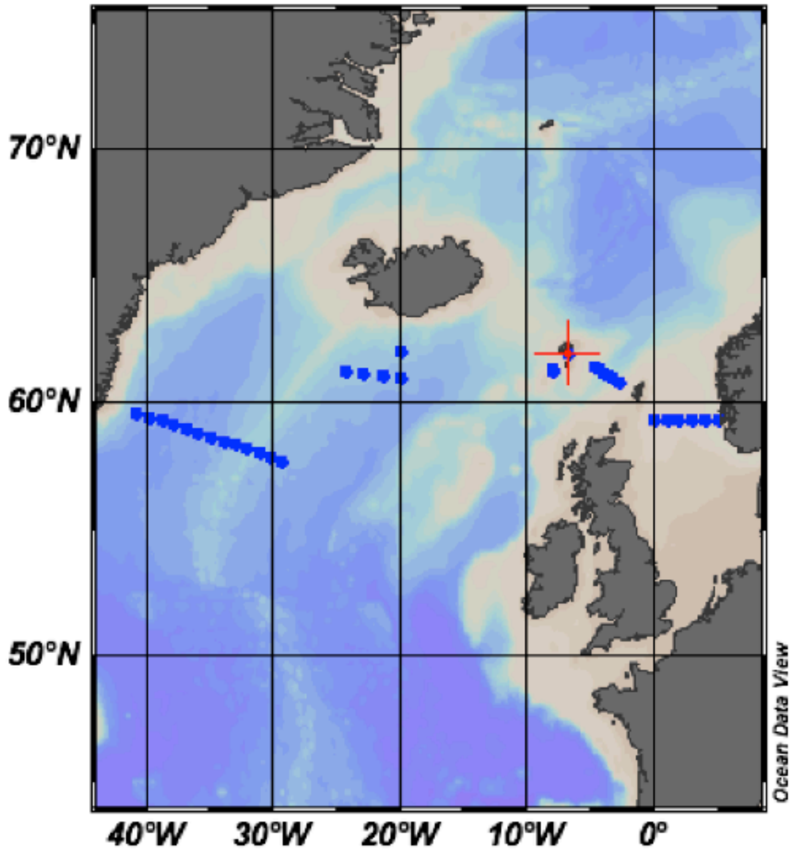
# CRUISE REPORT: A01/AR07E/A16N

*(Updated AUG 2018)*




## Highlights

### Cruise Summary Information

| | |
|---|---|
| Section Designation | **A01/AR07E/A16N** |
| Expedition designation (ExpoCodes) | **58GS20150410** |
| Chief Scientists | **Are Olsen / U. Bergen** |
| Dates | 2015 APR 10 - 2015 APR 26 |
| Ship | *G.O. Sars* |
| Ports of call | Torshavn, Denmark to Bergen, Norway |
| Geographic Boundaries | 61° 59' 20" N<br>40° 44' 16.8" W 5° 1' 52.7" E<br>57° 42' 0" N |
| Stations | 34 |
| Floats and drifters deployed | 0 |
| Moorings deployed or recovered | 0 |


**Contact Information:**

**Are Christian Sviggum Olsen, Prof.**

Geophysical Institute • University of Bergen

Postboks 7803 • 5020 BERGEN • Norway

phone: +47 55 58 47 81 • email: Are.Olsen@uib.no


Report assembled by Jerry Kappa, UCSD/SIO

## Links to Select Topics

Shaded sections are not relevant to this cruise or were not available when this report was compiled.

| Cruise Summary Information | Hydrographic Measurements |
|---|---|
| Description of Scientific Program | **CTD Data:** |
| Geographic Boundaries | Acquisition |
| Cruise Track (Figure) | Processing |
| Description of Stations | Calibration |
| Description of Parameters Sampled | Temperature Pressure |
| Bottle Depth Distributions (Figure) | Salinities Oxygens |
| | |
| Floats and Drifters Deployed | **Bottle Data** |
| Moorings Deployed or Recovered | Salinity |
| | Oxygen |
| Principal Investigators | Nutrients |
| Cruise Participants | Carbon System Parameters |
| | CFCs |
| Problems and Goals Not Achieved | Helium / Tritium |
| Other Incidents of Note | Radiocarbon |
| | |
| **Underway Data Information** | **Lowered Acoustic Doppler Current Profiler (LADCP)** |
| Acoustic Doppler Current Profiler (ADCP) | **References** |
| Navigation Bathymetry | |
| Thermosalinograph | |
| XBT and/or XCTD | |
| Meteorological Observations | |
| Atmospheric Chemistry Data | |
| Underway $pCO_2$ | |
| **Data Processing Notes** | **Acknowledgments** |

# Cruise report

# 58GS20150410
# (a.k.a. GOS2015107, SNACS CRUISE)

**Are Olsen[1,2],** Ailin Brakstad[1], Friederike Fröb[1,2], Nil Irvali[3,2], Kristin Jackson[1] , Emil Jeansson[4,2], Tor de Lange[1], Siv Lauvset[1,2], Stig Monsen[3], Ulysses Ninneman[3,2], Tore Onarheim[1], Abdirahman Omar[4,2], Balamuralli Rajasakaren[4,2], Jörg Schwinger[4,2], Asgeir Steinsland[5], Åse Sudmann[5], Magni Svanevik[1]

[1]Geophysical Institute, University of Bergen, Bergen, Norway
[2]Bjerknes Centre for Climate Research, Bergen, Norway
[3]Department of Earth Sciences, University of Bergen, Bergen, Norway
[4]Uni Climate, Uni Research, Bergen, Norway
[5]Institute of Marine Research, Bergen, Norway

## Contents

# 1. Introduction and Background

The cruise was conducted on board the Norwegian research vessel G. O. Sars, as part of the Norwegian Research Council funded project SNACS, Subpolar Atlantic Climate States. This project focus on North Atlantic Subpolar gyre dynamics and carbon cycling in the Holocene, present and future. The sampling program was designed to enable carbon budget calculations, mapping of sea water chemistry in various water masses, and coring at water sampling sites allowing for a direct comparison between sedimentary records and water chemistry, in particular focusing on stable carbon isotopes, $\delta^{13}C$.

For the cruise we, in particular planned to focus on a hydrographic section in the Irminger Sea, the center of the North Atlantic Subpolar Gyre. This section covers the western parts of WOCE line AR07E. Further we would obtain sediment cores on the western edge of the basin, at a site capturing the Denmark Strait Overflow Water and at the western slope of Reykjanes Ridge capturing the variability in polar front position. Further work was planned along the core of the Iceland Scotland Overflow Water from Faeroes-Shetland and southwards (Fig. 1). In particular coring at ODP 984 site, and do repeats of A16N stations at 20°W and 61° and 62°N, this gives us an opportunity to compare our $\delta^{13}C$ data with those obtained by US groups at the same stations, allowing for calibration of data across laboratories.

We also planned to install a new General Oceanics underway $pCO_2$ instrument on the ship during the cruise as part of the Norwegian Ocean Acidification monitoring program funded by the Norwegian Environment Agency.

The ship departed from Torshavn, Faeroe Islands, and the plan was to head towards Cape Farwell and work our way eastwards, home to Bergen.

The ship was equipped with a Seabird 911+ CTD with temperature, conductivity and oxygen sensors, a rosette water sampler. In addition the ship is equipped with a termosalinograph and a fluorometer that carries out underway measurements on water taken from a seawater inlet on the drop keel.

For the water sample analysis we brought along instruments for analysis of salinity, oxygen concentration, Dissolved Inorganic Carbon (DIC), Total Alkalinity (TA), and the transient tracers sulphur hexafluoride ($SF_6$) and chlorofluorocarbon-12 (CFC-12). Each of these is described later in this document. Further, we took water samples for nutrients, and $\delta^{13}C$ of DIC to be brought home and analyzed ashore.

For the sediment coring we used a gravity and a multicore from Department of Earth Sciences, UiB, and the ship's TOPAS seismic system for mapping coring locations.

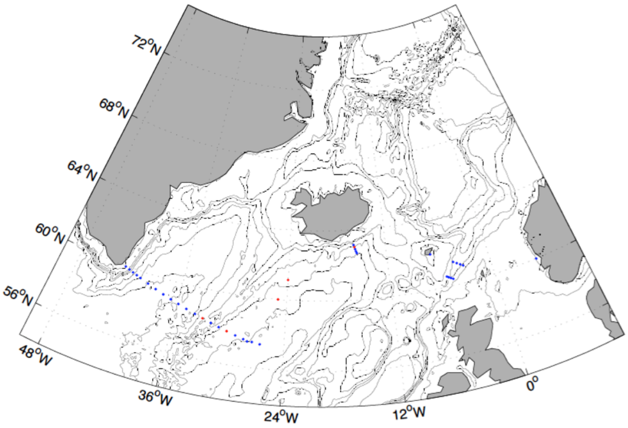



**Fig. 1:** Planned sampling locations for 58GS20150410, blue: hydrography and chemistry, red: hydrography, chemistry and potential coring sites.

