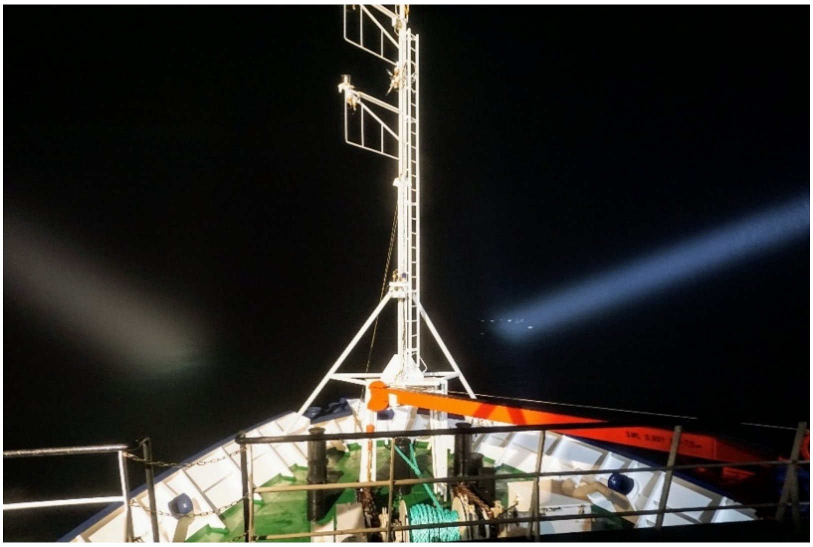
HEINCKE-Berichte

Submesoscale dynamics at the front of the Skagerrak

Cruise No. HE649

15.10.2024 – 28.10.2024
Bremerhaven – Bremerhaven (Germany)
EduObs2024



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University of Oldenburg (UOL)

2025

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1 Cruise Summary

1.1 Summary

(Jens Meyerjürgens)

The EduObs2024 cruise (HE649) aboard the RV HEINCKE took place from October 15 to 28, 2024, in the Skagerrak, a region where the North Sea, North Atlantic, and Baltic Sea meet. This convergence creates dynamic ocean fronts with sharp gradients in temperature, salinity, and density, driving essential mixing and transport processes for marine ecosystems. The cruise aimed to train University of Oldenburg Marine Environmental Science students in practical oceanographic research techniques and to investigate submesoscale processes at these fronts.

Students used advanced instruments, including surface drifters to track surface currents, a drifting sensor chain to measure vertical gradients of temperature, salinity, and density, CTD casts to gather detailed water column data, and ADCP measurements to monitor current velocities at various depths. The data revealed pronounced gradients and zones of mixing and stratification at the fronts, critical for understanding the distribution of materials such plastics. Despite variable weather, the cruise successfully achieved its educational and scientific objectives, providing students with hands-on experience in oceanographic research and advancing the understanding of submesoscale dynamics in the Skagerrak.

1.2 Zusammenfassung

(Jens Meyerjürgens)

Die EduObs2024-Expedition (HE649) an Bord der RV HEINCKE fand vom 15. bis 28. Oktober 2024 im Skagerrak statt, einer Region, in der Nordsee, Nordatlantik und Ostsee zusammenfließen. Dieses Zusammentreffen erzeugt dynamische Fronten mit ausgeprägten Temperatur-, Salzgehalts- und Dichtegradienten, die Mischungs- und Transportprozesse antreiben, die für marine Ökosysteme entscheidend sind. Ziel der Fahrt war es, Studierenden des Studiengangs Marine Umweltwissenschaften der Universität Oldenburg praktische ozeanografische Forschungserfahrungen zu vermitteln und submesoskalige Prozesse an diesen Fronten zu untersuchen.

Die Studierenden setzten verschiedene Instrumente ein, darunter Oberflächendrifter zur Verfolgung von Oberflächenströmungen, eine driftende Sensorkette zur Messung vertikaler Gradienten von Temperatur, Salzgehalt und Dichte, CTD-Sonden für detaillierte Daten der Wassersäule und ADCP-Messgeräte zur Erfassung von Strömungsgeschwindigkeiten in verschiedenen Tiefen. Die erhobenen Daten zeigten starke Gradienten sowie Zonen intensiver Vermischung und Schichtung, die für den Transport von Materialien wie Plastik entscheidend sind. Trotz wechselhafter Wetterbedingungen erreichte die Expedition erfolgreich ihre wissenschaftlichen und pädagogischen Ziele, vermittelte praktische Kenntnisse in der Ozeanografie und trug zur Erforschung submesoskaliger Dynamik im Skagerrak bei.

2 Participants

2.1 Principal Investigators

Name	Institution
Meyerjürgens, Jens, Dr.	UOL

2.2 Scientific Party

Name	Discipline	Institution
Meyerjürgens, Jens, Dr.	Oceanography, Chief Scientist	UOL
Albinus, Michelle	Oceanography	UOL
Voß, Daniela	Oceanography	UOL
Henkel, Rohan	Oceanography	UOL
Uittien, Marieke	Oceanography	UOL
Deyle, Lisa	Oceanography	UOL
Vilchez Bayer, Lea	Marine Environmental Sciences, student	UOL
Skiba, Carlsson	Marine Environmental Sciences, student	UOL
Beckmann, Heike	Marine Sensors, student	UOL
Janßen, Kai	Marine Environmental Sciences, student	UOL
Schnohr, Melanie	Marine Sensors, student	UOL
Günther, Isabel	Marine Environmental Sciences, student	UOL

2.3 Participating Institutions

UOL University of Oldenburg

3 Research Program

3.1 Description of the Work Area

(Lea Vilchez Bayer, Isabel Günther and Jens Meyerjürgens)

Three distinct water masses are present in the Skagerrak. The North Sea Water is transported via the Jutland Current (JC) and is saltier and denser than the Baltic Sea Water, which flows through the Baltic Outflow (BO) and forms the Norwegian Coastal Current (NCC). The interaction between the JC and NCC creates the Skagerrak Front (Christensen et al., 2018). At the bottom layer, Atlantic Water (AW) enters the Skagerrak through the Dooley Current (Dooley, 1974). The approximate position of the front was determined using satellite temperature images and salinity model data (Figure 3.1.1). During the HE649 cruise (15.10.23–28.10.23), the vessel frequently crossed the Skagerrak Front, allowing the Ferrybox system, an underway measurement system, to identify areas with strong gradients in salinity and temperature. The drifter deployments, marked on the map (Figure 3.1.2), were carried out in these regions. The vessel's track followed the drifters, with working stations along the route.

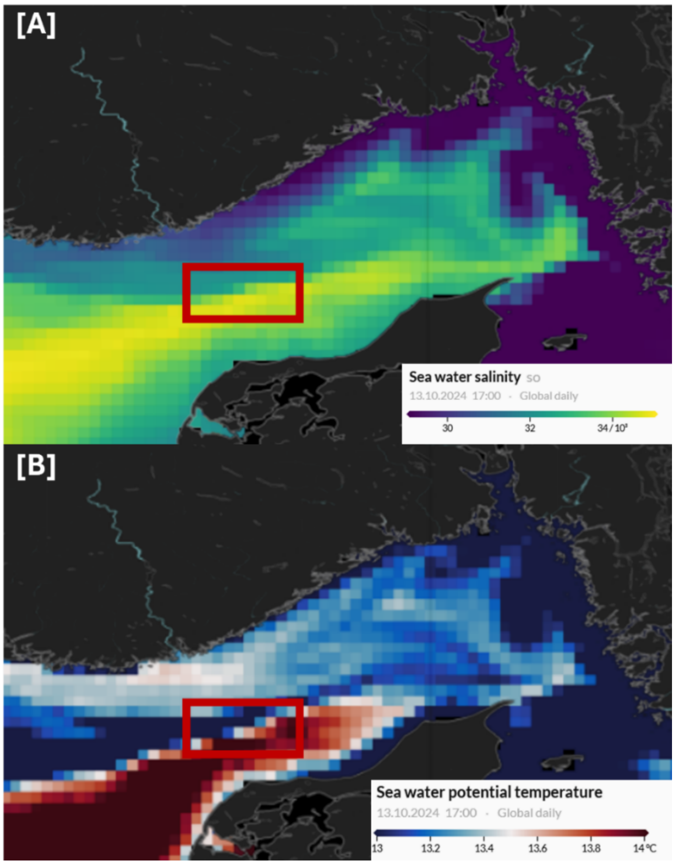

Fig. 3.1.1 Main working area with data for salinity and temperature for 13.10.24. The location of the suspected front is marked with a red square and thus the first target in the Skagerrak. (Data source: https://data.marine.copernicus.eu)

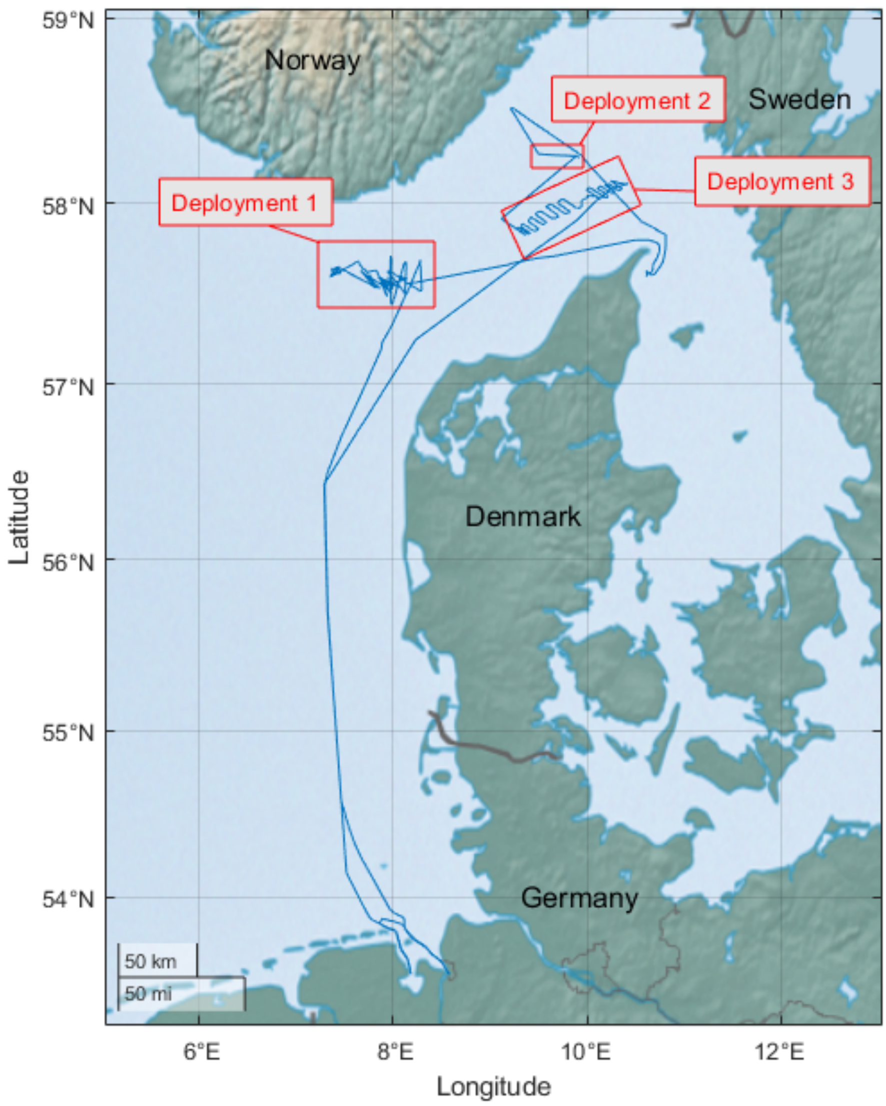

Fig. 3.1.2 Cruise track of the cruise HE649.

3.2 Aims of the Cruise

(Melanie Schnohr, Lea Vilchez Bayer and Jens Meyerjürgens)

The cruise aimed to examine physical parameters and the meso- and submesoscale currents along the Skagerrak front. The study area Skagerrak is especially interesting due to the water mass of the North Sea (cold, high density, with high salinity) and the Baltic Sea (warm, low density, brackish water with low salinity) that meet in that area since there is not much known about how exactly the submesoscale currents behave if warm less dense Baltic Water mixes with cold denser water of North Sea. Complex convergent currents are going alongside the front at this front, and several eddies are close to the front. Our primary interest was to understand the dynamics of flotsam convergence at the submesoscale and investigate the heat transport associated with the front. An additional focus was to understand which macro- and microplastic particles accumulate at this front and how the small-scale currents influence the mixing of the Norwegian Coastal Current and the Jutland Current.

3.3 Agenda of the Cruise

(Carlsson Skiba, Melanie Schnohr and Michelle Albinus)

On October 14th, 2024, the equipment was loaded onboard the RV HEINCKE, and 10 research group participants boarded the ship. The following morning, another participant joined the research group. In the late morning, we departed and headed to the Jade. On the way, we did a test station. The following day, a group of students of the Jade Hochschule joined us by boat. Two further test stations were done until the students left in the afternoon. In the evening, the Ferrybox was started, allowing the continuous measurement of biogeochemical properties, including temperature, salinity, and chlorophyll - at four-meter depth- throughout the cruise.

After that, the RV HEINCKE transit to the Skagerrak began. In the afternoon of October 17th the first CTD profile in the Skagerrak region was taken. To identify the exact location of the to-be-examined ocean fronts, RV HEINCKE drove “zigzag” overnight, measuring data with the Ferrybox. With this data, the front was located early on October 18th. Surface drifters (with and without attached CTD sensors) were deployed in a transect across the front, and BERND (a drifter with sensors in a chain attached to a rope up to 50 m depth) was deployed in the middle where the water masses meet. CTD profiles and ADCP measurements, Secchi, Profiler were used to investigate essential parameters near the front. In the following days, CTD profiles and ADCPs were taken north- and southwards the front in transects. Water samples from near the ground (up to 200 m depth), from the chlorophyll maximum (around 10-20 m depth), and from near the surface (around 2 m depth) were taken and later filtered for SPM and Chlorophyll in the laboratory on board. The measurements took place during the night and day. On Saturday during the day, drifters in the west were retrieved. During the night, the transects and CTD/ADCP measurements were continued. On the following day, October 20th, BERND and the remaining drifters in the east were retrieved. Afterward, due to strong winds and waves from the west, we stopped our measuring program, and RV HEINCKE headed to Skagen, where we stayed until the evening of 23rd October, where we headed to the Norwegian coast. The following day, the drifters with sensors and BERND were deployed again, and all were retrieved directly on the same day. On the morning of the 24th of October, they were deployed again in the middle of the Skagerrak, and during the night, we did the ADCP transects and CTD profiles again while following BERND. After collecting all the remaining drifters and finishing the last experiments, we started our journey back to Bremerhaven on October 26th, where we arrived on October 27th in the evening.

The planned research activities were conducted following the declarations on responsible marine research (Appendices 1 to 3 of the Cruise Proposal Preparation Instructions). For example, sampling occurred only in the water column and out of any protected areas so that we do not harm any conserved habitat as, for example, benthic surveys did. Scheduled ship time is the minimal time needed to realize our educational cruise to reduce resources and emissions.

4 Narrative of the Cruise

(Isabel Günther and Jens Meyerjürgens)

All scientists arrived on RV HEINCKE in Bremerhaven on 14.10.24 and received a warm welcome from the captain and the crew. During the day, the ship stayed in the harbour of Bremerhaven, so there was enough time to unpack the equipment, mount sensors, set up the laboratories, and prepare all devices.

After the first night of sleeping on board, RV HEINCKE left the harbour and started the short transit to the Jade Bight. Ferrybox and ADCP began to collect the first data on the cruise. On the way, the ship stops for a test station with CTD, ADCP, Secchi Disc, and Profiler. On the 16th of

October, the RV HEINCKE welcomed some more students and two supervisors to two stations in Jade Bay. The students enthusiastically learned about CTD, ADCP, Filtration, and Secchi Disk. After the cook had given a wonderful meal, the guests left the RV Heincke, and we started our transit in the Skagerrak.

