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The MOSES Sternfahrt Expeditions of the Research Vessels ALBIS, LITTORINA, LUDWIG PRANDTL, MYA II and UTHÖRN to the Elbe River, Elbe Estuary and German Bight in 2021

Edited by

Ingeborg Bussmann, Norbert Anselm, Holger Brix,
Philipp Fischer, Götz Flöser, Elisabeth von der Esch,
Norbert Kamjunke

with contributions of the participants

HELMHOLTZ

Die Berichte zur Polar- und Meeresforschung werden vom Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung (AWI) in Bremerhaven, Deutschland, in Fortsetzung der vormaligen Berichte zur Polarforschung herausgegeben. Sie erscheinen in unregelmäßiger Abfolge.

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Titel: Morgenstimmung auf der Elbe (Foto: I. Bussmann, AWI)

Cover: Morning atmosphere on the river Elbe (Photo: I. Bussmann, AWI)

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The MOSES Sternfahrten 2021
with RV *Albis*, RV *Littorina*, RV *Ludwig Prandtl*, RV *Mya II*, RV *Uthörn*

Sylt Transects	January – November 2021
Stern_6	25 March 2021
Binnen Elbe	April, June, August, October 2021
MaGeCH	April – September 2021
Stern_7	10 – 12 May 2021
Stern_8	10 – 16 September 2021

From Dresden to the North Sea

Modular Observation Solutions for Earth Systems

Chief Scientists
Ingeborg Bussmann (AWI) – RV *Mya II* and RV *Uthörn*
Holger Brix (HZG) – RV *Ludwig Prandtl*
Elisabeth von der Esch (GEOMAR) – RV *Littorina*
Norbert Kamjunke (UFZ) – RV *Albis*

Coordinator
Ingeborg Bussmann

Contents

1. ÜBERBLICK UND FAHRTVERLAUF

Ingeborg Bussmann[1], Philipp Fischer[1], Holger Brix[2]

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[2]DE.HEREON

Basierend auf den Ergebnissen und Erfahrungen der vorangegangenen MOSES Sternfahrten von 2019 bis 2020 hatten wir uns zum Ziel gesetzt, die Fahrten im Jahr 2021 fortzusetzen und zu erweitern (vgl. BzPM_0741_2020, BzPM_0751_2021). Auf den vorangegangenen Fahrten wurden die meisten der neuen MOSES-Sensorsysteme erfolgreich auf verschiedenen Schiffen getestet und die Datenkommunikation von Schiff zu Schiff zu Land optimiert. In Abstimmung mit Kollegen aus der Programmorientierten Förderung (PoF) IV der Helmholtz-Gemeinschaft und Wissenschaftlern des Projektes „Modular Observation Solutions for Earth Systems“ (MOSES) wurden die Fahrten “Sternfahrt_6, 7 und 8” im Jahr 2021 genutzt, um die wissenschaftliche, logistische und operationelle Zusammenarbeit zwischen dem MOSES-Team und der Helmholtz-Gemeinschaft zu erweitern und zu vertiefen. Die Fahrten dienten außerdem der Intensivierung der Kooperation zwischen der MOSES-Binnen-Elbe-Gruppe, welche hauptsächlich vom UFZ mit der *Albis* geleitet wird, der MOSES-Gezeiten-Gruppe, die hauptsächlich von Hereon mit der *Ludwig Prandtl* geleitet wird, und der MOSES-Küsten-Gruppe, welche vom AWI geleitet und von den drei Helmholtz-Schiffen *Uthörn* (AWI), *Littorina* (GEOMAR), *Ludwig Prandtl* (Hereon) unterstützt wird. Die Hauptaufgaben der Fahrten im Jahr 2021 waren daher die Konsolidierung und kompartimentübergreifende Zusammenführung der Messdaten von Treibhausgasen und anderen wichtigen MOSES-Daten aus dem Süßwasser, dem Gezeitenbereich und dem Küstenbereich. Darüber hinaus standen der schiffsübergreifende Echtzeit-Datenaustausch und die Echtzeit-Koordination zwischen den Schiffen im Mittelpunkt der Fahrten. Da die Vergleichbarkeit der Messdaten zwischen den Kompartimenten sowie den Probenahmeverfahren eine der Hauptaufgaben war, wurden soweit als möglich im Fluss-, im Tiden- und im Küstenbereich der Elbe die gleichen MOSES-Sensoren eingesetzt. Darüber hinaus wurde ein deutlicher Fokus auf spezifische Interkalibrierungsphasen und -zeiten gelegt, in denen verschiedene Sensoren auf verschiedenen Schiffen die Zielparameter zur gleichen Zeit und am gleichen Ort messen. Diese Interkalibrierungsphasen wurden bei allen Fahrten im Jahr 2021 regelmäßig durchgeführt.

Ein weiterer besonderer Schwerpunkt im Jahr 2021 war der Daten- und Informationsaustausch während der Fahrt in Echtzeit zwischen den verschiedenen Schiffen, aber auch zwischen den Schiffen und der Landstation des AWI und Hereon, wo Verfahren zur Echtzeit-Datenverarbeitung eingerichtet wurden. Um diesen Echtzeit-Datenaustausch zwischen den Schiffen und der Landstation zu sichern, trafen sich die IT-Gruppen von AWI, GEOMAR und Hereon in zwei getrennten Sitzungen, um die Kommunikation zwischen Schiff und Land für die Ausfahrten vorzubereiten. Das Hauptziel dieser Aktion war die Einrichtung von vier identischen Kommunikationshardware- und -Softwarekonfigurationen, eine auf jedem der Schiffe und eine auf der Landstation, um einen hochgradig redundanten und störungsfreien Datenaustausch zu gewährleisten, selbst für den Fall, dass eines der vier Systeme ausfällt.

Im Jahr 2021 wurden alle in den drei Kampagnenteilen verwendeten Sensoren im MOSES-Datenmanagement-Tool (https://moses-dmp.gfz-potsdam.de/) registriert, und alle Sensoren und Daten sind nun im neuen MOSES Data Discovery Portal (https://moses-data.gfz-potsdam de) verlinkt.

Ein besonderer wissenschaftlicher Schwerpunkt der Fahrten 2021 lag auf der Bewertung der zeitlichen / saisonalen Variabilität der hydrologischen Kerndaten. Die Fahrten auf der Binnen-Elbe wurden im April, Juni, August und Oktober durchgeführt, um die Frühjahrs- und Herbstblüte, aber auch die verschiedenen saisonalen Abflussregime zu erfassen. Dies geschah in enger Zusammenarbeit zwischen den Kollegen des UFZ und des AWI. Eine weitere anspruchsvolle Aufgabe im Jahr 2021 bestand darin, eine zeitlich koordinierte Bewertung der Methandynamik und -variabilität in den drei verschiedenen Kompartimenten Binnen-Elbe (in Magdeburg und Geesthacht), Tideelbe (in Cuxhaven) und Nordsee (in Helgoland) zu erstellen. Für diese Bewertung wurden von April bis September 2021 sukzessive und zeitlich überlappende Einsätze durch die Kollegen von UFZ, Hereon und AWI (Teilprojekt MaGeCH) durchgeführt, mit dem Ziel, den annähernd gleichen Elbwasserkörper von Magdeburg bis Helgoland in einem koordinierten institutsübergreifenden Probenahmeprogramm kontinuierlich zu erfassen.

Im Rahmen dieser intensiven gemeinsamen kompartimentübergreifenden Kampagnen wurden vor Cuxhaven detaillierte Einblicke in die zeitliche Dynamik der Kernparameter im Küstenbereich gewonnen, indem zwei Schiffe achtundvierzig Stunden lang ankerten und die Kernparameter kontinuierlich mit einer Frequenz von 1 Hz aufzeichneten. (Stern_7, 10. – 12. Mai 2021). Um die räumlich-zeitliche Dynamik im Küstenbereich besser beurteilen zu können, wurden auf der Sternfahrt_8 (10. – 16. September 2021) dieselben Transekte zwischen Helgoland und dem Festland viermal beprobt.

Die grundlegenden hydrographischen Parameter (Temperatur und Leitfähigkeit / Salzgehalt) wurden auf jedem Schiff mit FerryBoxen und CTD-Sonden gemessen. Auch die atmosphärischen und gelösten Treibhausgase (CH_4 und CO_2) wurden auf allen Schiffen gleichzeitig gemessen. Um mehr über das Phytoplankton oder die Produktivität des Wassers zu erfahren, wurden auch Chlorophyll *a*, Trübung und Nährstoffe bestimmt. Der Kohlenstoffkreislauf wurde mit den Parametern TA, DOC, POC und DIC (Gesamtalkalität, gelöster und partikulärer organischer Kohlenstoff und gelöster anorganischer Kohlenstoff) beschrieben.

Das Jahr 2021 war wie schon 2020 von Corona-Restriktionen geprägt. Aufgrund der Pandemie-Restriktionen mussten wir das wissenschaftliche Personal an Bord der Forschungsschiffe meist auf vier Personen reduzieren, was teilweise eine Herausforderung darstellte, da die Anzahl der Sensoren und der erforderlichen Referenzwasserproben bei allen Fahrten gleichblieb. Darüber hinaus mussten wir aufgrund institutioneller Vorschriften während der Fahrten regelmäßig Antigentests durchführen, durften uns aber nicht gemeinsam mit der Schiffsbesatzung der anderen Schiffe und dem wissenschaftlichen Personal zur Koordinierung der Fahrt auf einem Schiff treffen. Unser MOSES-Kommunikationssystem von Schiff zu Schiff erleichterte unsere Arbeit daher erheblich, da wir während der Fahrten sogar Videokonferenzen zwischen den Schiffen und den Partnern an Land abhalten konnten, um situativ über Änderungen der Fahrtroute zu entscheiden.

In den folgenden Kapiteln und den Tabellen im Anhang erläutern wir detaillierter den Aufbau der Fahrten und unsere Erfahrungen von den Sternfahrten 6 – 8 im Jahr 2021. Alle unsere Daten sind in der Datenbank unter https://sensor.awi.de und https://www.ufz.de/drp/de/ hinterlegt. Komplexe Aufbauten wie bei unseren kombinierten Elbe-2021-Fahrten lassen sich jedoch nicht ohne weiteres in einer Datenbank abbilden, so dass dieser Fahrtbericht auch die Nutzung der gewonnenen Daten und ihrer Metadaten entlang der Elbe und ihres Mündungsgebietes sowie in der südlichen Nordsee erleichtern soll.

SUMMARY AND ITINERARY

Ingeborg Bussmann[1], Philipp Fischer[1], Holger Brix[2]

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[2]DE.HEREON

Based on the results and experiences of the previous MOSES Sternfahrten 1 – 5 in 2019 and 2020 we aimed at continuing and expanding the cruises in 2021 (*cf*. BzPM_0741_2020, BzPM_751_2021). During the previous cruises, most of the new MOSES sensor systems were successfully tested on different ships and the ship to ship to land data communication was optimised. In coordination with colleagues from the Helmholtz Association's Program-oriented Funding (PoF IV) and scientists from the project "Modular Observation Solutions for Earth Systems (MOSES)", the cruises "Sternfahrt_6, 7 and 8" in 2021 were used to expand and intensify the scientific, logistic and operational collaboration between the MOSES Binnen-Elbe group mainly lead by the UFZ with *Albis*, the MOSES tidal group mainly lead by Hereon with *Ludwig Prandtl* and the MOSES Coastal group lead by the AWI and supported by the three Helmholtz ships *Uthörn* (AWI), *Littorina* (GEOMAR) and *Ludwig Prandtl* (Hereon). The core tasks of the 2021 cruises were therefore the consolidation and cross-compartment merging of greenhouse gas and other essential MOSES data coming from the freshwater, the tidal area and the coastal compartment. Furthermore, the real-time across-ship data exchange and real-time cruise coordination among ships were put in the focus of the cruises. As the comparability of the measured data across compartments as well as the sampling procedures were one of the focal tasks, the same MOSES sensors were used in the freshwater, the tidal and the coastal area of the Elbe. Furthermore, a distinct focus was laid on specific inter-calibration phases and times when different sensors on different ships measured the target parameters at the same time and location. These intercalibration phases were implemented on a regular basis in all cruises in 2021.

Another special focus in 2021 was on real-time data and information exchange between the different ships during the cruise but also between the ships and the land station at AWI and HEREON where real time data processing procedures were established. To facilitate this real-time data exchange between ships and the land station, the IT groups from AWI, GEOMAR and Hereon met in two separate meetings to prepare the ship-ship-land communication set-up for the cruises. The major aim of this action was to set up four identical communication hardware- and software set-ups, one on each of the coastal research vessels and one land station to guarantee a highly redundant and interference free data exchange even for cases such as the failure of one of the four systems.

In 2021, all sensors used in the three campaign parts were registered in the MOSES data management tool (https://moses-dmp.gfz-potsdam.de/) and all sensors and data are now linked in the new MOSES data discovery portal (https://moses-data.gfz-potsdam.de).

A special scientific focus of the 2021 cruises laid on the assessment of the temporal / seasonal variability of the MOSES Hydrological Extremes core data. The cruises on the Binnen-Elbe were performed in April, June, August and October to catch the spring and autumn blooms, but also the different seasonal discharge regimes. This was done in close cooperation between the UFZ and AWI colleagues. Another challenging task in 2021 was to set-up a temporally coordinated assessment of the methane dynamics and variability in the three different compartments of Binnen-Elbe (in Magdeburg and Geesthacht), Tidal Elbe (in Cuxhaven) and North Sea (in Heligoland). For this assessment, successive and temporally overlapping sensor deployments were done by colleagues from UFZ, Heron and AWI (Subproject MaGeCH) from April through September 2021, aiming at continuously sampling the approximately same Elbe water body from Magdeburg to Heligoland in a cross-institutionally coordinated sampling programme.

Within those intensive joint cross-compartmental campaigns, detailed views on the temporal dynamics of the core parameters in the coastal area were gained off Cuxhaven by anchoring two ships for forty-eight hours and continuously recording the core parameters with a frequency of 1 Hz. (Stern_7, 10 – 12 May 2021). To better assess the spatio-temporal dynamics in the coastal area, we sampled the same transects between Heligoland and the mainland four times during the Stern_8 campaign (10 – 16 September 2021).

On each ship basic hydrographic parameters (temperature and conductivity / salinity) were measured by FerryBoxes and CTD probes. Similarly, atmospheric and dissolved greenhouse gases (CH_4 and CO_2) were measured throughout on all ships simultaneously. To learn more about the phytoplankton or productivity of the water, chlorophyll *a*, turbidity and nutrients were also determined. The carbon cycle was continuously described with the parameters TA, DOC, POC and DIC (total alkalinity, dissolved and particulate organic carbon, and dissolved inorganic carbon).

The year 2021 was characterised by Corona restrictions, as had been 2020. Due to pandemic restrictions, we had to reduce the scientific staff on board of the research vessels most of the time to four people only which was partly a challenge as the number of sensors and required reference water samples remained the same for all cruises. Furthermore, due to institutional regulations, we had to perform antigen tests regularly during the cruises, while not being allowed to meet jointly on one ship with the other vessels' ship crew and the scientific staff for coordinating the cruise. Our MOSES ship-to-ship communication system therefore facilitated our work substantially as we were able to do even video-conferences during the cruises between and among the ships and the land-bases partners to make situational decisions about cruise track changes when e.g. following a methane plume in a certain area.

In the following chapters and the tables in the annex, we will explain the set-up of the cruises and our experiences from the Sternfahrt cruises 6 – 8 in 2021 in more details. Our data have been deposited in the database at https://sensor.awi.de and https://www.ufz.de/drp/de/. However, complex set-ups such as for our combined Elbe 2021 cruises are not easily mirrored in a database, thus this cruise report should also facilitate the use of the obtained data and their metadata along the river Elbe and its estuary as well as in the southern North Sea.

2. STERNFAHRT_6 (25 MARCH 2021)

Norbert Anselm[1], Claas Faber[2], Hendrik Rust[3]

[1]DE.AWI
[2]DE.GEOMAR
[3]DE.HEREON

Objectives

The objective of this meeting of IT specialists was to configurate and perform an initial set-up for all participating Kongsberg MBR systems at the same place and time. The new working gear (IPUs) were to be tested as well as the capabilities of data exchange. The ship-to-ship communication approach was to be verified.

Work at rough sea within sunny Geesthacht harbour

The (informal) ad hoc working group MOSES MBR (Maritime Broadband Radio) met on 25 March 2021 at Geesthacht facility for a test of prepared working gear and several (data) communication concepts and approaches (Fig. 2.1). With regard to the COVID pandemic the test took place outdoor under social distancing conditions. At the gathering all four available Kongsberg MBR were installed and were set up in a common network called “MOSES”. Several configuration possibilities were tested and a common level of awareness was established among all participants. Once the basic functionality of the network was given (each antenna ‘sees’ the others) data exchange capabilities were tested. This included:

Is each share mountable to the other IPUs (Intel Processing Units)? Are proper access rights granted (read, write, execute)? How is the connection behaving after short breakouts of the connections? Is the remote share synced locally as expected? How is the transfer performance when larger files are moved?

All tests were conducted with synthetic data. After successful exchange tests communication capabilities were explored. The technical premise was taken that the MBR-IPU pair at the Lighthouse Heligoland would be in line of sight of all participating antennas permanently. Thus, this pair was chosen to host the central communication services. One group tested mumble services, another one installed a docker container with a Jitsi-meet-server running.

Fig. 2.1: Impressions from MOSES Sternfahrt_6 (Photos by H. Rust)

Preliminary results of Sternfahrt_6

The MOSES MBR network is configured and operational as is. The antenna pairs share a common network. The remote access within the network is granted via Teamviewer or ssh. A semi-automatic data exchange is pre-configured and works with no regard to file types or naming schemes. Nonetheless, this process must be manually triggered by mounting the remote counterparts. We installed a centralised WebRTC that is comfortably accessible by browser or by respective desktop clients as well as mobile devices (if wifi access is given to Kongsberg MBR network). Finally, the group concluded to have such "technical" tests and meetings on a regular basis.

All processing scripts and their documentation are version controlled in the Helmholtz git https://gitlab.hzdr.de/moses-extreme-mbr/mbr-data-processing and are only accessible internally (meaning Helmholtz git user can request for access).

