Christian-Albrechts-Universität zu Kiel

Cruise Report R/V Littorina, Cruise No. L01-23

Dates of Cruise: 17.02.2023 – 24.02.2023

Areas of Research: Marine Geophysics, Baltic Sea

Port Calls: Kiel – WISMAR – Kiel

Institutes: Institute of Geoscience (CAU), German Aerospace Centre (Deutsches Luft- und Raumfahrtzentrum DLR)

Chief Scientist: Dr. Jens Schneider von Deimling

Number of Scientists: 2+6

Projects: CDRmare sea4soCiety, Marispace-X

Cruise Report

This cruise report consists of 13 pages including cover:

Christian-Albrechts-Universität zu Kiel

1. Scientific crew

Name	Function	Institute
Schneider von Deimling, Jens, Dr.	Marine Geophysics Chief Scientist	Kiel University
Geersen, Jacob, Dr.	Marine Geophysics	Kiel University
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2. Research program

The research program for the L01-23 cruise was twofold. First, we wanted to test our marine hydroacoustic equipment for the ongoing projects in Marispace-X and DAM sea4soCiety. The second goal was to investigate an about 1 km long stonewall in the Bay of Mecklenburg in about 21 m water depth. The wall may represent a new archeological site that dates back to the late Paleolithic period prior to the Littorina transgression (>8600 BP). We investigated this site with the modern Autonomous Underwater Vehicle (AUV) 'Seacat' from the German Aerospace Centre (DLR). The AUV, which was built by ATLAS, uses the same NORBIT WBMS multibeam echosounder, and a similar parametric subbottom profiler, as our group at the university. Therefore, the cooperation with the DLR also provided the opportunity to exchange knowledge and practically experience concerning shipborn hydroacoustic surveying methods (CAU's system) and AUV surveying methods (DLR's system).

The stonewall was initially discovered and further surveyed during the 2021 and 2022 Geophysical Student Field Trips to the Baltic Sea which take place on the R/V ALKOR (Geersen et al., 2021; Krastel et al., 2022). These marine geophysical field courses are conducted every year by the 'Marine Geophysics and Hydroacoustic' Group. During the 2021 expedition, we identified the ~970 m long and up to 0.9 m high structure on the seafloor using our NORBIT iWBMS multibeam echosounder. One year later, in summer 2022, we groundtruthed this structure during multiple ROV dives, which revealed that it represents a stonewall. In November 2022, we realized a Littorina cruise with the scientific diving team of the CAU to test the hypothesis that the stonewall represents a Late Paleolithic archeological site.

3. Narrative of cruise with technical details

Due to a severe storm on February 17th, and exceptionally low water levels the next day, we left Kiel in the morning of February 19th. After arriving near the study site 'Blinker Hill' in the Bay of Mecklenburg in the afternoon, we started the calibration of the motion sensor and sonar systems. Unfortunately, after installing the pole on the port side of the Littorina for the first time ever, we experienced some mechanical failures, resulting in a vibrating pole while sailing. We immediately abandoned the survey, lifted the pole including the hydroacoustic instruments out of the water and sailed to the port of Wismar, where we rested for the night. On Monday noon the 20th, the DLR AUV team from the *Institute for the Protection of Maritime Infrastructures* arrived from Bremerhaven and loaded and installed the ATLAS Seacat AUV system and equipment on the Littorina.

On Tuesday, February 21st, we left the port of Wismar at 6 am. After the arrival at the survey site the 'Blinker Hügel' around 8 am we first deployed our CTD to measure the current sound velocity profile. The ATLAS 'SeaCat' AUV was then deployed starboard under slightly windy (20 knots) and wavy (1 meter) conditions. The AUV surveyed the 21-meter deep seafloor around the stonewall, with the overarching goal to image the individual stones with the highest possible resolution. The integrated inertial navigation system was initialized with a surface RTK GPS fix prior to the dive. Littorina anchored at a distance of about 350 m away from the stonewall, allowing constant communication via an underwater acoustic modem, which was deployed on the port side. The AUV was initially programmed to conduct a 3-hour autonomous acoustic mission at survey speeds between 1and 4 knots including multibeam, sidescan sonar, subbottom profiling, and still pictures. The survey lines were spaced approximately 10 m apart in west-east direction across the entire stonewall. Intermittently, the AUV was sent to the surface for GNSS re-positioning to mitigate navigation drift offsetting.