On the 17th the ship arrived at our first station in the Skagerrak, with CTD and SHARKEY (a towed ADCP system). Throughout the night, the scientists collected data in a zigzag course with the help of the Ferrybox. In the early hours of the 18th of October, the surface drifters with and without CTD sensors were deployed at the front. The drifting sensor chain BERND was deployed at the steepest gradient of the front. Due to the weather forecast, the scientists were forced to collect the surface drifter starting at noon on the 19th of October. Owing to the early sunset, the remaining drifter and BERND were successfully collected the following day.

For two challenging days, the ship sought shelter in the Kattegat, alongside numerous other vessels. During the night of October 23rd to 24th, the ship returned to the Skagerrak, with renewed enthusiasm and determination among the scientists. On Thursday, the team successfully redeployed the surface drifter and BERND for a second time, observing their slow but steady movement toward the Swedish Economic Zone boundary, an area for which the team lacked authorization to enter. For this reason, the scientist decided to recover all instruments.

The scientists decided to move towards the middle of the Skagerrak to have more space towards the Swedish Border of the Economic Zone. On the evening of the 24^{th}, the scientists deployed everything again. Following the deployment, we continued our station work until the evening of the 25th of October. After this, the scientists started to collect every drifter again. They finished collecting around 11 pm. Then, they continued with station work till sunrise. After the sunrise, the scientists collected BERND, and the ship started its way home. While on the transit home, the scientists began to clean the laboratories and cabins, and everything was packed to be ready to leave the ship. On the evening of the 27th of October, the RV HEINCKE arrived in the harbor of Bremerhaven.

5 Preliminary Results

5.1 ADCP Measurements

(Melanie Schnohr, Heike Beckmann and Michelle Albinus)

A 150 kHz ADCP (Acoustic Doppler Current Profiler) attached to RV HEINCKE provided the water column's current data from around 12 m depth. It was measured for two different stations (F*ig. 5.1.1*).

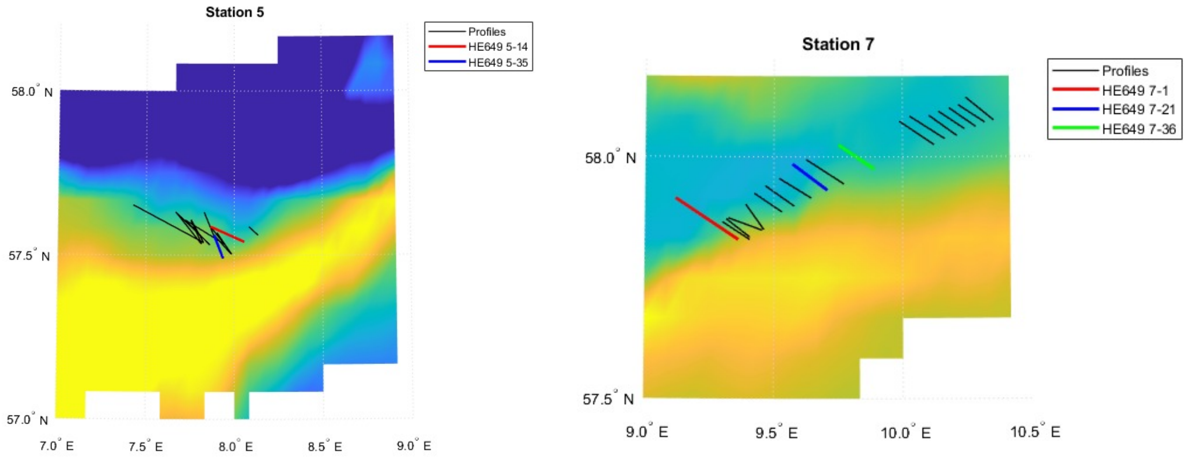

Fig. 5.1.1 ADCP profiles for station 5 (left) and station 7 (right), background: sea surface salinity numerical model (daily) of 20.10. (left) respectively 25.10. (right) using E.U. Copernicus Marine Service Information https://doi.org/10.48670/moi-00054 (left) and https://doi.org/10.48670/moi-00016 (right)

For the first deployment of the ADCP, from 18.10.2024 to 20.10.2024, two different strategies were used. First, the ADCP transects were chosen depending on the positions of clusters from the deployed drifters. Current velocity and direction data were measured while undergoing these zigzag manoeuvres across the front. This provides a detailed insight into the current velocity dynamics at the ocean front throughout the water column. Figure 5.1.2 shows the eastward velocity component (a), the northward velocity component (b), the current velocity amplitude (c), and the direction of the current velocity (d) on 18.10.2024 across the front. The current velocities reach up to approximately 0.3 m s^{-1} and show higher values in north-south direction. The magnitude is around 0.1 m s^{-1} and mostly shows a 100-200 degrees direction.

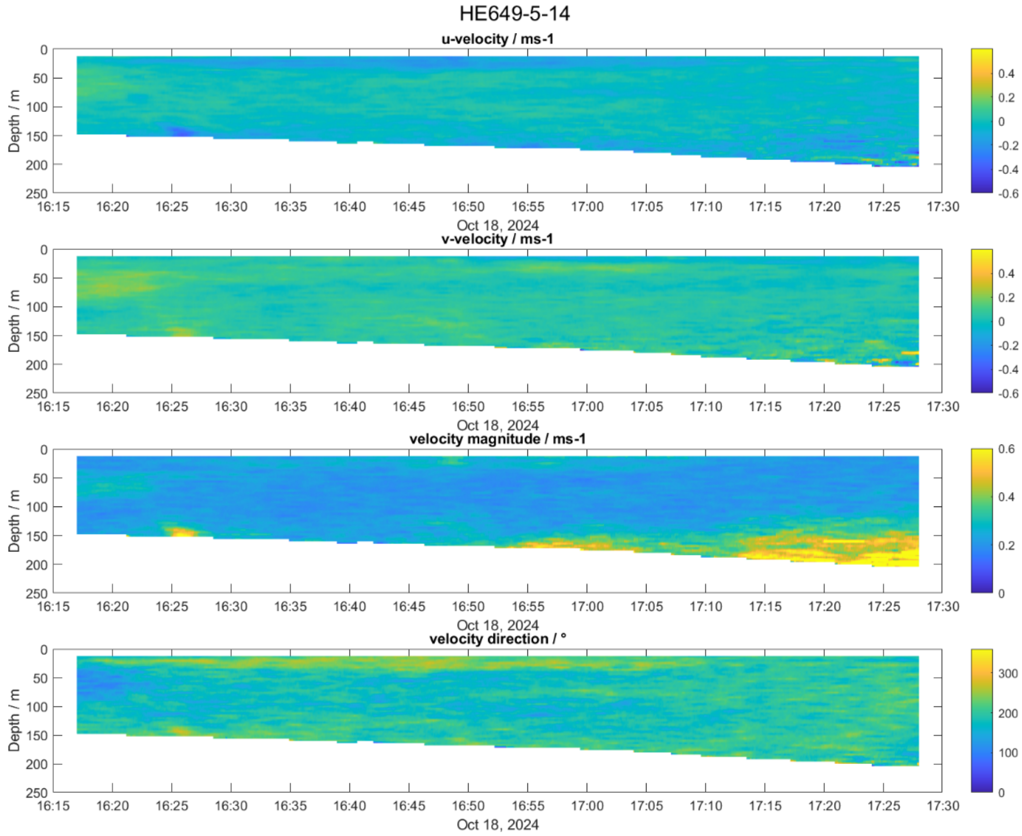

Fig. 5.1.2 Current velocity data from a 600-kHz ADCP, attached to RV HEINCKE. The eastward velocity component on 18.10.2024 measured near ocean front is shown in panel (a), the northward velocity component in panel (b), the velocity amplitude in panel (c), and the direction of the velocity in panel (d).

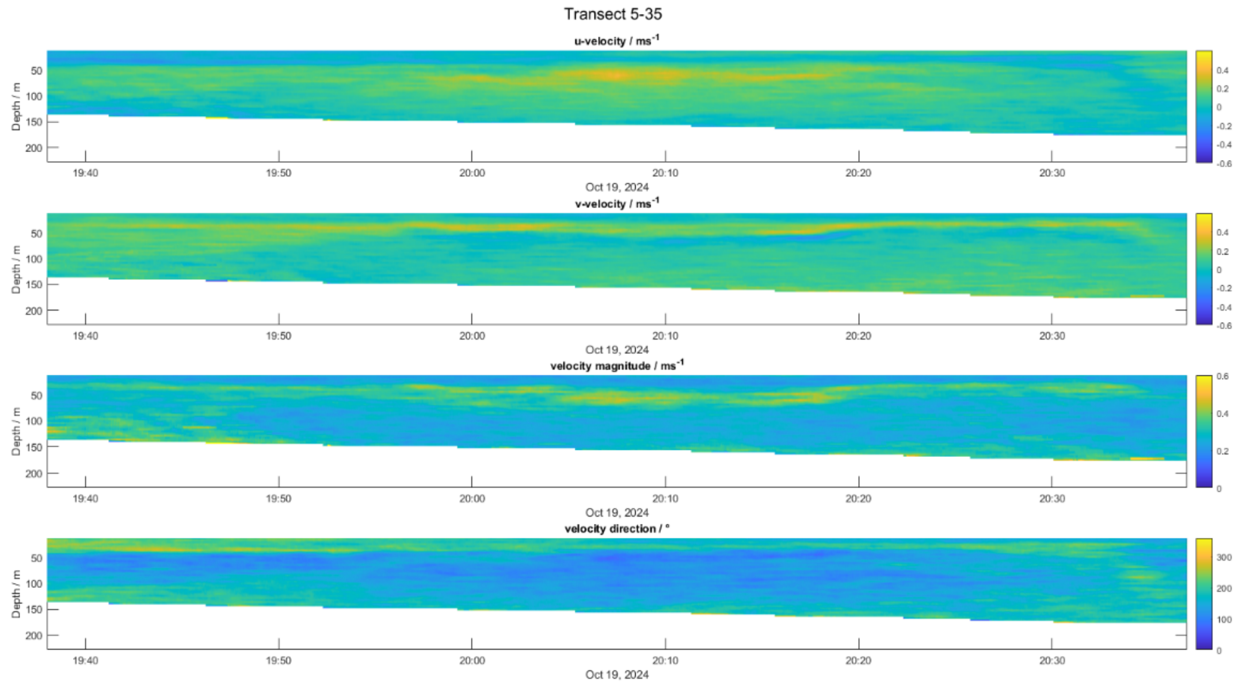

Fig. 5.1.3 Current velocity data from a 600-kHz ADCP, attached to RV HEINCKE on a section parallel to BERND. The eastward velocity component on 19.10.2024 measured near ocean front is shown in panel (a), the northward velocity component in panel (b), the velocity amplitude in panel (c), and the direction of the velocity in panel (d).

Another observation strategy was measuring velocity and direction data while navigating parallel to the drifting sensor chain BERND. This way, the data can be compared to data measured by BERND. Figure 5.1.3 shows the eastward velocity component (a), the northward velocity component (b), the current velocity amplitude (c), and the direction of the current velocity (d) from transect 5-35 on 19.10.2024 while navigating parallel to BERND. Current velocities up to 0.5 m s^{-1} and reversal of current directions can be observed with depth at different times. Comparing these results with the temperature profile measured by BERND (*Fig. 5.5.4*), it can be observed that the changes in current direction occur in ca. 30 m depth, which corresponds with the depth of the thermocline.

During the third deployment of BERND and the drifters, the ship followed them while crossing the front in a zig-zag course. Further ADCP measurements were taken on the straight lines across the front. Figure 5.1.4 shows the velocities during transect 7-1 while going south-east. The direction of the current during transect 7-1 is almost completely in the eastward direction up to 0.6 m s^{-1} with small northward components up to 0.4 m s^{-1}. The highest velocity magnitude is in the middle of the transect down to 80 m depth. At the beginning and end of the transect, the magnitude decreases to 0.3 m.

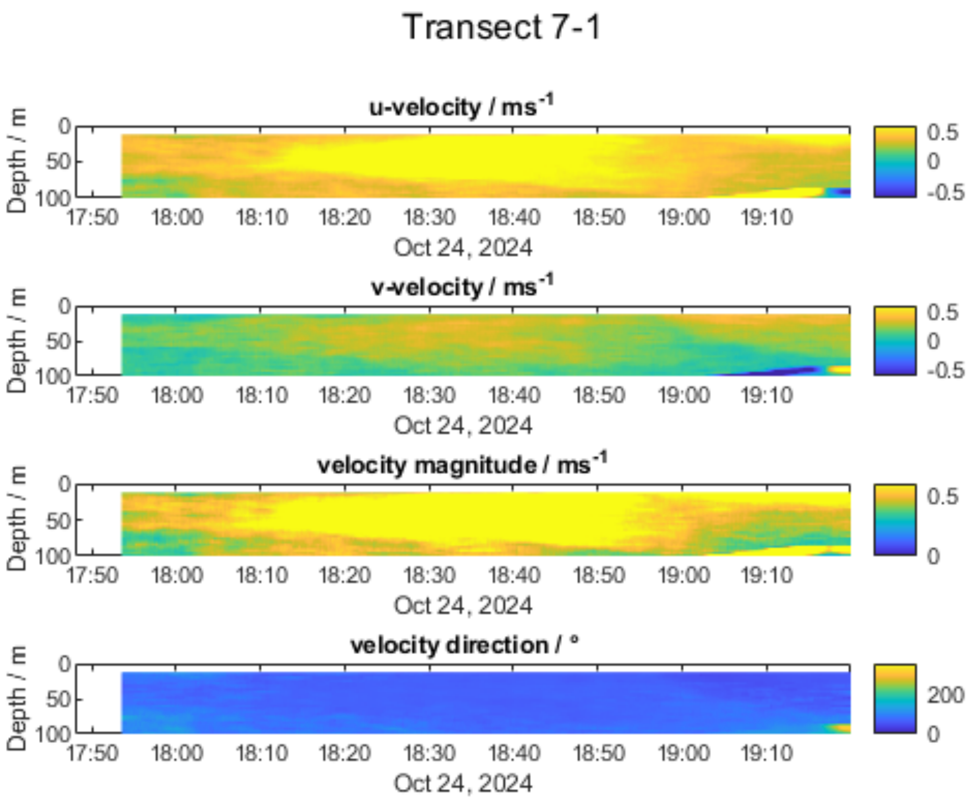

Fig. 5.1.4 Current velocity data from a 600-kHz ADCP, attached to RV HEINCKE on a section following BERND. The eastward velocity component on 24.10.2024 measured near ocean front is shown in panel (a), the northward velocity component in panel (b), the velocity amplitude in panel (c), and the direction of the velocity in panel (d).

In Figure 5.1.5, the eastward velocity component (a), the northward velocity component (b), the current velocity amplitude (c), and the direction of the current velocity (d) from transect 7-21 on 25.10.2024 while following BERND are shown. During transect 7-21, the ship was sailing northwestward. The main velocity direction in transect 7-21 is eastwards, similar to transect 7-1. The velocity magnitude has a maximum in the middle of the transect down to 80 m with up to 0.6 m s^{-1}. Also, there are areas with lower magnitudes up to 0.25 m s^{-1} at the beginning and the end of the transect, as well as in deeper water.

