# SFI Smart Ocean
Annual Report 2023
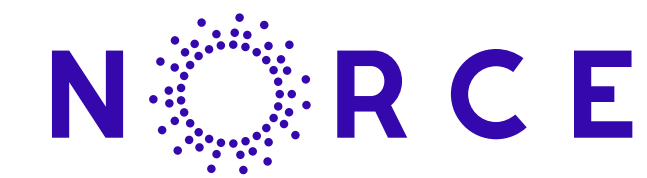
SFI **SMART OCEAN**

# Our Partners

SFI Smart Ocean is a Centre for Research-based Innovation (SFI) funded by the Research Council of Norway (grant number 309612). The consortium consists of research partners, user partners from industry and industry clusters, and national authority observers.

## Research Partners



UNIVERSITETET I BERGEN

INSTITUTE OF MARINE RESEARCH

FFI Norwegian Defence Research Establishment

NORCE

Western Norway University of Applied Sciences

NERSC NANSEN ENVIRONMENTAL AND REMOTE SENSING CENTER THE NANSEN CENTER · BERGEN · NORWAY

## User Partners / Industries

AANDERAA a xylem brand

W·SENSE INTEGRATED CABLELESS SOLUTIONS

bouvet

tampnet

TSC Part of Eddyfi Technologies

AkerBP

imenco SMART SOLUTIONS

KONGSBERG

REACH SUBSEA

## User Partners / Industry Clusters

GCE | NODE GLOBAL CENTER OF EXPERTISE

GCE Ocean Technology

NCE Seafood Innovation

## National Authority Observers

DIRECTORATE OF FISHERIES

Havtil

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**Ingvar Henne**
CENTRE DIRECTOR

Efficient data flow, interoperability and seamless integration are key to an observation system and thus essential research areas for SFI Smart Ocean. The research station of Institute of Marine Research (IMR) at Austevoll is very central to implementing and testing the functionality of the SFI Smart Ocean systems. The two measuring moorings with sensors are in continuous operation and deliver data to the finalized first version of SFI Smart Ocean's data and application platform, which is also integrated with NMDC (Norwegian Marine Data Centre). An automatic anomaly detection algorithm has also been developed and tested on data from the SFI partners. New protocols and modulation methods have also been tested, and equipment from several partners have been interconnected and data have been delivered to the SFI Smart Ocean platform. Acoustic channel measurements have been carried out, modems have sent data from the measuring rigs to land, and the SDM (Software-Defined Modem) from NORCE Norwegian Research Centre AS was also tested in the sea this autumn.

The Centre is becoming increasingly coordinated, and close collaboration produces good results as well as initiatives for expanded activity and new projects.

Several of the Centre's partners are now collaborating with initiatives for new research projects. The Centre provides grounds for spinoff projects and extended research on related topics, and new applications are prepared through close cooperation between partners in the SFI. This can provide significantly increased activity and financial frameworks for strengthening professional environments and cooperation between companies, institutes and academia. An example is the NORCE SDM that is currently used in a spin-off project as a tool for the development of protocols and modulation methods.

NCE Seafood Innovation joined the Centre as a partner early in January, representing a very important maritime sector and being a valuable point of contact with this industry. In combination with GCE Ocean Technology and GCE Node, the most relevant end-users, research environments and technology providers are well covered. The Marine Optics Research Group at UiB has now been included by a subproject in work package 1 devoted to their research.

The Centre organization and ways of cooperation have settled and matured since the start-up in the pandemic period. Plenary meetings are organized twice every year, covering topics across work packages and improving the coordination of activities in the Centre. The main activity at the spring gathering hosted by the Western University of Applied Sciences (HVL) was data flow from sensor to end-user. In October, we met at the University of Bergen (UiB) to follow up the interaction between work packages and coordinate work plans for 2024. All ongoing activities contribute to the Centre's overall goals, and the dialogue in the group work is very good across the work packages.  ●●●

The educational activities are increasing, and new PhD candidates on network architecture and fibre-optic acoustic sensing are employed this year, and our first associated PhD candidate defended his thesis. A total of 4 postdocs from the SEAS program are linked to SFI Smart Ocean on topics like marine optical sensors and nanophysics, particularly related to anti-biofouling. SFI Smart Ocean also has more Master's's students associated with the Centre, both at UiB and HVL. They are an important resource for our Centre, and actively participate in various parts of the work packages, and in meetings, seminars, trips and in the lab.

The Centre's participants present research and development that are being noticed both nationally and internationally. Articles are published in, among others, Frontiers of Marine Science, Frontiers in Ocean Observing, IEEE Internet of Things Journal, Ocean Engineering, Springer Nature, MethodsX, and Journal of Acoustical Society of America.

In August we organized workshops in Grimstad and Bergen together with GCE Ocean Technology, GCE Node, and SFI Offshore Mechatronics. The aim of these two gatherings was to explore new possibilities for the continuation of research areas that SFI Offshore Mechatronics has worked on, as well as extensions of the activities in SFI Smart Ocean. The challenges related to the operation and maintenance for the offshore and maritime sector are also relevant for SFI Smart Ocean and could be a basis for new

applications and collaboration between the partners and possibly new actors. SFI Smart Ocean also got valuable input on the need for sensors and communication solutions in the sea and opportunities to expand its activity. UiB, Aanderaa (a Xylem brand), Bouvet, Kongsberg Discovery, and NORCE presented on behalf of SFI Smart Ocean at these events.

The researchers and PhD research fellows are also active in the communication of research results from the Centre. Presentations have been given at the Arctic Frontiers conference, the Petroleum Safety Authority's Innovation Day, Scandinavian Symposium on Physical Acoustics, IEEE International Ultrasonics Symposium, International Conference on Model Driven Languages and Systems, Forum acusticum, IEEE International Requirements Engineering, Oceans, and the International Conference on the Internet of Things. Another somewhat exotic example is the participation by Aanderaa at a hybrid event organized by Nagaoka University of Technology in Japan to support the UN sustainable development goals. All good examples on dissemination of relevant knowledge.

The "SFI Seminar Series" continues with presentations on the last Friday of each month, and both students, researchers and industry partners contribute with useful sharing of knowledge. The seminars are open to everyone and always available digitally, and we appreciate input on topics or presenters for seminars to come. ●



**The new learning arena at UiB was the venue for the plenary meeting in October. The location was well suited for networking and cooperation between partners.**
PHOTO: TERJE RESTAD

**Cleaning and maintenance of the sensors are performed regularly to maintain data quality.**  PHOTO: IMR

Our vision is the realization of a generic, autonomous and flexible wireless multi-parameter marine observation system for reliable management of a productive and healthy ocean.

SFI Smart Ocean is focusing on enabling real-time high-quality data for increased autonomy, and increased value of coastal and oceanic management models and systems. This will lead to sustainable and profitable ocean industry operations, and to fact-based ocean resource management. The observation system's key factors are highly cross-disciplinary:

• sensors research and development

• measurement strategy

• flexible and adaptive sampling in time and space

• point measurement vs. monitoring over large areas

• distributed measurements

• measurement uncertainty and reliability

• data quality classification and metadata definitions

• compression methods and embedded signal processing

• time series as input to big-data analysis

• cloud-based data and application services

• data format aggregation and safety

• low power consumption and embedded sensor intelligence

Organising this as a centre that spans multiple scientific disciplines and sectors ensures a vendor-neutral approach to the system and enables a diversity of applications.

Standardized interfaces and data formats enable the integration of a diversity of sensor types, communication interoperability, and data sharing during and after the Centre's lifetime. SFI Smart Ocean implements sensors for monitoring environmental, structural, and marine life parameters.

These are all parameter values needed for well-founded decisions by industry and authorities, in optimization of operations or maintenance, and evaluations of license to operate. They are building blocks for filling the knowledge gaps and meeting societal challenges.

**Primary Objective**
The Centre objective is to create a wireless observation system for multi-parameter monitoring of underwater environments and installations. The system based on autonomous smart sensors will serve as an enabling fundament in realizing flexible, distributed, robust, energy efficient, cost-effective, and safe marine measurements and big-data handling, to support the Centre's vision in respect to societal and industrial challenges. ●

**Participants from WP1 and WP2 in discussion at the autumn gathering.**
PHOTO: TERJE RESTAD

Efficient and reliable data flow from underwater sensors to the end-users' applications is the main goal of the research activities in the Centre. To achieve focus on measurement methods and sensor design, underwater communications and data management, the activity in SFI Smart Ocean is divided into three work packages (WP) and two integrating functions (IF). The three WPs are edge-cutting disciplinary activities, with necessary and strong mutual interaction. The IFs are cross-cutting interdisciplinary activities, integrating the three WPs.

