Final Report

CIRFA

Centre for Integrated Remote Sensing and Forecasting for Arctic Operations
2015 – 2023

THE ARCTIC UNIVERSITY OF NORWAY • UIT •

sfi Centre for Research-based Innovation

Meeting the challenges of increasing maritime activity in icy waters, supporting environmental monitoring, and training tomorrow's specialists.

Partners in CIRFA

CIRFA was hosted by UiT The Arctic University of Norway and linked with the Earth Observation group at the Department of Physics and Technology at the Faculty of Science and Technology. It had a network of partners from the public and private sectors as well as from research institutes all over Norway. A few of the partners initially involved, namely TOTAL, GlobeSAR, Aranica, and Kongsberg SpaceTec, joined the consortium over shorter periods.

Past partners

Aranica

Kongsberg Spacetek

Key figures

	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
PhD degrees completed	0	0	0	2	2	2	4	2	2	**14**
MSc degrees completed (thesis with CIRFA)	3	2	5	6	8	1	7	3	6	**41**
Scientific publications (peer reviewed)	1	11	23	21	19	28	23	17	23	**166**
Dissemination measures for users	15	38	55	32	43	14	15	21	33	**266**
Dissemination measures for the general public	3		2	4	2	2	3	3	2	**21**
Fieldwork for data collection, validation & testing of new technology	5	7	10	12	13	6	10	8	5	**76**
* New/improved methods/models/ prototypes finalised										**16**
* New/improved products/ processes/services finalised										**10**

* Please see page 22 for a description of innovative outcomes, their scientific and operative status, and related references.

Content

Contact 3
Foreword 4
Branding UiT in Arctic Remote Sensing 5
Summary 6
Sammendrag 9
Vision and Objectives 11
Basic facts about the center 12
Glimpses of CIRFA`s production of knowledge and innovation 21
Research and Innovation Approach 24
Work package 1 Ocean Remote Sensing 24
Work package 2 Monitoring Sea Ice and Icebergs 27
Work package 3 Oil Spill Remote sensing 31
Work package 4 Drone Technology 33
Work package 5 Drift Modelling and Prediction 35
Work package 6 Data Collection and Fieldwork 38
Work package 7 Pilot Service Demonstration 44
Education and Training 47
Communication and dissemination 52
Effects of the center for host institutions and research partners 53
Effects of the center for company partners, public partners and society at large 55
Future Plans 56
Conclusions 57
List of PhD candidates, post docs, and master students during the full period of the center ... 58
Publication list 64
Financing through the lifetime of the center 78

Contact

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

Project coordinator: Andrea Schneider, e-mail: andrea.schneider@uit.no

Postal address: UiT – The Arctic University of Norway. P.O. Box 6050 Langnes, NO-9037 Tromsø, Norway

Visiting address: Siva Innovasjonssenter Tromsø (Forskningsparken), Sykehusvegen 21, 9019 Tromsø

Online: Cirfa - Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (uit.no)

DOI of the final report: 10.5281/zenodo.10785642

Foreword

The SFI-center CIRFA started up on September 1st, 2015. The Centre's overall goal was to conduct research and develop methods to advance remote sensing monitoring capabilities and forecasting skills, enabling *safer operations* and *reduced risk* of human-induced environmental hazards. It also had an ambition to become a knowledge hub for Arctic remote sensing, specifically addressing challenges of maritime industrial operations in Arctic waters. CIRFA's research was focused on three main use cases with high relevance to its industry partners: namely met-ocean remote sensing, sea ice remote sensing, and oil spill remote sensing. These application areas were supported by work packages addressing drone-based remote sensing, numerical modelling and forecasting, and field work and data collection.

Given the specific challenges of industrial activities in the Arctic, i.e., extreme weather events, polar night, and low visibility in the light season, a requirement for an adequate remote sensing system in these areas would be all-weather and light-independent sensors with high spatial and temporal resolution. CIRFA's research was mainly aiming for products and services based on synthetic aperture radar (SAR) data, provided by radars operating in the microwave spectral domain, or algorithms, where SAR data was used in combination with passive microwave or multi-spectral optical data. Microwave sensors have all-weather and light-independent capabilities, and are thus well suitable for high-north remote sensing tasks all year around.

The scope of CIRFA required a multi-disciplinary research team. The approach was to integrate experience in remote sensing with competences in several science disciplines and technologies, including geophysics, meteorology, radar physics, signal processing, drone technology, and numerical modelling. This turned out to be a successful strategy and resulted in several important scientific achievements. The approach is recommended in future projects and centres with similar research goals.

Previous annual reports of CIRFA present in text and figures the diverse set of activities the centre initiated and was involved in through the years. They resulted in many successful achievements. The Centre's researchers published an extensive number of peer-reviewed papers in internationally acknowledged journals, many with high citation rates, and the active participation in international and national conferences has made CIRFA known and well acknowledged in the scientific community. Likewise, the collaboration between academia and industry facilitated innovative processing lines and algorithms, some of which are already implemented for operational testing at MET Norway and KSAT. CIRFA's educational program supported many master candidates, PhDs, and Postdocs, and in this way the Centre has built competence and trained future researchers in the field. Many of the educated candidates now work at CIRFA's partners. Details about their work in the center can be found elsewhere in this report and in the individual annual reports.

The SFI CIRFA initiated and conducted several successful field campaigns, in which ground-based observations were coordinated with simultaneous satellite over-passes. The CIRFA-2022 cruise to the north-east coast of Greenland in April-May 2022, was a highlight. This was the first Norwegian cruise in the Arctic completely dedicated to testing and validating remote sensing products. It was a major success, and generated a legacy of in-situ and satellite data which can serve future Earth observation research for many years. The research cruise had participation from collaborating national and international groups, and thus also served the purpose of facilitating collaborations. CIRFA established connections to many outstanding international research groups e.g. at AWI, JPL. In addition, CIRFA had collaborative agreements with major national space agencies like: NASA (USA), ESA (EU), DLR (Germany), JAXA (Japan) and CSA (Canada), through which its researchers got access to satellite data on demand.

I would like to take the opportunity to acknowledge all who has contributed to CIRFA's achievements. UiT has been an outstanding host, providing generous financial and administrative support. I want to thank all partners for funding and support, and the scientific advisory board for its insightful feedback and advice. Last, but not the least, I want to express my gratitude the CIRFA's personnel; the Centre's coordinators for administrative help and support, and the whole scientific staff for its enthusiastic work throughout the whole project period. Without your commitment, the Centre would not have reached so many of its goals.

Torbjørn Eltoft
Center Leader

Branding UiT in Arctic Remote Sensing

Arne O. Smålas
Dean
Faculty of Science and Technology
UiT The Arctic University of Tromsø

As Dean of Faculty of Science and Technology, I am proud to acknowledge that the SFI CIRFA is a great success for UiT the Arctic University of Norway. As the name "Centre for Integrated Remote Sensing and Forecasting for Arctic Operations" indicates, the research of the Centre is about remote sensing and modelling technologies, topics which are essential to support safe industrial operations in the Arctic, as well as being important for monitoring effects of climate change and studying geophysical processes in the High North regions. Building competence in these disciplines is important to UiT, as we experience more frequent and more dramatic consequences of the global warming taking place.

CIRFA has been an asset to UiT in several aspects. The Centre has been strongly involved in UiT's education program in Earth Observation, and has, through the years, supervised many students at MSc and PhD students to their degrees. Many of the graduated candidates have found jobs with local and regional companies and research institutes. This is highly appreciated, as one of UiT's main responsibilities as a regional University is to educate high qualified personnel to the North of Norway.

CIRFA has built a strong network and established valuable collaboration with local and national industry. It has created international visibility, and connected UiT to internationally well-known research institutions like Alfred Wegener Institute in Germany, Jet Propulsion Laboratory in the USA, and IFREMER in France, and cooperated with important space agencies such as the European Space Agency, the German Space Center (DLR), the Japan Aerospace Exploration Agency (JAXA), and the Canadian Space Agency. These connections are very valuable for UiT and will hopefully foster new collaborations in the future.

In conclusion, CIRFA has been a highly successful SFI. Its research has been at a high international level, its innovation products have been greatly valued by its industrial partners, and through a professional environment, the Centre has been an inspiring working place for early career scientists. CIRFA has also been an important instrument for realizing the research strategy of UiT the Arctic University of Norway, and in collaboration with other big projects at UiT, branding UiT as a leading actor in Arctic remote sensing.

Summary

Brief description of objectives/vision

The vision of CIRFA, from the beginning in 2015, was to form a leading international research center, which through innovative research would contribute to make industrial operations in the Arctic safer, more effective, and environmentally friendly. To achieve this, the Centre would build competence and do research on integrated remote sensing and forecasting methodologies for high-north applications. Its research program included work packages on algorithm development for met ocean, sea ice and icebergs, marine oil slicks remote sensing, development of Remotely Piloted Air Systems (RPAS) and related sensor technologies for local high-resolution monitoring. In addition, research on numerical modelling and assimilation to improve forecasting of met ocean and sea ice conditions in the Barents Sea, collection of in-situ data from field cruises and RPAS field campaigns, and the demonstration of the provision of integrated environmental information to end-users involved in Arctic operations.

The consortium

As a center for research-based innovation, the CIRFA team did research and development which adressed important societal challenges and needs of its industrial partners. Over its lifetime, the center combined two universities, five research institutes and between 8 and 12 industry partners in Norway. 4 partners signed out after the midterm.

Research partners

Norwegian Meteorological Insitute (MET Norway)
Norwegian Research Centre (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), Faculty of Science and Technology, Department of Physics and Technology (host institution)

User partners

Aker BP
Aker Solutions
Equinor
Kongsberg Satellite Services (KSAT)
Maritime Robotics
Multiconsult
OMV Norge
Vår Energi

Past partners:
TOTAL, GlobeSAR, Aranica
Kongsberg SpaceTec

Research results and impact for industry, public sector and society at large

CIRFA's research has enabled new monitoring capabilities, which will improve situational awareness and decision-making in Arctic operations, and subsequently protect people, equipment, platforms, vessels, and the environment. More specifically, the research has resulted in more high-resolution sea ice maps, more reliable iceberg detection capabilities, better met-ocean information (wind, waves, currents), improved oil spill detection and characterization algorithms, a more high-resolution forecast model for the Barents Sea, and new, advanced drone technology for supporting navigation in sea ice and industrial operations in Arctic waters.

The CIRFA-team published over 150 peer-reviewed journal papers, some with quite high citation rates, and contributed widely to international conferences within its research domain.

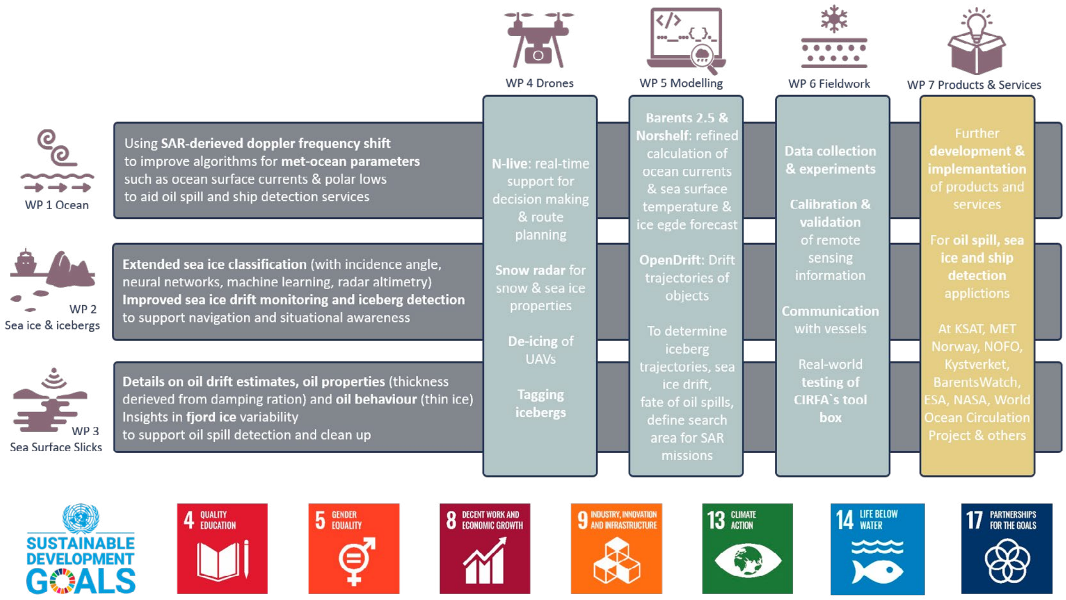


Figure: Andrea Schneider

CIRFA's internal work package structure with a summary of key research and innovation outcomes. We included a list of UN sustainable development goals that CIRFA has addressed.

From a more general point of view, CIRFA`s work has addressed UN sustainable development goals such as quality education (4), partnership between industry and academia to enhance innovation (9, 17), and support of climate protection through its Earth observation activities (13) and conservative and sustainable use of the oceans (14). Its inclusive work environment with a good gender balance supports another goal (5), and the technology that CIRFA has developed will contribute to making maritime workplaces and leisure activities safer, ensuring a decent and stable working life and sustainable economic growth (8).

Research training and MSc-level education

With research- and innovation-based education and training being an important element in the work of CIRFA, master students, PhD candidates and postdocs have benefitted from courses, workshops, seminars, case studies, experiments and fieldwork. Contact with partners from the public and private sector cultivated early career researcher`s awareness for the research and innovation needed to address real-world challenges.

International collaboration

Active international cooperation has been important throughout CIRFA's lifetime. The center collaborated with partners in Europe, the USA, Canada, Japan and Russia (the latter until March 2022). A good example of this is the CIRFA-2022 cruise, where 33 researchers from 17 nations participated. The center also had bilateral cooperation and data exchange agreements with major space organizations such as NASA (USA), JAXA (Japan), ESA (Europe), CSA (Canada) and DLR (Germany), and supported international exchange by offering internship opportunities to many foreign students.

Added value by being an SFI

The time perspective of 8 years, the well-sized budget and the well-selected consortium enabled the implementation of an ambitious research program, which could address real-world challenges related to industrial operations in the high north, and establish effective collaboration and networking between academia and industry. This made CIRFA`s strong innovation and publication record possible.

CIRFA has educated nearly 50 master candidates, supported 28 PhD candidates and many early career researchers (see pages 59-63 for details). Their communication with industry partners would make them realize the applicability of their work. Being part of a research center, with participation in fieldwork and experiments, served as excellent training for teambuilding. The broad education of early career scientists in CIRFA has produced a new generation of remote sensing specialists with deep competence in Arctic remote sensing, algorithms development, and handling of large datasets, and skills in publication and proposal writing, that will benefit society in years to come. Many CIRFA students and PhD candidates have already started a new work life with CIRFA`s partners in the public or private sector.

Climate change has increased the demand for competence in earth observation in society and industry, worldwide. UiT's educational programs in applied STEM subjects secure its leading role in this field. CIRFA strengthened Tromsø`s position as a leading remote sensing location in Norway and Europe, considering also that institutions in Tromsø have a strong background in remote sensing and plan for further large-scale initiatives (see below).

Future plans

The end of CIRFA will certainly scale down the coordinated research efforts in Arctic remote sensing. However, during the lifetime of CIRFA, many research projects of varying sizes have received funding. They will continue some of the research topics and consolidate some of the technologies that have been developed CIRFA.

Furthermore, research and innovation ideas, which took shape in CIRFA, is carried over into future initiatives; such as The ESA Arctic Phi Lab, which is planned in Tromsø, and the National Knowledge Center for Earth Observation, which has been given a start-up funding from the Norwegian Government in 2024.

Sammendrag

Forskningsresultater og effekt for industri, offentlig sektor og samfunnet

Visjonen til CIRFA, fra starten i 2015, var å skape et ledende internasjonalt forskningssenter, som gjennom innovativ forskning, skulle bidra til å gjøre industriell virksomhet i Arktis tryggere, mer effektiv og miljøvennlig. For å oppnå dette, ville senteret bygge kompetanse og forske på integrert fjernmåling og varslingsmodeller for hav og isforhold i nordområdene. Forskningsprogrammet inkluderte arbeidspakker for algoritmeutvikling for met-ocean, havis og isfjell, og fjernmåling av marint oljesøl, utvikling av droneteknologi og tilhørende sensorteknologier for dronebasert fjernmåling, forskning på numerisk modellering og assimilering for å forbedre prognoser for hav- og isforhold i Barentshavet, innsamling av in-situ data fra felttokt og dronekampanjer, og demonstrasjon av levering av satellittbaserte informasjonsprodukter til sluttbrukere involvert i arktiske operasjoner.

CIRFA-teamet publiserte over 150 journalartikler, noen ble sitert ganske ofte, og bidro med mange faglige bidrag til internasjonale konferanser innenfor forskningsdomenet.

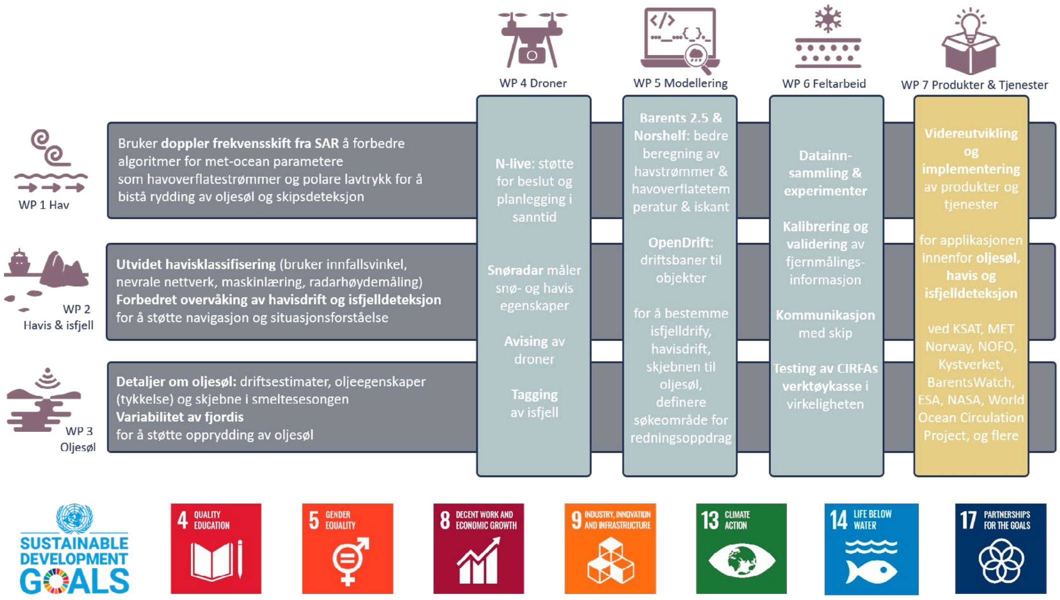


Figure: Andrea Schneider

CIRFA's interne arbeidspakkestruktur med en oppsummering av de viktigste resultater fra forskning og innovasjon. Vi inkluderte en liste over FNs mål for bærekraftig utvikling som CIRFA har jobbet mot.

I et overordnet bilde har CIRFA bidratt til å adressere FNs bærekraftigmål som kvalitetsutdanning (4), partnerskap mellom forskning og akademia for å øke innovasjon (9, 17), og klimatiltak gjennom miljøovervåking for å redusere miljøpåvirkningen (13) og konservativ og bærekraftig bruk av havene (14). Som et inkluderende arbeidsmiljø med god kjønnsbalanse understøttes bærekraftmål (5), og teknologien som CIRFA har utviklet, vil bidra til å gjøre maritime arbeidsplasser og fritidsaktiviteter tryggere, sikre et anstendig og stabilt arbeidsliv og en bærekraftig økonomisk vekst (8).

Partnere

Som Senter for Forskningsdrevet Innovasjon, har CIRFA-teamet gjort forskning og utvikling som ivaretok viktige behov hos sine industrielle partnere. I løpet av levetiden hadde senteret som partnere: to universiteter, fem forskningsinstitutter og mellom 8 og 12 industripartnere i Norge. 4 industripartnere forlot senteret etter første halvdel.

Forskerutdanning og utdanning på MSc-nivå

Med forsknings- og innovasjonsbasert utdanning og opplæring som et viktig element i CIRFA, har masterstudenter, PhD-kandidater og postdoktorer hatt nytte av kurs, workshops, seminarer, case-studier, eksperimenter og feltarbeid. Kontakt med partnere fra offentlig og privat sektor har gitt bevissthet om forskning og innovasjon som søker å løse reelle utfordringer.

Internasjonalt samarbeid

Aktivt internasjonalt samarbeid har vært viktig gjennom hele CIRFAs levetid. Senteret hadde samarbeid med partnere i Europa, USA, Canada, Japan og Russland (sistnevnte frem til mars 2022). Et godt eksempel på dette er CIRFA 2022-toktet, der 33 forskere fra 17 nasjoner deltok. Senteret hadde også bilaterale samarbeids- og datautvekslingsavtaler med store romfartsorganisasjoner som NASA (USA), JAXA (Japan), ESA (Europa), CSA (Canada) og DLR (Tyskland). Senteret støttet også internasjonal utveksling ved å tilby praksismuligheter til mange utenlandske studenter.

Merverdi ved å være SFI

Et tidsperspektiv på 8 år, et generøst budsjett og et velvalgt konsortium gjorde det mulig å etablere et ambisiøst forskningsprogram, som kunne adressere virkelige utfordringer knyttet til industriell virksomhet i nordområdene, samt etablere et effektivt samarbeid mellom akademia og industri. Dette gjorde CIRFAs gode innovasjons- og forskningsarbeid mulig.

CIRFA har utdannet nesten 50 masterstudenter, støttet 28 PhD-kandidater og mange unge forskere (detaljer på sidene 59-63). Gjennom god kommunikasjon med industripartnere har de fått se viktigheten forskningen de har gjort. Det å være en del av et forskningssenter, med deltakelse i feltarbeid og eksperimenter, har fungert som en god trening i teambuilding. Den brede utdanningen av unge forskere i CIRFA, har produsert en ny generasjon fjernmålingsspesialister med god kompetanse innen arktisk fjernmåling, algoritmeutvikling og håndtering av store datasett, vil komme samfunnet til gode i tiden som kommer. Mange CIRFA-studenter og PhD-kandidater har allerede startet et nytt arbeidsliv hos CIRFAs partnere i offentlig eller privat sektor.

Klimaendringer har økt etterspørselen etter kompetanse innen jordobservasjon i samfunnet og industrien, over hele verden. UiTs utdanningsprogrammer i anvendte STEM-fag sikrer en ledende rolle på dette feltet. CIRFA har styrket Tromsøs posisjon som et ledende fjernmålingsmiljø i Norge og Europa, og har, sammen med andre institusjoner i Tromsø med sterk bakgrunn i fjernmåling, lagt til rette for nye initiativer (se nedenfor) innenfor dette feltet.

Fremtidsplaner

Avslutningen av CIRFA vil skalere ned den koordinerte forskningsinnsatsen innen arktisk fjernmåling. I løpet av CIRFA's levetid har imidlertid mange andre forskningsprosjekter, av varierende størrelse, mottatt finansiering. Disse vil ta videre noen av forskningstemaene og konsolidere noen av teknologiene som er utviklet senteret. Videre blir forsknings- og innovasjonsideer, som ble til i CIRFA, bli tatt videre i fremtidige initiativer; som ESA Arctic Phi Lab, som er planlagt i Tromsø, og Nasjonalt kunnskapssenter for jordobservasjon, som har fått oppstarts midler fra den norske regjeringen i 2024.

Vision and Objectives

Scientific focus and technology development

CIRFA aimed to enhance information retrieval from remote sensing data and advance forecasting of oceanic and sea ice conditions for safer and efficient operations in ice-covered waters. This required:

(1) Research on monitoring technologies and geophysical processes to improve understanding and enable better forecasting of phenomena such as ocean surface currents and winds, polar lows, and atmosphere - sea ice - ocean interactions,
(2) Dealing with new approaches from statistics, deep learning and information theory in Arctic remote sensing,
(3) The development and improvement of oil spill and iceberg detection in open and ice-covered waters,
(4) Advancement of drone technology for local monitoring,
(5) Data assimilation into forecasting models,
(6) In-situ data acquisition for development and validation of the the new methods.