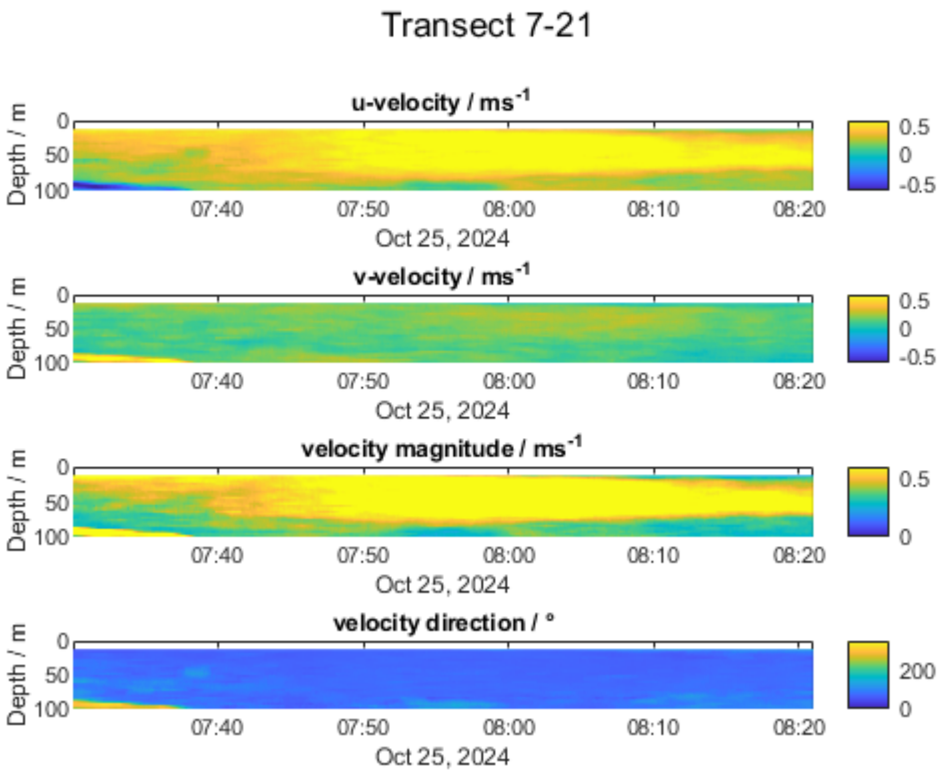

Fig. 5.1.5 Current velocity data from a 600-kHz ADCP, attached to RV HEINCKE on a section following BERND. The eastward velocity component on 25.10.2024 measured near ocean front is shown in panel (a), the northward velocity component in panel (b), the velocity amplitude in panel (c), and the direction of the velocity in panel (d).

Figure 5.1.6 shows transect 7-36 from 25.10.2024. Here, the ship was going in a southeastward direction again. The direction of the current is again mainly in the northeastern direction, with a maximum magnitude at the middle of the transect down to 80 m. Particularly at the beginning of the transect and in deeper waters (>80 m depth), the velocity magnitude is lower (~0.3 m s^{-1}).

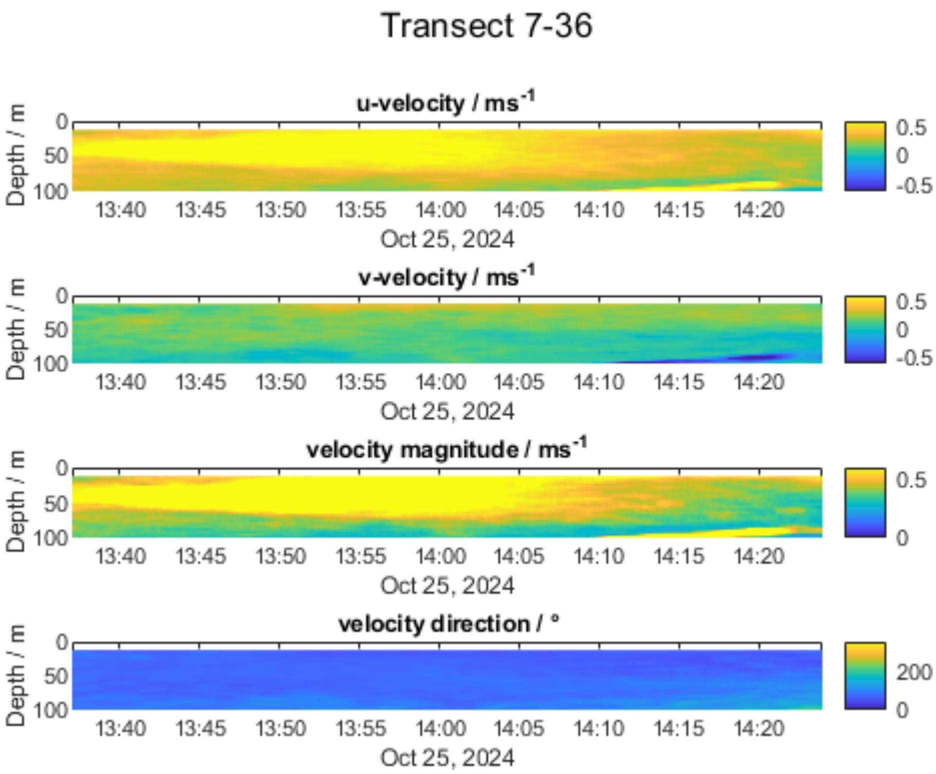

Fig. 5.1.6 Current velocity data from a 600-kHz ADCP, attached to RV HEINCKE on a section following BERND. The eastward velocity component on 25.10.2024 measured near ocean front is shown in panel (a), the northward velocity component in panel (b), the velocity amplitude in panel (c), and the direction of the velocity in panel (d).

The measurements taken during deployment 3 show a strong northeastward current in all three regarded transects. This will likely be the inflow of the North Atlantic/ Northern Sea water to the Skagerrak. As sections 7-1 were considerably longer than sections 7-21 and 7-36, the slowdown of the current could be seen on both sides of the transect. Meanwhile, in the other two sections, the weakening is more significant on the transect's southern side, suggesting that the south edge of the inflow current is present. Also, the vertical distribution of the velocity magnitude implies that the inflow is mainly reduced to the upper 80 m. However, no statement about the velocity distribution in the upper layer can be made as the ADCP starts the measurement at 12 m depth.

5.2 Towed ADCP

(Melanie Schnohr and Michelle Albinus)

Besides the ship's ADCP, the towed ADCP provides detailed insight into the current behavior at ocean fronts throughout the water column, especially the surface. Since the immersion depth of the towed ADCP is approximately 0.1 m, data can be collected from 0.3-0.4 m downwards (compared to the ship ADCP, which collects data from 4 m downwards). Furthermore, the influence of the vessel on the current measurements should be lower since it is towed next to it. The frequency of the acoustic pings amounts to 600 kHz. The towed ADCP is originally designed for fresh water. Therefore, the range of the measurements reaches up to 40 m. The bin size (resolution of the single cells) is 0.2 - 0.8 m, allowing precise measurement of the currents within these cells. Unfortunately, due to the weather conditions, the towed ADCP did not work correctly.

5.3 CTD Measurements

(Lea Vilchez Bayer and Rohan Henkel)

At the beginning of the front observation, the depth of the thermocline was determined with the CTD. The data was used to fit Bernd's chain with the sensors. During the "zigzag" course, the CTD measured the profile of the water column at each side of the front and also at night (*Fig. 5.3.1*). We took water samples at the most profound depth (4 m above the ground - if possible), the chlorophyll maximum and the surface (*Fig. 5.3.2*). The interesting part of the CTD cast were the mixed layer depth (MLD). In total, 48 CTD casts were performed.

Fig 5.3.1 CTD profile during nightwork.

Fig 5.3.2 CTD at RV HEINCKE, before profile (right) and after profile (left), water samples collected in canisters.

During the first deployment, the front's position with the surface's salinity could be recorded well (*Fig. 5.3.3* [A]). The salinity in the northern direction was significantly lower at approx. 31 psu. Towards the south/east, the salinity increased and reached values of around 34 psu.

Due to the situation during the second deployment, no CTD casts were performed. After the third deployment had taken place, a further CTD cast could be performed. Here, too, CTD profiles were run on both sides of the front. The front could not be recognized in the salinity of the surface measured with the CTD (*Fig. 5.3.3* [B]).

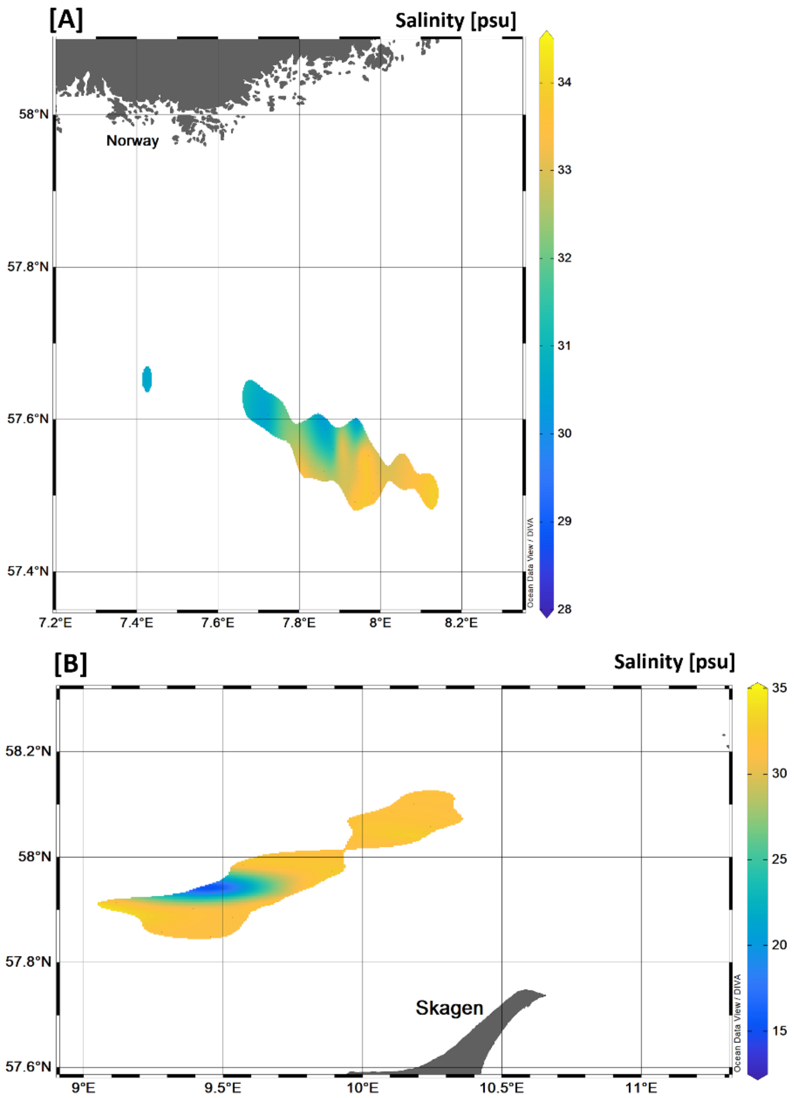

Fig: 5.3.3 The salinity of the sea surface measured with the CTD for the first [A] and third [B] deployment.

The CTD section plot shows a gradient for the first deployment (*Fig. 5.3.4* [A]) in the surface water up to approx. 5 m. This is located at a section distance of approx. 16 m. From 16 m the surface water has a salinity between 33 and 34 psu. In contrast, the salinity in the surface water between 0 and 16 m section distance has a salinity of 30.5 to 32 psu. Between a depth of 6 m and 23 m there is a layer with a salinity of approx. 34 psu. At 25 m a gradient can be recognized again. From 25 m water depth the salinity is clearly 35 psu or higher.

In the second deployment, the CTD data show a difference between the CTD stations on the Skagen side compared to the stations on the Norway side (*Fig. 5.3.4* [B], [C]). The surface water on the side towards Skagen (*Fig. 5.3.4* [B]) has a lower salinity of 31 psu compared to the salinity of the surface water towards Norway (*Fig. 5.3.4* [C]). A salinity of 31-33 psu was measured here. This increased with the section distance to 33 psu. The layer with the water with the lower salinity extends to a depth of approx. 10 m, with the layer at [C] reaching up to 15 m in places. The gradients are steeper in [B] than in [C].

When comparing the first and third deployments, it becomes clear that the gradients between the surface water and the more saline deep water are more clearly recognizable in the third deployment (*Fig. 5.3.4* [B], [C]). At the first deployment (*Fig. 5.3.4* [A]), a mixed layer was detected down to a depth of up to 25 meters. In contrast to [B] and [C], [A] shows a stronger gradient in the surface water. This is significantly higher on one side of the section than on the other, compared to [B] and [C].

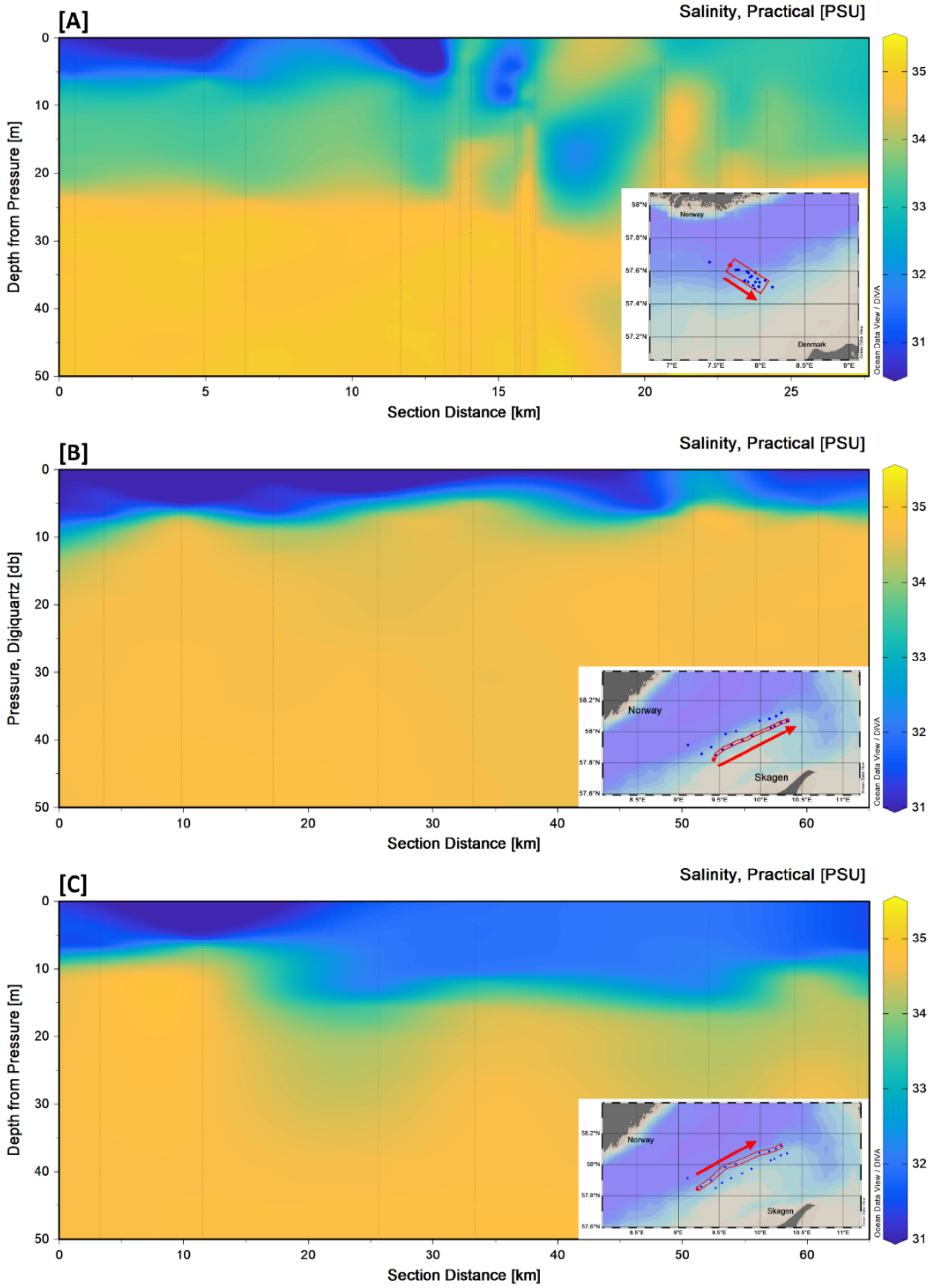

Fig. 5.3.4 Section plots of the CTD measurements for the salinity for the first [A] and third [B, C] deployment. The depth of the water column results from the pressure. The section and the direction of the section are shown in the maps.

It is assumed that the most substantial mixing between the fresher surface water and the saltier water below occurs in the more central regions of the Skagerrak, where the halocline is 10 to 20 meters below the surface (Gustafsson, 1997). This could explain the stronger mixing layer in the first deployment (*Fig. 5.3.4* [A]). This took place relatively centrally between Denmark and Norway. In the third deployment, the mixing layer is deeper on the side towards Norway (*Fig. 5.3.4* [C]) and, therefore, more central in the Skagerrak compared to the other section (*Fig. 5.3.4* [B]). This could also be related to the freshwater level described by Gustafsson (1997).

