Results of the Nordic Recognized Environmental Picture 2018 (NREP18) Sea Trial

Aniello Russo

This document, which describes work performed under the Project ACT000806 (Maritime Autonomous Networks and Smart Sensing for Stealth and Secure Battlespace Characterization) of the STO-CMRE Programme of Work, has been approved by the Director.

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Executive Summary: Operations in the maritime environment can benefit from the proper use of environmental knowledge obtained through sensing, data fusion and numerical predictions. Conversely, incomplete, uncertain, or incorrect environmental characterization can have a detrimental or even devastating impact on operations. The aim of the "Environmental Knowledge and Operational Effectiveness" (EKOE) Programme is to develop new technologies to help the Nations and NATO to build their fundamental capabilities in the areas of Inform, Engage and Protect.
This report deals with the results of the Nordic Recognized Environmental Picture 2018 (NREP18) sea trial, conducted by the EKOE Programme for environmental characterization in two strategic areas highly exposed to ongoing climate change, i.e. part of the so-called Greenland-Iceland-United Kingdom (GIUK) gap and the Barents Sea opening/Svalbard Islands. The sea trial execution was heavily affected by problems to the propulsion system of NRV Alliance. Despite the experienced difficulties, some activities were successfully conducted. In particular, underwater gliders (even if in smaller number, and shorter duration, than planned) successfully operated in challenging areas as the Iceland-Faroe Front (IFF) and the Barents Sea opening / Svalbard Islands. Partners' campaigns, i.e. Iceland-Faroe Experiment 2018 (IFEx 2018) led by the Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD 71; DEU) and High North 18 (HN18) led by the Italian Hydrographic Institute, provided a significant contribution (not discussed in this report) to supplement the collected oceanographic datasets.

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Abstract: This report concerns environmental characterization conducted during the NREP18 sea trial in two strategic areas highly exposed to ongloing climate change: the central part of the so-called Greenland-Iceland-United Kingdom (GIUK) gap and the Barents Sea opening / Svalbard Islands.

Because of problems affecting the propulsion system of NRV Alliance, the sea trial was not executed as planned and activities were severely limited. In the GIUK gap, the Iceland-Faroe Front (IFF) was characterized by means of eXandable BathyTermograph (XBT) launches and two underwater gliders. In the Barents Sea opening / Svalbard Islands, operations of underwater gliders were even more limited but it was possible to collect more data from shipborne instruments. The Polar Front was detected east of Bear Island and a short (one day) oceanographic-acoustic experiment was conducted.

Most of the planned NREP18 objectives were reached thanks to the oceanographic datasets integrations provided by the partners' campaigns (not discussed in this report): Iceland-Faroe Experiment 2018 (IFEx 2018) led by the Bundeswehr Technical Center for Ships and Naval Weapons, Maritime Technology and Research (WTD 71; DEU) and High North 18 (HN18) led by the Italian Hydrographic Institute.

Keywords: Environmental Characterization, Maritime ISR, METOC, Oceanography, High Latitudes, Arctic, High North domains, Underwater glider

Contents

1 Overview

This Report summarizes resuls of the Nordic Recognized Environmental Picture 2018 (NREP18) sea trial conducted by CMRE and partners in two high latitute areas, i.e. the Greenland-Iceland-United Kingdom (GIUK) gap and the western Barents Sea/Svalbard Islands area (Fig. 1). The GIUK gap represents the border between the North Atlantic Ocean and the high latitude region starting with the Nordic (Greenland, Norwegian and Iceland) Seas. The western Barents Sea is bordered by the Svalbard Islands to the north and by Norway to the south. This region assumes high interest because of the ongoing significant decrement of sea ice coverage (especially in summer) and the consequent opening of new maritime routes between the Atlantic and the Pacific Oceans through the Arctic Ocean.

The sea trial started on 4 June 2018, when the NATO Research Vessel (NRV) Alliance sailed from Almeria (ESP), and ended on 7 July 2018, when NRV Alliance docked in Tromsø (NOR). The first area of operation (east of Iceland) was reached on 11 June. The second area of operation (around Bear Island) was reached on 25 June.

Performed activities resulted to be significantly less than planned (Russo, 2018) because of NRV Alliance's propulsion system problems experienced during the execution of the sea trial. Coordinated partners' campaigns, i.e. Iceland-Faroe Experiment 2018 (IFEx 2018; Fiekas et al., 2019) led by the German WTD 71 and High North 18 (HN18; Ivaldi et al., 2018) led by the Italian Hydrographic Institute, allowed to integrate the limited datasets collected by NREP18.

The following Section summarizes the operations conducted in the GIUK gap between Iceland and Faroe Islands and provides preliminary results. The third Section does the same for the western Barents Sea opening / Svalbard Islands area. A summary is provided in the fourth Section.

