BUNDESAMT FÜR
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HYDROGRAPHIE

Scientific Cruise Report

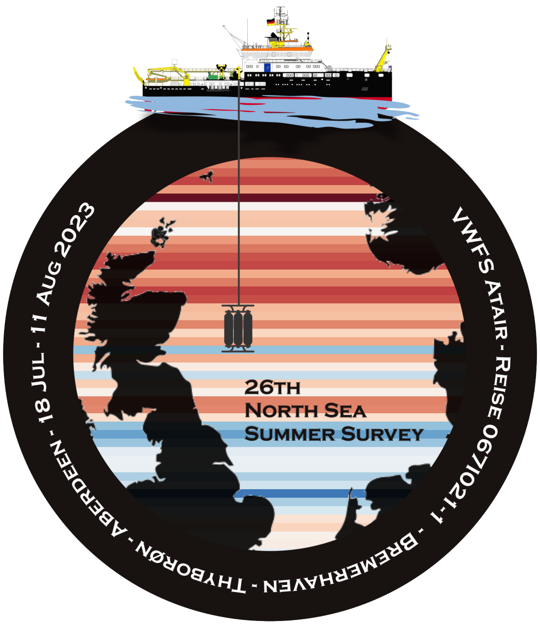
North Sea Summer Survey 2023
RV ATAIR, Cruise 067I021-1

18 Jul – 10 Aug 2023

Bremerhaven/Germany – Thyborøn/Denmark – Aberdeen/UK

Chief Scientist: Dr. Dagmar Kieke

Captain: Ulrich Klüber



Hamburg, August 2025

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1. Summary

English:

The scientific cruise *067I021-1* with the *Research Vessel (RV) ATAIR* dealt with investigating the physical and biological state of the North Sea during the summer of 2023. The focus was on surveying a large-scale network of standard station locations along specific latitudes to observe the major inflow and outflow conditions into and out of the North Sea. The overall aim was to obtain suitable physical oceanographic data that serves to further extend already existing time series on the hydrographic properties of the North Sea's water column over time. Furthermore, biological data obtained with respect to chlorophyll-a and phytoplankton will be used to compare and validate satellite data. Data collected during the cruise consisted of hydrographic casts at the standard station locations and underway measurements to analyse the hydrographic conditions near the sea surface along the cruise track. The resulting data set from cruise *067I021-1* is of high quality. Out of the intended 111 stations, 100, including a test station, were surveyed. Deteriorating weather conditions towards the end of the cruise preventred surveying the section following the latitude of 59°N.

German:

Die Forschungsexpedition 067I021-1 mit dem Vermessungs-, Wracksuch- und Forschungsschiff (VWFS) ATAIR befasste sich mit der Untersuchung des physikalischen und biologischen Zustands der Nordsee im Sommer 2023. Der Schwerpunkt lag auf der Vermessung eines großflächigen Netzes von Standardmessstationen entlang verschiedener Breitengrade, die zur Beobachtung der wichtigsten Zu- und Abflussbedingungen in die und aus der Nordsee dienen. Das übergeordnete Ziel bestand darin, geeignete physikalisch-ozeanographische Daten zu gewinnen, um bereits vorhandene Zeitreihen zu den hydrographischen Eigenschaften der Wassersäule der Nordsee zeitlich weiter auszubauen. Darüber hinaus sollen die gewonnenen biologischen Daten zu Chlorophyll-a und Phytoplankton zum Vergleich und zur Überprüfung von Satellitendaten herangezogen werden. Die während der Fahrt gewonnenen Daten bestehen aus hydrographischen Messungen an Standardmessstationen und Messungen während der Fahrt zur Analyse der hydrographischen Bedingungen nahe der Meeresoberfläche entlang der Fahrtroute. Der aus der Fahrt 067I021-1 resultierende Datensatz ist von hoher Qualität. Von 111 geplanten Stationen konnten 100, darunter eine Teststation, realisiert werden. Aufgrund der sich gegen Ende der Fahrt verschlechternden Wetterbedingungen konnte der Transekt entlang des 59. Breitengrades nicht vermessen werden.

2. Participants

	Name	Institute	Field of Activity/Responsibility
1.	Kieke, Dagmar, Dr. *	BSH	chief scientist
2.	Diercks, Thomas **	BSH	CTD watch, technics
3.	Hammermeister, Elke *	BSH	oxygen titration, Secchi disc, chlorophyll-a/phyto-plankton sampling
4.	Köllner, Manuela *	BSH	CTD watch, VMADCP, thermosalinograph, CTD/VMADCP data processing, water sampling
5.	Römer, Nadine *	BSH	CTD watch, salinometry, water sampling
6.	Weidner, Carl *	BSH	CTD watch, technics

* Bremerhaven – Aberdeen ** Bremerhaven – Thyborøn

BSH Federal Maritime and Hydrographic Agency, Hamburg, Germany

Table 1.1. *Scientific participants of cruise 067I021-1, summer 2023.*

3. Purpose of the Cruise and Research Objectives

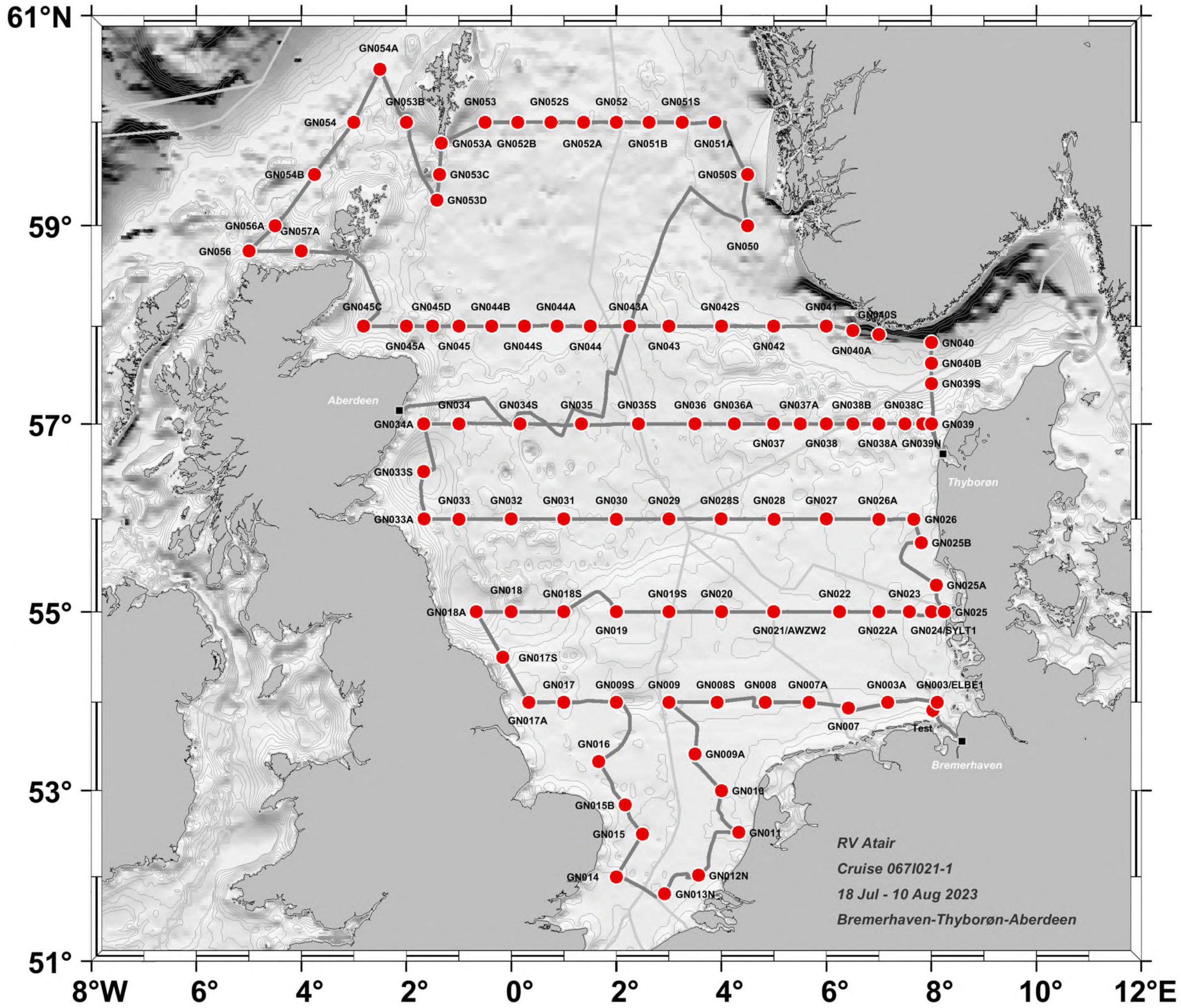

Figure 1.1 *Track of cruise 067I021-1 with RV ATAIR and locations of corresponding hydrographic stations shown as red markers. Text labels denote station names. Thin grey lines highlight limits of the various Exclusive Economic Zones (EEZ) according to the Maritime Boundaries Geodatabase version 11.0 of Flanders Marine (2019).*

Cruise *067I021-1* with *RV ATAIR* served to conduct the annual large-scale *North Sea Summer Survey* (NSSS) of the BSH. Surveys similar to cruise *067I021-1* have been undertaken annually by the BSH since 1998. These surveys generally follow a predefined net of standard stations forming zonal sections crossing the North Sea at different latitudes between 54°N and 60°N. Additional stations are located to the south of 54°N forming a loop-like station pattern that stretches to about 52°N near the southern entrance to the North Sea. The annual *North Sea Summer Survey* is typically carried out at or close to the time of the expected maximum stratification and phytoplankton productivity having passed its peak.

The particular cruise *067I021-1* of summer 2023 consisted of two legs, with leg 1 covering the southern to central part of the North Sea and leg 2 covering the central to northern part of the North Sea. Leg 1 with departure in Bremerhaven, Germany, on 18 July led to the port of Thyborøn, Denmark, where the vessel arrived on 30 July (compare Figure 1.1). The port stay during 30 July and 1 August was used to exchange crew members and scientific participants (see Section 2). The cruise was resumed on 1 August, when the vessel departed from Thyborøn in order to pursue leg 2 of cruise *067I021-1* in the northern part of the North Sea, which ended with the vessel arriving in Aberdeen, UK, on 10 August 2023.

Different from previous cruises, in summer 2023, the spatial resolution of the northern sections of cruise *067I021-1* was increased in order to resolve smaller scale oceanic structures. Furthermore, two survey lines located to the west and east of the Orkney and Shetland Islands covering the inflow of Atlantic Water into the North Sea were planned.

The major purpose of cruise *067I021-1* based on respective measurement is to assess the state of the North Sea in summer 2023 with focus on the physical state. Respective large-scale data will contribute to investigating the hydrographic state of the water column in different regions of the North Sea. Furthermore, temporal hydrographic changes as they become obvious when bringing the data into context with data from previous cruises shall be addressed.

Particular objectives related to cruise *067I021-1* addressing the state of the North Sea in 2023 are the following:

- How far does the Atlantic Water (AW) that enters the North Sea at its northern limits propagate southward in summer 2023?
- Where does the main inflow take place?
- How far does AW entering the southern North Sea via the English Channel penetrate northwards in summer 2023?
- What is the respective regional sharpness and depth of the thermocline?
- What is the total salt and heat content of the North Sea in summer 2023?
- Where is the Baltic outflow located?

Overarching objectives that address temporal changes on different time scales are:

- How do changes in the Northeast Atlantic happening on time scales ranging from seasonal to decadal affect the North Sea?
- Which processes are linked to the variability in the North Atlantic Oscillation (NAO) and to what extent?

Chlorophyll-a and phytoplankton sampling carried during the cruise will serve for improving remote-sensing products and satellite sensor validation by means of comparison with in situ data.

4. Narrative of the Cruise

RV ATAIR left its berth at Kohlenkai in Bremerhaven/Germany on 18 July 2023, at 11:00 UTC and subsequently passed the Bremerhaven Sleuth in order to start its cruise *067I021-1*, the *North Sea Summer Survey* of 2023. The scientific mission of cruise *067I021-1* started in the late afternoon/early evening hours of the same day, when a test station was conducted and continuous logging of underway data was switched on after having reached station #002/GN003/ELBE1. Course was set towards west and initially followed the latitude of 54°N. On 19 July, the Dutch EEZ was entered, and subsequent work at 9 hydrographic stations (#005/GN007A - #013/GN013N) was carried out. At station #008/GN009, the vessel turned southwards in order to reach the southernmost station of the cruise near the southern entrance to the North Sea (station #013/GN013N, reached on 21 July).

The vessel entered UK waters for the first time on 21 July and carried out work on stations #014/GN014 to #018/GN009S on a northward course in order to reach 54°N again and finish measurements along this latitude.

On 22 July, measurements started at the western end of the 55°N section at station #022/GN018A. UK waters were left shortly after finishing station #026/GN019S on 23 July, and Dutch waters were entered again. The vessel reached the eastern end of the 55°N section on 24 July (station #033/GN025, German waters) and headed north to continue measurements along 56°N in western direction. The easternmost station #036/GN026 of the 56°N section was conducted in Danish waters on 25 July, and the westernmost station #046/GN033A located in British waters was sampled on 27 July.

The 57°N section started at its western end (station #048/GN034A) on 27 July. The vessel headed eastward, crossed UK and Norwegian waters and reached its eastern end at station #062/GN039 on 30 July around noon. Between the afternoon of July 29th and the early morning hours of 30 July, the vessel was at anchor near station #058/GN038B, since the overall weather and sea state conditions prevailing so far had permitted to arrive quite early near the port of Thyborøn.

RV ATAIR was towed at Oliekaj in Thyborøn/Denmark on 30 July at 14:05 UTC in order to finish leg 1 of cruise *067I021-1*. The scientific mission was interrupted until 1 August, 05:30 UTC, when the vessel left Thyborøn in order to start leg 2 of cruise *067I021-1*. In between, crew members and scientific participants were exchanged.

Station work was resumed on 1 August, at station #063/GN039S, with the vessel heading north in order to reach the eastern end of the 58°N section in Norwegian waters. Starting at station #065/GN040 visited in the afternoon hours of 1 August, the vessel headed westwards, initially following the course of the Norwegian Trench. The western end of the 58°N section located in British waters was reached at station #080/GN045C on 3 August, around 21:00 UTC.

On 4 August, between around 03:00 and 06:00 UTC, the flow direction of the tidal stream allowed the vessel to pass the Pentland Firth in westward direction. Station work was resumed at station #081/GN057A around 06:45 UTC. Starting from station #082/GN056, the vessel followed a course towards the northeast in order to carry out sampling at five stations in total. These stations form a measurement line along the western side of the Orkney and Shetland Islands that crosses the Atlantic inflow pathways in this region (see Figure 1.1). The northernmost station of this line and that of the entire cruise was reached on 5 August shortly before 08:00 UTC (station #086/GN054A, 60°30'N).

Having finished station work on the western side of the Shetland Islands, the vessel headed towards the southeast, passed Fair Isle and reached station #088/GN053D on the northeastern side of the Orkney Islands (5 August). From there, the vessel turned to the north at first and subsequently started to pursue station work along the 60°N section at station #091/GN053 on 6 August. While following the 60°N section in eastward direction, weather and sea state conditions started to deteriorate. Stations #097/GN051S and #098/GN051A located in Norwegian waters could still be carried out on 7 August. However, the location of the originally planned station GN051 near the Norwegian coast could not be reached anymore. The 60°N section could thus not be completely followed until its eastern end. Instead, course was changed in order to reach station #099/GN050S at 59°30'N further to the south.

Station works finally had to be finished at station #100/GN050 in the afternoon hours of 7 August. Sampling work had to be aborted, and all remaining station work was canceled for the rest of the cruise time, since high sea swell and wind strengths of 9-10 Bf did not allow anymore for safe station work. Instead, the vessel was made 'storm-proof', all equipment was safely stored and scientific devices secured.

Between 7 and 10 August the vessel headed towards its destination port, which was Aberdeen, UK. The ship's speed had to be decreased considerably, and the course had to be changed frequently in order to adjust to the stormy weather and sea state conditions and to keep everyone on board safe. Further station work was not possible. Consequently, measurements along 59°N are not available for summer 2023 (except station GN050). Also, the originally intended and yet remaining stations located to the east of the Orkney Islands could not be sampled. Out of the originally 111 intended hydrographic stations, 100 including a test station could be successfully sampled, and data from 11 stations is thus not available due to weather conditions.

While heading towards the port of Aberdeen, the scientific crew aboard *RV ATAIR* received a request issued by British scientists in order to help retrieving a scientific glider, which was on mission near Aberdeen. While the request for help was answered positively and active help was offered, it was not needed in the end, since the British scientists could retrieve the glider by own means.

Continuous logging of underway data was stopped on 10 August, 07:00 UTC, which marked the end of the scientific mission of cruise *067I021-1* with *RV ATAIR*. At 10:00 UTC, the vessel arrived at the pilot station of Aberdeen and took the pilot onboard. The vessel was finally towed to Blaikies Quay no. 3 in the port of Aberdeen at 10:37 UTC, which marked the end of cruise *067I021-1*.

The port stay in Aberdeen was used for the disembarkment of scientific participants and crew members of cruise *067I021-1*, and the respective embarkment of the members of the subsequent cruise *067I021-2* (chief scienstist Dr. Simone Hasenbein, BSH) and installation of the required laboratory devices and instrumentation.

RV ATAIR left Aberdeen in the afternoon hours of 12 August in order to start its mission *067I021-2*, thereby heading back into German waters. Underway measurement started on 12 August, 16:15 UTC. A final test station was carried out near the border to the German EEZ but still in British waters on 13 August. All remaining work of cruise *067I021-2* was limited to the German EEZ without pursuing further station work in British waters. Cruise *067I021-2* was finally finished in Bremerhaven/Germany on 20 August.

5. Scientific Tools and Methods

5.1 Overview

Scientific tools that were in use during the cruise comprised profiling of the entire water column using a Conductivity-Temperature-Depth (CTD) unit attached to a carousel water sampler system and equipped with a number of sensors that will be detailed in the following sections. Additional sensors attached to the CTD-unit involved a sensor measuring dissolved oxygen, a dual-wavelength sensor measuring simultaneously both turbidity and fluorescence, and an altimeter for determining the distance of the underwater unit to the sea bottom in order to avoid contact.

The carousel water sampler was equipped with a fixed number of 10 litres Niskin bottles to allow for taking water samples at discrete depths of the water column. Water sampling activities consisted of taking oxygen and salinity samples for the sake of calibrating the conductivity and oxygen sensors of the CTD unit, water samples for water density, chlorophyll-a and phytoplankton for home-based laboratory analyses. In total, 100 stations involving the CTDO/water sampler system were carried out. Secchi depth determination, water sampling for chlorophyll-a and phytoplankton were only performed on daylight stations.

A vessel-mounted Acoustic Doppler Current Profiler (VMADCP) system operating at 150 kHz and in narrow-band mode delivered oceanic velocity data of the upper water column during the cruise. Further underway measurements focused on standard meteorological data, water depth, near-surface values for water temperatures, salinity, fluorescence/chlorophyll and turbidity.

5.2 CTD Sensor Unit and Water Sampler Setup

During cruise *067I021-1* a profiling conductivity-temperature-depth (pressure) sensor unit (CTD) of type *Sea-Bird Electronics (SBE) 9plus* (“*CTD Sonde S1*”) was in use. It was operated and power-supplied from out of the vessel’s hydrography lab via a deckunit of type *SBE11plus*. The CTD sensor package was mounted horizontally in the lower part of a water sampler frame of type *SBE32* potentially carrying up to 12 Niskin bottles of 10 litres volume. The recording of the raw data was done using the BSH software *Seasave_Start* that internally calls the *SBE*-software *SeaSave*, version 7.21f, and the data conversion software (from binary into ASCII) *SBEDataProcessing*, version 7.25.0.319.

The CTD sensor package consisted of a primary and a secondary pair of temperature (T) and conductivity (C) sensors that were each connected to a particular pump and the main CTD housing carrying a pressure sensor. A through-flow oxygen sensor was connected to the primary T/C sensor pair. In addition, a dual-wavelength sensor of type *WetlabECO* delivering simultaneously fluorescence and turbidity data was attached to and powered by the CTD system. The distance to the sea bottom was estimated from an altimeter of type *Teledyne Benthos*

PSA-916. Inlets of the two T/C sensor pairs were soaked in distilled water before the start and after the end of each CTD cast. A supplementary temperature sensor was installed at the height of Niskin bottle about 1 m above the CTD unit in order to record water temperature at the time of the bottle closing. All temperature and conductivity sensors were successfully re-calibrated in the BSH's calibration laboratory prior to the cruise. All devices and sensors that were in use are listed in Table 5.1, the Niskin bottle set-up is listed in Table 5.2. Temperatures are reported on the *ITS-90* scale. Derived salinities refer to the *Practical Salinity Scale* of 1978 (PSS-78). All respective densities have been inferred from the *EOS-80* equation.

Device	Serial Number	Calibration Date
CTD main housing with pressure sensor, SBE9plus	09P21787-0577, S1	06 Feb 2019
deckunit, SBE11plus	11P29178-0620, N1	---
temperature sensor 1, SBE3T, part of TC1	5290	29 Jun 2023
temperature sensor 2, SBE3T, part of TC2	4358	29 Jun 2023
conductivity sensor 1, SBE4C, part of TC1	3772	29 Jun 2023
conductivity sensor 2, SBE4C, part of TC2	2752	29 Jun 2023
oxygen sensor, SBE43	0171	16 Apr 2022
pump 1, SBE5	5839	---
pump 2, SBE5	5856	---
dual-wavelength sensor, WET Labs ECO-AFL/FL, fluorescence	4964	15 Jan 2018
dual-wavelength sensor, WET Labs ECO, turbidity	4964	15 Jan 2018
supplementary termperature sensor installed at the height of the Niskin bottles, SBE35	078	04 Jul 2016
altimeter, Teledyne Benthos, PSA-916	51678	11 Dec 2013
carousel water sampler with 12 positions for Niskin bottles, SBE32	3232948-0466, K1	---

Table 5.1. *Overview on CTD-related sensors or water sampler devices used during cruise 067I021-1.*

The CTD system worked well during the whole cruise, and all sensors showed reliable measurements. The differences between redundant sensors were small and mostly within uncertainty range as given by the manufacturer and later calibration. Larger differences were observed under rough measurement circumstances or due to large numbers of particles within the water column clogging the sensor packs for short times. One cast had to be stopped and redone due to computer failures (black screen), the CTD system itself was always reliable, NMEA-formatted GPS data were always available and added to the casts.