**WP1: Autonomous Sensors & Measurement Strategies**
This work package focuses on enabling and developing autono-mous sensor technology for marine environ-mental and structural integrity measurements. The research and development are both on existing marine sensors and novel sensor technologies for real-time observations in an underwater wireless network.

Marine smart sensors will have embedded pre-processing of data in the sensor, compression of data and headers, acoustic modem compatibility, and smart operation for low energy use. Research and innovation on new sensor technology include guided ultrasonic wave sensors for integrity measurements, distributed fibre optic sensors with acoustic sensing of environmental noise and structural vibrations, nano technology for improved pH sensors, and new or improved optical measurements and research on light propagation in the ocean. Our research also includes nanostructured sur-faces for anti-biofouling of sensor and modem surfaces, to ensure higher data quality and longer deployment in the ocean. Research

on measurement strategies aims to reduce measurement uncer-tainty and ensure trustworthy data. This includes self-validation and self-diagnostic capabilities of the smart marine sensors, and the uncertainty propagation from the marine sensors to the data pre-sented to the end user.

Existing sensors, new sensor technologies, nanostructured self-cleaning surfaces, and the measurement strategies for trust-worthy data are tested at pilot demonstrators in the Centre. Metadata definitions and standardization for data quality and measurement conditions are central to the measurement system design.

**WP2: Wireless Network Communications**
The realisation of the SFI Smart Ocean observation system de-pends heavily on underwater communications. This work package focuses on wireless communication technology, and will develop a low-cost, miniaturized, and a short-range acoustic underwater technology platform assembled to an energy-efficient underwater wireless sensor network (UWSN). Hardware and software will need to be optimized with respect to long-term operations in demand-ing environments, which puts high demands on energy efficiency and system reliability. To support a wider range of use cases, WP2 may also study longer-range links and/or links with moving plat-forms like AUVs.  Acoustic modem and communication protocols will build on state-of-the-art underwater acoustic communication technology. ●●●

The system will be interfaced towards mobile networks (4G, 5G), satellite communications, fibre optic "backbone" networks, and unmanned surface vehicles. The communication requirements for SFI Smart Ocean are established in cooperation with the other work packages. Communication solutions in SFI Smart Ocean are defined according to the application requirements and the limitations and possibilities for communication in the harsh underwater environment.

On the physical layer, a testbed is established to investigate different modulation methods and coding techniques and methods for energy optimization. On the network layer, different protocols and network architectures, including multi-hop and mesh protocols, are investigated with respect to efficient data transfer and low energy requirements. The testbed can be used also for testing compression methods as well as network layer functionality. Field trials are employing the infrastructure of IF1.

**WP3: Software Technology and Big-Data Middleware**
The work package on software technology and big-data middleware focuses on a digital ecosystem providing cloud-based ocean data services and supporting cost-effective development of software applications that provide and consume ocean data services.

The cloud-based smart ocean platform is to comprise a set of software frameworks enabling the integration of external and internal ocean data sources, data storage and processing, and application deployment. The platform is to enable data spaces based on a uniform and standardised set of APIs, data and metadata formats. The software technology being developed in the work package is validated through the development of application prototypes linked to consortium pilot demonstrators and through the deployment of a reference implementation that integrates with external systems and data services.

The main topics of the work package include development and implementation of the smart ocean platform, system-of-systems software architecture, engineering technology for smart software systems, sensor-cloud integration middleware and protocols, edge computing, interoperability and data service APIs, data quality- and integrity, software security and reliability, machine learning and analytics, and intelligent visualisation of big datasets. The first version of this platform is currently ready to be evaluated by all partners. The work package is organised into subprojects focussing on software system architecture, implementation, and deployment of the SFI Smart Ocean platform; software engineering technology research, modelling, and validation; and end-user application and use cases. ● ● ●



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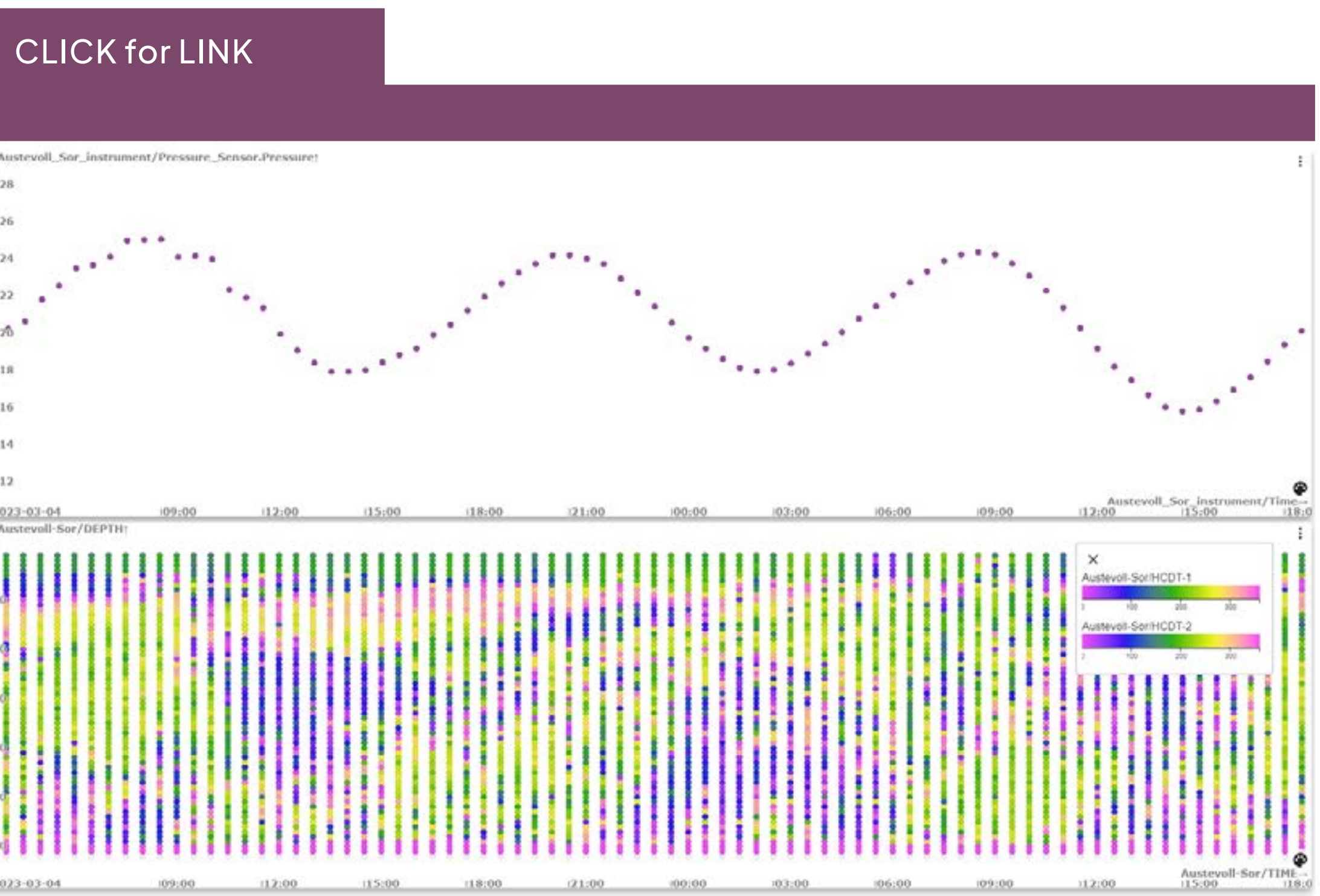
Tidal variations and current direction at different depths are easily displayed using the integration with NORCE Enlighten software. Explore the solution further by clicking on the image. IMAGE: NORCE

**IF1: Test Arenas**

This is an overarching Work Package that includes the sites where the results from WPs 1–3 are tested in various environments. The list of test sites is dynamic and is presumed to be expanded during the life cycle of SFI Smart Ocean.