The surface layer is, therefore, thinnest in the center of the Skagerrak, with a depth of 10 - 20 meters (Gustafsson und Stigebrandt 1996). This corresponds to the recorded data.

The different water masses in the Skagerrak can be recognized in all CTD plots (*Fig. 5.3.4*). The salty deep water came from the North Sea and is a mixture of the North Sea water and the AW. The AW is mainly located in the Norwegian Trench (Dooley 1974) with a salinity of 36 psu. We could not detect 'pure' AW with our measurements because we didn't measure 36 psu, so the water that we measured at a depth of over 30 meters must be a mixture of North Sea water and AW.

The difference between the NCC and the JC can be better recognized in the first deployment. The JC has a higher salinity in the surface water than the NCC (Christensen et al. 2018). The NCC transported fresher water from the Baltic Sea by a section distance from 0-16 m (*Fig. 5.3.4.* [A]). The JC transported saltier North Sea water into Skagerrak. Between the section distance 16 - 30 m the JC could be detected in the surface water (*Fig. 5.3.4* [A]).

In the third deployment, the lower salinity over both sections suggested that the NCC had a stronger influence on the surface water in this area. One reason for this could be that strong westerly winds in the Skagerrak influenced the sea between 20 October and 24 October. This influence is also transferred to the currents with an onset (Christensen et al. 2018). Nevertheless, the JC can be surmised (*Fig. 5.3.4* [C]).

5.4 Filtration from SPM and Chlorophyll

(Lea Vilchez Bayer and Lisa Deyle)

The CTD was used to take water samples at selected locations and depths to analyze the chlorophyll-a content and SPM in the water column. The water samples were filtrated in the wet lab (*Fig. 5.4.1*). We used pre-weighed GF/F glass microfiber filters to filtrate SPM. After a certain amount of filtered water, the filter was rinsed with 100 ml MQ. The filters were frozen at -20° C. SPM was taken from the water sample from the deepest depth of the CTD (max. 200 m) and the water surface (approx. 2 m depth). Chlorophyll-a was filtered at the chlorophyll maximum (around 10-20 m depth, depending on the fluorescence graph) and from the surface water samples. These water samples were also filtered with GF/F glass microfiber filters. The chlorophyll filter was rinsed with filtered seawater. The filters were frozen at 80° C. The frozen samples will be analyzed in our laboratory in Wilhelmshaven.

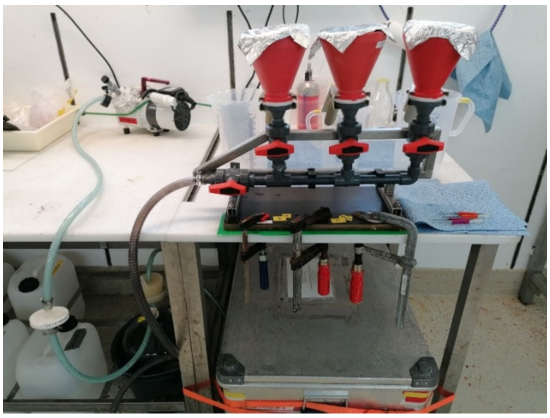

Fig. 5.4.1 Set-up of the filtration. The pump is set to approx. 400 mbar for SPM and approx. 200 bar for chlorophyll.

5.5 BERND

(Carlsson Skiba ,Kai Janßen and Lisa Deyle)

BERND is a drifting sensor chain (110 cm x 123 cm x 110 cm incl. buoys) with CTD sensors from various manufacturers (RDR (Solo, Brevio) and Sea and Sun), which were alternately attached to a 50-meter-long rope (*Fig 5.5.2*). BERND was deployed 3 times in the Skagerrak (*Fig. 5.5.1*). The drifter chain was deployed together with the other drifters. The first time it was deployed was on 18th October 2024 at 07:24 UTC in the area where, according to Ferrybox salinity data, the various water masses form a front (*Fig 5.8.2*). BERND was back on deck on 20th October at 06:55 UTC. BERND has collected many valuable CTD data (*Fig. 5.5.3 - 5.5.5*). In Figures 5.5.3 - 5.5.5 are Depth-Time-Temperature and Pressure-Time-Salinity Plots. It is noteworthy that BERND crossed the front on the morning of 19th October during the first deployment, which can be recognized by an intense vertical temperature and salinity gradient in the upper layers approximately halfway through the measurement series (*Fig 5.5.3*).

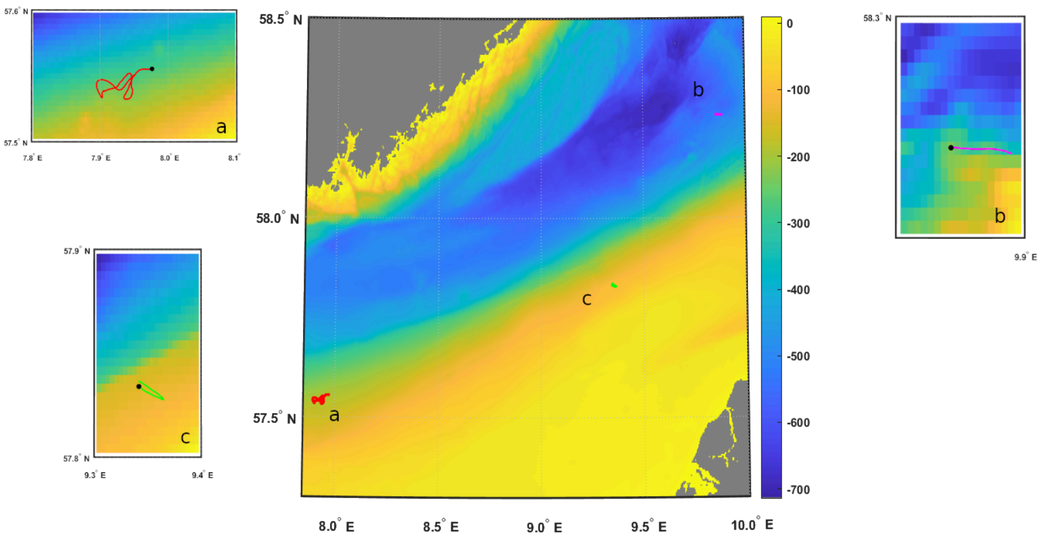

Fig. 5.5.1 Bathymetric map of the Skagerrak (Data: Gebco 2023 Grid (doi:10.5285/f98b053b-0cbc-6c23-e053-6c86abc0af7b)) with all three deployments and paths of the drifter chain. First Deployment(a) from 10/18/24 7:24 am UTC to 10/20/24 6:55 am UTC. Second Deployment (b) from 10/24/2024 09:08 am UTC to 10/24/2024 10:30 am UTC. Third Deployment (c) from 10/24/24 7:40 pm UTC to 10/25/24 6:52 pm UTC.

Fig 5.5.2 BERND before and during deployment at RV HEINCKE

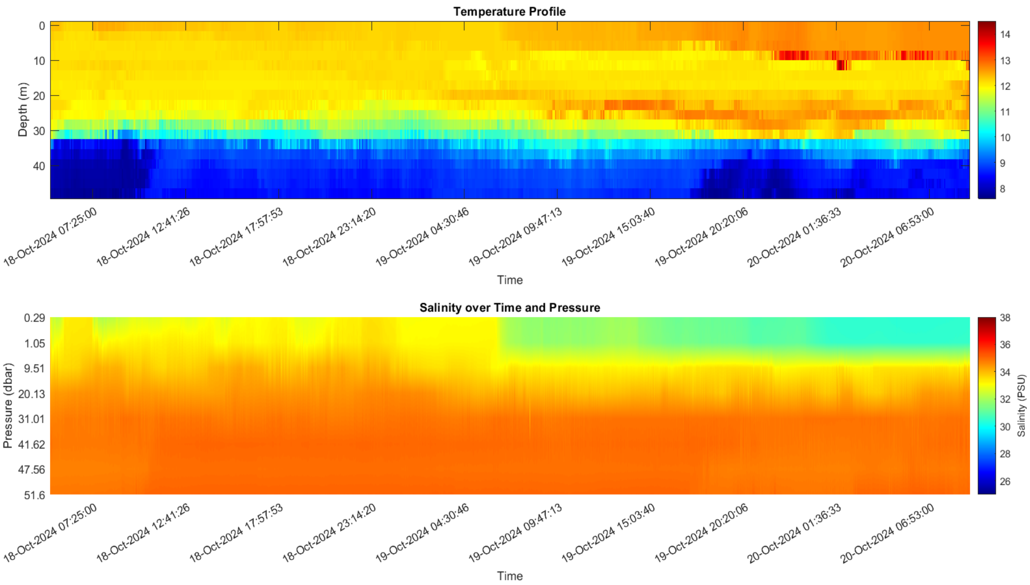

Fig. 5.5.3 Depth-Time-Temperature and Pressure-Time-Salinity Plots from BERND between 18th October and 20th October 2024

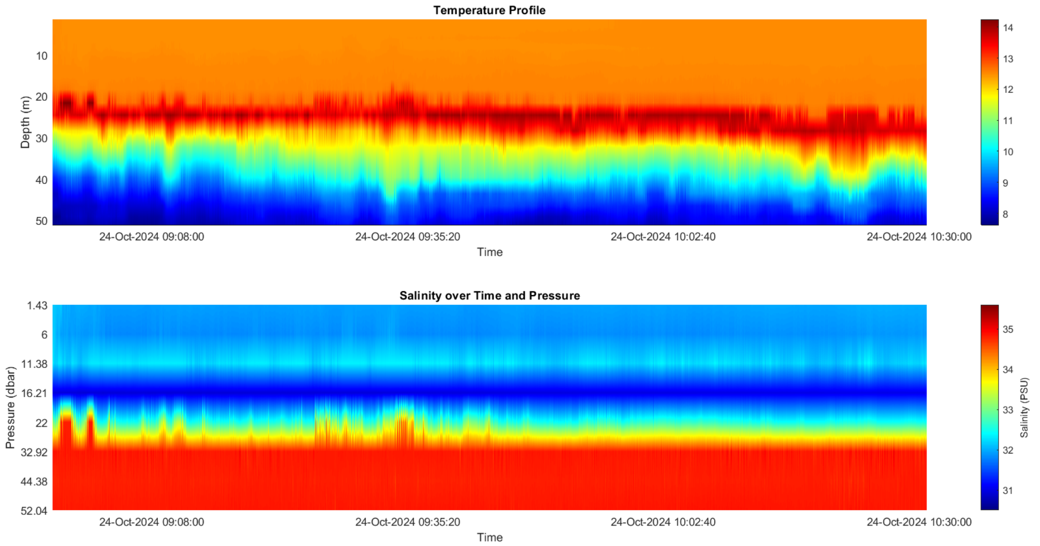

Fig. 5.5.4 Depth-Time-Temperature and Pressure-Time-Salinity Plots from BERND on 24th October 2024

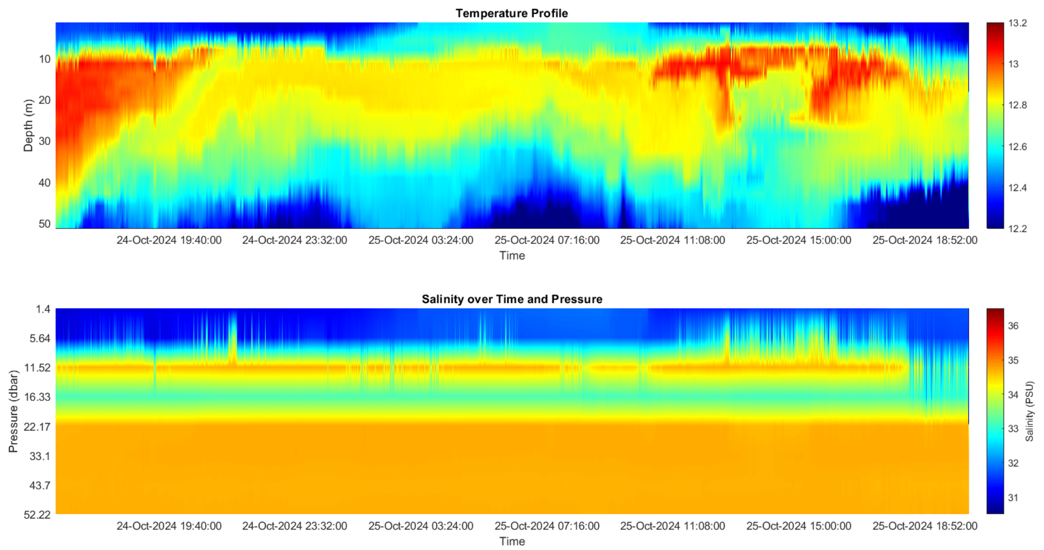

Fig. 5.5.5 Depth-Time-Temperature and Pressure-Time-Salinity Plots from BERND between 24th October and 25th October 2024

5.6 Secchi

(Lea Vilchez Bayer, Isabel Günther and Daniela Voß)

The colour of the sea was determined at selected locations using the Secchi disc in combination with the Forel-Ule-Scale. The significance of the Secchi disk is in identifying the water clarity, which reflects the amount of suspended particles like algae, sediment, or pollutants. The Forel-Ule-Scale indicates the water composition, such as dissolved organic matter, phytoplankton concentration, and sediments. The Secchi disc is lowered into the water until it is no longer visible. Then it is raised to half the depth (Secchi depth) and the value for the corresponding colour is noted with the Forel-Ule-Scale. The values from the test station and the stations in the Jade differed significantly from the values from the Skagerrak. The Secchi disc was visible for much longer in the Skagerrak and the colour of the water was also much bluer (*Fig. 5.6.1*).

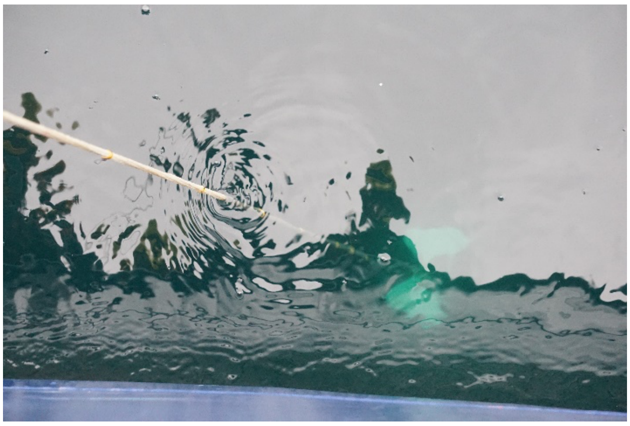

Fig. 5.6.1 Secchi disc in the Skagerrak

5.7 Profiler and Radiometer

(Melanie Schnohr and Daniela Voß)

Measurements of the light composition have been done in the air and underwater. They provide information about the distribution of the light, how much reaches the water, how much is reflected, and the availability of the organisms in the water. The ship's radiometer was used for the wavelength distribution in the air. The wavelength distribution is shown in figure 5.7.1.

Antennas are pointing in three different directions; the highest one should be unaffected by the shadow of the ship, two of them show a direction of 45°, and two others are pointing down towards the water.

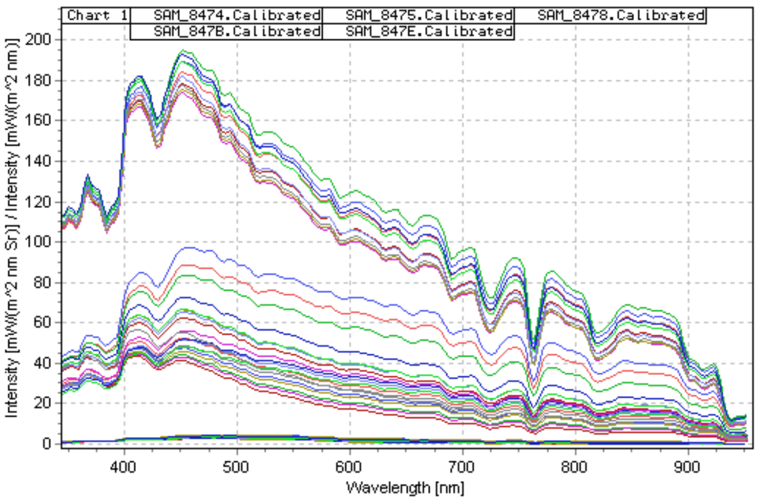

Fig 5.7.1 Measurement of the radiometer, showing the wavelength distribution over the intensity.