Position	Bottle ID	Manufacturer	Volume	Closing Depth
1	S-ID181015	*General Oceanics*	10 L	bottom
2	S-ID181004	“ “	“	bottom
3	S-ID181005	“ “	“	10 m
4	S-ID181014	“ “	“	7.5 m
5	S-ID181011	“ “	“	5 m
6	S-ID181010	“ “	“	5 m
7	S-ID181003	“ “	“	2.5 m

Table 5.2. *Overview on the Niskin bottle set-up and sampling scheme of cruise 067I021-1.*

All Niskin bottles were checked at the beginning of the cruise and then closed during the upcast at the designated sampling levels. Before closing, a 3 min waiting time was applied to avoid entrained water from different depth levels being taken as a sample. Salinity and oxygen samples were always taken from Niskin bottles located on positions 2 and 6, see Table 5.2. On station #090/GN053A, bottles were closed after 30 sec to 1 min waiting time due to strong currents and the risk for the CTD to be pushed underneath the vessel. On station #100/GN050, the surface salinity sample could not be taken due to cancellation of station work caused by extremely bad weather conditions.

5.3 Water Sampling with respect to Salinity

Water samples were collected at all stations during cruise *067I021-1* for the purpose of checking the quality of the CTD-derived conductivity and, consequently, salinity. An exception was made at the test station at the start of the cruise. Water samples were taken from Niskin bottles closed at 5 dbar near the surface and at the bottom. The bottles were numbered and rinsed three times with seawater before being filled and sealed airtight. The water samples were analysed using an *OSIL AUTOSAL 8400B* salinometer, s/n 68046. Analysis of salinometer samples was partly done already during the cruise. For standardisation, *IAPSO* standard seawater batches P-161 and P-167 were used. All samples were assigned a BSH sample identification number similar to a *Bedford* number.

Water Sampling with respect to Dissolved Oxygen

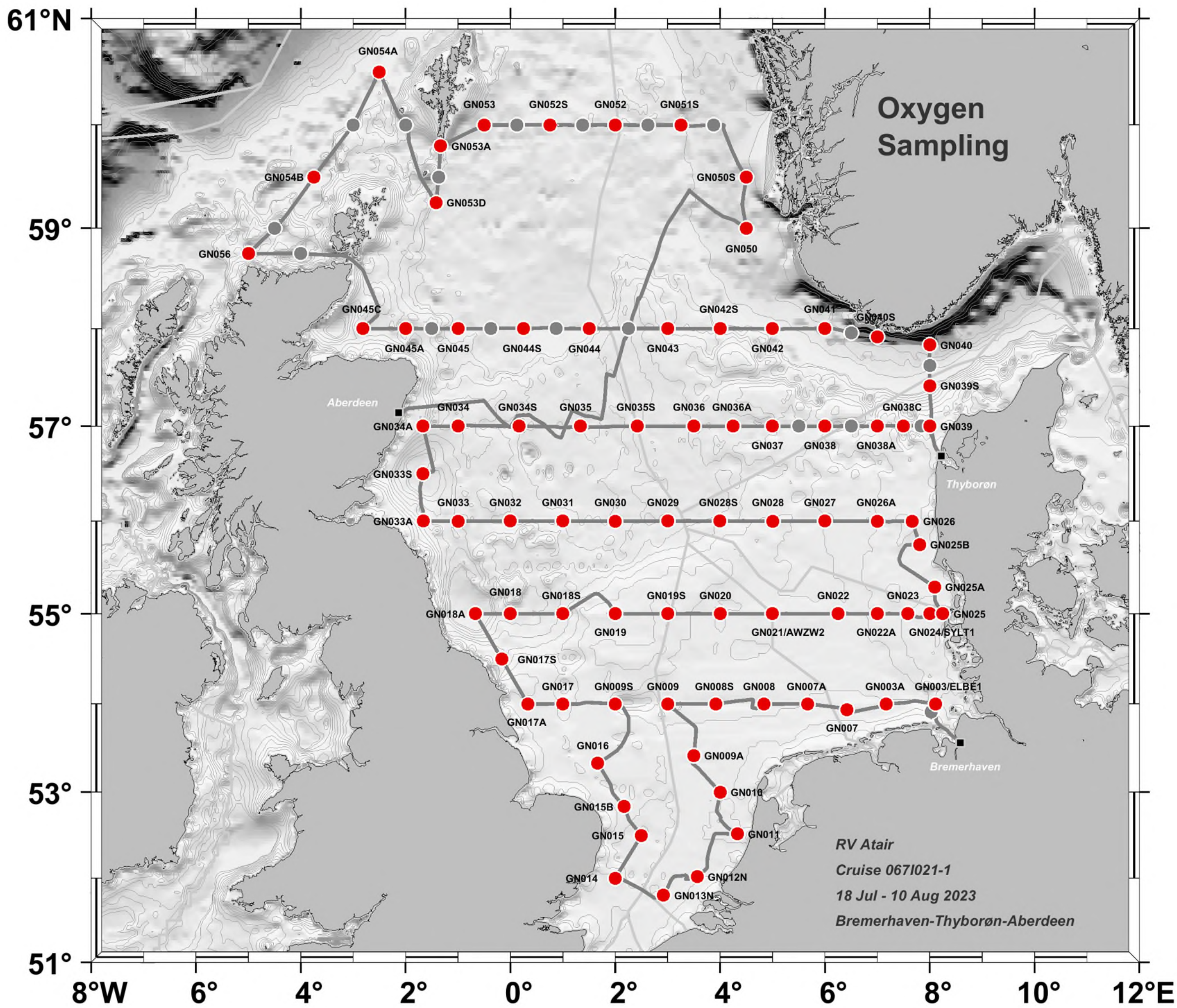

Figure 5.1. *Distribution of stations carried out during cruise 067I021-1 with oxygen sampling (red dots).*

Throughout cruise *067I021-1*, water samples were taken for the pupose of estimating the concentration of dissolved oxygen in seawater. Oxygen sampling stations are highlighted in Figure 5.1. Water samples were analysed already during the cruise through photometric methdods using a *Dissolved Oxygen Analyzer* (DOA) system. Procedures followed those described in *BSH (2021)*. The dissolved oxygen in seawater is determined using the Winkler method modified by *Carpenter (1965)*. The physically dissolved oxygen reacts in an alkaline medium with manganese(II) hydroxide to form higher manganese salts (manganese(III) hydroxide, manganese(IV) hydroxide). After fixing the oxygen and allowing the precipitate to settle, the sample is acidified (pH ~1-2.5). The precipitate dissolves and the iodine ions added during fixation are oxidised to an equivalent amount of iodine. The concentration of the released iodine is determined by titration with a standardised sodium thiosulphate solution. The consumption of thiosulphate is proportional to the original amount of dissolved oxygen.

Immediately after sampling, 1 ml of manganese(II) chloride solution and 1 ml of sodium iodide/sodium hydroxide solution were added to the sample. The sample bottle was then sealed with the appropriate ground glass stopper without trapping any air bubbles. It was subsequently shaken for approx. 2 minutes, during which time a white to brown precipitate formed (depending on the oxygen concentration). The samples were darkened, and after approx. 20 to 30 minutes the precipitate had settled. Before titration, a titre determination was carried out every working day, followed by a blank value determination once a week or when changing reagents. Calibration/standardisation for oxygen determination is carried out by titrating the titrant solution (sodium thiosulphate solution). Potassium iodate (KIO_3) is used as the standard titrant. The software used to operate the DOA performs the calculations to obtain values for dissolved oxygen internally. The calculations are based on internationally accepted recommendations. In order to assess the resulting data quality, double samples have been analysed. Unfortunately, any certified reference material (CRM) or interlaboratory performance studies (like QUASIMEME) do not exist for the parameter ‘dissolved oxygen in seawater’. The mean range for 20 samples taken as duplicates on this cruise was less than 0.03 ml/l DOXY. $KH(IO_3)_2$-solution was measured from 33 samples as an IRM (irnternal reference material) and resulted in a deviation of less than 0.01 ml/l for the titrant.

Oxygen data obtained from water samples were subsequently used for comparison with and verification of the CTD-based oxygen sensor *SBE43*.

5.5. Water Sampling with respect to Density

Water sampling with respect to density analysis was carried out on selected stations. Similarly to salinity, water samples were taken from the Niksin bottles that were closed near the surface at 5 dbar and close to the bottom. Numbered glass bottles were used and rinsed three times with seawater before finally filling the bottle. The sample was made air-tight by closing the bottle with a rubber plug and attaching a metal seal on top. All samples were given a BSH sample identification number similar to *Bedford* numbers. Back at the home lab, density samples were analysed with a densitymeter of type *Mettler Toledo Excellence D6*. In total, 36 samples taken from station locations distributed all across the North Sea were analysed for density. Figure 5.2 presents the station locations with density sampling carried out during cruise *067I021-1*. Sampling and analysis is done with respect to building up a density database for the North Sea for the sake of obtaining absolute salinity data, S_A. These should be based on density measurements that can be traced back to SI units, a prerequisite when considering the *Thermodynamic Equation of Seawater 2010* (TEOS-10).

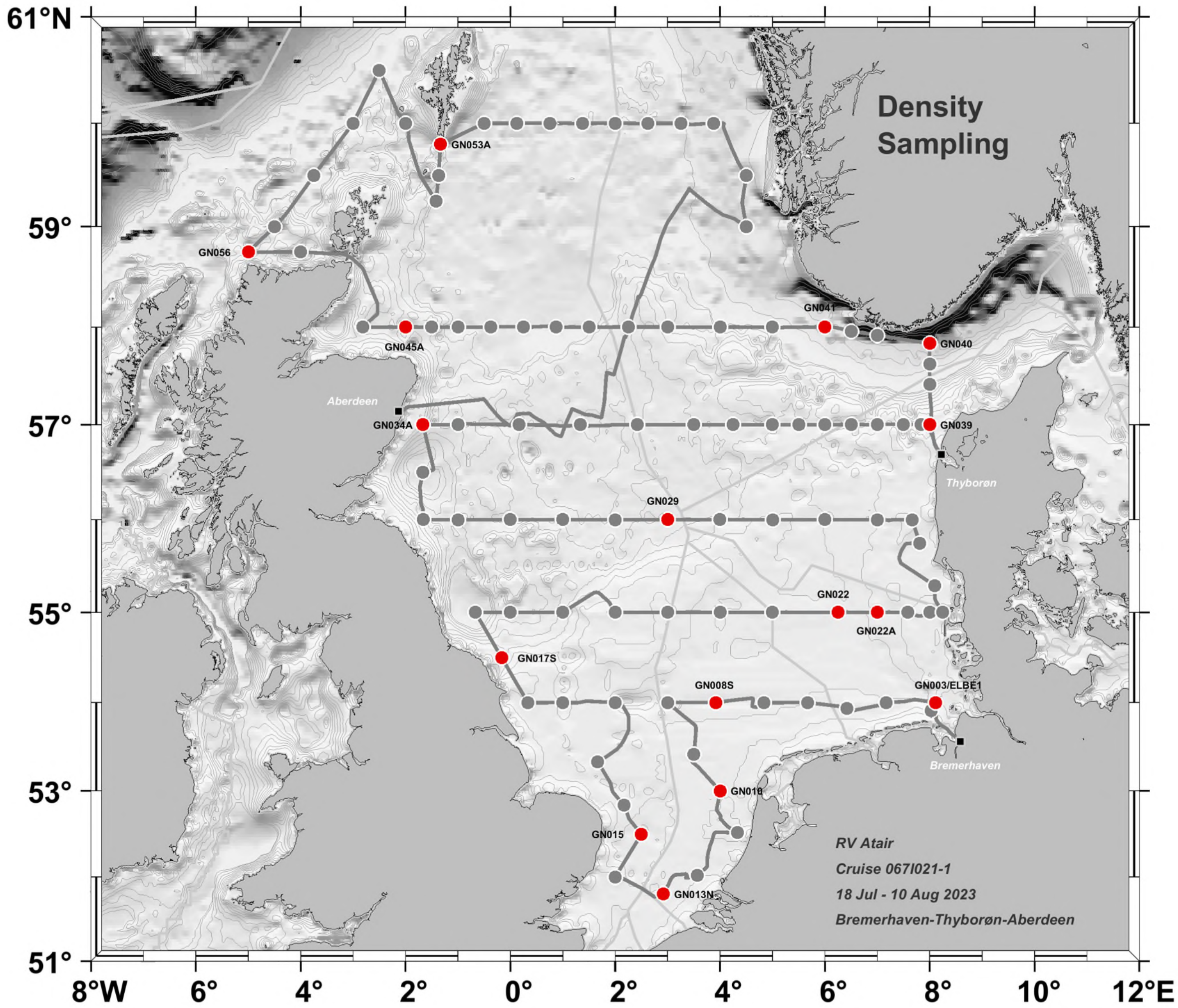

Figure 5.2. *Distribution of stations carried out during cruise 067I021-1 with density sampling (red dots).*

5.6 Near-Realtime Processing of CTD Data

All CTD data have been recorded at an original resolution of 24 Hz. Data have been checked and pre-processed during the cruise using the *SeaBird SBE Data Processing* software, version 7.26.7.129. The preliminary data taken from the downcast of each CTD profile were binned at 1 dbar resolution and sent on a daily basis during the cruise in near-real-time to the Maritime Data Centre at BSH, Hamburg, Germany and there were uploaded to the CrossDataPortal (https://cdp.srx.bsh.de), the open data portal of BSH, from where the data are available to the public. In total, near-realtime data for 97 CTD profiles were submitted and published during the cruise.

Pre-processing showed a better performance of the secondary temperature/conductivity sensor pack (TC2) for most of the cruise. CTD data of profiles #037/GN026A and #038/GN027 showed unusual peaks/signals after binning, which were not obvious in the initial raw data resulting in large differences between the sensor packs. Both profiles needed further post-processing before publishing.

Due to strong currents on station #090/GN053A located south of the Shetland Islands, the water sampler carrying the CTD unit was not in a straight vertical position during the cast. The altimeter was looking to the side, so lowering of the water sampler was stopped at a safety distance to the bottom. Due to the currents, the water sampler and the CTD were lifted during bottle stops and thus, the bottom samples were not taken at the deepest part of the profile. Nevertheless, processed data showed good quality as the water column was well mixed from the surface into depths.

Overall, the performance of the CTD sensor unit during the cruise was good. Several profiles showed larger spikes most times within the gradients or layers of high biological activity, which might have let to clogging of one or both sensor packs. More spikes were observed under bad weather conditions as was expected. Figure 5.3 shows a typical CTD cast conducted at favourable weather conditions, while Figure 5.4 shows an example of a cast impacted by rough weather conditions.

Stations #029/GN022 and #082/GN056 required a second CTD cast. The computer used for the data recording came to an unexpected malfunctioning in the first case, while the termination of the conducting wire that provided the power supply to the CTD system was faulty in the second case.

The supplementary *SBE 35* temperature sensor was read out after every station and compared to CTD-derived temperature recorded at the time of closing the Niskin bottles during the upcast. Data was downloaded directly from the sensor using the software *SeaTerm*, version 1.59. Temperature differences between the systems were within a range of ±0.03°C for 90% of the *SBE35* measurements. Bottles were often closed in layers with high temperature gradients, which can explain the high range of differences. The median of temperature differences over all data is -0.0016°C, which is within the range of the instrument uncertainties.

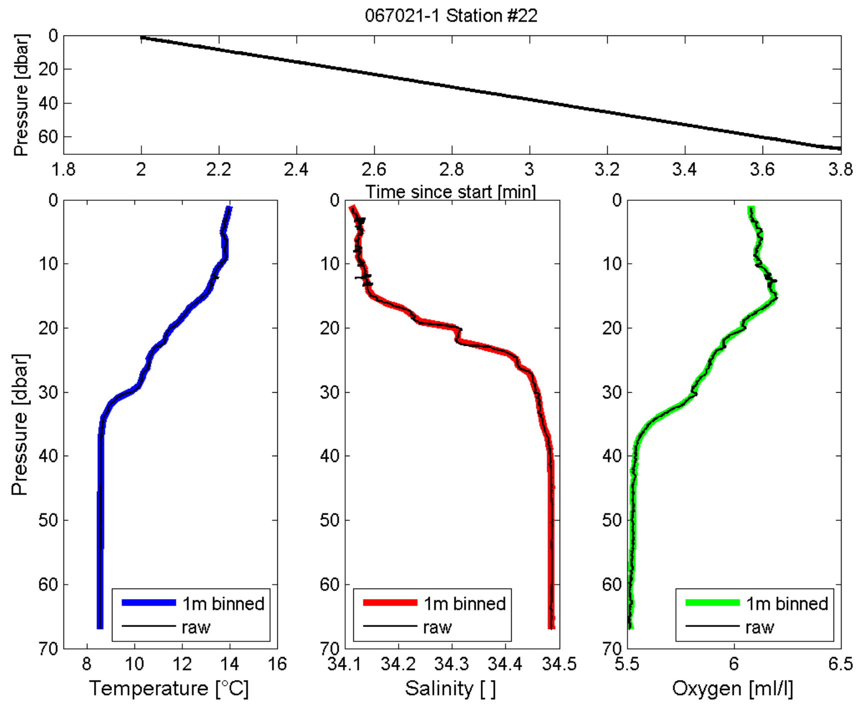

Figure 5.3. *Profile of CTD station #022/GN018A obtained during comfortable weather conditions (calm sea state).*

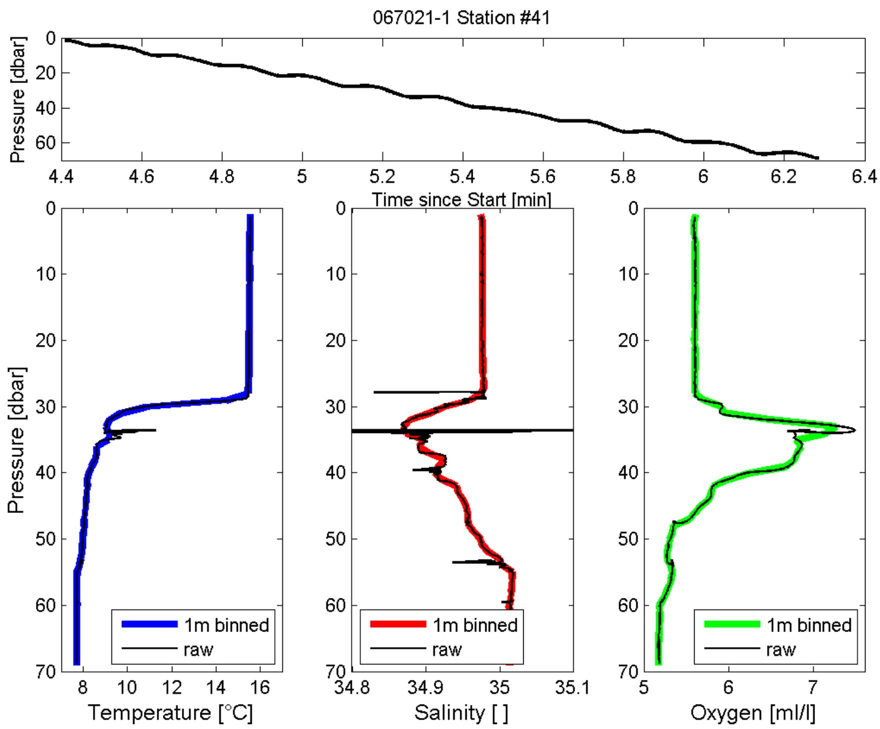

Figure 5.4. *CTD profile from station #041/GN029 obtained during bad weather condition (strong wind and high waves). Ship movement can be seen in the pressure time series of the downcast (top panel).*

5.7 Post-Cruise Processing of CTD Data

Post-cruise comparisons were made between CTD sensor packs TC1 and TC2 and between CTD temperatures and a supplementary temperature sensor of type *SBE35* installed at the height of the Niskin bottles. Furthermore, a comparison between CTD salinities and AUTOSAL-derived salinities was performed (compare Tables 5.3 and 5.4 and Figures 5.5 and 5.6).

The following correction procedure is applied to temperatue and conductivity/salinity measurements as well as oxygen data:

- Assumed measurement accuracy: T-CTD: ± 0.002, C-CTD: ± 0.003, S: estimated: ± 0.004
- A temperature correction will be applied in case the temperature difference (CTD vs. *SBE35*) exceeds 2x 0.002 and/or the difference between temperature sensors T1 and T2 exceeds 2x 0.002.
- A conductivity correction will be applied in case the salinity difference (AUTOSAL vs. CTD) exceeds 0.003 and/or the difference between conductivity sensors C1 and C2 exceeds 2x 0.003.
- The random error of oxygen samples obtained from titration is approximately 1%. Corrections are made if the oxygen difference (bottle vs. CTD oxygen) exceeds 1%.

Post-cruise quality control showed that differences between TC sensor pairs were small. All comparisons revealed small differences, which were within the error bounds and were slightly smaller for temperature, conductivity and salinity from the secondary sensors. In summary, any post-cruise correction was not applied, and the temperature, conductivity and salinity data were made available with flag 1 (good data). The usage of the data from the secondary sensor pair (TC2) is recommended.

Sampling and titration of oxygen samples was performed on cruise *067I021-1* to the North Sea and on the subsequent cruise *067I021-2* to the German Bight. Throughout both cruises, the CTD sensor setup remained the same, as did the use of the CTD-based *SBE43* oxygen sensor. Oxygen analysis, including a comparison between CTD-derived oxygen and bottle oxygen, was thus generated for the entire dataset of both cruises. This extended the time period of the data and enabled the temporal drift of the sensor to be more accurately recorded and corrected using a multi-parameter-fit (MPF) method. The analysed dataset comprised stations #002 – #100 of cruise *067I021-1* and stations #101 – #112, #114 – 138 and #140 and #142 of cruise 067I021-2. Obvious outliers were removed, and only data pairs with differences within ±1 standard deviation were included in the comparison. This reduced the dataset to 89% of the matching data pairs.