3. BINNEN ELBE WITH *ALBIS* (APRIL, JUNE, AUGUST AND OCTOBER 2021)

Sven Bauth[1], Heike Goretzka[1], Norbert Kamjunke[1], Ute Link[1], Ann-Kathrin Krönert[2] (not on board in April), Erik Evers[2] in August, Ingeborg Bussmann[2] in October

[1] DE.UFZ
[2] DE.AWI

Objectives

The objective of the measurements in the freshwater part of the Elbe River was to investigate riverine eutrophication, i.e., phytoplankton and nutrient dynamics, under different hydrological and seasonal conditions. For comparison, we performed four longitudinal cruises in April, June, August and October. High solar radiation in summer and low discharge increase underwater light intensity due to low water depth (enabling algal photosynthesis). As a consequence, we expect a longitudinal decrease of dissolved nutrients such as nitrate and phosphate taken up by algae. The growth of high algal biomass in the river might affect water quality in the estuary as the degradation of the algal bloom causes oxygen deficiency.

Work on the river

Sampling was performed using the research vessel *Albis* applying a Lagrangian approach, i.e., a sampling of nearly the same water body along the way downstream according to its travel time (Fig. 3.1 and Fig. 3.2). The cruises were performed between 19 – 23 April, 21 – 25 June, 23 – 27 August, and 25 –29 October 2021. Discharge at Magdeburg was 428 $m^3 s^{-1}$, 252 $m^3 s^{-1}$, 314 $m^3 s^{-1}$, and 312 $m^3 s^{-1}$ which is between the mean low discharge (231 $m^3 s^{-1}$) and mean discharge (554 $m^3 s^{-1}$). In April we had technical problems with the electricity on board, so there may be data gaps. In August the *Albis* had a grounding, so the Moon pool clogged with sand. Therefore, the pump of the LosGatos had to be replaced and there are data gaps.

Water samples were taken at fixed stations which were investigated in previous years / cruises. These stations are located along the Elbe, mainly at bridges and at the outlet of tributaries. At these stations the left side, the middle and right side of the river were sampled. At each location the ship was anchored. Basic hydrographic parameters were measured using a YSI multiparameter probe at each station. Each evening water samples were picked up from colleagues and transported to the home laboratory (UFZ Magdeburg) for subsequent analyses. Two ferries (in Westerhüsen and Werben) are crossing the Elbe several times per day. On these ferries two CTDs are installed and are measuring continuously the basic hydrographic parameters. The ferries and CTDs were in operation from April to October 2021.

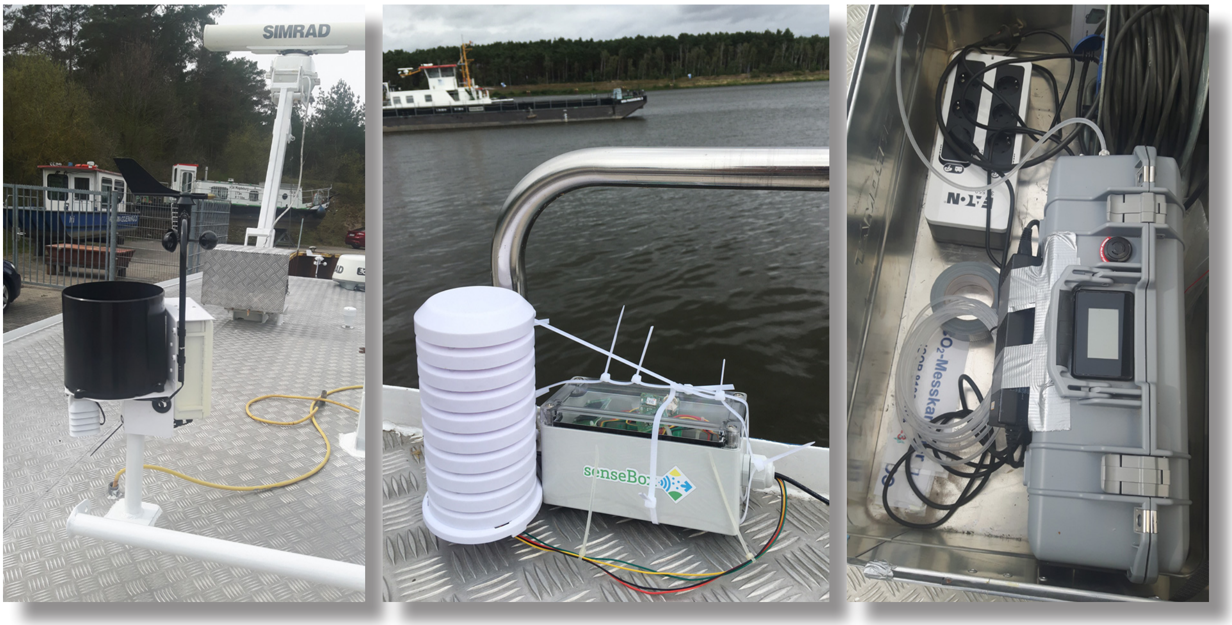
In addition to the programme of the colleagues from Magdeburg, a PocketFerryBox and a LosGatos Analyzer were set up to continuously measure the basic hydrographic parameters and dissolved methane. PocketFerryBox and LosGatos Analyzer were pumping water from the moon pool of the *Albis*. Its volume was approx. 14.7 L with a flow rate of approx. 0.8 L/sec, thus the turnover time (V/f) was 19 sec.

During the cruises in April, August and October, meteorological parameters and atmospheric gas concentrations were measured continuously. The LI-COR Trace Gas Analyzer LICOR 7810 uses Optical Feedback-Cavity Enhanced Absorption Spectroscopy (OF-CEAS) to measure the concentration of greenhouse gases such as CH_4 in ppb and CO_2 in ppm. This LICOR 7810 was installed on the upper deck to continuously measure these atmospheric gas concentrations every second. Required meteorological data such as air temperature, air pressure, relative humidity and rainfall were measured by the SenseBox and Watchdog 2700 weather station as well. Both devices were also installed on the upper deck (Fig. 3.3). The SenseBox consists of a case and a radiation shield with digital humidity, temperature and pressure sensors which are factory calibrated and a GPS-Modul. The weather station Watchdog 2700 measures air temperature in °C, relative humidity in %, rainfall and wind direction in degrees, wind speed in km/h and dew point in °C. Meteorological data measured by the weather station have a temporal resolution of 5 minutes and 1 minute for SenseBox data.

Details on station list, sensors applied and data access locations can be found in Table A.3 1 and Table A.3 2.

Fig. 3.1: Map of the Elbe sampling sites in Germany from Elster (Elbe km 199) towards Dömitz (Elbe km 506): Red dots indicate the sampling stations, blue dots the stations at tributary mouths.

Fig. 3.2: Albis on the Elbe by N. Kamjunke



(a) WatchDog 2700 weather station; photo: U.Koedel

(b) SenseBox; photo: U.Koedel/C. Schuetze

(c) LICOR 7810; photo: U.Koedel

Fig. 3.3: Measuring instruments installed at Albis' upper deck to measure meteorological parameters and atmospheric gas concentrations: (a) The full-featured Watchdog 2700 weather station measures air temperature, relative humidity, rainfall and wind direction and speed every 5 minutes; (b) the SenseBox is an environmental monitoring station equipped with temperature, humidity and pressure sensors; (c) the LICOR 7810 measures the atmospheric concentration of CH_4 and CO_2.

Preliminary results of Binnen-Elbe

Water temperature was lowest in April and October, highest in June, and intermediate in August (Fig. 3.4). Maximum chlorophyll *a* concentration was observed in April during a spring phytoplankton bloom. It was relatively low in June and showed the most pronounced longitudinal increase in August whereas algal biomass was consistently low in October. As a consequence of phytoplankton growth, dissolved nutrients concentrations decreased along the river stretch in most cases whereas pH values were generally high when algal biomass was high due to intensive photosynthesis.

The GHG measurements (Fig. 3.5) revealed both longitudinal gradients and differences between the 4 cruises. CH_4 was always over saturated and either increased (in June), decreased (in August), or showed little changes (in April and October) along the river. CO_2 was under saturated in April and June while it was over saturated with a decreasing trend in August and October. N_2O was over saturated (with the exception of June) and decreasing downstream.

Measurements of air temperature by the SenseBox and Watchdog show a good agreement (Fig. 3.6).

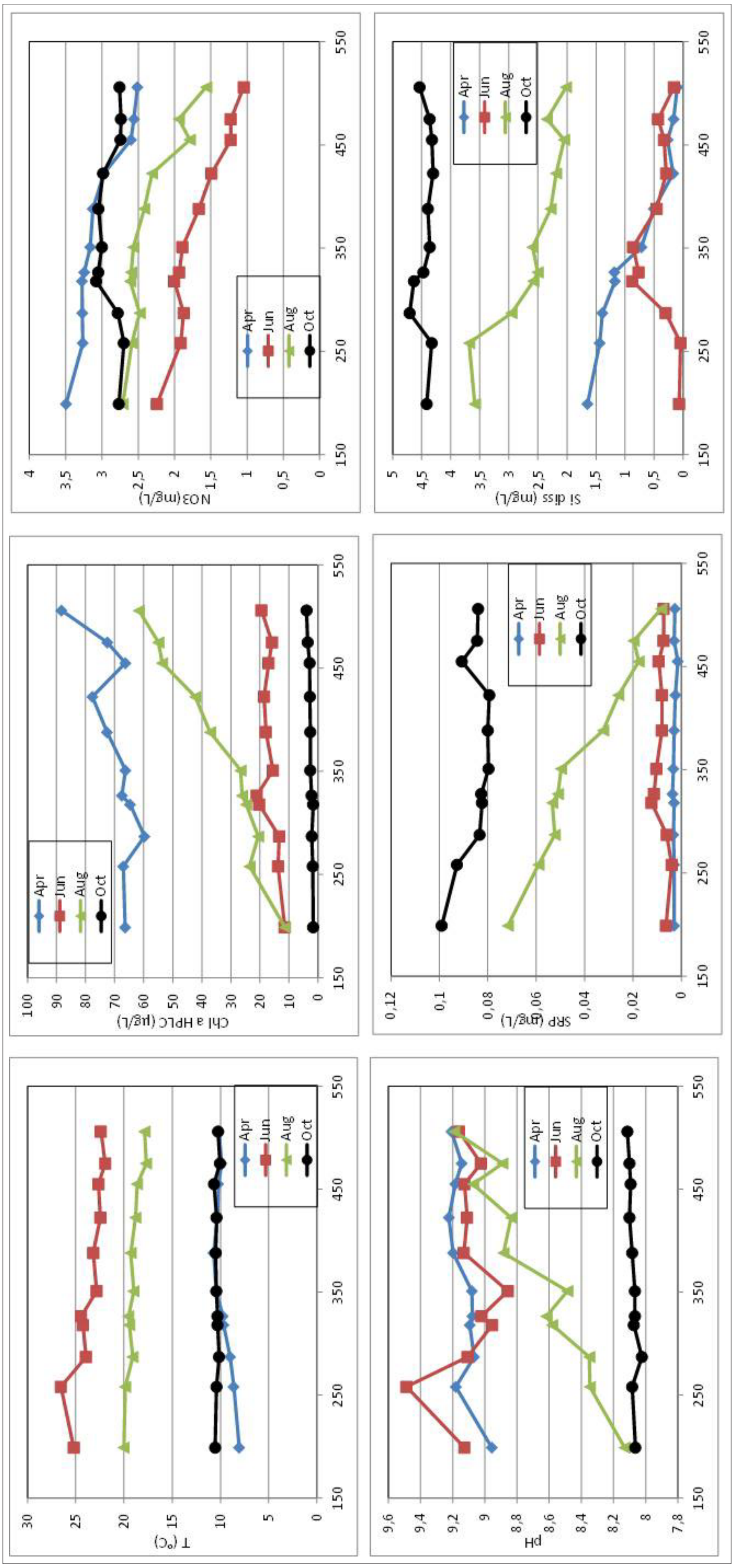


Fig. 3.5: Concentrations of greenhouse gases in River Elbe during the 4 cruises: The red dotted line indicates the atmospheric equilibrium concentration.

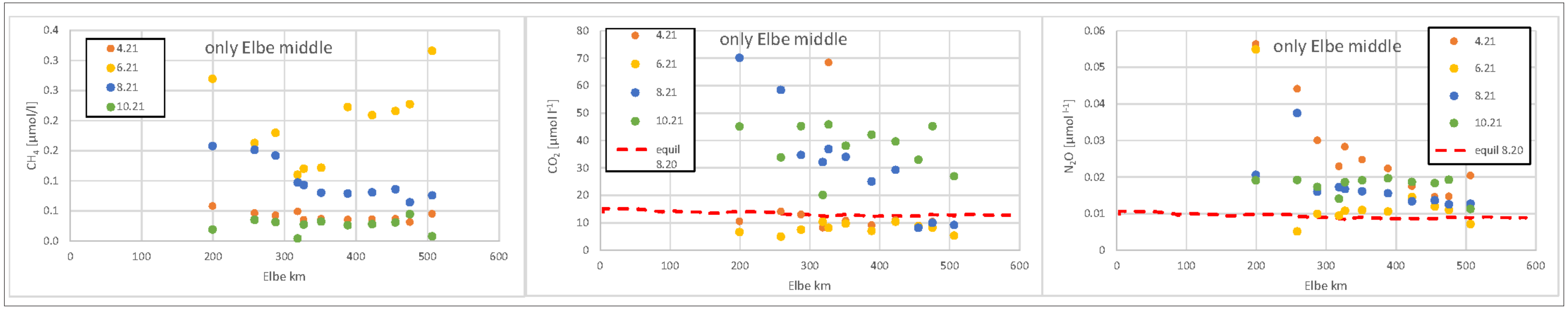


Fig. 3.4: Longitudinal probe measurements of water temperature, chlorophyll a concentration, nitrate concen-tration, pH, phosphate concentration, and dissolved silica; measurements causing some diurnal fluctuations were not performed at identical times each day.

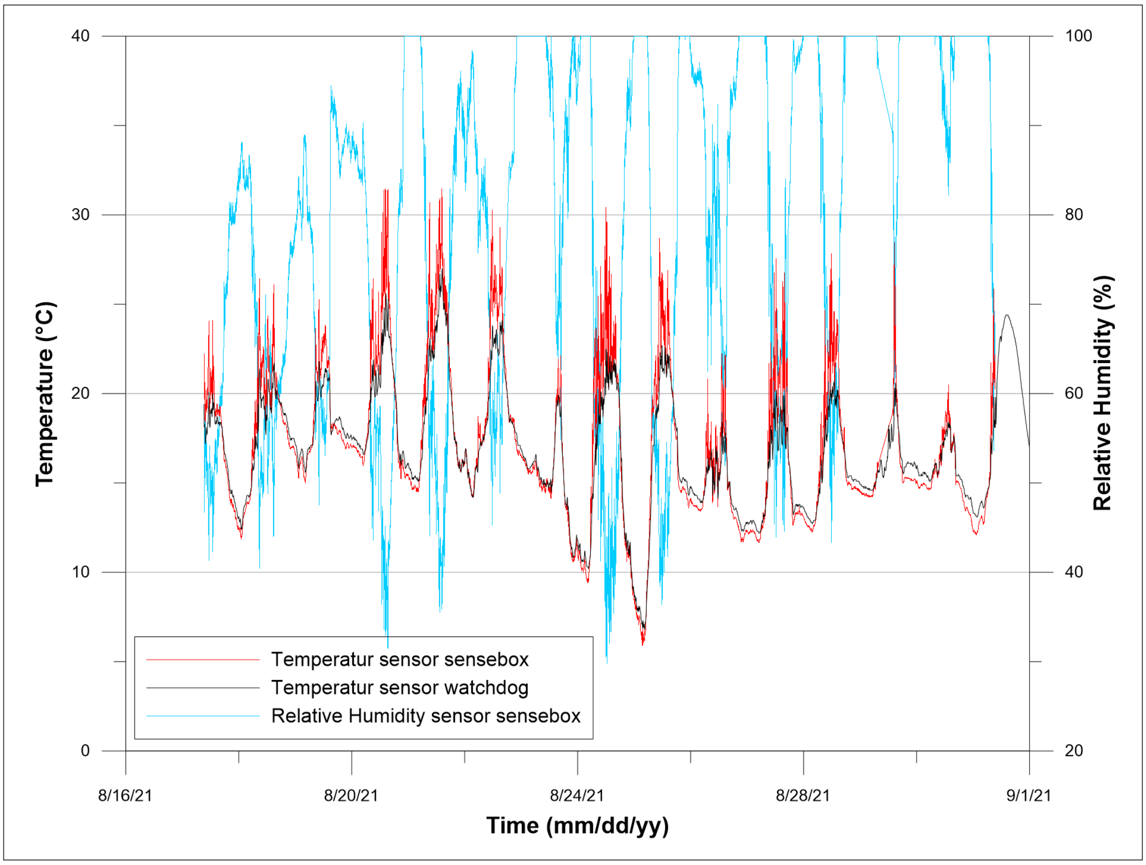


Fig. 3.6: Air temperature measured with Watchdog 2700 (black) and SenseBox during (red) the cruise in August 2021

4. NEU-DARCHAU – GEESTHACHT WITH *ZWERGSEESCHWALBE* (04 AND 05 MAY 2021)

Louise Rewrie[1], Marc Peters[1]   [1]DE.HEREON

Objectives

Since the plan for MOSES-Stern_7 was that *Albis* should cover the Elbe River from Magdeburg to Neu-Darchau and *Ludwig Prandtl* from Oortkaten to Cuxhaven, we decided to close the gap with the boat *Zwergseeschwalbe* on 4 May to 5 May 2021. The boat was transported from the Hereon Research Centre to the port in Geesthacht at 6:30 UTC on 4 May and launched.

Work on the river with *Zwergseeschwalbe*

The boat went to Neu-Darchau and started taking water samples on the way back to Geesthacht. A FerryBox was installed and running during the cruise. Six samples were taken between 8:51 and 13:15 UTC. Parameters were PIP, POP, Chlorophyll, oxygen, and nutrients; the water samples were taken from the FerryBox outlet. The boat spent the night in the little port of Tespe on the left side of the river, opposite from Geesthacht. On the second day, four samples were taken between 7:50 and 11:00 on the way from Tespe to the port Oortkaten where the *Ludwig Prandtl* started the tidal Elbe tour. The boat was back in the port of Geesthacht at 14:00 and transported back to Hereon.