## 2. Participants & responsibilities

| | |
|---|---|
| Are Olsen | Chief Scientist. |
| Abdirahman Omar | Dissolved Inorganic Carbon (DIC) & Total Alkalinity (TA) (PI) |
| Ailin Brakstad | Bottle salinity sampling and analysis |
| Asgeir Steinsland | CTD, instrument chief |
| Balamuralli Rajasakaren | CFC-12 & $SF_6$ |
| Emil Jeansson | CFC-12 & $SF_6$ (PI) and and underway $O_2$/Ar (PI) |
| Friederike Fröb | DIC & TA |
| Jörg Schwinger | Oxygen sampling |
| Kristin Jackson | Winkler oxygen, sampling and analysis (PI). |
| Magni Svanevik | DIC & TA |
| Nil Irvali | Coring, nutrient and salinity sampling |
| Siv Lauvset | underway $pCO_2$ and $\delta^{13}C$ sampling |
| Stig Monsen | Coring technician |
| Tor de Lange | DIC & TA |
| Tore Onarheim | $\delta^{13}C$ sampling |
| Ulysses Ninnemann | Coring (PI), nutrient sampling |
| Åse Sudmann | CTD, instrument |

# 3. WATCH LIST

| Who | When | What |
|---|---|---|
| Abdirahman Omar | 1200-2400 | Carbon |
| Ailin Brakstad | 1200-2400 | Salinity |
| Are Olsen | 0800-2000 | Chief Scientist |
| Asgeir Steinsland | 0600-1200 & 1800-0000 | CTD |
| Balamuralli Rajasakaren | 0000-1200 | Freons |
| Emil Jeansson | 1200-0000 | Freons |
| Friederike Frob | 1200-2400 | Carbon |
| Kristin Jackson | 0000-1200 | Oxygen |
| Magni Svanevik | 0000-1200 | Carbon |
| Nil Irvali | 0000-1200 | Nuts, Salin. sampling, sediments |
| Siv Lauvset | 1200-2400 | pCO2, $\delta^{13}C$ sampling |
| Stig Monsen | | Sediments |
| Tor de Lange | 0000-1200 | Carbon |
| Tore Onarheim | 0000-1200 | $\delta^{13}C$ sampling |
| Ulysses Ninnemann | 1200-2400 | Nuts. sampling, sediments |
| Åse Sudmann | 0000-0600 & 1200-1800 | CTD |

# 4. SAMPLING and INSTRUMENTS

## 4. 1 Water profile sampling

We used a 12-bottle rosette equipped with 10 l Niskin bottles from General Oceanics. This was done to save time, as this was short, and allow work in more adverse conditions than would be allowed with the 24-bottle rosette.

All water sampling was carried out following GO-SHIP protocols. The sampling order was: (1) CFC-12 & $SF_6$ (2) Oxygen (3) DIC & AT in one bottle (4) $\delta^{13}C$ (5) nutrients (6) salinity.

### CTD

Seabird 911+ with two sets of temperature (SBE 3, serial numbers: primary 4134; secondary 1445) and conductivity sensors (SBE 4, serial numbers: primary 2140, secondary 3080) and a SBE 43 dissolved oxygen sensor (serial number 0368).

The sensor pairs showed good correspondence throughout the cruise. The difference in salinity was typically short of 0.01, with the primary sensor higher. The difference in temperature was typically less than 0.004°C, with the primary being the higher most of the times.

The CTD was set to report temperature on the ITS-68 scale and Salinity on the PSS-78 scale. In the bottle data file the tempratures have been converted to ITS-90 using t90 = t68 * 0.99976

The oxygen sensor also showed good behavior over the cruise, reporting values that were typically around 0.3 ml $l^{-1}$ less than those obtained by Winkler titration of water samples.

The CTD salinity and Oxygen data were corrected with respect to the bottle salinity and Winkler oxygen data (described below) using GO-SHIP recommended practices (Hood et al., 2010). Importantly, for salinity the correction was carried out using conductivity. For the bottle files, the corrected salinity data are those from sensor 1. For the CTD files corrected data from both sensor 1 and 2 are included.

### CFC-12 and $SF_6$ analyses

Samples for analysis of CFC-12 and $SF_6$ were collected on all stations throughout the cruise. The samples were taken from the Niskin bottles in glass syringes (250 ml), which were stored immersed in cold seawater and analysis took place within six hours after sampling. The analysis is based on purge-and-trap work-up of the water samples followed by gas chromatographic separation and electron capture detection of the different compounds; the analytical technique is described by Fogelqvist (1999).

The standardization was achieved by calibration gas prepared at Deuste Steininger GmbH, Mühlhausen, Germany, and cross-calibrated against gas prepared at Scripps Institute of Oceanography. The standard gases were calibrated against the SIO-93 scale.

## Winkler oxygen

Oxygen concentrations in water samples, which were sampled from every Niskin were determined using Winkler titration on an instrument designed & built at Scripps Institute of Oceanography. The instrument functioned seamlessly at the cruise, apart from a few instances when we lost connection with the detector. Density for per l to per kg conversion was determined using draw temperature measurements.

## Carbon chemistry

Analysis of the DIC and TA in water samples followed standard operating procedures as described in Dickson et al. (2007) by using two instruments built by MARIANDA in Kiel, VINDTA. The DIC is determined through coulometric titration of the gas stream from an acidified water sample of known volume following Johnson et al. (1985). The TA is determined using potentiometric titration of a water sample with HCl with a known concentration and a curve-fitting routine.

The collected samples were first brought to the desired measurement temperatures (20°C) and analyzed first for DIC and then for TA (after heating further to 25°C). The heating of the samples were carried out by storing them in the lab, under a dark plastic sheet to minimize possible primary production.

All samples were analyzed within approx. 12 hours of collection, and there was no need of conserving these with mercury chloride. All sampling bottles had been thoroughly cleaned and baked prior to the cruise.

The accuracy of the DIC and TA measurement systems was kept under control by frequent measurements of Certified Reference Material (CRM) supplied by Andrew Dickson (Scripps Institute of Oceanography, USA). Typical offsets were 4 - 6 $\mu$mol kg$^{-1}$ for both, these offsets are corrected for in our final data file.

## $\delta^{13}$C

The $\delta^{13}$C samples were drawn from every Niskin into 250 ml serum vials and transferred into exitainers preflushed with helium and that contained an aliquot of phosphoric acid. The seawater from each sampling depth was injected into three exitainers, 1 ml in each, using a new syringe for each sample, and making sure there were no air bubbles in the syringe when injecting the water into the exitainers. The three exitainers were taken from separate flushing batches, for analysis in duplicate at the mass spectrometer - Thermoscientific Delta V with Gas Bench prep unit. at Department of Earth Sciences at University of Bergen. Standards: IAEA-CO-8 and NBS 18 and NBS 19 carbonate standards, each in triplicate on seperate carrousel at start.

## Nutrients

Samples for analysis of concentration of phosphate, nitrate and silicate were drawn from each Niskin into 24 ml scintillation vials and preserved with 0.2 ml chloroform. All samples were stored cold and in the dark before analyses on shore by IMR using an autoanalyser within two months after the cruise. Crossoveranalysis with GLODAPv2 data (Olsen et al., 2016) shows that the phosphate values are likely 12% too high. This has *not* been corrected for. The other nutrient data are consistent with GLODAPv2 data.

## Salinity

Salinity was determined onboard in bottle samples drawn from every Niskin on the rosette at each station, following GO-SHIP recommended practices. The samples were allowed to reach recommended analysis temperature by storing them in the climate controlled room on board, before analyzing them using a Guildline Portasal. This was also installed in the climate-controlled room. The stated accuracy of this instrument is 0.003.

# 4. 2 Surface Sampling

Surface sampling was carried out for the following parameters:

## Temperature and Salinity

Using the ships TSG, SBE21 from start until end of cruise.

## Chlorophyll

Using ships fluorometer, Wet Labs Wet Star from start until end of cruise. Note that the data until morning 15/4 are no good, fluorometer dirty, see diary.

## p$CO_2$

A new underway p$CO_2$ system from GO was installed in the clean seawater sampling room during the first days of the cruise. We used the intake on the keel, approx. 6 m depth. This was running all the time and used three certified standard gasses from NOAA for calibration of the Licor.

## Oxygen

An Anderaa optode was hooked up to the underway p$CO_2$ system, and was running all the time of the cruise.

## Oxygen/Argon

Measurements were carried out, but are not reported.

## Discrete samples

Discrete samples were collected at in the clean seawater sampling room from April 13. Until evening 15. we used water from the optode overflow, after that we used as separate outlet with lesser flow, better accuracy many be expected of

these later data. Samples for DIC, TA, oxygen and salinity were analyzed onboard using methods described above, while samples for nutrients and $\delta^{13}C$ was brought ashore for analysis at IMR and Department of Geosciences, respectively. Each surface station has three replicates
In the file with these data:

- Temperature + Salinity, as read from TSG display, same for all three replicates
- Btl_Salinity - from samples measured at portasal, 0/2 replicates
- Oxygen_down - from Winkler measurements of watersamples from underway lab. All replicate values are actual replicates. Unit, µmol/kg
- Oxygen_up - from Winkler measurements of watersamples from chemistry lab. Unit, µmol/kg
- All replicate values are actual replicates
- Temperature_down, as measured in underway lab during sampling
- Temperature_up, as measured in chemistry lab during sampling
- Nitrate, Nitrite, Silicate, Phosphate, all three values per station from actual replicates, Unit, µmol/kg
- Alkalinity and TCO2, all values at each station are actual replicates, units µmol/kg
- C13, one 250 ml serum vial per sample. Water injected into three exitainers as for the bottle samples. Mean of measurements of these three exitainers reported in file.

These data have not been quality controlled in any way

## 4. 3 SEDIMENT CORING

### TOPAS PS18 (Parametric Sub-bottom Profiler System)

For sub-bottom profiling and siting of sediment cores the SNACS cruise employed the TOPAS PS18 system. This is a single, narrow beam sub-bottom profiler system with electronic roll, pitch and heave stabilization. The range resolution is normally less than 0.3 m, and penetration capability is normally more than 150 m. These factors, however, depends on sediment, water depth and ambient noise.
There are several types of pulses that can be used, depending on the different depth and different use that is needed. High penetration (Chirp wavelet with longer wavelengths and greater penetration) was used throughout the cruise.