Regarding oxygen, corrections are made when the difference between the CTD-derived oxygen and titrated bottle samples exceeds 1% (titration measurement accuracy). For measured values of 5-6 ml/l, this threshold corresponds to 0.055 ml/l. Without correction, the average difference of the oxygen data is 0.0967 ml/l, i.e. greater than 1%; with correction, it is well below 1%. CTD oxygen was corrected according to:

O_{corr} (ml/l) = -0.888808751227 + 0.003882681122 * time + 0.021469570016 * oxygen (ml/l) + -0.000104482816 * pressure + 0.002460619138 * temperature

Oxygen saturation was recalculated afterwards. The corrected CTD-derived oxygen data was given the quality flag 1 (good data). Any quality control of fluorescence and turbidity data was not performed. Thus, the respective data were made available with flag 0 (no quality control applied).

Salinity Difference AUTOSAL-CTD	All samples	All samples with differences < +/- 1 standard deviation	All samples with differences < +/- 1 standard deviation for the 2nd mean
AUTOSAL - TSC1			
Number of data pairs	196	195	165
percentage		99.5%	84%
Mean difference	-0.0041	-0.0016	-0.0006
Median difference	-0.0015	-0.0014	-0.0009
Standard deviation	0.0358	0.0079	0.0036
AUTOSAL – TSC2			
Number of data pairs	196	193	161
percentage		98%	82%
Mean difference	-0.0030	-0.0007	-0.0005
Median difference	-0.0010	-0.0010	-0.0010
Standard deviation	0.0361	0.0072	0.0032

Table 5.3. *Results of the comparison between bottle salinity samples obtained from salinometer measurements (AUTOSAL) and conductivity/salinity recordings at the time of closing the Niskin bottles, the latter obtained from the two CTD sensor packs (TSC1 and TSC2).*

Temperature Difference SBE35 - CTD	All samples	All samples at a pressure > 3.8 dbar	All ± 1 standard deviation
SBE35 - T1			
Number of data pairs	673	607	557
percentage		90%	83%
Mean difference	0.0028	0.0029	-0.0004
Median difference	-0.0016	-0.0015	-0.0016
Standard deviation	0.0312	0.0288	0.0068
SBE35 – T2			
Number of data pairs	673	607	549
percentage		90%	82%
Mean difference	0.0027	0.0026	-0.0003
Median difference	-0.0011	-0.0011	-0.0011
Standard deviation	0.0298	0.0251	0.0065

Table 5.4. *Results of the comparison between temperature recordings from a supplementary SBE35 sensor installed at the height of the Niskin bottles at the time of closing the bottles, and from the two CTD-based sensors, T1 and T2.*

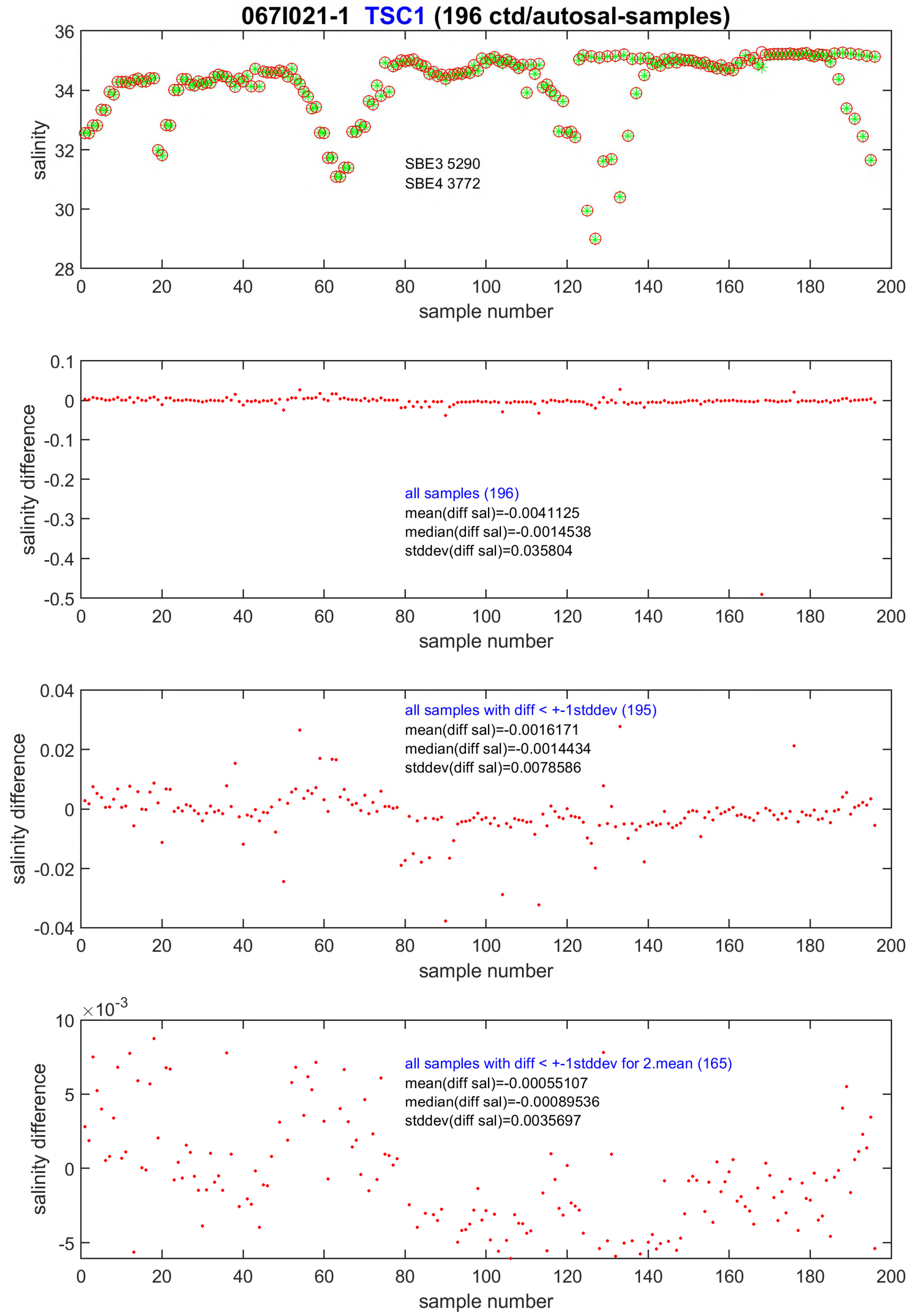

Figure 5.5. *Differences between bottle salinity samples measured with an AUTOSAL salinometer and CTD-derived salinity samples at the time of closing the Niskin bottles, here CTD sensor pack TSC1.*

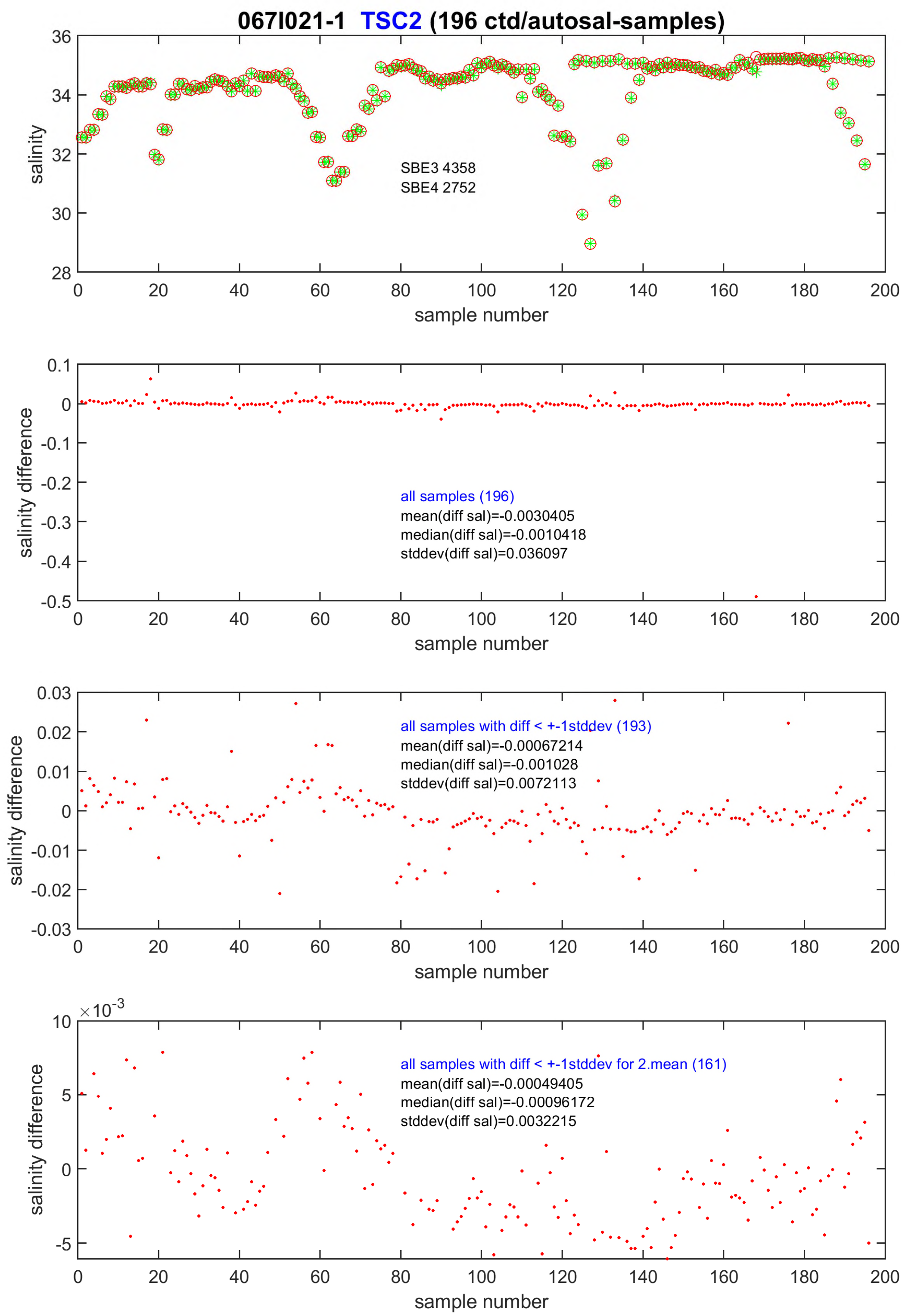

Figure 5.6. *Differences between bottle salinity samples measured with an AUTOSAL salinometer and CTD-derived salinity samples at the time of closing the Niskin bottles. Data as in Figure 5.5, but here shown for CTD sensor pack TSC2.*

5.8 Secchi Disc, Chlorophyll-a and Phytoplankton Sampling

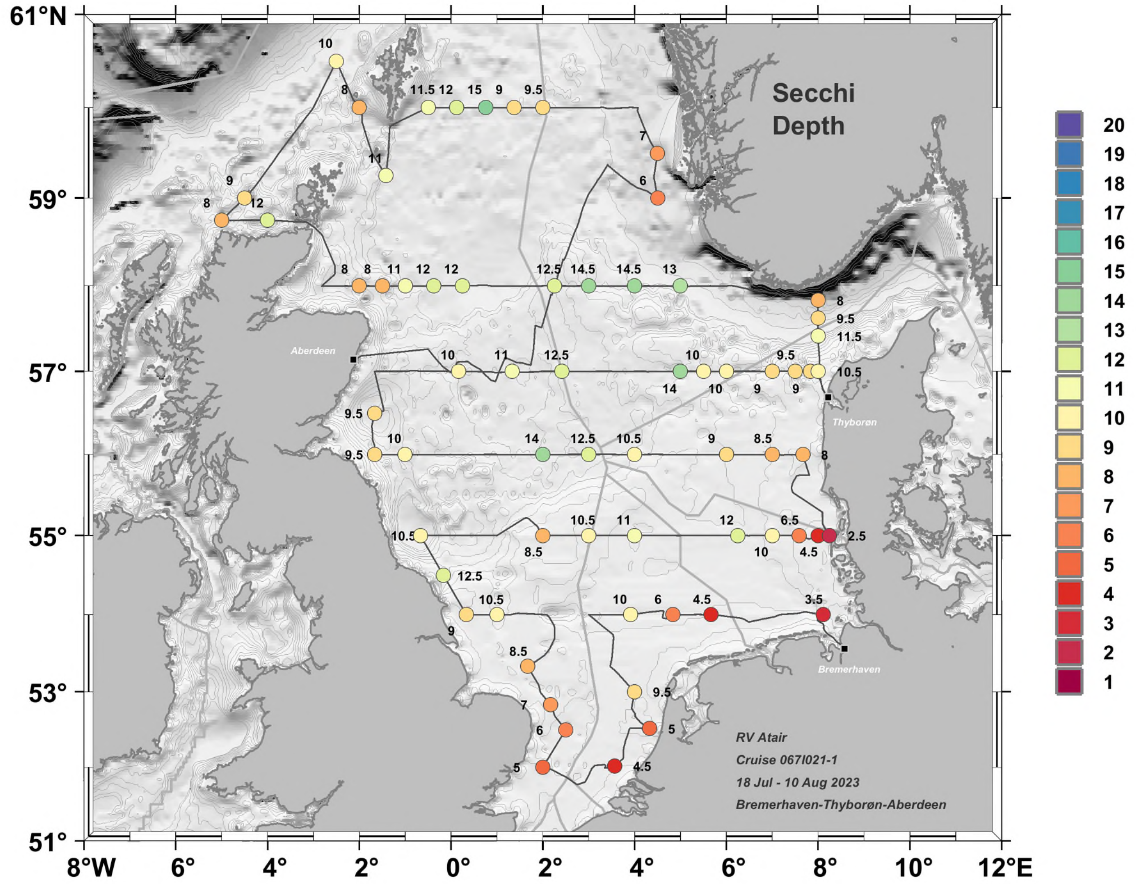

Figure 5.7. *Secchi depths observed during cruise 067I021-1, summer 2023.*

<u>Secchi Depth</u>

The Secchi depth is a measure for the transparency or clarity of the oceanic water column. Values typically range from < 1 m near estuaries to > 12 m in the open North Sea. Secchi depth measurements follow instructions described in *BSH (2007)*. The Secchi depth was measured using a Secchi disc, a white-painted metal plate with an additional weight, both connected to a rope. The rope in turn was connected to a mobile winch installed on the port side of the vessel. At daylight stations, the Secchi disc was lowered into the surface layer of the ocean until it was no longer visible. Coloured tapes at 0.5 m intervals along the rope mark every 0.5 m, 1 m, and 5 m. The mark on the rope closest to the sea surface represents the Secchi depth, i.e. the depth of transparency at that location. The accuracy of the Secchi depth observation is +/- 0.5 m. Figure 5.7 highlights the station locations and corresponding Secchi depths observed under daylight conditions during cruise *067I021-1*.

Chlorophyll-a Sampling and Filtration

To determine the chlorophyll-a content in the surface waters of the North Sea, water samples were taken during cruise *067I021-1* from the Niskin bottles closed at a depth of 5 m and filled into 3 l PE bottles. After sampling, the water sample was filtered using a low- pressure filtration system. Filtration was done through a glass fibre filter (ø = 47 mm and pore size 0.4µm) on a glass filter plate. For this purpose, the PE bottle was shaken at first to allow for homogensosation of the water sample. Then, a measured volume was filled into a filtration tulip, which was connected to a suction bottle. The volume to be measured was determined by the previously recorded Secchi depth, see Table 5.5. The exact sampling depth, the Secchi depth, the filtered volume and the room temperature were recorded. After filtration, the glass fibre filter with the sample residue was removed from the filtration tulip, folded twice and transferred to a PE centrifuge tube with a screw cap. This tube was wrapped in aluminium foil to avoid exposure to light. The sample was labelled by assigning a unique sample identification number similar to *Bedford* numbers, which was applied directly to the tube and the aluminium foil. The sample was then frozen and stored at -80°C to allow for later analysis in the home laboratory. One duplicate sample was analysed per day. On-board filtration was performed as described in *BSH (2022)*.

Figure 5.8 shows the location of stations with water sampling for subsequent chlorophyll-a determination. Corresponding water sampling was carried out on daylight stations with Secchi depth measurement. If there was a delay between collecting the water from the Niskin bottle and the filtration, the water sample was stored in the dark and cooled in the refridgerator.

Spectrophotometric analysis was carried out in the home laboratory after the cruise to determine the total chlorophyll-a content in seawater. The method follows *Jeffrey and Humphrey (1975),* and the phaeopigment content was determined according to *Lorenzen (1967)* and *Aminot & Rey (2001).* The interlaboratory performance study (QUASIMEME, R2023.2) for the parameter chlorophyll-a in seawater during the measuring period in the BSH laboratory was successfully. The resulting z-scores are 0.5 / 0.4 / 0.1. The mean range for the duplicates (19 samples) taken on cruise *067I021-1* was less than 0.02 µg/L CHLA.

Secchi Depth [m]	Required Volume [ml] for Filtration
0-2	up to 500, only for coastal stations
2-5	up to 1000
5-10	up to 1500
10-15	up to 3000

Table 5.5. *Secchi depth and corresponding sample volume required for the filtration of chlorophyll-a samples.*

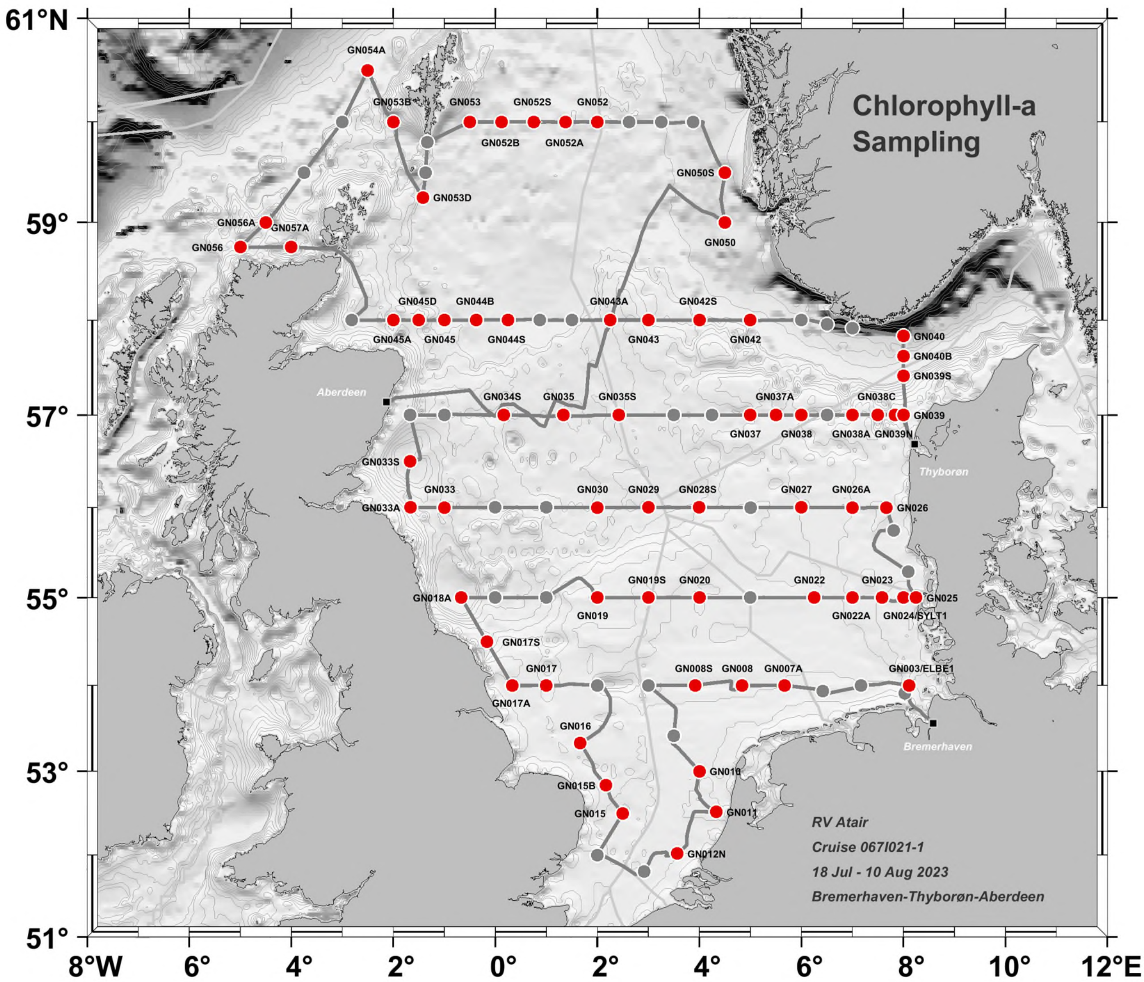

Figure 5.8. *Distribution of stations carried out during cruise 067I021-1 with water sampling and subsequent filtration for chlorophyll-a determination (red dots).*

The chlorophyll-a concentrations measured in the laboratory serve 1) as a rough measure of phytoplankton biomass and 2) are used for comparison with the chlorophyll-a concentrations determined by remote sensing (ground truthing).

<u>Phytoplankton Sampling</u>

Understanding the distribution and behaviour of plankton is key to deciphering the complex dynamics of marine ecosystems. The assimilation of satellite data bridges the gap between observation and theory. The *EnsAD* project aims to improve real-time forecasting capabilities for potentially problematic phytoplankton groups by integrating hyperspectral remote sensing data from the *EnMAP* and *PACE* satellites into biogeochemical models for the North Sea and Baltic Sea. In order to adapt the algorithms, the composition of the phytoplankton must be known during the satellites' flyover. For this purpose, the phytoplankton was collected and its taxonomic composition determined in the home laboratory.

During cruise *067I021-1*, water samples were taken at daylight stations with the purpose to determine the phytoplankton content in the surface layer of the North Sea, see Figure 5.9. The stations selected were consistent with those for Secchi depth observations and water sampling for chlorophyll-a analysis. For phytoplankton, 1 litre of seawater was taken from the Niskin bottles closed at 2.5 m, 5 m, 7.5 m and 10 m and placed in a glass bottle after rinsing the bottle three times with seawater. The resulting sample to be analysed was treated as a mixed sample from all four sampling levels plus a bucket sample taken directly at the sea surface. 200 ml of this sample was transferred to a smaller glass bottle using a graduated cylinder. Using a pipette, 2 ml of acidic Lugol's solution was added to the water sample in order to fix and preserve the phytoplankton samples during the field work. The glass jar was then sealed using a flexible parafilm and stored in the dark.

