HYDRO 2024 ROSTOCK

Conference Handbook

Sea you ABOVE and BELOW


Sea you
ABOVE and
BELOW

Welcome to HYDRO 2024

by: **Sabine Müller** and **Thomas Dehling** – Organising committee

The hydrographic world is gathering again in Rostock-Warnemünde already for the third time after 2010 and 2016. This means that we have established a tradition. Well, you may think that this is going to boring, but on the contrary, the participants in 2010 and 2016 emphasised the advantages of this cute and somewhat remote place. In particular the beautiful location, the surroundings, the proximity of all the conference events and the very special atmosphere generated by all of the participants.
And you are all here, either returning or for the first time, and we are delighted to welcome you.

After more than one year of intensive work, coordination, planning, decision-making and revision, we hope that everything is now in place and ready for another sequence in the series of HYDRO conferences. We would like to thank all those who have supported us, all the partners, colleagues and friends in the hydrographic field. The sponsors, exhibitors and speakers are the key to our success. The exhibition was once again fully booked with 58 exhibitors on 49 stands. Several user workshops and demonstrations of various hydrographic equipment await you.
But what is a conference without ambitious and interesting presentations? More than 50 papers on trendy topics have been accepted by the paper committee. Additionally, we have included two sessions with a broader scope in cooperation with the Rostock Ocean Convention.
So HYDRO 2024 participants can expect a high-quality conference programme.
The scene is set. Now it is up to you. We wish you inspiring talks and discussions, enjoyable events and new or renewed friendships within our hydrographic family.

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Welcome by the DHyG

by: **Thomas Dehling** and **Patrick Westfeld** – DHyG chairs

A very warm welcome to you here in Rostock-Warnemünde. Situated directly on the coast of the Baltic Sea, Rostock is the centre of hydrography in Germany. It is the home base of the Federal Hydrographic Office, research institutes, companies and other players in the hydrographic field. And for this week, Rostock will once again be the centre of hydrography worldwide. From the 5th to 7th November 2024, our German Hydrographic Society, the DHyG, is proud to host this international event in the beautiful resort of Hohe Düne. We are expecting more than 300 participants. 58 exhibitors will provide their latest developments. Presentations in 17 sessions will cover the emerging topics ranging from the »optical hydrography« to »autonomy«, covering strategic, practical and technical issues. All this will be accompanied by workshops, boat demos and open ships.

It is a great pleasure to welcome high-ranking representatives of the German government in the form of Parliamentary Undersecretary Daniela Kluckert (Federal Ministry for Digital and Transport) and the President of the Federal Maritime and Hydrographic Agency as well as the highest international representative of hydrography, the Secretary General of the International Hydrographic Organization (IHO).

A very important factor of this event is to attract young people to this wonderful profession, to support and promote young hydrographers and to raise the visibility of our hydrographic community. Student prizes will be awarded to outstanding papers and presentations, and the exhibition will be open to school kids on Wednesday.

Whether you are exhibiting your products, presenting a paper or are a regular attendee, the HYDRO conferences provide an excellent platform to exchange knowledge and experience, build and improve cooperation and friendship, recruit new personnel, promote the importance of our hydrographic business to a wider audience and, last but not least, enjoy the hydrographic community.

We'd like to wish you a lot of fruitful discussions with colleagues and friends from all over the world and a pleasant stay here in Rostock-Warnemünde.

The German Hydrographic Society

The »Deutsche Hydrographische Gesellschaft« (DHyG) is proud to host the HYDRO 2024. This is a good opportunity to give a short overview of the society.

The DHyG was founded 40 years ago in 1984 and is an association of individuals, companies, agencies and institutes involved in the broad spectrum of hydrography. The members are mainly from Germany, but there are several members from Austria and other neighbouring countries and quite a few corporate members from abroad.

The society's main goals are:

- To promote next generation hydrographers and students;
- To foster the practical and scientific hydrography;
- To inform the public and politicians about the importance and fields of our profession;
- To cooperate internationally.

Once a year a national conference is being organised, called »Hydrographentag«. It provides a forum of professional exchange of first-hand information and is accompanied by an exhibition and a social programme.

The DHyG publication »Journal of Applied Hydrography – Hydrographische Nachrichten« (HN) is the only hydrographic magazine in German. Sixteen years ago, the journal has had a complete redesign and become very successful. This success is mainly related to the editor-in-chief Lars Schiller and the high quality of the articles.

As hydrography is largely international and the journal has become well-known beyond the limits of German-speaking countries, you will find another completely English edition at the HYDRO 2024.

The advantages of a DHyG membership include:

- Printed version of the Journal of Applied Hydrography, free of charge;
- Students pay no membership fee;
- Reduced prices for conferences;
- Contact to and exchange with other professionals;
- DHyG Student Excellence Award.

Conference programme at a glance

Tuesday, 5th November 2024

Wednesday, 6th November 2024

Thursday, 7th November 2024

List of authors and presenters

Opening Ceremony

Keynote

K1	*Xavier Lurton*	Backscatter measurements by hydrographic multibeam echo sounders

Backscatter measurements by hydrographic multibeam echo sounders

by: **Xavier Lurton**[1]

Keywords: backscatter | multibeam echo sounder | hydrography | calibration

While it has been recognised for long that the measurement of acoustic backscatter level can provide information about the seabed type and some of its properties, this capability has been little used up to now in the framework of hydrography, contrarily to several other fields of activity (geoscience, biology and habitat mapping, industry, defence). Acoustic backscatter is a more complicated notion than bathymetry, in the sense that its level depends both on the seabed properties but also on the sonar measurement conditions (incidence angle and frequency). Known for long, the measurement principles of seabed backscatter by sonar imply to control the source and echo absolute levels, the signal footprint extent and angle, and the transmission loss in the water column; all these features are available in multibeam echo sounders used in hydrography, possibly completed by some dedicated calibration. Technically speaking, bathymetry and reflectivity measurements share many common features, both in the echo sounder input data, operation, processing and results. For example, the backscatter measurement implies acquisition of a good-quality bathymetry data and an accurate knowledge of the water column properties; both points are obvious key points in the current bathymetry standards. The optimisation of the operational requirements for bathymetry and reflectivity may be slightly different, however they are globally compatible and practical survey strategies (coverage, spatial sampling, data quality) can satisfy both expectations in most cases.

A particular practical difficulty is the measurement of reliable levels of backscatter, implying the calibration of the acoustical intensity recorded by the echo sounder. A backscatter measurement provides ideally an absolute value, typically usable for seabed characterisation and mapping, in an exploration perspective. However, it can also be limited to a comparative approach, for example for the monitoring of a given area, by using one same system sufficiently stable while not absolutely calibrated. The process of absolute calibration is a complicated one in the case of MBES; direct measurements on a reference target, akin to what is done for single-beam systems in fisheries applications, are possible but hardly practical. The concept of seafloor reference areas with controlled properties looks today more promising. The unification with the classical protocols of bathymetry calibration currently used in hydrography is still to be developed.

The complementarity of acoustical backscatter measurements with classical hydrographic bathymetry is now demonstrated, in terms of needs as well as compatibility of sonar tools and methods. A formalisation still has to be conducted; in this respect the incorporation of backscatter measurements in the new version of the S-44 IHO document is a first encouraging achievement; new steps are expected to be discussed and initiated along this conference.

1: Consultant in Underwater Acoustics, France

Session 1A

Opening session

1A1	*Jacob Geersen et al.*	A submerged stone age hunting architecture from the Western Baltic Sea
1A2	*Natalie Cornish*	Nippon Foundation – GEBCO Seabed 2030 and the International Bathymetric Chart of the Southern Ocean
1A3	*Holger Klindt*	Marine critical infrastructure – protecting the unseen

A submerged stone age hunting architecture from the Western Baltic Sea

by: **Jacob Geersen**[1], Marcel Bradtmöller[2], Jens Schneider von Deimling[3], Peter Feldens[1], Jens Auer[4], Harald Lübke[5]

Keywords: archaeology | Western Baltic Sea

After the retreat of the Weichselian glaciers, Northern Europe was populated by highly mobile hunter-gatherer groups. Due to their non-sedentary life style, traces of these societies are difficult to find, hampering our understanding of their life. Some remote basins of the Western Baltic Sea, however, only drowned in the Holocene, and may therefore preserve man-made architectures from these times. In 2021, we discovered an about 1 km long stonewall running near a shoreline of a sunken lake in the Bay of Mecklenburg, Germany. The wall is located in 21 m water depth and composed of about 1700 stones, predominantly less than 1 m in height, placed side by side in a way that argues against a natural origin. Combining shipborne and autonomous underwater vehicle (AUV) hydroacoustic data, optical images, sediment core data and archaeological expertise, we suggested that the wall represents a Late Pleistocene or Early Holocene drive lane for hunting reindeer. Ranging among the oldest hunting structures on Earth and the largest Stone Age structures in Europe, the Blinkerwall will become important for understanding the traditions, subsistence strategies, mobility patterns, hunting strategies and territorial developments of the first hunter-gatherers that followed on the ice. It may also pave the way for the discovery of other submerged Stone Age megastructures in some of the remote basins of the Western Baltic Sea.

1: Leibniz Institute for Baltic Sea Research (IOW), Germany
2: Rostock University, Germany
3: Kiel University, Germany
4: Landesamt für Kultur und Denkmalpflege Mecklenburg-Vorpommern, Germany
5: Leibniz Centre for Archaeology (LEIZA), Germany

Nippon Foundation – GEBCO Seabed 2030 and the International Bathymetric Chart of the Southern Ocean

by: **Natalie Cornish**[1]

Keywords: bathymetry | mapping | regional | Antarctica

Seabed 2030 is a flagship programme of the UN Ocean Decade of Ocean Science for Sustainable Development and has rapidly advanced the General Bathymetric Chart of the Oceans (GEBCO) in recent years. Since 2017, global measured bathymetric coverage has increased from approximately 6 % to over 25 % today. Four regional centres (Arctic and North Pacific, Atlantic and Indian Ocean, South and West Pacific Ocean, and Southern Ocean and adjacent waters) act as stewards for bathymetric data compilation, management and coordination. The Southern Ocean Regional Centre is responsible for collating bathymetry in waters south of 50°S and coordinates the International Bathymetric Chart of the Southern Ocean (IBCSO). The IBCSO database consist of more than 25 billion data points from more than one thousand multibeam and single-beam data sets. Both modern as well as traditional bathymetric measurements, such as digitised soundings from nautical charts, feed into the final product. In total, IBCSO contains data sets from 88 institutions across 22 countries. Handling that volume of data is only possible thanks to meticulously curated databases and modern workflows streamlined for big data. Today, IBCSO is gridded on the AWI high-performance computer Albedo. With this infrastructure, the 100-metre horizontal resolution IBCSO grid is computed in a matter of hours. With the workflows optimised, the Seabed 2030 Southern Ocean Regional Centre improves IBCSO's usability by providing annual releases in autumn, in time for the preparation of the Antarctic season. Furthermore, we aim to maximise the extent of globally mapped seafloors by carrying out regular expeditions in unchartered waters.

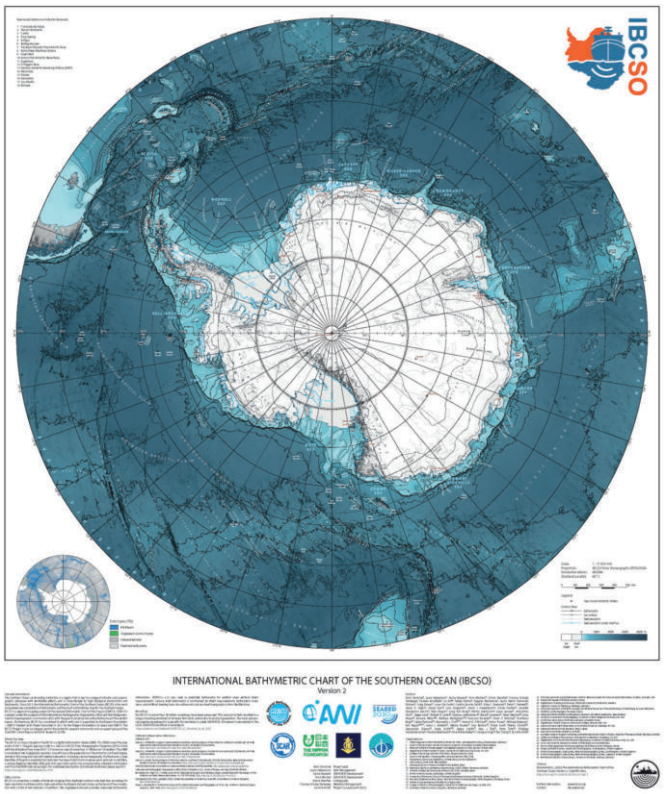


Figure: The latest release (version 2) of the International Bathymetric Chart of the Southern Ocean

1: Alfred Wegener Institute, Helmholtz-Zentrum für Polar- und Meeresforschung, Germany

Marine critical infrastructure – protecting the unseen

by: **Holger Klindt**[1]

Keywords: maritime critical infrastructures | underwater surveillance | deterrence and protection | threat and risk analysis | recognised operational picture

With the recent series of events just a few miles off the eastern coast of Bornholm in September 2022, global awareness has risen dramatically regarding the new threats imposed on maritime infrastructures off our coasts and at the High Seas. Although often been overlooked by the public, maritime underwater infrastructures play a major role in our societies, providing the communication backbone for the global digital community, transporting fossil fuels like oil and gas from the production sites to the consumer markets, or the provision of offshore produced electric energy or hydrogen to the national grids. It goes without saying, that major disruptions of these services can easily destabilise whole societies and bring normal public life to a halt. It thus doesn't come as a surprise, that the security of such maritime infrastructures, above and below the ocean surface has come into focus.

Today, intense national and international efforts are underway to establish and maintain surveillance and protection for the multitude of different installations at sea. Many of those are, as a whole or in parts located underwater and require particular attention when gapless 24/7 surveillance is at stake. At the same time, latest events show, that such attack scenarios often use a combination of covert approach elements in more than one spacial domain, including aerial, surface and underwater elements. This paper does address the needs and challenges for a robust and reliable deterrence and protection setup for endangered maritime infrastructures under the sea. It will take an holistic approach to identify the major elements and their interdependencies, including such as to:

- understand the threat landscape – analysis of potential attack strategies and vectors;
- who is who – the need for an all-encompassing recognised operational picture;
- how much are we prepared to expend – constraints in operational security;
- what is the mandate and who's going to carry it – the legal framework;
- how to protect the protector – prevent sabotage and counter strategies,

A short excursion into the world of modern technical solutions concludes the paper with a brief overview of electro-optical, acoustic and other oceanographic sensors and platforms. Existing industrial solutions range from the design and construction of more robust and resilient infrastructures to advanced monitoring, tracking and pursuance technologies. Many promising industrial solutions are available, such as autonomous surface and underwater vehicles, advanced marine sensors, and powerful AI-based data analytics. Others are still subject of intense research activities at various research institutions, like distributed acoustic sensing networks.

The paper concludes that, beyond any technical progress however, a successful protection of critical infrastructures can only be established and maintained in a joint and synchronized effort of all involved public as well as private stakeholders. This requires a trustful cooperation and exchange of available domain information. At the same time, continuous ongoing investment in research and innovation efforts is required to keep pace with creative attackers.

1: German Association for Marine Technology (GMT)

Session 2A

Student session

2A1	*Kilian Martlage et al.*	Bathymetry estimation using airborne remote sensing RGB image data
2A2	*Mona Reithmeier et al.*	Mapping and monitoring the global coast
2A3	*Annika Walter*	Global lakes and reservoirs – An investigation to which extent dynamic water body shapes have an impact on the estimates of the total water storage derived from GRACE

Bathymetry estimation using airborne remote sensing RGB image data

by: Ann-Christin Hackstein[1], **Kilian Martlage**[1], Tobias Schmid[1], Martin Kumm[1], Jens Wellhausen[1]

Keywords: optical hydrography | remote sensing | optical-bathymetry estimation | image-based wave detection

The intertidal zones of the mudflats and estuaries are highly spatial and temporal variable natural environments. Due to tidal dynamics, sediment is shifted and the bathymetry changes permanently. To survey the actual situation and understand the process of change is very important for security in nautical matters, coastal protection or other scientific questions. Acoustic in-situ measurements can provide data with high accuracy on transects, but are limited both in temporal coverage due to high costs and in spatial coverage due to limited accessibility. In this paper, a technique for assessing bathymetry based on airborne remote sensing RGB image data is presented. Because of the fact that many coastal waters in the regions of interest have a high diffuse attenuation coefficient, LiDAR-based sensor system are not suitable for this task. The approach to this solution is to investigate colour gradients of the water surface as well as the structure of surface waves. The RGB data are analysed for the colourmetric features brightness and intensity discriminated with the help of a k-means classifier. It is investigated whether similar optical properties are present in areas with the same water depth. In addition to the colourmetric parameters, surface wave properties are extracted from the image data and used to estimate the bathymetry. The dispersion relationship relates the wavelength of the surface waves to the water depth in the area of the shallow water waves. For this analysis, the image data is segmented and converted into the frequency domain using the two-dimensional Fast Fourier Transformation (2D-FFT). This multidimensional approach enables a finer differentiation of the sea surface and contributes to a more accurate area mapping. The georeferenced aerial image data offers the possibility to identify and document changes such as sediment shifts and the occurrence of sandbanks and subsequently.
A field campaign was conducted over the German Wadden Sea between the barrier island Langeoog and Spiekeroog (Schillbalje). In the following figure, an example of segmented image data using a k-means classifier is compared with bathymetric data from the Federal Maritime and Hydrographic Agency (BSH). The segmented image show regions of similar colourmetric and wave properties and the correlation to the bathymetric data is clearly visible. This method is intended to provide an initial overview of potential changes in the depth structure of the study area. In the very dynamic waters of the Wadden Sea, sediment shifts during storm surges can quickly change the depth conditions. Aircraft-based remote sensing using RGB aerial image data therefore has the potential to form a complementary measurement platform to conventional in-situ methods.

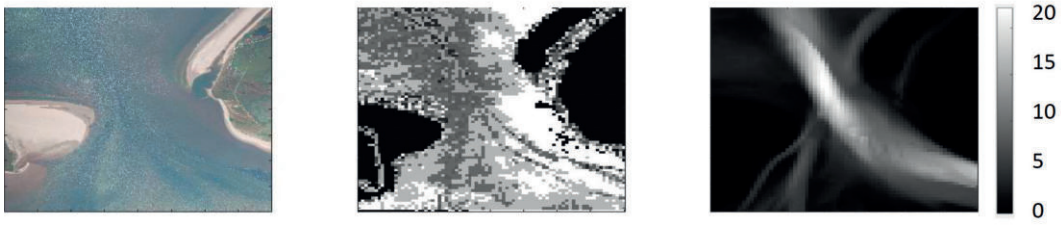


Figure: Airborne RGB-image over Langeoog and Spiekeroog (left); k-means classified image by brightness, intensity, wave frequency, wave amplitude and presence of harmonic series (middle); bathymetry between Langeoog and Spiekeroog from the BSH (right)

1: Jade University of Applied Sciences Wilhelmshaven/Oldenburg/Elsfleth, Germany

Mapping and monitoring the global coast

by: **Mona Reithmeier**[1], Knut Hartmann[1], George Spoelstra[2], Etiënne Kras[3], Thomas Heege[1]

Keywords: satellite-derived bathymetry | global coastal bathymetry | shallow water | coastal monitoring

As the United Nations marks the decade from 2021 to 2030 as the Ocean Decade, there is a pressing need to enhance our understanding and management of the world's oceans. This initiative aims to foster scientific research and technological innovations that nurture a sustainable relationship between societies and the vast marine ecosystems. The conservation and sustainable management of coastal zones are paramount in these efforts due to their dynamic and critical ecosystems, where significant challenges posed by climate change, such as rising sea levels and increased storm intensity, demand innovative monitoring and management strategies. One decisive technological advancement in this context is satellite-derived bathymetry (SDB). SDB has emerged as a transformative technique for understanding and managing coastal areas by providing accurate measurements of underwater topography. This method utilises data collected by earth observation (EO) satellites, including the European Union's Copernicus program and other high frequency observation satellites, like those operated by Planet and Maxar. The comprehensive data collected through these instruments play a crucial role in the global effort to monitor and manage coastal areas by offering detailed insights into coastal morphology, habitats and the various factors impacting them.

EO technologies facilitate continuous, global scale observations across vast and sometimes unreachable areas. Moreover, the accessibility of this data democratises the monitoring process, allowing regions with limited resources to benefit from advancements in EO technologies without substantial investments. The historical archives of EO data also establish comprehensive baselines, facilitating the analysis of long term environmental changes and aiding in the formulation of informed management strategies. This global and temporal coverage is critical for fostering international collaboration on coastal conservation by providing a unified data set for shared ecosystems. The immense potential of EO has attracted the attention of various stakeholders, including the European Commission, which has contracted Mercator Ocean International to partner with EOMAP (lead), Deltares and GGSgc to provide a global coastal bathymetry data set. This data set will ultimately be made available to the public in a 100-m spatial resolution grid. This presentation will describe the technologies involved in creating this data set. These range from the inversion of the radiative transfer equation and wave kinematics to active LiDAR measurements and will present initial results and findings. Knowing the spatial limitations of a 100-m grid, we will also demonstrate the value of high-frequent and high-resolution SDB grids for monitoring coastal zones with the same techniques.

1: EOMAP, Germany
2: GGSgc, The Netherlands
3: Deltares, The Netherlands

Global lakes and reservoirs – An investigation to which extent dynamic water body shapes have an impact on the estimates of the total water storage derived from GRACE

by: **Annika Walter**[1]

Keywords: surface water bodies | GRACE | dynamic surface area extent | forward modelling | freshwater resources

The satellite mission Gravity Recovery and Climate Experiment (GRACE) measures gravity field variations caused by mass redistributions across the atmosphere, the continents and the oceans. Since the redistributions over the continents are linked to changes in the total water storage (TWS), expressed as equivalent water heights (EWH), the observations can be used to quantitatively assess global freshwater variations, which is of great social importance in times of increasingly scarce water resources. If the focus of interest refers to groundwater related variations explicitly, all other storage compartments (here: surface waters) have to be reduced from the GRACE observations. Therefore, the retrieved signal has to be decomposed into its individual components. To achieve this, the water volume can be estimated by forward modelling satellite altimetry and remote sensing data, considering both static and dynamic surface expansions. It will be discussed, that using a dynamic instead of a static surface area extent (1) will change the equivalent water height values in a magnitude between 0.006 cm and 0.243 cm, (2) causes the largest deviation for the Lake Mead and (3) that the question whether a dynamic or a static water body shape should be considered is driven by the interaction of various parameters.

1: HafenCity University Hamburg, Germany

Session 3A

Optical hydrography I

3A1	*Charles de Jongh*	Airborne LiDAR bathymetry – advantages and challenges
3A2	*David Mader et al.*	Full-waveform stacking techniques applied to coastal LiDAR bathymetry data
3A3	*Gottfried Mandlburger*	Optical hydrography – the DGPF's contribution to mapping and monitoring inland coastal waters
3A4	*Niels Fuchs et al.*	Bathymetry of sea ice melt ponds reconstructed from aerial photographs using shallow water photogrammetry

Airborne LiDAR bathymetry – advantages and challenges

by: **Charles de Jongh**[1]

Keywords: Airborne LiDAR Bathymetry

This presentation will focus on airborne LiDAR bathymetry (ALB) as a hydrographic surveying technique. It will explore the technology, the required equipment as well as the advantages and challenges. Furthermore, a number of interesting use cases will be highlighted.

ALB is a surveying technique that utilises laser light to measure water depths from airborne platforms. ALB offers distinct advantages in mapping shallow water bodies, including high accuracy, rapid data acquisition and cost-effectiveness.

ALB's unique capacity to map both underwater depths and topographic elevations on land provides a comprehensive view of the coastal zone. As such, ALB complements other hydrographic surveying technologies, especially in shallow areas where methods like multibeam sonar may be less effective.

