADCP results with standard processing

LADCP casts were processed with using both LADCPs and the os38nb SADCP. This combination is the "standard" processing. The output of LDEO IX for each cast is stored at `/science_share/LADCP/data/processed_updo_sadcp_os38nb/CTD{`**`station number`**`}`

LADCP casts were grouped into transects. Details about each transect are given in the Table below. Matlab structs including a subset of LADCP variables for each transect are stored at `/science_share/LADCP/data/`

The results structures (struct) for each transect is named `LADCP_NORSE_{`**`short name in in Table 3.2`**`}`

Additionally, each transect has a secondary structure (struct) that simply lists the CTD/LADCP cast numbers constituting that transect. These structs are named `LADCPstations_{`**`short name in Table 3.2`**`}`

Section plots and TS diagrams of deep CTD temperature and salinity along with LADCP velocity were made using `plotLADCPsections.m`. Figure 3.10 shows an example of the produced sections corresponding to the Atlantic Front Current (AF3). These plots are stored at `/science_share/LADCP/plots/`.

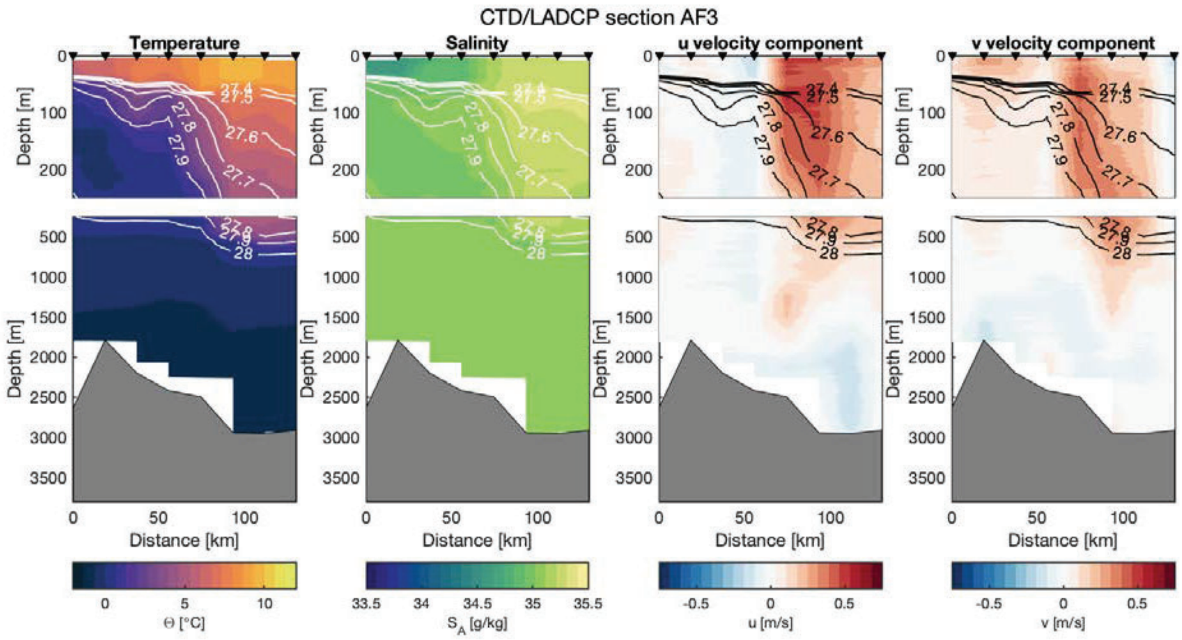


Figure 3.10. Example of combined CTD/LADCP transect across the Atlantic Front Current ("AF3"). The section goes from upstream to downstream of the AF, with the low surface salinity signature of the polar surface water visible on the left side of the transect. The shaded grey corresponds to the section bathymetry, taken at each CTD station from the Jan Mayen 500 m horizontal resolution bathymetry product. The triangles show the locations of the CTD/LADCP casts.

3.6 Autonomous gliders

Two glider classes were used for the 2021 study: Seagliders operated by UW/APL (2 from Rainville/Lee's group, one from Shapiro's group), and 1 Teledyne-Webb Slocum glider operated by APL and UAF (Shapiro and Simmons).

Deployments of Slocum glider 'Apollo' are discussed below (Acoustics).

2 Seagliders equipped with ADCP and microstructure sensors, both temperature and shear were deployed to sample the Atlantic Front Current. One glider (SG528) transited from the first section across the front that was sampled with the ship (near 68°30'N), and eventually met with the other Seaglider (SG135) and the Wave Glider. (Fig. 3.11) Microstructure temperature seems to have worked very well, but shear might have some issues.

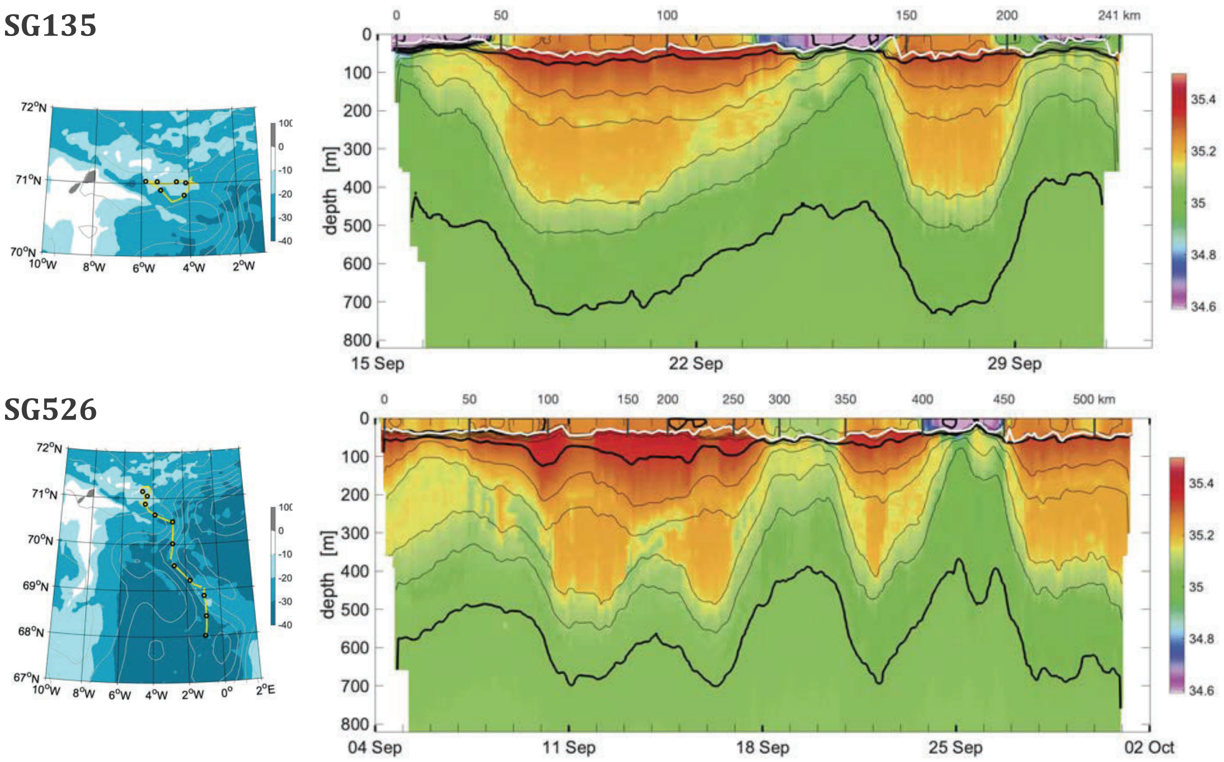


Figure 3.11: Track and absolute salinity from SG135 (top) and SG526 (bottom), crossing the Atlantic Front Currents several times. Starting in mid-September, both gliders sampled with the Wave Glider near Jan Mayen.

1 additional Seagliders (SG210, 'Maverick') was first deployed in the Lofoten Basin Eddy on 7 Sept. Shortly after deployment, it was established that the glider was not ballasted correctly and couldn't dive. Glider was recovered after about 8 hours. 150 g of lead was added, and the glider was deployed again on 15 Sept, near Jan Mayen, along with the Wave Glider, SG135, and SG562 (Norway). SG210 did several dives, but always had problems making phone calls. The glider was almost recovered the following day, but Justin Shapiro decided to keep it in the water. Calls became increasingly sparse, until Shapiro decided to leave it on the surface. We planned on recovering it on 20 Sept, but didn't have a recent GPS position so we decided to wait. SG210 has been calling once in a long while, drifting east, but it was completely silent during the last window we had for deployment (during sampling near the AF4 section).

Finally, we also deployed **Seaglider 562, operated by Norwegian group** (Våge et al.). This glider was deployed on 15 Sept. near Jan Mayen and will be sampling in the Greenland Sea (Fig. 3.12). The glider track, as of 03 Oct 2021, is shown below. It is a very complementary dataset and it will be great to collaborate with them to combine all the hydrographic data collected near Jan Mayen.

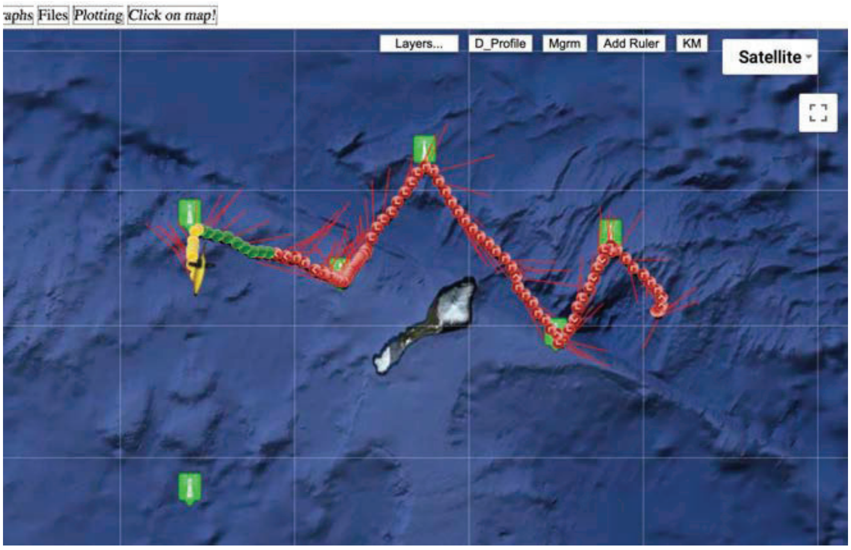


Figure 3.12: Track of SG562 from University of Bergen, from the Norwegian glider portal (http://gp.gfi.uib.no).

3.7 Acoustics on unmanned systems (Abbot & Premus, OASIS)

Dave Morton and Vince Premus (OASIS), Laur Ferris (VIMS)

OASIS (Abbot and Premus) and APL/UW (Shapiro) deployed a Slocum G2 (Shapiro/APL-UW) equipped with a 4th generation Low Power OASIS Towed Array (OTA-4) to collect data on the spatial and temporal variability of the acoustic noise distribution concurrently with oceanographic data to support a detailed examination of the link between oceanographic variability and characteristics of acoustic environment (Fig. 3.13). The glider did 3 deployments:

- 7-hour deployment on 7 Sept in the Lofoten Basin Eddy. Aborted early because of sign of leak into the pressure case
- 5-day deployment between 16 and 20 Sept. near Jan Mayen. Several acoustic transmissions are various ranges were obtained.
- 24-h deployment from 30 Sept – 1 Oct.

The glider was modified with a thruster assembly that proved to be instrumental in keeping the array on steady trajectories throughout the dives and ascents. In order to keep the array flowing behind the glider without the risk of entanglement in the propellor, a custom-built stainless bracket was added to the stern of the vehicle.

The Low Power OTA-4 array is the fourth generation, oil filled array designed by OASIS, and built under contract for ONR by L3 Chesapeake Sciences Corp. The array oil is Isopar L, an ExxonMobil hydrocarbon product with a typical specific gravity of 0.767and a strong dependance on temperature, and a slight compressibility dependance on pressure. As such, OASIS takes great care to ballast the array to the conditions expected at the target depths in the areas of interest. During the cruise, ballast lead was added to the array according to calculations based in-situ CTD data.

