2021 Annual Report

CIRFA

CIRFA – Centre for Integrated Remote Sensing and Forecasting for Arctic Operations

THE ARCTIC UNIVERSITY OF NORWAY · UiT ·

sfi Centre for Research-based Innovation

A partner's perspective

Lars-Anders Breivik

MET Norway is responsible for weather, ocean and climate services for Norway and Norwegian areas of interest, which means in particular over the oceans and polar areas. Our services are based on leading science in the field, and our capability to transform research and innovation into operational products. Research-based user-oriented services and a short route from research to operations are among our main assets. We are dependent on close collaboration with leading research communities, and hence rely on valuable partnerships through good projects. CIRFA is a very good example of this type of collaboration, as it focuses on important value chains and connects scientific experts directly with important users.

Operational meteorology and oceanography builds on the analysis of large amounts of observations, including the assimilation of these into numerical forecast models of weather, ocean and sea ice. Over the polar ocean the capability to utilize satellite data is crucial. In Tromsø we have leading expertise in remote sensing of ocean and sea ice represented by CIRFA and its partners, and MET Norway is lucky to be involved in ongoing research efforts.

In CIRFA one important focus has been the modeling of ocean and sea ice. The work has led to new operational data assimilation methods in our regional modeling systems: the "Barents" model, which covers the Barents Sea and the areas around Svalbard, and the "Norkyst" model, which covers the fjords and shelf seas of mainland Norway. New and better ocean surface analysis is important for both ocean and weather forecasting. The coupling between ocean and atmosphere is crucial, and CIRFA is in this context contributing to the development of the total forecast capability for the earth system. A very important application of the forecasting models is to deliver input to the contingency models (OpenDrift) which are used for e.g. oil spill monitoring and in Search and Rescue operations. In CIRFA an ensemble prediction system has been developed for the Barents model which is providing uncertainty estimates which are of great value in an operational context.

The data assimilation and modeling capabilities is one part of the value chain. The direct user contact and guidance through the weather forecast centers is another important part. In Tromsø the MET Norway weather forecast office VNN (Værvarslinga for Nord-Norge) is hosting the polar meteorology service including the Ice services. Being a part of the CIRFA team developing automatic sea ice classification from satellite data is mutually very beneficial for the success of CIRFA and MET Norway.

These are valuable examples of the importance of broad scientific collaboration in general, and CIRFA in particular, for the operational weather and ocean services. In the last part of the project there will be a focus on the CIRFA legacy, which brings us to another important point. The good relations that are built within the CIRFA consortium provide a solid foundation for collaborative research with high societal relevance in many years to come.

Lars-Anders Breivik
Norwegian Meteorological Institute, Research and Development Department, Director of Research

Foreword

Another year has passed. A second year of Covid-19 restrictions, social distancing, few physical meetings, and almost no travel. Scientific work often allows for flexible working arrangements, and if the technical prerequisites are fulfilled, working from home has some advantages. One of the obvious disadvantages is that collaboration between colleagues is hampered. One loses valuable discussions during coffee and lunch breaks, or in informal meetings in the corridor. Hence, it is most welcome that we are now gradually getting back to seeing our colleagues again. It is also much welcomed that visiting conferences and social events are allowed. For early carrier scientists, the lack of the ability to travel to conferences has been most unfortunate, as it takes away the inspiration that feedback and discussions with peers and international colleagues give.

Despite the challenges, CIRFA has continued to contribute to the scientific and technological development in Arctic remote sensing and climate research. In 2021, four PhD`s have successfully defended their thesis: Cornelius Quigley, Johannes Lohse, Artem Moiseev, and Rolf-Ole Rydeng Jenssen. CIRFA-researchers authored 16 journal papers, and are registered with 39 new entries in CRISTIN, the national research information system of Norway. The Centre's scientists were involved in several research proposals, and three applications were successful, two funded by RCN and one by EU.

In August, Camilla Brekke started in the position as Pro-Rector for Research and Development at UiT the Arctic University of Norway. This is a major career step for her and a great recognition of her competence and capacity. Camilla was work package leader for WP3 and her leave from CIRFA of course is a big loss to the Centre. However, we are delighted on Camilla's behalf, and wish her all the best in the new role as Pro-Rector.

CIRFA has had good progress through the years, and many of the deliverables described in the initial proposal for the Centre can be "ticked off" as achieved. We have developed models and algorithms for mapping and forecasting of sea ice, icebergs, and ocean surface dynamics. As CIRFA is approaching the end of its time of operation, the work ahead will be more focused on operational implementation and validation of algorithms and models. In this regard, CIRFA is currently planning a research cruise with *R/V Kronprins Haakon* to Fram Strait, Greenland Sea. During the cruise, we will combine shipboard observations with satellite acquisitions and aerial surveys using drones. We will deploy drifters, buoys, moorings as well as attaching GPS trackers to icebergs and floes. Comparing our models with real-world observations and collecting new data will help us to assess and improve the quality of our classification and forecast products.

As an SFI, CIRFA has facilitated collaboration between the industry sector and academia and connected multi-disciplinary research groups in a synergetic collaboration that has been quite successful. One of the original motivations when CIRFA started was the oil and gas companies' needs for increased monitoring and forecasting capacity in the high north, associated with their planned activities in the Barents Sea. Other motivations were directed towards environmental management and climate science. In years to come, it will be important to find ways to maintain the collaborations that have been established, to exploit the remote sensing technology which has been developed, and use it in new application areas. Two such new applications that already have been identified are in offshore wind power and environmental monitoring of coastal waters. There should be many more.

I finally would like to end by extending my sincere thanks to colleagues and partners in CIRFA for all work and achievements made during the year 2021. A special thank you to Andrea Schneider for structuring and editing this annual report so nicely.

Torbjørn Eltoft

Table of contents

Contact information

CIRFA is hosted by the Department of Physics and Technology and the Faculty of Science and Technology at UiT the Arctic University of Norway.

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Centre Leader: Prof. Torbjørn Eltoft, e-mail: torbjorn.eltoft@uit.no

Administrative Coordinator: Andrea Schneider, e-mail: andrea.schneider@uit.no

cirfa.uit.no

Objectives and Visions in the Centre

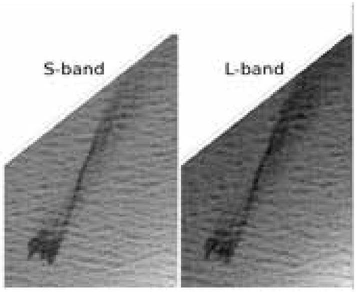
CIRFA is developing remote sensing knowledge and technology that helps to make operations and activities in icy waters safe and environmentally friendly. The research tasks are centered around three application areas:

Gatis Marcinkevics/Unsplash

Ocean Remote Sensing and Modelling

Alex Perz/Unsplash

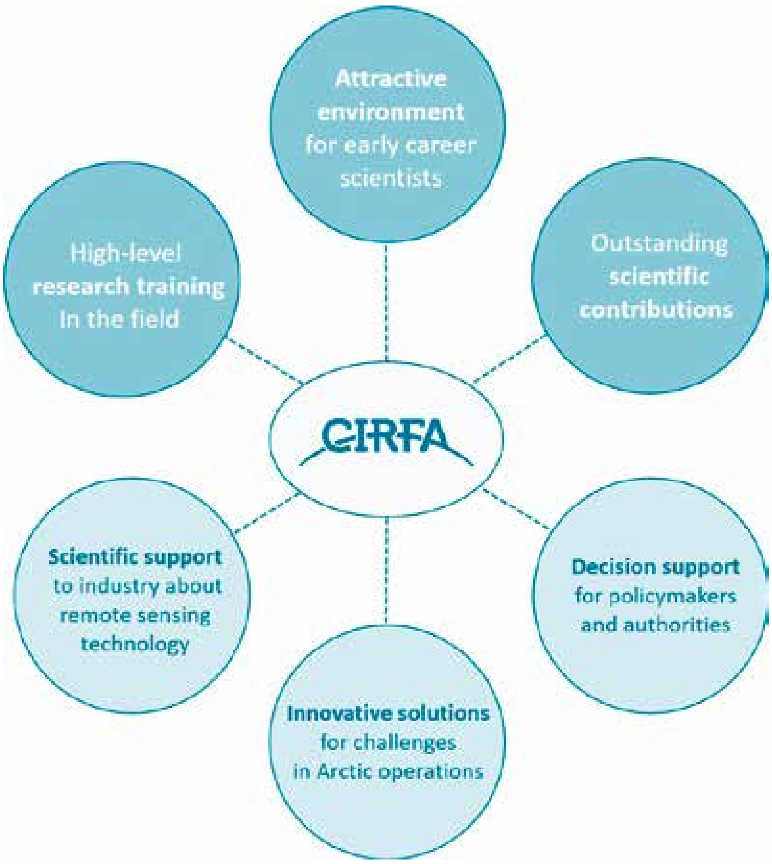
Monitoring Sea Ice and Icebergs



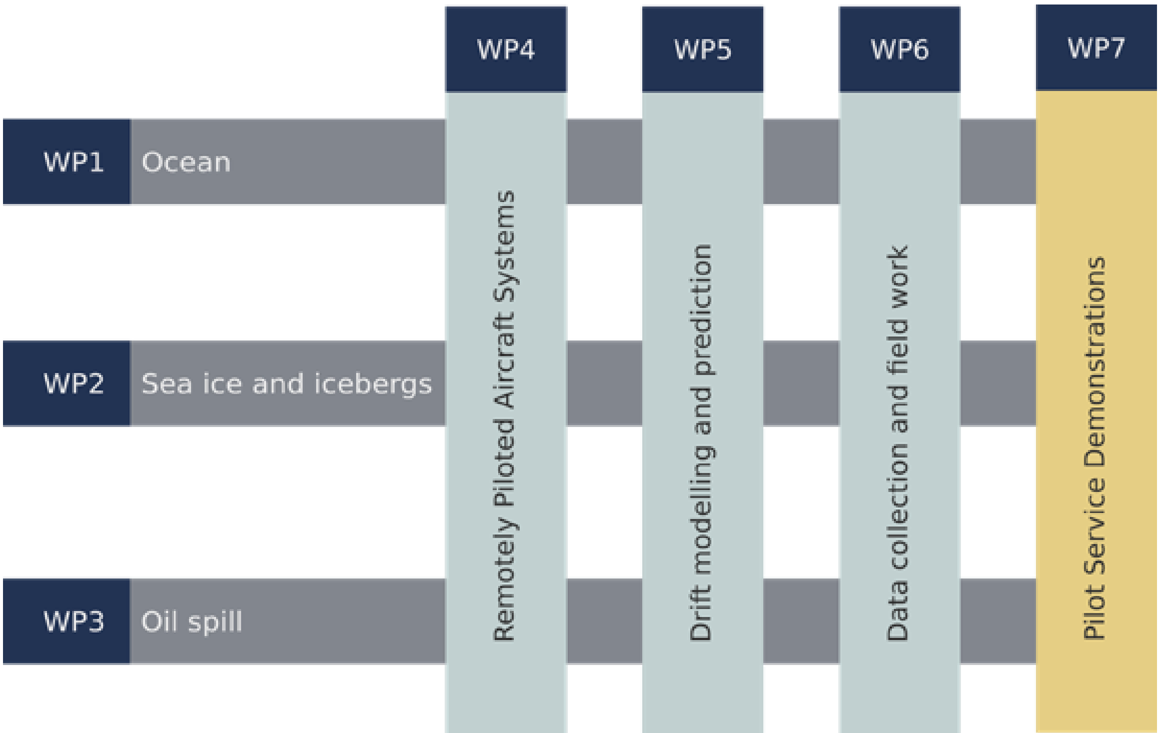
Brekke et al 2020, NORSE 2019

Monitoring Oil Spills

CIRFA is a leading international research center on integrated remote sensing and forecasting for the Arctic. We focus on improving monitoring, understanding and forecasting of the geophysical processes at the ocean surface, such as surface currents, wind fields and sea ice. We also do research on remote sensing of oil spills in ice-covered waters. In addition, research is conducted on drone technology, validation of remote sensing data in the field, data assimilation methods and numerical weather forecasting. With an international team of researchers from academia and industry, the vision of the center has many aspects:

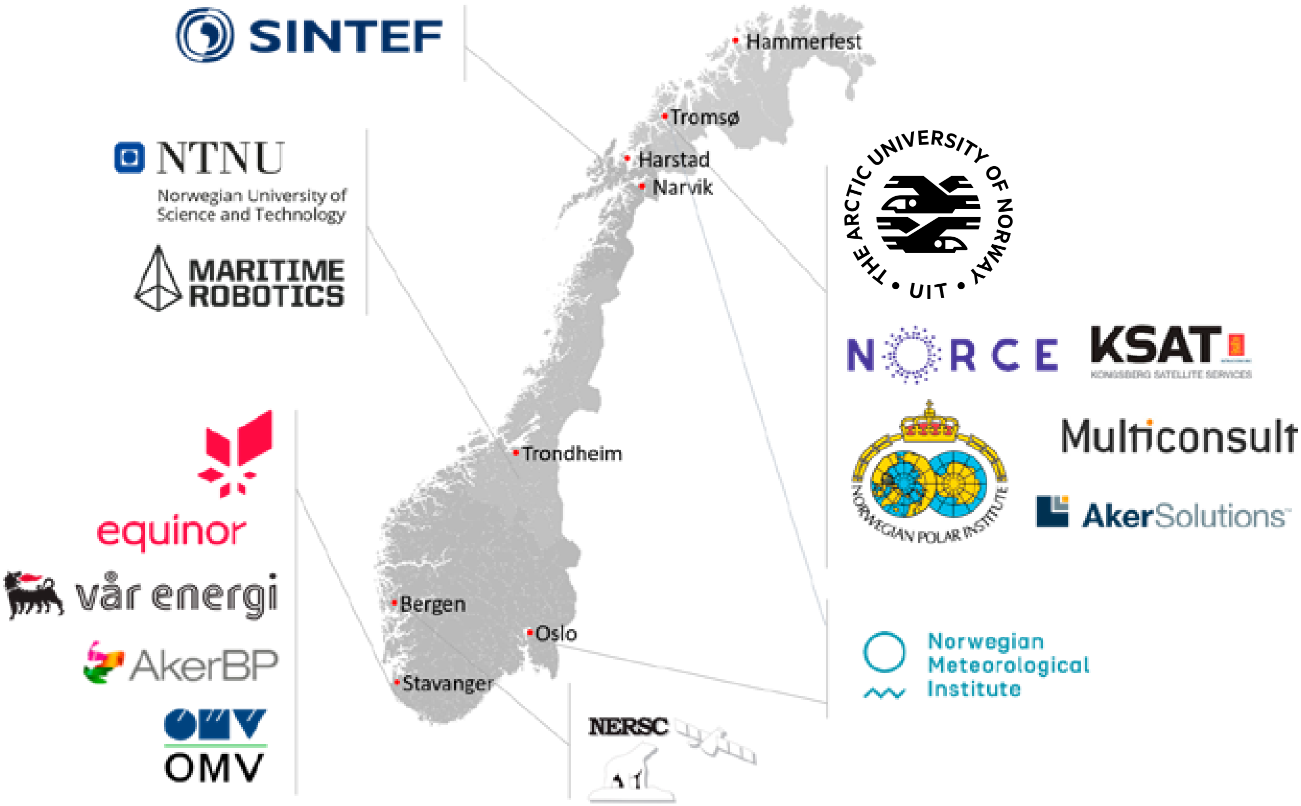


CIRFA is a facilitator for collaboration between industry and academia on issues related to remote sensing of Arctic phenomena. Our work generates new, innovative algorithms and processing schemes, which foster new services and products. The seven work packages collaborate closely to test and implement its services and products for societal benefit.



