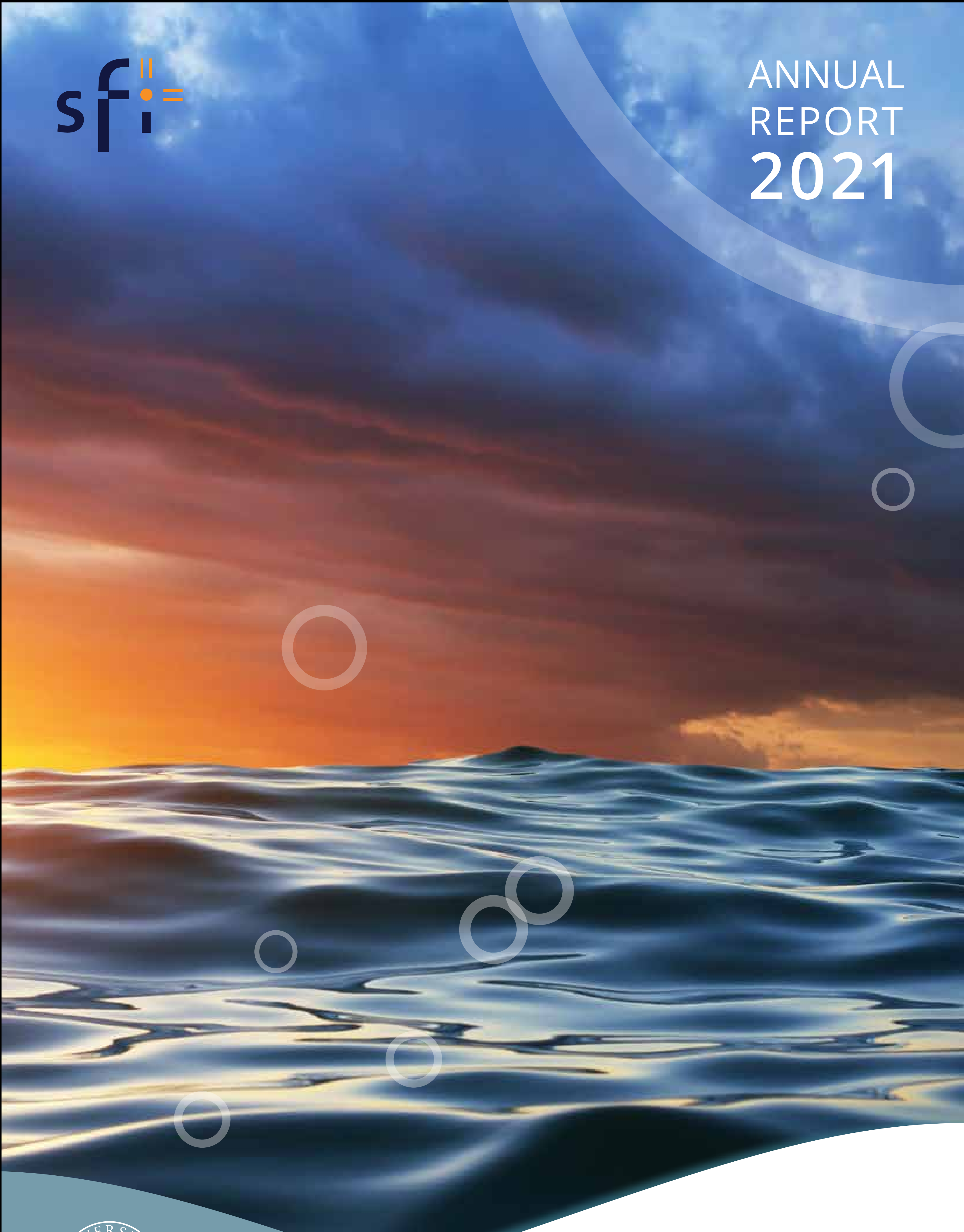
ANNUAL REPORT 2021



SFI SMART OCEAN

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

USER PARTNERS / INDUSTRIES

USER PARTNERS / INDUSTRY CLUSTERS

NATIONAL AUTHORITY OBSERVERS

CONTENTS

SUMMARY

Geir Anton Johansen
Centre Director

SFI Smart Ocean industry partners and cluster partners GCE Ocean Technology and GCE NODE are, of course, critically important when collecting input and knowledge from the industry, and we appreciate their participation in the Centre and look forward to further cooperation.

SFI Smart Ocean is a Centre for research-based innovation, funded by the Research Council of Norway. The Centre started on 1. December 2020, and has 6 research partners, 8 industry partners, 2 industry-cluster partners and 2 partners from national authorities. Our goal is to enable sustainable ocean management through real-time measurements from autonomous and smart sensor networks.

2021 has been a challenging year for SFI Smart Ocean due to the pandemic. It is not ideal to start a new Centre from home offices through digital meetings, and with strong restrictions on travel. However, in October we could finally have a physical meeting, and close to 50 representatives gathered at the delayed formal opening of SFI Smart Ocean. The formal opening was conducted by UiB's Vice-Rector for Innovation, Projects and Knowledge Clusters, Gottfried Greve. The opening was followed by a full a day of presentations and discussions, and with ample opportunities for socialising. With the Covid restrictions lifted, SFI Smart Ocean will promote team building and physical gatherings in the time to come.

Even though the Covid-restrictions have been challenging, the activities in the work-packages have started up and are well on their way. This first year, there has been a focus on mapping possibilities, limitations, and expectations, as well as development of basic system architecture. This provides a good foundation for development of SFI Smart Ocean technology as detailed on page 12.

Technology components and systems developed in SFI Smart Ocean will be tested through pilot demonstrators for environmental and structural integrity monitoring. Implementation of such demonstrators was started in 2021. The main pilot demonstrator at IMR's research station at Austevoll became operational in 2021, and field experiments to map the fjord environment in relation to the second pilot demonstrator in Bjørnafjorden were carried out during a research cruise in November.

In this first, fully operational year, it has been important for SFI Smart Ocean to get input from relevant stakeholders also outside the consortium. Close dialogue has been established with Bergen Offshore Wind Centre, and a presentation was held for the Norwegian Offshore Wind Cluster, followed by good discussions on requirements and needs within the wind industry. Dialogue has also been established with NCE Seafood Innovation as a representative for the aquaculture industry, aiming at identification of the requirements from this group of end users. Additionally, discussions with various relevant industry companies have given valuable insight into industry challenges and priorities. SFI Smart Ocean industry partners and cluster partners GCE Ocean Technology and GCE NODE are, of course, critically important when collecting input and knowledge from the industry, and we appreciate their participation in the Centre and look forward to further cooperation.