In the afternoon, the AUV was recovered for recharging the batteries and to attach a 1000 m long fiber optic umbilical for an on-the-fly video survey. A survey at less than 1 knot was planned but had to be abandoned because the AUV trim was too light. After re-trimming the AUV on deck, the stonewall was video surveyed with live data at an altitude above ground of 2 to 3.5 m. Due to the ATLAS' built-in obstacle avoidance, it was only possible to survey the seafloor from a minimum distance of 2 m.

Individual stones could be determined and inspected during the dive with and without artificial lighting, but overall visibility was poor throughout the entire survey. At 6 pm, the AUV was recovered and we sailed back to the port of Wismar, where the DLR team demobilized the AUV in the morning of Wednesday, February 22nd.

To prepare for the two remaining days of the cruise, we installed our hydroacoustic systems on the starbord side of Littorina using the usual CAU pole-mounted configuration. Using the NORBIT iWBMS multibeam echosounder in combination with a parametric subbottom profiler, we mapped the seafloor around the stonewall to extend the AUV survey farther towards the south of the Blinker Hill. The seafloor morphology and subbottom data were collected with the ultimate goal to reconstruct the ancient glacial landscape including a possible land-bridge connecting the stone wall site with the hinterland. These surveys were run between 5 and 8 knots during very calm sea conditions and little currents. Thursday at 6 am, we finally left Wismar, completed our survey of the previous days and sailed to Kiel, where we arrived at 9 pm. The hydroacoustic equipment consisting of the NORBIT iWBMS multibeam echosounder and the INNOMAR standard parametric echosounder was left on board for the subsequent mission of RV Littorina running a parametric 3D survey in the Bay of Eckernförde.

4. Scientific report and first results

AUV surveying

During the cruise we deployed the Autonomous Underwater Vehicle (AUV) from the German Aerospace Centre (DLR) which was manufactured by Atlas Elektronik (Atlas 2021, Fig. 1). The aim was to achieve a near-range super-high resolution of the seafloor around the stonewall (Kalwa 2019). The AUV offers the possibility to fly previously planned missions largely autonomously while acquiring data with the help of different sensors. The AUV is equipped with a doppler velocity log (DVL) for measuring velocity over ground, a pressure sensor for measuring depth, a sound velocity sensor, and a GNSS system for positioning at the sea surface. For underwater positioning the AUV uses a highly accurate inertial navigation system (INS, IXBLUE PHINS). The integrated INS enables the AUV to reach a high positioning accuracy meeting CEP99 (CEP: Circular Error Probability, referring to a circle in which 50% of the values occur. The radius of the circle is centered at the true position, containing the position estimate with probability of 50 %). This means that 50 % of the positions have an error lower or equal to the accuracy value. Even though today´s inertial navigation units (INS) are based on fiberoptical gyroscopes, a certain drift underwater appears and small errors in the accelerometer and gyroscope measurements accumulate over time. Due to weak or missing side accelerations, this occurs particularly when the vehicle operates on long straight tracks underwater. In addition to the Edgetech 2205 side-scan sonar on the hull, the AUV carries a camera with artificial illumination, a high-resolution Norbit WBMS multibeam echo sounder, and a parametric subbottom profiler (Tritech Seaking SBP) in its modular sensor head. The payload section at the front of the vehicle is exchangeable. This allows adaptation to different tasks an provides the possibility to integrate customized sensor applications to the AUV.

<u>Sensors and settings</u>

The side-scan data were collected at a frequency of 850 kHz. This frequency allows a resolution of 10 cm along and 4 cm across the direction of travel and a range of 75 m to each side. Swaths with a width of up to 300 m can be mapped with a lower frequency of 540 kHz. For sidescan surveying the AUV should travel at a height above ground of 8 to 10% of the selected sonar range.