By using the profiler, the light was measured underwater. It decreases with depth and is available up to roughly 60 m (*Fig. 5.7.2*).

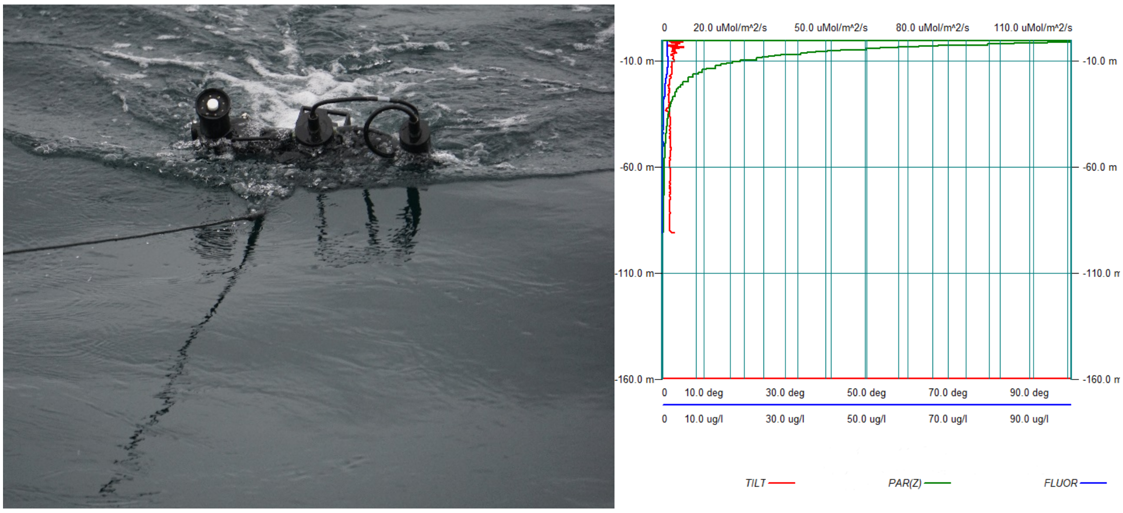

Fig 5.7.2 Profiler after measurement (left) and the measured Photosynthetically Active Radiation (PAR) over depth (right).

5.8 Ferrybox

(Lea Vilchez Bayer, Marieke Uttien and Michelle Albinus)

The Ferrybox was the ideal device for detecting ocean fronts. The Ferrybox was used to continuously measure physical, chemical, and biological parameters on board RV HEINCKE (*Fig. 5.8.1*). The Ferrybox was activated by leaving Jade Bay to prevent system pollution and deactivated on 26.10.2024 after our last experiment. The salinity, temperature and chlorophyll content were measured continuously to detect sharp gradients. Salinity was the main parameter for detecting the front. The temperature was only of secondary importance, as the gradients were not so clearly recognizable there. The North Sea water is characterized by a higher salinity and a lower temperature (*Fig. 5.8.2*). Due to the ship's structure and the Ferrybox installation, it can measure the surface water at a depth of 4 meters.

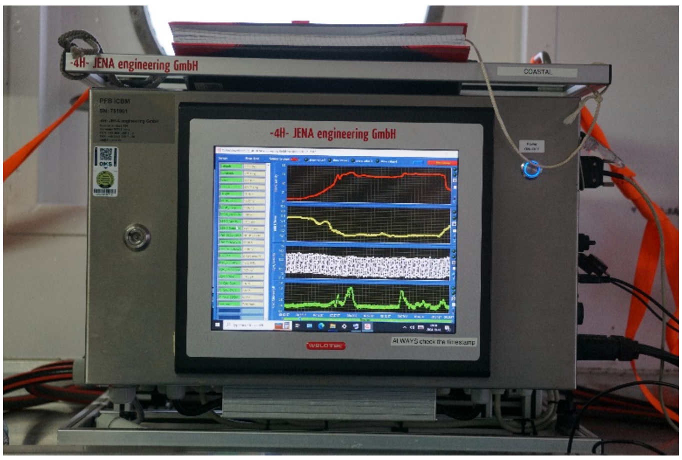

Fig 5.8.1 Ferrybox system

The data from the Ferrybox showed that the front could be visualized by measuring the salinity at the surface. In the first deployment, salinity values of 30 psu were measured in the direction of Norway. Values of up to 34 psu were measured in the direction of Danmark (*Fig. 5.8.2* [A]). The gradient was relatively steep, and the front was visible in color. In contrast, the temperature differences were not so apparent (*Fig. 5.8.2* [B]).

The gradient in salinity was also recognizable in the second deployment. Higher salinities were recorded towards the center of the Skagerrak (*Fig. 5.8.2* [C]). Values of 32.5 psu were measured here. Lower salinities of 29.5 psu were measured towards the Norwegian coast. In the second deployment, the differences were not as clear as in the first deployment. The temperature data also did not show such a clear picture (*Fig. 5.8.2* [D]).

The third deployment showed a lower gradient in salinity, but the position of the front could still be recognized (*Fig. 5.8.2* [E]). Values of around 30.6 psu were measured in the direction of the North Sea and 31.4 psu in the direction of Sweden. The difference was minimal. No pronounced gradient could be recognized in the temperature (*Fig. 5.8.2* [F]).

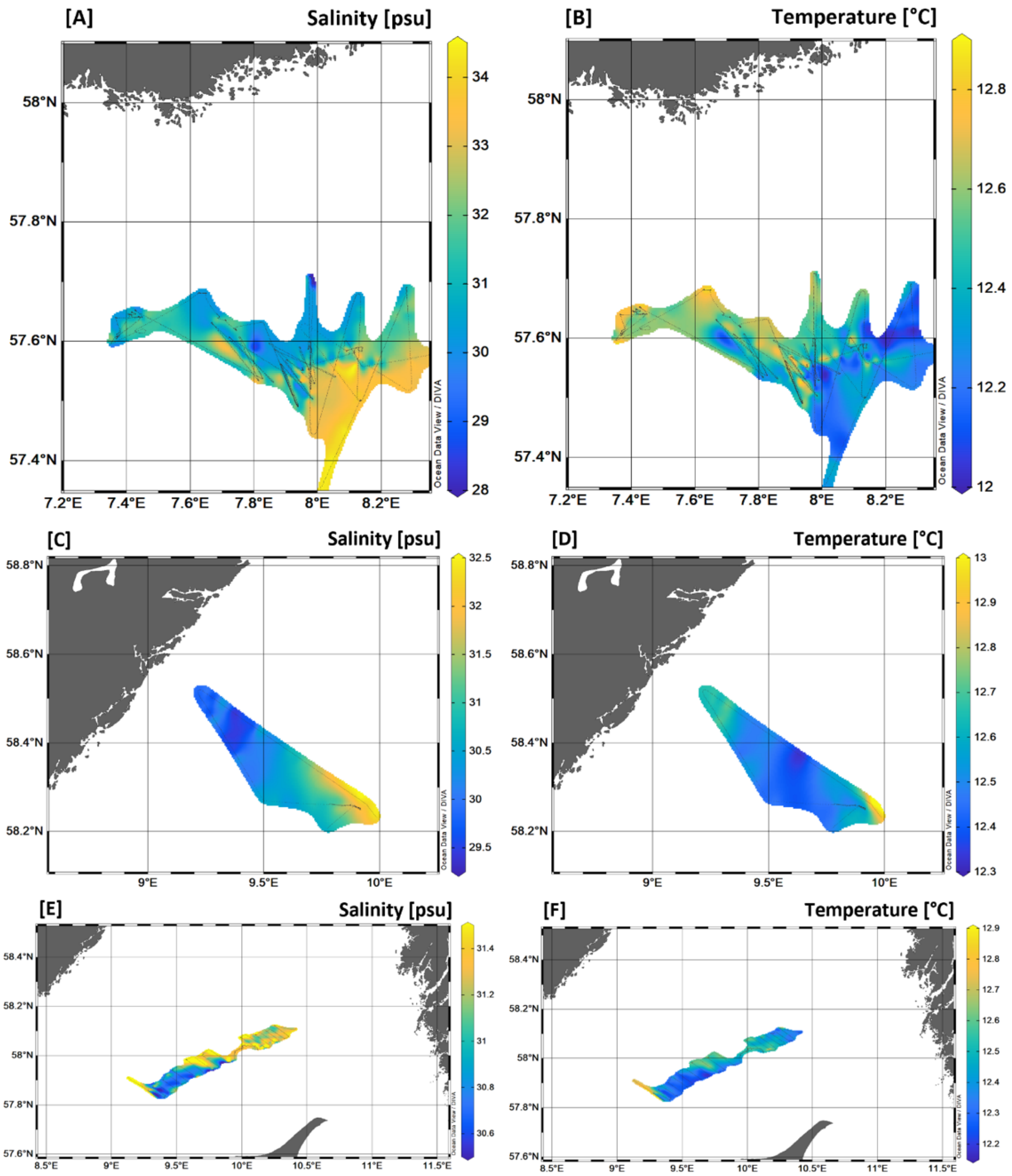

Fig. 5.8.2 Recording of the Ferrybox for salinity (left) and temperature (right) for the first (A, B) second (C, D) and third (E, F) deployment.

The Ferrybox could detect water masses of the NCC and the JC. The position of the front and the different water masses that form it can be recognized, especially in the first deployment (Fig. 5.8.2 [A]). The NCC has a lower salinity of approx. 30 psu and transports the Baltic Sea water (Christensen et al. 2018). In contrast, the JC has a higher salinity of approx. 34 psu and transports North Sea water (Christensen et al. 2018).

The second deployment should take place entirely in the NCC. Salinity values can recognize this (Fig. 5.8.2 [C]). The salinity is relatively low compared to the Norwegian coast. Accordingly, the drifters were deployed when the gradient was visible on the Ferrybox screen (Fig. 5.8.1). It was assumed that the drifters were being transported towards the North Sea by the NCC. Contrary to the assumption and the data from the Ferrybox, the drifters drifted towards Sweden. The westerly wind could have disrupted the currents in the Skagerrak. It has been proven that the wind can strongly influence the currents in the Skagerrak (Christensen et al. 2018).

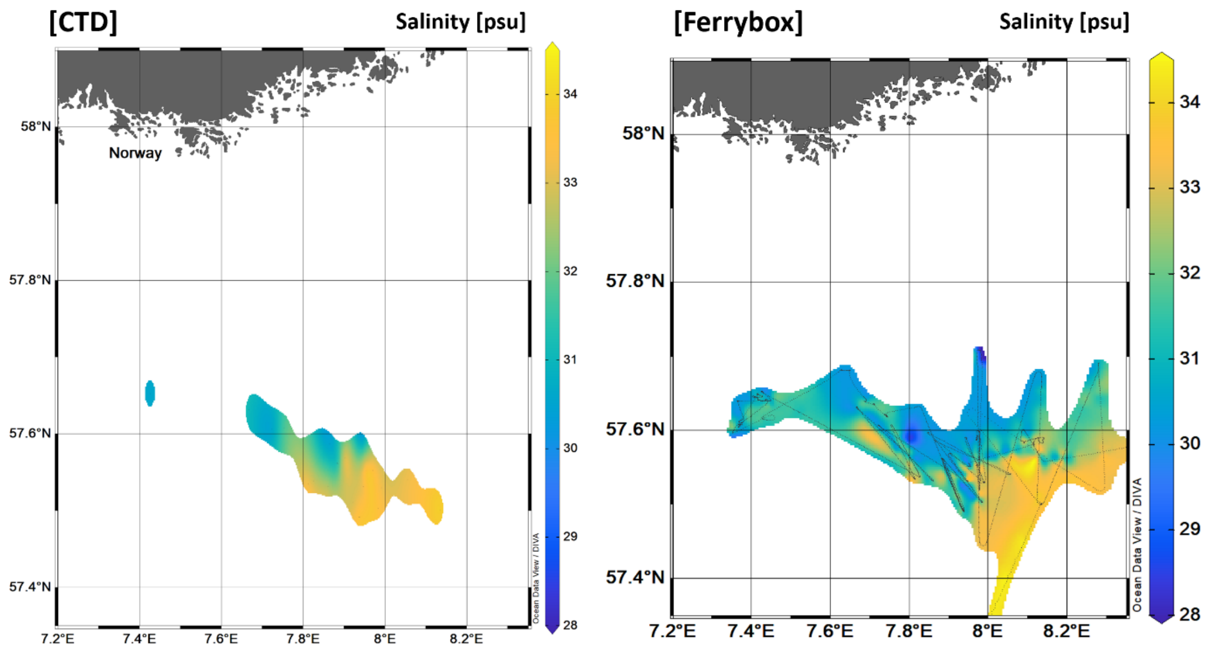

Fig. 5.8.3 Comparison between the data from the Ferrybox and the surface measurements from the CTD

The CTD measurements of salinity at the surface and the Ferrybox measurements support each other in their results (*Fig. 5.8.3*). As the Ferrybox has continuously recorded data, its data set is more significant and covers a larger spatial area. Accordingly, the data from the Ferrybox should be used as the basis for analyzing the drifter trajectories.

5.9 Surface Drifter Measurements

(Carlsson Skiba, Marieke Uttien and Lisa Deyle)

The drifter experiments aimed to follow the surface currents, and ocean fronts were particularly interesting here. Submesoscale dynamics (in particular at ocean fronts fronts) play a crucial role in oceanic energy transfer, stratification and interaction with larger and smaller scales, making them a key factor in understanding global ocean circulation and climate change (Taylor et al. 2023). The drifters (*Fig. 5.9.1*) are designed to be advected primarily by the ocean currents; the position can be determined, and the track can be tracked using a GPS transmitter.

Based on the description of the work area (see section 3.1), it was assumed that along salinity gradients, the salty water likely flows westward via the Jutland Current (JC), and the less salty brackish water likely flows eastward within the Norwegian Coastal Current (NCC) - together forming the Skagerrak front (Christensen et al. 2018).

Deployment 1:

In a transect across the ocean front, 28 drifters were set out from RV HEINCKE on 18th October. They were alternately deployed from port and starboard while sailing from north to south towards the front; some selected drifters with attached plastic traps (6 in total) were deployed in regular intervals from the stern of RV HEINCKE (*Fig. 5.9.2*). When setting out these drifters with plastic traps, a blank trap was opened during the settlement of the first, third and sixth drifter with plastic traps for the duration it was set overboard. Fourteen drifters had additional sensors (5 with temperature sensors and 9 with CTDs). Future analyses of the sensors attached to the drifters should provide further information on the small-scale and mesoscale processes along the front. All the drifters had GPS transmitters that sent their positions scheduled every two to five minutes.

The drifters were collected after a few days of drifting on 19th and 20th October. Some were found in regions with lots of flotsam (*Fig. 5.9.3*) or together, although they were released individually at a certain distance (*Fig. 5.9.4*) - presumably in convergence zones along the front.

Fig 5.9.1 Drifters at RV HEINCKE before deployment.

Fig. 5.9.2 Drifter with plastic trap during the deployment

Fig 5.9.3 Drifter with plastic trap was found in zone with lots of flotsam

Fig 5.9.4 Three drifters were found together, presumably in a convergence zone

A first look at the results/tracks (*Fig. 5.9.5* [A]) shows that drifters deployed in less salty waters in the north drifted westwards. In contrast, drifters deployed in saltier waters in the south drifted predominantly eastwards. It can also be seen that the drifters drifting westwards probably moved along the front (see Sea Surface Salinity Model for 20th October). In the case of the drifters drifting mainly eastwards, it can be seen that some may have circled in eddies. The drifters drifting westwards were probably transported by the Baltic Outflow, which forms the NCC. The other drifters were probably driven westwards by the JC.