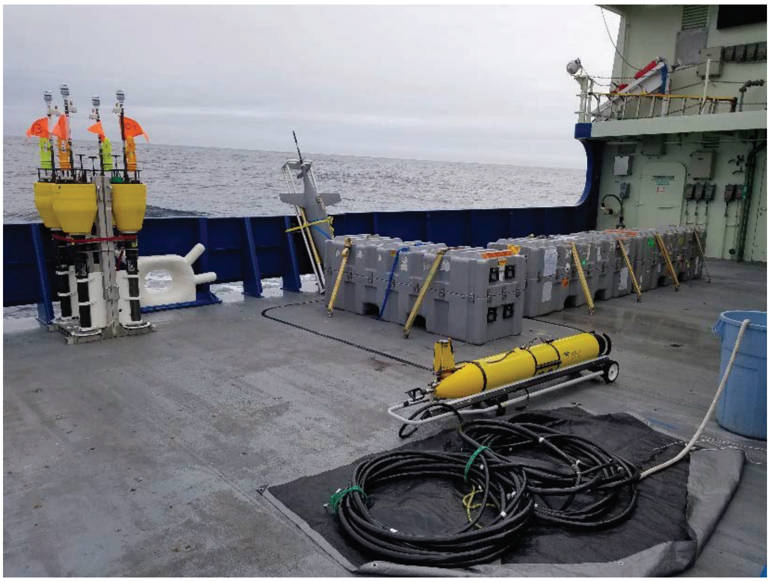


Figure 3.13: The Slocum G2 Glider Apollo, with Low Power OTA4 array, on the stern deck of the R/V Armstrong, just prior to the initial deployment on 07Sept21. The insert is a closeup of the tail, highlighting the option-added thruster, and the adaptor fitting that keeps the array away from the propellor. The drogue is shown submerged in salt water prior to the dive, and after being removed from the ship's CTD system. The drogue was sent down to 3,000m a few hours prior to deployment to eliminate extraneous air bubbles from the double braided nylon line

During the deployment, limited duration acoustic source operations occurred, using aJ-9 acoustic projector. The J-9 is lightweight (20 lbs), and easily hand-deployed over the side of the support vessel to depths of approximately 50'. OASIS constantly monitors source output with an HTI hydrophone with a sensitivity of -177 dB re 1V/μPa, mounted 1 meter above the center of the source face. At all times, levels were less than 150 dB re 1μPa@1m. Ranges were varied by re-locating the ship after set periods of time that were typically 1.5-2 hours long. At each location, half of the time was spent broadcasting the OASIS Red wavefile, consisting of 4 concurrent narrowband CWs at 389, 521, 661, and 773 Hz, and the other half of the time broadcasting linear FM upsweeps to support in-situ transmission loss measurement using the glider/towed array as a receiver (Fig. 3.14).

Preliminary key takeaways:

1) With proper ballasting, Slocum glider is capable of towing the array with enough speed through water to maintain array straightness and yield the desired array performance. The optimal glider operating profile seems to be 20 deg pitch and 75% thruster level.
2) In-situ CTD data pre-deployment is key to getting the array ballast right—prior to each deployment, the towed array ballast was adjusted for slightly (+100 g) positive net buoyancy at a water depth of 500 m. The oil-filled array seems to be doing fine with exposure to the extreme temps.

3) The J-9 acoustic source transmissions at de minimus (150 dB) source level have been detected at ranges of up to 12 nm. Broadband sweeps have also been transmitted to support TL estimation, which we will do in post-processing.

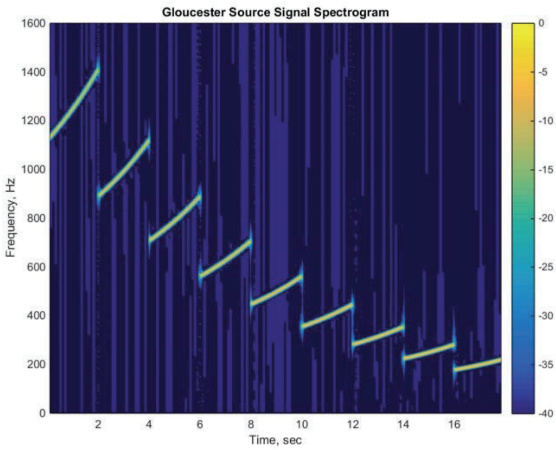
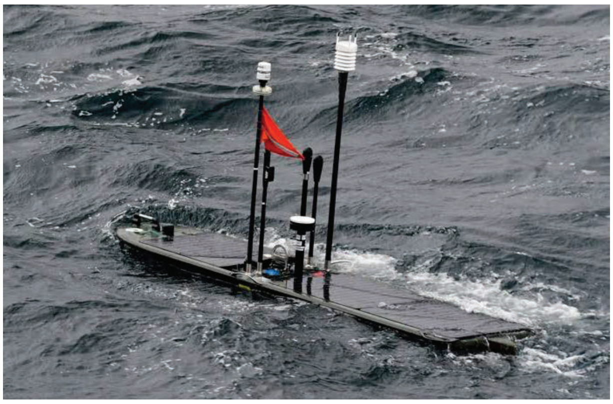


Figure 3.14: This figure presents a spectrogram of the FM upsweeps broadcast with the J9 to support in-situ transmission loss measurement using the glider/towed array as a receiver. The signals are automatically repeated throughout the 45-60 minute event(s).

3.7 Wave Glider SV3-253 Mission Summary

Alli Ho, Ray Young



A Boeing Liquid Robotics SV3 Wave Glider (SV3-253 aka 'Ole') comprised of a surface buoyancy unit tethered to the subsurface propulsion unit was deployed and recovered during the cruise. The Wave Glider carries various instruments, a command and control computer, and a data acquisition computer. The electronics are powered by batteries that are charged by solar panels. The wave glider has an 8m tether connecting the float to the sub. To capture surface forcing during the experiment, the Wave Glider was equipped with payloads that sample winds, waves, currents, and sub-surface temperature and salinity. Payloads included a downward-looking 300 kHz Teledyne RDI Workhorse Monitor Acoustic Doppler Current Profiler (ADCP), two meteorological sensors including one Airmar 200WX Weather Station and one SIO MetBuoy sensor, two surface waves sensors including one GPSWaves and one SIO-fabricated Miniature Wave Buoy (MWB) sensor, and a Seabird Glider Payload CTD on the sub.

The Wave Glider was deployed from 15 September to 30 September and measured a broad range of meteorological and oceanographic conditions (Fig. 3.15). Two significant low pressure systems dominated conditions during the Wave Glider deployment, with significant wave heights ranging from 2-7 meters and wind speeds ranging from 0-30 kts. Sea surface temperature ranged from 6.2-9.2 degrees Celsius across the Atlantic Current Front, further detailed below.

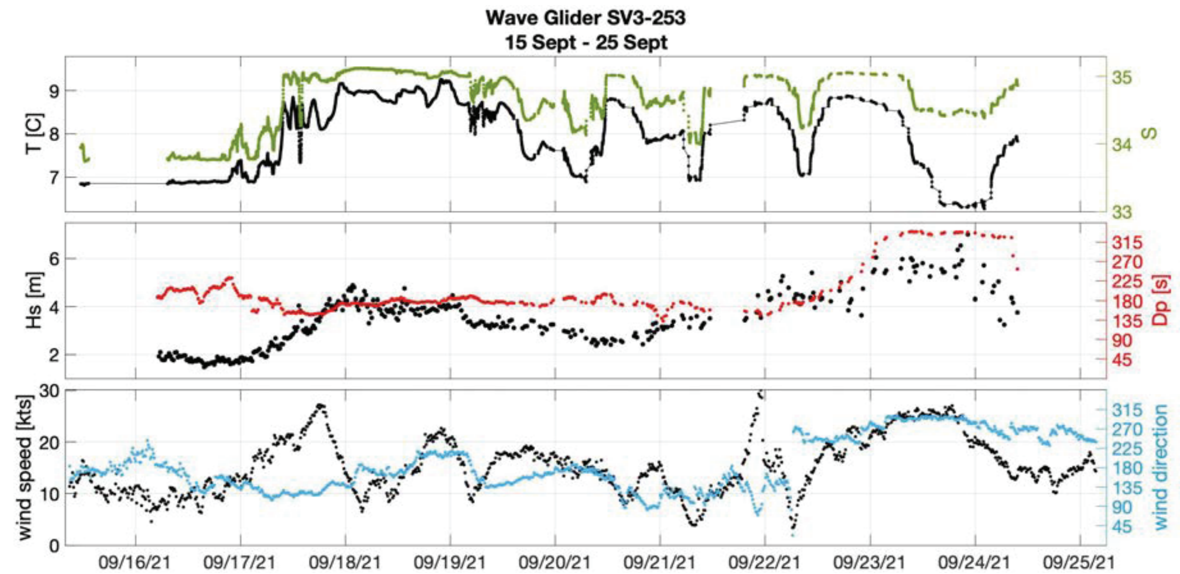


Figure 3.15: Time series of Wave Glider measurements. (Top) CTD measurements for temperature in degrees Celcius (black) and salinity (green). (Middle) Wave measurements for significant wave height in meters (black) and peak direction (red). (Bottom) meteorological measurements for wind speed in kts (black) and wind direction (blue).

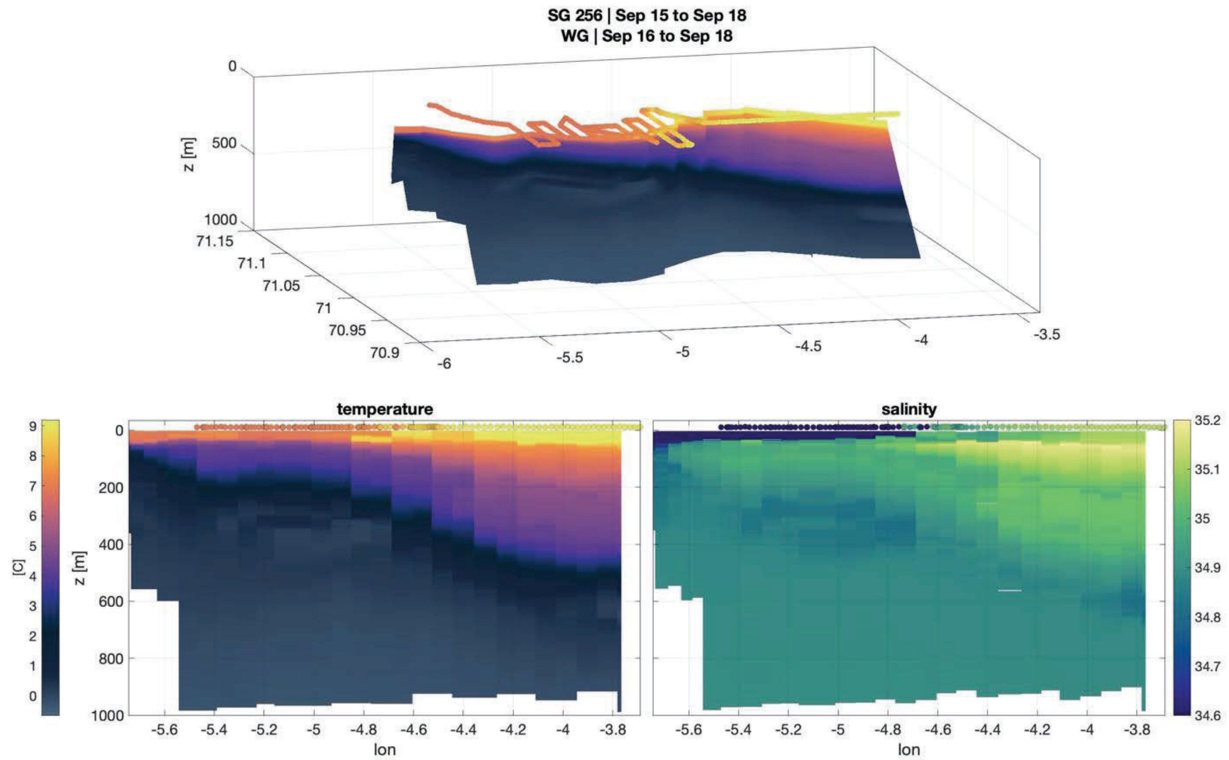


Figure 3.16: Seaglider 135 temperature (top, bottom left) and salinity (bottom right) profiles below Wave Glider surface tracks as they cross the Atlantic Current Front from 15 September to 18 September.