The starboard sidescan sonar has the following lever arms to the INS:

- <x_offset>0.4464</x_offset>
- <y_offset>0.1853</y_offset>
- <z_offset>0.0696</z_offset>

The port sidescan sonar has the following lever arms to the INS:

- <x_offset>0.4464</x_offset>
- <y_offset>-0.1939</y_offset>
- <z_offset>0.0696</z_offset>

The downward looking NORBIT WBMS multibeam adds a third dimension to the acquired data. In addition to classical bathymetry 3-dimensional objects can be mapped in great detail.
The Multibeam has the following lever arms to the INS:

- <x_offset>2.3166</x_offset>
- <y_offset>-0.0043</y_offset>
- <z_offset>-0.0114</z_offset>

Along with the side-scan and multibeam, a parametric subbottom profiler manufactured by Tritech was employed to gather information about the composition of the seafloor, or to detect objects covered by sediment. The profiler array has a high acoustic frequency of 200kHz and a low frequency of 20 kHz
The subbottom profiler has the following lever arms to the INS:

- <x_offset>2.1306</x_offset>
- <y_offset>-0.0043</y_offset>
- <z_offset>0.0986</z_offset>

In addition to topographic images, photographic images of the seafloor can be acquired with the AUV if visibility is sufficient. A high-resolution camera system with a Sony sensor IMX249, 1/1.2" with 5.86 µm pixel size and a resolution of 1920 x 1200 pixel (WUXGA) is able to automatically take overlapping color images. Using the shutter synchronized flash diodes, the camera system is not dependent on residual light. The images are automatically georeferenced. Camera and illumination are integrated at a fixed angle on the underside of the sensor head. Oblique view images to create a spatial impression are not feasible with the AUV model used. Implementation of an automatic exposure control adaptive to illumination and visibility conditions underwater would surely bring an advantage and increase the quality of the images.
The camera has the following lever arms to the INS:

- <x_offset>1.9666</x_offset>
- <y_offset>-0.0043</y_offset>
- <z_offset>0.0231</z_offset>

<u>Mission planning and navigation</u>
A slightly customized version of the Java based Neptus software from the University of Porto - Faculty of Engineering Laboratory for Underwater Systems and Technology (LSTS) (Dias 2005, Dias 2006) is used for mission planning (Fig. 2). With this software, waypoints can be intuitively selected on a nautical chart or on georeferenced satellite images. The waypoints are then merged to a mission sequence. For each distance between two waypoints, parameters such as depth, speed and required sensors can be specified. The required parameters can be selected for each sensor, for example the opening angle of the multibeam echosounder. In addition, with just a few clicks, rectangular areas of any size can be covered by lines evenly spaced next to each other or so-called Cross Hatch Patterns.

The latter are patterns in which an area is first covered by evenly spaced lines in one direction and then again at an angle of 90°. This type of pattern ensures that objects on the seafloor are captured from all sides.

The coordinates and other mission parameters are exported from Neptus into a document that has similarities to machine code. This document is passed to the SeaCat's control unit over Ethernet or Wifi. Its state-of-the-art positioning sensors enable the SeaCat to determine its current position, speed and orientation at any time with high accuracy. With this information in conjunction with a micron scanning sonar for obstacle detection, the SeaCat can independently react to unforeseen environmental conditions and disturbances such as currents (up to 3 kn), rising or falling seabed and unknown objects or structures on the seafloor.

To increase the navigation accuracy the software DelphINS is used to optimize the data by running a forward/backward process. The position at any point during a submerged mission is calculated forward from the point of submersion and backward from the point of surfacing using data from both GPS and IMU. This way the navigation solution can be improved by a factor of up to 2 in a best-case scenario. Sidescan, multibeam echosounder and sub-bottom profiler data are merged with the postprocessed navigation data and the exact positions of the sensors in relation to the IMU inside the AUV body to improve georeferencing.

Figure 1: Recovery of the Atlas SeaCat during this cruise in the Baltic Sea onboard the RV Littorina using a hydraulic crane and a specifically designed recovery hook. Launch and recovery by crane is possible up to sea state 3.

The AUV was programmed to run two acoustic surveys
-first with multibeam with line spacing as narrow as 10 meter with the following values:

⊟ Location	
Location	54N10.140548, 11E...
Z	18,0
Z-Units	DEPTH
⊟ Rows specific ...	
Length	1100,0
Width	150,0
Horizontal Alterna...	100
Horizontal Step	10,0
Bearing	82,0
Cross Angle	0,0
Speed	4.00 kn
Curve Offset	15,0
Square Curve	☑
First Curve Right	☑
Payload Shadow	☐
Shadow Size	5
⊟ Obstacle Avoi...	
Active	☐
⊟ External Control	
Active	☐
⊟ Acoms	
Auto Send	☑
Repetitions	1
In Curves Only	☐
Interval	1
⊟ Edgetech 2205	
Active	☑
Log On Lines Only	☑
Opmode	HF
Gain	100
Range	50
⊟ Norbit WBMS	
Active	☑
Log On Lines Only	☑
Angle	120
Opmode	Bathy
Gate Mode	Depth
Upper Gate	1
Lower Gate	20
Beam Distribution	Equidistant