The research was focused on synthetic aperture radar (SAR) sensors, and SARs used in combination with passive microwave and optical sensors. The collaborative efforts resulted in innovative solutions in terms of new technologies, information products and services, and exceptional scientific contributions, which is demonstrated in successful citation records.

Collaboration with industry

As a research-based innovation center, which should foster a strong interaction between academia, industry, and authorities, the foci in research and method developments were discussed and fixed between CIRFA partners, with the goal to create and test novel and improved end-user targeted tools which were mentioned above. These innovations aim to enhance:

(1) the situational awareness, decision-making, and protection of human life,
(2) the safety of maritime platforms and vessels,
(3) the protection of environment and ecosystems in Norwegian and international waters.

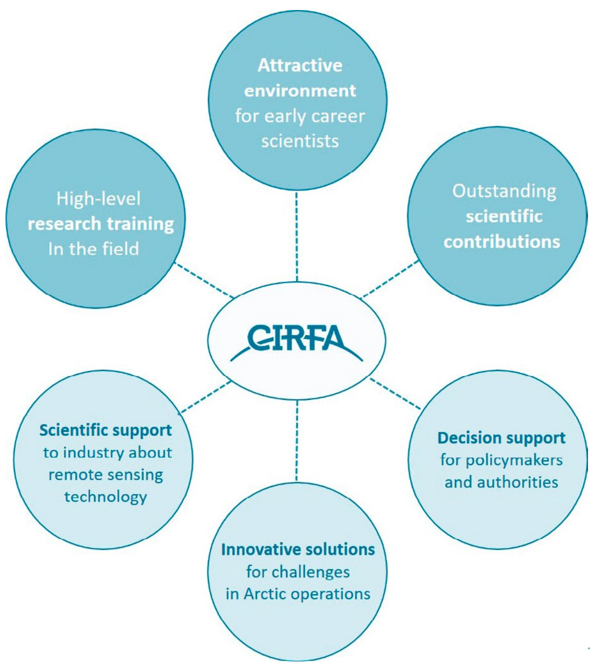
Notable developments include the Barents 2.5 model for forecasting sea ice conditions, the OpenDrift model for predictions of the spreading of oil spills, refined methods for satellite-based oil slick characterization, significant advances in automated sea ice mapping, and new innovative tools for drone operations and drone-based remote sensing in the Arctic.

The research and technologies were developed in close interaction with the Centre's partners, outlined in the annual working plans, and formally approved by the Consortium Board. The information exchange between research and industry partners was organized in dialog meetings, special workshops, and at the annual meetings. Examples of direct industry involvement in CIRFA activities are the information exchange between KSAT, NOFO, and the CIRFA team during the NORSE-2015 and -2019 field experiments, the investigation of remote sensing capabilities for mapping and modelling of produced water, and the interaction with the Ice Service at MET Norway on validating SAR-based sea ice and iceberg products.

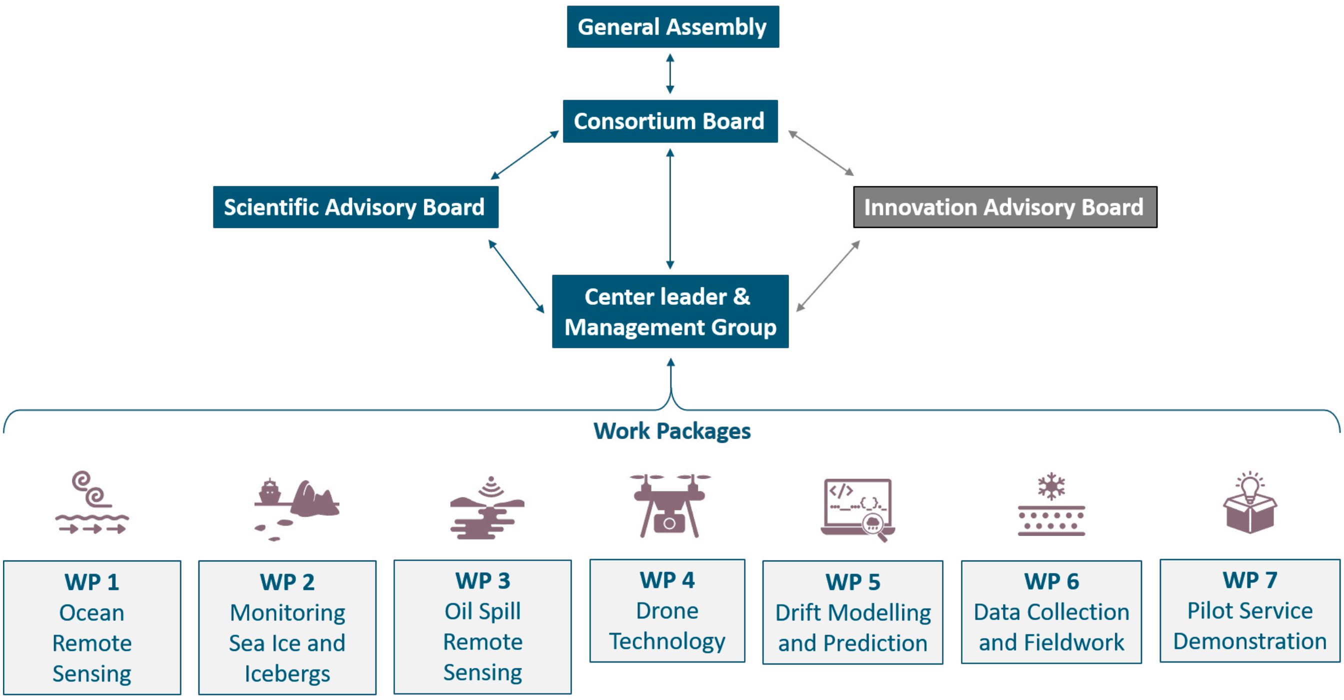
The industry partners had majority in the Consortium Board, which was chaired by UiT the Arctic University of Norway in the first and by Equinor in the second half of CIRFA's operation period.

Research-based education and training

Being a research-focused learning environment with a strong link to practical applications, CIRFA offered comprehensive training for master students, PhD candidates, and post-docs through special technical courses, workshops, conferences and fieldwork. The Centre established a Young Scientist Forum, which organized brief courses in technical skills (e.g. programming, data storing) and complementary skills (e.g. paper writing, research proposal writing), and some team members also gave online courses with a large audience of international students: AMERSIE (IEEE) and ARSET (NASA). Early career researchers gained insights into more specialized research topics and the respective broader research and innovation context. The experiences gained in fieldwork provided a more realistic perspective on Arctic conditions. Engaging with CIRFA's partners and stakeholders encouraged the young researchers to reflect on the societal relevance of their work.



Basic facts about the center



The Governance Structure

The governance structure is presented in this section. CIRFA`s General Assembly gathered representatives from all partners annually to ensure a direct exchange of information. The main responsibility of the General Assembly was to elect the members and the leader of the Consortium Board every second year.

CIRFA`s Consortium Board was responsible for the Centre's strategy, progress, budget and annual work plans. Its composition was changed every second year to allow all partners to participate.

Consortium Board members in the four different periods were:

2021 – 2023:
Richard Hall (Equinor), Kjell Arild Høgda (NORCE), Svein Olav Dragøy (OMV), Rune Pedersen (Vår Energi), Arne Smalås (UiT), Jan Petter Pedersen (KSAT), Lars Anders Breivik (MET Norway)

2019 – 2021:
Richard Hall (Equinor), Kjell Arild Høgda (NORCE), Edmond Hansen (Multiconsult), Terje Solheim (Aker BP), Arne Smalås (UiT), Jan Petter Pedersen (KSAT), Harald Steen (NPI)

2017 – 2019:
Richard Hall (Equinor), Kjell Arild Høgda (NORCE), Svein Olav Dragøy (OMV), Robert Bridges (Total), Arne Smalås (UiT), Jan Petter Pedersen (KSAT), Lars Anders Breivik (MET Norway)

2015 – 2017:
Richard Hall (Equinor), Kjell Arild Høgda (NORCE), Edmond Hansen (Multiconsult), Oddvar Ims (Vår Energi), Morten Hals (UiT), Jan Petter Pedersen (KSAT), Nalan Koc (NPI)

CIRFA`s Scientific Advisory Board provided assessments and recommendations regarding the practical execution of research tasks and implementation of work plans. Since the Scientific Advisory Board covered also the aspect of innovation activities, thoroughly considering the industry partners' needs, CIRFA`s Innovation Advisory Board was terminated early in CIRFA`s lifetime.

The work package leaders were members of the Centre Management Group (CMG) which was led by the Centre Leader, Professor Torbjørn Eltoft. The CMG met every three weeks to update each other about research progress, submitted and accepted publications, conference participations, ongoing collaborations, progress of PhD candidates and other relevant information.

The Work Package Structure of CIRFA

Since maritime operations in environmentally sensitive Arctic waters require reliable information about weather, ocean, and ice conditions, the CIRFA team had expertise in remote sensing and earth observation, numerical modelling and forecasting of ocean and sea ice conditions, drone technologies, and field work. Integrating information from remote sensing data and forecasting models into day-to-day operations and decision support enables safe and effective work routines for personnel, proper procedures for using equipment and less harm to the environment.

In CIRFA, scientific knowledge extent and technology development (software and hardware) was divided into 7 work packages (WPs):

WP1 – Ocean Remote Sensing: WP1 advanced the use of satellite technology to improve the understanding of the Arctic Ocean processes and dynamics in science and operational applications. Objectives were to improve predictions of polar lows and short-range forecasting of the ocean state through coupling of satellite data with high-resolution numerical models.

WP2 – Monitoring Sea Ice and Icebergs: WP2 used satellite data for mapping of sea ice and snow conditions, determination of ice drift patterns, and for detection of icebergs. The work included the development of (semi-) automatic classification and detection algorithms, thereby using statistical methods, deep learning, and information theory. Given the decrease of sea ice extent and thickness in the Arctic and associated growing ship traffic, satellite monitoring becomes essential for evaluating opportunities and risks.

WP3 – Oil Spill Remote Sensing: WP3 focused on advanced processing of remote sensing data for detecting and characterizing mineral oil spills on the open ocean surface and in sea ice, and for separating them from look-a-likes such as algae blooms, wind-induced ocean patterns, and newly formed sea ice. This is crucial for safeguarding marine and coastal environments from pollution caused by drifting oil spills and for planning of the clean-up and recovery.

WP4 – Drone Technology: The WP4 team developed robust and efficient RPAS and sensor technologies that can handle the widest possible range of Arctic meteorological conditions. The drone sensors can perform high-quality imaging of local sea ice conditions and iceberg occurrences as well as detecting and monitoring oil spills on the ocean and in sea ice.

WP5 – Drift Modelling and Prediction: WP5 enhanced short-term weather and ocean forecasts by integrating numerical models and remote sensing observations, aiming to quantify their uncertainty for more accurate predictions. Such forecasts are needed for predicting the drift behavior of sea ice, icebergs, oil slicks and passively floating objects such as buoys.

WP6 – Data Collection and Fieldwork: Team members from WP6 planned and led Arctic field campaigns which involved coordination of satellite overflights, helicopter and/or drone measurements, and ground data acquisitions. It included also measurements in the Hamburg Ship Model Basin and in Norwegian fjords. The main objective was to establish data archives which can be used for calibrating the developed methods and for validation of CIRFA's information products.

WP7 – Pilot Service Demonstration: WP7 focused on testing the prototypes of new methods and products developed in the other WPs. Collaborating with industry partners, WP7 has demonstrated the value of newly developed satellite-based products for oil spill detection, sea ice characterization and mapping, and iceberg monitoring, with the aim to integrate them into regular use.

In addition, an administrative work package (WP 0) carried responsibility for coordination, planning and reporting activities in the center as well as for budget control.

CIRFA`s work package structure is built like a matrix to visualise how methodologies and different research platforms (fieldwork, drones, modelling, testing and further development) benefit the three main research topics (ocean, sea ice and oil spills).

Key researchers

Harald Johnsen
Professor, NORCE
WP 1 leader

Wolfgang Dierking
Professor II at UiT, Senior
Researcher at AWI
WP 2 leader

Anthony P. Doulgeris
Professor, UiT
WP 2 leader

Camilla Brekke
Professor, UiT
(until July 2021)
Co-center leader, WP 3 leader,
WP 6 co-leader

Malin Johansson
Associate Professor, UiT
(from August 2021)
WP 3 leader, WP 6 co-leader

Christian Petrich
Research Manager, SINTEF Narvik
WP 3 leader

Rune Storvold
Associate Professor NORCE
WP 4 leader (until 2020/2021)
WP 6 co-leader

Agnar Sivertsen
Researcher, NORCE
WP 4 leader (from 2021)

Tor Arne Johansen
Professor, NTNU
WP 4 leader (until 2021)

Kai Christensen
Professor, Head of Division for Ocean and Ice at MET Norway
WP 5 leader (until 2020)

Johannes Röhrs
Researcher, MET Norway
WP 5 leader (from 2020)

Rune Graversen
Professor, UiT
WP 5 leader

Sebastian Gerland
Section leader and Researcher, NPI
WP 6 leader

Nick Hughes
Leader of the Ice Service at MET Norway
WP 6 leader

Mari-Ann Moen
Project manager, KSAT
WP 7 leader (2015)

Charles Debart
Project manager, KSAT
WP 7 leader (2016)

Torunn Tøllefsen
Project manager, KSAT
WP 7 leader (2017-2018)

Hugo Isaksen
Project manager, KSAT
WP 7 leader (from 2019)

Jan Petter Pedersen
Senior Vice President, KSAT
WP 7 leader (2016)

Project staff

During the full period of the center, CIRFA supported 20 PhD candidates, 8 PhD candidates in associated projects, 10 post-doctoral researchers, 8 post-doctoral researchers in associated projects, many researchers, three engineers and three administrative coordinators. Staff diversity was further increased by very active national and international collaboration, research visits and sabbaticals, and associated projects.

Anca Cristea
PostDoc
Sea ice classification from multimodal remote sensing data

Alberto Arienzo
PhD Candidate

Andrea Marinoni
Associate Professor

Andrea Schneider
Administrative Coordinator
(2020 - 2023)

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

Ann Kristin Sperrevik
PostDoc/Researcher
Drift modelling and prediction

Artem Moiseev
PhD/PostDoc
Ocean remote sensing

Catherine Taelman
Engineer
Technical support to all work packages

Cathleen Jones
Research Scientist / Professor II
NASA Jet Propulsion Lab / UiT

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

Debanshu Ratha
PostDoc (ExtremeEarth)
Polarimetric analyses of sea ice properties

Dmitry Divine
Researcher, NPI
Sea ice research

Edel Rikardsen
Researcher, MET Norway
Sea ice, ocean and oil spill modelling, data assimilation

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

Ellen Ingeborg Hætta
Administrative Coordinator
(2015 - 2017)

Henrik Fisser
PhD Candidate (RareIce)
Spatial and temporal distribution of icebergs and sea ice in the Barents Sea

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

Josef Ruzin
PhD Candidate (SIRANO)
Using passive microwave and SAR to improve Arctic sea ice concentration estimates

Jostein Brændshøi
Researcher, MET Norway
Ocean and sea ice models

Katalin Blix
PhD Candidate/PostDoc
Ocean Colour Remote Sensing

Knut-Frode Dagestad
Researcher
Drift modelling and prediction

Kristian Hindberg
Researcher
Technical support to all work packages

Laurent-Ferro Famil
Professor/Professor II
University of Rennes 1 / UiT

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

Lise Nordgård
Administrative Coordinator
(2017 - 2020)

Jakob Grahn
PhD Candidate
Multi-frequency radar remote sensing of sea ice

Marianne Myrnes
PhD Candidate
Oil spill research

Marina Durán Moro
Researcher
Assimilation of sea ice satellite observations into numerical models

Martina Idzanovic
PostDoc
Quantifying uncertainty and predictability in ocean current forecasts

Martine Espeseth
PhD/PostDoc
Oil spill remote sensing

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

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

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

Qiang Wang
PostDoc (ExtremeEarth)
Deep learning algorithms for sea ice classification

Richard Hann
PhD Candidate
Icing Penalties and Ice Protection Systems on Unmanned Aerial Vehicles

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

Runa Skarbø
PhD Candidate

Salman Khaleghian
PhD Candidate (ExtremeEarth)
Scalable computing in earth observation

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

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

Sindre Markus Fritzner
PhD/PostDoc
Machine-learning and dynamical models for sea-ice forecasting

Sophie Kuehnlenz
PhD Candidate

Stine Skrunes
PostDoc

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

Truls Karlsen
PhD Candidate
Multifrequency SAR classification of sea ice

Vegard Nilsen
PhD Candidate

Victor de Aguiar
PhD Candidate
Oil spill remote sensing and drift prediction

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

Jean Negrel
PostDoc
Sea ice observations

Wolfgang Dierking
Professor II/Senior Researcher
Alfed Wegener institute/ Helmholz Center for Polar and Marine Research / UiT

Yvonne Gusdal
Researcher, MET Norway

Temesgen G. Yitayew
PhD Candidate
Investigating Sea Ice Using Single and Multiple SAR Acquisitions

Scientific Advisory Committee

At the start of CIRFA, a Scientific Advisory Committee was formed to ensure research excellence. In the committee international experts with outstanding reputations in the fields relevant to CIRFA were gathered. Its tasks were to give feedback on the research quality, support networking, and facilitate internationalization of the center's activities. The committee's reports offered an objective evaluation of the scientific quality of the work conducted and gave recommendations for future activities.

The committee's annual feedback was presented and discussed in Consortium Board meetings.

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

Charlotte Bay Hasager
Technical University of Denmark (DTU)

Henning Skriver
Technical University of Denmark (DTU)

James Maslanik
University of Colorado in Boulder, Colorado, USA (until the end of 2019)

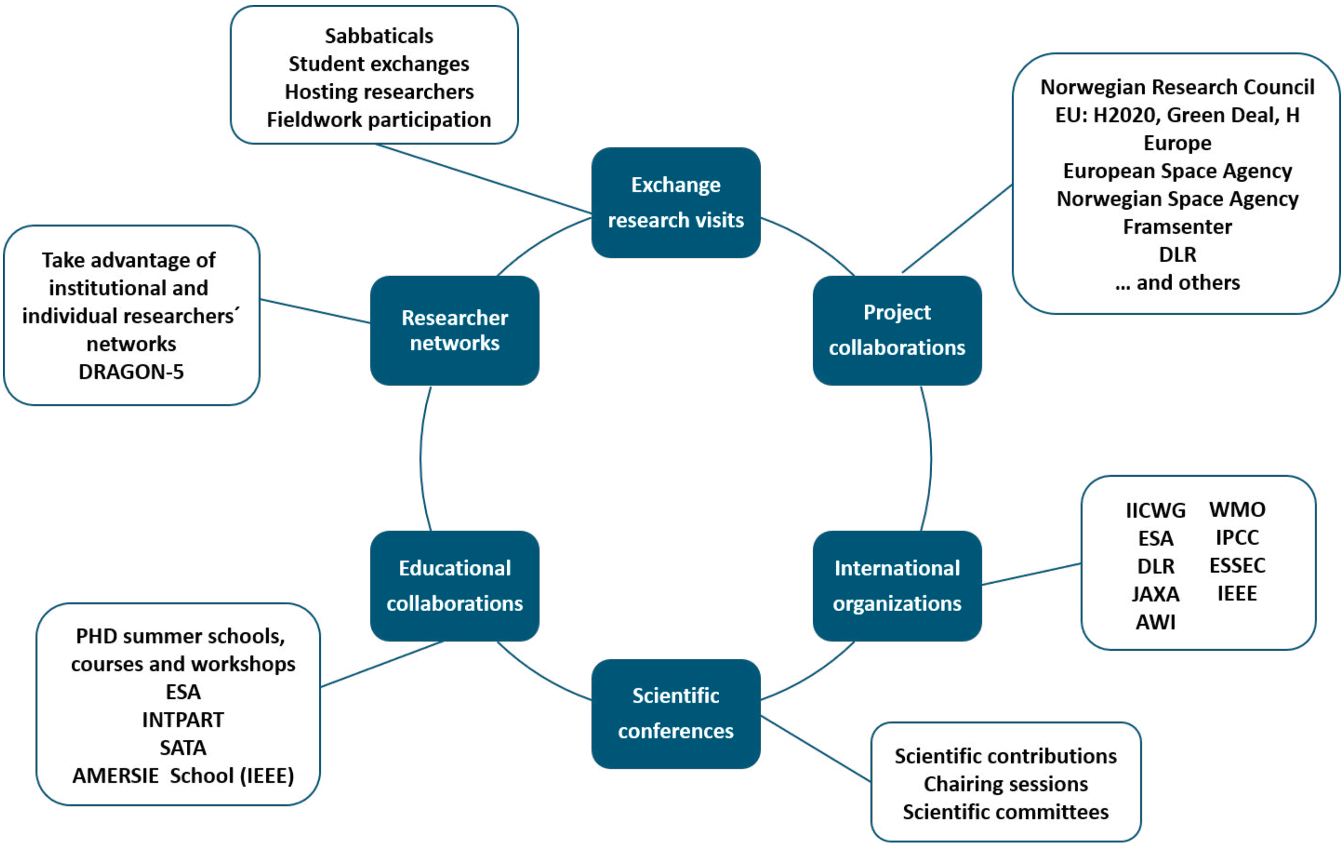
Cooperation within the center, national and international collaboration

Intensive **collaboration was fostered across all center work packages** through regular communication, meetings, and shared project and student supervision. Annual meetings, science seminars, workshops, and social events promoted networking opportunities across experience levels. Consistent leadership in work packages ensured continuity and facilitated collaboration within and outside the center, with online shared documents giving insight into work progress. Social events contributed to a cohesive and inclusive working environment at CIRFA.

Research visits, meetings, workshops, fieldwork training, and real-world fieldwork scenarios enhanced collaboration among **CIRFA partners**. Visits to MET Norway's Ice Service and KSAT facilities in Tromsø demonstrated how results from CIRFA were already applied or further developed in individual workflows. The 2022 expedition with *RV Kronprins Haakon* to the east-coast of Greenland was a team effort that tested CIRFA's algorithms for sea ice mapping, iceberg detection, and operational forecasts of ice conditions compared to the ice conditions observed around the ship. Another major goal of the cruise was to collect field data of sea ice properties and icebergs for improving the analysis of images of different satellite missions. It also allowed the drone team to demonstrate and test capabilities of drones to support ship navigation in ice-infested waters and do surveys under Arctic conditions to collect information for validation of satellite products. This expedition received satellite data from several national space agencies, and was partly funded by the European Space Agency (ESA).

The industry partners had a majority in the Consortium Board and chaired the board for the last four years. The advantage of choosing a chairperson from industry or a private company as leader of CIRFA's Consortium Board was that it provided a direct avenue to influence research and innovation. This helped to identify student project opportunities, expanded CIRFA's network, and fostered discussions between company employees and center researchers.

CIRFA initiated a high level of **collaboration with associated research projects and organisations**, some of which will facilitate sustaining research and innovation beyond the Centre's lifetime. Among these are several NFR funded projects (SFF CAGE, SFI Visual Intelligence, The Nansen Legacy, EU projects (EU Green Deal, Extreme Earth, KEPLER, Impetus, ACCIBERG), INTPART summer schools with partners from the USA, Canada, Japan (JAXA), collaborations with the European Space Agency ESA (L-C-ICE, DRAGON, ROSE-L), and many more. The projects vary in size and duration, many involve CIRFA partners, and objectives cover technology development and operational support, climate and environment, competence development and experimental fieldwork.



