

2022 Annual Report



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



sfi = Centre for
Research-based
Innovation



A partner's perspective



Kjell Arild Høgda
NORCE Norwegian Research Centre AS
Research Director, Earth Observation

NORCE is an independent research institute that conducts research and innovation for both public and private sectors in energy, healthcare, climate, the environment, society and technology. Our research address key challenges for society and contribute to value creation on the local, national and global levels. NORCE is one of Norway's leading research institutes in earth observation (EO) from satellites and drones, with expertise that spans across information technology, satellite and drone data processing, and physical understanding of sensors, signals, and the observed media. The EO activities involve 20-25 scientists, with focus on SAR (Synthetic Aperture Radar) processing and applications and drone technology development.

As a research institute we are dependent on project funding. Testing and validating drone technology for e.g. climate sciences is very expensive. It requires participation in deep field operations across several seasons to optimize the technology before state-of-the-art measurements can be retrieved and turned into valuable, proven data. Accordingly, projects like CIRFA with long term funding are essential to develop emerging ideas and technology from basic research into new, innovative solutions for industry, applied sciences and public users. CIRFA is also important in giving us resources for publication of our results, collaboration with other scientists and important users in the field.

During last year's CIRFA-2022 Cruise, both NORCE and Maritime Robotics demonstrated drones with capabilities for vessel-based operations. NORCE's drone demonstrated its capacity for mapping large areas of sea ice, providing data to the research vessel in real-time. The acquired data was not only appreciated for its scientific value but was also utilized for ice navigation and planning of the next ice station locations. In future research this data will be assimilated into fine-scale drift models for sea-ice nowcasting, model validations and satellite ground-truthing.

Another prioritized research area in CIRFA has been drone mounted radars for cryosphere research. NORCE performed several radar flights during last year's CIRFA-2022 Cruise, with focus on retrieval of sea-ice snow depth, one of the most difficult parameters to understand to successfully retrieve accurate sea-ice thickness from satellite data. The drone borne radar correlates extremely well with in situ measurements, paving the way for future campaigns where sea-ice snow thickness can be measured while the research vessel is underway in the ice. This will provide more data per vessel day and reduce the need for costly ice-stations and personnel for ground truth measurements.

In CIRFA, we have worked on developing the use of satellite technology to advance the understanding of the Arctic Ocean processes and dynamics, and contributed to better prediction of polar lows, now-casting, and short-range forecasting of ocean state through coupling with high resolution numerical models. A satellite SAR image is a snapshot of the sea surface, which provides information regarding the wind speed, ocean swell and significant wave height, as well as the velocity of the surface current. The observations have a relatively high spatial resolution, cover large areas and can be applied in e.g. offshore wind farm planning.

Offshore wind is believed to be one of the most important components in the green shift. However, in coastal areas, ocean surface wind, wave, and current show higher heterogeneity due to the coastline, bathymetry, orography, and land/sea surface temperature contrasts. SAR is a unique source for high-resolution observations of the wind at sea level. We focus on improving wind products for coastal areas, where both numerical models and existing SAR wind products have weaknesses. In 2022, the operational met-ocean processing system at NORCE (and KSAT) has been upgraded and extended to better support user and R&D needs. This system will now be further updated and applied for serving the emerging offshore wind farm industry and positioning CIRFA for contributing to the green shift.

Foreword – 2022



CIRFA had an interesting year and made great achievements in 2022.

Coming towards the end, it is anticipated that some non-permanent staff members will leave to seek opportunities elsewhere. Fortunately, it is surprisingly few who have left us, and thanks to several successful research applications and a generous exit-package from UiT, new PhD candidates will actually continue to join the CIRFA team. In 2022, two PhDs graduated, Megan O'Sadnick (USA) and Salman Khaleghian (Iran), and both have found work in Norway. We continued our collaboration with operational service providers who are using and validating CIRFA products for sea ice mapping and oil spill monitoring. The number and breadth of new journal publications and conference contributions demonstrate strong progress in research activities, and our international collaborations were strengthened through participation in field campaigns and research exchanges.

To many of us, the CIRFA-2022 Cruise was the highlight of the year. CIRFA-2022 Cruise was the research cruise we carried out with Research Vessel (R/V) Kronprins Haakon to the north-east coast of Greenland in April/May 2022. It was dedicated to the interpretation and validation of remote sensing products and was a big success. In preparation for the cruise, the Centre organized safety courses to train expedition members for work in the field, organized pre-cruise meetings to plan data collections, and had several post-cruise workshops to plan data storage and brainstorm analysis. Through its seven years of operation, the Centre has developed many remote sensing products, including algorithms for sea ice classification and iceberg detection, advanced numerical models for ocean circulation forecasting, and drone technologies. The CIRFA-2022 Cruise gave us the unique opportunity to test new technologies and validate satellite products while standing on the sea ice floes we were measuring. We were able to successfully achieve almost all our goals. We used drones to collect imagery from the ship, validated classification maps, and collected lots of coincident in-situ and satellite-based data which will support future research for many years to come (the cruise has its own section later in this report). I would take the opportunity to acknowledge UiT the Arctic University of Norway, CIRFA partners and European Space Agency for supporting the expedition financially. We are also indebted to the captain and crew of the R/V Kronprins Haakon who enabled us to achieve the goals of the cruise so successfully.

CIRFA started up on September 1st, 2015, with the vision to be a hub for developing integrated remote sensing technologies, and through its scientific activities make a strong contribution to the application of remote sensing in Arctic research. The Centre had a broad and ambitious research program, aiming to provide tools that would allow for improved monitoring capacities and decision support for industrial operations. Almost eight years

have passed and, even though we still have almost one year left with CIRFA ending on December 31st, 2023, we can allow ourselves to look back. From the perspective of the Centre Leader, I think CIRFA has managed to position itself as an important and visible contributor to Arctic sea ice and marine remote sensing. The collaboration with user partners has generated operational products which are now implemented in the processing chains of service providers or are being tested out in operational settings. We have made notable contributions to the research community, with several journal and conference papers receiving international recognition, while steadily increasing our international collaboration through guest visits from foreign peers and students. The importance of CIRFA has also been acknowledged by the Norwegian Space Agency, who have expressed concern for the Norwegian research capacity in earth observation when the Centre ends (Rapport: Utredning av behovet for nasjonalt senter for rombasert virksomhet.).

Looking ahead, the future may offer some interesting opportunities for Tromsø, when it comes to Earth Observation and space activities. In its white paper, "Hurdalserklæringen", the new government in 2021 promised to establish a new Knowledge Centre for Earth Observation in Tromsø. The position of this new Centre is still being explored. Hopefully, such a center can take on CIRFA's role as a facilitator for collaboration between different actors in the value chain of Earth Observation and continue its role in knowledge and technology creation. This is indeed necessary for Norway to establish a complete space technology chain. In addition to this Knowledge Centre, Tromsø is also likely to become host for an ESA Arctic Phi Lab. This Phi Lab has a mission to create transformational technological innovations which can accelerate value creation within space technology. Its goal is to transform research ideas into industrial and commercial revenue. Both initiatives would be a tremendous asset to Norway, a great motivating factor for young talented people to choose space technology and Earth Observation as a study direction, and an interesting career opportunity for young scientists, including those trained by CIRFA.

This annual report for 2022 is the last annual report from the SFI CIRFA. I would therefore like to take the opportunity to thank all former and present CIRFA team members for their dedicated contribution to the Centre. I would also like to express my gratitude to the members of our Scientific Advisory Board for guidance and recommendations, and to all members of the Centre's Executive Boards for inspiring discussions and encouraging support.

Tromsø March 2023,
Torbjørn Eltoft
Centre Leader

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Contact information

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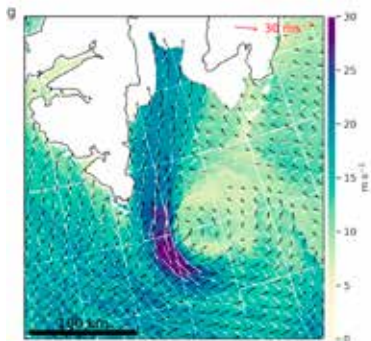
Centre Leader: Prof. Torbjørn Eltoft, e-mail: torbjorn.eltoft@uit.no

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

cirfa.uit.no

Objectives and Visions in the Centre

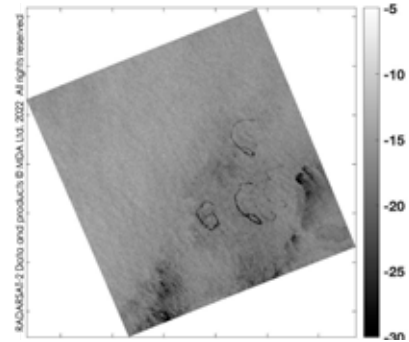
CIRFA is developing remote sensing knowledge and technology that helps to make operations and activities in ice infested waters safe and environmentally friendly. The research tasks are centered around three application areas:



*Ocean remote sensing and modelling.
Figure: M Tollinger*

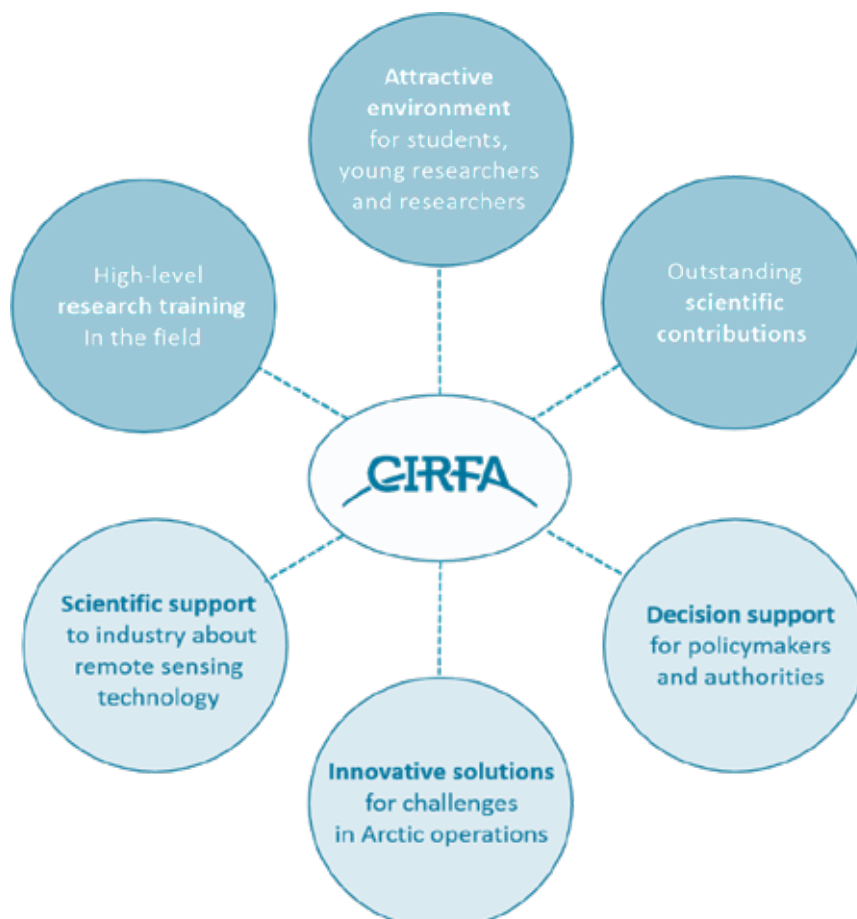


*Sea ice and icebergs.
Photo: W. Dierking*

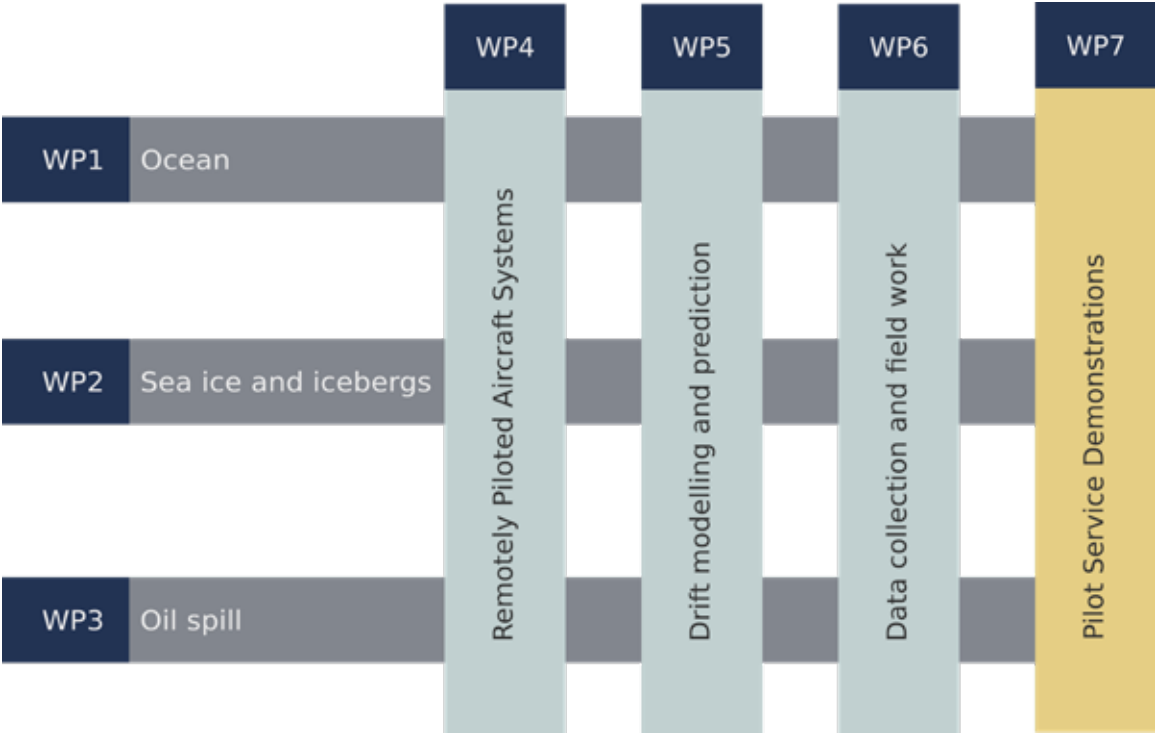


*Monitoring of oil spills.
Figure: M. Johansson*

CIRFA is a leading international research center on integrated remote sensing and forecasting for the Arctic. We focus on improving monitoring and forecasting of the geophysical processes, such as currents, wind fields and sea ice. We also do research on remote sensing of oil spills in open water and sea ice infested areas. In addition, CIRFA develops drone technology, collects data in the field for validation of remote sensing products, and does research on data assimilation methods and numerical weather forecasting.