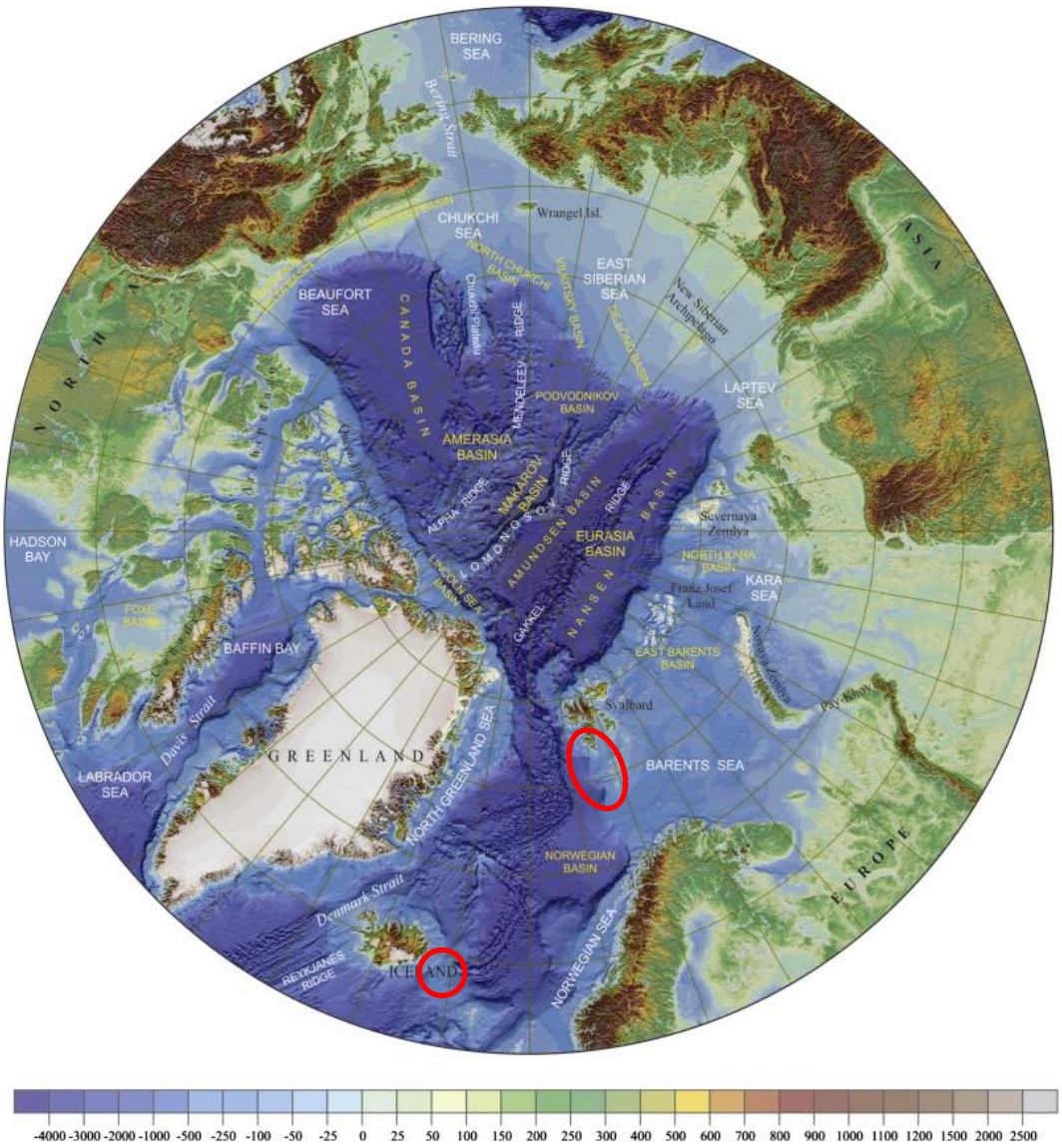

Figure 1: *Topography and bathymetry map of the Arctic region at 1:5M scale in a polar stereographic projection based on ETOPO1 Global Relief Model (NOAA, 2011) [extracted from Petrov et al., 2016]. The two areas of interest, i.e. the GIUK gap between Iceland and Faroe Islands and the western Barents Sea / Svalbard Islands, are evidenced in red.*

2
GIUK gap area

2.1 Sequence of Operations

NRV Alliance reached the operation area in the GIUK gap on 11 June 2018 and activities started at 20:00 (times are reported in Universal time Coordinate, UTC) by executing a series of eXpandable Bathy-Thermograph (XBT) launches spaced by 2 nautical miles (nm) (about 3.7 km) aimed to localize the position of the Iceland-Faroe Front (IFF). In total, 60 XBTs were launched along four transects completed on 12 June at 7:30. The IFF position was determined and from 9:00 to 10:30 a Multibeam survey line was conducted across the frontal zone while repeating part of the second transect launching 10 more XBTs spaced by 1 nm (1.85 km). The Multibeam survey was conducted in order to prepare the deployment of the planned oceanographic-acoustic buoys and moorings on both sides of the front. At 11:30 the CMRE Slocum G3 oceanographic glider named Freya was deployed. During the latter deployment, the ship propulsion system experienced a major failure that forced the interruption of the scientific operations in order to immediately sail toward Rekjavik (Iceland) for repair works.

The time needed for the (partial) repair works conducted in Rekjavik did not allow to restart operations in the GIUK gap area. On 16 June, NRV Alliance sailed from Rekjavik in order to reach Tromsø harbour at the originally planned date (21 June) and to complete repair works there.

2.2 Results

The oceanographic observations collected during NREP18 in the GIUK gap area include the data measured by XBTs and by shipborne instruments (Acoustic Doppler Current Profiler – ADCP and underway temperature-salinity) along the four surveyed transects, plus the data collected by two oceanographic gliders: the already cited Freya and capx690 (a demonstrator Slocum G3 glider deployed in eastern Iceland on 25 May 2018 by Teledyne Webb Research – TWR, USA).

Fig. 2 shows the tracks followed by the two gliders from their deployment until 23 June, when they were kindly recovered by the German R/V Planet (conducting the partner campaign Iceland-Faroe Experiment 2018 – IFEx 2018) due to the NRV Alliance problems.

Fig. 3 shows temperature and sound speed profiles and temperature-salinity diagram collected by the glider capx690 on 10-11 June across the IFF. It is evident the sharp separation between Atlantic and sub-Arctic waters, with the former ones being warmer (around 4 °C), saltier (around 0.4) and characterized by higher sound speeds (around 30 m s^{-1}) compared to the latter ones.

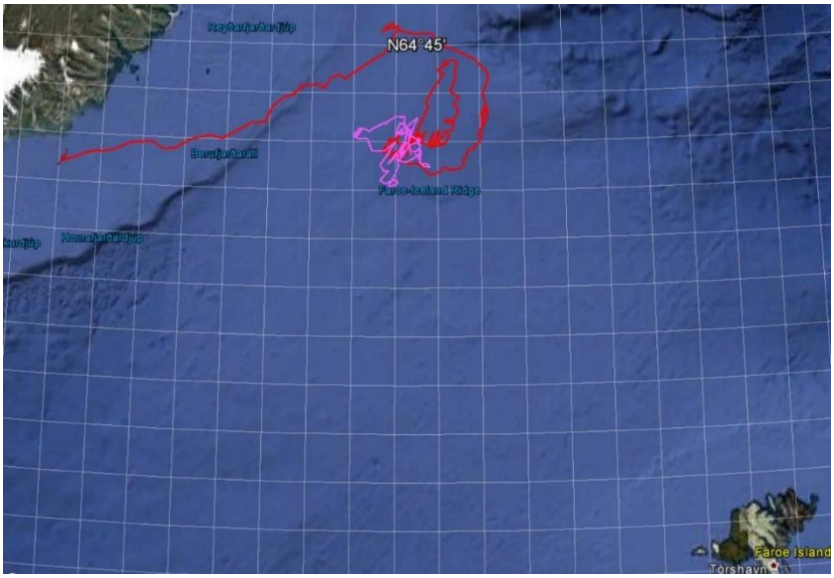

Figure 2: *Tracks followed by Slocum gliders capx690 (TWR, in red) and Freya (CMRE, magenta) in the GIUK gap area between Iceland and the Faroe Islands during NREP18 in May-June 2018.*