A deeper look compared with the Ferrybox's data (*Fig. 5.9.5* [B]) shows that the gradient was even higher than the model calculated. Moreover, they seem to confirm the model and the conclusions. In addition, the Ferrybox indicates that there were bodies with saltier water around which some drifters were drifting.

[A] [B]

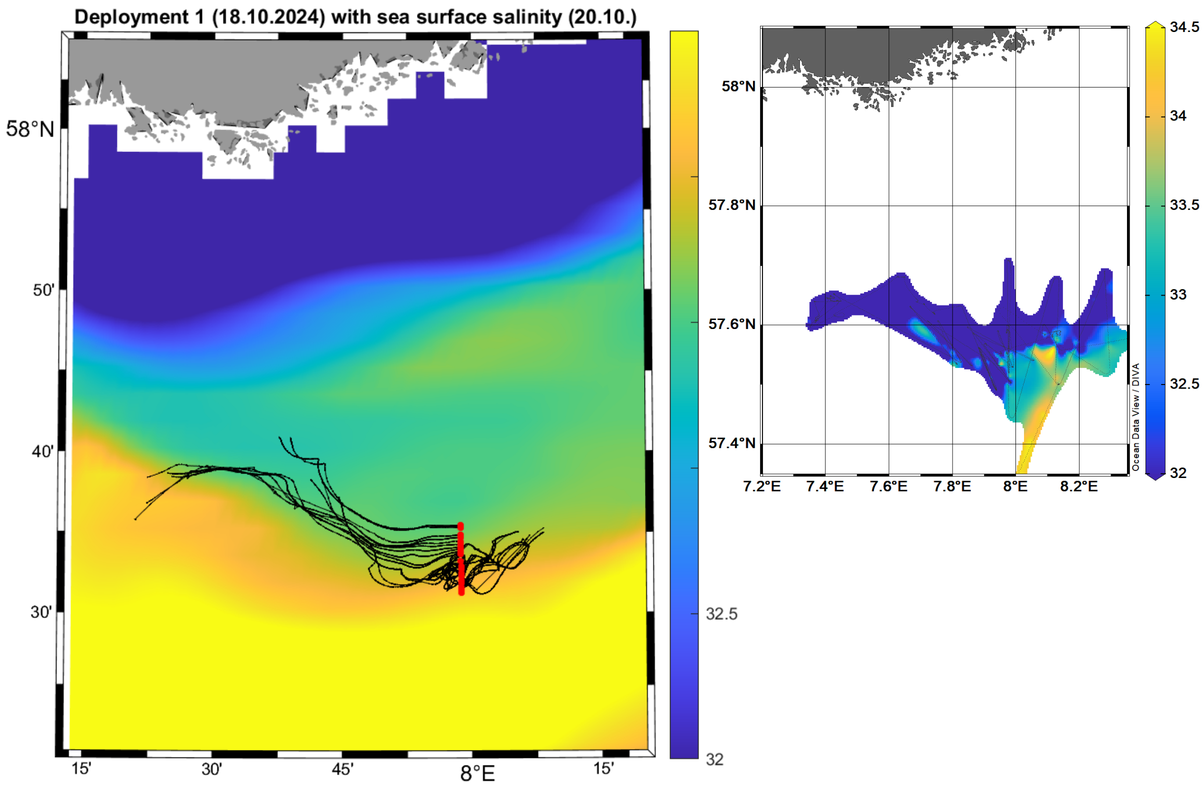

Fig 5.9.5 [A] Drifter Deployment 1 (red dots, date of deployment: 18.10.2024) with tracks (black lines, date of collecting 19. and 20.10.), background: sea surface salinity numerical model (daily) of 20.10. (last day of collecting) using E.U. Copernicus Marine Service Information https://doi.org/10.48670/moi-00054 [B] Sea Surface Salinity Data from the Ferrybox (see 5.8) in the same scale for salinity as the numerical model

Deployment 2:

The second deployment took place on October 24th, after a few days of strong westerly winds. In total, 13 drifters with attached CTD sensors were deployed alternately from port and starboard. This time, with shorter intervals than the first deployment, put all of them in the detected less salty water of the assumed NCC – with the expectation the drifters would all drift westwards. Instead, all of them started to drift eastwards (*Fig. 5.9.6* [A]) right in the direction of the Swedish Exclusive Economic Zone (for which we had no operating authorization), so we already collected them after a few hours of drifting.

Probably due to the wind event before, the currents were different than expected. Presumably, the strong winds have mainly reduced the Baltic Sea outflow and shifted the Norwegian coastal current further to the north (at least as far as can be deduced from the observed area). Flow changes in the NCC occur after sustained winds, with the most substantial changes occurring after seven days (response time) and earlier (Christensen et al. 2018). Such a change could be observed in our experiment.

The sea surface salinity model shows relatively high salinity values around 34 psu for the day of the second deployment (*Fig. 5.9.6* [A]), as would be expected from the JC – consistent with the observed trajectories, but not with the expectation of the deployment. Incidentally, the model for sea surface salinity shows much lower salinity values of around 33.5 psu for the same region one day later. This indicates that based on the model, the typical salinity and the currents would probably re-establish themselves in the following days.

However, it also shows that BERND's surface salinity data (see 5.5) and Ferrybox's data (see 5.8 and *Fig. 5.9.6* [B]) do not match those of the model. Our measurements show significantly lower salinity values (around 32 psu) than the model (which is precisely why we expected the NCC to move west at this point).

The model data can, therefore, only provide an initial explanation for the observed drift and surface currents. Still, a closer look does not yet provide a satisfying explanation for the drifter's eastwards drift, which may be caused by the limitation in accurately resolving submesoscale processes in the model.

[A] [B]

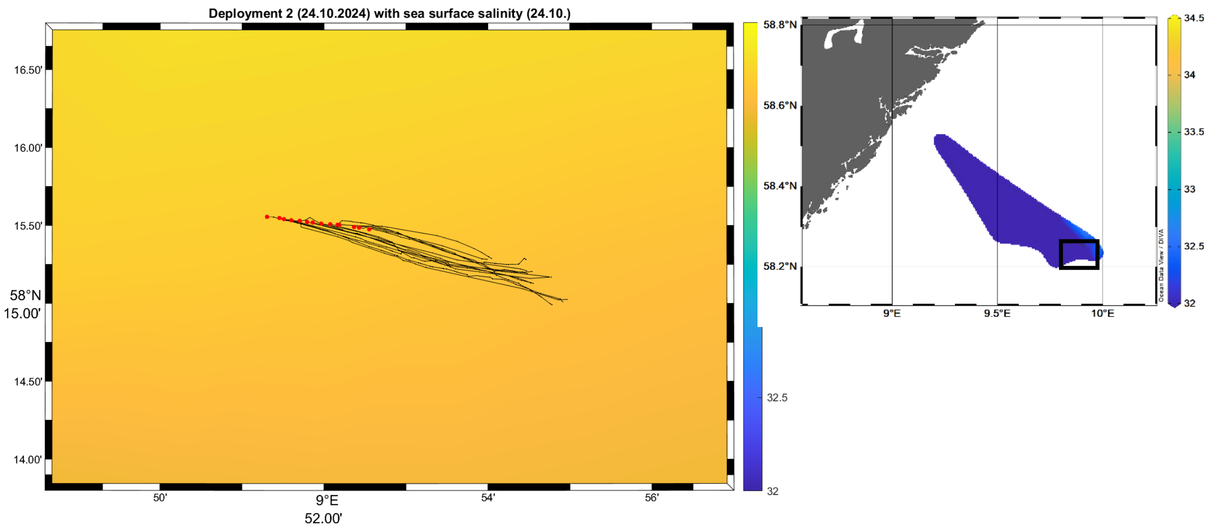

Fig 5.9.6 [A] Drifter Deployment 2 (red dots, date of deployment: 24.10.2024) with tracks (black lines, date of collecting 24.10.), background: sea surface salinity numerical model (daily) of 24.10. (day of deployment and collecting) using E.U. Copernicus Marine Service Information https://doi.org/10.48670/moi-00054 [B] Sea Surface Salinity Data from the Ferrybox (see 5.8) in the same scale for salinity as the numerical model, the approximate area of the drift as in [A] is marked with the black frame

Deployment 3:

On the same day, in the evening, deployment 3 took place. Further in the southwest, the drifters were deployed, again with the shorter intervals as in Deployment 2, with the expectation that all of them would drift north-eastward within the saltier water of the North Sea, with the Jutland Current. All the drifters behaved as expected and were collected after one day of drifting in the late evening of 25th October (*Fig. 5.5.7* [A]).

A first comparison with the numerical model shows a salty plume in which the drifters had drifted (*Fig. 5.5.7* [A]). The comparison with the data from the Ferrybox shows that the salinity values were significantly lower (*Fig. 5.5.7* [B]). Nevertheless, there appears to be a gradient along which the drifters drifted, presumably at the southern edge of the salt plume (*Fig. 5.5.7* [C]).

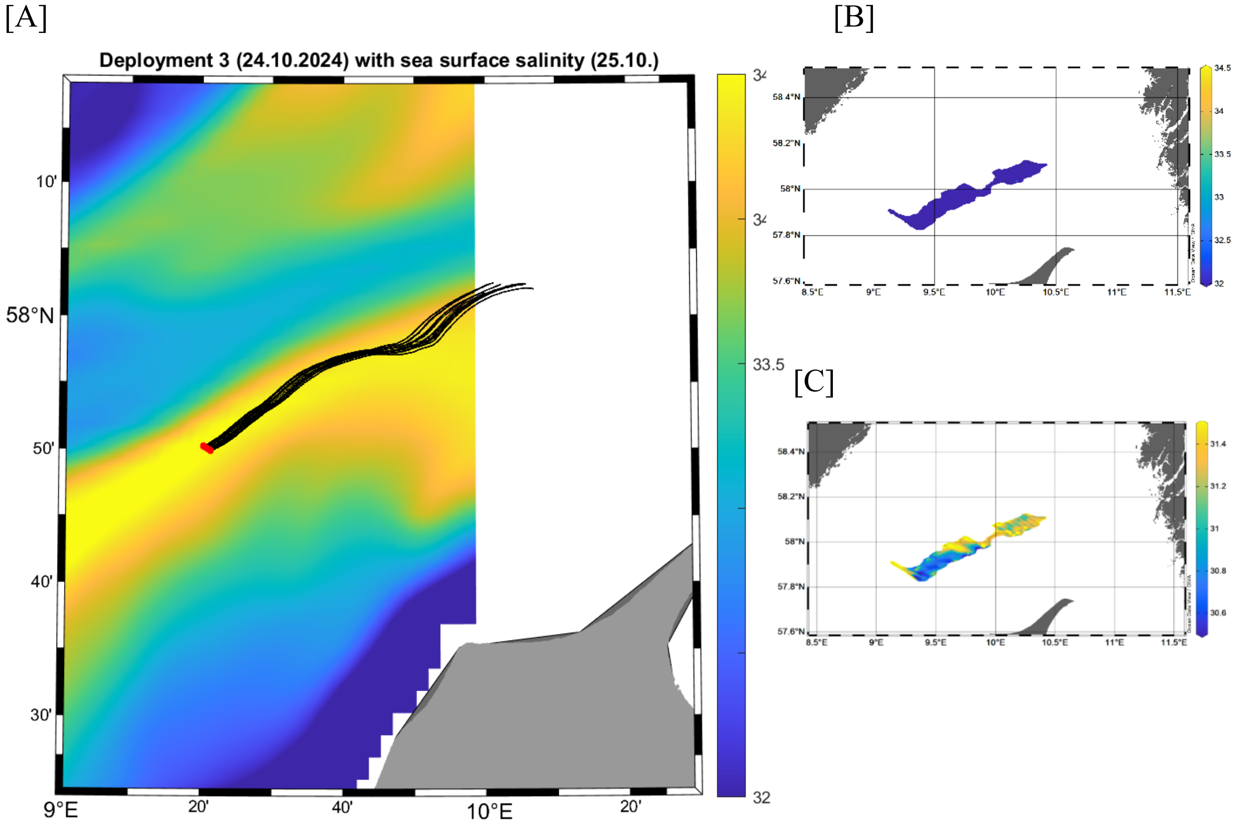

Fig 5.9.7 [A] Drifter Deployment 3 (red dots, date of deployment: 24.10.2024) with tracks (black lines, date of collecting 25.10.), background: sea surface salinity numerical model (daily) of 25.10. (day of collecting) using E.U. Copernicus Marine Service Information https://doi.org/10.48670/moi-00054 (model boundary at 9,98° E) [B] Sea Surface Salinity Data from the Ferrybox (see 5.8) in the same scale for salinity as the numerical model [C] Sea Surface Salinity Data from the Ferrybox (see 5.8)

The initial interpretation of our data provides first indications that surface currents in this region significantly depend on both salinity and wind conditions – thus confirming expectations from previous studies, e.g., Christensen et al. 2018. The Skagerrak Front is highly dynamic and has been observed to shift due to these external forces constantly. In addition, oceanographic models have shown limitations in accurately predicting actual currents, especially after strong wind events and at submesoscales and mesoscales.

These results should be considered as preliminary findings. A more detailed analysis of the sensor data collected by the drifters will enable a more comprehensive understanding of the complex processes in this area. Various factors thus determine submesoscale currents, heat exchange, and frontogenesis in the Skagerrak, and the drifter experiments can make a valuable contribution to our understanding of these submesoscale processes.

6 Ship's Meteorological Station

The ship's meteorological data were recorded using DShip.

7 Station List

7.1 Overall Station List

Station	Action	Event Date/Time	Latitude	Longitude	Depth (m)
HE649_0_Underway-5	WST	2024/10/15 10:57:39	53° 31,932' N	008° 34,700' E	5
HE649_0_Underway-5	WST	2024/10/27 17:00:02	53° 31,988' N	008° 34,861' E	0
HE649_1-1	CTD	2024/10/15 13:15:59	53° 50,074' N	008° 05,826' E	11
HE649_1-1	CTD	2024/10/15 13:32:07	53° 50,271' N	008° 05,534' E	10
HE649_1-2	CTD	2024/10/15 13:42:50	53° 50,352' N	008° 05,349' E	9
HE649_1-3	WP2	2024/10/15 13:49:46	53° 50,361' N	008° 05,295' E	9
HE649_1-3	WP2	2024/10/15 13:53:39	53° 50,360' N	008° 05,292' E	9
HE649_1-4	Secdisk	2024/10/15 13:58:10	53° 50,365' N	008° 05,268' E	9
HE649_1-4	Secdisk	2024/10/15 14:01:06	53° 50,389' N	008° 05,193' E	10
HE649_1-5	Profiler	2024/10/15 14:06:15	53° 50,398' N	008° 05,166' E	10
HE649_1-5	Profiler	2024/10/15 14:09:46	53° 50,382' N	008° 05,179' E	10
HE649_1-5	Profiler	2024/10/15 14:10:46	53° 50,378' N	008° 05,185' E	10
HE649_2-1	CTD	2024/10/16 08:18:35	53° 31,930' N	008° 10,998' E	14
HE649_2-1	CTD	2024/10/16 08:27:17	53° 31,929' N	008° 10,992' E	14
HE649_2-2	WP2	2024/10/16 08:34:18	53° 31,929' N	008° 10,981' E	14
HE649_2-2	WP2	2024/10/16 08:40:41	53° 31,930' N	008° 10,972' E	15
HE649_2-3	Secdisk	2024/10/16 08:34:44	53° 31,928' N	008° 10,980' E	14
HE649_2-3	Secdisk	2024/10/16 08:40:32	53° 31,930' N	008° 10,972' E	14
HE649_2-4	Profiler	2024/10/16 08:51:17	53° 31,934' N	008° 10,958' E	15
HE649_2-4	Profiler	2024/10/16 08:58:46	53° 31,933' N	008° 10,961' E	15
HE649_2-4	Profiler	2024/10/16 08:59:51	53° 31,933' N	008° 10,961' E	15
HE649_3-1	CTD	2024/10/16 11:00:16	53° 31,990' N	008° 10,939' E	15
HE649_3-1	CTD	2024/10/16 11:07:19	53° 31,983' N	008° 10,927' E	15
HE649_3-2	WP2	2024/10/16 11:12:30	53° 31,993' N	008° 10,942' E	15