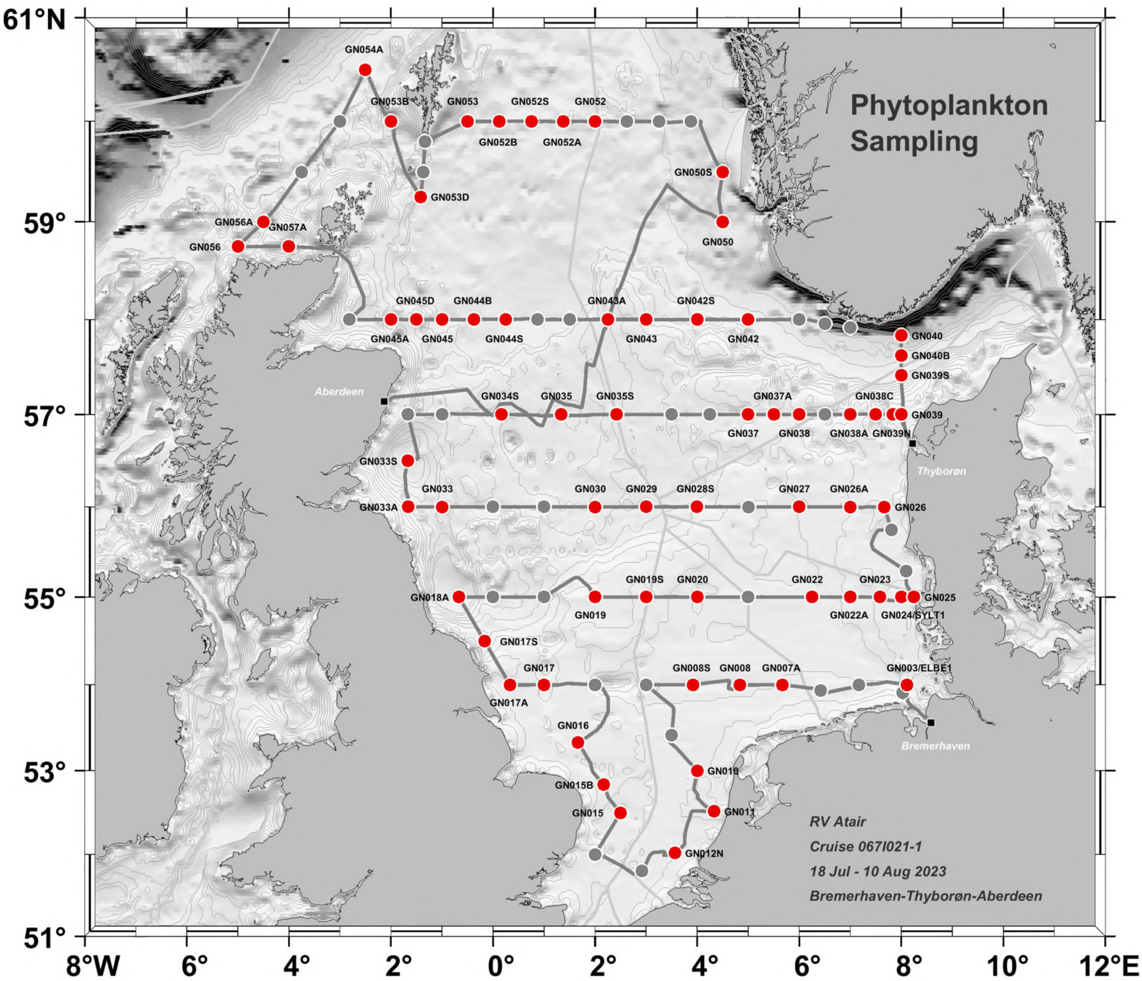

Figure 5.9. *Distribution of stations carried out during cruise 067I021-1 with phytoplankton sampling (red dots).*

Figure 5.10 presents an overview of the taxonomic composition and spatial distribution of phytoplankton as observed on the daylight stations of cruise *067I021-1*, summer 2023.

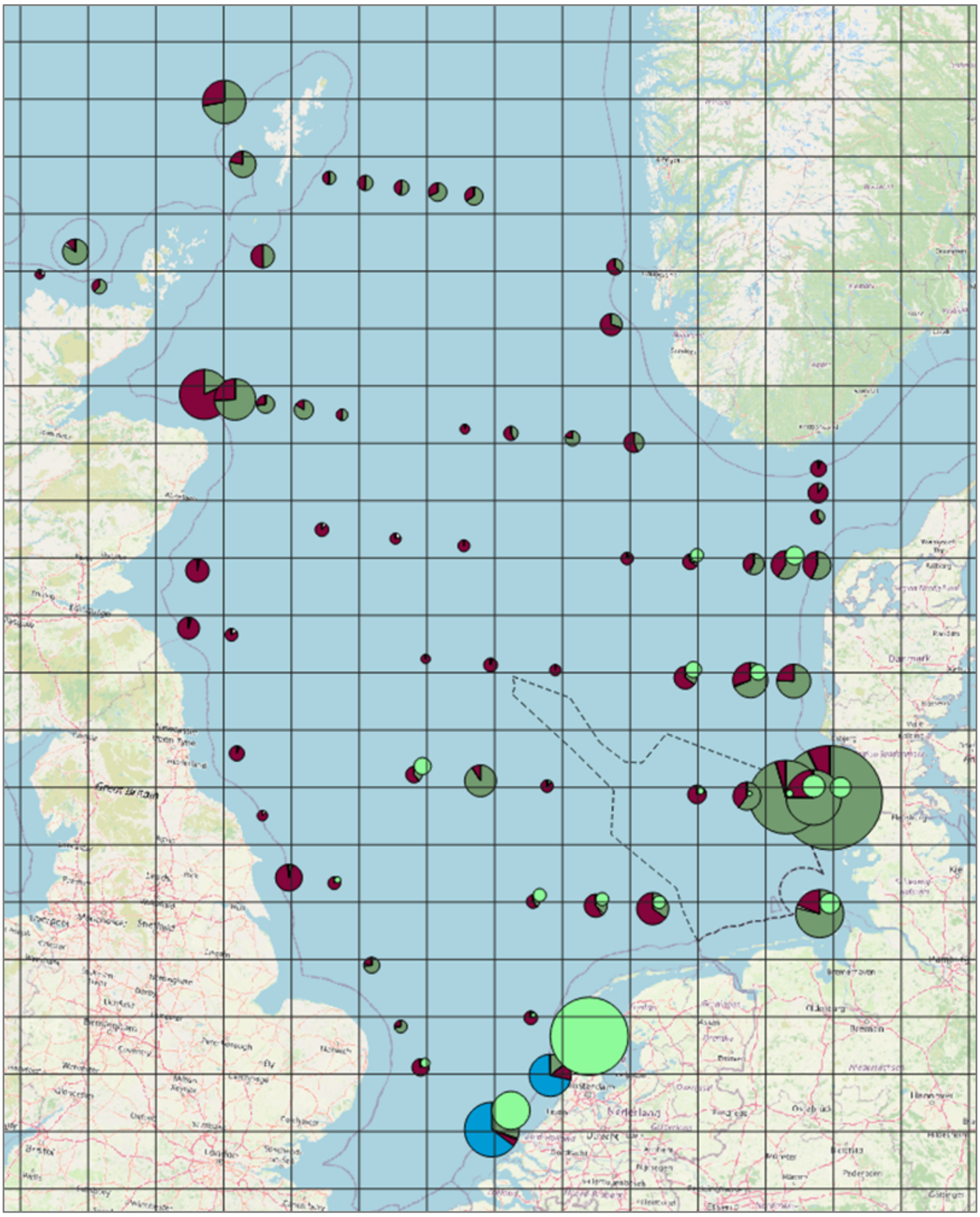

Figure 5.10. *Colour-coded main groups of phytoplankton based on biomass (µg C/L) at the phytoplankton sampling stations of cruise 067I021-1. Light green: Noctiluca spp.; dark green: Diatoms; dark red: Dinoflagellates; grey: Crypthophyta; blue: Haptophyta.*

6. Oceanographic Conditions in Summer 2023

The BSH produces and provides a comprehensive weekly analysis of sea surface temperatures (see https://www.bsh.de/EN/DATA/Climate-and-Sea/Sea_temperatures/Sea_surface_temperatures/sea_surface_temperatures_node.html). This approach combines all measurements collected from time series stations and ships with satellite data and uses statistical methods and spatial interpolation to generate a comprehensive data set. This contains estimates for the weekly mean values of sea surface temperature as a raster data set with a spatial resolution (pixel size) of 20 km x 20 km.

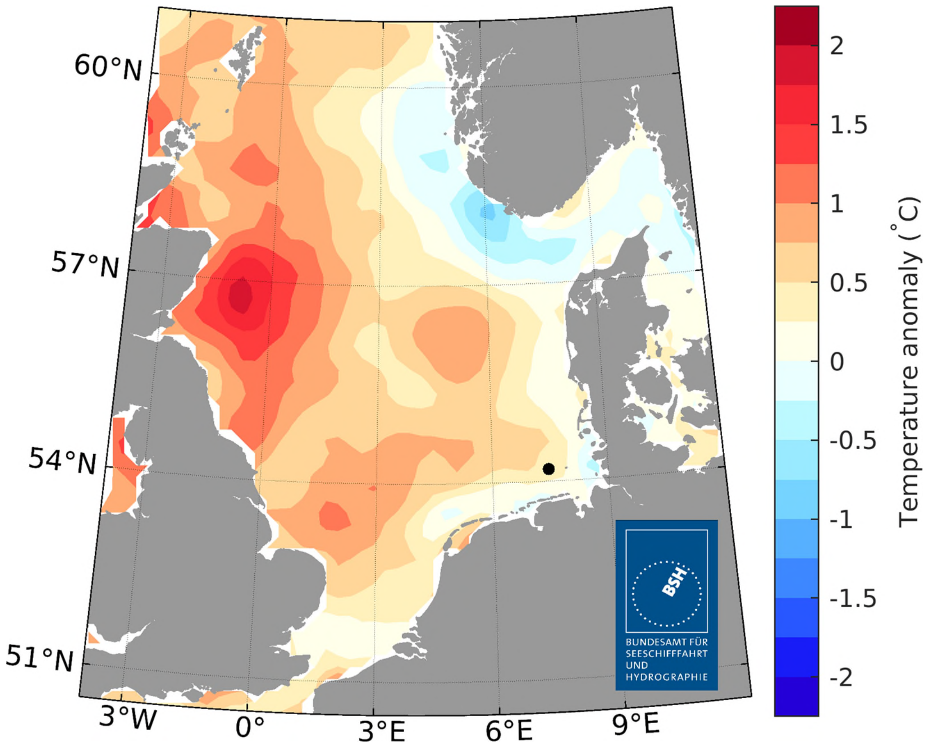

Figure 6.1. Spatial distribution of sea surface temperature (SST) anomalies for the summer of 2023 (June, July and August). Anomalies are shown relative to a climatological mean SST field comprising the summers of the years 1997-2021, i.e. 25 years. Source: BSH.

Information from this blended analysis SST analysis for the summer months of 2023 (June, July and August) reveals a region of pronounced warming in the western North Sea (Figure 6.1). The centre of this region was located at about 56°30'N off the British east coast and stretched from about 55°N towards the Orkney and Shetland Islands in the north. There, SSTs were about 0.75°C to 1.5°C warmer than the 1997-2021 climatological summer mean. Elevated surface warming (SST anomalies > 0.75°C) was also noteable west and north of the Dogger Bank as well as above it. The coastal regions surrounding the German Bight in the south and east did not show a comparable warming but rather normal conditions. The region of the Norwegian Trench off southern Norways was cooler than the climatological summer mean (~ -0.75°C).

A respective ranking map (Figure 6.2) demonstrates that the western North Sea between 56°N and 59°N succumbed to the warmest or second warmest summer conditions observed between 1997 and 2023. Conditions in the eastern half of the North Sea and regions surrounding the land masses of continental Europe were mostly normal.

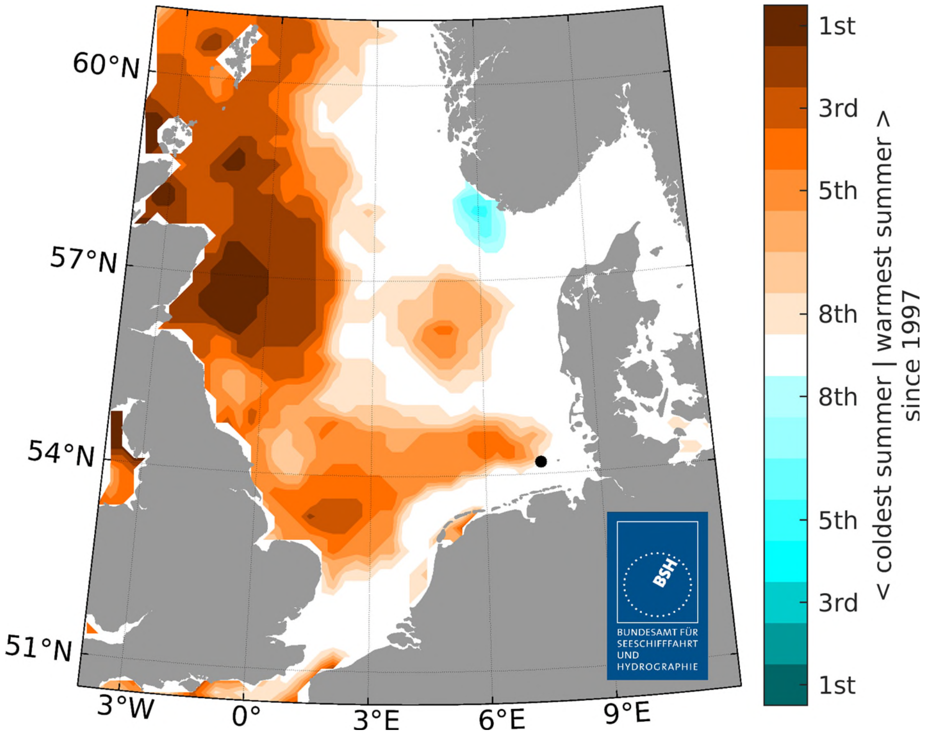

Figure 6.2. *Spatial distribution of the sea surface temperature (SST) ranking for summer 2023 (June, July and August), regionally indicating the nth coldest/warmest summer SST since 1997. Source: BSH.*

Figures 6.3 and 6.4 highlight the potential temperature obtained from CTD measurements during cruise *067I021-1* near the suface (5 dbar) and near the bottom. The respective temperatures are also compared to a long-term mean field comprised of CTD data from the summer months of the years 2000 to 2020 (*NSSS* surveys 2000 to 2020, except year 2019). Based on the ship observations, temperatures warmer than 18°C were prominent along the German, Dutch and Belgians coasts (Figure 6.3, left). A band-like pattern with cooler temperatures of < 15°C stretched along the eastern British coasts from the Shetland Islands to about 55°N. Also, the region east of the mouth of the Humber Estuary off the British coast showed a cool patch with temperatures < 15°C. The 16°C-isotherm showed a mostly meridional orientation north of 57°N and was located off western Norway. Between 57°N and 53°N, the orientation changed to northeast-southwest dividing the North Sea into a warmer half in the east and cooler half in the west. Temperature deviations from the long-term mean (Figure 6.3, right) reveal warmer conditions mostly in the northwestern part of the North Sea, west and southwest of the Dogger Bank and along the Belgian, Dutch and German coasts. The location of the warmest temperature deviation seen in the CTD data at 5 dbar matches the one seen in the SST anomaly distribution (Figure 6.1). Stronger cooling was observed off the western Danish coast and along the British coast.

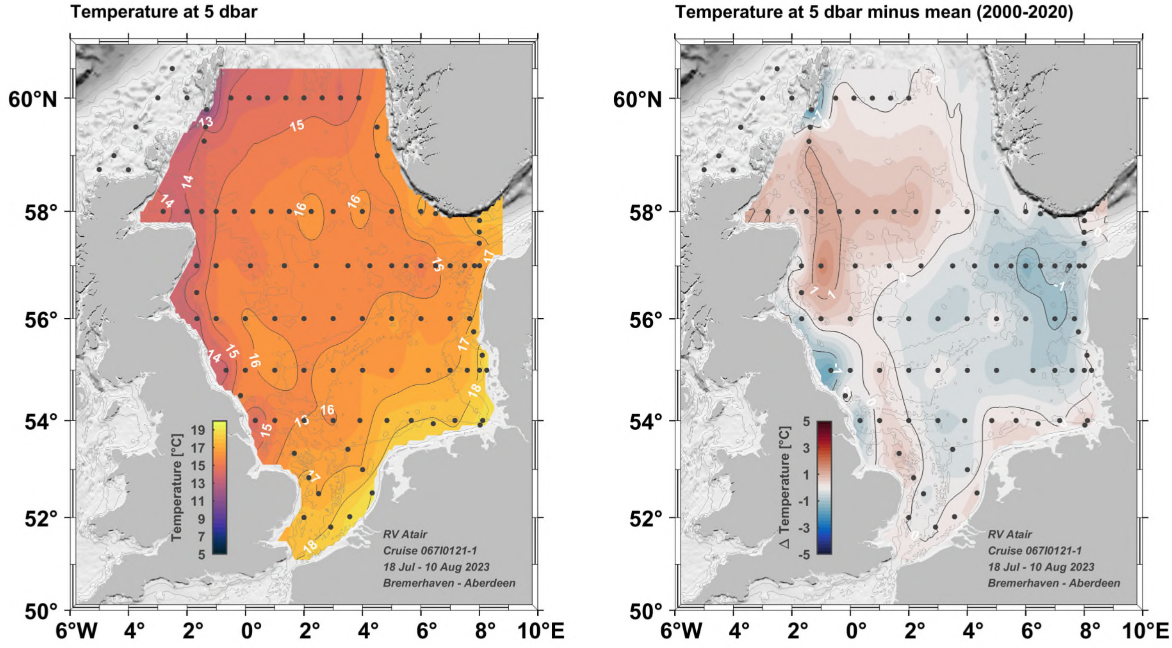

Figure 6.3. *CTD-derived spatial distribution for the potential temperature near the surface in summer 2023 (left) and respective temperature deviations (right) from a long-term mean, 20 years, comprising NSSS cruises of the years 2000-2020 (except 2019).*

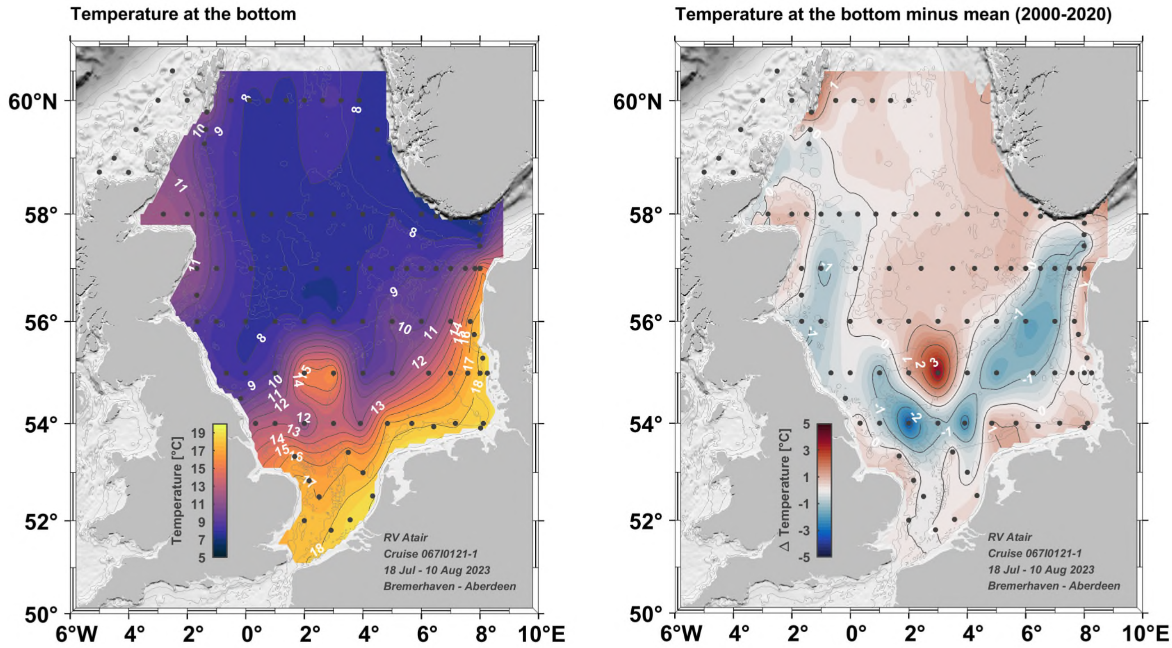

Figure 6.4. *CTD-derived spatial distribution for the potential temperature near the bottom in summer 2023 (left) and respective temperature deviations (right) from a long-term mean, 20 years, comprising NSSS cruises of the years 2000-2020 (except 2019).*

Bottom temperatures (Figure 6.4, left) are generally warmer south of 55°N, on the Dogger Bank and off the continental coasts compared to the central to northern North Sea due to shallower water depths. Bottom temperatures >18°C stretch along the Belgian, Dutch and German coast up to Denmark. The coldest bottom temperatures (< 8°C) are located in the Norwegian Trench or cover larger bottom areas of the central to northern North Sea (~56°-60°N, 0°-5°E). Bottom temperatures > 10°C stretch band-like along the eastern British coast from the Shetland Islands to 56°N.