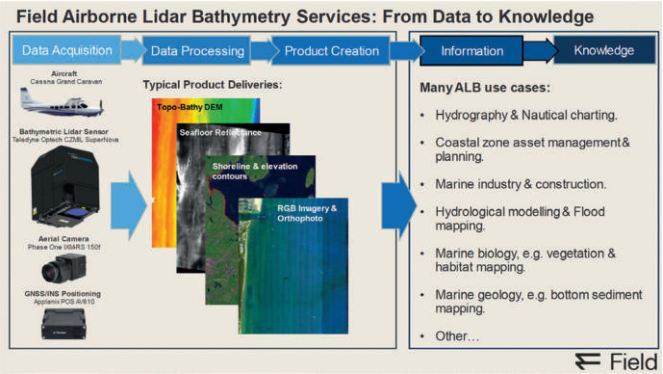
ALB survey planning must consider factors like sensor capabilities, bottom reflectivity and water turbidity, which can significantly impact survey execution and results. Given the significant local and temporal variation in water turbidity, this is one of the biggest challenges to deal with.

ALB survey products find application in multiple fields, including:

- hydrography and nautical charting;
- coastal zone management and planning;
- marine industry and infrastructure;
- volume calculation for water reservoirs;
- hydrological modelling and flood mapping;
- marine biology and marine geology.

The growing demand for improved coastal zone mapping and water management in general drives ALB's increasing popularity. Simultaneously, technological advancements in bathymetric LiDAR, including faster lasers, enhanced photon detection and advanced processing software, have increased the technique's competitiveness.

Field, a Norwegian aerial survey company specialising in ALB services, has conducted surveys in various coastal regions, rivers and lakes using the deep-penetrating CZMIL SuperNova bathymetric LiDAR sensor. Notable projects include mapping coastal zones in Norway, Catalonia, Northern Ireland and Florida as well as the island of Sylt in Germany. The results of some of these surveys will be highlighted during the presentation as well.



1: Field, Norway

Full-waveform stacking techniques applied to coastal LiDAR bathymetry data

by: **David Mader**[1], Katja Richter[1], Patrick Westfeld[2], Hans-Gerd Maas[1]

Keywords: LiDAR bathymetry | full-waveform processing | full-waveform stacking | seabed topography | coastal waters

Marine waters are subject to constant natural processes, including currents, tides and storm events, which have a significant impact on the seabed topography near the coast. Climate change-induced sea level rise is expected to increase the frequency of extreme events, such as storms and floods, posing new challenges for coastal management activities, including coastal protection. Continuous monitoring of the seabed topography is important for the early detection of changes, ensuring safe navigation, planning appropriate infrastructure and providing adequate coastal protection. This requires accurate, reliable and comprehensive information with high temporal resolution.

Shipborne hydroacoustic measurement techniques are well-established for an accurate and reliable acquisition of seabed topographies. However, using these methods in shallow water can be logistically challenging, and its effectiveness decreases with decreasing water depth. Airborne LiDAR bathymetry is an alternative or supplementary method for efficiently and comprehensively acquiring water bottom topographies in shallow coastal areas and inland waters. Bathymetric laser scanners use a green laser pulse for the acquisition of data from the water surface, the water column and the water bottom. The receiver of the sensor records the backscattered laser pulse components as a digital signal: the full-waveform (FWF). However, the signal strength of the returning signal is attenuated by the medium water and water turbidity. A weak signal strength often hampers the detection of water bottom echoes, limiting the measurement method's penetration depth and resulting in data gaps in the water bottom topography. By reprocessing the data with sophisticated approaches based on FWF stacking techniques, it is possible to improve the penetration depth and provide additional water bottom information.

We have proposed two processing methods based on a combined evaluation of closely neighbouring FWF data to generate additional water depth information: signal-based and volumetric FWF stacking (sigFWFS and volFWFS). FWF stacking is the process of linearly or non-linearly averaging or accumulating signal components from multiple individual FWFs into a pseudo-waveform. The two methods differ in the way the pseudo-waveform is generated. The pseudo-waveform has an improved signal-to-noise ratio, enabling the derivation of water depth information. This information allows the reliable detection of even weak water bottom echoes in individual FWFs.

To validate the methods for use in marine waters, LiDAR bathymetry data from an area in the German North Sea were processed and the results were analysed. The penetration depth could be increased by about 26 %, from 2.87 m to 3.62 m, compared to the standard processing method. This leads to a significant improvement in the coverage of the seabed with measurement points. The plausibility of the data was evaluated by comparing the sigFWFS and volFWFS points with hydroacoustic measurements. The RMS values for sigFWFS and volFWFS are 0.103 m and 0.101 m, respectively. Furthermore, more than 98 % of the points have an absolute height difference of less than 0.25 m. The results indicate that the seabed is well represented by the sigFWFS and volFWFS points.

1: Dresden University of Technology, Germany
2: Federal Maritime and Hydrographic Agency (BSH), Germany

Optical hydrography – the DGPF's contribution to mapping and monitoring inland coastal waters

by: **Gottfried Mandlburger**[1]

Keywords: spectrally derived bathymetry | multimedia photogrammetry | laser bathymetry | German Society for Photogrammetry and Remote Sensing

The German Society for Photogrammetry and Remote Sensing (DGPF) is an association of leading German-speaking scientists who specialise in passive and active optical measurement techniques, i.e. photogrammetry and remote sensing. In 2018, a special working group for optical hydrography was founded to promote research activities for mapping and monitoring inland and coastal waters. Areas covered include spectrally derived bathymetry based on multispectral aerial and satellite imagery, multimedia stereo-photogrammetry and laser bathymetry. The working group is responsible for the organisation of workshops, expert meetings, regular sessions at the annual meetings of the DGPF and special issues in the *Journal of Photogrammetry, Remote Sensing and Geoinformation Science (PFG)*. A particular focus is on establishing contact with researchers working on SONAR (Sound Navigation and Ranging) to identify synergies and overlaps in research, especially between the similar techniques of SONAR and bathymetric LiDAR (Light Detection and Ranging).

A recent study highlighted the rapid increase of research in all categories of optical hydrography. Spectrally derived bathymetry (SDB) enjoys increasing popularity due to the availability of open data, e.g. from ESA's Sentinel-2 mission. In addition, images from crewed or remotely piloted aerial platforms are often used to derive bathymetry exploiting the radiometric image content. Modern approaches combine classical photogrammetric techniques and deep learning for SDB. The necessary ground truth data stems either from bathymetric LiDAR or from multibeam echo sounders (MBES), which again highlights the synergetic nature of SONAR and photogrammetry. Especially in the context of machine learning, we see a growing need for trustworthy reference data for which the use of synthetic data is gaining importance.

In the field of multimedia photogrammetry, DGPF's community is active in both underwater and through-water photogrammetry. Next to advances in camera calibration and multimedia ray tracing, one of the currently investigated problems is capturing and modelling dynamic water surfaces in photo bathymetry. Especially in the underwater case, the benefits of using laser lightsheet triangulation for very precise close range 3D reconstruction are topics of current research.

Finally, the working group deals with various topics related to laser bathymetry. One focus is the improvement of depth performance through sophisticated averaging strategies based on the full laser waveforms. In general, understanding of the interaction of laser light with the medium water, refined geometric models of laser pulse propagation, use of laser waveform measurements as a means for turbidity estimation as well as reconstruction of submersed macrophytes are topics of ongoing research. Another focus of the group is the development of specialised software, especially for the non-trivial case in the littoral zone, where the signal of a single laser pulse contains components from vegetation, water surface, water column and the bottom. Finally, the working group also cooperates with administrative bodies such as waterway authorities and coastal protection agencies and aims to support them in the practical application by disseminating current research results.

There is a strong belief that future problems related to climate change, including sea level rise, increased flooding, invasion of alien species, etc., requires interdisciplinary collaboration with experts from all related fields. The DGPF is ready to play an active role in this regard.

1: TU Wien, Austria

Bathymetry of sea ice melt ponds reconstructed from aerial photographs using shallow water photogrammetry

by: **Niels Fuchs**[1,2], Luisa von Albedyll[2], Gerit Birnbaum[2], Christian Haas[2], Ellen Heffner[3]

Keywords: photogrammetry | shallow water | aerial images | sea ice | optical hydrography

Sea ice in the Arctic Ocean is a truly remote location and requires high financial, personal and logistical effort to collect observational data. Thus, melt ponds on the ice, forming from surface meltwater during summer, are rather under-sampled despite their great importance for estimating the surface energy balance of the Arctic sea ice cover. In contrast to the surrounding snow and ice, ponds reflect less of the incoming sunlight and, therefore, drastically reduce the surface albedo, leading to catalysed melt processes. Yet their depth has so far mostly been measured manually at a few points along transect lines only, making it difficult to correctly estimate the actual volumes and the three-dimensional evolution of the ponds. Based on aerial image data collected with the onboard helicopter of RV *Polarstern* during a research cruise in 2017, we developed an algorithm to derive entire pond bathymetries in centimetre-scale resolution with a typical depth error of < 4 cm. This algorithm is fully compatible with a commercial photogrammetry workflow and automatically corrects for light refraction at the pond surface that causes horizontal and vertical displacements of surface points. Our approach allows for the neglection of these horizontal displacements, reducing their negative effect on tie point detection, and it corrects for the vertical underestimation of depth. Using a surface type classification scheme, the method automatically detects pond margins and, with that, derives each individual pond level from the reconstructed sea ice surface topography to distinguish between ray paths in the air and water medium. Furthermore, we correct for the constantly moving surface caused by the sea ice drift and the lack of ground control point deployments on inaccessible ice floes.
We present here the photogrammetric reconstruction method and the first comprehensive analysis of the three-dimensional pond geometry of an entire ice floe, realised with data from the one-year Arctic drift expedition MOSAiC on RV *Polarstern*, 2019–2020. Due to its feasible implementation into a standard photogrammetric workflow, we assume that the algorithm's applicability lies beyond the scope of sea ice melt ponds in the Arctic and thus contributes to a series of recent developments in the field of two-media photogrammetry for shallow water hydrographic mappings.

1: University Hamburg, Germany
2: Alfred Wegener Institute, Helmholtz-Zentrum für Polar- und Meeresforschung, Germany
3: HafenCity University Hamburg, Germany

Session 3B

Data fusion and management

Hydro Portal: Enhancing hydrographic data management in the Port of Hamburg

by: Marylou Gentilhomme[2], Frank Josuttis-Köster[1], **Michael Kowalczyk[3]**, Jasmin Wellnitz[3]

Keywords: hydrographic data management | digital transformation in maritime operations | collaborative software development | user-centred design | GIS and remote eensing | cloud technology

The Port of Hamburg has experienced significant modernisation in hydrographic data processing and presentation through the development of the Hydro Portal. This web-based platform, which provides an integrated view of harbour operations, is the result of collaboration between the Hamburg Port Authority (HPA) and Hamburg-based software company SenseLabs. The Hydro Portal serves as an efficient interface to Teledyne Geospatial's CARIS Bathy DataBASE, providing access to HPA's more than 30,000 survey data records, expanding daily. This experience report outlines the key project steps, the collaborations of the involved parties and the results achieved.

The project aimed to replace HPA's legacy software used for the display and processing of depth data. A primary goal was the elimination of traditional paper sounding charts to enable a digitalised and more efficient processing and visualisation of depth data. The newly introduced solution – the Hydro Portal – brought about a significant improvement in performance, especially in the hydrographic data processing for the creation of depth numbers and lines accessible via browser as GIS layers. Innovative software tools, including PDF export capabilities, were implemented, contributing significantly to enhanced data handling and usage. The migration to CARIS Bathy DataBASE, which is based on a microservices architecture and provide a REST API illustrates the dynamic nature of the project, where close collaboration and interface coordination between SenseLabs and Teledyne Geospatial played a central role to ensure seamless integration and functionality.

Additionally, the project execution involved regular requirement workshops and coordination meetings to align with HPA's additional data sources, including Esri ArcGIS. The core of the web application is an interactive map based on the ArcGIS API for JavaScript, which allows for comprehensive visualisation of various geo-referenced harbour data.

The user-centred design of the portal was realised through certified UI/UX expertise from the SenseLabs team. Numerous workshops precisely captured the specific requirements of various departments to ensure both functionality and user-friendliness. The Hydro Portal supports not only data integration and visualisation but also facilitates complex, multi-stage work processes and eases collaboration between departments. Special developments like different user interfaces for desktop and touch applications further optimise the user experience and contribute to efficiency gains.

The result is an efficient software solution tailored to the special requirements of the Hamburg Port Authority, which also finds resonance in other ports. The Hydro Portal has achieved high user satisfaction rates due to its user-centred design and fast data processing. The project team continues to refine and expand the portal, with plans for additional functionalities and improvements based on user feedback and emerging technological developments.

In summary, the development of the Hydro Portal demonstrates effective collaboration in hydrography. By utilising advanced technologies and a partnership approach, the project has delivered a state-of-the-art system that not only improves current operations for the Hamburg Port Authority but also sets standards for future projects in hydrographic data management. This initiative showcases the potential of digital transformation to significantly enhance maritime and port operations through improved data processing and accessibility.

1: Hamburg Port Authority, Germany
2: Teledyne Geospatial, Canada
3: SenseLabs, Germany

Cloud and AI technologies are revolutionising hydrography – The cloud-native TrueOcean platform

by: **Jann Wendt**[1]

Keywords: hydrography | artificial intelligence | cloud computing | standardisation | microservices

The field of hydrography is at the beginning of a transformative revolution with the integration of cloud computing and artificial intelligence (AI). TrueOcean, developed by north.io, is at the forefront of this innovation, offering a new breed of cloud-native Software-as-a-Service (SaaS) solutions for oceanic data management and analytics. Management, collaboration, accessibility, findability and big data processing are the core components of the system.

The platform technology is based on a highly scalable microservices architecture, which significantly enhances scalability and agility compared to classical systems. Each microservice in TrueOcean operates independently, allowing for precise scaling and robust fault tolerance. This modular approach not only facilitates efficient resource utilisation but also ensures rapid scalability to changing data volumes and processing needs. Therefore, a diverse set programming languages and frameworks are used addressing the unique challenges of big geospatial data (Golang, Rust, Java, JavaScript, Python). The orchestration engine Kubernetes underpins the microservices architecture, providing a dynamic and resilient environment for container management.

TrueOcean has its own integrated Big Data analytics platform Zeus which leverages the open-source frameworks Apache Spark and Apache Sedona in a highly scalable Kubernetes environment. Zeus manages calculations on the raw point cloud level, skipping any rasterisation or interpolation steps avoiding any information loss. With cloud solutions like TrueOcean and computing engines as in Zeus, raster limitations become obsolete. Zeus runs the calculations on the raw data representing a fundamental shift in ocean data handling and analysis. Point clouds have the advantage of representing the origin of spatial data, devoid of any alterations. Zeus takes advantage of the column-based Parquet data format and standardises a multitude of multibeam data formats (e.g. GSF, XTF, KMALL, ALL, S7K, RAW) into a generic structure. Zeus offers an array of common geospatial data processing tools, called transformers, that translate raw data into typical domain metrics. Transformers are available for the following key categories in Zeus: data quality assessment, morphometric analysis, geometrical characterisation, geomorphons, signal processing and rasterisation.

Zeus also allows AI to be applied in a highly scalable way. For example, we used the Zeus framework to predict the SVP from raw MBES data using an artificial neural network. The AI calculates artificial SVPs for each individual sound pulse in the MBES data and matches the sound trajectories through the water column to the measured MBES sound arrivals. In addition to the raw MBES data, the calculations only require the surface sound velocity, which is usually stored in the raw MBES data. It has the ability to improve the accuracy of data and greatly simplify post-processing. It also restores the bathymetry for MBES data where no SVP is available.

Conclusion: TrueOcean provides a framework for managing and analysing hydrographic on tremendous scales. It automatises the handling of big data, ranging from data input via data harmonisation to translating and distributing big data calculations. AI approaches and the usage of GPUs show enormous potential for the future.

1: north.io GmbH, Germany

Fusing navigation: ECDIS, drones flights and aviation

by: **Gunnar Tietze**[1], Fabienne Vallée[2], Tim Strohbach[3]

Keywords: shared common situational picture | integration of maritime and aviation | real time data | S-100

ECDIS is the global platform in maritime navigation. Its common base is the ENC, electronic navigational chart, which has replaced paper charts. Actually, its globally agreed standard S-57 is to be updated to the new S-100 family of standards. This opens integration of many more information, environmental data, even in real time (forecasts?) like surface currents, waves, etc. being displayed as separate layers (S-111, etc.).

Nowadays, marine operations for offshore oil & gas or wind parks are supported on the water (supply vessels, tug boats, survey vessels, etc.), and receive additional support from the air, mainly helicopters and – this is new – from drones. Classically, there is the maritime space and the airspace (aviation). Both are vertically separated. Maritime space, apart from underwater operations, takes place two-dimensionally on the water surface and aviation takes place in the airspace above 500 ft (150 m), usually higher than 1000 ft (300 m).

Both worlds are highly professional and internationally harmonised. However, apart from military applications, today the two worlds are separated. This applies to both the technical infrastructure and the legal framework, which in the maritime sector is defined, regulated and controlled by international bodies like IMO, IHO, IALA, EMSA. The situation is similar in aviation.

More and more drones will play a role in complex operations. The trajectories of drones may overlap with both the maritime and aviation sectors. Collisions with manned aviation and with ships (antennas, superstructures, containers) must be avoided. This results in new challenges that need to be addressed. For the foreseeable future, the world of aviation and the maritime world will not be integrated, but there should be a certain level of awareness for each other.

Consequently, there is no common situational picture shared among all partners in complex operations. However, information about the mission and trajectories should be shared between the two worlds. Concerning the maritime, the data could be displayed as an additional layer in ECDIS, whenever needed.

Concrete tasks for the maritime:

- Definition of the required information from drones or from aviation in general, prioritising it.
- Importing this data in near real time, defining the interface, visualisation of the trajectories of flying objects on ECDIS, with direction and speed, plus flight altitude. Filters or alarms, e.g. with regard to flight height, might be helpful.
- Visualisation of data surveyed by flying drones

This calls for new applets within ECDIS to import and display this additional information. International bodies like IHO are open to define and add new S-100 numbers for these new types of information. The advantages are at hand: no costs for additional hardware, little investment in training people, as ECDIS is already well established.

Concerning aviation it is a similar situation. Information about ship traffic might be critical for drones. Providing this data via ECDIS interfaces (direct or via web) opens new opportunities for e.g. mission planning, providing a safe navigation across water. Integrating the newcomer »drones« in reliable standards adds to the safety gain.

This work is supported by the European Union, Interreg NorthSea and Horizon 2020.

1: SeaTopic SAS, France
2: Brest Port, France
3: Fraunhofer IFAM, Germany

Augmenting ocean data collection operations and enhancing information generation with Blue Insight

by: **Peer Fietzek**[1], Arne Johan Hestnes[2], Leif Edvard Bildøy[2]

Keywords: digitisation | remote operations | machine learning

The growing Blue Economy and maturing Ocean Enterprise demand for increased efficiency across all instances of the observing value chain and digitisation can help with that. Blue Insight (BI) is a digital platform to enhance ocean data related value generation from gliders to survey vessels and for any measuring parameter. It efficiently supports tasks around collection, integration, management, analysis, prediction, visualisation and sharing of data. Especially in connection with acoustic instruments its value proposition could be summarised as »From ping to insight«.

Strong collaborations between Kongsberg Discovery and scientific institutions help to advance BI functionalities and expand the use cases. Echo sounder related data processing and analysis, including machine learning and automated backscatter classification, are developed and improved e.g. through the centers for research-based innovation initiatives, SFI CRIMAC (https://crimac.no) and SFI Centre for Innovative Ultrasound Solutions (CIUS, www.ntnu.edu/cius) in Norway. Visualisations, e.g. in 2D map projections or accessible 3D environments, prove to be especially effective in cultural heritage related or dissemination- and outreach-heavy application such as within the Frisk Oslofjord project (www.friskoslofjord.no).

In the context of hydrography, BI enables to augment multibeam echo sounder operations with real-time capabilities. Automated processing of the data can be used for seafloor or water column target (e.g. gas bubbles) detection or for the immediate comparison with historic data to just name some options for real-time knowledge generation. At this, the same machine-learning-based processing workflows are containerised and therefore be run at the edge (e.g. on an uncrewed surface vehicle, USV, or a research vessel) or in the cloud for maximum flexibility. Automated processing pipelines have the advantage of delivering constant output quality and reducing user errors.

The digital platform also offers the possibility to remotely control and adjust settings of sophisticated acoustic instruments, offering the possibility for the needed experts to remain on land while the equipment is deployed at sea.

Professional operations can be further streamlined through seamless interfacing of managed workflows with other commercial processing solutions or survey workflows, delivering efficiency benefits to the users.

Short development cycles for features of the digital platform make it a highly dynamic and versatile solution as proven through many collaborations and various projects.

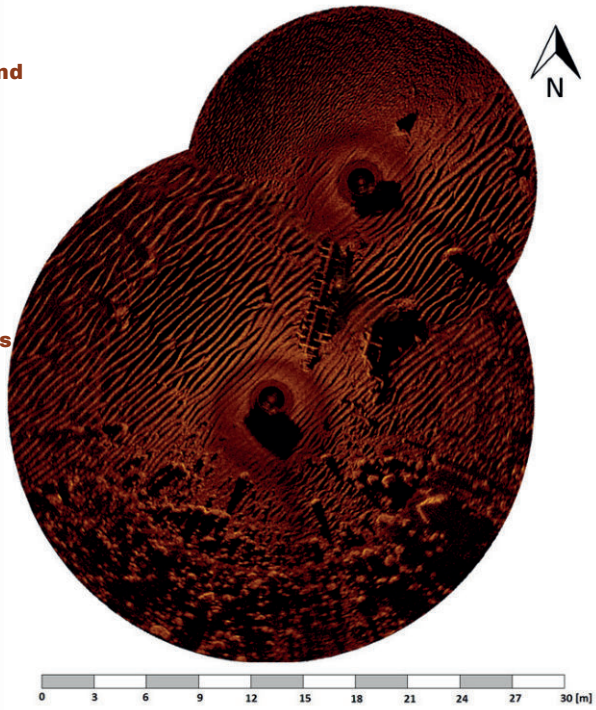
We intend to present the features and benefits of the digital platform underpinned by examples from former projects and initiatives with a special emphasis on operations with single- and multibeam echo sounder data.

1: Kongsberg Discovery, Germany
2: Kongsberg Discovery, Norway

UNDERWATER SONAR INVESTIGATIONS

Escort TECHNOLOGY

- **Hydrographic surveys in the area of Western Pomerania and Lubusz (Oder River, the port of Szczecin and Swinoujscie, the Swinoujscie-Szczecin fairway)**
- **Inventory of river spurs and banks on the Oder River**
- **Investigations of scours around bridge supports**
- **Sonar investigations of bridge supports and wharves**
- **Sonar search and wrecks investigations in shallow waters**
- **Underwater inspection and monitoring by means of acoustic camera**



Contact Us:

hydro@escort.com.pl
escort-technology.com
Szczecin, Poland

Session 4A

New trends in positioning

Potential of low-cost GNSS and satellite-based correction data for hydrographic surveying

by: **Anja Heßelbarth**[1]

Keywords: positioning | navigation | low-cost GNSS | correction data | satellite-based correction data | Galileo high accuracy service

Many applications in hydrographic surveying require precise positioning, navigation and orientation information. Global navigation satellite systems (GNSS) provides these data with accuracy at the centimetre level. But, in addition to standard code messages, more precise phase measurements are essential. Furthermore, high-accuracy correction data are required, and especially for real-time applications, they have to be available during the complete measurement time. Until a few years ago, high-grade GNSS-receivers and antennas were expensive and mainly used for surveying and geodetic applications. Furthermore, the transmission of continuous precise correction data in the application at sea or ocean posed a challenge. However, recent years have seen new trends in receiver equipment and correction data, which are also considerable for hydrographic surveying.

This contribution explores the new trends and potentials of low-cost GNSS equipment for precise positioning and navigation. Specifically, it will analyse the data quality and quantity in various environmental conditions. The focus will be on presenting the potential of low-cost GNSS devices, such as ZED-F9P from u-blox and Piksi® Multi from Swift Navigation, in terms of accuracy, convergence time, reliability and availability compared to high-grade equipment for kinematic applications.

Furthermore, GNSS correction data are essential for obtaining precise navigation and positioning results. This contribution will demonstrate the differences, advantages, disadvantages and limitations between state space representation (SSR) and observation state representation (OSR) corrections in concrete applications.