A local scale environmental monitoring test site is operational at the IMR Austevoll Research Station near Bergen. This is our main test arena, and the infrastructure is utilized for testing of components and systems developed in SFI Smart Ocean. Here, two modular test rigs with sensors are placed, and a range of sensors and communication systems are included and available for data collection and equipment tests. A third rig, connected with a new large-scale facility for aquaculture sea-cages, plus an underwater system operated in connection with the LoVe project (IMR) is planned. The research station has provided an existing infrastructure under continuous development, making modifications and maintenance of the rigs easier. The Austevoll facilities will be further developed to include a mesoscale test facility that will be established as an extension of the local scale system. This will pave the way for longer scale communication, geo-positioning, and mesoscale environmental monitoring, using acoustic tomography and passive acoustics. Logistically, this system will be an extension of the already developed system for local scale tests.

Furthermore, a mesoscale system for environmental monitoring will be established in the Arctic Ocean north of Svalbard in 2024 for two years in the Nansen and Amundsen Basin. Our partner NERSC (with partners including UoB, Kongsberg, IMR) was granted the EU project HiAOOS (High Arctic Ocean Observation System) where a large observation system will be installed for two years in the Nansen and Amundsen Basin. This system will provide year-round acoustic and oceanographic observations as well as facilitate testing of new technologies for observations and data recovery from underwater installations. The project is also facilitating testing of new technologies in 2025 for observations and data recovery from underwater installations using acoustic communication and docking of ROVs. Complementary to HiAOOS a mesoscale system for environmental monitoring will be established in north of Svalbard in 2025 as part of SFI Smart Ocean. This will again facilitate for testing of systems and equipment developed for SFI Smart Ocean in the harsh environment north of Svalbard. HiAOOS provide training events in oceanographic and acoustic methods and tools, and offers a unique opportunity to collaborate with international institutions.

A use case for an aquaculture observation system is currently developed, and this will ensure that the fish farmers' needs and requirements are considered and implemented when the SFI Smart Ocean technology is developed. The use case will enable all scientific work packages to maximise the relevance towards, and the value for, the aquaculture industry.



**The upgraded marine facility at Austevoll research station is very suitable for field trials and interoperability tests.** PHOTO: INGVAR HENNE

Test facilities for offshore wind installations are being prepared for deployment late 2024 in collaboration with MetCentre in Karmøy, Rogaland county, as are systems for monitoring oil and gas installations. Our activities also include the Norwegian Ocean Observation Laboratory, where several of the partners of SFI Smart Ocean are collaborating. ●●●

**IF2: Overarching Activities**
Integrating Function 2 includes the administration of the Centre, and coordination of overarching activities such as commercialisation, innovation and IPR aspects, internal and external communication. ●

| | Work Packages (WP) and Integrating Functions (IF) | IF1<br>Test Facilities | | IF2<br>Overarching Activities |
|---|---|---|---|---|
| **WP 1** | Autonomous Sensors and Measurement Strategy | Coordination of needs and testing facilities | Locations for techno-logical segments: | • Administration<br>• Education<br>• Data Management<br>• Communications<br>• Commercialisation<br>• Innovation & IPR |
| **WP 2** | Wireless Network Communication | | • Environment<br>• Offshore Wind<br>• Oil and Gas<br>• Aquaculture | |
| **WP 3** | Software Technology and Big-Data Middleware | | | |

SFI Smart Ocean is hosted by the University of Bergen (UiB), and the Centre is organized to ensure influence and contributions from all partners.

The General Assembly (GA) is the body responsible for major decisions regarding the Centre. All partners are represented in GA, and Dean Gunn Mangerud chairs the GA on behalf of UiB as host institution.

The Centre Board in 2023 consisted of Tom Fidjeland (chair, GCE Node), Jan Erik Faugstadmo (Kongsberg Discovery AS), Annette Fagerhaug Stephansen (NORCE), Gjermund Mathisen (Aker BP), Morten Mjelde (Bouvet AS), Lise Doksæter Sivle (IMR), and Øyvind Frette (UiB).

The members of the Scientific Advisory Committee (SAC) are Professor Frank Reichert (University of Agder), Professor João Borges de Sousa (Porto University) and Assistant Professor Paolo Casari (University of Trento). They give advice to the Centre Board on scientific issues and priorities, to ensure high-quality scientific impact. The Technology Advisory Committee (TAC) consists of one representative from each of the Consortium participants and advises the Centre Board via the Centre Director on technical issues and priorities, including IPR questions and possibilities for innovations, to ensure both industrial and scientific value creation. Camilla Sætre (UiB) is chair of TAC.  ●●●



**Centre Director Ingvar Henne and Chair of the board at SFI Smart Ocean Tom Fidjeland share views on underwater technology and Centre strategies.**
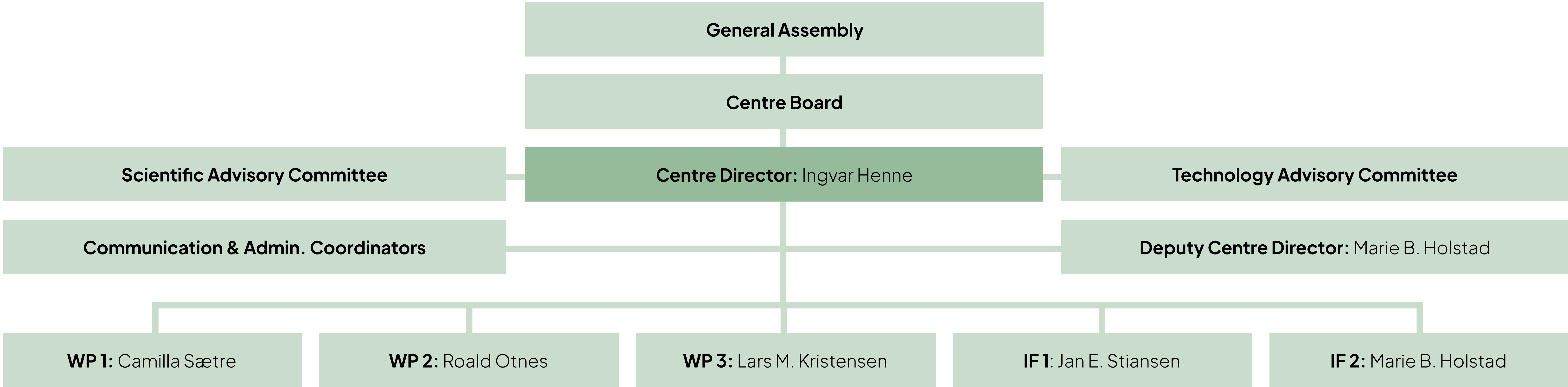PHOTO: TERJE RESTAD



**Participants at the plenary meeting at HVL in June 2023.** PHOTO: TERJE RESTAD

Some changes were made to the Centre administration through-out the year, and at the end of the year the Centre management team comprised of Centre Director Ingvar Henne (UiB), Deputy Director Marie Bueie Holstad (NORCE), Communication Manager Kavitha Østgaard (UiB), Administrative Coordinator Terje Restad (UiB) and work package managers Camilla Sætre (WP1, UiB), Roald Otnes (WP2, FFI), Lars Michael Kristensen (WP3, HVL), Øyvind Bergh (Acting IF1, IMR) and Marie Bueie Holstad (IF2, NORCE). ●

**General Assembly**

**Centre Board**

**Scientific Advisory Committee**

**Centre Director:** Ingvar Henne

**Technology Advisory Committee**

**Communication & Admin. Coordinators**

**Deputy Centre Director:** Marie B. Holstad

**WP 1:** Camilla Sætre

**WP 2:** Roald Otnes

**WP 3:** Lars M. Kristensen

**IF 1**: Jan E. Stiansen

**IF 2**: Marie B. Holstad

**FFI performs acoustic measurements at Austevoll.**
PHOTO: INGVAR HENNE

SFI Smart Ocean is working across multiple scientific disciplines, across several ocean industries and ocean management sectors, and integrates a significant amount of technology components. The technological challenge is complex and requires close cooperation between the various partners who have different, but complementary, technologies and competence areas.