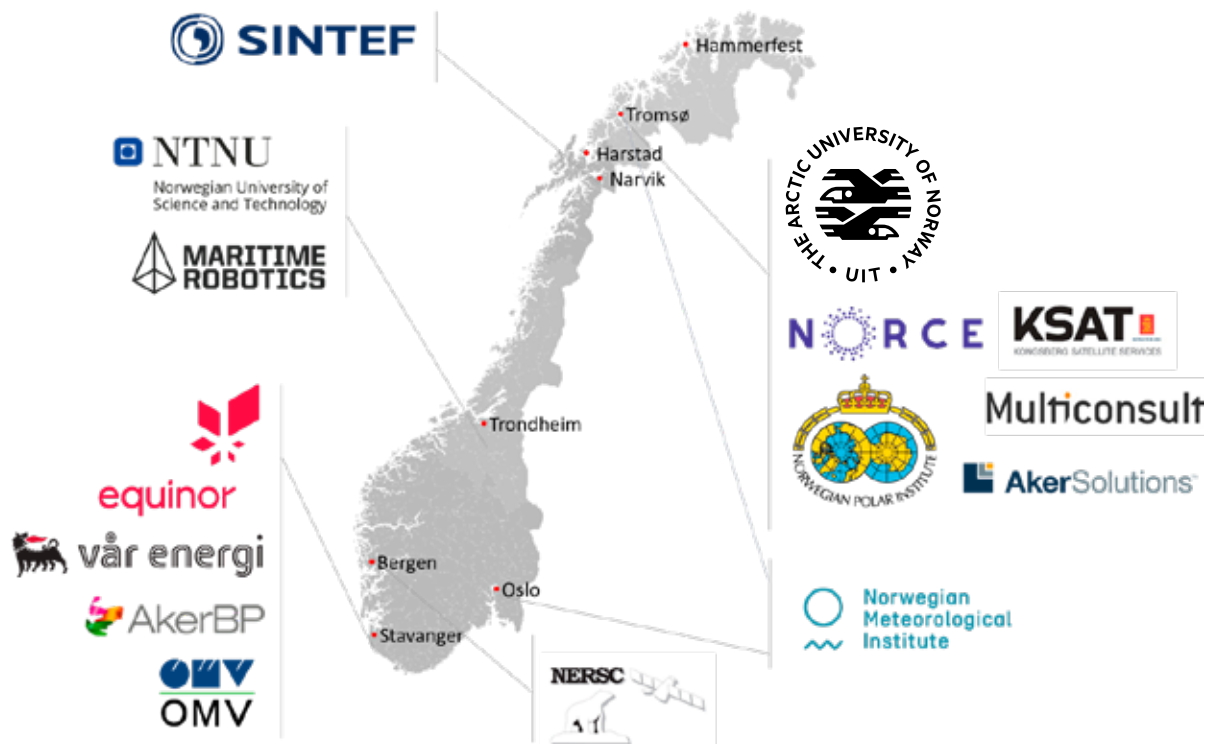
CIRFA is a facilitator for collaboration between industry and academia on questions related to remote sensing of Arctic phenomena. Our work generates new, innovative algorithms and processing schemes, which foster new services and products. The seven work packages collaborate closely to test and implement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



Group photo of the CIRFA-2022 Cruise Team. Photo: W. Guo

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.



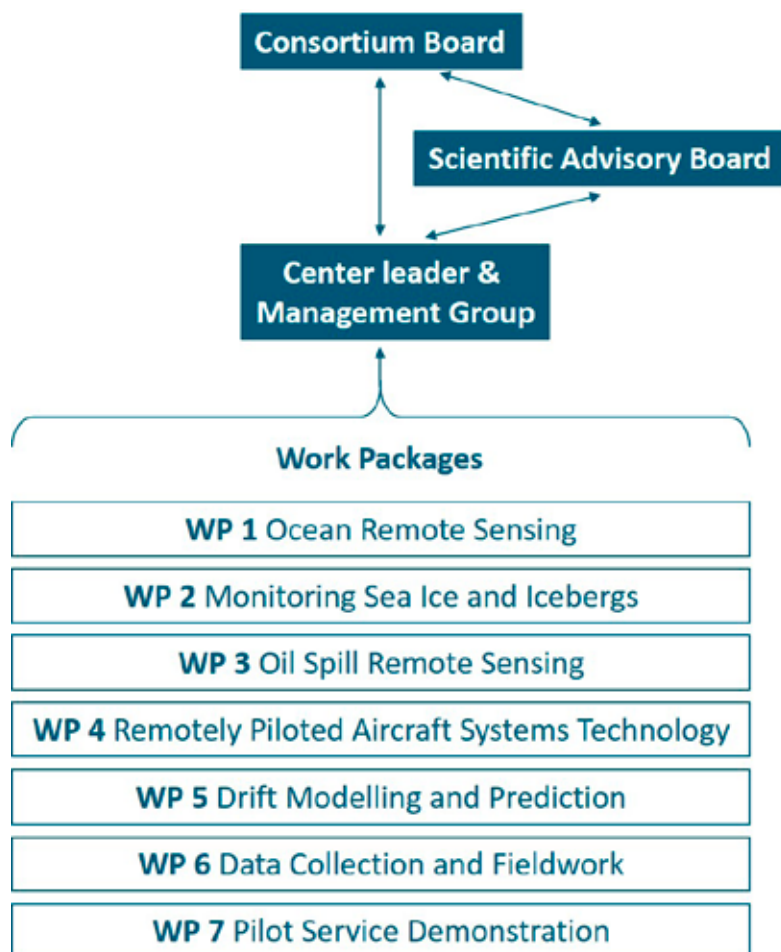
Research partners

MET Norway
NORCE
Nansen Environmental and Remote Sensing Centre (NERSC)
Norwegian Polar Institute (NPI)
Norwegian University of Science and Technology (NTNU)
SINTEF Narvik
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 CB guides the overall direction of the Centre.

Richard Hall (Chair)
Equinor

Kjell Arild Høgda
NORCE

Svein Olav Drangeid
OMV

Rune Pedersen
Vår Energi

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

Jan Petter Pedersen
KSAT

Lars Anders Breivik
MET Norway

Scientific Advisory Board

The Scientific Advisory Board (SAB) consists of international experts with outstanding reputations in the relevant fields and 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 Hajsek
*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
Malin Johansson, WP 6 Co-Leader, UiT
Rune Storvold, WP6 Co-leader, NORCE
Hugo Isaksen, WP 7 Leader, KSAT
Nick Hughes, WP 7 Co-leader, Norwegian Sea
Ice Service, MET Norway
Andrea Schneider, Adm. Coordinator, UiT

Research Fellows



Muhammad Asim
PhD Candidate

Optical Remote Sensing for
Water Quality Parameters
Retrieval in the Barents Sea



Saloua Chlaily
Post Doc

Automated Large-scale Sea
Ice Characterization and
Mapping



Anca Cristea
Post Doc

Sea ice classification from
multimodal remote sensing
data



Victor de Aguiar
PhD Candidate

Oil Spill Remote Sensing



Laust Færch
PhD Candidate

Mapping and Modeling of
Iceberg Occurrences in the
Barents Sea



Henrik Fisser
PhD Candidate

Studying the spatial and
temporal distribution of
icebergs and sea ice in the
Barents Sea



Wenkai Guo
Post Doc

Cross-platform application of
a sea ice classification method
for detecting deformed ice



Martina Idzanovic
Post Doc

Quantifying uncertainty and
predictability in ocean current
forecasts



Polona Itkin
Researcher

Sea ice deformation and its
impact on the sea ice mass
balance



Silje Christine Iversen
PhD Candidate

The impact of observations
in a high-resolution ocean
assimilation system for the
Norwegian seas



Malin Johansson
*Researcher/Associate
Professor*

Using satellite images to study
Arctic sea ice and oil spills



Truls Karlsen
PhD Candidate

Multi-frequency SAR
classification of sea ice



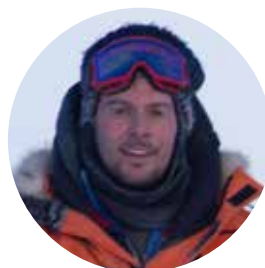
Eduard Khachatryan
PhD Candidate

Multimodal Integrated
Remote Sensing for Arctic Sea
Ice monitoring



Salman Khaleghian
PhD Candidate

Scalable computing in earth
observation



Jack Landy
*Researcher/Associate
Professor*

Using satellite laser and radar
altimetry to study the physical
properties of polar sea ice
and oceans



Johannes Lohse
Researcher

Automated Classification of
Sea Ice Types in SAR Imagery



Artem Moiseev
Researcher
Ocean remote sensing



Megan O'Sadnick
PhD Candidate
Ice in Norwegian Fjords:
Formation, breakup and
implications for oil spill
response activities



Cornelius Quigley
Post Doc
Determination of the
Dielectric Properties of Marine
Surface Slicks Using Synthetic
Aperture Radar



Debanshu Ratha
Post Doc
Polarimetric analyses of sea
ice properties



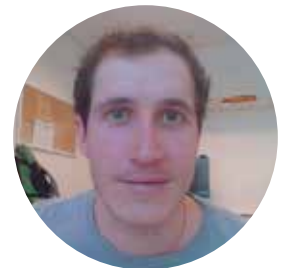
Jozef Rusin
PhD Candidate
Using passive microwave and
SAR to improve Arctic sea ice
concentration estimates



Catherine Taelman
Engineer
Supporting Development and
Pilot Demonstrations Across
Work Packages



Anna Telegina
PhD Candidate
Short-term forecast of sea ice
conditions using SAR imagery
and forecasts of ice drift



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



Qiang Wang
Post Doc
Deep learning algorithms for
sea ice classification

2022 in brief



CIRFA at the UiT-Andøya Space agreement WS

January



Participating in the Seal cruise (lead by IMR) to the East coast of Greenland. Sea ice drift products were provided to aid tracking the seals.

Courses and planning for the CIRFA-2022 Cruise

March



CIRFA-2022 Cruise, CAGE seminar, ESA Living Planet conference

May

February

Sea ice field training for participants in the CIRFA-2022 Cruise in Ramfjorden



April

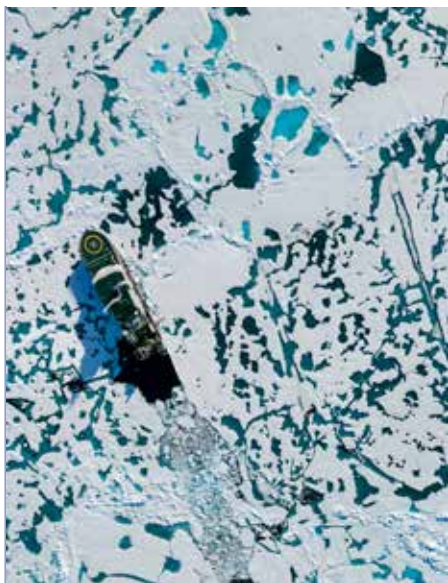
SUDARCO kick-off meeting, Snow field training in Kroken



June

INTERAAC kick-off meeting, Santa Barbara oil seepage fieldwork in collaboration with JPL, NOAA and Water Mapping Inc.





Arctic Ocean cruise. R/V Kronprins Haakon reached the North Pole. CIRFA provided satellite image data support to aid navigation

July



PhD defense for Megan O'Sadnick, Forskerdagene, Post CIRFA-2022 Cruise

September



Research visit to JPL, Singapore-Norway Science week

November

August

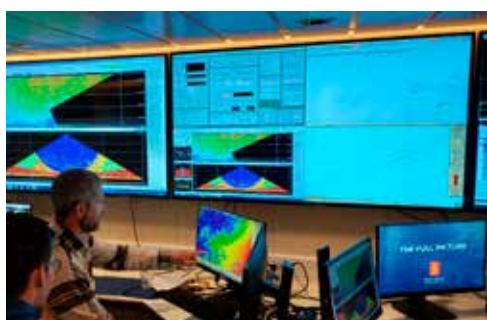
Natural oil seepage cruise to the Barents Sea, in collaboration with SFF CAGE and Norwegian Petroleum Directorate

October

NASA ARSET lecture, CIRFA Annual Conference

December

PhD defense Salman Khaleghian

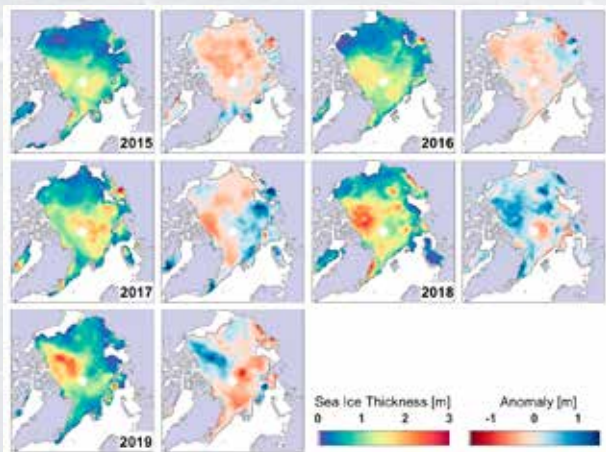


Research Highlights

Year-round Arctic sea ice thickness from the SAR Altimeter CryoSat-2

The European Space Agency launched the CryoSat-2 SAR Altimeter satellite as an Earth Explorer mission in 2010 to monitor the volume of the Earth's sea ice and land ice covers. However, when melt ponds form at the surface of sea ice they interfere with the radar return, so sea ice thickness information was only available from CryoSat-2 during the Arctic winter months of October-April. However, sea ice thickness information would be most valuable during the summer months, when maritime transportation is most active, and the Arctic ecosystem and biogeochemical cycles are strongest.

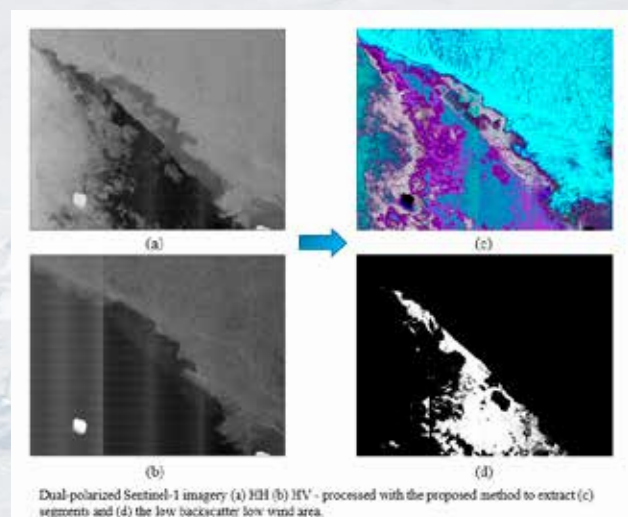
To reconcile this gap in observations, Landy et al. have developed several new approaches to process and interpret the CryoSat-2 radar waveform observations over melting sea ice. This includes deep learning to classify radar returns from sea ice floes and leads (cracks between diverging floes), and numerical simulations of the radar waveform to correct biases measuring the height of the sea ice. The height differences between ice floes and leads could then be used to derive the sea ice freeboard, converted to estimates of ice thickness with assumptions for the ice density and snow load. The new gap-free time series matched up well to independent airborne and *in situ* sensors. It was then demonstrated how sea ice thickness observations—particularly from the early summer—could extend operational forecasts of the sea ice extent by several months. *Read more in [Landy et al. \(2022\)](#).*



Example of the new CryoSat-2 sea ice thickness record every July between 2011 and 2019. Image made by Jack Landy (UiT)

Automatic Detection of Low-Backscatter Targets in the Arctic Using Wide Swath Sentinel-1 Imagery

Low backscatter signatures in Synthetic Aperture Radar (SAR) imagery in the Arctic Ocean primarily caused by newly formed sea ice, low wind or rain cell areas but at times also oil ocean surface slicks. The latter can be a result of both accidental releases and naturally occurring seepages. The operational monitoring of low backscatter targets can benefit from a stronger integration of freely available SAR imagery from Sentinel-1. The method makes use of an established statistical mixture-based segmentation framework and introduces a dynamic adjustment of the noise floor during the segmentation process, in order to mitigate artefacts that occur when considering the theoretical noise floor. Imagery was collected over the Barents Sea during the freeze-up season for testing and comparison with manual detection employed by operational services. The results have shown consistent detection of the targets of interest and potential for large-scale operational monitoring. *Read more in: Cristea et al. (2022).*

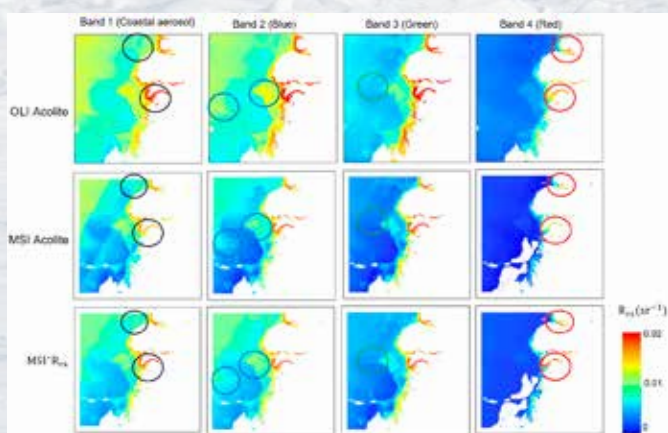


An example of using the algorithm to detect a low-backscatter area in a Sentinel-1 image.