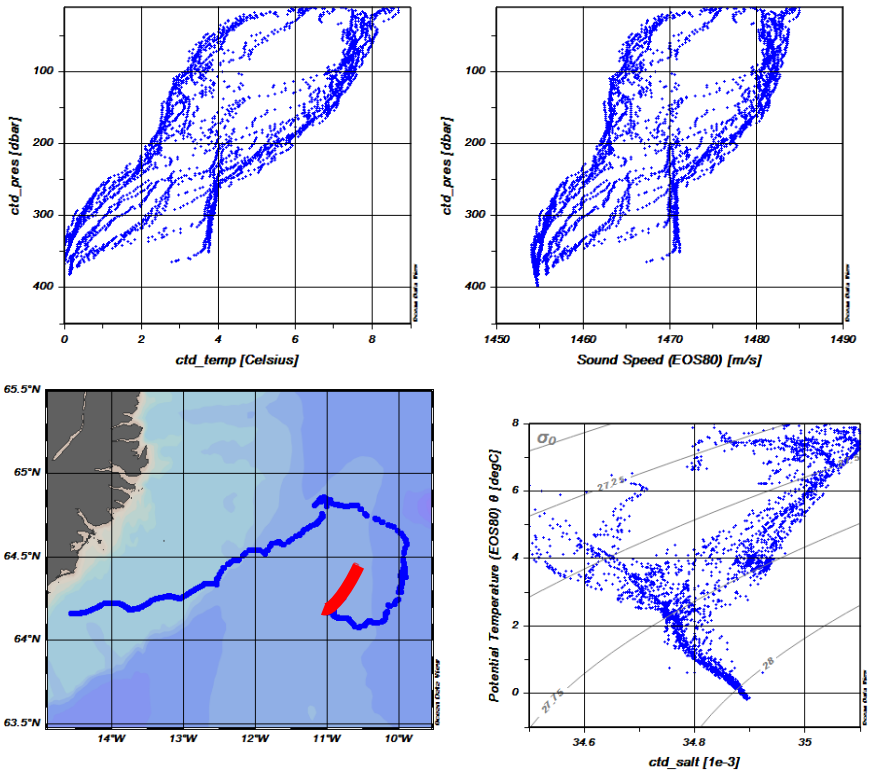

Figure 3: *Cumulative temperature (°C) and sound speed (m s^{-1}) profiles and potential temperature-salinity diagram from data collected by the Slocum gliders capx690 on 10-11 June 2018 across the IFF (the showed data are only from the area, evidenced in red in the map, covered by the glider on 10-11 June).*

Fig. 4 shows the vertical sections of temperature, salinity, sound speed and potential density anomaly collected by the glider capx690 on 10-11 June along the red line evidenced in the map of Fig. 3. The front is evident in the middle of the sections with the sharp temperature, salinity and sound speed contrast in the upper 150 m layer. Temperature and salinity partially compensate in density and consequently the potential density horizontal variation is less evident in the upper layer. In the deeper layer, cold waters propagate toward south with interesting structures formed by a layer of warmer Atlantic Waters shoaling from 250 to 100 m depth across the frontal structure.

Fig. 5 shows the temperature field deduced by XBTs launched on 11-12 June along a section roughly parallel to the capx690 one (about 12 km west of it) showed in the previous Figure. Here the frontal structure is less sharp in the surface layer but it is more extended in depth (substantially reaching the seafloor) and the bottom cold water layer does not propagate below the front.

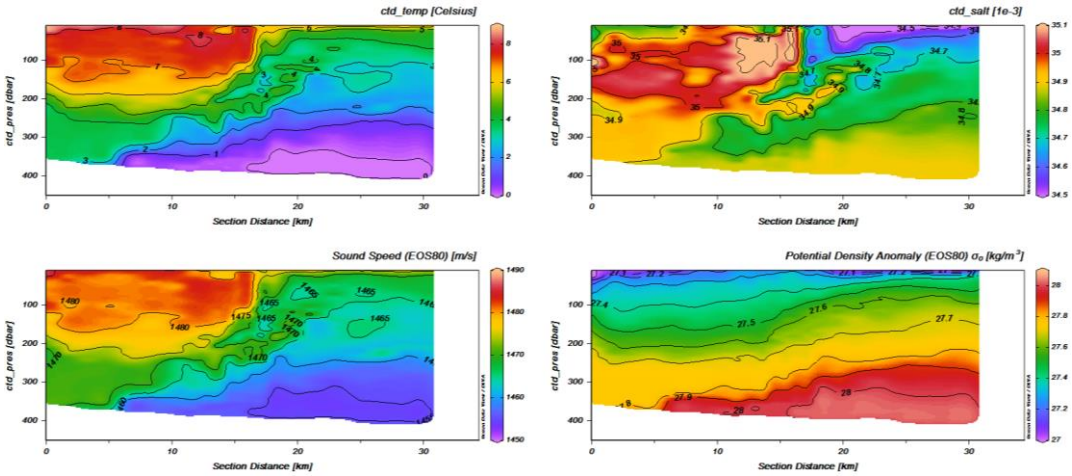

Figure 4: *Temperature (°C), salinity, sound speed (m s^{-1}) and potential density anomaly (kg m^{-3}) sections from data collected by the Slocum glider capx690 on 10-11 June 2018 across the IFF (along the line evidenced in red in the map of Fig. 3).*

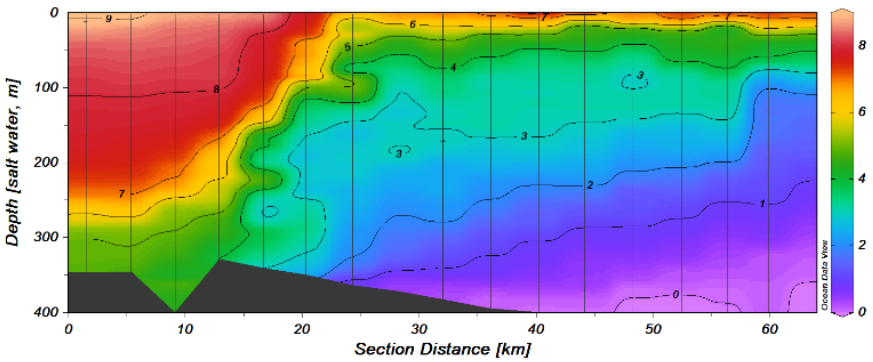

Figure 5: *Temperature (°C) section from XBTs launched on 11-12 June 2018 across the IFF (along the line evidenced in cyan in the map of Fig. 6).*

Fig. 6 provides an idea of the spatial distribution of the IFF by showing temperature data collected by glider capx60 and XBTs in the upper water layer (at 60 m depth). The yellow dotted circle in the upper panel shows an area where the IFF appears to form a meander and this area was selected in order to run the planned oceanographic-acoustic experiment (then the ship propulsion system failure prevented its execution).