User needs and industry input have also been important when defining the scope for PhD students starting up their work in SFI Smart Ocean, and also when defining Master's projects included in the Centre work. Even if it has been more challenging than expected to recruit PhD students, several projects have been started or will start in January 2022. In the years to come, defining relevant and attractive Master's and Bachelor projects will be important in improving the number of scientifically qualified PhD candidates, and candidates for the industry partners.

The importance of cooperation with other ongoing research has also been highlighted, and dialogue with several other projects has been established. This includes initial talks with another SFIs performing complementary research, and an ERA-NET COFUND MarTERA project developing communication and positioning technology for underwater drones.

Collaboration and initialisation of new research initiatives are also important in growing research activity, and the first activities on this have been started.

In summary, we are really excited to see the progress of SFI Smart Ocean, and we are truly looking forward to the continuation.

UiB's Vice-Rector for Innovation, Projects and Knowledge Clusters, Gottfried Greve (right, back) watches the ribbon cutting ceremony at the opening of SFI Smart Ocean.

VISION & OBJECTIVES

The SFI Smart Ocean 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, 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 key factors are highly cross-disciplinary:

- sensors and measurement parameters
- flexibility and adaptive sampling in time and space
- point measurement vs. monitoring over large areas
- distributed measurements
- measurement uncertainty and reliability
- time history as input to big-data analysis
- machine learning, prediction, and emergency response
- data format aggregation and safety
- low power consumption and local sensor intelligence

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

Standardized interfaces enable the integration of a diversity of sensor types, 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 needs and meeting the societal challenges.

Research Cruise with KV Tor showing students boarding.

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.

RESEARCH PLAN & STRATEGY

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 autonomous sensor technology for marine environmental 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, 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, and distributed fibre optic sensors with chemical sensing for environmental monitoring.

Our research also includes nanostructured surfaces for anti-biofouling of sensor and modem surfaces, to ensure high signal quality and longer deployment in the ocean. Research on measurement strategies aims to reduce measurement uncertainty and ensure trustworthy data. This includes self-validation and self-diagnostic capabilities of the smart marine sensors, and optimization of the sensor network layout with focus on the uncertainty propagation in the network from the marine sensors to the data presented to the end user.

Existing sensors, new sensor technologies, nanostructured self-cleaning surfaces, and the measurement strategies for trustworthy data will be tested at pilot demonstrators in the centre.

WP2: WIRELESS NETWORK COMMUNICATIONS

SFI Smart Ocean depends heavily on underwater communications. This work package focuses on communication technology for SFI Smart Ocean, and will develop a low-cost, miniaturized, and short-range acoustic underwater wireless technology platform assembled to an energy-efficient underwater wireless sensor network (UWSN). Hardware and software will need to be optimized with respect to limited battery capacity, efficiency, and reliability. Acoustic modem and communication protocols will build on state-of-the-art within underwater acoustic communication technology.

The system will be interfaced towards mobile networks (4G, 5G), satellite communication, fiber 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 to use in SFI Smart Ocean will be defined based on the requirements in combination with 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.

WORK PACKAGES (WP) & INTEGRATING FUNCTIONS (IF)	IF1				IF2
	PILOT DEMONSTRATORS				OVERARCHING ACTIVITIES
	ENVIRONMENT		INTEGRITY		
	PD1: LOCAL SCALE ENVIRONMENTAL MONITORING	PD2: MESOSCALE ENVIRONMENTAL MONITORING	PD3: INTEGRITY MEASUREMENTS OFFSHORE WIND	PD4: INTEGRITY MEASUREMENTS OIL & GAS	ADMINISTRATION EDUCATION DATA MANAGEMENT COMMUNICATION COMMERCIALISATION INNOVATION & IPR [ICP]
WP1: AUTONOMOUS SENSORS & MEASUREMENT STRATEGIES					
WP2: WIRELESS NETWORK COMMUNICATION					
WP3: SOFTWARE TECHNOLOGY & BIG-DATA MIDDLEWARE					

WP3: SOFTWARE TECHNOLOGY AND BIG-DATA MIDDLEWARE

The work package on software technology and big-data middleware focuses on digital eco-system providing cloud-based ocean data services and supporting cost-effective development of software applications that 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 and data 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.

IF1: PILOT DEMONSTRATORS

This is an overarching Work Package that includes the sites where results from WPs 1-3 will be tested out 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 presently being set up at the Austevoll Research Station near Bergen. Here three rigs with sensors are being placed; the rigs are modular, and a range of sensors and communication systems can be included. The research station provides an existing infrastructure, making modifications and maintenance of the rigs easier.

A meso-scale environmental monitoring will be established as an extension of the local scale system at Austevoll, paving the way for longer scale communication, geo-positioning, and mesoscale environmental monitoring, using acoustic tomography and passive acoustics.

Test facilities for offshore wind installations are being prepared, as are systems for monitoring oil and gas installations. The 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 overarching activities such as commercialisation, innovation and IPR aspects, internal and external communication (dissemination and outreach), data management plan, and education of Master's and PhD students.