A New Spectral Harmonization Algorithm for Landsat-8 and Sentinel-2 Remote Sensing Reflectance Products Using Machine Learning: A Case Study for the Barents Sea (European Arctic)

In order to understand how climate-related changes in physical and environmental conditions affect the ecosystem of the transitional Barents Sea, it is necessary to carry out temporally frequent observations of the biogeochemical “health” of the water columns. This can be done using satellite-derived remote sensing reflectance (R_{rs}), from which in-water constituents, such as Chlorophyll-*a* (Chl-*a*), can be derived. However, optical remote sensing of the Barents Sea is associated with several challenges. High north water bodies experience polar nights during the winter season and are frequently covered by clouds in the summer. This severely limits the availability of cloud-free satellite scenes. In addition, atmospheric correction (AC) is particularly challenging at high latitudes due to higher solar zenith angles and the potential presence of sea ice.

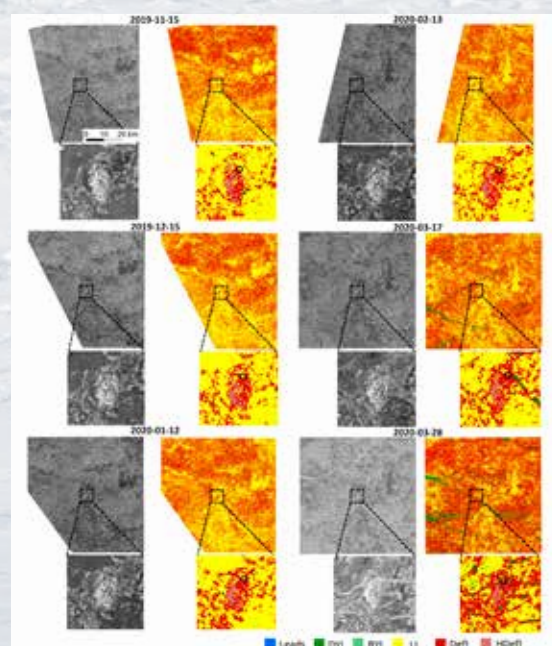
To increase the availability of useful optical satellite data for frequent monitoring of the Barents Sea, this paper investigates the merging of data products from the Multispectral Imager (MSI) on-board Sentinel-2A/2B and the Operational Land Imager (OLI) on-board Landsat-8. We investigate if the application of standard AC algorithms provides realistic R_{rs} values for these sensors at these latitudes by comparing them with in-situ measured R_{rs} spectra. Additionally, we introduce a new machine learning based band adjustment method for merging OLI and MSI-derived R_{rs} products. *Read more in* Asim et al. (2022).



Comparison of Remote Sensing Reflectance of OLI, MSI, and band adjusted MSI.

Sea ice classification of TerraSAR-X ScanSAR images for the MOSAiC expedition incorporating per-class incidence angle dependency of image texture

This study provides sea ice classification maps of a time series of TerraSAR-X ScanSAR (TSX SC) images for the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition, serving as a basic dataset for future MOSAiC studies on physical sea ice processes and ocean and climate modelling. Sea ice is classified into leads, young ice with different backscatter intensities, and first-year ice (FYI) or multi-year ice (MYI) with different degrees of deformation, using the Gaussian incidence angle (GIA) sea ice classifier developed in CIRFA on TSX SC intensities and Gray-Level Co-occurrence Matrix (GLCM) textures. We demonstrate per-class incidence angle (IA) dependencies of TSX SC intensities and textures and compare these to C-band IA dependencies. The classification yields an average overall accuracy of 83.70% and good correspondence to geometric ice surface roughness derived from in situ ice thickness measurements. Areal fractions of classes representing ice openings show prominent increases in mid-late November 2019 and March 2020, corresponding well with ice opening time series derived from in situ data in this study and those derived from other MOSAiC studies. *Read more in:* Guo et al. (2022).



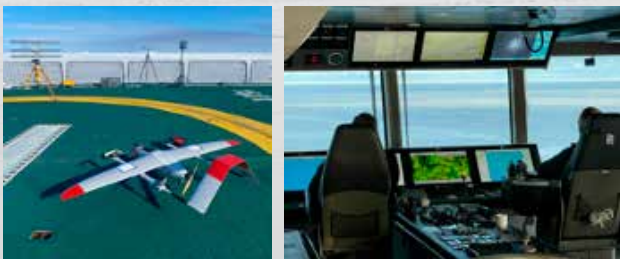
Example of sea ice classification for the area surrounding the MOSAiC sea ice floe. Image by Wenkai Guo

Innovation Highlights

Drone based decision support system for ice navigation

Making good decisions when navigating in drifting sea ice requires accurate and updated information regarding ice conditions. Satellite images, only a few hours old, are often outdated due to ice drift and therefore difficult to use for route planning. Currently, the navigators onboard base their navigation decisions on the ice conditions a few miles ahead, which is visible from the bridge and by the ship radar. This limited information can lead to inferior decisions and situations where the ship encounters heavy ice to pass. The result is that the ship must backtrack and find another route around heavy pack ice, costing both fuel and time.

In CIRFA, a drone-based system for real time monitoring of sea ice has been developed. The system is optimized for operating from helidecks of ice going vessels, and with respect to sharing data in near real time over limited communication links. Data from the multi-camera payload is georeferenced, processed and indexed in a local database onboard the aircraft. The database is synchronized, based on user requests, with the server onboard the ship and over internet when available. The data from the drone can be viewed in NLIVE, a NORCE developed web-based system for visualization of historical or real time geospatial data. The system was demonstrated during the CIRFA-2022 Cruise to the north-east coast of Greenland in the period April/May 2022. Data from the drone was used both for navigational purposes, but also for planning ice stations and areas for in-situ sampling.

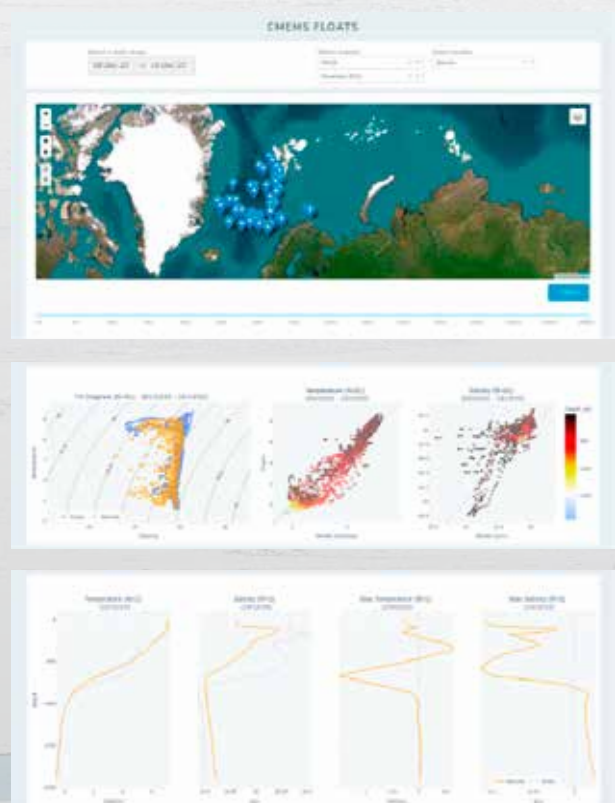


Right: CryoWing Shark at the helideck of KPH. Left: Nlive running on the center console at the bridge of KPH.

Validation interface for operational ocean and ice forecast system

Operational forecast models require continuous monitoring in order to assure data quality and to spot deviations in the technical setup. An interface has been developed in WP 5 to monitor the performance of the Barents-2.5 ocean and ice forecast model. The interface allows ocean modelers to follow validation metrics for the ocean state variables, using routinely collected data. Validation is carried out daily, and certain model scores are calculated on a weekly or monthly basis.

Remote sensing data for ice concentration and sea surface concentration are compared with surface fields from the model. In addition, in-situ hydrography from ship CTDs, drifting buoys, and other autonomous platforms is used to assess how vertical processes are resolved in the model system.



Interactive validation routine developed at MET Norway to monitor the performance of the Barents-2.5 ocean and ice forecast system. Observations and model subsets can be selected by the user, and validation metrics are updated daily using routine observation sources. The shown example compares model temperature and salinity with hydrography data provided by the Copernicus Marine Environmental Monitoring Service (CMEMS).

The making of a national public forecast service

Kai H. Christensen, MET Norway

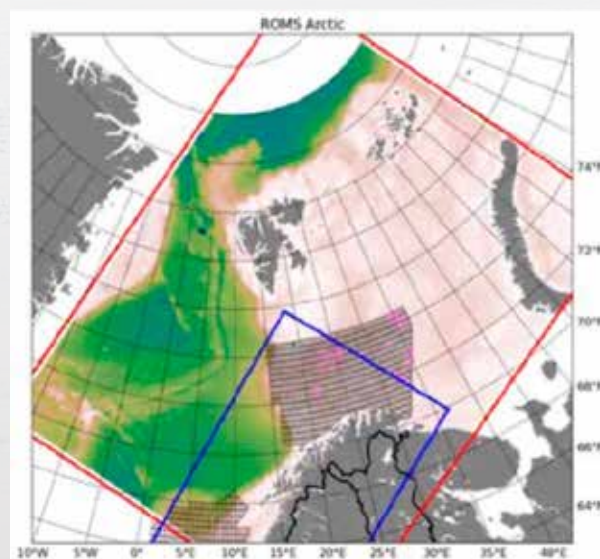
MET Norway's mandate is to "safeguard life and property", and we do this first and foremost by providing forecast services. Each service is based on a numerical modeling system that is embedded in a rather complex production chain. The various bits and pieces of the production chain are continuously scrutinized and worked on, with the overall aim to steadily increase the forecast quality: operational forecasting is *always* work in progress. Here you may ask yourself, how does it all start, then?

MET Norway's strategy document provides guidelines, and in *theory* the necessary R&D work to set up a new operational service could be done solely by researchers who receive their pay through the institute's core funding. In practice, however, new services are established through bottom-up processes initiated in externally funded research projects. This approach has benefits: external review of ideas implies better quality, and research projects provide excellent opportunities to build strong alliances with clever people elsewhere. With external funding we can also afford to have greater ambitions than what the core funding alone allows us to have.

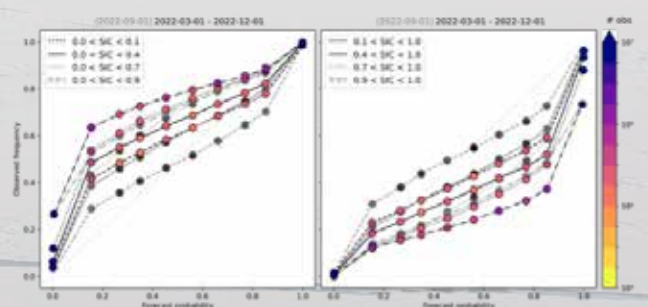
For the coupled ocean-sea ice forecast system *Barents-2.5km*, the start can be traced to a statement at the bottom of p. 8 in the revised CIRFA proposal (Aug. 27, 2015): "The end product of this WP is an observation-guided Ensemble Prediction System (EPS) that will give probabilistic forecasts of ocean, sea ice and drifting objects". The earliest visual reference to the forecast model is a plot of the model bathymetry dating back to April 2016. At that point we didn't have a name for what we were developing, hence the forecast system was referred to as "ROMS Arctic" or the "CIRFA model".

Almost seven years later *Barents-2.5km* is well established as a national forecast service. It uses a variety of near-real-time observation data streams and processing algorithms, advanced data assimilation and ensemble generation techniques, as well as complex pre- and post-processing tools for scheduling model execution on supercomputers, data management and dissemination. On top of that we have operational monitoring of forecast quality and a range of sophisticated tools to analyze performance, see figure. The point here is not to make everyone excited about reliability diagrams, but rather draw attention to the complex machinery that needs to be in place in order to produce them.

The road has not been straight, of course, and now that *Barents-2.5km* is officially part of MET Norway's public service, there is no finish in sight. In fact, working on operational systems is like working on a scientific paper that will be in review *indefinitely*, with an editor that randomly assigns new (and often quite vocal) reviewers from time to time. The upside is that we get to work closely with professional downstream users in industry and academia who provide us with essential feedback on model quality and relevance. In any case, for *Barents-2.5km* it all started on p. 8 in the CIRFA proposal, and without CIRFA we would certainly not have the national ocean and sea ice forecast service that we have now.



The model domain of the coupled ocean-sea ice forecast model Barents-2.5km (in red). The outline of our coastal ocean forecast model "Norkyst-800m" is shown in blue.



Reliability diagrams for sea ice concentration based on the Barents-2.5km ensemble prediction system. Such diagrams are used to investigate the statistical distribution of the observations vs. the ensemble members, providing a starting point for work on improving the ensemble spread (from Röhrs et al., in review, <https://doi.org/10.5194/gmd-2023-20>).

WORK PACKAGE 1

Ocean Remote Sensing



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Artem Moiseev,
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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.

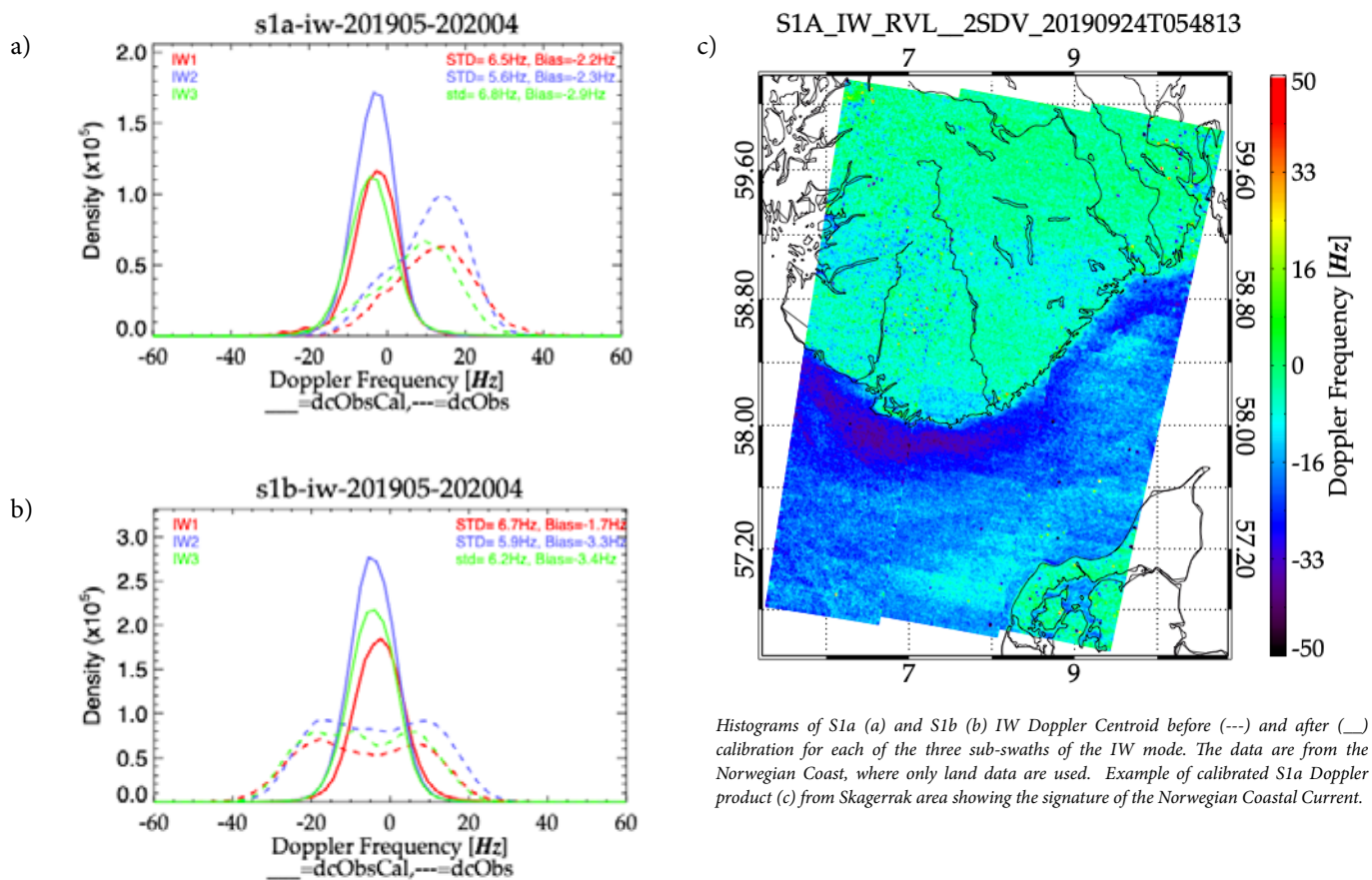
The Norwegian coastal area is industrialized and very important for the economy. Ship traffic, fisheries, renewable energy, offshore oil/gas, and public recreation are all activities conducted in the coastal areas. Many users ask for more precise and higher resolution prediction of wind/wave/currents 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 has focused on developing 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 2022

The R&D has been concentrated on the following key activities: 1) Assessment of Sentinel-1 ocean coastal and global current and wave measurements, 2) Operationalization of met-ocean processing system at NORCE based on achievements from CIRFA R&D. A branch of this system is operational at KSAT providing inputs to the maritime surveillance services.