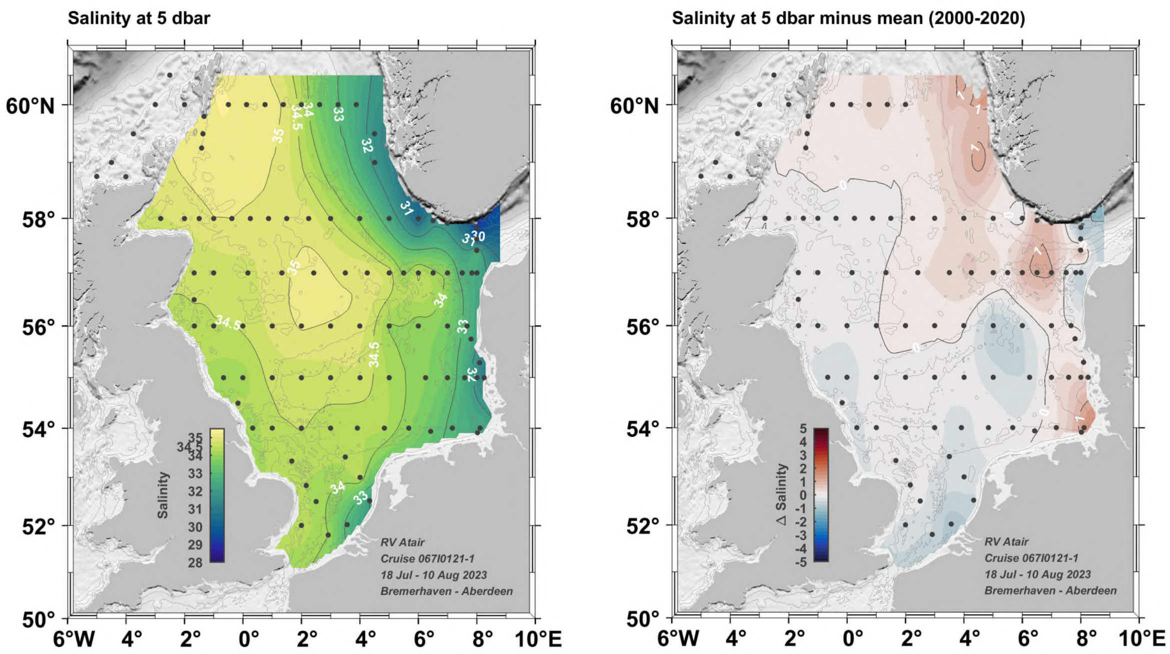

Figure 6.5. *CTD-derived spatial distribution for the salinity near the surface in summer 2023 (left) and respective salinity deviations (right) from a long-term mean, 20 years, comprising NSSS cruises of the years 2000-2020 (except 2019).*

In summer 2023, CTD-derived near-surface salinity > 35 was observed to appear in two separate patches (Figure 6.5, left). The larger patch was notable to the southeast of the Shetland Islands near 60°N and 59°N, with some saline signals appearing at 58°N. Due limited data available for the 59°N latitude in 2023, the connectivity between the Atlantic inflow near the Shetland Islands and spreading south until 58°N is less clear this year. The second patch, isolated from the northern patch, stretches across along ~4°E between 57°N and 56°N. The isohaline 34.5 formed a horseshoe pattern from about 57°N off the British coast to 54°N south of the Dogger Bank until 60°N, 4°E in the north of the North Sea. Near-surface water inside this horse-shoe shows salinities ranging from>= 34.5 to 35.2 with the highest values observed south of Shetland and along 59°N and 60°N. Coastal salinities off the eastern British coast fall well below 34.5 in a band-like pattern between ~57°N and the English Channel. Coastal salinities on the continental side of the North Sea show a local minimum near and north of the Rhine delta (S < 33) and off the North Frisian German and Danish coasts (S < 32). The Norwegian Trench shows the fresh Baltic outflow close to the Norwegian coast with salinity mostly < 32 and a local minimum with S < 30 directly south of Norway. Surface salinity deviations of summer 2023 from the long-term mean field point to the North Sea having been divided into a fresher half in the south and southwest and a more saline half in the east to northeast (Figure 6.5, right).

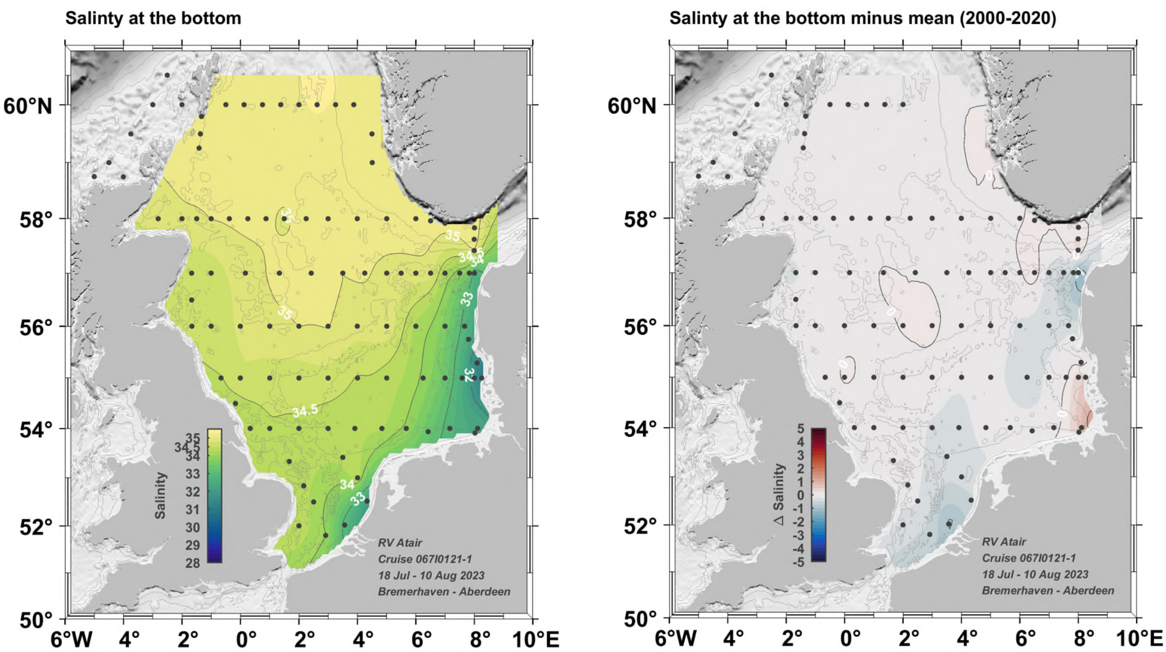

Figure 6.6. *CTD-derived spatial distribution for the salinity near the sea bottom in summer 2023 (left) and respective salinity deviations (right) from a long-term mean, 20 years, comprising NSSS cruises the years 2000-2020 (except 2019).*

Regarding the bottom layer (Figure 6.6, left), salinity > 35 fills most of the North Sea bottom regions near 58°N and to the north of it and reaches as far south as 56°N in the central part of the North Sea. Highest salinities (S > 35.2) appear along 60°N, near Shetland and near the western edge of the Norwegian Trench. Salinity as high as 34.5 spreading from the north is observed until 54°N. A local maximum with S = 34.60 north of the River Thames outlet points to traces of saline water entering the North Sea via the English Channel. Due to missing data in the English Channel south of 52°N, this signal cannot be further explored. Fresh salinity < 32 stretches along the western German and Danish coasts clearly pointing to the impact of freshwater runoff coming from continental rivers like Elbe or Weser. Bottom salinity deviations of summer 2023 from the long-term mean field show a freshening in the English Channel and off Jütland as well as more saline conditions near the outlet of the Elbe River.

Figures 6.7 and 6.8 present temperature and salinity along coast-to-coast sections following the latitudes 60°N, 58°N, 57°N, 56°N, 55°N and 54°N. Due to the varying water depths from the deep northern North Sea to the shallow southern North Sea, the lower part of the water column is typically colder in the north. The water column is typically more homogeneous in the south and becomes increasingly stratified in temperature towards the north. The input of Atlantic Water across the northern boundaries of the North Sea and its subsequent propagation within the North Sea is obvious through salinities exceeding 35 and in summer 2023 reaches as far south as 56°N.

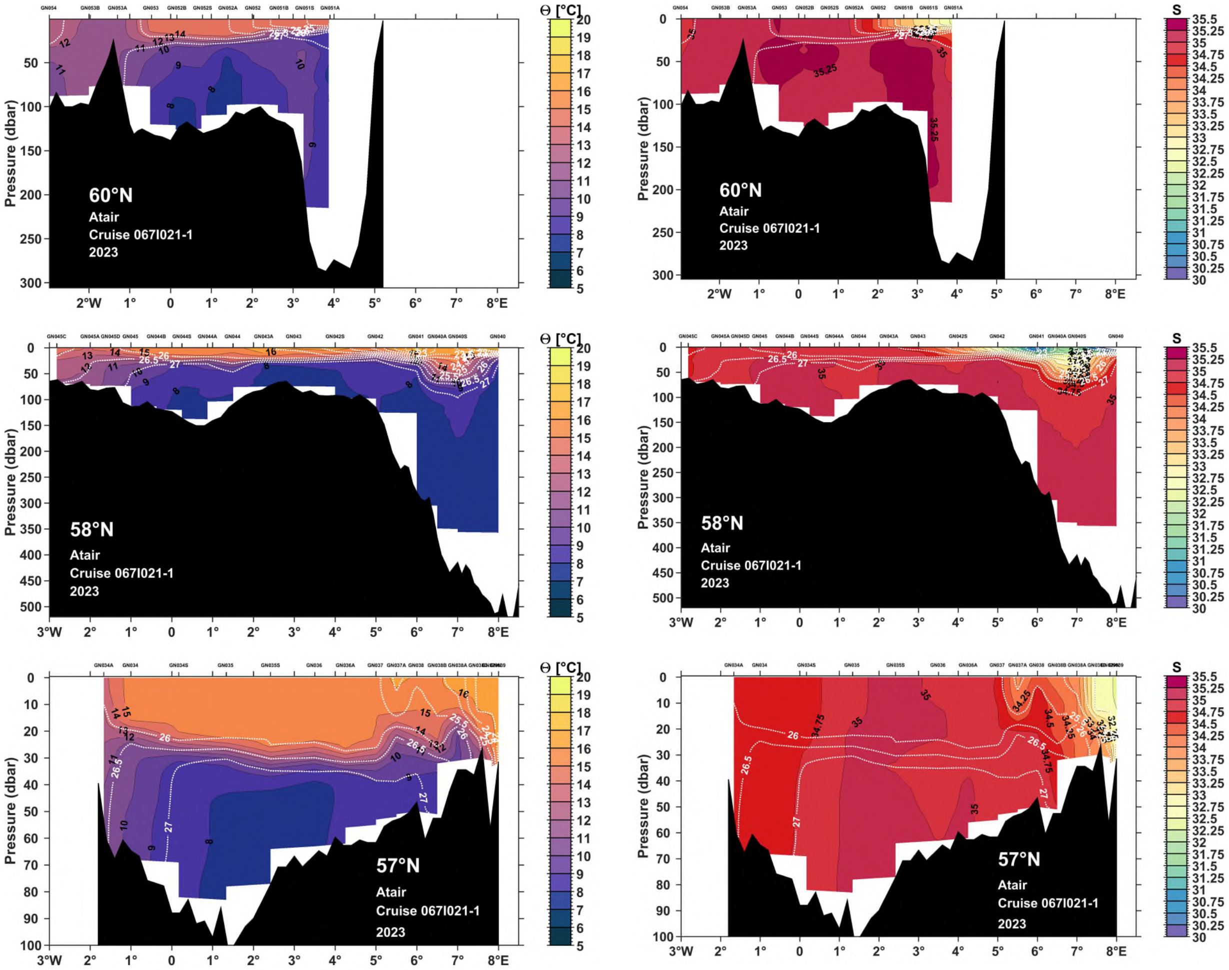

Figure 6.7. *Potential temperature [°C] (left) and salinity (right) along 60°N, 58°N and 57°N (from top to bottom) as observed during cruise 067I021-1, summer 2023. Superimposed white contours highlight selected* σ_θ*-isopycnals.*

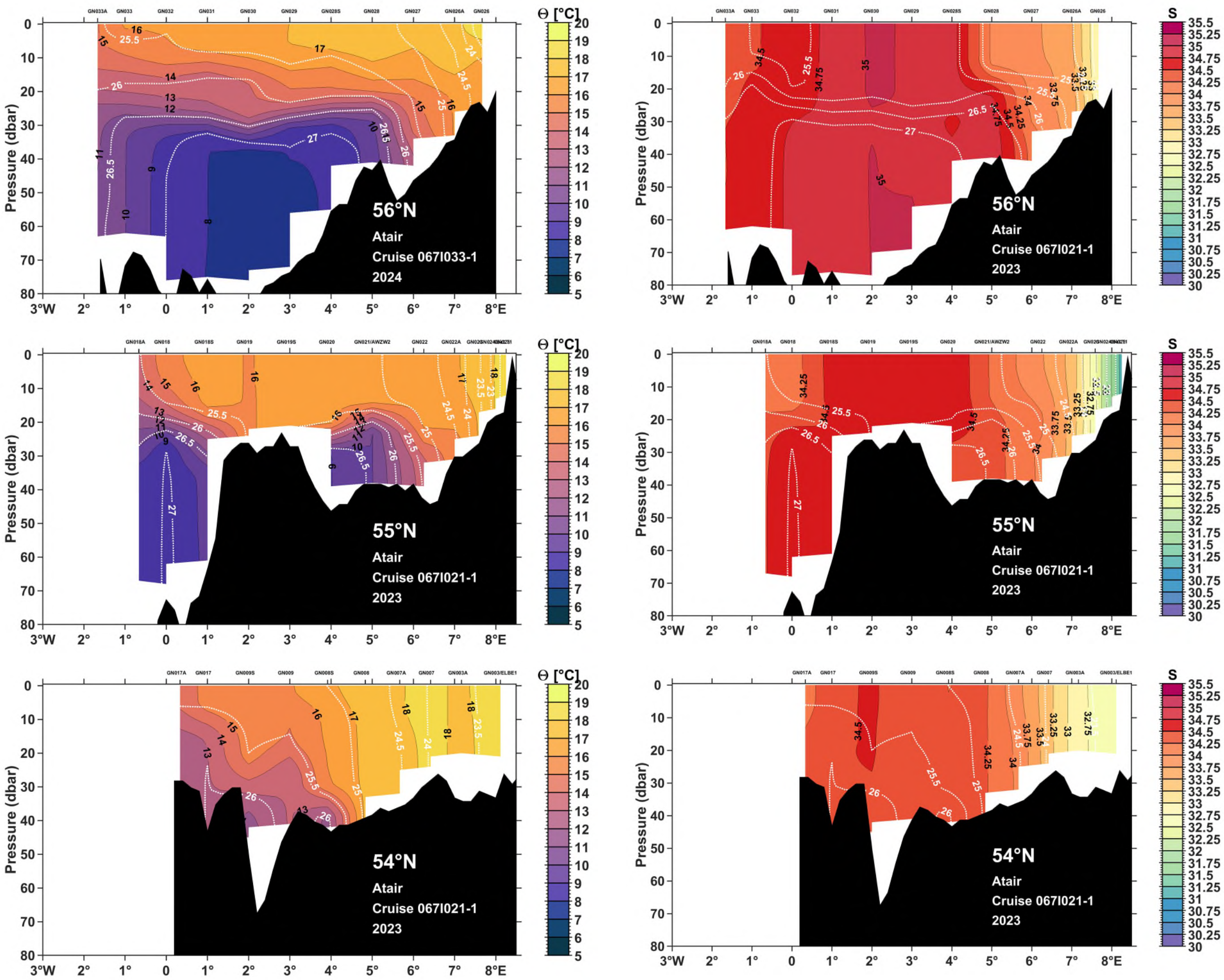

__Figure 6.8.__ Potential temperature [°C] (left) and salinity (right) along 56°N, 55°N and 54°N (from top to bottom) as observed during cruise 067I021-1, summer 2023. Superimposed white contours highlight selected σ_θ-isopycnals.

7. Underway Measurements

A variety of routine underway measurements were carried out during cruise *067I021-1*. Among the acquired data of interest were navigational information, near surface hydrography (temperature, conductivity, and thus salinity) measured by the vessel's thermosalinograph (TSG), near-surface fluorescence and turbidity obtained from a dual-wavelength *ECO* sensor attached to the TSG system, as well as meteorological parameters and water temperature recorded by the weather station operated by the *German Weather Service* (DWD) under the identifier *CVTKCAL*. Navigational and meteorological data was recorded from the beginning of the cruise on, recording of additional underway data was interrupted during the port stay in Thyborøn, Denmark, and resumed afterwards. Data was logged in time steps of 1 sec by the vessel's DSHIP system. All underway data relevant to this cruise were exported from the DSHIP database on a daily basis. Water depths were measured by a single-beam echosounder along the cruise track and on hydrographic stations. Depths provided by the vessel's echo-sounding device result in water depths when the vessels's draft of 5 m is added. Any further processing or quality control of water depth data was not carried out.

7.1 Ship's Meteorological Station

The autonomous weather station installed aboard *RV ATAIR* and operated by the DWD automatically records every second all meteorological standard parameters like wind speed and direction, air temperature and air pressure, relative humidity and surface water temperature and others. While corresponding data is sent directly to the Global Telecommunication System (GTS), it is also fed into the DSHIP database. Figure 7.1 provides an overview on the meteorological conditions encountered during cruise *067I021-1*. Raw data was smoothed by applying a moving median filter. Shortly before the port stay in Thyborøn, Denmark, on 30 Jul 2023 after 11:56 UTC, the DSHIP system showed an increasing number of missing values in the meteorological and navigational data recording. After resetting the DSHIP system and restarting necessary drivers (31 Jul 2023), data quality was improved again.

The average air temperature throughout the cruise was 14.9°C, but temperatures ranged from 9.9°C to 24.1°C while at sea. Maximum water temperatures exceeded 20°C right at the start of the cruise, minum water temperatures were 11.7°C, the average was 16.6°C. Average air pressure was 1006.3 hPa, and pressures ranged from 992.8 hPa to 1019.8 hPa. Notable periods of absolute wind speeds exceeding 7 Bf were observed on 25/26 July 2023, on 03/04 August 2023, and between 07 and 09 August 2023. The average wind speed throughout the cruise was 8.14 m/s, which corresponds to a wind strength of 5 Bf. The maximum wind speed was 26.6 m/s, corresponding to 10 Bf. Figure 7.2 displays the spatial distribution of absolute wind speeds and directions (15 min average values) along the cruise track. The high wind speeds (> 9 Bf) caused by a pronounced storm system encountered off Norway near the end of the cruise finally resulted in the cancellation of the remaining station program.

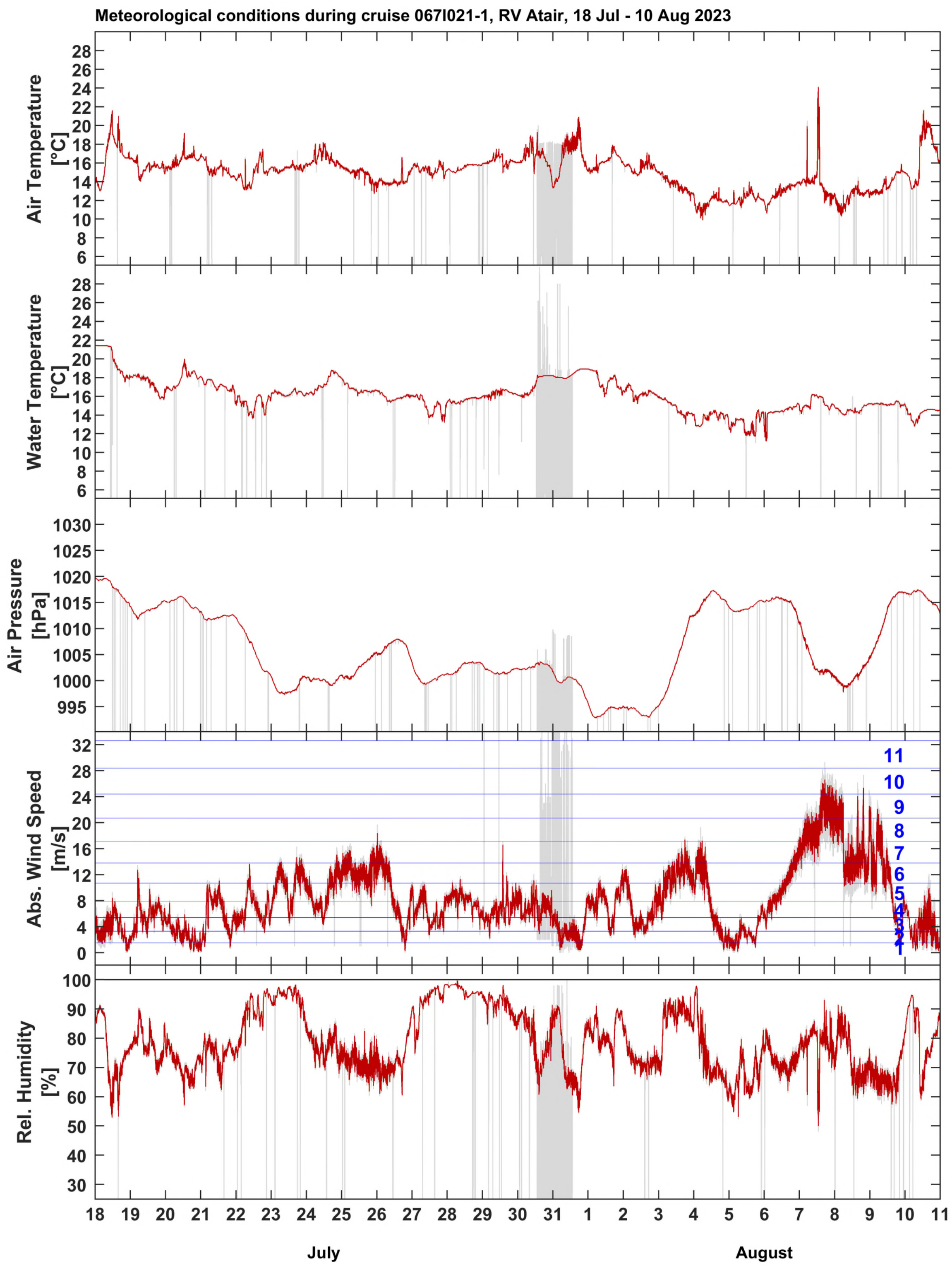

Figure 7.1. *Meteorological conditions observed during 18 July and 10 August, 2023, cruise 067I021-1. From top to bottom: Air temperature, near-surface water temperature, air pressure, absolute wind speed and relative humidity. Blue horizontal lines and labels on the right side of the figure indicate absolute wind speeds reported on the Beaufort scale. Grey: original data including missing values and outliers, red: smoothed data by applying a moving median filter.*