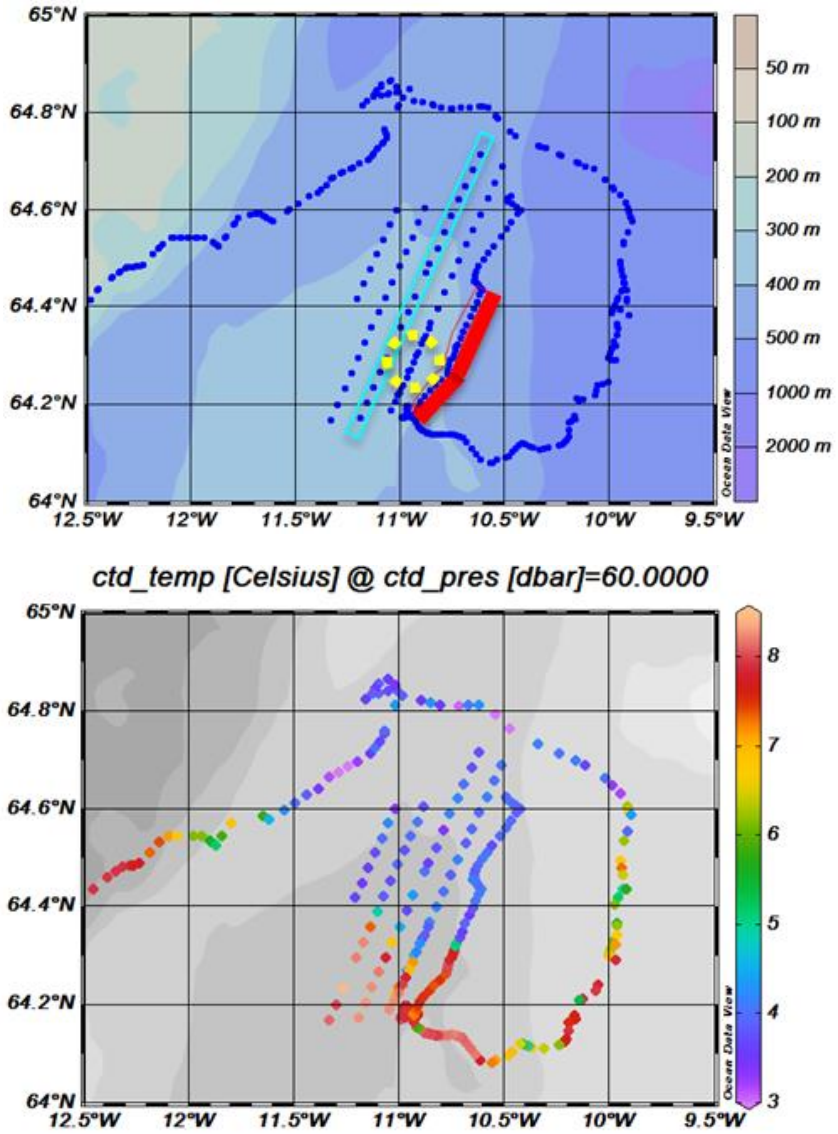

Figure 6: *Top panel: positions of the XBTs launched along 4 transects (the transect evidenced in cyan is showed in Fig. 5) and of the profiles collected by the glider capx690 until 12 June 2018 (the red box evidences profiles collected between 10 and 11 June, showed in Figs. 3-4); colours represent bathymetry and the yellow dotted circle denotes the selected IFF area where the oceanographic-acoustic experiment should have been conducted. Bottom panel: Temperature (°C) at 60 m depth; the IFF is individuated in the central part of the map by the sudden temperature drop between values above 7 °C and values below 5 °C.*

3
Barents Sea opening / Svalbard Islands area

Repair works of the NRV Alliance propulsion system continued during the port call scheduled on 21-22 June 2018 in Tromsø, where additional scientific personnel and partners' equipment were embarked as planned.

2.1 Sequence of Operations

On 23 June, NRV Alliance regularly sailed from Tromsø directed to the operation area in the Western Barents Sea (Fig. 7). Operations started west of Bear Island on 25 June at 3:00 with the deployment of the NOC Slocum G2 glider 439, followed at 8:30 by the CMRE Slocum G2 glider Dorajr (the track followed by these two gliders are reported in Figs. 8 and 9, respectively). At 9:40, the ship's propulsion system experienced serious problems again. As a storm was approaching from the south-west, immediate return to Tromsø could have been unsafe and consequently the ship moved toward Spitsbergen Island in order to reach an area not exposed to the storm (Fig. 7). On 26-27 June, 13 unscheduled Conductivity-Temperature-Depth (CTD) casts were performed west of Spitsbergen Island while waiting for the passage of the storm. Following the improvement of meteo-marine conditions, NRV Alliance moved back towards the western Barents Sea in order to conduct limited scientific activies before returning to Tromsø for the required repair works. On 29 June at 5:00, the glider 439 was recovered north-east of Bear Island (Fig. 7). On 29 June at 9:00, XBT launches started east of Bear Island aiming to identify the position of the Polar Front. Two XBT transects were executed to identify the position of the front and two drifting buoys (Naval Research Laboratory - NRL, USA) with hydrophones and temperature recorders (from both NRL and CMRE) were deployed at 18:45 and at 20:45 south and north of the front, respectively. At 21:00 marine mammal mitigation measures were initiated and at 22:36 NRV Alliance started towing an acoustic source along and across the Polar Front in an area surrounding the two deployed buoys (Fig. 7). On 30 June at 14:08 acoustic transmission was suspended in order to deploy the Slocum G1 glider Greta with a prototype compact Volumetric Array Sensor (cVAS) and then acoustic transmission was conducted while encircling the glider. At 18:30 acoustic transmission was definitively stopped and the recovery of all the deployed assets was completed at 23:59. The transit back to Tromsø began at midnight and NRV Alliance arrived in port on 2 July 2018 at 11:00. Most of the scientific personnel disembarked and repair works were conducted in port. From 4 to 6 July tests at sea of the propulsion system and of the shipborne equipment were conducted west of Tromsø. On 7 July the ship was back in Tromsø for the port call planned at the end of NREP18.

On 8 July 2018, NRV Alliance sailed from Tromsø in order to conduct the High North 18 campaign led by the Italian Hydrographic Institute. The oceanographic glider Dorajr, deployed on 25 June before the ship propulsion system problems, was recovered by NRV Alliance on 9 July at 16:45 west of Bear Island.