Transmitting real-time correction data to vessels or buoys beyond internet infrastructure requires satellite-based correction data. For many years, SBAS messages transmitted by geostationary satellites have improved position accuracies to one metre. Nowadays, new correction data, such as the Galileo High Accuracy Service (HAS), are available. By utilising these correction data, transmitted by E6-band, position accuracies within a few decimetres or better can be achieved. The figure illustrates 3D RMS results for GNSS positions of a vessel traveling in the Baltic Sea based on HAS correction data compared to a solution based on highly accurate correction data. Additionally, commercial correction data alternatives like SPARTN-messages provided by u-blox exist. The correction data are transmitted by L-Band and promise horizontal accuracies below clearly one decimetre. Hence, another focal point of this contribution is to outline the potential, availability, reliability, as well as the resulting position and navigation accuracy for these types of correction data.

The concluding section, or outlook, will give examples of integrating multiple antennas and the fusion of GNSS and inertial data. This integration aims to determine not only the position and velocity results but also the heading, pitch, and roll movements of vessels.

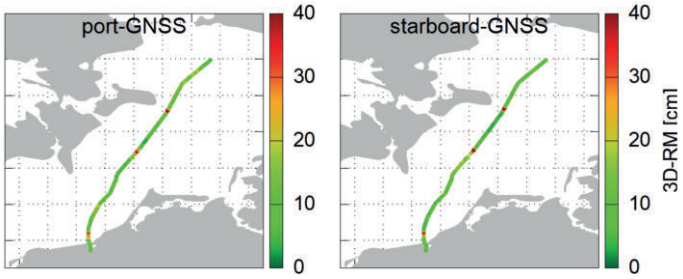


Figure: 3D-RMS position error of a vessel utilizing two GNSS-equipment setups (port side and starboard side) by using HAS correction data

1: University of Applied Science Dresden, Germany

Fugro Marinestar GNSS PPP service enhancements in 2024

by: Xianglin Liu[1], Yahya Memarzadeh[1], Artur Oruba[1], Dennis Odijk[1], **Hans Visser**[1]

Keywords: GNSS | PPP | enhancement | accuracy | convergence | scintillation | authentication

In Fugro's continuous efforts to improve GNSS positioning accuracy, various services making use of the L-band of geostationary satellites have been developed since 1997. Marinestar™ is one of the services that currently provides precise orbit, clock and phase bias corrections of satellites to marine clients. These corrections enable precise point positioning (PPP) with integer ambiguity resolution (IAR) with almost the same accuracy as traditional RTK produces, without using reference stations nearby. The service supports four constellations: GPS, GLONASS, Galileo and BeiDou, with approximately 120 satellites in total.

This presentation highlights several enhancements to the service achieved in 2024, with a focus on faster convergence, higher accuracy, scintillation mitigation and anti-spoofing.

A significant improvement involves the addition of third-frequency phase biases and inter-frequency code biases of GPS, Galileo and BeiDou to existing dual-frequency service. This enhancement allows clients to utilise third frequency GNSS measurements in conjunction with our more reliable and intelligent Integer Ambiguity Resolution strategies. This enhancement has been notably contributed to faster convergence and higher accuracy. Convergence time has been reduced from approximately 12 minutes to just 3 minutes (95 %), while the accuracy has seen a global improvement to 2.5 cm horizontally and 5.0 cm vertically (95 %). Many ideal experimental sites have achieved even higher accuracy, reaching 1.5 cm horizontally and 3.5 cm vertically (95 %), with almost instantaneous convergence (in one minute).

Currently, the ionospheric scintillation is experiencing a period of high activity. This phenomenon is frequently observed near the equator and in the Arctic region, where many of our clients have ongoing engineering projects. As a result, GNSS measurements are significantly degraded, leading to positioning with much lower accuracy and occasional positioning resets. To solve the issue, Fugro enhanced its PPP engine with various level of quality controls in 2024. These improvements have effectively mitigated or largely reduced the impact of scintillation. Consequently, the position performance is now significantly better than it was previously.

GNSS signal spoofing represents an intelligent and sophisticated form of signal interference, where malicious actors may employ a device to transmit fake GNSS ephemeris, measurements or corrections, deceiving a receiver into calculating an incorrect position. Fugro has introduced an authentication service called SATGUARD™, which has the capability to distinguish fake and true signals (i.e., navigation messages and Fugro corrections for the time being) from four constellations. The service offers an opportunity to prevent the injection of fake signals into the PPP engine, thereby, ensuring accurate positioning for clients.

1: Fugro, The Netherlands

An appraisal of backscatter removal and refraction calibration models for improving the performance of vision-based mapping and navigation in shallow underwater environments

by: **Fickrie Muhammad**[1,2], Harald Sternberg[2]

Keywords: underwater vision | vision-based mapping | refraction correction | backscatter removal | unstructured seabed

Vision-based mapping (VbM) is one of the fundamental origins of automation in remote and autonomous spatial data acquisitions. Complexity in obtaining accurate data arises when such a method is applied in the underwater environment. This research proposes an integrated backscatter removal and refraction calibration model within the VbM and navigation pipeline, as seen in the figure. It is argued that the proposed VbM-dedicated models can significantly improve the conformity of objects' positions underwater around the camera's motion during the deployment underwater. The research uses automatic refraction adjustment with a correction map to undistort images in real time, addressing issues including refraction distortion and non-uniform light exposure that arise in underwater environments. Furthermore, haze removal, contrast adjustment and colour correction are combined to achieve backscatter removal for image enhancement algorithms. We have structured the research sequences into three phases to evaluate the synthesised pipeline: simulation, fieldwork and accuracy assessment. The methodology commences by employing a simulated data set from underwater simulation tools and introducing varying turbidity levels from 0 % to 90 % turbidity to assess the image enhancement algorithm. As the simulation does not directly model refraction due to the presence of water and camera lens medium, the simulated underwater camera operates with predefined parameters for both in-air and underwater simulations. The subsequent fieldwork is tailored with GoPro 10 hardware, which features a 109-degree wide-angle lens recording images at a high resolution of 1980×1020, in Pramuka Island Waters, Indonesia. This setup offers real-world context for the research's relevance to distinct underwater circumstances and aims to examine the calibration impact on the lens and refraction distortion. The accuracy assessment involves comparing discrepancies among the VbM algorithms running offline and online (real-time process). Additionally, the visual-inertial data set collected from in-air and controlled environments named EASI data set is utilised. The EASI data set shares similar hardware specifications to analyse the performance and robustness of the derived camera parameters and hence is useful to test the visual-inertial VbM for both in-air and underwater environments. The results show that the backscatter removal and refraction adjustment fused into real-time VbM help lessen the difficulties of submerged environments. The research shows efficient backscatter removal improves feature detection robustness, especially in murky water conditions. Refraction correction also successfully eliminates the bowing effect from missing ground control points in underwater environments. The research is significant because it emphasises how vital image enhancement and refraction calibration are to obtaining centimetre-level map accuracy of VbM. The results highlight the need for a comprehensive strategy to advance underwater mapping and navigation technology to deliver accurate and dependable outcomes in various underwater situations.

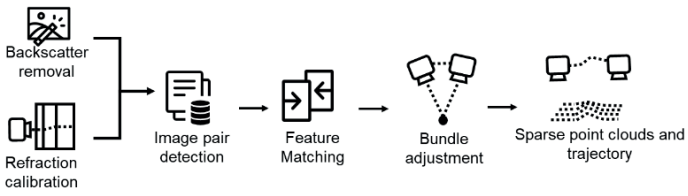


Figure: Pipeline of the underwater VbM algorithm. Image correction and camera calibration play a crucial part in enhancing the robustness of VbM

1: Bandung Institute of Technology, Indonesia
2: HafenCity University of Hamburg, Germany

Session 4B

Underwater infrastructure and monitoring

Advancing underwater inspection: High resolution pulsed time-of-flight laser scanning

by: Christoph S. Werner[1], **Jannis Gangelhoff**[1], Simon Frey[1], Daniel Steiger[1], Alexander Reiterer[1,2]

Keywords: underwater laser scanning | high-resolution inspection | LiDAR

Subsea pipelines and cables, wind energy and hydroelectric power plants are just a few examples of underwater installations which require detailed and highly resolved inspection and monitoring methods for construction and maintenance. Traditionally, these inspections are carried out by divers, cameras carried by remotely operated vehicles (ROVs) or sonar systems. But these solutions have limitations in terms of accuracy, resolution, time-efficiency and often cost-effectiveness. Our presented underwater laser scanner technology aims to address these limitations using a pulsed time-of-flight distance measurement combined with full-waveform digital signal recording and processing.

The presented laser scanner is intended for submerged operation and emits short laser pulses, in the order of one nanosecond, in the green spectral region to determine the target distance based on pulse propagation time. In combination with a laser pulse repetition rate of 100 kHz, the system can capture fine-scale structural details. The full-waveform data processing enables the scanner to achieve better performance in turbid conditions compared to camera-based solutions and achieve an exceptional measurement precision in the sub mm-range.

A key feature of the scanner is the use of a Risley prisms pair for two-dimensional beam deflection. Due to a variety of possible scan patterns, this deflection unit allows for flexible use of the scanner. For example, it can be used stationary on a tripod while still capturing a complete 2D scene. This allows the scanner to be operated without any underwater positioning solution. But mobile use on a remotely operated vehicle or autonomous underwater vehicle (AUV) is also possible. For this, the sensor data is fused with the position and attitude information of the carrier platform to calculate a coherent point cloud.

We present measurement results obtained from both lab-based and outdoor environments, highlighting the systems capability to detect structural anomalies, small-scale objects and other potential issues that are critical for the proactive maintenance of underwater installations. The implications of such high-resolution data acquisition extend beyond maintenance, offering significant benefits for environmental monitoring, scientific research and the removal of unexploded ordnance.

The lab-based measurements have been conducted in the facilities of Fraunhofer IPM using a 40-m-long underwater measurement range. For the outdoor tests, we have used a custom made remotely controlled surface vessel equipped with a satellite-based positioning system to perform measurements in lakes.

Despite the promising results, the deployment of this technology in real-world scenarios presents challenges, including technical limitations in harsh underwater conditions and the processing of vast amounts of data generated by the high-repetition scanning. Future work will focus on addressing these challenges, improving the system's performance and exploring new applications for this technology.

1: Fraunhofer IPM, Germany
2: Albert-Ludwigs-University Freiburg, Germany

Underwater laser scanning: Integration and testing on a survey vessel

by: **Annika Walter**[1], Ellen Heffner[1], Annette Scheider[1], Harald Sternberg[1]

Keywords: underwater laserscanner | sensor alignment | system integration | calibration | multi-sensor platform

Shipping routes, rivers and oceans are important arteries for the global trade. In addition, there is a growing underwater infrastructure in the form of drilling platforms, port infrastructure facilities and offshore wind turbines, which requires a regular inspection and maintenance. As a part of this work, deformations in the range of millimetres, which can indicate damage at an early stage, must be detected.

As sonar systems can only achieve resolutions in the range of a few centimetres even at a close range, the inspections are up to the present usually visually carried out by divers. This technique does not only require an enormous amount of time and money, but it also puts a great risk to the personnel involved. In this context, the usage of LiDAR technologies, which allow for a higher resolution than acoustic sensors, provide an alternative. However, since water presents physical difficulties to optical systems in terms of turbidity and reachable distance, up to date, only sparse information regarding the integration of an underwater laser scanner on a moving survey vessel and only view estimates about to the actual usability of such a system for corresponding purposes, are available.

With the integration and the testing of the underwater laser scanner ULi, which was developed by the Fraunhofer IPM, on the survey vessel *DVocean* of the HafenCity University Hamburg, this subject is to be changed. In this context, ULi attracts a special attention due to its usage of the pulsed time-of-flight method. Since this method has been adapted for the usage in turbid waters, the manufacturer states that the achievable measurement distance in those waters is up to three times larger compared to other optical systems.

To realise a respective integration, it must be determined at which exact position and orientation the underwater laser scanner is installed on the multi-sensory platform. Therefore, the system must not only be calibrated with respect to its position and its orientation angles, but an accurate time synchronisation with the other sensors on board, must be realised as well. Hence, the recorded data of the underwater laser scanner can be compared with the data collected from acoustic systems such as the EM2040 P MKII multibeam echo sounder. In this context, it can be determined to what extent the under laboratory conditions achieved performance of the underwater laser scanner can be reproduced in real environmental conditions. Based on the quantification of possible discrepancies, it can be assessed to what potential degree the usage of the ULi is suitable for realistic underwater applications and whether the system can be used for monitoring tasks by meeting the associated accuracy requirements.

1: HafenCity University Hamburg, Germany

Combined technologies for 3D cable tracking: Integrated data acquisition of a 3D sub-bottom profiler and an array of magnetometers

by: **Jens Wunderlich**[1], Jan-Erik Rygh[2], Michael Endler[1], Jens Lowag[1], Stein-Arild Nordrum[2]

Keywords: cable tracking | 3D sub-bottom visualisation | parametric acoustics | magnetometer | buried object localisation

With an increasing number of offshore cables being installed, surveys to obtain the depth-of-burial (DOB) are an important task and done on a regular basis. DOB surveys shall determine the exact position and burial depth of the cable directly after dredging and later in regular intervals during its entire lifetime. With expanding offshore wind farming site explorations, DOB surveys become increasingly important. Innomar and Aquadyne combined forces and technologies to use the locating and real-time steering information provided by Aquadyne's »MagTrack« system to efficiently acquire acoustic data using the Innomar »sixpack« SBP to produce a three-dimensional visualisation of the sub-seabed around a cable in a single pass along the target. This paper summarises user requirements for DOB surveys, discusses the technologies used and the physics behind as well as encouraging field data from initial trials in Rostock, Germany. Application of the methods shown is not limited to cable DOB surveys, they may also be used for pipeline surveys or other activities during construction and maintenance of offshore structures, e.g. to detect boulders, UXO or other debris during site and route surveys.

The »MagTrack« system consists of a control unit and two to eight sensors, each integrating a three-axis magnetometer and a two-axis inclinometer. During the tests different configurations with two and four sensors were used. The online cable position, derived from the tilt-compensated XYZ-components of the cable's magnetic field, is used in real time to aid the vehicle steering along the cable route and recorded within the SBP's acoustic data. The magnetic raw data are recorded time-stamped for quality assurance and optional post-processing, too. The »sixpack« SBP uses a rigid linear array of six transducers (combined projector and hydrophone) with adjustable separation, a motion sensor (providing heave, roll and pitch data) and a two-antenna RTK position and heading sensor. The acoustic data are recorded together with all auxiliary sensor data (position, heading, motion, cable position) into the same data file to generate a common data set without the need for matching time stamps or positions in post-processing. Both, the cable position and the acoustic data, are visualised in real time for quality assurance and cost-efficient data acquisition. The post-processing of the acoustic data includes motion compensation, amplitude correction and converting the point cloud into a regular grid to generate an easy-to-handle 3D model.

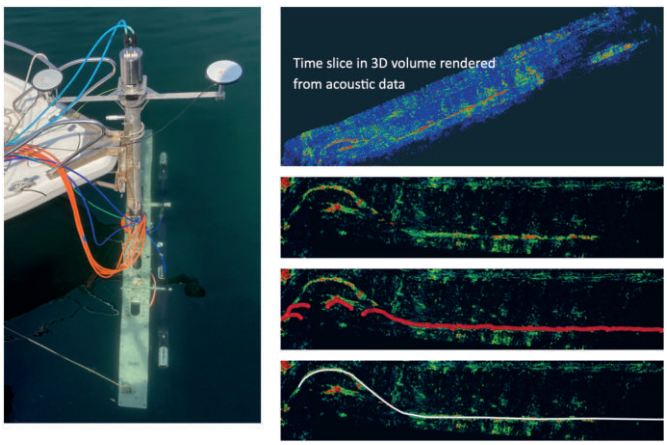


Figure: Experimental sensor setup (left); time slice of the acoustic data rendered into a 3D volume (top right); cable as seen in the acoustic data, post-processed cable position and real-time cable position

1: Innomar Technologie GmbH, Germany
2: Aquadyne AS, Norway

Session 5A

Harbours and inland waters

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Mapping Arctic lakes: a challenge for the 79°N parallel (Ny-Ålesund campaign – summer 2023)

by: **David Rossi**[1], Filippo Azzaro[2], Giulio Careddu[3], Michele Marasco[4], Daniele Montecchio[1], Nicolas Guyennon[1], Emanuele Romano[1], John Tamplin[5], Edoardo Calizza[3]

Keywords: 79°N parallel | Arctic lakes | USV | Eco-Climate Project | remote hydrography

The utilisation of hydrographic uncrewed survey vessels (hereafter USVs) is becoming increasingly prevalent in ocean research endeavours, particularly in extreme environments such as the Arctic and Antarctic. However, this study describe the use of a compact USV, that has been employed inland for the first time, specifically for mapping Arctic lakes at the 79°N parallel.

The »Eco-Climate Project«, funded by the Arctic Research Program (PRA), facilitated our journey to the northernmost inhabited area of the planet, the Ny-Ålesund Research Station (located in the polar archipelago of Svalbard). Our aim was to comprehend how climate change could impact the structure and functioning of Arctic lake ecosystems, which are regarded as biodiversity hotspots and crucial carbon sinks in the highest latitudes. Taking advantage of cutting-edge tools, including a portable hydrographic USV sponsored by Seafloor System Inc. and a third-generation GNSS antenna sponsored by Microgeo, we successfully reconstructed the bathymetries of 22 previously unexplored lakes (with only one being previously known). The USV was outfitted with a single-beam echo sounder (450 MHz and 5° angle). After processing PPK (post-processing kinematics) corrections, using two neighbouring base stations installed near the Ny-Ålesund research station, the positioning error was estimated to be ±20 cm. Data acquisition and processing were performed using Hypack Echo software, seamlessly integrated with the HydroLite-DFX echo sounder.

One of the primary challenges encountered in surveying Arctic lakes lies in their shapes, depths and positions. Most of the investigated lakes proved to be extremely shallow, ranging from –6 m to –0.4 m in depth, with one exceptional case reaching a depth of –13m. Moreover, as these lakes were previously undiscovered, manual operation of the USV was necessary to navigate through potentially submerged obstacles.

Two-dimensional and three-dimensional geometrical models of the lake basins were generated, and the volumes of individual lakes and residence times were evaluated using also a portable velocity meter. These data were correlated with biochemical data acquired simultaneously during the hydrographic survey.

Predictions suggest a decrease in snow cover, alongside an increase in vegetation cover and the density of migratory avifauna in the near future, driven by rising temperatures. Interestingly, our results indicate that the dimensions and outflow rates of lakes are not correlated with concentrations of nitrogen, phosphorus and carbon, which varied over one order of magnitude among the lakes investigated. Whereas, migratory birds predominantly contribute to nutrient concentration and export downstream from lake basins, unravelling a key biological control on the nutrient cycling in the Arctic Tundra.

The coupling of hydrological, chemical and ecological data obtained within the Eco-Climate Project significantly enhances our mechanistic understanding of nutrient cycling and food web dynamics in the Arctic Tundra, thereby improving our capacity to model anticipated effects of climate change across short-, medium- and long-term scenarios.

1: CNR-Water Research Institute, Italy
2: CNR-Institute of Polar Sciences, Italy
3: Sapienza University of Rome, Italy
4: Microgeo srl, Italy
5: Seafloor System Inc., USA

Ultra-compact bathymetric measurement system with processing chain for surveying shallow water bodies

by: **Jannis Gangelhoff**[1], Christoph S. Werner[1], Simon Frey[1], Daniel Steiger[1], Lida Asgharian-Pournodrati[2], Uwe Soergel[2], Alexander Reiterer[1,3]

Keywords: positioning | navigation | low-cost GNSS | correction data | satellite-based correction data | Galileo high accuracy service

Water bodies form an important foundation for all organisms. They not only provide us with drinking water, but also serve as crucial habitats for plants and animals. However, water bodies also pose a source of hazards. An extensive and up-to-date database is required to effectively protect water bodies and their surroundings. In addition to water quality parameters, water level and the geometric description of the underwater and shoreline areas are essential. Both the topographic geometry in the peripheral areas of the water body, as well as the subsurface are prerequisites for reliable flood and inundation simulations. Currently, for mapping water bodies, echo sounders and airborne bathymetric LiDAR (ABL) are used. However, both have disadvantages in shallow water bodies with depths below approximately 2 m. Echo sounders are used from ships, which can only be used at a certain water depth. The aircrafts carrying the ABL move too fast and fly to high for spatially high-resolution data acquisition and designed for deep-water penetration, the measurement performance is limited in shallow waters. Therefore, there is a high demand for systems closing this gap. They need to be quickly and easily deployed, ideally from unmanned aerial vehicles (UAVs). According to the Implementing Regulation (EU) 2019/947 of the European Commission, UAVs weighting more than 25 kg are only allowed to be flown in remote areas and with individual approval. This not only increases the cost of measurements but also makes them inflexible, as a significant lead time for flight approval is common. Moreover, the flight area must be appropriately restricted. We present a system chain, from a lightweight UAV-borne sensor to the generation of the final terrain model, including semantic classification of terrain and vegetation areas in and around the water body. The Fraunhofer Institute for Physical Measurement Techniques IPM developed a compact and lightweight dual wavelength bathymetric laser-scanning system, targeted at shallow water and topographic surveys. Simultaneously to the LiDAR measurements, multispectral images of the survey area are captured by an additional camera sensor. The combined sensor weight is about 3.5 kg, so operation with commercially available drones in the under 25-kg category is feasible. Both, an infrared and a green laser share a common optical path and are extended to a diameter of 5 cm, reducing the light intensity to a class 2M laser product at all flight altitudes. This ensures a safe operation and reduces the required safety measures.

The Institute for Photogrammetry from the University of Stuttgart expands the system chain from the sensor to the generation of the final terrain model, including semantic classification of terrain and vegetation areas in and around the water body. This classification takes advantage from complementing features provided by LiDAR point clouds and simultaneously acquired multispectral imagery. In pre-processing, bundle-block adjustment is applied to derive image orientation parameters as well as ensure precise co-registration with laser data. In the current set-up, a random forest model is applied. By combination of classification and segmentation we gain robustness against the outliers and spurious misclassification.

1: Fraunhofer IPM, Germany
2: University of Stuttgart, Germany
3: Albert-Ludwigs-University Freiburg, Germany

Merging underwater MBES pointcloud and 360° camera imagery into georeferenced 3D-Model of urban waterways and harbour infrastructure

by: **Markus Kraft**[1], Ali Alakbar Karaki[2], Lukas Klatt[1], Harald Sternberg[1]

Keywords: critical maritime infrastructure | echo sounder data acquisition | photogrammetry | waterway mapping | multi-sensor systems

Maintaining critical harbour infrastructure, quay walls, buildings with waterfronts or urban infrastructure in areas which are predominantly marked by waterways and channels are an ongoing challenge for any urban environment built at rivers or estuaries. The key issues to support critical infrastructure studies in harbour areas start from collecting reliable geospatial and hydrospatial data. In order to provide such spatial information about waterfront infrastructure above and below the water surface an integrated optical and acoustic survey can help to develop new services for marinas and blue economic operators. The methodology integrates topographic and underwater survey, namely a 360° camera and a multibeam echo sounder (MBES) mounted on a small research vessel, but possibly also on unmanned and/or autonomous surface vehicles. While the MBES provides the most efficient method to chart topography and infrastructure below the water surface, the 360° camera captures the surroundings in high-quality and immersive imagery and video. The high-resolution imagery resolves in a structure-for-motion (SfM) 3D-model for all areas above the waterline. RGB values are recorded by the camera enhancing the natural representation of the environment of interest. Both camera and MBES are instances of one multi-sensor platform and therefore synchronised in time and aligned regarding their on-board location. By ensuring an adequate GNSS positioning the presence of markers is no longer required. Below the water surface the 3D model's quality depends solemnly on the MBES's and can be stated as sub-10 cm resolution and sub-5 cm accuracy, both vertically and horizontally, evolving from shallow water measurement specifications for the Kongsberg EM2040.

Above the water surface the 3D model depends on the performance of the 360° camera. The 360° cameras offer flexibility for capturing images in any direction, and the large field of view benefits in reducing the number of images. However, it remains essential to ensure proper overlapping between images to enable accurate reconstruction of photogrammetric processes. A 3D model solution derived from photogrammetric workflow can vary depending on several factors including camera specifications and georeferencing method, reaching down to the millimetre scale. Since this approach relies on the GNSS solution for camera positioning, the ultimate precision corresponds to the GNSS accuracy itself.
The accuracies of both systems are further analysed by quantitatively comparing both measurements on the same location. By using predefined survey spots on significant structures during high and low tide, same quay wall structures are being surveyed once each by acoustic and optical measurement system.
Combining the photogrammetric imagery of the camera with the point cloud acquired under water by sonar measurements lead to a surface model providing a georeferenced 3D representation of any waterway surroundings. Possible further applications include a collective network of publicly accessible imagery data spatially connected, for instance a »street-view« for waterways and water channels in lagoon cities. This will enhance hydrographic measurements contributing to smart e-navigation solutions.