The low solar angle, clouds, and shortening days (Fig. 2.3) characteristic of mid-September in high latitudes created a solar-limited environment that greatly reduced the ability of the solar panels to recharge batteries and forced the Wave Glider to aggressively conserve power. Redundant sensors were disabled so the Wave Glider sampled with only the ADCP, MetBuoy, GPSWaves, and CTD both continuously and on duty cycle for the duration of the deployment. Duty cycling was done manually to better adaptively sample front gradients and because the Liquid Robotics automatic duty cycling plug-in caused either software or hardware issues pre-deployment at the beginning of the cruise. On 25 September all sensors were turned off to preserve energy to operate the core vehicle functions (hotel load ~6W) until the weather window for recovery on 30 September.

From 16 September to 19 September the Wave Glider followed Seaglider 135 eastward towards the Atlantic Current Front (Fig. 3.16). The assets crossed over the sharp gradient (surface temperature increased 7.3 to 8.7 C over less than 1 km) of the Atlantic Current Front on 17 September.

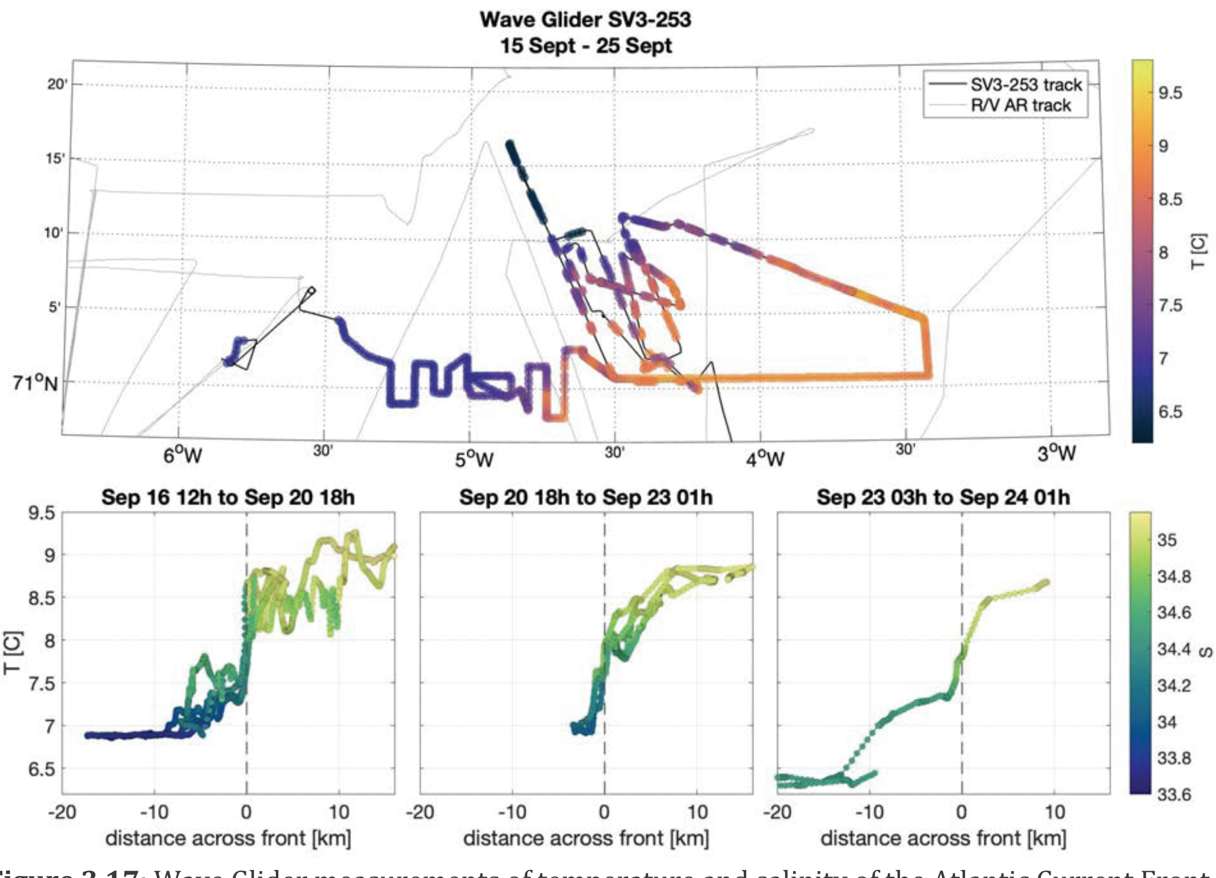


Figure 3.17: Wave Glider measurements of temperature and salinity of the Atlantic Current Front. (Top) Glider tracks colored by temperature showing the approximate location of the front and the attempts to map the evolving gradient. (Bottom three panels) Cross-frontal changes in temperature (y-axis) during three separate times, colored by salinity. Leftmost panel from early-on in deployment shows the sharpest gradients in both temperature and salinity; rightmost panel at the end of the deployment shows the weakest gradients and coldest, northernmost measured temperatures.

The Wave Glider surveyed a portion of Atlantic Current Front repeatedly from 19 September to 24 September in extreme conditions with 30 kt winds and up to 7m waves, highlighting the utility of autonomous measurements when ship-based sampling is not possible. Over five days the Wave Glider made eight front crossings, and provided real-time information about the location and evolution of the front to inform the Seagliders mission to make 20km profiles across the front. The front is mapped in Fig. 3.17. We observed sharp gradients in both temperature and salinity from 16 September until 20 September, at which point the warm sharp edge began to sag. The Wave Glider made one crossing after the storm system on 24 September began to die down, at which point the gradient had weakened significantly, the cold side a degree colder than before and saltier than prior to the storm.

Sensor configuration

The ADCP was configured to sample continuously at 1 Hz using 2 meter bins up to 100 meters. Translational motion of the glider is corrected for by removing the float's horizontal velocity. GPSWaves is configured to run continuously at 4Hz GPS and 8Hz AHRS, telemetering wave information every 20 or 30 minutes. CTD ran three samples every 10 seconds, flushed for 20 seconds, and remained off for two or three minutes.

Power usage

A summary of Wave Glider payload and devices power usage is provided below to inform power conservation ability for future high-latitude Wave Glider deployments.

Device / port	**Power [Wh]**	**1. Eliminate redundancy [ON/OFF]**	**2. Duty cycle [ON/OFF]**	**3. Core vehicle function [ON/OFF]**
Airmar	1.36	OFF	OFF	OFF
Ethernet switch	2.17	ON	OFF	OFF
S2	0.18	ON	ON	ON
S1 (SIO METOC package)	2.35	1/2 OFF	ON	OFF
AIS	1.36	OFF	OFF	OFF
CCU Vconsumers	0.46	ON	ON	ON
Iridium GPS Module	0.41	ON	ON	ON
Vehicle Management Computer	1.79	ON	ON	ON
Thrudder	0.26	ON	ON	ON
Sensor Management Computer	1.3	ON	OFF	OFF
ADCP	1.17	ON	OFF	OFF
GPSWaves	0.7	ON	OFF	OFF
CTD	?	ON	OFF	OFF
TOTAL	13.51	10.79	5.45	3.1
OBSERVED OUTPUT PORTS		11.7	5.5	3.88
OBSERVED BATTERY DISCHARGE		14.38	7.7	6.68

We operated under **1. Eliminate redundancy** from deployment on 15 September until 20 September, at which point we transitioned to **2. Duty cycle** for manual power cycling with 30 minute to 2 hour intervals. This persisted until 24 September when we reached 650 Wh left. With at least five days until recovery and slim chances of significant solar charging, operations were reduced to **3. Core vehicle function** for navigation and telemetry. Notably the reported power usage differs from the battery discharge by an additional 2Wh, so even though the reported hotel load for core vehicle functioning is 3.8Wh, the Wave Glider still used 6.6 Wh and the battery discharged on average 77Wh per day with solar. When the Wave Glider was recovered, the power reservoir was at 160Wh.

Solar quickly dwindled throughout the Wave Glider's fifteen day deployment. Not a single day's solar was able to generate enough power to charge the battery beyond its usage for that day. By the end of the deployment, available solar power had dropped by half.

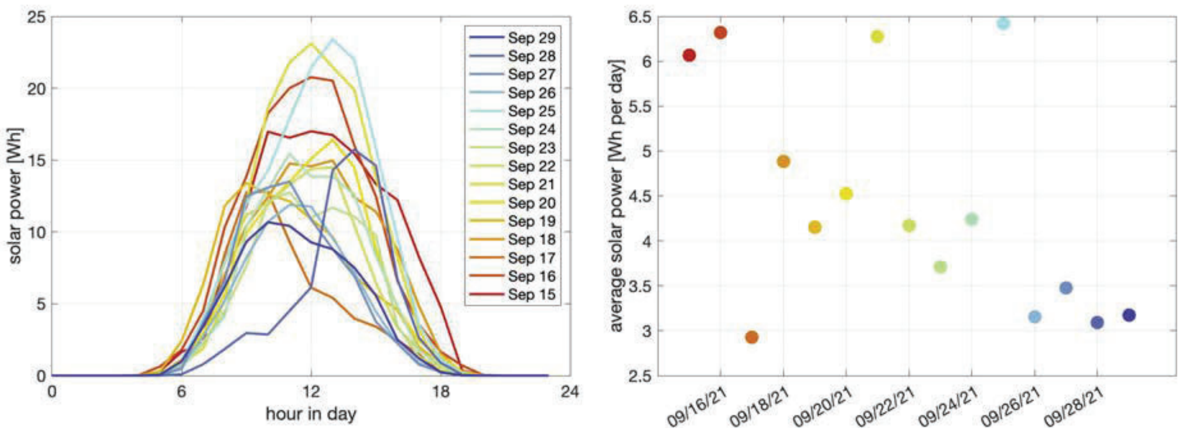


Figure 3.18: Power generated from Wave Glider solar panels each day of deployment each hour (left) and averaged per day (right). Sunny days were able to generate an average of 6Wh, but cloudy days towards the end of deployment only provided an average 3Wh, nowhere near enough to sustain even core vehicle functioning.

3.8 ALAMO FLOATS

Steve Jayne

3 ALAMO profiling floats were deployed to observe the upper ocean temperature and salinity structure. One float was deployed in the Lofoten Basin Eddy, one just east of Jan Mayen, and one just northwest of Jan Mayen. Floats were programmed to profile to 500m once per day. The floats will provide a persistent observing system after the ship departs and measure the rapid response of the upper ocean during strong forcing events.

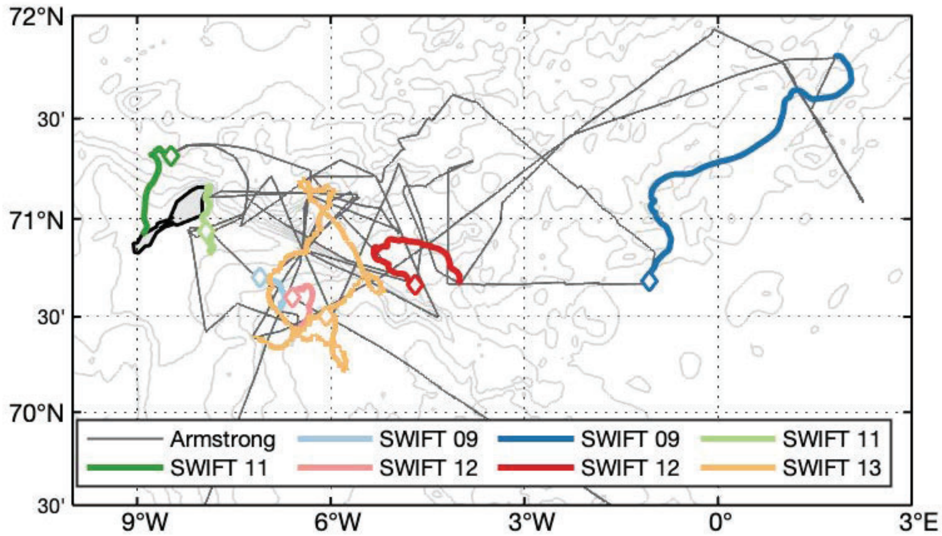


Figure 3.19: Map of SWIFT deployment and drift locations with Armstrong ship track. Pale colors correspond to the first deployment and strong colors correspond to the second deployment. Diamond symbols show the deployment location.