In cooperation with Chalmers University, a paper (lead by Anis Elyouncha) on the comparison of ocean surface velocities derived from Sentinel-1 Doppler measurements and from TerraSAR-X ATI measurements were published in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 15, pp. 2425-2436, 2022, doi: 10.1109/JSTARS.2022.3158190.

Research is undertaken to develop and implement ocean wave spectra processing from Sentinel-1 TOPS mode. This activity is a direct outcome of previous CIRFA research and publications. Wave spectra from TOPS mode will improve the monitoring of swell in North-Atlantic and circumvent and even surpass the lack of Sentinel-1 Wave Mode coverage in these ocean areas.

The operational met-ocean processing system at NORCE (and KSAT) has been upgraded and extended to better support user and R&D needs. This includes the processing of wind, wave and ocean current fields 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.

Results of the Doppler calibration methodology developed for Sentinel-1 are shown in the figure above.

WORK PACKAGE 2

Sea ice and Iceberg detection

Background and Objectives



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Professor II at UiT, Senior
Researcher AWI



WP leader
Anthony P. Doulgeris
Associate Professor, UiT

The goal of this work package is to further develop remote sensing methodologies and algorithms to enable detailed characterization and mapping of Arctic sea-ice conditions, and to provide improved methodologies for the detection of icebergs.

Requirements regarding the output and performance of algorithms are defined in collaboration with WP 5 and WP 7 and with partners from operational ice services and industry. Besides SAR images as key data source in this WP, also optical and thermal satellite images, as well as passive microwave and altimeter data are employed in special investigations. 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 which we use 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 imaging, weather, and ice conditions. WP 2 and WP 3 are jointly working on issues regarding detection of thin ice as look-alike of oil spills and on the use of compact polarimetry. Testing and validating of algorithms take place in collaboration with WP 4, WP 6 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 images from different satellite SAR systems as well as data of 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, including investigations of the detection rates at different radar frequencies and spatial resolutions.

Team members

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Achievements in 2022

Major progress was made on four main fronts:

1. Continuation of work on sea ice classification
2. Testing of different CFAR (constant false alarm rate) algorithms for iceberg identification with quantification of false alarms and missed detections.
3. Retrieval of year-round pan-Arctic sea ice thickness
4. Measurements of in-situ ice properties with parallel multi-sensor satellite image acquisitions during CIRFA cruise

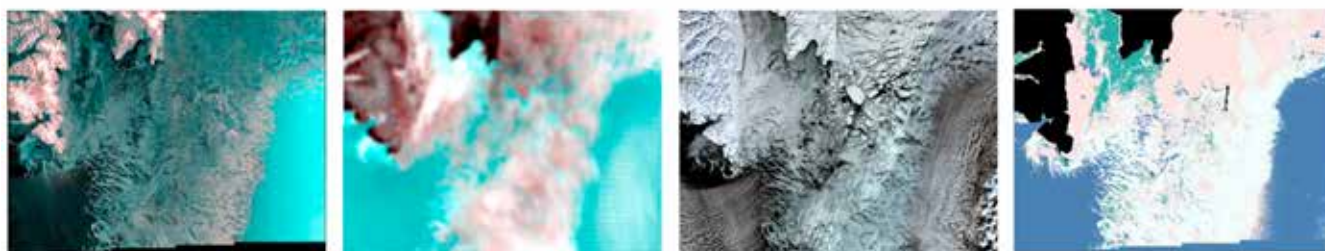
Having the goal of a more advanced use of multiple satellite data for ice type separation in mind, we developed a method for information selection and applied it to combinations of SAR plus optical imagery and to SAR plus passive microwave radiometer data. The tests showed promising results and may contribute to discussions about the coordination of future satellite missions for near-simultaneous data acquisitions. Our work on sea ice classification considering the incidence angle dependence of backscattering intensity and texture was further extended using X-band SAR data from the MOSAIC expedition (see also research highlights).

A paper on the performance of six different CFAR algorithms for automated detection of icebergs drifting in the open ocean using wide-swath Sentinel-1 and ALOS-2 PALSAR-2 images was submitted to “The Cryosphere”. Almost 500 icebergs were manually identified in an optical Sentinel-2 image for comparison. The detection rate for smaller icebergs (< 60 m) was only between 10 and 15 percent, for large icebergs (>120 m), it increased to values between 80 and 95 percent. This result demonstrates many smaller icebergs are missed in the operationally used wide-swath SAR images.

A Nature paper described a method to retrieve the year-round pan-Arctic sea ice thickness from satellite data, with future opportunities to support climate research, maritime activities, and sea ice forecasting in the Arctic. The data are being used for innovation activities (model-data assimilation) by groups in the US, Germany and China. This work generated media interest, with around 40 news articles and more than 300 tweets linked to the research findings (see research highlights).

The WP-2 team was involved in preparing the CIRFA cruise to Belgica Bank and in the measurement program while on the ship. In cooperation with the Norwegian Ice Service, ice charts and SAR images were transferred to the ship, and tests of automated ice classification were carried out. By combining the information of the different data sources, sea ice type separation, iceberg detection, and the understanding of different scattering mechanisms will be improved.

The ice service at Met.no in Tromsø has continued to run CIRFA algorithms for daily large-scale testing. The process of updating and sharing new versions of our algorithms, via a GIT code repository, has progressed as well as the process to push the image results to a ship for navigation and research assistance during the CIRFA cruise.



Color representation of the data set (left to right): false-color composite of Sentinel-1 SAR backscattering coefficients (HV, HH, and HH as RGB), brightness temperature from AMSR-2 Advanced Microwave Scanning Radiometer (H, V, and V as RGB), natural-color composite optical image from Sentinel-3 Ocean and Land Color Instrument (bands 8, 6, 4). To the right are the classified maps based on our new adaptive attribute selection method combining SAR backscattering intensity and texture with brightness temperature. Blue: open water, black: land mask, cyan: grey ice, pink: first-year ice, white: brash and broken ice (modified from Khachatryan et al., *Geophysical Research Letters* 50, 2023).

WORK PACKAGE 3

Oil Spill Remote sensing



WP leader
Malin Johansson
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.



WP leader
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SINTEF Narvik

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 than in sea ice conditions. This may have an impact in the case of a near-coastal oil pollution incident.

Team members

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Cathleen Jones,
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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 2022

Oil slick characterization and produced water detection

The damping ratio is an important parameter for detection of actionable oil and two papers were submitted one where different method were compared to detect those that provide consistent estimates of the damping ratio and one paper where a new method to calculate the damping ratio was proposed. The first paper was led by post-Doc Cornelius Quigley with the aim towards improving oil spill thickness retrieval from SAR. This work was carried out in close collaboration with colleagues at NASA/JPL, USA. In June 2022, Cornelius participated in a two-week fieldwork campaign in the coastal waters outside Santa Barbara.

The UAVSAR plane from NASA acquired targeted SAR and optical images over the seepage area, while in-situ viscosity measurements, oil and water concentration data as well as ocean wind and current data were collected to overlap with overflying UAVSAR data and spaceborne SAR and optical satellite images. This work will be carried over also into 2023 when the data from the Santa Barbara campaign is being further analyzed.

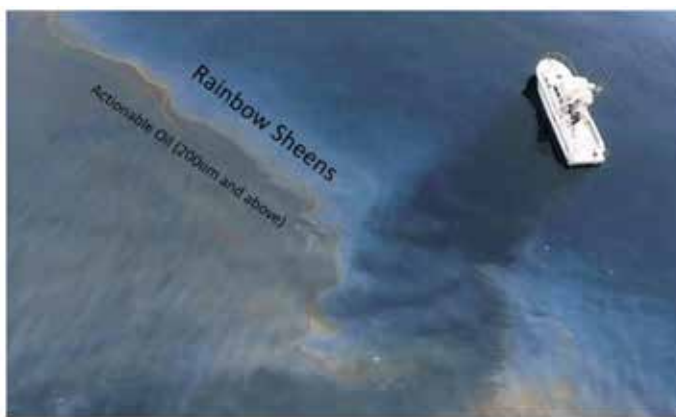
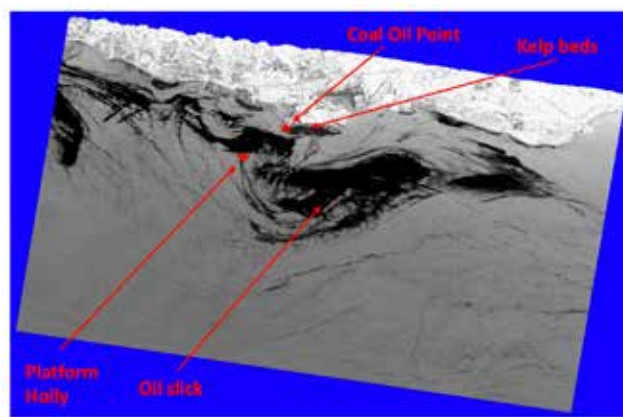
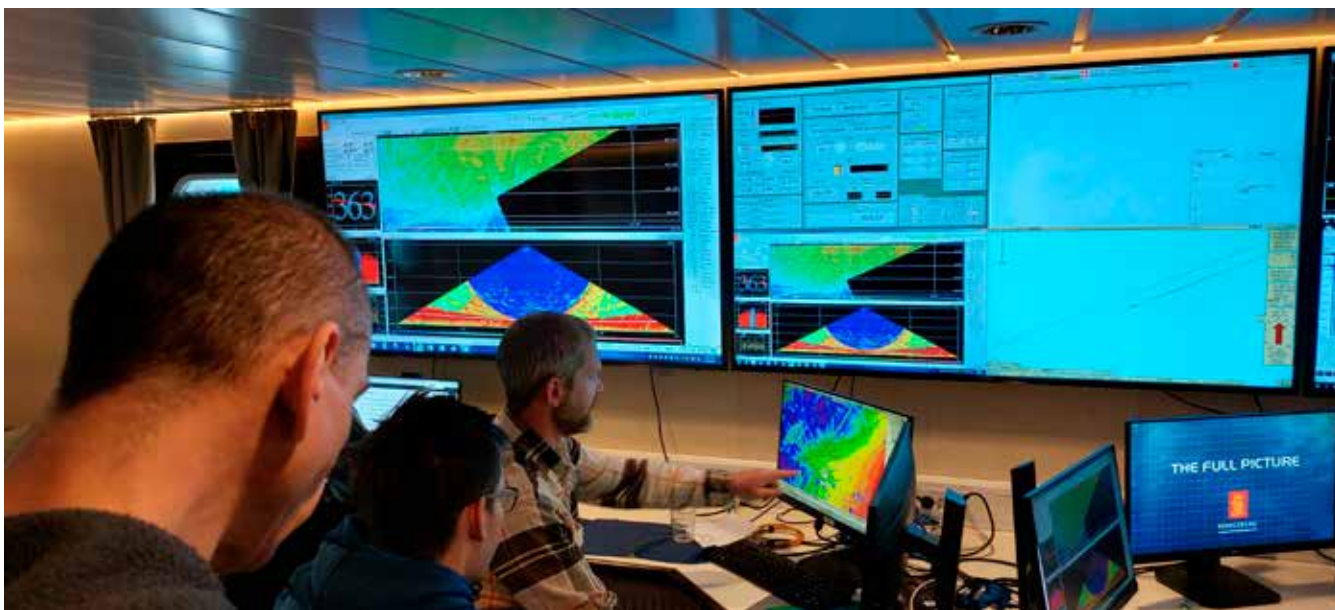


Photo: Oscar Garcia, Water Mapping LLC



Source: UAVSAR, NASA

Images from the Santa Barbara, (California, USA) field campaign, with a drone image on the left showing the oil film as well as the research boat used and an overlapping UAVSAR image (right).



Working environment onboard R/V Kronprins Haakon. Photo: Victor de Aguiar

As a part of this collaboration, Cornelius and Malin visited Cathleen Jones at JPL in November 2022 to work on this data set, as well as detection of harmful algae blooms using SAR images.

PhD student Victor de Aguiar was working with produced water slick surface drift pattern estimates using SAR observations, drift estimates from OpenDrift and how the use of Barents 2.5 and Norkyst-800 forcings affect the drift estimates. A full year of SAR oil slicks observations from the Norne platform were used and combined with wind information from the platform as well as release data provided by CIRFA partner Equinor. The study is collaborative work between WP3 and WP5. The outcome of this study shows that both ocean currents and wind data are essential to fully capture marine surface slick drift patterns. The results also show that both the Barents 2.5 model and the NorKyst-800m can be used to accurately estimate marine oil spill drift patterns for thin surface oil slicks. And it is an important step forward as thin oil films drift patterns are underrepresented in the literature.

During the Norwegian conference “Forum for framtidens oljevern” the use of satellite images for oil spill detection and monitoring was presented and very well received among the 80 participants from all over Norway and from a range of companies and organizations dealing with safe shipping.

Malin Johansson was invited by NASA to give an ARSET lecture on Oil spill remote sensing in October.

Dark feature detection in SAR images was successfully addressed by Post-Doc Anca Cristea (see research highlights), resulting in an accepted journal publication. In summary, dark feature detection, improved oil spill thickness and drift estimates are valuable tools for oil spill clean-ups.

Fjord ice work

Megan O’Sadnick successfully defended her PhD thesis in September 2022 about ice in Norwegian subarctic fjords and coastal regions. In her work, she used optical satellite images as well as in-situ data, to investigate fjord ice. The research questions were: Where and when does it form, what are its properties, and what are the impacts on surrounding communities?

WORK PACKAGE 4

Remotely Piloted Aircraft Systems (RPAS) Technology



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Background and Objectives

Managing maritime operations in ice infested water or navigating in drifting sea ice requires accurate and updated information regarding ice conditions. Satellite images, only a few hours old, are often outdated due to ice drift and therefore difficult to use for route planning. Currently, the navigators onboard the ship base their navigation decisions on the ice conditions visible from the bridge, using binoculars and the ship radar. These observations are limited to a few miles in front of the ship and can lead to inferior decisions and situations where the ship encounters ice that is too heavy to pass, costing fuel and time. The systems needed by the operators in the arctic must be robust and reliable and the system must be able to handle disruption in service by individual components.

Key research tasks

- ❑ Develop a robust RPAS system for sea ice monitoring and capable of operating from helideck of ice going vessels.
- ❑ Develop a drone-based camera system for wide area coverage and high-resolution monitoring of sea ice and ice bergs.
- ❑ Develop methods and algorithms for onboard and real time processing of the camera images.
- ❑ Develop a system for real time distribution and visualization of the information from the camera payload.
- ❑ Develop a drone-based radar system for snow on sea-ice measurements and investigate the capabilities and limitations of the system.