Several partners are involved in all the activities in the Centre, and in particular, the increasing activities related to testing of various solutions in the ocean outside Bergen, has increased the need for coordination of activities between work packages. At the test site at Austevoll, industrial partners and research partners have worked together to complete test set-ups, giving us valuable experience on both technology components and integrated systems. The collected data has been used by several scientists and PhD students working on measurement strategy and software architecture.

In addition to the ordinary, day-to-day collaboration between partners, we continue to set up supervision of students as a cooperative effort among partners with complementary competences in order to strengthen the students' learning experience. Students at Master's and PhD levels are in general a very valuable resource to the Centre and contribute to various project and Centre meetings and workshops. They have become a very important part of the project team.

Collaboration between partners also brings additional, valuable input from industry as both scientific and industrial associates have an extended network of collaborators with whom they are working on related technological challenges. The industry clusters GCE Ocean Technology, GCE NODE, and NCE Seafood Innovation in particular – all partners in SFI Smart Ocean – bring contributions from a wider group of member companies. This year GCE Ocean Technology and GCE Node arranged two workshops in cooperation with SFI Offshore Mechatronics and SFI Smart Ocean to look for opportunities to create new applications and collaboration between the partners and possibly new actors on topics related to the ocean. ●

Theoretical model for the prediction of the fluorescence lifetime of pH–sensitive molecules

The close cooperation between partners is very fruitful, and a range of goals have been achieved during 2023. Emphasis has been on sensor development, data flow from sensor to end user, and data quality.

**Novel Sensor Technology**

For novel sensor technology, nano technologies for pH indicators have been further investigated and tested in laboratory. Guided ultrasonic wave (GUW) for structural measurements of layered materials is theoretically investigated and small-scale tests are initiated. Distributed acoustic sensing technologies have been evaluated for marine noise measurement, and an additional PhD student started in December performing laboratory experiments for sensor technology development based on ultrasound and acoustic-fibre optic measurements. For marine optics, the work in 2023 includes research cruises for in-situ measurements, correction method for light scattering measurements, biogeochemical optical measurements, and in collaboration with among others NERSC and Aanderaa start of the Useful Arctic Knowledge project. Late November, the first associated PhD thesis with the title "Characterization and correction of errors in measured inherent optical properties: Multiple scattering errors in LISST-VSF measurements" was completed. Within anti biofouling, work on development of novel anti biofouling coatings has been carried out throughout the year, with an extended scope for the new SEAS postdocs.

**Securing data quality**

Trustworthy, quality assured data is a necessity for optimized management of ocean resources and ocean industries. Artificial intelligence (AI) for data analysis and digital twins for optimized operations both heavily depend on high quality data, and methods for securing data quality are essential parts of the Smart Ocean system design. The Centre is focusing both on data quality at the sensors, being the data sources of the system, as well as metadata for communicating the data quality to the analysis tools and eventually the end-users. The work on physics-driven automatic quality control of marine data includes deep-water oceanographic sensors and sensors exposed to biofouling in shallower waters. The collaboration on data quality also from a software perspective, has given valuable insights to the challenges of different requirements of measurement uncertainty and strategies for data availability and metadata.

A novel automatic anomaly detection algorithm called AdapAD was developed by HVL and will also be applied to the data streams of the SFI Smart Ocean platform. AdapAD was tested on data from the SFI partners, and work on algorithms for ensuring data quality has been published in several scientific papers. ●●●

Furthermore, nine marine sector use cases were identified from a series of workshops and dedicated interviews and analysed in terms of data quality requirements for data acquisition and usage. Additional guidelines and recommendations towards marine data reusability were also proposed to elevate data producers' activities to a broader range of marine data consumers.

**Efficient data flow**

The system requirements for underwater observations depend heavily on the type of application and the actual conditions, and a report on network architecture and overhead compression with efficient handling of metadata was prepared. The report also includes data acquisition strategy for sensors and recommendations for modem interfacing.

On the cloud-service side, where multiple real-time marine data sources converge, metadata information regarding the sensors is crucial for merging with data from other sources and determining the adequacy of different use cases. Because of the limitations on the underwater observations' levels, there is a trade-off among the volume of data collected and sent, the power required to transmit the data, the density of the wireless communicating nodes in the area to cover, and their impacts when transmitting data wirelessly. Consequently, depending on the use case-specific requirements, distributed processing units and transmission units must be carefully placed in the system's overall architecture.

Lastly, the end-to-end data flow is being studied from a software architecture perspective to analyse software and data-related quality attributes that can be affected by the many challenges of processing and sharing marine data in real-time from observing systems.
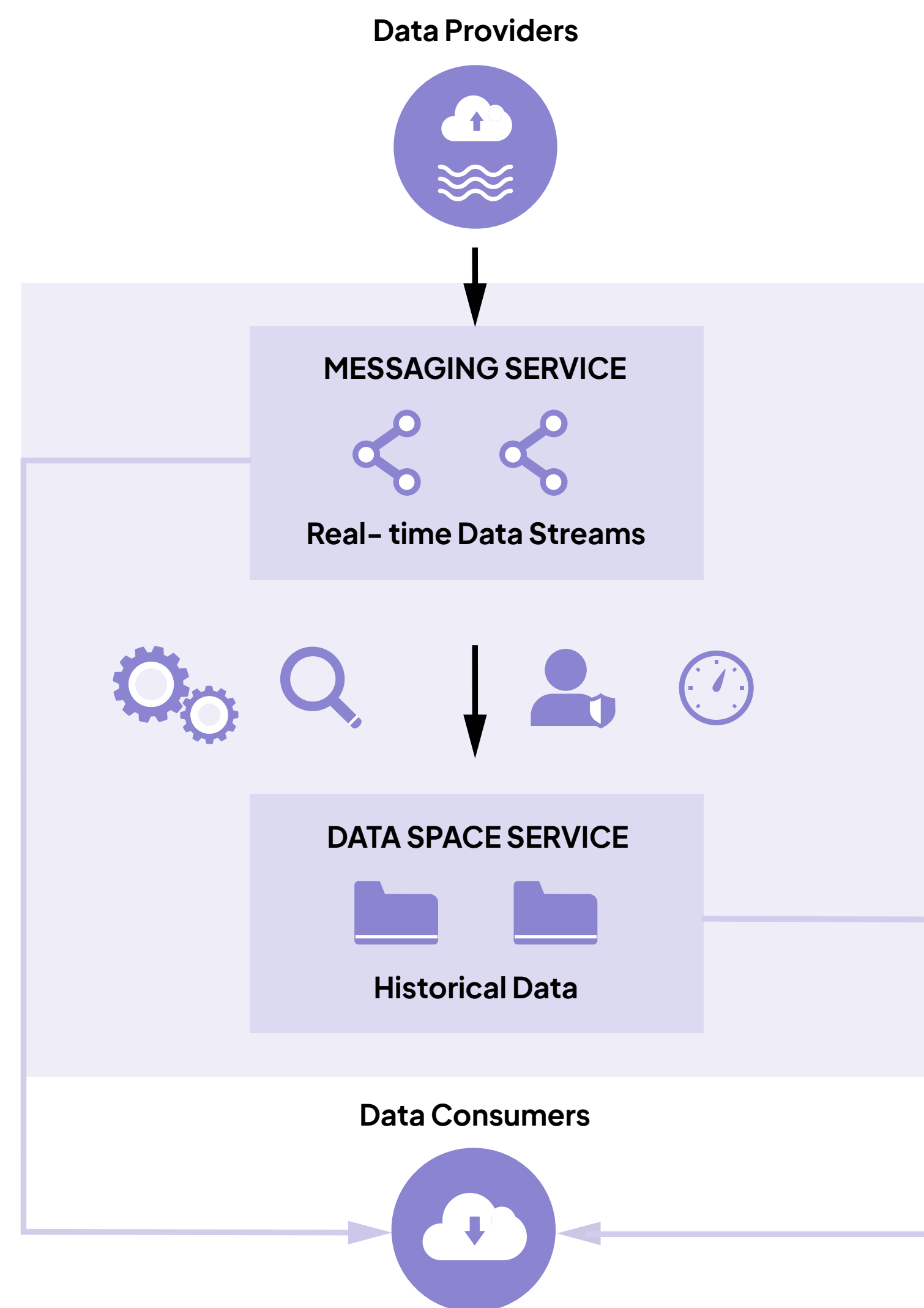
**Acoustic underwater communication**

Sensor data collected at the seafloor were successfully uploaded from sensors at Austevoll to the cloud with acoustic communication and a backhaul system. Other tests include long-term modem deployments and measurements of propagation channel characteristics and noise. As a first step towards interoperability, acoustic signals transmitted with the hardware of one partner were received and processed by another partner. A Software Defined Modem (SDM) has been designed to evaluate modulation schemes, coding methods and transmission protocols. Two SDM's were deployed at Austevoll test site to test the design and the test site infrastructure. Furthermore, some channel sounding experiments were conducted. The results are promising, and all functionality worked as expected.

