2020 Annual Report

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

A partner's perspective

Svein Olav Drangeid
(OMV)

COVID-19 has truly made this year a remarkably unusual year. Thinking back to when COVID-19 first struck us; who would have thought that we should experience more than a full year with hardly any travel, hardly anyone in the office? In fact, hardly meeting anyone at all, except our closest family members. I remember, when it all started back in March, we were discussing whether the working from home would last for two or maybe three weeks, or in worst case possibly until Easter. How wrong could we be? Here we are, more than one year later, still in the same situation.

That said, it has in fact worked out remarkably well. As Richard Hall stated in our previous annual report; "I was reminded of the old English proverb that states "necessity is the mother of invention". Which, according to the Oxford Dictionary is "when the need for something becomes imperative, you are forced to find ways of getting or achieving it". If I may dare say that the COVID-19 calamities have had a positive effect, I would claim that we are all experts in remote working by now, spending hours every day in large and small Teams- and Zoom meetings, storing our common files in shared cloud-solutions.

However, I must say I missed the social aspect of the annual CIRFA Conference at Sommarøy this year. But in fact, the conference itself turned out to work quite well in its new virtual format. Great thanks to Andrea for managing the event in such an excellent manner. Another positive aspect is of cause the low carbon footprint of such a virtual conference, with allows participants to join from all over the globe without travel. As far as I can judge, the scientific work of CIRFA is progressing well despite the COVID-19 challenges and is being highly recognized by the participating partners and the research council.

As the future operator of the Wisting-field, which will be the most northerly producing field in Norway, OMV realizes that the output of CIRFA's work is of great importance for us to operate the field safely. Our ambition is to operate the field with low manning and high levels of autonomy utilizing the most advanced technical solutions, including onshore control and monitoring, integrated operations and remote sensing technology.

The number of publications resulting from CIRFA's scientific research is impressive. What is even more impressive is the fact that much of what has been achieved by the scientists has already been implemented in operational solutions, especially with MET Norway and KSAT. From what I can see, there is more to come. The good thing about CIRFA is the fine mix of academia and public/private institutions and -companies that makes such a direct application of the results possible.

From the very beginning of CIRFA, I have urged that we should seek all opportunities to implement the scientific results into operational and commercial applications to the fullest extent possible. I am very pleased to see that this has already happened to such a large extent. I am confident that even more of the proposed solutions will soon be qualified for commercial use.

Keep up the good work and stay safe.

Best regards,
Svein Olav Drangeid (OMV)

Foreword

Despite 2020 being a very unusual year, CIRFA has in fact had good progress on all research areas. Due to travel restrictions, we have less nice images to show from international conferences at spectacular places around the world, as most conferences were organized online or postponed. One of the conferences we enjoy visiting the most, IGARSS, was to be held at Big Island Hawaii in 2020 – an attractive and warm place. To the disappointment of many, certainly the researchers residing in the often chilly Arctic, it was held digital instead. The same with our own conference – the Annual CIRFA Conference, which usually is held at the beautiful venue of Sommarøya. Unfortunately, we could not meet there this year. However, the advantages with digital meetings and workshops are that they allow researchers who cannot travel to join, and are more inclusive towards students on a tighter budget. Moreover, we also have fewer scenic images of scientists on exiting fieldwork collecting ground-truth data for algorithm validation, since many of the field campaigns we planned to join were cancelled.

However, it seems like many CIRFA researchers exploited the situation with closed borders to concentrate on more tedious tasks like data analysis and paper and funding application writing. 2020 has been a record year in terms of published papers, with around 25 peer-reviewed papers, and 13 applications submitted to the Research Council of Norway and European Commission with CIRFA researchers in the lead or accompanying the projects. CIRFA has also been present at several important digital conferences, including IGARSS-2020. In fact, when it comes to producing papers and conference contributions, CIRFA has already reached the goals promised in the proposal for the Centre.

We have had two PhD defenses in 2020, Sindre Fritzner (UiT) and Richard Hann (NTNU). Both are continuing their scientific careers within their research fields, Sindre as a Postdoc at UiT funded by CIRFA, and Richard at NTNU funded by a new research-council project.

The annual reports of CIRFA showcase in text and images the diverse set of activities the CIRFA-team has been involved in through the years. One characteristic that is often highlighted is multi-disciplinarity. This is to a large degree the nature of remote sensing research, and a nice feature with the SFI-program is that it facilitates and enables collaboration across disciplines. In CIRFA, physicists work with modelers, meteorologists, and data analysists, and the Centre's area of expertise ranges from complex scatting physics and understanding of SAR image formation to Big Data analysis and Artificial Intelligence.

Remote sensing is a field characterized by rapid technological development. New and improved sensors are introduced, and constellations of platforms and sensors demand advances in data analysis and information extraction methods. Norway invests large amounts to be member of ESA and EU's Earth observation and navigation programs, Copernicus and Galileo. It is expected that the prize-tag for next finical period 2021-2027 will amount to 3.4 billon NOK. To justify this expenditure and ensure benefit to society, Norway needs to also invest in *research, innovation* and *education*.

In this regard, the SFI CIRFA could be a good model. The coordinated and long-term multi-disciplinary research in CIRFA ensures that the Norwegian society is at the forefront when it comes to analysing and extracting information from satellite data. Likewise, the collaboration between academia and industry facilitates innovations and builds capacities for using the information to provide services to authorities and industries to make knowledge-based decisions. Efforts in education build competence and trains future researchers to the field. So far, CIRFA has educated 32 master candidates, and 6 PhDs (including associated PhDs). Of these, 6 master candidates and 1 PhD work at KSAT, 2 master candidates work at Met Norway, 2 PhDs work at NORCE, and 3 PhDs work at universities, all are consortium members in CIRFA. Hence, as the end of CIRFA is gradually approaching, it is time to think beyond 2023. We think there are many good arguments for CIRFA to be continued in some form, and we suggest a new *National Research and Innovation Centre,* which can carry on some of CIRFA's activities.

Finally, I would like to end this foreword by congratulating us all and giving my sincere thanks to colleagues and partners in CIRFA for all work achieved during the last challenging year.

Best regards,
Torbjørn Eltoft (Center leader)

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Contact information

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

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cirfa.uit.no

Objectives

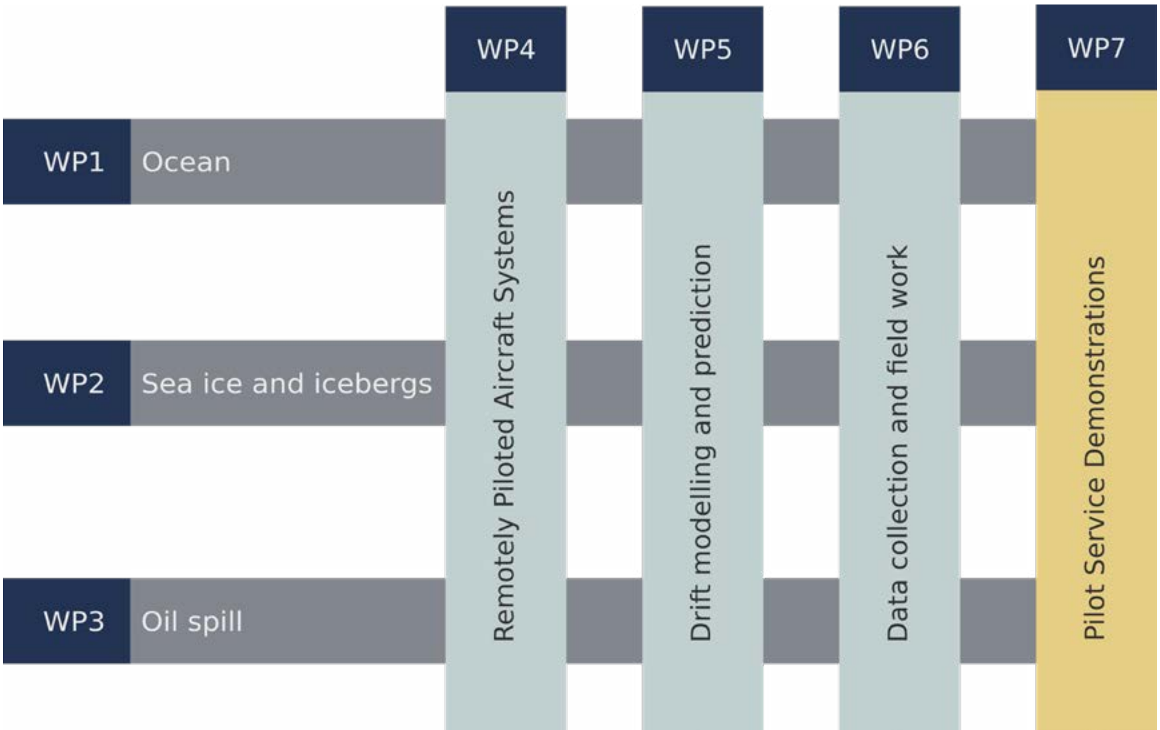
CIRFA is developing remote sensing knowledge and technology that helps to make industrial operations in Arctic waters safe and environmentally friendly.

The research tasks are organized in seven work packages centered around three application areas:

- Ocean
- Monitoring Sea Ice and Icebergs
- Oil Spill Remote Sensing

We focus on improving monitoring, understanding and forecasting of the important geophysical processes in northern and Arctic waters, such as currents, wind fields and sea ice. We also do research on remote sensing of oil spills in ice-covered waters. In addition to these applications, research is done on drone technology, validation of remote sensing data in the field, data assimilation methods and numerical weather forecasting.

CIRFA`s work generates new, innovative algorithms and processing schemes, which foster new services and products. The work packages work together closely for implementing and demonstrating its services and products. Much of the knowledge and technology that is developed in CIRFA has global relevance.



Vision

CIRFA shall become an international leading research center on integrated remote sensing and forecasting for the Arctic, providing:

- An attractive environment to scientists, young researchers and students
- Outstanding scientific contributions
- High-level research training for new researchers in the field

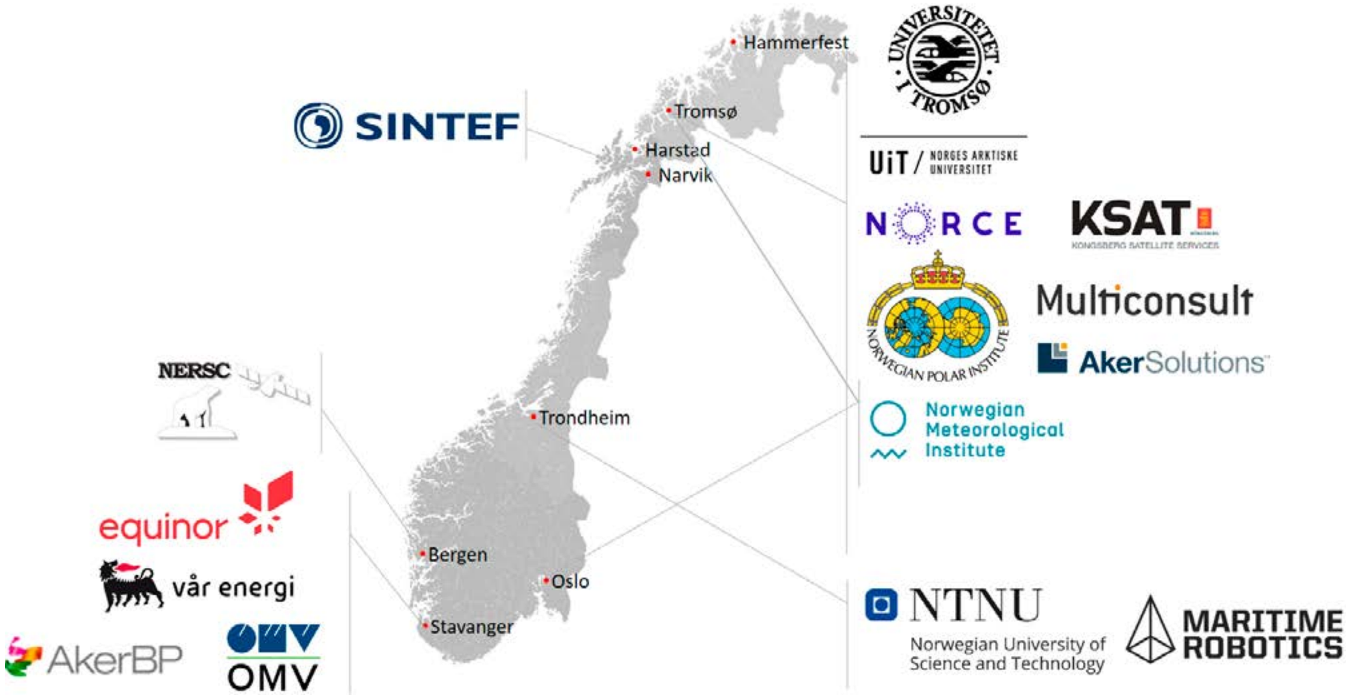
CIRFA shall become a facilitator for collaboration between industry and academia on issues related to remote sensing of Arctic phenomena, providing

- Innovative integrated solutions to challenges in Arctic operations
- Scientific support to industry on issues related to remote sensing technology
- Decision support to policymakers and authorities

Photo: Marius Bratrein.

The CIRFA partners

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



Research partners:

MET Norway

NORCE

Nansen Environmental and Remote Sensing Centre (NERSC)

Norwegian Polar Institute (NPI)

Norwegian University of Science and Technology (NTNU)

SINTEF

UiT The Arctic University of Norway (UiT)

User partners:

Aker BP

Aker Solutions

Equinor

Kongsberg Satellite Services (KSAT)

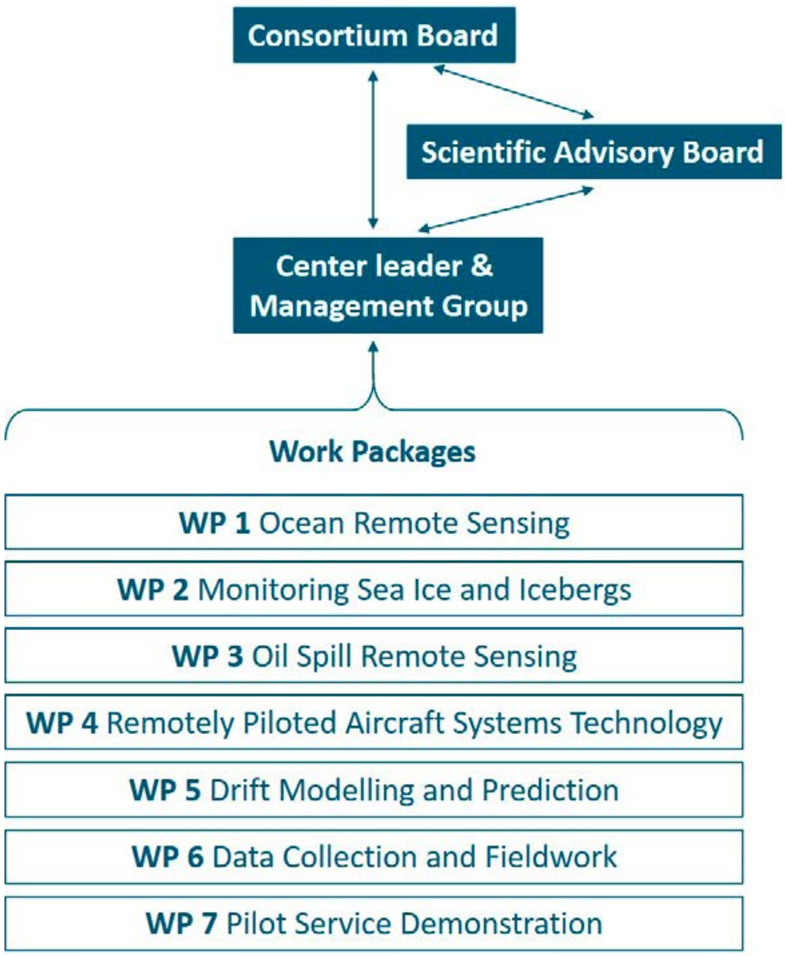
Maritime Robotics

Multiconsult

OMV Norge

Vår Energi

Organisation



Consortium Board

The CB is CIRFA's main decision-making body. The CB consists of representatives from the user partners and research partners. The CB guides the overall direction of the Centre. During the CIRFA General Assembly Meeting in October 2020, it was decided that Richard Hall (Equinor) will take over the chair of the Board from Arne O. Smålas (UiT).

Richard Hall (Chair)
Equinor

Kjell Arild Høgda
NORCE

Edmond Hansen
Multiconsult

Terje Solheim
AkerBP

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

Jan Petter Pedersen
KSAT

Harald Steen
Norwegian Polar Institute

Scientific Advisory Board

The Scientific Advisory Board (SAB) consisting of international experts with outstanding reputations in the relevant fields has been established to ensure excellence in research. The SAB will provide scientific input, review progress reports and provide support for networking and internationalizing of the centre's activities. James Maslanik (University of Colorado in Boulder, Colorado, USA) has decided to leave the SAB at the end of 2019. CIRFA thanks him for his dedicated work and valued advice.

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

Charlotte Hasager
Technical University of Denmark (DTU)

Henning Skriver
Technical University of Denmark (DTU)

CIRFA Management Group

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

Center leadership group

The center leadership consists of center leader Torbjørn Eltoft, deputy leader Camilla Brekke, head engineer Thomas Kræmer and project coordinator Andrea Schneider.