Fig. 4.1: Zwergseeschwalbe port of Geesthacht, December 2020 (Photo: Marius Cysewski)

Preliminary results

Towards the port of Hamburg (10.1°E) nutrients (Si, NO_2 and NH_4) increased (Fig. 4.2). Details on the station list can be found in Tab. A.4 1.

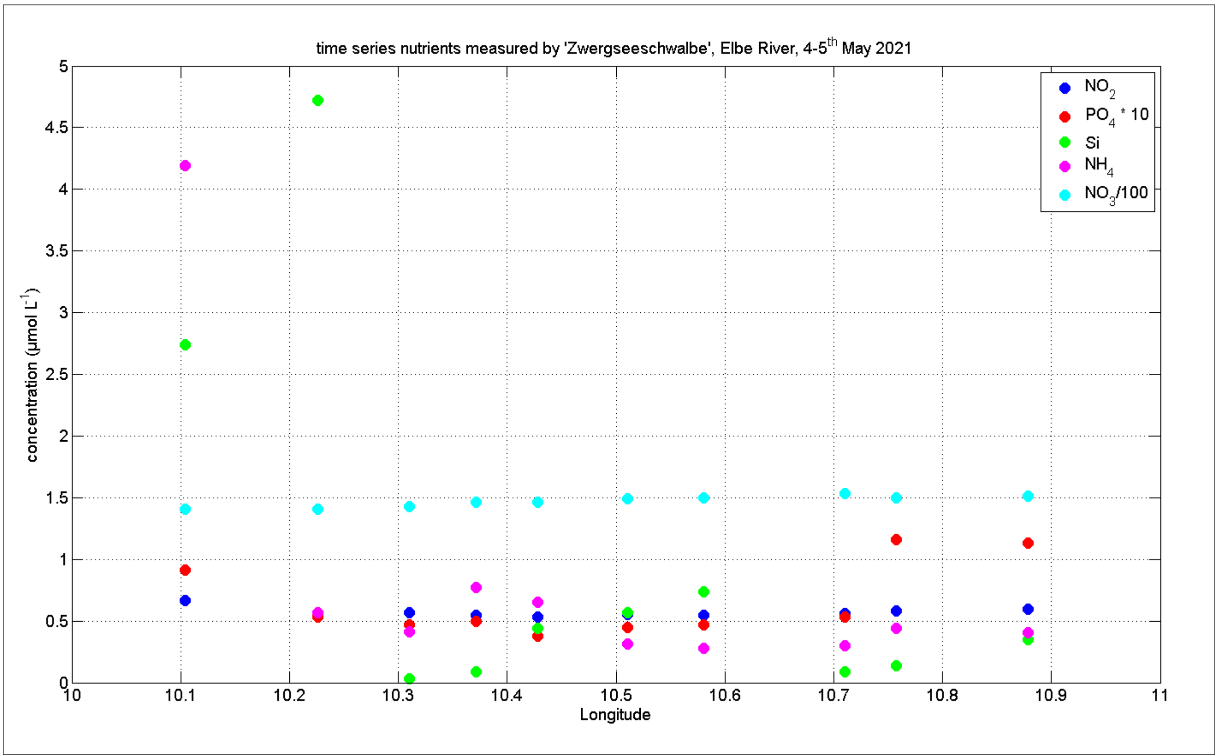


Fig. 4.2 Nutrient concentrations measured by Zwergseeschwalbe in the transition between river and estuary of the Elbe

5. MAGECH – DISSOLVED METHANE AT MAGDEBURG, GEESTHACHT, CUXHAVEN, AND HELIGOLAND

Ingeborg Bussmann[1], Philipp Fischer[1], Matthias Koschorrek[2]

[1] DE.AWI
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Objectives

The River Elbe is emitting methane to the atmosphere but also transporting methane from the lowland towards the estuary and finally into the North Sea. Not much is known about the temporal variability of CH_4 in such coupled river-estuary systems. Therefore, we monitored the concentration of methane with high frequency at 4 sites along the freshwater-sea continuum. Four methane sensors were installed at fixed stations (opposite to Lagrangian sampling with *Albis*) at different water depths. The sensors were deployed in **Ma**gdeburg, **G**eesthacht, **C**uxhaven, and **H**eligoland.

Work on the river

The sensor in Magdeburg was installed at the UFZ monitoring station Magdeburg Strombrücke (Fig. 5.1). That station also contains a CTD and CO_2 probe as well as a barometric pressure sensor and biweekly water samples were taken for analysis. The station is located on the right bank of the Elbe in the center of Magdeburg and the probe was deployed near to the shore at a depth of 0.5 m. Power was supplied by a battery and the data were logged on a small logger (TANDD-MCR-4V). Due to sinking water level, the probe felt dry between 28 April and 1 May 2021.

Fig. 5.1: Left: Monitoring site Magdeburg Strombrücke; right: Box with battery and data logger (Photos: M. Koschorreck)

For the sensor in Geesthacht, the pier near the cooling water outlet structure of the decommissioned nuclear power plant Krümmel turned out to be a suitable location. With strong support from their personnel, the methane sensor and a small CTD were positioned with heavy chains in a water depth of about 2 m.

The sensor in Cuxhaven was positioned at the lifting device for the mussel collector from D. Pröfrock (Hereon). Depending on the tidal level the water depth at the sensor ranges from 2 – 7 m. Hydrographic parameters will be obtained from the Cosyna Container (Hereon) nearby.

The sensor on Heligoland was located at the UW-laboratory in a water depth ranging from 9 to 12 m. Hydrographic parameters will be obtained from the UW-node.

Preliminary results of MaGeCH

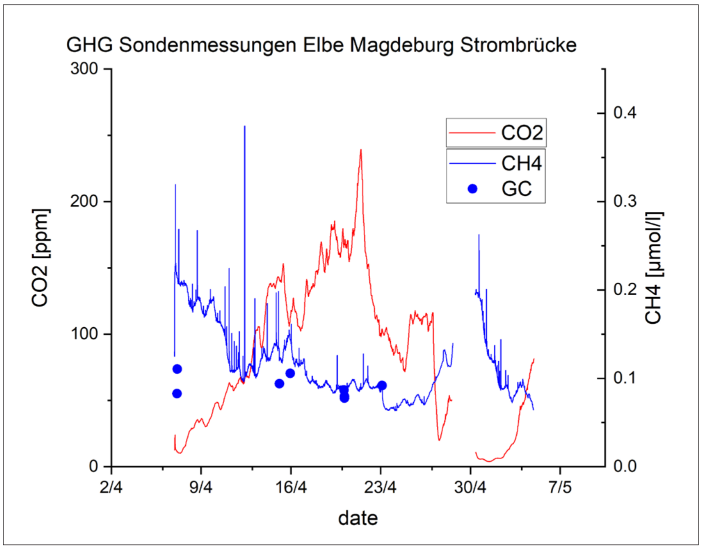

Fig. 5.2: High frequency data measured at Magdeburg of CH_4 (blue line) and CO_2 (red line) compared to discrete CH_4 sample data measured by GC (blue dots)

The methane concentration at Magdeburg (Fig. 5.2) showed temporal variability both on a daily and weekly scale as well as occasional short peaks of elevated CH_4. Control measurements in water samples showed reasonable agreement but did not confirm elevated methane concentrations at the beginning of April.

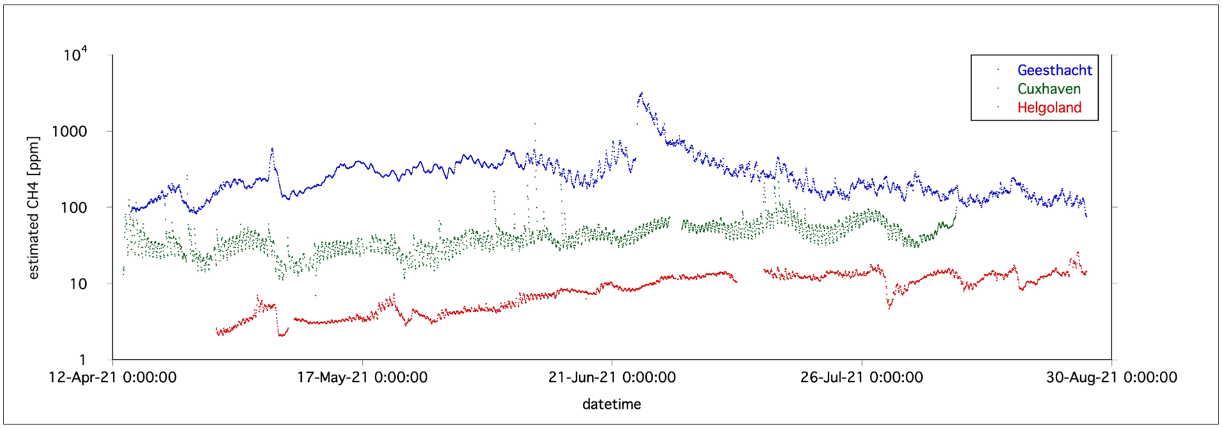

Fig. 5.3: Estimated methane concentrations (not yet corrected for temperature and salinity) in 2021, in Geesthacht (blue), Cuxhaven (green) and Heligoland (red)

The three methane sensors were deployed for 128 to 185 days in three different environmental settings (Fig. 5.3). The Contros sensors have a chamber in front of the membrane through which the methane has to diffuse from the water to the detecting system. This chamber is flushed with an SBE pump, which in turn is protected by a copperhead. In this course we had to learn that the power of this pump varied strongly. However, there was no obvious direct relation to the estimated methane concentration.

As a reference water samples were taken ± regularly near the sensor in Magdeburg, Cuxhaven, and Heligoland, but not in Geesthacht.

The sensor in Geesthacht (Fig. 5.4) was difficult to reach (only by boat from AKW Krümmel), therefore no maintenance was possible and no reference water samples were taken. The sensor was connected to a Linux laptop and accessible via modem. All data were transferred hourly to the AWI near-real-time sensor database O2A. In May we were able to check the sensor and exchange its copperhead. An algae was attached and had reduced its flow. Additional data on water temperature and oxygen content were provided by AKW Krümmel. First inspection of the data indicates strong daily variations, with maximum values in the early morning.

Fig. 5.4: Deployment of the methane sensor in Geesthacht, AKW pier; the Zarges box with computer and WLAN router can be seen at the "bridge" with chains and the sensor attached going downward. (Photo: A. Krönert)

The sensor in Cuxhaven was deployed in a harsh environment, with very turbid water and strong biofouling (Fig. 5.5).

Fig. 5.5: Methane sensor 4 weeks after deployment in Cuxhaven; photo: I. Bussmann

6. TRANSECT CRUISES WEST OF SYLT

Ingeborg Bussmann[1], Finn Mielck[1]

[1] DE.AWI

Objectives

As a spatial extension of our main research area, the monthly cruises with *Mya II* were continued in 2021 (if possible, every first Wednesday of the month), called Butendiek-Transects.

Work at sea

Starting from List (Sylt), these cruises headed towards about 7.5°E to the north-west (Fig. 6.1) while the inboard FerryBox continuously measured the basic hydrographic parameters (T, S, pH, O_2, chlorophyll, pCO_2, turbidity). We thus hoped to assess the influence of the Elbe inflow to the northern German Bight. These trips took place on the following dates: 14 January 2021; 01 Febuary 2021; 02 March 2021; 23 March 2021; 01 July 2021; 07 July 2021; 08 July 2021; 04 August 2021; 02 September 2021; 09 October 2021 and 03 November 2021. In July and November, the vessel had to return to the port due to bad weather.

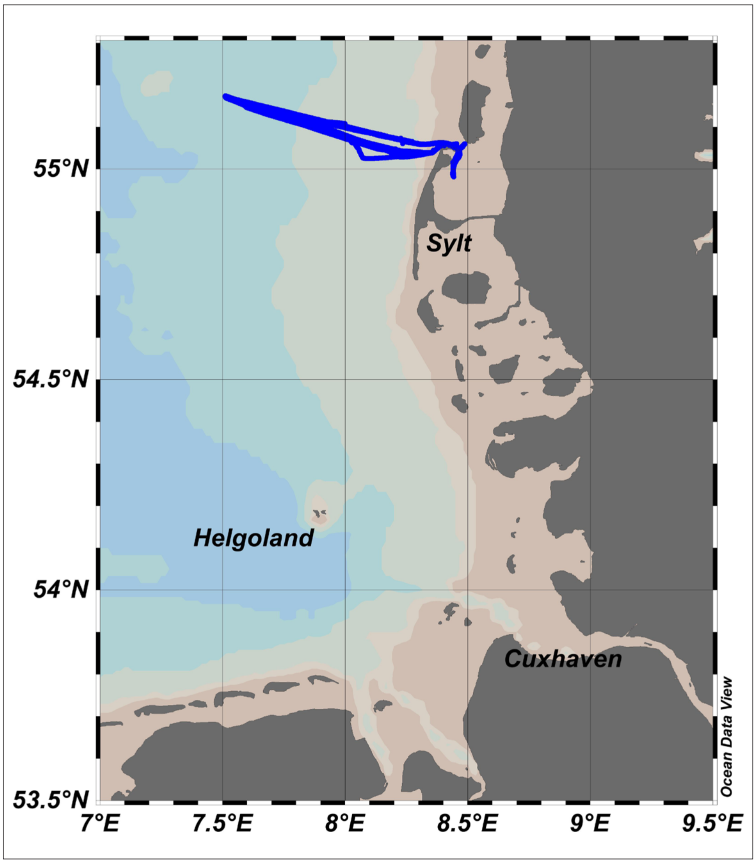

Fig. 6.1: Track of Mya II on the monthly western cruises

+

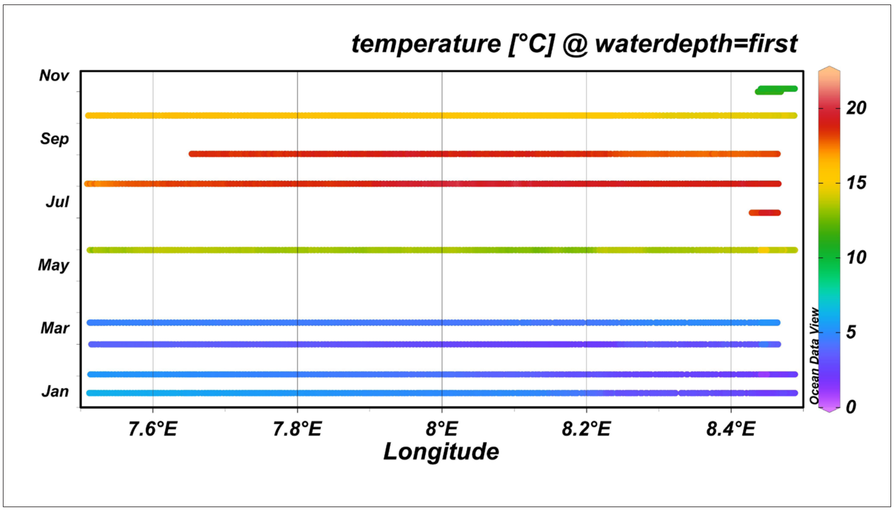

Fig. 6.2: Temperature profile in the surface waters during 2021

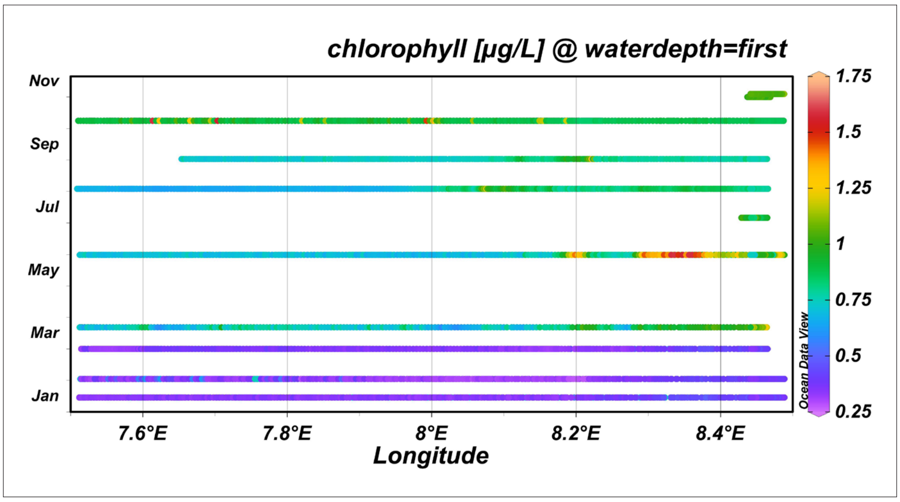

Fig. 6.3: Chlorophyll profile in the surface waters during 2021

Preliminary results

The average water temperature in 2021 was 11.6 ± 6.5° C, ranging from 1.0 to 20.4° C. The water stayed cold until the end of March; highest temperatures were recorded in July, near the shore. In November the water was still warm, around 10° C (Fig. 6.2).

The average chlorophyll concentration in 2021 was 0.7 ± 0.3 µg/L, ranging from 0.3 to 1.7 µg/L. At the end of March chlorophyll concentration doubled, indicating the phytoplankton spring bloom. Highest values were recorded in the beginning of June, just off the coast. In October small patches of increased chlorophyll values were observed at the western parts of our transects (Fig. 6.3).

Data management

The data can be found at https://dashboard.awi.de/data-ingest/index.html# (vessel:mya_ii) and the respective dates.

7. STERNFAHRT_7 (10 – 12 MAY 2021)

Objectives

The objective of this cruise was to compare the different board water supplies of the ship in respect to their reliability of dissolved gases, such as oxygen and methane. Therefore, it was planned that both ships would anchor nearby to sample the same water body and continuously sample for these gases using different sensors and water samples. Transfers from and to the anchored vessels were organised with a local transfer company. We also wanted to apply the experiences gained by the IT group on Sternfahrt_6.