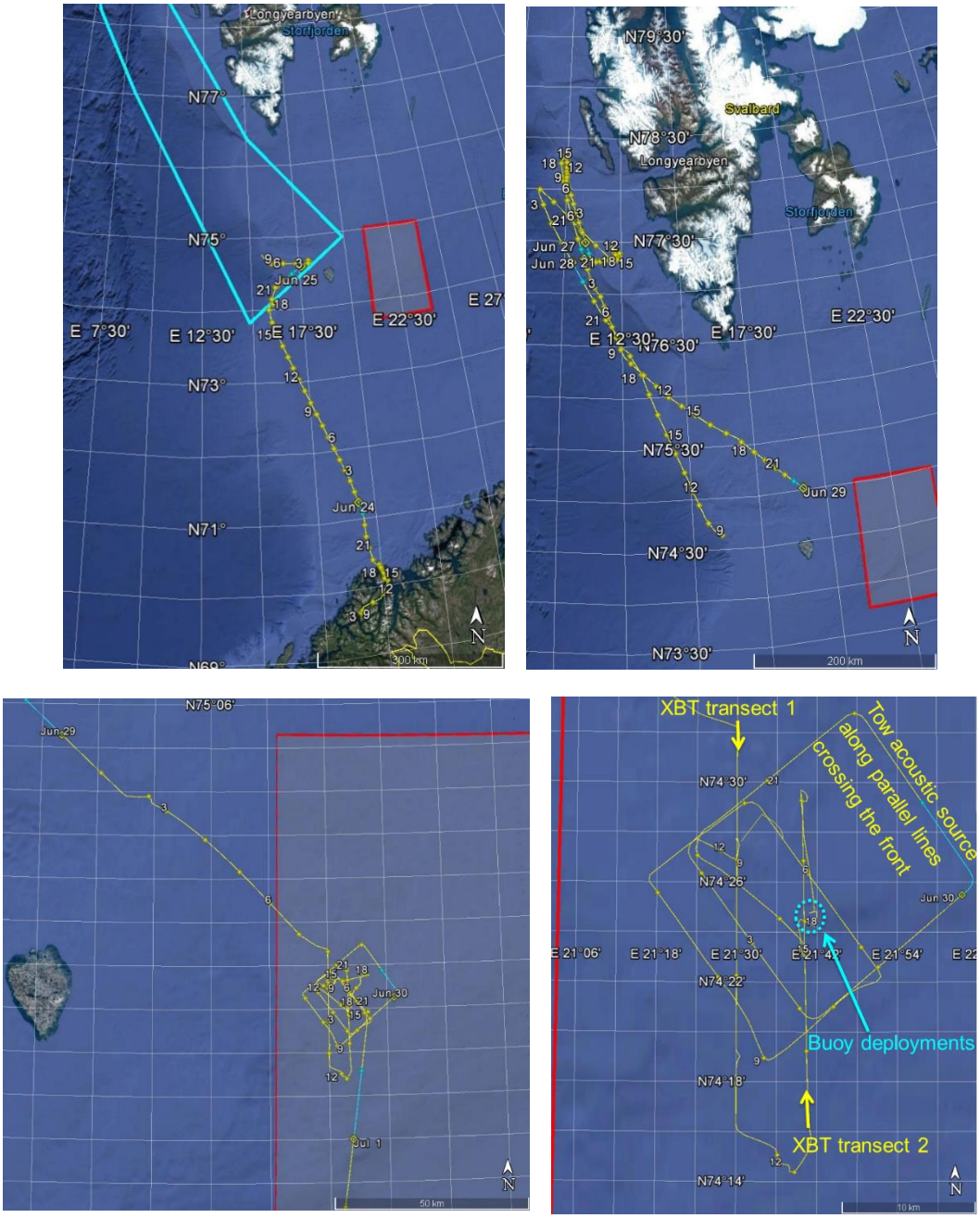

Figure 7: *Tracks followed by NRV Alliance from 23 June to 1 July 2018 in the western Barents Sea/ Bear Island area (red rectangle: area planned for oceanographic-acoustic activities; cyan polygon: area planned for oceanographic activities). Upper left: from Tromsø Harbour to the deployment point of 439 and Dorajr Slocum gliders (then ship propulsion system failed); upper right: from 25 (reaching a safe area west of Spitsbergen Island) to 29 June (recovery of 439 Slocum glider); lower left: from 29 June to 1 July (oceanographic-acoustic activiites east of Bear Island); lower right: zoom on the oceanographic-acoustic activities area.*

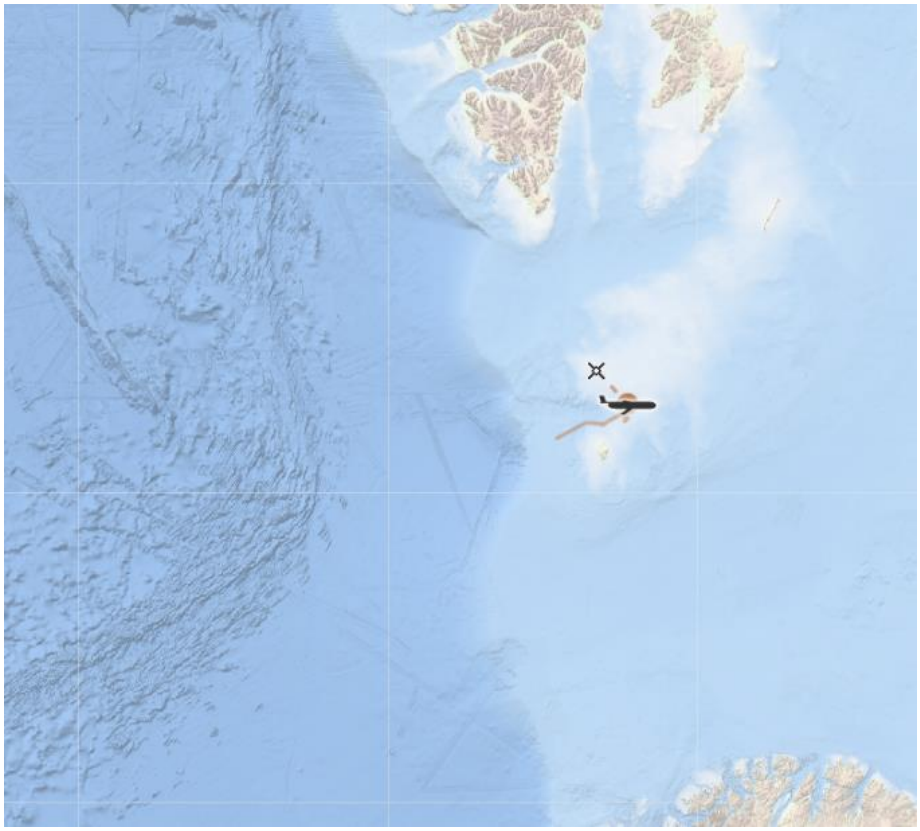

Figure 8: *Tracks followed by the Slocum glider 439 (NOC) from 25 to 29 June 2018 in the western Barents Sea/ Bear Island area.*

Figure 9: *Track followed by the Slocum glider Dorajr (CMRE, green) west of Bear Island from 25 June (deployment, northern position at about 74° 40' N) to 9 July 2018 (recovery).*

2.2 Results

The oceanographic observations collected during NREP18 in the western Barents Sea / Svalbard Islands area consist of the data measured by XBTs and by shipborne instruments (CTD, Acoustic Doppler Current Profiler - ADCP and underway temperature-salinity), plus the data collected by the two oceanographic gliders (439 and Dorajr) and by the two oceanographic/acoustic buoys.

Both glider missions were jeopardized by the ship propulsion system failure, consequently thegliders were kept safe around Bear Island while waiting for an opportunity for their recovery. Fig. 10 shows an interesting feature observed by Dorajr south-west of Bear Island, where a cold and fresh water body intrudes in the warm and salty Atlantic Water layer.