1: HafenCity University Hamburg, Germany
2: University of Genoa, Italy

CATZOC mapping in layered media

by: Pawel Pocwiardowski[1], **Uni Bull**[1]

Keywords: fluid mud | navigable bottom | mapping | multibeam | CATZOC

This paper presents a novel approach for achieving CATZOC category A1 in areas with suspended muds, utilising multibeam echo sounders operating within an ultra-wide frequency range of 80 to 400 kHz. This method demonstrates comparable performance to single-beam systems in accurately determining the navigable bottom in a presence of fluid muds and producing high-resolution bathymetric maps through comprehensive coverage. Contrary to single-beam echo sounders, which are inherently limited in their ability to fulfil the coverage requirements specified by CATZOC standards for modern electronic navigational charting, this method uses swath coverage multibeam sonars for mapping. It has the potential to replace methodologies relying on intrusive single-point techniques that utilise in-situ density or shear strength measurements, or low-frequency single-beam echo sounders.

1: NORBIT, Denmark

Session 5B

Education

Cat A, Cat B or … next individual certification!

by: Denis Hains[1], **Derrick Peyton**[2]

Keywords: hydrographer | individual certification | Cat A / Cat B | education | evaluation

This presentation delves into the importance of the individual Hydrographer Certification within the hydrographic community. It acts as a suggested direction, guiding individuals who have successfully completed Category S-5A (Cat A) or S-5B (Cat B) programmes recognised by the: International Hydrographic Organization (IHO), International Surveyors Federation (FIG) and International Cartography Association (ICA), composing the membership of the International Board on Standards of Competences (IBSC) for Hydrographic Surveyors and Nautical Cartographers. The individuals, enriched with pertinent hydrographic experience, are encouraged to actively pursue individual certification as hydrographic surveyors.

It's crucial to understand that obtaining a successful Cat A or Cat B certificate from a recognised IBSC's academic institution is not sufficient, but key to individual hydrographer certification. While a noteworthy achievement, Cat A or Cat B marks one important step towards individual certification. The presentation also extends its recognition to individuals holding geomatics degrees or diplomas, coupled with relevant hydrographic experience, who are also eligible for individual certification.

The all-encompassing eligibility framework recognises and celebrates the diverse talents and backgrounds contributing to the hydrographic competencies. The presentation is dedicated to dispelling prevalent myths surrounding the distinction between the importance of academic successful completion of Cat A or Cat B and the individual hydrographer certification. The completion of a Cat A or Cat B programme signifies academic preparedness for the individual certification process – a formal, rigorous evaluation ensuring that individual certification of hydrographers truly embody hydrographic surveyor competencies.

In summary, whether emerging from a Cat A or Cat B programme or possessing a geomatics degree/diploma, the journey towards individual certification as a hydrographic surveyor necessitates the step of formal peer-evaluation. This step serves as a confirmation of competency within the global hydrographic community. By demystifying the intricacies of the individual certification process, the presentation endeavours to empower and inspire aspiring hydrographic surveyors towards achieving their career aspirations in the global hydrographic community.

1: H2i, Canada
2: IIC Technologies, Canada

Lessons learned from the enhanced Belgian e-learning-oriented IBSC certified »Hydrographic Surveying Cat B« programme

by: **Alain De Wulf**[1], Jana Ameye[2], Axel Annaert[2], Greet Deruyter[3], Philippe De Maeyer[1]

Keywords: education | hydrographic surveying Cat B | e-learning | curriculum development | professional training

In light of a significant gap in hydrographic training within Belgium, identified a decade ago, efforts have been made to enhance the educational pathways available to hydrographic surveyors. This group traditionally finds employment within major Belgian and Dutch dredging companies that provide in-house specialised, albeit narrow, training tailored to immediate operational needs. Recognising the broader educational needs in this sector, the Geography Department of Ghent University and the Institute for Hydrography at the Antwerp Maritime Academy collaboratively developed a new educational programme. Launched in 2013 and accredited by the International Board on Standards of Competence for hydrographic surveyors and nautical cartographers (IBSC), the postgraduate programme »Hydrographic Surveying Cat B« was specifically designed to address these deficiencies.

The 1-year curriculum, conducted entirely in English to accommodate a wider array of students, initially aimed to provide a comprehensive foundation in hydrographic principles and practices. However, recognising the evolving needs of the industry and the increasing demand for flexible learning options, the programme underwent a significant revision in 2020. The updated curriculum, which started after a new IBSC accreditation in September 2021, incorporated extensive e-learning facilities that allowed students to engage with the material remotely and at their own pace. This flexibility was especially tailored to accommodate professionals who might already be working part-time in the field, thus allowing them to continue their education without sacrificing their professional responsibilities.

The programme operates under a dual-campus system, leveraging the unique strengths and resources of both the Antwerp Maritime Academy and Ghent University. This strategic use of multiple locations ensures that students receive the highest quality of education, with theoretical courses taught by experts in their respective fields. The coursework is complemented by practical, on-the-job training offered through partnerships with industry leaders, thereby ensuring that students not only learn the theory but also apply it in real-world settings.

The inaugural run of this redesigned programme has provided numerous insights into effective programme delivery and student engagement in a primarily e-learning environment. Challenges in student activation and engagement were met with innovative pedagogical approaches, and the programme's effectiveness was continuously assessed through feedback collected from the students themselves. This feedback is crucial for ongoing improvements and ensuring that the programme meets the evolving needs of the hydrographic sector. Much attention and effort is put in a 3-week integrated fieldwork in the port of Ostend (Belgium), where students learn to install equipment on the vessels, to calibrate bathymetric sensors, to clean hydrographic data, to experience different modelling techniques and, finally, to perform complex multi-layer volume computations.

These experiences and the lessons learned from the feedback of the students are invaluable, not only to the programme's administrators but also to the broader community of hydrographic education providers. Sharing these findings can help inform similar programmes globally, contributing to the advancement of hydrographic training and ensuring that professionals in this field are well-prepared to meet the demands of a dynamic and technically complex industry.

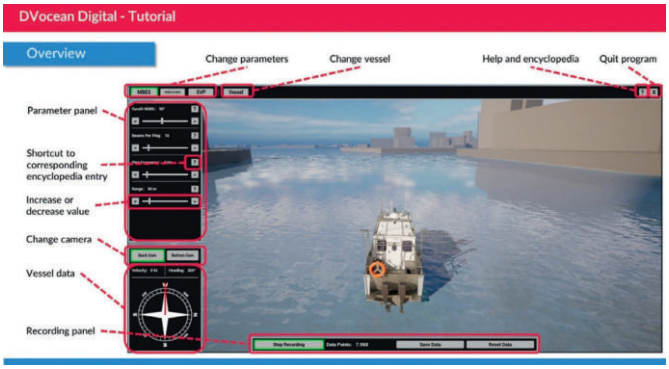
1: Ghent University, Department of Geography, Belgium
2: Antwerp Maritime Academy, Belgium
3: Ghent University, Department of Civil Engineering, Belgium

DVocean Digital – a surveying vessel for simulating bathymetric measurements

by: Simon Deggim[1], **Thomas Kersten**[1]

Keywords: 3D | hydrography | knowledge transfer | QGIS | simulation | training | Unreal Engine

Maritime shipping is of great importance to the Port of Hamburg as an economic factor. Therefore, the safety of maritime navigation is an important prerequisite for ensuring the smooth exchange of goods in the port. Safe shipping routes are achieved through permanent surveying of the shipping channels, river environment and seas, where up-to-date maritime charts are continuously produced. The production of up-to-date and precise maps requires modern equipment (ships and corresponding sensors) and trained personnel. In the hydrography specialisation of the Master's degree programme in Geodesy & Geoinformatics at HafenCity University (HCU) Hamburg, hydrographic students are trained according to the standard of the IHO (International Hydrographic Organisation). The (practical) training of hydrography students is an important and challenging task for HCU Hamburg, as graduates will continue to be urgently needed for surveying the world's oceans and inland waters in the future. Since the ship capacities for students training in hydrography in the Geodesy and Geoinformatics study programme are limited in terms of time and space, an interactive 3D application was developed to simulate hydrographic measurements in the Port of Hamburg.
This article describes the development of the application for the simulation of hydrographic 3D measurements using a multibeam echo sounder (MBES) in combination with GNSS/IMU positioning sensors integrated in the virtual 3D model of the surveying vessel *DVocean* of HCU Hamburg. The first version of the application includes the following six key elements: 1) modelling a detailed 3D version of the exterior of the *DVocean* to be used as the standard avatar vessel for the simulation, 2) simulate basic ship behaviour (floating) and movement (steering, acceleration) to navigate around the 3D environment, 3) design a virtual environment with underwater elements (dynamic seafloor features, shipwrecks, cables) to provide diverse simulation scenarios as well as features above water (shoreline elements or harbour/city model) for better orientation, 4) simulate the functionality of an MBES as well as the possibility to switch several parameters in real time, 5) provide additional educational content suited both for understanding the programme and gaining general knowledge about hydrographic surveying and 6) develop an interface for data export to allow post-processing of simulated measurements as real data in external programmes.
The figure displays the main interface along with an explanatory overlay from the tutorial. The ship can be steered with the arrow keys of the keyboard. A panel in the lower left corner provides the user with basic information about heading and speed. Above that, the camera view can be switched between »Back Cam« (steering mode) and »Bottom Cam« (instrument mode), with the latter making the water surface transparent and visualising every beam of the MBES. A panel at the top lists the menus for the different instruments, for switching the vessel, the encyclopaedia and ending the simulation. The instrument menus consist of subpanels that offer parameter switching functionality. The lower menu bar at the bottom of the screen shows information about the data recording status, buttons for starting and stopping data recording as well as for resetting and exporting data.



1: HafenCity University Hamburg, Germany

Session 6A

Environmental and habitat mapping

Taking into account more simply the environmental impact of hydrographic echo sounders

by: **Xavier Lurton**[1]

Keywords: environmental impact | echo sounder | hydrography | marine mammals

In the framework of the general effort to decrease the impact of man-caused underwater noise on the marine animal populations, the operation of sonar systems has been, for several decades, more and more subject to regulation and control. The initial concern was the impact of naval LFA sonars on marine mammals; it was then extended to all kinds of active sonar systems, including today echo sounders used for seafloor mapping.

In many countries, conducting seafloor-mapping survey cruises (for scientific, industrial or hydrographic purposes) implies a preliminary request for an authorisation based on the prediction of the field radiated by the sonars to be operated, compared to the acceptable impact thresholds established for the concerned marine animals (most often cetaceans) and different levels of impact (from disturbance to physical injury). When properly conducted for echo sounders, these studies usually lead to the conclusion of a very moderate impact, for a number of objective reasons: most echo sounders transmit high-frequency signals in the upper part of the animals' auditory ranges if not outside – and attenuating very fast in the seawater; surveying sonar sources are mobile and ensonify very briefly a given point; the echo sounder signals are very short (tens of microseconds to a few milliseconds) although relatively narrow-band (hence non-impulsive), and are transmitted inside narrow angular sectors (typically one degree), all factors dramatically minimising the time-space occupation by the sonar radiation. After comparison with the acceptable thresholds (mainly for cumulated received intensity), this leads logically to an absence of constraining measures for these systems.

It is very likely that such impact studies systematically conducted today are very redundant since they always concern the same sonar systems which are finally quite few. This is obviously a waste of time and efforts for both the applying operators and the regulating authorities: for a given system the resulting conclusion is always the same and could have been established once for all through a common preliminary effort involving the regulators and the constructors.

Although the subject of acoustical noise impact on marine life is a real concern today for a number of causes (increase of the shipping traffic, of offshore industrial activity and of various coastal activities), the specific case of echo sounders should be reconsidered. In this respect, it is suggested that the regulatory authorities should explicitly consider the current seafloor-mapping echo sounders, confirm their moderate impact according to current methodologies and standards and, when appropriate, exonerate them from preliminary impact studies. This could be helped by a joint effort from the echo sounders constructors in providing all the necessary technical information. Such an evolution could be supported by IHO and/or the main actors in the field of ocean mapping (hydrographic services, public agencies, oceanography institutes …).

1: Consultant in Underwater Acoustics, France

Hydrographic data from survey design to final habitat maps in the Norwegian seabed mapping programme MAREANO

by: **Terje Thorsnes**[1], Margaret Dolan[1], Lilja Bjarnadottir[1], Markus Diesing[1], Alexandre Schimel[1], Valerie Bellec[1], Daniel Wiberg[1]

Keywords: MAREANO | habitat map | sediment map

MAREANO is a Norwegian government-funded programme dedicated to providing knowledge for ecosystem-based management of the seafloor of Norwegian offshore waters. Running since 2005, the programme has a multi-disciplinary approach and focusing on seabed ecosystems, including mapping of bathymetry, geology, biology and chemistry.

Hydrographic data from multibeam surveys forms the backbone for the programme's wide range of products. First, a spatially balanced sampling survey is designed from the bathymetry (and morphological variables derived from bathymetry, such as rugosity and slope), backscatter data and oceanographic data (current, speed, temperature, etc.). The goal is to ensure that the sampling design covers the entire range of a site's environmental variation.

During subsequent sampling surveys, we collect a combination of video footage (or AUV images) and physical samples. Expert marine geologists then integrate this ground-truth data with the bathymetry and backscatter data to produce seabed sediment maps. Two types of sediment maps are produced: grain size (e.g. mud, sand, gravel, etc.) and genesis (e.g. suspension deposit, glaciomarine deposit, bedload deposit, etc.). Sub-bottom profiler data are used as supporting evidence for these sediment maps and to identify suitable stations for geochemistry multi-corer sampling (i.e. soft, layered sediments). High-quality backscatter data is necessary for accurate geological interpretation, even more so if machine learning algorithms are to be applied to this data for further mapping or research. A software for quality control of backscatter data has therefore been developed in-house.

Habitat maps are produced using multivariate statistical analysis and machine learning algorithms. Classified video data are combined with geological data, multibeam data and oceanographic data, and the final products are full coverage predicted biotope distribution maps and modelling summary. Another type of habitat map is the »Likely occurrences of coral reefs«, which shows cold-water coral carbonate mounds that can be identified based on specific geomorphometric features of the high-resolution bathymetry data. More than 200,000 likely occurrences of coral reefs have thus predicted on the Mid-Norwegian shelf, each with a confidence estimate. Water column data (WCD) are used for identifying natural gas seeps, where authigenic carbonate crusts often form parts of chemosynthetic habitats.

Recent findings from the North Sea indicate that geomorphology based on multibeam bathymetry may guide the search for vulnerable habitats. For example, a prominent moraine ridge investigated in 2023 appeared to host a northern horsemussel (Modiolus modiolus) reef, likely qualifying for the »OSPAR threatened and/or declining habitat« conservation status. A similar moraine ridge in one of the designated offshore wind areas in the North Sea was surveyed in March 2024 and similarly had presence of this habitat.

Most recently, we have been using synthetic-aperture sonar (SAS) data, collected with autonomous underwater vehicles (AUVs). The extremely highly detailed imagery from these systems provide important information about the sedimentary environment and hence the habitats. They may also give an estimate for the number of living corals on coral carbonate mounds and help documenting anthropogenic disturbance of the seabed habitats by bottom-trawling fisheries.

1: Geological Survey of Norway, Norway

Unveiling complex seafloor environments: Expanding the potential of multibeam echo sounders (MBES)

by: **Jens Schneider von Deimling**[1], Peter Feldens[2]

Keywords: multibeam | habitat mapping | backscatter | multifrequency | point clouds

Multibeam echo sounder systems (MBES) have become the gold standard for bathymetric surveys. However, their capabilities extend beyond traditional hydrography and have established as very powerful tools for marine geosciences. High-quality bathymetry and co-registered backscatter data collected by MBES offers valuable insights into diverse underwater environments, including seafloor substrate analysis, habitat mapping, and modelling. This study reviews the expanding role of MBES in environmental applications. We present a series of case studies conducted in acoustically challenging environments with various MBES systems, demonstrating their power to resolve complex seafloor features of geogenic or biogenic nature. Next to backscattering strength data from MBES, we explore water column records, multispectral and multidetect soundings. A one fits all solution for environmental and seafloor acoustic habitat mapping does not exist yet, neither any standards have been set so far. Our targets include backscatter signatures of gas seeps and spills, spurious and multispectral MBES soundings caused by different grain sizes and submerged aquatic vegetation (seagrass, algae), faint acoustic returns from black corals, and we present some examples of MBES penetration effects in acoustically soft seafloors. These investigations highlight how complex environments can lead to unconventional MBES data including seafloor echo misdetections. Conversely, a deeper understanding of such survey environments can inform mitigation strategies, leading to more accurate data acquisition. Overall our findings showcase some expanding potential of MBES for detailed environmental and seafloor habitat mapping.

1: Kiel University, Germany
2: Leibniz Institute for Baltic Sea Research (IOW), Germany

Machine learning and backscatter for spatial mapping of deep-sea polymetallic nodules

by: **Iason-Zois Gazis**[1], Francois Charlet[2], Jens Greinert[1,2]

Keywords: machine learning | backscatter | polymetallic nodules

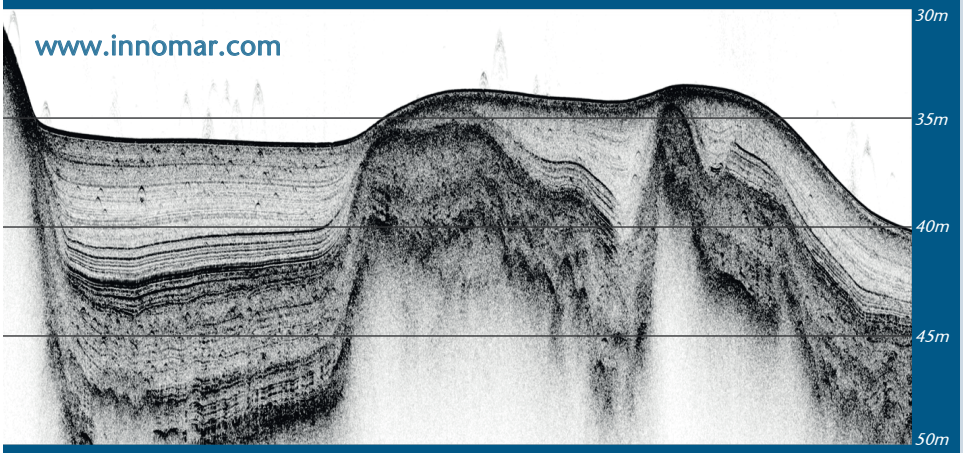
The decarbonisation of energy production is based on minerals and rare-earth elements such as those contained in deep-sea polymetallic nodules in water depths of 4500 m. This work focuses on advances in deep-sea polymetallic nodules spatial mapping in the Clarion-Clipperton Fracture Zone (eastern equatorial Pacific), where the International Seabed Authority (ISA) has issued the majority of exploration licenses and is currently drafting the exploitation regulations.

An autonomous underwater vehicle (AUV) mapped a geomorphologically complex part of the Global Sea Minerals Resources contract area using a multibeam echo sounder system (MBES) at 400 kHz and a side-scan sonar (SSS) at 260 kHz. In addition, more than 30,000 high-definition (4096 × 3072 pixels) seafloor images were obtained within the same study area and automated analysed with computer vision methods to extract the seafloor polymetallic nodule coverage. The MBES and SSS backscatter response was studied using an angular range analysis approach, showing the ability of MBES and SSS to discriminate areas and seafloor patches with a different polymetallic nodule coverage, even at steps of less than 10 %.

Five different machine learning regression algorithms (Generalised Linear Models, Generalised Additive Models, Support Vector Machines, Random Forests and Neural Networks) were used to develop a detailed and accurate spatial model of polymetallic nodule coverage, combining the image-derived information with the SSS and MBES-derived predictors such as backscatter mosaics at different angles, bathymetry, slope, slope orientation and seafloor ruggedness. The combined analysis and use of explainable artificial intelligence (XAI) techniques (e.g. 2D and 3D partial dependence plots, Shapley values) shed light on the black box character of machine learning models and provided valuable feedback regarding the contribution of each predictor. Moreover, local seafloor orthophoto-mosaics and image-derived digital elevation models supported the interpretation of the results.

Such high-resolution spatial modelling is needed to enable accurate resource estimation, define the mining path planning and improve our understanding of polymetallic nodule occurrences.

1: DeepSea Monitoring Group, GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany
2: GSR Global Sea Minerals Resources NV, DEME Group, Belgium
3: Kiel University, Germany



Data Example from a Norwegian Fjord (Innomar "standard" SBP, 10kHz)

Innomar Parametric Sub-Bottom Profilers

- Discover sub-seafloor structures and buried objects (cables, pipelines)
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Session 6B

OceanCon – Research

6B1	*Sascha Krohmann*	Innovation through applied research: Testing and development of hydrographic innovations within the Digital Ocean Lab
6B2	*Sebastian Bader*	Model-based underwater object detection and probabilistic digital twins
6B3	*Sven Junga*	Highly parallel Lattice Boltzmann simulation of an underwater testing site
6B4	*Daniel Stepputtis*	Fishing technology in transition

Innovation through applied research: Testing and development of hydrographic innovations within the Digital Ocean Lab

by: **Sascha Krohmann**[1]

Keywords: Digital Ocean Lab | testing | hydrographic research | sea trials | industry | sea surveillance | UXO | critical infrastructure | subsea cable

The development of innovative technologies in the field of hydrography is crucial for the sustainable exploration and utilisation of the oceans. The Digital Ocean Lab (DOL) provides a state-of-the-art testing environment that offers ideal conditions for testing and advancing new hydrographic innovations through applied research. The DOL offers multiple vehicle platforms that enable the quick and reliable integration of a wide variety of sensors, allowing for flexible and efficient testing setups. Of particular note is the ability to analyse hydroacoustic backscattering in an open water environment, which plays a key role in the development and optimisation of sensor and communication systems for shallow waters.

This presentation highlights the potential and opportunities of applied research, showing how an extensive infrastructure can efficiently support and facilitate innovation through rigorous testing processes. An interdisciplinary research group from the Fraunhofer Institutes is also dedicated to developing the innovations of tomorrow. Furthermore, the presentation emphasises the role of the DOL as an innovation platform that accelerates the transfer of research results into industrial practice, thereby enabling more efficient, precise and sustainable technologies for hydrography.

1: Fraunhofer IGD, Germany

Model-based underwater object detection and probabilistic digital twins

by: **Sebastian Bader**[1]

Keywords: digital twin | digital shadow | object detection | AUV

The detection of objects under water and the integration of all available information into a single high-level model are two important problems for building autonomous underwater vehicles (AUVs), or for supporting human pilots of remotely operated vehicles (ROVs).
Detecting objects under water based on sonar scans is challenging. Modern deep-learning based approaches require large amounts of real-world training data, which are either not available at all, or very hard to obtain. Therefore, we investigate learning free, model-based approaches to detect objects under water. Those approaches are able to detect objects with known shapes in noisy data.

Based on the detected objects and telemetry data of an ROV (remotely operated vehicle) or AUV (autonomous underwater vehicle), we construct probabilistic digital twins of the scene. Those twins (or to be precise digital shadows) contain available information as well as estimated uncertainties. In addition to integrating updates, the models must also be able to communicate the current state and the internal uncertainties to the user.
Both methods – the model-based detection and the construction of probabilistic digital twins – will be introduced and first results will be shown.

1: Universität Rostock, Germany

Highly parallel Lattice Boltzmann simulation of an underwater testing site

by: **Sven Junga**[1]

Keywords: Lattice Boltzmann method | computational fluid dynamics

Within the realm of computational fluid dynamics (CFD), the Lattice Boltzmann method has established itself as an alternative to the more traditional approach of solving the Navier-Stokes equations through finite-volume-solvers.
A distinct advantage of the Lattice Boltzmann method (LBM) is found in the explicit and local nature of its calculation scheme. This makes the Lattice-Boltzmann method inherently suitable to parallel computation on modern multiprocessor architectures. Especially graphics processing units allow for natural parallelisation of LBM algorithms enabling rapid large-scale simulation.
To channel this potential, an effort was made to create a CFD model of the currents of an area within the Baltic Sea. Located in the Digital Ocean Lab the Nienhagen artificial reef serves as an ideal site to collect data of current profiles and bathymetry. These are employed as boundary condition of the devised model.
The aim of the resulting LBM-based simulation is to demonstrate a multitude of possibilities that high performance GPU offers to support various use cases in a digital twin.
Such use cases include monitoring of current conditions occurring around offshore structures, training and mission planning for remotely operated and autonomous underwater vehicles. Hence the resulting current velocity data was interfaced with a robotics simulation framework.