Visual summary of national and international collaboration strategies within CIRFA.

For example, in 2017, CIRFA WP's 3 and 6 performed a 3-week oil-in-ice tank experiment jointly with the PETROMAKS2 project MOSIDEO (#243812) at the HSVA ice tank in Hamburg, Germany, where several PhD candidates were involved. In addition, joint fieldwork with for example The Norwegian Clean Seas Association for Operating Companies (NOFO) and the Norwegian Coastal Administration (Kystverket) contributed to a better understanding of how the partners in CIRFA work, and what is needed to make the research outcomes become applied and better address user needs.

Five PhD candidates from associated projects like the Nansen Legacy (# 276730), the NFR projects SFI Visual Intelligence (# 309439), RareIce (#326834) and SIRANO (# 302917), and the EU Horizon 2020 project ExtremeEarth (# 825258) are integrated in CIRFA's activities through shared supervision, directly using research outcomes from CIRFA, or transferring methods that were developed in the center to new applications. In a collaboration with SFF CAGE (# 223259), one CIRFA PhD candidate joined CAGE research cruises to deploy ocean drifters in different ocean regions to collect datasets for ocean drift model analysis.

Active personnel exchange and research visits between CIRFA and external researcher institutions, and attendance at national and international conferences, workshops and courses were strongly promoted. Collaborations within the center, with partners and external projects, are evident in highly cited papers which emphasized the successful development of innovative tools, products, and services.

CIRFA`s researchers are also engaged in **national and international committees**, for example as members of Mission Advisory Groups of the European Space Agency (ESA), or the advisory board of the European Space Sciences Committee (ESSEC). Additionally, CIRFA personnel are members of the International Ice Charting Working Group (IICWG), Intergovernmental Panel on Climate Change (IPCC), World Meteorological Organization (WMO), IEEE Technical Committees, JAXA's ALOS-4 Calibration/ Validation and Science Team, the EU Commission Polar Task Force, and others.

Glimpses of CIRFA`s production of knowledge and innovation

The CIRFA team contributed extensively to a more detailed understanding of satellite remote sensing data products with a focus on Arctic marine applications. Over the past 8 years, the team delivered a wealth of peer-reviewed articles in international journals. The 15 most cited papers in CIRFA originate often from cross-disciplinary collaborations across work packages and all together gathered over 800 citations (by December 2023):

Year	No of citations	Publication
2018	188	**Dagestad** et al. (2018). OpenDrift v1.0: a generic framework for trajectory modelling, Geosci. Model Dev., 11, 1405–1420, https://doi.org/10.5194/gmd-11-1405-2018.
2016	100	**Jones** et al (2016). Measurement and modeling of oil slick transport. Journal of Geophysical Research: Oceans, 121(10), 7759-7775.
2018	85	**Johansson** et al (2018). X-, C-, and L-band SAR signatures of newly formed sea ice in Arctic leads during winter and spring. Remote Sensing of Environment, 204, 162-180.
2018	83	**Röhrs** et al (2018). The effect of vertical mixing on the horizontal drift of oil spills. Ocean Science, 14(6), 1581-1601.
2017	59	**Espeseth** et al (2017). Analysis of evolving oil spills in full-polarimetric and hybrid-polarity SAR. IEEE Transactions on Geoscience and Remote Sensing, 55(7), 4190-4210. https://doi.org/10.1109/TGRS.2017.2690001.
2019	54	Pavlova et al (2019). Changes in Sea-Ice Extent and Thickness in Kongsfjorden, Svalbard (2003–2016). In: The Ecosystem of Kongsfjorden, Svalbard. Advances in Polar Ecology, vol 2. Springer. https://doi.org/10.1007/978-3-319-46425-1_4.
2018	54	**Blix** et al (2018). Remote Sensing of Water Quality Parameters over Lake Balaton by Using Sentinel-3 OLCI. Water 2018, 10, 1428. https://doi.org/10.3390/w10101428.
2021	44	**Khaleghian** et al (2021). Sea Ice Classification of SAR Imagery Based on Convolution Neural Networks. Remote Sens. 13, 1734. https://doi.org/10.3390/rs13091734.
2022	38	**Landy** et al (2022). A year-round satellite sea-ice thickness record from CryoSat-2. Nature 609, 517–522. https://doi.org/10.1038/s41586-022-05058-5.
2020	37	**Lohse** et al (2020). Mapping sea-ice types from Sentinel-1 considering the surface-type dependent effect of incidence angle. Annals of Glaciology. 2020, 6 1(83): 260-270. doi:10.1017/aog.2020.45.
2019	36	**Hann** et al (2019). Experimental Investigations of an Icing Protection System for UAVs. SAE Technical Paper 2019-01-2038, 2019, https://doi.org/10.4271/2019-01-2038.
2020	29	**Moiseev** et al (2020). Evaluation of radial ocean surface currents derived from Sentinel-1 IW Doppler shift using coastal radar and Lagrangian surface drifter observations. Journal of Geophysical Research: Oceans,125, e2019JC015743. https://doi.org/10.1029/2019JC015743.
2019	32	Faijt et al (2019). The Influence of Meteorological Conditions on the Icing Performance Penalties on a UAV Airfoil. 8th European Conference for Aeronautics and Space Sciences (EUCASS) 2019. DOI: 10.13009/EUCASS2019-240.
2016	25	**Johnsen** et al (2016). Ocean doppler anomaly and ocean surface current from Sentinel 1 tops mode. 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Beijing, China, 2016, pp. 3993-3996, doi: 10.1109/IGARSS.2016.7730038.
2023	23	**Röhrs** et al (2023). Surface currents in operational oceanography: Key applications, mechanisms, and methods. Journal of Operational Oceanography, 16:1, 60-88, doi: 10.1080/1755876X.2021.1903221.

Together with its partners, CIRFA worked on bringing research into practice by developing a range of **prototypes algorithms and products.** Out of these 16, 10 are on their way of becoming or are already parts of **operational services:**

Prototypes algorithms. *Description of task.*	Scientific status. *«Proof of concept».*	Product/Service. *Operational status.*	Literature. *User information.*
Wind retrieval from SAR	✓	**Used by KSAT`s oil spill detection service.**	Nilsen et al. (2019), KSAT Oil Spill Service
Wave retrieval from SAR	✓	**Used by KSAT`s oil spill detection service.**	Monteban et al. (2019), KSAT Oil Spill Service
Ocean surface currents from SAR	✓ • More research needed		Moiseev et al. (2021)
Statistical sea ice type classification from SAR • With incidence angle (IA) and texture	✓	**Under validation at MET Norway`s Ice Service.**	Lohse et al. (2019), Lohse et al. (2020), MET Norway Ice Service
Deep learning-based sea ice type classification from SAR	✓ • More comprehensive studies needed		Khaleghian et al. (2021)
Ice-vs-water maps from SAR • High-resolution • Using deep learning approaches	✓ • More studies needed to increase robustness		Wang et al. (2023)
Detecting icebergs in open water and sea ice from SAR • Using Constant False Alarm rates	✓	**Under operationalisation at MET Norway`s Ice Service.**	Akbari & Brekke (2017), Færch et al. (2023), Færch et al. (2024), MET Norway Ice Service
"Damping ratio" for marine oil spill characterization • From SAR images	✓	**Used by KSAT and USGS oil spill detection service.** • Currently being implemented and validated by NOAA oil spill service	Quigley et al. (2023), Jones et al. (2023), KSAT Oil Spill Service, USGS Oil Spill Service
Dielectric constant to estimate oil spill thickness • From SAR images	✓ • More comprehensive studies needed		Quigley et al. (2020)
NLive system • 3D visualization of georeferenced and time-stamped data in real time	✓ • Tested on drones in Arctic operations during the CIRFA-2022 cruise	**Implemented in drones and used at InSAR Norway.**	NORCE NLive
UWB snow radar • Flown in an octocopter drone • Associated signal processing software	✓ • Tested on drones in Arctic operations during the CIRFA-2022 cruise		Jenssen & Jacobsen (2020)
Development of a vertical take-off and landing drone • Equipped with optical remote sensing sensors	✓ • Tested on drones in Arctic operations during the CIRFA-2022 cruise		NORCE Drones & Autonomous Systems
"De-icing" solution for drones • Allows flights in Arctic weather	✓ • Tested under laboratory conditions	**Used by UBIQ Aerospace and NTNU`s UAV icing lab** • UBIQ Aerospace is a start-up company	Hann et al. (2021), UBIQ Aerospace, NTNU UAV Icing Lab
Barents 2.5 model • Ocean and Sea Ice ensemble prediction system with data assimilation	✓ • Tested specifically on assimilation of sea ice parameters	**Implemented in operational forecasting at MET Norway**	Röhrs et al. (2023), MET Norway Ocean Models
2 new contributions to OpenDrift • Vertical oil mixing scheme • Framework for ensemble simulations	✓ • Tested on data from NORSE-2015 experiment	**Used by KSAT`s oil spill detection service.**	Dagestad & Röhrs (2019), MET Norway Ocean Models
Development of a low-cost buoy for fjord ice monitoring	✓	**Deployed during 4 winter seasons in PhD project.**	Petrich et al. (2019), SINTEF Ice in Fjords

Technological Readiness Level

Research — Development — Implementation

CIRFA

Figure: Andrea Schneider
Icons: ShareIcon

SFI # 237906 (2015 – 2023)

In addition, a wide variety of research and development advances pushed the boundaries of knowledge and technology.

New research directions on **coastal & fjord ice** and **ocean color & water quality** were established.

Calibration and validation datasets for the classification of Arctic sea ice were expanded for different seasons.

The CIRFA-2022 cruise **improved navigation planning routines** and strategies for Arctic marine fieldwork using drones and near-real time local ice maps.

Australia`s Commonwealth Scientific and Industrial Research Organisation (CSIRO) validates the **sea ice segmentation algorithm in an Antarctic context.**

Work is ongoing on the generation **of near-future ice charts** based on sea ice drift forecasts.

A PhD project from CIRFA and NTNU has led to initiating the **UAV Icing Lab** at NTNU in Trondheim and the spin-off company **UBIQ Aerospace.**

Photo: Christian Zoelly, NPI.

WP leader
Harald Johnsen
Professor, NORCE

Team members

Geir Engen, Senior *Researcher, NORCE*

Heidi Hindberg, Senior *Researcher, NORCE*

Tom Grydeland, *Senior Researcher, NORCE*

Mathias Tollinger, *PhD Candidate, UiT*

Artem Moiseev, *Researcher, NERSC*

Vegard Nilsen, *PhD Candidate, NORCE*

Katalin Blix, *PhD Candidate, UiT*

Research and Innovation Approach

WORK PACKAGE 1

Ocean Remote Sensing

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 of ocean surface winds, waves and currents made from space 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 series of Sentinel satellites has greatly improved the capabilities of providing such high-resolution information from space due to the enhanced time and space coverage offered.

The scientific driver has been to develop the use of satellite technology such as to advance our understanding of the Arctic Ocean processes and dynamics. A particular focus was placed on achieving better prediction of polar lows, now-casting, and short-range forecasting of the ocean state through coupling of remote sensing approaches 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 sea 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 other work packages of CIRFA.

Achievements

The R&D were concentrated on the following key activities:

(1) Assessment of Sentinel-1 ocean coastal and global wind/wave/current measurements capabilities,

(2) PhD education and peer-review publications,

(3) Operationalization of met-ocean processing system at Kongsberg Satellite Services (KSAT) based on achievements from CIRFA R&D activities.

The R&D on the assessment of Sentinel-1 met ocean data capabilities has resulted in several peer review papers published in IEEE and AGU journals. Retrieval of ocean wind field from Synthetic Aperture Radar (SAR) observations are traditionally based on combining the radar intensity with ancillary wind information from numerical models. Nielsen et al. (2019) developed and demonstrated a new wind vector retrieval methodology solely based on radar observations. This was achieved by combining radar intensity and the radar spectral signatures of wind driven ocean waves. The methodology is now defined as the key approach for wind retrieval from ESA Explorer 10 Harmony mission.

Tollinger et. al. (2021) further exploited the potential of using SAR observations to provide details on the complex mesoscale wind structure during polar low events. The methodology is based on combing the co- and cross-polarization channels together with the Doppler frequency shift, all derived from the SAR observations.

In addition, ocean wave spectra retrieval from SAR observations are utilizing the temporal integration along the flight direction to achieve ambiguity free observation of the 2D swell field. However, this is not straightforward for TOPS mode of Sentinel-1 because of the sweeping of the antenna during the data take. Monteban et al. (2019) demonstrated the use of a specific feature of the TOPS mode to derive ambiguity free 2D ocean swell field and wave dispersion relation. These achievements have initiated the development of an ocean wave spectra product from the Sentinel-1 TOPS mode within the ESA Copernicus Sentinel Ground Segment.

The lack of global and regional measurements of ocean surface current have triggered the use of satellite SAR to measure the ocean surface motion through the Doppler frequency shift. The Sentinel-1 are the leading missions in that respect. In the papers by Moiseev et al. (2020a), Moiseev et al. (2020b)

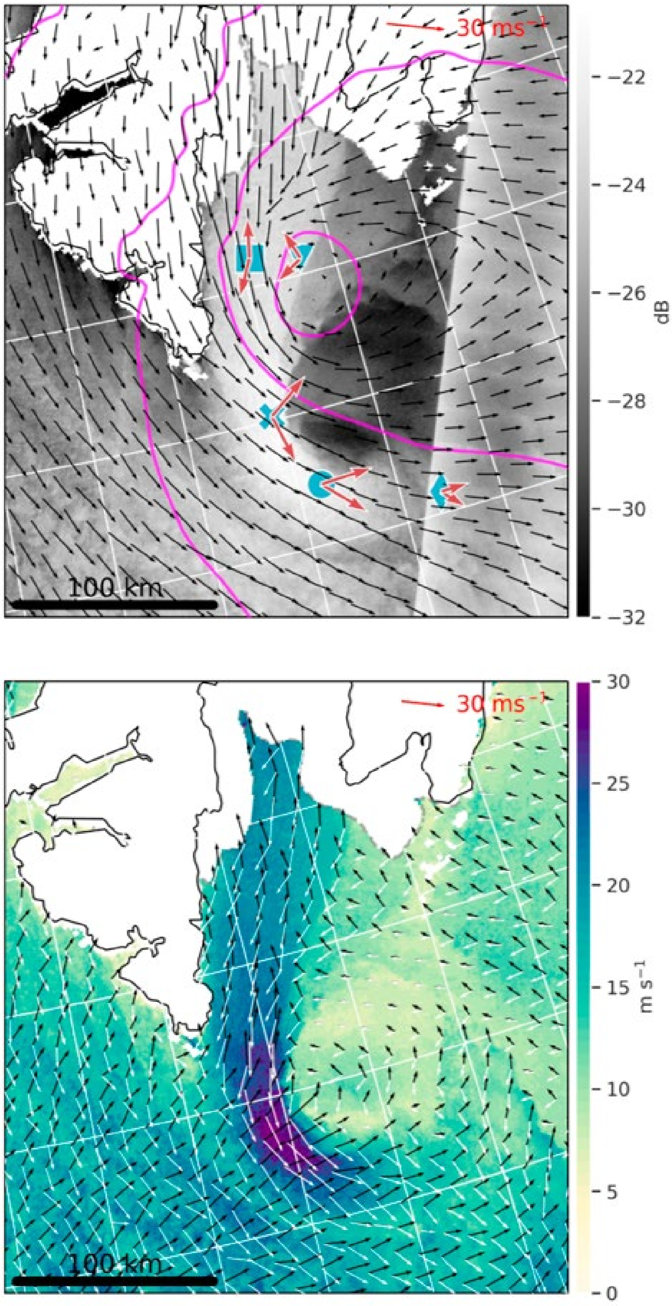


Figure 1-1 *Wind speed and direction estimates from SAR in an atmospheric forecast model. The complete wind field of the SAR-only retrieval is shown with white and black arrows indicating a two-wind-direction solution. Figure from Tollinger et al. 2021.*

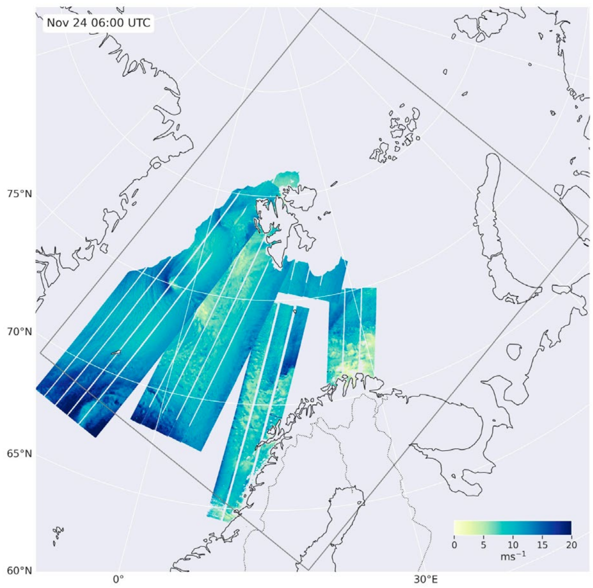


Figure 1-2 *A SAR wind retrieval scene (24 November 2021) inside the AROME-Arctic area that can be assimilated. Shading is surface-wind velocities in m/s. AROME-Arctic is an operational weather-prediction model at MET Norway. Figure by Mathias Tollinger, UiT.*

and Moiseev et al. (2022), we have demonstrated the retrival method and assessed the geophysical quality of ocean surface current derived from the Sentinel-1 missions. As a result of these activities, ocean current products from Sentinel-1 are for the first time made available to a wider user community through the World Ocean Circulation Project. The capabilities of Sentinel-1 mission to measure and quantify ocean features such as eddies within the Norwegian Coastal Current (NCC) is demonstrated and shown in Figure 1-3. These Sentinel-1 surface current features are comparable with the surface current magnitudes and pattern derived from regional model simulations (ROMS), although the simulations are partly misplacing some features. Moreover, the mesoscale structures derived from the satellite-based (MODIS) Sea Surface Temperature (SST) fields are also found to agree with features derived from the Sentinel-1 Doppler measurements.

The operational met-ocean processing system established at KSAT has been upgraded and extended to better support end-user and research needs. This includes the processing of met-ocean parameters as inputs to the 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.

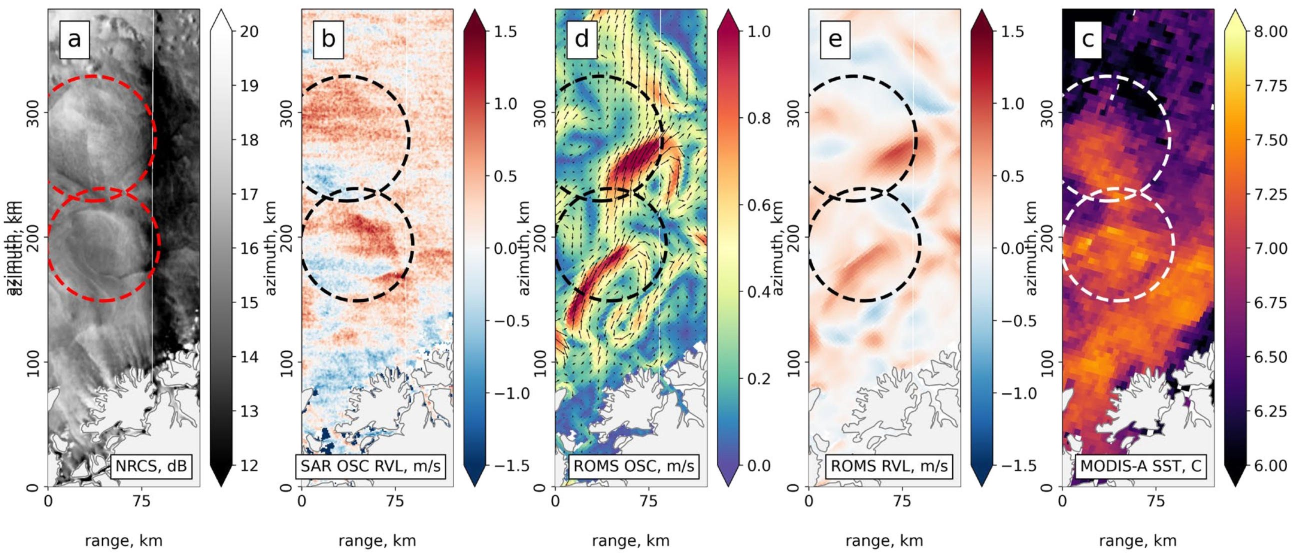


Figure 1-3 *Ascending Sentinel-1B IW VV scene acquired in IW mode on 10 December 2017 at 16:06:07. a) Sentinel-1B Normalized Radar Cross-Section (NRCS) in dB; b) Ocean surface current radial velocity derived from the Doppler observations using a new geophysical model function; c) Ocean surface current velocity from ROMS model at 16:00; d) shows ocean current field from the ROMS model; d) shows the ocean current radial velocity from the ROMSmodel. c) night-time Sea surface temperature from MODIS-Aqua averaged between 3rd and 10th December 2017. The positive/negative radial velocities ocean surface current to the right/left. The dashed circles indicate the areas of eddies detected in part a). Figure from Moiseev et al. 2021.*

WP leader
Wolfgang Dierking
Professor II at UiT, Senior Researcher AWI

WP leader
Anthony P. Doulgeris
Professor, UiT

Team members

Anna Telegina, *PhD Candidate, UiT*

Eduard Khachatrian, *PhD Candidate, UiT*

Laust Færch, *PhD Candidate, UiT*

Ingri Halland Soldal, *PhD Candidate, NERSC*

Sophie Kuehnlenz, *PhD Candidate, UiT*

Temesgen G. Yitayev, *Associate PhD Candidate, UiT*

Jakob Grahn, *Associate PhD Candidate, UiT*

Johannes Lohse, *PhD Candidate/Researcher/ PostDoc, UiT*

Anca Cristea, *PostDoc, NPI*

Jean Negrel, *PostDoc, NPI*

Saloua Chlaily, *PostDoc, UiT*

Wenkai Guo, *PostDoc, UiT*

Qiang Wang, *PostDoc, UiT*

Debanshu Ratha, *PostDoc, UiT*

Polona Itkin, *Researcher, UiT*

Andrea Marinoni, *Associate Professor, UiT*

Malin Johansson, *Associate Professor, UiT*

Jack Landy, *Associate Professor, UiT*

Catherine Taelman, *Engineer, UiT*

Christian Hindberg, *Engineer, UiT*

WORK PACKAGE 2

Monitoring Sea Ice and Icebergs

Objectives and motivation

Arctic sea ice decline, linked to climate change, leads to severe consequences—Arctic warming, global weather changes, coastal erosion, and challenges for ecosystems and communities. Growing Arctic accessibility increases marine traffic and resource exploitation. Thus, continuous satellite monitoring is essential to evaluate societal, economic, and Arctic ecosystem impacts, balancing opportunities and risks.

The threat that sea ice and icebergs pose to ships in the open ocean has been in public awareness ever since the Titanic sank in 1912. Our goal was to advance remote sensing methods to help avoid future incidents, with a particular focus on sea ice classification, sea ice drift monitoring, and iceberg detection for operational applications. Satellite and airborne monitoring with imaging radar examines ocean-ice-atmosphere interactions in the local and regional context. Various CIRFA studies explored radar signature sensitivity to different ice properties, investigating their impact on image segmentation and sea ice classification. Radar data are used to produce ice charts that support navigation by identifying open water, ice types, concentration, floe sizes, and thickness. We used statistical analysis, anomaly detection, constant false alarm rates (CFAR), and machine/deep learning techniques. In addition, validation involved field data and a diverse image database combining radar and optical images of different ice conditions.