Work at sea with *Ludwig Prandtl*

Holger Brix[1], Götz Flöser[1]
[1] DE.HEREON

Both ships (*Ludwig Prandtl* and *Reykjanes*) were ready for operation on Monday, 10 May, 7:00 UTC in Cuxhaven's Niedersachsenkai in Neuer Fischereihafen, when the cars arrived with equipment. Installation and preparation lasted until 12:45. *Ludwig Prandtl* left the Niedersachsenkai at 12:48 UTC and reached the anchor position on Medem Reede (53.8844 N, 8.7176 E) at 13:25. While *Reykjanes* was anchored, *Ludwig Prandtl* circled it until 14:17, when a CTD station with attached water supply pump for CH_4 measurements was run. This station lasted through 14:41 and *Ludwig Prandtl* dropped anchor approximately 0.5 miles upstream at 14:47. Both ships stayed at their respective positions until 12 May, 07:30. During the first night, *Ludwig Prandtl* had to change position several times due to strong tidal currents until a position was found and anchor was dropped reliably.

The scientific teams from both ships de-boarded on Monday and Tuesday evening (15:15 and 14:55 UTC, respectively for the *Ludwig Prandtl*) and were taxied to Cuxhaven by the tug "Taucher O. Wulf 3" and back to the ships at 6:00 (departure Cuxhaven with 10-minute transfer) on 11 and 12 May.

On 12 May, *Ludwig Prandtl* left its position at 06:20 UTC and circled *Reykjanes* until 07:20 UTC. Due to strong currents and the existing winch problems (see below) a planned CTD station was abandoned. At 07:45 UTC both ships left their position and steamed towards Heligoland to find an improved signal from the Heligoland communications tower / light house. At 09:10, the course was reversed and the ships returned to Cuxhaven with an arrival time of 10:20 at Alter Fischereihafen.

Measurements

Preparations were made to take O_2, turbidity and CH_4 samples. All samples were taken from the FerryBox outlet, i.e., using surface water. The O_2 samples were analysed by titration on board. This procedure was chosen as transporting the samples to the lab (the day following the campaign was a holiday) would have caused undue time delay in analysis (which should not happen later than two days after sampling). During the campaign, the O_2 samples taken on board the *Reykjanes* during the day were brought to *Ludwig Prandtl* in the evening and analysed on the following day. Permanent measurements were recorded by the FerryBox and the Los Gatos CH_4 analyser installed by AWI.

On the second day, both ships remained in anchor position throughout the day. Four vertical profiles were recorded and O_2, turbidity and CH_4 samples were taken. The chemical reactants necessary for on-board O_2 analysis ran out that day, so that no O_2 samples were taken on the last (third) day. Also, three samples from the second day could not be analysed.

The water supply for the LosGatos was taken from the same source that of the FerryBox and piped into an open bucket from where the CH_4 analysers pump took the water flow.

The A-frame at the starboard side of the ship (by which usually the CTD is lowered) was out of order due to electronics problems that could not be fixed without replacement parts; therefore, the vessel's smaller winch was used. In this setup the CTD is supported by a rope instead of a steel-armored wire. A pump was attached to the CTD frame and delivered *in situ* water for the CH_4 measurements (bucket intake was switched to the CTD pump while submersed).

The heave and sink velocity of the smaller winch cannot be controlled; as it was rather high, the deep casts were interrupted approximately every three meters for one minute. On 12 May, no vertical profiles were taken because the fixing of the CTD seemed too unstable for the heavy (180 kg) CTD at high current velocities.

Details on the station list, the sensors used and locations for data access can be found in Table A.6.1 and Tab. A.6.2.

Fig. 7.1: Ludwig Prandtl as seen from the tow ship, photo: A. Krönert

Fig. 7.2: Glass bottles prepared for Winkler titration, photo: A. Krönert

Work at sea with *Reykjanes*

Norbert Anselm[1], Ingeborg Bussmann[1], Philipp Fischer[1], Lea Happel[1], Ann-Kathrin Krönert[1]

[1] DE.AWI

About one week before our cruise, we received the information that our planned ship the *Uthörn* would not be available, as repairs in the shipyard took longer than anticipated. On such short notice we had to decide either to cancel the cruise, or look for alternatives. We, the scientists, were able to organise and charter the *Reykjanes*.

On Monday morning 10 May we arrived in Cuxhaven's Niedersachsenkai at Neuer Fischereihafen to set up our equipment on the *Reykjanes*. However, the communication between the ship's charterer about our requirement on the ship and the ship's crew was incomplete. Thus, we had to improvise to set up our laboratory in the storage room and workshop in the ship's bow. Using several extension cords, tape and cable ties we set up our communication unit on top of one freezer. The tower for the *in situ* pump was set up outside, in front of the workshop and had a direct connection to the ships water supply. The water sampler, the *in situ* pump and the vertical CTD were attached to a rope and lowered manually.

The set-up and preparations lasted until approx. 13:00 UTC. After passing the lock, *Reykjanes* set anchor at Medem Reede (53.8844 N, 8.7176 E). We were circled by *Ludwig Prandtl* as close as possible – to sample the same water for comparison. *Reykjanes* stayed on anchor until Wednesday 2021-05-12T07:37. Transfer from the ships to Cuxhaven and back again was performed with *Otto Wulf* tow ships on Monday afternoon, Tuesday morning, Tuesday afternoon and Wednesday morning.

On Wednesday at 2021-05-12T07:37:00.000, we cleared anchor and set out for a north-westerly course to reduce the distance to Heligoland. Until then the connection to the antenna on the lighthouse Heligoland has been only weak. We steamed until 8.53°E 53.97°N at approx. 9:00 UTC and then returned to Cuxhaven port (around 13:00), where we disassembled all our equipment.

To compare the dissolved methane concentration as measured with the degasser and LosGatos set-up and water samples, we took several water samples, at the outlet of the tower of the *in-situ* pump, directly from the ships water supply and with the water sampler. Oxygen samples were taken in triplicate and fixed immediately for further Winkler titration. Methane samples were taken in duplicate, poisoned with 0.25 ml H_2SO_4 for further analysis via gas chromatography.

The FerryBox was running smoothly for the whole time. In contrast, the degasser (Fig. 7.3) for methane analysis could hardly cope with the turbid water, and water flow was decreasing over time, even after thorough cleaning of the filters each morning.

Details on the station list, the sensors used and locations for data access can be found in Table A.6.3 and Table 10.17.

Fig. 7.3: Setup of the FerryBox and LosGatos Analyser in the ship's bow; photo: A. Krönert

Fig. 7.4: Preparing to get over to the water-taxi; photo: A. Krönert

Communication, IT and data management

Basic idea of the Kongsberg MBR-IPU network is that each antenna (MBR – Maritime Broadband Radio) is installed with a small but powerful desktop computer (IPU – Intel Processing Unit) attached. This combination is fixed, since the IP and MAC-addresses of IPU are registered in the MBR configuration. Then each IPU provides a network share that serves as a staging area for data that shall be distributed and that is accessible by the other IPU-MBR pairs. The remote folders are synchronized locally, in case connectivity is disturbed or the participants join the network only temporarily so that the data will be still available.

The Kongsberg antenna aboard *Reykjanes* was installed at the front deck's backboard side reeling and the corresponding power supply, switch, screen, and IPU were installed and wired close to the measuring facilities at the ship's workshop in the bow. There was no on-board network available.

Littorina did not participate in the cruise, but the hard- and software of the MBR-IPU was installed at the Research and Technology Center West Coast of the University of Kiel located in Büsum. This enabled us to test the capabilities of the system under near ideal conditions. The FTZ provides an elevated platform 16 m.a.s.l. with a clear line of sight towards the Lighthouse at Heligoland at a distance of about 64 km. Power and network infrastructure, easy access to the Kongsberg antenna and a working space for the operator were provided. Although the FTZ operates a meteorological station, time was too short to set up a real time connection, and so only synthetic data were shared in real time. We would like to thank Dr. Klaus Ricklefs and especially Dr. Klaus Vanselow for providing the location and for the great hospitality we received there. MBR is permanently installed at *Ludwig Prandtl*. The corresponding IPU was installed at the computer lab. No maintenance was necessary/available during the cruise.

On Heligoland a MBR-IPU pair was installed at the lighthouse. In addition to the data sharing capabilities it hosted a Jitsi server instance that should guarantee the ship-to-ship communication during the cruise. Moreover a LTE modem (Mikrotik) was plugged, thus the internet connection of this site served as a gateway for the entire Kongsberg network.

Fig. 7.5: Land station at Büsum:
Top: Research and Technology Center West Coast;
bottom: Antenna location and operations room;
photo: C. Faber.

Operation

After final adjustments to the internal network integration of the measuring PCs (if available) the main focus was to establish a connection between all participating sites. On Monday 10 May the weather was sunny and clear during the setup, all systems appeared to be running perfectly.

A direct connection between Büsum and Heligoland was barely possible, the antennas were visible to each other but connection was frail. The first campaign day was rainy and dull, which reduced the capabilities of the antennas significantly. No connection to the Heligoland site was possible, neither from the land station nor from the vessels. In return, that meant we had no internet connectivity and no central communication server available.

In the course of the day we tried to adapt to the (unexpected) circumstances. An alternative Jitsi server was installed at the Büsum site so that after extended testing the communication between Büsum and *Reykjanes* was possible. Later that day the weather conditions cleared up a little bit. In combination with the rising tide the Heligoland lighthouse antenna became reachable. By configuring the *Reykjanes* antenna as a relay, communication between Büsum and Heligoland was possible. Unfortunately, the taxi came to pick us up when a slow but steady internet connection was available via Heligoland allowing the Jitsi server to communicate more easily. Despite the technical challenges, all automatically saved data from the devices was prepared for ingest (O_2A) and made available to all connected sites (*Ludwig Prandtl*, *Reykjanes*, and Büsum).

On the second day we tried to come within communication distance of the Heligoland antenna with the ship steaming northwards until 11 a.m. Relatively bad weather and low tide made this endeavor unsuccessful.

From late Tuesday afternoon until the end of the campaign from the MBR-IPU at *Reykjanes* a ping test was conducted every minute. A correlation analysis with tidal cycle was not possible. Hence, only ping times can be plotted in Figure 7.6.

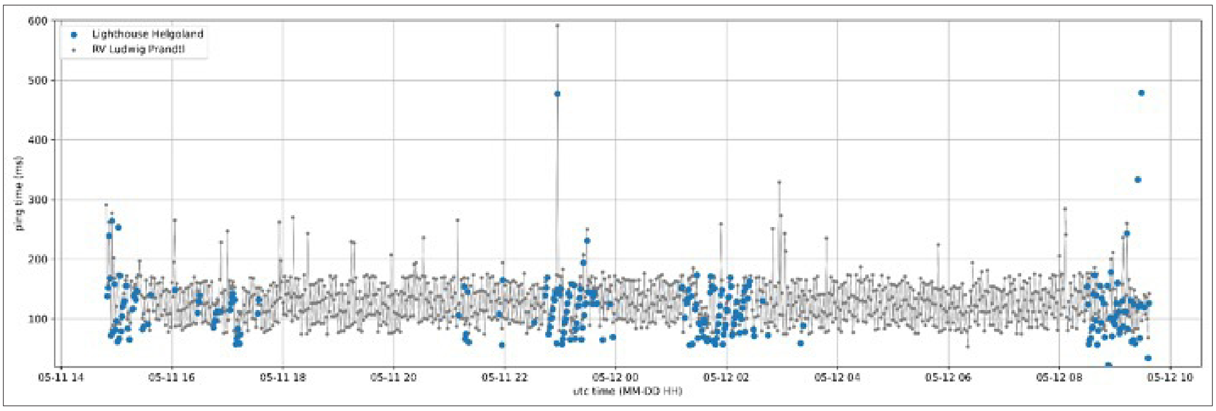

Fig. 7.6: From 2021-05-11 14:49 to 2021-05-12 09:37 there was a 99.645 % network availability between Reykjanes and Ludwig Prandtl. In contrast to this the Heligoland lighthouse was only 21.206 % of the time available.

Fig. 7.7: Communication headquarters (Photo: A. Krönert)

Preliminary results of Sternfahrt_7

During Sternfahrt_7 both ships stayed on anchor with all on the way systems running. During the day additional vertical profiles and water sampling were performed. As shown in Figure 7.8, the salinity measurements of both ships agreed well, especially during rising tide, while during falling tide the values from the *Reykjanes* were a bit higher. This might be due to the lateral distance of approx. 100 m between the ships. In contrast are the oxygen measurements (Fig. 7.9). For this parameter the course of the curve was similar, however there was a strong offset of 10 %. We assume this is due to the different water lines before the actual sensor.

The anchoring position close to Cuxhaven resulted in very turbid water, which posed a problem for the fine water filters of the degassers to measure dissolved methane. They clogged after running overnight, and had to be cleaned extensively. Here, a spare set of filters would speed up the change over time.

From a logistic aspect, we decided to plan a laboratory container, that could be easily moved between ships in case one ship is not available or we have to react on short notice. This would also reduce the time needed to set up the instruments and communication devices on each ship.

For the monitoring of an Elbe flood, it might be a good idea to anchor one of the ships near the Elbe outflow, to better monitor the Elbe inflow versus the tidal water surge.

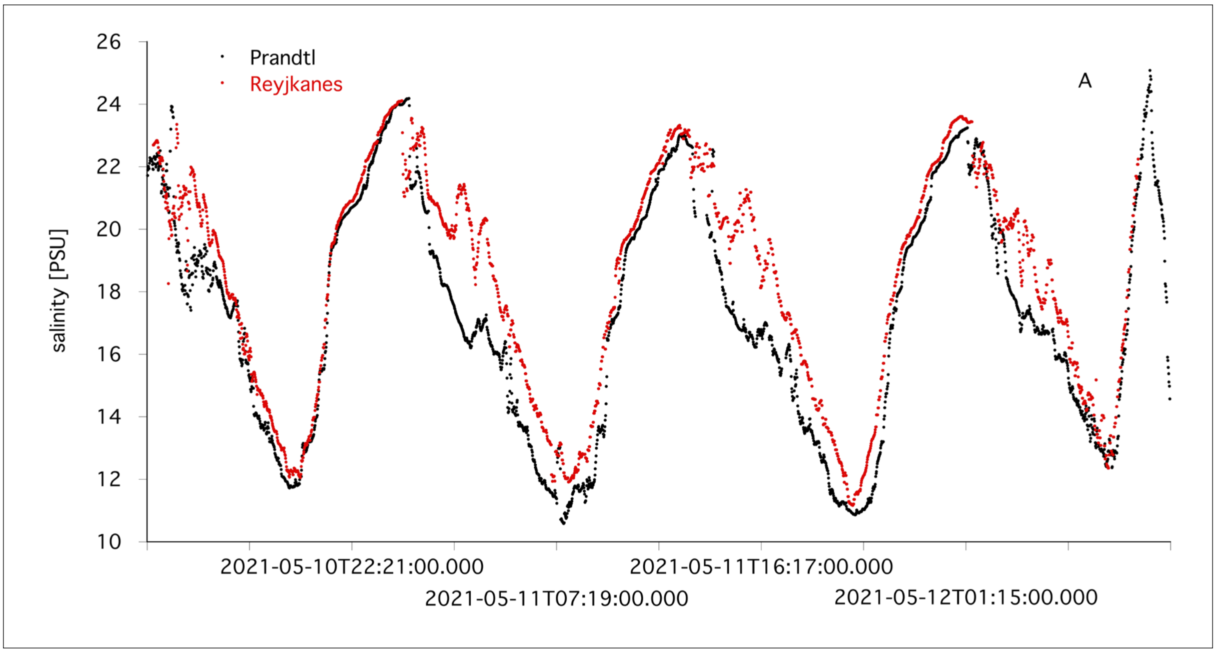

Fig. 7.8: Salinity saturation measured by the FerryBoxes on the Ludwig Prandtl (black) and Reykjanes (red) over three days at anchor

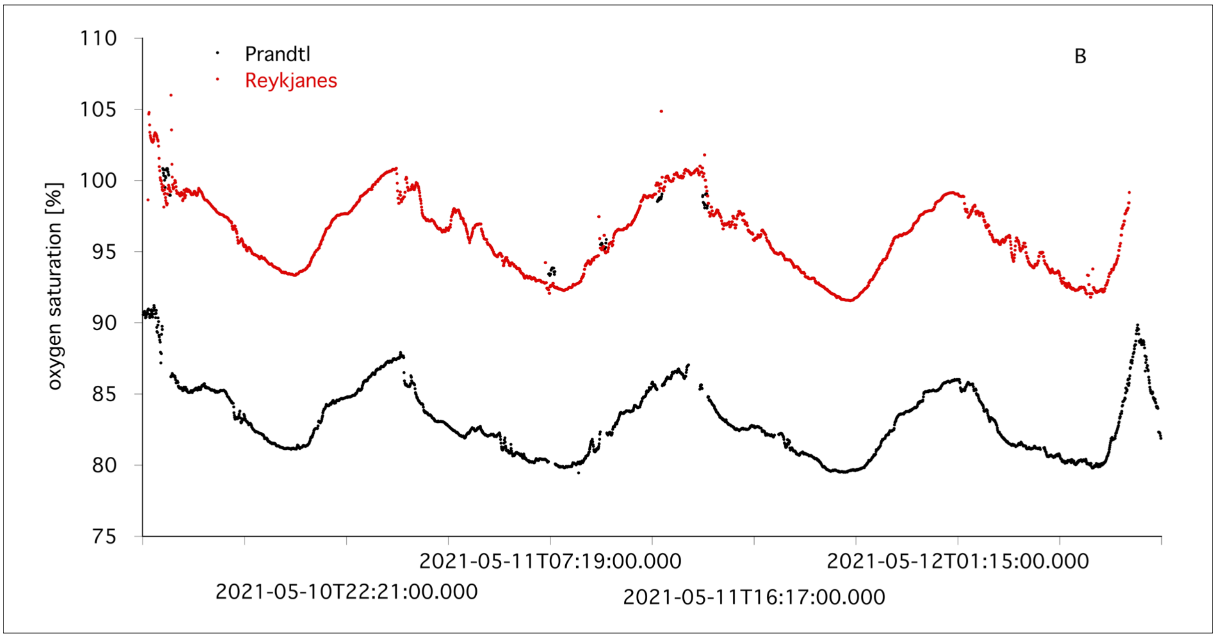

Fig. 7.9: Oxygen saturation measured by the FerryBoxes on the Ludwig Prandtl (black) and Reykjanes (red) over three days at anchor

8. SETUP AND TESTS OF COMMUNICATIONS AND IT IN KIEL (26 AUGUST 2021)

Norbert Anselm[1], Jan Bödewadt[2], Henning Burmester[2], Claas Faber[3], Stefan Lingner[3], Oliver Listing[2], Hendrik Rust[2]

[1] DE.AWI
[2] DE.HEREON
[3] DE.GEOMAR

Objectives

The objective of this meeting was to update the configuration of all participating Kongsberg MBR at the same time and place; to finalize and implement Kongsberg & IPU network changes (hostnames and IP-addresses); to exchange hardware and to integrate and test of hardware and software prior to Sternfahrt_8

Results

The MOSES MBR (Maritime Broadband Radio) working group met in Kiel on 26 August. In a continuation of the Stern_6 meeting, all components of the communications and data exchange system (Kongsberg hardware, processing IPUs, networking hardware) were brought together in one place. The communication system was set up in a configuration as close as possible to the planned deployment during Sternfahrt_8.