3.9 SWIFT

Sam Brenner, Jim Thomson

SWIFT drifters measure turbulence at the ocean surface in a wave-following reference frame, as well as directional wave spectra, surface winds, salinity, water temperature, air temperature, and surface images. We had four SWIFT drifters available for deployment, labeled SWIFT 09, 11, 12, and 13.

Initial testing on deck from 02-03 Sept (during transit) showed some data collection issues with SWIFTs 09, 11, and 12. It was found that the internal compact flash (CF) memory cards for these 3 drifters were not seated (which was corrected) and additionally that the internal batteries for the Aquadopps was drained (voltages below 11 V). These three SWIFTs also had slightly different programming than standard: data from all bursts (every 12 minutes) was sent back via telemetry instead of the standard 1 telemetered burst each hour. To reduce risk associated with losing equipment, we removed the dead Aquadopps from these SWIFTs 09, 11, and 12. SWIFT 13 did not have the same data collection issues, Aquadopp voltage was 11.1V, and telemetry/sampling was per standard. Each SWIFT was paired with a separate, internally recording, hydrophone (connected with a shackle and line to the rudder of each SWIFT).

The SWIFTs were deployed to capture distributed data during two large, forecasted storm events.

The 4 SWIFTs (with hydrophones) were deployed shortly before the first wind event on 11 Sept in a line 90 km approaching Jan Mayan, with the final deployment (SWIFT 11) in the lee of the island where we sheltered from the storm (Fig. 3.18, pale colors). This deployment provided a contrast between sheltered and exposed conditions. Following the storm, SWIFTs 09, 11, and 12 were recovered opportunistically from 13-16 Sept, while

SWIFT 13 remained asea. On recovery, the hydrophone was missing from SWIFT 09 (the whole shackle was missing).

The 3 SWIFTs aboard (09, 11, 12) were redeployed from 19-21 Sept in anticipation of another storm; SWIFTs 11 and 12 were deployed with hydrophones and SWIFT 09 without. During this deployment, the SWIFTs were distributed over a broader area than previously (Fig. 3.19, strong colors). SWIFT 09 was deployed at the easternmost point we had visited (up to then) on the cruise and near a strong northward current, and it was unclear if recovery would be possible. SWIFT 11 was deployed north of Jan Mayan. On 23 Sept, during the storm, SWIFT 11 stopped transmitting; it had been drifting towards the north shore of Jan Mayan, and for the last hour before transmissions ceased it experienced strongly elevated wave conditions (possibly due to shoaling/coastal interaction) so presumably it crashed into the island. Following the storm, the remaining SWIFTs were all recovered from 25-28 Sept. On recovery, both the hydrophone and the drogue recovery line were missing from SWIFT 13.

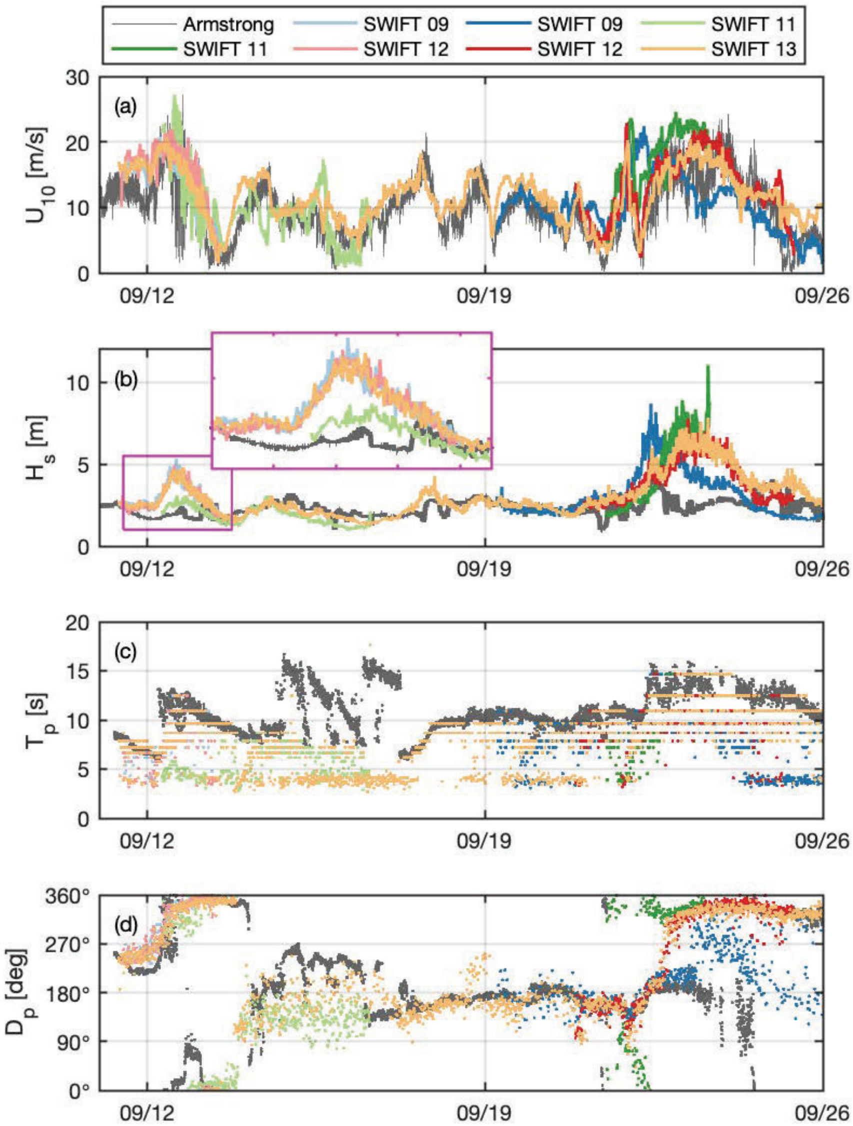


Figure 3.20: Timeseries of SWIFT-measured (a) wind speed (adjusted to 10 m reference height by multiplication of a constant 1.55 factor); (b) significant wave height, with an inset zooming in on the first storm event; (c) peak wave period; and (d) peak wave direction (true). Shipboard measurements of wind and bulk wave conditions (derived from the ships wave radar) are also shown for comparison. Color-coding matches Fig. 3.19.

Initial results

During the first storm event (approx. 12 Sept) SWIFTs 09, 12, and 13 all measured equivalent wave conditions (Fig. 3.20b-d), with significant wave heights of approx. 4-5 m. SWIFT 11, which was placed south of Jan Mayan, had much smaller waves (Fig. 3.20b, inset). Despite the shelter of the island, wind speeds measured by the SWIFT 11 and by the ship were similar to those measured by the farther SWIFTs and exceeded 20 m/s (

Figure a), so the decrease in wave height may instead be a result of fetch limited wave growth rather than changes in the wind. Additionally, meteorological measurements from the ship and from SWIFT 11 showed some oscillatory behavior that may be consistent with atmospheric lee waves in the wake of the island's volcano (not yet confirmed). Hydrophone data from this deployment has not yet been processed, but data were recovered from SWIFTs 11 and 12, which should provide an interesting contrast.

During the second deployment of SWIFTs 09, 11 and 12 (19-28 Sept), there was slightly more regional variation in wind speeds and wave heights (Fig. 3.20), though all still showed similar wind/wave patterns. Waves in the eastern part of the domain (measured by SWIFT 09) peaked early on 22 Sept, following a short-lived peak in wind speed after which winds slowly calmed over the following days. Sustained 20 m/s wind speeds through 23 Sept., measured by SWIFTs 11-13 corresponded with approx. 7-9 m significant wave heights seen by those drifters. Before SWIFT 11 ceased transmissions it recorded a significant wave height of 11 m. Hydrophone data from this storm were only recovered from SWIFT 12.

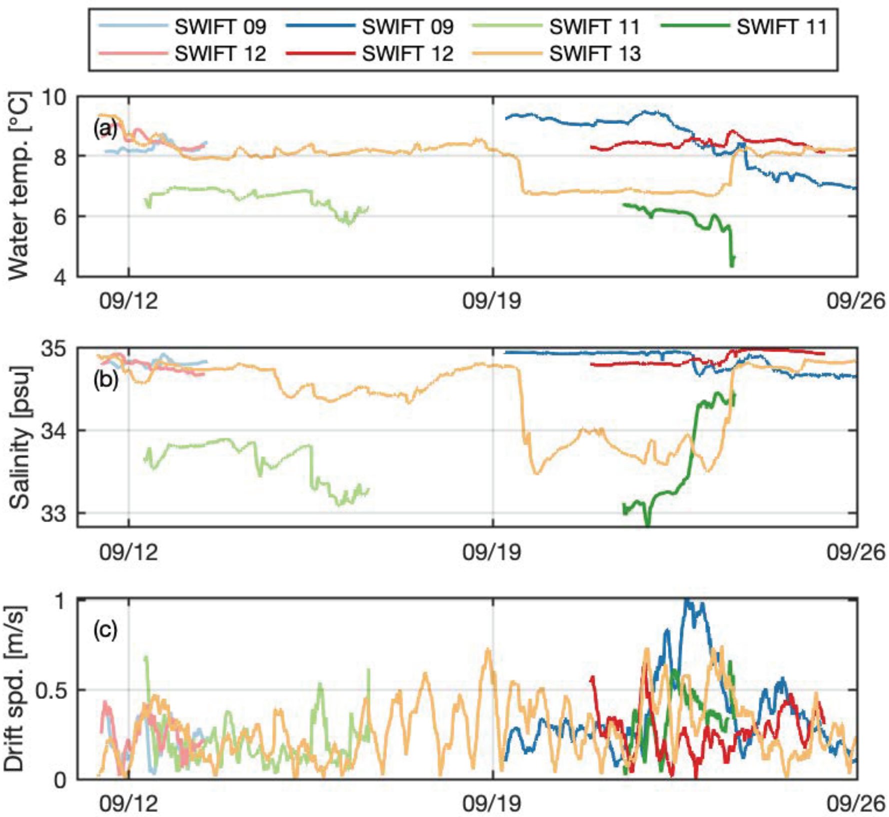


Figure 3.21. Timeseries of SWIFT-measured (a) water temperature; (b) salinity; and (c) drift speed. Color-coding matches Fig. 3.18.

The longer timeseries from SWIFT 13 covers both storms, but also some of the interceding period. During that time, the SWIFT meandered in an area a little west of the Atlantic Front Current (driftrack shown in Fig. 3.19). The measured water temperature and salinity show a few abrupt changes that may correspond with the SWIFT crossing a front (Fig. 3.21a,b). Additionally, the drift speed shows some periods with apparent oscillatory motion (Fig 3.21c) with a period consistent with inertial oscillations (not shown). TKE dissipation profiles from SWIFT 13 include negative values, and a banded structure that appears unphysical; these data and associated processing should be reviewed before any other use.

3.10. Surface Drifters

Kerstin Bergentz

12 SVP drifters drogued at 15-m depth and with sea surface temperature (SST) sensors were deployed during the cruise. In addition, we also deployed 1Minimet drifter, an SVP surface drifters equipped with barometers, a high-quality sonic anemometers and an internal compass, measuring the wind velocity, and one DWS drifter (without a drogue to measure surface waves.

Most of the drifters were deployed in the Lofoten Basin Eddy, as a coherent array to directly estimate vorticity and dispersion (Fig. 3.22). One Alamo float is also part of this array. We hoped that one Seaglider (SG210, 'Maverick') would sample the eddy for the duration of the cruise, but ballasting issues forced us to recover the glider.