Key research tasks

- Application of relevant statistical methods and image processing techniques for robust and reliable sea ice classification suitable for operational applications.
- Development of improved methods for monitoring and short-term forecasting of sea ice drift and deformation by combining SAR image analysis and sea ice modelling.
- Investigation of different detection methods for monitoring icebergs including quantifying the fraction of false and missed detections relative to correct identifications.
- Integration of selected algorithms for sea ice classification and iceberg detection into the workflow of operational ice centers.

Achievements

Sea ice classification

The separation of sea ice classes and retrieval of sea ice parameters from SAR images pose challenges due to the complexity of natural sea ice conditions and open water areas. In WP 2, a key enhancement in ice type separation involves directly incorporating radar parameters in the classification process. Researchers at CIRFA introduced a novel approach integrating type-specific **radar incidence angle dependencies** into image segmentation (Cristea et al. 2020), see Figure 2-1. This method, applied to an Arctic-wide dataset with Sentinel-1 SAR, Sentinel-2, and Landsat-8 images, demonstrated significant performance improvement for a Bayesian sea ice classifier.

Lohse et al. (2019) introduced a decision-tree algorithm for sea ice classification, achieving comparable accuracy to all-at-once methods. Notably, it allows finding optimal radar feature combinations for each ice class. The algorithm, applied to simulated and airborne imagery over Fram Strait, employs the incidence angle (IA) sensitivity as a direct classifier, enhancing ice type separation and mitigating radar backscattering variations within SAR images (Figure 2-2) (Lohse et al. 2020). An additional investigation on the incidence angle dependence of texture parameters further improved the separation of sea ice and water, as well as the separation between young and multi-year ice (Lohse et al. 2021). The new segmentation and classification algorithms were developed and tested using Sentinel-1 SAR and Sentinel-2 optical images. The Gaussian Incidence Angle (GIA) classifier was also successfully applied to TerraSAR-X images (Guo et al. 2022).

Recent studies (Singha et al. 2020; Khaleghian et al. 2021a, 2021b) explored the **application of neural networks and machine learning** for sea ice classification, emphasizing their future relevance. Additional research, utilizing field or airborne data, focused on the advantages of multi-frequency polarimetric data (Johansson et al. 2017, 2018; Singha et al. 2018). Polarimetric SAR images, analyzed through decomposition methods, proved beneficial for distinguishing specific ice types. Eltoft and Doulgeris (2019) introduced a new framework for polarimetric decompositions, utilizing statistical information and radar texture models. The U-net neural network family has recently been employed for

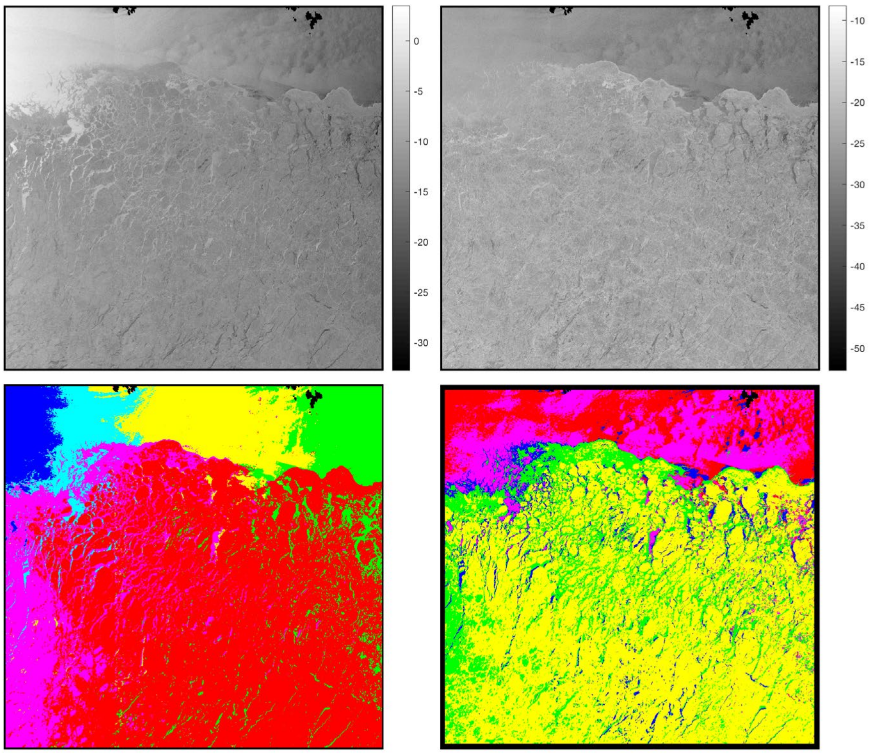


Figure 2-1 *Incidence-angle guided image segmentation: The images in the upper row are Sentinel-1 HH- (left) and HV- (right) polarized intensities, acquired over Fram Strait. The result of segmentation (based on both HH- and HV-polarization) without considering the incidence angle effect is shown to the lower left, and with considering it to the lower right. The colors of segments were selected arbitrarily and do not match between the lower images. The water surface, in the uppermost part of the intensity images, shows decreasing brightness from left to right (near-range to far-range) at HH-polarization that reveals the systematic incidence angle effect, which is less obvious at HV. Brighter and darker patches are likely due to varying wind speeds over open water or due to new ice formation.*

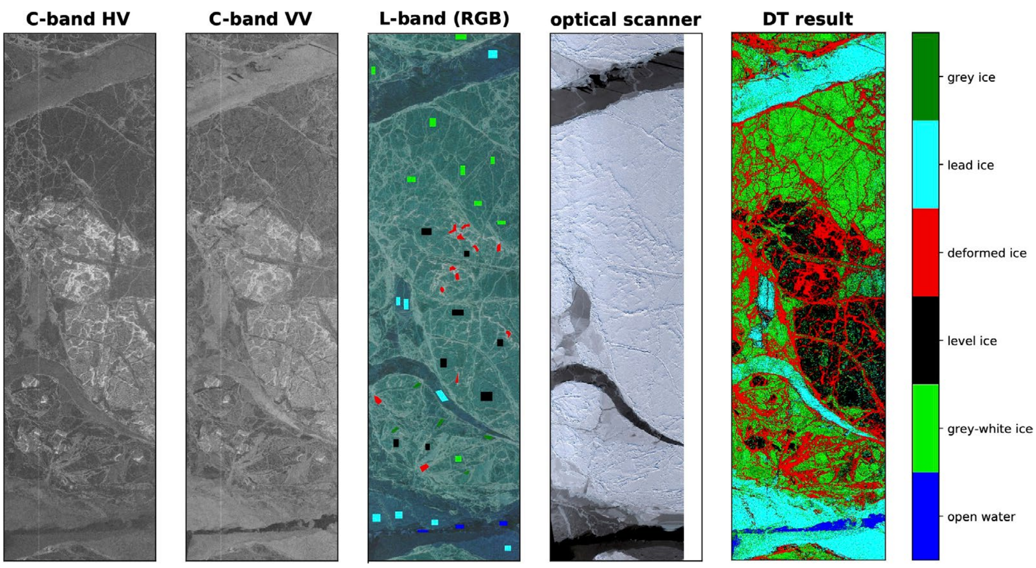


Figure 2-2 *First and second image from left: HH- and HV-polarized C-band radar images taken over sea ice in Fram Strait from an airplane. Third image: Data from an L-band radar acquired simultaneously with the C-band images. This RGB presentation combines the HV-, HH-, and VV-polarized channels. The boxes show locations of different areas used for training the classifier. Fourth image: data of an optical scanner used for visual confirmation of ice classes. The result of classification is shown on the right. Classes are: blue – open water, green – grey-white ice, black – level ice, red – deformed ice, cyan – nilas, dark green – grey ice.*

pixel-wise sea-ice versus water mapping by Wang (2023), with ongoing validation and immanent on-demand result generation. CIRFA researchers aimed to enhance ice type separation using multiple satellite data and developed an **adaptive data fusion** scheme. They applied this approach to combinations of SAR + optical imagery and SAR + passive microwave radiometer data, yielding promising results (Khachatrian et al. 2021 and 2023, Figure 2-3). These findings contribute valuable insights to discussions on coordinating future satellite missions for near-simultaneous data acquisition using diverse sensor types.

Ordinary radar images provide information assuming a horizontal plane but do not consider the height from which the radar signal arises. The latter can be achieved using Interferometric SAR (InSAR). Yitajew et al. (2018) conducted a feasibility study comparing TanDEM-X InSAR data with stereo-photography and a laser profiler to **quantify sea ice ridge density and height**. The InSAR-derived ice surface elevation correlated well with measurements for ridge heights exceeding 0.5 m. However, current satellite constellations limit InSAR use to fast ice areas, necessitating specific constellations for broader sea ice research applications (Dierking et al. 2017).

In the later stages of WP 2, the potential of **radar altimeter data**, specifically from CryoSat-2, for retrieving sea ice thickness was explored. Traditionally, sea ice thickness information was limited to Arctic winter months due to uncertainties caused by melt ponds during summer. Landy et al. (2022) introduced a novel approach utilizing deep learning and numerical simulations to process CryoSat-2 altimeter data from melting sea ice, yielding a continuous time series of ice thickness validated against airborne and in situ sensor data.

Sea ice drift monitoring

Local ice conditions can change rapidly due to sea ice drift and deformation, making ice charts outdated quickly. Challenges arise in aligning images from various satellite missions at different times. To address this, CIRFA researchers have explored solutions, such as incorporating **short-term forecasts derived from sea ice models driven by predicted atmospheric and oceanic parameters** to provide more

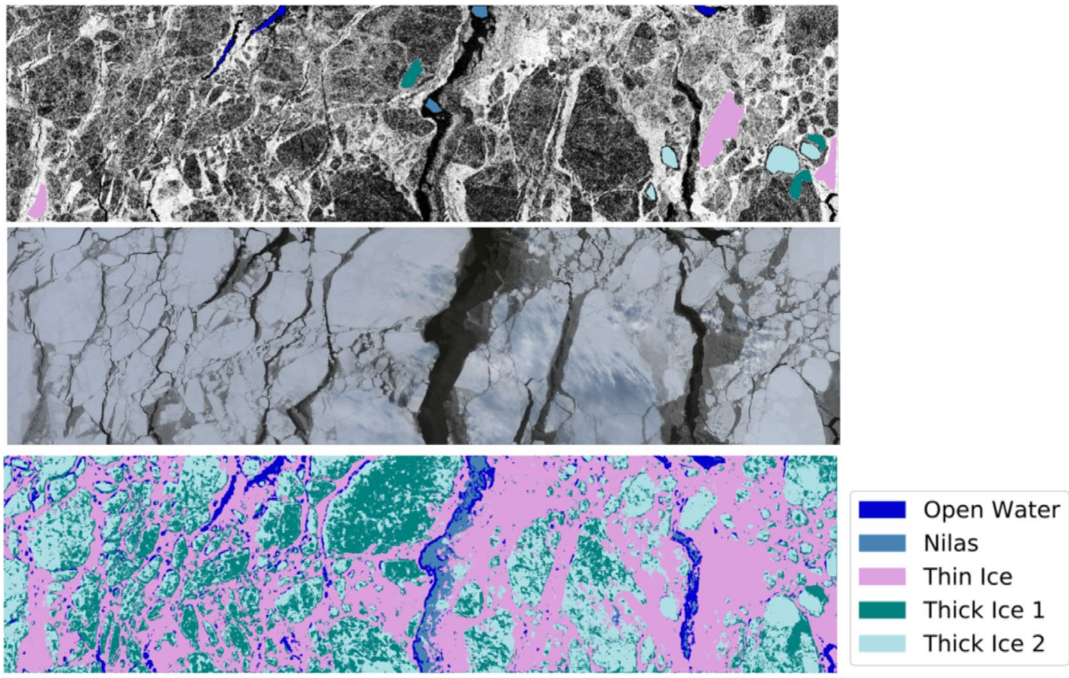


Figure 2-3 *Top: HH-polarized SAR image from Radarsat-2 with boxes for retrieval of training data, middle: optical data from Landsat-8, bottom: classification map as a result of adaptive data fusion.*

accurate and timely information. The primary approach involves validating sea ice drift and deformation model predictions by comparing them with SAR image-derived drift field retrievals. A key challenge lies in addressing deformation zones that create discontinuities in the drift field, as explored by Griebel and Dierking (2017, 2018), while Dierking et al. (2020) offered a broader perspective on error propagation in these retrievals. Current efforts concentrate on resolving technical challenges in aligning drift fields from models and SAR retrievals. Initial comparisons revealed larger deviations, attributed to potential shortcomings in the model simulations' atmospheric and oceanic forcing parameter details, prompting ongoing work for improvement.

Iceberg detection

Detecting icebergs remains challenging but crucial for navigational safety and scientific inquiry, requiring a set of "background" conditions (icebergs in calm or wind-roughened open water, in smooth level sea ice or deformed sea ice) and high enough SAR image resolution. Early in the project, a **rule classifier** was used that adopts radar brightness, boundaries for realistic sizes of icebergs, and typical horizontal iceberg shapes as criteria for iceberg identification in SAR image segments (Akbari and C. Brekke 2017). Halland-Soldal et al. (2019) implemented a **two-step detection method** and applied it on HH+HV-polarized Sentinel-1 images acquired over small icebergs trapped in smooth and rough fast ice in the Barents Sea. The study marked over 2000 icebergs, revealing that the tested method yielded high false alarm rates and missed detections.

Therefore, Færch et al. (2023a) conducted a comprehensive comparison of six **Constant-False-Alarm-Rate** (CFAR) algorithms for iceberg detection in SAR images, assessing the impact of radar frequency by comparing C- and L-band detection performance. The study facilitates the selection of an optimal detector and radar frequency and reveals difficulties for detecting small icebergs which cover only very few pixels in the SAR image. Another investigation by Færch et al. (2023b) explored **C- and L-band ability to detect icebergs** in level and deformed fast sea ice across seasons, utilizing a time series of Sentinel-1 and AOS-2 SAR images. Results indicated L-band preference for high sea ice concentration environments and in melting conditions. However, it was recognized that the strongest L-band radar return is slightly shifted relative to the actual iceberg position (Figure 2-4) because of the larger radar signal penetration into the low-salinity ice. This has to be considered in operational iceberg mapping.

Operational applications

The Norwegian Ice Service in Tromsø currently utilizes CIRFA sea ice classification and iceberg detection algorithms for daily large-scale testing, necessitating frequent updates and sharing of algorithm versions. During the CIRFA cruise 2022, the practical application of an operational Sentinel-1 sea ice classification algorithm was tested by CIRFA and ice service members. Ice charts, SAR images, and classification results were sent to the ship and validated through onboard observations, demonstrating robust classification of deformed ice but occasional misclassification of young ice as level ice (Lohse et al. 2023, submitted manuscript).

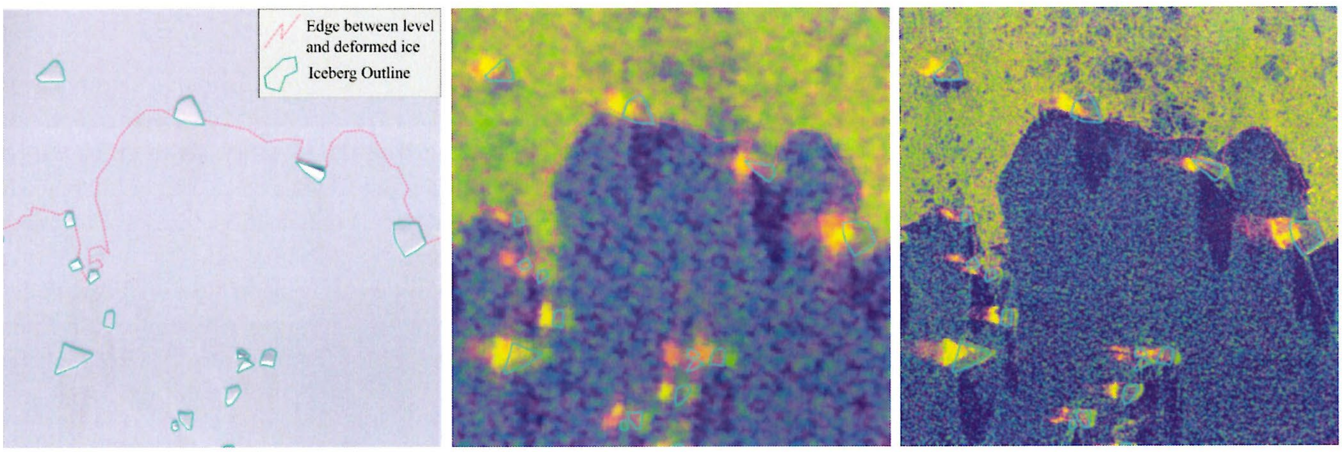


Figure 2-4 *Iceberg detection in satellite L-band SAR images. Left: Optical satellite image with marked icebergs. Center and right: Coarse and high spatial resolution SAR images. In addition to the main radar return with a shift in position (yellow), a ghost reflection (purple) occurs which is shifted even more because of multiple reflections at and in the icebergs.*

WORK PACKAGE 3

Oil Spill Remote sensing

WP leader
Malin Johansson
Associate Professor, UiT

WP leader
Camilla Brekke
Professor, UiT

WP leader
Christian Petrich
Research Manager, SINTEF Narvik

Team members

Victor de Aguiar, *PhD Candidate, UiT*

Megan O'Sadnick, *PhD Candidate, SINTEF Narvik/UiT*

Muhammad Asim, *PhD Candidate, UiT*

Marianne Myrnes, *PhD Candidate, UiT*

Alberto Arienzo, *PhD Candidate, UiT*

Martine Espeseth, *PhD Candidate/PostDoc, UiT*

Cornelius Quigley, *PhD Candidate/PostDoc, UiT*

Anca Cristea, *PostDoc, NPI*

Stine Skrunes, *PostDoc, UiT*

Katalin Blix, *PhD Candidate/Researcher, UiT*

Andrea Marinoni, *Associate Professor, UiT*

Cathleen Jones, *Adjunct Professor, NASA`s Jet Propulsion Laboratory*

Laurent Ferro-Famil, *Adj. Professor, University of Rennes 1/UiT*

Objectives and motivation

In case of a major oil spill event, remote sensing will be instrumental in providing the authorities with both spatial information regarding distribution and qualitative properties of the spill guiding the clean-up operations. WP3 has seen several Master students, international interns, PhD candidates and Postdocs. Their work has resulted in many important scientific papers and presentations, and successful PhD defences. CIRFA has facilitated collaborative work between modelers (WP5), remote sensers (WP3), sea ice scientists (WP2), and the industry (KSAT, NOFO and Equinor) and as such has helped drive oil spill science forward.

Figure 3-1 *PhD defences of Martine Espeseth (left), Cornelius Quigley (center), and Megan O'Sadnick (right). Photos: Malin Johansson & Anthony Doulgeris, UiT.*

In an incident and clean-up mission, it is important to predict the drift direction and speed of any oil spills on the ocean surface. Hence, the integration of remote sensing measurement and modelling efforts is essential in validating and improving drift models for oil spills. Remote sensing imagery from satellites is today applied in operational oil spill screening operations where, however, false alarms are a challenge. There is also a need to establish reliable methods for oil spill detection in icy waters as oil and gas exploration, shipping, and tourism are expanding their activities into Arctic regions.

Developing remote sensing techniques for sea ice conditions requires at first instance an understanding of the oil's interactions and migration within the sea ice medium, and secondly knowledge about the interaction between the remote sensing signal and the oil-ice mixture. This work package aimed to develop new techniques for solving the look-alikes ambiguity related to detection of oil on water, and to study methods for detecting and monitoring of oil in ice.

Key research tasks

- Develop accurate remote sensing information retrieval techniques for reliable oil slick detection and characterization on open water.
- Improve the modelling of oil behavior, transport and fate in open water and sea ice infested areas.
- Investigate the potential of remote sensing techniques for oil spill detection and characterization in sea ice-infested waters.
- Provide input data for the EPS-based forecast system for Lagrangian oil spill drift (WP5).

Oil-on-water campaigns

An important activity for WP3 has been the participation in the yearly oil-on-water exercises in the North Sea lead by the Norwegian Clean Seas Association for Operating Companies (NOFO). Oils of different origin and properties were released onto the ocean surface and were imaged from both airborne and satellite borne sensors. Complementary meteorological and oceanographic information were collected from vessels that were part of these campaigns.

For CIRFA`s researchers participating in these campaigns provided a unique possibility to collect near coincident images from radar sensors operating at different frequency bands to help answer questions about how to best select sensors and frequencies, revealing their advantages and limitations. The exercises have provided a well-suited arena for CIRFA, KSAT and NOFO to jointly test new satellite missions for oil spill monitoring. For more information about the campaigns see WP6. For CIRFA, the two most notably exercises were the ones in 2015 (Norwegian Radar Oil Spill Experiment 2015 - NORSE2015) and 2019 (NORSE2019). In both campaigns, time series of the developing slicks were collected from airplanes and have been used to evaluate the effect of different sensor properties, changing slick characteristics and the effect of weather conditions on the ability to detect and characterize oil spills.

Novel science was done using data from these exercises, including a noise impact analysis, led by Martine Espeseth, the influence of oil type on drift characteristics, led by Cathleen Jones and Johannes Röhrs, and the usefulness of fully polarimetric SAR signatures for oil spill characterization, led by Stine Skrunes. In addition, data from these exercises were used in recent work of Cornelius Quigley to compare different methods estimating the relative thickness, an important parameter for oil spill clean-up responders. In addition, a robust model to derive the relative oil spill thickness has been developed by Cathleen Jones and is currently being implemented by NOAA and KSAT for operational oil spill detection and characterization.

Implications for Coastal Ice

Oil-in-ice experiments were conducted to investigate how sea ice properties mattered to the fate and behavior of oil in ice and to remote sensing. Ocean water salinity was found to have a greater influence than previously estimated, and fjord ice shows a large interannual variability.

Megan O'Sadnick embarked on a PhD project to investigate the prevalence, properties, and processes of ice in fjords along the Norwegian mainland. A key result was that ice properties are highly variable both in space and time. In some years, fjord ice was salty while other years it was nearly fresh. In other years, not all fjords within an area formed an ice cover while the surrounding fjords did. Hence, there is a general need to be prepared for a wide range of scenarios when considering the behavior of oil trapped below sea ice during spring melt.

Megan's work resulted in the development of low-cost ice buoys, elements of which were subsequently used commercially. She also developed an overview over ice-affected fjords in Norway and models of ice property development. Her work also indicated that fjord ice variability is likely to be more prevalent due to its connection to climate variations with increasing precipitation in fall and milder winters, which in turn has a breadth of implications for transportation, fish farming, and emergency and oil spill response.

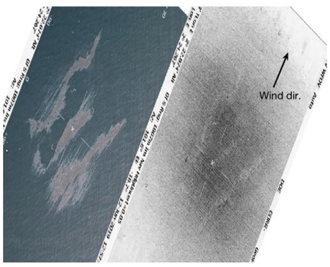


Figure 3-2 *Norwegian Radar Oil Spill Experiment (NORSE) 2019. The team onboard R/V Helmer Hansen during the experiment (left) and the ground team plus the DLR F-SAR team (right) and the resulting infrared images from the plane that is showing the oil slicks (bottom). Photos: NOFO and CIRFA.*

Figure 3-3 *Megan O'Sadnick during field work on ice in Beisfjorden. Photo: Christian Petrich, SINTEF.*

WORK PACKAGE 4

Drone Technology

WP leader
Agnar Sivertsen
Senior Researcher, NORCE

WP leader
Rune Storvold, *SVP Observing Systems, NORCE*

WP leader
Tor Arne Johansen,
Professor, NTNU

Team members

Richard Hann,
PhD Candidate, NTNU

Rolf-Ole Rydeng Jenssen, *PhD Candidate/Researcher, NORCE*

Tom Rune Lauknes,
Senior Researcher, NORCE

Daniel Stødle,
Senior Researcher, NORCE

Stian A. Solbø,
Senior Researcher, NORCE

Jakop Reistad,
Chief Engineer, NORCE

Tore Riise, *Flight Operations Manager, NORCE*

Andre Kjellstrup,
Chief Engineer, NORCE

Svein Jacobsen,
Professor UiT/NORCE

Objectives and motivation

Both satellite-based systems and drones have their strengths and weaknesses. Satellites have superior coverage and repeatability, but limitations when it comes to imaging geometry and spatial and temporal resolution needed for high-resolution studies of snow and sea ice properties, such as snow thickness distribution and local sea ice drift. Drones can achieve high temporal and spatial resolution measurements available to the operator in real time, but have limited spatial coverage and range, and are weather sensitive. The objective in WP4 is to develop robust drone and sensor technologies capable of operating in the Arctic maritime domain, while collecting, processing and sharing information regarding sea-ice and iceberg properties as well as monitoring oil spills in ice covered areas.