Changes to the system, such as distribution of antennas, new hostnames and IP addresses, software updates on the IPUs, were discussed, implemented and tested on site. The meeting was also used to exchange bits of hardware, e.g. antenna mounts.

9. STERNFAHRT_8 (10 – 16 SEPTEMBER 2021)

Objectives

The aim of Sternfahrt_8 was to assess not only the spatial variability of our core parameters but also their temporal variance. Therefore, the cruise plan was set up to repeat the same track and repeat the same stations for four days (Fig. 9.1). The *Uthörn* should cover the western part of our study area, the *Ludwig Prandtl* should cover the middle part between Cuxhaven and Heligoland, and the *Littorina* should cover the northern part (Büsum – Heligoland). Again, the IT group aimed for a direct data exchange between all ships and the central server at AWI, Bremerhaven.

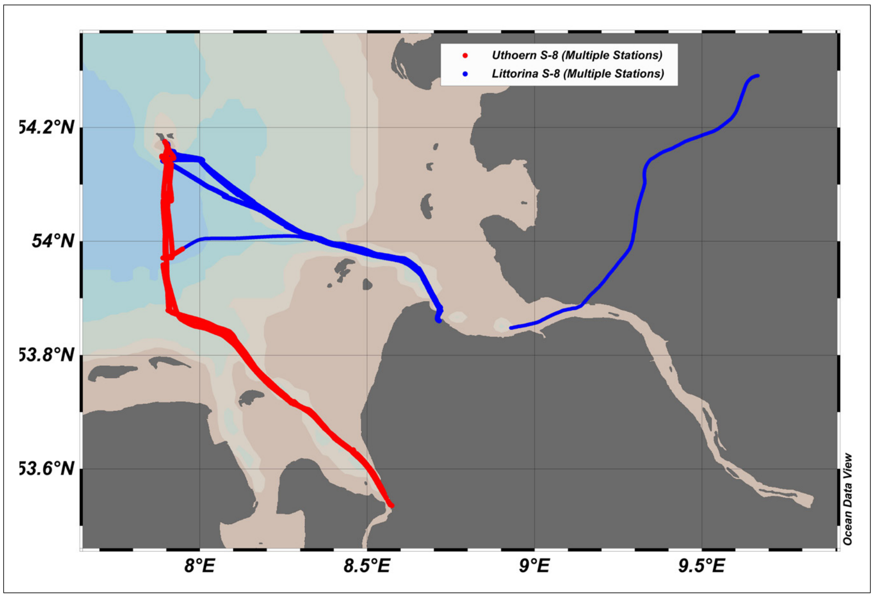

Fig. 9.1 Cruise track of Littorina (blue) and Uthörn (red) on Sternfahrt_8

Work at sea with *Ludwig Prandtl*

Holger Brix[1], Götz Flöser[1] [1] DE.HEREON

Due to vandalism damage that occurred during the night from 11 September to 12 September, a window of the bridge was severely damaged, resulting in *Ludwig Prandtl* not being able to participate in this cruise (no permission to go onto the North Sea, no speedy repair possible). The methane probe that was supposed to be operated on the *Ludwig Prandtl* was transferred to the *Funny Girl* which operates between Büsum and Heligoland, to make sure that at least part of the measurement programme could be salvaged. As a consequence, *Littorina* was rerouted to serve the Cuxhaven-Heligoland leg of the cruise programme.

Work at sea with *Littorina*

Mahmoud Altahan[1], Sayoni Bhattacharya[1],
Elisabeth von der Esch[1], Claas Faber[1],
Hannah Jebens[2],

[1]DE.GEOMAR
[2]DE.AWI

Together with the *Uthörn*, oceanographic data could be collected in real time in the Elbe influence area between Cuxhaven and Heligoland. For this purpose, a water basin was installed on deck during the transit from Kiel to Cuxhaven, which was continuously fed with surface water. Various sensors were placed in this basin (e.g. CTDs, nitrate, pH, pCO_2) to continuously record chemical and physical parameters. In addition, six CTD stations were run each day, which delivered discrete water samples for DIC, TA, DOC, methane, nutrients and explosive materials. An *in-situ* pump was attached to the frame of the CTD to feed a FerryBox and a methane analyser (Los Gatos) with surface as well as deep water. Atmospheric methane and CO_2 were continuously measured using a Picarro sensor. Shared stations with the *Uthörn* were used to intercalibrate all measurements. See Table A.7 2 and Table A.7 3.

Communication and exchange of near real time data was performed using Kongsberg Marine Broadcast Radio (MBR) antennas. One antenna each was installed on *Littorina*, on *Uthörn* and on a radio tower in Cuxhaven. Unfortunately, the antenna in Cuxhaven, which was intended to serve as an internet relay for the vessels, failed on Monday and was not available for the rest of the cruise, limiting communications and data exchange to a bilateral link between *Littorina* and *Uthörn* while antennas were in reach.

Furthermore "ArcGIS Mission Responder" was tested for live digital documentation of all sampling. The application seemed very helpful and upon comparison with the pen and paper notations all protocols were in agreement, the only problem was that the app required an internet connection for data entry, which was not stable throughout the cruise trajectory.

Due to a forecast of rough seas for the 16 September the *Littorina* only travelled between Cuxhaven and Heligoland from 13 – 15 September.

Work at sea with *Uthörn*

Norbert Anselm[1], Ingeborg Bussmann[1],
Philipp Fischer[1], Lea Happel[1]

[1] DE.AWI

The *Uthörn* had returned from her previous cruise directly to Cuxhaven. So we were able to set-up our instruments already on Friday 10 September 21. We left the lock in Cuxhaven around 6:00 UTC, heading for our first intercalibration station with the *Littorina*. We reached the port of Heligoland in the early afternoon, around 13:00 UTC. Next day (14 September) we returned to Bremerhaven, headed toward Heligoland on 15 September, where we had another intercalibration station with *Littorina*, just off Heligoland. The weather on the last day (16 September) was rough, so we could only do one water sampling station off Heligoland, and another 2 before returning to Bremerhaven.

The set-up of our instruments was done as on the previous cruises. The "tower" of the *in-situ* pump was located in the sink of the wet-lab, from which the FerryBox and LosGatos took their water supply. The tower was connected to the ship's water supply, but could be switched to the *in-situ* pump which was fixed on the rosette containing the Niskin bottles. As the tubing connecting the *in-situ* pump with its tower was about 23 m long, this restricted our maximum water depth to about 20 m. With the rosette and attached CTD surface water samples were taken, and a CTD profile towards the maximum depth. At the surface and at maximum depth, the tower of the *in-situ* pump was flushed for at least 3 minutes or until stable recordings were realized before the rosette was lowered or hauled. The Picarro for measuring atmospheric methane and CO_2 was set up in the dry lab. It was pumping air through a long tubing attached to the portside railing.

In addition, six CTD stations were run each day, which delivered discrete water samples for DIC, TA, DOC, POC, methane and nutrients (see Tab. A.7.2 and Tab. A.7.4). The instruments applied during this cruise on the *Uthörn* are shown in Table A.7.5.

Communication, IT and data management

On the *Uthörn,* the hardware was deployed and installed on 10 September 2021 at Cuxhaven (Neuer Fischereihafen, Hansakai). The Kongsberg antenna was mounted on portside and its power unit and IPU were installed on the bridge.

Due to construction works at the Lighthouse Heligoland it was not possible to install a MBR-IPU unit there. As an alternative location for the internet gateway the broadcasting mast at the Maritime Safety Centre (MSZ) in Cuxhaven appeared feasible. In a valuable collaboration with WSA the MBR-IPU unit was installed there at approx. at a height of 90 m a.s.l.. Since none of us was allowed to enter this mast the MBR-IPU unit needed to be prepared. It was put in a (rain-)waterproof ZargesBox with a siphon as a cable duct. All possible plugs were already plugged, smaller parts, such as the IPU, its power unit, and loose cables, were screwed to a plank, and in combination with the upright position of the power unit and some filling material the Zargesbox was made reasonably shockproof. It could then be transported and installed on the mast. Operating 90 m a.s.l., the LTE modem network was made available to the entire MBR network via port-forwarding (Fig. 9.2). All was tested and operational by 12 September 2021 (Sunday) afternoon.

Fig. 9.2: ZargesBox containing all modules for the land station (left) and the antenna mounted approx. at a height of 90 m a.s.l. in the direction of the German Bight (right); photo: P. Sprich, WSA

On Monday (13 September 2021) after leaving the lock all manual parts of the workflow were initiated. This encompasses the mounting of the participating external network shares, a communication (jitsi) test and the internet connectivity via the LTE gateway (MSZ mast). All tests then performed properly.

Unfortunately, the gateway became unavailable very soon during the first day. However, the direct transfer and communication between *Uthörn* and *Littorina* remained available as long as the MBR antennas were in the line of sight. The automated data exchange for near-real time data worked. Thus, as soon as internet connectivity was available measuring data was ingested by the O2A dataflow framework. The outage of the land station MBR (MSZ mast) was irritating and still subject to investigation, especially since the LTE modem and the corresponding IPU were performing well during the cruise.

On Tuesday (14 September 2021) and Wednesday (15 September 2021) *Littorina* and *Uthörn* had frequent contact via Jitsi video chat depending on the signal strength and quality as well as the line of sight. The background data exchange was ongoing. Thursday (16 September 2021) no Kongsberg MBR partner was available, since *Littorina* left on Wednesday. Cuxhaven land station (MSZ mast) remained silence to the MBR network.

All measuring data that was made available during the cruise was ingested in delayed mode via https://ingest.awi.de and made publicly available then via https://dashboard.awi.de/data-ingest/index.html#.

Preliminary results of Sternfahrt_8

To illustrate the short-term temporal variability of the basic hydrographic parameters, each ship repeated its transect for four consecutive days. This resulted in consecutive sampling of the same location after 21, 25.5, and 20 hours. In Fig. 9.3 and Fig. 9.4 the salinity and chlorophyll data versus time and longitude are shown.

We observed a pronounced difference between the consecutive sampling days: At 54°N, salinity increased from 30.7 PSU on 13 September 2021 to 32.3 PSU on 16 September 2021, while chlorophyll decreased from 2.3 to 1.2 µg/L. A bit more south, at 53.8°N, a similar pattern was obvious: salinity increased from 28.6 to 32.2 PSU. However, the change in Chlorophyll was minor, from 1.32 on 14 September 2021 to 1.4 on 16 September 2021. By applying the drift app tool (https://hcdc.hereon.de/drift-now/; Fig. 9.5), it became apparent that the water parcel that was present on 16 September at the location 54.00N, 7.915E has been moving in from about 123 km to the west and transporting a water mass with higher salinity.

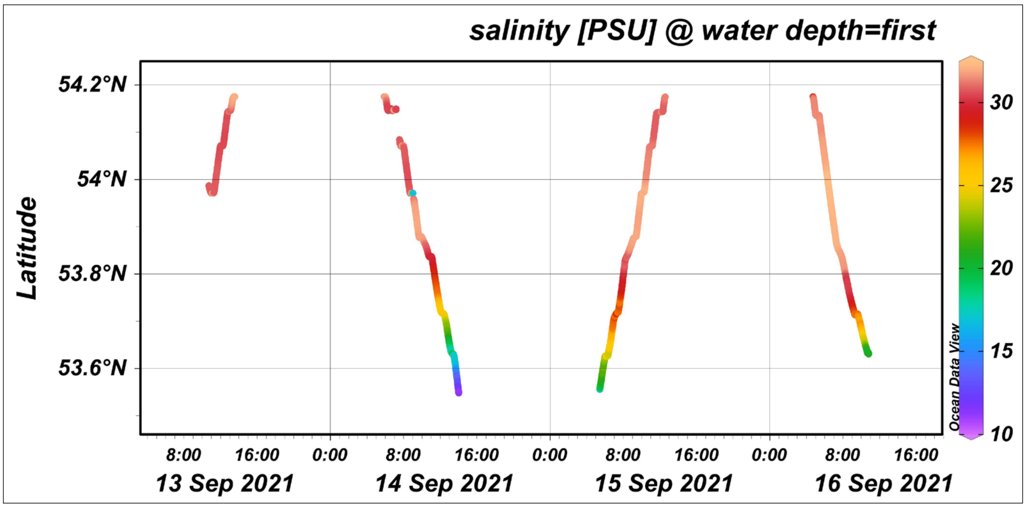

Fig. 9.3: Temporal variability of salinity on the south-north transect of Uthörn on 13 –16 September 2021

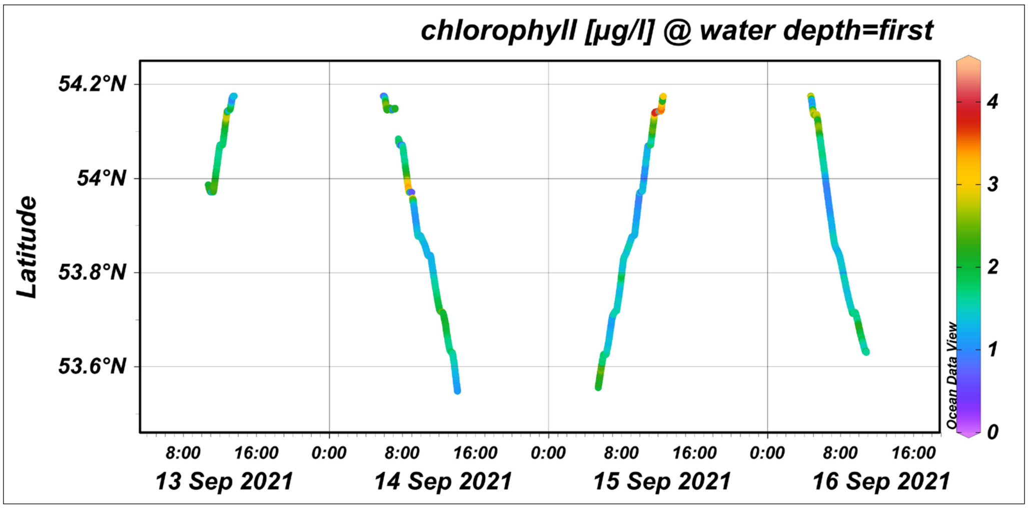

Fig. 9.4: Temporal variability of chlorophyll concentration on the south-north transect of Uthörn on 13 – 16 September

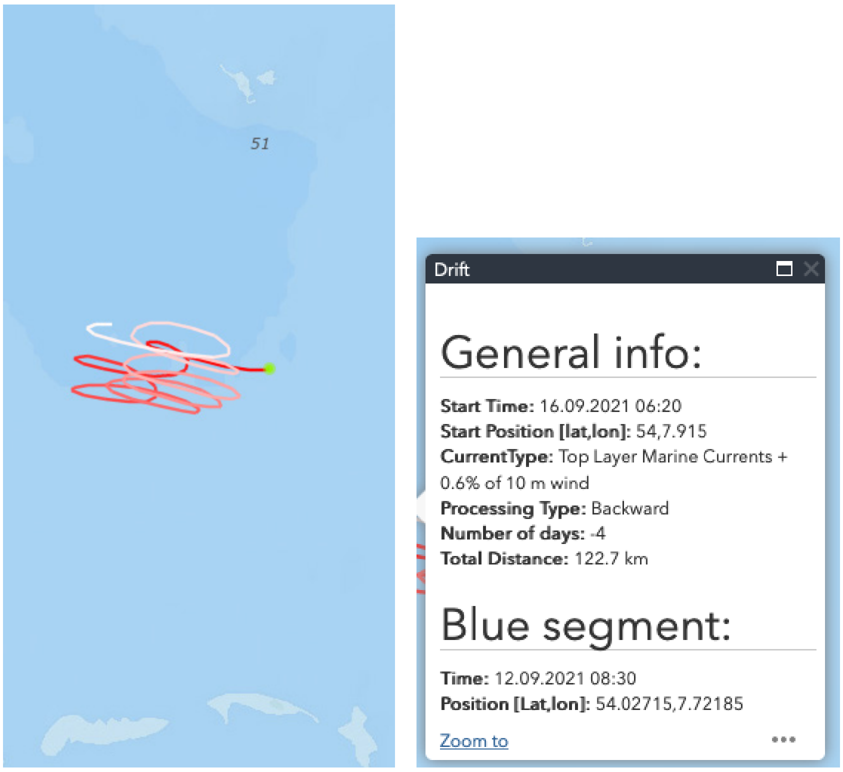

Fig. 9.5: Four day back-trajectories of water mass for a point at 54N, 7.9 E (left):
The green dot indicates the start position and start time of the water mass.
The red colour represents the start time, white colour depicts the position 4 days before.

For a better orientation Heligoland and East Frisian islands are indicated (right):
The insert shows the input data for the app.

10. RESUME AND OUTLOOK

The year 2021 was challenging with respect to multiple issues. First of all, the Corona pandemic situation prevented normal cruise procedures with face-to-face planning and coordination meetings. All those actions had to be performed online via video conferencing which was sometimes challenging especially with the ship's crews. Furthermore, the pandemic situation required the implementation of an infection prevention plan for each cruise and ship which was even more challenging as each participating ship and institute had its own regulations which differed from each other. Nevertheless, despite these pandemic-related logistical, organizational and personal complications, all cruises could be undertaken and the scientific test programme could be accomplished.

Cooperation with colleagues from the UFZ has been consolidated, so that a large- and small-scale follow-up Elbe cruise is planned for 2022.