⊟ Tritech Subbot...	
Active	☑
Range	10
LF Gain	50
LF Threshold	50
LF Contrast	50
HF Gain	50
HF Threshold	50
HF Contrast	50
⊟ Camera	
Active	☑
Framerate	4
Show Video	☑
Gain	0
Image Format	JPEG
Image Compression	AUTO
Shutter Time	0
Strobe	☐
Strobe Intensity	0

Figure. 2a: Settings for the AUV multibeam survey

-second sidescan mission with line spacing of 50 meter with the following values:

⊟ Location	
Location	54N10.133294, 11E...
Z	16,0
Z-Units	DEPTH
⊟ Rows specific ...	
Length	1100,0
Width	150,0
Horizontal Alterna...	100
Horizontal Step	50,0
Bearing	82,0
Cross Angle	0,0
Speed	4.00 kn
Curve Offset	15,0
Square Curve	☑
First Curve Right	☑
Payload Shadow	☑
Shadow Size	30
⊟ Obstacle Avoi...	
Active	☐
⊟ External Control	
Active	☐
⊟ Acoms	
Auto Send	☑
Repetitions	1
In Curves Only	☐
Interval	1
⊟ Edgetech 2205	
Active	☑
Log On Lines Only	☑
Opmode	HF
Gain	100
Range	50
⊟ Norbit WBMS	
Active	☑
Log On Lines Only	☑
Angle	120
Opmode	Bathy
Gate Mode	Depth
Upper Gate	1
Lower Gate	20
Beam Distribution	Equidistant

⊟ Tritech Subbot...	
Active	☑
Range	10
LF Gain	50
LF Threshold	50
LF Contrast	50
HF Gain	50
HF Threshold	50
HF Contrast	50
⊟ Camera	
Active	☐
Framerate	4
Show Video	☐
Gain	25
Image Format	JPEG
Image Compression	NO
Shutter Time	0
Strobe	☐
Strobe Intensity	0

Figure 2b: Settings for the AUV sidescan survey.

Results from the AUV survey

First unprocessed multibeam and sidescan data from the AUV dive image the stonewall in high resolution. Individual stones can be resolved and separated. It becomes obvious that the western end of the wall is formed by an extraordinary large stone with a diameter >3 m (Fig. 3a). While the vast majority of stones are below 50 cm in diameter, a number of stones exceed 2-3 m. Often the strike direction of the wall changes at these large boulders. In both, multibeam (Fig. 3a), and sidescan data (Fig. 3b) we found several anomalies that might guide future diving campaigns to find further evidence of anthropogenic activities.