Results from preliminary channel sounding tests, and results from the system integration of Seaguard and cNODE experiments performed in 2022 were published in 2023 at the Forum Acusticum conference. NORCE also started improving the system integration between Seaguard and cNODE. ●●●
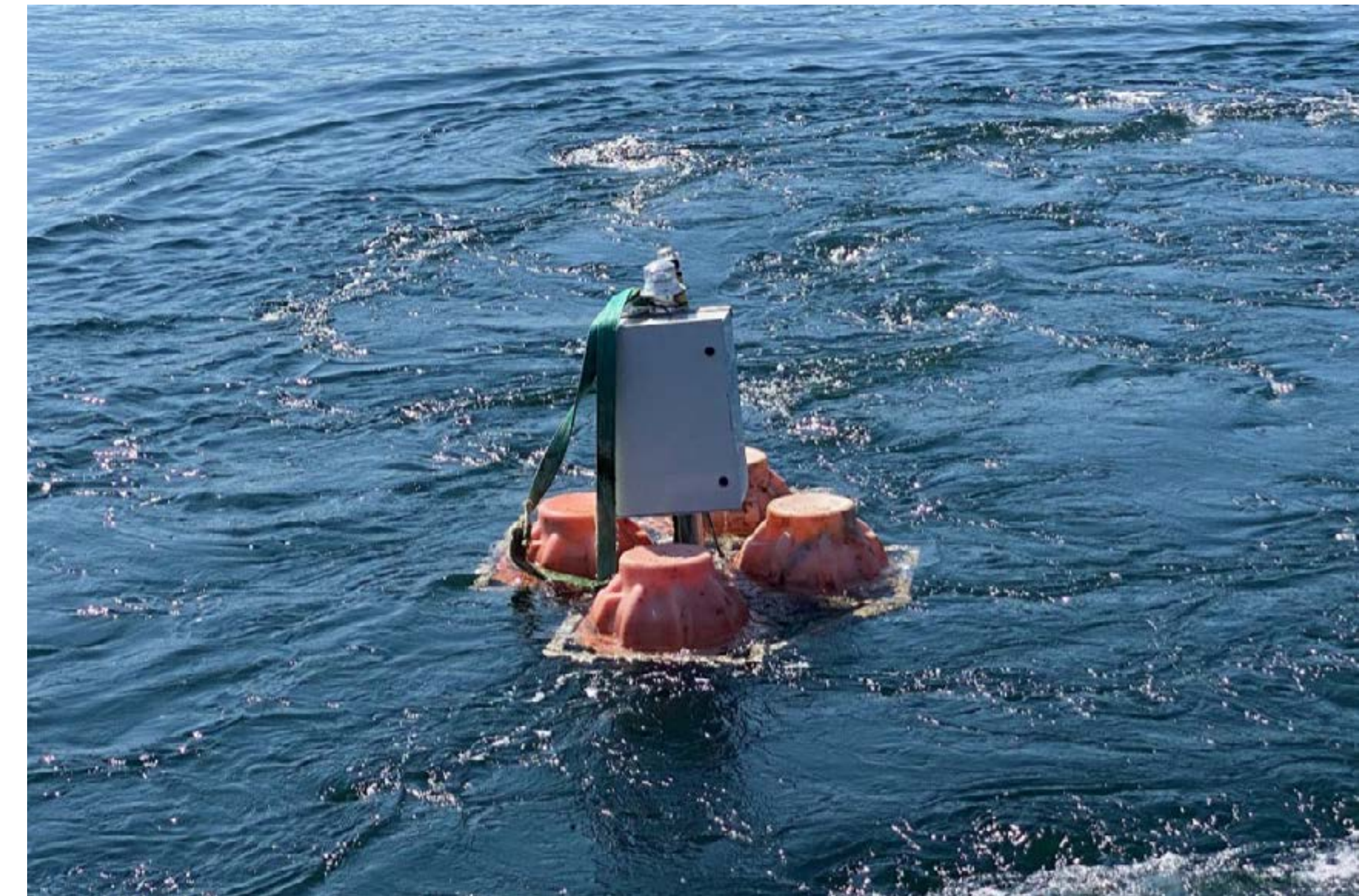


There are currently two observation buoys equipped with equipment from Aanderaa outside the Austevoll research station. The buoys measure and transmit sensor data with sensors on the surface and at a number of depths below the surface. Data is transmitted regularly and can be viewed online in near real time. PHOTO: IMR

**Data Providers**

**MESSAGING SERVICE**

**Real– time Data Streams**

**DATA SPACE SERVICE**

**Historical Data**

**Data Consumers**

**The first version of the SFI Smart Ocean Data and Application Platform was released in 2023. The platform handles both real–time and historical data from various sources. Explore the solution further by clicking on the image.**

Kongsberg Discovery and Aanderaa provided the software upgrade to allow two-ways communications between Seaguard and cNODE and the communication interface definition.

Empirical models for propagation loss and noise have been combined in an overall acoustic model to predict communication ranges and feasible data rates. The model provides guidance to choosing the optimal frequency band for acoustic modems, given an energy budget, range requirements, and weather conditions. The predictions are in agreement with range-rate relationships published in literature.

A PhD research fellow started at HVL in June 2023. He will investigate and assess the existing data link and network layer protocol designs for UWSN and propose improved solutions to be tested through simulations and field trials. A bachelor assignment was developed for three students to initiate simulations and cooperate with the PhD fellow using the selected DESERT simulator framework.

**The SFI Smart Ocean Data and Application Platform**
The SFI Smart Ocean Data and Application Platform is the cloud-hub for data flow in the SFI Smart Ocean digital eco-system interconnecting sensors and data services. The first version of the platform cloud-services was completed at the end of 2023, and has been deployed consuming data flows from the Aanderaa

sensor hub and the WSense underwater sensor network at the Austevoll test-site. Norwegian Defence Research Establishment (FFI) has also performed initial tests delivering data from NILUS to the platform.

The first version of the platform provides an MQTT-based messaging service for providing and consuming real-time data streams, and a REST APIs-based data space service based on noSQL database technology for long-term storage and retrieval of historical data time series. The development of the platform services also covers the design and implementation of the SFI Smart Ocean data model and format for time series data. Work completed in relation to the platform also includes an improved version of the SFI Smart Ocean data explorer based on NORCE Enlighten, evaluation and review of the WSense cloud API, integration studies concerning the NMDC infrastructure, and initial experiments with data sets from Oslofjorden provided by Kongsberg Discovery.

One Master's thesis on software engineering was completed at HVL focussing on software tools for modelling distributed systems which is closely related to the cloud platform middleware being developed in the Centre. As part of a PhD project in maritime digital twins, work has also started on developing a digital twin of the Austevoll test site. In the first iteration, this will entail the development of a 'digital shadow' for real-time monitoring, predictive maintenance assistance, and potential test site improvements. The end-goal is to develop a digital twin such that data can be automated from the cloud toward the test site to facilitate its automation and optimization.

**NORCE performed a successful test of their SDM modem in sea for the first time at the marine facility at Austevoll.** PHOTO: INGVAR HENNE

**Field trials at the Austevoll Research Station**

All work packages are involved with developments and testing of equipment, and the project has had a data stream providing oceanographic data from the two rigs adjacent to the Austevoll Research Station. Adaptation of the rigs was performed to provide a permanent near-real-time data flow. The instruments provide data on wave direction, oxygen, conductivity, turbidity, and temperature. Both rigs communicate via the LTE network, but acoustic underwater communication via equipment from WSense is also operational.

The sea-cage facility at Austevoll has been replaced during the first months of 2023, and a third rig will soon be placed adjacent to the sea-cages. Also, an advanced underwater node, obtained from IMR´s collaborating LoVe-project will be placed within the test area at the station.