Key research tasks

- Robust drone platform: Develop drone-based measurement systems for monitoring and tracking sea-ice and icebergs. The system must be able to operate from ships in the Arctic Ocean, with limited bandwidth requirements and have improved wind and icing resistance.
- New drone sensor technologies: Develop sensors capable of measuring ice properties on a fine scale, while providing input to operational decisions such as navigating in ice covered waters.

Achievements

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

There are many challenges and risks related to the increased utilization of drones. One particular risk is related to ice accretions in clouds and cold weather, which can lead to unwanted crashes and losses. WP 4 is targeting this challenge with great success (Hann et al. 2020). The PhD project dedicated to 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.

Sensors for measurements of snow and sea-ice properties

The PhD project on Ultra-wide-band (UWB) radar for measurements of snow and sea-ice properties was successfully completed by Rolf-Ole Rydeng Jensen in May 2021. The radar was used to measure snowpack parameters such as snow depth and characterize sea-ice properties. A method to reliably and remotely estimate snow water equivalent was also developed. This led to improved accuracy in snow density estimates (Jenssen and Jacobsen 2020; Jenssen et al. 2020).

The radar system has been constantly evolving throughout CIRFA and has spun out to several other applications. During the CIRFA 2022 cruise to the Fram Strait, the radar was flown on a multicopter from the helideck of *RV Kronprins Haakon* and derived snow depth measurements which were validated against manual (magnaprobe) measurements with excellent results.

Multisensor sea-ice properties retrieval for real-time operational support

A new payload system, consisting of multiple optical cameras, onboard computers and a web-based tool (NLive) has been developed. The payload is mounted onto a fixed wing Vertical Take-Off and Landing (VTOL) drone, capable of operating from the helideck of any ship. The combined wide area field of view provides significantly higher coverage and a significantly better situational awareness than what can be achieved from a single downward facing camera. Due to bandwidth limitations, the images must be processed and georectified onboard the drone, and the information is downloaded in a prioritized order based on the user requests via Nlive. The complete system was demonstrated during the CIRFA-2022 cruise to the western Fram Strait. The live and historical data from the drone was available to anyone on the ship via the web interface. The system was used for navigation decisions and for planning the next ice stations. A system for onboard instantaneous sea-ice drift estimation has been developed and this was also tested during the cruise.

Tagging icebergs using drones

During the CIRFA 2022 cruise a modified multirotor was used for placing Iridium/GNSS trackers onto icebergs. This technology is both robust and efficient, and capable of placing trackers up to 1 kg in weight, withing 1 m accuracy several km out from the ship.

Figure 4-1 *Ultra Wideband Snow Sounder (UWiBaSS) on flight during the 2022 CIRFA cruise. Foto: NORCE.*

Figure 4-3 *The images from the two optical cameras onboard the VTOL drone were georectified and shared with the navigators and scientists onboard the ship in real time. Real time and historical data were available to everyone onboard via the ships`s web server, and the information was used for planning ice stations and navigation routes. Photos: NORCE.*

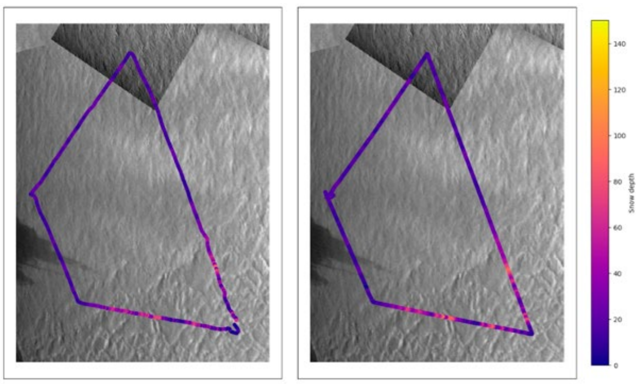


Figure 4-2 *Validation transect with magnaprobe (left) and UWiBaSS (right). Foto: NORCE.*

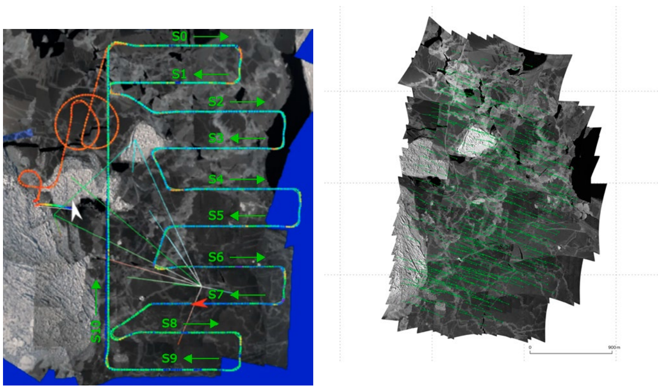


Figure 4-4 *Each flight line (S0-S10) was repeated four times with a repetition time of approximately 12 minutes. SIFT features are tracked between repeated flightlines, so that their drift speed and direction can be estimated. Tracks of selected features are visualized as green arrows on the mosaic, generated from the images captured during the first repetition. Photos: NORCE.*

WORK PACKAGE 5

Drift Modelling and Prediction

WP leader
Johannes Röhrs
Senior Scientist, MET Norway

WP leader
Rune Graversen
Professor, UiT

WP leader
Kai Håkon Christensen,
Professor, MET Norway/UiO

Team members

Silje Christine Iversen,
PhD Candidate, UiT

Victor de Aguiar,
PhD Candidate, UiT

Sindre Fritzner,
PhD Candidate, UiT

Runa Skarbø,
PhD Candidate, UiT

Martina Idzanovic,
Researcher, UiT

Keguang Wang,
Researcher, MET Norway

Edel Rikardsen,
Researcher, MET Norway

Jostein Brændshøi,
Researcher, MET Norway

Ann Kristin Sperrevik,
Researcher, MET Norway

Yvonne Gusdal,
Researcher, MET Norway

Knut-Frode Dagestad,
Senior Scientist, MET Norway

Objectives and motivation

The overall objective is to improve operational ocean, sea-ice, and weather forecast models by developing new algorithms and by including and using new types of observations provided in other WPs. Within CIRFA, WP5 connects satellite retrievals of ocean, sea-ice and atmosphere that are improving products for the end user of weather and ocean circulation forecasts. Data assimilation techniques combine the model state with various types of ocean and sea-ice observations including retrievals developed within CIRFA, providing an analysis of the ocean state and sea ice cover. This current state is then projected into the near-future (1-3 days ahead). In addition, machine learning (ML) algorithms can complement the model forecasts, trained by past performance of the models.

For Arctic operations, forecasts of the position of the sea ice edge, the ocean currents, as well as the weather are critical. In addition, Ocean current forecasts are used to drive trajectory models for the description of oil spill fate, iceberg trajectories, and search-and-rescue missions. 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 state – commonly known as ensemble predictions.

Key research tasks

- Barents 2.5 forecast and validation
- Ocean reanalysis from Barents-2.4 and Norshelf
- Assimilation of sea ice concentration in EnKF
- Assimilation of passive microwave SST
- Ensemble prediction systems for ocean, ice, and drift models
- ML-based sea ice prediction
- Uncertainty estimates from ocean current and drift predictions
- Contingency modeling for oil spill drift and icebergs
- SAR wind retrieval and assimilation

Achievements

Activities in WP5 are distributed across the topics of data assimilation, trajectory modelling, and SAR wind retrieval.

A **coupled ocean and sea ice forecast model** was developed in CIRFA – a system that assimilates observed sea ice concentration in a regional scale (2.5km) ensemble prediction system. During the second half of the project period, this system was extended to ingest sea surface temperature and in-situ hydrography. The model has been operationalized and a system for monitoring the model performance has been developed. Advances in data assimilation in a costal ocean circulation model have been made to assimilate sea surface height and surface currents from HF radar into an operational ocean forecast system, and to complement this with also using observed hydrography. During the second half of the project period, refined methodology for assimilating sea surface temperature from various satellite sources has been developed. This system has been operationalized at MET Norway and are now executed daily (Röhrs et al. 2023). An important advancement in operational oceanography from this project lies in the extension of the ocean circulation model to an ensemble prediction system, and the project team has demonstrated that the ocean component of the Ensemble Prediction System (EPS) can successfully predict uncertainty of near-shore currents (Idzanovic et al. 2023), and trajectories (de Aguiar et al. in preparation).

Trajectory models for drift modelling represent a layer on top of the ocean circulation model that give additional value to the end user by providing predictions of particle positions for icebergs, oil spills and search areas for rescue operations (Dagestad et al. 2018). Such predictions come with a high degree of uncertainty, and the trajectory modeling system used here has been extended to benefit from ensemble predictions of the ocean circulation model. Elaborate work has been done on the refinement of the oil spill trajectory component (Röhrs et al. 2018), which now resolves vertical mixing of various oil types, and field experiments during CIRFA demonstrate the capability of the model to describe horizontal and vertical distribution mechanisms (Brekke et al. 2020).

WP5 in collaboration with WP1 has provided development of **wind retrievals by SAR**. The SAR backscatter signal from the ocean surface is dependent on small-scale capillary waves generated by winds, which implies that the wind can be retrieved from the backscatter signal. This SAR-based observation type has a resolution at the kilometer scale, which is much higher than other satellite-based types and is therefore very useful associated with meso-scale weather phenomena such as polar lows. Conventional retrievals are based on auxiliary information of wind direction provided for instance by weather models. In CIRFA, we developed a retrieval system that is independent of auxiliary information (Tollinger et al. 2021; see WP1). This so-called SAR-only retrieval has been tested in complex wind situations around Svalbard and the Norwegian coast and found to outperform the conventional method in complex wind situations where model-derived auxiliary information is prone to be erroneous (Tollinger and Graversen 2024). The CIRFA-developed SAR-only retrieval is now tested in operational use for a polar-low situation in the AROME-Arctic weather-prediction model used operational at MET Norway (Tollinger et al., in preparation).

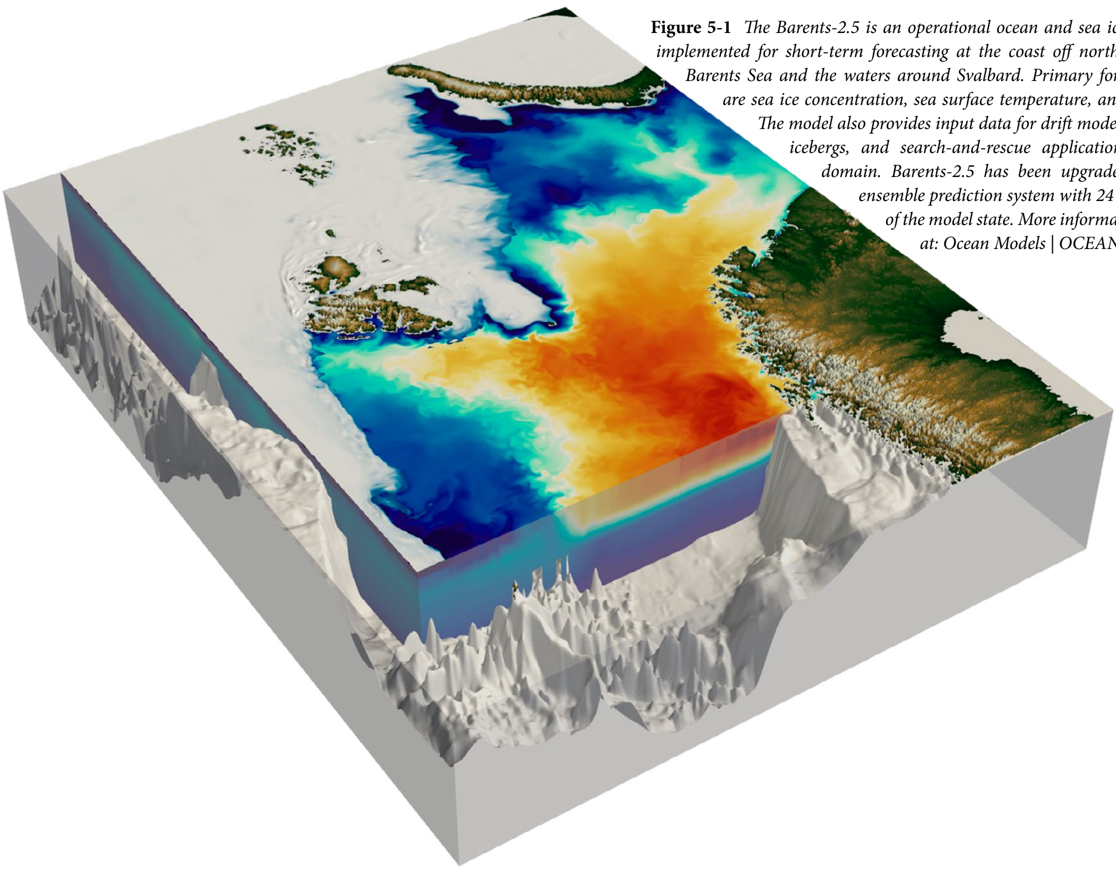


Figure 5-1 *The Barents-2.5 is an operational ocean and sea ice forecast model, implemented for short-term forecasting at the coast off northern Norway, the Barents Sea and the waters around Svalbard. Primary forecast parameters are sea ice concentration, sea surface temperature, and ocean currents. The model also provides input data for drift modeling of pollutants, icebergs, and search-and-rescue applications in the Arctic domain. Barents-2.5 has been upgraded to include an ensemble prediction system with 24 daily realizations of the model state. More information can be found at: Ocean Models | OCEAN.MET.NO.*

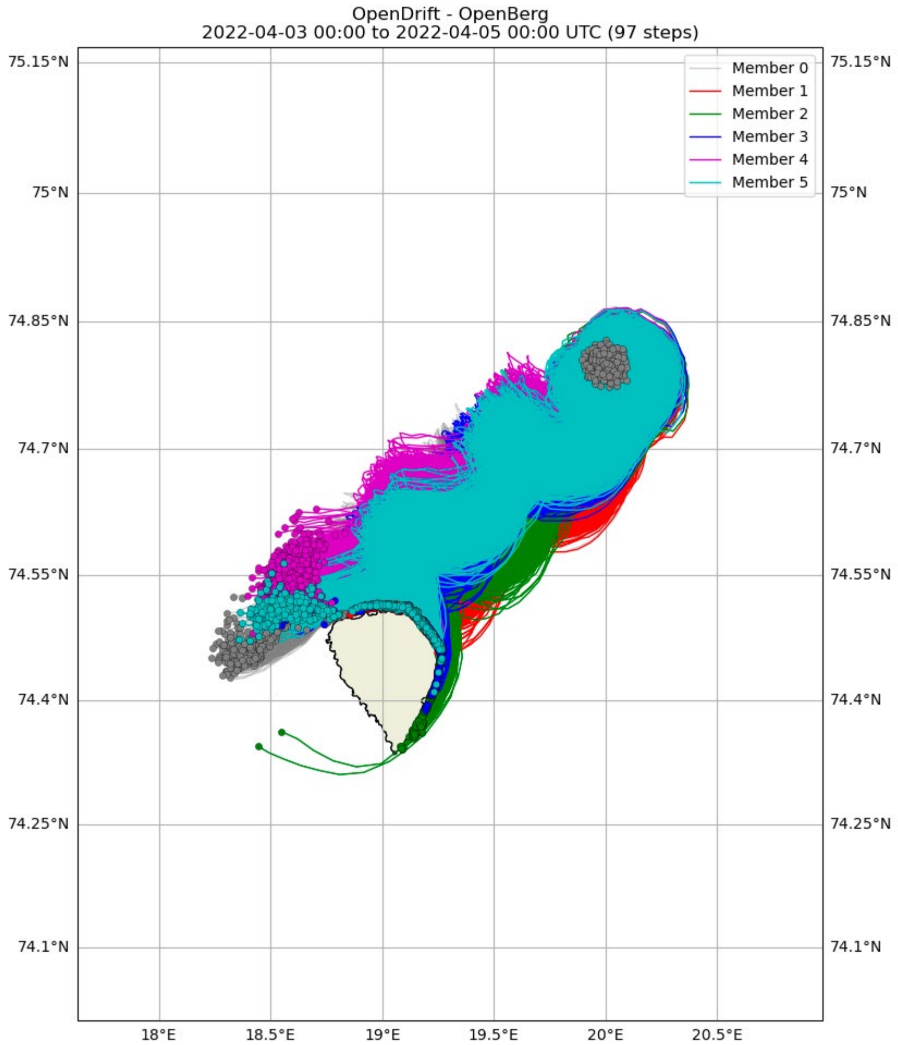


Figure 5-2 *Ice berg drift simulation near Bjørnøya. Results from 6 ensemble members of Barents-2.5 are shown in different colors. Each ice berg particle is forced by surface currents from the ocean model ensemble, as well as wind drift from an atmospheric ensemble (EC-IFS) and Arome-Arctic. Figure by Knut-Frode Dagestad, MET Norway.*

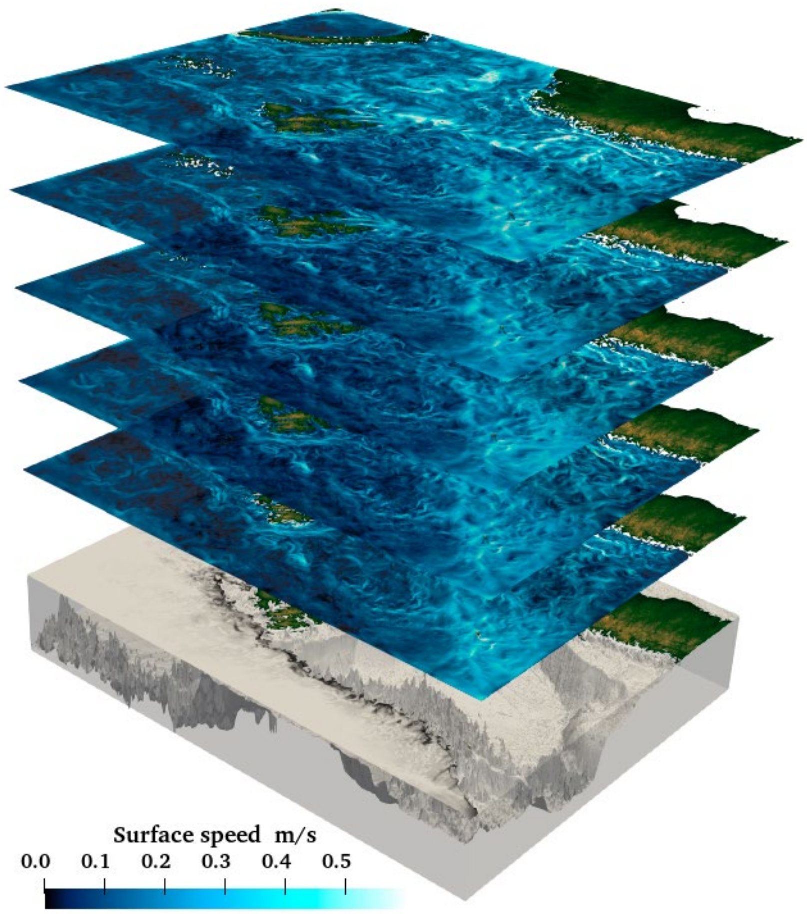


Figure 5-3 *Illustration of surface current realisations from 5 ensemble members of the Barents-2.5km ocean and sea ice model. Surface current speed is coloured in blue shading. Each ensemble member includes sea ice concentration forecasts (shown in bottom layer) and realistic bathymetry. Figure by Marta Trodahl, MET Norway.*

WORK PACKAGE 6

Data Collection and Fieldwork

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

WP leader
Malin Johansson
Associate Professor, UiT, WP co-lead from 08/2021

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

WP leader
Camilla Brekke
Professor, UiT, WP co-lead until 07/2021

Team members

Anca Cristea, *PostDoc, NPI*
Jean Negrel, *PostDoc, NPI*
Dmitry Divine, *Researcher, NPI*

Objectives and motivation

The work package focuses on designing field campaigns that integrate satellite and drone measurements for calibrating and validating remote sensing products for sea ice, snow and oil spills. WP 6 closely coordinates and collaborates with other work packages within CIRFA and involves centrally (but not exclusively) the Norwegian Polar Institute, NORCE, UiT The Arctic University of Norway and NOFO.

Key research tasks

- Plan and conduct 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 challenges by seeking and implementing new and refined measurement concepts and methods using new technologies and platforms.
- Provide archived and new quality ground-truth data for other CIRFA work packages.

CIRFA researchers participated in various national and international sea ice fieldwork campaigns (see table 6-1), such as N-ICE2015, annual Norwegian Polar Institute campaigns to the Fram Strait, the MOSAiC expedition (2019-2020), and several Nansen Legacy cruises to the northern Barents Sea and the central Arctic Ocean. In addition, fieldwork was performed on landfast ice in Kongsfjorden, Svalbard, which is part of Norwegian Polar Institute`s sea ice monitoring program. CIRFA scientists used the opportunities to study diverse sea ice conditions throughout the year, with various phases of ice growth and melt, snow cover, surface and temperature conditions, in the Fram Strait, Barents Sea and Svalbard fjords, to validate and calibrate satellite remote sensing products. Interaction with research from other projects and institutes adds value, new perspectives and networking opportunities. In the two last years of CIRFA (2022 and 2023), central sea ice research-related field activities within WP 6 were the CIRFA-2022 cruise with *RV Kronprins Haakon* to the Fram Strait in April-May 2022 (see details below), and field activities in which also CIRFA scientists took part to Svalbard (Kongsfjorden, spring 2023) and to Fram Strait (late summer 2023), again with *RV Kronprins Haakon*.

CIRFA also utilizes coastal and fjord-based long-term monitoring data for the calibration and validation of remote sensing research, for, e.g., wind data retrieval, sea ice vs open water algorithm development. In addition, WP 2 has arranged three INTPART field schools with sea ice-related fieldwork.

A central activity in WP 3, 5 and 6 was experimental fieldwork focusing on oil spill detection during experimental fieldwork in 2017, the annual oil on water exercises conducted by NOFO in 2015-2019 with CIRFA leading the data collection during the 2015 and 2019 exercises (see details below) as well as participation in a Santa Barbara oil spill detection campaign in 2022 (ROSES). In 2017, the behavior and detectability of oil enclosed in artificially grown sea ice was studied (see details below). Furthermore, ocean drift trackers have been deployed in the Barents Sea during a cruise with SFF CAGE in 2022 and their drift trajectories were matched with SAR observations from naturally released oil slicks. During the NASA + NOAA led ROSES oil seepage campaign, naturally occurring oil seepages outside Santa Barbara were overflown with the NASA UAVSAR instrument and used to improve damping ratio estimates and the separation between oil and low wind areas.

The extensive fieldwork activity enabled comprehensive validation and calibration of a wide range of satellite remote sensing products with overlapping satellite data collected during most campaigns. Additional significant tasks, often in collaboration with other WPs and CIRFA partners, included data processing, scientific publications, conference presentations, and reporting/data publishing.