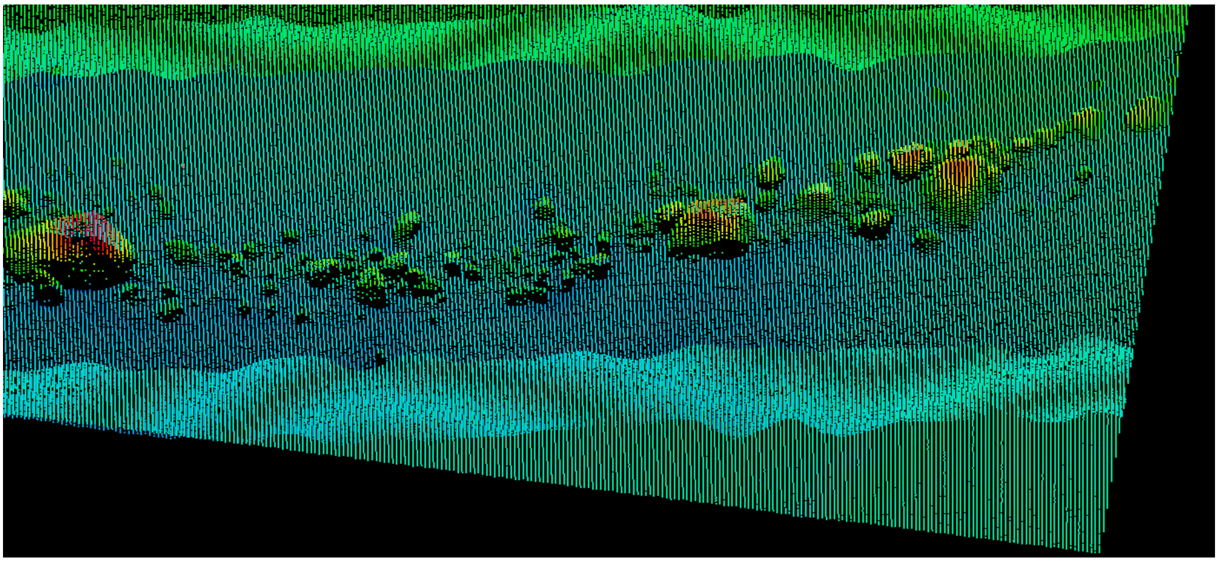

Figure 3a: Point cloud presentation of the stone wall recorded by the AUV Seacat with its in-built NORBIT WBMS multibeam echosounder. The stone in the very left of the image has a diameter of approximately 3.5 meters.

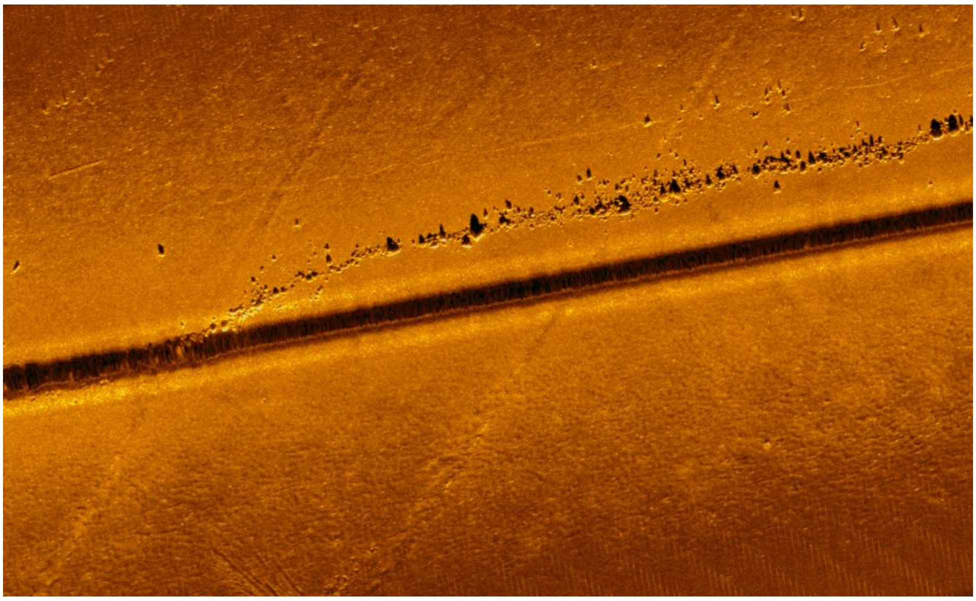

Figure 3b: Edgetech 2205 side-scan sonar record, the westerly end of the wall is obscured due to near nadir effects.

Ship-born Multibeam Echosounding

To extend the AUV survey area we installed the NORBIT shallow water iWBMS multibeam echosounder from the Marine and Hydroacoustic working group from CAU (https://www.marinegeophysik.ifg.uni-kiel.de/) via our massive side pole mounting starboard on the RV Littorina. The NORBIT iWBMS chirp multibeam system was operated with a protoype firmware kindly provided by NORBIT allowing for ultra-high density mode, multispectral records, and multidetect soundings. The MBES is coupled with an Applanix Wavemaster IMU and the dual Antenna GPS positions of the primary antenna is projected into the sonar head itself and written to s7k-files. The lever arms between MBES and the MRU are fixed, and we set the offsets between the primary antenna and the MBES flange (Table 1). We fully calibrated our Applanix IMU and the multibeam echosounder (Fig. 4) to finally achieve a resolution of a few centimeters in range.