The CIRFA partners

CIRFA is a Centre for Research-based Innovation (SFI) funded by the Research Council of Norway (grant number 237906). The center combines competence and innovative ideas from two universities, five research institutes and seven industry partners in Norway.



Research partners

MET Norway

NORCE

Nansen Environmental and Remote Sensing Centre (NERSC)

Norwegian Polar Institute (NPI)

Norwegian University of Science and Technology (NTNU)

SINTEF

UiT The Arctic University of Norway (UiT)

User partners

Aker BP

Aker Solutions

Equinor

Kongsberg Satellite Services (KSAT)

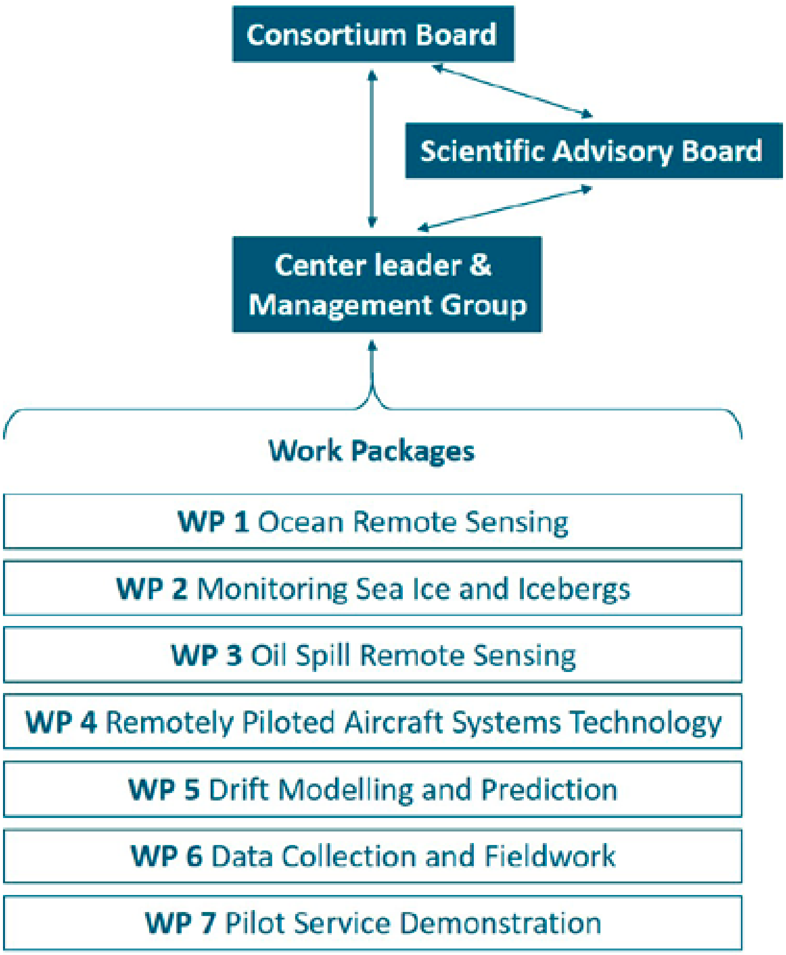
Maritime Robotics

Multiconsult

OMV Norge

Vår Energi

Organisation



Consortium Board

The Consortium Board is CIRFA's main decision-making body. It consists of representatives from the user partners and research partners. The Consortium Board guides the overall direction of the Centre.

Richard Hall (Chair)
Equinor

Kjell Arild Høgda
NORCE

Svein Olav Drangeid
OMV

Gjertrud Halset
Vår Energi

Arne O. Smalås
Dean, Faculty of Science and Technology, UiT

Jan Petter Pedersen
KSAT

Harald Steen
Norwegian Polar Institute

Lars Anders Breivik
MET Norway

Scientific Advisory Board

The Scientific Advisory Board consists of international experts with outstanding reputations in the relevant fields has been established to ensure excellence in research. The SAB will provide scientific input, review progress reports and provide support for networking and internationalizing of the centre's activities.

Irena Hajnsek
Swiss Federal Institute of Technology (ETH) Zürich, Switzerland

Charlotte Hasager
Technical University of Denmark (DTU)

Henning Skriver
Technical University of Denmark (DTU)

CIRFA Management Group

Torbjørn Eltoft, Centre Leader, UiT
Harald Johnsen, WP 1 Leader, NORCE
Wolfgang Dierking, WP 2 Leader, AWI/UiT
Anthony Doulgeris, WP 2 Co-Leader, UiT
Malin Johansson, WP 3 Leader, UiT
Christian Petrich, WP 3 Co-Leader, SINTEF Narvik
Agnar Sivertsen, WP 4 Leader, NORCE
Tor Arne Johansen, WP 4 Co-Leader, NTNU
Johannes Röhrs, WP 5 Leader, MET Norway
Rune Graversen, WP 5 Co-Leader, UiT
Sebastian Gerland, WP 6 Leader, NPI
Hugo Isaksen, WP 7 Leader, KSAT
Nick Hughes, WP 7 Co-leader, Norwegian Sea Ice Service, MET Norway

Research Fellows

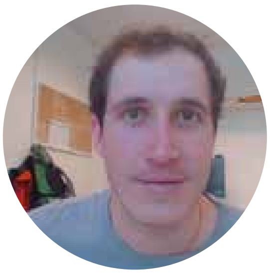
Silje Christine Iversen
PhD Candidate
The Impact of Observations in a High-Resolution Ocean Assimilation System for the Norwegian Seas

Cornelius Quigley
PhD Candidate /PostDoc
Determination of the Dielectric Properties of Marine Surface Slicks Using Synthetic Aperture Radar

Megan O`Sadnick
PhD Candidate
Ice in Norwegian Fjords: Formation, Breakup and Implications for Oil Spill Response Activities

Muhammad Asim
PhD Candidate
Optical Remote Sensing for Water Quality Parameters Retrieval in the Barents Sea

Johannes Lohse
PhD Candidate / Researcher
Automated Classification of Sea Ice Types in SAR Imagery



Mathias Tollinger
PhD Candidate
Using Synthetic Aperture Radar observations for investigation and forecasting of polar lows

Rolf-Ole Rydeng Jenssen
PhD Candidate
Radar System Development for Drone Borne Applications with Focus on Snowpack Parameters

Eduard Khachatrian
PhD Candidate
Multimodal Integrated Remote Sensing for Arctic Sea Ice monitoring

Victor de Aguiar
PhD Candidate
Oil Spill Remote Sensing

Anna Telegina
PhD Candidate
Short-term Forecast of Sea Ice Conditions using SAR Imagery and Forecasts of Ice Drift

Laust Færch
PhD Candidate
Mapping and Modeling of Iceberg Occurrences in the Barents Sea

Artem Moiseev
PhD Candidate /PostDoc
Ocean Remote Sensing

Anca Cristea
PostDoc
Sea Ice Classification from Multimodal Remote Sensing Data

Sindre Markus Fritzner
PostDoc
Machine-Learning and Dynamical Models for Sea Ice Forecasting

Martina Idzanovic
PostDoc
Quantifying Uncertainty and Predictability in Ocean Current Forecasts

Wenkai Guo
Researcher (SiDRIFT)
Cross-Platform Application of a Sea Ice Classification Method for Detecting Deformed Ice

Salman Khaleghian
PhD Candidate (ExtremeEarth)
Scalable Computing in Earth Observation

Debashu Ratha
PostDoc (ExtremeEarth)
Polarimetric Analyses of Sea Ice Properties

Quiang Wang
PostDoc (ExtremeEarth)
Deep Learning Algorithms for Sea Ice Classification

Habib Ullah
PostDoc (ExtremeEarth)
Deep Learning Algorithms for Sea Ice Classification

Saloua Chlaily
Researcher
Automised Large-scale Sea Ice Characterisation and Mapping

Malin Johansson
Researcher
Using Satellite Images to study Arctic Sea Ice and Oil Spill

Polona Itkin
Researcher
Sea Ice Deformation and its Impact on the Sea Ice Mass Balance

Jack Landy
Researcher
Using Satellite Laser and Radar Altimetry to study the Physical Properties of Polar Sea Ice and Oceans

Catherine Taelman
Engineer
Technical Support to all Work Packages

Thomas Kræmer
Head Engineer
Supporting Development and Pilot Demonstrations Across Work Packages

Jelte van Oostveen
Head Engineer
Implementing an Algorithm for Sea Ice Drift Retrieval and Supporting CIRFA Researchers

With members coming from more than 20 home countries, CIRFA has a highly international profile. Map from www.mapchart.net.

2021 in brief

Drifting sensors that watch very young sea ice were tested.
Photo: Paul Dodd


PhD defense Johannes Lohse &Cornelius Quigley


PhD defense Rolf-Ole Rydeng Jensen & Artem Moiseev

February

Fieldwork training on the sea ice in Ramfjorden.
Photo: Andrea Schneider

March

April

Fieldwork during various research cruises, seen through an infrared camera of Adam Steer.

Fieldwork on Svalbard using drones to measure snow thickness and layers.
Foto: Anders Martinsen

May

June

Camilla Brekke (left) was appointed pro-rector for research at UiT, together with the new rector Dag Rune Olsen (center) and pro-rector for education, Kathrine Tveiterås (right).
Photo: Jensen Media

Plans for a National Center for Earth Observation in Tromsø advance.
Image: ESA

Postdoc Wenkai Guo starts his year-long research stay in Bremen, Germany

CIRFA held its Annual Meeting at Sommarøy.
Photo: Andrea Schneider

CIRFA was joining the Space Day at Vitensenter.
Photo: Vibeke Os

CIRFA`s Young Scientist Forum takes place.
Photo: Johannes Lohse

July

October

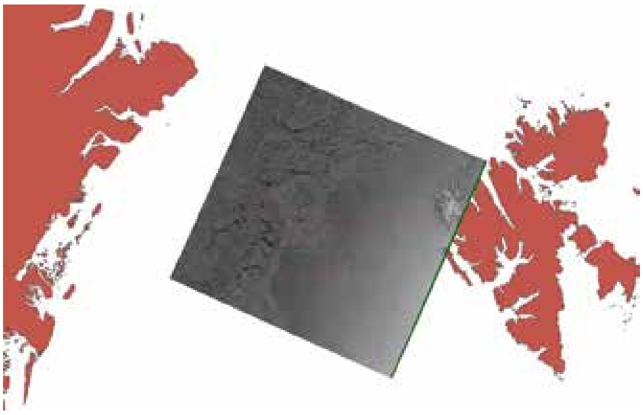
December

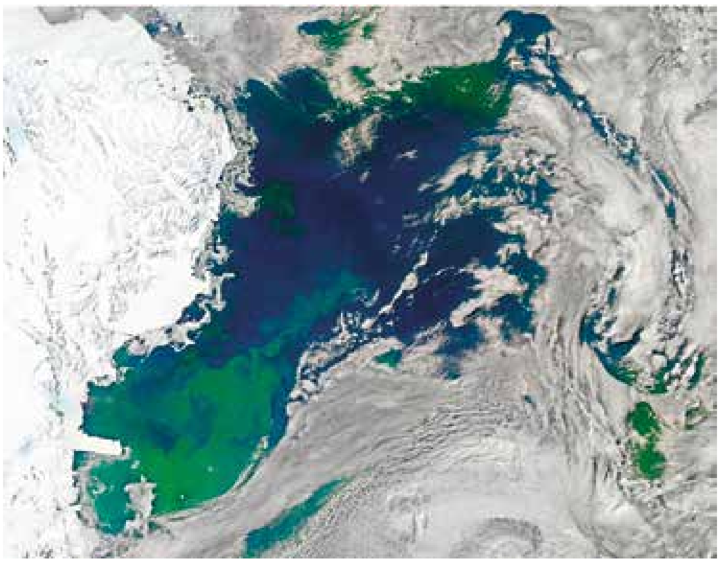
September

CIRFA is running a workshop on sea ice classification.
Image: Johannes Lohse / Sentinel-1 and Copernicus

November

Course on Physics of Ocean Colour Remote Sensing.
Image: Katalin Blix / ESA





Research Highlights

A new Architecture for Deep Semi-Supervised Learning for Sea Ice Application

Deep learning (DL) architectures refer to a subset of machine learning algorithms which are neural networks with three or more layers. These networks try to mimic the behavior of the human brain, they can learn from data, and are the foundation of many artificial intelligence applications. In the CIRFA context, these algorithms are highly interesting because they have proved efficient in classification and prediction tasks, and hence have been explored as a tool in sea ice applications. However, DL networks rely on lots of reliable training data to function properly. Generating lots of good quality training data for the sea ice case is challenging because of the difficulties of acquiring good ground truth information in the Arctic.

To address this problem, Khaleghian et al. have developed new semi-supervised learning approach which can handle the situation where one wants to combine a small amount of reliable labeled data with a large amount of unlabeled data. The architecture consists of two 13-layer convolutional neural networks, a Teacher model, and a Student model. The Teacher model is trained in a two-step procedure. In the first step, the model is trained in a supervised manner using only the labeled data. Subsequently, both the labeled and unlabeled samples are fed to the trained Teacher model. Based on an evaluation of the samples' neighborhood relations and similarities in the feature space, pseudo-labels are generated for the unlabeled data through a label propagation procedure to train the Student model. *Read more in Khaleghian et al. (2021)*.