### Coring equipment

The multi-corer used on the cruise is a customized KC multi-corer (see figure 2). The corer is equipped with 4 tubes, each with a diameter of 110mm and a length of 600mm. The corer is designed to slowly penetrate the sediment after setting down on the seafloor. After sampling the lid closes creating a vacuum holding the sediment in place until the core is raised free of the sediment triggering the shovel foot to swing into place sealing the base of the tube. Further information of the corer can be found at KC's home page at: http://www.kc-denmark.dk/

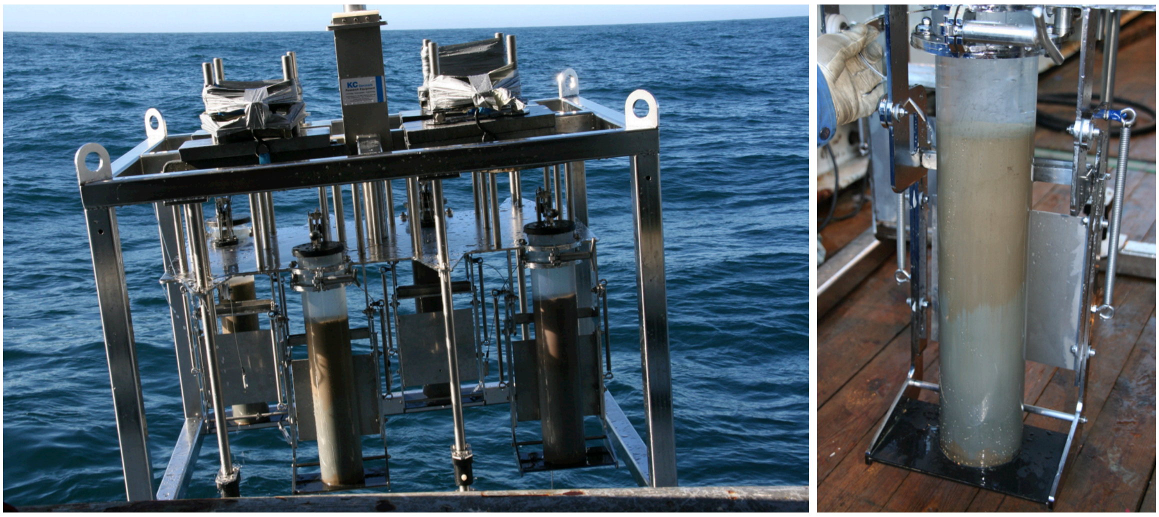


**Fig. 2:** KC Multicorer that was used on the cruise, with close up of one of the sampling tubes (photo Stig Monsen).

The GEO-UoB gravity coring system capable of taking up to 5m long cores was also employed. The core liner is rigged directly onto the weighted coring head with a cutting head/core catcher combo installed at the base of the liner.

# 5. PRELIMINARY RESULTS

## 5.1 Water profile sampling

Despite a lot of bad weather we managed to conduct most of the planned sampling program. Water was sampled at 34 unique station locations, excluding a test station off Torshavn. All but one location was sampled using a single CTD cast; at 62°N 20°W, two casts were carried out. Each of these was assigned a station number, 192 and 193, in accordance with IMRs operating protocols. In our bottle data file 193 has been remaned to 192 cast 2. The positions of the stations are presented in Fig 4. In summary after leaving Torshavn we first sampled the western part of the AR07E section, i.e. the Irminger Basin and Reykjanes Ridge. Next we sampled the ODP 984 drilling site and watermasses eastwards to 20°E, where we repeated the A16N stations at 61° and 62° N. After this we sampled 4 stations in the Faroe Bank channel, and 7 stations between Faroes and Shetland mapping overflow waters upstream of the FBC. Finally, as we had time on our hands we visited 6 locations at the so-called Utsira section at 59.28°N in the North Sea, as we headed home to Bergen

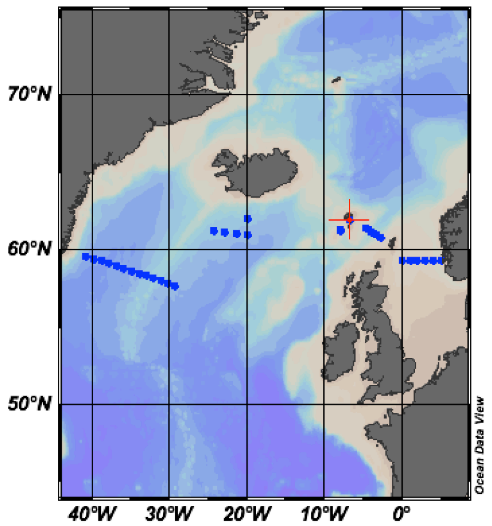



**Fig 3**: Positions of stations occupied during the cruise.

Fig. 4 (prepared using final data - this is the case for all section plots) shows distribution of temperature, salinity and Apparent Oxygen Utilization (AOU) at the section across the Irminger Basin. The upper 1000 m of the water column are occupied by recently ventilated Labrador Sea the west and Atlantic waters in the east. Denmark Strait Overflow Water is visible towards the bottom in the western parts, while in the eastern parts, Northeast Atlantic Deep Water dominates.

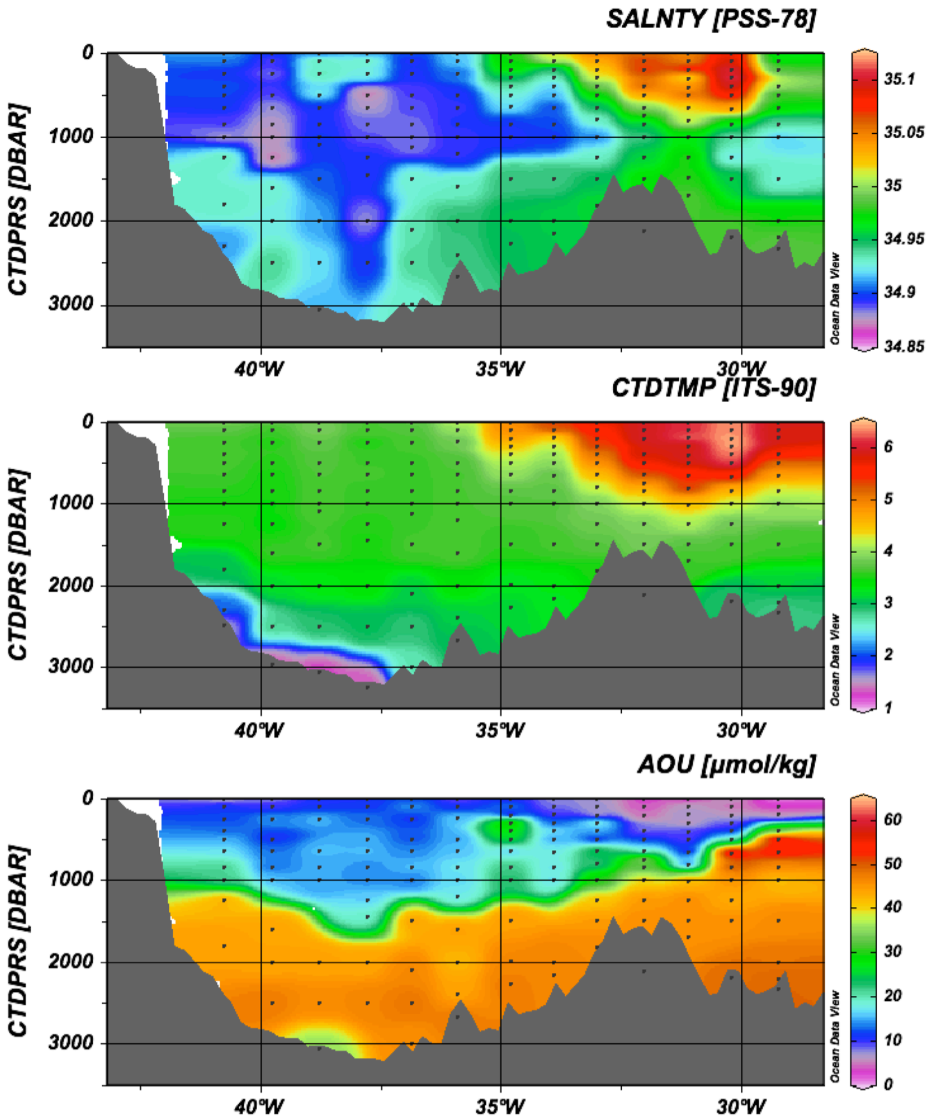



**Fig. 4:** Distribution of temperature, salinity and AOU in the Irminger Sea and right across the Reykjanes Ridge, based on the bottle data from the cruise. Black points are sampling locations/depths.

Figure 5 shows the DIC and TA distribution along the same section displayed above. In the Irminger basin the gradients are fairly small. To the east of the Reykjanes Ridge, the high DIC intermediate waters beneath the Atlantic waters are the most prominent feature. The TA distribution by and large aligns with salinity. DIC beneath 1000 at ~37W appears a tad low, but nothing our measurements indicate that these are questionable.

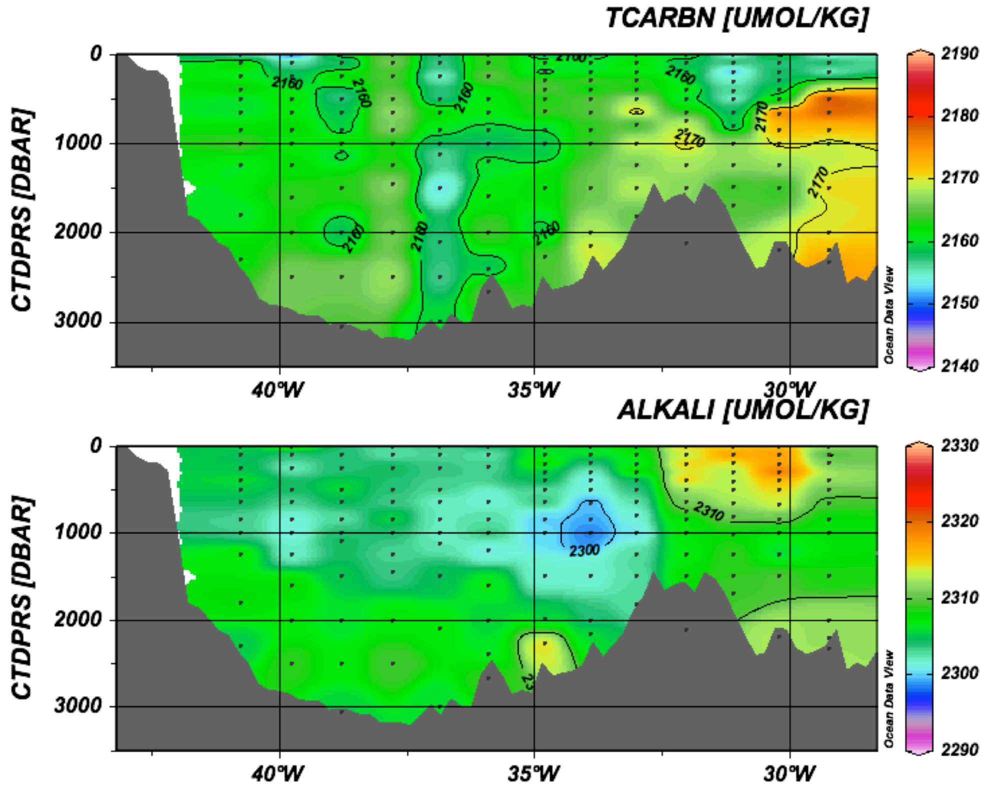



**Fig 4:** Sections of DIC and TA across the Reykjanes Ridge

Figure 6 shows sections of temperature, salinity and AOU on the section eastwards from the ODP 984 site at the eastern flank of the Reykjanes Ridge and into the Iceland Basin at approx. 61°N. The upper 500 dbar are dominated by Atlantic water, right beneath there is a layer of oxygen poor intermediate water. The low salinity core centered at 21.5°W and 1500 dbar is Labrador Sea Water, and overflow waters in various stages of entrainment are found beneath.