ORGANIZATION

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

GEIR A. JOHANSEN
Centre Director

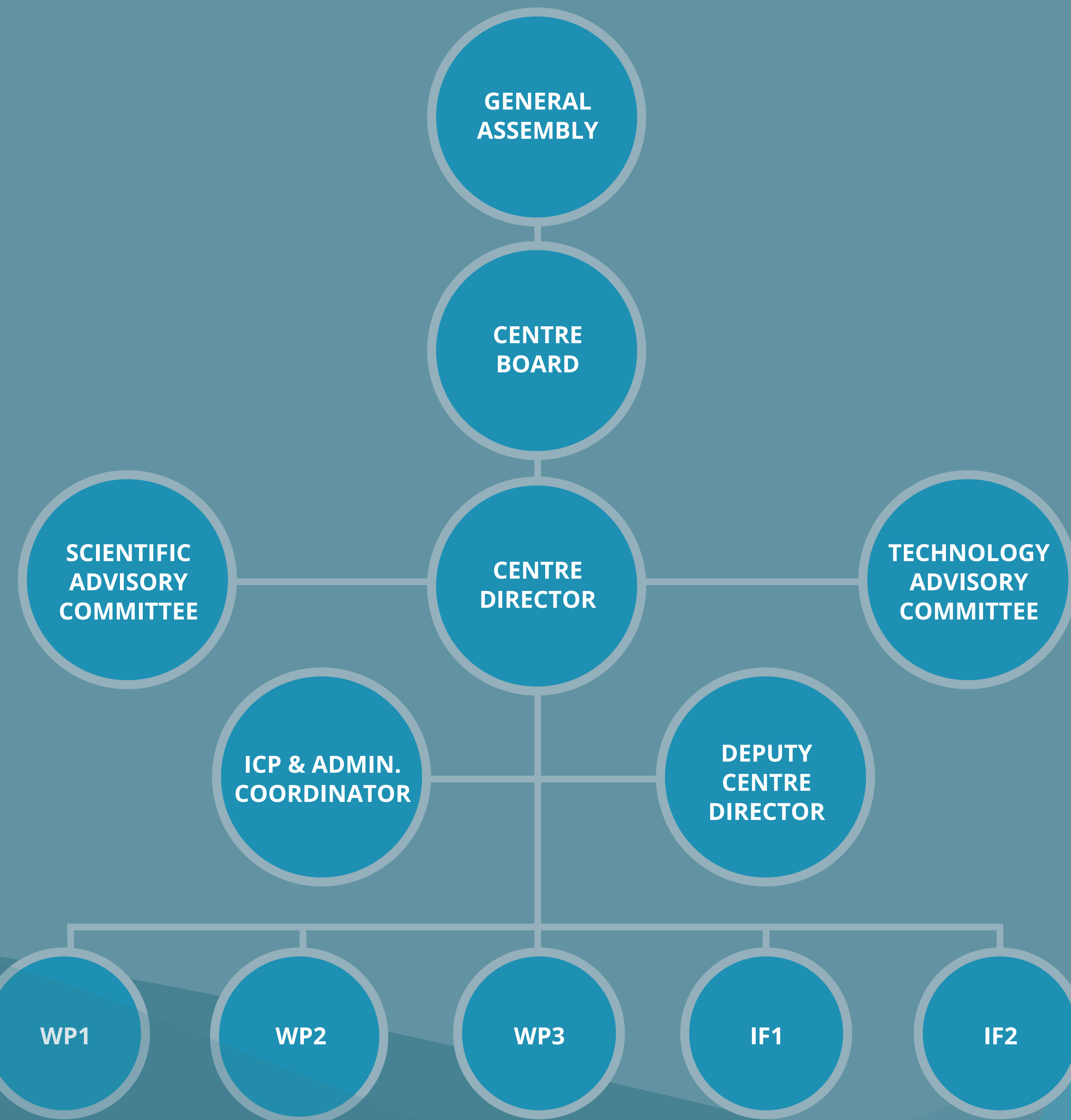
The General Assembly (GA) is the body responsible for major decisions regarding the Centre. All partners are represented in GA, and UiB as host institution chairs the GA. Dean Helge K. Dahle was chair of GA at the start, in 2020, and from August 2021, Dean Gunn Mangerud has taken over the role.

The Centre Board consists of Tove Lie (chair, Lundin Energy Norway AS), Owe Hagesæther (GCE Ocean Technology), Jan Erik Faugstadmo (Kongsberg Maritime AS), Inger Graves (Aanderaa Data Instruments AS), Annette Fagerhaug Stephansen (NORCE Norwegian Research Centre AS), Jens Kristian Fosse (Western Norway University of Applied Sciences), Øyvind Frette (University of Bergen).

The members of the Scientific Advisory Committee (SAC) are Professor Frank Reichert (University of Agder), Professor Jerker Delsing (Luleå University of Technology), Professor João Borges de Sousa (Porto University) and Assistant Professor Paolo Casari (University of Trento). They will give advice to the Centre Board on scientific issues and priorities, to ensure high-quality scientific impact.

The TAC consists of a representative from each of the Consortium participants and advises the Centre Board via the Centre Director on technical issues and priorities, including ICP, to ensure industrial, innovation, research and value creation impact. Camilla Sætre (UiB) is hair of TAC.

The Centre management team is comprised of Centre Director Geir Anton Johansen, Technology Director/Deputy Director Marie Bueie Holstad (NORCE), Communication Manager Randi H. Eilertsen and Admini-strative Coordinator Terje Restad (UiB).