The focus of the activities at Austevoll on underwater communication has been continued during 2023. The project partners Aanderaa, Kongsberg Discovery, WSense, IMR, FFI, and NORCE have worked together, testing different instruments for acoustic underwater communication and performing channel sounding in the testing area. The field trials were combined with testing of the NORCE coastal drone, and two underwater drones: the Seasam by Notilo Plus and Blueye X3 by Blueye robotics, from the MarTERA UNDINA project.

The sensors and communication systems are providing stable data access, and it is very encouraging to confirm that consortium participants are working efficiently together, combining knowledge and technologies into a more complete system. ●

**International cooperation allows students to get greater exposure and build networks. Below: Phd student Wiktoria Szapoczka and Master's student Denise Dilshener on an academic sojourn to the University of Cagliari, Italy.**

All Centre partners have international cooperation and/or offices abroad, and cooperation with their international networks directly or via affiliated activities is an important part of the Centre activities. As SFI Smart Ocean aims at a flexible, open, and vendor neutral network technology, cooperation with end users and vendors worldwide is crucial. Such cooperation will ensure that the Centre maximises the impact for the technology solutions developed in the Centre, but also implements standard technology solutions where such are available..

The Centre continues the collaborations with the international industry standardization initiative Subsea Wireless Group (SWiG), and the ERANET Cofund MarTERA project "The underwater robotics with multimodal communication and network-aided positioning system" (UNDINA). In UNDINA, the Centre participants are collaborating with, amongst others, ISEN in France, and this collaboration has during the last year expanded to also include other activities relevant to SFI Smart Ocean.

Further, the Centre continues the cooperation with Helmholz Institute for Environmental Research and Max Planck Institute for Medical Research related to anti biofouling treatments for transparent substrates. This activity is crucial for the Centre to make underwater sensors more robust towards biofouling. The PhD students within software development and their supervisor have established cooperation with Gran Sasso Science Institute in

Italy, and as part of their 2023 activities, one PhD candidate and one Master's student had an internship at the institute. In addition, the research group in software engineering is cooperating with Chalmers University of Technology (Sweden), and University Sorbonne Paris Nord (France). Two PhD students at HVL has had several shorter international research visits, and one researcher has spent one month at University Sorbonne Paris Nord as a visiting professor.

The University of Bergen is participating in the SEAS program, a cofund PostDoc mobility program. In relation to this, an American PostDoc has been hired by UiB, and his activities are strongly associated with SFI Smart Ocean. Three more PostDocs were hired in 2023, working closely with the Centre on optics and nanotechnology for sensor development. One SEAS Postdoc started as a visiting researcher at the University of Strathclyde, Glascow, on marine optics investigating the intersection between physics, biology and oceanography.

The Centre will cooperate with OLAMUR (governed by IMR) related to field trials of components from our observation system.

SFI Smart Ocean cooperates with The Nansen Environmental and Remote Sensing Centre (NERSC) on two international projects: The EU-funded project HiAOOS – High Arctic Observation ●●●

system, and the INTPART-project UAK – Useful Arctic Knowledge, both which will work to strengthen education, research, and innovation within ocean observation technologies and include field trials in the arctic sea. These projects involve partners like Scripps, University of Rhodes Island, and the University of Laval.

Metas AS is cooperating with Brazilian partners in the project "Development of a Stand- Alone Subsea Instrumentation (SASI) Platform for hydrocarbon leakage detection". They are exploiting common need for data, and share their experiences and relevant data from that project with SFI Smart Ocean.

Additionally, funding applications have been sent to Horizon Europe and the Research Council of Norway together with a long list of international partners, and both the project development work and future potential cooperation projects strengthen our international cooperation and impact. ●

CLICK for VIDEO



**Students at UiB contribute to the development of novel sensor technology through close cooperation with the Centre partners and universities abroad. Pictured above: Phd student Wiktoria Szapoczka.** VIDEO & EDITING: FRODE IMS / UIB LEARNING LAB

**Md. Al Shayokh**
PHD STUDENT / HVL



**Julian D. P. Quiñones**
PHD STUDENT / UIB



**Håkon Sandven**
POSTDOC / UIB



**Bichitra Nanda Sahoo**
POSTDOC / SEAS



**Paul Thomas**
POSTDOC / SEAS



**Ivan Spajic**
PHD STUDENT / HVL



**Ingvar Henne**
CENTER DIRECTOR

In 2023, SFI Smart Ocean recruited two new PhDs and a new Centre Director. In addition, three associated post-docs and one associated PhD also stared.

**Md Al Shayokh** started working as a PhD in June 2022 at HVL, with Anne-Lena Kampen, Kjell Eivind Frøysa and Lars Michael Kristensen as supervisors. Shayokh will be working on developing communication protocols, and will especially focus on network architecture, multi-hop and mesh protocols with respect to efficient data transfer and low energy requirements.

**Julian David Pelaez Quiñones** joined the Centre as a PhD at UiB from 1. Decembre 2023. He will focus on the use of fibre-optic cables to investigate natural and anthropogenic wavefields (primarily acoustic) in the ocean for diverse purposes, including ambient noise monitoring and source-medium characterization. His supervisor team is Per Lunde (UiB), Peter Thomas (NORCE) and Steinar Bjørnstad (Tampnet).

In May 2023, **Håkon Sandven** started as a Postdoc at UiB, funded by the SEAS Fellowship Programme. Sandven will be working on improving our capabilities to model and measure underwater light in a changing climate. This will also be applied to Norwegian coastal waters, where increased erosion from land may decrease the available light for life underwater. This project will be conducted together with UiB collaborators and David McKee at the University of Strathclyde.

**Bichitra Nanda Sahoo** started at UiB in a SEAS-postdoc in November 2023. His project focuses on the development of anti-biofouling coatings for oceanographic sensors. This multidisciplinary project aims to develop an anti-biofouling coating, which provides long-term fouling resistance and enhances the life span of both optical and non-optical marine sensors. Sahoo will be working with Martin Greve (UiB) and Peter J. Thomas (NORCE).

**Paul Thomas** also started in November 2023 at UiB in a SEAS-postdoc. Thomas will be investigating the prospective of nanometal oxide composite based coating to prevent biofouling. The new nanomaterial-based coating design is expected to minimize capital costs and to provide better durability without compromising eco-friendly characteristics.

**Ivan Spajic** is an associated Phd at HVL. Spajic will work on digital twins in the maritime domain and the software tools and middleware surrounding them. His main focus will be within the shipping industry; however, he will embed with the SFI Smart Ocean project to work on a digital twin case study.

**Ingvar Henne** is the new director of the Centre and was recruited from NORCE during the spring 2023. Henne has been involved in the Centre all the way from the application phase, and therefore knows the plans and partners of the Centre well. ●

Our website, www.sfismartocean.no, contains public information, along with news about the Centre. Our LinkedIn profile is used for publication of recent, important happenings and upcoming events.

An open seminar series was started in September 2022 and has been continued throughout 2023. Topics from the seminars cover results from the Centre activities and other associated activities, and both industry and academia are represented. The seminars serve as a channel for information both internally in the Centre and externally.

We organized two open workshops in Grimstad and Bergen together with GCE Ocean Technology, GCE Node, and SFI Offshore Mechatronics. The aim of these gatherings was to explore new possibilities for the continuation of research areas that SFI Offshore Mechatronics has worked on and relate this to SFI Smart Ocean activities and the potential for new initiatives. Aanderaa, Bouvet, Kongsberg, and NORCE gave presentations of SFI Smart Ocean activities at these events.

We have been very visible in both the scientific communities, industry and in the educational system, particularly at HVL and UiB. A range of publications, presentations and other contributions have been prepared:

- **14** scientific papers published in journals or conference proceedings
- **22** scientific presentations, posters or guest lectures at industrial and scientific conferences, workshops and seminars
- **8** overall presentations of SFI Smart Ocean and activities in the Centre to industry and other users
- **8** contributions to external papers, web pages and exhibitions
- **12** Master's students working on topics related to SFI Smart Ocean completed their studies

Our PhD students have been active also this year:

**Wiktoria Szapoczka** participated in a panel debate entitled "Food on the move" during the Arctic Frontiers conference in Tromsø in January, and recently gave input to a web post at UiB on how she "saves the world by monitoring the ocean environment". She also published the new article "Fluorescence intensity and fluorescence lifetime measurements of various carbon dots as a function of pH" in Scientific Reports from Nature.