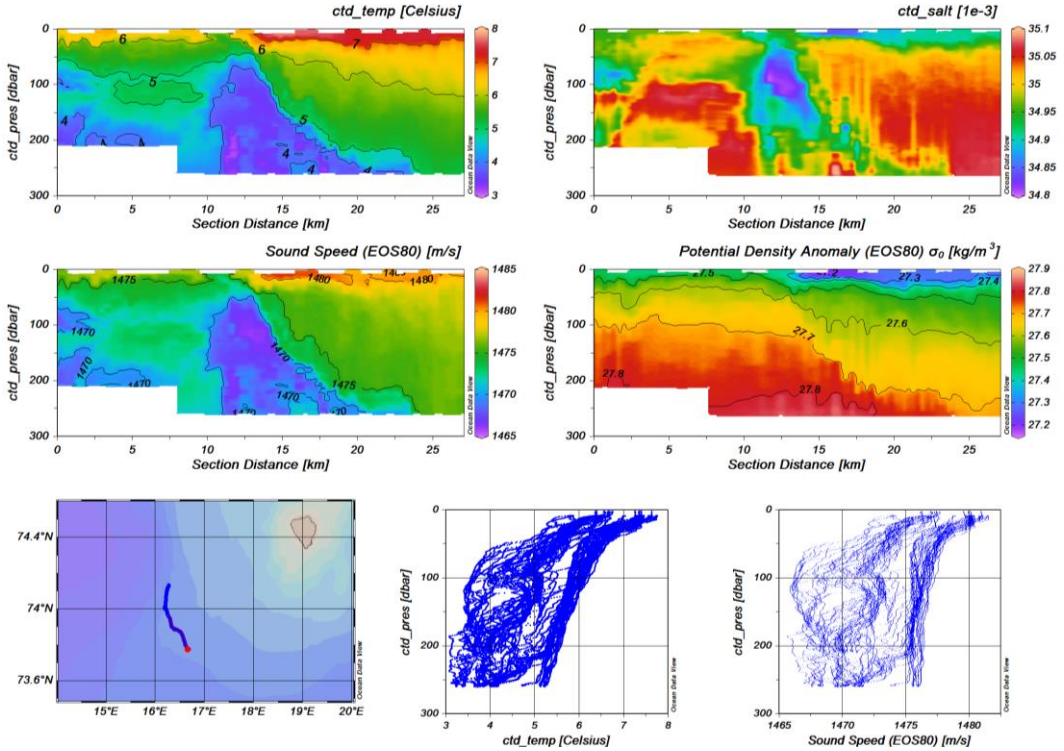

Figure 10: *Temperature (°C), salinity, sound speed (m s^{-1}) and potential density anomaly (kg m^{-3}) sections (going from south to north) plus cumulative temperature and sound speed profiles collected by the Slocum glider Dorajr on 7-8 July 2018 south-west of Bear Island.*

Figs. 11 and 12 depict the CTD sections collected west of Spitsbergen Island on 26 and 27 June. The first section (26 June; Fig. 11) is showed going from the continental slope toward the shelf. In the upper layer, Atlantic Water with salinity close (or over) 35 can be seen entering on the shelf area, while the bottom layer is characterized by colder waters with high turbidity and low light transmission (indicative of turbid bottom currents going from the shelf toward the continental slope).

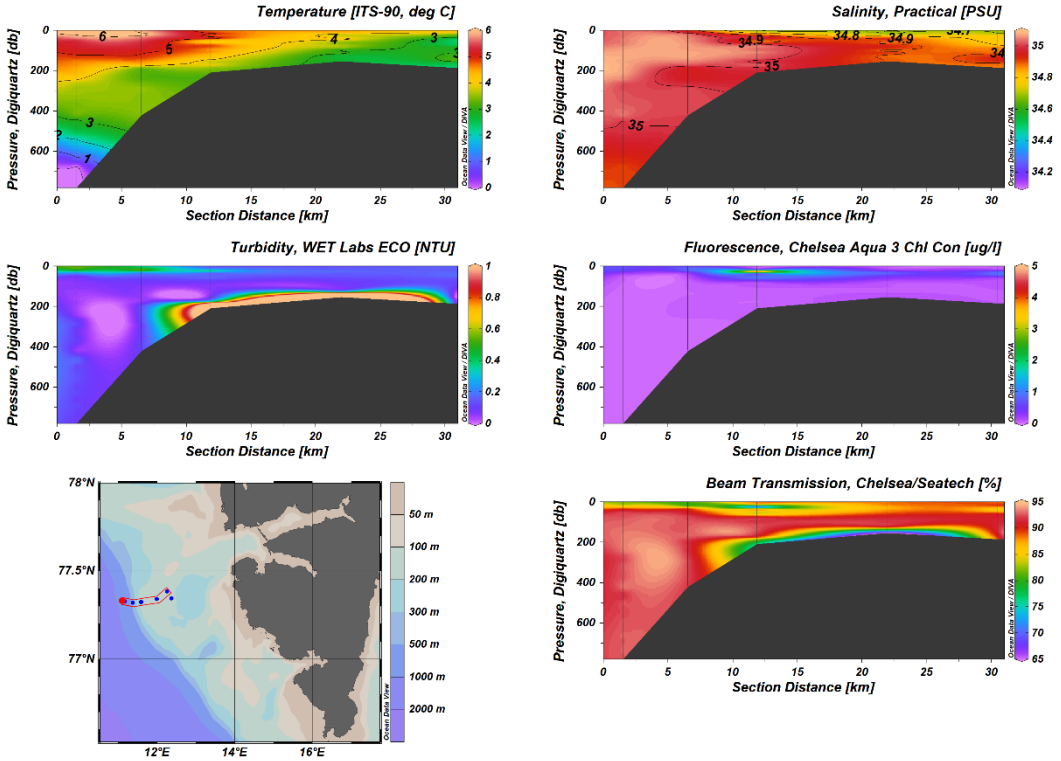

Figure 11: *Temperature (°C), salinity, Turbidity (NTU), Fluorescence (µg l^{-1}) and Beam Transmission (%) sections (going from west to east) by CTD profiles collected on 26 June 2018 off Van Mijenfjorden (west Spitsbergen Island).*

The second section (27 June; Fig. 12) is showed from south to north. Separation among water masses can be seen both horizontally and vertically. Warm and salty Atlantic Waters occupy the southern upper layer of the section, while colder and much fresher waters are in the northern upper layer. The deeper layer mostly includes cold and salty waters probably originated in the Isfjorden.