MARIE B. HOLSTAD
Deputy Ctr. Director

CAMILLA SÆTRE
WP1

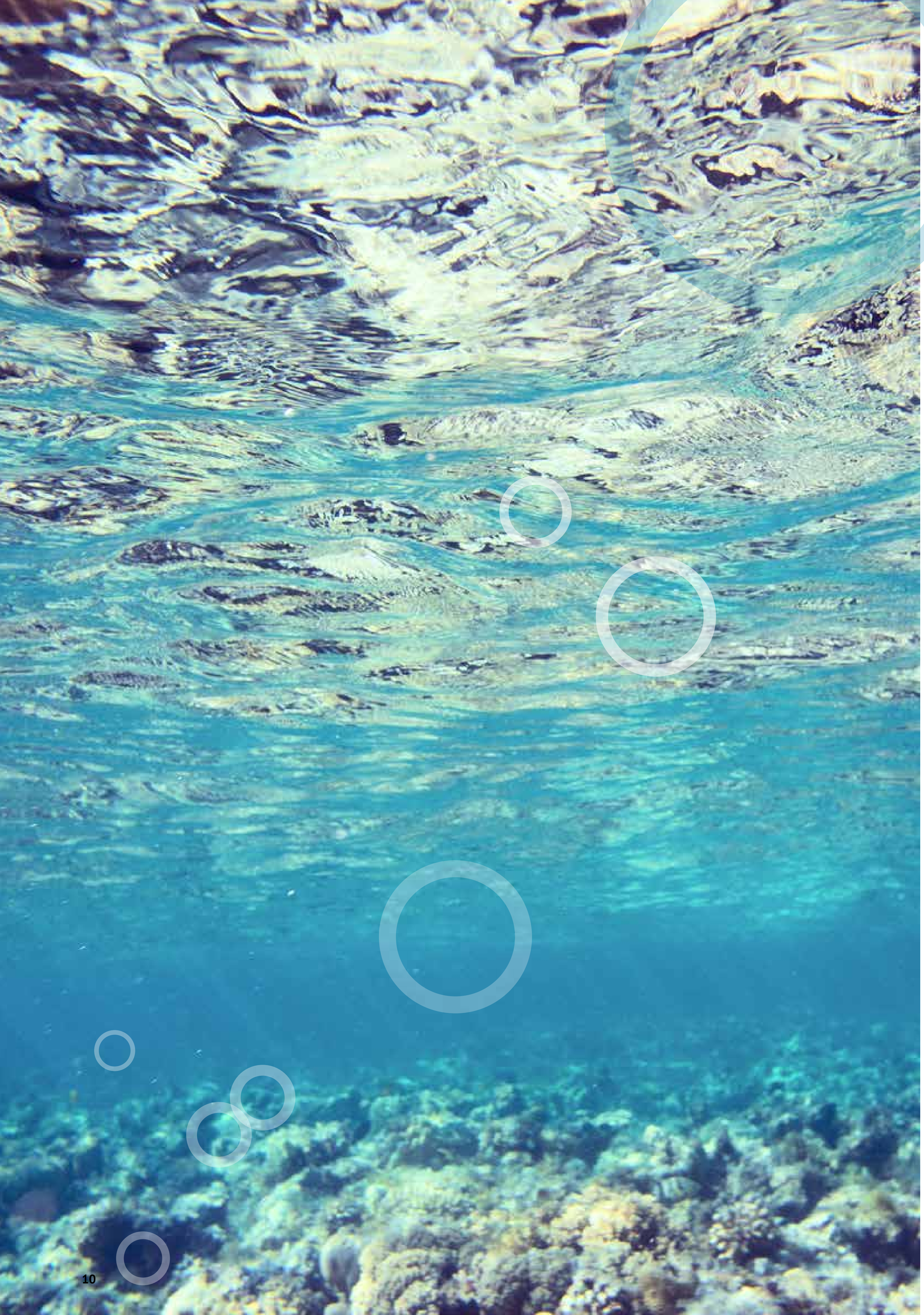
ROALD OTNES
WP2

LARS M. KRISTENSEN
WP3

JAN E. STIANSEN
IF1

MARIE B. HOLSTAD
IF2

TERJE RESTAD
ADM. COORDINATOR



COOPERATION BETWEEN THE CENTRE'S PARTNERS

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 technology challenge is complex and requires close cooperation between the various partners who have different, but complementary, technologies and competence areas.

During 2021, close cooperation between partners was established. Discussions and scientific cooperation on topics spanning across partners have been crucial to establishing a solid fundament for the further technology development in the Centre.

In addition to the ordinary, day-to-day collaboration between partners, supervision of students has been set up as a cooperative effort among partners with complementary competences in order to strengthen the student's learning experience.

Collaboration between partners also brings additional, invaluable 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 and GCE NODE in particular – both partners in SFI Smart Ocean – bring with them contributions from a wider group of member companies.

Inger Graves demonstrating Aanderaa's equipment at the kick-off gathering.

SCIENTIFIC ACTIVITIES & RESULTS

Optimizing the foundation for development of the SFI Smart Ocean technology

Creating a holistic, flexible, and component based system for multi- parameter monitoring involves complex technology development. The project partners have to evaluate possibilities and limitations of the system, all the way from the needs of the end users, to the specifications of the single sensor units. To ensure that all aspects were covered and that all competence in the consortium was exploited, several activities were started to investigate interfaces, requirements, limitations, value potential, business models and physical boundary conditions in more detail. Significant investigations have been carried out to tackle the complexity and develop the best possible starting point for the SFI Smart Ocean technology.

From the sensor side, different applications require different sensor types, sampling rates, and amount of data to describe the conditions and acquire sufficient information for decisions or actions. A survey on sensor types and associated raw data rates was carried out, and requirements for embedded signal processing/compression as a function of available transmission rates and available energy for the sensors were investigated. Further, the sensor specifications and interfacing towards acoustic modem were addressed.

Also, the underwater communication requirements for SFI Smart Ocean had to be defined. Requirements, limitations and possibilities for underwater data communication in SFI Smart Ocean were investigated and compared to the sensor data volume and sampling frequency requirements. A literature review was performed on acoustic propagation channels, modulation formats, network protocols, available acoustic modems, optical communication systems, gateway radio solutions, cloud connectivity, and existing standards on underwater communications. A software defined testbed for underwater communication was established to enable simulation of modulation types, coding techniques and signal processing. Finally, the network technology to be developed must provide reliable and efficient data transfer while limiting network traffic and energy consumption. Various Medium Access Control (MAC) and Network layer protocols were investigated. The most promising solutions will be subject to further evaluation.

It is essential for SFI Smart Ocean that the limitations and possibilities of wireless underwater communications are well understood throughout the consortium, and that the communications requirements of sensor systems relying on such communications are not unrealistically high. This is ensured by involvement of many partners in WP2, and coordination between WP2 and WP1. In parallel, technology development for innovative underwater wireless communication systems and network protocols in SFI Smart Ocean has started. – Roald Otnes, FFI

A foundation for the digital ecosystem and software architecture for smart ocean was established by outlining a first version of the data service platform architecture. The work has concentrated on establishing an approach to support the continuous development of a data service platform, and to develop and demonstrate some first Minimum Viable Products (MVPs) based on the initial data service platform architecture and existing ecosystems. The MVPs have served to establish an initial proof-of-concept and identify software technology challenges. Mapping of consortium and literature state-of-the-art on micro- and macro- software architecture for smart software systems with a focus on system-of-systems (SoS) was carried out. The focus was on gathering requirements on how to build a system to monitor the ocean based on data collection through acoustic communication. A comprehensive interview study among consortium partners aimed at increasing the joint understanding of the smart ocean system and platform to be built is now in place. This enables an initial draft of the systems requirements and strengthens the collaboration within the consortium.

During 2021, we have identified concepts to build our smart ocean architecture based on 17 interviews with 9 partners. This work has led to an initial architecture based on data spaces and a minimum viable product. However, we also identified several issues that we need to investigate further, such as how to best share, combine, filter and protect data within our initial architecture.