Achievements in 2022

During the CIRFA-2022 cruise a lot of the RPAS technology developed during CIRFA was fully integrated and demonstrated for the first time under operational conditions. The drone technology was used actively during the cruise for navigation support, to collect in-situ data for satellite product validation, to operationally support planning of ice stations, and for deploying GNSS drifters on icebergs.

Major progress was made in 2022 on two main fronts:

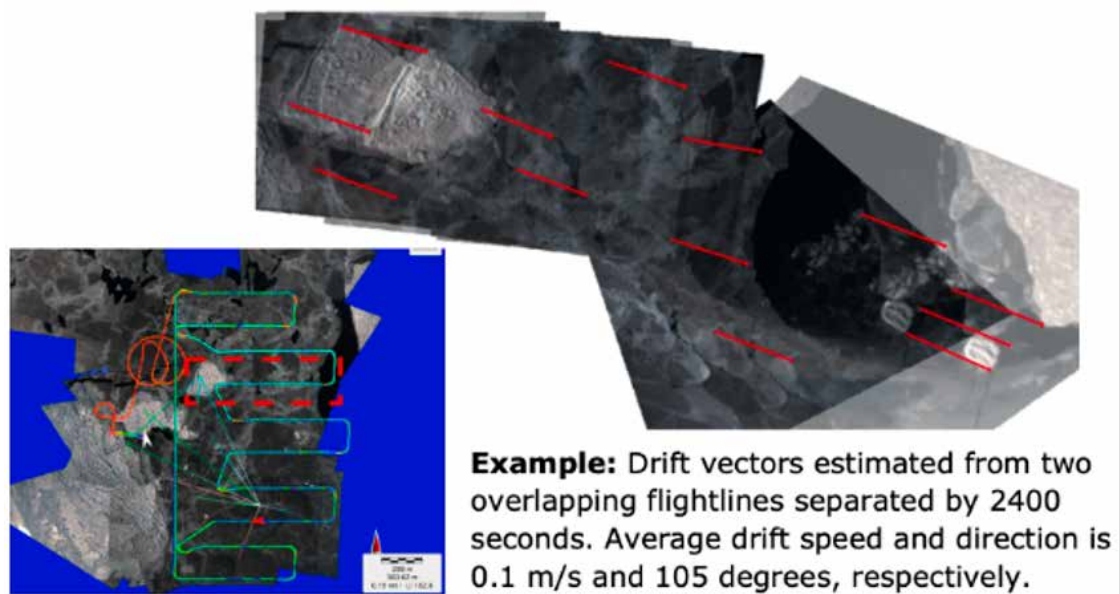
1. Development of a fixed wing vertical take-off and landing (VTOL) system for real time ice monitoring as a tool for navigation in ice infested waters.
2. Development of a UAV-borne radar for measuring snow depth on sea ice.

The Shark

In CIRFA, a drone-based system for real time monitoring of sea ice has been developed. The system is based on a fixed wing VTOL aircraft, the CryoWing Shark, optimized for operating from helidecks of ice going vessels, and for sharing data in near real time over limited communication links. Also, a new camera payload has been developed, optimized for wide area high resolution imaging of sea ice. The camera payload consists of multiple synchronized optical machine vision cameras, each with a small, embedded computer. Data from the multi-camera payload is georeferenced, processed and indexed in a local database onboard the aircraft. The database

is synchronized, based on user requests, with the server onboard the ship and over internet when available. The data from the drone can be viewed in NLIVE, a NORCE developed web-based system for visualization of historical or real time geospatial data.

The system was demonstrated during the CIRFA-2022 Cruise. Data from the drone was used both for navigational purposes, but also for planning ice stations and areas for in-situ sampling. In addition to the aircraft platform, a set of software tools for automatic route planning regarding ship position and radio coverage, has been developed and was also demonstrated during the CIRFA-2022 Cruise. It can also be used for estimating sea ice drift and one experiment was conducted during the cruise to demonstrate the capability for accurate and high-resolution estimates of sea ice drift. Future work will focus on optimizing the drift estimation methods, with the objective of running these onboard the aircraft in near real time to provide dynamic ice maps for tactical navigation in ice infested waters.



Automatic route planning for estimating sea ice drift from the Shark platform.

Cryocopter FOX multirotor UAV and Ultra Wideband Snow Sounder (UWiBaSS)

The multirotor platform Cryocopter FOX completed flights on every fast-ice station during the CIRFA cruise carrying the UWiBaSS (Ultra Wideband Snow Sounder) snow radar payload.

Main research tasks (RT) for the radar-based snow on sea ice measurements were:

1. Demonstrate snow on sea ice measurements across km-scale transects.
2. Validate radar snow depth measurements with in-situ snow depth across 100 m scale “cal/val” transects.
3. Evaluate the capability of the system, for different snow types (wind-packed, wetted, etc.), to map various ‘snow scenarios’, including snow on deformed sea ice and snow on thin ice.
4. Investigate the impact of snow properties on satellite retrievals that are sensitive to snow on sea ice using UAV and in-situ measurements from the field experiments.

RT1 includes challenges related to both UAV operation and the radar system itself. The surveys conducted during the campaign demonstrate the ability to perform detailed km-scale snow surveys while operating from the ship helicopter-deck. Such surveys require low altitude flights (approx. 8 m) to gather detailed snowpack information. This type of low altitude survey path was achieved using a laser altimeter enabling the autopilot to fly on the preset altitude relative to the terrain. Snow depth collected with the UWiBaSS compares well with optical features collected with the Shark UAV. Buried ridges and rubble fields show more dynamic snow cover than areas of flat sea ice. The initial results of **RT2** show a high correlation with manual snow depth measurements across different ice types.

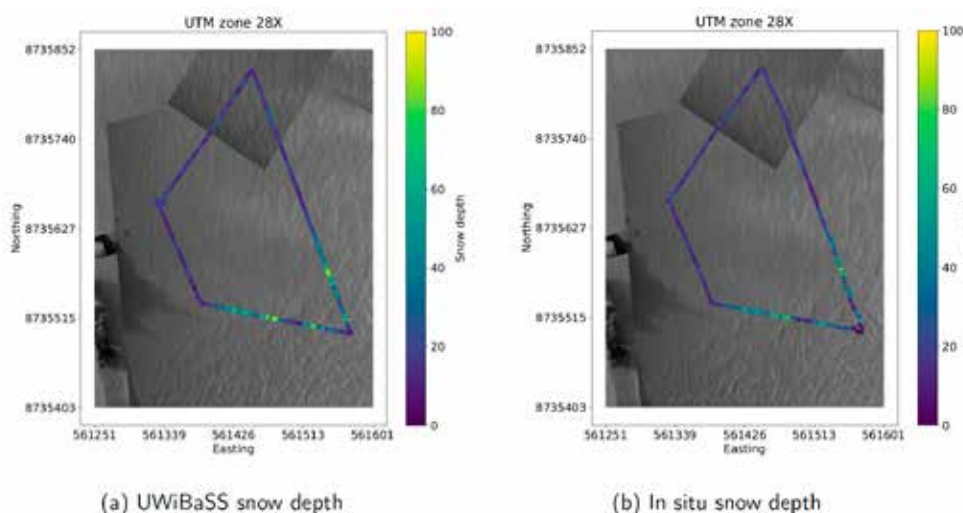
The collected datasets will be used to further evaluate the impact of snow properties on satellite derived parameters that are sensitive to snow on sea ice (**RT 4**).

Deploying iceberg drifters using drones

During the CIRFA-2022 Cruise GNSS trackers were placed onto icebergs using a modified multicopter (DJI Matrice 210). The multicopter was equipped with a payload drop system (Talon dromight), and the tracker was connected to the drop system using a 10m long line. By using the onboard video camera, the tracker was placed very accurately onto a suitable surface on icebergs several km away from the ship. This turned out to be a very safe and cost-efficient method for deploying sensors onto sea ice floes or icebergs.



An iceberg drifter being flown out to an iceberg using the DJI Matrice 210. Photo taken just after takeoff from the KPH helideck. Photo: William Copeland, Met.no



Validation transect crossing over rubble field. (a) Snow depth from radar. (b) Snow depth from on-ice transects.

WORK PACKAGE 5

Drift Modelling and Prediction



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WP leader
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Edel Rikardsen,
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Ann Kristin Sperrevik,
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Yvonne Gusdal,
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Knut-Frode Dagestad,
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Kai Christensen,
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MET/UiO

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

- Configuration of the Ensemble Kalman Filter (EnKF) DA scheme in the regional ocean and ice forecast model *Barents-2.5*
- Development of an operational validation routine for the Barents-2.5 forecast model
- Configuration of an ocean and ice reanalysis using the Barents-2.5 model
- Assessment of ensemble drift simulations for oil slicks
- 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 2022

Having completed the operational implementation of the ocean and ice ensemble forecast model Barents-2.5 in 2021, much of the work 2022 has been on validations and applications of the forecast data produced by this model system, in addition to development and research on the coastal forecast model Norshel. A routine validation system has been implemented, allowing us to monitor daily validation metrics of sea surface temperature, sea ice concentration and in-situ hydrography (figure on the next page).

Detailed developments of the 4d-var assimilation scheme in Norshel included an advancement in assimilation of passive microwave sea surface temperature (SST) – using a supermod operator that allows to constrain model fields at a higher resolution than the observed SST fields.



Validation metrics (RMSE) of sea surface temperature (top panel) and ice concentration (lower panel) from the Barents-2.5 forecast model.

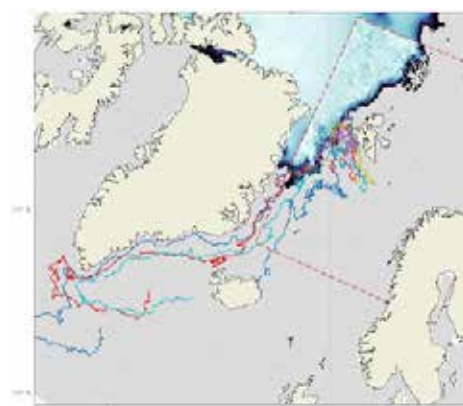
The forecasts of surface currents from Barents-2.5 have been analyzed in terms of a validation against high-frequency (HF) radars. Surface currents are expected to yield low predictive skill, but the ability of the EPS to forecast its own uncertainty has been shown to be rather accurate and spread in modeled surface current relates to the model error when comparing with radial currents from the HF radar. A similar analysis was conducted based on oil slick observations, wherein the ability of the model to estimate uncertainties in oil slick drift was assessed.

Direct observations of Lagrangian surface currents were obtained from free floating surface drifters deployed during the CIRFA cruise with RV Kronprins Håkon. 15 open water surface drifters were deployed in the model domain of Barents-2.5, which allows us to evaluate forecast surface currents and drift trajectories more directly than using HF radar or oil slicks. The data set expands from May 2022 into February 2023.

Figure 5-2. Trajectories of open water surface drifters deployed during the CIRFA cruise. The drifters were deployed during transit from Longyearbyen to Belgica Bank, and on the return voyage. The longest transmitting drifters ceased to send data in February 2023. Ice extent at September 15, 2022 is shown in the background.

Retrieval of surface winds from SAR backscatter signals can provide high-resolution wind structure associated with complex wind situations such as polar lows. Numerical Weather-Prediction (NWP) models have difficulties in

forecasting such weather types, and the hope is that by assimilating the high-resolution SAR wind observations into these models, forecast skills can be improved. Classical SAR wind retrievals need auxiliary information of wind direction from an external source, for instance an NWP model. A new surface-wind retrieval has been developed providing both wind speed and wind direction based on different SAR backscatter signals, and hence independent of auxiliary information. The retrieval has been tested against wind observations from ships, Norwegian Coast Guard vessels along the Norwegian coast and tourist boats in Svalbard fjords. Currently, the SAR-wind observations, based on the new retrieval algorithm, are assimilated into the Arome MedCoOp NWP to test the ability of these observations to improve forecasts of a polar lows.



Trajectories of open water surface drifters deployed during the CIRFA cruise. The drifters were deployed during transit from Longyearbyen to Belgica Bank, and on the return voyage. The longest transmitting drifters ceased to send data in February 2023. Ice extent at September 15, 2022 is shown in the background.

WORK PACKAGE 6

Data Collection and Fieldwork



WP leader
Sebastian Gerland
Section leader and
Researcher, NPI, WP lead



WP leader
Malin Johansson
Associate Professor,
UiT, WP co-lead



WP leader
Rune Størvold
Research Director, NORCE,
WP co-lead

Team members

Anca Cristea
PostDoc, NPI

Dmitry Divine
Researcher, NPI

Background and Objectives

The work package designs field campaigns in connection with satellite and drone measurements, and carefully plans and conducts 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 involves centrally (but not exclusively) the partners Norwegian Polar Institute, NORCE, and UiT The Arctic University of Norway.

Aside from 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 remote sensing research. Examples of such auxiliary data sets collected during previously national and international campaigns, e.g., N-ICE2015, annual campaigns of the Norwegian Polar Institute in Fram Strait and in Svalbard fjords, NOFO's annual oil-on water exercises, data from the international one-year long Arctic MOSAiC expedition (2019-2020) with RV Polarstern in the central Arctic Ocean, and several cruises with RV Kronprins Haakon in the northern Barents Sea, in the Norwegian Nansen Legacy project between 2018 and 2021. In 2022, a central activity within this work package was the CIRFA 2022 cruise with RV Kronprins Haakon to the Fram Strait in April-May 2022 (see own section in this report).

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 2022

Sea ice related fieldwork cruises

Several field activities with close connection to CIRFA happened in 2022: First, the CIRFA 2022 cruise to Fram Strait with RV Kronprins Haakon, which was a main, and all-in-all, the largest CIRFA-lead field activity, took place in April and May 2022 (see own section in this report). Here, numerous sea ice, ocean and iceberg remote sensing validation experiments were conducted, involving a variety of manual, automatic and autonomous measurements setups.



Lots of in-situ data was collected during the CIRFA-22 cruise at the same time as airborne and satellite-borne took place. Sea ice data collection using the crane on RV Kronprins Haakon (left) and snow sampling (right). Photo: Wolfgang Dierking (left), William Copeland (right).



Sea ice drifter deployment (left) during the seal (right) cruise lead by IMR. Photo: A. Garcia (left) and Cornelius Quigley (right).

Furthermore, in-situ work on landfast sea ice in Kongsfjorden, with snow and sea ice thickness measurements, was carried out by NPI researchers in spring 2022. This work added to earlier CIRFA campaigns, and SAR satellite observations were acquired to give additional information on the sea ice concentration in the fjord.

In March, Cornelius Quigley joined an Institute of Marine Research based cruise onboard RV Kronprins Haakon to the east coast of Greenland for the seal counting. Sea ice drift products were delivered to the ship to aid the tracking of the sea ice floes on which the seal pups were born. Sea ice drifters, which had integrated temperature and wave spectrum sensors, were deployed during the cruise to be combined with overlapping SAR images and high resolution Maxar optical images.

In July, CIRFA assisted the SUDARCO (a new FRAM Centre funded project, see own section) sea ice cruise with satellite data ordering to aid navigation when the ship reached the North Pole.

On all the above-mentioned cruises that took place within sea ice covered waters, also standardized IceWatch-ASSIST sea ice observations were done regularly. Part of the data (Nansen Legacy Q1, Q2 and UAK 2021 cruises) is already uploaded to [IceWatch portal](#), the rest will follow soon.

Oil related fieldwork cruises

Together with the *CAGE – Centre for Arctic gas hydrate, environment and climate* at UiT The Arctic University of Norway, collection of overlapping in-situ and satellite data over naturally occurring oil and methane seepages in the Barents Sea was continued, with special focus on the area around Hopen djupet in collaboration with WP3. PhD student Victor de Aguiar joined a CAGE led cruise in August 2022, where he deployed six open ocean drifters and collected in-situ data over the naturally occurring seepages and algae bloom affected waters. The Oil-on-water 2022 was carried out by NOFO, CIRFA and KSAT, collected overlapping satellite data coincident with the oil releases. In June 2022, CIRFA, NOAA and NASA/JPL carried out a field campaign over the natural seepages in the Coal Oil Point seep field near Santa Barbara, California.