Besides the above-mentioned pandemic complications, we also faced multiple technical failures of our research vessels which led to the situation that one of the planned ships could not join the cruise at all (*Ludwig Prandtl* – Sternfahrt_8) or had to be replaced on short notice by a commercial vessel serving as a MOSES research vessel (*Reykjanes* – Sternfahrt_7). The latter situation provided an unintentional possibility to prove our concept of setting up a mobile sensor system as we had to set up the entire MOSES sensor suite on a ship which was not prepared at all for taking up high-tech sensors and ship-to-ship communication on Helmholtz research vessels. This can also be seen as a test case for capturing an actual extreme event on short notice when some of our regular infrastructure and/or ships might not be available.

Taking these challenges into account, the MOSES concept for mobile and modular sensors worked perfectly as we were able to perform all measurements also on this commercial vessel and were able to seamlessly integrate this ship into the Helmholtz coastal research vessel fleet. In this context, the MOSES IT group made considerable efforts to stabilize and improve the data exchange and communication between ships and between the data portals even under adverse conditions.

Thus, most sensor and discrete sampling data were available in the respective data repositories (AWI O2A) even during or at least shortly after each cruise. In 2021 we were also able to allocate dedicated IT personnel at each participating institution who are now familiar with setting up the communication and data collection systems on each ship and are well prepared to accompany the cruises. This is most important for the success of the cruises as in contrast to larger ships, the sensor and network devices in the MOSES cruises have to be installed and uninstalled for each cruise. This had the effect that the IT configuration for the MOSES cruises is now highly flexible with respect to the set-up at different locations and circumstances as proved in Sternfahrt_8, as the Heligoland Tower normally used as ship-land interface was not available on short notice due to construction work and our installations had to be relocated to a similar tower in Cuxhaven which had to be used as land-contact during Sternfahrt_8.

These experiences, even though quite challenging and cumbersome when confronted with them on short notice, on the other hand forced the entire MOSES team to re-think and optimize the sampling and logistic procedures for maximum resilience and stability with respect to unexpected circumstances again and again. As this will certainly also be the case when a real flood situation occurs, drawbacks and problems in the test phase from 2018 to 2021 can be seen as “training” units to be prepared for a real flood event when the preparation time will also be short, the institute ships may not be available or other unexpected things happen.

We have therefore learned to be highly flexible, also on short notice, managed to handle situations where the planned ships were not available (repairs of *Uthörn* took longer than anticipated, vandalism on *Ludwig Prandtl*) and have therefore well adapted our procedures for a real extreme event/flood. Major logistic improvements in 2021 were the purchase of a MOSES lab-container, which can be fixed on most coastal vessels and our ability to install some of our instruments on a commercial ferry (*Funny Girl*) at short notice during the test campaigns. This was only possible due to strong support from the shipping company Cassen Eils and the FerryBox working group from HEREON.

Our efforts from the previous cruises resulted in several publications and further publications are planned and in preparation. We had planned to hold a several-day workshop to jointly work on our data and publications. However, due to Corona restrictions, this workshop had, again, to be performed completely online. We sincerely hope to be able to return to an in-person-workshop format in the coming year.

For 2022, we are planning again for cross-compartmental cruises to monitor a spring (bloom) situation (in contrast to our previous late summer cruises), starting with the Binnen Elbe near the Czech border (and even extending to the Czech part of the Elbe in collaboration with Czech partners), followed by the tidal Elbe and again the German Bight.

APPENDIX

A.1 PARTICIPATING INSTITUTIONS

Tab. A.1.1: Participating Institutions and their address

Institution	Address
DE.AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Postfach 120161 27515 Bremerhaven Germany
DE.Geomar	Geomar Helmholtz-Zentrum für Ozeanforschung Kiel Wischhofstraße 1-3 24148 Kiel Germany
DE.HZG	Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung Max-Planck-Str. 1 21502 Geesthacht Germany
DE.UFZ	Helmholtz Centre for Environmental Research GmbH – UFZ Brückstr. 3a 39114 Magdeburg Germany
DE.UFZ	Helmholtz Centre for Environmental Research GmbH – UFZ Permoserstr. 15 04318 Leipzig Germany

A.2 CRUISE PARTICIPANTS

Tab. A.2.1: Cruise Participants of Sternfahrt_6

Name / Last name	Vorname / First name	Institut / Institute	Beruf / Profession
Anselm	Norbert	DE.AWI	IT/Data Management
Bödewadt	Jan	DE.HZG	IT/Data Management
Burmester	Henning	DE.HZG	IT/Data Management
Eilers	Janik	DE.AWI	IT/Data Management
Faber	Claas	DE.GEOMAR	IT/Data Management
Lingner	Stefan	DE.GEOMAR	IT/Data Management
Rust	Hendrik	DE.HZG	IT/Data Management

Tab. A.2.2: Cruise Participants of Binnen-Elbe

Ship	Name / Last name	Vorname / First name	Institut / Institute	Beruf / Profession
Albis	Bauth	Sven	DE.UFZ	Captain
Albis	Bussmann	Ingeborg	DE.AWI	Scientist, in October
Albis	Evers	Erik	DE.AWI	Student, in August
Albis	Goretzka	Heike	DE.UFZ	Technician
Albis	Kamjunke	Norbert	DE.UFZ	Scientist
Albis	Krönert	Ann-Kathrin	DE.AWI	Internship, in April
Albis	Link	Ute	DE.UFZ	Technician

Tab. A.2.3: Cruise Participants of Sternfahrt_7

Ship	Name / Last name	Vorname / First name	Institut / Institute	Beruf / Profession
Ludwig Prandtl	Brix	Holger	DE.HZG	Scientist
Ludwig Prandtl	Gehrung	Martina	DE.HZG	Engineer
Ludwig Prandtl	Flöser	Götz	DE.HZG	Scientist
Ludwig Prandtl	Schacht	Marco	Reederei Laeisz	Captain
Ludwig Prandtl	Heinze	Detlef	Reederei Laeisz	Shipman
Ludwig Prandtl	Krönert	Ann-Kathrin	DE.AWI	Internship
Reykjanes	Anselm	Norbert	DE.AWI	IT
Reykjanes	Bussmann	Ingeborg	DE.AWI	Scientist

Ship	**Name / Last name**	**Vorname / First name**	**Institut / Institute**	**Beruf / Profession**
Reykjanes	Fischer	Philipp	DE.AWI	Scientist
Reykjanes	Happel	Lea	DE.AWI	Scientific technician
Reykjanes	Krönert	Ann-Kathrin	DE. AWI	Internship

Tab. A.2.4: Cruise Participants of cruise Geesthacht – Neu-Darchau

Ship	**Name / Last name**	**Vorname / First name**	**Institut / Institute**	**Beruf / Profession**
Zwergseeschwalbe	Rewrie	Louise	DE.HZG	Scientist
Zwergseeschwalbe	Peters	Marc	DE.HZG	Technical assistant

Tab. A.2.5: Cruise Participants of Sternfahrt_8

Ship	**Name / Last name**	**Vorname / First name**	**Institut / Institute**	**Beruf / Profession**
Littorina	Altahan	Mahmoud	DE.GEOMAR	Scientist
Littorina	Bhattacharya	Sayoni	DE.GEOMAR	Scientist
Littorina	Faber	Claas	DE.GEOMAR	IT / Scientist
Littorina	Jebens	Hannah	DE.AWI	TA
Littorina	von der Esch	Elisabeth	DE.GEOMAR	Scientist
Littorina	Lingner	Stefan	DE.GEOMAR	IT / Scientist (Transit Kiel → Cux only)
Uthörn	Becker	David	Reederei Laeisz	Captain
Uthörn	Plewe	Lucas	Reederei Laeisz	Navigation officer
Uthörn	Mühle	Erik	Reederei Laeisz	Technical officer
Uthörn	Niebuhr	Tim	Reederei Laeisz	Shipman
Uthörn	Peper	Sven	Reederei Laeisz	Shipman
Uthörn	Anselm	Norbert	DE.AWI	IT
Uthörn	Bussmann	Ingeborg	DE.AWI	Scientist
Uthörn	Fischer	Philipp	DE.AWI	Scientist
Uthörn	Happel	Lea	DE.AWI	Scientific technician

A.3 TABLES FOR FRESHWATER ELBE

Tab. A.3.1: Station list for Freshwater Elbe

Four cruises in April, June, August and October 2021

At each station the following parameters were determined: carbon, nutrients, ions, basic parameters, pigments, dissolved and particulate metals*. All times are given in CEST (Central European Summer Time).*carbon: DIC, DOC, POC, TIC, TOC, nutrients: NH_4, NO_2, NO*3*, PN, SRP, TP, Si, TSi, ions: K, Ca, Mg, Na, Cl, SO_4, basic parameters: SPM, UV254, pigments with HPLC: Chl a, Chl *b*, phaeophytin *a* & *b*, dissolved and particulate metals: Al, As, Cd, Cr, Co, Cu, Fe, Hg, Mn, Ni, Pb, Sn, Zn

Site	km	Latitude	Longitude	April (CEST)	June (CEST)	August (CEST)	October (CEST)
Elster li	198.9	51.8171	12.8308	19.04.2021 12:32	21.06.2021 11:29	23.08.2021 11:29	25.10.2021 11:32
Elster Mi	198.9	51.8168	12.8310	19.04.2021 12:45	21.06.2021 11:38	23.08.2021 11:39	25.10.2021 11:42
Elster re	198.9	51.8164	12.8312	19.04.2021 12:57	21.06.2021 11:46	23.08.2021 11:48	25.10.2021 11:51
Schwarze Elster Münd.	199.0	51.8230	12.8390	19.04.2021 13:10	21.06.2021 11:58	23.08.2021 12:03	25.10.2021 12:01
Roßlau li	258.0	51.8600	12.2110	19.04.2021 18:07	21.06.2021 16:48	23.08.2021 16:53	25.10.2021 16:55
Roßlau Mi	258.0	51.8811	12.2342	19.04.2021 18:15	21.06.2021 16:57	23.08.2021 17:01	25.10.2021 17:02
Roßlau re	258.0	51.8600	12.2110	19.04.2021 18:23	21.06.2021 17:04	23.08.2021 17:10	25.10.2021 17:09
Mulde Münd.	259.0	51.8737	12.2458	20.04.2021 09:58	21.06.2021 09:10	24.08.2021 09:48	26.10.2021 08:57
Breitenhagen li	287.0	51.9570	11.9130	20.04.2021 11:54	2021.06.2021 11:10	24.08.2021 11:42	26.10.2021 10:57
Breitenhagen Mi	287.0	51.9570	11.9130	20.04.2021 12:06	2021.06.2021 11:19	24.08.2021 11:52	26.10.2021 11:05
Breitenhagen re	287.0	51.9302	11.9558	20.04.2021 12:16	2021.06.2021 11:28	24.08.2021 12:01	26.10.2021 11:13
Saale Münd.	290.7	51.9770	11.8860	20.04.2021 12:41	2021.06.2021 11:52	24.08.2021 12:24	26.10.2021 11:38

Site	km	Latitude	Longitude	April (CEST)	June (CEST)	August (CEST)	October (CEST)
MD Westerhüsen li	318.0	52.0669	11.6792	20.04.2021 15:12	2021.06.2021 13:50	24.08.2021 15:12	26.10.2021 14:12
MD Westerhüsen Mi	318.0	52.0672	11.6805	20.04.2021 15:20	2021.06.2021 13:58	24.08.2021 15:2021	26.10.2021 14:20
MD Westerhüsen re	318.0	52.0673	11.6816	20.04.2021 15:29	2021.06.2021 14:06	24.08.2021 15:31	26.10.2021 14:30
MD Strombrücke li	326.53	52.1291	11.6437	20.04.2021 16:12	2021.06.2021 14:53	24.08.2021 16:18	26.10.2021 15:19
MD Strombrücke Mi	326.53	52.1290	11.6442	20.04.2021 16:23	2021.06.2021 15:01	24.08.2021 16:26	26.10.2021 15:27
MD Strombrücke re	326.53	52.1287	11.6446	20.04.2021 16:48	2021.06.2021 15:09	24.08.2021 16:33	26.10.2021 15:34
Rogätz li	351.0	52.3340	11.8130	21.04.2021 12:34	23.06.2021 12:11	25.08.2021 12:01	27.10.2021 13:16
Rogätz Mi	351.0	52.3340	11.8130	21.04.2021 12:44	23.06.2021 12:20	25.08.2021 12:16	27.10.2021 13:23
Rogätz re	351.0	52.3340	11.8130	21.04.2021 12:56	23.06.2021 12:28	25.08.2021 12:08	27.10.2021 13:36
Tangermünde li	388.0	52.5398	11.9790	21.04.2021 16:10	23.06.2021 16:24	25.08.2021 16:06	27.10.2021 16:13
Tangermünde Mi	388.0	52.5397	11.9803	21.04.2021 16:19	23.06.2021 16:32	25.08.2021 16:17	27.10.2021 16:20
Tangermünde re	388.0	52.5396	11.9815	21.04.2021 16:28	23.06.2021 16:39	25.08.2021 16:29	27.10.2021 16:31
Werben li	422.25	52.8379	12.0393	21.04.2021 12:59	24.06.2021 11:43	26.08.2021 11:41	28.10.2021 11:48
Werben Mi	422.25	52.8376	12.0405	21.04.2021 13:07	24.06.2021 11:53	26.08.2021 11:49	28.10.2021 11:58
Werben re	422.25	52.8374	12.0417	21.04.2021 13:34	24.06.2021 12:01	26.08.2021 11:57	28.10.2021 12:06
Havel Münd.	438.0	52.9081	11.8795	21.04.2021 14:57	24.06.2021 13:20	26.08.2021 13:08	28.10.2021 13:19

Tab. A.3.1: Station list for Freshwater Elbe

Site	km	Latitude	Longitude	April (CEST)	June (CEST)	August (CEST)	October (CEST)
Wittenberge li	454.9	52.9863	11.7516	21.04.2021 16:26	24.06.2021 15:46	26.08.2021 14:37	28.10.2021 14:42
Wittenberge Mi	454.9	52.9870	11.7519	21.04.2021 16:33	24.06.2021 15:54	26.08.2021 14:45	28.10.2021 14:49
Wittenberge re	454.9	52.9875	11.7523	21.04.2021 16:43	24.06.2021 16:01	26.08.2021 14:53	28.10.2021 14:57
Schnackenburg li	475.0	53.0472	11.5542	23.04.2021 11:07	25.06.2021 10:15	27.08.2021 09:55	29.10.2021 09:55
Schnackenburg Mi	475.0	53.0480	11.5560	23.04.2021 11:14	25.06.2021 10:24	27.08.2021 10:02	29.10.2021 10:02
Schnackenburg re	475.0	53.0481	11.5572	23.04.2021 11:23	25.06.2021 10:33	27.08.2021 10:11	29.10.2021 10:10
Dömitz li	506.0	53.1335	11.2488	23.04.2021 13:44	25.06.2021 13:32	27.08.2021 12:53	29.10.2021 12:52
Dömitz Mi	506.0	53.1342	11.2492	23.04.2021 13:53	25.06.2021 13:40	27.08.2021 13:02	29.10.2021 12:59
Dömitz re	506.0	53.1345	11.2508	23.04.2021 14:01	25.06.2021 13:48	27.08.2021 13:10	29.10.2021 13:07

Tab. A.3.2: Instruments on the *Albis*

On the way / vertical	Air / Water	Parameter(s)	Responsible person	Instrument name	Sensor ID at	Remarks
On the way	air	Atmospheric CH_4 (ppb) and CO_2 (ppm)	U.Ködel/ C.Schütze	LICOR 7810 $CH_4/CO_2/H_2O$ Trace Gas Analyzer	vessel:Albis:ufz_ licor_7810:diag	only UTC time no GPS coordinates
On the way	air	Latitude, Longitude, Temperature,Relative Humidity, Air pressure (hPa),	U.Ködel/ C.Schütze	Sensebox	vessel:Albis:ufz_sensebox_ Albis:air_pressure	
On the way	air	RH (%), temperature (*C), rainfall (mm), wind Dir (Deg), wind gust (km/h), wind speed (km/h), dew point (*C)	U. Ködel/ C. Schütze	Watchdog 2700	vessel:Albis:ufz_ watchdog:dewpoint	
On the way	water	dissolved CH_4 and CO2	I. Bussmann	Losgatos_ awi_3599	vessel:Albis:losgatos_ awi_3599:CH_4_ppm	time offset 170 sec
On the way	water	Hydrography: Latitude_0001, longitude_0001, speed_0001, course_over_ground_0001, flow_main_0001, temperature_sbe45_0001, conductivity_sbe45_0001, salinity_sbe45_0001,temperature_ phsensor_0001, oxygen_ concentration_0001, oxygen_saturation_0001, temperature_0001,	I. Bussmann	pfb_ awi_751801	vessel:Albis:pfb_ awi_751801:latitude_0001	time offset of 19 sec
at stations	water	Hydrography: water temperature, pH, turbidity, chlorophyll a, oxygen, conductivity	N. Kamjunke	YSI probe	https://www.ufz.de/record/ dmp/logger/1493/de/	only surface water at 0.3 m depth
Fixed stations	water	Hydrography: water temperature, pH, turbidity, chlorophyll a, oxygen, conductivity	N. Kamjunke	YSI probe	https://www.ufz.de/record/ dmp/logger/1245/de/ https://www.ufz.de/record/ dmp/logger/1261/de/	ferry at Westerhüsen (km 318) and Werben (km 42021), crossing the Elbe several times each day

A.4 TABLES FOR NEU-DARCHAU – GEESTHACHT

Tab. A.4.1: Station list

Water samples were taken from the surface at the FerryBox outlet and analyzed for different parameters: Oxygen, Chl (Chlorophyll-*a*), PIP and POP (particulate inorganic and organic phosphate), salinity and nutrients. For information on the data management please read A.8.