A holistic approach considering the whole chain from the sensors to the data service platform via acoustic communication is essential to building a system where all parts fit together. One needs to know if one can trust the sensors and the communication from the platform side, and if we have sufficiently good data quality to understand the current situation and use it to make future predictions of the ocean.

Our idea is that companies, research institutes and universities in this consortium work together to accelerate the adoption of novel approaches to make a world-leading data service platform. We had several workshops to initiate this collaboration. In parallel, we have studied the literature to inline our findings with the current state of research so that we know that we tackle new innovative ideas. – Rogardt Heldal, HVL

Enabling improved data quality and reliability

In addition to the development of target specifications and functionality, it is a prerequisite that data quality and system reliability are handled at all technology levels where data-based decisions are made. In SFI Smart Ocean, this is a focus through all scientific activities, and specifically through two activities dedicated particularly to this challenge.

The first activity is the development of general methodologies related to robustification of smart underwater sensors connected to an underwater sensor network. The focus this first year has been on needs and expectations for generic sensor self-calibration and self-diagnostic properties. Such properties are important for reliability and uncertainty reduction in long-term subsea operations.

The other activity is related to biofouling on underwater sensors and communication nodes, which is well known to cause problems for the data quality and signal-to-noise ratio for resident sensors and wireless communication nodes in the fjords and oceans. To tackle this challenge, development of methodologies for nano surface treatment that will improve surface anti-biofouling properties has been started.

Phd candidate Wiktoria Szapoczka

In September 2021, Wiktoria Karolina Szapoczka started her PhD position at UiB and SFI Smart Ocean to work on anti-biofouling. As part of her project, she will develop and investigate different anti-biofouling nano-treatments to ensure smooth and maintenance-free surfaces. A pH sensor will also be developed as part of her PhD project. The pH of the sea water is a measurement parameter highly valuable for the environmental monitoring focus of SFI Smart Ocean.

Since September 2021 a lot of exciting things have happened. An anti-biofouling lab setup was put together at NORCE. The setup makes it easy to test anti-biofouling treatments on various surfaces under controlled conditions. Initial experiments were performed using biofouling samples from NORCE's algae lab. Our team has also expanded by two master's students: Mohanad Lotfi Abdallah and Viljar Hesenget Larsen. Together, we examine different anti-biofouling treatments e.g., diamond coatings, sharkskin inspired nanopatterns and ultra-slippery surfaces.

At the end of the year, we asked our partners to send us samples of surfaces that are negatively affected by biofouling in order to test anti-biofouling treatments. The response has been positive, and we have received samples from Aanderaa and Kongsberg Maritime.

During the autumn, a procedure to measure very short fluorescence lifetimes reliably and consistently was devised. This procedure is the backbone for the development of the pH sensor and was obtained by examining fluorescent carbon dots, provided by a fellow UiB colleague, Adam Leo Truskewycz. The compounds were measured at the unique fluorescence lifetime measuring setup at NORCE. The thorough analysis of the carbon dots was not only beneficial to the development of the pH sensor but also led to novel scientific results ready to be published. In the meantime, the main compound of interest has been ordered from a German manufacturer with estimated delivery in Spring 2022.

As part of my PhD study, I aim to develop a compact, stable, and affordable optical pH sensor for use in seawater. This will be done by synthesizing an indicator with pH-dependent fluorescence properties and optimizing its response with different spectral filtering and membrane choices. – Wiktoria Szapoczka, UiB

Testing and demonstrating new technology

To test and demonstrate the feasibility, functionality and capabilities of developed technology components and system configurations, SFI Smart Ocean is establishing several pilot demonstrators. The need for these pilot demonstrators will increase throughout the lifetime of the Centre, but important work has been started on two of them.

The main pilot demonstrator will be a local scale demonstrator focussing on environmental monitoring, and when relevant and possible, on integrity measurements. This pilot demonstrator has been involved in the mapping activities carried out this year, to ensure that the necessary functionality and specifications can be met when new technology is ready to be tested. The pilot demonstrator became operational in the 3d quarter of 2021, and focus has been on the planning and development of three observation rigs that will be implemented close to IMR's sea cage facility at their research station at Austevoll.

A second pilot demonstrator covers a real-time integrated and scalable ocean multipurpose observing system. To design the acoustic networks and systems, it is important to learn how the fjord environment will influence the propagation conditions. It is also important for the data processing and analysis to have real data to work with. Field experiments are being carried out in different seasons to learn about the ocean stratification in the fjord and to test the acoustics. The first cruise was carried out with KV Tor in Bjørnafjorden and Langenuen area the second week of November 2021. During the cruise oceanographic data were collected along sections. Furthermore, acoustic communication signals were sent from the KV Tor and received onboard the small boat to test the capability to send signals in this environment. Seven students and five scientists from NERSC and Department for Physics and Technology at UiB took part in the cruise.

Aanderaa has accurate sensors that stand at different depths and produce data that is used by many different industries related to the ocean. The challenge today is to get this data to the end user in real-time so that they can use sensor data for decision support. Today's solutions are characterized by poorly utilized bandwidth, too high a cost, too little robustness, too little standardization and too much inspection in the operational phase.

In the demonstrator in SFI Smart Ocean, we will explore how we can improve the solutions around data delivery so that we can have a user-friendly total system of sensors, wireless underwater communication, data display and analysis. Aanderaa will contribute expertise in data flow from sensors and collaborate with the Institute of Marine Research to design and release the first 4 demo sites in the first half of 2022. We will also test new improved solutions developed by the SFI as they become available during the project. – Inger Graves, Aanderaa

INTERNATIONAL COOPERATION

Centre partners all have international cooperation and/or offices abroad, and cooperation with the international networks of the partners directly or via affiliated activities is, and will be, an increasingly important part of the focus in the Centre. As SFI Smart Ocean aims at a flexible, vendor neutral network technology, cooperation with end users and vendors on the world market is important.

As an example, to achieve a vendor neutral system, it will be important to implement standard communication protocols used by the ocean industries. SFI Smart Ocean has established a direct dialog with the Subsea Wireless Group (SWiG) to ensure that SFI Smart Ocean complies with relevant international industry standards being developed. SWiG is an international oil and gas industry network promoting interoperability for subsea wireless communications (radio frequency, acoustic, free-space optic, inductive power, hybrid).