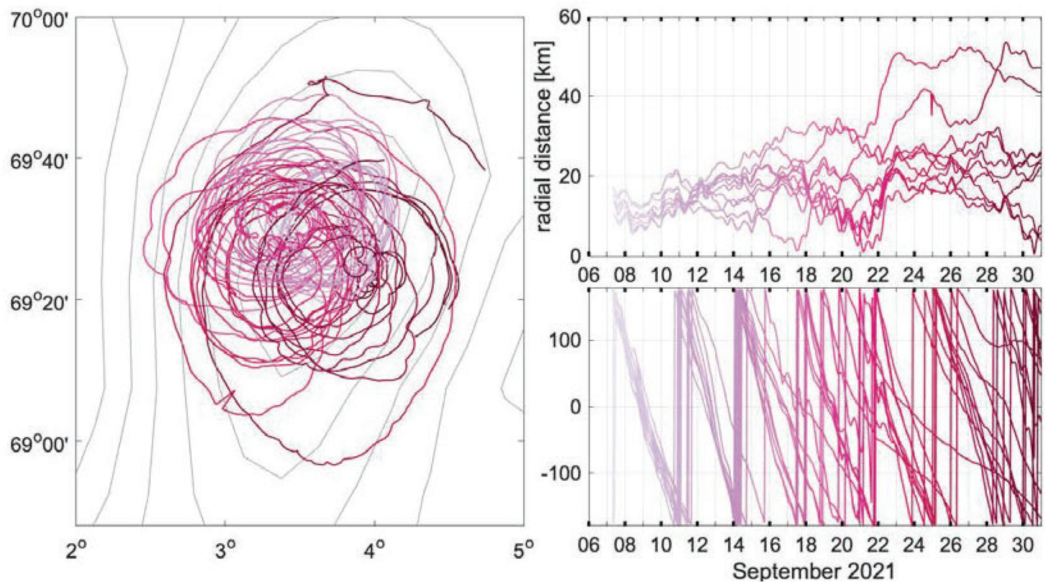


Figure 3.22: Track of the 9 SVPs and 1 Minimet, all drogued at 15-m, deployed in the Lofoten Eddy, colored by time. Distance from the center of the eddy, as determined by an objective map, versus time is plotted on the right.

Before the storm of 22-24 Sept, 3 more drifters were deployed near Jan Mayen, to constrain a bit more the circulation in the region and link the JMA transect with the region sampled by the gliders and Wave Glider (Fig. 3.23). These 3 drifters didn't exactly go where we thought they would go, which is both interesting and a bit confusing…

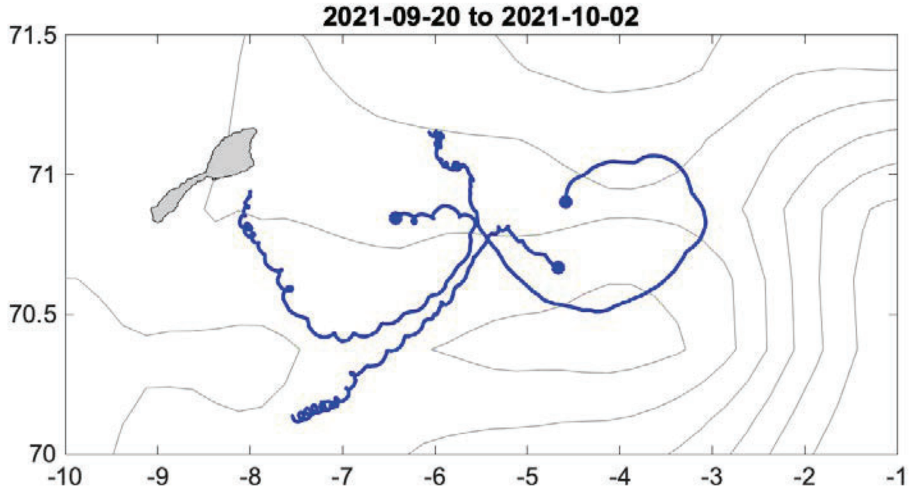


Figure 3.23: Tracks of the 3 SVP drifters deployed near Jan Mayen on 20 Sept (blue dots), with averaged SSH contours from Aviso during the same time period. Drifters didn't go where we expected.

4. Initial summary of surveys and science results / questions

4.1 Proposed mooring site

For the NORSE main field program, Megan Ballard has proposed to deploy the acoustic array near Jan Mayen, with the source at 71.2102° N 6.3098° W and the receiver at 70.8448° N 6.4422° W. These correspond to our stations JM5 and JM9, respectively (Fig 4.1).

The line between the proposed mooring sites was occupied 6 times with the uCTD (Table 3.1; Fig. 3.2), 5 times with the bow chain (Table 3.1, Fig. 3.4), and 2 times with full-ocean CTD stations (Fig. 4.2). It will be interesting to do acoustic ray tracing through all of these.

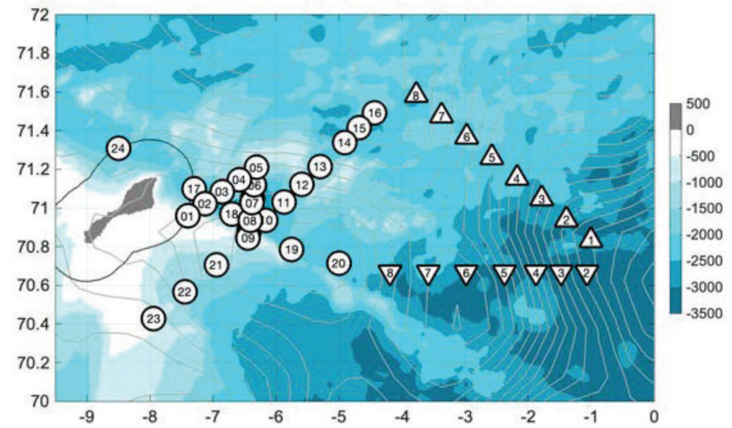


Figure 4.1: Locations of the CTD stations near Jan Mayen. JM stations are shown by circles. AF2 with by inverted triangles, and AF3 by triangles.

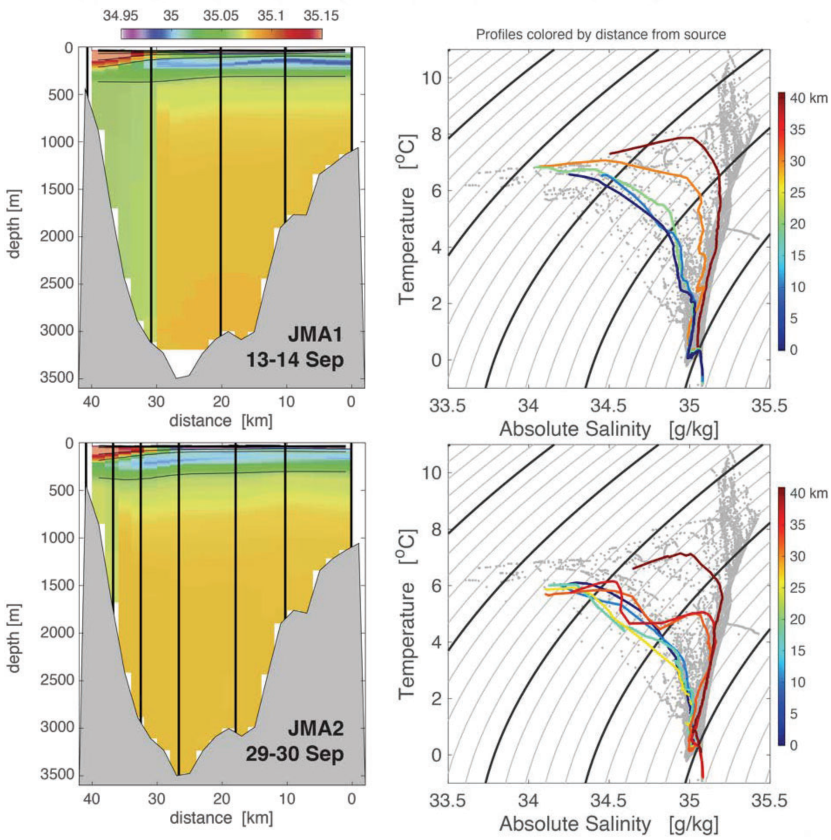


Figure 4.2: Absolute salinity as a function of depth and distance (from JM5) for the first (top) and second (bottom) occupation of Jan Mayen transect A. Temperature-salinity diagram of the stations 5-9 (top), and repeated stations 5, 6, 9 and stations 25-27 (more densely distributed) are shown on the right. Note the fresher intermediate water flowing from the Greenland Sea along the south wall of the Jan Mayen Channel at depth (colored in orange in the TS diagram). .

4.2 Jan Mayen Channel

Repeat transects of an approximately 26 km north/south line conducted across the Jan Mayen channel show changes in temperature and salinity characteristics over various time scales (Figures 4.3 and 4.4). A persistent front exists between 70.9° N and 71° N, and changes in shape on the time scales of hours to days. The surface temperatures decrease by approximately 0.5°C over the course of several days, during a large storm event in the region. Additionally, near-surface salinity increases over this time period.

The changes in temperature and salinity observed in the cross-section repetitions can be analyze using spice as a tracer. Spice allows to follow density compensated temperature and salinity changes and highlights where different water masses are present. Using only values observed in this region, spice was estimated using the temperature and salinity mean along isopycnal values (Figure 4.7). In the JMA cross sections, spice distribution shows three separate regions: the warm and salty southwest region that extends down below 180 meters, the variable surface layer that becomes fresher and colder with time, and the intermediate layer (below 50m) that maintains a constant TS value (Figure 4.8). This values of spice are relative only to this cross-section and not to the entire basin. Further analysis will be needed to understand how the flow and the surface forcing changes the TS values in the surface layer and what created the high spice mass observed in the two first cross-section that appears to move eastward.

Using deep CTD stations and Seaglider transects we can contextualize the underway CTD transects and the observed temperature and salinity structure. The cold and fresh side of the front can be traced back to the Greenland Sea on the north west side of the island, as observed in the deep CTD TS distribution (Figure 4.8), while the warm and salty side of the front comes from the Atlantic Front current that extends past Jan Mayen along the Mohn Ridge. Analysis of the shipboard velocities (Figures 4.5 and 4.6) show a steady eastward flow on the warm and salty side of the front. Near-surface meridional velocities switch directions, flowing primarily from the north when near-surface salinity is at a minimum. In the following section we identify the water masses present during the survey and the evolution of temperature and salinity values during NORSE 2021

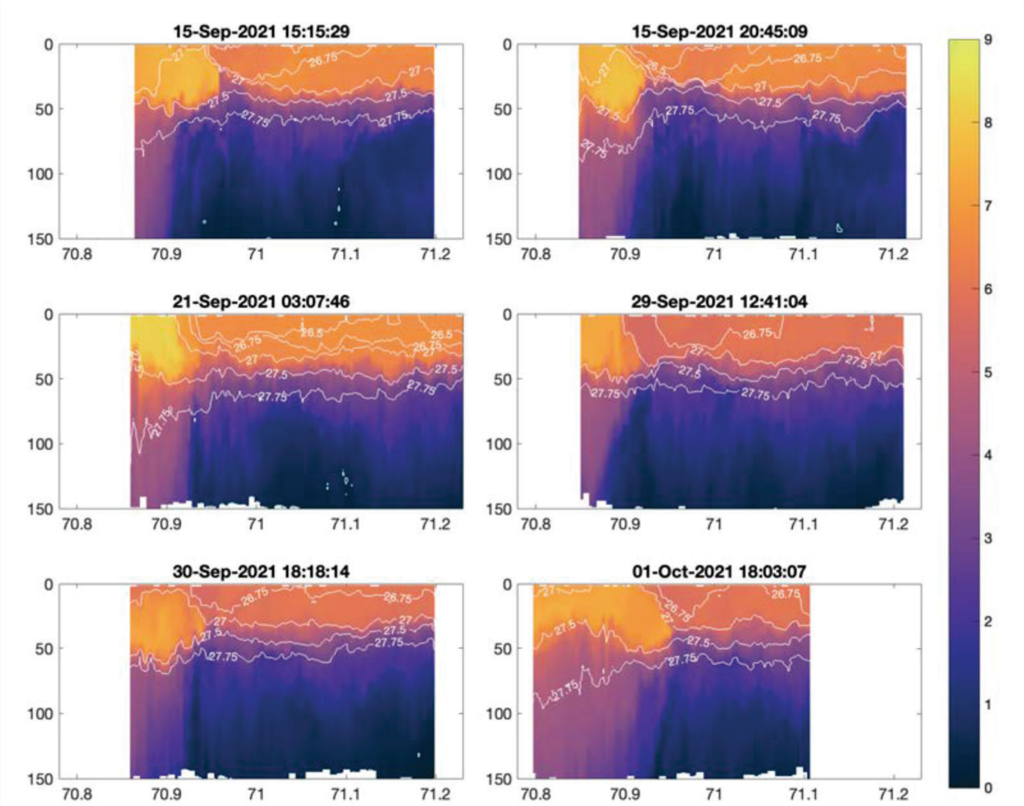


Figure 4.3. Temperature measured using the uCTD system from six transects of the JM05-JM09 line