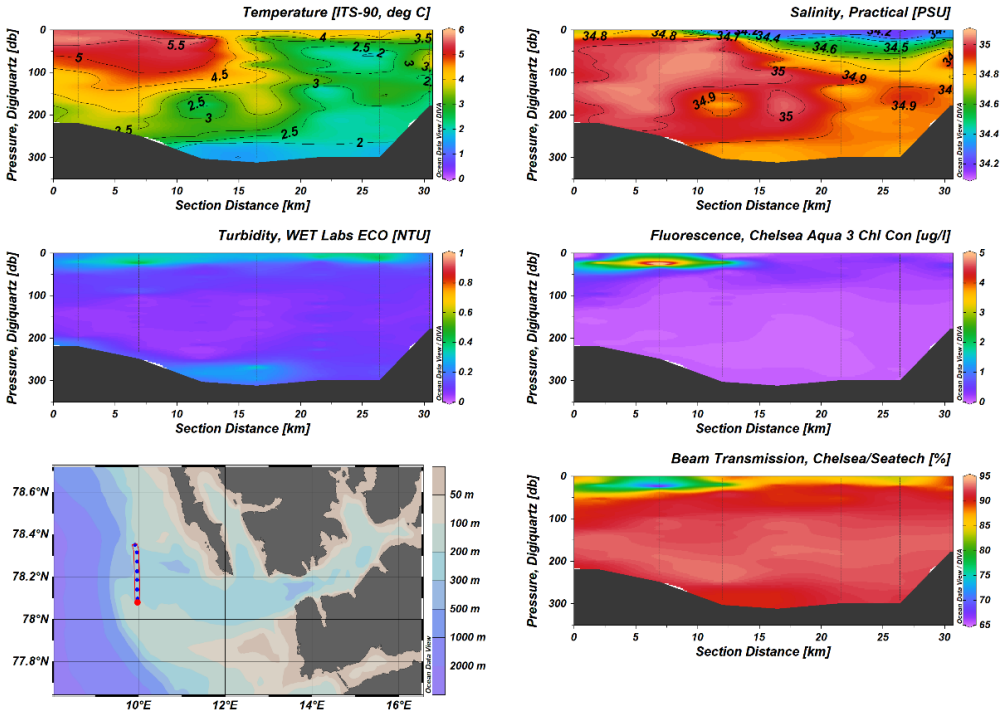

Figure 12: *Temperature (°C), salinity, Turbidity (NTU), Fluorescence (µg l^{-1}) and Beam Transmission (%) sections (going from south to north) by CTD profiles collected on 27 June 2018 off Isfjorden (west Spitsbergen Island).*

The next figures show results from the activities conducted on 29 June 2018 east of Bear Island. Fig. 13 reports the first XBT transect that allowed to detect the position of the Polar Front. It can be seen that in the upper 50 m, at the frontal location, temperature varies by 3-4 °C in less than 10 km, while in the deeper layer the front is less sharp and its position appears to be located about 20 km southward.

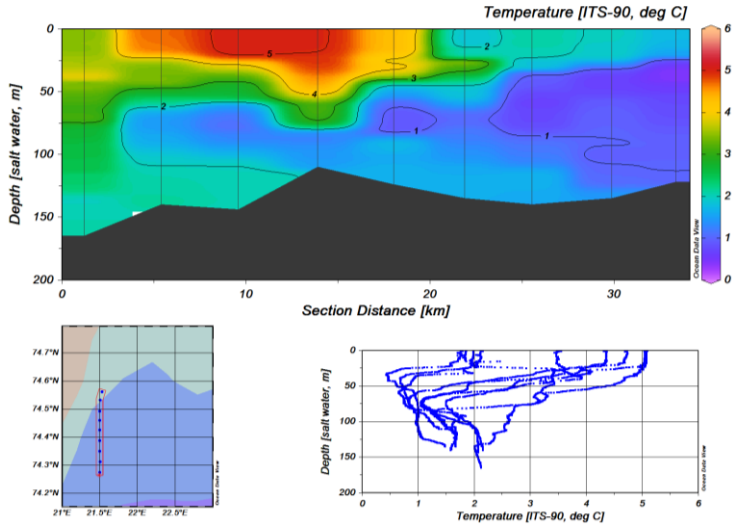

Figure 13: *Temperature (°C) section (from south to north) and profiles collected by XBT launches across the Polar Front east of Bear Island on 29 June 2018.*

Horizontal distributions of observed temperature at 5, 30 and 75 m are shown in Fig. 14. The warmer Atlantic Waters are located in the southern part of the investigated area, while colder Arctic waters are in the northern part. Variations along the vertical are evident.

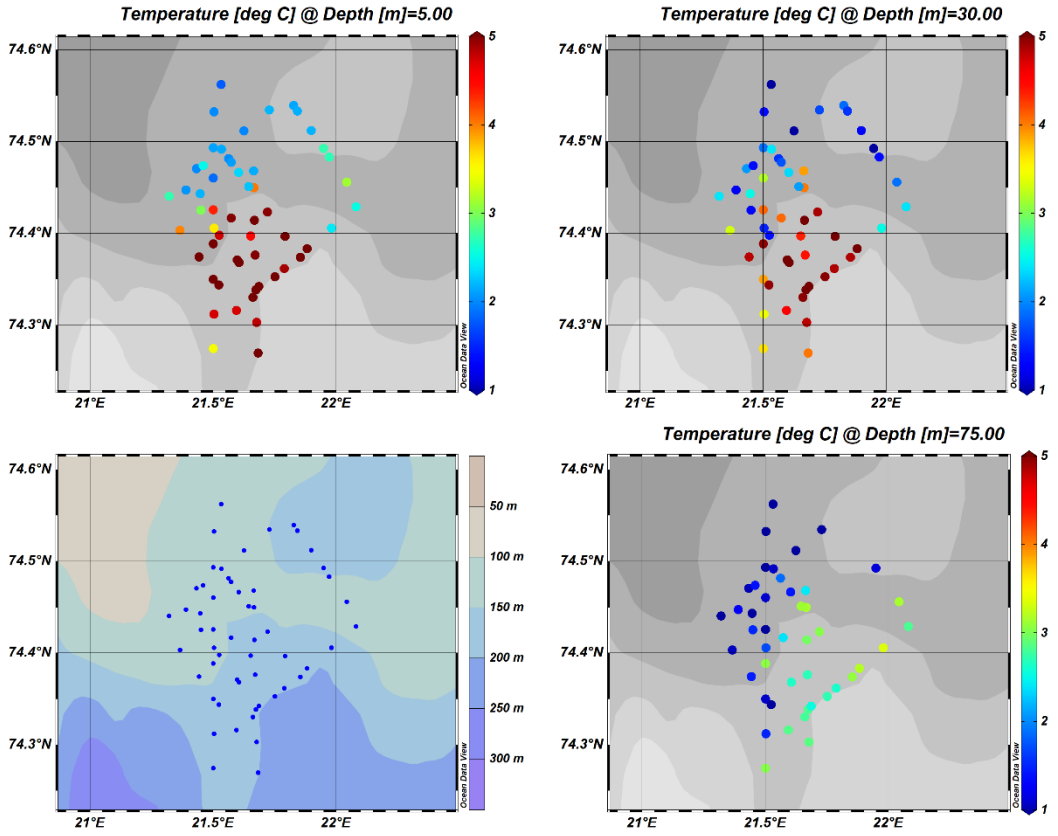

Figure 14: *Horizontal distribution of Temperature (°C) at 5, 30 and 75 m depth observed by XBT launches and CTD casts on 29-30 June 2018 in the Polar Front region east of Bear Island; bathymetry of the investigated area is also reported.*