Khaleghian, Salman; Ullah, Habib; Kræmer, Thomas; Eltoft, Torbjørn; Marinoni, Andrea. Deep Semisupervised Teacher–Student Model Based on Label Propagation for Sea Ice Classification. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 2021

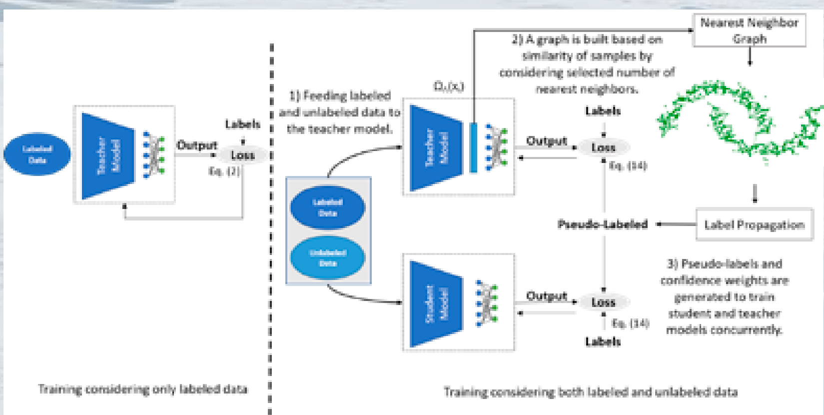
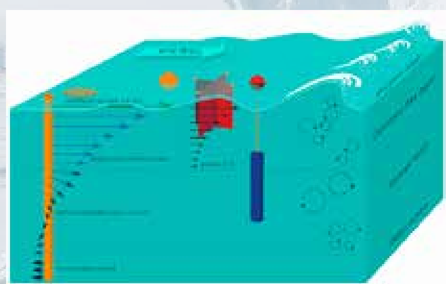


Illustration of the training methodology of the Teacher-Student semi-supervised learning model for label-propagation. Image from Khaleghian et al. 2021.

Review Article on "Surface Currents in Operational Oceanography: Key Applications, Mechanisms, and Methods"

A review article, published by the Journal of Operational Oceanography, combines remote sensing and modelling, and presents an overview of dynamics, observation methods and modelling of upper ocean surface currents. The article is an attempt to unify knowledge between various scientific communities, i.e. remote sensing, modellers, in-situ observationalists and theoreticians. In addition, applications for industries are discussed. By presenting a terminology for various aspects of surface currents, we aim to foster better exchange between these disciplines. *Read more in Röhrs et al. 2021*.

Röhrs et al. Surface currents in operational oceanography: Key applications, mechanisms, and methods. *Journal of Operational Oceanography*, 2021.



Processes in the surface ocean and how they can be studied. The illustration was made by Gunnar Follesø (Follesø Animasjon).

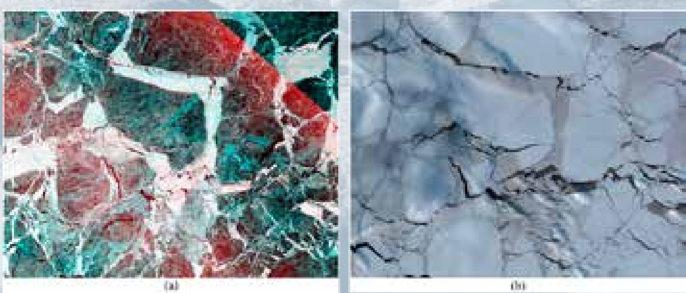
Photo by Christian Zoelly

Automatic Feature Selection in Multi-Sensor Sea Ice Classification

Sea ice classification refers to the process of separating a sea ice area into areas of distinct ice types (e.g., first year ice, multi-year ice, leveled ice, deformed, brash ice, etc.). The main data source for this task is usually spaceborne synthetic aperture radar (SAR) systems, which combine high spatial resolution and independence of cloud and light conditions to provide year-around coverage over polar regions. SAR images are, however, difficult to interpret, and, in this regard, optical sensors can provide additional information to help resolve ambiguities. Combining information from multiple sensors may thus allow for better characterization of sea ice surfaces.

In a recently published article in the IEEE JSTARS journal, Khachatrian et al. present a new graph-based method for selecting the most relevant image features (attributes) captured from multi-sensor data that combine SAR and optical satellite data to perform sea ice classification. Their method combines a Gaussian kernel (GK) and mutual information (MI) to create a similarity metrics, which incorporates both local and global image properties. The approach is therefore referred to as the GKMI method. The attribute selection consists of three processing tasks: segmentation (to generate super pixels, i.e., homogeneous areas), graph building, and graph clustering. For each super pixel, the GKMI method can select an optimal set of attributes. Hence, it presents an adaptive feature selection scheme where the best performing attributes depend on sensor types, imaging modes, and environmental and ice conditions during data acquisitions. *Read more in Khachatrian et al., 2021*.

Khachatrian, Eduard; Chlaily, Saloua; Eltoft, Torbjørn; Dierking, Wolfgang; Dinessen, Frode; Marinoni, Andrea. Automatic Selection of Relevant Attributes for Multi-Sensor Remote Sensing Analysis: A Case Study on Sea Ice Classification. *IEEE Journal of Selected Topics in Applied Earth*, 2021.



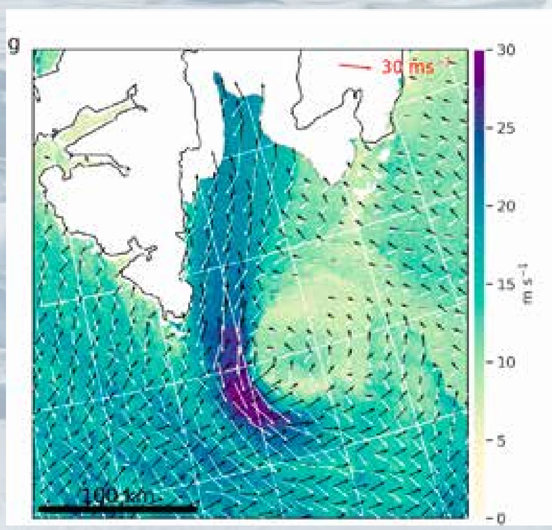
Color representation of Sentinel-1 (left)/Sentinel-2 (right) images of sea ice. (a) SAR false-color composite (HV, HH, HH as RGB). (b) Optical natural color composite (RGB). Image source: Sentinel-1 and Sentinel-2 Copernicus data.

Estimating Polar-Low Winds from SAR

Polar lows are intense, marine, mesoscale cyclones, which develop rapidly in cold air masses which advance over large bodies of relatively warm water. They typically have a lifetime of some *days* and a horizontal extent of around *100 kilometers*. Polar lows often cause heavy snowfall and strong winds. Due to their rapid development and small extent, they are difficult to predict by weather models.

Tollinger et al. describe how high-resolution sea surface observations from spaceborne synthetic aperture radars (SARs) can be used for meteorological applications in polar regions. They show how radar observations can provide information about wind speed and direction based on the wind-induced roughness of the sea surface. Earlier wind-retrieval methods normally provided only wind speed, but the authors suggest a new method that provides both wind direction and wind speed, and the latter to a higher accuracy than was previously the case. Their method is anticipated to be particularly beneficial for numerical forecasting of weather systems with strong wind gradients, which is the case for polar lows. *Read more in Tollinger et al. 2021*.

Tollinger, Mathias; Graversen, Rune; Johnsen, Harald. High-resolution polar low winds obtained from unsupervised sar wind retrieval. *Remote Sensing*, 2021.



Wind speed and direction estimates from SAR in an atmospheric forecast model. The complete wind field of the SAR-only retrieval is shown with white and black arrows indicating a two wind-direction solutions. Figure by Mathias Tollinger.

Innovation Highlights

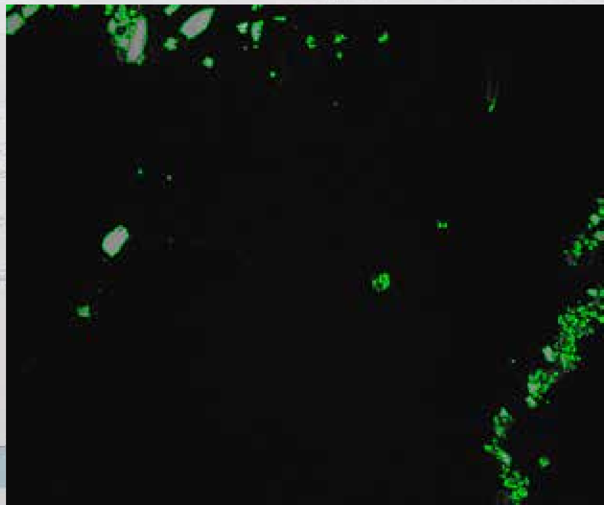
High resolution mapping of sea ice dynamics using drones

As part of CIRFA, new methods and algorithms are developed for mapping and classifying sea ice using radar images recorded from satellites. The objective is to better understand the processes in the Arctic Ocean, but also provide operational data for marine operations in ice infested water.

High-resolution data, such as images captured from drones, is a valuable tool for understanding the radar backscatter recorded by the satellites and for providing local and real time information on sea ice dynamics. There are multiple operational and technical challenges with acquiring and processing high quality data using drones in the Arctic Ocean. Covering large areas require a fixed wing drone capable of flying for several hours but operating from a ship deck usually requires a multirotor.

The sea ice is drifting fast, and standard methods for georeferencing images over larger areas does not work well for this application. Sharing high-resolution images from multiple cameras over long distances is not feasible in the high north, and for the near real-time requirements for operational data the images must be processed onboard the drone so that only the information regarding sea ice distribution and dynamics can be shared with the ship.

In CIRFA, work has been carried out developing robust technology for ship-based drone operations, accurate georeferencing of images for quantifying sea ice distribution and dynamics, path planning for mapping of drifting sea ice and onboard processing. With onboard data processing capabilities, the information regarding ice flow distribution and sea ice dynamics can be browsed in near real-time via a web interface on the ship. This system will be used during the CIRFA cruise in May 2022.

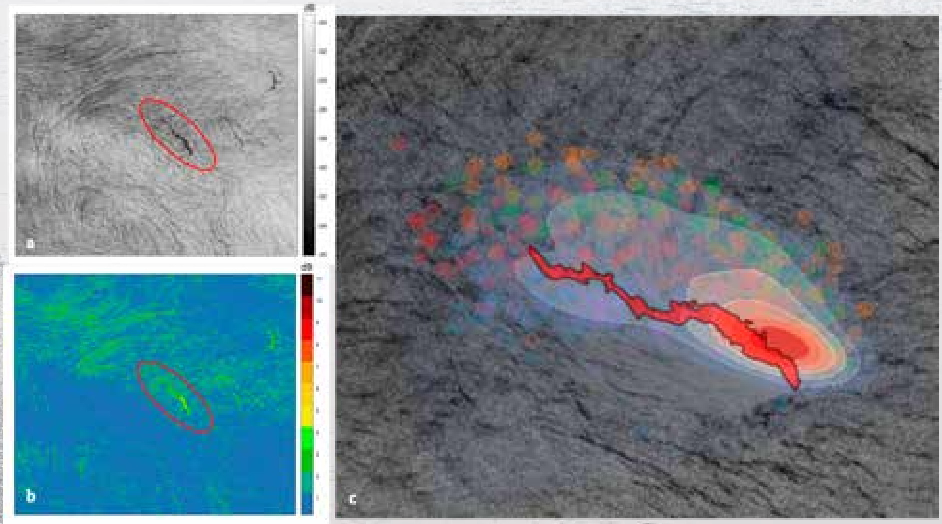


Left: A drone has been optimized for ship-based operations in the far north. With a flight time of 2 hours, carrying multiple cameras, the drone will be able to map an area close to 100 square km per flight. Right: The result is a map of ice floes (green) and open water areas (black) on a near real-time web interface. The map covers and area of 800m x 800m. Photos: Agnar Sievertsen, NORCE.

Deriving Oil Spill Thickness from SAR to help Resolving Slick Drift Patterns

Only a small fraction of detected oil slicks contains thick actionable oil, and by using the damping ratio these areas can be identified and targeted in a clean-up operation. The damping ratio is a well-known oil spill SAR parameter that can be used to infer relative oil thickness from SAR satellite images. The damping ratio is a calculated feature that measures the contrast between the oil slick and open ocean.

Much work has been carried out at CIRFA in collaboration with KSAT and NOFO (Norsk Oljevernforening For Operatørselskap / The Norwegian Clean Seas Association for Operating Companies) into making this parameter operational, and it is presently being implemented for the oil spill detection service at KSAT. At the same time, Cornelius Quigley is investigating an alternative robust approach for calculating the SAR damping ratio using verified oil slicks. The updated damping ratio will be used as input into the OilDrift model, where the first study initiating the OilDrift model based on varying thickness levels has been successfully carried out. This way information about the thickest parts of the oil can be incorporated into the forecast, thus focusing efforts on a potential clean-up scenario. This work was a successful collaborative effort between WP3, WP5 and WP7, and we expect further advances in 2022.



Surface oil seepages, as well as other natural phenomena, are shown in a Radarsat-2 image. Left, the damping ratio for the image is shown. Images processed by Cornelius Quigley.
The damping ratio is used to derive oil spill shapes from satellite images and provide input to the OpenOil drift model. The damping ratio shape is seen as the solid dark red area. The Barents-2.5 km Ensemble Prediction System is used as forcing, and results from 6 different ensemble members are used. The output for the 6 different ensemble members are seen as different colours (dots). Image processed by Victor de Aguiar, UiT.

Photo by William Copeland

WORK PACKAGE 1

Ocean Remote Sensing

WP leader
Harald Johnsen
Professor, NORCE

Team members

Mathias Tollinger
PhD Candidate, UiT

Artem Moiseev
PhD Candidate /Researcher, NERSC

Dr. Geir Engen
Senior Researcher, NORCE

Dr. Heidi Hindberg
Senior Researcher, NORCE

Background and Objectives

The ocean surface is the complex boundary between two very dynamic and stochastic media, the ocean and the atmosphere. Better forecasting of the ocean state and improved understanding of the physical processes at the ocean/atmosphere interface require combined capacity in remote sensing, numerical modelling, and in-situ observations.

The Norwegian coastal area is very industrialized and important for the economy. Ship traffic, fisheries, renewable energy, offshore oil/gas, and public recreation are all activities conducted in the coastal areas. Many users ask for more precise and higher resolution prediction of wind/wave/currents in the coastal areas to better support their activities.

The prediction skills of numerical models are still limited by uncertainties in the parameterisations used to represent the processes not resolved explicitly by the models. These unresolved scales must first be observed and measured, before approximate models can lead to efficient parameterisations. The newly launched Sentinel satellites will greatly improve the capabilities of providing such high-resolution information from space due to the enhanced temporal and spatial coverage.