Torbjørn Eltoft
Center leader

Camilla Brekke
Deputy leader

Andrea Schneider
Project coordinator

Thomas Kræmer
Head engineer

Research Fellows

Silje Christine Iversen
PhD Candidate
The impact of observations in a high-resolution ocean assimilation system for the Norwegian coastal and shelf seas

Cornelius Quigley
PhD Candidate
Determination of the Dielectric Properties of Marie Surface Slicks Using Synthetic Aperture Radar

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

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

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

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

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

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

Salman Khaleghian
PhD Candidate
Scalable computing in earth observation

Ingri Halland Soldal
PhD Candidate
Monitoring Sea Ice and Icebergs

Sophie Kühnlenz
PhD Candidate
Monitoring Sea Ice and Icebergs

Marianne Myrnes
PhD Candidate
Oil Spill Remote Sensing

Martine Espeseth
Post doc
Oil spill remote sensing

Anca Cristea
Post doc
Sea ice classification from multimodal remote sensing data

Sindre Markus Fritzner
Post doc
Machine-learning and dynamical models for sea-ice forecasting

Habib Ullah
Post doc (ExtremeEarth)
Deep learning for sea ice classification

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

Malin Johansson
Researcher
Using satellite images to study Arctic sea ice and oil spills

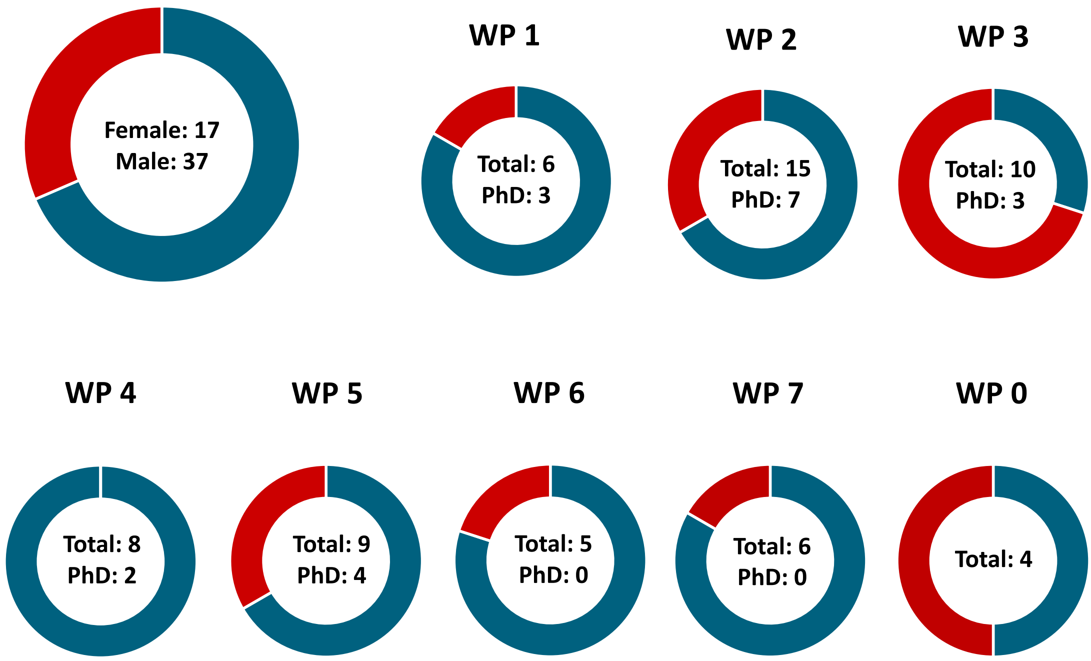
Polona Itkin
Researcher
Sea ice deformation and its impact on the sea ice mass balance

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

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

Thomas Kræmer
Head Engineer
Supporting development and pilot demonstrations across work packages

Jelte van Oostveen
Head Engineer
Implementing an algorithm for sea ice drift retrieval and supporting CIRFA researchers



CIRFA is proud to have a good gender balance in a STEM (science, technology, engineering and mathematics) subject. Red colors represent female team members, blue colors represent male team members.

2020 in brief

January

During the **Arctic Frontiers Conference** under the theme "The Power of Knowledge", CIRFA was well represented with multiple talks and in the organizing committee of the APECS Nansen Poster Awards.

February

A **Winter School on interpreting sea ice signatures in SAR imagery** with presentations, workshops and discussions attracted 25 participants.

The ***CIRFA Young Scientist Forum 2020*** was held on February 27th and 28th in Tromsø under the theme "Communication – Cooperation – Career & Care."

Camilla Brekke visited the **California Institute of Technology**, U.S., where she gave a presentation on behalf of UiT's Faculty of Science where CIRFA work was included. Martin Ludvigsen from the Nansen Legacy project was also present.

March

SIDRiFT/CIRFA researchers return from the final leg of the **international Arctic drift expedition** into a world that has changed.

May

Sindre Fritzner successfully defended his PhD "On sea-ice forecasting".

Image credits: Arctic Froniers, MOSAiC, UN, Renate Ovesen (Hemis), Sindre Fritzner, Richard Hann (NTNU), Marius Bratrein (NPI), NFR, AMERSIE
UiT Graphics support, Rudi Jozef Maria Caeyers

Richard Hann successfully defended his PhD on "Atmospheric Ice Accretions, Aerodynamic Icing Penalties, and Ice Protection Systems on Unmanned Aerial Vehicles".

July

August - September

A **research cruise** with R/V Kronprins Haakon to the Fram Strait for data collection and ground validation was successfully conducted.

The **CIRFA Annual Conference** takes place in a fully digital environment over three days, with > 50 participants each day. The **Scientific Advisory Board** meeting followed the conference.

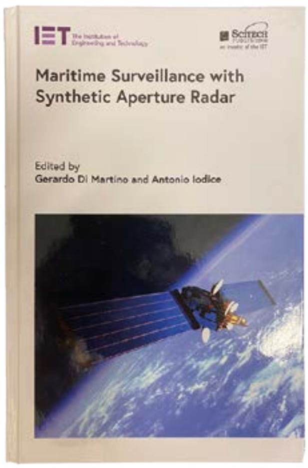
October

The Norwegian Research Council conducted a digital **Site Visit.**

Forskningsrådet
The Research Council of Norway

November

WP 2 and 3 researchers contributed to **a new book on Maritime Surveillance with Synthetic Aperture Radar** that was published in November.



amersie 2020

IEEE AMERSIE School on *"Advanced methods for remote sensing information extraction"*

Research Highlights

Ice extent in sub-arctic Norwegian fjords

PhD Fellow Megan O'Sadnick has studied fjord-ice extent in North-Norwegian fjords and coastal waters by analyzing time series of optical satellite images. A total of 386 fjords and coastal areas were outlined and grouped into regions to assess seasonal and long-term trends in ice cover. The findings showed no statistically significant trend in ice extent over this period of time. Of the 386 areas outlined, 47 fjords/coastal areas held >5 km2 of ice at least once between 2001 and 2019, but there were significant variations between regions and years. Ice extent was assessed through comparisons to three weather variables – freezing degree days (FDD), daily new snowfall and daily freshwater supply from rainfall plus snowmelt. *Six out of ten regions* were significantly positively correlated ($p < 0.05$) to FDD. In addition, ice in *two regions* was significantly positively correlated to daily new snowfall, and in one region negatively correlated to rainfall plus snowmelt. The importance of fjord geometry and bathymetry as well as other weather variables including wind were also explored. The work illustrates the importance of knowing what factors, and combinations of factors, are most likely to lead to ice formation in each region or fjord, and how these allow for understanding of the properties of the ice, such as thickness and porosity.

Read more: O'Sadnick et al.: *"Ice extent in sub-arctic fjords and coastal areas from 2001 to 2019 analyzed from MODIS imagery"*, Annals of Glaciology, June 2020.

Estimating sea surface currents from Sentinel-1 SAR observations

Knowledge of ocean surface currents is crucial in many applications, such as tracking of oil spills and marine debris (e.g., plastic), search and rescue operations, and fisheries. Traditionally, surface currents are studied using shipboard measurements or trajectory of buoys drifting within the surface water. Despite their good accuracy, these measurements are costly to collect and irregular in time and space. The Doppler shift recorded by a radar placed on board of a satellite can be used to provide systematic snapshots of the radial (i.e. the component along the radar's line-of-sight) surface currents over vast areas of the ocean. However, these observations must be evaluated before they can be used in applications or assimilated into numerical forecast models. In a recent study, researchers at CIRFA evaluated observations of the Norwegian Coastal Current acquired by the Sentinel-1 satellite in October–November 2017. Satellite observations were compared with collocated coastal radar and ocean surface drifter data. The analysis shows that distinct patterns of the surface current can be systematically detected in the Sentinel-1 data. The accuracy of the observations is within the range of user requirements and shows a mean bias of 0.1 m/s and a root mean squared deviation of 0.24 m/s compared to land-mounted HF-radars. The importance of accurate information about wind field and ocean waves for analysis of the radar observation is underlined. The performed study demonstrates that the use of Sentinel-1 SAR observations for the ocean surface current retrieval is a promising technology, which in may have high impact on e.g. future modelling activities.

Read more: Moiseev et al.: "*Evaluation of Radial Ocean Surface Currents Derived from Sentinel-1 IW Doppler Shift Using Coastal Radar and Lagrangian Surface Drifter Observations*", JGR Oceans, 2020.

Estimating physical sea ice properties from wide-swath Sentinel-1 data

This work describes how the learning capabilities of new machine learning (ML) algorithms can be used to overcome the trade-off between the *large coverage-dual polarimetric* and *small coverage-quad polarimetric* synthetic aperture radar (SAR) data. The SAR sensor onboard the Canadian satellite Radarsat-2 (RS2) allows for quad polarimetric (quad-pol) observations, which enables us to generate parameters that are correlated to sea ice characteristics, such as surface roughness and salinity. However, the swath-width of quad-pol RS2 scenes is too small to be of practical use in operational sea ice monitoring. On the other hand, the Copernicus Sentinel 1 (S1) satellite provides large coverage, the dual-pol scenes, which are extensively used by operational Ice Centers in their services. Dual-pol SAR data is known to contain less target information and does not allow us to retrieve the same detailed sea ice information as quad-pol data.

CIRFA researchers have demonstrated how a functional relationship between coincidently obtained by RS2 and S1 data can be learnt by ML algorithms during a training process. The trained models are subsequently shown to be able to infer 'proper' estimates of the learnt parameters on new large swath, dual-pol S1 data, a property known as the "generalization capability" in ML terminology. Hence, the paper illustrates how the advances in the ML domain can potentially help to achieve improved, cost-effective, large-scale sea ice monitoring from free and open dual-pol S1 data, which at the outset requires full quad-pol observations.

Read more: Blix et al., "*Machine Learning for Arctic Sea Ice Physical Properties Estimation Using Dual-Polarimetric SAR Data*", IEEE Transactions on Geoscience and Remote Sensing, 2020.

A free-floating oil experiment in the open ocean

The scientific results presented in this paper are of relevance for agencies providing and using oil spill monitoring services and organizations engaged in oil spill contingency and preparedness planning. In particular, we present the results from a free-floating oil spill experiment in the open ocean.

We look at ways in which to characterize mineral and soybean oil spills through integration of oil drift simulations, data collected from imaging sensors in air and space, and data collected locally on-site. Both oils are similar in their viscosity and hence behave similar in their drift patterns. The OpenDrift trajectory model developed in WP 5 is used to compare oil drift simulations (OpenOil), applying various configurations of wind, wave, and current information, with the observed slick positions and shape.

The results of this experiment document that it is possible to obtain good agreement between predicted drift and observations. Our findings indicate that biological oil potentially could replace mineral oil in oil spill contingency and rehearsal campaigns as a more environmentally friendly alternative, but this result is only supported when the purpose is to study oil spill monitoring and trajectory simulations. This study also reveals differences in oil detection capabilities between the different sensors studied. For example, F-SAR appears to be more sensitive to thinner oil and detect a larger extent, and differences between the thinner and thicker parts are observed.

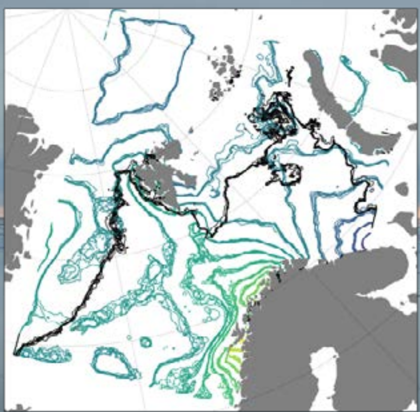
Read more: Brekke, C. et al.: "*Integrated analysis of multi-sensor datasets and oil drift simulations – a free floating oil experiment in the open ocean*", JGR Oceans, 2020.

Photo by Anca Cristea

Innovation Highlights

Ensemble Prediction System for Barents-2.5 ocean circulation and sea ice model

Similar to atmospheric weather prediction, forecasting of ocean currents and sea ice requires time- integration of numerical ocean models. First, an analysis of today's ocean state is obtained by merging observations and past model states. The analysis is then projected into the near future using the physical laws that are implemented in ocean and sea ice models. Observations, the analysis, and numerical models all bear uncertainty – and due to the ocean circulation's chaotic nature (widely known as butterfly effect) the uncertainty grows during the time-integration of models. To provide users with useful forecasts, it is therefore important to quantify this uncertainty, and issue forecasts with a set of possible outcomes. This is achieved with ensemble prediction systems, in which multiple realizations of the ocean's future state is calculated. Ensembles are particularly relevant for predictions of sea ice edge and meso-scale ocean currents, which bear a high degree of uncertainty from observations and model physics.



Ensemble prediction using the Barents-2.5 ocean circulation and sea ice model. Black lines: Isoline of 50% Sea ice concentration. Colored lines: Sea surface height in 20 cm steps. Shown are 6 different realizations of a 12-hour forecast from the operational model initialized at 2021-03-11 00:00.

Within CIRFA WP 5, researchers at MET Norway (Johannes Röhrs and Jostein Bræandshøi) and UiT (Sindre Fritzner) have set up an operational ensemble prediction system using the Barents-2.5 modeling system resolving the meso-scale ocean circulation and sea ice dynamics. The model predicts 24 realizations of the ocean's future state for the following 3 days. We believe this system will be particularly useful in sea ice forecasts for tactical application by ships, and iceberg drift simulations (with WP 7). As each individual model realization suffers from very poor predictability for such forecasts, the ensemble of predictions can be used to assess the certainty of a forecasts, or to detect a most likely iceberg drift scenario based on satellite detection algorithms (with WP 2). The figure above shows an example of 6 ensemble members for a 12h-forecast. Each ensemble member (individual lines) shows a slightly different position for the sea ice edge and sea surface height isolines.

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

A complete representation of the Arctic cryosphere has historically been restricted by its remoteness, large extent, and restrictions in measurement methods and equipment. Here, remote sensing of snow-cover is a central method to improve the current knowledge of the Earth's ecosystem, and hence a critical component in cryospheric models. The use of drone-borne radar systems has seen considerable advances over recent years, allowing for the application of drone-mounted remote sensing of snow properties. In WP 4, we have developed an ultra-wideband radar system for drone-mounted snow measurements. The includes the technical implementation, initial testing, field trials, and method development for more advanced radar data analysis to estimate snow parameters. The WP has been developing new lightweight and high-bandwidth radar systems, intending to understand the limitations of design parameters for drone-borne radar systems and how these parameters influence the ability to measure snow conditions. Such understanding includes antenna theory and ultra-wideband radar theory, where most design choices involve compromises.

An integrated approach to account for class-dependent Incidence Angle and a variable Noise Floor

It is a well-known fact that radar backscattering from the Earth's surface is dependent on the angle the radar pulse hit the surface. This angle is defined as the incidence angle (IA) of the electromagnetic wave, and the dependency is tightly connected to the type of the surface target. An appropriate treatment of this IA sensitivity is mandatory in order to enable separation between classes, such as ice types, and for classification algorithms to be able to separate between different targets surfaces. CIRFA researchers have developed and implemented a completely new approach to analysing sea ice SAR data (Cristea et al, 2020; Lohse et al, 2020), which actively integrates type-wise incidence angle dependencies into the classification process.

Additionally, a variable noise-floor (the mean system noise level) across range (or azimuth) is also more naturally incorporated into the modelling by modifying the class mean function, thus keeping the full dynamic range of the data values, allowing for statistical optimisation of the imprecisely noise-floor given with the meta data. This represents a re-positioning of where the IA and noise level behavior of SAR data is considered - *from an image-wise pre-processing correction to a class specific property*. The consequence of this paradigm change is a neat framework that overcomes the limitation of the previous one common backscatter *IA-change-rate-for-all*, and a set-up that allows *different rates for each class*, estimated during segmentation/classification process itself. The solution rounds off the many research papers that have measured different rates for different classes and puts this knowledge into practical use. The methodology is considered to impact many aspects of SAR data analysis and applications, including fundamental scattering physics, texture and full polarimetric features analysis, polarimetric decomposition analysis and land surface topography corrections.

Photo by Anca Cristea

WORK PACKAGE 1

Ocean Remote Sensing

WP leader
Harald Johnsen
Professor, NORCE

Team members

Artem Moiseev
PhD candidate, NERSC

Geir Engen
Senior Researcher, NORCE

Heidi Hindberg
Senior Researcher, NORCE

General perspective on applications for ocean surface studies and scientific drivers

Traditionally, coastal zones are areas with increased human activity, such as fishing, aquaculture, vessel and ferry traffic, offshore industry, recreational activities and others. In coastal areas, ocean surface wind, wave, current show higher heterogeneity due to the coastline, bathymetry, orography, and land/sea surface temperature contrasts. Especially ocean surface winds are used to estimate momentum transfer (surface stress) between atmosphere and ocean and are important in describing ocean circulation and transport. The wind field is required to estimate the ageostrophic (Ekman) component and consequently linked to the horizontal and vertical transport and mixing.

Recent research indicates that processes at sub-mesoscale impact ocean stratification, nutrient supply, primary production, marine ecosystems and carbon uptake. Modelling and prediction of meso- and sub-mesoscale processes (i.e., current jets, eddies, thermal fronts) in coastal areas are very challenging and not well understood. Still, numerical models are the essential tool for predicting drifts for instance of chemical (oil spill, plastic), biological species (fish lice, fish eggs). A synergetic used of satellite data, in-situ observations and numerical models can provide new insight into atmospheric boundary layer processes and a step forward in coastal ocean modelling that benefits the society.