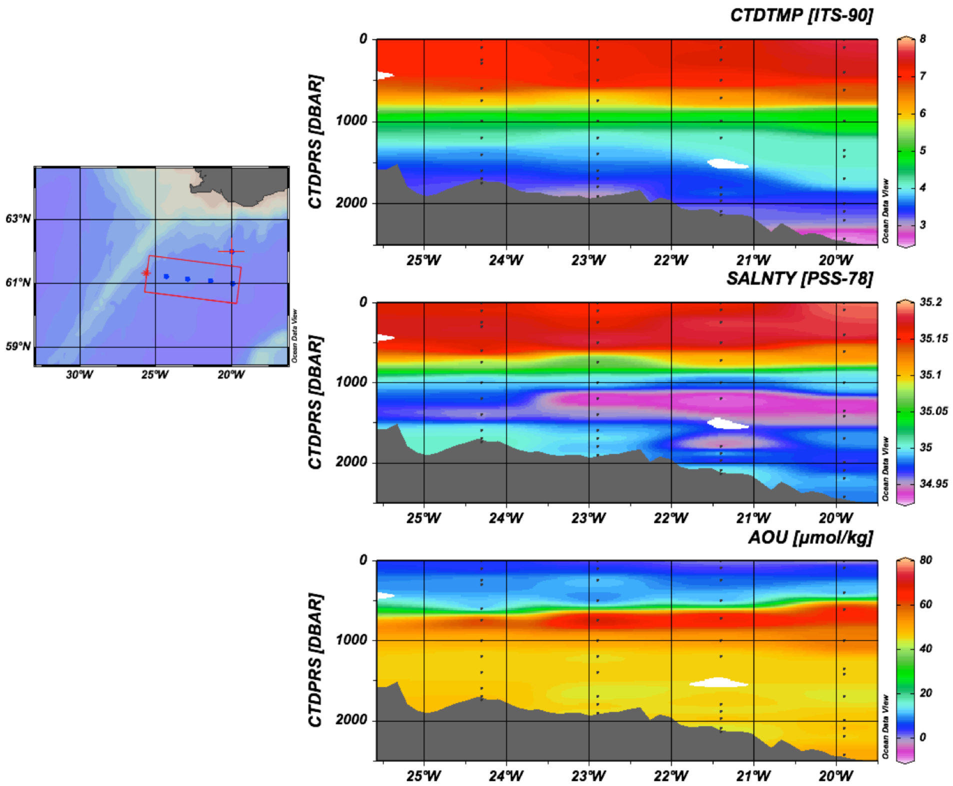



**Fig 6:** Sections of temperature, salinity and AOU at the section from ODP 984 coring site and westwards into the Iceland Basin, preliminary data.

Fig. 7 shows sections of temperature, salinity and AOU in the Faeroe Bank Channel with the saline Atlantic inflow in the upper 500 dbar or so, and the fresher and but colder overflow waters beneath. The overflow waters have higher AOU, reflecting their less ventilated stage.

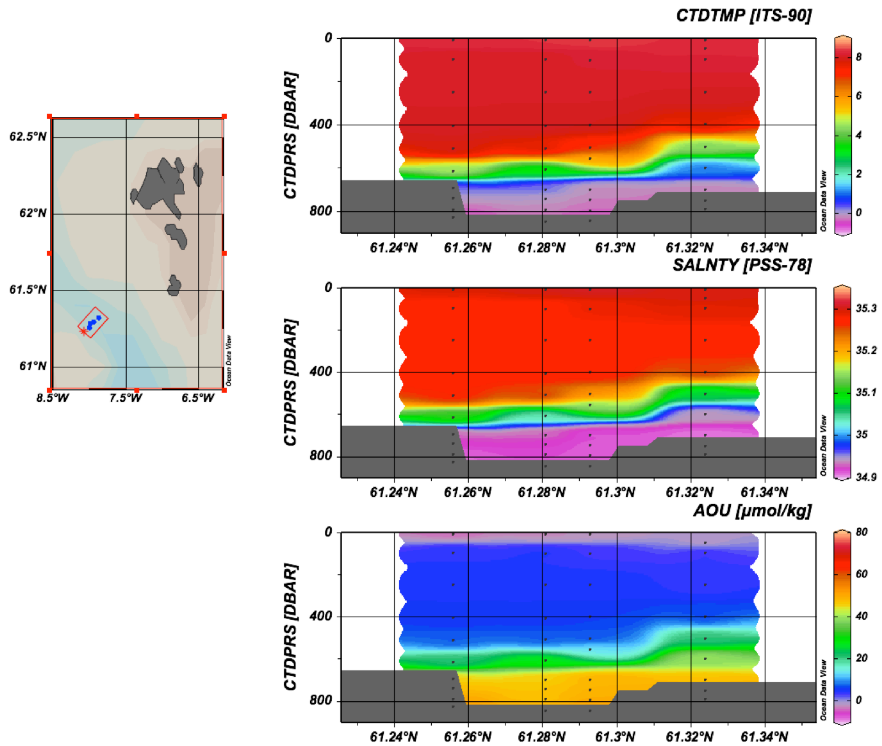



**Fig. 7:** Sections of temperature, salinity and AOU in the Faeroe Bank Channel.

Fig. 8 shows the distribution of temperature, salinity and AOU in the Faeroe-Shetland channel, with the warm, saline and oxygen rich Atlantic water lying over the colder, fresher and oxygen poor overflow waters.

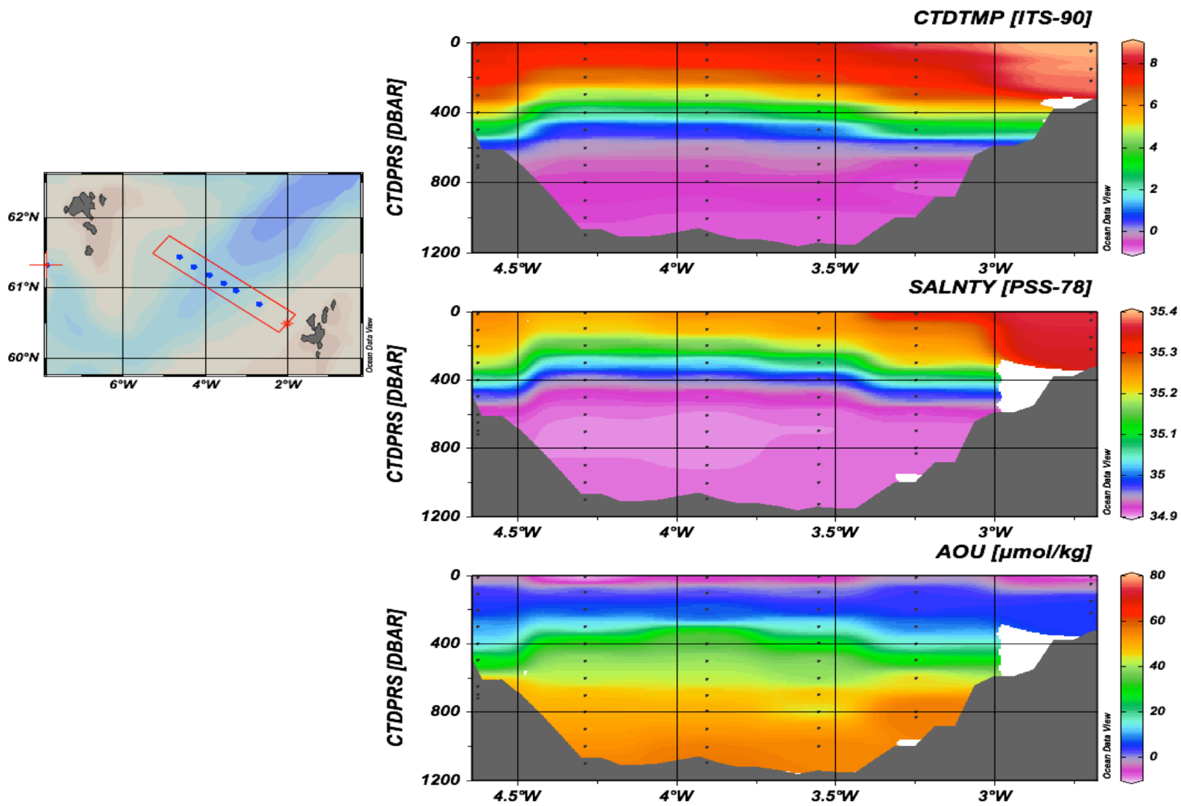



**Fig. 8:** Sections of temperature, salinity and AOU across the Faeroe-Shetland channel.

Finally Figure 9 shows the data obtained along the Utsira section. This shows the wedge of coastal current waters, overlying Atlantic Water, over the Norwegian trench. A core of waters with negative AOU in the surface a 2°E witness of high primary production. Over the trench there is a lens of colder water. As evaluated from AOU, the waters in the trench are the least ventilated at this section.