Table 1: Installation offsets for the CAU Pole required for IMU calibration

Offset from Flange to prim. Antenna	Offset [m]
+Fwd	0.685
+Stb	-0,145
+Down	4,987

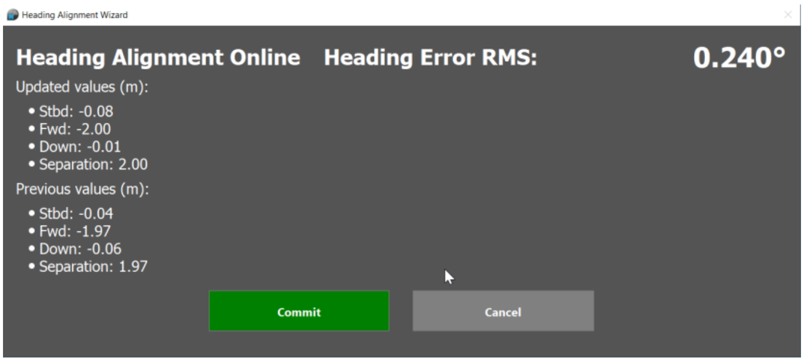

Figure. 4: Heading alignment calculation after running figures of eights.

To keep the data consistent and backscatter comparable throughout the survey we fixed the pulse length and bandwidth, gains, and filter setting in the beginning of each working area as recommended (Lamarche and Lurton , 2018). We used two modes, one with snippets and the last lines across the wall with NORBITs ultra high density mode.

An AML C-keel velocity probe is permanently mounted next to the transducer head in the system and measures c-keel on the fly. Surface sound velocity was found constant throughout the survey due to a very well mixed water column. Nevertheless, we also conducted CTD casts with an AML MINOS-X probe to prevent the AUV from flying within a halocline. The CTD cast on the 21st of February showed only little stratification at depth. Though, significant stratification in Mecklenburg Bay occurred with a denser, more saline bottom water below 15 meter water depth.

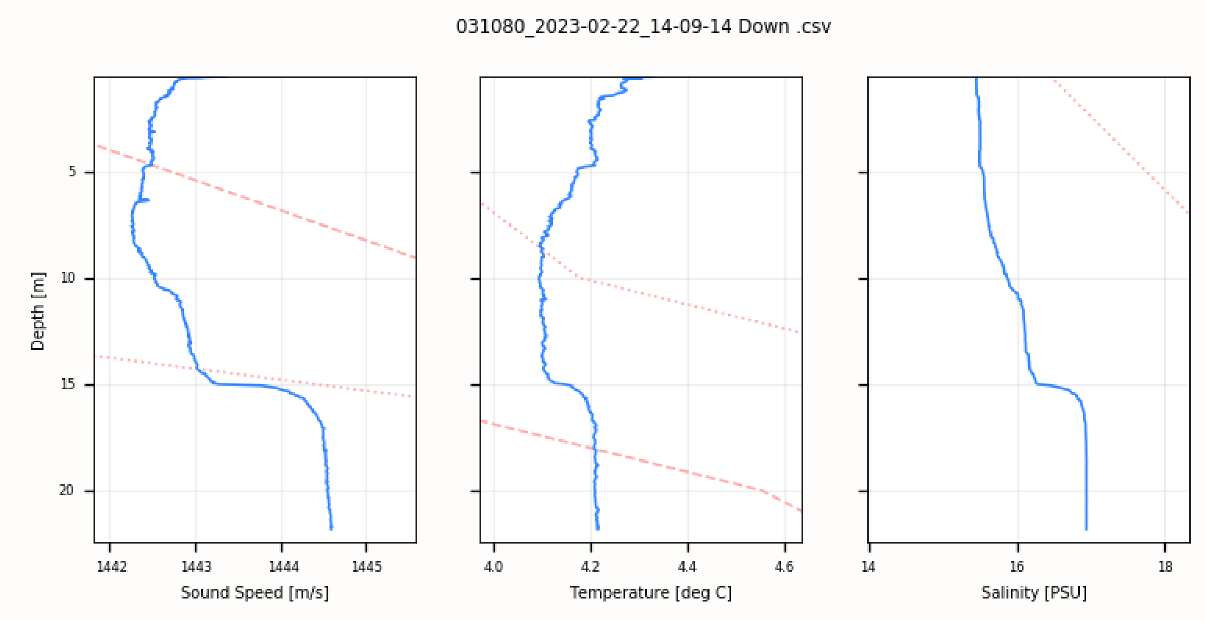

Figure. 5: Sound velocity (left), temperature (center), and salinity (right) profiles from the CTD cast on the 22th of February 2023 in the Bay of Mecklenburg.