The Marginal Ice Zone (MIZ) is becoming increasingly important for fisheries, offshore industry and tourist cruises. Several recent, unexpected and dangerous happenings occurred due to rapid change of sea ice formation and drift. Better wind predictions in the MIZ can help improve the prediction of sea ice formation and drift. As for coastal areas, the MIZ is a challenging area for estimating reliable SAR winds. In the MIZ, the presence of sea ice will further complicate the estimated SAR wind field. At the same time, wind roughening of the ocean surface is a major source of ambiguity in the identification of sea ice in SAR scenes. With the required resolution of the SAR wind field (1 km) and sea ice information for marine applications (<1 km), a synergetic use of Sentinel-1 EW/IW dual-pol channels to infer wind and sea ice will provide a step forward for operational marine applications in the MIZ and provide better forcing to the prediction of the sea ice drift.

Objectives and motivation

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.

Synoptic maps made from space of ocean surface winds, waves and currents are core inputs to better characterization and parameterizations of oceanic mesoscale and sub-mesoscale dynamics, as well as important contributions to the understanding of ocean-atmosphere interaction and research on numerical modeling. The newly launched Sentinel satellites will greatly improve the capabilities of providing such high-resolution information from space due to the enhanced time and space coverage offered.

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

Key research tasks

- Develop physical and statistical methodologies 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 2020

The R&D has been concentrated on the following three key activities: 1) Assessment of Sentinel-1 ocean coastal and global current measurements, 2) Preparing peer-review publications, 3) Operationalization of met-ocean processing system at Kongsberg Satellite Services (KSAT) based on achievements from CIRFA R&D.

The R&D on the retrieval and geophysical validation of coastal current retrieved from Sentinel-1 data has resulted in two peer review papers published in JGR Ocean, (Moiseev et al. 2020a, and Moiseev et al. 2020b). A third paper on the gyro-based Doppler calibration and surface current retrieval from Sentinel-1 Interferometric Wide (IW) swath mode acquired over Norwegian coastal area is under review process. These activities are also preparations for the surface current assimilation experiment to be performed during 2021 from the Skagerrak area (see Figure 1). A PhD study on polar lows is progressing, and several interesting cases are under analysis utilizing the dual-pol mode of Sentinel-1.

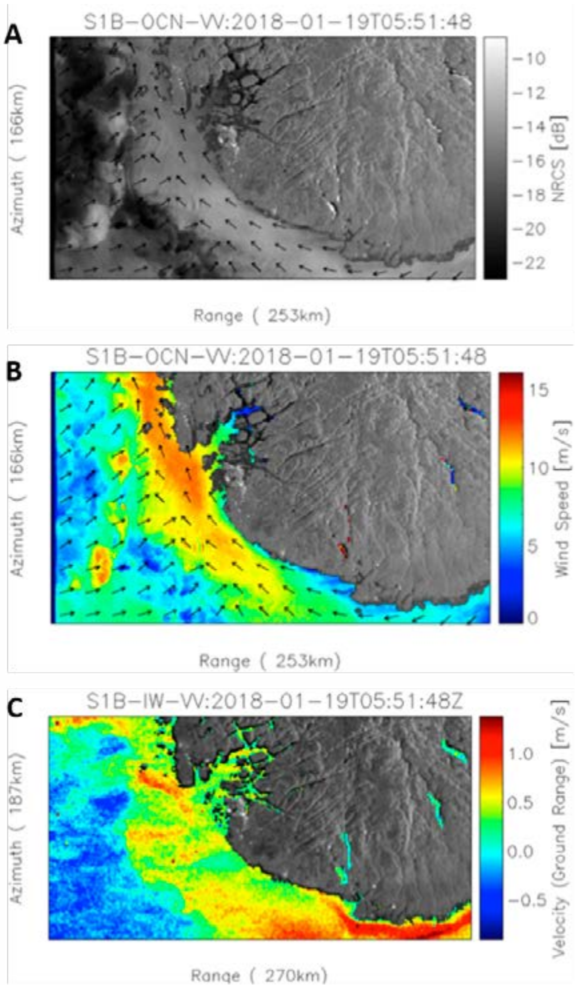
The operational met-ocean processing system established at KSAT has been upgraded and extended to better support user and R&D needs. This includes the processing of wind field and ocean current field as for oil spill and ship detection services that KSAT supplies in near real-time to the European Maritime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

Relation to users, stakeholders and research communities

The WP 1 team has a close cooperation with the European Space Centre (both ESRIN (Italy) and ESTEC (The Netherlands)), as well as with research institutes in Europe such as Ifremer (France), OceanDataLab (France), CLS (France), TU Delft (The Netherlands), Aresys Ltd (Italy) and DLR (Germany). The research activity has been presented at various international workshops/conferences such as EGU and IGARSS. The polar low activity has also achieved external funding (ESA) to develop machine leaning techniques for polar low detection and tracking from SAR data.

Harmony mission

The research activity on ocean surface dynamics has led to a joint effort between CIRFA, NORCE, ESA and Airbus Ltd for testing a new satellite mission. The Harmony concept envisions two new identical satellites to fly in a convoy with an existing Copernicus Sentinel-1 satellite. Each Harmony satellite is being designed to carry a synthetic aperture radar as its main instrument to monitor ocean, ice and land dynamics. Working together with Sentinel-1's radar, the new satellite mission is expected to provide new data to measure 3D changes in the shape of the land surface such as those related to landslides and subsidence activities, earthquakes and volcanic activity, thereby contributing to risk monitoring. Both Harmony satellites would also carry a multibeam thermal-infrared instrument, which in the presence of clouds can detect cloud movements. In the absence of clouds, this instrument measures temperature differences at the sea-surface. The current development phase includes feasibility assessments, the design of the satellite platform and instruments, test flight operations, technology developments and investigations on how best to exploit the data. CIRFA and NORCE in collaboration with ESA and Airbus Ltd will assess the performance of the new passive follower satellites to Sentinel-1.



*Sentinel-1 IW data acquired over the south-west coast of Norway in a descending mode. **A)** Intensity image. **B)** Ocean wind field. **C)** Radial velocity field. Note the strong signature (red colour) of the Norwegian Coastal Current in lower right corner of image c. Image: ESA/EU Copernicus and NORCE.*

WORK PACKAGE 2

Monitoring Sea Ice and Icebergs

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WP leader
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Sophie Kühnlenz
PhD candidate, UiT, Until September 2020

Ingri Halland-Soldal
PhD candidate, UiT, Until April 2020

General perspective on monitoring sea ice and icebergs

The progressive decline of sea ice in the Arctic, observed in the last decades particularly for the summer minimum ice extent, is well documented and repeatedly reported in the public media. The data collected by Earth observing satellites are essential for understanding the reasons for this decrease. Satellite and airborne monitoring of sea ice conditions with imaging radar is a requirement for studying the interaction of ocean–ice–atmosphere on local and regional scales, and for following the movement and deformation of the ice. Radar images are also needed for operational production of ice charts, which show the local distribution of open water areas and different ice types and may also provide information about ice concentration, floe sizes, and ice thickness. Ice drift is displayed in maps of vector fields, often supplemented by measures of the degree of ice deformation.

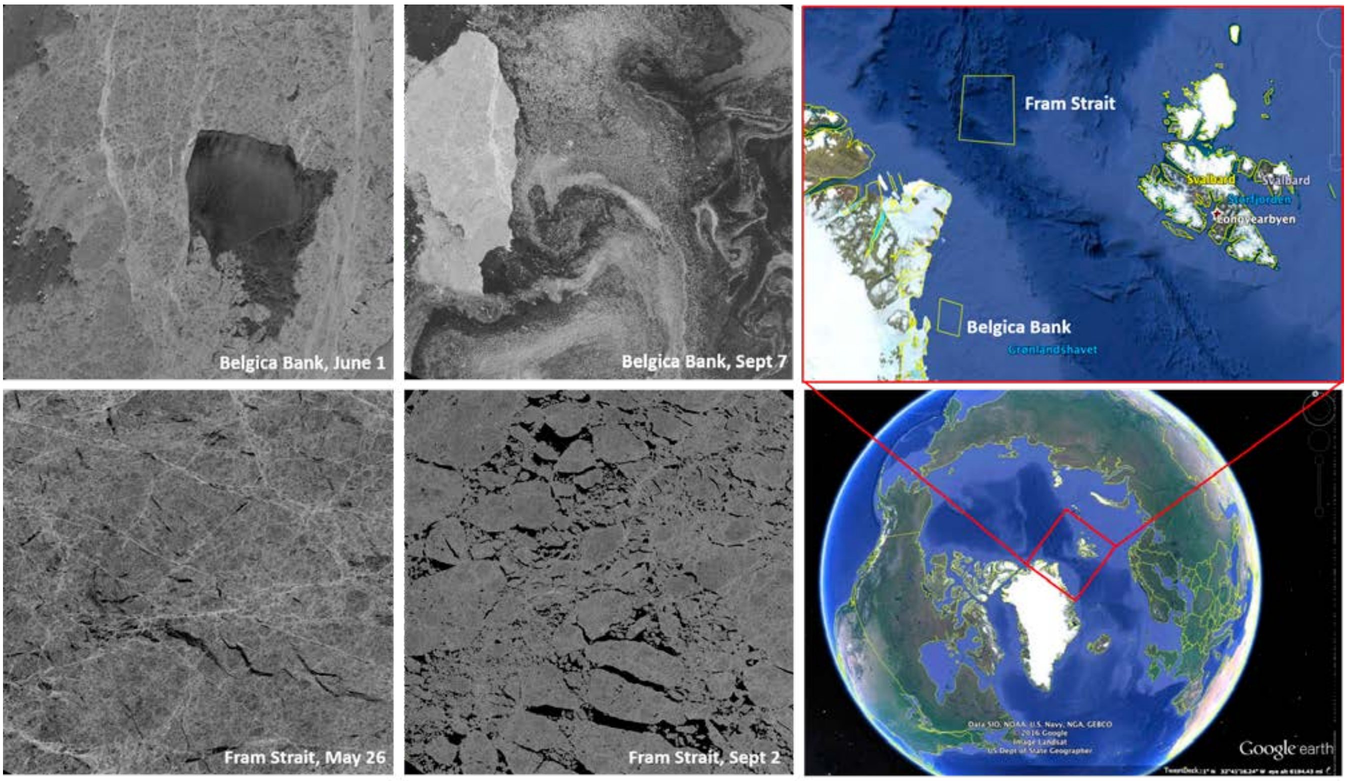
Also important, but still very challenging, is the detection and tracking of icebergs. The threat that icebergs pose to ships in the open ocean has been in the public awareness ever since the sinking of the Titanic. Ice charts and information on ice movements and iceberg occurrences are essential for the safety of ship traffic and offshore operations, and for several specific scientific issues. Examples for the latter are changes in the areal fractions of thick multi-year ice and thin young ice, the frequency of leads in sea ice as locations of strong heat fluxes, changing regional ice drift and deformation patterns, and processes in the lower atmospheric layer due to interaction between wind and ice of varying surface roughness. Iceberg calving is influenced by the increase of temperatures in the Arctic and contributes to the freshwater flux into the Arctic ocean, and tracking of icebergs reveals patterns of ocean currents. Icebergs may as well affect the growth and areal distribution of sea ice and the local primary biological production.

Objectives and motivation

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 detection and characterization of icebergs. Requirements regarding the potential 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 satellite images from optical and thermal channels are employed. Studies focus on semi- and fully automated sea ice classification, on retrieving parameters quantifying sea ice drift and deformation, and on observing temporal and spatial variations of sea ice conditions. The methods used include multivariate statistical analysis, anomaly detection, and machine learning/deep learning techniques. WP 2 and WP 3 are jointly working on issues regarding detection of thin ice as look-alike of oil spills and the use of compact polarimetry. Testing and validating 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 modeling activities of WP 5 to produce information products for the pilot services of WP 7.

Key research tasks

- Develop algorithms for sea ice type classification.
- Determination of ice drift and deformation.
- Iceberg detection and tracking.



Test sites "Fram Strait" and "Belgica Bank" for the ESA project L-C-Ice. Here, ALOS-2 PALSAR-2 images from 2019 are shown, acquired in late spring at temperatures below 0°C and late summer under melting conditions. Dark areas in the images are open water or thin ice, sea ice appears grey or almost white. In the ***upper left panel (Belgica Bank)****, small bright spots in the left part of the SAR scene are icebergs. In the center, an extended area covered with different stages of young ice is visible, whereas the light grey area at the lower right corner is interpreted as open water roughened by wind. In the upper right panel, the effect of disintegration of the ice cover is shown, which results in small pieces of ice that are carried by ocean currents and eddies. The large ice floe to the left appears bright because of strong backscattering. In the* ***lower left panel (Fram Strait)****, bright lines are caused by radar backscattering from ice ridges or narrow areas of brash which consists of ice fragments of less than 2 m in size. The lower right panel reveals that the radar intensity contrast between deformed and smooth level ice is lower, which is due to the wetness of the ice surface and the snow during summer. Investigations of the images are ongoing. Image acquisition modes are: Stripmap Mode, pixel size 6.25 m, swath width 70 km, HH-polarization. The ALOS-2/PALSAR-2 data was provided by JAXA through the 2019 to 2022 mutual cooperation project between ESA and JAXA on Using Synthetic Aperture Radar Satellites In Earth Science and Applications.*

Achievements in 2020

Main R&D activities were focused on sea ice classification. Progress was made for including the incidence angle sensitivity of the measured radar intensity as an additional class property for different ice types and thus improve their separability in semi- and fully-automated classification algorithms. This was tested both on Sentinel-1 and RADARSAT-2 imagery. Furthermore, the incidence angle sensitivity of selected texture parameters was investigated, since they improve classification particularly when using single-frequency single- or dual-polarization data such as from the Sentinel-1 SAR, which is one of the major data sources for the operational sea ice services. Prototypes for optimised noise-floor integration in the statistical modelling were developed, but the results are not yet robust, and full evaluation is ongoing. Other alternatives for improving sea ice mapping that are based on concepts of information theory and deep learning were developed and described in different papers that have been submitted for publication. One advantage of those methods is their large flexibility to adapt to locally varying imaging conditions and ice properties. Team members have also worked on an assessment of the influence of seasonal variations and incidence angle sensitivity for sea ice classification using L-band SAR. In a book chapter on maritime surveillance using SAR, an overview on recent methods and results in the fields of sea ice mapping and iceberg detection was provided, covering the expertise of the WP-2 team. For a project CIRFA is running for ESA (see below), an extensive literature report regarding the advantages of employing L-band in addition to C-band SAR was finished. Work on the implementation of software for the retrieval of ice drift has made progress, and a paper on the estimation of statistical errors in ice velocity and deformation parameters was published.

- Publication January 2020: Johansson, M., Malnes, E., Gerland, S., Cristea, A., Doulgeris, A.P., Divine, D.V., Pavlova, O. and Lauknes, T.R. (2020) *"Consistent ice and open water classification combining historical synthetic aperture radar satellite images from ERS-1/2, Envisat ASAR, RADARSAT-2, and Sentinel-1A/B."* Annals of Glaciology. 61(82), 40-50. doi:10.1017/aog.2019.52.
- Publication May 2020: A. Cristea, J. van Houtte and A. P. Doulgeris, *"Integrating Incidence Angle Dependencies into the Clustering-Based Segmentation of SAR Images,"* in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 13, pp. 2925-2939, 2020, doi: 10.1109/JSTARS.2020.2993067.
- Publication June 2020: Lohse, J., Doulgeris, A., & Dierking, W. (2020). "*Mapping sea-ice types from Sentinel-1 considering the surface-type dependent effect of incidence angle.*" Annals of Glaciology, 1-11. doi:10.1017/aog.2020.45.

- Publication September 2020: Dierking, W., Stern, H.; Hutchings, J., *"Estimating statistical errors in retrievals of ice velocity and deformation parameters from satellite images and buoy arrays,"* The Cryosphere, 14, 2999–3016, https://doi.org/10.5194/tc-14-2999-2020, 2020.
- Publication November 2020: Singha, S., Johansson A.M., Doulgeris, A.P., (2020), *"Robustness of SAR Sea Ice Type classification across incidence angles and seasons at L-band."*, IEEE Transactions on Geoscience and Remote Sensing, doi: 10.1109/TGRS.2020.3035029.
- Submission of PhD Thesis by Johannes Lohse, December 2020.

Relation to users, stakeholders, and research communities

WP 2 members are closely interconnected with the national and international research landscape through various activities:

In 2020, CIRFA was awarded – within a collaboration with Meteorologisk Institutt (MET) and Norsk PolarInstitutt (NPI) - a project from the Fram Centre "Polhavet" flagship program, named "Automatic Multisensor remote sensing for Sea Ice Characterization" (AMUSIC). Its focus is on the development and investigation of architectures for multimodal remote sensing data analysis in order to retrieve accurate and efficient analysis of sea ice properties. The objective of AMUSIC is to produce a framework to automatically extract reliable information about sea ice from multiple remote sensing datasets. By leveraging different physical principles of acquisition, various sensors (e.g., satellite-based synthetic aperture radar (SAR), passive microwave radiometers, multispectral, airborne laser scans) can grasp different aspects of the sea ice medium. Integrating this information hence enables a new way of understanding sea ice characteristics and dynamics. Taking advantage of the cruises organized by NPI to be conducted in 2021, AMUSIC is expected to increase the robustness of the developed data analysis methods. Within the AMUSIC project awarded by FramCentre, CIRFA will collaborate with DLR, Germany (Suman Singha), Univ. of Pavia, Italy (Paolo Gamba), Grenoble INP, France (Christian Jutten).

In addition, CIRFA was awarded a contract with ESA on the synergistic use of L- and C-band SAR for sea ice monitoring. The project named L-C-ICE started in June 2020 and will finish at the end of 2021. In this project, the WP-2 team works closely with the Department of Space, Earth, and Environment at Chalmers University of Technology in Gothenburg, the ice services in Norway (MET Norway), Denmark, and Canada, and with the International Ice Patrol which is responsible for providing data on iceberg sightings. Besides the literature survey mentioned above, the project includes investigations on matching C- and L-band images acquired at different times through applying results of ice drift and deformation retrievals, and judgements of improvements that can be achieved with a combined use C- and L-band SAR images in automated classification and operational sea ice monitoring.