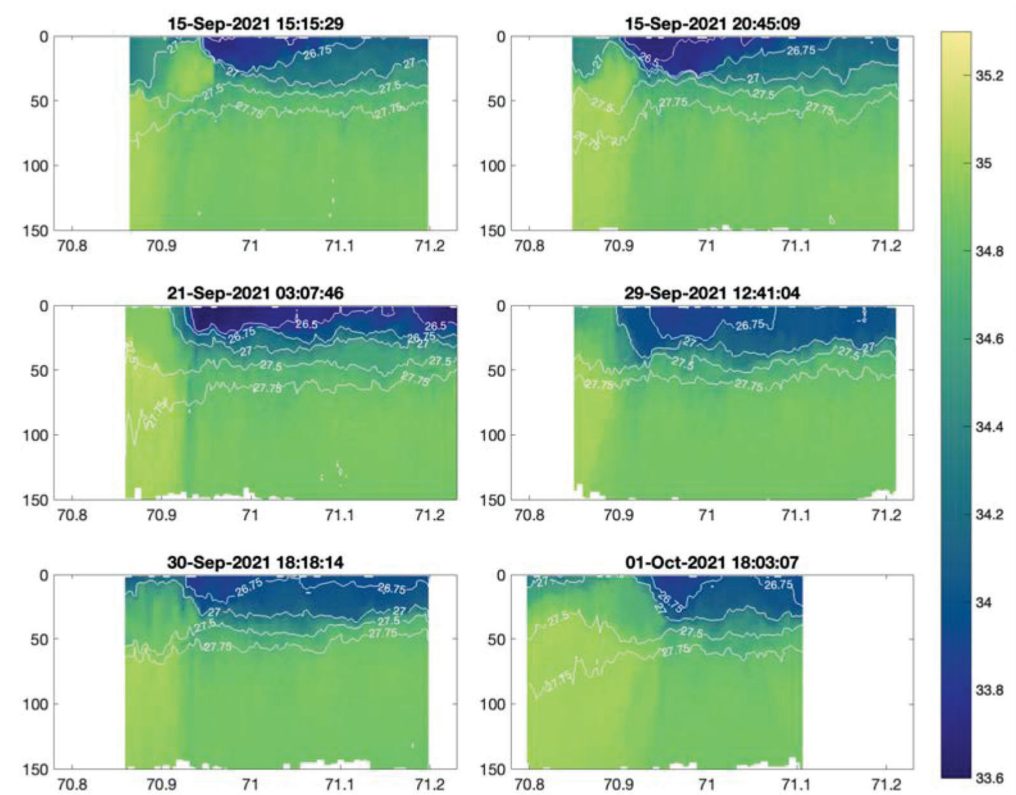


Figure 4.4: As in the above figure for salinity.

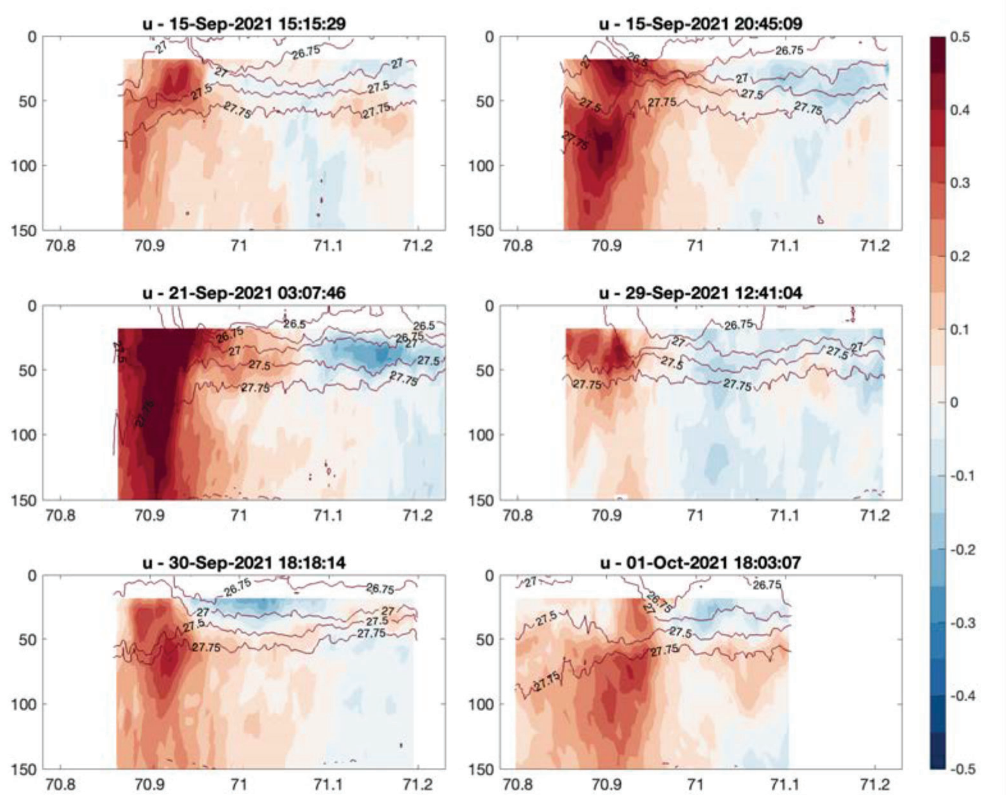


Figure 4.5: Zonal velocity for six transects of JM05-JM09 uCTD line...

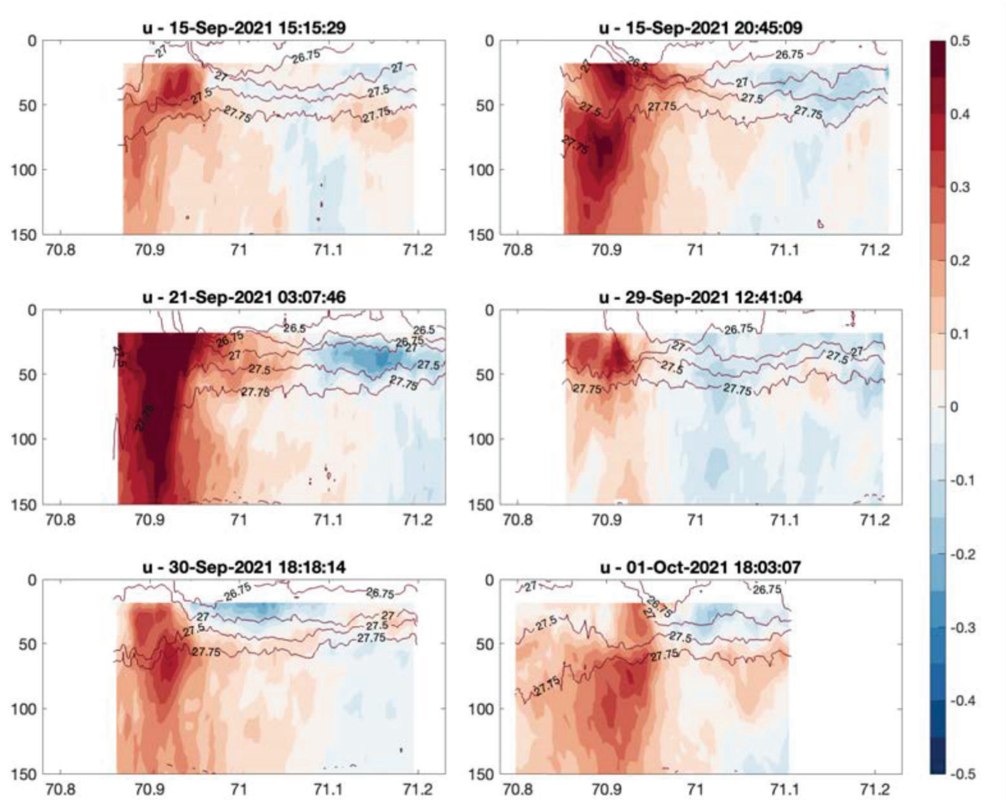

u - 15-Sep-2021 15:15:29
u - 15-Sep-2021 20:45:09
u - 21-Sep-2021 03:07:46
u - 29-Sep-2021 12:41:04
u - 30-Sep-2021 18:18:14
u - 01-Oct-2021 18:03:07

Figure 4.6: Meridional velocity for six transects of JM05-JM09 uCTD line.

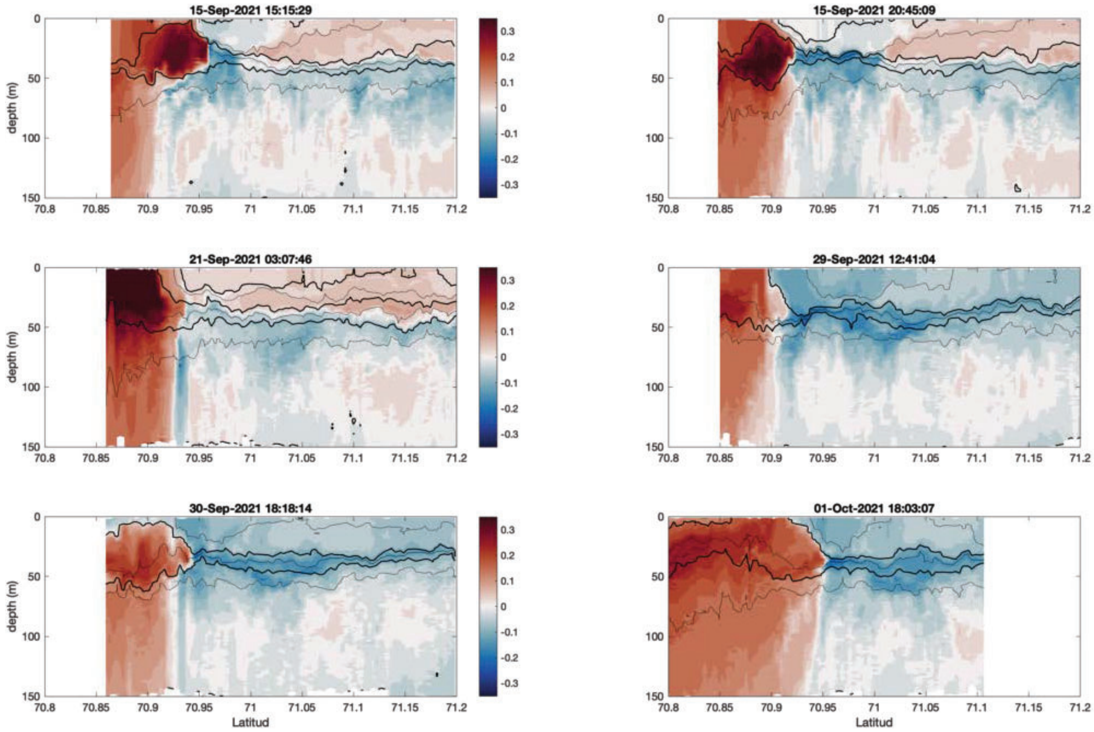


Figure 4.7: Estimated spice value for the repeated JMA cross-section. Only values sampled in this region were used to estimated the mean temperature and salinity along isopycnal values.