Table 6-1 *The CIRFA team participated in, used data from, and tested and demonstrated new technology in over 70 occasions of fieldwork between 2015 and 2023. The 4 large-scale key campaigns where CIRFA was involved in planning, participation and (partial) funding, are highlighted in bold text. See the annual report of the respective year for more details on key fieldwork campaigns.*

AWI – Alfred Wegener Institute for Polar and Marine Science. CAGE – Center for Arctic Gas Hydrate, Environment and Climate, Center of Excellence at UiT (SFF, 2013 - 2023). NPI – Norwegian Polar Institute. NOFO – Norwegian Clean Seas Association for Operating Companies. SMHI – Swedish Meteorological and Hydrological Institute.

Year	Fieldwork activity	Sea ice, iceberg & snow studies	Oil-related studies	Lake, river ice, fjord ice	Water quality and ocean colour
2015	N-ICE2015 with *RV Lance* being frozen for 6 months into drifting sea ice north of Svalbard	X			
	Annual NPI Fram Strait monitoring cruise	X			
	Norwegian Radar Oil Spill Experiment 2015 (NORSE 2015)		**X**		
	MeltEx2015 airborne campaign by AWI to monitor the melting of sea ice	X			
	Drone fieldwork in Kongsfjorden – Testing of drone system for detection of small icebergs	X			
2016	Annual NPI monitoring campaign to Kongsfjorden (Svalbard)	X			
	Annual NPI Fram Strait monitoring cruise	X			
	NOFO Oil-on-water (OPV) campaign 2016		X		
	Algae bloom study in the Baltic Sea with SMHI				X
	TIFAX airborne survey by AWI to study sea ice during summer	X			
	Swedish-Canadian Arctic Ocean 2016 research cruise on *RV Oden* to model iceberg drift	X			
	Drone- and ground-based interferometric radar experiment in Kongsfjorden for small iceberg tracking and drift estimation validation	X			
2017	Annual NPI monitoring campaign to Kongsfjorden (Svalbard)	X			
	Annual NPI Fram Strait monitoring cruise	X			
	Oil in sea ice tank experiment at Hamburg Ship Model Basin (HSVA) in Germany		**X**		
	Fieldwork in fjords in mainland Troms and Nordland			X	
	Sea Keeping Trials in Ice (SKT) in the northern Baltic Sea for ice drift estimates	X			
	NOFO oil-on-water (OPV) campaign 2017		X		
	1st INTPART Arctic Field Summer School in Tromsø & Svalbard, visit of the marginal ice zone with *RV Lance*	X			

Year	Fieldwork activity	Sea ice, iceberg & snow studies	Oil-related studies	Lake, river ice, fjord ice	Water quality and ocean colour
	PAMARCMIP and TIFAX airborne campaigns by AWI to study sea ice during summer and winter	X			
	Algae bloom study in the Baltic Sea with SMHI				X
	Drone experiments Kongsfjorden. Svalbard, testing of de-ice system, and real-time data distribution and feedback to navigation	X			
2018	Annual NPI monitoring campaign to Kongsfjorden (Svalbard)	X			
	Annual NPI Fram Strait monitoring cruise	X			
	Nansen Legacy cruise 1-2 with *RV Kronprins Haakon* to the marginal ice zone north of Svalbard	X			
	Fieldwork in fjords in mainland Troms and Nordland			X	
	Data collection on produced water from operational oil platform *Brage*		X		
	UWiBaSS drone flights in Bardu (Troms) – ice thickness and snow cover of lake ice	X		X	
	2nd INTPART Arctic Field Summer School in Barrow, Alaska (US)	X			
	Scout drone flights in Ny-Ålesund, Svalbard, for mapping sea ice with a new tailored sensor package	X			
	NOFO oil-on-water experiment 2018		X		
	TIFAX airborne survey by AWI to study sea ice during summer	X			
	Stationary radar and SAR comparison over oil seepages on the *Edvard Grieg* platform		X		
	Limnological fieldwork at Lake Balaton (Hungary) to study water quality				X
2019	Annual NPI Fram Strait monitoring cruise	X			
	Involvement in 3 Nansen Legacy cruises with *RV Kronprins Haakon*	X			
	Involvement in MOSAiC expedition with transpolar drift of *RV Polarstern*	X			
	Norwegian Radar Oil Spill Experiment 2019 (NORSE 2019)		**X**		
	Fieldwork in fjords in mainland Troms and Nordland			X	
	Data collection on produced water from operational oil platform *Brage*		X		
	SIOS Field campaign for mapping terrestrial snow parameters with UWiBaSS	X			
	CAATEX2019 cruise with *KV Svalbard* to demonstrate radar imaging system for of sea ice	X			
	3rd INTPART Arctic Field Summer School in Canada	X			
	IceBird airborne survey by AWI to study sea ice during summer	X			
	Scout drone flight in Ny-Ålesund - mapping sea ice, onboard processing	X			
2020	Involvement in MOSAiC expedition with transpolar drift of *RV Polarstern*	X			
	Annual NPI Fram Strait monitoring cruise	X			
	Fieldwork in fjords in mainland Troms and Nordland			X	

Year	Fieldwork activity	Sea ice, iceberg & snow studies	Oil-related studies	Lake, river ice, fjord ice	Water quality and ocean colour
	Data collection on produced water from operational oil platforms *Brage* and *Norne*		X		
	CAATEX2020 cruise with *KV Svalbard*, sea ice observations using radar and ground-based fieldwork	X			
	1 Nansen Legacy cruise with *RV Kronprins Haakon* to collect sea ice data	X			
2021	3 Nansen Legacy cruises with *RV Kronprins Haakon* to collect sea ice and ocean color datasets	X			X
	UAK2021 campaign with *KV Svalbard* to test automatic sea ice classification	X			
	Annual NPI monitoring campaign to Kongsfjorden (Svalbard)	X			
	Annual NPI Fram Strait monitoring cruise	X			
	Fieldwork in fjords in mainland Troms and Nordland			X	
	Thin (young) sea ice monitoring in Ramfjorden near Tromsø	X			
	Data collection on produced water from operational oil platforms *Brage* and *Norne*		X		
	Limnological fieldwork at Lake Balaton (Hungary) to study water quality				X
2022	IMR monitoring cruise to NE Greenland to test sea ice remote sensing products	X			
	CIRFA-2022 cruise to western Fram Strait and Belgica Bank (NE Greenland) with RV Kronprins Haakon: 1st Norwegian-lead field Arctic expedition with remote sensing and ground validation at its core, and a wide array of associated research	**X**			
	Annual NPI monitoring campaign to Kongsfjorden (Svalbard)	X			
	Annual NPI Fram Strait monitoring cruise	X			
	Field campaign offshore St. Barbara (California, US) to retrieve oil spill thickness from SAR		X		
	CAGE (UiT)-lead cruise to study naturally occurring oil and methane seeps		X		
	NOFO oil-on-water experiment 2022		X		
	Arctic Ocean cruise on *RV Kronprins Haakon* to study sea ice in summer	X			
2023	Annual NPI monitoring campaign to Kongsfjorden (Svalbard)	X			
	Annual NPI Fram Strait monitoring cruise	X			
	ArtOfMelt by the Swedish Polar Research Secretariat using *RV Oden* to study the melt onset of sea ice	X			
	Breathe and SiDRIFT field school on board *RV Kronprins Haakon*	X			
	IceBird airborne survey to North-East Greenland with AWI`s research airplane *Polar 5*	X			

Selected sea ice fieldwork and in situ studies

The CIRFA-2022 cruise
In April/May 2022, a CIRFA team embarked on *RV Kronprins Haakon* for Norway's first ship-based Arctic research expedition with a focus on satellite remote sensing of floating ice. The main goal was to collect a set of ground truth validation data at different spatial scales for the validation of satellite remote sensing products for sea ice, icebergs, and ocean in the western Fram Strait. The European Space Agency (ESA) contributed to the funding of the cruise, since the collected data are of considerable interest for the Mission Advisory Groups who prepare the ROSE-L (Radar Observing System for Europe at L-band), Sentinel-1 Next Generation, and Harmony space missions.

The science team collected data and samples ranging in scale from micrometers (snow pits and sea ice coring) to kilometers (ski transects and drone flights), and in-situ surface samples of snow and sea ice. A laser roughness profiler was used to measure surface topography characteristics and autonomous sensors were deployed in sea ice and ocean to reveal sea ice and ocean changes and dynamics. During the expedition, ground-based measurements could be geographically co-located with satellite images acquired close in time. In addition, several other synergetic projects addressed regional changes in sea ice and ocean.

More information about our research, preliminary results and safety standards can be found in the cruise report. The combined ground truth and satellite measurements will allow future studies to address important research questions in Arctic remote sensing and development of new technologies.


Figure 6.1 *Left: CIRFA postdoc Jean Negrel inspecting thin landfast sea ice in Kongsfjorden for remote sensing in situ validation. Fieldwork on landfast sea ice in Kongsfjorden, Svalbard, is part of NPI's Svalbard annual sea ice monitoring program. Right: In situ measurements of sea ice surface and snow properties during the CIRFA-2022 cruise, such as surface roughness, temperature, density, salinity, internal microscopic snow structure. Photos: Sebastian Gerland, NPI.*

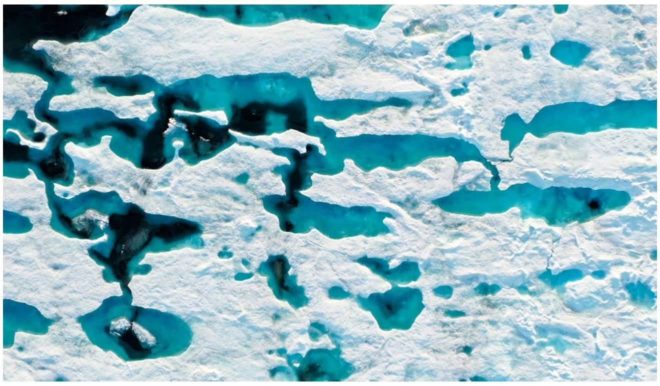



Figure 6.2 *Left: CIRFA scientists participated in several of the annual late summer cruises to Fram Strait, lead by the Norwegian Polar Institute. In late summer, the sea ice has only little snow and melt ponds that developed during summer are visible. Photo: T.L. Sviggum Helgerud, NPI. Right: Airborne helicopter surveys with electromagnetic ice thickness measurements supported regional calibration and validation of satellite SAR data, as here during a cruise of the Nansen Legacy project with RV Kronprins Haakon in the northern Barents Sea, in March 2021. Photo: Sebastian Gerland, NPI.*

Figure 6.3 *Polar bear safety is part of the daily routine while doing research on Arctic sea ice, here during the CIRFA-2022 cruise with RV Kronprins Haakon. Photo: Sebastian Gerland, NPI.*

Larger fieldwork with in-situ oil slick studies

NORSE2015 and NORSE2019

CIRFA participated in NOFO-led oil-on-water exercises in 2015 and 2019, employing airborne SAR instruments from NASA in 2015 and from DLR in 2019. Drifters were released during both campaigns to help address the uncertainty and accuracy of the open oil drift algorithm (WP5) that provides estimates of ocean current and wind affecting the drift behavior of an oil slick. Satellite images were strategically acquired to coincide with oil releases.

The 2019 exercise involved many CIRFA scientists to conduct in-situ data collection and to test estimates of the relative oil thickness through KSAT's Oil Spill Detection Service. The relative thickness is an important parameter as it enables the detection of actionable oil. The improved information was fed directly into NORCE's NLive system for visualization on board the ship, and at NOFO's headquarters.

Both exercises fostered cross-disciplinary collaboration within CIRFA (WP3, WP5, WP6, and WP7) and between industrial partners and scientists.

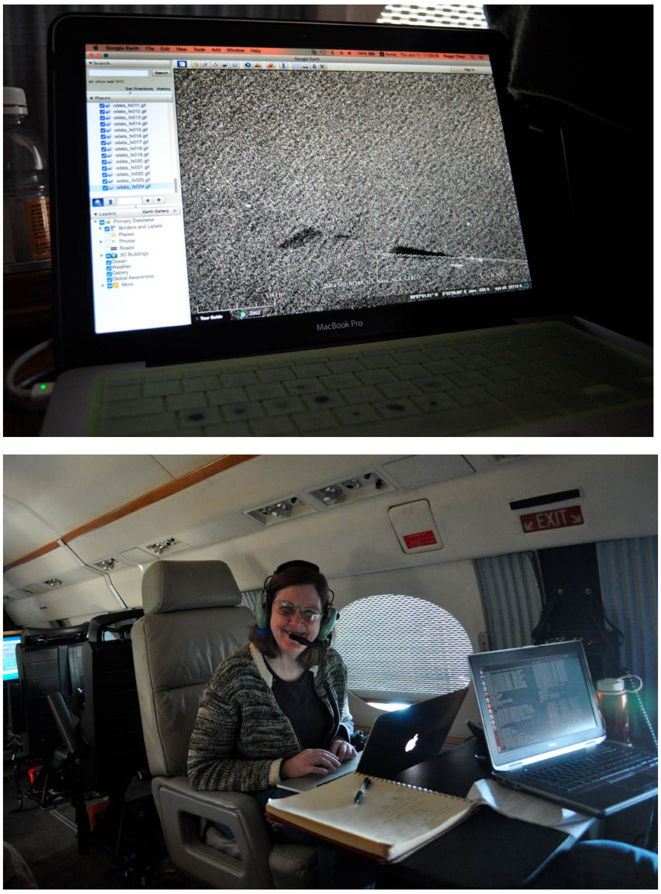


Figure 6.4 *From NORSE2015: Live monitoring of the oil slicks as observed from the UAVSAR plane (left) and Cathleen Jones monitoring the UAVSAR instrument and oil slick detection onboard the plane (right). Photos Stine Skrunes, UiT.*

Indoor Oil-in-Ice Experiment

To optimize oil spill response actions and minimize the environmental impact, oil-in-ice experiments were performed at the HSVA Arctic Environmental Test Basin in Hamburg, Germany, for 3 weeks in spring 2017. CIRFA conducted experiments on artificially grown sea ice jointly with the RCN PETROMAKS2 project MOSIDEO (#243812), involving 14 researchers and PhD students from 7 institutes. From CIRFA, PhD candidates Marianne Myrnes and Megan O'Sadnick joined.

Following an under-ice spill during simulated springtime warming, the microscopic movement and distribution of oil in the sea ice pore space were investigated. Two ice types were studied simultaneously: columnar ice with and without a granular ice surface layer. The detection techniques included electromagnetic (radar, tomographic SAR) and optical (fluorescent, hyperspectral, thermal) sensors, and X-ray computed tomography (CT) to determine the microscopic distribution of oil inside sea ice.

Different behaviors of oil were observed in various ice types, with oil initially trapped at the bottom during a winter spill but surfacing in spring as ice warms and pore spaces expand. The experiments were designed to investigate the detectability of the oil-filled pore space near the surface with a range of remote sensing techniques. Predicting the behavior of oil in ice based on environmental and seasonal conditions will help optimize oil spill detection and response strategies.

Figure 6.5 *Top: Preparations for tomographic SAR measurements of oil surfacing warm sea ice at the Arctic Environmental Test Basin during the oil in ice experiment in Hamburg, Germany. Bottom: Megan O'Sadnick analyzing oil content in sea ice during the oil in ice experiment in Hamburg. Photos: Giuliani von Giese.*

WORK PACKAGE 7

Pilot Service Demonstration

WP leader since 2019
Hugo Isaksen
Project manager, KSAT

WP leader in 2015
Mari-Ann Moen, *Project Manager KSAT*

WP leader since 2015
Nick Hughes
Leader of the Ice Service, MET Norway

WP leader in 2017
Torunn Tøllefsen, *Project Manager KSAT*

WP leader 2016-2017
Jan Petter Pedersen, *KSAT*

WP leader in 2016
Charles Debart, *Project Manager KSAT*

Team members

Salman Khaleghian, *PhD Candidate EU Horizon 2020 ExtremeEarth*

Habib Ullah, *PostDoc EU Horizon 2020 ExtremeEarth*

Martine M. Espeseth, *Project Manager and Researcher, KSAT*

Catherine Taelman, *Engineer, UiT*

Thomas Kræmer, *PhD Candidate/Engineer UiT/ Developer, KSAT*

Jelte G. van Oostveen, *Engineer, UiT*

Gudmundur Jøkulsson, *Director Systems Development, KSAT*

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 in the environmentally sensitive Arctic that have not been met, such as monitoring technologies integrated into their day-to-day operations for decision support.

WP7 has integrated CIRFA`s R&D outputs into user partner`s existing routines at KSAT and MET Norway to demonstrate the implementation of R&D results for end-users with operational needs. The services are based on multi-sensor data acquired from various sensors and platforms, accessed via improved communication infrastructure, and brought into analysis and decision making through dedicated user interfaces.

Key research tasks

- Support WP 1-6 with development and large-scale testing of their results and prototypes.
- Establish an infrastructure that allows the WP partners to access and perform processing the project data in a technically efficient way close to 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.
- Ensure visibility through participation in industrial conferences.

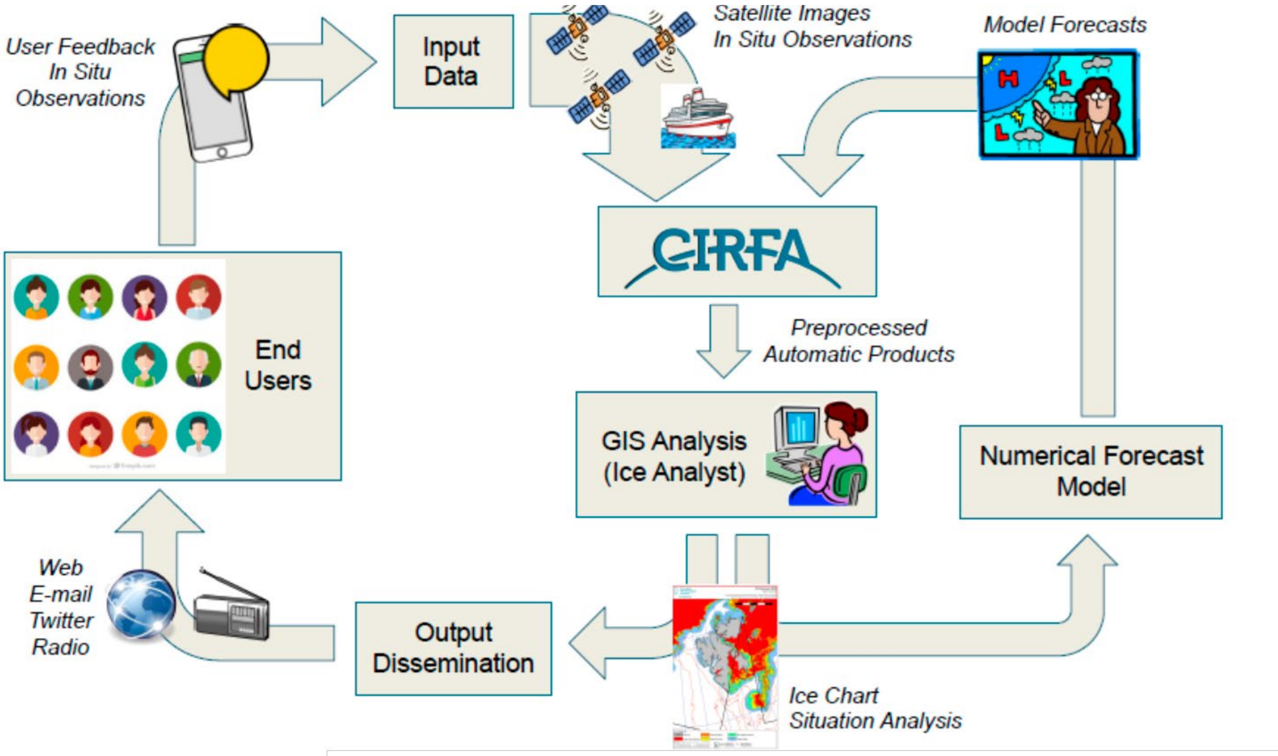


Figure 7-1 *Data collection, analyses and information delivery of Ice Charts from MET Norway`s Ice Service to end users (vessels in Arctic waters with Norwegian responsibility). Source: MET Norway.*

Sea ice mapping

With increasing ship traffic in polar waters, especially around Svalbard, the Polar code covers special demands for vessels operating in polar waters (ship design, equipment, crew training, environmental protection measures). Chapter 5 of SOLAS 1974 requires meteorological services for ships, navigational support, ice patrol services, and the maintenance of search and rescue services.

At most ice services, including MET Norway`s Ice Service, sea ice maps have traditionally been drawn manually which is resource-consuming, has human error sources, and is available only on 5 out of 7 weekdays. CIRFA developed integrated remote sensing and forecast products that provide automatically processed information on ice type (WP 2), and take forecasts of ice drift and ice edge position (WP 5) into account.

CIRFA has made considerable progress in algorithm development for (semi-)automated sea ice mapping from SAR, but the transfer from research into operations remains challenging. During the CIRFA-2022 cruise (WP 6), a technical setup was tested that transferred geo-referenced sea ice classification results to the vessel *RV Kronprins Haakon* within 2.5 hours after satellite image acquisition. The information was compared with ice observations, drone imagery and in-situ data. The classification results successfully guided the captain`s route choice and the science crew`s work plans.

However, certain ice types, seasonal variations and geophysical sensor characteristics remain challenging for the automated analyses as well as integrating the new method into the ice analyst's daily workflow. MET Norway`s Ice Service has ambitions to include automated iceberg detection and fjord ice monitoring into its services.

For fjord ice extent, SINTEF and WP3 have established a data portal with time lapse photography and MODIS imagery starting in 2001. Initial background information on fjord ice and thin sea ice lead to the evaluation of thin ice and oil spill look-a-likes (Johansson et al. 2020).

Oil spill response

Unintended oil spills or oil slicks at the ocean surface are monitored globally with satellite remote sensing. In case of an incident, warnings and detailed information need to be provided quickly by KSAT`s Oil Spill Detection Service. This information covers what kind of spill it is, where the thickest oil is, where the oil comes from, where to and how fast it drifts. NOFO´s oil on water exercises have been an excellent testing arena for CIRFA's research on oil spill monitoring since 2015.

CIRFA`s work helped to gain more relevant details, such as identifying the thickest part of an oil spill (where the highest concentration of oil is) through its relative thickness product derived from SAR (Jones 2023). KSAT and NOAA have successfully integrated WP3`s relative thickness product into their Oil Spill Detection Services.

In addition, improved drift estimates from WP1 and WP5 on wind and ocean models indicates to where and how fast an oil slick may move. KSAT has been working on operationalizing WP5`s OpenDrift in KSAT`s Oil Spill Detection Service with both developing a programming interface for a new application, forecasts, and integrating and validating forecasts and hindcasts.

More accurate and comprehensive oil spill information is an excellent example how research and innovation from CIRFA has been operationalized into the industry, providing more and better information for decision making to guide clean up missions with the goal to reduce environmental impact. Inside Norway, KSAT supplies NOFO, the Norwegian Coast Guard and Kystverket with oil spill detection information. Since April 2023, KSAT provides Oil Spill Detection Services to the European Maritime Safety Agency (EMSA) to support multiple maritime user communities in Europe and beyond.

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

Education and Training

Most **PhD candidates** in CIRFA were employed at UiT as the host organization. Some were employed at UiT but funded by associated projects like the Nansen Legacy (RCN #276730), RareIce (RCN #326834), SIRANO (RCN #302917) and the EU H2020 project Extreme Earth (#825258). Nine CIRFA-funded and 6 associated PhD candidates have completed their thesis, while five more funded and 2 more associated PhD candidates are expected to finalize their studies in 2024. In addition, UiT sponsors five new PhD positions and one new post doc at the end of the center.

CIRFA's staff supervised over 50 **master students** from a range of different countries, partly with international funding for student exchanges or internships, and more than one third of them were female. Their efforts resulted in 41 master theses. Master students were invited to join CIRFA`s activities and meetings to present and discuss their work. Some interested and talented master students published parts of their work and successfully continued as PhD candidates.