PhD student **Astrid Marie Skålvik** gave the lecture "How can we trust measurement data?" at the Petroleum Safety Authority's Innovation Day in Stavanger on 1 February. She also published "Challenges, limitations, and measurement strategies to ● ● ●



**Partner Aanderaa's (a Xylem brand) Environmental Sales Director Inger M. Graves gives a presentation at the August workshop in Bergen.**
PHOTO: GCO OCEAN TECHNOLOGY
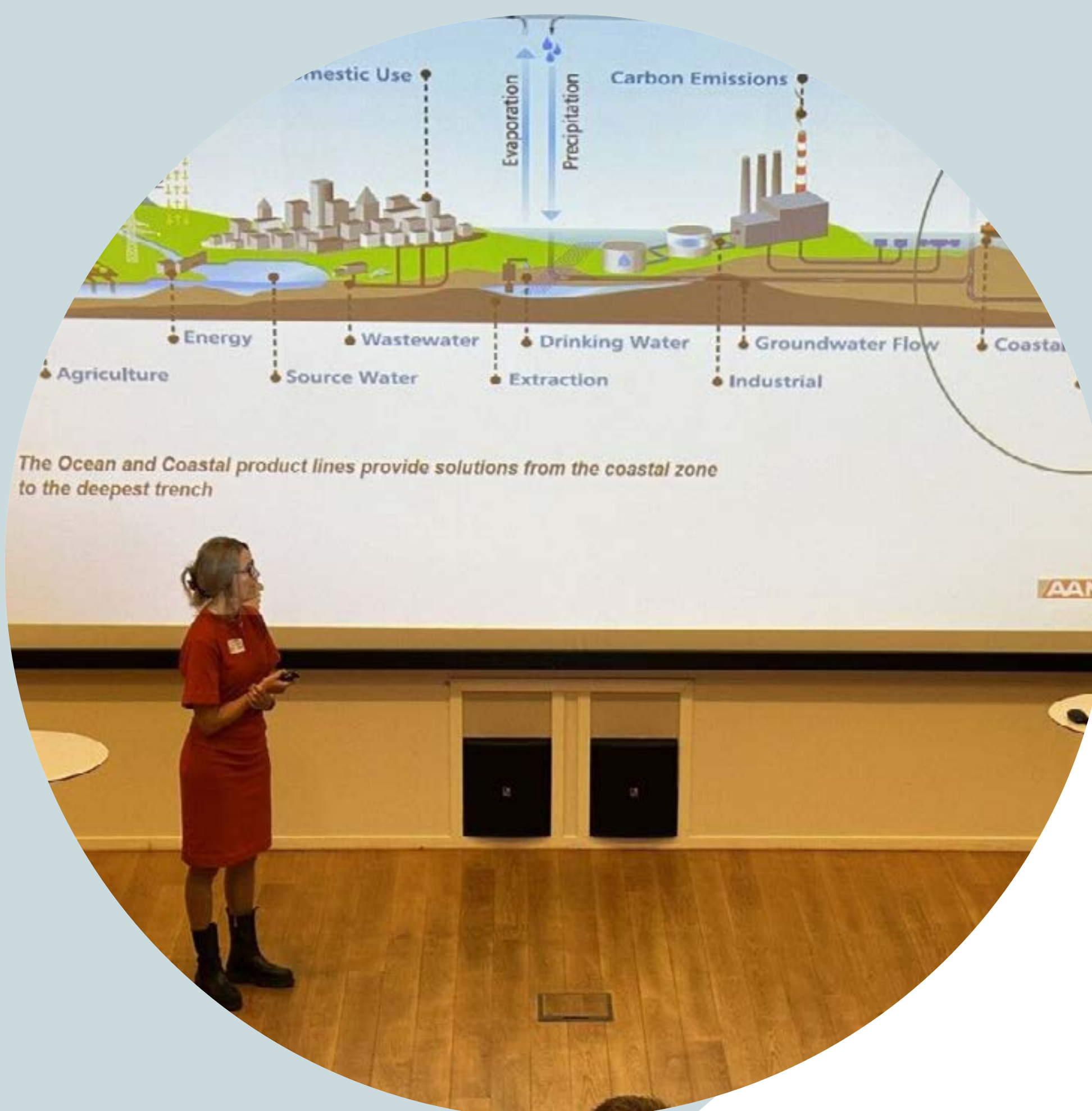
ensure data quality in deep–sea sensors" in the journal Frontiers of Marine Science.

• PhD Student **Ngoc Thanh Nguyen** has published the article "Engineering Challenges of Stationary Wireless Smart Ocean Observation Systems" in the IEEE Internet of Things Journal.

• PhD Student **Keila Lima** has presented the work "Marine Data Observability using KPIS: An MDSE Approach" at the 26th International Conference on Model Driven Engineering Languages and Systems that resulted from international cooperation with the Gran Sasso Science Institute (GSSI).

Another somewhat exotic example is the participation by Aanderaa at a hybrid event organized by Nagaoka University of Technology in Japan, where various examples of collaboration Aanderaa has with both SFI Smart Ocean/UiB and other international research institutions were presented.

An interview with the new Centre director, **Ingvar Henne** entitled "Data from ocean to cloud" was published by GCE Ocean Technology in June, and presentations of SFI Smart Ocean were given at the biannual strategy meeting at The Faculty of Mathematics and Natural Sciences, UiB.

**Håvard Stavn Ugulen** defended his PhD thesis with the title "Characterization and correction of errors in measured inherent optical properties: Multiple scattering errors in LISST–VSF measurements". He is the Centre's first associated PhD student to complete his doctorate.

The 4 postdocs from the SEAS program that are linked to SFI Smart Ocean (**Daniel Koestner** and **Håkon Sandven** in optics, and **Bichitra Nanda Sahoo** and **Paul Thomas** in nanophysics) presented their work at the SEAS gathering "Shaping European Research Leaders for Marine Sustainability" at UiB.

Internally in the Centre, communication was significantly strengthened by the two physical workshops held over two days each, one in May and one in October. ●



A total of 4 postdocs from the SEAS program are linked to SFI Smart Ocean. Paul Thomas (L) and Bichitra Nanda Sahoo explain their work on anti–fouling protective nano–coatings for oceanographic sensors in a dialogue with Margareth Hagen, Rector at UiB.  PHOTO: OLE DRØNEN

## Funding

|  | Amount (1000 NOK) |
|---|---|
| The Research Council | 12 594 |
| The Host Institution (UoB) | 4 857 |
| Research Partners* | 5 343 |
| Enterprise Partners** | 6 432 |
| Public Partners*** | 148 |
| TOTAL | 29 374 |

## Costs

|  | Amount (1000 NOK) |
|---|---|
| The Host Institution (UoB) | 8 440 |
| Research Partners | 14 773 |
| Enterprise Partners | 6 016 |
| Public Partners | 148 |
| TOTAL | 29 374 |

\*    NORCE, HVL, NERSC, IMR, FFI

\*\*   Aanderaa Data Instruments AS, ReachSubsea AS, TSC Subsea AS, IMENCO AS, Kongsberg
Discovery AS,  Tampnet AS, Bouvet Norge AS, Aker BP AS, WSENSE AS, GCE NODE
Service AS, GCE Ocean Technology, NCE Seafood Innovation

\*\*\* Directorate of Fisheries, Norwegian Ocean Industry Authority

## Centre Administration

| | | |
|---|---|---|
| Henne, Ingvar | UiB | Centre Director (from April) |
| Holstad, Marie Bueie | NORCE | Deputy Centre Dir. (from April) |
| Holstad, Marie Bueie | UiB | Centre Director (until April) |
| Sætre, Camilla | UiB | Deputy Centre Dir. (until April) |
| Terje Restad | UiB | Administrative Manager |
| Kavitha Østgaard | UiB | Communication Manager |