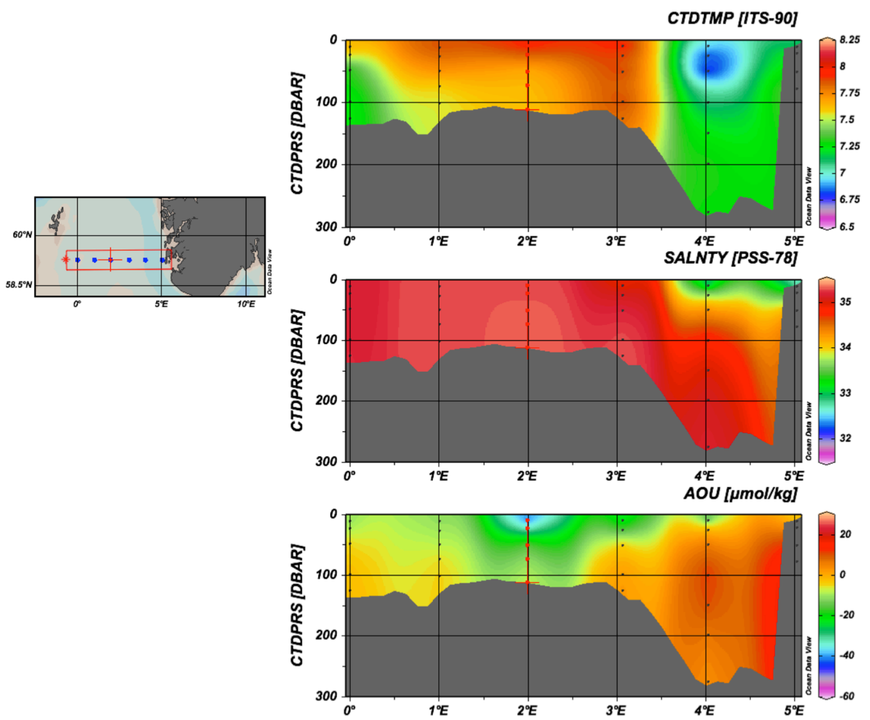



**Fig. 9:** Temperature, salinity and apparent oxygen utilisation along the Utsira section.

The Irminger Sea data are further used in Fröb et al. (2016) and Fröb et al. (2018)

## 5.2 Surface sampling

Surface samples were collected at 239 locations (Fig. 10), starting at ~62°N 20°W, southwest to Greenland, southeast across the Irminger Sea, northeast along the Reykjanes Ridge, east to the Faeroes, and then in the North Sea. These were analyzed as described above and will be distributed in a separate file.

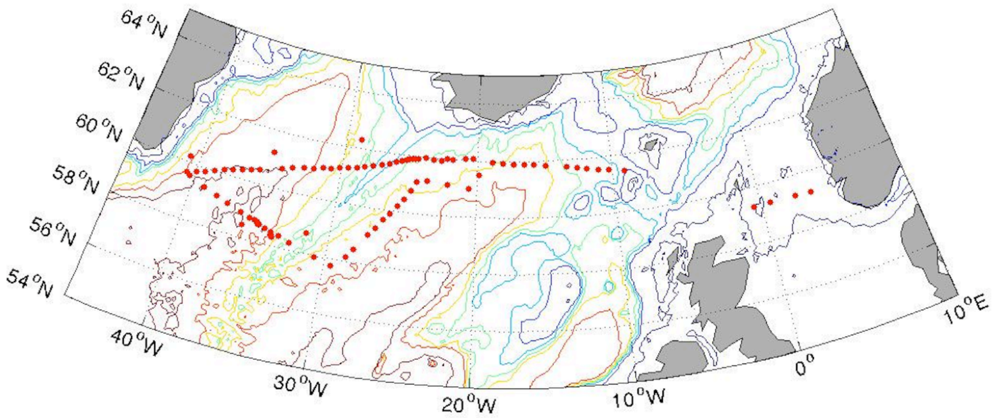



**Fig 10:** surface samling locations

## 5. 3 Sediment coring

Sediment cores were obtained at three sites, Eirik Drift, Reykjanes Ridge and Bjorn Drift, detailed information on each is provided in Table 1, while a brief description of each is provided in the following.

**Table 1: Sediment cores obtained at 58GS201503410**

| Station | Core name | Latitude Longitude | Depth | Length | Notes | Stat. |
|---|---|---|---|---|---|---|
| 1: Eirik Drift SE Greenland (DSOW) | GS15-196-01MC | 59° 37.1 N<br>40° 44.28 W | 2468m | A=23.5cm<br>B=14cm<br>C=disturbed<br>D=no recovery | Barrel D empty, C drained & disturbed | 175 |
| | GS15-196-02GC | 59° 37.1 N<br>40° 44.28 W | 2468m | 341cm<br>Sec.I*=150cm<br>Sec. II=150cm<br>Sec.III=41cm | Soupy at top, ~5cm oasis added so Sec.I-145cm mud | 175 |
| 2: Reykjanes Ridge | GS15-196-03GC | 58° 28.46 N<br>33° 52.72 W | 2407m | 400cm<br>Sec.I*=150cm<br>Sec. II=150cm<br>Sec.III=100cm | *MC not allowed due to winch weight* | 182 |
| 3: Bjorn Drift South of ODP 984 (ISOW) | GS15-196-04GC | 61° 13.31 N<br>24° 18.20 W | 1735m | 500cm<br>Sec.I*=150cm<br>Sec. II=150cm<br>Sec.III=100cm<br>SecI.V=100cm | overpenetration by 2-3cm; in core head. Sec. I soupy, oasis in top and bottom. | 188 |
| | GS15-196-05MC | 61° 13.31 N<br>24° 18.20 W | 1735m | A=47.5cm<br>B=38cm<br>C=47.5cm<br>D= no recovery | A and B nicest tops and clean overlying water | 188 |

*sections ordered from top down (e.g. Section I is top)

## Station 1 (Eirik Drift, SE Greenland within DSOW)

Multi and Gravity coring was carried out SE of Greenland in order to recover material for reconstructing DSOW variability and its relationship to surface climate and changes in Greenland. 2 barrels of the multicore were successful in recovering undisturbed sediment water interfaces. TOPAS (fig. 11) revealed soft bottom sediments down to approximately 3.4 m and the gravity core was rigged for 3.5 m length with 342 cm was recovered. Core tops were light brown IRD and foram bearing mud. The core catcher (GC) was grey IRD, foraminiferal, and diatom rich mud with a predominantly polar (*Neogloboquadrina pachyderma* sinistral) foraminiferal assemblage—distinctly more IRD and polar species rich than the core top. Ash grains were also observed in the base of the core (CC sample). Samples from the foot of the MC also included very high abundances of polar *Neogloboquadrina pachyderma* sinistral and IRD, with only trace amounts of subpolar-transitional species *Globigerina bulloides*.

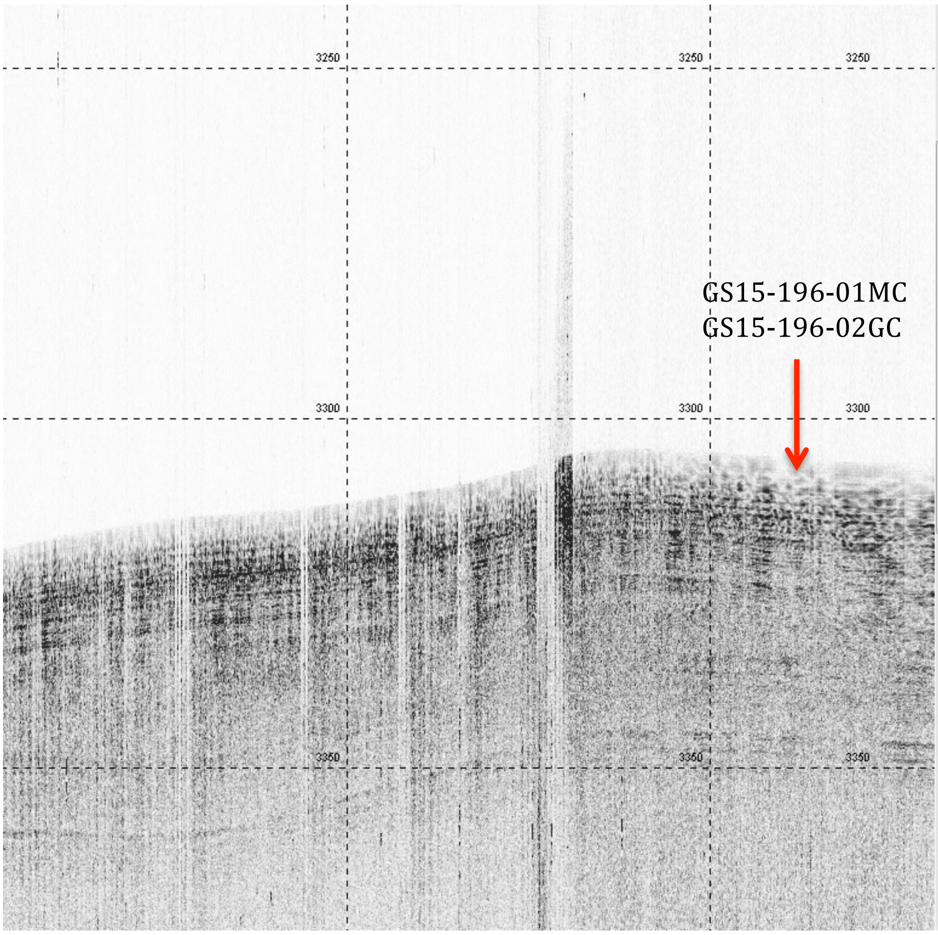



**Fig 11**: TOPAS image of Eirik Drift coring station

## Station 2 (Reykjanes Ridge)

A gravity core was taken on the Reykjanes ridge near the edge of the subpolar gyre in order to reconstruct shifts in the position of the subpolar gyre and Atlantic Water boundary (i.e. subpolar gyre eastward extent). The gravity corer was deployed first due to concerns over wireline weight on the winch (despite being only 2407m water depth). Based on the TOPAS (Fig. 12) , the GC liner was cut at 4m where it appeared there was a stronger reflector. 4m of core was recovered with no over penetration (@1m/s wireline speed). The top and CC were carbonate (foram) ooze with abundant warm water (Atlantic Water) foraminiferal species as well as subpolar species such as *Neogloboquadrina pachyderma* dextral, *Turborotaloita quinqueloba*, *Globigerina bulloides*, *Globigerinita glutinata*, *Globorotalia scitula* and *Globorotalia inflata*. Subtropical species such as *Orbulina universa*, *Neogloboquadrina dutertrei*, *Globorotalia hirsuta* and *Globorotalia crassaformis* were also present. Trace amounts of polar *Neogloboquadrina pachyderma* sinistral and high amounts of ice rafted detritus were observed. Sponge spicules and ostracods were occasionally also present.