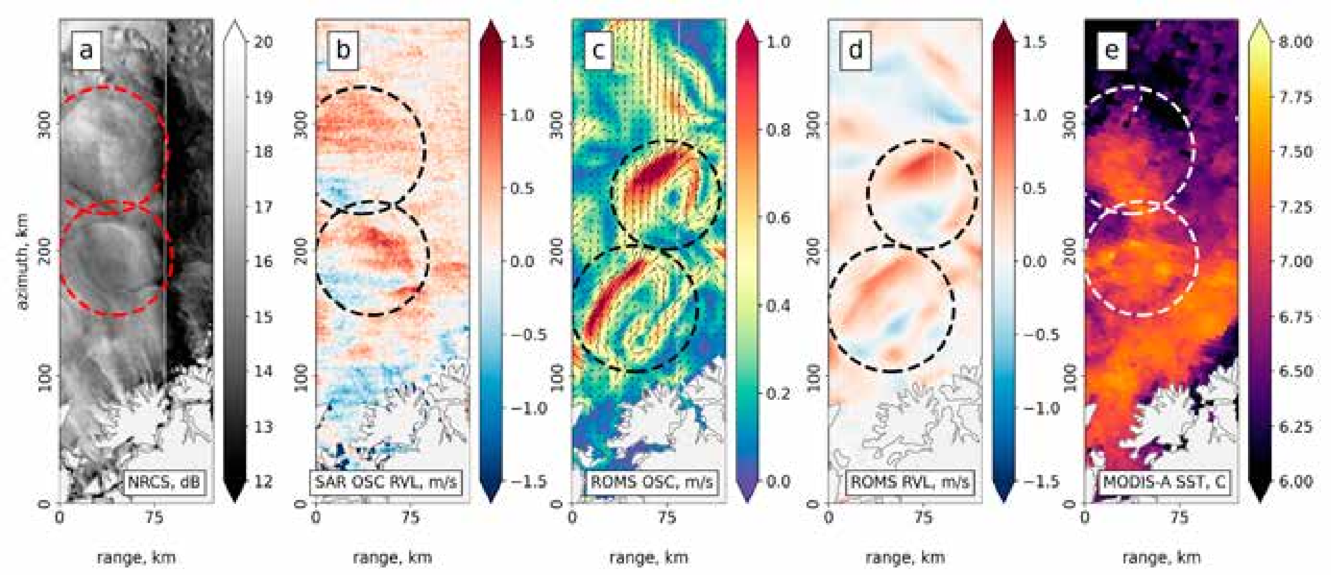
This work package will develop the use of satellite technology to advance the understanding of the Arctic Ocean processes and dynamics, and contribute to better prediction of polar lows, now-casting, and short-range forecasting of ocean state through coupling with high-resolution numerical models.

Key research tasks

- Develop physical and statistical methods to improve the reliability of satellite-derived met-ocean parameters.
- Develop algorithms, products, and a processing system for providing ocean state parameters from satellite observations beyond what is achievable today.
- Perform extensive satellite product calibration and validation analysis using independent measurements and models.
- Study the dynamics of polar lows by combining remote sensing and numerical modeling.
- Support short range forecasting of ocean state through coupling with high-resolution numerical models in collaboration with WP 5.

Achievements in 2021

The R&D has been concentrated on the following three key activities: 1) Assessment of Sentinel-1 ocean coastal and global current measurements, 2) Assessment of Sentinel-1 data from polar low wind detection, 2) Operationalization of met-ocean processing system at Kongsberg Satellite Services (KSAT) based on achievements from CIRFA R&D. The research will contribute to better characterization of and possibly improve the modelling of the Norwegian Coastal Current and Polar Low events.



Ocean Surface Currents in the Coastal Zone From the Sentinel-1B Doppler Shift Observations. a) is a Sentinel-1B SAR scene acquired in IW mode on 10 December 2017 and provided by Copernicus; b) shows the ocean current velocity from the Radar; c) shows ocean currents from a model; d) shows the night time ocean surface temperature; e) shows the ocean current velocity from a model. Image credit: Moiseev et al. 2021.

One year of Sentinel-1 Doppler measurements acquired over Skagerrak/North-Sea in IW mode and globally in WV mode are calibrated using restituted attitude data. These data led to a journal paper recently accepted for publication in *JGR – Ocean*. These results also contribute to the preparations for the surface current assimilation experiment. The PhD study on polar lows has resulted in a publication in *Remote Sensing*. A third paper has evolved from the cooperation with Chalmers University on the comparison of ocean surface velocities derived from Sentinel-1 Doppler measurements and from TerraSAR-X ATI measurements.

The operational met-ocean processing system established at KSAT has been upgraded and extended to better support user and R&D needs. This includes the processing of wind field and ocean current field as for oil spill and ship detection services that KSAT supplies in near real-time to the European Maritime Survey Agency (EMSA) as well as BarentsWatch and Kystverket (the Norwegian Coastal Administration) to increase safety for Arctic maritime traffic.

WORK PACKAGE 2

Monitoring Sea Ice and Icebergs

Background and Objectives

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Because of the thinning and retreating of sea ice in the Arctic, marine traffic and activities such as fishing, shipping, oil and mineral exploitation are intensifying and are expected to further increase in the future. To handle navigation challenges in ice-covered waters, vessel crews need appropriate planning support.

The goal of this work package is to refine remote sensing methodologies and algorithms to characterize and map Arctic sea-ice conditions, and to provide improved methodologies for detecting icebergs. Requirements regarding the potential output and performance of algorithms are defined in collaboration with partners from operational ice services and industry.

Besides SAR images as key data source in this WP, also optical and thermal satellite images, passive microwave and altimeter data are employed. Studies focus on semi- and fully automated sea ice classification, on sea ice drift and deformation retrieval, on observing temporal and spatial variations of sea ice conditions, and on finding optimal algorithms and radar configurations for monitoring icebergs in open water and in sea ice. The methods used include multivariate statistical analysis, anomaly detection, CFAR (constant false alarm rate) approaches, and machine learning/deep learning techniques, supplemented by investigations of radar signatures of ice types and icebergs measured under different meteorological conditions.

WP 2 and WP 3 are jointly working on issues regarding detection of thin ice as look-alike of oil spills and the use of compact polarimetry. Testing and validating algorithms takes place in collaboration with other work packages and MET Norway. The methodologies, tools and products developed within WP 2 will be integrated with the modelling activities of WP 5 to produce information products for the pilot services of WP 7.

Key research tasks

- Development and improvement of (semi-)automated algorithms for sea ice type classification, using satellite SAR images at different frequencies and complementary satellite sensors, and testing them under operational conditions.
- Building a data base of optical and SAR image pairs for validating the algorithms' outputs.
- Determination of ice drift and deformation from sequences of SAR images in combination with ice classification and sea ice model simulations for short-term forecasting of ice conditions.
- Selection and improvement of algorithms for the detection of icebergs in open water and in sea ice, considering the detection rates at different radar frequencies and spatial resolutions.

Achievements in 2021

The Norwegian Sea Ice Service at MET in Tromsø has taken CIRFA algorithms one step closer to operation in 2021. We have routinely shared and updated our algorithms and demonstrated using such algorithms to automatically process and provide results to a ship for navigation and research assistance during a teaching cruise called UAK 2021 with the Norwegian coast guard vessel *KV Svalbard*. This collaboration had many technical challenges to test and solve. The CIRFA team is now well prepared for new versions and tests in the future.

More in detail, further progress was made on four main fronts:

1. Sea ice classification approaches extended to multi-frequency and multi-sensor data
2. Sea ice concentration confidence being developed using our algorithms
3. Ice drift PhD in place and building CIRFA drift algorithm knowledge
4. Iceberg PhD in place and exploring false-alarm-rate algorithms and L-band iceberg detection

The success of including incidence angle into the supervised sea ice classification algorithm for Sentinel-1 data has led to our ambition to extend this same approach to other sensors. CIRFA members have successfully explored transfer learning and re-training for RADARSAT-2 data (also a C-band system like Sentinel-1) and are now extending to TerraSAR-X (X-band) and ALOS-2-PALSAR-2 (L-band) data. Although re-training is generally required, the background algorithm is consistent. Our next step is to explore using multiple training-sets, for the common algorithm and per sensor, to potentially overcome the temperature-dependent seasonal differences for year-round sea ice classification.

Another new method for sea ice classification using combinations of optical and SAR images, multi-frequency SAR images, and passive microwave and SAR data was developed. This method reveals a significant flexibility, i.e., it adapts to local environmental and imaging conditions by automatically selecting only those input parameters (radar intensity, texture) that are optimal for classification in the respective area.

After classification, we are also interested in the confidence of the class decision to provide good ice classification products and data input for modelling systems. This will have at least two components, an external error that can only be measured in comparison to ground-truth auxiliary data sets, and an internal error, or confidence, in the classification decision. This second internal component has been explored statistically and the error has been propagated to the numerical error, or uncertainty, in a sea ice concentration product and is ready for rigorous evaluation.

For the ESA L-C-Ice project, a new version of a coupled pyramid-cascade ice drift retrieval algorithm was implemented for providing short-term forecast of sea ice conditions using SAR imagery and forecasts of ice drift. This development is based on experiments with the CIRFA drift algorithm.

Our work on iceberg detection focusses now on the comparison of constant-false-alarm-rate algorithms that are applied to SAR images acquired at C- and L-band, considering iceberg occurrences in open water and sea ice. Tests are based on the use of optical satellite images and supplemented by investigations of iceberg detectability dependent on radar frequency and polarization. In PALSAR-2 L-band satellite images, we observed ghost reflections next to the radar returns from icebergs (see Fig. 2-1). In 1991, a study reported the observation of ghost reflections in airborne L-band SAR images of icebergs that, however, were not observed in SEASAT satellite images. Our investigations have not been finished yet, but one plausible explanation is the occurrence of multiple reflections in the interior of the iceberg, considering that the penetration depths of radar waves at L-band are much larger than of the shorter waves at C- and X-band. In fact, we did not observe shifts and ghosts in C- and X-band images.

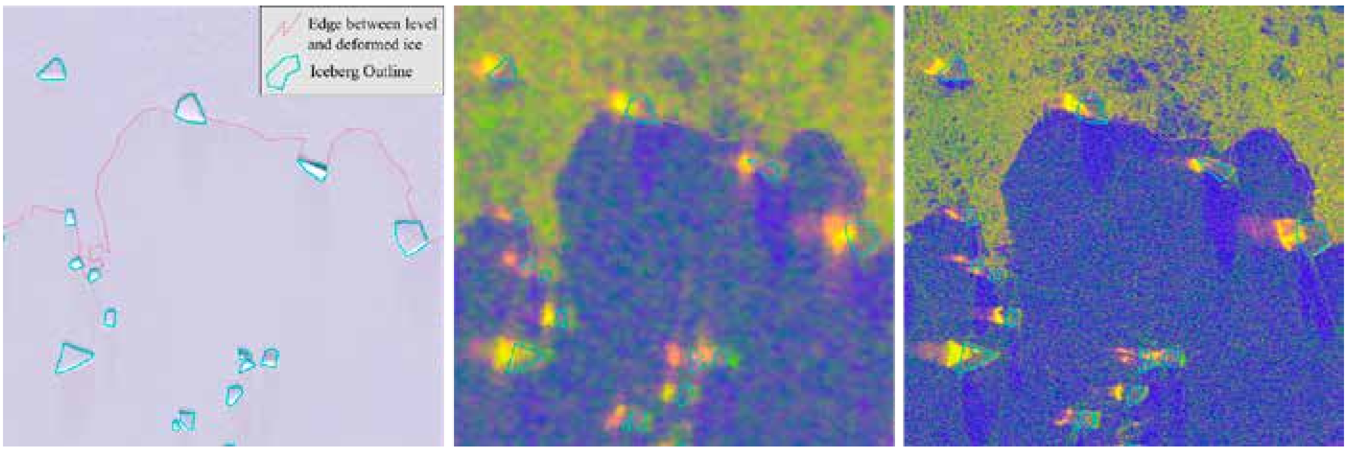

Figure 2-1 shows icebergs in L-band SAR images. Left: Optical images, Right: Coarse and high spatial resolution. In our recent work on iceberg detection in L-band satellite SAR images we found shifts of iceberg positions in comparison to optical data, and next to the main shifted radar return (in yellow) ghost reflections (in purple). Sentinel-2 (left), and PALSAR-2 Wide Beam (Center) and Fine Beam (right).

WORK PACKAGE 3

Oil Spill Remote sensing

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Katalin Blix
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Adjunct Professor, NASA`s Jet Propulsion Laboratory

Andrea Marinoni
Associate Professor, UiT

Background and Objectives

In-situ data and fieldwork are of major importance for technology development for marine monitoring. The objective of this work package is to develop accurate remote sensing technologies for reliable oil slick detection and characterization, and to improve modeling of oil behavior and fate in sea icy waters.

Marine pollution is a significant problem in the World's oceans. As the sea ice in the Arctic retreats, maritime traffic and offshore operations are expected to increase. At the same time, the risk of oil spills increases. In addition, offshore oil and gas platforms are known to release produced water that still contains hydrocarbons despite treatment. During oil spill clean-up operations, the authorities need to know where thicker mineral oil is located, and where it may be moving due to wind and ocean currents. Radar remote sensing technology is a key solution to this problem, as it can see through clouds and operate during the polar night. By integrating remote sensing imagery and numerical drift modelling, we can predict where an oil slick is heading.

In the coastal areas, which in Norway are most often composed of long and narrow fjords, the seawater can be a mix of saline and more brackish water. In fjord sea ice with mixed salinities, oil behaves differently as in sea ice conditions. This may have an impact in case of a near-costal oil pollution incident. A natural extension of CIRFA`s research is to include marine primary production and water quality studies.

Key research tasks

- Detection and characterization of oil spills on open water
- Detection of oil spills in fjord sea ice
- Integration of drift modelling and remote sensing for marine environmental monitoring

Achievements in 2021

Oil slick and produced water detection

Cornelius Quigley successfully defended his PhD thesis about oil spill remote sensing using SAR images in March 2021 and presented his work at two international conferences. As a PostDoc, Cornelius continues improving oil spill thickness retrievals in collaboration with KSAT and other researchers in WP3. Cornelius' work will also be connected to newly appointed PhD student Victor de Aguiar's work about oil spill drift. Victor is working with produced water slick surface drift pattern estimates in collaboration with WP5. Master student Brynjar Andersen Saus contributed to produced water detection through his master's thesis work that also was presented to industry partners at Equinor, KSAT and NOFO. In summary, improved oil spill thickness and drift estimates are valuable tools for oil spill clean-ups.

Fjord ice work

Another work focus is the PhD thesis of Megan O'Sadnick on fjord ice - where and when it forms, its properties, and impacts on surrounding communities. The direct usefulness of her work was demonstrated in early 2022, where after a large avalanche in February the road to the community in Beisfjord (Nordland, Norway) was closed. The army tried to provide supplies to residents by boat but was prevented from accessing the community by boat because of ice surrounding the dock. This forced the army to land further away from the town on a rocky coastline that is not always accessible due to tides.

Figure 3-1, Left: The fjord two days after the avalanche with the location of avalanche and the dock noted. Right: A navy boat delivers supplies at an alternative landing spot. Photos: Vidar Løkeng, Fremover.

Ocean Color Remote Sensing

CIRFA is consolidating its work on Ocean Colour with the work of associate scientists Katalin Blix, PhD candidate Muhammad Asim, and Camilla Brekke. Muhammad Asim joined a research cruise where he collected water samples and measured radiance to better understand the biological structure of the water column. Katalin was granted the project ITEX (Innovative Technological solutions to monitor water quality in optically complex waters) by the Norwegian Research Council to organize and conduct a 1-year data collection campaign at Lake Balaton in Hungary starting in summer 2021. Katalin developed machine learning algorithms that were transferred to the optically complex waters of the Barents Sea and surrounding oceans to understand their influences.