Beyond the planning and conduction of fieldwork, time was spent in WP6 on data processing and curation, editing and writing of the CIRFA-2022 Cruise report, writing scientific manuscripts, and presenting results at workshops and conferences. Cristea et al. (2022) published a paper on Automatic detection of low-backscatter targets in the Arctic using wide swath Sentinel-1 imagery in the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. Furthermore, scientists from this work package presented first research results from sea ice remote sensing work from 2021 cruises (Gerland et al. 2022), and from work on the automatic detection of newly formed sea ice as oil spill look-alikes (Cristea et al. 2022) at the international ESA Living Planet Symposium in Bonn, Germany, in May 2022.



Oil fraction measurements (left) and hyperspectral drone observations (right) from the Santa Barbara field work. Photo: Oscar Garcia (left) Cornelius Quigley (right).

WORK PACKAGE 7

Pilot Service Demonstration



WP leader
Hugo Isaksen
Project manager, KSAT



WP leader
Nick Hughes
*Leader of the Norwegian
Ice Service, MET*

Team members

Martine Espeseth
*Project Manager and
Researcher, KSAT*

Catherine Taelman
Engineer, UiT

Thomas Kræmer
Developer, KSAT

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 2022

In 2022, WP7 was involved in several activities to develop demonstrations and support other CIRFA WPs. We developed standardized codes for geocoding, feature extractions, and labeling, which is expected to be beneficial to other WPs towards the end of CIRFA. The WP provided support during the CIRFA cruise with satellite data, and weather forecasts, and after the cruise, UiT set up a cloud-based data repository for CIRFA-2022 Cruise data and made it accessible to all participants. WP7 was involved in a successful “Følgemiddelsøkna” to Norwegian Space Agency together with NORCE and made several presentation presentations at international conferences.

In summary, the work of WP7 in 2022 includes the following activities:

WP1

- Processing chain for met-ocean at KSAT upgrade to cloud infrastructure in progress
- “SAR wind products for a wide range of SAR satellites” presented at IAF Earth Observation Symposium, Paris

WP2

- MET supported the CIRFA-22 cruise with satellite data supply (e.g. COSMO-SkyMed and ICEYE) and processing, Ice Watch post cruise data processing
- Implementation of Sentinel-1 classification for sea ice type (from Johannes Lohse) processing chain at MET. Addition of post-processing to NetCDF including addition of comparison datasets.
- Presentation and discussion of WP2 and WP7 collaboration at CIRFA at IICWG-XXIII (Nick, Johannes Lohse, Wolfgang Dierking)
- KSAT supported CIRFA with Iceye data for the Oil on Water Exercise

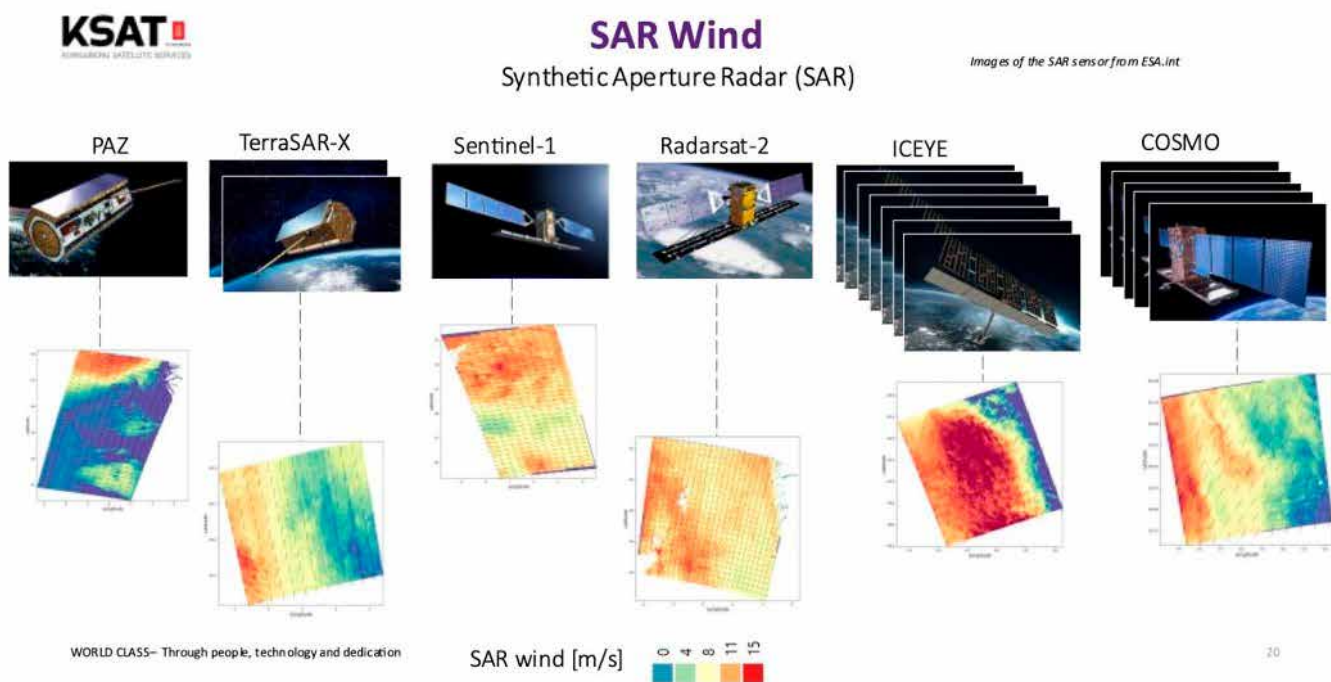
WP3

- Processing chain for damping ratio still ongoing. USGS has implemented this product in their service and therefore there's an increased confidence to the results of the product. Plan to finalize this in Q3 2023
- Open Drift Model and relative thickness model presented at Interspill (Martine, Knut-Frode Dagestad and Hugo) Initiating Oil Spill Drift Model with Thickness Variations. A WP3, WP5 and WP7 collaboration
- Beyond oil Spill detection - Satellite Based Environmental Monitoring of Slicks” Clean Gulf Conference in New Orleans, Louisiana. Focus on both oil and algae. (Martine, Hugo, Andreas H.K.)
- Oil spill detection presentation in September together with NOFO and Equinor at “Forum for framtidas oljevern 2022” (Hugo, Martine og Kristin Klem Husebye (NOFO))

WP 5

- Continued cooperation with WP5 and Knut-Frode Dagestad on the OpenDrift model to Operationalize oil drift as a part of the standard KSAT oil product. The operational service will start in April 2023.

PhD candidate Salman Khaleghian, associated to WP7, defended his PhD thesis in December 2022.

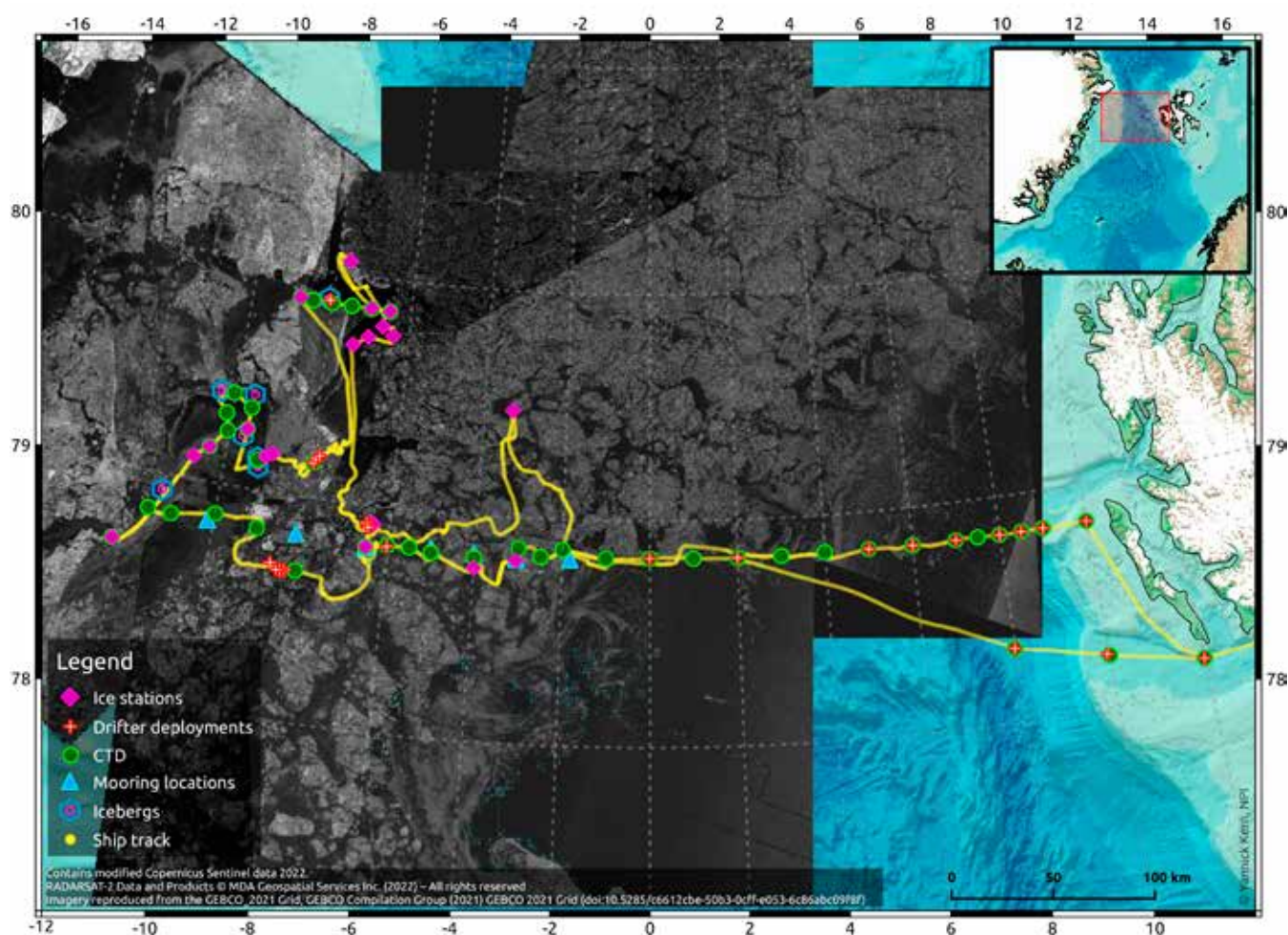


SAR wind products for a wide range of SAR satellites.

The CIRFA-2022 Cruise

In late April and early May 2022, a team of 33 scientists and engineers from Norway and France conducted the CIRFA-2022 Cruise, Norway's first ship-based Arctic research expedition, with a main focus on satellite remote sensing of floating ice. The expedition's main goal was to collect ground-truth data for validating remote sensing products on sea ice, icebergs, and ocean, which have been developed by CIRFA since its start in 2015. The cruise took place on the Norwegian research icebreaker *Kronprins Haakon* and went to the northeastern coast of Greenland. All seven CIRFA work packages were involved in this unique opportunity for coordinated, combined in-situ and satellite data collection.

After all cruise participants had undergone extensive preparation and training, the expedition started from Longyearbyen, Svalbard, and took course to the west towards northeastern Greenland. Work started soon with deployments of drifters in open water in the eastern Fram Strait, CTD casts and water sampling, before reaching the sea ice edge, from where regular visual sea ice observations started, following the Icewatch ASSIST protocol (<https://icewatch.met.no/>). RV *Kronprins Haakon* reached the landfast (i.e. stationary) sea ice in the western Fram Strait, the so-called Norske Øer Ice Barrier, after four days of sailing. With its experienced crew, well-equipped laboratories, helicopter deck, and hangars, RV *Kronprins Haakon*, owned by the Norwegian Polar Institute and run by the Institute of Marine Research in Norway, proved to be an ideal platform for performing the planned validation studies.



Map of the CIRFA Cruise route in April and May 2022, including the locations of oceanography, snow and sea ice, and iceberg-related sampling stations. Map created by Yannick Kern (NPI).

In western Fram Strait, the team visited both drifting and landfast sea ice. We collected data and ice samples with surface information ranging in scale from micrometres, inferred from snow pits and sea ice coring, to kilometers, obtained from transects and drone surveys. In addition, autonomous drifters and buoys, recording instantaneous position and sea ice mass balance, were deployed on sea ice and in the ocean to measure sea ice and ocean dynamics and changes over time. The team met a variety of sea ice conditions, from young sea ice in leads and polynyas, to level first-year ice and moderate or partly heavily deformed sea ice.

For the science team and crew on board RV Kronprins Haakon, land support was crucial for the expedition's success. Colleagues on land kept up the communication with satellite product providers and helped with inspecting and analyzing a larger amount of satellite imagery than was available on board the ship, to support the expedition operationally in getting to suitable locations for perform planned activities. During the expedition, we regularly achieved coincident ground-based measurements with satellite acquisitions, thanks to the detailed planning and communication between the field and land teams. A whole suite of satellite images was acquired, including scenes from the European Space Agency Sentinel-1, the Canadian RADARSAT-2, the German TerraSAR-X and the Japanese ALOS-2 satellites. The European Space Agency financially supported the expedition since some of the ground truth data and subsequent analysis would be of direct relevance to its ongoing and upcoming missions.



*Work on a sea ice station with both level and deformed sea ice.
Photo: Sebastian Gerland, NPI*



*Use of a fixed wing drone from CIRFA partner NORCE over sea ice in western Fram Strait.
Photo: Sebastian Gerland, NPI*

During the cruise, updates on work progress were given through posts on social media (e.g. <https://www.facebook.com/cirfasfi/>, https://twitter.com/cirfa_sfi and <https://twitter.com/oceanseaicenpi>). Through the CIRFA website (<https://cirfa.uit.no/>) the cruise report (Dierking et al. 2022) with more detailed information about the data acquisitions is available.

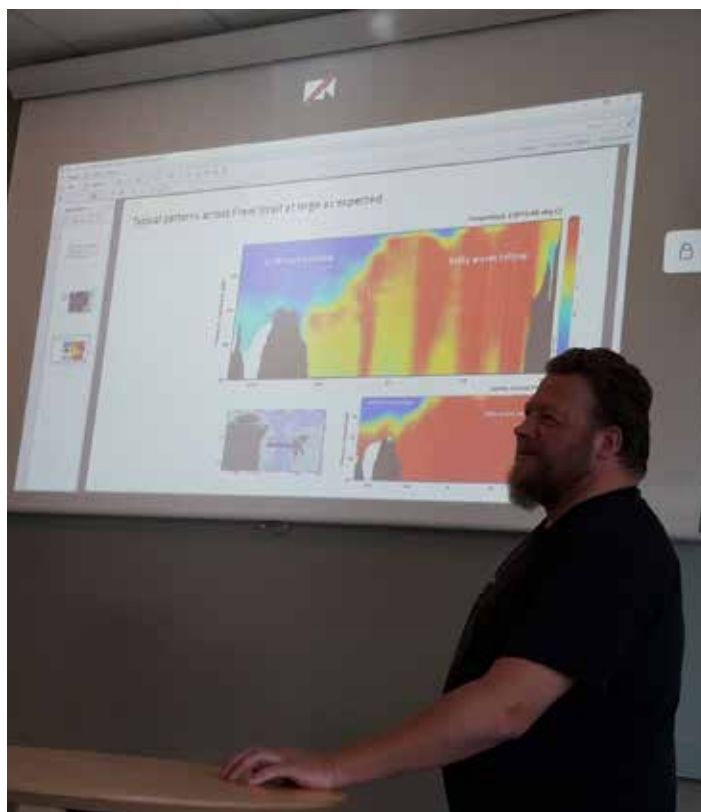
After the cruise, preliminary results were presented in CIRFA seminars, a post-cruise workshop took place in the autumn 2022, and a contribution (Eltoft et al., 2023) for the 2023 issue of Fram Forum was prepared. Work with the combined ground truth and satellite data sets, as well as the sample analyses, is now going on within the CIRFA team to address important research questions in Arctic remote sensing and development of new technologies. Since ESA contributed to the funding of the cruise, an archive of the collected data will be made available to the public.