Cooperation with affiliated projects can be exemplified through the MarTERA project "The underwater robotics with multimodal communication and network-aided positioning system" (UNDINA) that aims at providing a reliable, compact, plug-and-play communication, networking, and positioning system specifically designed for resource constrained AUVs, having easy maneuverability, low weight, small dimensions, and low associated operational costs. SFI Smart Ocean focuses on development of static, smart sensor network technology, whereas UNDINA focuses on communication and network technology for underwater drones. Value for both will be increased through future interoperability, and cooperation has been established through project partner NORCE participating in both. UNDINA includes 8 partners from Norway, Germany and France.

Cruise participants on the survey cruise with KV Tor to Bjørnafjorden in November. The aim of the cruise was to characterize the oceanograpic conditins in the area in preparation for Pilot Demonstrator 2 (PD2).

RECRUITMENT – PHD/POSTDOC

The first PhD to be recruited at SFI Smart Ocean (from 1. September 2021) was Wiktoria Karolina Szapoczka, at UiB. She is supervised by Prof. Bodil Holst (UiB), Tore Skodvin (UiB), and Peter James Thomas (NORCE). Wiktoria will be working in WP1.

In her project, the main objective is to develop a compact, stable, and affordable optical pH sensor for use in seawater. An additional part of the project is to develop and investigate different anti-biofouling nano-treatments to ensure as smooth and maintenance-free user experience of the pH sensor as possible.

From 1. January 2022 two new PhDs will start.

Keila Lima (HVL) is going to work on the software architecture for smart monitoring of the ocean (WP3). Keila's supervisors are Rogardt Heldal and Tosin Oyetoyan (both of HVL).

Astrid Marie Skålvik (UiB) will be working on sensor self-diagnostics and self-validation in subsea sensor networks in WP1. She will be supervised by Camilla Sætre (UiB), Kjell-Eivind Frøysa (HVL) and Ranveig N. Bjørk (NORCE).

In 2022 we also anticipate employing 3 more PhDs and one postdoc. The PhDs will have focus on Guided Ultrasonic Waves (UiB, WP1), Distributed Acoustic Sensing (UiB, WP1) and communication protocols for underwater wireless sensor networks (HVL, WP2). The postdoc (at NERSC) will work with 3D acoustic modelling in combination with oceanographic data and high-resolution models in IF1.

In addition to the PhDs being part of the Centre budget, the Centre is cooperating with affiliated projects including PhDs:

PhD candidate Ngoc-Thanh Nguyen (HVL, internal funding) is working on big-data analytics and is being supervised by Rogardt Heldal (HVL) and Patrizio Pelliccione (Gran Sasso Science Institute).

PhD-candidate Håvard Stavn Ugulen (UiB, internal funding) is working on "Underwater Optical Wireless Communication in Norwegian Coastal Waters and Fjords". His supervisors are Camilla Sætre (main supervisor), Børge Hamre and Arne Skodvin Kristoffersen, all from UiB.

KEILA LIMA
HVL

WIKTORIA SZAPOCZKA
UIB

ASTRID MARIE SKÅLVIK
UIB

NGOC-THANH NGUYEN
HVL

HÅVARD S. UGULEN
UIB

COMMUNICATION & DISSEMINATION

Our website, www.sfismartocean.no, contains public information, along with news, about the Centre.

Deputy director Marie B. Holstad and Camilla Sætre (leader of WP1 and chair of TAC) presented the Centre in a campaign about "Kvinner i karrieren" (Women in Careers).

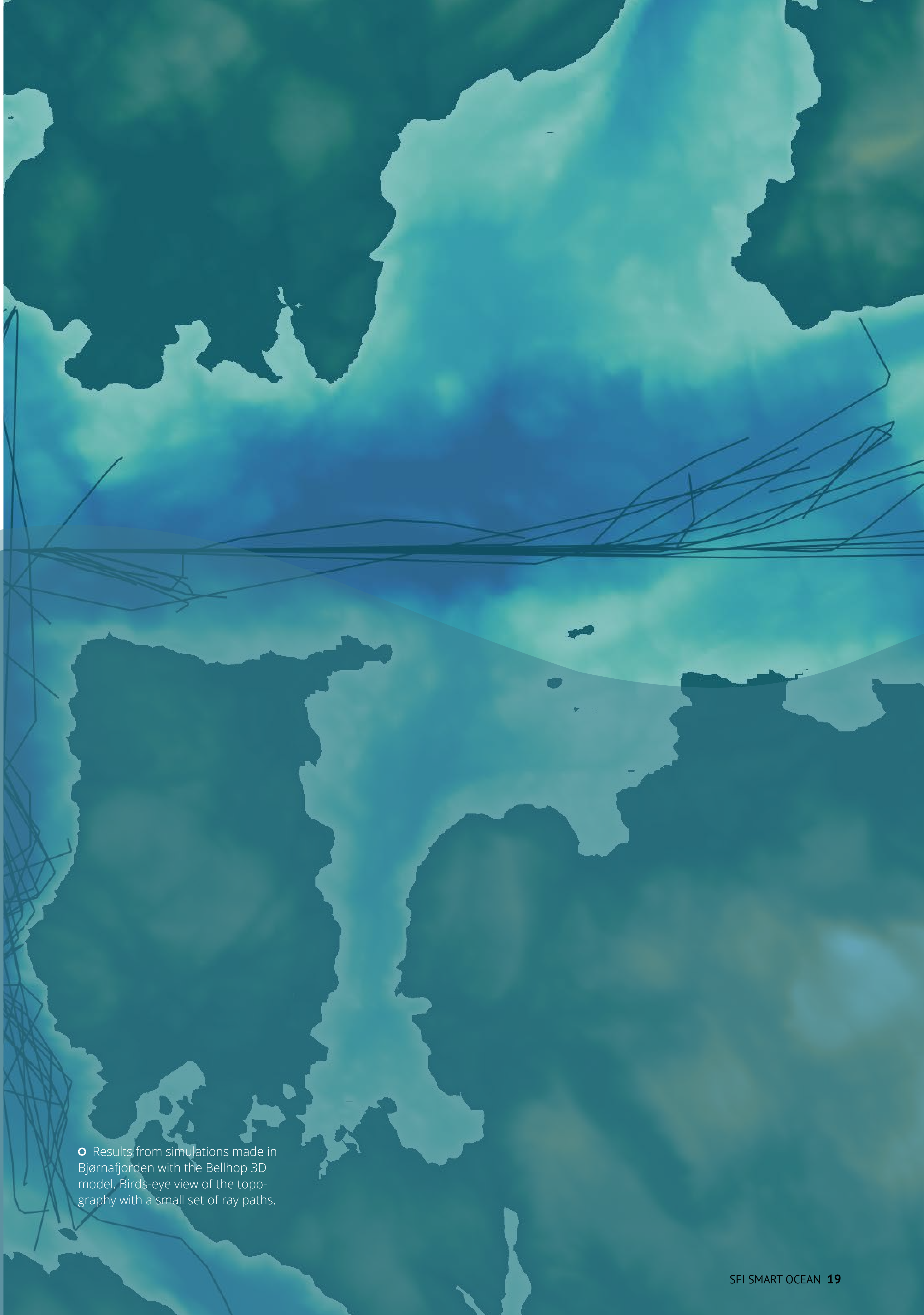
Ingvar Henne (NORCE) and Camilla Sætre also presented SFI Smart Ocean in the e-magazine *Elektronikk*.