WP-2 members are involved in the activities of the International Ice Charting Working Group (IICWG). Wolfgang Dierking is leading a task team of the IICWG for supporting the ROSE-L MAG. Malin Johansson and Anthony Doulgeris continued their close collaboration with Dr. Suman Singha from the German Aerospace Center (DLR). In addition, Wolfgang Dierking and Dr. Xi Zhang from the First Institute of Oceanography in Qingdao/China are jointly leading the project "Synergistic Monitoring of Arctic sea ice from multi-satellite-sensors" in the framework of the Dragon 5 cooperation between ESA and the Ministry of Science and Technology (MOST) of the P.R. China. Wolfgang Dierking was also invited to ESA's Ad-hoc expert group for Sentinel-1 Next Generation and continues to serve as a member of ESA's ROSE-L Mission Advisory Group.

ROSE-L, the Radar Observing System for Europe at L-Band is one of the six High Priority Expansion Missions of Europe's Copernicus programme. The satellite radar antenna measures an impressive 11 metres by 3.6 metres – roughly the size of 10 ping-pong tables. With launch planned in 2028, ROSE-L will provide continuous day-and-night all-weather monitoring of Earth's land cover, oceans and ice, and offer frequent images at a high spatial resolution. Since L-band radar signals penetrate deeper into vegetation, soil, and ice than signals transmitted at C-band, ROSE-L is an important complement to the Sentinel-1 C-band radar mission. The European Copernicus programme provides satellite and *in situ* data for Earth observations, as well as a broad range of services for environmental monitoring and protection, climate research, and natural disaster assessment to improve the quality of life of European citizens.

WORK PACKAGE 3

Oil Spill Remote sensing

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Professor, UiT

WP leader
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Research Manager, SINTEF Narvik

Team members

Cornelius Quigley
PhD candidate, UiT
PostDoc from March 2021

Megan O'Sadnick
PhD candidate, SINTEF Narvik/UiT

Martine Espeseth
PostDoc, UiT, starts in a new position at KSAT from April 2021

Malin Johansson
Researcher in the OIBSAR project, UiT, associated with WP 3 & WP 6

Cathleen Jones
Adjunct Professor, NASA`s Jet Propulsion Laboratory, California Institute of Technology, US

Andrea Marinoni
Associate Professor, UiT

Muhammad Asim
PhD student in the Nansen Legacy project, UiT, associated with WP 3

Katalin Blix
PostDoc in the Nansen Legacy project, UiT, associated with WP 3

Anca Cristea
Researcher, UiT, associated with OIBSAR and WP3 CIRFA, from August 2020 WP 2/6 PostDoc at NPI

General perspective on oil spill remote sensing

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 in the vulnerable Arctic regions. At the same time, the risk of major oil spills increases. At the first warning stage of any incident, it is important to detect and characterize these slicks. Mineral oil must be distinguished from other types of surface films, e.g., biogenic slicks, grease ice, low wind fields, and produced water. Produced water is water that is brought to the surface together with oil and gas e.g. at offshore oil and gas platforms, and that still contains some oil when it is released to the sea again, despite treatment.

During oil spill clean-up operations, the authorities need to know where the combatable thicker mineral oil is located, and where it may be moving due to wind and ocean currents. Remote sensing technology is a key solution to this problem, and in particular, radars as they see through clouds and operate during the polar night as well as mid-summer. If an oil spill hits land, it can be devastating for animals and nature as well as coastal settlements and communities. By integrating remote sensing imagery and numerical drift modelling, we can predict where the 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. The migration of oil from underneath the ice up to the surface may be different in fjord ice as compared to in sea ice conditions. This may have an impact in case of a costal-near oil pollution incident.

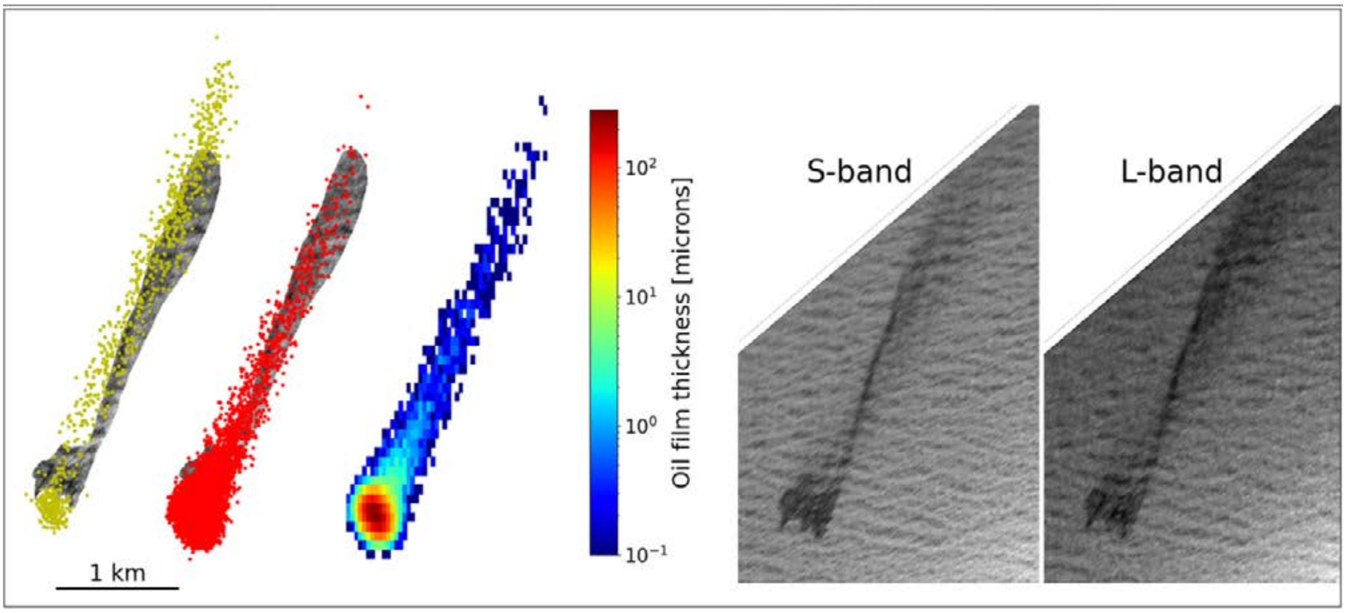
In-situ data and fieldwork are hence of major importance for research to progress in the interdisciplinary field of marine environmental studies and technology development for marine pollution and water quality monitoring. A natural extension of CIRFA`s research on oil spill remote sensing is to include marine primary production and water quality studies based on ocean color, e.g. Chlorophyll-a (chl-a) estimation as an indication of phytoplankton biomass. In this respect, data science and machine learning play a major role.

Objectives and motivation

The objective of this work package is to develop accurate remote sensing information retrieval techniques for reliable oil slick detection and characterization, and to improve modeling of oil behavior and fate in sea ice covered waters.

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.



Graphic from the joint NORSE2019 paper in JGR: Oceans showing a comparison between the simulated oil slick location and extent from an F-SAR imagery. © 2020. The Authors.

Achievements in 2020

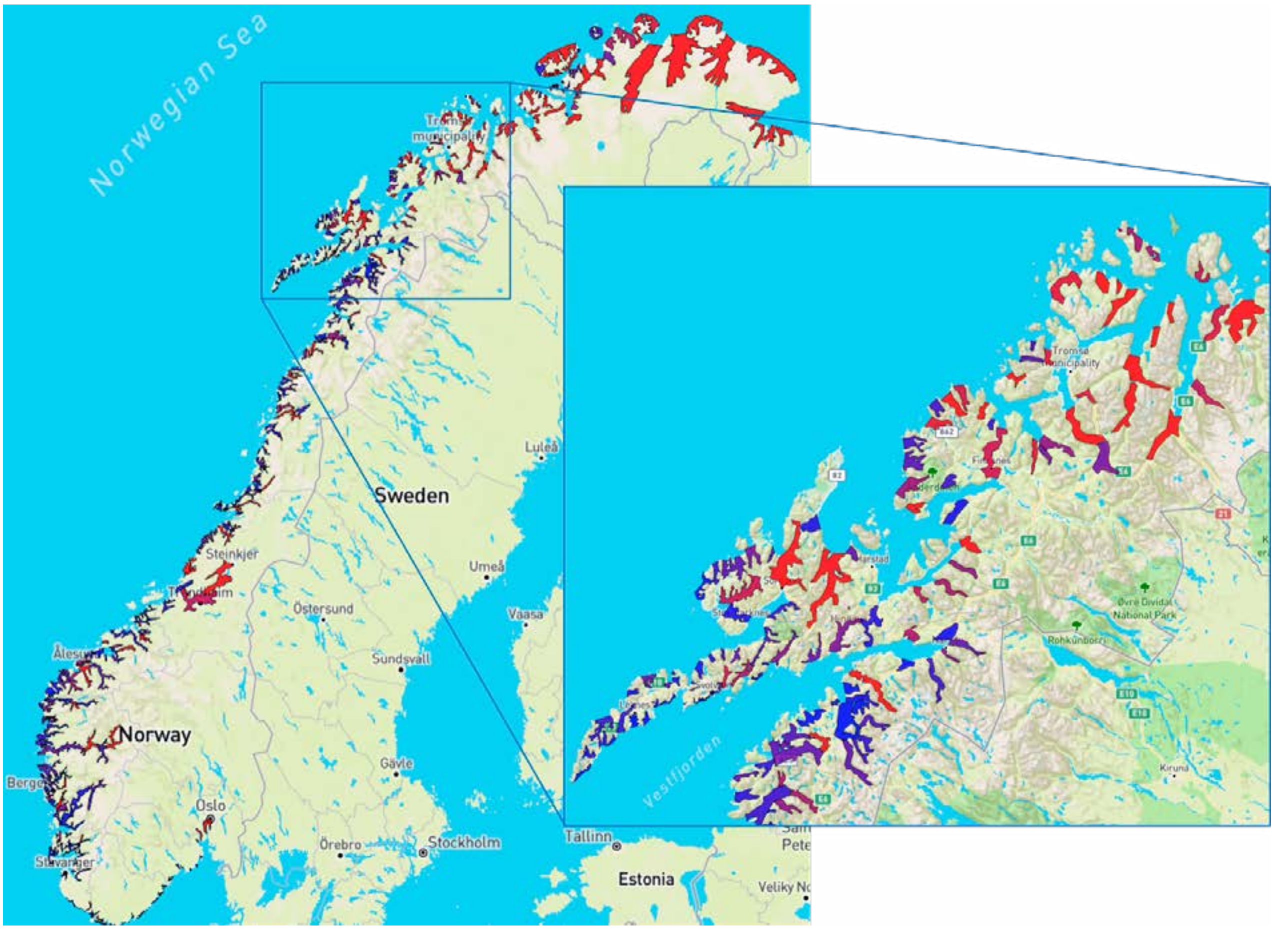
Oil slick and produced water detection

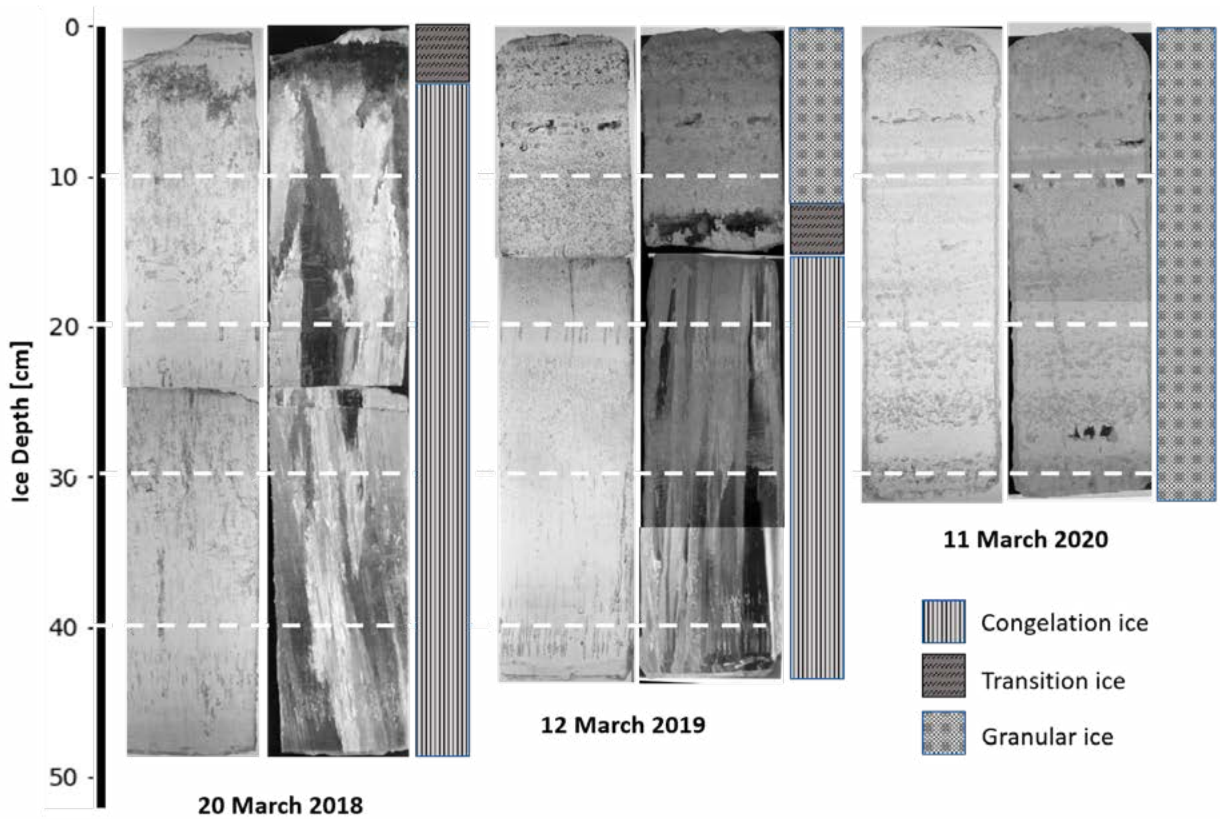
Detecting and differentiating different types of marine surface layers, such as mineral oil spills or produced water, is best done using SAR imagery. Combining image acquisition with fieldwork at sea, where an oil slick can be released and studied such as in the NORSE2019 exercise, ship- and satellite-based observations can be timed and combined to optimize results and equipment testing.

- A joint paper (UiT, MET Norway, DLR) from NORSE2019 is published in JGR (see Figure 5): Oceans. Brekke, Camilla; Espeseth, Martine; Dagestad, Knut-Frode; Röhrs, Johannes; Hole, Lars Robert; Reigber, Andreas. *Integrated analysis of multi-sensor datasets and oil drift simulations - a free floating oil experiment in the open ocean*. Journal of Geophysical Research (JGR): Oceans 2020; Volume 126 (1). ISSN 2169-9275.s doi: https://doi.org/10.1029/2020JC016499. A talk about this paper will be given at EGU 2021 (online).
- PhD student Cornelius Quigley finished writing his thesis in December. The thesis was submitted in January 2021 and has received positive response from the evaluation committee. Quigley will defend his PhD thesis in March 2021. The title of the thesis is: "*Determination of the Dielectric Properties of Marine Surface Slicks Using Synthetic Aperture Radar*".
- PostDoc Martine Espeseth published a paper in IEEE TGRS on the system noise impact in polarimetric SAR imagery of oil pollution: Espeseth, Martine; Brekke, Camilla; Jones, Cathleen Elaine; Holt, Benjamin; Freeman, Anthony. *The Impact of System Noise in Polarimetric SAR Imagery on Oil Spill Observations*. IEEE Transactions on Geoscience and Remote Sensing 2020; Volume 58 (6). ISSN 0196-2892.s 4194 - 4214.s doi: 10.1109/TGRS.2019.2961684. Martine Espeseth left her position at UiT in the fall and continues at KSAT.
- WP 3 Associated researcher Malin Johansson had a paper published in IEEE JSTARS on the topic of distinguishing mineral oil slicks from newly formed sea ice: Johansson, Malin; Espeseth, Martine; Brekke, Camilla; Holt, Benjamin. Can Mineral Oil Slicks Be Distinguished From Newly Formed Sea Ice Using Synthetic Aperture Radar? IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2020; Volume 13. ISSN 1939-1404.s 4996 - 5010.s doi: 10.1109/JSTARS.2020.3017278.
- WP 3`s contribution at IGARSS2020 was: Cristea, Anca; Johansson, Malin; Filimonova, Natalya A.; Ivonin, Dmitry; Hughes, Nick; Doulgeris, Anthony Paul; Brekke, Camilla. Towards automatic detection of dark features in the Barents Sea using synthetic aperture radar. IEEE International Geoscience and Remote Sensing Symposium proceedings 2020. ISSN 2153-6996.

Fjord sea ice work

The PhD project of Megan O'Sadnick focuses on the examination of fjord ice in northern Norway. The project is investigating the spatial and temporal variation of ice thickness, extent, and properties such as bulk salinity and porosity. Ice formation can influence the overall environmental conditions in a fjord from both physical and biological perspectives. The ice properties will also determine its strength, which is relevant for travels across the ice and its interaction with structures. In addition, ice properties influence how pollutants such as oil will behave if emplaced underneath due to spills from ships or larger operations. A map of the fjord ice extend can be found online (https://ndat.no/fjords/ice/), and the ice cores show different ice types. The aim of the PhD project is to improve the understanding of why ice conditions vary between fjords, and its implications for future development in these areas, both in Norway and throughout the sub-arctic.





Variatons in fjord ice over a three-year period: Thick sections of ice cores gathered in Ramfjord, Troms in 2018, 2019, and 2020. For each year, the core is presented backlit, through cross polarized films, and as a schematic with boundaries between ice crystal structure defined.

Fjord ice extent map and examples of inter-annual variability of fjord ice properties in recent years based on Megan O`Sadnick's PhD project. Red regions in the map have seen the most notable ice extent in at least one winter since 2000. The map is available at https://ndat.no/fjords/ice/.