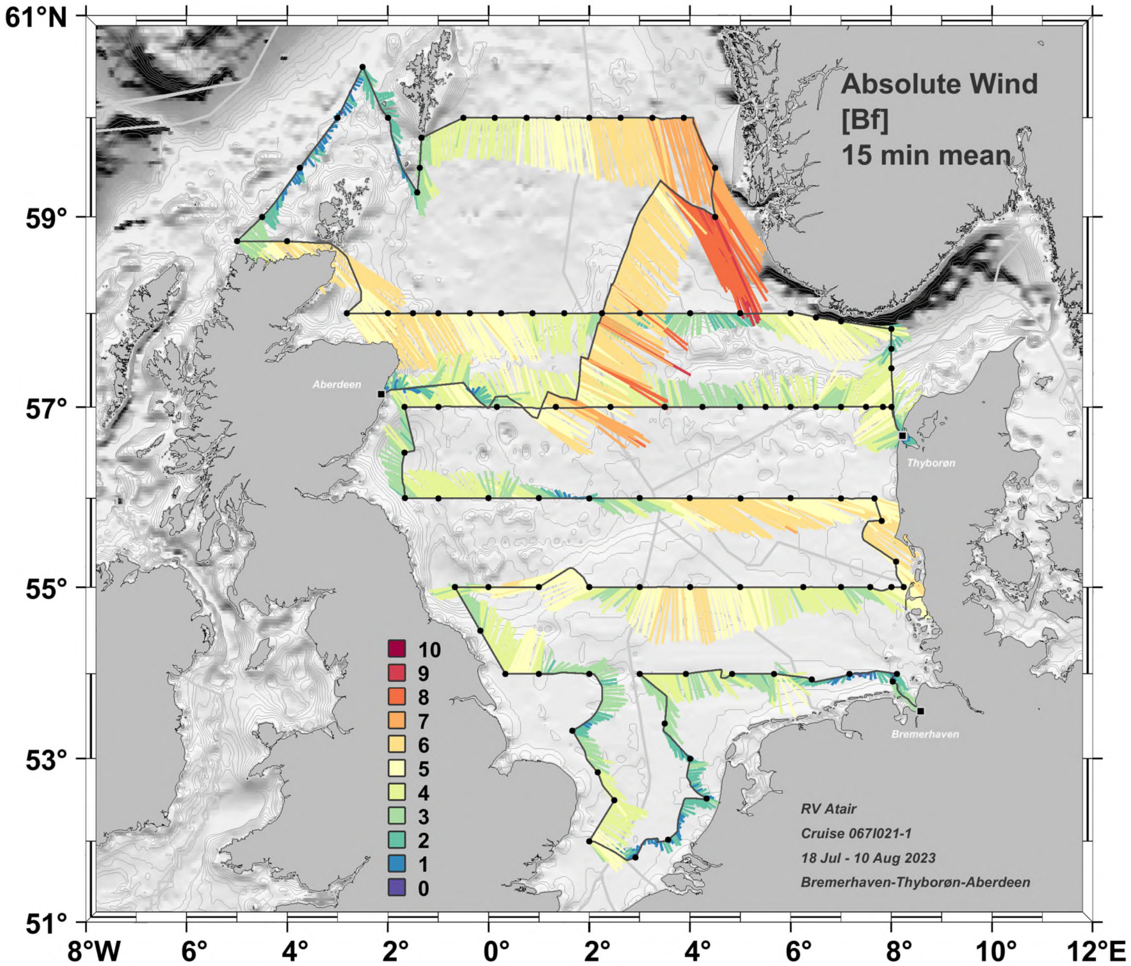

Figure 7.2. *Spatial distribution of the absolute wind strength and direction during cruise 067I021-1. Wind information is reported on the Beaufort scale (see colour bar) and averaged over 15 min intervals. The stick orientation denotes the wind direction.*

7.2 Thermosalinograph and Fluororescence & Turbidity

The thermosalinograph (TSG) system aboard *RV ATAIR* is operated as a throughflow system with the pure seawater inlet installed in the vessel's hull at a depth of 4 m. It consists of a *SBE21 Seacat thermosalinograph* device delivering near-surface conductivity and internal temperature measurements that are matched with an additional external temperature sensor of type *SBE38* located near the water inlet. Next to the TSG system, a dual-wavelength sensor of type *WET Labs Environmental Characterization Optics* (ECO) is installed delivering near-surface underway measurements for fluorescence and turbidity through optical measurements at fixed wavelengths. Table 7.1 provides an overview on sensor specifications. Data are recorded at time steps of 10 sec.

In order to check on quality performance of the TSG system, water samples were taken once a day directly from the TSG system and analysed with an *AUTOSAL* salinometer. Standard operational procedures (SOP) to assess the data quality of the near-surface temperature and conductivity/salinity measurements from the TSG system installed aboard *RV ATAIR* are presently under development on a national level and carried out in collaboration with the *German Marine Research Alliance* (DAM). Once the SOP have been implmented, and the data quality control has been finalised and documented, resulting data will be made publically available via submission to the PANGAEA database (https://www.pangaea.de). Regarding the dual-wavelength ECO sensor data for fluorescence and turbidity, there are not yet any defined SOP, and any data quality check is presently not carried out regarding near-surface mesurements for fluorescence and turbidity.

Sensor Device	Sensor Type	Serial Number	Calibration Date
SBE21	thermosalinograph, conductivity and internal temperature	3469	01 Jun 2023
SBE38	external temperature	0363	31 May 2023
WetLabs ECO FLNTURT	fluorescence and turbidity	FLNTURT-5883	---

Table 7.1. *Sensor specification of the Thermosalinograph/fluormeter system operated during cruise 067I021-1.*

Figures 7.3 provides an overview on the temporal evolution of the TSG/ECO-sensor-derived properties. TSG-derived temperature at a depth of 4 m ranged from 11.3°C to 19°C and was on average 15.8°C. TSG-derived salinity ranged from 27.59 to 35.24 and was on average 33.97. Fluorescence ranged from 0.17 µg/l to 4.17 µg/l and was on average 0.72 µg/l. Turbidity ranged from 0.17 NTU to 4.33 NTU and was on average 0.38 NTU. Figures 7.4 to 7.7 show spatial distributions of the respective near-surface temperature, salinity, fluorescence and turbidity.

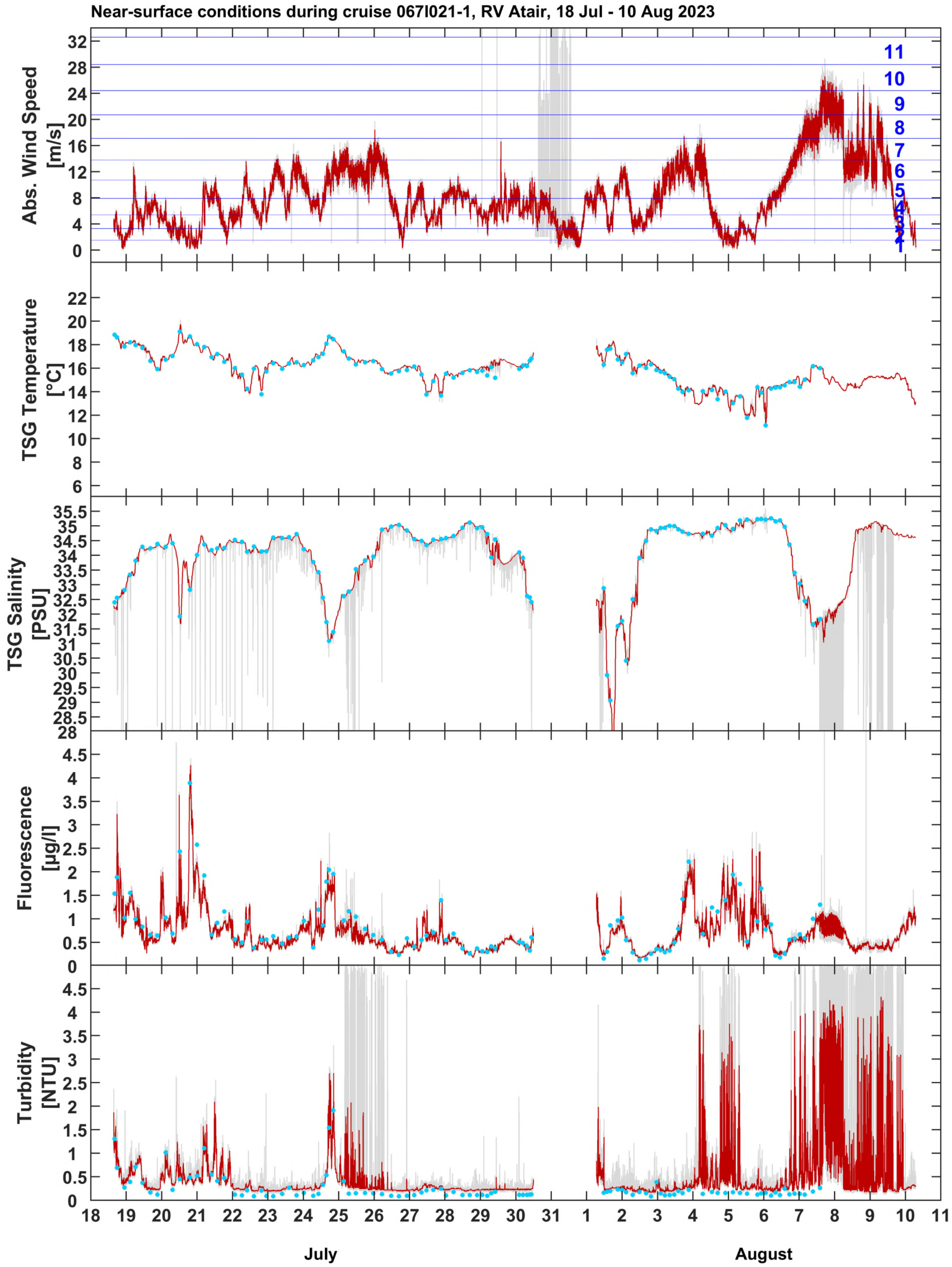

__Figure 7.3.__ Temporal evolution of absolute wind speed, TSG-derived near-surface (4 m) temperature, TSG-derived near-surface salinity, fluorometer-derived near-surface fluorescence, and fluorometer-derived near-surface turbidity (from top to bottom) recorded during cruise 067I021-1. Grey: original data including outliers, red: smoothed data by applying a moving median filter. Lightblue dots: CTD-derived values from a 4 dbar level. CTD data was no longer available after late 07 Aug 2023.

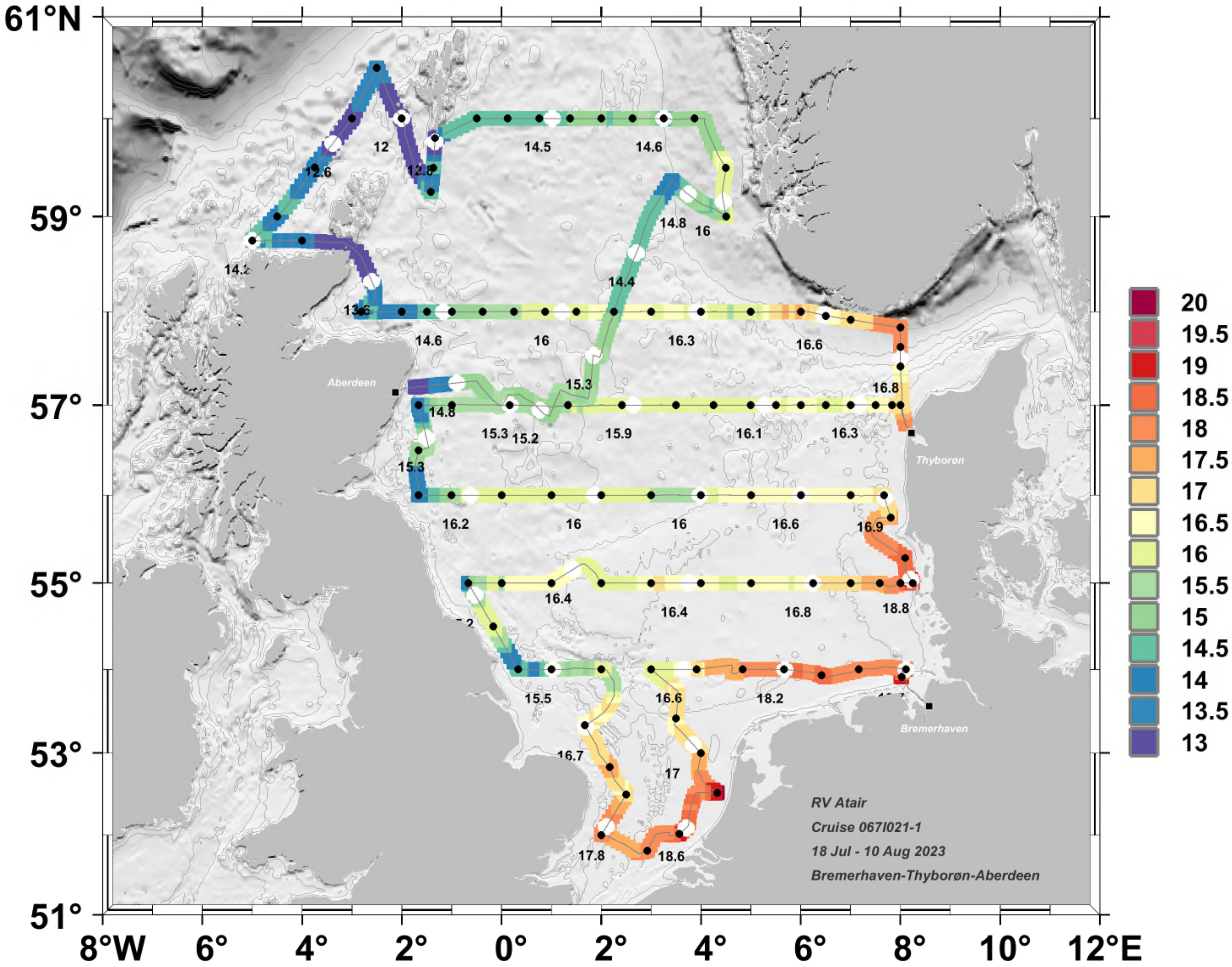

Figure 7.4. *Spatial distribution of the near-suface temperature during cruise 067I021-1 obtained from the TSG system and displayed as 30 min averages. Colours denote temperatures in the range 13°-20°C, individual values are highlighted every 12 hours.*

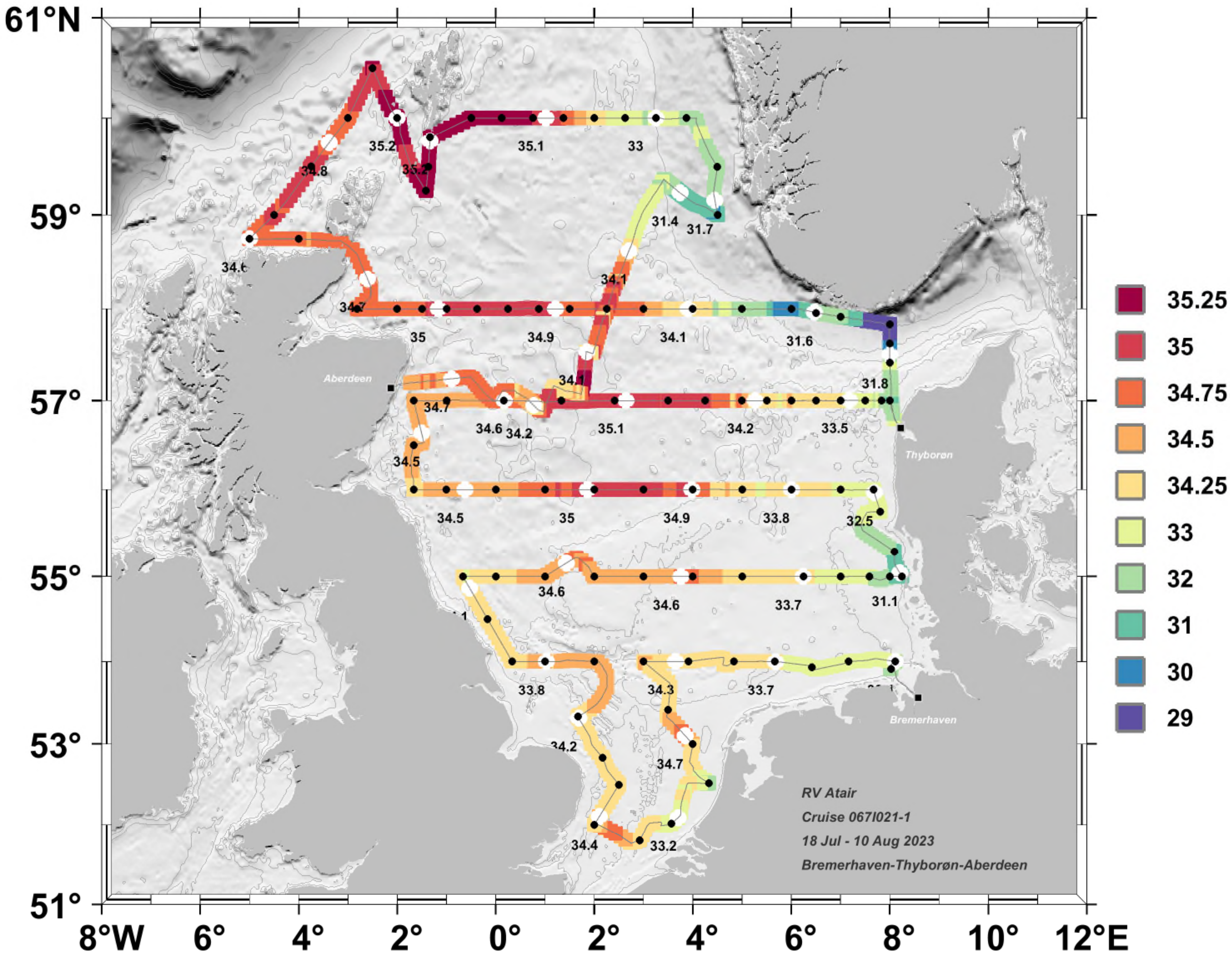

Figure 7.5. *Spatial distribution of the near-suface salinity during cruise 067I021-1 obtained from the TSG system and displayed as 30 min averages. Colours denote salinities in the range 29-35.25, individual values are highlighted every 12 hours.*

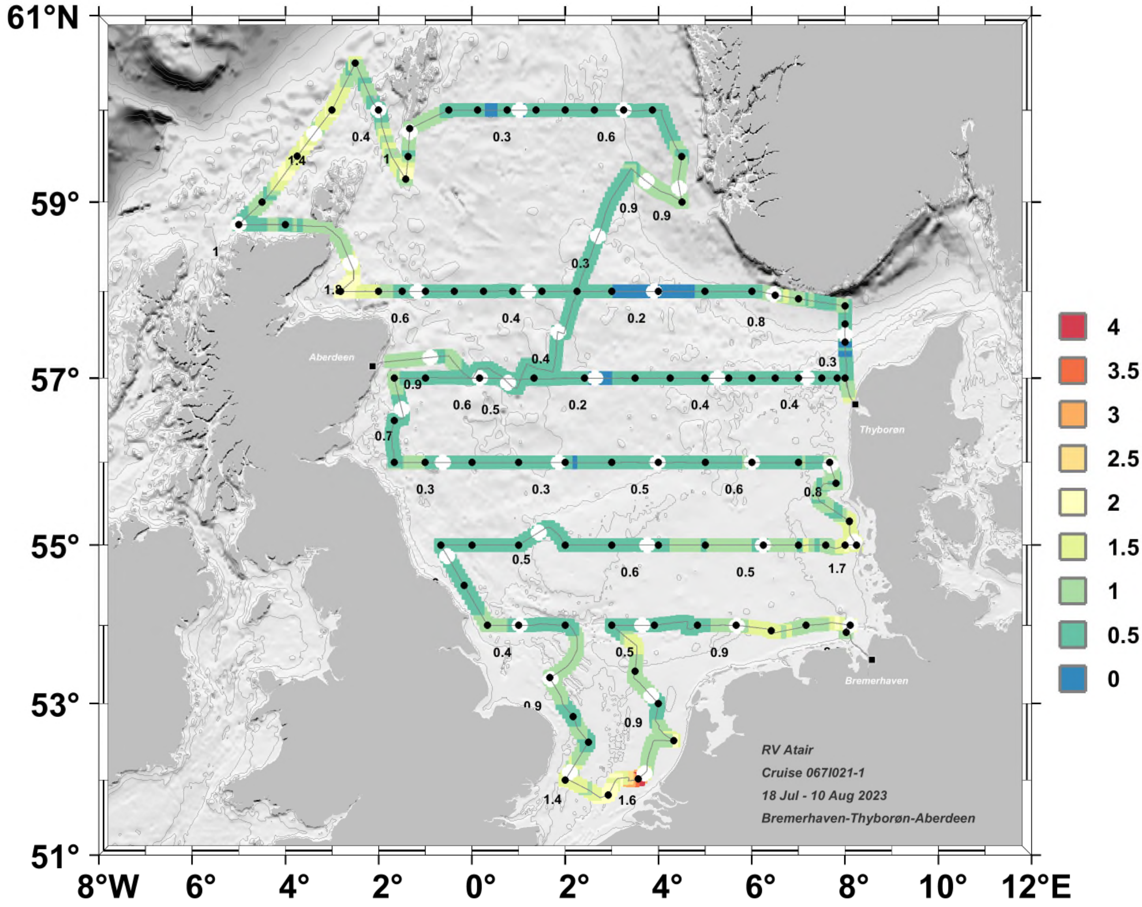

Figure 7.6. *Spatial distribution of the near-suface fluorescence [µg/l] during cruise 067I021-1 obtained from the flow-through ECO sensor and displayed as 30 min averages. Colours denote fluorescence values in the range 0-4 µg/l, individual values are highlighted every 12 hours.*