1: Fraunhofer IGD, Germany

Fishing technology in transition

by: **Daniel Stepputtis**[1]

Keywords: fishery | sustainable use of marine living resources | technology | vessel of the future

The presentation takes a look at the complex ecological and economic interplay of fishing and fishing technology under changing societal and ecological conditions.
The increased focus on sustainable use of marine living resources, environmental impacts, climate effects and economic pressures calls for (amongst others) technical innovations in fisheries, including fishing gears and fishing vessels. Additionally, the business model of fisheries will likely change, including contributing to data collection for a better understanding of the marine environment.
Dr Stepputtis is fishing gear technologist, involved in international and interdisciplinary collaboration with other research institutions, industry and stakeholders. He actively seeks dialogue with fishermen, environmentalists and political decision-makers to contribute to a better fishing and hence to a better marine environment.

The lecture »Fishing technology in transition« will highlight innovations in fishing technology that aim to improve the efficiency and sustainability of fishing. It will also discuss the challenges and opportunities arising from the integration of new technologies into traditional fishing practices, as well as the general need for substantial transformation of the fishing sector – and gives an outlook to future projects.

1: Thünen Insitute of Baltic Sea Fisheries, Germany

Session 7A

Autonomy I

REPMUS: a catalyst for innovation in uncrewed hydrography

by: **Rui Miguel Cândido**[1], António Gonçalves Tavares[1], Laurenţiu-Florin Constantinoiu[2]

Keywords: REPMUS | rapid environmental assessment, REA | bathymetry | multibeam | LiDAR | critical underwater infrastructures | uncrewed | unmanned | military

REPMUS (Robotic Experimentation and Prototyping with Maritime Unmanned Systems) is an exercise series spearheaded by the Portuguese Navy, designed to foster large scale experimentation with unmanned systems, while promoting collaborative efforts among military, academia and industry stakeholders. Its ultimate goal is to develop, assess and validate state-of-the-art technology applicable to both maritime security and naval operations. In its 2023 iteration, REPMUS23 convened a large-scale international participation. Over 2,000 personnel were involved, encompassing a diverse range of expertise. These participants included civilian and military personnel, with representation from more than 25 navies, eight North Atlantic Treaty Organization (NATO) bodies and over 30 companies and universities.

A primary focus of REPMUS lies in the deployment of uncrewed assets for rapid environmental assessment (REA) operations, geared towards the swift evaluation of the area where a military operation is going to occur. Naturally, in the maritime domain, REA endeavours are heavily oriented towards characterising the bathymetry and the oceanography of a given location. The REPMUS23 REA scenario included the characterisation of a shallow water area in the vicinity of the Sado Estuary in Setúbal, Portugal. To accomplish this, the following systems were used: a DriX, an unmanned surface vehicle fitted with an EM712 multibeam echo sounder, a Camcopter S-100, an unmanned aerial vehicle equipped with a PILLS topographic and bathymetric LiDAR and satellite-derived bathymetry from Sentinel-2 multispectral imagery.

Furthermore, REA operations also encompassed the deployment of several gliders, which collected data crucial for constructing a 4D oceanographic model of the area of operations. This model not only supported the ongoing underwater warfare scenario but also facilitated the dissemination of sound speed profiles to assets engaged in offshore bathymetric surveys. Under the scope of the exercise, these data were promptly processed and fused together to quickly generate an operational product tailored to support the command and control of the subsequent naval operations.

REPMUS24, scheduled to occur in September, will provide yet another sandbox for uncrewed hydrography experimentation. This year's focus will be on the utilisation of maritime unmanned systems for critical underwater infrastructure monitoring, encompassing both shallow and deep water scenarios. Examples of such infrastructure include pipelines, communication cables and offshore wind turbine power cables.

This presentation aims to highlight the major lessons learned from previous REPMUS iterations. The REA workflow will be delineated, encompassing data acquisition, data processing, data fusion and the dissemination of the finalised products, with particular emphasis on the tasking of each asset. Moreover, results from REPMUS24 will also be incorporated, especially those pertaining the involvement of hydrography capable assets in the monitoring of critical underwater infrastructures.

1: Instituto Hidrográfico, Portugal
2: Maritime Geospatial, Meteorological and Oceanographic Centre of Excellence, NATO, Portugal

Maritime innovation and new technologies for future navigation and communication

by: Hans Herrmann[1], **Doreen Thoma**[1]

Keywords: GNSS jamming | R-Mode | autonomous ship

As a maritime service provider, the Federal Maritime and Hydrographic Agency (BSH) supports the development of devices and systems for navigation and communication in maritime shipping, from the initial idea in R&D projects, through standardisation and regulatory framework, to the type testing and national approval. We support the Federal Ministry of Digital and Transport, as well as partners in the maritime industry, science institutes and other authorities with our expertise.

We would like to provide a brief overview of research projects and the relevant standardisation work of current research projects in the field of shipping regarding smart e-navigation and new trends and demands in positioning. GNSS signals can be affected by jamming. Therefore, we developed GNSS receivers, which are more resistant to disturbances. We will inform about a new maritime GNSS backup system for resilient and resistant positioning. Another project deals with the automated berthing manoeuvre, for which electronic nautical charts are essential for manoeuvre planning. That's why we are currently actively working on the S-100 based product specifications like S-101 (Electronic Navigational Chart) in order to design the next generation of digital nautical charts. Finally, we will present a project, in which the ship's bridge should be able to be temporarily unmanned, with an autonomous navigation system taking over the crew's tasks for up to eight hours.

Thus, the BSH actively participates in the innovation process of maritime technologies through scientific and technological research and development. Particularly for (highly) automated maritime communication and navigation systems, the opportunities and risks of the application of artificial intelligence (e.g. for collision avoidance and object detection with vision equipment) will be considered.

1: Federal Maritime and Hydrographic Agency, Germany

True autonomy in offshore wind operations and maintenance

by: **Mona Lütjens**[1], Sören Themann[1]

Keywords: true autonomy | USV | O&M | wind farms

Subsea marine data is indispensable for wind farms, serving critical functions not only for preliminary site investigations and licensing requirements but further to monitoring the long-term health of underwater infrastructure throughout extensive Operations & Maintenance (O&M) cycles that often span decades.

Traditionally, gathering this vital data has been an expensive and lengthy process. However, advancements in autonomous marine survey and underwater inspection technologies, combined with workflow automation, are transforming the sector. These innovations promise to significantly diminish both the cost and time implications for wind farm O&M operations.

By automating mission planning and data acquisition, these cutting-edge systems minimise the need for human intervention, drastically cutting operational costs and duration. The deployment of such technologies offers several immediate benefits for wind farm O&M, including increased safety by limiting human exposure to risky underwater environments, enhanced precision in data collection, and the ability to reach previously inaccessible areas.

The emergence of »True Autonomy« represents a significant leap forward, moving towards fully self-governing systems capable of intelligent decision-making and real-time adaptation to environmental feedback. This advancement will facilitate a change in the efficiency with which marine data is collected, analysed and utilised, significantly impacting the long-term sustainability and operational viability of wind farms. As we move towards this future, the strategic adoption of autonomous technologies in wind farm O&M is set to transform marine surveying methods and elevate the benchmarks for operational efficiency and ecological responsibility within the renewable energy industry.

1: Subsea Europe Services GmbH, Germany

Transfer of autonomous mapping concepts to a small uncrewed surface vehicle

by: **Tom Schmidt**[1], Jan Witte[1], Uwe Lichtenstein[2], Angelika Zube[1], Philipp Woock[1]

Keywords: autonomy | mapping | obstacle | sonar | ASV

Further developments at the Fraunhofer IOSB improve on the autonomous mapping capabilities introduced in Zube et al. (2022) are presented using a different, much more compact platform with recent field applications on lakes, rivers and in harbour areas.

The autonomous surface vessel (ASV) is based on the Otter platform from Maritime Robotics and has been equipped with sensors and autonomy software by Fraunhofer IOSB. The platform carries a LiDAR for obstacle detection and avoidance as well as two cameras for 3D reconstruction of the environment. A Norbit iWBMSe multibeam sonar with 512 beams is used for underwater mapping. For ego-motion estimation, the platform is equipped with a dual-antenna GNSS receiver and a Waterlinked A-125 Doppler Velocity Log (DVL) as well as with an Applanix POSMV SurfMaster IMU. As the vessel is much smaller and easier to handle than its predecessor, measurement campaigns are performed with much less effort.

The vessel's autonomy is realised in IOSB's autonomy kit, which is added to the vessel's existing control computer. The on-board control computer is capable of receiving instructions in an algorithmic manner, i.e., no human has to be involved in commanding the vessel. The complete processing pipeline for autonomous navigation has been implemented, from obstacle detection and avoidance, through trajectory planning and control, to multi-sensor localisation and mapping. The autonomy kit continuously evaluates the situation around the vessel to determine if the given mission plan can be executed as initially planned or if it needs to be modified. The autonomous platform is designed to support waterway mapping, where an operator only specifies the area to be mapped and the vessel then performs this task while continuously reacting to either static or dynamic obstacles (moving ships or boats). A versatile user interface enables simple control via a notebook and controller or via an interactive digital map table, which allows intuitive mission specification and evaluation.

As part of the Smart Ocean Technologies research group in Rostock, the Fraunhofer IOSB has deployed the autonomous surface vessel with various settings in a variety of environments and weather conditions, demonstrating its ability to map embankments and shipping lanes. Mapping with this type of compact ASV in areas that are difficult to navigate clearly presents an advantage for the operator who is supervising the process rather than having to be aware of every challenge that may occur during a mission. The key for achieving an extensive operational area is an accurate perception of the surroundings that cumulates in a robust algorithm for obstacle avoidance.

In April, a test deployment was carried out in Schwerin's Inner Lake in cooperation with the Technical Operations Unit of the Mecklenburg-Vorpommern police force, during which areas of the lake ground were mapped autonomously so that identified objects could then be inspected by police divers. We assume that autonomous ASVs of such small size will become an indispensable tool for hydrographers to keep all maps of interest current with little effort.

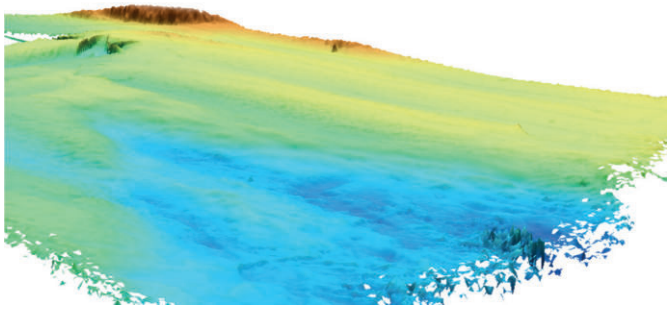
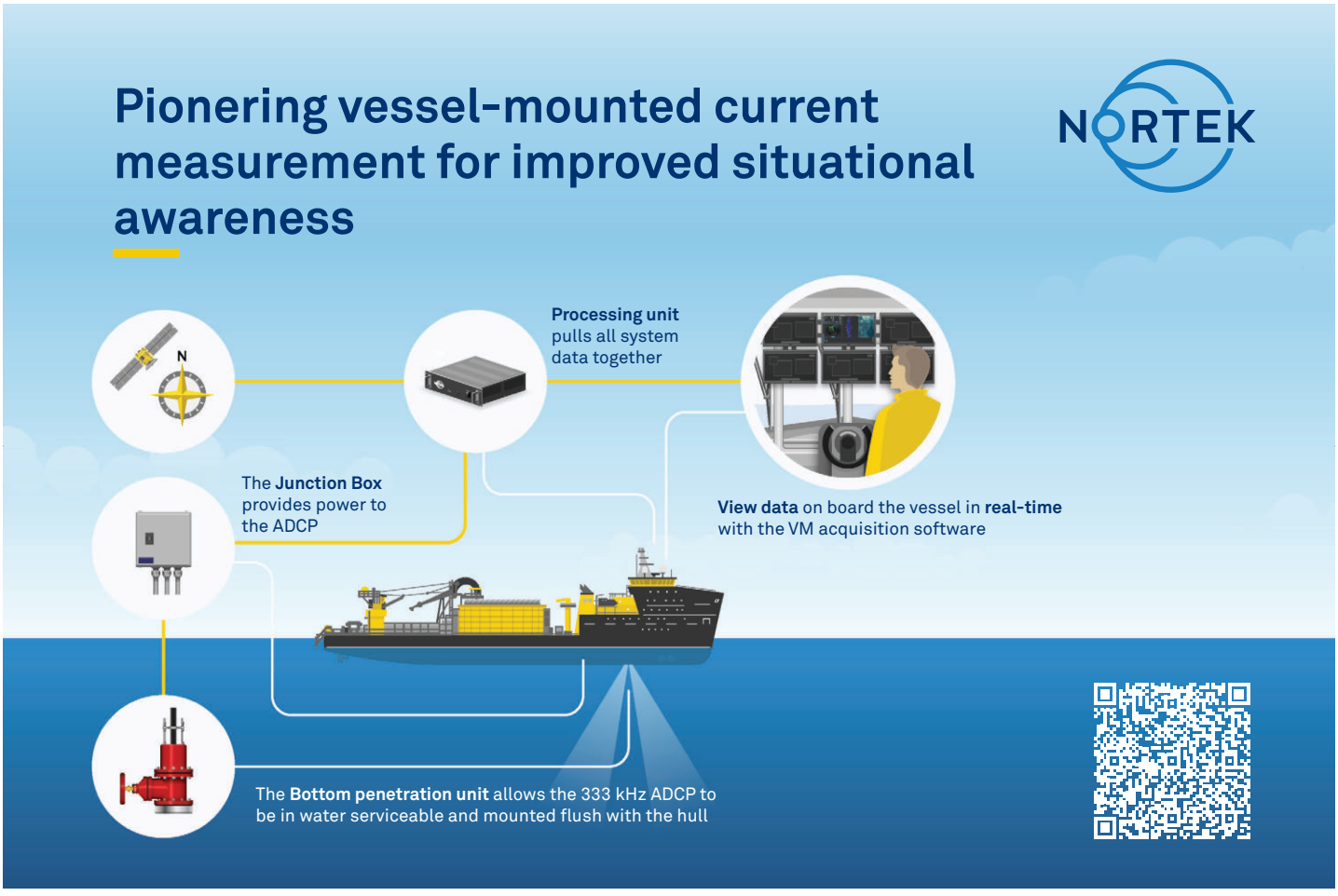


Figure: Real multibeam sonar data recorded by the now much smaller vessel at the Inner Lake of Schwerin

1: Fraunhofer IOSB, Germany
2: Fraunhofer IGD, Germany

Pioneering vessel-mounted current measurement for improved situational awareness



Session 7B

Water column analysis

Hydrography on Fishing Vessels (HyFiVe): A new monitoring system enables cost-effective and scalable ocean monitoring

by: **Andreas Hermann**[1], Frederik Furkert[1], Mathis Björner[2], Michael Naumann[2], Daniel Stepputtis[1], Martin Gag[3], Stanislas Klein[3]

Keywords: hydrography | monitoring system | vessels of opportunity | open source | citizen science

Whether for modelling climate change or for our understanding of fish stocks – ocean data is essential for many disciplines. Usually, this data is collected by research vessels, which are cost-intensive and thus limited in space and time. To increase data resolution »vessels of opportunity« can be a scalable alternative. In this concept vessels are used as measuring platforms, that are originally financed for a non-scientific purpose. Especially fishing vessels are of interest as they deploy gear in deep water and so make the whole water column accessible for an attached measuring system. In comparison to gliders and floats this approach is also suitable for shallow areas with high traffic, e.g. the Baltic Sea.

For this use case we developed a very flexible autonomous measuring system. This was done over the past three years within the project »Hydrography on Fishing Vessels – HyFiVe«. This measuring system essentially consists of three components: A sensor carrier, which is mounted on the fishing gear and gathers underwater data, a deck unit for geo-referencing and data transfer as well as a server onshore for automatic quality control and storage of the data. The data is accessible on- and offshore on a web server and via interfaces to international databases. During development particular attention was paid to modularity of the system as well as open standards and open sub-components. All development results are published under open-source licences, including source code, drawings, assembly instructions, etc. This enables the public to use and adapt the system for their needs and contributes to the sustainability of the public funding made in the project. Within the presentation we will give an overview of the HyFiVe measuring system and summarise the results of measurement campaigns carried out so far. We will show the benefit of the system for the community and explain ways, how to use it and adapt it to other applications and measurement parameters. Finally, we will report on current and future steps to further develop the system and bring it into widespread use.

1: Thuenen Institute of Baltic Sea Fisheries, Germany
2: Leibniz Institute for Baltic Sea Research (IOW), Germany
3: Hensel Elektronik GmbH, Germany

Benthic habitat mapping using airborne topo-bathymetric LiDAR – a case study in Lake Superior

by: **Malek Singer**[1], Ben Babbel[2]

Keywords: LiDAR | topo-bathymetric | habitat mapping | reflectance

This paper focuses on the use of airborne LiDAR to map the coastline and lakebed of part of Lake Superior in the northern United States. The topo-bathymetric data was used to create accurate digital elevation models and reflectance products to aid in enhancing the understanding of the Great Lakes hydrography and ecosystem. Specifically, the data was classified using the Coastal and Marine Ecological Classification Standard (CMECS) as defined by the National Oceanic and Atmospheric Administration (NOAA). The standard incorporates water column, geoform, substrate and biotic input to infer a habitat classification which is crucial for applications like aquatic resource identification, restoration and planning. The three dimensional and radiometric data from the topo-bathymetric LiDAR will be unpacked in this presentation, as well as a discussion on the benefits and challenges of using a laser based method for hydrographic mapping.

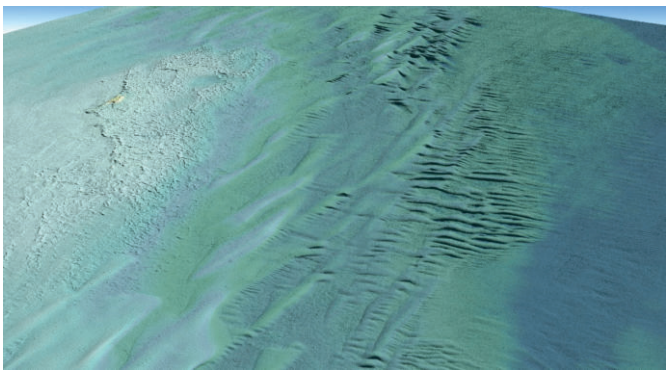


Figure: An oblique view of a digital elevation model (DEM) derived from topo-bathymetric LiDAR. This view is looking northwest across Lake Superior towards Tahquamenon Island in Whitefish Bay

1: Teledyne Geospatial, Canada
2: TetraTech, USA

Quantification of water turbidity by volumetric analysis of LiDAR bathymetry data

by: **Katja Richter**[1], David Mader[1], Hans-Gerd Maas[1]

Keywords: depth-resolved turbidity parameters | spatially resolved decay parameter fields | exponential function approximation | UAV LiDAR bathymetry

Monitoring water quality is essential for the ability to respond to changes affecting the ecosystem. An important metric of water quality is the turbidity of the water, which is an optical measure of the water transparency. Turbidity in natural water bodies results from suspended inorganic particles, such as sediment and organic particles. Additionally, the presence of coloured dissolved materials that absorb and scatter light decreases water transparency. Turbidity levels in surface water may vary significantly over space and time, even in the same water body. Such variations may for instance indicate increased algae growth caused by agricultural fertiliser inputs or increased concentrations of suspended sediments that enter the water body through erosion processes or are stirred up by wave action. In addition, nutrient inputs, freshwater inputs, and temperature changes may create thin layers with high concentrations of organisms or particles, resulting in higher water turbidity. The turbidity level of a water body significantly determines the light transmission through the water, which in turn affects the amount of light available for photosynthesis and the visual range relevant to predator hunting. Therefore, turbidity is an important indicator of the environmental conditions of water bodies. In particular, the analysis of the vertical stratification of turbidity provides information on the dynamics of the upper water layer and gives insight into ecological processes. Determining vertical turbidity stratification using conventional in-situ measurement methods (e.g. turbidimetry and nephelometry) is time-consuming and cost-effective, especially when large areas of water bodies need to be investigated. In addition, conventional measurement methods are limited to interactive local measurements that rarely represent the turbidity of a larger area.

Airborne LiDAR bathymetry (ALB) is a promising alternative for the comprehensive derivation of depth-resolved turbidity information. ALB systems measure the backscattered laser energy in the green wavelength range, which is affected by the scattering particles contained in the water. Turbidity results in a decrease in the intensity of the received signal. Information about water turbidity can be derived by analysing the full-waveform of the backscattered LiDAR signal.

We propose a robust signal analysis approach that allows the derivation of depth-resolved turbidity parameter fields. The basic idea is to transform the measurement data into a voxel space representation in which spatially resolved decay parameter fields are determined. For this purpose, the individual full-waveforms are integrated into a voxel space. Subsequently, an ortho full-waveform is assembled from the voxel attributes of each voxel space column. In the next step, the water column part of the ortho full-waveform is extracted. Finally, depth-resolved turbidity parameters are derived for each water column part by fitting multiple exponential segments into the volume backscatter.

The methodology was tested on a clear water lake using UAV LiDAR bathymetry data. For validation purposes, a comprehensive set of in-situ reference measurements is available, which were collected at the same time as the bathymetric data. The results show that the turbidity determined from the LiDAR data is confirmed by the reference measurements.

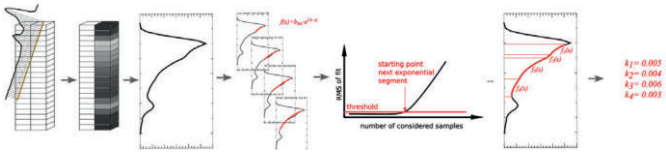


Figure: Schematic representation of segment-wise exponential function approximation

1: Dresden University of Technology, Germany

Using AUVs for measuring sedimentation processes in reservoirs

by: **Arnau Carrera Vinas**[1], Frederic M. Evers[2], Thomas Vonach[1]

Keywords: autonomous underwater vehicle | reservoir sedimentation | turbidity currents | inland waters

Hydropower-generated energy is vital in renewable electricity production due to its reliability and flexibility. In the United States of America, it represents 31.5 % of renewable energy produced, while in the European Union, it represents 29 %. However, the current storage capacities of hydropower reservoirs are decreasing annually due to sedimentation. It is predicted that by 2050, the capacity loss will be 26 % compared to the current 16 %. Therefore, managing sedimentation in reservoirs is necessary to prevent the loss of capacity and even extend the current capacity.

Detailed information on sediment accumulation, especially around the intake and low-level outlet structure and turbidity currents, are required to improve sedimentation management. Currently, surface vessels and moored sensors acquire sedimentation data in reservoirs, which are then used to create sedimentation accumulation maps and turbidity flow models. However, these measurements may not be enough to capture in detail the accumulation around the intake and outlets or to measure the evolution of gravity currents. Moreover, the existing models cannot capture the interaction of movable reservoir ground and the turbidity current.

In recent decades, autonomous underwater vehicles (AUVs) have been used in oceanography to investigate turbidity in marine environments. However, this is the first time that AUVs will be used in a reservoir to obtain turbidity measurements. Using AUVs increases accuracy and enables new measurement types by bringing sensors closer to the target. Subdron navigation algorithms will be used to safely navigate the AUV along the thalweg and close to underwater infrastructure such as intakes or dam walls. The AUV will characterise the environment using acoustic Doppler current profiler (ADCP) measurements and multibeam echo sounder (MBES). The ADCP signal-to-noise ratio (SNR) will be analysed to measure suspended sediment concentration (SSC) and high-resolution bathymetry collected with the MBES will be used to generate sediment accumulation map and study the interaction and erosional/depositional processes between turbidity currents and the reservoir floor.