During the full period of the center, CIRFA arranged **research training activities** that were open for CIRFA master students, PhD candidates, postdocs and early career researchers and members of UiT`s Earth Observation Group. Regular activities included a weekly Young Scientist Meeting, an annual Young Scientists Forum, and a variety of academic training activities.

The weekly Young Scientist Meeting featured presentation and discussion of relevant publications, introduced programming and coding tools, and highlighted other practical questions. An annual two-day Young Scientists Forum provided transferable skills training and team-building activities, enhancing a shared CIRFA identity. Organized informally by early career researchers, the event served as a valuable platform for networking, exchanging ideas, and socializing within the group. Specific event details can be found in the respective annual reports.

CIRFA arranged different academic courses and workshops, or participated in activities together with partners and third-party stakeholders, to enhance research-based education in the center:

PhD course in Radar Remote Sensing (2016)
The course gave an overview about key aspects of radar remote sensing. 26 participants met at UiT in Tromsø.

Photo: Ellen I. Hætta, UiT.

ESA Cryosphere Remote Sensing Training course (2018)
CIRFA PhD students and PostDocs learned about a wide range of measurement techniques that are applied in the Arctic environment. The course was held in Longyearbyen, Svalbard.

CIRFA students and PostDocs in front of the Sentinel-1 downlink antenna at KSAT's Svalbard station. Photo: Anja Strømme

PhD course Society and Advanced Technology in the Arctic (2019)
Three lectures were given by CIRFA team members Torbjørn Eltoft, Camilla Brekke (both UiT) and Hugo Isaksen (KSAT) in Longyearbyen, Svalbard. In addition, Malin Johansson, Thomas Kræmer and Johannes Lohse were involved and gave presentations.

Lectures inside a SVALSAT antenna. Photo: Hugo Isaksen, KSAT.

INTPART Arctic Field Summer Schools (2017 – 2019)
CIRFA received funding to establish "Arctic Field Summer Schools" that engaged 48 graduate students from Norway, USA (Alaska) and Canada in exploring science questions related to Arctic research topics and fieldwork methods through a series of 3 summer schools, held on-board RV Lance in 2017, at Fairbanks and Barrow (Alaska, US) in 2018, and in Calgary (Canada) in 2019.

On board RV Lance: Anthony Doulgeris, UiT.

Winter school on Sea Ice Signatures in SAR Images (2020)
The winter school, held at UiT facilities in Tromsø, and was attended by 25 participants from NPI, MET Norway and UiT.

Photo: Malin Johansson, UiT.

Sea Ice Classification Workshop (2021)
2 methodological workshops were held at UiT facilities in Tromsø in September and November.

Photo: Johannes Lohse, UiT.

Field Excursion Ramfjorden (since 2021)
Hands-on training ground-based sea ice and snow measurements for master students, PhD candidates, PostDocs and researchers of CIRFA partners.

Photo: Olaf Schneider, NPI.

Ocean Color Remote Sensing (2021 - 2022)
Course with six digital lectures from CIRFA team members Katalin Blix, Muhammad Asim, Atsushi Matsuoka and Torbjørn Eltoft.

Photo: ESA`s Copernicus Sentinel-2 capturing algae blooms in the Baltic Sea on 20 July 2019.

NASA's Applied Remote Sensing Training Program (ARSET)

Online lectures given by Malin Johansson on using SAR for monitoring oil spills and sea ice as part of NASA`s Applied Remote Sensing Training (ARSET) program in 2022 and 2023.

PhD candidates and their motivation to join CIRFA

PhD positions were announced on Jobbnorge and communicated through relevant research networks to reach suitable candidates from Norway and abroad. Some master students have continued their research path with a PhD project and later as PostDoc or researcher at CIRFA, or transitioned into different roles in the academic or private sector. Below are examples of opinions from CIRFA and associated early career researchers about why they found CIRFA an attractive place to work at or closely collaborate with:

Martine Espeseth (Master student, PhD candidate and PostDoc in CIRFA, transitioned after the postdoc period to be a project manager at CIRFA-partner KSAT):

"I did my Master's degree at UiT on the same topic. After finishing my Master's thesis, I was curious to know more about this field. I knew that I was far from done with this topic and ultimately chose it as my main area of interest."

Anna Telegina (PhD candidate in CIRFA):

"I have been participating in several conferences and workshops where CIRFA's work was presented, and the research presentations and their results would always catch my eye with their out-of-the-box approach and thorough analysis. I am very excited to [be] a part of this project and hope my technical and research skills I will develop [...] my work on sea ice at the more profound and advanced level further on."

Laust Færch (PhD candidate in CIRFA):

"As a PhD, I have the opportunity to dive deep into my subject. This is something that wouldn't be possible to the same extent if I was working in a private company. In that sense, a PhD [at CIRFA] will enable me to develop my technical skills like no job I can imagine. At the same time, it is an amazing learning environment, where you get the chance to learn from and work with some of the world's top experts."

Jozef Rusin (PhD candidate in the NFR-funded project SIRANO and collaborating with CIRFA)

"By undertaking the PhD there is the unique opportunity to learn and work alongside leading experts from a range of different academic backgrounds. This multidisciplinary environment will enable me to constantly develop new technical skills and methods to apply in the research and overall become a more versatile researcher in my later professional career."

Martina Idzanovic (Post doc in CIRFA):

"Ocean and sea-ice modelling is a quite new field for me and I'm acquiring new knowledge on a daily basis. [...] Being thrown into a new field is extremely challenging but also very exciting. I'm really grateful that I got the opportunity to join [CIRFA and] MET Norway and work on exciting topics highly relevant for society."

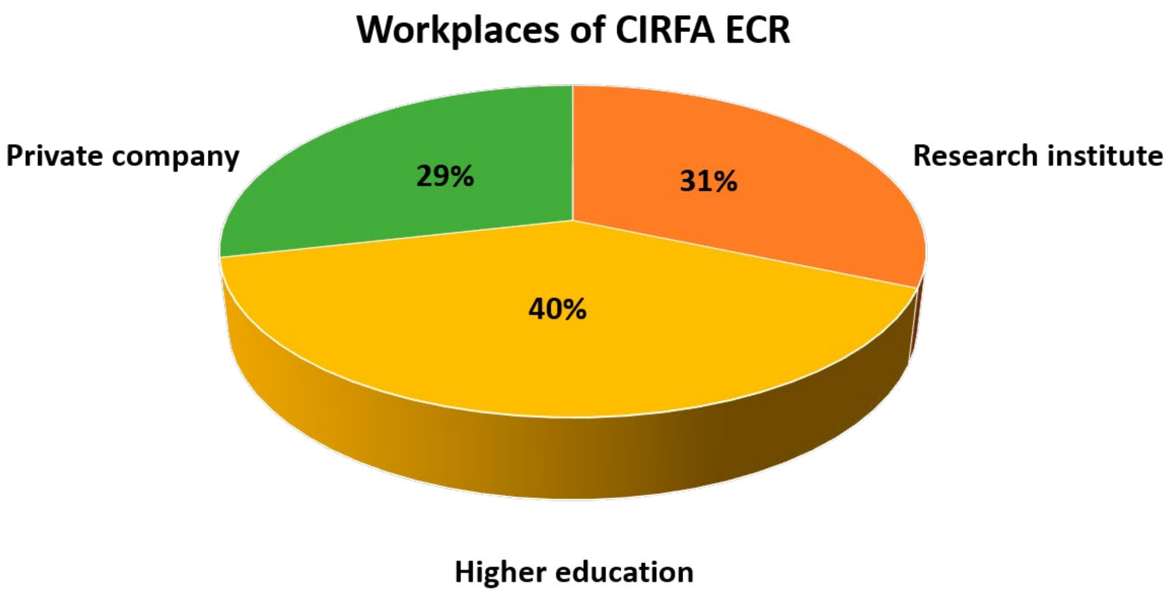
Employment of earlier CIRFA PhD candidates

After completing their degree, 10 earlier CIRFA-funded doctoral candidates are employed by UiT as PostDocs, other universities (NTNU), research institutes (NORCE, SINTEF), private companies (KSAT, Multiconsult, IBM) and a start-up (UBIQ aerospace). We have also included 4 PhD candidates into this view who were funded by associated projects but worked closely together with CIRFA.

Two doctoral candidates have had first a PostDoc position within CIRFA at UiT before their transitioned to private companies. One doctoral candidate transitioned to NTNU and a start-up company. Hence, the number for employment is higher than the actual number of doctoral candidates that were funded by CIRFA or closely associated projects and had finished their degree at the time the center concluded.

After gathering work experience in the SFI CIRFA, the wider circle of early career researchers (ECR; including master students after completing their thesis, PhD candidates after their successful defense, and PostDocs) moved on to positions in the private sector (29%) with KSAT, Multiconsult or IBM, research institutes (31%) such as SINTEF, NORCE, Norwegian Polar Institute, NERSC or MET Norway, or higher education (40%) at UiT or NTNU.

Employment of PhD candidates (number)							**Total**
By centre company (UiT)	By other companies	By public organisations	By university	By research institute	Outside Norway	Other	
7	3	-	1	5	-	1	**17**



Workplaces of early career researchers (ECR; master students after completing their thesis, PhD candidates after their successful defense, and PostDocs) by sector after being a member of CIRFA.

Communication and dissemination

CIRFA as a center and its individual researchers have been active in engaging with a wide academic and public audience. Below, we visually summarize the key elements of CIRFA`s communication and dissemination that was directed at the research community, stakeholders, students, high school students and the public at local, national and international levels.

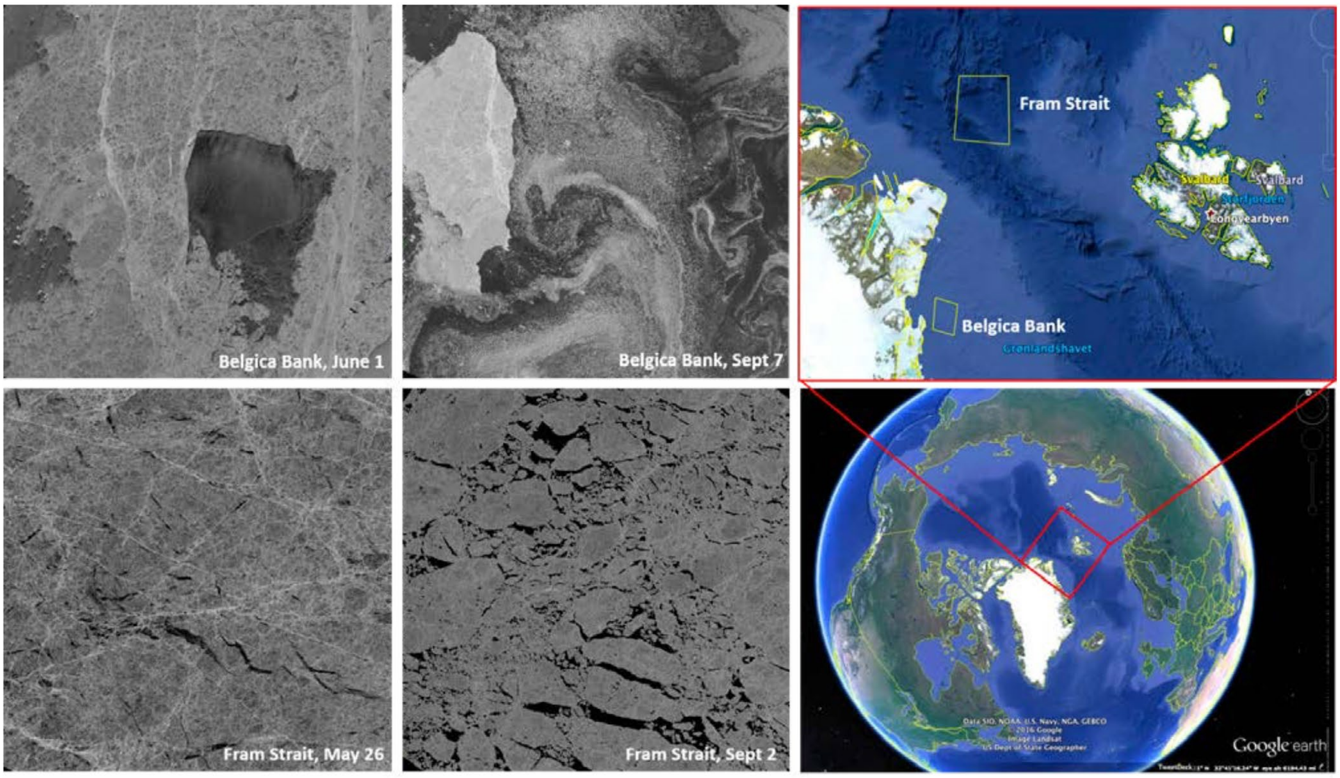
Research results have been actively communicated during academic conferences, workshops and meetings over the years. Examples include IGARSS, EGU, EUSAR, Arctic Frontiers, meetings of the International Ice Charting Working Group, symposia of the International Glaciological Society, Svalbard Science Conference, AIDingArtic: Artificial Intelligence & Data Science for the Arctic, Forum for Framtidas Oljevern, Interspill, and others.

Effects of the center for host institutions and research partners

Tromsø, with UiT's Earth Observation Laboratory, MET Norway and the Norwegian Ice Service, NORCE, NPI and KSAT, has a robust foundation for Earth Observation and satellite remote sensing. SFI CIRFA naturally evolved into and significantly expanded this environment. After eight years of research and innovation, the center has yielded tangible results, recognizing that ongoing progress and potential future impacts continue to unfold.

CIRFA has accumulated extensive knowledge, reflected in a noteworthy publication record with ongoing contributions. In addition to research papers and conference contributions, the center has produced textbook chapters, reports, teaching material, outreach articles, datasets, and algorithms. The publicly available datasets and algorithms developed within CIRFA are anticipated to be valuable resources for the scientific community well beyond the project's duration. In addition, many of CIRFA`s innovative outcomes are being implemented at user partners and refine operational monitoring and forecasting services of environmental aspects.

Through CIRFA, UiT's Earth Observation Laboratory has significantly expanded in activity and personnel. In addition, Anthony Doulgeris and Andrea Marinoni have been promoted Professor, and Malin Johansson and Jack Landy have been promoted Associate Professor. Strong connections to projects like the Nansen Legacy, the SFF CAGE, and the SFI Visual Intelligence have led to enhanced research and teaching quality, featuring transdisciplinary presentations, courses, workshops, research expeditions, publications, proposals, shared PhD supervision, and personnel exchange. This collaboration has enabled new research directions in coastal and fjord ice, ocean color, and water quality. Various spin-off projects involving CIRFA partners have been initiated,



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 middle panel, the effect of ice cover disintegration is shown, resulting in small pieces of ice 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 backscattering from ice ridges or narrow areas of brash ice consisting of ice fragments of less than 2 m. The lower middle 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. The ALOS-2/PALSAR-2 data was provided by JAXA through the 2019 to 2022 cooperation project between ESA and JAXA on "Using Synthetic Aperture Radar Satellites in Earth Science and Applications".

including contributions to EU projects like Extreme Earth and IMPETUS (Green Deal), and national projects funded by the RCN, such as InterAAC and DynAMIC. Additionally, an ERC starting grant was secured, and an attempt for the new SFF (CRESCENCE) in the past will possibly be followed by a new try for a SFI in 2024.

CIRFA was *awarded* a contract with ESA for the synergistic use of L- and C-band SAR in sea ice monitoring (ESA ROSE-L). Collaborating closely with Chalmers University of Technology (Sweden), MET Norway, the Ice Services in Denmark and Canada, and the International Ice Patrol, WP 2 produced a literature survey, a method for aligning C- and L-band SAR images, and examples demonstrating enhancements in automated classification and operational sea ice monitoring across six test sites. For aligning satellite image pairs acquired over drifting sea ice at different times a method was developed that uses the ice drift and deformation information directly retrieved from an image pair. Examples of L-band SAR images from two test sites are shown in the figure on page 53.

CIRFA researchers actively engaged in teaching at both bachelor and master level at UiT, establishing partnerships with over 50 master's students for projects and theses. The center attracted 12 exchange students and interns from abroad, contributing to recruitment as some of the students and colleagues advanced into PhD or PostDoc projects within CIRFA or transitioned to partners for knowledge transfer and research product implementation.

UiT, CIRFA`s partners and Tromsø as a city have strengthened their position as the leading Arctic location for satellite remote sensing. Notably, former WP 3 leader Prof. Camilla Brekke assumed the role of Prorector for Research and Development at UiT in August 2021, leveraging her position to incorporate Arctic satellite remote sensing into UiT`s strategy towards 2030.

In acknowledgment of CIRFA's success, UiT sponsors five new PhD positions and one new PostDoc position within the Earth Observation group, ensuring the continuation of innovation and value creation with partners. Since 2021, a field excursion to a local fjord near Tromsø was organized together with the Norwegian Polar Institute when the fjord was covered by thick sea ice in mid-winter. In part, the excursions served as training opportunity for the CIRFA cruise in 2022, but it also gave an excellent opportunity for teambuilding across career stages and fostering collaboration among students and researchers from UiT, NPI, MET Norway, and NORCE. Due to its success, this activity will continue after the end of CIRFA as an annual excursion and transdisciplinary networking opportunity within Tromsø`s Earth Observation community.

CIRFA has served as an umbrella for its research partners, offering networking opportunities, access to resources, and competent personnel to enhance datasets through fieldwork, fostering a robust scientific foundation. This support has facilitated the advancement and improvement of products and services beneficial to society, particularly in the maritime sector.

Photo: Christian Zoelly, NPI

Effects of the center for company partners, public partners and society at large

CIRFA made the gap between science and real-life applications narrower, and some research work has already been transferred to user partners and integrated into their services. **CIRFA has successfully refined the toolbox at hand for situational awareness in the maritime sector:**

- Improved weather, drift and wave forecasts in the Barents 2.5 and Open Drift models are valuable for drift trajectories of sea ice, ice edge, icebergs, as well as oil spill drift forecasts and for search and rescue in Arctic waters. A set of other applications builds on these advances:
  - The Ice Service at MET Norway is incorporating CIRFA's sea classification into its operational services and enhancing communication with vessels. This collaboration has prompted the Ice Service to include iceberg detection and fjord ice information in the future. This improved information contributes to enhanced situational awareness and decision-making for navigation, benefiting both professional maritime activities and public leisure activities.
  - KSAT and NOAA are integrating the 'damping ratio' in their operational oil spill detection services. This allows identifying where oil slicks are thickest. Enhanced drift estimates that are integrated into oil spill detection services provide valuable insights into the potential movement and speed of an oil slick. This detailed information facilitates more precise and effective clean-up operations, contributing to the protection of healthy and clean coastal environments in Norway, Europe, and beyond.
- During CIRFA`s lifetime, drone technologies were developed to suit the Arctic environment: The ultra-wide band radar was developed to measure snowpack parameters and characterize sea-ice properties. The system can be used for scientific purposes, avalanche safety, and to remotely estimate snow water equivalent. In addition, a new real-time operational support system was developed to aid vessels with ice navigation: A drone with multiple optical cameras and a web-based visualisation tool (NLive) shows ice conditions that may aid navigation decisions and route planning in polar waters.
- A former CIRFA PhD candidate`s career path has led to initiating the UAV Icing Lab at NTNU in Trondheim with 6 PhD candidates and the spin-off company UBIQ Aerospace with 26 employees. Both are working on D-ICE, a commercially valuable de-icing system for aircraft that increases their robustness and expands their operational window to conditions where such aircraft previously could not fly. Both initiatives employ master students, PhD candidates from NTNU, engineers and technicians. In 2024, UBIQ areospace received major research funding from RCN: https://www.forskningsradet.no/nyheter/2024/pilot-t-ny-teknologi-transportsektoren/

CIRFA has played a pivotal role in training a new generation of remote sensing and data analysis professionals, cultivating attentiveness to the needs of stakeholders and society. Graduates, equipped with interdisciplinary and innovative skills, pursue diverse careers in academia, industry, or the public sector. Their future careers hold the potential to translate into the development of new and more valuable services and products.

CIRFA colleagues were actively engaged in science communication and education efforts, aiming to promote awareness of satellite technology's significance in STEM subjects. These initiatives, often tailored for schoolchildren, provided tangible insights into research and innovation work, aiding them in navigating future career choices. Additionally, these actions helped the public grasp how research and innovation improve everyday products and services, such as weather, wind and ice forecasts, for safeguarding Norway's unique coast and ensuring safety in maritime workplaces.

Future Plans

Building on a strong tradition of satellite remote sensing, CIRFA certainly contributed that Tromsø`s Earth Observation community consolidated its stand as a leading research environment both at national and international level. The Centre's active contribution to remote sensing research and innovations, its widespread network of collaborators, and its visibility at international conferences and meetings have attracted attention. As a result, ESA wants to establish an "Arctic PhiLab" in Tromsø for satellite-based earth observation with the goal to commercialize research outcomes and innovative ideas. This will further strengthen the remote sensing community in Tromsø, generate new research and innovation projects, and create job opportunities for young scientists.

In addition, the plans for a future National Knowledge Centre for Earth Observation in Tromsø will enable a wider exploitation of some of the remote sensing competence built during the CIRFA period to other application areas.

The research group at UiT will continue many of the activities undertaken during CIRFA thanks to a generous exit-package from the University and several successful research applications. New research projects, of varying size, have received funding from the Norwegian Research Council, the European Union, and others, including a prestigous ERC Starting Grant to a researcher from UiT`s Earth Observation Group. UiT has acknowledged CIRFA`s success with 5 new PhD positions and one new post-doc position starting in 2023 and 2024. Furthermore, a new SFI proposal may be developed in 2024, or later, building on the experiences from the SFI CIRFA. The Earth Observation group at UiT, maintaining its strong ties to local, national and international collaborators, is keeping a high research and teaching activity. Existing and newly proposed projects build on published results, field data collected, and remote sensing technologies developed in CIRFA, aiming to re-use the data and further develop innovative aspects.

When it comes to educational aspects, UiT acknowledges the importance of STEM subjects as a basis for earth observation and remote sensing, and prioritizes Arctic satellite remote sensing as part of UiT`s strategy towards 2030.

Photo: William Copeland

Conclusions

The “I”, standing for **innovation**, has in CIRFA been carried out by developing new information retrieval algorithms, products and services with testing and direct application in user cases. Having developed many information products which are, or soon will be, taken in daily use, significantly expands the research outcomes of an SFI far beyond its publication and dissemination record, and “putting research into practice” creates new value. We strongly recommend that such contributions from our researchers will be recognized as part of their academic success when seeking future projects and funding.

Participation from the partners has been active and dedicated in various ways, for example through discussion of **research topics** at special workshops, feedback on achievements in CIRFA`s annual conferences, and strategic suggestions in the Consortium Board. More specifically, KSAT and MET Norway were involved in testing and further developing and implementing CIRFA`s research outcomes. The Norwegian Polar Institute provided access to ship and ground-based sea ice fieldwork and infrastructures, and to laboratories for processing and storing of snow and sea ice samples. NORCE and Maritime Robotics joined fieldwork activities with their specialized drones and personnel and provided airborne calibration and validation data. During the CIRFA-2022 cruise, their drone systems guided ice navigation, safety aspects (polar bears guarding, Arctic conditions, safety at sea), validated snow thickness transects, and complemented satellite-based ice observations.

The support of “third party stakeholders”, such as NOFO and Kystverket, has been valuable for CIRFA, and very much appreciated. They provided researchers access to their infrastructure and large-scale oil-on-water exercises, which gave realistic testing grounds for CIRFA’s oil slick characterization products.

The **educational aspect** of CIRFA encouraged interactions of early career researchers across the entire center and included its associated projects. The interaction between early career researchers, with some transitioning to industry partners, ensures renewal and added value for Tromsø`s Earth Observation community.