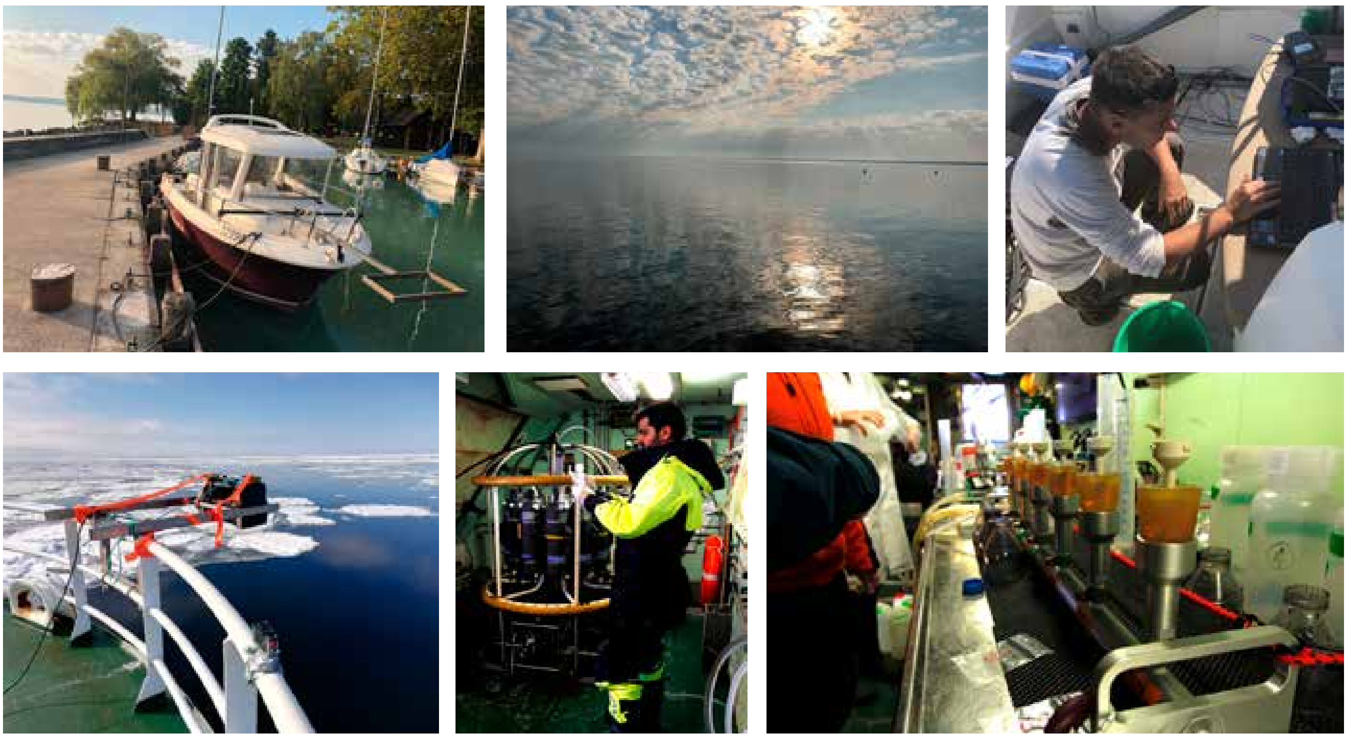

Figure 3-2 shows impressions from Ocean Color fieldwork on lake Balaton (top row, Photos: Katalin Blix, UiT) and in the Barents Sea (bottom row, Photos: Muhammad Asim, UiT).

WORK PACKAGE 4

Remotely Piloted Aircraft Systems Technology

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WP leader
Tor Arne Johansen
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Background and Objectives

Both satellite based systems and RPAS (Remotely Piloted Aircraft Systems) have their strengths and weaknesses. Satellites have superior coverage and repeatability, but limitations when it comes to accurate fine spatial and temporal scale measurements of thickness distribution, drift, convergence and divergence. RPAS can achieve accurate high-resolution measurements, but have limited spatial coverage and range, and are weather sensitive.

The systems needed by industrial operators in the Arctic should be robust and reliable, and the system should be able to handle disruption in service by individual components. This work package aims to develop robust and efficient RPAS and sensor technologies suited to support arctic operations, that are flexible and that can handle the widest possible ranges of environmental conditions enabling high quality measurements of sea-ice and iceberg properties, as well as detecting and monitoring oil spills in ice affected areas. RPAS combined with satellites and state of the art models provide the optimal data based situational awareness tool.

Key research tasks

- Develop platforms with improved take-off and landing capabilities, de-icing performance, wind tolerance, and fault tolerance.
- Improve communication links, robustness and bandwidth in Arctic RPAS operations.
- Develop RPAS sensors for sea ice characterization, ocean surface parameters measurements, and oil-in-ice detection and tracking.
- Develop onboard data processing and improve 'concepts of operation' allowing for real-time operation support and ultimately integration into non-segregated airspace.

Achievements in 2021

UWB radar development for measurements of snow and sea-ice properties

The PhD project on Ultra-wide-band (UWB) radar was successfully completed by Rolf-Ole Rydeng Jensen in May 2021. The radar was used to measure snow pack parameters such as snow depth and characterize sea-ice properties. A method to reliably and remotely estimate snow water equivalent was also developed. This led to improved accuracy in snow density estimates.

Figure 4-1 shows the drone that carries the snow radar being prepared for its next flight. Photo: Anders Martinsen.

Multisensor sea-ice properties retrieval for real time operational support

A sensor system has been designed for mounting on a fixed wing VTOL drone to be operated from the *R/V Kronprins Haakon* during the CIRFA cruise planned for 2022. The goal is to provide real time operational support for vessels navigating through sea-ice, and to demonstrate this on the 2022 cruise. The system consists of four cameras, one nadir looking and three forward looking as shown in Figure 4-2.

This system will give better situational awareness at the same time as accurate quantification of the surface below the aircraft can be retrieved. Georeferenced data will be displayed in real time in the web based NLIVE application on the ship bridge. A dual antenna GPS compass has been integrated in the drone to improve accuracy in orientation and avoid problems with use of magnetic compass in ship environment and at high latitudes.

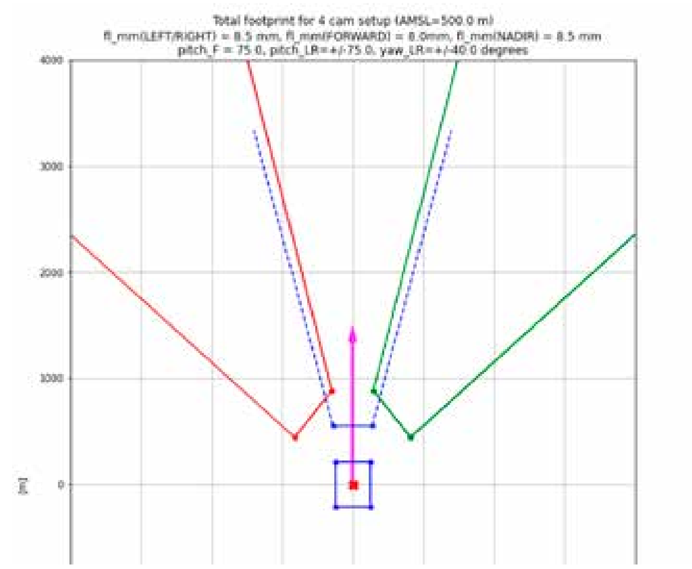

Figure 4-2 shows a NORCE Shark drone that is instrumented for ship based operations for supporting sea-ice navigation, oil spill detection and mapping. On the right side, the footprints of the mounted camera system are presented. Photos: NORCE.

WORK PACKAGE 5
Drift Modelling and Prediction

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WP leader
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Sindre Fritzner
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Keguang Wang
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Edel Rikardsen
Researcher, MET

Ann Kristin Sperrevik
Researcher, MET

Yvonne Gusdal
Researcher, MET

Kai Christensen
Researcher, MET

Jostein Brændshøi
Researcher, MET

Background and Objectives

Forecast models for the ocean and sea ice cover predict oceanic conditions in the near future (1-3 days ahead) and use two steps. In the first step, the forecast systems ingest observations from remote sensing and in-situ platforms to estimate the current state of the ocean. In the second step, the ocean's state is projected forward in time by solving physical laws numerically.

Our overall objective is to improve operational ocean, sea-ice, and weather forecast models by developing new data assimilation (DA) algorithms and by using new types of observations provided in other work packages. DA techniques combine the model state with various types of ocean and sea-ice observations, providing an analysis of the ocean's state and sea ice cover. For Arctic operations, critical forecast parameters are the position of the sea ice edge and ocean currents as well as the weather. Quantification of uncertainty in model predictions is key for dealing with the ocean's chaotic nature, and it is therefore necessary to calculate multiple realization of the ocean's state – commonly known as ensemble prediction systems (EPS).

Key research tasks

- Application of the Ensemble Kalman Filter (EnKF) DA scheme in the regional ocean and ice forecast model *Barents-2.5*
- Quantification of forecast skill in ocean current predictions from the *Barents-2.5* EPS
- Application of ensemble forecast methods in trajectory modeling
- Assimilation of sea surface temperature (SST) observations from various platforms in the coastal forecast model *NorKyst-DA,* using a 4D-var DA scheme.
- Improving SAR-based wind retrieval algorithms in polar low and extreme wind situations, working towards DA of SAR-winds in atmospheric forecasts.

Achievements in 2021

After nearly 5 years of research on data assimilation methodology in the Barents-2.5 model, we have launched an operational implementation of the EnKF in Barents 2.5 in August 2021. At present, real-time sea ice concentration, SST, and in-situ data are assimilated. This system is based on the Barents 2.5 EPS developed in the previous year, consisting of 24 daily members that allow us to assert the uncertainty in predictions for sea ice, currents, and temperature fields (Figure 5-1).

Newly employed PostDoc Martina Idzanovic has started to investigate predictive skill of the Barents 2.5 model to forecast surface currents, using HF radar observations of surface currents as reference for validation. PhD candidate Silje Iversen investigates how to best use the information from various SST observing platforms including both passive microwave and infrared sensors.

PhD student Mathias Tollinger works on obtaining surface wind information with high spatial resolution over sea from SAR observations. These can provide new detailed wind information regarding high-latitude extreme wind events such as polar lows. Mathias has provided important improvement to the wind-retrieval algorithm and works on assimilating these high-resolution, SAR-based wind retrievals into the Harmonie-Arome weather prediction model, used operationally at MET Norway, to improve predictions of weather events with strong wind gradients.

In collaboration with WP3, PhD candidate Victor de Aguiar uses ocean model ensembles to drive respective trajectory model simulations for marine pollution studies. In addition to understanding the drift of pollution, the ensemble allows us to quantify uncertainty and asses the true range of possible drift scenarios.

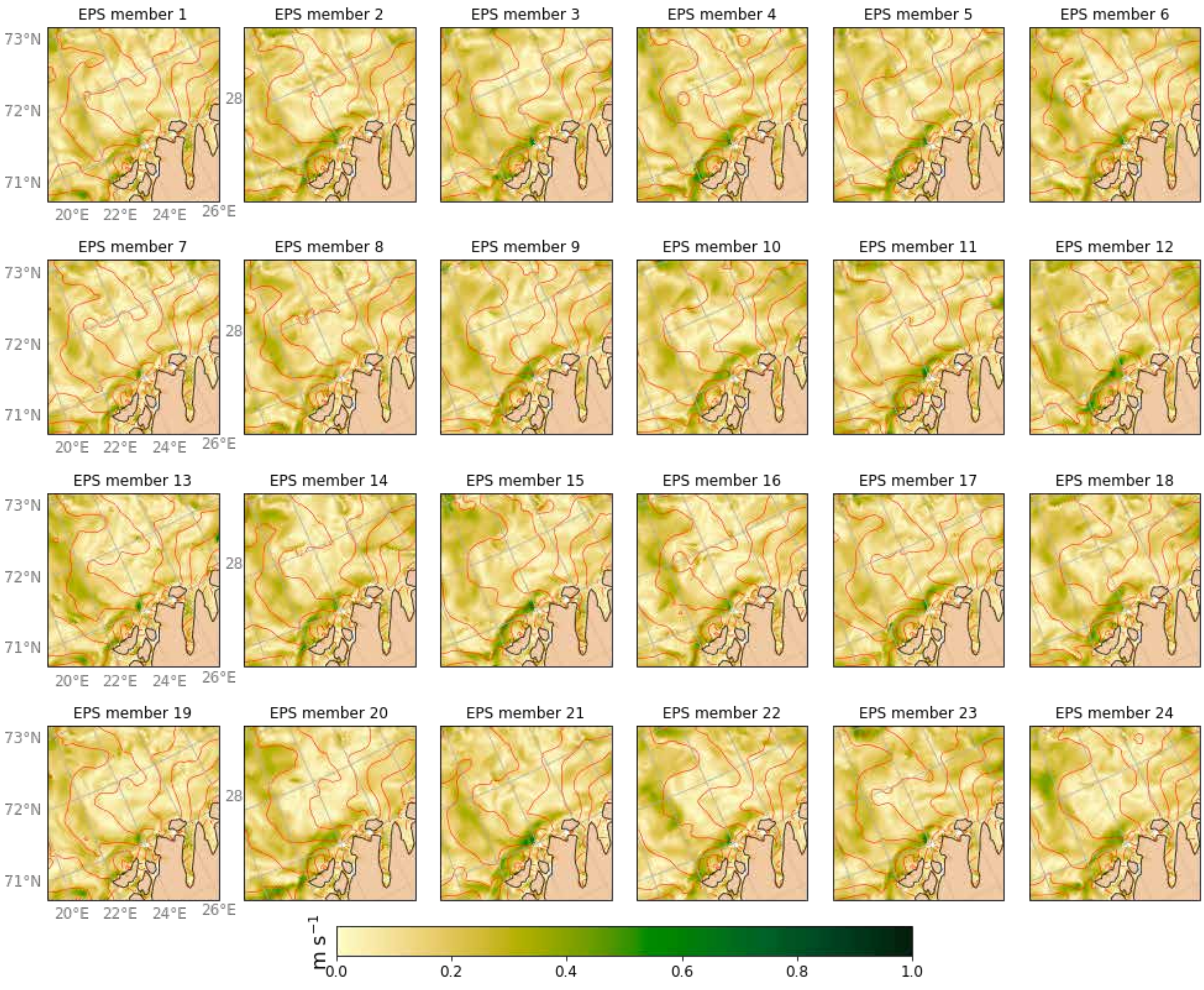

Figure 5-1 shows surface current speed (green shading) and sea surface height (red contours) at the coast of Finnmark, northern Norway, from 24 ensemble members of Barents 2.5 at 2021-11-15 18:00. The ensemble members represent different realizations of ocean forecasts, where each is one possible outcome of equal likelihood to occur. The members exhibit both similarities (e.g. position of coastal current jet) as well as distinct differences (e.g. strength of coastal current).