We linked the native NORBIT recording software, the GPS information from approximately 15-20 satellites on each antenna, and corrections kindly provided by Axio-Net via the NTRIP protocol and Mountpoint #15 (GPS + GLONASS, caution, this time auto-trans-GCG2016 was chosen for on-the-fly tidal reduction) using the on board internet. With this we achieved GPS RTK FIX status most of the times with accuracies ranging between 2 and 4 cm for positioning and height. The NORBIT offset were determined earlier and we sailed figures of eights to calibrate the IMU system succeeding after a few minutes. After full calibration, the system performed excellently and we extended the existing multibeam grid from the 'Blinker Hill' further towards the south in order to analyze a possible former land connection between the Blinker Hill and the hinterland.

Parametric Sub bottom Echosounding

Parallel to the multibeam system, we installed an INNOMAR SES2000 standard. The parametric echosounder device operates with two primary frequencies centered around 100 kHz to form the parametric 'difference frequency' with a corresponding wavelength of 0.1 m (approximated by the ratio of 1,500 m/s sound velocity and 15 kHz signal). The acoustic array generates a narrow ±1.8°, 3 dB transmit beam for primary and secondary frequencies, whereas the 3 dB receive beam width for the low secondary frequency is ±12.3°.

The advantage of a parametric system is that a small array is sufficient to generate narrow low-frequency beams having high horizontal and vertical resolution and very little side lobe cross-talk. For further technical information, the reader is referred to Wunderlich (2007). The given motion was compensated by a Seatex motion sensor installed right next to the transducer on the pole frame, and GPS was fed from the Applanix Wavemaster MRU. The INNOMAR has a forward lever arm offset of about 43 cm, that was not yet corrected, because no heading is fed into the system. Though, positioning of the soundings can be assumed to be very accurate and should be identical to the MBES .s7k positionings. Note that the RTK-guided Applanix positions are projected into the NORBIT sonar head.

Transmit and receive cycles between the multibeam and the Innomar sub-bottom profiling systems were successfully triggered by the NORBIT acting as master and the INNOMAR being the slave (Fig. 6). Though, the trigger mechanism failed when operating the INNOMAR in its multifrequency mode, even though 'the number of pings for one sync pulse' was increased accordingly (Fig. 6). The device was running without problems and the data will be suitable for paleo-landscape reconstruction.