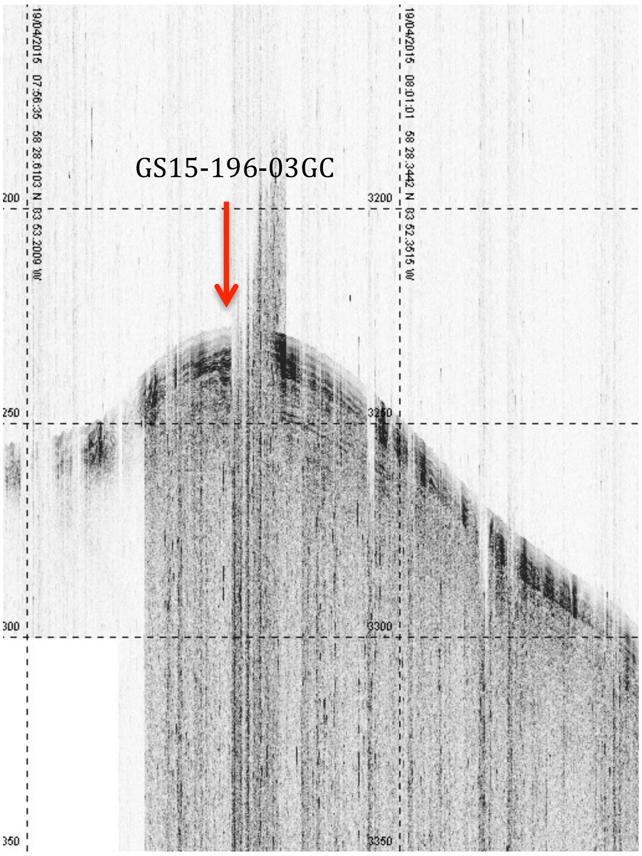



**Fig. 12:** TOPAS image of Rekjanes Ridge coring station

## Station 3 south of ODP Site 984

Station 3 was cored near ODP Site 984 near the upper limits of Iceland Scotland Overflow Water and just below Labrador Sea Water in the region. Based on the soft sediment characteristics inferred from the TOPAS (fig. 13) a full 5m liner was used for the gravity coring and the winch speed lowered to 0.8m/s for penetrating. The gravity core was full with ~3cm additional mud in the head of the gravity corer above the core liner. The core was dark olive gray silty foraminifera bearing mud. The multicorer was deployed next and recovered 3 long cores with well-preserved sediment water interfaces. Cores A and B had the clearest bottom water (B was pristine) suggesting little sediment entrainment or disturbance and barrel B was sampled for $\delta^{13}C_{DIC}$. The top of the GC contained subpolar to transitional (i.e., *Neogloboquadrina pachyderma* dextral, *Turborotaloita quinqueloba*, *Globigerina bulloides*, *Globigerinita glutinata*, *Globorotalia scitula* and *Globorotalia inflata*) and subtropical species (such as *Orbulina universa*, *Neogloboquadrina dutertrei*, *Globorotalia hirsuta* and *Globorotalia crassaformis*) with trace amounts of polar *Neogloboquadrina pachyderma* sinistral reflecting near modern conditions whereas the CC sample from >500cm contained predominantly polar foraminifera (*Neogloboquadrina pachyderma* sinistral), trace amounts of subpolar-transitional foraminifera (*Neogloboquadrina pachyderma* dextral and *Globigerina bulloides*) and high amounts of ice rafted detritus. Ostracods were occasionally also present at the top of the GC.

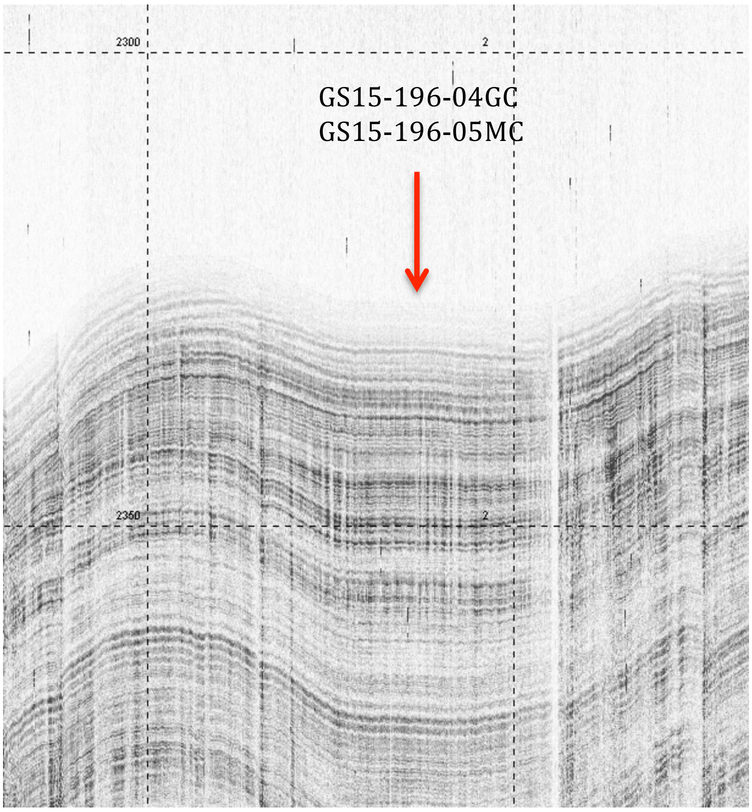



**Fig. 13:** TOPAS image of Bjorn Drift coring station

# 6. DIARY

Dates and times are local ship (Bergen, UTC+1) time

**9/4**
Abdirahman Omar, Are Olsen, Emil Jeansson, Kristin Jackson and Tor de Lange unpacks and installs our equipment in Torshavn. We also remove the old GO underway $pCO_2$ system and get the new one up hanging on the wall. Leave for Siv to connect power, water and gas lines when she arrives.

**10/4**
Left Torshavn 15:00, a bit delayed as the vacuum cleaner at the ship needed repair before we left (local service man onboard). Head for Cape Farewell.
Do test station before we reach open water, No 174. Will not be included in data files. Use 24 btl rosette, all bottles closed and no visible leaks. Everybody practice water sampling

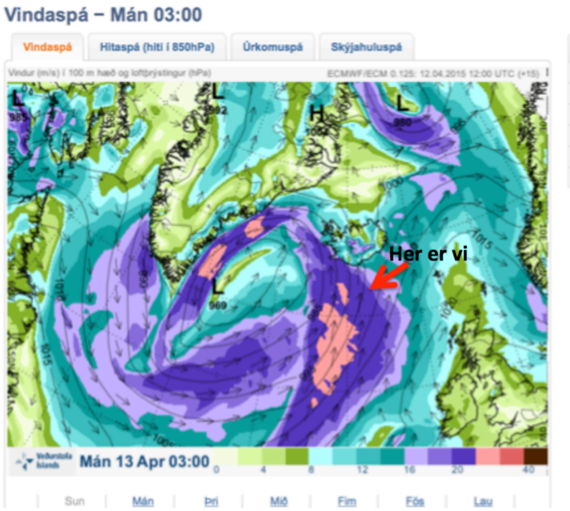
**11/4.**
Morning, at approx. 62°N, 10°W, foul weather, lying essentially still, backing against the wind. Heading west at a few knots during the day.

**12/4**
Morning, at 62°N, 13°W, foul weather. Heading west at 5 knots.
Ulysses and me consider to head for A16N stations at 62°N and 61°N, both at 20°W, to see if we can get something done there, and then to ODP 984 at 61° 25' N, 24°W, while we are waiting for weather to pass.

**13/4**
Another low-pressure system hits during night. Discard A16 stations, and ODP 824, press westwards to get away and into Irminger Sea following a northern trajectory on the outskirts of the low-pressure system.
No internet onboard, need to change satellite.

As everybody was impatient go get some work started we start with surface sampling on Abdir's initiative. Sample for oxygen, DIC, TA, $\delta^{13}C$ and nutrients every second hour, at 14:00, 16:00... hrs, ship time from the seawater outlet in the clean seawater sampling room, where the $pCO_2$ system is installed, to map out surface gradients as we move across Atlantic waters and into the Arctic Waters in the west. Note that for $O_2$ we only sampled during daytime the first few days. Note also that for $O_2$ we also sampled at the seawater outlet in the lab, to evaluate the occurrence of respiration in the lines up there, in particular pertinent as the oxygen/argon system was hooked up to this outlet.

Do triplicates of all but $\delta^{13}C$, if the first two replicates agree for DIC/AT and $O_2$, do not measure the third one.



North Atlantic weather 03:00 April 13, and our position

Towards evening we are escaping from low-pressure system, going north of it, see Fig. 2, catching up speed. 8 knots.

**14/4**
Over the night, winds increased again and we were moving slowly. Asgeir got the internet back up in the morning, and it seems as if weather will clear up and that we can make the Irminger Sea in time. We head towards Cape Farewell. Start making speed during evening.

Make the decision to use 12, instead of 24, bottle rosette for hydrocasts, to save time, allow use in rougher values and to allow coring equipment to be deployed from the main hangar while we are sampling the 12 btl for water next door.

20:09, ship time, notice that fluorescence sensor returns unrealistically high values for this area, around 7-8 mg/m$^3$, - also when we run freshwater from ship's supply through it! We decide to clean it. Triton and $CH_3CH_2OH$. Back online 21:30 ship time. Values of ~20 mg/m$^3$, but decreasing slowly.

**15/4**
Morning. Still steaming towards first station. Data from fluorometer much better, around 1.6 mg/m$^3$, which is realistic.

For the 22:00 (ship time) surface sampling I moved the water sampling point to a separate outlet. Until now the water had been drawn from the optode overflow, which has quite a high flow speed, I moved it to a separate outlet with a needle valve regulator and I could get a much more reasonable flow. Expect better precision for surface samples beyond this point. (This was confirmed by Kristin and Abdir, their gut feeling was that agreement among the replicate samples improved after we did this modification).