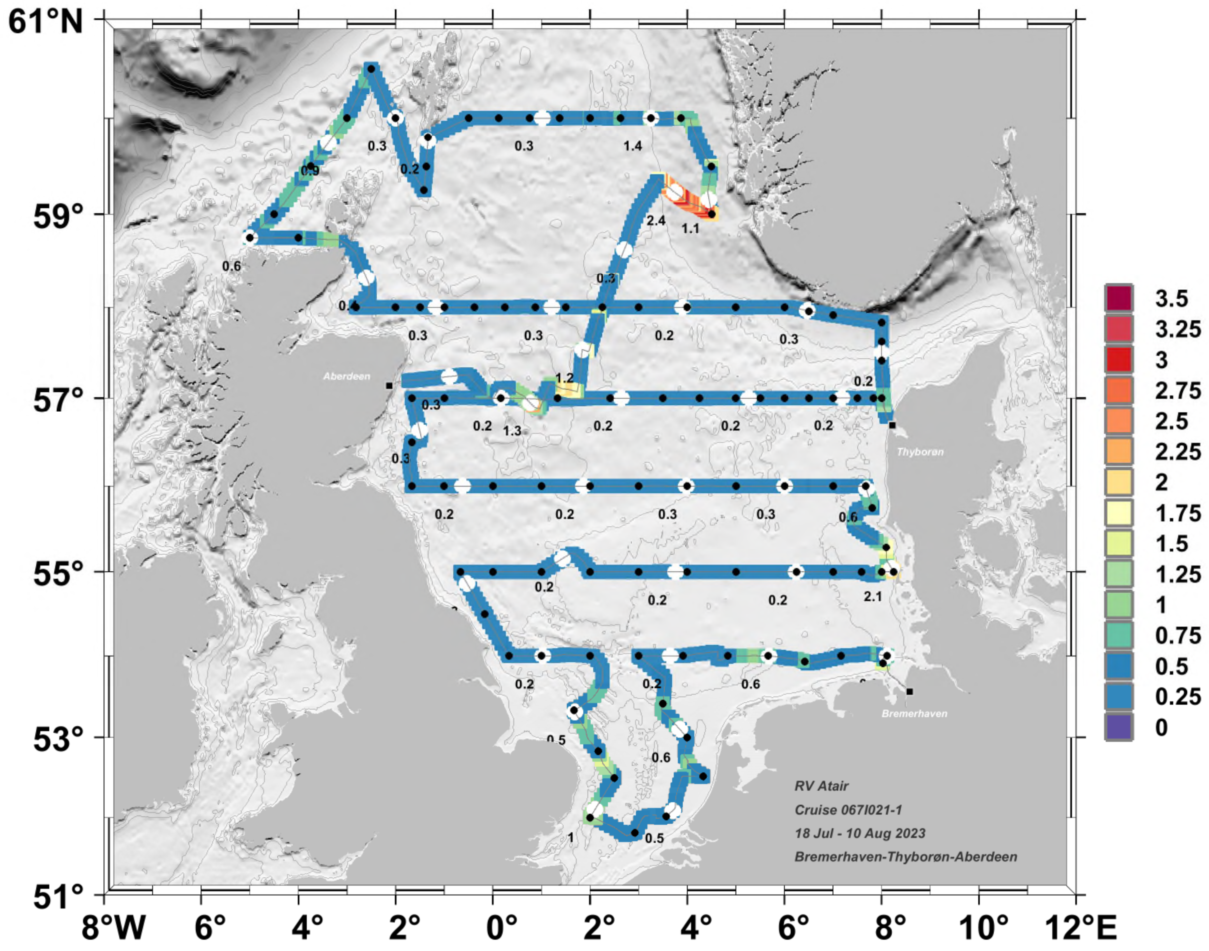

Figure 7.7. *Spatial distribution of the near-suface turbidity [NTU] during cruise 067I021-1 obtained from the flow-through ECO sensor and displayed as 30 min averages. Colours denote turbidity in the range 0- 3.5 NTU, individual values are highlighted every 12 hours.*

7.3 Perfomance of the Vessel-Mounted Acoustic Doppler Current Profiler

A vessel-mounted Acoustic Doppler Current Profiler (VMADCP) was used for continuous recording of single ping velocity data in the water column. The instrument is of type *Teledyne RD Instruments* (TRDI) *Ocean Surveyor* (OS), operating at 150 kHz, with a flat phased-array transducer mounted in the hull of the ship. Since the VMADCP does not have any further built-in sensors, additional data on heading and tilt were obtained from the ship's *Hydrins* system. Data recording was carried out with the TRDI *VmDas* software, version 1.50.19. Characteristic parameters of the device installed on *RV ATAIR* are listed in Table 7.2.

OS 150 kHz	
Blanking Distance [m]	6
Maximum Range [m]	400
Transducer Depth [m]	5
Transducer Angle [°]	-1.6°

Table. 7.2. *Specification of the vessel-mounted Acoustic Doppler Current Profiler (VMADCP) in use during cruise 067I021-1.*

During the cruise the VMADCP was operated in narrow-band mode to provide maximum data quality. Bin sizes were kept constant to sustain consistency during the cruise, while the bottom search threshold was kept constant at 100 m during the southern part of the cruise until Thyborøn and at 400 m for the northern part. Detailed parameter settings are listed in Table 7.3. The obtained raw data were processed using the *CODAS*-toolbox “codas_focal_20.04” of the *School of Ocean and Earth Science and Technology* (SOEST), University of Hawaii, USA. Details regarding the toolbox are provided on the CODAS web page: https://currents.soest.hawaii.edu/docs/adcp_doc/. Settings and procedures follow recommendations presented by *Firing and Hummon (2010)*.

During the cruise, single-ping editing was not performed due to the lack of sufficient calibration data. A full single-ping post-processing has to be done after the cruise and is still pending. During the cruise the long-term averaged data (LTA, 5 min averages) were processed. Processing resulted in data sets of zonal and meridional current velocities, distributed over latitude, longitude, time, depth along the ship track. The processed data were stored in several output files in the native *MATLAB* format (*.mat) as well as *netcdf*. Erroneous signals from the sea bottom were removed from the data. Overview plots were stored along with the data.

Data recording started on 18 July 2023 at 17:27 UTC between the test station and the first official CTD station. Recording was stopped after finishing transects along latitudes to be able to run the data pre-processing. Recording was stopped on 29 July 2023 at 14:05 UTC while anchoring off Thyborøn Harbour and was restarted on 30 July 2023 at 01:19 UTC for a short transect towards the port. The VMADCP recording was stopped on 30 July 2023 at 13:32 UTC before crossing the Danish 3 nm limit. After leaving Thyborøn and crossing the 3 nm limit, VMADCP data recording started again on 01 August 2023 at 06:40 UTC. Recording was stopped after finishing transects along latitudes to be able to run the pre-processing. When heading for the port of Aberdeen at the end of the cruise, the VMADCP recording was stopped on 10 August 2023 at 06:37 UTC when entering the British 12 nm zone.

Whenever the VMADCP was restarted, an individual file was created, and the file counter was automatically increased. Operation of the VMADCP was manually documented throughout the cruise in a log file. Configuration setup-up files were stored along with the data whenever the configuration was changed.

#	Start Date, Time (UTC)	Stop Date, Time (UTC)	Mode of Operation	Bin Size [m]	Number of Bins	Bottom Search [m]
1	18 Jul 2023 17:27	22 Jul 2023 15:57	narrowband	4	45	100
2	22 Jul 2023 15:57	22 Jul 2023 16:02	narrowband	4	45	100
3	22 Jul 2023 16:04	25 Jul 2023 04:36	narrowband	4	45	100
4	25 Jul 2023 04:39	27 Jul 2023 18:18	narrowband	4	45	100
5	27 Jul 2023 18:19	29 Jul 2023 14:05	narrowband	4	45	100
6	30 Jul 2023 01:19	30 Jul 2023 13:32	narrowband	4	120	400
7	01 Aug 2023 06:39	01 Aug 2023 06:39	narrowband	4	120	400
8	01 Aug 2023 06:40	03 Aug 2023 21:57	narrowband	4	120	400
9	03 Aug 2023 21:57	07 Aug 2023 05:03	narrowband	4	120	400
10	07 Aug 2023 05:03	10 Aug 2023 06:37	narrowband	4	120	400

Table. 7.3. *VMADCP settings for different periods of cruise 067I021-1.*

The VMADCP worked properly during the whole cruise, and the data are of good quality. Some exceptions have to be made due to very bad weather between 07 August 2023 and the end of cruise leading to disturbed data due to prevalent air bubbles in the water layer beneath the ship. The data need further additional post-cruise quality control and post-processing steps to obtain a final dataset, e.g. detailed inspection and manual editing of suspicious measurements.

A first overview shows clear tidal signals in the shallow parts of the North Sea, which need to be removed for further analysis of the currents. Highest velocities due to tides were measured in the Pentland Firth and south of the Shetland Islands (Figures 7.8 and 7.9).

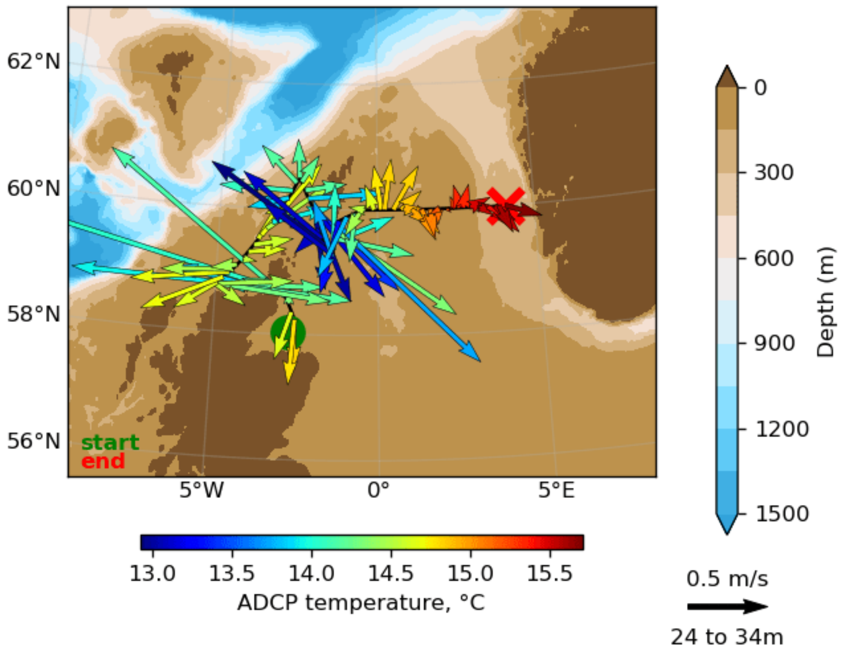

Figure 7.8. *Pre-processed LTA-VMADCP velocities at ~30 m depth (including tides) in the northern North Sea. Arrows indicate the strength and direction of the oceanic flow field, colours denote VMADCP-derived temperature at 5 m depth.*

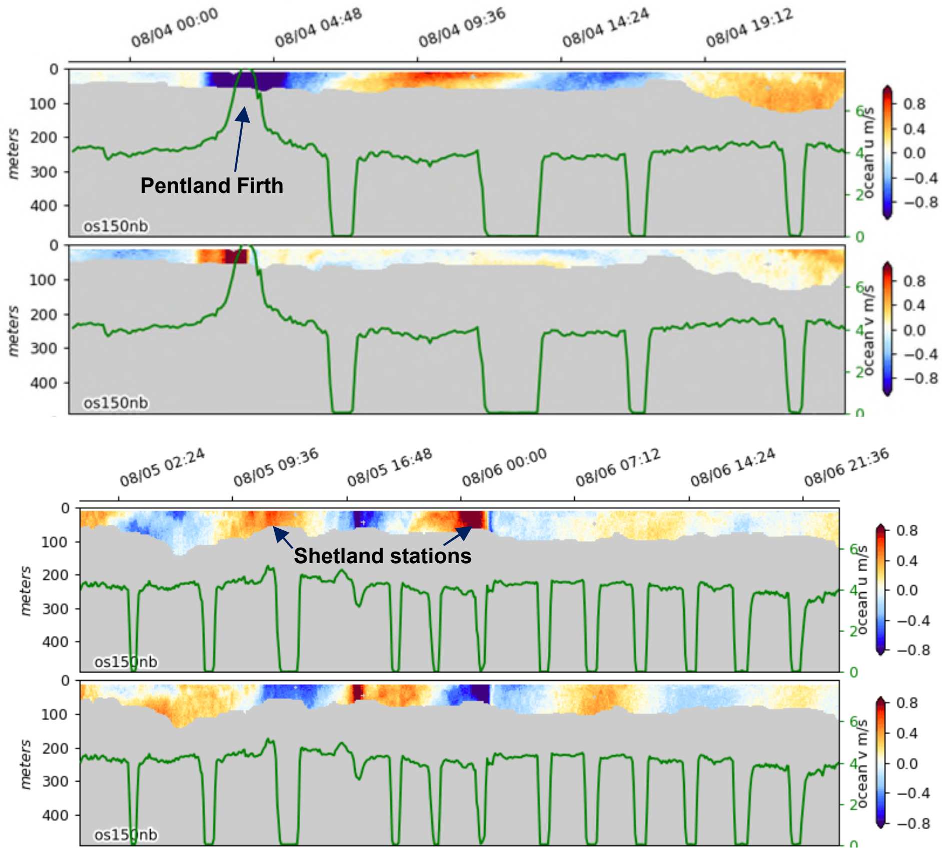

Figure 7.9. *Pre-processed LTA-VMADCP velocity time series over depth (including tides) for a part of the northern transect. Top: from the Pentland Firth to the western side of the Orkney Islands. Bottom: western side of the Orkney Islands and along 60°N from the Shetland Islands towards the Norwegian Trench. The green line shows the vessel velocity, zero velocity indicates CTD station work.*

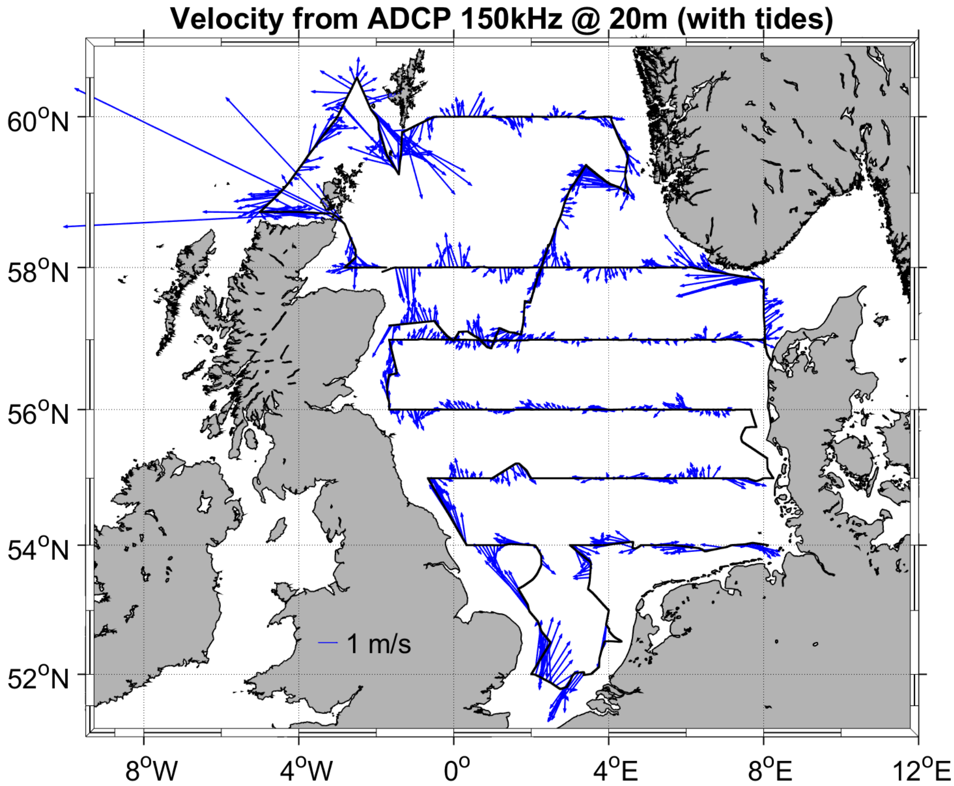

Figure 7.10. *The oceanic flow field at a depth of 20 m as observed with a VMADCP system during cruise 067I021-1, summer 2023. The tidal contribution to the flow field is still included.*

Figure 7.10 shows a first example of the ocean flow field at 20 m as observed during the entire cruise. The tidal contribution is still included.

8. Data Availability and Sample Storage

Further data analysis and interpretation will be carried out together with national and international collaborators in the framework of e.g. BSH's contribution to the international *Working Group on Oceanic Hydrography* (WGOH) hosted by the *International Council for the Explorations of the Seas* (ICES). Data from this cruise will be used for respective assessment reports and reporting in the framework of the *Marine Strategy Framework Directive* (MSFD) of the European Union. The data also serve for validating numerical operational ocean and climate models, for the calibration of satellite-based ocean colour data, hyper-spectral satellite data and downstream products (e.g. Secchi depth, turbidity, fluorescence, chlorophyll-a). In particular, chlorophyll-a data contributes to the EOMAP effort (https://eomap.com), while phytoplankton sampling contributes to the EnSAD project, which is part of the *Environmental Mapping and Analysis Program* (EnMAP, https://www.enmap.org).

A cruise summary report (CSR) is available on the SeaDataNet portal, CSR reference number: 21032482; https://csr.seadatanet.org/report/21032482. See also: https://www2.bsh.de/aktdat/dod/fahrtergebnis/2023/20230087.htm.

Data related to cruise *067I021-1* is genereally stored at the German Oceanographic Data Service hosted at BSH (DOD, email: dod@bsh.de), DOD reference number: 20230087, https://www.bsh.de/EN/DATA/Climate-and-Sea/Oceanographic_Data_Center/oceanographic_data_center_node.html

Near-realtime CTD data has been submitted and is available for download on the BSH data portal:

Temperature: https://gdi.bsh.de/en/feed/temperature-of-sea-water-2023.xml

Salinity: https://gdi.bsh.de/en/feed/salinity-of-sea-water-2023.xml

Dissolved oxygen: https://gdi.bsh.de/en/feed/dissolved-oxygen-in-sea-water-2023.xml

Fluorescence (chlorophyll): https://gdi.bsh.de/en/feed/chlorophyll-a-in-sea-water-2023.xml

Turbidity: https://gdi.bsh.de/en/feed/turbidity-in-sea-water-2023.xml

Finally processed CTD data has been submitted to DOD and is available at the MUDAB data portal (https://geoportal.bafg.de/MUDABAnwendung/), the mandatory data portal for German governmental agencies. Therein, data of cruise *067I021-1* contribute to the "Bund-Länder Monitoring-Programm" (BLMP/BLMP+). Respective data will be provided via MUDAB to the ICES data portal (https://www.ices.dk). Also, data regarding chlorophyll-a concentrations measured in the home laboratory, Secchi depths and oxygen are available via the MUDAB database and will be pushed forward to ICES. The following ICES divisions were sampled: IIIa, IVa, IVb, IVc and VIa. The respective ICES ecoregion is the Greater North Sea.

Data from water sampling regarding phytoplankton can be requested from BSH via contact person Dr. Karin Heyer, Karin.Heyer@bsh.de. This data will be available in the MUDAB data portal (see link above) in 2026.

VMADCP data is kept on long-time archives of the BSH's oceanography group as the establishment of an official data storage work flow is in the making through collaboration with the *German Marine Research Alliance* (DAM). Data can be obtained on request from: M22_obs@bsh.de

9. References

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10. Acknowledgments

We would like to express our gratitude to the master of *RV ATAIR*, Ulrich Klüber, and his entire crew for the assistance and great support granted to us during cruise *067I021-1*. We have greatly appreciated the very friendly working environment, the hospitality experienced onboard the vessel, and the very professional and constructive cooperation between the scientific team and the ship's crew. We further thank our colleagues at our home laboratories for assistance in the preparation of the cruise and processing of the cruise-related data. We particularly acknowledge the support of the BSH's shipping company *N3* and the respective sections *N32-Vessel Operation* and *N31-Technology and Equipment of Vessels*. We furthermore thank the international authorities for granting us permission to undertake this survey in the various national waters.