Several experimental campaigns will be carried out in a Swiss reservoir between May and August 2024. The AUV-based measurements are expected to collect high-resolution bathymetric data of the sediment accumulate on key points of the reservoir and possibly provide details on the characteristics of turbidity currents, including flow velocities and bathymetric data. The link between flow velocities and bathymetric data will help scientists to better understand turbidity currents' erosional and depositional potential. In a future, the data obtained with the AUVs could be used to set up laboratory experiments and numerical simulations to model more accurately the sediments behaviours in a reservoir. The aim of the new models and simulations is to support the development of innovative and efficient sediment management strategies.

1: Subdron GmbH, Austria
2: ETH Zurich, Switzerland

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Session 8A

Autonomy II

Satellites, the autonomous surveyors – rapid assessment of storm-induced impacts to coastlines

by: **Kim Knauer**[1], Knut Hartmann[1], Edward Albada[1], Lindino Benedet[2], Morjana Signorin[2], Thomas Heege[1]

Keywords: satellite-derived bathymetry | post-storm mapping | shallow water | coastal monitoring

The mapping and monitoring of beaches affected by storm events is often a challenging task for local stakeholders. However, rapid assessments play an important role in quantifying losses and assisting in the decision-making process regarding disaster declarations. Traditionally, the immediate post-storm beach measurement is a beach profile measured along regularly spaced transects from the back of the beach to a safe wading depth. The offshore portion of the beach profile (from wading depth to the depth of closure) is typically collected at a later date via single-side beam sonar from a shallow-water vessel. This divided approach often results in data gaps due to the vessel's limiting safe draft clearance as well as any wave breaking zones, and may not capture the immediate post-storm profile. In addition, errors are introduced as further seabed movement may occur between the storm's passing and the survey date.

Utilising satellite-derived bathymetry (SDB) to map the changes could significantly help to improve the results. Bathymetry based on satellite data can be derived rapidly (often within 1 to 2 days) after the impact and is able to map the entire transect from the beach down to the deeper areas depending on the water clarity. In addition, there are often multiple recording dates pre- and post-storm available which allows for a mapping of impacts even if no traditional survey has been conducted before the storm event.

The applicability of SDB is assessed thorough comparative analysis between pre- and post-storm surveys SDB provided by EOMAP and hydrographic surveys conducted at Coquina Beach, located at the southern end of Anna Maria Island, Manatee County, Florida. By conducting this comparative analysis and examining the differences between hydrographic surveys and SDB, we outline the usefulness and effectiveness of using SDB in estimating preliminary volume losses after a storm event. This can contribute to greater accuracy in post-storm assessments for disaster declarations and facilitate a faster disaster response.

1: EOMAP, Germany
2: Coastal Protection Engineering, USA

Automating aquatic vegetation detection using airborne bathymetric LiDAR and high dimensional data analysis

by: **Jan Rhomberg-Kauert**[1], Martin Pfennigbauer[2], Gottfried Mandlburger[1]

Keywords: water-penetrating LiDAR | high dimensional data | vegetation | clustering | bathymetry

Aquatic vegetation plays a vital role in freshwater and marine ecosystems, as the interaction between flora and fauna creates intricate systems susceptible to ecological changes. Thus the monitoring of these systems, by means of broadening the analysis of aquatic vegetation, can greatly improve the understanding of climatic factors upon the ecosystem. Due to recent improvements in bathymetric LiDAR technology, detailed aquatic vegetation can be extracted using UAV based solutions for large quantities of coastal and inland water regions. One of the challenges of the underwater data analysis is the classification of terrain and vegetation, which can not sufficiently be achieved by established methods, due to the larger footprint of the green LiDAR, which often makes the seafloor, beneath vegetation, undetectable. Thus new methods need to be developed, adapting and improving current algorithms to overcome the challenges and provide new insights into the aquatic ecosystem.

Building upon the generally available features of bathymetric LiDAR, such as the coordinates, amplitude, normal vectors and eigenvalues, and combing these with calculated features, such as volume, curvature and entropy, we can create a high dimensional data set where each point contains an array of attributes. This so-called attribute space can now be scaled using a standard scaler to create a space, where each point of the point cloud is described by these attributes. All the points of the point cloud are now in a form that allow us to look for patterns regarding their attributes. But as these attributes are given in a high dimensional space they are affected by the »curse of high dimensionality«, meaning that commonly utilised unsupervised methods create unconventional results depending on the metrics utilised. Therefore, we deploy a technique often used in single-cell clustering, where we employ topology to project the attribute space into a regular two dimensional space, using Uniform Manifold Approximation and Projection for dimension reduction (UMAP). The projection of the attribute space preserves the high dimensional topological structure. Hence preserving high dimensional similarities and creating a projection in which points with close spatial proximity share high dimensional features. This projection can now be grouped using commonly used density-based clustering algorithms to generate sets of similar points.

Lastly, to separate those groups into the initial two categories, terrain and vegetation, we fit a plane into each cluster of points. This allows us to estimate the planarity of the cluster as a whole, as vegetation generally exhibits uneven surfaces and the terrain, on the other hand, is quite planar. Therefore, the plane fitting creates two groups of clusters, those with almost no pointwise deviation from the plane and those with a high pointwise deviation.

By selecting only the points with high residuum, we can accurately separate vegetation from water bottom topography, creating an unsupervised workflow for aquatic vegetation identification.

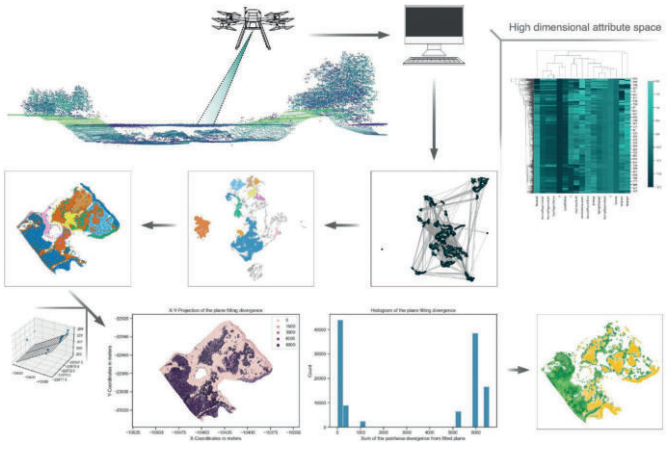

Figure: Illustration of the underwater vegetation analysis workflow

1: TU Wien, Austria
2: RIEGL Research Forschungsgesellschaft mbH, Austria

Boulders on the seafloor: Automatic detection, importance and challenges

by: **Peter Feldens**[1], Matthias Hinz[2,1], Patrick Westfeld[2], Agata Feldens[3], Sören Themann[3], Svenja Papenmeier[1]

Keywords: habitat mapping | hydroacoustic surveys | machine learning | object detection

The detection of boulders in sonar data is important for ecological and geological assessments, marine planning and offshore operations. Automated detection methods are required, as manual delineation of boulder fields can only give a coarse view of the actual situation on the seafloor. Boulder-detecting convolutional neural networks have been applied to sonar backscatter mosaics and bathymetric rasters to identify boulder distributions over large areas and delineate geogenic reefs in a fraction of the time required for manual mapping. After training on large data sets of boulders and related objects, the accuracy of these models has been validated against expert interpretation, achieving 70 % to 90 % agreement with human experts. However, interpreter bias in the creation of training and validation data sets remains a challenge. In addition, misclassification of water column noise, identification of artificial features such as plough marks, and the difficulty of detecting small objects with few pixels affect model performance. Upscaling of sonar mosaics has shown potential for improving the detection of small boulders, with resolutions of 0.5 m or finer improving the accuracy of boulder density grids, although further refinement is required to meet practical applications. Bathymetric data and data derivatives, where available, were found to produce better results than backscatter mosaics, likely due to fewer artefacts in the final data products. Despite the advantages of AI-driven methods, the routine integration of these models into hydrographic and oceanographic workflows has been limited.
A recent project has developed a graphical user interface for model training, evaluation and application, demonstrating the potential for full automation of boulder detection. While AI can significantly improve the speed and reproducibility of boulder detection, challenges remain in terms of data quality, resolution and environmental conditions, requiring quality checks of the final products by experienced hydroacoustic data interpreters.

1: Leibniz Institute for Baltic Sea Research (IOW), Germany
2: Federal Maritime and Hydrographic Agency, Germany
3: Subsea Europe Services, Germany

Session 9A

Optical hydrography II

9A1	*Ramona Baran et al.*	15 years practical experience in airborne laser bathymetry – project examples for continued sensor development and survey demands on data
9A2	*Peter Grabbert et al.*	Satellite imagery for intelligent hydrographic resource planning
9A3	*Laure-Anne Gueguen et al.*	Lab experiment for simultaneous reconstruction of water surface and bottom with a synchronised camera rig
9A4	*Christian Mulsow et al.*	Methods for geometric modelling of refraction in photo-bathymetry

15 years practical experience in airborne laser bathymetry – project examples for continued sensor development and survey demands on data

by: **Ramona Baran**[1], Ursula Riegl[2], Frank Steinbacher[1], Martin Pfennigbauer[2]

Keywords: shallow bathymetry | airborne laser systems

Over the last 10 to 15 years, airborne laser bathymetry of shallow waters became a standard survey tool bridging the gap between the classic topographic ALS and echo sounding of deeper water areas. Topo-bathymetric laser systems are especially characterised by a small footprint and high measurement rates yielding high resolution point clouds covering water depths down to 25 m under clear water conditions, and thereby reproducing great morphological detail. During the last years, also UAV-based survey by means of compact topo-bathymetric LiDAR sensors was established as viable method to efficiently complement ALB. UAV-borne data acquisition provides very high-resolution from low flying altitudes and slow flight speeds. But in both cases, the water quality is a limiting factor, water bodies often exhibit characteristics challenging the performance of ALB surveys, e.g. turbidity, dark-coloured water ground, etc. In such cases not only the laser configuration itself and the signal digitisation by the sensor during the survey (so-called online waveform processing) is of importance to achieve best possible results, but also the post-survey data processing is crucial to improving depth penetration and thereby enhances aerial coverage of the water bottom. The latter is accomplished by the full waveform processing of recorded laser signals right after the survey, e.g. using the FWF pipeline in the HydroVISH software developed by the Austrian-based airborne hydro mapping service and analysis company AHM. AHM, early adopter of the technology, and LiDAR system provider RIEGL have entertained a mutually inspiring cooperation over the years. Thus, for example, the added value of FWF processing by AHM triggered further developments on manufacturer side (RIEGL), e.g. establishing laser configuration settings with timely extended FWF recording, providing new possibilities on surveyor side (AHM) to directly adjust the laser configuration during survey in case of deteriorated water conditions related turbidity, and allow for maintaining survey requirements in terms of desired water depth. In our presentation, we focus on demonstrating the outcomes and advantages of a close manufacturer/surveyor cooperation based on project results over the last years as well as recently finished projects.

1: Airborne HydroMapping GmbH, Austria
2: RIEGL Laser Measurement Systems GmbH, Austria

Satellite imagery for intelligent hydrographic resource planning

by: **Peter Grabbert**[1], Patrick Westfeld[1]

Keywords: satellite-derived bathymetry | change detection and monitoring | convolutional neural network | Copernicus | intelligent resource planning

The Federal Maritime and Hydrographic Agency (BSH) is responsible for the continuous monitoring of the German coastal waters of the North Sea and the Baltic Sea, including the Exclusive Economic Zones. In particular, the shape of shallow coastal areas is constantly changing due to tides and swell. More frequent surveys of the seabed are needed to provide accurate, reliable and up-to-date information. Multispectral Copernicus Sentinel-2 satellite imagery can be used to detect changes in the seabed. Better knowledge of seabed changes means that ship deployment times can be prioritised much more efficiently and shipborne hydrographic surveys can be better planned. Impacts on the fragile marine environment can also be minimised or avoided through carefully planned re-surveys.

The presentation will summarise the results achieved so far in the research and development project »Integrated processing of multispectral Sentinel-2 satellite image sequences for satellite-based operational planning in hydrographic surveying (S·O·S)«. The objective of S·O·S is to develop techniques for reliable detection of seabed topographic changes from optical satellite imagery and to implement a prototype operational service based on this. This service will analyse the information provided on seabed variations and other factors, derive location-specific metrics and decision parameters, and provide an intuitive traffic light system for operational resource planning and guidance.

In a first step, the bathymetry of optically well penetrable shallow water areas is derived for each pixel of a Sentinel-2 satellite image scene using seven Sentinel-2 bands between B1 (coastal aerosol) and B8 (near infrared). This is done using AI-based methods for spectral depth determination. The presentation will show examples from the German Baltic Sea, where a convolutional neural network (CNN)-based approach provides bathymetric information with high temporal resolution for coastal waters down to about 10 m depth with an accuracy in the range of a few decimetres.

In a second step, the previously extracted depth values are augmented with spatio-temporal information on wave conditions and ocean currents. Using various change analysis techniques, parameters describing the dynamics of each area are derived from all available data. The derived parameters are weighted and agglomerated, and the areas are then clustered. The results of the change analysis are presented in the presentation and an outlook is given on how to derive the magnitude and direction of seabed displacements.

Finally, the progress made in developing the fully automated workflow implemented in a prototyped service is presented. This service will have a positive impact on the efficiency of workflows in the hydrographic survey service of the BSH, optimising the distribution of scarce resources and consequently increasing the timeliness of the hydrographic survey data acquired.

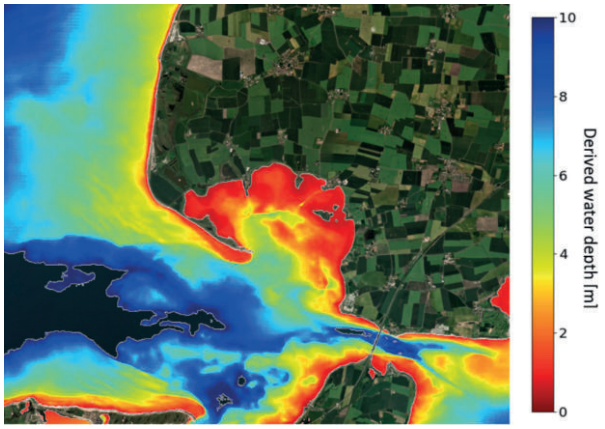

Figure: Survey and monitoring of shallow waters around Fehmarn Island (Germany) using satellite imagery

1: Federal Maritime and Hydrographic Agency, Germany

Lab experiment for simultaneous reconstruction of water surface and bottom with a synchronised camera rig

by: **Laure-Anne Gueguen**[1], Gottfried Mandlburger[1]

Keywords: photo bathymetry | water surface | synchronised camera rig

Photo bathymetry is the use of photogrammetry for the reconstruction of the underwater topography. The imaging systems are located above water and the optical rays go through two different media, air and water, which means the rays are refracted at the water surface according to Snell's law. This refraction leads to a blur in the images and an error in the reconstruction of the topography, and represents today the main limitation to achieving high-accuracy photo bathymetry. A 3D model of the water surface at the time of capture of the topography is therefore a prerequisite to correct the ray paths. Our method aims to solve the problem of simultaneous reconstruction of the water bottom and the water surface. In this contribution, we present the setup and the results of an experiment carried out in the measurement lab of TU Wien.

We have borrowed a complete camera rig from IfP Stuttgart. This setup is composed of four cameras and lenses, an Arduino Leonardo and the associated cabling. The Arduino serves as a controller and synchronises the cameras by sending a trigger signal in user-definable intervals via a cabled USB connection. Two cameras are used to capture the water surface, looking obliquely from the side, and the other two to capture the water bottom, looking nadir from above. A water tank is filled with water and two layers of stones to obtain a textured topography. Finally, we use an indoor fountain pump to create a dynamic water surface. Prior to the data acquisition, we first installed an array of coded photogrammetric targets on the floor, walls and measurement pillars in the corner of the lab and measured the 3D coordinates with sub-mm precision with a total station. These targets served as control and check points in the bundle block adjustment. In a second step, we measured the topography of the empty water tank with a conventional image block using a Structure-from-Motion and Dense Image Matching approach to obtain a reference model that will serve as validation.

As an example, the figure shows the overlap of two consecutive models of the dynamic water surface from pairs of simultaneous images taken from the oblique cameras. At the time of writing this abstract, our results don't allow us to obtain a complete 3D reconstruction of the water surface at time T but data processing is still in progress. Depending on the final success, we further plan to use a drone squadron for capturing real world scenes with the same concept.

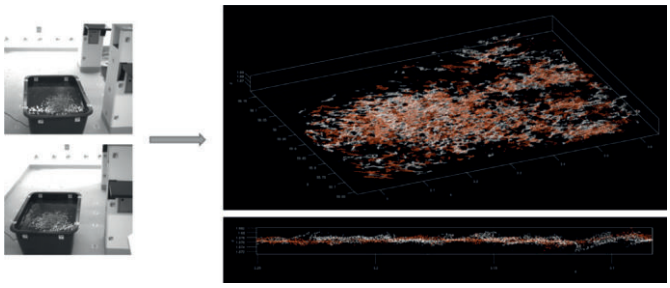

Figure: Overlap of two consecutive models of the water surface obtained from pairs of synchronised images (white: T, orange: T + 1s)

1: TU Wien, Austria

Methods for geometric modelling of refraction in photo-bathymetry

by: **Christian Mulsow**[1], Hannes Sardemann[1], Hans-Gerd Maas[1]

Keywords: underwater photogrammetry | photobathymetry | Snell's law | water surface | water bottom

Image based bathymetry (photobathymetry, also referred to as through water or multimedia photogrammetry) has a long history as a method for airplane-based capture of submerged topography of shallow water bodies, such as shore lines or riverbanks. While the method lost its stand as the standard method for such measurement tasks with the advent of laser bathymetry, the introduction of highly automated techniques for image orientation and 3D reconstruction from image data (e.g. Structure from Motion, SfM) and dense image matching led to a renaissance of photobathymetry in the last decade.
When using images for the generation of point clouds of submerged objects or of the water bottom, refraction has to be considered. Precise knowledge of the water level height and orientation as well as the refractive index is crucial for modelling refraction. While the refractive index for a specific water body can be estimated from salinity and temperature, the determination of the shape of the water surface, especially in wavy conditions, is much more complex – and essential for obtaining satisfactory underwater photogrammetric measurement accuracies.
In the case of calm water, the water surface may be approximated as a horizontal plane. However, this is rarely the case, especially in marine environments.
The Institute of Photogrammetry and Remote Sensing at TU Dresden works on different projects in the field of photobathymetry, from laboratory scale to aerial imagery. We will present universal approaches for strict modelling of refraction and their integration into standard photogrammetric procedures. Further, mathematical descriptions of non-planar water surfaces will be discussed. A major benefit of the mentioned methods is the possibility of simultaneous determination of all parameters of a through-water image block. This includes the image orientation and camera calibration as well as underwater points and the water surface itself. The method can also be applied to scenarios with underwater cameras. The proof of concept was given by several projects carried out under different conditions and in different scales.

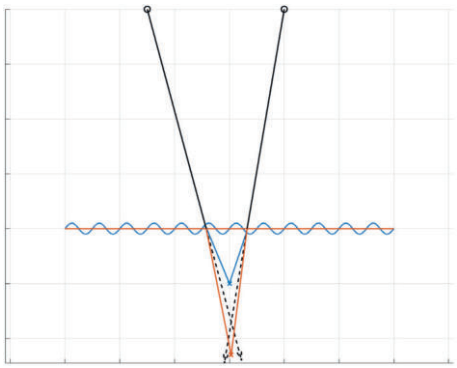

Figure: Object point locations (2D projection) depending on water surface. Black rays depict image rays above the water (solid) and assuming that there is no water present (dashed). The red rays show the refracted image rays assuming a planar water surface and the blue rays assuming a sinusoidal water surface. The large deviations underline the need for strict modelling of refraction as well as a proper mathematical description of the actual water surface

1: Dresden University of Technology, Germany

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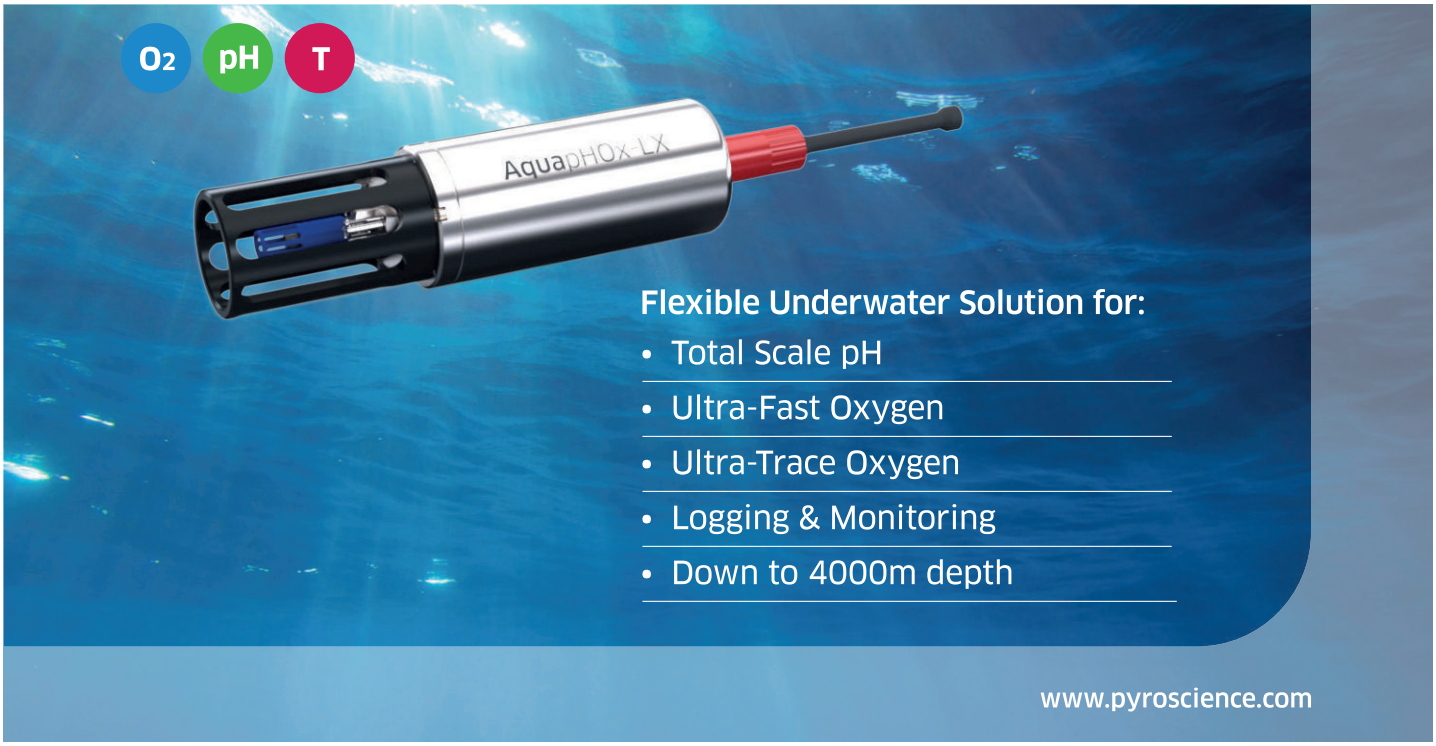

Session 9B

OceanCon – Commercial applications

9B1	*Peter Menzel*	Innovation through collaboration: New services and opportunities at and with the Digital Ocean Lab
9B2	*Florin Kümin*	Underwater close range mapping
9B3	*Janne Silden*	Innovative quay wall surveys: Leveraging unmanned surface vehicles
9B4	*Nico Günzel et al.*	Platform-based sensor fusion to improve data quality

Innovation through collaboration: New services and opportunities at and with the Digital Ocean Lab

by: **Peter Menzel**[1]

Keywords: Digital Ocean Lab | sea trials | industry | sea surveillance | UXO | critical infrastructure | subsea cable | service | testing

The founding of the Rostock Institute for Ocean Technologies GmbH (RIOT) represents the next significant step in the development of the Ocean Technology Campus Rostock and the Digital Ocean Lab. With its shareholders, who have been anchored in the maritime industry for many years, RIOT pools the expertise of around 120 employees.
RIOT's main task is to identify the needs of the maritime industry directly from the end user and to place them at the Rostock location by means of good industry knowledge and established networks with the key players in the market.
In order to realise this, RIOT works very closely with the Digital Ocean Lab and provides the necessary flexibility, knowledge, engineering and background information to quickly, unbureaucratically and confidentially implement complex issues and services. This collaboration with Fraunhofer will be communicated to the public for the first time in the presentation.
Currently, RIOT's main fields of activity in the technology sector are:

- maritime surveillance,
- surveillance of critical maritime infrastructure,
- maritime operations and operation of maritime infrastructure.