Station ID	Date Time [UTC]	Latitude	Longitude	Parameters
1	04.05.2021 08:51	53.24094	10.87846	Turb/sal, PIP, POP, Chl, nutrients, oxygen
2	04.05.2021 10:00	53.29326	10.75769	PIP, POP, Chl, nutrients
3	04.05.2021 10:55	53.36536	10.70995	Turb/sal, PIP, POP, Chl, nutrients
4	04.05.2021 11:45	53.36001	10.58083	PIP, POP, Chl, nutrients
5	04.05.2021 12:31	53.3721	10.51034	Turb/sal, PIP, POP, Chl, nutrients
6	04.05.2021 13:15	53.39913	10.42837	PIP, POP, Chl, nutrients, oxygen
7	05.05.2021 07:50	53.42623	10.37146	PIP, POP, Chl, nutrients, oxygen
8	05.05.2021 09:27	53.43349	10.30992	PIP, POP, Chl, nutrients
9	05.05.2021 10:11	53.39451	10.2021578	Turb/sal, PIP, POP, Chl, nutrients
10	05.05.2021 11:00	53.4307	10.10388	PIP, POP, Chl, nutrients, oxygen

A.5 TABLES FOR MAGECH

Tab. A.5.1: Instruments of the MaGeCH campaign

Instruments, location, duration of deployment and data availability. For information on the data management please read A.8.

Location	**Position**	**Start date**	**End date**	**Parameter**	**Sensor type and ID**	**Data location**
Magdeburg	52.1287 N; 11.6446 E	07.04.2021	05.05.2021	diss. CH_4, diss. CO_2, temperature, conductivity, O_2	METS sensor (Franatech) AMT CO_2sensor	most of the data are in the UFZ DMP
Geesthacht	53.4112 N; 10.4032 E	14.04.2021	29.09.2021	diss. methane, temperature, oxygen concentration (from AKW)	Contros HydroC CH_4, CH_4_awi_leih_0321_001 ATM CTD	https://dashboard.awi.de/data-ingest/index.html# hydrex_2021_MaGeCH Cuxhaven hydrex_2021_MaGeCH Geesthacht laboratory:awi_csd:CH_4_awi_leih_0321_003:conc_estimate
Cuxhaven	53.8771 N; 8.7048 E	13.04.2021	19.08.2021	diss. methane,	Contros HydroC CH_4 CH_4_awi_leih_0321_002	
Heligoland	54.1833 N; 7.8667 E	26.04.2021	28.10.2021	diss. methane, diss. CO_2	Contros HydroC CH_4 CH_4_awi_leih_0321_003 Contros HydroC CO_2 co2_awi_8020_001	
Heligoland	54.1874 N; 7.8737 E	01.06.2021	09.09.2021	atmosph. CH_4 and CO_2	Greenhouse Gas Analyser losgatos_awi_1303	

A.6 TABLES FOR STERNFAHRT_7

Tab. A.6.1: Station list for *Ludwig Prandtl* on Stern_7

Water samples were taken from the FerryBox outlet in order to determine turbidity, oxygen and methane. For information on the data management please see A.8.

Station ID	DateTime [UTC]	Latitude	Longitude	Water depth [m]	Remarks
1	10.05.21 14:02	53.8844	8.7176	1	turbidity (1)
2	10.05.21 14:16	53.8869	8.7157	1	CH_4 (Cux 19)
3	10.05.21 14:16	53.8869	8.7157	1	vertical CTD profile
4	10.05.21 14:45	53.8863	8.7158	1	oxygen bottles 69,95,96
5	11.05.21 07:15	53.8793	8.7230	1	vertical CTD profile
6	11.05.21 07:44	53.8792	8.7202	1	turbidity (2), CH_4 (Cux26), oxygen bottles 95,96,69
7	11.05.21 09:29	53.8786	8.7237	1	vertical CTD profile
8	11.05.21 09:53	53.8786	8.7238	1	turbidity 3, CH_4 (xx), O2 (95, 67, 23)
9	11.05.21 11:37	53.8786	8.7237	1	CH_4 (Cux28)
10	11.05.21 12:00	53.8786	8.7237	1	vertical CTD profile
11	11.05.21 12:20	53.8786	8.7237	1	turbidity (4)
12	11.05.21 13:15	53.8786	8.7231	1	40 L water for Celia Bento, Hereon
13	11.05.21 14:00	53.8792	8.7230	1	vertical CTD profile
	11.05.21 14:19	53.8792	8.7230		turbidity (5), CH_4 (Cux38), oxygen bottles 67,32,23
14	12.05.21 07:25	53.8836	8.7171	1	CH_4 (Cux29)
15	12.05.21 07:28	53.8858	8.7170	1	CH_4 (Cux21)
16	12.05.21 07:50	53.9028	8.7007	1	turbidity (6)

Tab. A.6.2: Instruments on *Ludwig Prandtl* on Stern_7

On the way / vertical	**Water / Air**	**Parameter(s)**	**Responsible person**	**Instrument name**	**Sensor ID** at https://sensor.awi.de/ Mission: MOSES Sternfahrt_7 mission	**Remarks**
On the way		Position: latitude_0001, longitude_0001	G. Flöser	D-Ship *Ludwig Prandtl*		no data available
On the way		Position: latitude_0001, longitude_0001	G. Flöser	Ferrybox	vessel:*Prandtl*_hzg:fb_hzg_orion	No time offset
On the way	air	Weather: meteo_air_pressure_0001 Meteo_air_temperature_0001, meteo_radiation_0001, relative_humidity_0001, meteo_wind_east_0001, meteo_wind_direction_0001, meteo_wind_north_0001, meteo_wind_speed_0001,	G. Flöser	Weather Station GMX600	vessel:*Prandtl*_hzg:weather_station_hzg_1957ps001	no data available
On the way	water	Hydrography: cdom_cyclops_0001, oxygen_concentration_aanderaa_0001, oxygen_saturation_0001, ph_meinsberg_ega_0001, salinity_0001, temperature_citadel_0001	G. Flöser	Ferrybox	vessel:*Prandtl*_hzg:fb_hzg_orion	Time offset till 10:11 UTC = 19 sec, from 10:12 UTC = 15 sec

Tab. A.6.3: Station list for water samples taken on *Reykjanes* on Stern_7

Water samles were taken at 53.88N, 8.71E and a water depth of approx. 1 m (surface) and 12 m (bottom)

DateTime [UTC]	FerryBox	*In-situ* pump	Water sampler	GGA	Depth	Remarks
10.05.21 13:44						at anchor, approx. 12 m water depth
10.05.21 13:45	on			on	surface	200 bar, Gas 0.4, Water 1.6
10.05.21 14:24		on			surface	
10.05.21 14:32			fired		surface	
10.05.21 14:33		off			surface	estimated time for pump off
10.05.21 14:42		on			bottom	
10.05.21 14:49			fired		bottom	
10.05.21 14:50		off			bottom	estimated time for pump off
11.05.21 07:10		on			surface	
11.05.21 07:20			fired		surface	
11.05.21 07:21		off			surface	
11.05.21 07:31		on			bottom	
11.05.21 07:36			fired		bottom	
11.05.21 07:40		off		off		
11.05.21 08:32				on		
11.05.21 09:33		on			surface	
11.05.21 09:39		off	fired		surface	
11.05.21 09:46		on				no further information available
11.05.21 09:56		off				no further information available

DateTime [UTC]	FerryBox	*In-situ* pump	Water sampler	GGA	Depth	Remarks
11.05.21 09:59		on			bottom	
11.05.21 10:07			fired		bottom	was not closed properly
11.05.21 10:08		off			bottom	
11.05.21 12:03		on			surface	
11.05.21 12:09			fired		surface	
11.05.21 12:10		off			surface	
11.05.21 12:16		on			bottom	
11.05.21 12:23			fired		bottom	
11.05.21 12:24		off			bottom	
11.05.21 13:59		on			surface	
11.05.21 14:05			fired		surface	
11.05.21 14:06		off			surface	
11.05.21 14:10		on			bottom	
11.05.21 14:18			fired		bottom	
11.05.21 14:19		off			bottom	
12.05.21 06:18				off		
12.05.21 06:40				on		
12.05.21 07:02		on			surface	
12.05.21 07:09			fired		surface	
12.05.21 07:10		off			surface	
12.05.21 07:15		on			bottom	

DateTime [UTC]	FerryBox	*In-situ* pump	Water sampler	GGA	Depth	Remarks
12.05.21 07:23			fired		bottom	
12.05.21 07:24		off			bottom	
12.05.21 07:26	off			off		

Tab. A.6.4: Station list for oxygen water samples taken on Reykjanes on Stern_7

Water samples were taken at 53.88N, 8.71E at the surface and a water depth of approx. 12 m. For information on the data management please see A.8.

Bottle number	DateTime [UTC]	Depth	Sample origin
11/12/13	10.05.21 14:14 – 14:16	bottom	ship's water supply
14/17/21	10.05.21 14:28 –14:30	bottom	*in-situ* pump
2021/23/24	10.05.21 14:14	bottom	niskin bottle
31/32/32	11.05.21 07:08 – 07:09	surface	ship's water supply
34/35/36	11.05.21 07:18 – 07:20	surface	*in-situ* pump
37/40/41	11.05.21 07:20	surface	niskin bottle
11/12/13	11.05.21 09:30 – 09:31	surface	ship's water supply
14/17/21	11.05.21 09:51 – 09:54	surface	*in-situ* pump
2021/28/29	11.05.21 09:39	surface	niskin bottle
21/30	11.05.21 10:08	bottom	niskin bottle

Tab. A.6.5: Station list for methane water samples taken on *Reykjanes* on Stern_7

Water samples were taken at 53.88N, 8.71E at the surface and a water depth of approx. 12 m. For information on the data management please see A.8.

Bottle number	DateTime [UTC]	Depth	Sample origin
U-1/2	10.05.21 14:10 / 14:12	surface	ship's water supply
U-3/4	10.05.21 14:26 /14:27	surface	*in-situ* pump
U-5/6	10.05.21 14:32	surface	niskin bottle
U-9/10	10.05.21 14:48	bottom	*in-situ* pump
U-11/12	10.05.21 14:49	bottom	niskin bottle
U-13/14	11.05.21 07:06	surface	ship's water supply
U-15/16	11.05.21 07:16 / 07:17	surface	*in-situ* pump
U-17/18	11.05.21 07:20	surface	niskin bottle
U-19/20	11.05.21 07:36	bottom	*in-situ* pump
U-21/2021	11.05.21 07:36	bottom	niskin bottle
U-23/24	11.05.21 09:28 / 09:29	surface	ship's water supply
U-25/26	11.05.21 09:38 / 09:39	surface	*in-situ* pump
U-27/28	11.05.21 09:39	surface	niskin bottle
U-29/30	11.05.21 10:05 / 10:06	bottom	*in-situ* pump
U-31/32	11.05.21 10:08	bottom	niskin bottle
U-33/34	11.05.21 12:01 / 12:02	surface	ship's water supply
U-35/36	11.05.21 12:08 / 12:09	surface	*in-situ* pump
U-37/38	11.05.21 12:10	surface	niskin bottle
U-39/40	11.05.21 12:2021 / 12:23	bottom	*in-situ* pump
U-41/42	11.05.21 12:24	bottom	niskin bottle
U-7/8	11.05.21 13:57 / 13:58	surface	ship's water supply
U-X/43	11.05.21 14:04 / 14:05	surface	*in-situ* pump
U-44/45	11.05.21 14:05	surface	niskin bottle
U-46/47	11.05.21 14:17	bottom	*in-situ* pump
U-48/49	11.05.21 14:18	bottom	niskin bottle
U-51/52	12.05.21 07:00 / 07:01	surface	ship's water supply
U-53/54	12.05.21 07:08 / 07:09	surface	*in-situ* pump
U-55/56	12.05.21 07:09	surface	niskin bottle
U-57/58	12.05.21 07:2021 / 07:23	bottom	*in-situ* pump
U-59/60	12.05.21 07:23	bottom	niskin bottle

Tab. A.6.6: Instruments on *Reykjanes* on Stern_7

On the way / vertical	Parameter(s)	Responsible person	Instrument name	Sensor ID at https://dashboard.awi.de	Remarks
On the way	Hydrography: Latitude_0001, longitude_0001, speed_0001, course_over_ground_0001, flow_main_0001, temperature_sbe45_0001, conductivity_sbe45_0001, salinity_sbe45_0001,temperature_phsensor_0001, oxygen_concentration_0001, oxygen_saturation_0001, temperature_0001	I. Bussmann	Pocket FerryBox	vessel:*Reykjanes*:pfb_awi_751801:ph_0001	no pH, attached to in-situ pump, 5 min at surface, 5 min at bottom, time offset 349 sec,
vertical	Hydrography: pressure_01 Temperature_406, chlorophyll_a_awi_211t0078, turbidity_16157, salinity_17060902, oxygen_saturation_20214140948, oxygen_concentration_mg_l_20214140948, oxygen_concentration_ml_l_20214140948	L. Happel	Sea and Sun CTD 1420	vessel:*Reykjanes*:ctd_awi_1420:conductivity_01	attached to in-situ pump, 5 min at surface and 5 min at bottom
On the way & vertical with *in-situ* pump	Dissolved methane: ambtemp, CH_4, CH_4dry, co2, co2dry, fitflag, gaspressure, gastemp, CH_4_dissolved_calculated	I. Bussmann	LosGatos #1142	vessel:*Reykjanes*:losgatos_awi_1142:ambt_c	attached to in-situ pump, 5 min at surface and 5 min at bottom, time offset 410 sec

A.7 TABLES FOR STERNFAHRT_8

Tab. A.7.1: List for Intercal-Stations on Stern_8

Both ships were close together with all under-way systems running

Station ID	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Distance [m]
L-1	13.09.21 07:05	13.09.21 07:16	53.8855	8.7153	
U-1	13.09.21 6:40	13.09.21 7:21	53.8783	8.7202	864
L-7	14.09.21 06:51	14.09.21 07:08	54.1350	7.8853	
U-7	14.09.21 6:50	14.09.21 07:08	54.1458	7.8904	1247
L-18	15.09.21 12:05	15.09.21 12:20	54.1347	7.8847	
U-20	15.09.21 12:06	15.09.21 12:21	54.1429	7.8931	1065

Tab. A.7.2: Station list for water samples taken on *Littorina* on Stern_8

Water samples were taken from a niskin water sampler for methane (CH_4), dissolved organic carbon (DOC), particulate carbon (POC), dissolved inorganic carbon (DIC), total alkalinity (TA), explosives and nutrients (NS) For information on the data management please read A.8.

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
*L-1	*in situ* CTD	13.09.21 07:05	13.09.21 07:16	53.8855	8.7153		
	in situ pump surface	13.09.21 07:05	13.09.21 07:16			1	
	in situ pump bottom	13.09.21 07:09	13.09.21 07:12			9	
	water sampler	13.09.21 07:16				1	CH_4, DOC, POC (250 ml), DIC, TA, Explosives, NS
L-2	*in situ* CTD	13.09.21 07:50	13.09.21 08:11	53.9430	8.6582		

Tab. A.7.2: Station list for water samples taken on Littorina on Stern_8

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
	in situ pump surface	13.09.21 07:55	13.09.21 07:58			2	
	in situ pump bottom	13.09.21 07:59	13.09.21 08:02			10	
	water sampler	13.09.21 08:11				1	CH_4, DOC, POC (250 ml), DIC, TA, NS
L-3	*in situ* CTD	13.09.21 08:55	13.09.21 09:04	54.0131	8.4375		
	in situ pump surface	13.09.21 08:58	13.09.21 08:59			2	
	in situ pump bottom	13.09.21 08:59	13.09.21 09:02			8	
	water sampler	13.09.21 09:04					CH_4, DOC, POC (250 ml), DIC, TA, Explosives, NS
L-4	*in situ* CTD	13.09.21 10:25	13.09.21 10:36	54.0756	8.1419		
	in situ pump surface	13.09.21 10:26	13.09.21 10:29			2	
	in situ pump bottom	13.09.21 10:30	13.09.21 10:34			12	
	water sampler	13.09.21 10:35				1	CH_4, DOC, POC (400 ml), DIC, TA, Explosives, Nutrients
L-5	*in situ* CTD	13.09.21 11:28	13.09.21 11:40	54.1436	8.0067		
	in situ pump surface	13.09.21 11:30	13.09.21 11:33			2	

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
	in situ pump bottom	13.09.21 11:35	13.09.21 11:38			12	
	water sampler	13.09.21 11:39					CH_4, DOC, POC (450 ml), DIC, TA, Nutrients
L-6	*in situ* CTD	13.09.21 12:28	13.09.21 12:38	54.1358	7.9019		
	in situ pump surface	13.09.21 12:29	13.09.21 12:32			2	
	in situ pump bottom	13.09.21 12:33	13.09.21 12:36			14	
	water sampler	13.09.21 12:37					CH_4, DOC, POC (450 ml), DIC, TA, Nutrients
*L-7	*in situ* CTD	14.09.21 06:51	14.09.21 07:08	54.1350	7.8853		
	in situ pump surface	14.09.21 06:53	14.09.21 06:59			2	
	in situ pump bottom	14.09.21 07:00	14.09.21 07:05			13	
	water sampler	14.09.21 7:05					CH_4, DOC, POC (450 ml), DIC, TA, Explosives, Nutrients
L-8	*in situ* CTD	14.09.21 08:09	14.09.21 08:23	54.0686	8.0689		
	in situ pump surface	14.09.21 08:10	14.09.21 08:15			2	
	in situ pump bottom	14.09.21 08:16	14.09.21 08:21			13	

Tab. A.7.2: Station list for water samples taken on Littorina on Stern_8

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
	water sampler	14.09.21 08:2021					CH_4, DOC, POC (450 ml), DIC, TA, Explosives, Nutrients
L-9	*in situ* CTD	14.09.21 09:23	14.09.21 09:37	54.0181	8.2517		
	in situ pump surface	14.09.21 09:25	14.09.21 09:30			2	
	in situ pump bottom	14.09.21 09:30	14.09.21 09:36			6	
	water sampler	14.09.21 09:36					CH_4, DOC, POC (450 ml), DIC, TA, Nutrients
L-10	*in situ* CTD	14.09.21 10:35	14.09.21 10:48	53.9847	8.4178		
	in situ pump surface	14.09.21 10:36	14.09.21 10:41			2	
	in situ pump bottom	14.09.21 10:42	14.09.21 10:47			6	
	water sampler	14.09.21 10:48				1	CH_4, DOC, POC (450 ml), DIC, TA, Nutrients
L-11	*in situ* CTD	14.09.21 12:02	14.09.21 12:16	53.9356	8.6511		
	in situ pump surface	14.09.21 12:03	14.09.21 12:09			2	
	in situ pump bottom	14.09.21 12:09	14.09.21 12:14			8	
	water sampler	14.09.21 12:15				1	CH_4, DOC, POC (350 ml), DIC, TA, Nutrients