First post cruise workshop – 2022

The workshop from 7 to 9 September, hosted at SIVA Innovation center, brought together the CIRFA-2022 Cruise participants, their onshore support team and any other CIRFA members interested in the cruise data to kick-start the joint analysis of the collected data. Besides the overview in the 'Data Show', we also discussed individual research focuses:

1. Sea ice classification
2. Landfast ice extent and sea ice and dense water production
3. Sea ice and ocean drift
4. Sea ice mass balance and altimetry
5. Sea ice Scattering, polarimetry, and data from drones
6. Outreach

The work with these and other topics is ongoing, and it will be jointly reviewed in a follow-up workshop in 2023.



Postworkshop BBQ in Grotfjord (left) and workshop presentation by Mats Granskog (NPI). Photos: Andrea Schneider

Research training

Every year CIRFA arranges research training activities that are open for our master students, PhD candidates, postdocs and researchers. In 2022 two such activities were related to establishing good practice for field measurements during the CIRFA cruise. The weekly young scientists meeting continued also in 2022 ensuring knowledge transfer on topics such as georeferencing your data and how to set up efficient processing chains etc.

Ramfjorden sea ice training and snow pit training in Kroken

In February 2022 CIRFA and SIDRiFT collaborated with the Nansen Legacy Project in organizing fieldwork training on fjord ice in Ramfjorden. This was carried out as preparation for the planned sea ice cruises in 2022, though everyone was welcome to join. With 7 instructors and 20 participants from Tromsø and Oslo we practiced extraction of sea ice cores and snow, and sea ice transects on the safe ice at the southern edge of the fjord. The ice was nearly 40 cm thick, and it was covered with a few cm of snow. The activity was also used as testbed for clothing, tent and ice hole preparation for launch of underwater remotely operated vehicle. Our luck with good weather also ensured successful team building for people with a wide spread of career stage across various institutions associated with CIRFA!

After the sea ice training in Ramfjorden, it was time for the snow training where we searched for a deep snow cover to train snow properties measurements in snow pits. We found it at the Kroken ski resort in March. An experienced instructor trained 8 students and young scientists from CIRFA in measuring snow temperature, grain properties and density.



Photo: Polona Itkin

CIRFA Young Scientist Meeting

The *CIRFA Young Scientist Meeting* (YSM) is a weekly meeting for early career scientists at CIRFA. It provides a platform for interns, master students, PhD candidates, and post-docs to connect in an informal setting and to discuss their work. The focus of the YSM is supposed to be mostly on technical challenges and programming issues, as well as organizational topics and questions regarding conferences, publications, or presentations. All participants are encouraged to share pieces of code from their current work, either demonstrating how these could be useful for other projects or asking questions and seeking help about implementation details or code efficiency. This often triggers fruitful discussions and facilitates the exchange of technical knowledge between early career scientists, sometimes resulting in extended collaborations on programming projects that are beneficial for the entire group.

While the meeting is usually held in person in the Earth Observation group at UiT, it is open for online participation on Teams for remote participants.



Photo: Johannes Lohse

Master Degrees and Doctoral Dissertations

Since the start of the center, CIRFA scientists provided supervision and training to remote sensing students. In 2022, two PhD candidates successfully defended their PhD thesis, two master students graduated, and three conducted internships at CIRFA.

Msc student	Title of the thesis	Supervisor(s)
Pigi Lozou (intern)	Gaussian processes and variational autoencoder for multimodal remote sensing data analysis and sea ice characterization	Andrea Marinoni, Saloua Chlaily
Morgane Batelier (intern)	Developing an architecture of a transductive learning approach for sea ice characterization and oil spill classification	Andrea Marinoni, Saloua Chlaily
Martijn Clemenkowff	Estimation of snow density from a drone-mounted ultra-wideband radar	Anthony Doulgeris, Rolf-Ole Ryding Jensen
Silje Grue	Machine Learning for Classifying Marine Vegetation from Hyperspectral Drone Data in the Norwegian coast	Katalin Blix
Mathilde Lyford Jahnsen	Naturally occurring seepages in the Barents Sea	Malin Johansson
Janina Osanen (intern)	CIRFA cruise ice core analysis	Polona Itkin, Johannes Lohse, Jack Landy

PhD Dissertations

16 September 2022 – Megan O'Sadnick

“Ice in Norwegian subarctic fjords and coastal regions”

A wide breadth of work exists examining mainland Norwegian fjords, however very little research has focused specifically on sea ice in these locations. The overarching goal of the work presented here is to address this gap in research and knowledge. To do so, first an assessment of ice extent in fjords and other coastal areas along the coast of mainland Norway from 2001 to 2019 between February through May is completed. Next, seven fjords located in northern Norway are studied in-depth through the collection of ice and ocean measurements over the course of three winter seasons spanning 2017 into 2020. Possible connections to temperature, snowfall, and river runoff are examined revealing variations in ice extent, ice properties, and the factors driving ice formation. Lastly, ice property measurements are given a closer look to develop a promising method to deduce ocean and weather conditions during ice growth in fjords and coastal areas where measurement through winter is not possible.



Megan O'Sadnick with her supervisors and evaluation Committee.
Photo: Malin Johansson

15 December 2022 - Salman Khaleghian

“Scalable computing for earth observation – Application on Sea Ice analysis”

In recent years, Deep learning (DL) networks have shown considerable improvements and have become a preferred methodology in many different applications. In earth observation, DL algorithms have demonstrated the ability to accurately learn complicated nonlinear relationships in input data. Although a larger quantity of training data enhances the accuracy of the trained models in general, the computational cost often restricts the amount of analysis that can be done. This issue is particularly critical in satellite remote sensing, where many satellites collect a huge amount of data, and acquiring in-situ ground truth to build a large training dataset is a fundamental prerequisite. By using sea ice classification as a case, this work investigates novel DL methods to cope with the problems of scarce training data and addresses the computational cost of the training process by proposing a distributed training model. We analyze DL network capabilities based on self-designed architectures and learning strategies, such as transfer learning. We also address the scarcity of training data by proposing a novel deep semi-supervised learning method for SAR data, which also uses unlabeled data in the training process. Finally, a new distributed DL method is used in a semi-supervised architecture to address the computational complexity of training deep neural networks.



Salman Khaleghian gives his trial lecture during the PhD defense.
Photo: Polona Itkin

Communication and Dissemination Activities

The **CIRFA seminars** in 2022 allowed for both in-person and digital attendance. The seminars serve a threefold purpose; to present and discuss ongoing work or results, to update on field campaigns and new data and observations, and to encourage networking. In 2022, CIRFA hosted 9 seminars with international speakers and a wide range of topics:

Presenter	Affiliation	Country	Month	Title of the talk	Audience
Per Pippin Aspaas, Niels Cadée, Tanja Larssen	UiT	NOR	Feb	Open access publication	17 (internal)
Espen Tangen, Rolf Andersen	UiT	NOR	March	IT resources at UiT	18 (internal)
Jari Haapala	FMI	FIN	April	New findings on sea ice deformation from the MOSAiC measurement	33
Morven Muilwijk	NPI	NOR	May	Impact of sea ice transport on Beaufort Gyre liquid freshwater content	23
Torbjørn Eltoft & Sebastian Gerland	NPI & UiT	NOR	June	CIRFA cruise	32
Adam Steer	NPI	NOR	Oct	Filling in the gaps – using small drones to add context in sea ice research	35
Anca Cristea	NPI	NOR	Nov	Automatic detection of low-backscatter targets in the Arctic using Wide Swath Sentinel-1 imagery	26
David Arthurs	Polar View	NOR	Nov	The Polar Thematic Exploitation Platform (Polar TEP)	33
Saloua Chlaily	UiT	NOR	Dec	On modified variance measures for quantifying uncertainty in classification	45



The audience at a CIRFA seminar. Photo: Polona Itkin



Participants at the CIRFA Annual Conference 2022 at Sommarøy Arctic Hotel November 1-3, 2022.

The **CIRFA Annual Conference 2022** took place on November 1-3 at the Sommarøy Arctic Hotel near Tromsø. It followed the template of previous conferences, starting with a nice poster session with mingling, shortly after arriving to the hotel. The next day continued with sessions on *modelling*, with focus on the Barents Model, *sea ice research*, with focus on sea ice classification and its climate impact, and *field work*, with a nice summary of the CIRFA-2022 Cruise. The conference also had sessions on new *associated research projects* and on *innovative methods*. On the last day, a panel discussion with members from industry was organized to discuss CIRFA's contributions to user partners, and a feedback meeting with the Scientific Advisory Board was squeezed in. This year's conference had two international and two national invited speakers. The 2022 CIRFA Annual Conference had 62 participants, most were present, but a few participated on-line. The CIRFA conference was followed by a one-day CIRFA-2022 cruise workshop on Friday November 4th.



Conferences and Workshops where CIRFA was represented in 2022

- ▣ EUSAR 2022, Leipzig, July
- ▣ IGARSS 2022, Kuala Lumpur, July
- ▣ ESA Living Planet Symposium, Bonn, May
- ▣ SIOS Remote Sensing Conference, Svalbard, October
- ▣ AGU Fall Meeting, Chicago, December
- ▣ EGU Assembly, Vienna, May
- ▣ 'Forum for framtidas oljevern', Svolvær, September
- ▣ International Ice Charting Group Workshop, Buenos Aires, September
- ▣ Second international SAR Coordination Workshop, Frascati, September
- ▣ Changing Arctic: Ocean, Ice and Climate, Tromsø, May
- ▣ Arctic Science Summit Week, Tromsø, March-April
- ▣ MOSAiC International Conference, Potsdam, April

Outreach

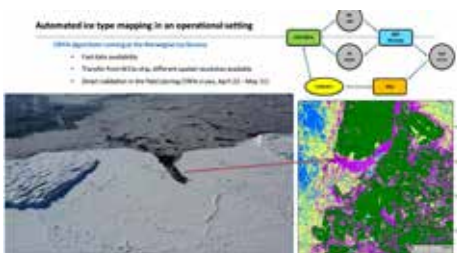
CIRFA communicated its science through many different activities in 2022. Naturally, the CIRFA sea ice cruise in April and May was a highlight, and was disseminated mostly through social media channels, with all CIRFA partners contributing to the great output. The outreach also consisted of promoting the CIRFA sea ice classification work, as well as weighing in on the future for SAR coordination between sensors from different countries and organizations. The public and students were reached through a NASA ARSET lecture, as well as open days at the university.

Seminars and presentations

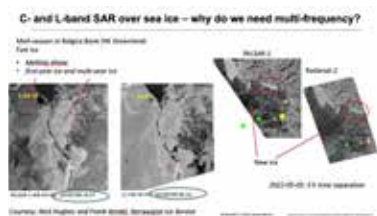
Torbjørn Eltoft made a talk at the seminar organized at UiT in connection with the signing of a collaboration agreement between UiT and Andøya Space where he presented CIRFA and ideas on future collaborations.



Johannes Lohse presented work from the CIRFA cruise and the ROSE-L project at the International Ice Charting Working Group in Buenos Aires in September.



Malin Johansson presented work on “Why do we need multi-frequency SAR data for ocean applications?” at the 2nd workshop on International Coordination for Spaceborne SAR in September 2022. The workshop was organized by ESA and attended by representatives from, e.g., NASA, ESA, JAXA, DLR, Iceye, Planet.



As part of the Forskningsdagene in September, an evening session was dedicated to the topic ‘Havsøppel’ (i.e. ‘Ocean Pollution’). Experts from different scientific disciplines were invited and **Malin Johansson** presented CIRFA’s work about the use of satellite images to detect oil spills.



Andrea Marinoni represented CIRFA in the Norway-Singapore Science week in Singapore 30.10 - 02.11.2022. He met with scientists from the National University of Singapore and the Earth Observatory of Singapore to discuss collaborative connections. This was a successful event, and Andrea is revisiting the Earth Observatory in the spring of 2023.



Social media outreach

The CIRFA sea ice cruise was broadcasted through a range of social media posts by CIRFA, the Norwegian Polar Institute, Yr, NORCE and MET Norway, on their different social media channels.



Publication outreach

Jack Landy gave interviews to the BBC, EoS, Global News Canada, Scientific American, and ESA, as outreach for the publication of first year-round estimates of Arctic sea ice thickness from CryoSat-2 in September. A group of co-authors on the publication teamed up with the ESA CryoSat-2 mission manager Jerome Bouffard to give a Twitter Live audio Q&A session, answering questions about the paper and its impacts from a public audience on Twitter.



Meeting students

Catherine Taelman and Andrea Schneider had interactive discussions with local and international high school students about remote sensing and satellites during Skoledagarna in June and Forskningdagene in September. In October, Malin Johansson was invited to give a NASA ARSET lecture about oil spill detection, which was attended by 750 students from all over the world.



National and International Collaboration

Through collaborative research projects, CIRFA partners have an extensive national and international collaboration. In 2022, the Centre's partners were involved in 28 projects, either as a direct spin-off from its research or projects which are associated with the activities. The main funded sources for these projects are the Research Council of Norway, The European Space Agency, The Norwegian Space Agency, The Fram Centre, and EU (through Horizon 2020 and Horizon Europe). In addition, CIRFA has access to satellite data through bilateral agreements with the Japanese Space Agency (JAXA), the Canadian Space Agency (CSA), and the German Space Agency (DLR).

Four projects are briefly described below:

RareIce (Risk of sea ice and icebergs for field development in the southwestern Barents Sea) is a collaborative project between the CIRFA partners NTNU (host), UiT, Equinor and Multiconsult, funded by RCN. The uncertainty in estimation of the southward extent of sea ice and icebergs in the Barents Sea threatens a low-risk exploitation of hydrocarbons in these waters and may endanger activities such as fishing, shipping, tourist traffic, and seabed mining. RareIce deals specifically with methods to quantify the risk from sea ice and icebergs to production and ship traffic in the opened sectors of the Barents Sea. It shall achieve this by quantifying abundant observations of icebergs and sea ice in the north, connecting to seasonal and climatic drivers, and combining with drift and deterioration modelling as the ice moves southwards to predict the risks of the rare ice events in the southwestern Barents Sea. The project combines knowledge from the two SFIs SAMCoT (NTNU) and CIRFA (UiT) and will generate new knowledge and competence that will address present industry needs.

The L-C Ice project (Synergistic Use of L- and C-band SAR Satellites for Sea Ice Monitoring), which was funded by the European Space Agency (ESA) and led by CIRFA, was successfully finished at the end of the year. It aimed at combining multi-frequency satellite SAR images. The last project reports prepared in 2022 deal with the practical alignment of C- and L-band SAR images acquired at different times and with automated multi-frequency classification of the aligned images. A major question was on the acceptable time gaps between C- and L-band acquisitions depending on the mobility of the ice cover. Members of CIRFA and Chalmers University of Technology presented the corresponding results and a summary of the overall project outcome at the annual meeting of the International Ice Charting Working Group (IICWG) 2022 in Buenos Aires.

INTERAAC (air-snow-ice-ocean INTERactions transforming Atlantic Arctic Climate) is funded by the NFR for NOK 10 million, 2022 – 2026, within the Polarforskningsprogram. This is a bilateral project between Norway and China, involving UiT, Norwegian Polar Institute, University of Tsinghua, Polar Research Institute of China, and China Meteorological Administration. The project aims to generate a reconciled multi-mission Climate Data Record (CDR) of sea ice properties in the Atlantic Sector of the Arctic, to investigate coupled air-snow-ice-ocean processes driving sea ice retreat along the Atlantic Polar Front.