The Centre could finally arrange a physical meeting for all partners in October, when the Covid-19 restrictions were lifted. The meeting served as a good opportunity for internal communication, a positive addition to the regular digital meetings in the work packages. Regular physical meetings will also be held each year in the future.

During 2021 we also established regular meetings between the work-package leaders and the Centre administration, which simplifies the ongoing internal administration of the centre.

In 2021 SFI Smart Ocean has been presented at various conferences, workshops, and other fora.

VENUE	TOPIC	PRESENTER(S)
OTD Energy 2021	Sustainable and fact-based ocean management	G.A. Johansen
Aqua NOR	SMART Ocean: contribution to future environmental surveillance!	G.A. Johansen
Marin Resource Group, Bergen Chamber of Commerce & Industry	Presentation of SFI Smart Ocean	G.A. Johansen
R&D Working Group Webinar, Norwegian Offshore Wind Cluster	SFI Smart Ocean – an overview. Benefits to the offshore wind industry	G.A. Johansen, M.B. Holstad
Blue Days 2021	Presentation of SFI Smart Ocean	G.A. Johansen, M.B. Holstad
The offshore wind conference – Science Meets Industry 2021	SFI Smart Ocean: Sustainable operation and fact-based ocean management	C. Sætre



Results from simulations made in Bjørnafjorden with the Bellhop 3D model. Birds-eye view of the topography with a small set of ray paths.

PERSONNEL SFI SMART OCEAN 2021

CENTRE ADMINISTRATION		
GEIR ANTON JOHANSEN	UIB	CENTRE DIRECTOR
MARIE BUEIE HOLSTAD	NORCE	DEPUTY CENTRE DIRECTOR
TERJE RESTAD	UIB	ADMINISTRATIVE COORDINATOR
RANDI H. EILERTSEN	UIB	COMMUNICATION ADVISOR

KEY RESEARCHERS		MAIN CONTRIBUTIONS
BJØRN TORE HJERTAKER	UIB	MEASUREMENT STRATEGY AND UNCERTAINTY
BODIL HOLST	UIB	NOVEL SENSOR TECHNOLOGY & ANTI-BIOFOULING: PH SENS
PER LUNDE	UIB	GUIDED ULTRASONIC WAVES (GUW)/DISTRIBUTED ACOUSTIC SENSING (DAS)
CAMILLA SÆTRE	UIB	MEASUREMENT STRATEGY AND UNCERTAINTY/LEADER WP1 AND TAC
TORE SKODVIN	UIB	NOVEL SENSOR TECHNOLOGY & ANTI-BIOFOULING: PH SENSOR
LARS M. KRISTENSEN	HVL	ADAPTIVE DATA RETRIEVAL METHODS AND VISUALISATION/LEADER WP3
ROGARDT HELDAL	HVL	SOFTWARE ENG. METHODOLOGY: SOFTWARE QUALITY, MODELLING & VALIDATION
KJELL-EIVIND FRØYSA	HVL	MEASUREMENT STRATEGY AND UNCERTAINTY
TOSIN D. OYETOYAN	HVL	SOFTWARE ENG. METHODOLOGY: SOFTWARE QUALITY, MODELLING AND VALIDATION
ANNE LENA KAMPEN	HVL	COMMUNICATION PROTOCOLS AND NETWORK ARCHITECTURE
JEREMY COOK	NORCE	ADAPTIVE DATA RETRIEVAL METHODS AND VISUALISATION
INGVAR HENNE	NORCE	UNDERWATER COMMUNICATIONS: REQUIREMENTS, LIMITATIONS, AND POSSIBILITIES
BÅRD HENRIKSEN	NORCE	UNDERWATER COMMUNICATIONS: REQUIREMENTS, LIMITATIONS, AND POSSIBILITIES
MARIE B. HOLSTAD	NORCE	DEPUTY CENTRE DIRECTOR/LEADER IF2
OVE D. LAMPE	NORCE	ADAPTIVE DATA RETRIEVAL METHODS AND VISUALISATION
TOR LANGELAND	NORCE	ADAPTIVE DATA RETRIEVAL METHODS AND VISUALISATION
PETER J. THOMAS	NORCE	NOVEL SENSOR TECHNOLOGY – DISTRIBUTED ACOUSTIC SENSING (DAS)
RUNE ØYERHAMN	NORCE	UNDERWATER COMMUNICATIONS: REQUIREMENTS, LIMITATIONS, AND POSSIBILITIES
GRO FONNES	NORCE	ADAPTIVE DATA RETRIEVAL METHODS AND VISUALISATION
ØIVIND BERG	IMR	MAIN PILOT DEMONSTRATOR: AUSTEVOLL OCEAN TECH TESTING FACILITY
JAN ERIK STIANSEN	IMR	MAIN PILOT DEMONSTRATOR: AUSTEVOLL OCEAN TECH TESTING FACILITY
INGER GRAVES	AADI	MAIN PILOT DEMONSTRATOR: AUSTEVOLL OCEAN TECH TESTING FACILITY
JAN FLATLANDSMO	AADI	SOFTWARE TECHNOLOGY
MARTHA LIEN	MONVIRO	MEASUREMENT STRATEGY AND UNCERTAINTY
RENATE GRINDHEIM	TSC SUBSEA	MEASUREMENT STRATEGY AND UNCERTAINTY, PILOT DEMONSTRATOR OFFSHORE WIND
MICHAEL T. SMITH	METAS	MEASUREMENT STRATEGY AND UNCERTAINTY
JAN ERIK FAUGSTADMO	KONGSBERG	UNDERWATER COMMUNICATIONS: REQUIREMENTS, LIMITATIONS, AND POSSIBILITIES
ARNE J. HESTNES	KONGSBERG	ADAPTIVE DATA RETRIEVAL METHODS AND VISUALISATION