PhD student Megan O'Sadnick published a paper in Annals of Glaciology on the topic of sub-arctic fjord ice: O'Sadnick, M.; Petrich, C.; Brekke, C.; Skardhamar, J. Ice extent in sub-arctic fjords and coastal areas from 2001 to 2019 analyzed from MODIS imagery. Annals of Glaciology 2020; Volume 61 (82). ISSN 0260-3055.s 210 - 226.s doi: [10.1017/aog.2020.34](https://doi.org/10.1017/aog.2020.34)

Ocean Colour

PhD student Muhammad Asim and postdoc Katalin Blix are studying phytoplankton biomass production, or in other words, algae blooms, and their impact on water quality. Remote sensing can also be used as increases in Chlorophyll-a (chl-a) from algae that live near the ocean surface change the color of the water. This work connects CIRFA WP 3 with the Nansen Legacy project, and fieldwork and data collection are an important aspect.

The Trios/Ramses instruments were purchased by UiT and installed on UiTs research vessel Hyas. In the first quarter of 2021 it was moved to the research vessel R/V *Kronprins Haakon*. We are preparing for data collection with this instrument during the Q1, Q2 and the PhD cruises in the Nansen Legacy project in 2021.

Trios/Ramses instruments installed on R/V Kronprins Haakon. Photo by Asgeir Steinsland.

Relation to users, stakeholders and research communities

WP 3 has secured a very good relationship with NOFO (Norsk Oljevernforening For Operatørselskap/The Norwegian Clean Seas Association for Operating Companies) - an organisation whose core task is to limit the extend and damage of oil spills at sea. In addition to collaborating at several previous occasions on field work (OPV – NORSE2015 and NORSE2019 in particular), we also collaborate on a project related to produced water and we update each other on relevant news.

We meet on regular basis online where also KSAT (WP 7) and other stakeholders may participate. In-situ produced water data collection from the oil rig Brage and the production ship Norne are done in close collaboration with Wintershall Dea and Equinor. Student Brynjar Andersen Saus did a pilot project in the fall semester to be followed up by MSc project in the spring. He is working on detection of produced water from Sentinel-1 imagery based on machine learning. His supervisors are Malin Johansson, Anthony Doulgeris and Camilla Brekke. Brynjar is also invited to the regular dialog meetings with NOFO.

A talk will be given at EUSAR in 2021 (postponed from 2020) about produced water detection in SAR and optical images. Johansson, Malin; Skrunes, Stine; Brekke Camilla and Isaksen Hugo: Multi-mission remote sensing of low concentration produced water slicks.

WP 3 researchers lead or participate in numerous associated research projects. To name a few:

- Oil spill and newly formed sea ice detection, characterization, and mapping in the Barents Sea using remote sensing by SAR – OIBSAR (funding: RCN)
- Collaboration with the Institute of Oceanology of the Russian Academy of Sciences (IO RAS): Post doc Anca Cristea leads the work on a paper focusing on detection and classification of thin ice and lookalikes in the Barents Sea. This work is connected to the OIBSAR project and our long-term collaboration with Russian colleagues at P. P. Shirshov Institute of Oceanology of the Russian Academy of Sciences (IO RAS) in Moscow. The paper is in preparation and is expected submitted in spring 2021. A poster lead by our colleagues at IO RAS about distinction of newly formed sea ice will be presented at EUSAR 2021 (postponed from 2020). Ivonin D.V; Ivanov A.Y; Johansson M; Brekke C., Newly formed sea ice distinction near the oil platform Prirazlomnaya in the Pechora Sea using polarimetric Radarsat-2 SAR observations.
- The Nansen Legacy (funding: RCN). PhD student Muhammad Asim had a contribution to IGARSS2020: Asim, Muhammad; Brekke, Camilla; Mahmood, Arif; Eltoft, Torbjørn; Reigstad, Marit. Ocean Color Net (OCN) for the Barents Sea. IEEE International Geoscience and Remote Sensing Symposium proceedings 2021. ISSN 2153-6996.
- Mapping of Algae and Seagrass using Spectral Imaging and Machine Learning – MASSIMAL (funding: RCN)
- SFI Visual Intelligence (funding: SFI/RCN and partners): Together with Centre Leader Robert Jensen, Andrea Marinoni and Camilla Brekke embarked on a new SFI journey with the launch of the new SFI Visual Intelligence.
- WP 3 is also involved in the development and implementation of remote sensing techniques for oil spill monitoring and storm damage assessment in an operational context (NASA/ROSES 2018).

Furthermore, WP 3 is well connected with the national and international academic landscape through Camilla Brekke, who is the Deputy Centre Leader at CIRFA and Vice-Dean Research at the Faculty of Science. She has promoted CIRFA at various occasions; examples are an invited talk at CalTech. From 2020, she is also a member of European Space Sciences Committee (ESSC). The ESSC provides expert advice to the European Space Agency (ESA), the European Commission, EU national space agencies, and other decision-makers in the space domain. It has become the reference body in Europe for independent scientific advice on space matters and a focal point for international research collaboration since its funding date in 1974.

WORK PACKAGE 4

Remotely Piloted Aircraft Systems Technology

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WP leader
Tor-Arne Johansen
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Team members

Rolf-Ole Rydeng Jenssen
PhD candidate, UiT

Richard Hann
PhD candidate, NTNU

Stian Solbø
Senior Scientist, NORCE

Agnar Sivertsen
Senior Scientist, NORCE

Tom Rune Lauknes
Senior Scientist, NORCE

Svein Jacobsen
Professor, UiT

Objectives and motivation

Remotely Piloted Aircraft Systems (RPAS) - also known as unmanned aerial vehicles (UAVs), or more commonly called drones - are an emerging technology that are becoming an integral part of our everyday lives. Until recently, RPAS were mostly used by selected defense forces around the world and by hobbyists in freetime activities. As RPAS technology becomes widely available, new applications are under development for a wide range of commercial purposes, such as agriculture, construction, film industry, infrastructure inspections, shipping, meteorology, remote sensing, mapping, urban and remote air mobility (such as package deliveries), and research.

For Earth Observation, RPAS cover an intermediate elevation airspace between observations from the ground and observations from airplanes or satellites. This means their observations can offer a high degree of detail and flexibility. In addition, RPAS are highly mobile, can carry various sensors and can easily be moved to a location of interest within short time frames. Hence, they are emerging as a useful tool to be combined with satellite-based and on-ground observations.

Both satellite-based systems and Remotely Piloted Aircraft Systems (RPAS) have their strengths and weaknesses. Satellites have superior coverage and repeatability, but limitations when it comes to accurate fine spatial and temporal scale measurements of thickness distribution, drift, convergence and divergence. RPAS can achieve accurate high-resolution measurements, but have limited spatial coverage and range, and are weather sensitive. The systems needed by industrial operators in the Arctic should be robust and reliable, and the system should be able to handle disruption in service by individual components.

This work package aims to develop robust and efficient RPAS and sensor technologies suited to support arctic operations, that are flexible and that can handle the widest possible ranges of environmental conditions enabling high quality measurements of sea-ice and iceberg properties, as well as detecting and monitoring oil spills in ice affected areas. RPAS combined with satellites and state of the art models provide the optimal data based situational awareness tool.

Key research tasks

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

Achievements in 2020

Aircraft robustness: The development of the D-ICE drone de-icing system

There are many challenges and risks related to the increased utilization of RPAS. One particular risk is related to ice accretions in clouds and cold weather, which can lead to unplanned crashes and losses. WP 4 is targeting this challenge in detail and with great success. The dedicated PhD project drone aircraft icing was completed with the successful defense by Richard Hann on July 1st, 2020. This work has included collaboration with UBIQ Aerospace and their development of the D-ICE drone de-icing system. In this connection three papers were published in 2020:

- Hann, R., Johansen, T.A. (2020). Unsettled Topics in Unmanned Aerial Vehicle Icing. SAE International, SAE EDGE Research Report EPR2020008.
- Hann, R., Hearst, R.J., Sætran, L.R., Bacchi, T. (2020). Experimental and Numerical Icing Penalties of an S826 Airfoil at Low Reynolds Numbers. Aerospace, 7(4), 46. [Data] DOI: 10.3390/aerospace7040046.
- Hann, R., Enache, A., Nielsen, M.C., Stovner, B.N., Johansen, T.A., Borup, K.T. (2020). UAV Icing: Experimental Heat Loads for Electrothermal Anti-Icing and De-Icing. AIAA Atmospheric and Space Environments Conference.

Sensors for measurements of snow and sea-ice properties
RPAS technology can be utilized in research. The PhD project of Rolf-Ole Jenssen on a UWB Radar for characterization of snow and sea-ice properties has progressed well. The final field validations were performed in spring. Here, the plans changed from a campaign on Svalbard to a local campaign close to Tromsø due to travel restrictions connected to the Covid-19 pandemic. PhD candidate Rolf-Ole Jenssen plans to deliver his thesis in February and defend in May 2021. In 2020 the following papers were published on the UWB work:

- Jenssen, R.O.R. and S. Jacobsen (2020) "Drone-mounted UWB snow radar: Technical improvements and field results", Journal of Electromagnetic Waves and Applications, 34:14, 1930-1954, DOI: 10.1080/09205071.2020.1799871.
- Jenssen, R.0.R., M. Eckerstorfer and S. Jacobsen (2020) "Drone-Mounted Ultrawideband Radar for Retrieval of Snowpack Properties", IEEE Transactions on Instrumentation and Measurement, vol. 69, no. 1, pp. 221-230, doi: 10.1109/TIM.2019.2893043.

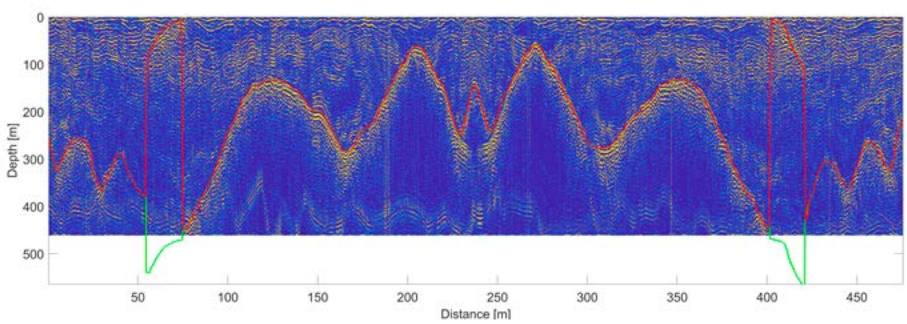
Multisensor sea-ice properties retrieval for real-time operational support
With sea-ice cover reducing due to global warming, shipping operations in the Arctic region see a rapid rise. Reduced travel times between continents, new fishing grounds, and exploration/tourism is exposing ships, their crews, passengers and freight to some of the harshest sailing conditions on the planet. Therefore, vessels that are visiting or travelling through icy waters need to have access to information about the sea surface and ice conditions in near-real time to improve situational awareness and to support the crew in their decision making.

Combined ship-based radar and drone-camera data for support of ice navigation were tested on the CAATEX 2020 cruise. The work combined detecting ridges in sea-ice and the height of floating ice above the water surface (called freeboard). This is a collaboration between the CIRFA partners with the "Digital Arctic Shipping" project. In this 3-year project under the lead of NERSC, Chinese and Norwegian partners will advance sensor technology, analysis methodologies and visualisation services to aid shipping and navigation in rapidly changing Arctic sea ice conditions.

Direct drone measurements of sea-ice thickness
A white paper on design of low frequency drone-borne UWB radar for direct sea-ice thickness measurements was prepared in collaboration with Polona Itkin in WP 2.

Outreach Activities

The team presented results at the AIAA Atmospheric and Space Environments Conference and through publications. Use of drones in support of ice navigation was presented by Rune Storvold as a keynote talk: "Importance of machine vision in creating safe and efficient drone-based services; Applications from climate research to human transport" at the European Conference on Computer Vision in August 2020.



Ultra-Wideband Snow Sounder (UWiBaSS) mounted under the UAV Cryocopter FOX. Below is a B-scan radar image of one pass -back and forth- across a 250 m transect. The red line indicates the snow-ground interface and the green line indicates the transition between snow and ground. The interfaces are detected in second ambiguity window (I.e., deeper than 460cm for \epsillon_r = 1:68). Both images provided by Rolf-Ole Jensen.

K/V Svalbard in the ice, and a combines GPRI and Drone mosaic. Images provided by Tom Rune Lauknes, NORCE.

Fieldwork and collaboration

CIRFA has in collaboration with NERSC, Maritime Robotics and Bergen Robotics through the spin off project Digital Arctic Shipping and collaboration with CAATEX and the Norwegian Coast Guard that supported fieldwork in summer of 2020. The goal is to demonstrate use of satellite ice charts (WP 2), ship-based radar and drones (WP 4 and WP 6) in support of real time ship navigation in seaice. Data analysis and development of an end-to-end system (WP 7) will be done in 2021/22 with final demonstration in 2022.

Fieldwork with drones is important to test new senors and technology in cold climate. Image credit: NORCE

WORK PACKAGE 5

Drift Modelling and Prediction

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WP leader
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Team members

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Mathias Tollinger
PhD candidate, UiT

Sindre Fritzner
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Researcher, MET

Knut-Frode Dagestad
Researcher, MET

Kai Christensen
Professor, MET/UiO

Jostein Brændshøi
Researcher, MET

Yvonne Gusdal
Researcher, MET

Objectives and motivation

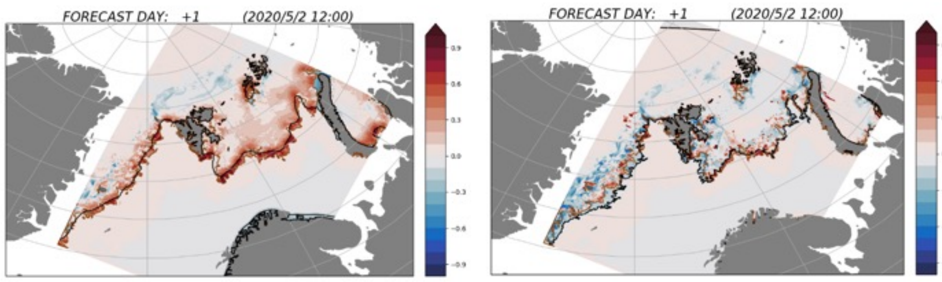
The overall objectives of this work package are to improve operational ocean, sea-ice, and weather forecast models by developing new algorithms and by using new types of observations provided in other WPs. Data assimilation techniques combine the model state with various types of ocean and sea-ice observations, providing an analysis of the ocean's state and sea ice cover. The current state is then projected into the near-future (1-3 days ahead), in order to issue forecasts. 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 predictions.

Key research and development tasks

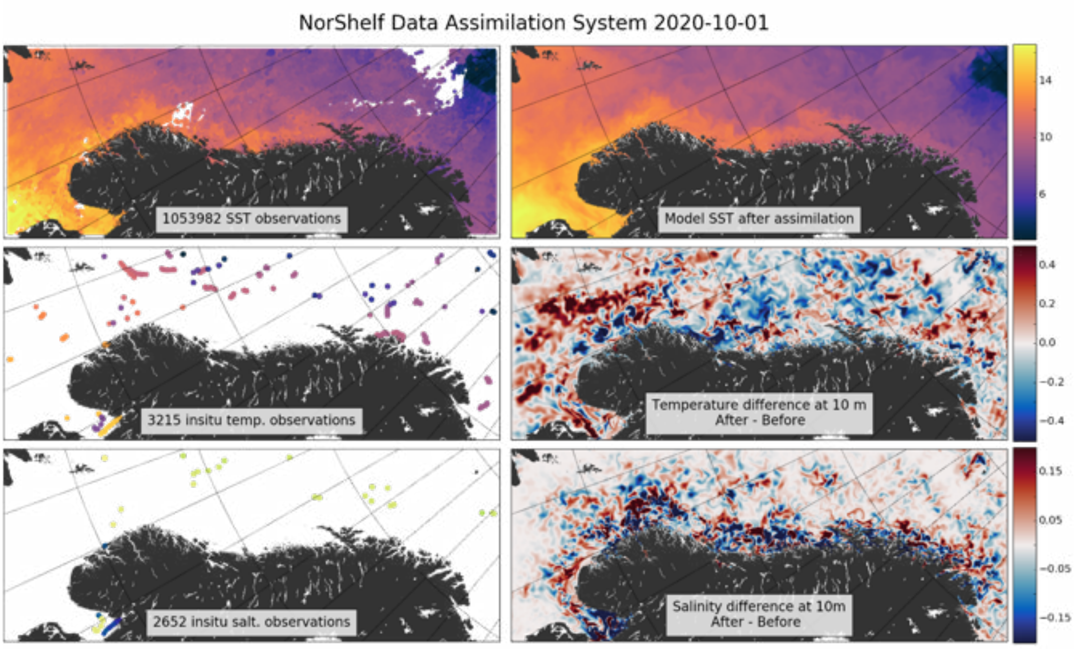
The research in WP 5 is centered around three modeling systems, the Barents-2.5 ocean circulation and sea ice model for predictions in the Barents Sea and around Svalbard; the Norkyst-DA ocean circulation model for data assimilation for the coast of Norway, and OpenDrift, a trajectory model for specific drift applications such as oil spills, ice bergs, and search-and-rescue operations. In addition to model development and specific research tasks on model algorithms, we investigate physical processes important at high latitudes for which improved understanding is expected to add value in forecasting for arctic operations. These processes include polar lows (see below), behavior of oil spills during strong winds and in areas with sea ice, and drift of ice bergs in response to ocean currents, waves, and winds.

Barents-2.5 ocean circulation and sea ice model

The Barents-2.5 model, developed within CIRFA, has been the main research tool in Sindre Fritzner's PhD who defended his thesis in spring 2020. Sindre implemented an Ensemble Kalman filter data assimilation technique to initialize the model with sea ice concentration maps obtained from remote sensing. While Sindre is currently working on reanalysis with the model system – simulation past states of the ocean and sea ice – researchers at MET (J. Brændshøi, Y. Gusdal and J. Röhrs) have setup a a instance of the Barents-2.5 model for use in operational ocean forecasting, meaning that the model now provides predictions for next three days on a daily basis. As a step towards an operational Ensemble Kalman filter, the operational Barents-2.5 has now been extended with an ensemble prediction system which is also the basis for uncertainty estimates of the ocean and ice forecasts (see Innovation Highlights). However, it remains to transfer more of Sindre's PhD research into the operational model, in particular the Ensemble Kalman filter data assimilation algorithm for sea-ice related observations.