**16/4**

At ca 13:00 ship time we arrive at the first station. No. 175 at 40° 45' W.
We start here because of ice further west, and since strong winds were expected in our section's western parts, so we had to get out of this area before they reach us in order not spend valuable time waiting here for weather to pass.

STATION 175 (~40° 45' W, 59° 37' N)
Wait 2 mins before tripping bottle at each depth, and a few secs after (trip confirmation time), agree to do at all stations.
Denmark Strait overflow down deep. Move planned 1500 dbar and 2000 dbar to 1800 dbar and 2300 dbar to get this. Very homogenous $O_2$ in upper 1000 dbar. Some differences in the upper 1000 dbar between down and upcast.
All 12 bottles closed and no apparent leaks.

TOPAS reveals nice sediments with clearly defined layers approaching and at station.
Multi corer deployed, 3 out of four tubes filled halfway, one broke off.

Gravity corer deployed. 340 cm of sediments retrieved. This was basically according to plan, top was well preserved.

STATION 176 (~39° 45' W, 59° 27' N)
~21:00 ship time
A lot of variability in upper 600 dbar. Spike at just above 900 dbar, in salinity and oxygen. Check other sensor. - Checked, spike in sensor 1, will be cleaned by Asgeir, but check when you get data.

Move 1500 dbar sampling to 1600 dbar, to avoid sampling in strong gradient between upper and deeper water masses.

**17/4**
STATION 177
02:00 ship time.

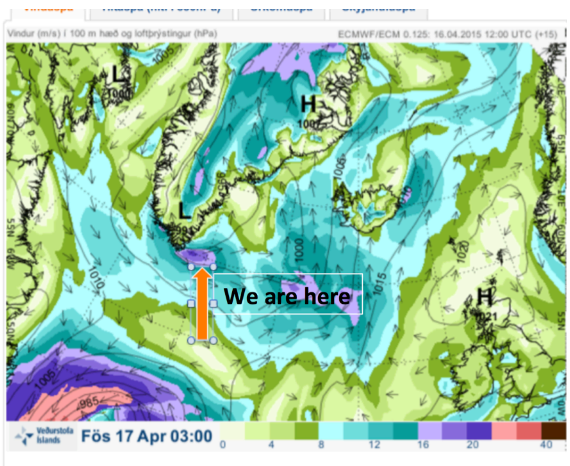



Fig. 3: North Atlantic weather and our position 03:00 April 17

15 m/s, gale force winds, seems as if it is picking up, good that we are heading east.

Not so much variability in upper water, still strong gradient at beneath 1000 dbar. 1250 dbar sample right in this, move to just above gradient, 1100 dbar.

STATION 178
08:00 ship time.
Not so much variability in upper water, still strong gradient at beneath 1000 dbar.
1500 dbar sample right in this, move to 1450 dbar.

STATION 179
~14:00 ship time.
Not so much variability in upper water, still strong gradient at beneath 1000 dbar. 1250 dbar sample in gradient, moved to 1120 dbar to get at top.

2000 dbar sample shifted to 2100 bar to get low salinity wedge centered at this depth.

Niskin 6 & 7 seems to be leaking at the lower cap.

STATION 180
19:30 ship time.
Shifted 1250 dbar to 1200 dbar, and 1500 dbar to 1600 dbar in order to not sample in the gradient.

No leaks visible, but still O-ring at valve at bottle 7 broken, replaced.

At 22:55 ship time, winds catching up, 24-25 m $s^{-1}$. If it is not possible to sample at next station we will wait until it calms down.

**18/4**
Winds calm down over the day, and we start again after lunch.

STATION 181
14:23 Ship time
Done 8 minutes east of the intended position, as we were here when the winds calmed down.
$O_2$ minimum at 200-600 m.

Less deep than 2500 dbar, planned 2400 dbar sampling point shifted to 200 dbar instead.

This evening I discovered that there seemed to have been a leak in bottle 1 at station 175, 176, and 177, as evaluated from offsets between CTD sensors and bottle sample data. Niskin 1 replaced.

**19/4**

STATION 182
~08:00 ship time

Gravity corer deployed 10:40 ship time, targeting small mound with sediments. At 58° 28.460' N 33° 52.715' W

STATION 184
20:30 ship time
Dropped planned 300 dbar to 750 dbar, few structures in upper but more in intermediate layers.

**20/4**
STATION 185
01:30 ship time

At 500 m seasave MFC stopped working, error with display program
Terminate, up on deck, empty bottles
Reset station number and do 185 again.
-repeated with no problems

STATION 186.
08:00 ship time
No issues a this station

STATION 187
13:11 ship time
Final station at this section, we will head northwards to core at ODP 984 site and sample overflow water at a section ~perpendicular to the ridge slope to A16 station at 20 W, 61N and next 62 N, then Faroe Bank Channel. No issues at station.

**21/4**
STATION 188
15:35 ship time
This is close to ODP 984 drilling site where Ulysses planned to core. Evaluating TOPAS Ulysses figured that the position we're at 61° 25.507 N and 24° 04.939W is a good location so we stop here. CTD first, flawless. Many structures in deeper waters, overflow plumes?, so I sampled many depths here.

Gravity corer, 5 m of sediment obtained, multi corer, 3 out of 4 tubes filled. Here I took a $\delta^{13}C$ sample of the water in one of the tubes. Labeled as such with the rest of the $\delta^{13}C$ samples
Plan for section of four stations from here to (and including) A16N repeat at 20°W and 61°N

**22/4**
STATION 189

00:20 shiptime, continue on section from ODP 984 to A16 repeat at ~20°W and 61°N. No issues at station, still many overflow features, sample heavily in deep waters.

STATION 190
06:11 ship time.
No issues at station, still many overflow features, sample heavily in deep waters.

STATION 191
12:06 ship time
A16N, 20°W 61°N repeat
No issues at station, still many overflow features, sample heavily in deep waters.

STATION192
20:00 ship time
A16N, 20°W 62°N repeat
Here we do two casts, these are labeled as two stations, one focus on deep and the second on waters 600 and above, here we also trip 2 bottles at selected depths for tracking our precision. Second cast get unique station number.

STATION 193
22:00 ship time
Cast two at 20°W 62°N repeat, 600 dbar and up.

**23/4**
Steaming towards the Faroes.
Some issues with TA measurements in the evening, returns too high values, electrode replaced over night by Kristin.

**24/4**
Some TA measurements return a value of 0, even though titration seems fine. Kristin figures out this is because the first guess E0 value is off so curve fit misses the target completely, possible to recalculate values by using a more appropriate first guess E0.

06:30 Arrive at first station in the Faroe Bank Channel,

STATION 194.
Overflow waters, 10 bottles samples

STATION 195
08:30 Ship time,
still Faroe Bank channel with overflow water, 10 sample depths.

STATION 196
~10:00 Ship time
Third station in Faroe Bank channel,

STATION 197

~1130 ship time
Last Faroe Bank Channel with overflow.

STATION 198

~21:30 ship time
On the slope east of Faroes.

STATION 199
~23:30 ship time
In the basin, sample at every 100 bar, maintain at next 2 stations, which are also 1100 m.

**25/4**
STATION 200
~02:00 ship time, sample at every 100 dbar.

STATION 201
~04:40 ship time, sample at every 100 dbar.

STATION 202
~07:05 ship time, 830 dbar sample at every 100 dbar.

STATION 203
10:00
Among oil rigs at Shetland Shelf, 224 dbar, sample bottom, 100, 50 and 10 dbar

Decide to head for Utsira section, we have time to sample at every degree along this, purpose, Abdir's North Sea work and map δ13C gradients from Atlantic and into coastal waters.

STATION 204
21:20 Ship time
First station at Utsira section.
A bit thermal stratification, and a bit more saline towards bottom. Sample 5 depths, bottom, 100, 50, 25 and 10 dbar.

**26/4**
STATION 205
00:50 ship time,
5 sampling depths, no issues.

STATION 206
03:57 ship time
5 sampling depths, no issues

STATION 207
07:23 ship time
5 sampling depths, no issues.

STATION 208
10:20 ship time.
Above Norwegian trench, some 230 m, 7 sampling depths

STATION 209
13:42 ship time
Final station, 80 m depth, inside Utsira. 4 depths sampled, rest of Niskins tripped for fun.

# 7. Surface sampling notes

Oxygen not sampled at night before before 15/4

Ailin draws during salinity samples during day from 16/4

For Carbon we add 1000 to the surface station number, in order to not mix up with ordinary stations. Else stations are called S 1- S XXX

Instances:
No 43, no samples, number apparently skipped
No 40-41, only salinity was sampled.

**References:**


Fogelqvist E. (1999), Determination of volatile halocarbons in seawater. In: *Methods of seawater analysis.* 3rd edition, p 501-519. Edited by K. Grasshoff, K. Kremling, M. Ehrhardt. Wiley-VCH.

Fröb, F., A. Olsen. F. F. Pérez, M. I. García-Ibàñez, E. Jeansson, A. M. Omar and S. K. Lauvset (2018), Inorganic carbon and water masses in the Irminger sea since 1991, *Biogeosciences, 15*, 51-72.

Fröb, F., A. Olsen, K. Våge, G. W. K. Moore, I. Yashayaev, E. Jeansson & B. Rajasakaren (2016). Irminger Sea deep convection injects oxygen and anthropogenic carbon to the ocean interior, *Nature Communications*, 7:13244.

Happell J.D. and D.W.R. Wallace. (1997) Gravimetric preparation of gas phase working standards containing volatile halogenated compounds for oceanographic applications. *Deep-Sea Res. I*, *44*, 1725-1738.

Hood, E. M., C. L. Sabine, and B. M. Sloyan (2010), The GO-Ship repeat hydrography manual : A collection of expert reports and guidelines. IOCCP report number 14, ICPO Publication Series Number 134, available online at http://www.go-ship.org/HydroMan.html.

Johnson, K.M. et. al. (1985), Coulometric $TCO_2$ analyses for marine studies; an introduction, *Marine Chemistry*, *16*, 61-82.