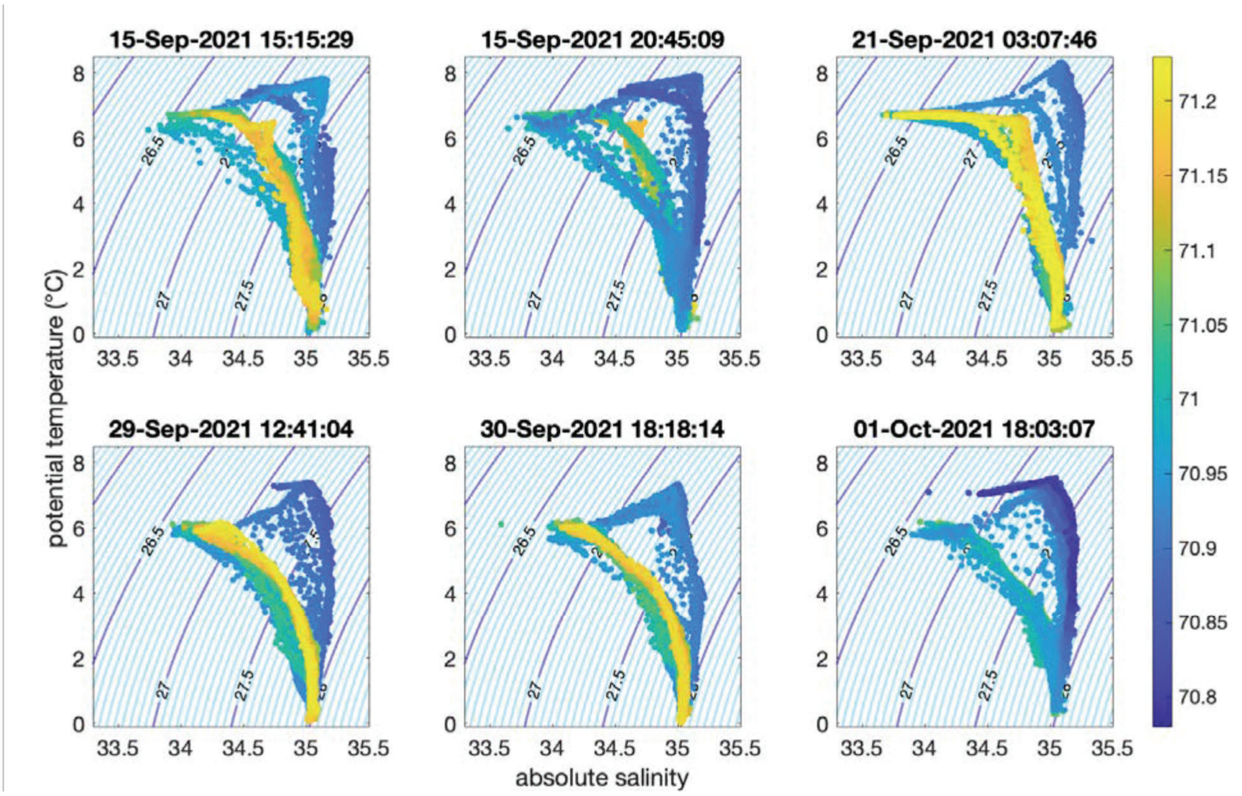


Figure 4.8: Temperature-salinity diagrams from the six underway CTD transects conducted across the Jan Mayen Channel. Color is latitude.

4.2 TS Distribution and water masses observed in the region

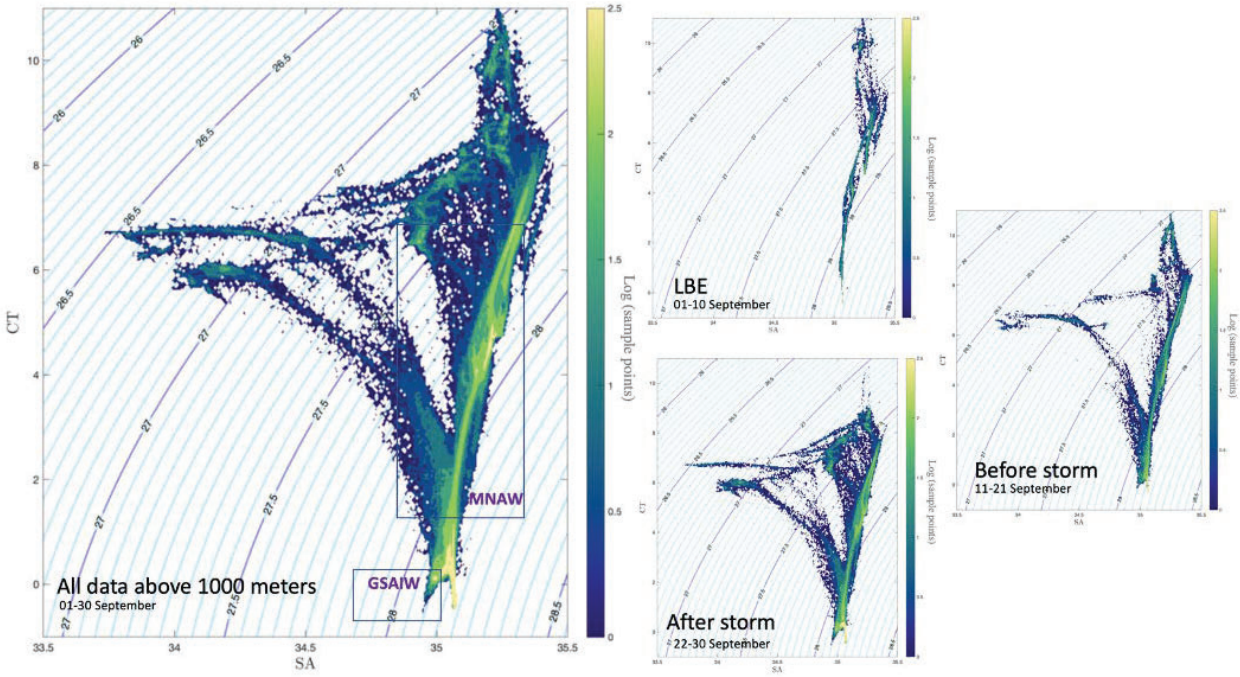


Figure 4.9 Histograms of temperature and salinity distribution above 1000 meters depth sampled by uCTD, seagliders and deep CTD cast for: (a) the entire survey time period (01-30 September), (b) measurements collected near the Lofoten Basin Eddie (LBE), (c) measurements collected between 10-09-2021 and 21-09-2021, and (d) measurements collected after 21-09-2021.

To better characterized the TS distribution and the water masses we created a TS histogram for the entire NORSE 2021 survey (Figure 4.9). Only using values above 1000 meters (gliders' diving depth), the histogram highlights the range of temperature and salinity primarily observed in the Norwegian basin (Figure 4.9a) which correspond to what Wang et. al. (2021) identified as Modified Norwegian Atlantic water (MNAW). This water mass has the maximum of both temperature and salinity (becoming the supplier of spice to the region during this time of year). We also sampled Greenland Sea Arctic Intermediate Water (GSAIW). Besides these two water masses, the TS distribution shows fresher water than the MNAW but with similar temperature. We divided the samples into three different time intervals.

- The Lofoten Basin Eddy (LBE) survey (01 Sep – 10 Sep)
- Before the storm of September 22 (11 Sep – 21 Sep)
- After the storm of September 22 (22 Sep – 30 Sep)

The changes in the TS distribution between these three time intervals show both, a difference in regional values and temporal changes. During the LBE survey we were south of the Mohn ridge. In this area we observed a small salinity range and a TS distribution concentrated in several distinctive curve lines (Figure 4.9b). While surveying the Lofoten basin, we measured across the anticyclonic LBE into a cyclonic eddy. The changes in temperature highlights the front between these two eddies (Figs 3.4a, 3.8, with the cross section of LBE survey). After September 10, we sampled along and across the Mohn Ridge and Jan Mayen ridge, which are influenced by the freshwater of the Greenland basin. It is during these surveys that GSAIW can be identified (Figure 4.9cand 4.9d). The temporal difference in TS distribution can be observed before and after the storm, where both, salinity and temperature decreased in this region. These changes were density compensated, as observed by the spice evolution of the Jan Mayen uCTD sections (Figure 4.7). The temperature-salinity diagrams specifically from the uCTD sections (Figure 4.8) show three distinct cross-density pathways from the near-surface water to the more uniform, deeper water in the first three transects, conducted prior to the storm.

4.4 Lofoten Basin Eddy

Non-divergent velocity, vorticity maps.

The background velocity and vorticity fields are estimated using all available velocity observations. The ship ADCP data is averaged vertically between 25 and 50 m in 10- min regular bins. Current speed derived from the Lagrangian drifters drogued at 15 m depth are filtered for timescales larger than two inertial periods. The resulting velocity vectors are mapped into a scalar streamfunction (surface pressure map) using objective analysis techniques. The satellite-derived Aviso geostrophic velocity are used a background for the objective map. By definition, the streamfunction produced by the objective analysis results in a non-divergent velocity field. Uncertainty estimates can be obtained by producing different maps using a Gaussian covariance function with a range of spatial and temporal scales (30-80 km; to 6 inertial period, removing some the data, and by adding reasonable random or systematic noise to the ship ADCP and drifter estimates.

The maps are particularly interesting for the Lofoten Basin Eddy (Fig. 4.10), but also works for the Jan Mayen region (with larger spatial and temporal decorrelation scales).

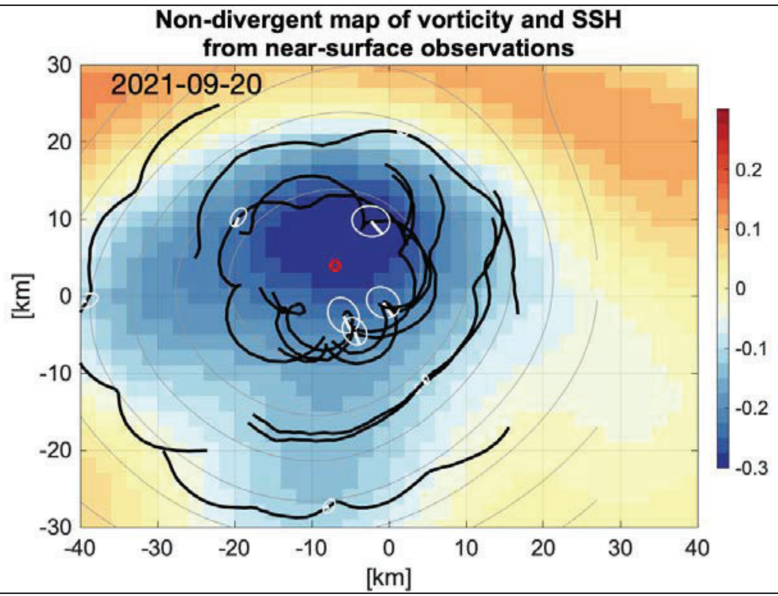


Figure 4.10: Map of the vorticity in the Lofoten Basin eddy on 20 Sept, based on drifters only (black lines). Inertial ellipses are plotted in white, and the center of the eddy is indicated in red.

30 km spatial scale, 4 inertial period time scale.

Inertial Oscillations from drifters

Given a certain time scale (here 2 inertial time scales), the amplitude and phase of the inertial signal is determined from the local inertial frequency, while its phase is identified using a constant reference inertial frequency (initial center of the eddy). Sub inertial velocity is the mean over that time scale. This is done separately to the zonal and meridional components of drifter velocity (from drifter positions), and we obtain the slowly varying sub-inertial and inertial velocity components.

Following on the work done during the NISKINe project, we plan on looking at how the background surface vorticity impacts the generation and evolution of inertial oscillations (Fig. 4.11).