The main services of RIOT are:

- the final development steps from prototype to qualification and implementation in industry (TRL 7 to 9),
- retention of skilled labour from research and qualification for industry,
- personnel services,
- support for the Ocean Technology Campus,
- consultancy for industry and research,
- research and development,
- complex data acquisition services.

The presentation provides information on how this is achieved.
A second first-time announcement will be the co-operation between north.io, Subsea Europe Services and RIOT. By pooling their expertise, the consortium plans to implement not only a maritime information platform, but also the associated acquisition, transfer, processing, storage and provision of maritime data from a single source. This will create enormous added value for the Rostock location, including the research landscape around the Digital Ocean Lab, in the future.
In future, RIOT will therefore be able to work with Fraunhofer and other partners from the maritime industry to place joint service offerings on the market that go far beyond the capabilities of each individual partner and thus facilitate access to the international offshore market.
A comprehensive service package will be put together for the partners in order to be able to answer even complex questions quickly and competently.

1: Rostock Institute for Ocean Technologies, Germany

Underwater close range mapping

by: **Florin Kümin**[1]

Keywords: underwater mapping | 3D reconstruction | photogrammetry

Having a representation of an environment is crucial for humans and machines alike if they aim to interact with it. This is the case above and below the water surface, but what separates these worlds is how perception is possible. The main differentiator is the high reliance on visuals and light that humans and robots shifted towards. With good reason. The precise propagation of light and the recognisability of points based on their appearance are rich sources of information that enable 3D perception. This is true above and below water, but the range at which light is a valuable source of information is greatly reduced underwater, rendering cameras and laser-scanners useless in most applications.

The most common alternative to visual measurements underwater are acoustic sensors that rely on physical waves instead of electromagnetic. Their working principle drastically increases in effectiveness with increasing density of the medium they work. This makes them a good fit for underwater environments. Despite greatly outperforming visual sensors at range, the main drawback of acoustic sensors is their precision, accuracy and the anomalies when relying on physical waves instead of light. These drawbacks can be minimised by means of quality components and software, but such measures come at a high price when compared to costs of good cameras and laser scanners. What Tethys Robotics recognised is that one can mitigate the most prominent drawbacks that acoustic sensors have and thereby redefine how the cost-effectiveness of acoustic sensors is evaluated.

The main factor that enables high resolution acoustic maps without top-shelf sensors is to rely on accurate global localisation underwater and map infrastructure from closer ranges. This yields accurate acoustic measurements even with low-cost multibeam sonars while greatly outperforming cameras and laser-scanners in time and cost to map infrastructure like hydropower dams, bridges and harbours. The developed method of acoustic 3D mapping is real-time capable and scalable to map sizes above 300×300m.

In cases where the visual information is key for the assessment of the infrastructure, distance is again key. Clear images of hydropower dams can be obtained when within half a metre of the wall, which means that the field of view covers less than one square metre. Mapping out large areas in this fashion is only feasible fully autonomously, which poses high requirements on perception, localisation and control to perform reliably and safely. With consistent data acquisition this enables construction of post-processed orthophotos covering large flat structures, all enabled by using acoustic and visual sensors at ultra-close range.

The presented methods give insight into the efforts made by Tethys Robotics to provide real-time 3D mapping and meaningful visual information for large environments. The results represent a company's work of several years in the underwater ROV sector and their most recent advancements in underwater mapping, a growing field in robotics that has a bar set above sea level to be measured against, and a dedicated community undaunted by the challenges.

1: Tethys Robotics, Germany

Innovative quay wall surveys: Leveraging unmanned surface vehicles

by: **Janne Silden**[1], Ezekiel David[1], Jorge Ibaceta[1]

Keywords: quay wall survey | 3D model | USV

Regular surveys of quay walls ensure they remain structurally sound and operational, but traditional inspection methods can be labour-intensive and limited by access constraints. However, new approaches that leverage autonomous technologies are advancing the field in terms of operational efficiency on the water, data quality and the extent to which 3D models can be created and applied for engineering and maintenance purposes.
Subsea Europe Services GmbH, a marine survey and underwater inspection specialist has been working on a solution based on the integration of a tilted multibeam echo sounder (MBES) mounted on an unmanned surface vehicle (USV). It was put to the test this summer in the Alter Hafen Süd port in Rostock, Germany, during a successful quay wall survey that demonstrated how the combination of cutting-edge acoustic and autonomous systems can significantly enhance surveying and analysis in complex harbour environments.

1: Subsea Europe Services, Germany

Platform-based sensor fusion to improve data quality

by: **Nico Günzel**[1], Christopher Riess[1]

Keywords: sensor fusion | position accuracy | modular platform | data collection

This presentation will focus on sensor fusion as an approach to improving data quality. By integrating different sensor inputs into a coherent framework, we can significantly improve the position accuracy and reliability of underwater vehicles based on our modular platform.

We want to use a case study to show participants how the use of sensor fusion can lead to better data collection and informed decisions in data post-processing. Which in the end significantly increases the value of the collected data at a comparatively low cost.

1: Framework Robotics, Germany

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Session 10A

Quality aspects of MBES measurements

The Belgian Kwinte reference area – Part A: A bathymetric reference area for quality control of shallow-water multibeam echo sounders

by: **Samuel Deleu**[1], Marc Roche[2], Kris Vanparys[1], Koen Degrendele[2], Florian Barette[2], Johan Verstraeten[1]

Keywords: multibeam echo sounder | reference area | bathymetry | quality control

In order to assess the quality of the bathymetric data sets from different multibeam systems and different vessels, a reference area on the Belgian part of the North Sea has been established: the Kwinte area. This reference area has been included in the Marine Spatial Plan (MSP) 2020–2026 for the Belgian Part of the North Sea as a reference area for underwater acoustic sensors. In practice, all seabed disturbing activities are prohibited inside this area in order to preserve at long term an undisturbed seabed for bathymetric and backscatter measurements. Extensive survey work by Flemish Hydrography (VH), Continental Shelf Service (COPCO) and other participants to this project has been carried out during the last decade here. Multiple surveys allow to cross-check the depths and positioning of the different measurements and to build up a reference bathymetric model of the area.

Over a period of ten years, the seabed of the Kwinte reference area can be considered as bathymetric stable. The area is to a large extent flat. The sedimentary cover of the Kwinte reference area consists of gravelly Sand (gS) and sandy Gravel (sG) with a high carbonate content exceeding 15 %, due to the abundance of shells.

Data sets are examined on overlap, visible artefacts, spikes, confidence level, statistical analysis and checked with reference to the TVO of the IHO Exclusive Order Norm. Difference maps are generated to compare each survey with any other survey and with the model. In this presentation these results and the methods for quality control will be discussed. After each new accepted survey, the model is updated. Of course, it is clear that over time, a discussion is necessary on what a »stable seabed« means. In the plot one could or could not see a trend in mean depth value over time of the control area.

A mean value per survey on a small subarea is calculated for each survey and plotted in time with reference to the mean model value and the IHO Exclusive Order Norm limits. The results of all these analyses determine if a new survey is accepted or not and provides certainty of the quality of the multibeam setup. It is also used as an acceptation test for survey companies carrying out survey work on the Belgian part of the North Sea for Flemish Hydrography.

Next to that in the second presentation »The Belgian Kwinte reference area – Part B« by Roche et al., the backscatter results on the Kwinte area will be discussed and its use for backscatter calibration.

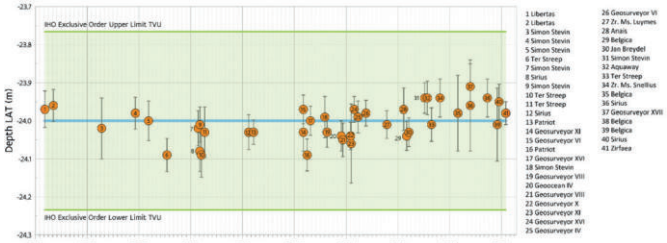

Figure: Bathymetric time series of the Kwinte reference area. Orange dots are mean depth values of all soundings with 95 % confidence error bars. The blue line is the mean depth value of the model and in green are the IHO Exclusive Order Norm values

1: Flemish Hydrography, Belgium
2: Continental Shelf Service, Belgium

The Belgian Kwinte reference area – Part B: Its use for calibrating backscatter levels of shallow-water multibeam echo sounders

by: **Marc Roche**[1], Samuel Deleu[2], Ridha Fezzani[3], Arnaud Gaillot[3], Kris Vanparys[2], Jan Vercaemst[2], Koen Degrendele[1], Florian Barette[1], Johan Verstraeten[2]

Keywords: multibeam echo sounder | reference area | backscatter | cross calibration

The increasing use of backscatter (BS) in seafloor habitat mapping highlights the need to calibrate survey sonars used to measure seafloor BS intensity alongside bathymetry. Indeed, calibrated BS data acquired by different sonars at similar frequencies are intercomparable and allow access to sediment properties.

However, even today, the majority of multibeam echo sounder (MBES) are not calibrated for BS. This lack is such a handicap to the optimal use of BS data from different MBES in scientific seafloor mapping and monitoring projects that it is legitimate to wonder why this situation persists, despite the recommendations and requests published on this subject for two decades. Certainly, even for shallow-water MBES, technical requirements and additional costs of in-tank calibration have hampered the use of BS calibration. In addition, calibration using reference spheres of known frequency response is also a serious challenge due to the difficulty to precisely locate the target inside the narrow beams of modern MBES.

Calibration on a reference area provides a pragmatic solution for calibrating MBES BS. This approach is based on the assumption of stability and coherence of the sediment cover of a seabed reference area where measurements are made at different angles of incidence using a calibrated single-beam echo sounder. The angular response models derived from these calibrated measurements are in turn used as a reference to calibrate the MBES for each of its operating modes (frequency, sector mode, pulse length) based on its own measurements of the same reference area.

The Kwinte reference area (KRA) near Oostende Harbour in the Belgian part of the North Sea (BPNS) is used to control the hydrographic quality of bathymetric data (see »The Belgian Kwinte reference area – Part A«).

In order to use the KRA for MBES BS calibration, multi-frequency (50–440 kHz) angular backscatter measurements were performed with a calibrated EK80 single-beam echo sounder steered using a pan&tilt unit. The BS angular response curves derived from these calibrated measurements are made public so that they can be used as reference levels for calibrating any MBES used in the BPNS and in neighbouring countries.

For surveys in the BPNS, a protocol organises the calibration based on systematic measurement of the KRA and integration of the correction derived from these measurements into the MBES acquisition system when starting a survey cruise. By this way, calibrated bottom and water column BS data can be obtained in real time.

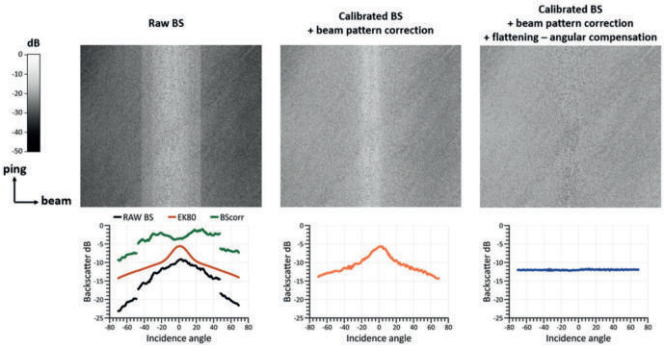

Figure: Principle of BS calibration on a reference area

1: Continental Shelf Service, Belgium
2: Flemish Hydrography, Belgium
3: Ifremer, France

A revaluation of multibeam beam-steering accuracy

by: **Jean-Guy Nistad**[1], Patrick Westfeld[1]

Keywords: sound speed | multibeam | beam-steering

Sound speed related errors in multibeam echo sounder bathymetric measurements are a common occurrence in highly stratified marine environments. Thankfully, the error dynamics are well understood and can thus easily be identified during survey data acquisition or post-processing as non-linear tilting signatures of the multibeam swath. Many methods and several commercially available software tools aim to mitigate or at least constrain the effect of sound speed errors to a manageable portion of the entire survey error budget. However, most of these methods assume that the measurements of the (surface) sound speed sensor located near the transducer array is perfectly known. This assumption simplifies the error dynamics to a ray-tracing problem with in-phase non-linear tilting. Surface sound speed errors, if present, would add a beam steering error component, which, when combined with ray-tracing errors, would create more complex errors signatures, including possibly out-of-phase linear tilting. Validating the absolute accuracy of (surface) sound speed measurements being practically impossible, surveyors are left with few QC/QA options to validate (surface) sound speed measurement accuracy. These include regular laboratory sensor calibration and constant monitoring of the sensor with the more sparsely spaced sound speed profiles.

Previous work on high-resolution sound speed profile measurement and interpolation techniques conducted at BSH demonstrated their benefit to mitigate ray-tracing errors. Yet, faced with the presence of residual non-linear tilting, also demonstrated their limitations. Therefore, an attempt to investigate the relative accuracy of (surface) sound speed measurements was initiated. During routine multibeam survey operations in the Baltic Sea in the summer of 2023, two (surface) sound speed sensors were simultaneously registered and alternately operated for real-time beam steering (Figure). Sound speed profile measurements from a continuously operating moving vessel profiler (MVP) were also collected, thus enabling a comparison between three independent sound speed sensors. Moreover, the MVP provided a portrait of the water column variability, thus facilitating the identification of times/locations of concern for the (surface) sound speed accuracy and consequently the beam steering. A beam steering recomputation routine was applied in the NOAA/OCS Kluster software in order to post-process the bathymetric data using both (surface) sound speed sources. Analysis results demonstrate deviations from the manufactory stated accuracies that lead to a detrimental impact on depth measurements. The presence of a mean difference of 0.75 m/s between both (surface) sound speed sensors leads to biases in exceed of 0.25 % w.d. (water depth) in the depth measurements, thus exceeding the sound speed error contribution limit to the overall error budget. Depth measurement redundancy from overlapping parallel swaths and on a pseudo-reference surface allows for the determination of the approximate (surface) sound speed error. The impact of (surface) sound speed filtering is also investigated in order to evaluate its effect on residual motion correlated depth artefacts. It is shown that the length scale of the filtered (surface) sound speed is different from that of the depth artefacts.

1: Federal Maritime and Hydrographic Agency (BSH), Germany

Enhancing digital bathymetric models by advanced measurement uncertainty analysis

by: **Bahareh Mohammadivojdan**[1], Frederic Hake[1], Felix Lorenz[2], Robert Weiß[2], Thomas Artz[2], Hamza Alkhatib[1], Ingo Neumann[1]

Keywords: DBM | surface model | MBES | uncertainty modelling | uncertainty budget

Ensuring safe navigation on waterways requires accurate and reliable digital bathymetric models (DBM). A reliable model is based on accurate measurements and a reliable modelling technique. Underwater measurements are highly error prone due to harsh environmental conditions, and the lack of knowledge about the true underwater geometry makes the task of evaluating the measurements and DBMs very difficult. This paper investigates how measurement uncertainty affects the quality of DBMs. We propose a pipeline on how to model these uncertainties and how this information can be used to build a more reliable DBM. We use a simulation to reproduce measurements acquired by a multibeam echo sounder system (MBES) in terms of 3D coordinates and their corresponding uncertainties. Our method focuses on improving the accuracy and reliability of DBMs based on measurement uncertainties, which are critical for navigational safety.

Our approach consists of two main steps. First, we determine the total propagated uncertainty (TPU) for each point measured by an exemplary MBES. The TPU is determined using the law of error propagation, taking into account various uncertainties from factors such as instrument accuracy to environmental conditions. To accurately assess these uncertainties, we use a Monte Carlo Simulation (MCS) approach. This is a critical step because it provides a detailed understanding of the uncertainties that affect our measurements. The second step is to assess how these uncertainties affect the final DBM. By analysing the uncertainty of each point, we adjust its influence in the model, resulting in a more reliable DBM. This methodical adjustment is not only the key to improving the reliability of the DBM, but also allows to build a quality assured model. These results are used as a basis for assessing the quality of the DBM and the required error budget. We validate our approach in a controlled simulation where the true geometry and uncertainties are known. This confirms the effectiveness and practicality of our method for producing accurate DBMs.

This research, conducted in collaboration with the Federal Institute of Hydrology (BfG), proposes a method to improve the accuracy and reliability of digital bathymetric models by carefully analysing and adjusting for measurement uncertainties. The results not only provide insights into the technical aspects of uncertainty modelling and surface modelling, but also emphasises the importance of measurement uncertainty for navigational safety and model quality.

1: Leibniz University Hannover, Germany
2: Federal Institute of Hydrology (BfG), Germany

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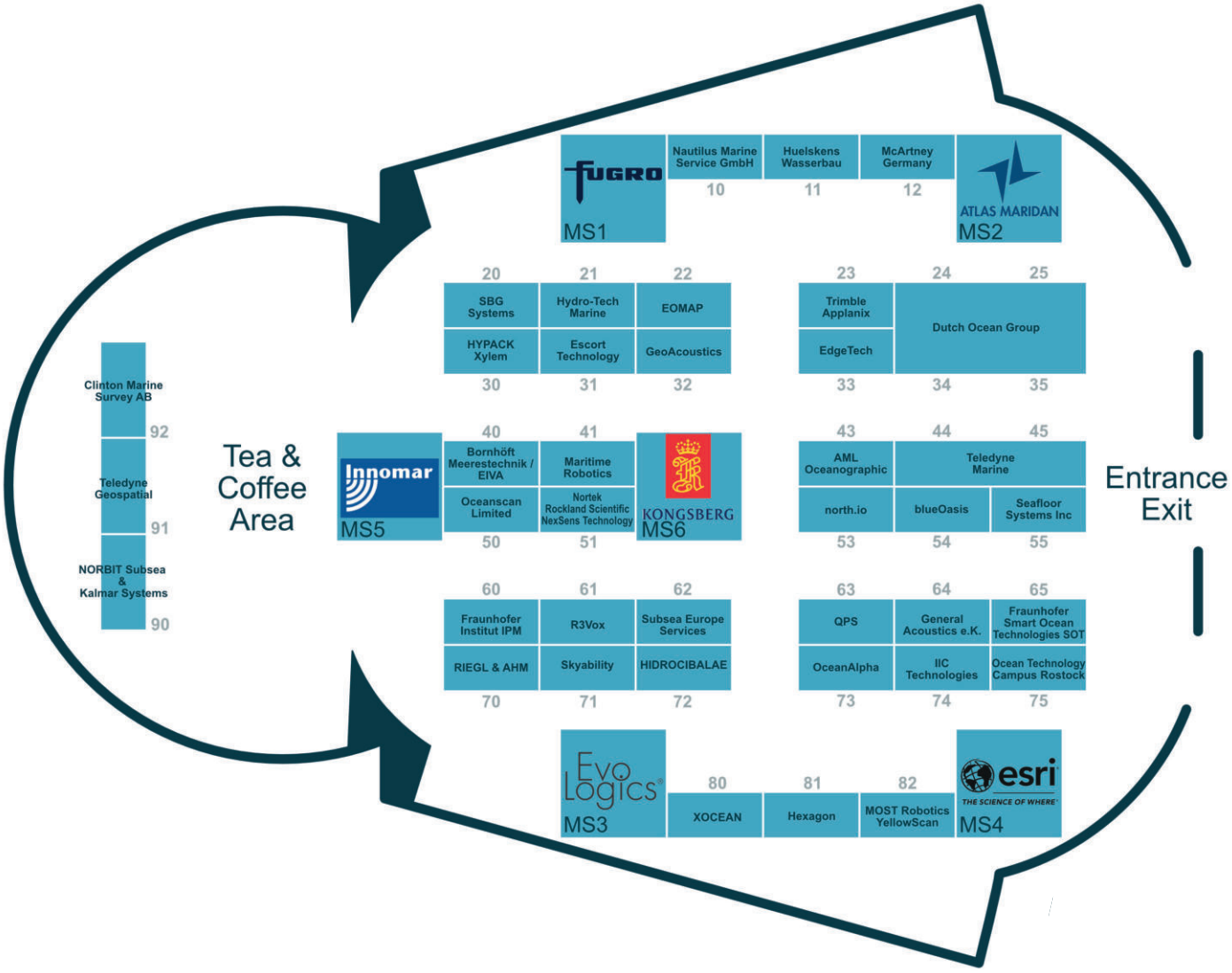
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AHM – Airborne HydroMapping

AHM is your cooperation partner for high-level spatial data capturing and analysis. We focus on customer dedicated analysis and development of soft- and hardware solutions, mainly covering the fields of environmental needs. Airborne HydroMapping was founded as an academic spin-off in 2010 located at the University Innsbruck, after the successful development of a topo-bathymetric LiDAR sensor with RIEGL LMS (FFG research project 2007–2010). AHM services comprise multifunctional airborne data acquisition – topo-bathymetric LiDAR, RGB, thermal and spectral imaging – operated from its own twin-engine aircraft (Tecnam P2012 SMP) and comprehensive data processing, analysis and modelling using own software framework HydroVISH.

ahm.co.at // Stand 70

AML Oceanographic

AML Oceanographic has 50 years experience designing and manufacturing high-performance hydrographic and oceanographic equipment. We offer 3 product lines – hydrographic instrumentation, CTDs and multiparameter sondes, and underway profiling systems.

In hydrography, AML invented time-of-flight sound velocity technology, now the market standard for multibeam sonar correction. In CTDs and sondes, we have the market's most extensive sensor ecosystem, with an array of 20 sensors that can be directly installed on the instrument end cap. AML has delivered more underway profiling systems than any other company in the world, with over 200 MVPs installed on autonomous platforms, small launches and large vessels.

amloceanographic.com // Stand 43

ATLAS MARIDAN

ATLAS MARIDAN, a fully owned subsidiary of Germany's ATLAS ELEKTRONIK and thyssenkrupp Marine Systems, located in Denmark and Germany, has been conducting specialised subsea business for over 20 years. Recently, the company has focused on AUV rental and services for major industry clients. In early 2024, MARIDAN expanded its capabilities by integrating a survey company specialised in UXO surveys and a team of seismic experts, positioning itself as a one-stop-shop for offshore site investigations. The team, comprising over 40 specialists, manages a technology park featuring everything from conventional nearshore survey boats and offshore ROTVs to AUVs, SAS and seismic systems.

atlasmaridan.com // Stand MS2

blueOASIS

blueOASIS is a Portuguese R&D start-up fostering the development of ocean engineering solutions, using modern Industry 4.0 approaches, such as data science, numerical modelling (design tools, high-fidelity CFD, modern oceanographic models), high-performance computing and artificial intelligence tools, with focus on maritime and renewables, underwater acoustics and digital twinning. Apart from R&D and commercial services, blueOASIS is developing smart AI, IoT-based products. A special highlight is given to HydroTWIN, a solution that combines underwater noise monitoring with spotter oceanographic buoys, with on-water demonstration in this exhibition, RAINDROP for underwater noise maps production and SmartFisher for habitat monitoring based on image processing.

blueoasis.pt // Stand 54

Bornhöft Meerestechnik

Precision in Marine Technology
We supply everything you need to measure, explore, survey, view, sample, or communicate under water. Just a few examples: Underwater vehicles like ROVs and AUVs, underwater measuring instruments like CTD profilers and Doppler current meters, detection systems like side-scan sonar and sub-bottom profilers, navigation aids like transponders, pingers and solar lights, drifters and gliders, buoyancy spheres, underwater cable, underwater connectors SUBCONN, etc.

bornhoeft.de // Stand 40

Clinton Marine Survey

Clinton Marine Survey, founded in 2015, is at the forefront of the offshore geophysical survey industry, delivering high-quality hydrographic and geophysical solutions. With a passion for the ocean and a commitment to sustainability, we offer state-of-the-art, cost-effective services tailored to each client's needs. Our experienced team, supported by a modern fleet equipped with cutting-edge technology, ensures precise data collection and analysis. We are dedicated to pushing boundaries, improving environmental impact, and fostering a collaborative culture. Join us as we chart new horizons in marine surveying.

clinton.se/marine // Stand 92

Dutch Ocean Group

Headquartered in the Netherlands, The Dutch Ocean Group is a premier maritime association. Our expertise spans oceanography, hydrography, geophysics and geotechnical surveys, as well as supply and training services. We provide holistic solutions to the global maritime industry, leveraging cutting-edge technology for operational efficiency and environmental stewardship. Our seasoned members deliver top-tier services, fostering long-term synergies. As a trusted name in maritime excellence, The Dutch Ocean Group propels the industry forward, ensuring a brighter future for oceanic endeavours.

dutchoceangroup.nl // Stands 24, 25, 34, 35

EdgeTech

EdgeTech is a leading manufacturer of underwater technology solutions. We are known worldwide for our products which include: side-scan sonars, sub-bottom profilers, bathymetry sonar systems, combined and customised solutions. In addition, we provide reliable transponder beacons, acoustic releases for deep sea or shallow water or long life, and customised underwater acoustic command and control systems. We have a comprehensive suite of in-house testing facilities including test tanks, pressure test chambers and company research vessels used for testing and sea trials. These facilities allow the company to ensure the delivery of the most reliable and highest quality products.

edgetech.com // Stand 33

EIVA

EIVA is an engineering company with more than 45 years experience in the offshore and shallow water construction and survey industry.
EIVA provides software, equipment, integrated system solutions, rental services, 24/7 support and training to a wide range of segments, covering virtually any offshore and shallow water operation task.

eiva.com // Stand 40

EOMAP

Creating decision support from satellite data is where we excel. Clients worldwide trust our digital twins of inland and coastal waters – combinations of Earth Observation, data science, in-situ data and software engineering. Meet our team at booth #22 to learn about use cases ranging from alpine lakes to the coasts of the world. Or experience the new eoapps COASTS, AQUA and SDB-Online: These online apps provide key information on bathymetry, water quality and coastal change. Fill data gaps, monitor morphodynamics and habitats or track coastal waters – all from the comfort of your desk.