SUDARCO: CIRFA WP2 researchers are involved in the Fram Centre project SUDARCO (Sustainable Development of the Arctic Ocean), 2022 – 2026, led by the Norwegian Polar Institute. The full project involves 70 participants from Northern Norway providing research to form the basis for advice on the best possible management of the Arctic Ocean. Our contribution from CIRFA involves developing novel SAR and satellite altimetry sea ice classification and thickness datasets, together with NORCE and UNIS, for operational use by MET Norway within the project.

In 2022, five new projects were awarded/started up:

- RareIce (RCN) – Risk of Sea Ice and icebergs for Field Development in the Southwestern Barents Sea
- SUDARCO (Fram Centre) – Sustainable Development of the Arctic Ocean.
- HEEPS (ESA) – Harmony End-to-End Performance Simulator.
- Cryo-TEMPO (ESA) – The aim is to deliver a new paradigm of simplified, harmonized, and agile CryoSat-2 products.
- NATALIE (EU: H-Europe) – Accelerating and mainstreaming transformative Nature-based solutions to enhance resilience to climate change for diverse biogeographical European regions (Starts in 2023)

International and national exchanges in 2022

Jari Haapala visited CIRFA to work on the common MOSAiC expedition datasets in April and November 2022.

Wenkai Guo was a visiting research fellow (funded by The Research Council of Norway as SIDRiFT post-doc) at the German Aerospace Agency (DLR) in Bremen from July 2021 to July 2022.

Cathleen Jones (JPL) was visiting CIRFA in September to work on the dataset collected over the Santa Barbara campaign in June 2022.

Cornelius Quigley and Malin Johansson spent November at JPL (USA) continuing the work that was started in September on the Santa Barbara data (Cornelius) as well as work on Harmful Algae Blooms (Malin) together with Cathleen Jones and Benjamin Holt at JPL.

Torbjørn Eltoft spent 3 months at ISAE- SUPAERO in Toulouse to work with Professor Laurent Ferro-Famil on research questions related to polarimetric scattering from sea ice based on data from the CIRFA-2022 Cruise.

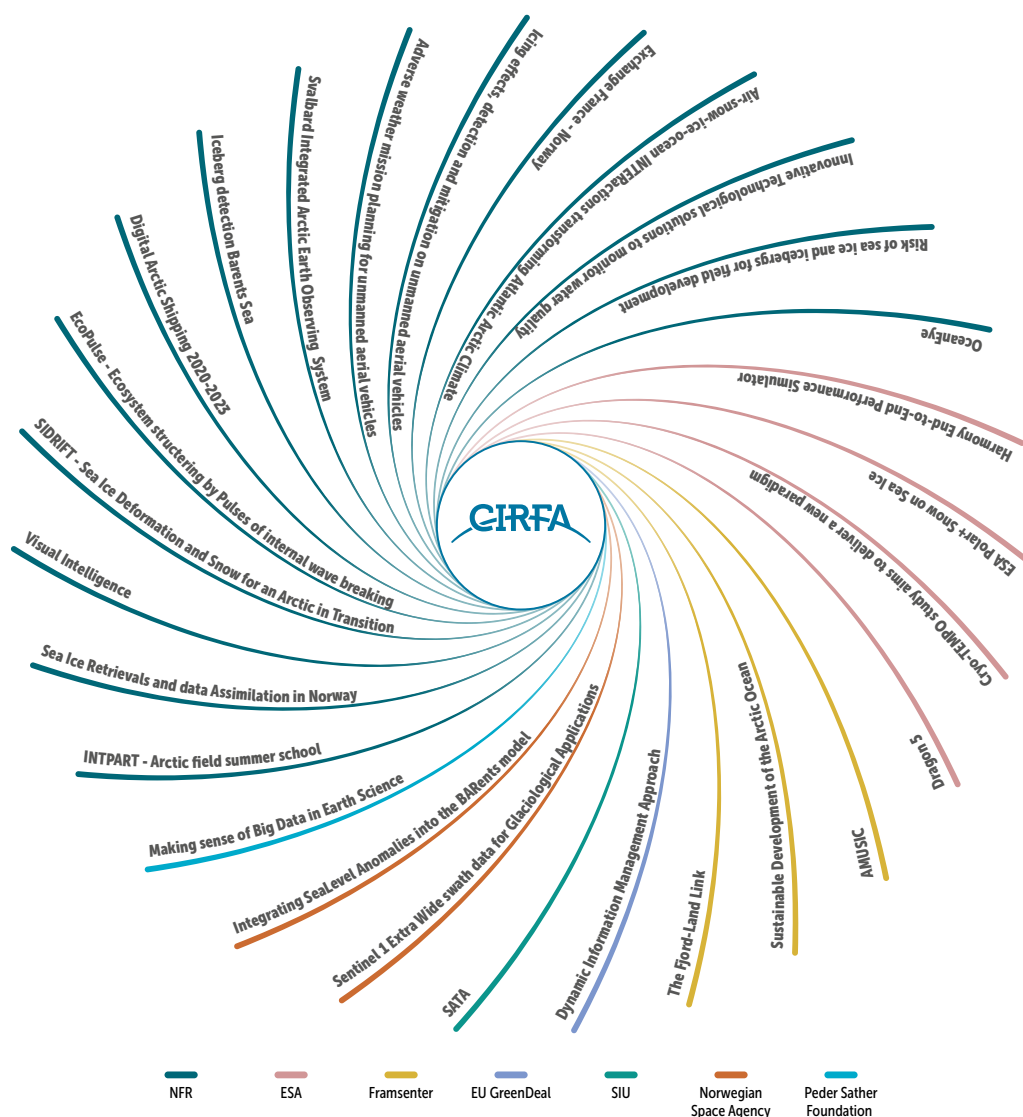
Anthony Doulgeris spent a second sabbatical visit (June-August) in Hobart, Australia, to continue implementing the CIRFA developed Sentinel-1 segmentation algorithm into an operational workflow at the CSIRO. The project first performs our novel incidence-angle aware wide-swath segmentation

over the ocean before automatically applying CFAR ship detection methods on the segments.

Laurent Ferro-Famil and Frederic Boutet from ISAE-SUPAERO, Toulouse and University of Rennes-1, respectively, were participants on the CIRFA-2022 Cruise, adding a ground-based tomographic C-band radar to the equipment portfolio.



Photo: Malin Johansson



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

Engagements on national and global dimension

ALOS-4

Malin Johansson is a member of Cal/Val Scientist team for ALOS-4

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

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

ESA SINX'S

Jack Landy is on the Scientific Advisory Committee for the ESA-led Sea Ice Thickness Intercomparison Exercise

EU COMMISSION POLAR TASK FORCE

Polona Itkin is a member of the EU Commission Polar Task Force that will meet in 2023 to prepare guidelines for future EU activities in polar observations.

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

World Meteorological Organization (WMO)

Nick Hughes is a member of the Standing Committee on Marine Meteorological and Oceanographic Services Expert Team on Maritime Safety

2nd International Coordination for Spaceborne SAR

Malin Johansson and Wolfgang Dierking presented the state-of-the-art and suggestions for the future for SAR coordination of PolSAR/Multi-frequency marine applications.



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ORGANIZATION





CIRFA

Publications 2022

Peer reviewed publication

Babb, David G; Galley, Ryan; Howell, Stephen; **Landy, Jack**; Stroeve, J.C.; Barber, David G. Increasing Multiyear Sea Ice Loss in the Beaufort Sea: A New Export Pathway for the Diminishing Multiyear Ice Cover of the Arctic Ocean. *Geophysical Research Letters* 2022; 49(9)

Campbell, Karley; Lange, Benjamin; **Landy, Jack**; Katlein, Christian; Nicolaus, Marcel; Anhaus, Philipp; Matero, Ilkka; Gradinger, Rolf; Charette, Joannie; Duerksen, Steven; Tremblay, Pascal; Rysgaard, Søren; Tranter, Martyn; Haas, Christian; Michel, Christine, *Net heterotrophy in High Arctic first-year and multi-year spring sea ice*. *Elementa: Science of the Anthropocene* 2022; 10(1)

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Landy, Jack; Dawson, Geoffrey; Tsamados, Michel; Bushuk, Mitchell; Stroeve, Julianne C.; Howell, Stephen; Krumpen, Thomas; Babb, David G.; Komarov, Alexander S.; Heorten, Harold; Belter, H. Jakob; Aksenov, Yevgeny. A year-round satellite sea-ice thickness record from CryoSat-2. *Nature* 2022; 609(7927):517-522

Liu, Mengxi; Shi, Qian; **Marinoni, Andrea**; He, Da; Liu, Xiaoping; Zhang, Liangpei. *Super-Resolution-Based Change Detection Network with Stacked Attention Module for Images with Different Resolutions*. *IEEE Transactions on Geoscience and Remote Sensing* 2022; 60.

Mallett, Robbie; Stroeve, Julianne C.; Tsamados, Michel; Willatt, Rosemary; Newman, Thomas; Nandan, Vishnu; **Landy, Jack; Itkin, Polona**; Oggier, Marc; Jaggi, Matthias; Perovich, Don. *Sub-kilometre scale distribution of snow depth on Arctic sea ice from Soviet drifting stations*. *Journal of Glaciology* 2022; 68(271):1014-1026

Quigley, Cornelius; Johansson, Malin; Jones, Cathleen. *An alternative approach for calculating the SAR damping ratio of verified oil slicks*. *IEEE International Geoscience and Remote Sensing Symposium proceedings* 2022 s.4327-4330

Rabault, Jean; Nose, Takehiko; Hope, Gaute; Müller, Malte; Breivik, Øyvind; Voermans, Joey; Hole, Lars Robert; Bohlinger, Patrik; Waseda, Takuji; Kodaira, Tsubasa; Katsuno, Tomotaka; Johnson, Mark; Sutherland, Graig; **Johansson, Malin**; Christensen, Kai Håkon; Garbo, Adam; Jensen, Atle; Gundersen, Olav; Marchenko, Aleksey; Babanin, Alexander. *OpenMetBuoy-v2021: An Easy-to-Build, Affordable, Customizable, Open-Source Instrument for Oceanographic Measurements of Drift and Waves in Sea Ice and the Open Ocean*. *Geosciences* 2022; 12(3)

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Ratha, Debanshu; Johansson, Malin; Marinoni, Andrea; Eltoft, Torbjørn. *Performance Analysis of Roll-Invariant PolSAR Parameters from C-band images with Regard to Sea Ice Type Separation*. *Electronic proceedings (EUSAR)* 2022

Taelman, Catherine; Chlailly, Saloua; Khachatryan, Eduard; Van Der Sommen, Fons; **Marinoni, Andrea**. *On the Exploitation of Heterophily in Graph-Based Multimodal Remote Sensing Data Analysis*. *CEUR Workshop Proceedings* 2022

Other publications

Biuw, Martin; Nilssen, Kjell Tormod; Kristiansen, Martin; Lindblom, Lotta; Poltermann, Michael Tino; Haug, Tore; **Johansson, Malin**. *Report From Surveys To Assess Harp And Hooded Seal Pup Production In The Greenland Sea Pack-Ice In 2022*. Bergen: Havforskningsinstituttet 2022 29 s. Toktrapport (2022 - 7)

Cristea, Anca; Johansson, Malin; Doulgeris, Anthony. *Automatic detection of newly formed sea ice and lookalikes in the Barents Sea using Wide-Swath Synthetic Aperture Radar*. ESA Living Planet Symposium 2022; 2022-05-22 - 2022-05-27

Færch, Laust; Dierking, Wolfgang; Doulgeris, Anthony; Hughes, Nick. A comparison of Backscatter Intensity of Icebergs in C- and L-band SAR Imagery. EGU General Assembly 2022; 2022-05-23 - 2022-05-27

Dierking, Wolfgang; Schneider, Andrea; Eltoft, Torbjørn; Gerland, Sebastian. *CIRFA Cruise 2022. Cruise report*. UiT, Department of Physics and Technology. 2022 123s. <https://zenodo.org/record/7314066#.ZA77Y3bMJPa>.

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Færch, Laust; Dierking, Wolfgang. *Comparison of CFAR algorithms for detection of icebergs in SAR imagery*. 2022 DRAGON 5 mid-term results symposium; 2022-10-19 - 2022-10-19

Gerland, Sebastian; Divine, Dmitry; Granskog, Mats; Itkin, Polona; Johansson, Malin; Steer, Adam; Cristea, Anca; Jaggi, Matthias; Schneebeli, Martin. *Coordinated SAR satellite observations, airborne and ground surveys over Arctic sea ice and snow for different seasons*. Living Planet Symposium 2022; 2022-05-23 - 2022-05-27

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Johansson, Malin. *Bruk av satellitter til å oppdage oljesøl*. Forskningsdagene 2022; 2022-09-21

Johansson, Malin. *Disaster Assessment Using Synthetic Aperture Radar: Part 3 – Oil Spill Detection*. NASA ARSET Lecture series; 2022-10-27

Johansson, Malin. *Satellite images overlapping field-work campaigns*. KSAT seminar; 2022-10-21

Johansson, Malin; Dierking, Wolfgang. *POLSAR/Multi-frequency Theme 3: Sea ice and ocean*. Second Workshop on International Coordination for Spaceborne Synthetic Aperture Radar; 2022-09-27 - 2022-09-29

Johansson, Malin; Itkin, Polona; Taelman, Catherine; Lohse, Johannes; Landy, Jack; Schneider, Andrea. *CIRFA science communicated*. CIRFA Annual conference; 2022-11-01 - 2022-11-03

Johansson, Malin; Lohse, Johannes. *Arctic sea ice monitoring using synthetic aperture radar satellite imagery at C- and L-band frequency*. Arctic Science Summit Week; 2022-03-27 - 2022-04-01

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Johansson, Malin; Singha, Suman; Spreen, Gunnar; Howell, Stephen; Sobue, Shin-ichi; Davidson, Malcolm. *Fully-polarimetric L- and C-band Synthetic Aperture Radar data analysis from the yearlong MOSAiC expedition*. ESA Living Planet Symposium 2022; 2022-05-22 - 2022-05-27

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Lohse, Johannes; Eltoft, Torbjørn; Khaleghian, Salman; Wang, Qiang. *Sea ice classification methodologies developed in CIRFA*. Arctic Science Summit Week; 2022-03-27 - 2022-04-01

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Röhrs, J., Gusdal, Y., Rikardsen, E., Duran Moro, M., Brændshøi, J., Kristensen, N. M., Fritzner, S., Wang, K., Sperrevik, A. K., Idžanović, M., Laverigne, T., Debernard, J., and Christensen, K. H.: Barents-2.5km v2.0: An operational data-assimilative coupled ocean and sea ice ensemble prediction model for the Barents Sea and Svalbard, Geosci. Model Dev. Discuss. [preprint], <https://doi.org/10.5194/gmd-2023-20>, in review, 2023.

Taelman, Catherine; Lohse, Johannes; Khachatryan, Eduard; Marinoni, Andrea; Cremers, Sam. *Semi-automated classification of sea ice types using C- and L-band SAR data*. Living Planet Symposium; 2022-05-23 - 2022-05-27

Accounts

All amounts are in 1000 NOK.

Funding sources

The Research Council of Norway	17 794
Industry partners	6 248
The host institution (UiT)	6 025
Research partners	5 066
Total	35 133

Costs per activity

WP 1 Ocean RS	1 867
WP 2 Sea Ice RS	7 239
WP 3 Oils Spill RS	4 483
WP 4 RPAS Technology	3 604
WP 5 Drift Modeling and Prediction	5 478
WP 6 Fieldwork and Data Collection	1 149
WP 7 Pilot Service Demonstration	5 067
Management	6 246
Total	35 133

Costs per partner

Research partners

UiT	21 368
NORCE	6 023
Sintef Narvik	467
NTNU	0
NPI	1 990
MET Norway	4 159
NERSC	92

Industry partners

Equinor	380
Vår Energi	11
Total E&P Norge	0
OMV Norge	101
Aker BP	0
Aker Solutions	0
Multiconsult	97
KSAT	309
Maritime Robotics	138
Total	35 133