## Key Researchers

| Key Researchers | Institution | Main Contributions |
|---|---|---|
| Holst, Bodil | UiB | Novel sensor technology & anti-biofouling: pH sensor |
| Greve, Martin M. | UiB | Novel sensor technology & anti-biofouling: pH sensor |
| Lunde, Per | UiB | Guided Ultrasonic Waves (GUW)/Distributed Acoustic Sensing (DAS) |
| Sætre, Camilla | UiB | Measurement strategy and uncertainty/Marine optics |
| Pedersen, Audun O. | UiB | Guided Ultrasonic Waves (GUW)/Distributed Acoustic Sensing (DAS) |
| Skodvin, Tore | UiB | Novel sensor technology & anti-biofouling: pH sensor |
| Hamre, Børge | UiB | Marine Optics |
| Kristensen, Lars M. | HVL | Adaptive Data Retrieval Methods and Visualisation |
| Heldal, Rogart | HVL | Software Engineering: Software Quality, Modelling and Validation |
| Frøysa, Kjell–Eivind | HVL | Measurement strategy and uncertainty |
| Oyetoyan, Tosin Daniel | HVL | Software Engineering: Software Quality, Modelling and Validation |
| Kampen, Anne Lena | HVL | Communication Protocols and Network Architecture |
| Holstad, Marie Bueie | NORCE | Deputy Centre Director (from April) |
| Cook, Jeremy | NORCE | Adaptive Data Retrieval Methods and Visualisation |
| Henne, Ingvar | NORCE | Underwater communications: Requirements, lim., and pos. (Jan. – Apr.) |
| Henriksen, Bård | NORCE | Underwater communications: Requirements, limitations, and possibilities |
| Kocbach, Jan | NORCE | Guided Ultrasonic Waves (GUW) |
| Langeland, Tor | NORCE | Adaptive Data Retrieval Methods and Visualisation |
| Thomas, Peter James | NORCE | Distributed Acoustic Sensing (DAS) |
| Øyerhamn, Rune | NORCE | Underwater communications: Requirements, limitations, and possibilities |
| Bergh, Øivind | IMR | Coordinate activities in IF1 |
| Stiansen, Jan Erik | IMR | Coordinate activities in IF1 |
| Sagen, Hanne | NERSC | Geographical testing location Svalbard Nord |
| Storheim, Espen | NERSC | Geographical testing location Svalbard Nord |
| Otnes, Roald | FFI | Underwater communications: Requirements, limitations, and possibilities |
| van Walree, Paul | | FFI Underwater communications: Requirements, limitations, and possibilities |

**Postdoctoral researchers working on projects in the Centre with financial support from other sources**

| Name | Funding | Nationality | Period | Sex | Topic |
|---|---|---|---|---|---|
| Koestner, Daniel | EU/UiB | USA | 06.22 – 05.25 | M | Improving the capabilities of autonomous platforms in marine science with optical sensors |
| Sandven, Håkon J. | EU/UIB | Norway | 06.23 – 05.26 | M | Development and use of instrumentation for monitoring of light scattering and absorption by marine particles |
| Sahoo, Bichitra N. | EU/UiB | India | 10.23 – 9.23 | M | Reinventing anti-biofouling coatings for combating biofouling of marine sensors |
| Thomas, Paul | EU/UiB | India | 11.23 – 10.26 | M | Study on bifunctional nanozyme activities of layered double hydroxide derived Zn-Mo films for anti-biofouling and anti-corrosion applications in the subsea environment |

**Ph.d. students with financial support from the Centre budget**

| Name | Nationality | Period | Sex | Topic |
|---|---|---|---|---|
| Szapoczka, Wiktoria | Norway | 09/21–8/24 | F | Novel sensor technology & anti-biofouling: pH sensor |
| Skålvik, Astrid M. | Norway | 1/22–12/25 | F | Self-diagnostics and self-calibration methodologies for underwater sensors |
| Lima, Keila | Cape Verde | 1/22–31/24 | F | Software Engineering Methodology: Software Quality, Modelling and Validation |
| Ngoc-Thanh Nguyen | Vietnam | 04/21–04/25 | M | A framework for real-time marine data quality control |
| Abboud, Amr | Syria | 9/22–8/26 | M | Guided Ultrasonic waves (GUW) |
| Al Shayokh, Md. | Bangladesh | 6/23–5/27 | M | Communication Protocols |
| Pelaez Quiñones, J. D. | Colombia | 12/23– 11/27 | M | Distributed Acoustic Sensing |

**Master's Degrees**

| Name | Sex | Topic |
|---|---|---|
| Isaksen, Irene D. | F | Guided ultrasonic waves: Transmitted transducer field as a function of distance from the plate and ka number |
| Løland, Robert | M | Triangulation method for measurement of fisheries echo- sounder 2–way equivalent beam solid angle |
| Økland , Håvard R. | M | Finite-element modelling, construction, and experimental characterization of piezoelectric transducers for gas |
| Helleve, Mathias | M | Ship noise measurement and analysis |
| Thorbjørnsen, Aslak J. | M | Nonlinearity in piezoelectric transducers |
| Larsen, Viljar | M | Smart surfaces for anti-biofouling and anti-icing |
| Fjellheim, Mats J. | M | Defect detection and acoustic penetration of grout in offshore structures |

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B. Tomasi, R. Øyerhamn, R. Otnes, Design method for long-term evaluation of underwater acoustic communications and networks in a Norwegian fjord environment, Forum Acusticum 2023 Convention of the European Acoustics Association, 2023

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**Szapoczka, W.:** "Big Picture: Food on the Move", Arctic Frontiers 2023 Moving North

**Henne, I.:** "SFI Smart Ocean – Samfunnsutfordringer i det grønne skiftet", UiB sommerseminar

**Sagen, H., Stallemo, A., Storheim, E., Sandven, S., Geyer, F., Hamre, T.:** "IF1: SFI Smart Ocean collaboration with HiAOOS", Autumn Gathering, SFI Smart Ocean.

**Storheim, E., Sagen, H.:** "Acoustics in fjord environments", Multidisciplinary Fjord Workshop, Solstrand

**Szapoczka, W.K., Truskewycz, A.L., Skodvin, T., Holst, B., Thomas, P.J.:** "Fluorescence Emission and Fluorescence Lifetime Measurements of Five Carbon Dots as a Function of pH", 33rd International Conference on Diamond and Carbon Materials

**Ø. Bergh, J.-B. Danre, K.Stensland, K. Lima, N.-T. Nguyen, R. Heidal, L. M. Kristensen, T. D. Oyetoyan, I. Graves, C. Sætre, A. M. Skålvik, M. B. Holstad, I. Henne, J. E. Stiansen:** "A modular Smart Ocean Observatory for sensor and communication development, and surveillance of environmental parameters in and around an aquaculture research facility", The Ocean Race – Grand Finale, Ocean Data Week 2023, Genova, Italia June 27–30, 2023

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**L.M. Kristensen:** "Towards a Formal and Executable Software Architecture Specification of the Smart Ocean Data Service Platform", Petri Nets and Software Engineering, 2023

**L.M. Kristensen:** "Coloured Petri Nets for Concurrent Software Systems Engineering", Advanced Course on Petri Nets 2023

**N.-T. Nguyen:** "Synthesized data quality requirements and roadmap for improving reusability of in-situ marine data", 31st IEEE International Requirements Engineering 2023 Conference.

**K. Lima:** "Marine Data Observability using KPIs: An MDSE Approach", 26th International Conference on Model Driven Engineering Languages and Systems

**M.B. Holstad:** "SFI Smart Ocean – an observation system for ocean industries", Meeting with Norwegian Offshore Wind Cluster

**I. Henne:** "Smart Ocean program overview", Informasjonsdelingsmøte/Technology focus point, Aker BP

**I. Henne:** "Wireless network", Informasjonsdelingsmøte/Technology focus point, Aker BP

**C. Sætre:** "Autonomous sensors", Informasjonsdelingsmøte/Technology focus point, Aker BP

**I. Henne:** "Introduction of SFI Smart Ocean", Innovasjonsworkshop, Grimstad

**E. Bjerke:** "Technology and appliations of acoustic positioning and communication systems", Innovasjonsworkshop, Grimstad

**P.J. Thomas:** "New sensor technology development in SFI Smart Ocean", Innovasjonsworkshop, Grimstad

I. Henne: "Smart sensor networks in the ocean", Innovasjonsworkshop – Ocean Technology, Bergen

I. Graves: "Monitoring solutions for marine observations", Innovasjonsworkshop – Ocean Technology, Bergen

Y. Kvinnsland: "Visualization of marine observations and infrastructure status", Innovasjonsworkshop – Ocean Technology, Bergen