KEY RESEARCHERS		MAIN CONTRIBUTIONS
STEINAR BJØRNSTAD	TAMPNET	NOVEL SENSOR TECHNOLOGY – DISTRIBUTED ACOUSTIC SENSING (DAS)
KJETIL HØYDAL	BOUVET	SYSTEM ARCHITECT. FOUNDATION & REQUIREMENTS FOR A SMART OCEAN SOFTWARE SYSTEM
YNGVE KVINNSLAND	BOUVET	SYSTEM ARCHITECT. FOUNDATION & REQUIREMENTS FOR A SMART OCEAN SOFTWARE SYSTEM
PÅL A. REIERSGÅRD	BOUVET	SYSTEM ARCHITECT. FOUNDATION & REQUIREMENTS FOR A SMART OCEAN SOFTWARE SYSTEM
KJETIL LYGRE	NERSC	MESO-SCALE PILOT DEMONSTRATOR
HANNE SAGEN	NERSC	MESO-SCALE PILOT DEMONSTRATOR
TORILL HAMRE	NERSC	SOFTWARE ENG. METHODOLOGY: SOFTWARE QUALITY, MODELLING AND VALIDATION
ESPEN STORHEIM	NERSC	SOFTWARE ENG. METHODOLOGY: SOFTWARE QUALITY, MODELLING AND VALIDATION
ROALD OTNES	FFI	UNDERWATER COMMUNICATIONS: REQUIREMENTS, LIMITATIONS, AND POSSIBILITIES
KRISTIN MIKKELSEN	FFI	SENSOR TECHNOLOGY ADAPTATION
JOACHIM EASTWOOD	FFI	SENSOR TECHNOLOGY ADAPTATION
HÅVARD AUSTAD	FFI	SENSOR TECHNOLOGY ADAPTATION
PAUL VAN WALREE	FFI	UNDERWATER COMMUNICATIONS: REQUIREMENTS, LIMITATIONS, AND POSSIBILITIES

PHD STUDENTS WITH FINANCIAL SUPPORT FROM THE CENTRE BUDGET	
WIKTORIA SZAPOCZKA	UIB

PHD STUDENTS WORKING ON CENTRE PROJECTS WITH FINANCIAL SUPPORT FROM OTHER SOURCES		
NGOC-THANH NGUYEN	HVL	INTERNAL FUNDING HVL
HÅVARD S. UGULEN	UIB	INTERNAL FUNDING UIB

MASTER'S STUDENTS		
EIRIN SOGNNES *12.20 – 06.21*	HVL	REFACTORING OF OCEAN DATA PROCESSING AND VISUALIZATION SOFTWARE USING SCIENTIFIC WORK MODELING
MAGNUS Ø. BERGERSEN *12.2020 – 06.2021*	HVL	AN EXPERIMENTAL EVALUATION OF SOFTWARE FRAMEWORKS FOR THE WEB-OF-THINGS
TORE BERVEN 06.2021 – 06.2022	HVL	AN EXPERIMENTAL EVALUATION OF THE KOGNIFAI PLATFORM FOR SMART-OCEAN APPLICATIONS
SVERRE K.M. FINSTAD *12.2020 – 06.2021*	UIB	CHARACTERIZATION AND FINITE ELEMENT MODELLING OF PIEZOELECTRIC CERAMIC DISCS VIBRATING IN AIR, FOR A FREQUENCY RANGE INCLUDING THE FIRST TWO RADIAL MODES

ANNUAL ACCOUNTS 2021

FUNDING	AMOUNT (1000 NOK)
THE RESEARCH COUNCIL	5 834
UIB	3 455
RESEARCH PARTNERS*	2 960
ENTERPRISE PARTNERS**	2 857
PUBLIC PARTNERS***	91
TOTAL	**15 197**

COSTS	AMOUNT (1000 NOK)
THE RESEARCH COUNCIL	
UIB	4 801
RESEARCH PARTNERS	7 408
ENTERPRISE PARTNERS	2 409
PUBLIC PARTNERS	91
EQUIPMENT	488
TOTAL	**15 197**

* *NORCE, HVL, NERSC, IMR, FFI*

** *Aanderaa Data Instruments AS, Monviro AS, TSC Subsea AS, Metas AS, Kongsberg Maritime AS, Tampnet AS, Bouvet Norge AS, Lundin Energy Norway AS, GCE NODE Service AS, GCE Ocean Technology SA*

*** *Directorate of Fisheries, Petroleum Safety Authority Norway*

PUBLICATIONS 2021

Ahishakiye F., Requeno Jarabo J.I., Kristensen L.M., Stolz V. (2021) MC/DC Test Cases Generation Based on BDDs. In: Qin S., Woodcock J., Zhang W. (eds) Dependable Software Engineering. Theories, Tools, and Applications. SETTA 2021. *Lecture Notes in Computer Science*, vol 13071. Springer, Cham. https://doi.org/10.1007/978-3-030-91265-9_10

Rodríguez A., Kristensen L.M., Rutle A. (2021) Verification of the MQTT IoT Protocol Using Property-Specific CTL Sweep-Line Algorithms. In: Koutny M., Kordon F., Pomello L. (eds) Transactions on Petri Nets and Other Models of Concurrency XV. *Lecture Notes in Computer Science*, vol 12530. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-63079-2_8

Rodríguez, A., Durán, F. & Kristensen, L.M. Simulation and analysis of MultEcore multilevel models based on rewriting logic. *Softw Syst Model* (2021). https://doi.org/10.1007/s10270-021-00947-1

H. Ugulen, H. Sandven, B. Hamre, A. Kristoffersen, and C. Sætre. Analysis of multiple scattering errors in LISST-VSF volume scattering function measurements using Monte Carlo simulations and experimental data. *Opt. Express 29,* 12413-12428 (2021). https://doi.org/10.1364/OE.419116