WORK PACKAGE 6

Data Collection and Fieldwork

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WP leader
Malin Johansson
Researcher, UiT (from August 2021)

WP leader
Rune Storvold
Research Director, NORCE

Team members

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PostDoc, NPI,

Dmitry Divine
Researcher, NPI

Background and Objectives

The work package designs field campaigns in connection with satellite and drone measurements, and aims to carefully plan and conduct the measurements needed for calibration and validation of remote sensing products. The work is done in close coordination and collaboration with other work packages within CIRFA, and centrally involved partners such as the Norwegian Polar Institute, NORCE, and UiT The Arctic University of Norway.

Work package 6 functions as a validation and calibration platform for remote sensing data, as well as organizing the collection of ground truth data for assessing the work conducted in other work packages, with emphasis on the link to work package 2.

Aside new expeditions organized by CIRFA, coastal and fjord-based long-term monitoring data from land stations are used for calibration and validation purposes to support the remote sensing research. Examples of such auxiliary data sets are archived data collected during previously conducted national and international campaigns, like N-ICE2015 (a half year experiment where the research vessel *RV Lance* of the Norwegian Polar Institute was frozen into drifting ice in the Arctic Ocean north of Svalbard), annual campaigns of the Norwegian Polar Institute, NOFO's annual oil-on water exercises, data from the international one-year long Arctic MOSAiC expedition (2019-2020) in the central Arctic Ocean, and cruises with *RV Kronprins Haakon* within the Norwegian Nansen Legacy project.

In 2021, several cruises with *RV Kronprins Haakon* (Nansen Legacy/Norwegian Polar Institute) were conducted with direct links to CIRFA work. In addition, the planning for a specific CIRFA cruise in April-May 2022 began.

Key research tasks

- Plan and conduct dedicated field campaigns on Arctic sea ice, oceans, and oil spills to combine accurate direct measurements of surface properties with airborne data and satellite-based data.
- Improve validation shortcomings by seeking and implementing new and refined measurement concepts and methods using new technologies and platforms.
- Provide quality ground-truth data from archives and new campaigns for assessing the theoretical work in other work packages.

Achievements in 2021

During three cruises within the Nansen Legacy project from the northern Barents Sea and transition to the deep Arctic Basin (March and April-May), and from the central Arctic Ocean (August/September), sea ice datasets were collected. This includes ice core samples, snow depth and ice thickness measurements and transects, as well as aerial photography

Figure 6-1: During two cruises, regional-scale Helicopter-borne Electro Magnetic (HEM) ice thickness measurements were also performed in overlap with remote sensing imagery and ground data. This overlap aides in the validation of remote sensing measurements and algorithms. Photos: Sebastian Gerland, NPI.

from a Remote-Piloted Aircraft System (RPAS). CIRFA Postdoc Anca Cristea participated in the JC2-2 cruise and had the opportunity to measure and sample some of the northernmost Arctic summer sea ice. Furthermore, scientists Dmitry Divine and Sebastian Gerland participated in the cruise Nansen Legacy Q1 in March.

The UAK 2021 campaign with the Norwegian coast guard vessel *KV Svalbard*, led by Hanne Sagen and Stein Sandven from NERSC, took place in June. CIRFA PhD students Laust Færch and Anna Telegina as well as associate PhD student Jozef Rusin were onboard. During the cruise, results from the CIRFA sea ice classification algorithm (Lohse et al., 2020) were sent directly to the ship for near-real time validation. In addition, sea ice classifications using RADARSAT-2 images were sent to the ship for validation making this a successful collaboration between WP2, WP6 and WP7.

More is to come in 2022 when the algorithms using both C- and X-band SAR satellite data will be validated during the planned CIRFA 2022 cruise. On all cruises mentioned here, standardized IceWatch-ASSIST sea ice observations were done regularly and uploaded to IceWatch online portal.

Furthermore, in-situ work in Kongsfjorden on landfast sea ice was carried out by NPI researchers in spring 2021 adding onto earlier CIRFA work where SAR satellite observations to give additional information on the sea ice concentration in the fjord.

Satellite and oil slick detection work was carried out, both in collaboration with Wintershall Dea, Equinor and CAGE (an SFF based at UiT). The collaboration with Wintershall Dea and Equinor saw further overlaps between in-situ data of produced water and satellite images from the Brage and Norne platforms. Together with scientists from CAGE, overlapping in situ and satellite data was collected over naturally occurring oil and methane seepages in the Barents Sea, with special focus on Hopendjupet during in-situ data campaigns lead by CAGE in July and December.

Beyond the fieldwork, time was spend in WP6 on data processing and curation, developing and writing of scientific manuscripts, presenting results, and preparing for the CIRFA 2022 cruise with *RV Kronprins Haakon*.

WORK PACKAGE 7

Pilot Service Demonstration

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WP leader
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Team members

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Head Engineer, UiT

Jelte Geert van Oostveen
Head Engineer, UiT

Background and Objectives

Satellite-based operational capabilities including oil spill detection, ship traffic monitoring and sea ice mapping have been demonstrated and developed into regular use. However, there are still requirements for industrial maritime operations in the environmentally sensitive Arctic that have not been met, such as monitoring technologies integrated into their day-to-day operations for decision support.

In this work package, we will demonstrate pilot services showing the provision of integrated environmental information to end-users involved in Arctic operations. The objective of this work package is to demonstrate the implementation of R&D results into pilot services to be delivered to end-users with operational needs. The services will be based on multi-sensor data acquired from various sensors and platforms, accessed via improved communication infrastructure and brought into analysis and decision through dedicated interfaces.

Key research tasks

- Establish an infrastructure that allows the WP partners to access and perform processing on the project data in a technically efficient way close to the data storage.
- Integrate the R&D results from the other WPs into service demonstrations at KSAT and/or MET Norway to show the provision of integrated environmental information to end-users involved in Arctic operations.
- Develop a visualization solution associated with the integrated pilot services demonstrations.

Achievements in 2021

Work package 7 continues to provide support to the other work packages in their activities. In 2021, work has been concerned with the following activities:

- Support with data handling
- Support with processing chain for met-ocean at KSAT (WP 1), damping ration (WP 3), and OpenDrift model (WP 3)
- Initiating the OpenDrift model with different thickness classes (WP 3)
- Software for decision-tree for Sentinel-1 image classification transferred to MET Norway and now running routinely with generation of GeoTIFF-format images, and NetCDF files containing comparison datasets (ice charts, passive microwave SIC, etc) (WP 2)
- Ice Watch observations from Nansen Legacy cruises together with WP2 and WP6
- Funding applications and abstracts

Detecting the presence of oil spills, the thickness of the oil and its drift direction and speed are helpful information in case of an oil spill. The OpenOil model is now set up at KSAT in collaboration with MET for a testing phase. It has been improved by including the damping ratio. Results about *"Oil Spill drift model Initiated with Thickness Variations"* were presented at the Esri European Petroleum GIS Conference by Martine M. Espeseth, Hugo Isaksen, Alastair Cannell, and Charlotte Bishop.

Figure 7-1 shows drift trajectories around Jacarta, Indonesia, calculated using the OpenDrift model. The model was initialized based on oil detected with two thickness classes from an optical Sentinel-2 image compiled by Martine Espeseth, KSAT.

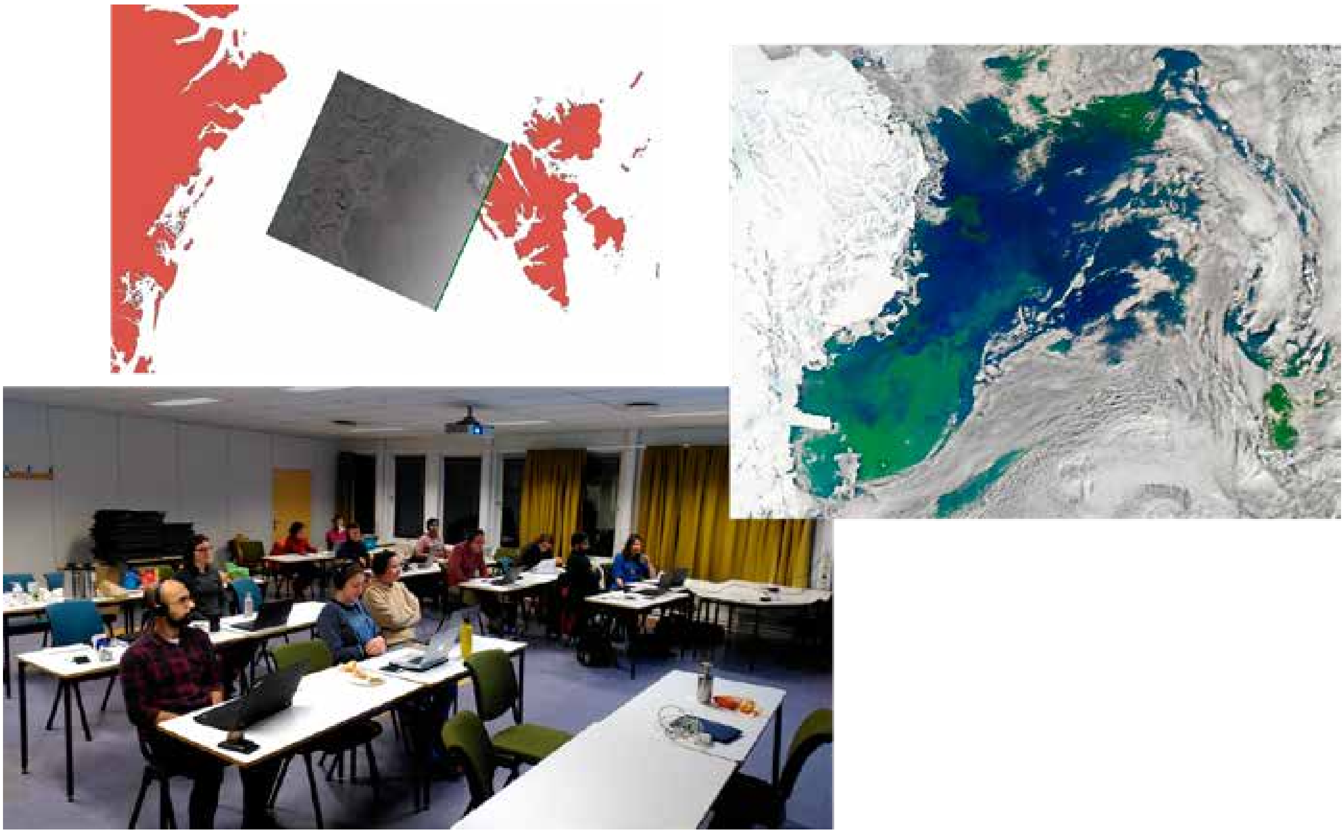
Research training

CIRFA arranges research training activities that are open for our master students, PhD candidates, postdocs and researchers.

In September and November, CIRFA arranged a **methodological workshop on sea ice classification.** The workshop had two practical sessions and was organised by Johannes Lohse. It reviews the basics of SAR image classification, the installation of data processing packages, and the main workflow steps of data analyses for SAR image classification.

Throughout the autumn semester between September and November, Katalin Blix, Muhammad Asim, Atsushi Matsuoka and Torbjørn Eltoft were giving a **special course on Ocean Color Remote Sensing.** The six lectures covered the basics of Ocean Color remote sensing, atmospheric properties and correction, ocean biology from space, inversion algorithms and calibration, validation and errors. With the lecturers based in the US, Hungary and Norway, the course was run digitally.

The traditional **CIRFA Young Scientist Forum 2021** took place in December. PhD candidates Megan O`Sadnick and Muhammad Asim arranged a 2-day workshop with focus on external research funding, career design thinking, stress management and mindfulness. In the evening, games with Bumperball, Lasertag, and a pizza dinner offered the participants pleasant diversion and teambuilding.



A screenshot from the workshop on sea ice classification (Sentinel-1 & Copernicus, a satellite`s perspective on ocean color (data from the European Space Agency, processed by Katalin Blix); and a photo from the Young Scientist Forum (Johannes Lohse).

Master Degrees and Doctoral Dissertations

Since the start of the center, CIRFA scientists provided supervision and training to remote sensing students. In 2021, three internship students visited CIRFA, five master students graduated, and four successfully defended their PhD dissertations:

Internship student	Topic	Supervisor(s)	Home institution
Catherine Taelman	Feature selection using deep spectral clustering for remote sensing applications	Andrea Marinoni	Eindhoven Technical University, The Netherlands
Sam Cremers	Scalable semisuperivised graph-based data analysis of multimodal remote sensing records	Andrea Marinoni	Eindhoven Technical University, The Netherlands
Piyi Lozou	Gaussian processes and variational autoencoder for multimodal remote sensing data analysis and sea ice characterization	Andrea Marinoni, Saloa Claily	National Technical University of Athens, Greece

Msc student	Title of the thesis	Supervisor(s)
Brynjar Andersen Saus	Detection and Delineation of Produced Water Slicks in Sentinel-1 Synthetic Aperture Radar Images	Malin Johansson, Anthony Doulgeris, Camilla Brekke
Truls Thorsen Karlsen	Measuring velocities of a surge type glacier with SAR interferometry using ALOS-2 data	Malin Johansson, Geir Moholt, Jelte van Oostveen
Tora Båtvik	Detection of Marine Plastic Debris in the North Pacific Ocean using Optical Satellite Imagery	Anthony Doulgeris
Torjus Nilsen	Semisupervised learning of sea ice characteristics in multimodal remote sensing data	Andrea Marinoni
Ida Graabræck Kinderås	A Study of Polarimetric Parameters Used for Sea Ice Classification	Malin Johansson, Torbjørn Eltoft
Catherine Taelman	Label propagation for multi-modal remote sensing data	Andrea Marinoni
Dana King	Uncompleted thesis	
Martin Blengsli	Automatic snow layer detection in drone-borne radar data using edge detection and morphology	Anthony Doulgeris, Rolf-Ole Rydeng Jenssen

Completed PhD projects

Cornelius Quigley - 3 March 2021

«Determination of the Dielectric Properties of Marine Surface Slicks Using Synthetic Aperture Radar»

Over the course of the last three decades, Synthetic Aperture Radar (SAR) has proven itself to be an effective monitoring technology for marine applications. With increasing levels of maritime traffic due to declines in Arctic multiyear sea ice as well as risks associated with oil and gas exploration in the Arctic, being able to derive important geophysical information on the state of an oil slick is important for the decision-making process of first responders and clean-up personnel. Cornelius` work is concerned with attempting to determine the dielectric properties of oil slick using SAR for marine slick characterization.

Rolf-Ole Rydeng Jenssen - 11 May 2021

«Radar System Development for Drone Borne Applications with Focus on Snowpack Parameters»

A complete representation of the Arctic cryosphere has historically been restricted by its remoteness, large extent, and restrictions in measurement methods and equipment. Rolf-Ole`s work presents the development of a small and lightweight radar-system developed for drone-mounted snow measurements.