Let's transform the way we understand and manage the environment!

eomap.com // Stand 22

ESCORT

ESCORT was established in 1990, starting in the marine electronics sector.
We supply, install and service navigation and radio communication and hydrographic equipment.
We are authorised distributor of products from world leaders in marine electronics, hydroacoustics and underwater monitoring.
For many years, we have been building a strong team, which includes specialists in many fields, which allows us to constantly develop and expand our business.
Over time, we have expanded our offerings to include hydrographic surveying, the provision of underwater monitoring services for the seabed and hydrotechnical facilities, as well as search and survey of wrecks.

escort-technology.com // Stand 31

Esri

Esri, the global leader in GIS software and location intelligence, helps customers unlock the full potential of data to improve operational and business results. Esri software is deployed in more than 350,000 organizations globally and in over 200,000 institutions in the Americas, Asia and the Pacific, Europe, Africa, and the Middle East, including Fortune 500 companies, government agencies, nonprofits, and universities. Esri has regional offices, international distributors, and partners providing local support in over 100 countries on six continents.
Esri engineers the most innovative solutions for digital transformation, the Internet of Things (IoT), and advanced analytics.

esri.com/en-us/industries/national-maritime-hydrography/overview // Stand MS4

EvoLogics

EvoLogics, founded in 2000, focuses on pioneering maritime technologies. Specialising in underwater smart robotics, sensor systems, acoustic communication and positioning networks, EvoLogics integrates advanced engineering with bionic principles.
The company's development strategy centres on an underwater »Internet of Things« for intelligent vehicle and sensor cooperation. Smart underwater networks build on EvoLogics' S2C spread-spectrum communication technology that combines underwater acoustic data networks with integrated real-time positioning. The company designs highly capable underwater solutions for complex mission scenarios with advanced sensor systems, AI-based object recognition and analytics, diver navigation systems, and autonomous subsea and surface vehicles for survey and support operations.

evologics.com // Stand MS3

Fraunhofer Smart Ocean Technologies

Within the Digital Ocean Lab, we offer excellent expertise and infrastructure for testing and quality assurance of hydrographic technologies, as well as complex underwater scenarios for AUVs and sensor development.
The interdisciplinary research group Smart Ocean Technologies develops cutting-edge marine technologies and new solutions for the sustainable use of the oceans, including: 3D surveying and quality control, condition monitoring, robotics, AI-based image processing, investigation of polymer weathering, environmental and solid state analytics as well as sensor data evaluation.
Our developments are tested in both digital and offshore environments thanks to the nearby underwater test bed, the Digital Ocean Lab.

smart-ocean.fraunhofer.de // Stand 65

Fraunhofer IPM

Discover cutting-edge underwater measurement technology with Fraunhofer IPM. We present two laser-based measurement systems, ULi (Underwater LiDAR) and ABS (Airborne Bathymetric System), both utilising the time-of-flight method for high-precision underwater surveying. ULi is an underwater laser scanner designed for high-resolution inspection and mapping of underwater structures, offering versatile use in both stationary and mobile applications. ABS is a highly compact, multi-wavelength drone-mounted bathymetric scanner, perfect for surveying shallow waters. Its lightweight design allows easy deployment using sub-25-kg drones. Visit our booth to learn how our innovative solutions can enhance your underwater measurement needs.

ipm.fraunhofer.de // Stand 60

Fugro

Fugro is the world's leading geo-data specialist, we unlock insights from geo-data. Our high-speed hydrography solution leverage state-of-the-art technologies as Fugro's uncrewed surface vessels, airborne LiDAR and earth observation analytics delivering high quality data from the coastal zone to deep oceans in a more efficient, safer and sustainable way.

fugro.com // Stand MS1

General Acoustics

General Acoustics is a leading developer and producer of sophisticated remote measuring technology tailored for marine applications, specialising in ultrasonic and radar systems. Our solutions found broad application in ports, inland waters, coastal zones, offshore and lab facilities as towing tanks. Our lineup features remote water level and wave sensing systems including tide prediction solutions, sophisticated sub-bottom profilers and advanced multichannel ultrasonic lab wave gauges, complemented by user-friendly software. As an OEM with a dedicated R&D department, we develop our own technologies while also integrating third-party hardware to supply turnkey solutions and seamlessly incorporate our measuring systems into larger frameworks.

generalacoustics.com // Stand 64

GeoAcoustics

GeoAcoustics is the pioneer in interferometric sonar for bathymetry and a leading supplier of sub-bottom profilers and side-scan sonars. The company has been providing subsea sensors and equipment since 1978 and continues to develop innovative technologies to optimise marine surveying and environmental monitoring.
GeoAcoustics Ltd is recognised as a leading provider of high-quality underwater acoustic solutions for customers working in both inland waterway and marine hydrographic surveying, dredging and marine-research fields. From AI-powered sonar to dependable, field-proven subsea data acquisition systems, GeoAcoustics provides high-performance and globally supported technologies that improve productivity while streamlining bathymetric survey workflows to lower costs.

geoacoustics.com // Stand 32

Leica Geosystems part of Hexagon

Hexagon is the global leader in digital reality solutions, combining sensor, software and autonomous technologies putting data to work to boost efficiency, productivity, quality and safety.
With more than 200 years of history, Leica Geosystems, part of Hexagon, is the trusted provider of premium sensors, software and services. Its state-of-the-art airborne bathymetric solutions portfolio combines bathymetric and topographic LiDAR sensors with medium-format cameras to provide seamless data from the seabed (bathymetry) onto land (topography).

Our expertise in hydrography, airborne surveys, operating sensors and extracting the maximum value from the data enables us to support bathymetric applications and offer major productivity gains.

leica-geosystems.com/products/airborne-systems/bathymetric-lidar-sensors // Stand 81

Hidrocibalae

Hidrocibalae is a marine geophysical data processing company at the forefront of automated processing solutions.
With a team of over 60 experts from diverse fields, we provide comprehensive services, including project management, geophysical data analysis (multibeam, side-scan sonar, magnetometer, sub-bottom, shallow seismic) and offshore construction data support.
Our focus on process automation has led to the development of over 100 automated solutions, significantly enhancing efficiency and productivity while maintaining top-tier quality.
We continually push boundaries in marine geophysical data processing, delivering innovative solutions to meet the industry's evolving needs.

hidrocibalae.hr // Stand 72

Hülskens Wasserbau

Hülskens Wasserbau has been realising complex hydraulic engineering projects for over 100 years. We do this using the expertise of our hydraulic engineers and hydrographers, the experience of our employees and our own floating equipment, making us one of the leading hydraulic engineering companies in Germany and neighbouring countries. With our extensive fleet of machinery and floating equipment, we are on the waterways for our customers throughout Europe. We realise projects in coastal protection, flood protection, harbour construction, culvert construction, river construction and dredging. We operate a hydrographic department with five of our own sounding boats and an autonomous sounding boat from 2025. We also carry out hydrographic surveys for other customers as an individual service.

huelskens-wasserbau.de // Stand 11

Hydro-Tech Marine

Hydro-Tech Marine is a professional sonar supplier who specialised in design and manufacturing hydrographic survey equipment for underwater exploration. With years of technology accumulation, we can manufacture not only full series of multibeam echo sounder with inertial navigation system and side-scan sonar, but also related auxiliary devices including sound velocity profiler and sensor, etc. Every Hydro-Tech product have been fully tested and assured great performance and high quality. That's why we can win customers loyalty and lots of industry awards. Nowadays, Hydro-Tech occupies the leading market share of multibeam in China and expands business footprint to nearly 30 countries.

hydro-techmarine.com // Stand 21

Hypack

Hypack, a Xylem brand, is a world leader in software development for the hydrographic and dredging industries since 1984. Our software is one of the most widely used hydrographic software packages in the world with more than 10,000 users in over 140 countries.

Our commitment to the industry and partnership with manufacturers allow us to provide solutions to all your surveying needs. From simple areas to complex projects, our versatile software solutions can help fulfil your requirements.
Whether you are collecting hydrographic survey data, environmental data, or just positioning your vessel in an engineering project, our software has you covered.

xylem.com/en-us/brands/hypack // Stand 30

IIC Technologies

Come and visit IIC Technologies at Stand 74 to discuss your geospatial needs. As a provider with decades of experience, worldwide, we specialise in developing and delivering geospatial solutions across all environments (air, land or sea). Services include survey, mapping, charting, training and consultancy. Having delivered projects for many of the world leading national mapping and hydrographic organisations we have a unique wealth of experience to support you in the delivery of your business objectives. Please come and speak to us today at Stand 74.

iictechnologies.com // Stand 74

Innomar

For 27 years Innomar has been providing innovative and high-quality equipment and software for the marine and offshore business. The well-known Innomar parametric sub-bottom profilers and associated software are perfectly suited for high-resolution sub-seabed visualisation in water depths from less than one meter to full ocean depth. Applications include, but are not limited to, dredging and geophysical surveys, mapping of buried pipelines, cables and UXO or reconnaissance and route surveys at prospective offshore construction sites, such as wind farms. The current product development is focused on solutions for USV and AUV integration.

innomar.com // Stand MS5

Kalmar Systems

Kalmar Systems is a provider of hydrographic solutions, specialising in the sales and support of advanced technologies. The company offers a comprehensive range of products, including multibeam and single-beam echo sounders for high-resolution seabed mapping, precise positioning systems, user-friendly software solutions for data acquisition and processing, and autonomous surface vehicles for efficient data collection in challenging areas. Kalmar Systems services to various industries, including ports, waterways and offshore operations.

kalmar-systems.de // Stand 90

Kongsberg Discovery

In a constantly changing market environment, Kongsberg Discovery serves the ocean space, from the deepest sea to outer space. We continuously develop systems, solutions and products that are key to understanding environmental implications for the ocean ecosystem, and address the complex sustainability challenges the world is facing. Monitoring critical infrastructure in the ocean space involves systematic and continuous observation of key assets and facilities, including ports, harbours, bridges, dams, energy production assets and communication cables. Kongsberg Discovery has the solutions for this crucial activity, allowing for real-time monitoring and early detection and response to anomalies or disturbances underwater, on the surface and in the air.

kongsberg.com/discovery // Stand MS6

MacArtney Germany

MacArtney GmbH is an engineering office for marine technology providing sales of instrumentation and system solutions. Our effort focuses on engineering services and sales of oceanographic and hydrographic instrumentation. In addition, we offer consulting for solutions in marine environmental monitoring. Our staff has extensive experience in the operation of hydrographic systems onboard survey vessels as well as its installation and commissioning. MacArtney offers qualified services – from integration to training and maintenance. In addition, MacArtney operates a manufacturer-independent calibration lab for oceanographic sensors and test facility for sonar systems. MacArtney is your competent partner for all questions of marine measurements from inland to coastal waters and the deep sea.

macartney.com // Stand 12

MacArtney
UNDERWATER TECHNOLOGY

Maritime Robotics

Maritime Robotics is a leading supplier of autonomous navigation systems and uncrewed platforms, enabling ocean space access through autonomy. The company delivers innovative solutions world-wide, facilitating safe and cost-effective ocean operations that significantly reduce CO_2 emissions.

Since 2005, Maritime Robotics has been developing and supplying autonomous and remotely-operated systems and platforms for ocean operations including marine mapping and surveying, met-ocean data acquisition, harbour security, research and ROV-support to global industry professionals. The company is situated in Trondheim and Vanvikan with a highly skilled team of industry experts in every aspect of the supply chain internally.

maritimerobotics.com // Stand 41

MARITIME
ROBOTICS

MOST Robotics – YellowScan

Since 2021, we have been a sales and development service provider for drones and robotics in the B2B sector. In addition to an extensive portfolio of innovative technology, we also offer individual developments and customised solutions to meet the specific requirements of our customers. With comprehensive consulting, training and support, we work closely with our customers and partners to ensure that they can realise the full potential of our systems.

mostrobotics.com // Stand 82

MOST
ROBOTICS

Nautilus Marine Service

Nautilus Marine Service is a Germany-based manufacturer of pressure housings since 1985 and a distributor of rescue equipment and products for oceanography and hydrography. We offer a wide range of products and services for maritime operations, shipping, and research institutions worldwide. For hydrographic and oceanographic applications, in addition to the standard products, there is a wide range of other products in our portfolio, including the option of developing and commissioning customised solutions. Thanks to our many years of experience, Nautilus Marine Services stands for competence and trust.

nautilus-gmbh.com // Stand 10

NexSens Technology

NexSens Technology is specialising in the design and manufacture of real-time environmental measurement systems. NexSens data buoys serve as a platform in various sizes with buoyancy of around 35 to 567 kg, which optionally include solar chargers, internal batteries, integrated data loggers, sensors and more. NexSens measurement systems provide high-quality data, transmitted by cellular, satellite or radio, and shared in real-time on a secure web data centre. Environmental professionals around the world configure and deploy these systems in a wide variety of applications supported by the NexSens application engineers, which helps ensure successful project startup and operation, into the future.

nexsens.com // Stand 51

NORBIT Subsea

NORBIT Subsea designs and develops wideband multibeam sonars for a variety of hydrographic applications, forward-looking applications as well as advanced subsea leakage detection. Our solutions are based on the latest in analogue and digital signal processing and our products provide wide coverage monitoring combined with high sensitivity and accuracy. NORBIT Subsea is headquartered in Trondheim, Norway and is a part of the segment Oceans in NORBIT ASA.

norbit.com // Stand 90

Nortek

Nortek designs, develops and manufactures acoustic underwater ADCPs, DVLs, current metre and velocimetre that are used to measure currents and motion in the marine environment. Nortek's ocean technology is used in many applications, from understanding the impact of climate change to providing underwater navigational assistance. Engineers use the sensors to conduct offshore operations including construction, maintenance and surveying. Scientists learn more about our marine environment and discover the unexplored depths of our oceans and underwater robotics developers can provide new solutions that aim to increase the safety and efficiency of their vehicles. Nortek supports every step of the way.

nortekgroup.com // Stand 51

north.io

Established in 2011 and headquartered in Kiel, Germany, north.io is the go-to expert for efficient geospatial data management – on land and at sea. We enable companies, governments and professionals to use geodata with speed and ease, to move their projects forward. This is how we address complex challenges such as climate change, energy transition and digital transformation.

North.io's ocean data platform, TrueOcean, is specially designed for the offshore wind industry. TrueOcean makes marine, geo-referenced data accessible, shareable, visualisable and understandable. With TrueOcean, data accessibility and seamless collaboration empower informed decision-making for all project stakeholders, regardless of their expertise level.

north.io // Stand 53

OceanAlpha

OceanAlpha is a leading manufacturer specialising in uncrewed surface vehicle (USV) technology, committed to inspiring maritime autonomy and delivering tailored solutions across various sectors. Comprised of more than 200 professionals, OceanAlpha brings over a decade of expertise in R&D and manufacturing, with an exceptional track record of serving over 600 users worldwide and covering more than 1,200,000 kilometres of operational excellence. Our USVs are effectively utilised in inland and offshore surveying, environmental monitoring, marine engineering, maritime safety and rescue operations and recreational activities.

oceanalpha.com // Stand 73

Oceanscan

Oceanscan Limited is a leading international subsea technology rental and personnel supply company providing equipment and personnel to the offshore renewable energy and hydrocarbon markets.
Oceanscan owns Geoforce Technical Services Ltd. in Lowestoft who in turn provide a Geotechnical (CPT) service by providing robust, new, high-quality equipment to the offshore renewables market.
Another Oceanscan company, HPR (UK) provides our customers with access to a combined pool of qualified ROV, survey, data acquisition and processing personnel.
Our Personnel management team is a mixture of individuals with offshore experience or an extensive project management background and as a result Oceanscan Limited has proved to be a key supplier of skilled personnel either individually or as complete teams, for both short and long-term projects.

oceanscan.net // Stand 50

Ocean Technology Campus Rostock

Oceans cover the majority of our planet. They have a significant influence on shaping the climate, generate 80 % of the world's oxygen and provide habitat for countless species. But they also provide food, energy and a variety of raw materials that are essential for our modern society.
Only through the synergy of a comprehensive understanding of the ocean ecosystem through excellent research and a sustainable use of the marine habitat through innovative technologies at the highest level, lies the key to reconcile ecology and economy.
The Ocean Technology Campus aims to strengthen the German marine technology by opening up important markets and providing impulses for a worldwide knowledge-based sustainable use of the oceans. Therefore, Rostock – one of Germany's most traditional maritime locations with an exceptionally high density of marine and maritime research – is the best location.

oceantechnologycampus.com // Stand 75

QPS

Quality Positioning Services BV (QPS), headquartered in Zeist, The Netherlands, is an independent software design company founded in 1986. QPS subsidiary offices are located in Canada, the USA and the UK.
QPS are experts in maritime geomatics software and services. QPS solutions are used across a variety of industries, including hydrographic surveying, offshore construction, chart production and piloting. Marine construction solutions are highly focused in oil and gas, offshore wind farms and the dredging industry. Services include on-site and on-board training, setup and support.
With the highest capabilities and industry-renowned stability, QPS keeps even the most complex jobs running smoothly.

qps.nl // Stand 63

R3Vox

R3Vox based in Malta – sister company to R2Sonic in the USA – manufactures, services and supports a comprehensive range of cutting-edge survey solutions, from the most light and compact, to the most sophisticated survey technology available in the market. Our brands include the Sonic-V and Sonic-V Plus range of multibeam echo sounders as well as the Voxometer® MA3® multi-aspect hydrospatial survey system, designed to greatly reduce survey time and complexity, delivering near end-quality data like never before.
A solution for every survey mission.

r3vox.com // Stand 61

RIEGL

Airborne LiDAR bathymetry (ALB) provides detailed data for coastal mapping and offers high efficiency for large-scale projects and unsurpassed detail for smaller projects. It is also successful in surveying inland waters for natural habitat monitoring or hydraulic engineering projects. RIEGL offers a range of high-performance topo-bathymetric LiDAR sensors and systems for integration with UAVs, helicopters and fixed-wing aircraft and provides corresponding software packages for data acquisition and processing. By combining topo-bathymetric LiDAR with topographically high-resolution 3D terrestrial LiDAR or with data from other acquisition sources, comprehensive data sets with even higher information density are created.

riegl.com // Stand 70

Rockland Scientific

Rockland Scientific is dedicated to the measurement of turbulent flow in the marine environment and provides measurement services, assists with technical questions and consults on the design of measurement campaigns, experimental instrumentation, and data collection and processing. At Rockland, an eclectic team works in an inclusive environment to deliver sensor and software solutions to oceanographers in 30 countries. A thriving ocean technology company headquartered in Victoria, with satellite offices in the USA and France, Rockland helps scientists understand climate change. Rockland takes pride in their customer-first culture, which is reflected by raving referrals and a growing number of scientific publications.

rocklandscientific.com // Stand 51

SBG Systems

SBG Systems, established in 2007, is a leading manufacturer of motion and navigation solutions. Headquartered in France, with subsidiaries in California and Singapore.
The company designs and manufactures advanced inertial sensors, including IMUs, AHRS and INS/GNSS. Their products use MEMS technology, stringent sensor selection, advanced calibration, and powerful embedded algorithms to provide miniature, affordable solutions with exceptional performance.
Their Motion Sensors and Inertial Navigation Systems are ideal for ship motion monitoring, sonar, LiDAR, and buoy orientation and position, ROV and AUV control. Qinertia, their post-processing software, completes the offer.

sbg-systems.com // Stand 20

Seafloor Systems

Seafloor Systems is a pioneer and leading manufacturer of uncrewed surface vessels (USVs). With over 25 years experience with multibeam sonar systems and hydrographic equipment, and 14 years evolving a fleet of USVs, we offer a flexible, scaled range of turnkey hydrographic USV solutions ranging from simple 1.2 m single-beam platforms, to 5.5 m multi-payload offshore platforms. Please come by our booth to learn more about our Hydrone, EchoBoat and HydroCat systems and how they could be a value added option for your hydrographic, engineering, dredging, marine construction, research or offshore operations.

seafloorsystems.com // Stand 55

Skyability

Skyability is a full-service provider of drone-based and airborne LiDAR services and has established itself throughout Europe over the last ten years through quality and reliability. In data collection as in processing, Skyability stands for quality and is not willing to make compromise on that.
Our top priority is satisfaction. Both for our customers and for ourselves. We see every project as a reference project and work on it until we are satisfied ourselves.
Precision is our passion. We work meticulously and attach great importance to the highest level of accuracy.
We deliver. Always. Our customers can rely on that. We pay attention to details, but always keep the overall solution in mind.

skyability.com // Stand 71

Subsea Europe Services

Subsea Europe Services is at the forefront of marine survey technology. We develop an array of cutting-edge solutions such as uncrewed surface vessels (USVs) with powerful hydroacoustic payloads including the groundbreaking R3Vox Voxometer. Close partnerships with innovators like BeamworX, BeeX, MARTAC Systems, R2Sonic, Sonardyne and north.io, and an R&D emphasis on autonomy software and the seamless integration of sensors, vessels and new cloud data platforms ensure that Subsea Europe Services can deliver on its mission to Simplify Marine Data Acquisition & Analysis. The company's latest autonomous marine survey breakthroughs will be demonstrated live on-water at HYDRO 2024.

subsea-europe.com // Stand 62

Teledyne Geospatial

Teledyne Geospatial unifies the hardware and software expertise of both Teledyne CARIS and Teledyne Optech providing customers with innovative, integrated solutions. Offerings include turnkey systems, LiDAR and sonar integrated workflows and a range of systems and solutions that support holistic, precision data collection.

Visit Teledyne Geospatial at HYDRO 2024 to learn about Fathom, the world's fastest, most intuitive topo-bathy solution.

teledynecaris.com
teledyneoptech.com // Stand 91

Teledyne Marine

Teledyne Marine is a global leader in marine technology, now enhanced with the addition of Teledyne Valeport. Our diverse portfolio spans imaging, instruments and vehicles, providing cutting-edge solutions for any marine challenge from surface to seabed.
With 24 premier brands under one roof, we offer unmatched expertise, exceptional service and comprehensive support. From customised systems to complete turnkey solutions, Teledyne Marine delivers the widest range of technology through a single supplier.

Stop by stand no. 44/45 and discover the latest within marine technologies.
Teledyne Marine – Our Passion Runs Deep.

teledynemarine.com // Stands 44, 45

Trimble Applanix

Trimble Applanix designs, builds, delivers and supports products and solutions designed specifically for the hydrographic survey industry. Trimble's Applanix POS MV has become the industry standard in position for hydrographic vessels. With over 20 years of established leadership in the marine sector, we have become synonymous with providing advanced products and trusted scalable solutions that maximise productivity through mobile mapping and positioning.

applanix.com // Stand 23

XOCEAN

Using uncrewed surface vessels (USVs), XOCEAN provides turnkey ocean data. From mapping the seabed to environmental monitoring, XOCEAN offers a safe, economic and carbon neutral solution to ocean data delivery.

xocean.com // Stands 80

Acknowledgements

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Website
Tobias Knapp

Conference handbook
Lars Schiller (Zindel AG)