Difference between forecasted and observed sea ice concentration. Left: Difference between OSISAF and Barents-2.5 Sea ice concentration. Right: Difference between ice charts from the Norwegian Ice Service and the Barents-2.5 model. Image provided by MET Norway.



Observation data and data assimilation model increment during an assimilation cycle on 2020-10-01. The left panels show observations, and the right panels show model SST and the differences before and after the assimilation cycle. Image provided by MET Norway.

Norkyst-DA-2.4 coastal data assimilation system

The Norkyst-DA model is used for data assimilation in a forecast model for the coast of Norway and its shelf sea. This model is operational since 2017 (A. K. Sperrevik and J. Röhrs) and uses a 4D-variational data assimilation technique that provides a large degree of flexibility with regard to observation data. During 2018 and 2019, A. K. Sperrevik extended the model to assimilate radial ocean currents from HF radars and added improvements for quality control of observed HF radar currents in 2020. This system will be extended with additional HF radar stations in 2021 to cover larger parts of the coast of Western Norway. The technique for assimilation of radial currents has further been used to assimilate ocean currents observed by space-bourne Synthetic Aperture Radar, tested in reanalysis experiments using the Norkyst-DA model.

A new PhD candidate, Silje Christine Iversen, is joining the Norkyst-DA team led by A. K. Sperrevik, focusing on assimilation of sea surface temperature and developing diagnostics for the performance of the assimilation system. An essential piece for improving ocean temperature forecasts is a bias correction algorithm for the assimilation of sea surface temperature (SST) from infrared sensors that is now part of the operational setup. Assimilation of SST has been extended in 2020 to include a larger range of infrared sensors, now including data from Sentinel 3a and b, MetOp B, VIIRS NPP and NOAA-20.

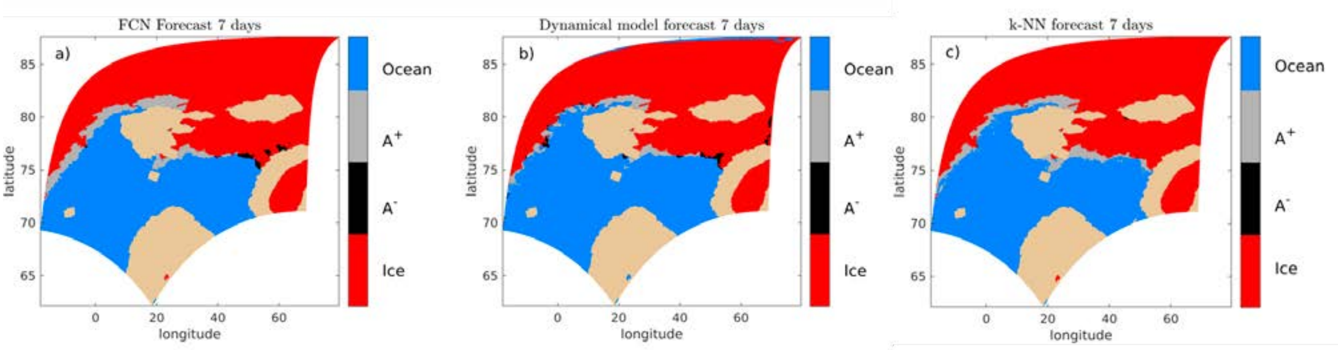
Sea surface temperature observations from passive microwave sensors will provide another pivot for constraining the model state with observations, as these are also available during the dark season and presence of cloud cover. Since passive microwave observations have a much lower resolution than the ocean model, S. Iversen is now focusing on a so-called super-modding operator sythesizing course resolution observations with high-resolution model data to prepare the Norkyst-DA model for assimilation of passive microwave SST.

While the ultimate goal in operational oceanography is that our developed methods become operational, our research on the model system is foremost based on running reanalysis of past states with the model system to control the study design. A.K. Sperrevik and S. Iversen are performing model reanalysis with the Norkyst-DA model for the period of 2017-2018 with various configurations to study the observation impact of HF radar currents and sea level anomaly and perform validation of reanalysis products.

OpenDrift trajectory model

The OpenDrift trajectory model is an additional step in the value chain between remote sensing, ocean modeling, and the forecasts to specific users (opendrift.github.io). While the hydrodynamic models provide wind, waves, ocean currents and sea ice velocities, arctic operations often require drift forecasts for specific objects. These are computed through time-integration of the velocities from hydrodynamic models. Such simulations are case-specific for the required applications, e.g. oil spill simulations, iceberg drift, and other objects drifting in the sea. Numerical schemes for the behavior of specific particles are implemented directly in OpenDrift; in 2019 a drift module for icebergs was added, and in 2020 a graphical user interface for the ready-to-use module OpenBerg has been developed (K.-F. Dagestad).

An oil spill module, OpenOil, is further improved in Cirfa WP 5 (K.-F. Dagestad, J. Röhrs) in close collaboration with WP 3 (Camilla Brekke, Malin Johannson). This model has been applied to track oil films originating during produced water releases, and in 2020 two new oil-in-ice schemes have been implemented in OpenOil to answer to the increased need for oil drift simulations in high latitudes. Finally, the oil spill experiments during the joint NORSE 2019 cruise concluded with a demonstration on the initialization of OpenOil from oil slick detections by WP 3. Ongoing work focuses on the details



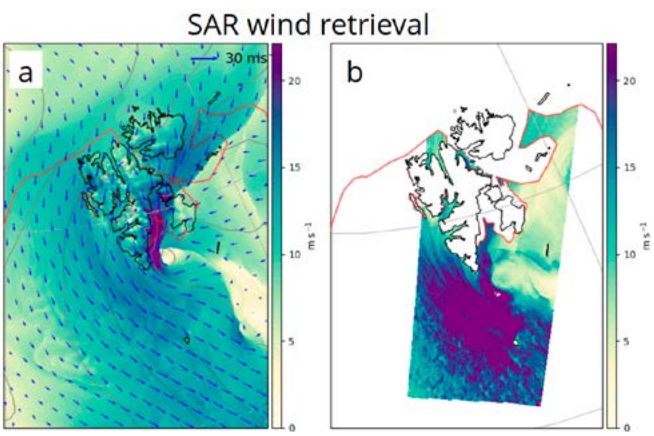
Seven-day predictions of two machine-learning methods (a) the FCN method and (c) the k-NN method compared to (b) the dynamical ROMS-CICE (Barents-2.5) assimilation system for May 8th, 2018. Blue areas represent the ocean in both validation observations and model, and red areas represent ice in both model and observations. Gray areas represent areas where the model has ice, while the observations have no ice, and vice versa for black areas. Image provided by Sindre Fritzner.

of ocean current and turbulence conditions during the oil spill release.

Polar lows

Polar lows are small scale storms that can develop rapidly when cold air moves over open water. Because of their small size and short lifetime, and due to few weather observations in polar regions, polar lows are difficult to predict by numerical weather-prediction (NWP) models. Synthetic aperture radars (SAR) aboard polar orbiting satellites observe the radar reflectivity of the ocean surface in polar regions in high detail and frequently. The water surface and its reflection of electromagnetic waves from SAR radar is affected by the winds. Therefore, there is a potential for retrieving wind speed from SAR observations.

Current wind retrieval techniques that relate SAR signals to wind speed appear inadequate for applications of polar low winds, since these winds can vary strongly over a short distance as regard magnitude and direction. A study is in progress that assesses and further develop state-of-the-art wind retrieval techniques for polar lows and compare to *in situ* observations and NWP models, as shown in the figure below. Part of the effort related to this study is to develop a new wind vector retrieval technique that exploits the full information content of SAR images and thereby improves the quality of SAR wind retrievals in extreme wind situations beyond the scope of polar low applications.



Representations of a polar low south of Svalbard in the AROME-Arctic NWP model in a). Color shading and arrows show wind speed and direction. An example of SAR-retrieved wind speed is shown in b). The red line marks border of the southward extent of sea ice. Image provided by Mathias Tollinger.

Machine learning for ice prediction

Machine-learning methods for sea-ice prediction provide an alternative to the traditional dynamical models. With machine-learning methods the sea-ice prediction can be performed in seconds on a regular laptop, while normally a dynamical model is run for hours/days on a supercomputer. Thus, there is a strong computational benefit of applying machine learning to sea-ice prediction. The machine-learning methods are based on historical data, and through training, the models learn to predict future sea ice. In a recent study (Fritzner *et al.*, 2020), two different machine-learning methods for sea-ice predictions were compared to a dynamical model. The comparison between the two machine-learning models and the dynamical model is shown in the figure below. The machine-learning models are found to predict a similar ice edge as the dynamical model and thus provides a cost-efficient alternative to the dynamical model. Work using more advanced methods and including more historical data to further improve accuracy of the prediction model is ongoing.

Achievements in 2020

- PhD defense Sindre Fritzner
- Demonstration with OpenDrift/OpenOil initialized from remote sensing spill detectio
- Operational Ensemble Prediction System (EPS) with the Barents-2.5 ocean and ice model

Publications

- Brekke, C., Espeseth, M. M., Dagestad, K. F., Röhrs, J., Hole, L. R., & Reigber, A. (2020). Integrated analysis of multi-sensor datasets and oil drift simulations-a free floating oil experiment in the open ocean. *Journal of Geophysical Research: Oceans*, e2020JC016499.
- Fritzner, S., Graversen, R., & Christensen, K. H. (2020). Assessment of High-Resolution Dynamical and Machine Learning Models for Prediction of Sea Ice Concentration in a Regional Application. *Journal of Geophysical Research: Oceans*, *125* (11), e2020JC016277.
- Röhrs, J., Sutherland, G., Jeans, G., Bedington, M., Sperrevik, A.K., Dagestad, K.-F., Gusdal, Y., Mauritzen, C., Dale, A.C., LaCasce, J.H., 2021. Surface Currents in Operational Oceanography - Key Applications, Mechanisms and Methods. Journal of Operational Oceanography (in print), 10.1080/1755876X.2021.1903221.

WORK PACKAGE 6

Data Collection and Fieldwork

WP leader
Sebastian Gerland
Senior Scientist, NPI, associated with WP 2 & WP 6

WP leader
Camilla Brekke (co)
Professor, UiT, associated with WP 3 & WP 6

WP leader
Rune Storvold (co)
Research Director, NORCE, associated with WP 4 & W P6

Team members

Anca Cristea
Post Doc, NPI, associated with WP 2 & WP 6

Dmitry Divine
Senior Scientist, NPI

Objectives and motivation

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

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

Some of those cruises are completed already, while some 2020 fieldwork plans were affected by the pandemic and thus postponed to 2021. Hence, the aim of WP 6 is to design field campaigns in connection with satellite and RPAS measurements, and to carefully plan and conduct the measurements needed for calibration and validation of remote sensing products, with close coordination and collaboration with other CIRFA work packages and partners. Partners centrally involved in this work package are the Norwegian Polar Institute, NORCE, and UiT The Arctic University of Norway.

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.

Researchers are investigating an ice ridge during the MOSAiC expedition. Photo by Polona Itkin, UiT.

Achievements in 2020

WP 6 has been coordinating and participating in fieldwork observations and remote sensing (together with other CIRFA work packages), for the NPI Fram Strait 2020 cruise with R/V *Kronprins Haakon* and the 2020 part of the MOSAiC Expedition in the transpolar drift with R/V *Polarstern*. The fieldwork is collecting a wealth of new observations, data and sample collections.

The work package is also involved in high level publications, such as a new paper about how to optimize helicopter flights for investigating the sea ice flown over was successfully published in Annals of Glaciology (Negrel et al. 2020). Another paper on the sea ice evolution in Kongsfjorden over more than two decades based on SAR satellite data was successfully published in Annals of Glaciology (Johansson et al. 2020). A review of the Kongsfjorden land fast ice studies was published in the SIOS SESS report 2019 (Gerland et al. 2020).

Relation to users, stakeholders and research communities

WP 6 researchers have presented an e-poster at the European Polar Science Week, an online conference organised by ESA. The e-poster with the title "Use of in situ and airborne Arctic sea ice surveys for SAR Satellite remote sensing application improvements" is available on https://www.youtube.com/watch?v=eTZhbxu4wVo&feature=emb_logo

In addition, WP 6 researchers have contributed to the IAHR International Symposium on Ice with an oral presentation and proceedings article on "Svalbard fjord sea ice environments as arenas for climate research, monitoring, remote sensing validation, and dedicated process studies".

WORK PACKAGE 7

Pilot Service Demonstration

WP leader
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WP leader
Nick Hughes
(co) Leader of the Norwegian Ice Service, MET

Team members

Thomas Kræmer
Head Engineer, UiT

Jelte Geert van Oostveen
Head Engineer, UiT

Salman Khaleghian
PhD candidate in Extreme Earth project, associated with WP 2

Habib Ullah
PostDoc in Extreme Earth project, associated with WP 2

Objectives and motivation

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 that have not been met.

Oil and gas companies operating in the environmentally sensitive Arctic areas need monitoring technologies integrated into their day-to-day operations for operational 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 though 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 2020

WP 7 continues to provide support to the other work packages in their activities. In 2020 work has been concerned with the following activities:

Much of the activity has been related to WP 2, which is natural given its size. In the beginning of the year, a processing chain was set up to run automatic ice type classification, together with Johannes Lohse in WP 2. We demonstrated that we could create Arctic-wide maps of sea ice type and highlighted some areas that needed further improvements. The processing chain is now being transferred to KSAT infrastructure to demonstrate that the processing can also be run in near real-time.

Jelte van Oostveen has finished converting the AWI ice drift from SAR code to python and initial testing has begun. The new code is currently in use by a master student and can be used for other projects in CIRFA. Jelte has left UIT to take a position with NORCE, where he will continue working on ice drift, but applied to glaciers with interferometric SAR.

Thomas Kræmer implemented an iceberg drift model in the OpenDrift framework and tested it on a region close to Franz Josef Land. Unfortunately, the predicted drift was not at all accurate and the tests emphasized the need for better model wind and current forcing. Since MET is now in the process of developing an ensemble version of the Barents 2.5 km model, it is natural to run the experiments again to see if the predicted drift is improved or if better uncertainty estimates can be obtained.

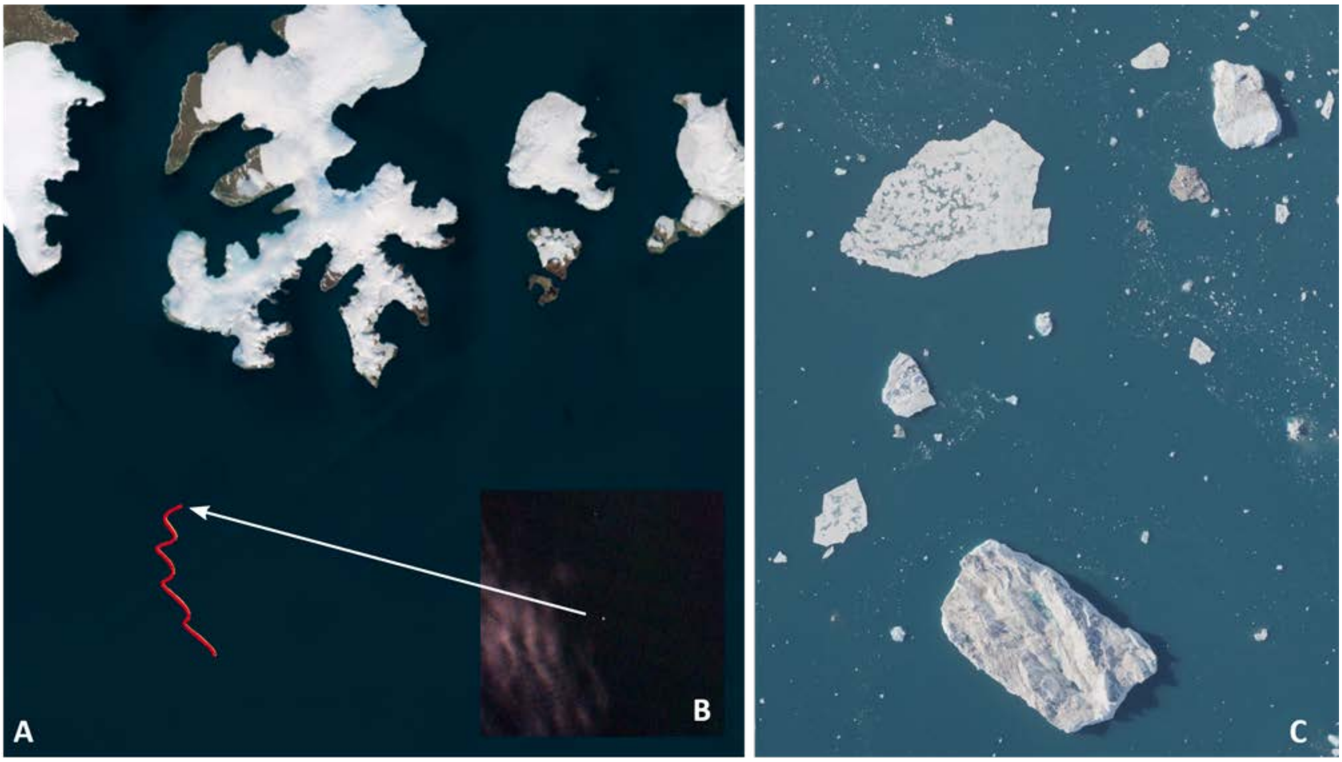


Image A shows predicted iceberg drift trajectories around Franz Josef Land, calculated using the OpenDrift framework. The drift model was initialized based on a small iceberg detected from an optical Sentinel-2 image (small bright spot in image B). Image C shows icebergs close to Negribreen in Svalbard, observed by the high-resolution camera on the Dornier aircraft. Images compiled by Thomas Kræmer.