Johannes Lohse - 12 March 2021

«On Automated Classification of Sea Ice Types in SAR Imagery»

With the Arctic sea ice continuously decreasing in both extent and thickness, fast and robust production of reliable ice charts becomes more important to ensure the safety of Arctic operations. Johannes`thesis focuses on the development of automated algorithms for the mapping of sea ice from synthetic aperture radar (SAR) images. It presents a thorough background on the topics of sea ice observations and ice charting, sea ice image classification, and the appearance of sea ice in SAR imagery.

Artem Moiseev - 20 May 2021

«Ocean surface currents derived from Sentinel-1 SAR Doppler shift measurements»

Information about upper ocean currents is key for monitoring life below water, including conservation of marine biodiversity, climate research, and are needed to support the maritime transport sector, renewable marine energy, as well as for monitoring and tracking of marine pollution. Still, a lot of unknowns remain about upper ocean currents and their variability. The PhD thesis of Artem sheds new light into Ocean surface currents derived from Sentinel-1 SAR Doppler shift measurements.

Communication and Dissemination Activities

The **CIRFA seminars** are a valuable platform for invited speakers or scientists who work on related topics. The seminars serve a threefold purpose; to present and discuss ongoing work or results, to update about field campaigns and new data and observations, and to encourage networking. In 2021, CIRFA hosted 10 seminars with international speakers, a wide range of topics, and mainly a remote audience due to covid-19:

Presenter	Affiliation	Country	Month	Title of the talk	Audience
Daniel Stødle & Agnar Sivertsen	NORCE	NOR	January	Capabilities, processing and visualization of airborne remote sensing data using NLive	39
Hiroshi Sumata	NPI	NOR	February	Unprecedented decline of sea ice thickness and ice export through Fram Strait in 2018	27
John Yackel	University of Calgary	CAN	March	The salient role of saline snow on seasonal sea ice	26
Atsushi Matsuoka	University of New Hampshire	JAP	March	Ocean color remote sensing in the Arctic Ocean	25
Arttu Jutila (AWI), Wenkai Guo (UiT)	AWI & UiT	GER & NOR	April	A. Jutila: "On the consistency of airborne sea ice thickness, freeboard, and snow depth measurements in the late-winter Arctic: application to sea ice bulk density" W. Guo: "Combining ALS, EM and snow radar for sea ice studies & Sea ice classification"	32
Geoffrey Dawson, Sindre Fritzner	Bristol & UiT	NOR & UK	May	G. Dawson: "Summer sea ice freeboard from CryoSat-2 radar altimetry" S. Fritzner: "Machine-learning prediction of Arctic sea ice Summer ice thickness"	25
Trygve Kvåle Løken (UiO), Laust Færch (UiT), Thomas Kræmer (UiT), Nick Hughes (MET)	UiO + UiT, MET	NOR	May	T. K. Løken: "Iceberg stability during towing in a wave field" L. Færch, T. Kræmer, N. Hughues: "Latest iceberg research in CIRFA: Results and applications"	31
Robbie Mallett	UCL	UK	September	Snow on Arctic sea ice – much still to learn from Soviet Drifting stations	40
Johannes Röhrs	MET Norway	NOR	October	Forecasting of surface currents and drift trajectories	23
Debanshu Ratha	UiT	NOR	November	The Geodesic Distance-Based Approach to PolSAR Data Analysis and its Potential for Sea-Ice Applications	16

The **CIRFA Annual Conference 2021** took place during October 19-21 at the Sommarøy Arctic Hotel near Tromsø. This year's conference featured sessions on key research topics such as ocean modelling and data assimilation, recent advances in sea ice classification, iceberg detection, oil slicks and natural oil seeps in the Barents Sea, and relevant developments and applications of machine learning. The conference started with a poster session with mingling, had a session on research cruise planning, early career researcher presentations, and two workshop sessions to advance ongoing projects. This year's conference in a hybrid format had 42 in-person and 22 remote participants.

Participants of the CIRFA Annual Conference 2021 at the Sommarøy Arctic Hotel near Tromsø. Photo: CIRFA.

Conferences and Workshops where CIRFA was represented in 2021

- EUSAR
- IGARSS
- EGU General Assembly
- Phi-Week
- Svalbard Science Conference
- International Ice Charting Group Workshop
- AIDingArtic: Artificial Intelligence & Data Science for the Arctic
- Esri European Petroleum GIS Conference
- Online conference on Remote Sensing on Svalbard
- JAXA Earth Observation Missions

Podcast and webinar

In the **podcast** series "Behind the Scenes" of the EU Research and Innovation Exhibition, journalist Jennifer Baker spends time with some of Europe's most brilliant scientists and innovators whose discoveries are having a lasting and important impact on our daily lives. The episode "A village on ice" is connected to the MOSAiC expedition and open questions in Earth climate sciences, but it also talks about Polona Itkin`s inspiration to become a researcher. This podcast series is an initiative of the European Commission and part of the European Research and Innovation Days.

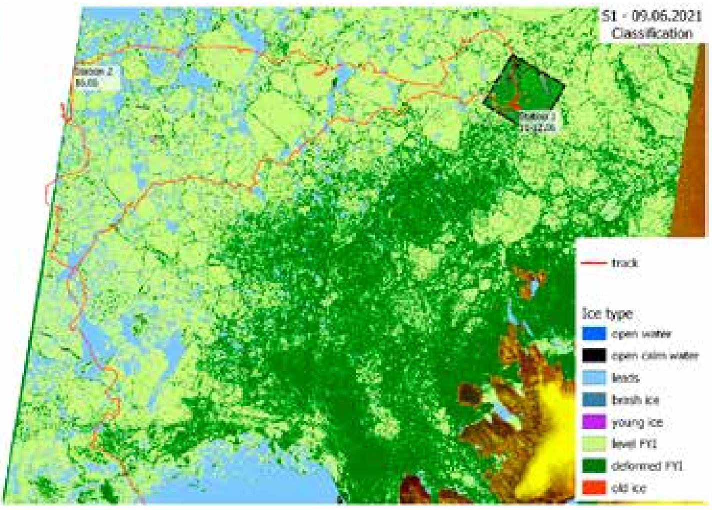
Polona was also a speaker of the APECS-ARICE **webinar** on DEARice in MOSAiC – Connecting the world of snow, ice and ecosystem processes. The DEARice project (DEvelopment of snow/ice/ecosystem models using winter-to-summer ARctic observations of coupled snow, ice, and ecosystem processes) took part during the MOSAiC expedition. The aim was to collect unique data on snow and sea ice over a full year to improve our understanding of the vulnerability of the Arctic sea ice system, and decrease uncertainties in climate projections.

Detecting mineral oil slicks in ice covered seas from space

The thinning and retreat of the arctic sea ice has led to increased human presence in Arctic seas. Marine traffic is most likely to increase in the future, as are activities such as fishing, oil and mineral exploitation. All these activities increase the risk for oil spills in ice-covered waters. Yet, the technology used to monitor for marine oil spills in the World's oceans is not yet applicable for ice-covered seas. A new study (Johansson et al, 2020) presents a first approach to overcome this limitation.

EGU Blog Post: Mapping Sea ice from Space

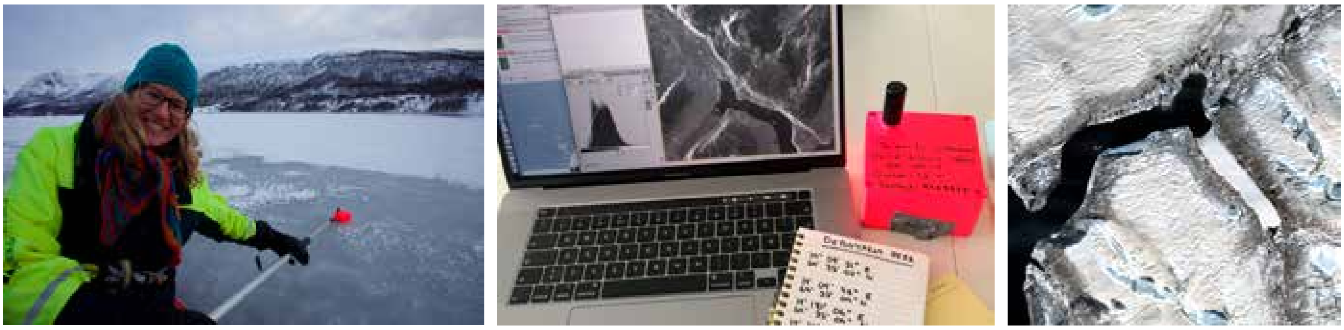
Reduced and thinner sea ice makes Arctic waters increasingly appealing for shipping, fishing, tourism, and mineral exploration. However, with increased accessibility and more dynamic ice conditions comes a greater risk for ship crews to encounter sea ice and icebergs outside of their usual seasonal limits. To help them navigate, timely and reliable sea ice information is key. Have you wondered how sea ice information can be provided for vast and remote areas such as the Arctic Ocean? CIRFA has a post on the award-winning blog of the European Geosciences Union (EGU) about mapping sea ice from space.



Left: A cargo ship navigating through icy waters, seen from a drone. Photo: Alex Perz/Unsplash. Right: Example of the sea ice classification in satellite images North of Svalbard. The different colours represent different ice types and open water. The red line outlines the ship track. Data used to produce this figure come from Sentinel (Copernicus) and Radarsat-2 (NSC/KSAT, Norwegian-Canadian Radarsat agreement 2021). The map is made by Anna Telegina and Johannes Lohse (UiT).

Monitoring thin ice

Of all sea ice types, freshly growing ice that is only a few cm thick yet is most challenging to observe via satellite images and to accurately monitor automatically. To improve this, CIRFA researcher Malin Johansson has built and tested a small instrument with sensors watched thin ice growing and drifting near Tromsø in May. It sends its measurements in real time via its GPS antenna. The work is part of the project ThinTec, where Malin and her colleagues at MET and UNIS are developing open-source technology to measure thin ice growth in near-real time and subsequent drift to support automatic sea ice classification and mapping.



Malin Johansson deploys the ThinTec instrument in Ramfjorden near Tromsø with the ice edge at the innermost part of the fjord. Preparation work included analyzing the latest satellite image. Sea ice on the fjord appears white and open water appears black in the satellite image. Images: Paul Dodd (NPI), Malin Johansson (UiT), and ESA/Copernicus.

Side event on Machine Learning during ESA`s Phi Week

Katalin Blix organized and chaired a side event on ESA's Phi week 2021 on "Machine Learning In Ocean Color Remote Sensing". The event gathered expertise in the field to discuss gaps, challenges and solutions in ocean color remote sensing with focus on machine learning. There were three invited speakers: Ewa Kwiatkowska (EUMETSAT, S3 OLCI mission leader), Ana Belen Ruescas (University of Valencia) and Torbjørn Eltoft. The session had many participants, and the speakers made an amazing job to initiate discussion and engage the audience for fruitful conversations.

Screenshot from a Twitter announcement of the Phi Week Side event. Compilation by Katalin Blix, UiT.

Space Day at Vitensenter

In late October, CIRFA participated at the Space Day 2021 at Vitensenter in Tromsø. The event was arranged by Vitensenter and Andøya Space. It was designed to introduce high school students and students to career opportunities in space-related research and businesses in northern Norway.

Andrea Schneider and Vibeke Os represent CIRFA at the SpaceDay 2021 at Vitensenter. Photo: Vibeke Os, UiT.

IPCC report contribution

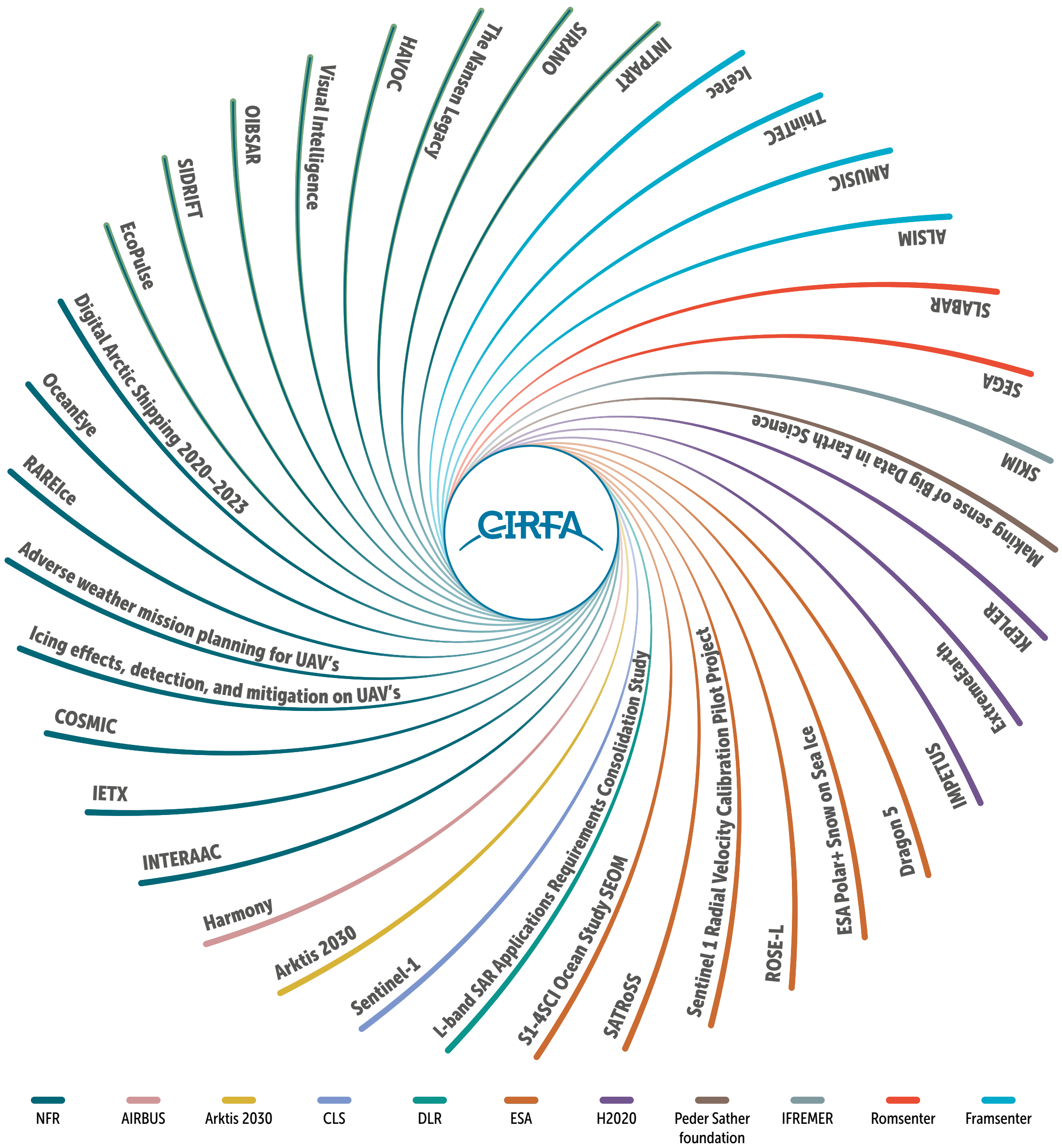
Sebastian Gerland has contributed to the 6th Assessment Report of the IPCC (Working Group 1) in a chapter on evidence-basis for large-scale past changes in the climate system. More in detail, the chapter focuses upon changes in climate system drivers and changes in key selected large-scale indicators of climate change. Working on an assessment of changes in the global climate system shows how widely remote sensing technology can be used.