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
L-12	*in situ* CTD	14.09.21 14:56	14.09.21 15:07	53.8833	8.7167		according to CTD data, the time should be 12:56
	in situ pump surface	14.09.21 15:57	14.09.21 15:02				no data
	in situ pump bottom	14.09.21 15:02	14.09.21 15:07				
	water sampler	14.09.21 15:07					CH_4, DOC, POC (250 ml), DIC, TA, Nutrients
L-13	*in situ* CTD	15.09.21 06:20	15.09.21 06:37	53.8833	8.7169		
	in situ pump surface	15.09.21 06:24	15.09.21 06:29			1	
	in situ pump bottom	15.09.21 06:30	15.09.21 06:35			8	
	water sampler	15.09.21 06:36				1	CH_4, DOC, POC (250 ml), DIC, TA, Explosives, NS
L-14	*in situ* CTD	15.09.21 07:06	15.09.21 07:21	53.9464	8.6519		
	in situ pump surface	15.09.21 07:08	15.09.21 07:13			1	
	in situ pump bottom	15.09.21 07:13	15.09.21 07:19			10	
	water sampler	15.09.21 7:20				1	CH_4, DOC, POC (350 ml), DIC, TA, Nutrients
L-15	*in situ* CTD	15.09.21 08:10	15.09.21 08:25	53.9850	8.4189		

Tab. A.7.2: Station list for water samples taken on Littorina on Stern_8

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
	in situ pump surface	15.09.21 08:12	15.09.21 08:18			1	
	in situ pump bottom	15.09.21 08:18	15.09.21 08:23			7	
	water sampler	15.09.21 08:24				1	CH_4, DOC, POC (450 ml), DIC, TA, Explosives, NS
L-16	*in situ* CTD	15.09.21 09:25	15.09.21 9:39	54.0525	8.152021		
	in situ pump surface	15.09.21 09:26	15.09.21 09:31			2	
	in situ pump bottom	15.09.21 09:32	15.09.21 09:37			11	
	water sampler	15.09.21 09:38					CH_4, DOC, POC (450 ml), DIC, TA, Explosives, NS
L-17	*in situ* CTD	15.09.21 10:25	15.09.21 10:39	54.1342	8.0006		
	in situ pump surface	15.09.21 10:26	15.09.21 10:31			2	
	in situ pump bottom	15.09.21 10:32	15.09.21 10:37			14	
	water sampler	15.09.21 10:38				1	CH_4, DOC, POC (450 ml), DIC, TA, NS
*L-18	*in situ* CTD	15.09.21 12:05	15.09.21 12:20	54.1347	7.8847		
	in situ pump surface	15.09.21 12:06	15.09.21 12:11			2	

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
	in situ pump bottom	15.09.21 12:13	15.09.21 12:18			14	
	water sampler	15.09.21 12:19					CH_4, DOC, POC (400 ml), DIC, TA, NS
L-19	*in situ* CTD	15.09.21 12:52	15.09.21 13:06	54.1353	7.9686		no CTD data
	in situ pump surface	15.09.21 12:53	15.09.21 12:59				
	in situ pump bottom	15.09.21 13:00	15.09.21 13:05				
	water sampler	15.09.21 13:06					CH_4, DOC, POC (400 ml), DIC, TA, NS
L-20	*in situ* CTD	15.09.21 13:48	15.09.21 14:04	54.0850	8.1186		no CTD data
	in situ pump surface	15.09.21 13:51	15.09.21 13:56				
	in situ pump bottom	15.09.21 13:57	15.09.21 14:02				
	water sampler	15.09.21 14:03					CH_4, DOC, POC (400 ml), DIC, TA, NS
L-21	*in situ* CTD	15.09.21 15:21	15.09.21 15:33	53.9358	8.6506		no CTD data
	in situ pump surface	15.09.21 15:2021	15.09.21 15:27				
	in situ pump bottom	15.09.21 15:27	15.09.21 15:32				
	water sampler	15.09.21 15:33					CH_4, DOC, POC (400 ml), DIC, TA, NS

Tab. A.7.2: Station list for water samples taken on Littorina on Stern_8

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude (N)	Longitude (E)	Water depth [m]	Remarks
L-2021	*in situ* CTD	15.09.21 16:38	15.09.21 16:52	53.9450	8.402021		no CTD data
	in situ pump surface	15.09.21 16:39	15.09.21 16:44				
	in situ pump bottom	15.09.21 16:45	15.09.21 16:50				
	water sampler	15.09.21 16:51					CH_4, DOC, POC (400 ml), DIC, TA, NS
L-23	*in situ* CTD	15.09.21 17:20	15.09.21 17:34	53.8833	8.7025		
	in situ pump surface	15.09.21 17:21	15.09.21 17:26				
	in situ pump bottom	15.09.21 17:27	15.09.21 17:32				
	water sampler	15.09.21 17:32					CH_4, DOC, POC (400 ml), DIC, TA, NS

Tab. A.7.3: Instruments on *Littorina* on Stern_8

On the way / vertical	Parameter(s)	Responsible person	Instrument name	Sensor ID at https://dashboard.awi.de/data-ingest/index.html MOSES Sternfahrt_8 mission	Remarks
On the way	longitude / Latitude	C.Faber	GPS Hemisphere Cresent R131RCVR	vessel:*Littorina*:gps_gmr_120218-160664-0011	data also included in Picarro dataset
On the way	wind speed, wind direction	C. Faber	Furuno FI-501 Wind logger	vessel:*Littorina*:wind_furuno_fi-501_001	data also included in Picarro dataset
On the way & vertical	pH, salinity, dissolved oxygen, temperature, turbidity, chlorophyll, CDOM	H. Rust	PFB_SN751903_Ernie		no data available
On the way & vertical	dissolved CH_4 and CO_2	I. Bussmann	Los Gatos #1142	vessel:*Littorina*:losgatos_awi_1142:temp_status_ma_sd	Time off set 260 sec
On the way	atmospheric CH_4 and CO_2, longitude / latitude	J. Greinert	Picarro	vessel:*Littorina*:crds_cfbds2040	
vertical	pressure, temperature, salinity, oxygen, pH, sound velocity	C. Faber	GEOMAR CTD_1070210	vessel:*Littorina*:ctd_geomar_1070210	large CTD with water sampler
On the way	dissolved CO_2	E. von der Esch	HydroC $CO_2$0319-001	vessel:*Littorina*:co2_geomar_0319001:carbon_dioxide_conc_estimate_0001	
On the way	pressure, temperature, salinity, oxygen, tds, tss, turbidity	E. von der Esch	CTD YSI_MPP_EXO1	vessel:*Littorina*:exo1_geomar_0001	small CTD from basin on deck

Tab. A.7.3: Instruments on Littorina on Stern_8

On the way / vertical	Parameter(s)	Responsible person	Instrument name	Sensor ID at https://dashboard.awi.de/data-ingest/index.html MOSES Sternfahrt_8 mission	Remarks
On the way	dissolved CH_4	E. von der Esch	GEOMAR_Methane sensor_37-477-25	vessel:*Littorina*:methane_geomar_37-477-25:corrected_CH_4	
On the way	nitrate, salinity, temperature	E. von der Esch	OPUS Nitrate Sensor 71F9 GEOMAR	vessel:*Littorina*:opus_geomar_71f9	no data available
On the way	pH, temperature	E. von der Esch	SAMI pH Geomar P0235	vessel:*Littorina*:sami_ph_geomar_p0235:ph_P0235	
On the way	communication		Kongsberg Antenne	storm (Hereon)	

Tab. A.7.4: Station list for *Uthörn* on Stern_8

Water samples were taken from a niskin water sampler

For analysis of methane, DOC and POC (dissolved and particulate carbon), DIC (dissolved inorganic carbon), TA (total alkalinity) and NS (nutrients). For information on the data management please read A.8.

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude	Longitude	Water depth [m]	Remarks
U-1	*in situ* CTD	13.09.21 06:40	13.09.21 07:21	53.8783	8.7202		
	in situ pump surface	13.09.21 07:11	13.09.21 07:13			1	
	in situ pump bottom	13.09.21 07:15	13.09.21 07:18			16	
	water sampler	13.09.21 07:20				1	CH_4, DOC, POC (500 ml), DIC, TA, NS
U-2	*in situ* CTD	13.09.21 7:46	13.09.21 7:56	53.9375	8.6643		
	in situ pump surface	13.09.21 07:46	13.09.21 07:50			1	
	in situ pump bottom	13.09.21 07:51	13.09.21 07:54			14	
	water sampler	13.09.21 07:56				1	CH_4, DOC, POC (500 ml), DIC, TA, NS
U-3	*in situ* CTD	13.09.21 08:49	13.09.21 09:00	53.9949	8.3968		no CTD data
	in situ pump surface	13.09.21 08:50	13.09.21 08:54				
	in situ pump bottom	13.09.21 08:55	13.09.21 08:58				
	water sampler	13.09.21 08:59					CH_4, DIC, TA
	2. water sampler	13.09.21 09:04					DOC, POC (500 ml), NS
U-4	*in situ* CTD	13.09.21 11:03	13.09.21 11:17	53.9716	7.9048		

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude	Longitude	Water depth [m]	Remarks
	in situ pump surface	13.09.21 11:03	13.09.21 11:08			1	
	in situ pump bottom	13.09.21 11:09	13.09.21 11:15			16	
	water sampler	13.09.21 11:16				1	CH_4, DOC, POC (500 ml), DIC, TA, NS
U-5	*in situ* CTD	13.09.21 12:03	13.09.21 12:18	54.0716	7.9029		no CTD data
	in situ pump surface	13.09.21 12:04	13.09.21 12:09			1	
	in situ pump bottom	13.09.21 12:10	13.09.21 12:16			13	
	water sampler	13.09.21 12:17					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-6	*in situ* CTD	13.09.21 12:50	13.09.21 13:07	54.1434	7.9061		no CTD data
	in situ pump surface	13.09.21 12:51	13.09.21 12:57			1	
	in situ pump bottom	13.09.21 12:59	13.09.21 12:59				
	water sampler	13.09.21 13:06					CH_4, DOC, POC (500 ml), DIC, TA, NS
*U-7	*in situ* CTD	14.09.21 06:50	14.09.21 07:08	54.1458	7.8904		
	in situ pump surface	14.09.21 06:52	14.09.21 06:57			1	
	in situ pump bottom	14.09.21 06:59	14.09.21 07:06			12	
	water sampler	14.09.21 07:07					CH_4, DOC, POC (500 ml), DIC, TA, NS

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude	Longitude	Water depth [m]	Remarks
U-8	*in situ* CTD	14.09.21 07:44	14.09.21 08:02	54.0712	7.8937		
	in situ pump surface	14.09.21 07:45	14.09.21 07:51			2	
	in situ pump bottom	14.09.21 07:52	14.09.21 07:59			18	
	water sampler	14.09.21 08:01					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-9	*in situ* CTD	14.09.21 08:47	14.09.21 9:05	53.9708	7.8987	2	
	in situ pump surface	14.09.21 08:48	14.09.21 08:53			17	
	in situ pump bottom	14.09.21 08:54	14.09.21 09:01				
	water sampler	14.09.21 09:04					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-10	*in situ* CTD	14.09.21 9:45	14.09.21 9:59	53.8771	7.9099		
	in situ pump surface	14.09.21 09:45	14.09.21 09:51			2	
	in situ pump bottom	14.09.21 09:52	14.09.21 09:57			8	
	water sampler	14.09.21 09:58					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-11	*in situ* CTD	14.09.21 10:51	14.09.21 11:05	53.8362	8.0911		
	in situ pump surface	14.09.21 10:52	14.09.21 10:57			2	
	in situ pump bottom	14.09.21 10:58	14.09.21 11:03			6	

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude	Longitude	Water depth [m]	Remarks
	water sampler	14.09.21 11:04					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-12	*in situ* CTD	14.09.21 12:12	14.09.21 12:26	53.7168	8.2718		no CTD data
	in situ pump surface	14.09.21 12:13	14.09.21 12:19				
	in situ pump bottom	14.09.21 12:19	14.09.21 12:25				
	water sampler	14.09.21 12:25					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-13	*in situ* CTD	14.09.21 13:15	14.09.21 13:29	53.6317	8.4544		
	in situ pump surface	14.09.21 13:16	14.09.21 13:21			2	
	in situ pump bottom	14.09.21 13:2021	14.09.21 13:27			9	
	water sampler	14.09.21 13:28					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-14	*in situ* CTD	15.09.21 06:08	15.09.21 06:23	53.6265	8.4680		
	in situ pump surface	15.09.21 06:09	15.09.21 06:15				
	in situ pump bottom	15.09.21 06:15	15.09.21 06:21				
	water sampler	15.09.21 06:2021					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-15	*in situ* CTD	15.09.21 07:10	15.09.21 07:30	53.7128	8.2908		
	in situ pump surface	15.09.21 07:12	15.09.21 07:17			2	

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude	Longitude	Water depth [m]	Remarks
	in situ pump bottom	15.09.21 07:18	15.09.21 07:23			7	
	water sampler	15.09.21 07:29					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-16	*in situ* CTD	15.09.21 08:18	15.09.21 08:33	53.8311	8.1030		
	in situ pump surface	15.09.21 08:20	15.09.21 08:25			2	
	in situ pump bottom	15.09.21 08:26	15.09.21 08:31			9	
	water sampler	15.09.21 08:32					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-17	*in situ* CTD	15.09.21 09:12	15.09.21 09:27	53.8775	7.9125		
	in situ pump surface	15.09.21 09:14	15.09.21 09:20			2	
	in situ pump bottom	15.09.21 09:20	15.09.21 09:25			11	
	water sampler	15.09.21 09:26					CH_4, TA
	2nd water sampler	15.09.21 09:29					DIC, DOC, POC (500 ml), NS
U-18	*in situ* CTD	15.09.21 10:05	15.09.21 10:20	53.9718	7.8988		
	in situ pump surface	15.09.21 10:06	15.09.21 10:12			2	
	in situ pump bottom	15.09.21 10:13	15.09.21 10:18			17	
	water sampler	15.09.21 10:19					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-19	*in situ* CTD	15.09.21 10:58	15.09.21 11:14	54.0704	7.9007		

Tab. A.7.4: Station list for Uthörn on Stern_8

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude	Longitude	Water depth [m]	Remarks
	in situ pump surface	15.09.21 10:59	15.09.21 11:04			2	
	in situ pump bottom	15.09.21 11:05	15.09.21 11:11			15	
	water sampler	15.09.21 11:13					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-20	*in situ* CTD	15.09.21 12:06	15.09.21 12:21	54.1429	7.8931		
Intercal II	*in situ* pump surface	15.09.21 12:06	15.09.21 12:12			2	
13:44 - 14:04	*in situ* pump bottom	15.09.21 12:13	15.09.21 12:19			16	
	water sampler	15.09.21 12:20					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-21	*in situ* CTD	16.09.21 5:10	16.09.21 5:25	54.1349	7.9045		
	in situ pump surface	16.09.21 05:11	16.09.21 05:16			2	
	in situ pump bottom	16.09.21 05:17	16.09.21 5:22			9	
	water sampler	16.09.21 05:24					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-2021	*in situ* CTD	16.09.21 09:23	16.09.21 09:41	53.7138	8.2813		
	in situ pump surface	16.09.21 09:24	16.09.21 09:29			2	
	in situ pump bottom	16.09.21 09:34	16.09.21 09:39			5	

Station ID	Device	Start time [UTC]	Stop time [UTC]	Latitude	Longitude	Water depth [m]	Remarks
	water sampler	16.09.21 09:40					CH_4, DOC, POC (500 ml), DIC, TA, NS
U-23	*in situ* CTD	16.09.21 10:49	16.09.21 11:05	53.6325	8.4585		no CTD data
	in situ pump surface	16.09.21 10:50	16.09.21 10:55				
	in situ pump bottom	16.09.21 11:10	16.09.21 11:15				
	water sampler	16.09.21 11:04					CH_4, DOC, POC (500 ml), DIC, TA, NS

Tab. A.7.5: Instruments on *Uthörn* on Stern_8

On the way / vertical	**Parameter(s)**	**Responsible person**	**Instrument name**	**Sensor ID** at https://dashboard.awi.de/data-ingest/index.html MOSES Sternfahrt_8 mission	**Remarks**
On the way	Longitude / Latitude	N. Anselm	D-Ship	vessel:uthoern:weather:latitude	with respective date(s)
On the way & vertical		Fischer P.	pocket FerryBox	vessel:uthoern:pfb_awi_751801	
On the way	atmospheric CH_4 and CO_2	I. Bussmann	Picarro	vessel:uthoern:picarro_awi_cfads2156	time offset of 180 sec, calibration in the lab with 5 ppm CH_4 =4.95ppm; with 500 ppm CO_2=459 ppm, with pure N_2 = -0.000 ppm CH_4; 0.576ppm CO_2
On the way	wind speed, wind direction	N. Anselm	D-Ship	vessel:uthoern:weather:true_wind_direction	with respective date(s)
On the way & vertical	dissolved CH_4 and CO_2	I. Bussmann	LosGatos #1303 with Degasser: RYT100769	#1303 Radarturm: station:radar_tower_helgoland:losgatos_awi_1303	Time off set 260 sec, degasser settings, water flow 1,67 L/min, gas 0.5 L/min, the water flow could not be regulated, with N2 gas
vertical		L. Happel	*in situ* pump #1		
vertical	pressure, temperature, salinity, oxygen, chlorophyll, turbidity	L. Happel	CTD-1420	vessel:uthoern:ctd_awi_1420	
On the way			Kongsberg Antenna	hulk (Hereon)	

Tab. A.7.6: Instruments on *Funny Girl* on Stern_8

On the way / vertical	Responsible person	Instrument name	Sensor ID at https://dashboard.awi.de/data-ingest/index.html MOSES Sternfahrt_8 mission	Remarks
On the way	H. Rust	FerryBox	http://ferrydata.hereon.de	
On the way	H. Rust	FerryBox	http://ferrydata.hereon.de	
On the way	I. Bussmann	Los Gatos #1142	vessel:uthoern:losgatos_awi_1142	

A.8 DATA MANAGEMENT

Data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

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