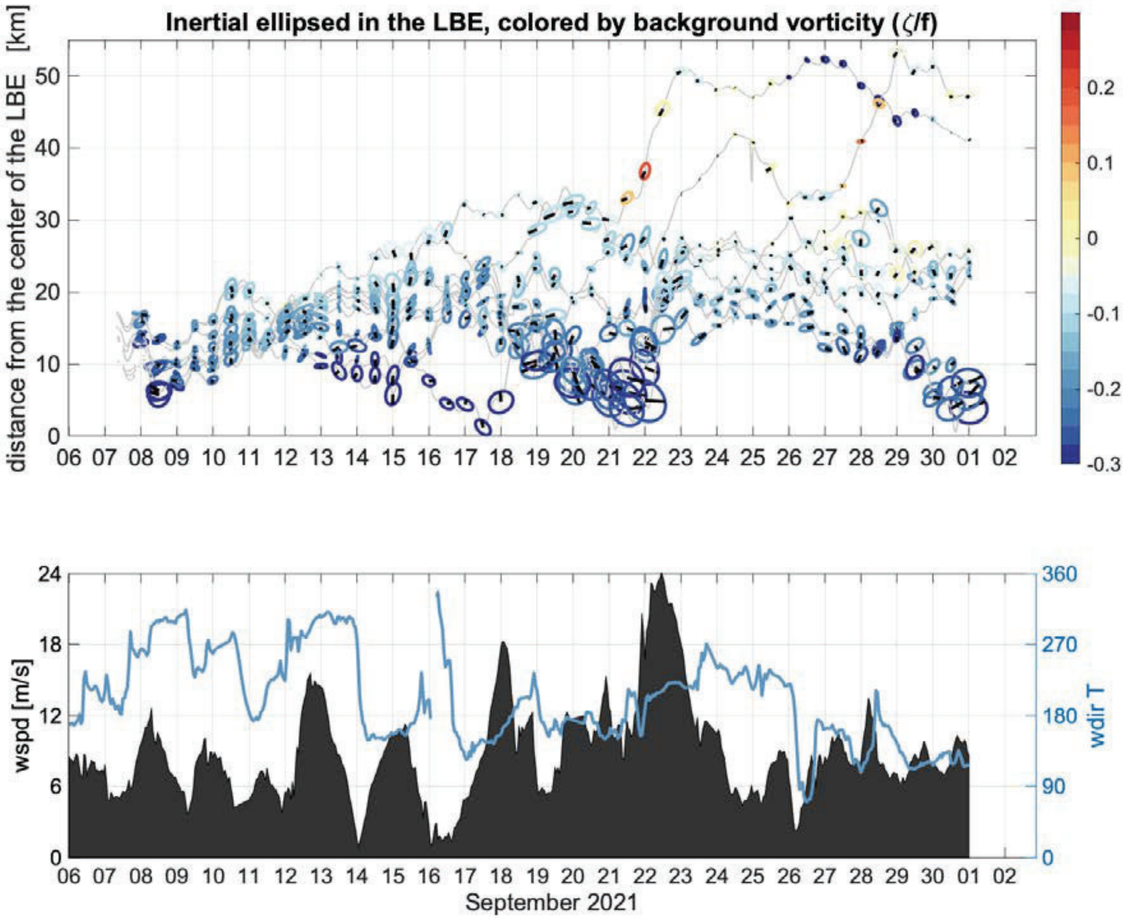


Figure 4.11: Top: Estimates of inertial oscillations, plotted as displacement ellipses in an east-north coordinate system (in km, as labeled in the vertical axis), as a function of time and distance from the eddy center, colored by background vorticity. Bottom: Wind speed (black) and direction (blue) as a function of time, at the center of the Lofoten Basin Eddy.

Science Personnel

		Primary Role	Institution	Email
1	Luc Rainville	Chief Scientist	APL-UW	lucrain@uw.edu
2	Anna Savage	PI	SIO	a4savage@ucsd.edu
3	Angel Ruiz-Angulo	PI	U. Iceland	angel@hi.is
4	Alejandra Sanchez-Rios	Bow chain, ...	SIO	asanchezrios@ucsd.edu
5	Justin Burnett	uCTD, gliders, SWIFTs, ...	APL-UW	jburnett@apl.uw.edu
6	Dave Morton ('Mort')	Acoustics	OASIS	morton@oasislex.com
7	Laur Ferris	Gliders	VIMS	lnferris@vims.edu
8	Sam Brenner	LADCP, SWIFTs, ...	APL-UW	sdbren@uw.edu
9	Laura Crews	uCTD, gliders, ...	APL-UW	lcrews@uw.edu
10	Kerstin Bergentz	Drifters, bow chain, ...	SIO	kbergent@ucsd.edu
11	Raymond Young	Wave Glider, ...	SIO	ray011@ucsd.edu
12	Allison Ho	Surface Waves, ...	SIO	aho@ucsd.edu

We acknowledge the fantastic support from Croy Carlin and Emily Cheung (SSSG), Capt. Singleton, and the entire crew of R/V Neil Armstrong.

Situational Awareness

In addition to providing Google Earth kml, simple files with the track of all instruments were generated and available both on shore and from the ship.

https://iop.apl.washington.edu/norse2021

Table A1: Bow-chain instrument list and location along the line. For deployments B-H, for deployment A solos located every 0.75 meters were not yet attached.

depth (m)	*Serial number*	*instrument*
1.2578	207048	solo
1.75	207022	solo
2.2578	207045	solo
2.75	207040	solo
3.2578	60183	concerto
3.75	207041	solo
4.2578	207057	solo
4.75	207031	solo
5.2578	207054	solo
5.75	207034	solo
6.2578	207018	solo
6.75	207061	solo
7.2578	207052	solo
7.75	207037	solo
8.2578	207050	solo
9.2578	207033	solo
10.2578	207028	solo
11.2578	60559	concerto
12.2578	207058	solo
13.2578	207023	solo
14.2578	207024	solo
15.2578	207060	solo
16.2578	207021	solo
17.2578	207027	solo
18.2578	207030	solo
19.2578	60523	concerto
20.2578	207046	solo
21.2578	207032	solo
22.2578	207036	solo
23.2578	207063	solo
24.2578	207025	solo
25.2578	207038	solo
26.2578	207020	solo
27.2578	60558	concerto
28.2578	207044	solo
29.2578	207029	solo

Table A2. List of all deep CTD stations.

Cast Number	Station name	Time	latitude	longitude	bottom depth	target depth	Comment
1	test	9/4 0830	67 59.8N	00 59.0 W	3700	200	Quick cast where SG526 was deployed.
2	LBE01	9/5 2129	69 27.8 N	03 40.6 E	3221	3200	winch problems
3	LBE02	9/6 0420	69 27.8 N	03 34.9 E	3234	3200	comms problems. Cancelled
4	LBE02	9/6 0530	69 27.8 N	03 34.9 E	3232	3210	
5	LBE03	9/6 0813	69 27.8 N	03 29.2 E	3234	3210	
6	LBE04	9/6 1112	69 27.8 N	03 23.5 E	3234	3210	
7	LBE05	9/6 1417	69 27.8 N	03 17.8 E	3235	3210	
8	LBE06	9/6 1727	69 27.8 N	03 12.1 E	3235	3210	
9	LBE07	9/6 2029	69 27.8 N	03 06.4 E	3238	3215	
10	LBE08	9/6 2355	69 27.8 N	02 57.2 E	3238	3208	
11	LBE09	9/7 0321	69 27.8 N	02 47.9 E	3240	3215	
12	LBE10	9/7 2125	69 27.8 N	02 38.7 E	3237	3210	comms problems. Cancelled
13	LBE10	9/7 2229	69 27.8 N	02 38.7 E	3237	3210	Repeat of cast 12
14	LBE11	9/8 0212	69 27.8 N	02 29.4 E	3229	3215	
15	LBE12	9/8 0500	69 27.8 N	02 20.2 E	3233	3210	
16	LBE13	9/8 0840	69 27.8 N	02 00.3 E	3230	3210	
17	LBE14	9/8 1222	69 27.8 N	01 40.3 E	3220	3200	
18	AF1_01	9/9 0930	69 20.0 N	01 00.0 W	3156	3100	Start of AF1 section, was originally named CTD15
19	AF1_02	9/9 1300	69 15.4 N	01 18.5 W	2695	2685	was originally named CTD16
20	AF1_03	9/9 1620	69 10.8 N	01 37.0 W	3119	3099	was originally named CTD17
21	AF1_04	9/9 1930	69 08.0 N	01 48.5 W	3599	3576	was originally named CTD18
22	AF1_05	9/9 2259	69 05.1 N	02 00.0 W	3547	3520	
23	AF1_06	9/10 0220	69 00.5 N	02 18.3 W	3678	3658	
24	AF1_07	9/10 0556	68 55.9 N	02 36.6 W	3426	3390	
25	Jan Mayen	9/11 1100	70 57.6 N	07 56.2 W	219	200	Jan Mayen, while sheltering (not for public dist).
26	JM23	9/13 0550	70 25.7 N	07 56.3 W	530	515	
27	JM22	9/13 0740	70 34.0 N	07 27.7 W	1502	1450	
28	JM21	9/13 1410	70 42.4 N	06 56.6 W	1266	1260	
29	JM09	9/13 1650	70 50.7 N	06 26.5 W	422	407	
30	JM08	9/13 1834	70 56.2 N	06 24.6 W	3210	3195	
31	JM07	9/13 2145	71 01.7 N	06 22.6 W	3050	3030	
32	JM06	9/14 0106	71 07.1 N	06 20.6 W	1786	1745	
33	JM05	9/14 0300	71 12.6 N	06 18.6 W	1155	1400	
34	JM04	9/14 0455	71 08.9 N	06 35.0 W	1414	1385	
35	JM03	9/14 0657	71 05.1 N	06 51.4 W	1162	1140	
36	JM02	9/14 0855	71 01.4 N	07 07.7 W	2407	2390	
37	JM01	9/14 1137	70 57.6 N	07 24.0 W	407	390	
38	JM17	9/14 1304	71 06.0 N	07 18.0 W	2342	2320	
39	JM18	9/14 1710	70 58.2 N	06 42.0 W	3730	3710	Altimeter kept jumping
40	JM19	9/14 2156	70 47.3 N	05 45.0 W	2393	2380	
41	JM20	9/15 0107	70 43.1 N	05 00.0 W	2139	2130	
42	JM11	9/15 0537	71 01.8 N	05 52.5 W	1792	1772	
43	JM10	9/16 0055	70 56.2 N	06 09.6 W	2476	2455	
44	JM12	9/16 0530	71 07.4 N	05 35.4 W	1575	1550	
45	JM13	9/17 0915	71 12.9 N	05 18.2 W	1391	1320	
46	JM13b	9/17 1450	71 17.1 N	055 03.5 W	2295	2270	Free CTD!
47	JM14	9/17 1913	71 20.4 N	04 54.6 W	2368	2343	
48	JM15	9/17 2017	71 24.9 N	04 40.8 W	2770	2760	
49	JM16	9/18 0115	71 29.6 N	04 26.0 W	1711	1690	
50	AF3_08	9/18 0431	71 35.0 N	03 46.5 W	2764	2700	
51	AF3_07	9/18 0745	71 28.6 N	03 22.3 W	1795	1720	
52	AF3_06	9/18 1030	71 22.1 N	02 58.3 W	2090	2010	Software glitch. First half of this station
52b	AF3_06	9/18 1103	71 22.1 N	02 58.3 W	2090	2014	Contains the rest of cast 52
54	AF3_05	9/18 1320	71 15.7 N	02 34.3 W	2368	2300	
55	AF3_04	9/18 1632	71 09.3 N	02 10.6 W	2284	2275	Too close to the bottom!
56	AF3_03	9/18 1923	71 02.9 N	01 46.9 W	2990	2965	
57	AF3_02	9/18 2056	70 56.4 N	01 23.4 W	3194	3180	
58	AF3_01	9/19 0225	70 50.0 N	01 00.0 W	2954	2930	
59	AF2_02	9/19 0545	70 40.0 N	01 04.2 W	3169	3150	
60	AF2_03	9/19 0845	70 40.0 N	01 28.3 W	3076	3010	
61	AF2_04	9/19 1200	70 40.0 N	01 52.5 W	3011	2996	
62	AF2_05	9/19 1535	70 40.0 N	02 22.7 W	3100	3080	
63	AF2_06	9/19 1909	70 40.0 N	02 58.9 W	2205	2180	
64	AF2_07	9/19 2200	70 40.0 N	03 35.2 W	2425	2415	
65	AF2_08	9/20 0119	70 40.0 N	04 11.4 W	3041	3020	
66	JM24	9/21 1028	71 18.9 N	08 30.3 W	2160	2140	North side of Jan Mayen
67	AF4_07	9/25 2218	71 46.5 N	00 59.6 E	2005	1950	
68	AF4_06	9/26 055	71 39.7 N	01 12.5 E	2666	2633	
69	AF4_05	9/26 0332	71 32.7 N	01 25.2 E	2689	2609	
70	AF4_01	9/26 2059	71 05.0 N	02 15.0 E	3116	3090	
71	AF4_02	9/26 2359	71 11.9 N	02 02.5 E	3140	3131	
72	AF4_03	9/27 0300	71 18.8 N	01 50.0 E	2766	2740	
73	AF4_05	9/27 0557	71 25.8 N	01 37.8 E	2981	2965	
74	AF4_09	9/27 2102	71 56.0 N	00 4.5 E	1820	1780	
75	JM_05	9/29 1545	70 12.6 N	06 18.6 W	1181	1160	Repeat of Jan Mayen transect A
76	JM_06	9/29 1730	71 07.1 N	06 20.6 W	1770	1680	
77	JM_27	9/29 1942	71 03.0 N	06 24.9 W	3128	3100	
78	JM_26	9/29 2258	70 58.3 N	06 24.6 W	3580	3550	
79	JM_25	9/30 0215	70 55.2 N	06 24.9 W	3158	3140	
80	JM_28	9/30 0502	70 52.9 N	06 25.8 W	2005	1985	
81	JM_09		70 50.7 N	06 26.5 W	422	405	