Olsen, A., R. M. Key, S. van Heuven, S. K. Lauvset, A. Velo, X. Lin, C. Schirnick, A. Kozyr, T. Tanhua, M. Hoppema, S. Jutterström, R. Steinfeldt, E. Jeansson, M. Ishii, F. F. Pérez & T. Suzuki (2016), The Global Ocean Data Analysis Project version 2 (GLODAPv2) - an internally consistent data product for the world ocean, *Earth System Science Data*, 8, 297-323.

**CCHDO Data Processing Notes**

- **File Merge** **Carolina Berys**

58GS20150410_QCnotes.txt (download) #dac9c
**Date:** 2018-08-20
**Current Status:** merged

- **File Online** **Carolina Berys**

58GS20150410.exc.csv (download) #72745
**Date:** 2018-08-20
**Current Status:** unprocessed

- **File Online** **Carolina Berys**

58GS20150410_surf.csv (download) #47510
**Date:** 2018-08-20
**Current Status:** unprocessed

- **File Online** **Carolina Berys**

59GS20150410_CruiseReport.pdf (download) #9bcb4
**Date:** 2018-08-20
**Current Status:** unprocessed

- **File Online** **Carolina Berys**

58GS20150410_QCnotes.txt (download) #dac9c
**Date:** 2018-08-20
**Current Status:** merged

- **File Online** **Carolina Berys**

58GS20150410_ct1.zip (download) #7a8c2
**Date:** 2018-08-20
**Current Status:** unprocessed

- **File Online** **Carolina Berys**

58GS20150410_nc_ctd.zip (download) #cbba5
**Date:** 2018-08-20
**Current Status:** unprocessed

- **File Online** **Carolina Berys**

58GS20150410_QCnotes.txt (download) #dc72a
**Date:** 2018-08-20
**Current Status:** unprocessed

- **File Submission** **Robert Key**

58GS20150410_QCnotes.txt (download) #dc72a
**Date:** 2018-08-09
**Current Status:** unprocessed
**Notes**

```
58GS20150410
This file is a replacement for one of the same name I submitted earlier today.
Sorry for the hassle
```

- **File Submission** **Robert Key**

58GS20150410_nc_ctd.zip (download) #cbba5
**Date:** 2018-08-09
**Current Status:** unprocessed
**Notes**

```
Are Olsen has contacted the Norwegian Marine Data Centre to obtain  a DOI for these
data so that they get appropriate credit. Once known I will forward that
information.

For now the pCO2 data is available at the following URL. Once Alex has posted at
OCADS we can change that.
https://doi.pangaea.de/10.1594/PANGAEA.866724

Sharon reformatted the provided CTD data. I created the bottle file and worked with
Are to finalize

The file named "58GS20150410_surf.csv" contains additional surface sample results.
This file is "as submitted".

I used A01 for the SECTID but other choices would have been as good.
```

- **File Submission** **Robert Key**

58GS20150410_ct1.zip (download) #7a8c2
**Date:** 2018-08-09
**Current Status:** unprocessed
**Notes**

```
Are Olsen has contacted the Norwegian Marine Data Centre to obtain  a DOI for these
data so that they get appropriate credit. Once known I will forward that
information.
```

For now the pCO2 data is available at the following URL. Once Alex has posted at OCADS we can change that.
https://doi.pangaea.de/10.1594/PANGAEA.866724

Sharon reformatted the provided CTD data. I created the bottle file and worked with Are to finalize

The file named "58GS20150410_surf.csv" contains additional surface sample results. This file is "as submitted".

I used A01 for the SECTID but other choices would have been as good.

- **File Submission Robert Key**

[58GS20150410_QCnotes.txt (download)](58GS20150410_QCnotes.txt) #dac9c
**Date:** 2018-08-09
**Current Status:** merged
**Notes**
Are Olsen has contacted the Norwegian Marine Data Centre to obtain  a DOI for these data so that they get appropriate credit. Once known I will forward that information.

For now the pCO2 data is available at the following URL. Once Alex has posted at OCADS we can change that.
https://doi.pangaea.de/10.1594/PANGAEA.866724

Sharon reformatted the provided CTD data. I created the bottle file and worked with Are to finalize

The file named "58GS20150410_surf.csv" contains additional surface sample results. This file is "as submitted".

I used A01 for the SECTID but other choices would have been as good.

- **File Submission Robert Key**

[59GS20150410_CruiseReport.pdf (download)](59GS20150410_CruiseReport.pdf) #9bcb4
**Date:** 2018-08-09
**Current Status:** unprocessed
**Notes**
Are Olsen has contacted the Norwegian Marine Data Centre to obtain  a DOI for these data so that they get appropriate credit. Once known I will forward that information.

For now the pCO2 data is available at the following URL. Once Alex has posted at OCADS we can change that.
https://doi.pangaea.de/10.1594/PANGAEA.866724

Sharon reformatted the provided CTD data. I created the bottle file and worked with Are to finalize

The file named "58GS20150410_surf.csv" contains additional surface sample results. This file is "as submitted".

I used A01 for the SECTID but other choices would have been as good.

- **File Submission Robert Key**

58GS20150410_surf.csv (download) #47510
**Date:** 2018-08-09
**Current Status:** unprocessed
**Notes**
Are Olsen has contacted the Norwegian Marine Data Centre to obtain  a DOI for these data so that they get appropriate credit. Once known I will forward that information.

For now the pCO2 data is available at the following URL. Once Alex has posted at OCADS we can change that.
https://doi.pangaea.de/10.1594/PANGAEA.866724

Sharon reformatted the provided CTD data. I created the bottle file and worked with Are to finalize

The file named "58GS20150410_surf.csv" contains additional surface sample results. This file is "as submitted".

I used A01 for the SECTID but other choices would have been as good.

- **File Submission Robert Key**

58GS20150410.exc.csv (download) #72745
**Date:** 2018-08-09
**Current Status:** unprocessed
**Notes**
Are Olsen has contacted the Norwegian Marine Data Centre to obtain  a DOI for these data so that they get appropriate credit. Once known I will forward that information.

For now the pCO2 data is available at the following URL. Once Alex has posted at OCADS we can change that.
https://doi.pangaea.de/10.1594/PANGAEA.866724

Sharon reformatted the provided CTD data. I created the bottle file and worked with Are to finalize

The file named "58GS20150410_surf.csv" contains additional surface sample results. This file is "as submitted".

I used A01 for the SECTID but other choices would have been as good.

**58GS20150410 QC and workup notes**
Are Olsen June 2017

This document has three sections, one for Bottle, one for surface and one for CTD data
****************************************************************************************
BOTTLE
****************************************************************************************

Started with /MergedFromRike/Current/data_58GS20150410_current.txt

---

EDITS and NOTES BEFORE QC

---

theta, aou and sigma0-3 columns deleted

Changed format and column headers to WHP EXCHANGE.

Station 193 renamed to 192 Cast 2

BTLNBR_FLAG_W
for BTLNBR 1 set to 3 by Friederike. Reset to 2, change later.

CTDSAL_FLAG_W
came with all flags 2.

SALNTY_FLAG_W
came with all flags 2.

CTDOXY_FLAG_W
came with all flags 2.

OXYGEN
missing values set from NaN to -999, flag from 4 to 9

SILCAT
below detection level set to NaN with flag to 2 by Rike. Changes to 0 with flag 2
(only two instances, STATION 206 BTL 4 & 5).

NITRAT
came with all flags 2.

NITRIT
below detection level set to NaN with flag to 5 by Rike. Changed value to 0 and
flag to 2, make a note in header (many instances).

PHSPHT
came with all flags 2.

CFC-12 and SF&
came with QC notes from Emil implemented as flags.

DIC and TALK
181/1
TCARBON changed from 2161 to 2164.5
The Carbon chemistry had three replicates, all three used in Rikes file, but final replicate clearly too low so I removed that one and calculated new average.

Otherwise all flagged 2 or 6

Note, the readme file for TCARBON and ALKALI data notes several values should be set
to NaN.
But all TCARBON values appears to have been kept in file, and all flagged 2. Checked the carbon 'master file', these had been measured twice and bad duplicate removed.
Only two ALKALI values are NaN, these were not present in carbon chemistry master file,
so obviously not measured

DEL13C
all flags kept.

All remaining NaNs changed to -999. Set all missing data flags to 9.

---

QUALITY CONTROL

---

Flags:
Station 175, 176, 178
Bottle 1, bottle flags set to 3, as leak suspected. Flags for all Niskin sampled variables set to 3.
(Note same bottle was used in position 1 for station 175-181, but large difference in CTDOXY-OXY only visible for stats 175, 176, 178)

176
btl 5 Oxygen high vs CTDOXY and CTDPRS, flag 3.

177
btl 9 Oxygen high vs CTDOXY and CTDPRS, flag 3.

179
btl 5 Oxygen high vs CTDOXY and CTDPRS, flag 3.

180
btl 9, ALK high vs SALNTY and CTDPRS, flag 3.

185
btls 2,4,7 PO4 low vs NO3 and CTDPRS, flag 3

189
btl 4 Oxygen high vs CTDOXY and CTDPRS, flag 3.

190
btls 5 & 6 Oxygen likely swapped during work up, swapped.

192, Cast 1
btl 4 Oxygen high vs CTDOXY and CTDPRS, flag 3.

194
btl 4 & 9, ALK very high vs SALNTY and CTDPRS, flag 4.

198
btl 4 Oxygen high vs CTDOXY and CTDPRS, flag 3.

202
btl 3 Oxygen high vs CTDOXY and CTDPRS, flag 3.
btl 4, ALK very low vs SALNTY and CTDPRS, flag 3.

saved as 58GS20150410_hy1.csv
**********************************************************************************************
SURFACE
**********************************************************************************************
Started with MergedFromRike/Current/data/data_58GS20150410surf.csv

added 13C data, from Surface13C_Marie. All data with high standard deviation among replicate analysis deleted
All NaN replaced by -999
Changed headers, added units

saved as 58GS20150410_surf.csv

**********************************************************************************************
CTD
**********************************************************************************************
Started with MergedFromRike/Current/data/data_58GS20150410ctd_current.csv
did nothing
saved as 58GS20150410_ctd.csv