In addition, there has been collaboration between WPs 7, 6, 4 and 2 in obtaining observations that can be useful for validation of WP 2 products. R/V *Kronprins Haakon* now routinely captures data when the ship is moving through ice. The ship has three radars, one of which is a Seahawk ice radar. In collaboration with the instrument crew on the ship, we have set up automatic export of images from a forward facing, CCTV camera and the ice radar at one-minute intervals. These images can then be cross-referenced with satellite data. CIRFA also took advantage of the opportunity to use the Dornier aircraft in Svalbard that was made available via the InfraNor project. The flight provided high-resolution optical images of icebergs, which is important for quantification of detection limits.

Together with WP 3, an oil spill drift demonstration has been set up that can take a satellite oil slick detection and run the OpenOil model on the detected mask. The backend integrations are in place, but what is missing is reliable automated detection of the oil spills. The demonstration can also be improved by including the damping ratio product.

Relation to users, stakeholders and research communities

MET supports WP 2 activities both in CIRFA and the related ExtremeEarth project by providing training data for machine learning activities, giving feedback on classification results presented in UIT papers and by running CIRFA algorithms in a test setting.

MET will also take WP 2 iceberg detection algorithms from CIRFA and run these routinely to generate a larger dataset both for algorithm intercomparison, and as input to drift forecasts. This will be done for the Barents Sea as the CIRFA Pilot Service, and in addition for Antarctic images for IICWG Task Team 14 "Southern Ocean Limit of All Known Ice (SOLAKI)".

KSAT and CIRFA are working together on demonstrating and validation of the relative oil thickness product developed by Martine Espeseth in WP 3. The product will be delivered to NOFO on a daily basis, and feedback will be collected in our monthly meetings between CIRFA, NOFA and KSAT.

KSAT is also supporting CIRFA's research on produced water by coordinating satellite acquisitions in quad polarization mode. In 2021 we will also support Brynjar Andersen Saus's master thesis project on produced water, by providing data and share our knowledge on detections and classification.

A closer look at selected field studies

Produced water studies

The collaboration between Wintershall Dea, KSAT and UiT continued also in 2020 with further satellite and in-situ data collection over the operational oil platform Brage. In addition, were production ship Norne, operated by Equinor, added to the data collection campaign. Both platforms release produced water; a mixture of low concentration oil and water, and these releases can often be observed in satellite images. The released produced water volumes and accompanying oil concentrations are supplied to UiT from the platforms, ensuring that we can work on connecting the satellite image detections with the release information. Three years of overlapping satellite and in-situ data were used in a conference proceeding (Johansson et. al., 2021) at the end of 2020, and a conference presentation and further data collection for 2021 is already in the pipeline. We are also happy to report that one master's student is currently working on the data and will put forward his thesis in early summer 2021.

Fram Strait 2020

The Norwegian Polar Institute annual Fram Strait monitoring cruise took place in August/September 2020. Researchers Anca Cristea, Dmitry Divine and Hiroshi Sumata joined the cruise. Sea ice work has focused on ground and airborne measurements of ice thickness, in addition to the usual sample collection in the form of ice cores. The scientists on board R/V *Kronprins Haakon* have had the opportunity to measure and sample thick second-year/multiyear ice, new ice, and the thin snow layer present during this time of the year. The sea ice team also performed sea ice and iceberg observations from the bridge continuously, every 1 to 3 hours while in the ice pack, and logged these into the ASSIST system.

High-resolution SAR imagery was again collected with support from both NPI and UiT scientists based in Tromsø. Field challenges render the collection of overlapping remote sensing and ground data difficult, if not impossible in many cases. This year, the process was successful during a fast ice station, with near-coincident helicopter-borne measurements and high-resolution SAR imagery being collected, in good synchronization with an AWI overflight associated with the MOSAiC campaign.

Researchers performing sea ice measurements during the Fram Strait 2020 research cruise, R/V Kronprins Haakon in the background. Photo: Marius Bratrein (NPI).

During the MOSAiC expedeition, R/V Polarstern was surrounded by a network of research sites on the ice. Photo: Ivo Beck.

CAATEX

The CAATEX (Coordinated Arctic Acoustic Thermometry Experiment) initiative addresses research in the central Arctic Ocean, especially the topic of ocean climate change. CAATEX is a research project funded by the Research Council of Norway and the US Office of Naval Research. The CAATEX is a joint project between NERSC, Scripps Institution of Oceanography (SIO), the Norwegian Polar Institute (NPI), Woods Hole Oceanographic Institution (WHOI), the University in Texas at Austin (UT Austin) and the Naval Postgraduate School.

In June 2020, eleven scientists from different Norwegian and European institutions were on board the Norwegian Coast Guard icebreaker K/V *Svalbard*. Sea ice observations are made using radars and drones as well as drilling holes in the ice to obtain information about the thickness and age of the sea ice. Several buoys were installed on the ice to monitor the ice drift and to calibrate ice drift models. Satellite radar images are extensively used during the cruise to support navigation and planning of complex operations in the ice. WP 4 researchers tested a combined ship-based radar and drone-camera data for support of ice navigation on the CAATEX 2020 cruise.

The MOSAiC expedition is successfully completed!

The international community of Arctic scientists has been designing the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) for over a decade. The expedition has started from Tromsø in September 2019 and finished in Bremerhaven, Germany in October 2020. With some smart logistic adjustments and the endurance of all involved not even the global pandemic was able to stop it.

MOSAiC was the first year-round expedition into the central Arctic exploring the Arctic climate system. It's concept was inspired by the drift of Fritjof Nansen's wooden ship "Fram" 127 years ago. The expedition with a total budget exceeding € 150 Million lasted for 389 days, out of which scientific observations were done for more than 300 days. It involved 20 nations form all over the world with 442 experts participating on board research icebreaker R/V *Polarstern* and more than 300 others supporting them from the mainland. The heart of the expedition was R/V *Polarstern* that drifted for more than 34 000 km in a zigzagging drift pattern together with the sea ice from the Northern Laptev Sea and towards the Fram Strait. To be able to regularly exchange the crew on board and to supply the observatory with provisions, seven other ice breakers and research ships were involved in the logistics of MOSAiC. For example, the resupply with a diesel-electric ice breaker *Kapitan Dranitsyn* lasted from January to March. At that time, R/V *Polarstern* was at times less than 200 km south of the North Pole. A tribute of skill and dedication of the Russian crew, or another evidence of the thinning Arctic sea ice cover? While the scientific team on board was interdisciplinary, just the sea ice and snow physics group among other work gathered more than 1 000 ice cores and snow samples, collected measurements over more than 100 km of snow and ice surface on the ground and by helicopter on nearly hundred scientific missions. That will hopefully enable to realize the ultimate goal of MOSAiC expedition - to contribute to a quantum leap in our understanding of the coupled Arctic climate system and its representation in global climate models.

The Earth Observation Laboratory at UiT has been directly involved in the MOSAiC expedition with a Research Council of Norway Young Research Talent project 'Sea Ice Deformation and Snow for an Arctic in Transition' (SIDRiFT, project number 287871). SIDRiFT started in 2019 and will last until 2023. We are currently involved in the analyses of data collected by the expedition. In this exciting phase of the project we are collocating the in-situ data with the satellite remote sensing imagery and we feel in perfect spot in the CIRFA family – we are learning from one of the best in SAR!

Education and Training

Young Scientist Forum 2020

The *CIRFA Young Scientist Forum 2020* was held on February 27th and 28th in Tromsø under the theme "*Communication – Cooperation – Career & Care*." This annual event offers seminars and workshops about relevant topics for our Ph.D. students, postdocs, and young scientists, which also represents a good platform to meet up, exchange about current activities, and to socialize among the group.

Given the fact that our research group currently includes quite a few new members as well as people that are about to finish their work in CIRFA, the forum provided a diverse program with different topics of interest. We had the pleasure of Theresa Mikalsen and Balpreet Singh Ahluwalia from the *UiT* joining the forum and giving presentations and advice about EU funding strategies. In a debate covering the topic "Academia vs. Industry," we learned about major differences between those two potential carrier paths, thanks to the input of Edmond Hansen from *Multiconsult* and Alfred Hanssen from the *UiT* that were happy to share their experience. A workshop about "How to publish a scientific paper" by Anthony P. Doulgeris as *GRSL* Associate Editor gave us a good insight into the editor's point of view of publishing and an excellent opportunity to exchange experience among the group. Last but not least, we learned how to avoid or reduce stress and how to organize our workplace healthier in a seminar given by Renathe Ovesen from *HEMIS*.

On Thursday afternoon, all participants were sent out on an Arctic Treasure Hunt through Tromsø, which gave them the chance to strengthen their team working abilities as well as their competitiveness as two teams were competing with each other. During a nice dinner, we were able to round off the day and evaluate the accomplishments of the treasure hunt.

Impressions from the CIRFA 2020 Young Scientist Forum. Photo: Renathe Ovesen (HEMIS).

Sea ice signatures in SAR images: Winter school in February 2020

How to interpret the sea ice signatures in SAR images and how we could improve our knowledge of this was raised over lunch on the CIRFA Annual Conference in 2019. Many of the CIRFA partners have extensive knowledge about SAR and sea ice and importantly have access to a great many satellite images where a discussion could help further improve our joint knowledge. All said and done and a winter school where this was the focus was decided upon, arranged by Wolfgang Dierking, Johannes Lohse, Thomas Kræmer and Malin Johansson. Wolfgang kicked off the meeting with a presentation about how the sea ice forms and what sea ice development looks like in SAR images. The presentation included input not only from Wolfgang, but also from Trond Robertsen (Norwegian Ice Service), the Canadian Ice Service through Melanie Lacelle and Tom Zagon as well from UiT through Johannes Lohse and Malin Johansson. The winter school was very well attended by 25 members from NPI, Met and UiT. The discussions continued both over lunch and spurred on by recently found "difficult to interpret" sea ice situations on SAR images well into the afternoon.

The successful sea ice in SAR winterschool attracted 25 researchers. Photo: Malin Johansson.

Completed PhD and MSc theses

In 2020, CIRFA celebrated two completed PhD projects, while two more candidates came close to completing their thesis in December, with the PhD thesis of Johannes Lohse submitted on December 24, 2020.

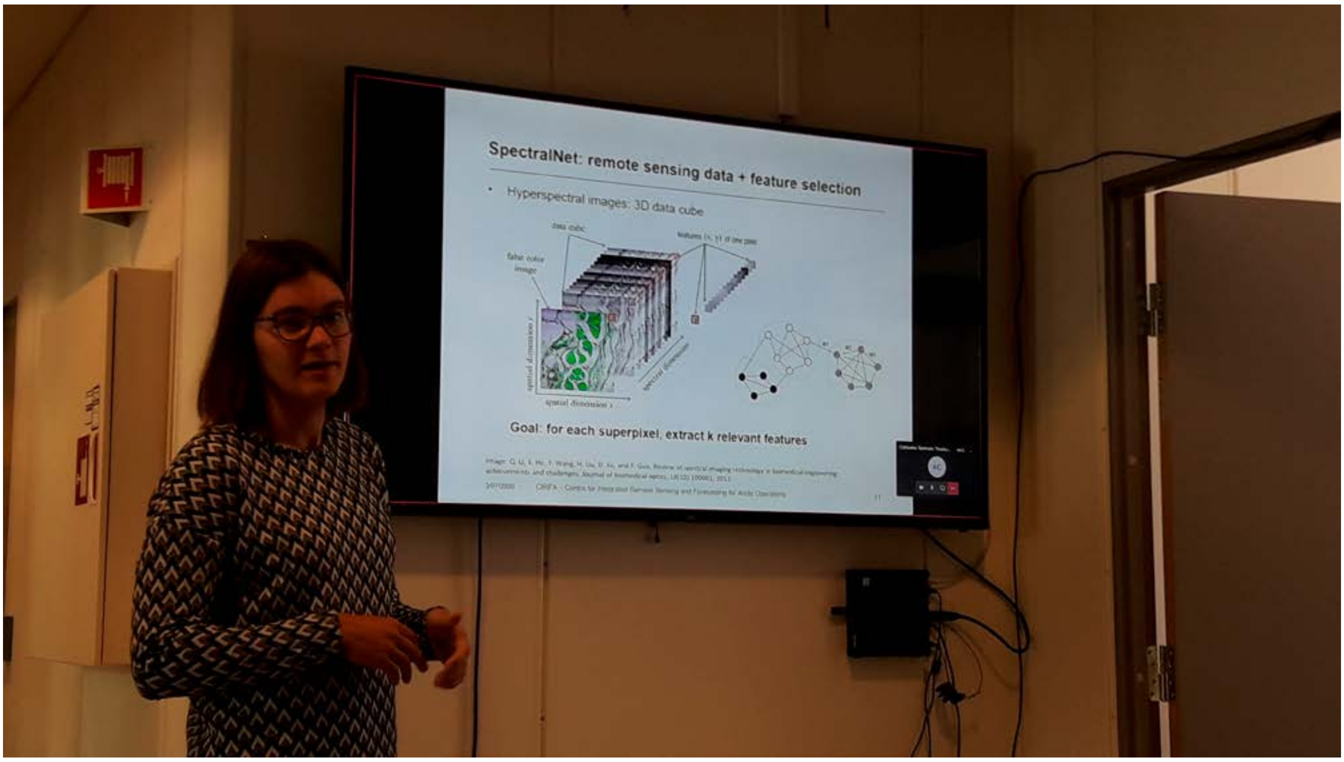
PhD candidate	Title of the thesis	Supervisors
Sindre Fritzner	On sea-ice forecasting	Rune Graversen (UiT)
Richard Hann	Atmospheric Ice Accretions, Aerodynamic Icing Penalties, and Ice Protection Systems on Unmanned Aerial Vehicles	Tor Arne Johansen (NTNU)

In 2020, CIRFA got two new PhD`s; Richard Hann and Sindre Fritzner.

Since 2016, CIRFA has attracted master students from Tromsø, other places in Norway and abroad. The number of master students has constantly been growing and 2020 was the top year with eight master students that were associated with the project through their pilot projects or thesis work.

MSc student	Title of the thesis	Supervisors
Catherine Taelmann	Feature selection using deep spectral clustering for remote sensing applications	Andrea Marinoni
Andreas Hansen Asbjørnslett	Analysis of the potential of the Ku-band Gamma Portable Radar Interferometer for sea ice information extraction	Thomas Kræmer Torbjørn Eltoft
Brynjar Andersen Saus	Produced water (Pilot project)	Anthony Doulgeris Malin Johansson Camilla Brekke
Truls Thorsen Karlsen	Glacier velocities (Pilot project)	Malin Johansson Jelte van Oostveen Geir Moholt (NPI)
Torjus Nilsen	Semisupervised learning of sea ice characteristics in multimodal remote sensing data (Pilot project)	Andrea Marinoni
Martin Bengsli	Pilot project	Anthony Doulgeris
Tora Båtvik	Pilot project	Anthony Doulgeris

Bachelor of Science student Catherine Taelmann from the Technical University of Eindhoven in the Netherlands, visited CIRFA from January to June 2020. Catherine conducted her internship on "Feature selection using deep spectral clustering for remote sensing applications" under the supervision of Andrea Marinoni. Catherine very much enjoyed being part of CIRFA and is looking to return to the group for her graduation project.



Catherine Taelmann is giving a presentation that summarizes the outcomes of her internship. Photo: Andrea Schneider.

Success story: CIRFA PhD candidate starts research lab on unmanned aircraft icing

Richard Hann started as a PhD candidate in CIRFA in 2016 to develop all-weather capable RPAS technologies. His work focused on the challenge of unmanned aircraft in cold weather operations and icing conditions. Richard successfully defended his thesis in June 2020 in front of well-known representatives of the aircraft icing community.

Atmospheric in-flight icing is a major risk and a severe threat to RPAS. Today, RPAS cannot fly in icing conditions and are grounded when icing conditions are prevalent. This is a major limitation of the flight envelope and operational availability of RPAS – especially in the Arctic – and is hence in the focus of WP 4 in CIRFA.

In his thesis, Richard studied how icing affects RPAS and how systems can be designed to protect them against icing. Richard conducted his PhD at NTNU and worked in close collaboration with the NTNU spin-off company UBIQ Aerospace. Together, they develop ice protection systems for RPAS and have applied for several research funds. Richard was an essential contributor in two successful funding proposals to the Research Council of Norway with a total volume of 27 Million NOK.

With the help of this funding, Richard is now taking research on RPAS icing to the next level. This funding from the research council is used to create four new PhD positions at NTNU. In addition, two more PhD positions are created through industrial PhD schemes. As a result, a total of six PhD students and several master students will continue to work on RPAS icing challenges at NTNU. The UAV Icing Lab will provide knowledge and solutions for RPAS in icing conditions under the leadership of Dr. Richard Hann and Prof. Tor Arne Johansen. Their contributions will be essential to unlock regular and safe RPAS operations in cold climate environments all around the globe.

Icing on a propeller during a test campaign in an icing wind tunnel. Ice accretion on the leading-edge of a wing. Photos: Richard Hann.

Communication and Dissemination Activities

CIRFA Seminars

The CIRFA seminars are a valuable platform for invited speakers and CIRFA researchers or scientists who work in associated projects. The seminars serve a threefold purpose; to present and discuss ongoing work or results, to update about field campaigns and new data and observations, and to ease networking with external invited speakers. In addition, the opponents of PhD defenses are invited to give a seminar. Throughout 2020, ten seminar occasions took place. The CIRFA Seminar Series went fully online from April 2020 which made it easy for presenters to join regardless of their location, and the seminars were open to a wide audience to join the web-based presentations and discussions.