National and International Collaboration

In its research field, CIRFA is associated with 37 active national and international research and innovation projects or varying funding amount, time line and complexity. CIRFA researchers were successful to secure funding from DLR, RCN, Framsenter, Norwegian Space Agency and others. About half of them are international projects that involve organisations such as DLR, IICWG, ESA and JAXA. Many of the projects employ artificial intelligence and/or machine learning to analyze climate and environmental data, and research training and competence building. The largest associated projects are The Nansen Legacy, KEPLER, ExtremeEarth, and the new Horizon 2020 Green Deal project IMPETUS.

Five new projects were awarded funding in 2021:

- SLABAR - Integrating SeaLevel Anomalies into the BARents model with funding from the Norwegian Space Agency to Martina Idzanovic
- ITEX - Innovative Technological solutions to monitor water quality in optically complex waters with funding from RCN to Katalin Blix
- INTERAAC - Air-snow-ice-ocean INTERactions transforming Atlantic Arctic Climate with funding from NFR to Jack Landy;
- the Peder Sather foundation grant to Andrea Marinoni;
- and the IMPETUS H2020 grant to Andrea Marinoni.

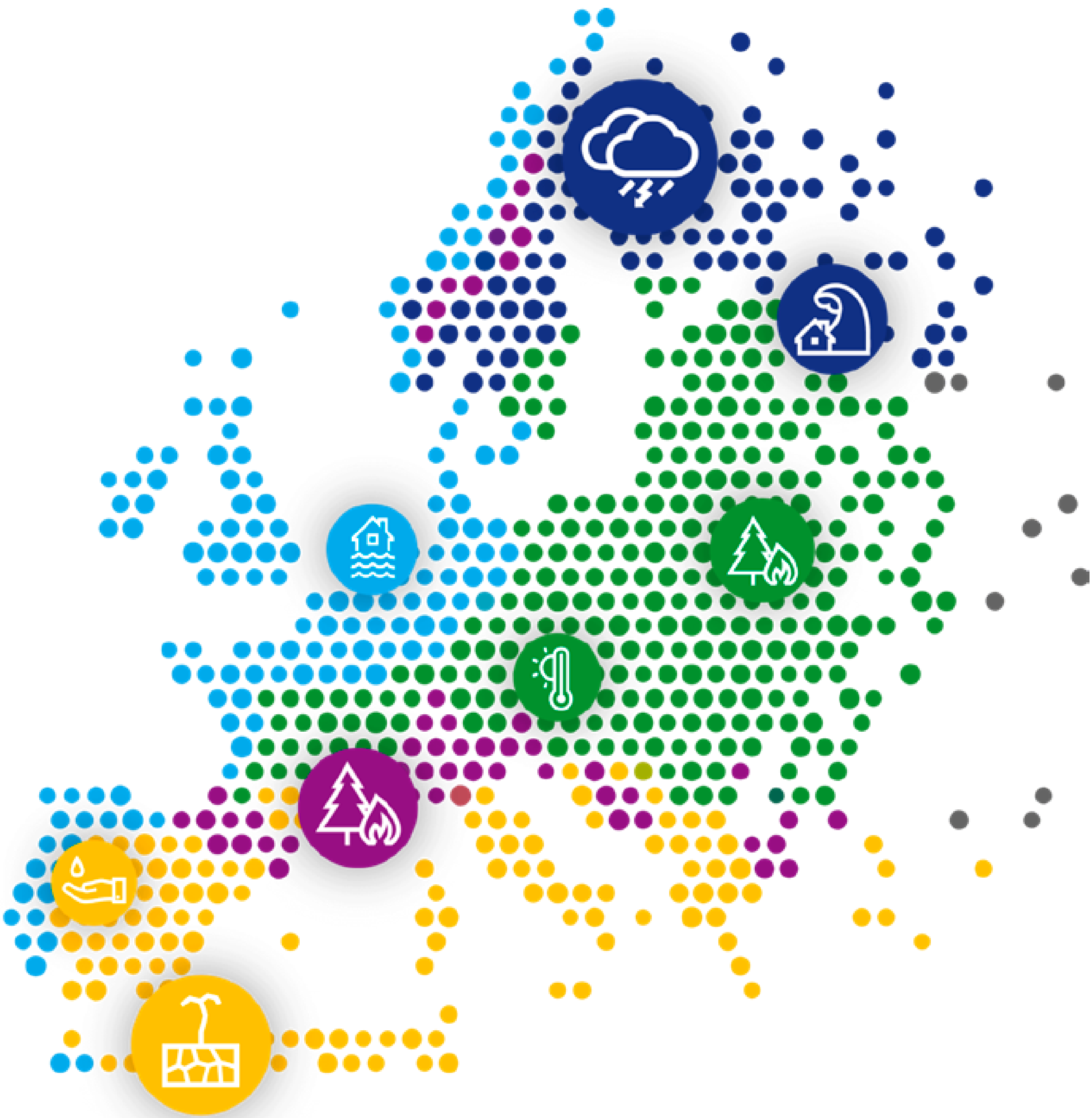


An overview of related projects and funding sources. Image credit: Torger Grytå, YUiT.

The Horizon 2020 Green Deal Project IMPETUS

The European Union (EU) strategy on adaptation to climate change recently adopted by the European Commission (EC) addresses the importance of improved adaptation and resilience to climate change. The impact of climate change is already visible on economies, communities and ecosystems worldwide with consequences on citizens' wellbeing as well as the natural and built environment. Remote sensing can play a key role in this context.

The H2020 Green Deal project IMPETUS aims to integrate remote sensing datasets and products to accelerate the transition towards a climate-neutral and sustainable economy. Remote sensing data will be complemented by additional data collected on the ground and assessment methods to support decision and policy making within a process of co-creation with local stakeholder communities. The result of this approach will be the co-creation of regional Adaptation Pathways, aiming at optimizing adaptation and mitigation approaches to climate change in a specific region based on the needs of local communities. IMPETUS is expected to lead to increased community empowerment in all seven EU biogeographical regions (Continental, Coastal, Mediterranean, Atlantic, Arctic, Boreal, Mountainous) covering key community systems, climate threats, and multi-level governance regimes.



The key research topics of the IMPETUS project. Image: IMPETUS.

Engagements on National and International Dimension

ESA Earth Explorer 11
Malin Johansson is a member of the ESA Earth Explorer 11 Mission Scientific Advisory Board

ESA ROSE-L
Wolfgang Dierking is a member of the Mission Advisory Group for ROSE-L (Radar Observing System for Europe at L-band)

ESA Sentinel-1 Next Generation
Wolfgang Dierking is a member of the Mission Advisory Group

European Space Sciences Committee (ESSC)
Camilla Brekke is a member of the European Space Sciences Committee

International Ice Charting Working Group (IICWG)
Wolfgang Dierking is a leader, and Nick Hughes a member of the ROSE-L and SAOCOM task team in the International Ice Charting Working Group

IEEE Geoscience and Remote Sensing Society (GRSS)
Andrea Marinoni is a member of the IEEE GRSS AdCom and the leader of the committee for the organization of the IEEE GRSS schools worldwide

IEEE IGARSS 2021
Andrea Marinoni is Technical Program Committee member of IEEE IGARSS 2021

International Panel on Climate Change (IPCC)
Sebastian Gerland is one of the Norwegian lead authors to the IPCC WG1 assessment on the physical climate change sciences

World Meteorological Organization (WMO)
Nick Hughes is a member of the Standing Committee on Marine Meteorological and Oceanographic Services Expert Team on Maritime Safety


Photo by Wenkai Guo

Publications in 2021

Peer reviewed publications

Asim, Muhammad; Brekke, Camilla; Mahmood, Arif; **Eltoft, Torbjørn;** Reigstad, Marit. Improving Chlorophyll-a Estimation from Sentinel-2 (MSI) in the Barents Sea using Machine Learning. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 2021. doi: 10.1109/JSTARS.2021.3074975.

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Hann, Richard; Enache, Adriana; Nielsen, Mikkel Cornelius; Stovner, Bård Nagy; Van Beeck, Jeroen; Johansen, Tor Arne; Borup, Kasper Trolle. Experimental Heat Loads for Electrothermal Anti-Icing and De-Icing on UAVs. *Aerospace* 2021. doi: 10.3390/aerospace8030083

Hann, Richard; Johansen, Tor Arne. UAV icing: the influence of airspeed and chord length on performance degradation. *Aircraft Engineering* 2021. ISSN: 0002-2667

Heorton, Harold; Tsamados, Michel; Armitage, Thomas; Ridout, Andy; **Landy, Jack C.** Cryosat-2 significant wave height in polar oceans derived using a semi-analytical model of synthetic aperture radar 2011-2019. *Remote Sensing* 2021. doi: doi.org/10.3390/rs13204166

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Mallett, Robbie; Stroeve, Julienne C.; Tsamados, Michel; **Landy, Jack C.;** Willatt, Rosemary; Nandan, Vishnu; Liston, Glen. Faster decline and higher variability in the sea ice thickness of the marginal Arctic seas when accounting for dynamic snow cover. *The Cryosphere* 2021. doi: 10.5194/tc-15-2429-2021

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Eltoft, Torbjørn. Challenges in DL-based sea ice classification from SAR. Lessons from ExtremeEarth. *PHI-Week - Side event*: Earth Observation and AI for Operational Sea Ice Charting. 2021.

Eltoft, Torbjørn. CIRFA: Remote Sensing in Arctic Applications. *Online Conference on Remote Sensing in Svalbard.* 2021.

Eltoft, Torbjørn. Deep Learning Challenges in Sea Ice Classification. *AIDingArctic.* 2021.

Eltoft, Torbjørn; Brekke, Camilla; Kristiansen, Raymond. Nasjonalt senter for jordobservasjon i Tromsø. *Nordlys.* 2021

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Færch, Laust; Dierking, Wolfgang Fritz Otto; Doulgeris, Anthony Paul. Iceberg Detections with SAR at C- and L-band. *22nd Meeting of the International Ice Charting Working Group*. 2021.

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Johansson, M., Singha, S., Spreen, G., Howell, S., Sobue, S., and Davidson, M., 2021, High spatial and temporal resolution L- and C-band Synthetic Aperture Radar data analysis from the yearlong MOSAiC expedition, *EGU General Assembly*. 2021.

Johansson, Malin; Eltoft, Torbjørn; Singha, Suman; **Itkin, Polona;** Spreen, Gunnar; Howell, Stephen; Shin-ichi, Sobue; Davidson, Malcolm. L- and C-band Synthetic Aperture Radar data analysis from the yearlong MOSAiC expedition. *Joint PI Meeting of JAXA Earth Observation Missions*. 2021.

Johansson, Malin; Skrunes, Stine; Brekke, Camilla; Isaksen, Hugo. Multi-mission remote sensing of low concentration produced water slicks. *EUSAR 2021: 13th European Conference on Synthetic Aperture Radar.* 2021.

Khachatrian, Eduard; Chlaily, Saloua; Eltoft, Torbjørn; Gamba, Paolo; **Marinoni, Andrea.** Unsupervised Band Selection for Hyperspectral Datasets by Double Graph Laplacian Diagonalization. *IEEE International Geoscience and Remote Sensing Symposium proceedings*. 2021.

Khachatrian, Eduard; Chlaily, Saloua; Eltoft, Torbjørn; Marinoni, Andrea. Selecting principal attributes in multimodal remote sensing for sea ice characterization. I: *EUSAR 2021: 13th European Conference on Synthetic Aperture Radar*. 2021.

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Quigley, Cornelius. Inferring the Dielectric Properties of Oil Slick from Multifrequency SAR imagery via a Polarimetric Two-Scale Model. *EUSAR 2021: 13th European Conference on Synthetic Aperture Radar.* 2021.

Quigley, Cornelius; Brekke, Camilla; Eltoft, Torbjørn. Inferring the Dielectric Properties of Oil Slick from Multifrequency SAR imagery via a Polarimetric Two-Scale Model. *EUSAR 2021: 13th European Conference on Synthetic Aperture Radar.* 2021.

Ratha, Debanshu; Eltoft, Torbjørn; Marinoni, Andrea. Discrimination of Ice and Water using PolSAR Parameter-based Clustering. *CIRFA Annual Conference*. 2021.

Schneider, Andrea. Ny kartteknologi gjør det tryggere å seile i arktiske farvann. *Forskerhjørnet* 2021.

Schneider, Andrea; Kræmer, Thomas; Everett, Alistair; Lohse, Johannes; Hughues, Nick; Lauknes, Tom Rune. Mapping sea ice from space. *EGU Cryospheric Sciences Blog* 2021.

Schneider, Andrea; Rasch, Morten; Topp-Jørgensen, Elmer; Frost Arndal, Marie. INTERACT Fieldwork Communication and Navigation Guidebook. Aarhus University, Aarhus, Denmark: *DCE - Danish Centre for Environment and Energy* 2021.

Singha, Suman; **Johansson, Malin;** Spreen, Gunnar; Howell, Stephen; Shin-ichi, Sobue; Davidson, Malcolm. Year-around C- and L-band observation around the MOSAiC ice floe with high spatial and temporal resolution. *IEEE International Geoscience and Remote Sensing Symposium proceedings* 2021.

Accounts

Funding sources

The Research Council of Norway	11 221
Industry partners	5 245
The host institution (UiT)	7 338
Research partners	2 011
Total	**26 716**

Costs per activity

WP 1 Ocean RS	1 610
WP 2 Sea Ice RS	6 720
WP 3 Oils Spill RS	4 335
WP 4 RPAS Technology	1 788
WP 5 Drift Modeling and Prediction	5 686
WP 6 Fieldwork and Data Collection	929
WP 7 Pilot Service Demonstration	1 505
Management	4 143
Total	**26 716**

Costs per partner

Research partners	
UiT	16 230
NORCE	3 773
Sintef Narvik	892
NTNU	
NPI	1 789
MET Norway	3 097
NERSC	89
Industry partners	
Equinor	302
Vår Energi	59
Total E&P Norge	
OMV Norge	117
Aker BP	
Aker Solutions	
Multiconsult	50
KSAT	317
Maritime Robotics	
Total	**26 716**

All amounts are in 1000 NOK.

Photo by Adam Steer, NPI, Arven etter Nansen

LUNDBLAD Photo by Wenkai Guo, UiT.