Fig. 15 shows the sound speed distribution interpolated at 15 m depth and overlapped with the trajectory followed by the two oceanographic-acoustic buoys and by NRV Alliance. Of course sound speed reflects temperature fields (for sound speed calculation, salinities collected by the two CTD casts collected north and south of the Polar Front were combined with temperature measured by XBT probes) and crossing the front shows a variation of about 10 m s^{-1}. Buoy 2 was fully south of the front, while Buoy 1 appeared to be just north of the frontal area. Neverthless Buoy 2 was located in an apparently stabler area, at around 55 m depth it shows larger temperature variations than Buoy 1 (Fig. 16). On 30 June, at around 1:00-2:00 and again at 13:00-14:00, temperature values recorded by Buoy 2 lowered to values similar to the ones observed by Buoy 1. This could indicate that temperatures recorded near 55 m by Buoy 2 were influenced by internal tides.

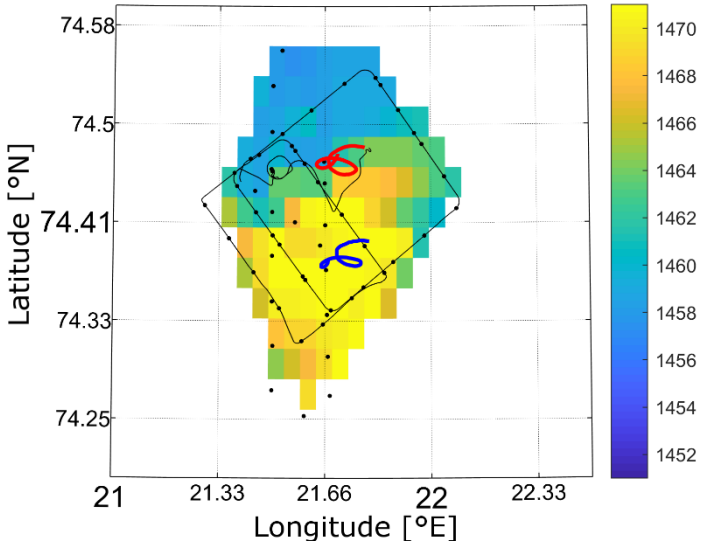

Figure 15: *Horizontal map of sound speed (colorbar in m s^{-1}) at a depth of 15 m in the Polar Front region east of Bear Island on 29-30 June 2018. Dots denote the position of in situ measurements, while the red and blue lines denote the tracks followed by the drifting buoys (red = Buoy 1; blue = Buoy 2). The track followed by NRV Alliance is marked with a thin black line.*

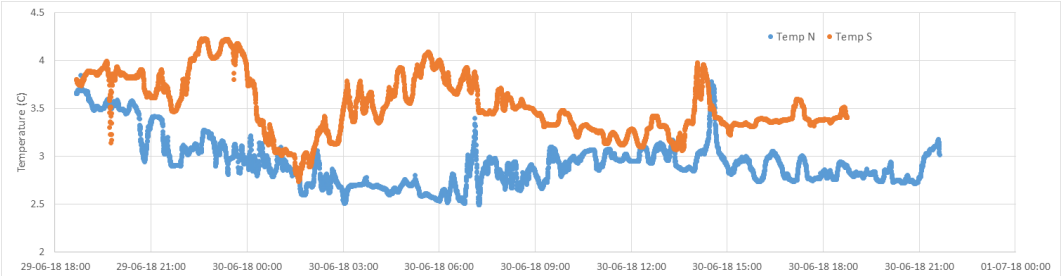

Figure 16: *Time series of Temperature (°C) collected north (Buoy 1, blue; average observed depth: 56 m) and south (Buoy 2, orange; average observed depth: 53 m) of the Polar Front region, respectively, east of Bear Island on 29-30 June 2018.*

4 Summary

The execution of the NREP18 sea trial was severely affected by failures of the NRV Alliance propulsion system. Neverthless, a significant amount of data was collected and, thanks to the substantial integration provided by partners's campaigns (IFEx 2018 in the GIUK gap and HN18 in the Barents Sea opening / Svalbard Islands area; not described in this report), the majority of the NREP18 objectives was fulfilled.

The oceanographic data collected from NRV Alliance during NREP18 include 15 CTD casts and 125 XBT profiles, plus underway measurements from hull-mounted Acoustic Doppler Current Profiler (ADCP) and temperature-conductivity measurements through hull intake at about 5 m depth.

In total, five underwater gliders were operated during the NREP18 sea trial. Four of them were Slocum G3 and G2 oceanographic gliders. During the activities west of Bear Island, a CMRE Slocum G1 glider (named Greta) performed a short deployment (for a few hours) on 30 June 2018 for testing of the new CMRE compact Volumetric Acoustic Sensor.

Datasets collected east of Iceland allowed the identification of the IFF and to describe its characteristics. Data are being used for validating oceanographic-acoustic models in the IFF area and for improving their performance in such a challenging area.

Datasets collected in the Barents Sea opening / Svalbard Islands area allowed the identification of the position of the Polar Front east of Bear Island and to conduct a short oceanographic-acoustic experimentation using drifting acoustic-oceanographic buoys (deployed just north and south of the front) and an acoustic source towed by NRV Alliance.

Acknowledgments

NATO Allied Command Transformation (ACT) Future Solutions Branch is gratefully acknowledged for financial support of the EKOE program.

The Italian Navy Commander and crew of NRV Alliance are gratefully acknowleged for safely conducting operations in very difficult situations, and the CMRE's Engineering and Information Technology Division personnel for conducting the data acquisition both onboard and ashore.

Part of the data and equipment described in this report originates from NREP18 partners, which are gratefully acknowledged: Teledyne Webb Research (TWR; USA) for capx690 Slocum glider; National Oceanographic Centre (NOC; GBR) for Slocum glider 439; Naval Research Laboratory (NRL; USA) for two instrumented drifting buoys.

The Freya and capx690 Slocum gliders were recovered by the German R/V Planet, whose Captain and crew are gratefully acknowledged, as well as the onboard Chief Scientist Dr. Heinz-Volker Fiekas (WTD 71; DEU). The Dorajr glider was recovered by NRV Alliance during the HN18 campaign, whose Chief Scientist and Project Manager (Prof. Roberta Ivaldi and CDR Maurizio Demarte, Italian Hydrographic Institute) are gratefully acknowledged.

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