Presenter	Affiliation	Country	Month	Title of the talk	Audience
Rafael Gonçalves-Araujo	DTU	DK	January	Light in the dark: retrieving underwater irradiance in shallow eutrophic waters from absorption and beam attenuation spectral measurements	No record
Polona Itkin	UiT/SIDRIFT	NOR	April	MOSAiC winter experience – field work impressions and early results	No record
Thomas Lavergne	Met Norway	NOR	May	Microwave radiometry for sea-ice monitoring, and the SIRANO project	No record
Naomi Ochwat	-	US	August	Break-Up of Hunt Fjord Ice Shelf, Northern Greenland	23
Jack Landy	University of Bristol	UK	August	Exploiting a growing fleet of satellite altimeters to gain new perspectives on the Arctic's ocean and ice cover	23
Geir Moholdt	NPI	NOR	October	Ocean erosion of Svalbard glaciers seen from Space	23
Robert Ricker	AWI	GER	October	Evidence for an increasing role of ocean heat in Arctic winter sea ice growth	18
Alexander Komarov	Environment and Climate Change Canada	CAN	November	Retrieval of ice information from SAR for data assimilation	23
Ronny Hänsch	DLR	GER	November	Shallow learners are dead – Long live shallow learners! Random Forests in the age of Deep Learning	30
Rolf-Ole Rydeng Jensen	UIT/CIRFA	NOR	December	Snow parameter estimation with drone-mounted radar system – Theory and practical solutions	41

Conferences and Workshops

CIRFA researchers participated in a variety of conferences throughout the year of 2020 despite the conferences became online events after March. The Arctic Frontiers conference in Tromsø in January 2020 and the Polar Night Week in Longyearbyen, Svalbard, were among the few events that could take place as an in-person event.

Name of the conference	Month
Arctic Frontiers 2020	January
Polar Night Week	January
EGU	May
AIAA Atmospheric and Space Environments Conference	June
European Conference on Computer Vision	August
IGARSS 2020	September/ October
ESA European Polar Science Week	October
CIRFA conference	October
The 25th IAHR International Symposium on Ice	November

WP 3 and WP 7 had a joint contribution at Arctic Frontiers 2020 at The Edge Hotel in Tromsø. Hugo Isaksen (KSAT) presented on "Satellite Oil Spill Monitoring using multiple sensors" in the session on Disruptive Technologies during the conference. Kjell-Arild Høgda (NORCE) is introducing the speaker. Photo: Camilla Brekke.

Katalin Blix (since fall 2020 associated PostDoc in WP 3) in action at Arctic Frontiers. At this event, Katalin gave two talks, she was chair for one session, and she was involved in the APECS committee. Photo: Camilla Brekke.

Arctic Frontiers 2020

During the Arctic Frontiers conference in January 2020 under the theme "The Power of Knowledge", CIRFA was well represented with researchers presenting the latest research and innovation advances to a diverse audience of scientists, business leaders, decision makers, indigenous peoples and others with a strong panarctic perspective. The Arctic Frontiers conference is an annual platform to exchange ideas with known and new partners and initiates collaboration and innovation that contributed to developing ideas for new project proposals.

In addition, the Arctic Frontiers conference celebrates its participating Early Career Researchers. For the 6th time, the Association of Polar Early Career Scientists (APECS) arranged the Nansen Poster Awards. CIRFA researcher Katalin Blix was part of the organizing committee and Center Leader Torbjørn Eltoft joined the group of poster evaluators. During the conference, 17 poster judges evaluated 28 posters. The evaluation criteria included the visual appearance of the posters, the content and presentation of data, the quality of research, and the skills of the presenter. The winners receive travel support and/or registration for an Arctic Frontiers conference during the upcoming three years.

CIRFA Annual Conference

From October 12-14 the CIRFA Annual Conference took place in the digital universe. To complete our round through different online meeting platforms, this time we used Zoom. Nearly 50 participants joined us on each day for presentations of posters and talks by early career scientists as well as insights in the latest research and innovation highlights. Plenary talks were presented by Jan Petter Pedersen from Kongsberg Satellite Services AS ("New Challenges in the Industry"), Cathleen Jones from the NASA Jet Propulsion Laboratory ("US research landscape in CIRFA perspective") and Charlotte Bay Hasager from the Technical University of Denmark ("Offshore wind energy meteorology using Earth Observation data"). The 2020 General Assembly and Scientific Advisory Board Meeting followed the conference.

State of the art in Maritime Surveillance using Synthetic Aperture Radar

Thanks to their internationally renowned expertise, WP 2 and 3 researchers have successfully contributed to two chapters in a book that is summarizing the state of the art of "Maritime Surveillance with Synthetic Aperture Radar", edited by Gerardo Di Martino and Antonio Iodice: Brekke, Camilla and Jones, Cathleen Elaine. SAR oil spill imaging, interpretation and information retrieval techniques, and Dierking, Wolfgang. Sea ice and icebergs, in: G. Di Martino and A. Iodice, Maritime Surveillance with Synthetic Aperture Radar, IET The Institution of Engineering and Technology, 300 pp., 2020, ISBN-13: 978-1-78561-601-3.

The CIRFA researchers gathered online during this year`s annual conference.

Contribution to the SESS report

Every year, the Svalbard Integrated Earth Observing System (SIOS) publishes the State of Environmental Science in Svalbard (SESS) report. The report summarizes the state of current knowledge of key Earth System Science parameters and analyses how these parameters influence one another. It combines the long-term monitoring data that form the core of the observing system with new, innovative monitoring and research.

Sebastian Gerland, leader of CIRFA WP 6, contributed with a chapter on "Long-term monitoring of landfast sea ice extent and thickness in Kongsfjorden, and related applications (FastIce)" to the 2019 report that has been released during the SIOS Polar Night Week in Longyearbyen in January 2020. Richard Hann from CIRFA WP 4 prepared a review of "Scientific Applications of Unmanned Vehicles in Svalbard (UAV Svalbard)" for the 2020 report that has been released during the SIOS Polar Night Week in Longyearbyen in January 2021.

In addition to evaluating the state of current knowledge, the SESS reports highlight questions that remain unanswered and recommends solutions in terms of research infrastructure improvements and research priorities. We are proud to see contributions from our CIRFA researchers included.

Interview by Naturvetaren

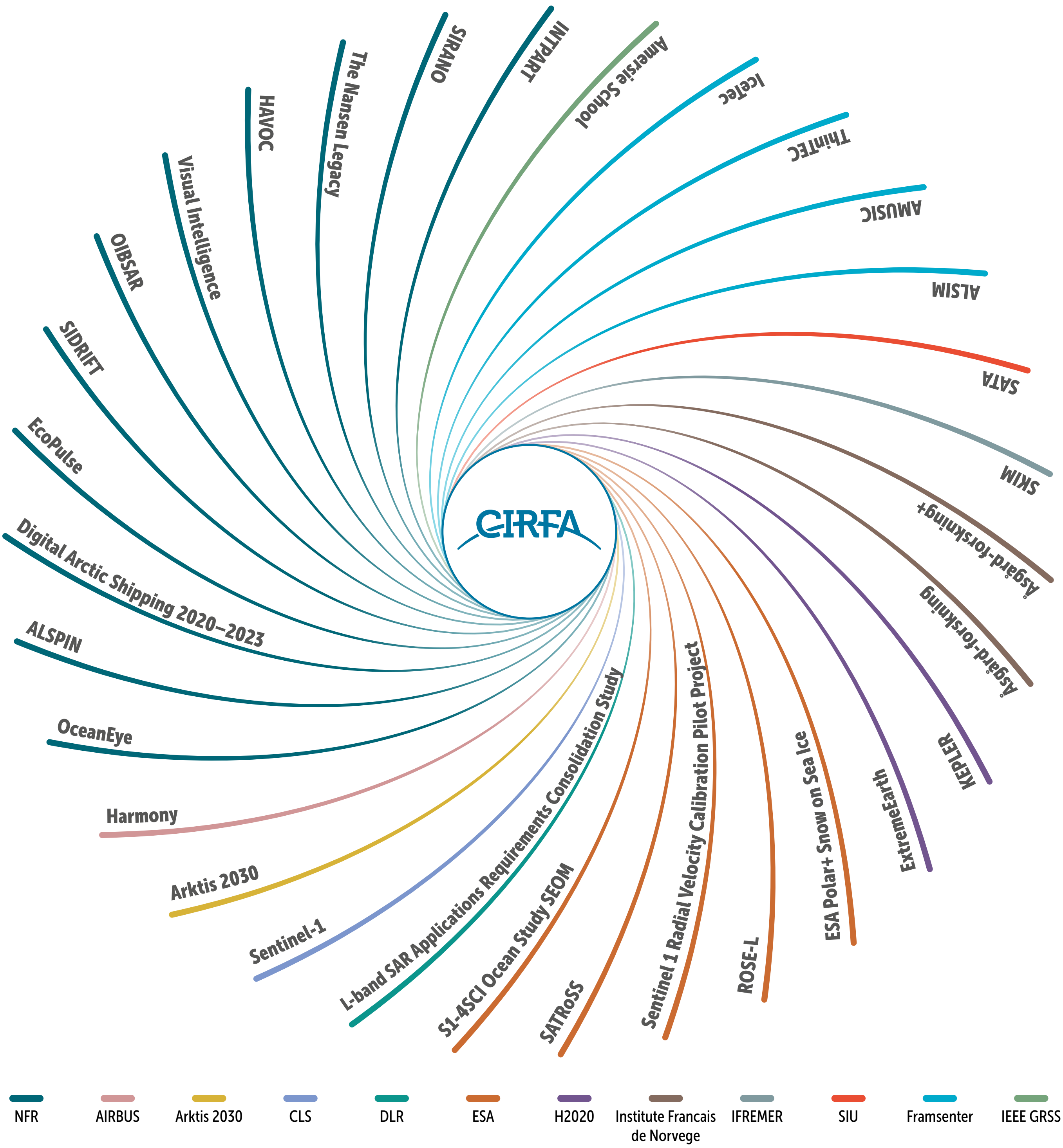
Malin Johansson was interviewed about working in Norway as a Swede. Photo: Paul Dodd.

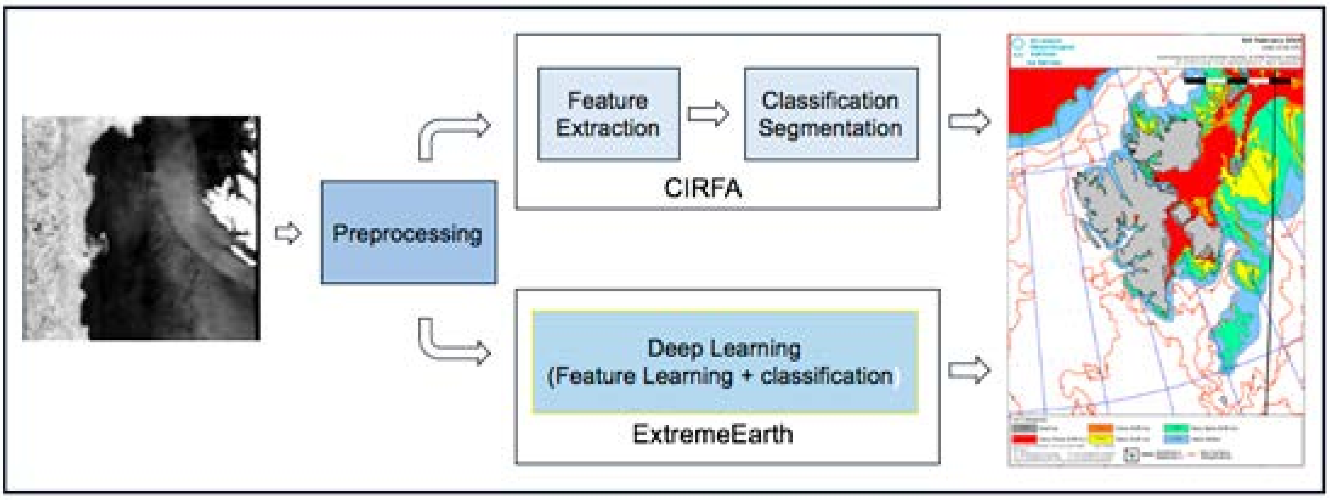
Researcher Malin Johansson was interviewed by the Swedish magazine, "Naturvetaren" (approx. "The Environmental Scientist") about her work about oil spill detection in the Barents Sea, how she got to know about relevant research at the world`s northernmost university, and what it's like for a Swede to work in Norway.

An iceberg with entrained bands of dark sediment in sea offshore western Svalbard. Photo: Sebastian Gerland (NPI).

The CIRFA "Ecosystem"

In its field of research, CIRFA is associated with 31 national and international research and innovation projects or varying funding amount and complexity. About half of them are international projects that involve organisations such as DLR, IICWG, ESA and JAXA. Many of the projects employs artificial intelligence and/or machine learning to analyze climate and environmental data, and training and competence building. The closest connection to these associated projects with the largest efforts are the ExtremeEarth and KEPLER projects.





ExtremeEarth is a three-year H2020 ICT *research and innovation* project. Its main objective is to investigate how Artificial Intelligence and Big Data technologies can generate information and knowledge from the Copernicus large volumes of free and open satellite data. The CIRFA partners UiT and Met are the leading contributors in the project's Polar Use Case, where the goal is to produce high resolution ice charts, primarily from synthetic aperture radar data (i.e. Sentinel-1 data). In this regard, our work in the project is highly relevant to the research and development in CIRFA's work package 2. As illustrated below, on the methodology side, ExtremeEarth is complementary to CIRFA work when it comes to how the high-resolution ice charts are constructed, but the end goal is the same. The research so far has experimented with several deep learning architectures and demonstrated model performance for *ice-versus-water* separation. The challenge of deep learning models requiring large training data has been looked into by exploring semi-supervised deep models. ExtremEarth addresses the Big Data issue by also studying distributed computational aspects of training and implementing deep learning algorithms. This work is currently under investigation by PhD fellow Saman Khaleghian.

KEPLER (**K**ey **E**nvironmental monitoring for **P**olar **L**atitudes and **E**uropean **R**eadiness) is a Horizon2020 initiative funded by the European Commission. KEPLER unites the arctic ice information services with the Copernicus Land Monitoring Service. The project is collecting requirements from users and stakeholders that are operating in the polar regions to make recommendations for future improvements and their implementation. Identifying research capacities and gaps as well as improving sea ice mapping and forecasting will lead to a roadmap of an end-to-end operational system. Being associated with the KEPLER project provides CIRFA with valuable feedback on research and innovation needs.

Competence development and outreach are focus points of other projects and efforts such as INTPART and the **IEEE AMERSIE School** that Saloua Chlaily and Andrea Marinoni were involved with. The IEEE AMERSIE School on "*Advanced methods for remote sensing information extraction*" in November 3-5 aims at introducing the participants to advanced signal processing methods for information retrieval in large scale datasets collected by multiple remote sensors. To achieve this, the school will bring together leading researchers from academic institutions, data providers, and industry end-users.

Taking advantage of **institutional networks, exchanges, sabbaticals and research visits** are encouraged and supported to extend individual researcher`s networks. For example, Cathleen Jones (JPL-NASA, USA) and Wolfgang Dierking (AWI), who are adjunct professors in CIRFA, and the Scientific Advisory Board of CIRFA with members from Germany and Danmark contribute to research exchange and innovation across borders. Furthermore, WP3 is well connected with the national and international academic landscape through Camilla Brekke, who is the Deputy Centre Leader at CIRFA and Vice-Dean Research at the Faculty of Science. She has promoted CIRFA at various occasions; examples are an invited talk at CalTech and at UiT board meetings. From 2020, she is also a member of European Space Sciences Committee (ESSC). The ESSC provides expert advice to the European Space Agency (ESA), the European Commission, EU national space agencies, and other decision-makers in the space domain. It has become the reference body in Europe for independent scientific advice on space matters and a focal point for international research collaboration since its funding date in 1974.

Post doc Katalin Blix visited the Image Signal Processing group at the University of Valencia (Spain) between December 2019 and October 2020. The research visit was an amazing experience, even though the second part of it was digital. Katalin was surrounded by a highly skilled team in machine learning algorithm development for Earth observations, a breathtaking nature (sandy beaches and mountains with springs), excellent

Camilla Brekke visited The California Insititute of Technology in California, U.S., in February/March just before the covid-19 pandemic. She gave a presentation on behalf of the Faculty of Science where CIRFA and WP 3 work were also covered. Martin Ludvigsen (left) in the Nansen Legacy project was also present at the meeting. Photo by fellow participant at a guided tour at JPL.

Katalin Blix enjoys her research stay in Valencia, Spain.

training facilities both indoors and outdoors and super social, happy people. Katalin believes the latter is due to the no variations in weather; it is always sunny. In a very short time, Katalin became part of this fantastic local community. Katalin has not only developed her skills professionally, but also learnt how to work very efficiently, while having a pleasant work environment and a calm work pace. Although COVID-19 ended this fantastic way of working, but the collaboration still lasts. Katalin cherish the people and her time in Valencia, and she is looking forward to return!

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Dierking, W. F. O. & Davidson, M.: Enhanced sea ice monitoring at L- and C-bands using ROSE-L and Sentinel-1. IGARSS International Geoscience and Remote Sensing Symposium 2020

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Gerland, S.; Divine, D. V.; Dierking, W. F. O.; Doulgeris, A. P.; Eltoft, T.; Johansson, M.: Use of in situ and airborne Arctic sea ice surveys for SAR satellite remote sensing application improvements. 2020 ESA European Polar Science Week. Video on Youtube: https://www.youtube.com/watch?v=eTZhbxu4wVo&feature=emb_logo

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Hann, R. & Johansen, T. A.: Unsettled Topics in Unmanned Aerial Vehicle Icing. Society of Automotive Engineers

Johansson, M.; Espeseth, M.; Brekke, C.; Holt, B.: Can Mineral Oil Slicks be Distinguished From Newly Formed Sea Ice Using Synthetic Aperture Radar? CIRFA annual conference

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Accounts

Funding sources

The Research Council of Norway	10 439
Industry partners	4 977
The host institution (UiT)	6 186
Research partners	2 065
Total	**23 669**

Costs per activity

WP 1 Ocean RS	1 422
WP 2 Sea Ice RS	4 690
WP 3 Oils Spill RS	4 539
WP 4 RPAS Technology	2 587
WP 5 Drift Modeling and Prediction	4 532
WP 6 Fieldwork and Data Collection	808
WP 7 Pilot Service Demonstration	2 118
Management	2 972
Total	**23 669**

Costs per partner

Research partners	
UiT	13 549
NORCE	3 869
Sintef Narvik	1 530
NTNU	
NPI	905
MET Norway	2 524
NERSC	408
Industry partners	
Equinor	304
Vår Energi	139
Total E&P Norge	59
OMV Norge	57
Aker BP	
Aker Solutions	
Multiconsult	64
KSAT	258
Maritime Robotics	
Total	**23 669**


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