11. Station List

Station Number	Stat ion Name	Date, Station Begin	Time [UTC], Station Begin	Latitude, Station Begin	Longitude, Station Begin	Water Depth [m], Station Begin	Date, Station End	Time [UTC], Station End	Latitude, Station End	Longitude, Station End	Water Depth [m], Station End	CTD	Water samples (Niskin)	Secchi Depth	Bottle Salinity	Bottle Oxygen	BottleWater Density	Bottle Chlorophyll-a	Bottle Plankton	Comment
001	Teststation	18-Jul-2023	15:33	53° 54.675' N	008° 01.493' E	14	18-Jul-2023	16:38	53° 54.662' N	008° 01.466' E	14	x								no water sampling, CTD A001X002, 2nd cast due to problem with setting
002	GN003/ELBE1	18-Jul-2023	17:46	54° 00.030' N	008° 06.694' E	25	18-Jul-2023	18:29	54° 00.026' N	008° 06.700' E	26	x	x	x	x	x	x	x	x	CTD A002X001
003	GN003A	18-Jul-2023	22:58	53° 59.997' N	007° 09.981' E	25	18-Jul-2023	23:14	53° 59.996' N	007° 09.981' E	25	x	x		x	x				CTD A003X001
004	GN007	19-Jul-2023	02:43	53° 55.997' N	006° 24.997' E	26	19-Jul-2023	03:00	53° 56.006' N	006° 25.002' E	26	x	x		x	x				CTD A004X001
005	GN007A	19-Jul-2023	06:21	54° 00.013' N	005° 40.096' E	37	19-Jul-2023	07:09	54° 00.010' N	005° 40.089' E	39	x	x	x	x	x		x	x	CTD A005X001
006	GN008	19-Jul-2023	10:58	54° 00.001' N	004° 49.996' E	43	19-Jul-2023	11:26	54° 00.002' N	004° 49.995' E	44	x	x	x	x	x		x	x	CTD A006X001
007	GN008S	19-Jul-2023	16:22	53° 59.995' N	003° 54.954' E	47	19-Jul-2023	17:01	53° 59.992' N	003° 54.952' E	47	x	x	x	x	x	x	x	x	CTD A007X001
008	GN009	19-Jul-2023	21:10	53° 59.989' N	002° 59.936' E	42	19-Jul-2023	21:28	53° 59.988' N	002° 59.937' E	42	x	x		x	x				CTD A008X001
009	GN009A	20-Jul-2023	02:50	53° 25.023' N	003° 30.001' E	29	20-Jul-2023	03:05	53° 25.028' N	003° 29.991' E	30	x	x		x	x				CTD A009X001
010	GN010	20-Jul-2023	07:24	52° 59.999' N	004° 00.057' E	32	20-Jul-2023	08:00	53° 00.000' N	004° 00.056' E	32	x	x	x	x	x	x	x	x	CTD A010X001
011	GN011	20-Jul-2023	12:25	52° 31.020' N	004° 19.899' E	19	20-Jul-2023	12:48	52° 31.021' N	004° 19.900' E	19	x	x	x	x	x		x	x	CTD A011X001, called GN011 in some protocols
012	GN012N	20-Jul-2023	19:10	52° 01.002' N	003° 34.008' E	28	20-Jul-2023	19:36	52° 00.997' N	003° 34.015' E	28	x	x	x	x	x		x	x	CTD A012X001
013	GN013N	21-Jul-2023	00:00	51° 48.001' N	002° 55.190' E	33	21-Jul-2023	00:13	51° 48.003' N	002° 55.190' E	34	x	x		x	x	x			CTD A013X001
014	GN014	21-Jul-2023	04:56	52° 00.012' N	002° 00.011' E	32	21-Jul-2023	05:18	52° 00.010' N	002° 00.013' E	30	x	x	x	x	x				CTD A014X001
015	GN015	21-Jul-2023	09:49	52° 29.930' N	002° 29.938' E	48	21-Jul-2023	10:17	52° 29.934' N	002° 29.939' E	48	x	x	x	x	x	x	x	x	CTD A015X001
016	GN015B	21-Jul-2023	13:43	52° 50.000' N	002° 09.962' E	40	21-Jul-2023	14:08	52° 50.000' N	002° 09.960' E	41	x	x	x	x	x		x	x	CTD A016X001
017	GN016	21-Jul-2023	18:29	53° 19.982' N	001° 40.022' E	30	21-Jul-2023	18:57	53° 19.984' N	001° 40.018' E	30	x	x	x	x	x		x	x	CTD A017X001
018	GN009S	22-Jul-2023	01:40	54° 00.008' N	001° 59.948' E	73	22-Jul-2023	01:58	54° 00.008' N	001° 59.953' E	73	x	x		x	x				CTD A018X001
019	GN017	22-Jul-2023	06:28	53° 59.969' N	001° 00.021' E	46	22-Jul-2023	06:39	53° 59.969' N	001° 00.010' E	47	x	x	x	x	x				CTD A019X001
020	GN017A	22-Jul-2023	10:01	54° 00.019' N	000° 20.000' E	54	22-Jul-2023	10:28	54° 00.018' N	000° 19.998' E	54	x	x	x	x	x		x	x	CTD A020X001
021	GN017S	22-Jul-2023	14:39	54° 29.999' N	000° 09.978' W	61	22-Jul-2023	15:04	54° 29.995' N	000° 09.982' W	61	x	x	x	x	x		x	x	CTD A021X001
022	GN018A	22-Jul-2023	19:30	54° 59.976' N	000° 39.990' W	68	22-Jul-2023	20:02	54° 59.978' N	000° 39.982' W	68	x	x	x	x	x	x	x	x	CTD A022X001
023	GN018	22-Jul-2023	22:59	54° 59.980' N	000° 00.018' W	74	22-Jul-2023	23:17	54° 59.988' N	000° 00.025' W	74	x	x		x	x				CTD A023X001
024	GN018S	23-Jul-2023	03:36	55° 00.006' N	000° 59.980' E	63	23-Jul-2023	03:52	55° 00.003' N	000° 59.983' E	63	x	x		x	x				CTD A024X001

Station Number	Stat ion Name	Date, Station Begin	Time [UTC], Station Begin	Latitude, Station Begin	Longitude, Station Begin	Water Depth [m], Station Begin	Date, Station End	Time [UTC], Station End	Latitude, Station End	Longitude, Station End	Water Depth [m], Station End	CTD	Water samples (Niskin)	Secchi Depth	Bottle Salinity	Bottle Oxygen	BottleWater Density	Bottle Chlorophyll-a	Bottle Plankton	Comment
025	GN019	23-Jul-2023	09:40	54° 59.994' N	001° 59.981' E	28	23-Jul-2023	10:09	54° 59.991' N	001° 59.985' E	28	x	x	x	x	x		x	x	CTD A025X001
026	GN019S	23-Jul-2023	14:24	55° 00.011' N	002° 59.989' E	24	23-Jul-2023	14:49	54° 59.992' N	002° 59.987' E	24	x	x	x	x	x		x	x	CTD A026X001
027	GN020	23-Jul-2023	19:25	54° 59.974' N	004° 00.010' E	48	23-Jul-2023	20:01	54° 59.977' N	004° 00.016' E	48	x	x	x	x	x		x	x	CTD A027X001
028	GN021/AWZW2	24-Jul-2023	00:20	54° 59.978' N	005° 00.026' E	41	24-Jul-2023	00:54	54° 59.981' N	005° 00.023' E	42	x	x		x	x				CTD A028X001
029	GN022	24-Jul-2023	06:18	54° 59.992' N	006° 15.012' E	45	24-Jul-2023	07:07	54° 59.991' N	006° 15.009' E	45	x	x	x	x	x	x	x	x	CTD A029X002, 2nd cast due to computer failure
030	GN022A	24-Jul-2023	10:19	54° 59.993' N	007° 00.046' E	34	24-Jul-2023	10:34	54° 59.995' N	007° 00.042' E	33	x	x	x	x	x	x	x	x	CTD A030X001
031	GN023	24-Jul-2023	13:16	54° 59.984' N	007° 35.025' E	28	24-Jul-2023	13:39	54° 59.989' N	007° 35.022' E	28	x	x	x	x	x		x	x	CTD A031X001
032	GN024/SYLT1	24-Jul-2023	15:44	55° 00.041' N	008° 00.036' E	18	24-Jul-2023	16:07	55° 00.038' N	008° 00.032' E	18	x	x	x	x	x		x	x	CTD A032X001
033	GN025	24-Jul-2023	17:23	54° 59.969' N	008° 15.009' E	15	24-Jul-2023	17:48	54° 59.973' N	008° 15.006' E	15	x	x	x	x	x		x	x	CTD A033X001
034	GN025A	24-Jul-2023	20:18	55° 17.469' N	008° 05.499' E	16	24-Jul-2023	20:34	55° 17.469' N	008° 05.499' E	16	x	x		x	x				CTD A034X001
035	GN025B	25-Jul-2023	03:30	55° 44.983' N	007° 48.471' E	19	25-Jul-2023	03:58	55° 44.988' N	007° 48.473' E	19	x	x		x	x				CTD A035X001
036	GN026	25-Jul-2023	06:47	56° 00.000' N	007° 40.092' E	30	25-Jul-2023	07:38	55° 59.999' N	007° 40.092' E	27	x	x	x	x	x		x	x	CTD A036X001
037	GN026A	25-Jul-2023	11:35	55° 59.981' N	006° 59.960' E	36	25-Jul-2023	11:39	55° 59.977' N	006° 59.954' E	36	x	x	x	x	x		x	x	CTD A037X001
038	GN027	25-Jul-2023	17:47	56° 00.005' N	005° 59.977' E	49	25-Jul-2023	18:31	56° 00.009' N	005° 59.977' E	48	x	x	x	x	x		x	x	CTD A038X001
039	GN028	25-Jul-2023	23:31	55° 59.984' N	005° 00.078' E	43	26-Jul-2023	00:03	55° 59.981' N	005° 00.074' E	43	x	x		x	x				CTD A039X001
040	GN028S	26-Jul-2023	05:22	55° 59.999' N	003° 59.884' E	58	26-Jul-2023	06:10	56° 00.004' N	003° 59.825' E	59	x	x	x	x	x		x	x	CTD A040X001
041	GN029	26-Jul-2023	11:33	56° 00.030' N	003° 00.028' E	73	26-Jul-2023	12:25	56° 00.034' N	003° 00.023' E	73	x	x	x	x	x	x	x	x	CTD A041X001
042	GN030	26-Jul-2023	16:48	55° 59.992' N	001° 59.986' E	85	26-Jul-2023	17:35	55° 59.998' N	001° 59.994' E	85	x	x	x	x	x		x	x	CTD A042X001
043	GN031	26-Jul-2023	22:09	56° 00.036' N	000° 59.973' E	77	26-Jul-2023	22:38	56° 00.037' N	000° 59.978' E	77	x	x		x	x				CTD A043X001
044	GN032	27-Jul-2023	03:12	56° 00.007' N	000° 00.046' W	84	27-Jul-2023	03:31	56° 00.014' N	000° 00.048' W	84	x	x		x	x				CTD A044X001
045	GN033	27-Jul-2023	08:03	56° 00.001' N	001° 00.051' W	65	27-Jul-2023	08:28	55° 59.998' N	001° 00.053' W	65	x	x	x	x	x		x	x	CTD A045X001
046	GN033A	27-Jul-2023	11:33	56° 00.045' N	001° 39.940' W	66	27-Jul-2023	11:59	56° 00.043' N	001° 39.935' W	66	x	x	x	x	x		x	x	CTD A046X001
047	GN033S	27-Jul-2023	16:03	56° 30.025' N	001° 40.016' W	50	27-Jul-2023	16:28	56° 30.021' N	001° 40.012' W	52	x	x	x	x	x		x	x	CTD A047X001
048	GN034A	27-Jul-2023	21:19	56° 59.983' N	001° 39.993' W	75	27-Jul-2023	21:38	56° 59.982' N	001° 39.974' W	75	x	x		x	x	x			CTD A048X001
049	GN034	28-Jul-2023	00:41	57° 00.009' N	001° 00.012' W	71	28-Jul-2023	00:58	57° 00.011' N	001° 00.013' W	71	x	x		x	x				CTD A049X001
050	GN034S	28-Jul-2023	05:52	56° 59.993' N	000° 09.985' E	84	28-Jul-2023	06:19	56° 59.994' N	000° 09.985' E	84	x	x	x	x	x		x	x	CTD A050X001
051	GN035	28-Jul-2023	11:53	57° 00.015' N	001° 20.021' E	98	28-Jul-2023	12:20	57° 00.015' N	001° 20.021' E	98	x	x	x	x	x		x	x	CTD A051X001

Station Number	Stat ion Name	Date, Station Begin	Time [UTC], Station Begin	Latitude, Station Begin	Longitude, Station Begin	Water Depth [m], Station Begin	Date, Station End	Time [UTC], Station End	Latitude, Station End	Longitude, Station End	Water Depth [m], Station End	CTD	Water samples (Niskin)	Secchi Depth	Bottle Salinity	Bottle Oxygen	BottleWater Density	Bottle Chlorophyll-a	Bottle Plankton	Comment
052	GN035S	28-Jul-2023	16:50	57° 00.003' N	002° 25.037' E	79	28-Jul-2023	17:19	56° 59.992' N	002° 25.023' E	79	x	x	x	x	x		x	x	CTD A052X001
053	GN036	28-Jul-2023	21:45	57° 00.003' N	003° 30.052' E	64	28-Jul-2023	22:20	56° 59.992' N	003° 30.630' E	64	x	x		x	x				CTD A053X001
054	GN036A	29-Jul-2023	01:21	56° 59.977' N	004° 14.985' E	63	29-Jul-2023	01:37	56° 59.978' N	004° 14.982' E	63	x	x		x	x				CTD A054X001
055	GN037	29-Jul-2023	04:41	57° 00.007' N	005° 00.002' E	57	29-Jul-2023	05:05	57° 00.008' N	005° 00.000' E	57	x	x	x	x	x		x	x	CTD A055X001
056	GN037A	29-Jul-2023	07:15	56° 59.998' N	005° 30.053' E	54	29-Jul-2023	07:40	56° 59.999' N	005° 30.047' E	55	x	x	x	x			x		CTD A056X001
057	GN038	29-Jul-2023	10:05	56° 59.985' N	005° 59.975' E	53	29-Jul-2023	10:32	56° 59.981' N	005° 59.967' E	53	x	x	x	x	x		x	x	CTD A057X001
058	GN038B	30-Jul-2023	02:22	57° 00.018' N	006° 30.068' E	60	30-Jul-2023	02:42	57° 00.017' N	006° 30.035' E	61	x	x		x					CTD A058X001
059	GN038A	30-Jul-2023	04:55	56° 59.994' N	007° 00.011' E	35	30-Jul-2023	05:19	56° 59.993' N	007° 00.006' E	35	x	x	x	x	x		x	x	CTD A059X001
060	GN038C	30-Jul-2023	07:33	56° 59.999' N	007° 30.029' E	34	30-Jul-2023	07:57	56° 59.996' N	007° 30.030' E	34	x	x	x	x	x		x	x	CTD A060X001
061	GN039N	30-Jul-2023	09:24	57° 00.003' N	007° 50.039' E	41	30-Jul-2023	09:50	57° 00.005' N	007° 50.031' E	42	x	x	x	x			x		CTD A061X001
062	GN039	30-Jul-2023	10:43	56° 59.992' N	008° 00.023' E	36	30-Jul-2023	11:08	56° 59.992' N	008° 00.029' E	36	x	x	x	x	x	x	x	x	CTD A062X001
063	GN039S	01-Aug-2023	11:30	57° 25.035' N	008° 00.000' E	93	01-Aug-2023	11:56	57° 25.033' N	007° 59.996' E	93	x	x	x	x	x		x	x	CTD A063X001
064	GN040B	01-Aug-2023	13:45	57° 37.485' N	007° 59.979' E	268	01-Aug-2023	14:22	57° 37.481' N	007° 59.983' E	268	x	x	x	x			x	x	CTD A064X001
065	GN040	01-Aug-2023	16:02	57° 50.020' N	008° 00.022' E	524	01-Aug-2023	16:52	57° 50.021' N	008° 00.022' E	523	x	x	x	x	x	x	x	x	CTD A065X001
066	GN040S	01-Aug-2023	21:08	57° 54.996' N	006° 59.951' E	362	01-Aug-2023	21:42	57° 54.996' N	006° 59.955' E	361	x	x		x	x				CTD A066X001
067	GN040A	02-Aug-2023	00:00	57° 57.471' N	006° 30.001' E	354	02-Aug-2023	00:30	57° 57.468' N	006° 30.001' E	354	x	x		x					CTD A067X001
068	GN041	02-Aug-2023	02:40	57° 59.994' N	005° 59.989' E	310	02-Aug-2023	03:10	57° 59.995' N	005° 59.988' E	310	x	x		x	x	x			CTD A068X001
069	GN042	02-Aug-2023	07:13	57° 59.991' N	004° 59.966' E	127	02-Aug-2023	07:41	57° 59.992' N	004° 59.967' E	127	x	x	x	x	x		x	x	CTD A069X001
070	GN042S	02-Aug-2023	11:50	57° 59.995' N	003° 59.966' E	100	02-Aug-2023	12:15	57° 59.995' N	003° 59.964' E	100	x	x	x	x	x		x	x	CTD A070X001
071	GN043	02-Aug-2023	16:15	58° 00.031' N	002° 59.951' E	82	02-Aug-2023	16:40	58° 00.030' N	002° 59.952' E	82	x	x	x	x	x	x	x	x	CTD A071X001
072	GN043A	02-Aug-2023	19:42	57° 59.964' N	002° 15.022' E	77	02-Aug-2023	20:06	57° 59.963' N	002° 15.026' E	77	x	x	x	x			x	x	CTD A072X001
073	GN044	02-Aug-2023	23:15	57° 59.961' N	001° 29.966' E	111	02-Aug-2023	23:33	57° 59.963' N	001° 29.963' E	111	x	x		x	x				CTD A073X001
074	GN044A	03-Aug-2023	02:09	57° 59.994' N	000° 52.401' E	149	03-Aug-2023	02:29	57° 59.998' N	000° 52.415' E	149	x	x		x					CTD A074X001
075	GN044S	03-Aug-2023	05:05	58° 00.024' N	000° 14.901' E	140	03-Aug-2023	05:35	58° 00.022' N	000° 14.899' E	141	x	x	x	x	x		x	x	CTD A075X001
076	GN044B	03-Aug-2023	08:13	57° 59.993' N	000° 22.531' W	122	03-Aug-2023	08:38	57° 59.994' N	000° 22.529' W	121	x	x	x	x			x	x	CTD A076X001
077	GN045	03-Aug-2023	11:21	57° 59.974' N	001° 00.019' W	115	03-Aug-2023	11:58	57° 59.971' N	001° 00.020' W	115	x	x	x	x	x		x	x	CTD A077X001
078	GN045D	03-Aug-2023	14:10	57° 59.991' N	001° 29.942' W	74	03-Aug-2023	14:51	57° 59.993' N	001° 29.948' W	74	x	x	x	x			x	x	CTD A078X001

Station Number	Stat ion Name	Date, Station Begin	Time [UTC], Station Begin	Latitude, Station Begin	Longitude, Station Begin	Water Depth [m], Station Begin	Date, Station End	Time [UTC], Station End	Latitude, Station End	Longitude, Station End	Water Depth [m], Station End	CTD	Water samples (Niskin)	Secchi Depth	Bottle Salinity	Bottle Oxygen	BottleWater Density	Bottle Chlorophyll-a	Bottle Plankton	Comment
079	GN045A	03-Aug-2023	16:58	58° 00.021' N	002° 00.057' W	86	03-Aug-2023	17:40	58° 00.022' N	002° 00.048' W	85	x	x	x	x	x	x	x	x	CTD A079X001
080	GN045C	03-Aug-2023	21:02	57° 59.974' N	002° 49.071' W	72	03-Aug-2023	21:34	57° 59.975' N	002° 49.075' W	72	x	x		x	x				CTD A080X001
081	GN057A	04-Aug-2023	06:44	58° 44.982' N	004° 00.042' W	83	04-Aug-2023	07:23	58° 44.983' N	004° 00.048' W	83	x	x	x	x			x	x	CTD A081X001
082	GN056	04-Aug-2023	11:55	58° 44.996' N	004° 59.988' W	86	04-Aug-2023	13:31	58° 44.999' N	004° 59.991' W	85	x	x	x	x	x	x	x	x	CTD A082X002, 2nd cast due to electronic failure
083	GN056A	04-Aug-2023	16:40	58° 59.998' N	004° 30.015' W	82	04-Aug-2023	17:09	59° 00.000' N	004° 30.013' W	82	x	x	x	x			x	x	CTD A083X001
084	GN054B	04-Aug-2023	22:02	59° 29.996' N	003° 44.995' W	163	04-Aug-2023	22:24	59° 29.996' N	003° 45.005' W	162	x	x		x	x				CTD A084X001
085	GN054	05-Aug-2023	03:11	59° 59.994' N	002° 59.994' W	105	05-Aug-2023	03:29	59° 59.997' N	002° 59.994' W	105	x	x		x					CTD A085X001
086	GN054A	05-Aug-2023	07:50	60° 29.994' N	002° 29.979' W	145	05-Aug-2023	08:23	60° 29.995' N	002° 29.980' W	145	x	x	x	x	x		x	x	CTD A086X001
087	GN053B	05-Aug-2023	12:35	59° 59.992' N	001° 59.979' W	88	05-Aug-2023	13:40	59° 59.994' N	001° 59.975' W	88	x	x	x	x			x	x	CTD A087X001
088	GN053D	05-Aug-2023	19:39	59° 15.001' N	001° 25.000' W	104	05-Aug-2023	20:05	59° 15.001' N	001° 25.000' W	102	x	x	x	x	x		x	x	CTD A088X001
089	GN053C	05-Aug-2023	22:18	59° 29.986' N	001° 21.922' W	103	05-Aug-2023	22:37	59° 29.985' N	001° 21.920' W	104	x	x		x					CTD A089X001
090	GN053A	06-Aug-2023	01:14	59° 47.971' N	001° 19.847' W	87	06-Aug-2023	01:31	59° 47.957' N	001° 19.659' W	87	x	x		x	x	x			CTD A090X001
091	GN053	06-Aug-2023	05:00	59° 59.986' N	000° 30.001' W	128	06-Aug-2023	05:30	59° 59.988' N	000° 30.006' W	130	x	x	x	x	x		x	x	CTD A091X001
092	GN052B	06-Aug-2023	07:58	60° 00.001' N	000° 07.519' E	150	06-Aug-2023	08:35	60° 00.002' N	000° 07.517' E	149	x	x	x	x			x	x	CTD A092X001
093	GN052S	06-Aug-2023	11:01	60° 00.004' N	000° 45.107' E	128	06-Aug-2023	11:41	60° 00.004' N	000° 45.104' E	128	x	x	x	x	x		x	x	CTD A093X001
094	GN052A	06-Aug-2023	14:12	59° 59.983' N	001° 22.484' E	111	06-Aug-2023	14:50	59° 59.989' N	001° 22.496' E	110	x	x	x	x			x	x	CTD A094X001
095	GN052	06-Aug-2023	17:21	59° 59.970' N	002° 00.018' E	102	06-Aug-2023	18:07	59° 59.973' N	002° 00.010' E	101	x	x	x	x	x		x	x	CTD A095X001
096	GN051B	06-Aug-2023	20:56	59° 59.998' N	002° 37.611' E	112	06-Aug-2023	21:27	60° 00.001' N	002° 37.619' E	113	x	x		x					CTD A096X001
097	GN051S	07-Aug-2023	00:19	59° 59.969' N	003° 15.168' E	215	07-Aug-2023	00:53	59° 59.974' N	003° 15.167' E	215	x	x		x	x				CTD A097X001
098	GN051A	07-Aug-2023	03:41	59° 59.979' N	003° 52.458' E	295	07-Aug-2023	04:09	59° 59.978' N	003° 52.463' E	295	x	x		x					CTD A098X001
099	GN050S	07-Aug-2023	09:14	59° 29.931' N	004° 30.062' E	266	07-Aug-2023	10:01	59° 29.934' N	004° 30.070' E	266	x	x	x	x	x		x	x	CTD A099X001
100	GN050	07-Aug-2023	14:06	59° 00.009' N	004° 30.229' E	261	07-Aug-2023	15:14	59° 00.008' N	004° 30.240' E	262	x	x	x	x	x		x	x	CTD A100X001