HE649_3-2	WP2	2024/10/16 11:17:50	53° 31,994' N	008° 10,944' E	15
HE649_3-3	Secdisk	2024/10/16 11:16:24	53° 31,990' N	008° 10,940' E	15
HE649_3-3	Secdisk	2024/10/16 11:18:50	53° 31,989' N	008° 10,932' E	15
HE649_3-4	Profiler	2024/10/16 11:23:36	53° 31,993' N	008° 10,936' E	15
HE649_3-4	Profiler	2024/10/16 11:28:58	53° 31,995' N	008° 10,939' E	15
HE649_3-5	ADCP	2024/10/16 11:29:24	53° 31,993' N	008° 10,935' E	15
HE649_3-5	ADCP	2024/10/16 14:20:21	53° 31,999' N	008° 10,955' E	13
HE649_3-5	ADCP	2024/10/16 14:20:27	53° 31,999' N	008° 10,955' E	13
HE649_0_Underway-6	TSG	2024/10/16 16:36:59	53° 50,540' N	007° 51,210' E	13
HE649_0_Underway-6	TSG	2024/10/27 12:02:01	53° 54,009' N	008° 01,646' E	18
HE649_4-1	CTD	2024/10/17 14:15:57	57° 30,039' N	008° 08,072' E	135
HE649_4-1	CTD	2024/10/17 14:34:46	57° 29,985' N	008° 08,161' E	135
HE649_4-1	CTD	2024/10/17 14:45:07	57° 30,007' N	008° 08,211' E	136
HE649_0_Underway-7	ADCP	2024/10/17 17:40:35	57° 35,407' N	008° 17,386' E	169
HE649_0_Underway-7	ADCP	2024/10/17 17:51:55	57° 37,252' N	008° 17,212' E	195
HE649_0_Underway-7	ADCP	2024/10/17 19:58:26	57° 33,309' N	008° 10,914' E	166
HE649_0_Underway-7	ADCP	2024/10/17 19:58:48	57° 33,274' N	008° 10,888' E	170
HE649_5-1	dif	2024/10/18 06:05:39	57° 35,277' N	007° 58,353' E	221
HE649_5-1	dif	2024/10/18 06:42:15	57° 35,423' N	007° 58,731' E	222
HE649_5-1	dif	2024/10/18 06:44:59	57° 35,303' N	007° 58,731' E	221
HE649_5-1	dif	2024/10/18 06:48:02	57° 35,149' N	007° 58,734' E	218
HE649_5-1	dif	2024/10/18 06:51:05	57° 34,986' N	007° 58,727' E	215
HE649_5-1	dif	2024/10/18 06:53:25	57° 34,856' N	007° 58,728' E	213
HE649_5-1	dif	2024/10/18 06:56:13	57° 34,695' N	007° 58,728' E	210
HE649_5-1	dif	2024/10/18 06:58:34	57° 34,558' N	007° 58,723' E	208
HE649_5-1	dif	2024/10/18 07:01:34	57° 34,406' N	007° 58,721' E	206
HE649_5-1	dif	2024/10/18 07:04:43	57° 34,256' N	007° 58,720' E	204
HE649_5-1	dif	2024/10/18 07:07:07	57° 34,108' N	007° 58,730' E	202
HE649_5-1	dif	2024/10/18 07:09:32	57° 33,962' N	007° 58,731' E	200
HE649_5-1	dif	2024/10/18 07:12:10	57° 33,807' N	007° 58,729' E	198
HE649_5-1	dif	2024/10/18 07:15:04	57° 33,655' N	007° 58,721' E	198

HE649_5-1	dif	2024/10/18 07:18:03	57° 33,506' N	007° 58,712' E	195
HE649_5-1	dif	2024/10/18 07:24:43	57° 33,319' N	007° 58,692' E	192
HE649_5-1	dif	2024/10/18 07:27:39	57° 33,204' N	007° 58,723' E	190
HE649_5-1	dif	2024/10/18 07:30:18	57° 33,062' N	007° 58,722' E	189
HE649_5-1	dif	2024/10/18 07:32:45	57° 32,910' N	007° 58,725' E	188
HE649_5-1	dif	2024/10/18 07:35:34	57° 32,745' N	007° 58,730' E	185
HE649_5-1	dif	2024/10/18 07:38:02	57° 32,615' N	007° 58,741' E	186
HE649_5-1	dif	2024/10/18 07:40:55	57° 32,455' N	007° 58,741' E	186
HE649_5-1	dif	2024/10/18 07:43:22	57° 32,312' N	007° 58,743' E	183
HE649_5-1	dif	2024/10/18 07:45:48	57° 32,162' N	007° 58,746' E	180
HE649_5-1	dif	2024/10/18 07:48:22	57° 32,015' N	007° 58,749' E	178
HE649_5-1	dif	2024/10/18 07:51:28	57° 31,862' N	007° 58,746' E	178
HE649_5-1	dif	2024/10/18 07:53:47	57° 31,716' N	007° 58,742' E	176
HE649_5-1	dif	2024/10/18 07:56:11	57° 31,565' N	007° 58,739' E	176
HE649_5-1	dif	2024/10/18 07:58:47	57° 31,416' N	007° 58,734' E	175
HE649_5-1	dif	2024/10/18 08:01:47	57° 31,257' N	007° 58,736' E	174
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HE649_5-10	WP2	2024/10/18 14:18:26	57° 35,800' N	007° 50,892' E	257
HE649_5-11	Secdisk	2024/10/18 14:22:45	57° 35,800' N	007° 50,893' E	258

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HE649_5-12	ADCP	2024/10/18 14:33:58	57° 35,819' N	007° 50,856' E	259
HE649_5-12	ADCP	2024/10/18 15:43:25	57° 32,504' N	008° 02,761' E	179
HE649_5-13	CTD	2024/10/18 16:06:47	57° 32,426' N	008° 03,341' E	176
HE649_5-14	ADCP	2024/10/18 16:17:09	57° 32,441' N	008° 03,399' E	176
HE649_5-14	ADCP	2024/10/18 17:28:51	57° 35,214' N	007° 51,890' E	242
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HE649_5-18	ADCP	2024/10/18 19:05:06	57° 31,898' N	007° 57,022' E	181
HE649_5-18	ADCP	2024/10/18 20:23:26	57° 36,361' N	007° 43,469' E	307
HE649_5-19	CTD	2024/10/18 20:40:18	57° 36,403' N	007° 43,330' E	296
HE649_5-20	ADCP	2024/10/18 20:50:32	57° 36,434' N	007° 43,271' E	297
HE649_5-20	ADCP	2024/10/18 22:05:47	57° 31,886' N	007° 51,630' E	189
HE649_5-21	CTD	2024/10/18 22:20:10	57° 31,876' N	007° 51,650' E	190
HE649_5-22	ADCP	2024/10/18 22:38:06	57° 31,903' N	007° 51,705' E	190
HE649_5-22	ADCP	2024/10/19 00:09:05	57° 37,890' N	007° 40,026' E	348
HE649_5-23	CTD	2024/10/19 00:26:51	57° 37,882' N	007° 40,076' E	348
HE649_5-24	ADCP	2024/10/19 01:04:33	57° 37,885' N	007° 40,067' E	349
HE649_5-24	ADCP	2024/10/19 02:28:50	57° 32,067' N	007° 48,766' E	198
HE649_5-25	CTD	2024/10/19 02:45:26	57° 32,055' N	007° 48,851' E	198
HE649_5-26	ADCP	2024/10/19 02:59:57	57° 32,056' N	007° 48,921' E	197
HE649_5-26	ADCP	2024/10/19 03:48:40	57° 36,407' N	007° 45,199' E	293
HE649_5-27	CTD	2024/10/19 04:05:07	57° 36,447' N	007° 45,293' E	293
HE649_5-28	ADCP	2024/10/19 04:23:10	57° 36,430' N	007° 45,371' E	293
HE649_5-28	ADCP	2024/10/19 05:30:00	57° 32,305' N	007° 49,560' E	198
HE649_5-29	CTD	2024/10/19 05:42:22	57° 32,323' N	007° 49,561' E	198
HE649_5-30	ADCP	2024/10/19 05:55:24	57° 32,288' N	007° 49,627' E	204
HE649_5-30	ADCP	2024/10/19 08:09:16	57° 39,140' N	007° 25,552' E	329
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HE649_5-32	dif	2024/10/19 09:00:06	57° 38,402' N	007° 26,576' E	321
HE649_5-32	dif	2024/10/19 09:26:59	57° 38,369' N	007° 21,921' E	309
HE649_5-32	dif	2024/10/19 09:56:21	57° 36,781' N	007° 22,250' E	301
HE649_5-32	dif	2024/10/19 11:44:21	57° 38,442' N	007° 25,140' E	315
HE649_5-32	dif	2024/10/19 12:04:57	57° 38,650' N	007° 24,670' E	318
HE649_5-32	dif	2024/10/19 12:11:18	57° 38,663' N	007° 24,437' E	321
HE649_5-32	dif	2024/10/19 13:25:04	57° 35,766' N	007° 21,091' E	290
HE649_5-32	dif	2024/10/19 14:59:37	57° 40,887' N	007° 37,620' E	392
HE649_5-32	dif	2024/10/19 15:21:45	57° 40,865' N	007° 38,951' E	393
HE649_5-32	dif	2024/10/19 15:58:50	57° 38,334' N	007° 41,182' E	354
HE649_5-32	dif	2024/10/19 16:25:12	57° 38,132' N	007° 42,601' E	353
HE649_5-32	dif	2024/10/19 16:52:44	57° 37,174' N	007° 44,565' E	309
HE649_5-32	dif	2024/10/19 16:54:50	57° 37,205' N	007° 44,550' E	311
HE649_5-33	ADCP	2024/10/19 17:27:49	57° 37,862' N	007° 49,746' E	304
HE649_5-33	ADCP	2024/10/19 19:38:00	57° 29,405' N	007° 56,234' E	160
HE649_5-34	CTD	2024/10/19 19:11:33	57° 30,613' N	007° 55,342' E	172
HE649_5-35	ADCP	2024/10/19 19:38:23	57° 29,426' N	007° 56,190' E	161
HE649_5-35	ADCP	2024/10/19 20:36:31	57° 33,681' N	007° 53,102' E	209
HE649_5-36	CTD	2024/10/19 20:50:54	57° 33,658' N	007° 53,217' E	209
HE649_5-37	ADCP	2024/10/19 21:02:30	57° 33,616' N	007° 53,298' E	206
HE649_5-37	ADCP	2024/10/19 21:59:17	57° 29,487' N	007° 56,308' E	161
HE649_5-38	CTD	2024/10/19 22:16:37	57° 29,482' N	007° 56,272' E	161
HE649_5-39	ADCP	2024/10/19 22:27:51	57° 29,459' N	007° 56,273' E	161
HE649_5-39	ADCP	2024/10/19 23:27:20	57° 33,675' N	007° 53,150' E	208
HE649_5-40	CTD	2024/10/19 23:45:26	57° 33,726' N	007° 52,972' E	209
HE649_5-41	ADCP	2024/10/20 00:01:41	57° 33,764' N	007° 52,937' E	211
HE649_5-41	ADCP	2024/10/20 01:05:27	57° 29,488' N	007° 56,210' E	161
HE649_5-42	CTD	2024/10/20 01:17:49	57° 29,500' N	007° 56,140' E	162
HE649_5-43	ADCP	2024/10/20 01:27:48	57° 29,495' N	007° 56,168' E	162
HE649_5-43	ADCP	2024/10/20 02:25:02	57° 33,707' N	007° 52,936' E	210

HE649_5-44	CTD	2024/10/20 02:41:31	57° 33,688' N	007° 53,053' E	209
HE649_5-45	ADCP	2024/10/20 02:55:50	57° 33,683' N	007° 53,081' E	209
HE649_5-45	ADCP	2024/10/20 03:56:21	57° 30,195' N	007° 58,976' E	170
HE649_5-46	CTD	2024/10/20 04:12:54	57° 30,188' N	007° 59,040' E	167
HE649_5-47	ADCP	2024/10/20 04:29:51	57° 30,174' N	007° 59,131' E	163
HE649_5-47	ADCP	2024/10/20 05:39:47	57° 34,105' N	007° 54,102' E	216
HE649_5-48	CTD	2024/10/20 05:56:43	57° 34,111' N	007° 54,281' E	212
HE649_5-49	CTD	2024/10/20 06:39:18	57° 33,060' N	007° 57,322' E	192
HE649_5-50	dif	2024/10/20 06:55:18	57° 33,164' N	007° 57,211' E	193
HE649_5-51	dif	2024/10/20 07:47:32	57° 34,964' N	008° 06,941' E	198
HE649_5-51	dif	2024/10/20 08:38:14	57° 35,056' N	008° 08,380' E	195
HE649_5-51	dif	2024/10/20 08:47:01	57° 35,303' N	008° 08,418' E	198
HE649_5-51	dif	2024/10/20 09:18:40	57° 35,028' N	008° 05,473' E	201
HE649_5-51	dif	2024/10/20 09:19:19	57° 35,039' N	008° 05,479' E	202
HE649_5-51	dif	2024/10/20 09:23:06	57° 35,013' N	008° 05,506' E	203
HE649_5-51	dif	2024/10/20 10:13:26	57° 33,573' N	008° 08,205' E	178
HE649_5-52	ADCP	2024/10/20 09:29:27	57° 35,200' N	008° 04,993' E	203
HE649_5-52	ADCP	2024/10/20 10:12:27	57° 33,647' N	008° 08,100' E	179
HE649_6-1	ADCP	2024/10/24 00:50:02	58° 15,311' N	009° 57,134' E	499
HE649_6-1	ADCP	2024/10/24 00:53:56	58° 15,654' N	009° 56,628' E	320
HE649_6-1	ADCP	2024/10/24 04:37:32	58° 31,137' N	009° 13,872' E	311
HE649_6-2	ADCP	2024/10/24 04:46:04	58° 30,544' N	009° 13,170' E	314
HE649_6-2	ADCP	2024/10/24 08:36:55	58° 15,436' N	009° 53,607' E	533
HE649_6-3	dif	2024/10/24 08:45:31	58° 15,478' N	009° 52,551' E	523
HE649_6-3	dif	2024/10/24 08:46:17	58° 15,486' N	009° 52,427' E	527
HE649_6-3	dif	2024/10/24 08:46:41	58° 15,492' N	009° 52,368' E	530
HE649_6-3	dif	2024/10/24 08:47:40	58° 15,505' N	009° 52,225' E	531
HE649_6-3	dif	2024/10/24 08:48:03	58° 15,507' N	009° 52,166' E	533
HE649_6-3	dif	2024/10/24 08:48:34	58° 15,509' N	009° 52,080' E	531
HE649_6-3	dif	2024/10/24 08:49:08	58° 15,513' N	009° 51,976' E	532
HE649_6-3	dif	2024/10/24 08:49:47	58° 15,519' N	009° 51,865' E	532