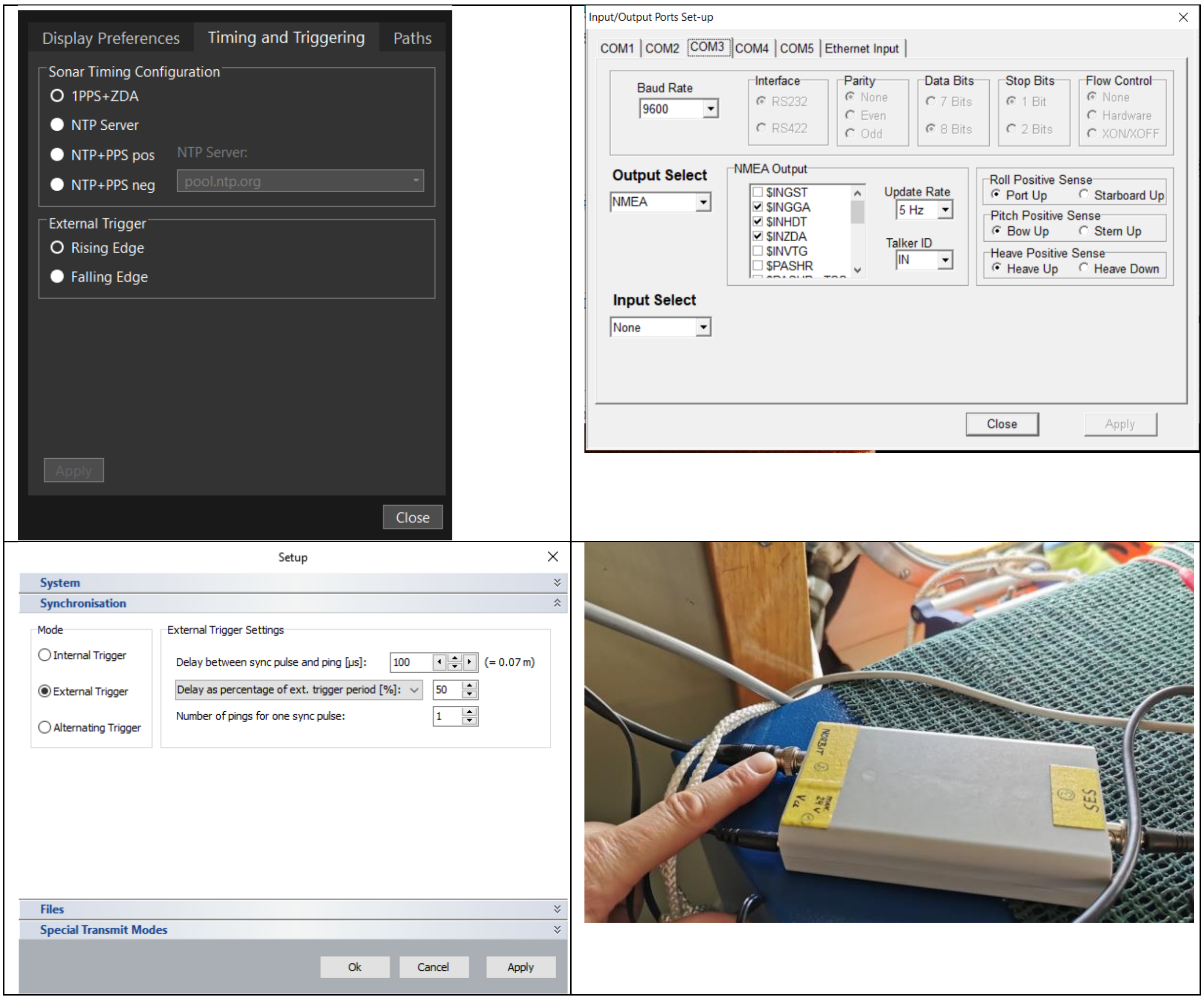

Figure. 6: Integration of NORBIT, Applanix, and INNOMAR with Triggerbox and GGA Output from Applanix to INNOMAR to allow RTK-GPS accuracy for the INNOMAR transducer position.

5. Acknowledgements

We very much appreciate the great support of captain Danny Flindt and his crew, DLR's AUV team, their friendly communication, and expert knowledge. It was simply a pleasure to work with the different teams on board of RV Littorina.

6. Appendix

A. Map

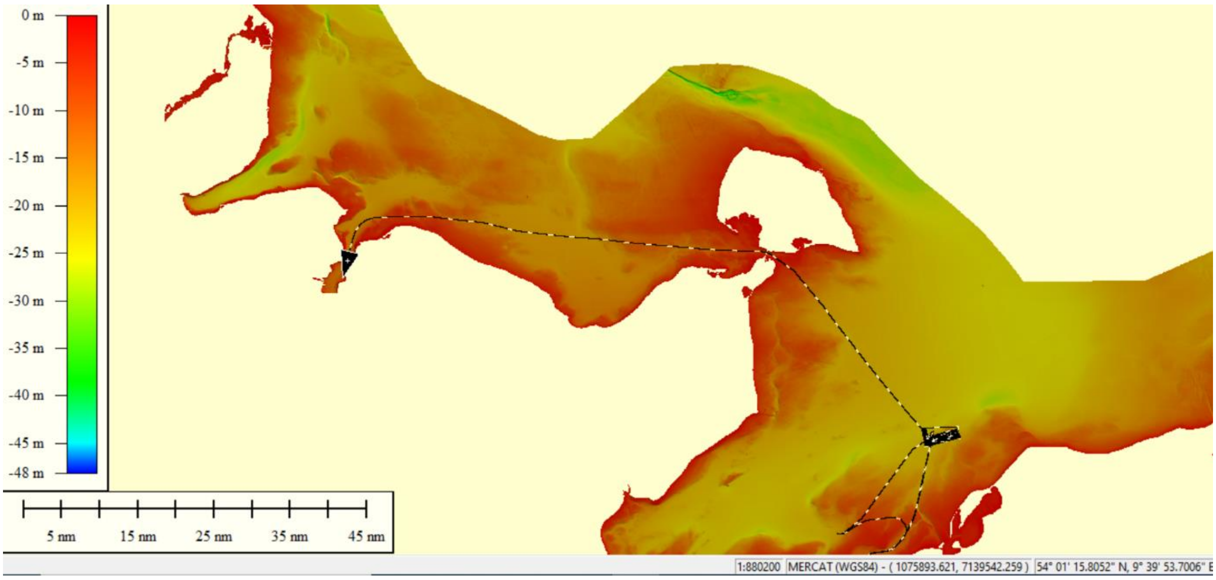

Figure. A1: L0123 cruise trackplot from Kiel to Wismar and back to Kiel harbor.

7. References

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