HE649_6-3	dif	2024/10/24 08:50:13	58° 15,523' N	009° 51,796' E	529
HE649_6-3	dif	2024/10/24 08:50:46	58° 15,529' N	009° 51,706' E	525
HE649_6-3	dif	2024/10/24 08:51:24	58° 15,535' N	009° 51,601' E	520
HE649_6-3	dif	2024/10/24 08:51:57	58° 15,541' N	009° 51,510' E	520
HE649_6-3	dif	2024/10/24 08:52:37	58° 15,548' N	009° 51,407' E	520
HE649_6-3	dif	2024/10/24 08:53:17	58° 15,555' N	009° 51,303' E	520
HE649_6-4	dif	2024/10/24 09:05:28	58° 15,487' N	009° 51,127' E	522
HE649_6-5	ADCP	2024/10/24 09:10:31	58° 15,394' N	009° 51,010' E	520
HE649_6-5	ADCP	2024/10/24 10:17:31	58° 15,515' N	009° 52,534' E	527
HE649_6-6	dif	2024/10/24 11:00:35	58° 15,290' N	009° 54,034' E	526
HE649_6-7	dif	2024/10/24 11:02:25	58° 15,307' N	009° 54,084' E	522
HE649_6-8	dif	2024/10/24 11:19:19	58° 15,216' N	009° 54,498' E	584
HE649_6-9	dif	2024/10/24 11:26:01	58° 15,195' N	009° 54,522' E	520
HE649_6-10	dif	2024/10/24 11:39:35	58° 15,234' N	009° 54,424' E	517
HE649_6-11	dif	2024/10/24 11:49:24	58° 15,275' N	009° 54,484' E	562
HE649_6-12	dif	2024/10/24 11:59:52	58° 15,203' N	009° 54,481' E	514
HE649_6-13	dif	2024/10/24 12:08:08	58° 15,106' N	009° 54,573' E	511
HE649_6-14	dif	2024/10/24 12:11:19	58° 15,125' N	009° 54,569' E	0
HE649_6-15	dif	2024/10/24 12:25:34	58° 15,137' N	009° 54,839' E	511
HE649_6-16	dif	2024/10/24 12:34:39	58° 15,093' N	009° 55,006' E	512
HE649_6-17	dif	2024/10/24 12:42:33	58° 14,997' N	009° 54,952' E	506
HE649_6-18	dif	2024/10/24 12:42:51	58° 14,996' N	009° 54,963' E	509
HE649_6-19	dif	2024/10/24 12:54:10	58° 14,984' N	009° 54,810' E	0
HE649_6-20	dif	2024/10/24 13:16:55	58° 15,408' N	009° 53,640' E	469
HE649_6-21	CTD	2024/10/24 17:37:14	57° 54,855' N	009° 07,100' E	347
HE649_6-21	CTD	2024/10/24 17:47:22	57° 54,863' N	009° 07,120' E	347
HE649_7-1	ADCP	2024/10/24 17:48:06	57° 54,868' N	009° 07,124' E	347
HE649_7-1	ADCP	2024/10/24 17:48:15	57° 54,869' N	009° 07,124' E	347
HE649_7-1	ADCP	2024/10/24 19:19:15	57° 49,730' N	009° 21,760' E	98
HE649_7-2	dif	2024/10/24 19:23:45	57° 49,908' N	009° 21,337' E	101
HE649_7-2	dif	2024/10/24 19:24:07	57° 49,921' N	009° 21,298' E	102

HE649_7-2	dif	2024/10/24 19:25:22	57° 49,965' N	009° 21,166' E	102
HE649_7-2	dif	2024/10/24 19:26:09	57° 49,990' N	009° 21,086' E	104
HE649_7-2	dif	2024/10/24 19:26:53	57° 50,017' N	009° 21,008' E	104
HE649_7-2	dif	2024/10/24 19:27:33	57° 50,041' N	009° 20,936' E	104
HE649_7-2	dif	2024/10/24 19:28:11	57° 50,065' N	009° 20,865' E	106
HE649_7-2	dif	2024/10/24 19:28:59	57° 50,094' N	009° 20,776' E	106
HE649_7-2	dif	2024/10/24 19:29:44	57° 50,123' N	009° 20,690' E	107
HE649_7-2	dif	2024/10/24 19:30:26	57° 50,148' N	009° 20,614' E	107
HE649_7-2	dif	2024/10/24 19:31:10	57° 50,174' N	009° 20,535' E	107
HE649_7-2	dif	2024/10/24 19:31:57	57° 50,202' N	009° 20,452' E	108
HE649_7-2	dif	2024/10/24 19:32:46	57° 50,232' N	009° 20,368' E	108
HE649_7-2	dif	2024/10/24 19:33:25	57° 50,256' N	009° 20,298' E	109
HE649_7-3	dif	2024/10/24 19:39:51	57° 50,314' N	009° 20,120' E	110
HE649_7-4	ADCP	2024/10/24 19:40:12	57° 50,312' N	009° 20,120' E	110
HE649_7-4	ADCP	2024/10/24 20:10:36	57° 51,442' N	009° 16,802' E	144
HE649_7-5	CTD	2024/10/24 20:24:11	57° 51,462' N	009° 16,842' E	143
HE649_7-6	ADCP	2024/10/24 20:44:48	57° 51,942' N	009° 18,026' E	147
HE649_7-6	ADCP	2024/10/24 21:36:54	57° 49,734' N	009° 24,399' E	89
HE649_7-7	CTD	2024/10/24 21:47:41	57° 49,781' N	009° 24,360' E	90
HE649_7-8	ADCP	2024/10/24 21:57:15	57° 50,023' N	009° 24,464' E	92
HE649_7-8	ADCP	2024/10/24 22:50:59	57° 52,306' N	009° 18,908' E	144
HE649_7-9	CTD	2024/10/24 23:04:32	57° 52,356' N	009° 19,188' E	144
HE649_7-10	ADCP	2024/10/24 23:12:16	57° 52,421' N	009° 19,385' E	144
HE649_7-10	ADCP	2024/10/25 00:16:42	57° 50,900' N	009° 27,280' E	91
HE649_7-11	CTD	2024/10/25 00:27:58	57° 50,950' N	009° 27,512' E	92
HE649_7-12	ADCP	2024/10/25 00:34:55	57° 50,970' N	009° 27,696' E	91
HE649_7-12	ADCP	2024/10/25 01:42:56	57° 54,100' N	009° 23,473' E	155
HE649_7-13	CTD	2024/10/25 01:56:23	57° 54,097' N	009° 23,719' E	153
HE649_7-14	ADCP	2024/10/25 02:25:28	57° 55,465' N	009° 25,441' E	175
HE649_7-14	ADCP	2024/10/25 03:15:53	57° 53,172' N	009° 31,910' E	101
HE649_7-15	CTD	2024/10/25 03:28:30	57° 53,081' N	009° 32,266' E	98

HE649_7-16	ADCP	2024/10/25 03:56:47	57° 53,889' N	009° 34,764' E	102
HE649_7-16	ADCP	2024/10/25 04:50:42	57° 56,408' N	009° 27,989' E	187
HE649_7-17	CTD	2024/10/25 05:08:24	57° 56,432' N	009° 28,273' E	182
HE649_7-18	ADCP	2024/10/25 05:41:43	57° 57,318' N	009° 31,243' E	180
HE649_7-18	ADCP	2024/10/25 06:38:24	57° 54,898' N	009° 38,703' E	99
HE649_7-19	CTD	2024/10/25 06:53:32	57° 54,885' N	009° 38,776' E	100
HE649_7-20	WP2	2024/10/25 07:04:19	57° 54,887' N	009° 38,888' E	99
HE649_7-20	WP2	2024/10/25 07:07:44	57° 54,892' N	009° 38,937' E	99
HE649_7-21	ADCP	2024/10/25 07:30:32	57° 55,866' N	009° 42,470' E	98
HE649_7-21	ADCP	2024/10/25 08:20:12	57° 59,097' N	009° 34,325' E	206
HE649_7-22	CTD	2024/10/25 08:35:24	57° 59,058' N	009° 34,397' E	204
HE649_7-23	WP2	2024/10/25 08:45:40	57° 59,053' N	009° 34,534' E	205
HE649_7-23	WP2	2024/10/25 08:46:57	57° 59,052' N	009° 34,552' E	205
HE649_7-24	Secdisk	2024/10/25 08:48:16	57° 59,050' N	009° 34,568' E	206
HE649_7-24	Secdisk	2024/10/25 08:52:26	57° 59,050' N	009° 34,618' E	206
HE649_7-25	Profiler	2024/10/25 08:54:22	57° 59,042' N	009° 34,624' E	207
HE649_7-25	Profiler	2024/10/25 09:06:17	57° 58,862' N	009° 34,693' E	202
HE649_7-26	ADCP	2024/10/25 09:25:49	57° 59,658' N	009° 37,524' E	201
HE649_7-26	ADCP	2024/10/25 10:13:34	57° 56,641' N	009° 46,334' E	93
HE649_7-27	CTD	2024/10/25 10:27:37	57° 56,645' N	009° 46,652' E	93
HE649_7-28	WP2	2024/10/25 10:32:26	57° 56,672' N	009° 46,738' E	93
HE649_7-28	WP2	2024/10/25 10:33:34	57° 56,677' N	009° 46,752' E	93
HE649_7-29	Secdisk	2024/10/25 10:33:14	57° 56,675' N	009° 46,748' E	93
HE649_7-29	Secdisk	2024/10/25 10:36:09	57° 56,695' N	009° 46,775' E	93
HE649_7-30	Profiler	2024/10/25 10:42:39	57° 56,682' N	009° 46,809' E	93
HE649_7-30	Profiler	2024/10/25 10:51:37	57° 56,642' N	009° 46,816' E	93
HE649_7-31	ADCP	2024/10/25 11:35:56	57° 57,423' N	009° 49,183' E	96
HE649_7-31	ADCP	2024/10/25 12:32:27	57° 59,969' N	009° 42,077' E	181
HE649_7-32	CTD	2024/10/25 12:54:26	58° 00,229' N	009° 42,068' E	192
HE649_7-33	WP2	2024/10/25 13:01:37	58° 00,274' N	009° 42,192' E	193
HE649_7-33	WP2	2024/10/25 13:03:14	58° 00,287' N	009° 42,221' E	192

HE649_7-34	Secdisk	2024/10/25 13:02:53	58° 00,284' N	009° 42,215' E	192
HE649_7-34	Secdisk	2024/10/25 13:04:51	58° 00,300' N	009° 42,247' E	193
HE649_7-35	Profiler	2024/10/25 13:08:05	58° 00,328' N	009° 42,301' E	193
HE649_7-35	Profiler	2024/10/25 13:15:18	58° 00,330' N	009° 42,408' E	196
HE649_7-36	ADCP	2024/10/25 13:37:40	58° 01,469' N	009° 45,087' E	219
HE649_7-36	ADCP	2024/10/25 14:23:28	57° 58,471' N	009° 53,430' E	93
HE649_7-37	CTD	2024/10/25 14:35:24	57° 58,428' N	009° 53,669' E	93
HE649_7-38	Secdisk	2024/10/25 14:45:32	57° 58,403' N	009° 53,939' E	91
HE649_7-38	Secdisk	2024/10/25 14:47:34	57° 58,413' N	009° 53,992' E	91
HE649_7-39	WP2	2024/10/25 14:45:48	57° 58,404' N	009° 53,945' E	91
HE649_7-39	WP2	2024/10/25 14:47:45	57° 58,414' N	009° 53,996' E	91
HE649_7-40	dif	2024/10/25 16:15:38	58° 01,446' N	009° 57,985' E	115
HE649_7-40	dif	2024/10/25 16:25:34	58° 01,511' N	009° 58,489' E	115
HE649_7-40	dif	2024/10/25 16:33:23	58° 01,612' N	009° 58,912' E	116
HE649_7-40	dif	2024/10/25 16:50:14	58° 01,755' N	009° 59,857' E	129
HE649_7-40	dif	2024/10/25 17:00:45	58° 01,848' N	010° 00,483' E	116
HE649_7-40	dif	2024/10/25 17:19:37	58° 02,353' N	010° 00,219' E	119
HE649_7-40	dif	2024/10/25 17:25:32	58° 02,420' N	010° 00,388' E	119
HE649_7-40	dif	2024/10/25 17:49:18	58° 02,533' N	010° 01,350' E	123
HE649_7-40	dif	2024/10/25 18:07:09	58° 02,380' N	010° 02,237' E	113
HE649_7-40	dif	2024/10/25 18:26:49	58° 02,335' N	010° 04,563' E	105
HE649_7-40	dif	2024/10/25 18:36:29	58° 02,351' N	010° 05,481' E	103
HE649_7-40	dif	2024/10/25 18:46:24	58° 02,396' N	010° 05,821' E	103
HE649_7-40	dif	2024/10/25 18:52:23	58° 02,427' N	010° 06,016' E	102
HE649_7-40	dif	2024/10/25 19:07:47	58° 02,008' N	010° 06,971' E	98
HE649_7-41	CTD	2024/10/25 19:34:23	58° 01,553' N	010° 07,428' E	95
HE649_7-42	ADCP	2024/10/25 19:43:51	58° 01,505' N	010° 07,393' E	96
HE649_7-42	ADCP	2024/10/25 20:36:18	58° 04,409' N	009° 59,281' E	163
HE649_7-43	CTD	2024/10/25 20:46:29	58° 04,353' N	009° 59,420' E	162
HE649_7-44	ADCP	2024/10/25 21:08:05	58° 05,043' N	010° 01,662' E	169
HE649_7-44	ADCP	2024/10/25 21:51:21	58° 02,239' N	010° 09,901' E	95

HE649_7-45	CTD	2024/10/25 22:03:14	58° 02,122' N	010° 10,223' E	93
HE649_7-46	ADCP	2024/10/25 22:35:13	58° 02,607' N	010° 12,754' E	97
HE649_7-46	ADCP	2024/10/25 23:21:42	58° 05,129' N	010° 06,187' E	142
HE649_7-47	CTD	2024/10/25 23:35:01	58° 05,098' N	010° 06,463' E	141
HE649_7-48	ADCP	2024/10/25 23:59:42	58° 05,640' N	010° 08,413' E	140
HE649_7-48	ADCP	2024/10/26 00:35:43	58° 03,461' N	010° 14,543' E	102
HE649_7-49	CTD	2024/10/26 00:47:10	58° 03,433' N	010° 14,793' E	102
HE649_7-50	ADCP	2024/10/26 01:10:43	58° 03,737' N	010° 17,120' E	104
HE649_7-50	ADCP	2024/10/26 01:51:42	58° 06,054' N	010° 10,895' E	142
HE649_7-51	CTD	2024/10/26 02:06:22	58° 05,996' N	010° 11,621' E	137
HE649_7-52	ADCP	2024/10/26 02:26:25	58° 06,434' N	010° 13,072' E	145
HE649_7-52	ADCP	2024/10/26 03:13:51	58° 04,263' N	010° 19,247' E	111
HE649_7-53	CTD	2024/10/26 03:27:51	58° 04,233' N	010° 19,828' E	112
HE649_7-54	ADCP	2024/10/26 03:42:55	58° 04,509' N	010° 21,345' E	118
HE649_7-54	ADCP	2024/10/26 04:40:11	58° 07,365' N	010° 14,794' E	156
HE649_7-55	CTD	2024/10/26 04:57:27	58° 07,306' N	010° 15,351' E	154
HE649_7-56	CTD	2024/10/26 06:08:25	58° 06,251' N	010° 23,905' E	142
HE649_7-57	dif	2024/10/26 06:29:30	58° 06,500' N	010° 25,186' E	151
HE649_7-57	dif	2024/10/26 06:29:40	58° 06,501' N	010° 25,190' E	151

8 Data and Sample Storage and Availability

All collected data will be made available to all participants as a preliminary dataset within two months following the cruise. During the data analysis phase, drifter and drifting sensor chain data high-resolution data will be averaged over suitable intervals using MATLAB routines developed within our research group. These routines include quality control, flagging, and processing level identification.

The dataset will also include approximately CTD profiles and continuous measurements from ADCP. For long-term storage and accessibility, all data will be archived at the University of Oldenburg. Finalized datasets will be transferred to the PANGAEA data center and made publicly available at publication.

Data from instruments	Data responsibility	Date avaiable
Ferrybox data	Daniela Voß (daniela.voss@uol.de)	Within 12 months
Vessel-mounted and towed ADCP	Michelle Albinus (michelle.albinus@uol.de)	Within 12 months

Surface drifters + attached CTDs	Jens Meyerjürgens (jens.meyerjuergens@uol.de)	Within 12 months
DSHIP and meteorological data	Jens Meyerjürgens (jens.meyerjuergens@uol.de)	Within 12 months
Drifting sensor chains	Jens Meyerjürgens (jens.meyerjuergens@uol.de)	Within 12 months
Profiler	Daniela Voß (daniela.voss@uol.de)	Within 12 months
CTD	Rohan Henkel (rohan.henkel@uol.de)	Within 12 months
Secchi, , SPM	Michelle Albinus (michelle.albinus@uol.de)	Within 12 months

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All photographs were taken during the cruise by Carlsson Skiba, except Fig. 5.4.1 was taken by Lea Vilchez Bayer.