The **project management** in the CIRFA SFI and certainly also in other SFIs, is dominated by coordinating activities, holding regular meetings of work package leaders with the SFI leadership and administration, documenting activity in annual reports, developing annual plans, initiating and organising workshops and meetings to keep the daily research and innovation work on track with agreed deliverables. In addition, PhD defenses, fieldwork and fieldwork training, visits to partner institutions, travels to and participation in conferences or courses have been arranged with support from the research team, the center’s administrative coordinator, and UiT. Center building activities surrounded these main events throughout the year and complemented them with different social activities to build a cohesive group. Celebrations of PhD defenses, recognition of personal successes of group members, and an informal, inclusive and international work environment contributed to an efficient, creative and welcoming work environment at CIRFA.

In conclusion, the SFI model is a unique opportunity to bring together academia and industry with the prospect to co-create new knowledge, stimulate for innovation, develop products and services with application in user cases, and educate a new generation of research-field specific competent professionals over a longer time than a regular RCN project. CIRFA has fulfilled these expectations, and successfully delivered on most of the success criteria set up for an SFI.

List of PhD candidates, post docs, and master students during the full period of the center

Postdoctoral researchers with financial support from the centre budget (10)

Name	M/F	Years/period in the centre	Scientific topic	Main contact
Sindre M. Fritzner	M	09/2020 – 08/2021	Drift modelling and prediction	Johannes Röhrs (MET Norway)
Martine M. Espeseth	F	12/2019 – 10/2020	Oil Spill Remote Sensing	Malin Johansson (UiT)
Anca Cristea	F	08/2020 – 07/2023	Improving arctic sea ice classification using remote sensing and ground-based observations	Sebastian Gerland (NPI)
Stine Skrunes	F	02/2016 – 09/2019	Oil Spill Remote Sensing	Malin Johansson (UiT)
Ann Kristin Sperrevik	F	07/2017 – 06/2020	Drift modelling and prediction	Johannes Röhrs (MET Norway)
Jean Negrel	M	02/2016 – 01/2019	Data collection and fieldwork for sea ice remote sensing	Sebastian Gerland (NPI)
Cornelius Quigley	M	04/2021 – 08/2023	Oil Spill Remote Sensing	Camilla Brekke (UiT)
Debanshu Ratha	M	01/2022 – 12/2023	Radar polarimetry for sea ice applications	Torbjørn Eltoft (UiT)
Qiang Wang	M	01/2022 – 12/2023	Sea ice classification with AI methods	Torbjørn Eltoft (UiT)
Johannes Lohse	M	09/2023 – 12/2023	Automatic sea ice classification	Wolfgang Dierking (UiT/AWI)

Postdoctoral researchers working on projects in the centre with financial support from other sources (8)

Name	M/F	Source of funding	Years/period in the centre	Scientific topic	Main contact
Martina Idzanovic	F	SLABAR	01/2022 – 08/2023	Drift modelling and prediction	Johannes Röhrs (MET Norway)
Habib Ullah	M	Extreme Earth	07/2020 – 02/2021	Deep learning for sea ice classification	Torbjørn Eltoft (UiT)
Wenkai Guo	M	NFR SiDRIFT	11/2019 – 12/2022	Sea ice deformation and snow on sea ice in the Earth System Models	Polona Itkin (UiT)
Anca Cristea	F	Akademia avtale	05/2016 – 05/2018	Statistical modelling of SAR images	Torbjørn Eltoft (UiT)
Debanshu Ratha	M	EU Horizon 2020/Extreme Earth	04/2021 – 12/2021	Polarimetric analyses of sea ice properties	Torbjørn Eltoft (UiT)
Qiang Wang	M	EU Horizon 2020/Extreme Earth	05/2021 – 12/2021	Deep learning algorithms for sea ice classification	Torbjørn Eltoft (UiT)
Rolf Ole Rydeng Jenssen	M	NORCE	From May 2021	Drone-based sensors	Svein Jacobsen (NORCE)
Johannes Lohse	M	ESA ROSE-L	11/2020 – 07/2021	Combining C- and L-band images for operational ice charting	Wolfgang Dierking (UiT/AWI)

PhD candidates who have completed with financial support from the centre budget (9)

Name	M/F	Scientific area	Years/period in the centre	Thesis title	Main thesis advisor
Martine Espeseth	F	Oil Spill Remote Sensing	11/2015 – 11/2019	Analysis of Oil Spill and Sea Ice Measurements Using Full-Polarimetric and Hybrid-Polarity Synthetic Aperture Radar data	Camilla Brekke (UiT)
Sindre M. Fritzner	M	Drift modelling and prediction	01/2016 – 12/2019	On sea-ice forecasting	Rune Graversen (UiT)
Richard Hann	M	RPAS Technology, Icing	07/2016 – 08/2019	Atmospheric Ice Accretions, Aerodynamic Icing Penalties, and Ice Protection Systems on Unmanned Aerial Vehicles	Tor Arne Johansen (NTNU)
Cornelius Quigley	M	Oil Spill Remote Sensing	09/2017 – 12/2020	Determination of the Dielectric Properties of Marine Surface Slicks Using Synthetic Aperture Radar	Camilla Brekke (UiT)
Johannes Lohse	M	Monitoring Sea Ice and Icebergs	01/2016 – 04/2020	On Automated Classification of Sea Ice Types in SAR Imagery	Wolfgang Dierking (UiT/AWI)
Rolf-Ole Rydeng Jenssen	M	RPAS Technology	04/2017 – 04/2021	Radar System Development for Drone Borne Applications with Focus on Snowpack Parameters	Svein Jacobsson (UiT)
Megan O`Sadnick	F	Oil Spill Remote Sensing	08/2017 – 07/2021	Ice in Norwegian subarctic fjords and coastal regions	Christian Petrich (SINTEF)
Salman Khaleghian	M	Deep learning architectures for sea ice characterization	01/2019 – 12/2019 and 01/2022 – 06/2022	Scalable computing for earth observation – Application on Sea Ice analysis	Andrea Marinoni (UiT)
Eduard Khachatrian	M	Monitoring Sea Ice and Icebergs	02/2019 – 03/2022 and 10/2022 – 07/2023	Multimodal Integrated Remote Sensing for Arctic Sea Ice Monitoring	Andrea Marinoni (UiT)

PhD students with financial support from the centre budget who still are in the process of completing their studies (5)

Name	M/F	Scientific area	Years in the centre	Main thesis Advisor
Mathias Tollinger	M	Using Synthetic Aperture Radar (SAR) to improve prediction of Polar Lows	05/2019 - 04/2023	Rune Graversen
Laust Færch	M	Monitoring Sea Ice and Icebergs	01/2021 – 06/2024	Wolfgang Dierking/ Anthony Doulgeris
Anna Telegina	F	Monitoring Sea Ice and Icebergs	02/2021 – 02/2024	Wolfgang Dierking/ Anthony Doulgeris
Silje C. Iversen	F	Drift modelling and prediction	09/2020 – 10/2024	Ann Kristin Sperrevik
Victor de Aguiar	M	Oil Spill Remote Sensing and Modelling	08/2021 – 07/2024	Malin Johansson

PhD candidates with financial support from the centre budget, uncompleted thesis (6)

Name	M/F	Scientific area	Years/period in the centre	Main thesis advisor
Sophie Anna Loreen Kuehnlenz	F	Monitoring Sea Ice and Icebergs	09/2029-09/2020	Wolfgang Dierking (UiT/AWI)
Alberto Arienzo	M	Oil Spill Remote Sensing	01/2016 – 04/2017	Torbjørn Eltoft (UiT)
Vegard Nilsen	M	Ocean Remote Sensing	01/2016 – 10/2019	Harald Johnsen (NORCE)
Runa Skarbø	F	Drift modelling and prediction	10/2015 – 09/2018	Sveinung Løset (NTNU)
Marianne Myrnes	F	Oil Spill Remote Sensing	03/2017 – 04/2020	Camilla Brekke (UiT)
Ingri Halland Soldal	F	Monitoring Sea Ice and Icebergs	07/2016 – 04/2020	Wolfgang Dierking (UiT/AWI)

PhD candidates who have completed with other financial support, but associated with the centre (6)

Name	M/F	Funding	Scientific area	Years in the centre	Thesis title	Main thesis Advisor
Katalin Blix	F	UiT	Ocean Colour Remote Sensing	07/2016 – 09/2019	Machine Learning Water Quality Monitoring	Torbjørn Eltoft (UiT)
Artem Moiseev	M	NERSC	Ocean Remote Sensing	2018 – 2021	Ocean surface currents derived from Sentinel-1 SAR Doppler shift measurements	Johnny A. Johannessen (UiB)
Muhammad Asim	M	The Nansen Legacy	Ocean Colour Remote Sensing	02/2018 – 03/2023	Model for Artificial Neural Networks (ANNs) to estimate Chlorophyll-a (Chl-a) in the Barents Sea	Katalin Blix (UiT)
Salman Khaleghian	M	EU H2020 (Extreme Earth)	Deep learning architectures for sea ice characterization	01/2020 – 12/2021	Scalable computing for earth observation – Application on Sea Ice analysis	Andrea Marinoni (UiT)
Temesgen Yitayew	M	UiT	SAR Sea Ice Remote Sensing	Until 2018	Investigation of Sea Ice Using Single and Multiple Synthetic Aperture Radar Acquisitions	Torbjørn Eltoft (UiT)
Jakob Grahn	M	UiT	SAR Sea Ice Remote Sensing	Until 2018	Multi-frequency radar remote sensing of sea ice	Camilla Brekke (UiT)

PhD candidates who have other financial support, but associated with the centre, and are in the process of completing their studies (2)

Name	M/F	Funding	Years in the centre	Thesis topic	Main thesis Advisor
Josef Ruzin	M	SIRANO	10/2020 – 09/2023	Merging passive microwave and SAR for sea ice concentration products	Thomas Laverne (MET)
Henrik Fisser	M	RareIce	09/2022 – 09/2025	Sea ice and icebergs in the Barents Sea	Anthony Doulgeris (UiT)

MSc candidates with thesis related to the centre research agenda and an advisor from the centre. Supervision for the master students was provided by CIRFA members/UiT unless noted differently.

Name	M/F	Time in the centre	Thesis title	Main thesis advisor
Martine Mostervik Espeseth	F	2015	A Review of Compact Polarimetry for Synthetic Aperture Radars	Stian Anfinsen, Camilla Brekke
Marianne Myrnes	F	2015	Ship detection products based on complex SAR data in TOPS mode	Stian Anfinsen, Camilla Brekke, Lars Petter Gjøvik
Tina Eliassen Nyhlen	F	2015	Fast Estimation of Ocean Background Reflectivity in Synthetic Aperture Radar Images	Stian Anfinsen, Camilla Brekke, Lars Petter Gjøvik
Johannes Arctander Larsen	M	2016	Useful GPGPU Programming Abstractions. A thorough analysis of GPGPU development frameworks	Anthony Doulgeris
Audun Leonard Høifødt	M	2016	Oil Spill Analysis Using Hybrid-Polarization Synthetic Aperture Radar	Camilla Brekke, Stine Skruenes
Arja Beate Kvamme	F	2017	A classification Strategy for Multi-Sensor Remote Sensing Data	Anthony Doulgeris, Torbjørn Eltoft
Jonas Toennis	M	2017	Spectral measurement improvement through optical tree delineation	Anthony Doulgeris
Kai Magne Kaspersen	M	2017	Marine radar properties, analysis and applications	Anthony Doulgeris
Cornelius Quigley	M	2017	A comparison between optical and SAR classification results for thin sea ice in Storfjorden	Anthony Doulgeris
Stefano Anzilotti	M	2017	Speckle filtering of Polarimetric SAR data	Torbjørn Eltoft
Magnus Wilhelmsen	M	2018	Classification of Marine Oil Spills and Look-alikes in Sentinel-1 TOPSAR and Radarsat-2 ScanSAR Images	Camilla Brekke, Stine Skruenes
Vebjørn Karisari	M	2018	A Sensitivity Study of L-Band SAR Measurements of the Internal Variations and Evolving Nature of Oil Slicks	Camilla Brekke, Martine Espeseth
Magnus Hvidsten	M	2018	Comparing sea ice areas identified within quad-polarimetry high-resolution SAR satellite scenes with the same areas in dual-polarimetry medium resolution SAR scenes	Camilla Brekke, Malin Johansson
Stein Cato Lindberg	M	2018	SAR imaging and detection of partially coherent targets	Torbjørn Eltoft, Thomas Kræmer
Ole Baadshaug	M	2018	Iceberg Drift-Trajectory Modelling and Probability Distributions of the Predictions	Torbjørn Eltoft
Jon Anders Hallaråke	M	2018	Incidence Angle dependency in SAR	Anthony Doulgeris, Andrea Marinoni
Torbjørn Tveito	M	2019	6-meter wavelength polarimetric inverse synthetic aperture radar mapping of the Moon	Anthony Doulgeris
Øystein Fredriksen Skogvold	M	2019	Arctic Thin Sea Ice Thickness Regression Models for Sentinel-2	Anthony Doulgeris
Åshild Kiærbech	F	2019	An investigation of the robustness of distance measure-based supervised labelling of segmented remote sensing images	Anthony Doulgeris
Joakim Lillehaug Pedersen	M	2019	Comparison of the Ice Watch Database and Sea Ice Classification from Sentinel-1 Imagery	Anthony Doulgeris
Sandra Susann Solheim Nesse	F	2019	Remote Sensing of Coastal Waters	Torbjørn Eltoft
August Krokan	M	2019	Ice-water Classification in the Barents Sea from Sentinel-1 EW SLC Images	Torbjørn Eltoft

Daniel Norum Danielsen	M	2019	Target Decomposition of Quad-Polarimetric SAR Images as an Unmixing Problem	Torbjørn Eltoft, Andrea Marinoni
Jarle Langseth Pedersen	M	2019	Automatic validation of Sentinel-1 borne snow avalanche detections	Anthony Doulgeris
Andreas Hansen Asbjørnslett	M	2020	Analysis of the potential of the Ku-band Gamma Portable Radar Interferometer for sea ice information extraction	Torbjørn Eltoft
Martin Bengsli	M	2021	Automatic snow layer detection in drone-borne radar data using edge detection and morphology	Anthony Doulgeris, Rolf-Ole Rydeng Jenssen
Ida Graabræck Kinderås	F	2021	Sea ice and polarimetry	Malin Johansson, Torbjørn Eltoft
Brynjar Andersen Saus	M	2021	Detection and Delineation of Produced Water Slicks in Sentinel-1 Synthetic Aperture Radar Images	Malin Johansson, Anthony Doulgeris
Truls Thorsen Karlsen	M	2021	Measuring velocities of a surge type glacier with SAR interferometry using ALOS-2 data	Malin Johansson, Geir Moholt, Jelte van Ostveen
Tora Båtvik	F	2021	Detection of Marine Plastic Debris in the North Pacific Ocean using Optical Satellite Imagery	Anthony Doulgeris
Torjus Nilsen	M	2021	Semisupervised learning of sea ice characteristics in multimodal remote sensing data	Andrea Marinoni
Catherine Taelman	F	2021	Feature selection using deep spectral clustering for remote sensing applications	Andrea Marinoni
Martijn Clemenkowff	M	2022	Estimation of snow density from a drone-mounted ultra-wideband radar	Anthony Doulgeris, Rolf-Ole Rydeng Jenssen
Silje Birgitte Segrem Grue	F	2022	Machine Learning for Classifying Marine Vegetation from Hyperspectral Drone Data in the Norwegian coast	Katalin Blix
Mathilde Lyford Jahnsen	F	2022	Naturally occurring seepages in the Barents Sea	Malin Johansson, Anders Schomacker
Sander Hindernes	M	2023	Can bottom trawling cause oil seepages?	Malin Johansson
Martin Hagerup Evenseth	M	2023	Oil spill classification using machine learning on optical satellite data	Katalin Blix, Martine Espeseth, Hugo Isaksen
Mateusz Matuszak (MET Oslo)	M	2023	Lagrangian Coherent Structures in an ocean ensemble prediction system	Johannes Röhrs (MET), Martina Idzanovic (MET), P.E. Isachsen (UiO)
Julie Sortland	F	2023	Seasonal variability in hydrography & currents along the Nansen Legacy transect across the Barents Sea	Angelika Renner (IMR), Polona Itkin
Anna Odh	F	2024	Influence of tidal and air pressure on the ice shelf grounding line in the Fimbul ice shelf, Antarctica	Malin Johansson, Jelte van Oostveen
Johanna Mankova Buseth	F	2024	On the use of satellite images to measure methane gas releases	Malin Johansson
Thibault Desjonquères	M	2024	Sea ice drift and wave motion measured using SAR and drift buoys from the Art of melt cruise 2023	Malin Johansson

International master students with projects related to the centre research agenda and an advisor from the centre staff (12)

Name	M/F	Nationality	Exchange program	Time in the centre	Thesis title	Main advisor
Dashika Manral	F	India	Erasmus+	2015	Assessing sensitivity of oil spill drift modeling	Camilla Brekke
Catherine Taelman	F	Be		2020	Label propagation algorithm for multimodal remote sensing data	Andrea Marinoni
Marine Mercier	F	Fr		2020	Geometric deep learning for remote sensing	Andrea Marinoni
Quitterie Chambon	F	Fr		2020	Detection algorithms present in airborne and satellite radars	Andrea Marinoni
Lotte Wendt	F	Ger	Erasmus	2020	SAR physics and statistics, as well as polarimetry and applications in sea ice mapping	Anthony Doulgeris, Wolfgang Dierking
Sam Cremers	M	NL	Erasmus Internship	2021	Scalable semisuperivised graph-based data analysis of multimodal remote sensing records	Andrea Marinoni
Pigi Lozou	F	Greece	Erasmus Internship	2021/ 2022	Gaussian processes and variational autoencoder for multimodal remote sensing data analysis and sea ice characterization	Andrea Marinoni, Saloa Claily
Morgane Batelier	F	Fr	Erasmus Internship	2022	Developing an architecture of a transductive learning approach for sea ice characterization and oil spill classification	Andrea Marinoni, Saloa Claily
Janina Osanen	F	FIN	Paid Internship	2022	CIRFA cruise ice core analysis	Polona Itkin
Clément Théo Alexandre Stouls	M	Fr	Paid Internship	2023	Workflow implementation for deep-learning classification of SAR sea ice imagery	Anthony Doulgeris, Johannes Lohse
Sree Ram Radha Krishnan	M	I	Erasmus+ Internship	2023	Land-based IA segmentation	Anthony Doulgeris
Chamika Nethmalie	F	Sri Lanka	UiT-Sri Lanka agreement	2023	Detection of marine oil spills using SAR over the economical zone of Sri Lanka	Jorge Santos, Cornelius Quigley
Cora Hoppe	F	France	Erasmus Internship	2023	Sea ice type separation using S- and L-band Synthetic Aperture Radar (SAR) - A NISAR prestudy	Malin Johansson

Publication list

PhD theses

Eduard Khachatrian (2023) Multimodal Integrated Remote Sensing for Arctic Sea Ice Monitoring. https://hdl.handle.net/10037/29338

Muhammad Asim (2023) Optical remote sensing of water quality parameters retrieval in the Barents Sea. https://hdl.handle.net/10037/28787

Megan O`Sadnick (2022) Ice in Norwegian subarctic fjords and coastal regions: An examination of ice formation, properties, and trends based on remote sensing and in situ data. https://hdl.handle.net/10037/26462

Salman Khaleghian (2022) Scalable computing for earth observation - Application on Sea Ice analysis. https://hdl.handle.net/10037/27513

Artem Moiseev (2021) Ocean surface currents derived from Sentinel-1 SAR Doppler shift measurements. https://app.cristin.no/results/show.jsf?id=2016077

Rolf-Ole Rydeng Jenssen (2021) Radar System Development for Drone Borne Applications with Focus on Snowpack Parameters. https://hdl.handle.net/10037/21043

Johannes Lohse (2021) On Automated Classification of Sea Ice Types in SAR Imagery. https://hdl.handle.net/10037/20606

Cornelius Quigley (2021) Determination of the Dielectric Properties of Marine Surface Slicks Using Synthetic Aperture Radar. https://hdl.handle.net/10037/20597

Richard Hann (2020) Atmospheric Ice Accretions, Aerodynamic Icing Penalties, and Ice Protection Systems on Unmanned Aerial Vehicles. https://hdl.handle.net/11250/2657638

Sindre Markus Fritzner (2020) On sea-ice forecasting. https://hdl.handle.net/10037/18141

Katalin Blix (2019) Machine Learning Water Quality Monitoring. https://hdl.handle.net/10037/16502

Martine Espeseth (2019) Analysis of Oil Spill and Sea Ice Measurements Using Full-Polarimetric and Hybrid-Polarity Synthetic Aperture Radar data. https://hdl.handle.net/10037/16973

Temesgen Yitayew (2018) Investigation of Sea Ice Using Single and Multiple Synthetic Aperture Radar Acquisitions. https://hdl.handle.net/10037/12244

Jakob Grahn (2018) Multi-frequency radar remote sensing of sea ice. Modelling and interpretation of polarimetric multi-frequency radar signatures of sea ice. https://hdl.handle.net/10037/13373

2015

Peer-reviewed publications

Espeseth, M.M., Brekke, C., Anfinsen, S.N. (2016) *Hybrid-Polarity and Reconstruction Methods for Sea Ice with L- and C-band SAR.* IEEE Geoscience and Remote Sensing Letters, 13 (3). March 2016. DOI: 10.1109/LGRS.2016.2519824.

Other publications

Akbari, V., Anfinsen, S.N., Doulgeris, A.P., Eltoft, T. (2015) *A Change Detector for Polarimetric SAR Data Based on the Relaxed Wishart Distribution.* IGARSS Milan, Italy, 26-31 July 2015.

Brekke, C. (2015) *Joint UiT/JPL/NASA oil spill campaign: first impressions.* SOLab workshop "Remote Sensing and Modelling of the Atmospheric-Ocean System", 22-24 June 2015.

Doulgeris, A.P., Eltoft, T. (2015) *Aspects of model-based decompositions in radar polarimetry.* IGARSS Milan, Italy, 26-31 July 2015.

Eltoft, T., Doulgeris, A.P., Brekke, C., Solbø, S., Gerland, S., Hanssen, A. (2015) *Imaging Sea Ice Structure by Remote Sensing Sensors.* Proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions 2015.

Eltoft, T. (2015) *Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA).* Oljeindustriens Miljø & Teknologikonferanse, 2015.

Eltoft, T., Johansson, M. (2015) *Monitoring Sea Ice with Space-borne Synthetic Aperture Radar.* ALOS-2 Symposium, Akihabara, Tokyo, Japan, 17 Nov, 2015.

Eltoft, T. (2015) *Remote Sensing - hvordan kan fjernanalyse bidra til å løse utfordringer i nordområdene.* Arctic Safety Summit 2015.

Eltoft, T. (2015) *CIRFA: Radar remote sensing of Arctic sea ice.* SOLab workshop, St. Petersburg, Russia, 22-24 June 2015.

Eltoft, T., Brekke, C., Skrunes, S. (2015) *Centre for Integrated Remote Sensing and Forecasting for Arctic Operations (CIRFA): Oil Spill Detection and Characterization.* Interspill 2015, Amsterdam, Netherlands, 2015.

Eltoft, T., Doulgeris, A.P., Brekke, C., et al. (2015) *Imaging sea ice structure by remote sensing sensors.* POAC Trondheim, Norway, 14-18 June 2015.

Eltoft, T., Grahn, J., Doulgeris, A.P., et al. (2015) *A first analysis of polarimetric Arctic sea ice scenes from PALSAR-2.* ALOS-2 2nd PI Workshop, 2015.

Fors, A.S., **Doulgeris, A.P.**, Renner, A.H.H., et al. (2015) *On the relation between polarimetric synthetic aperture radar (SAR) features and sea ice melt pond fraction.* IGARSS Milan, Italy, 26-31 July 2015.

Gerland, S., Spreen, G., Granskog, M., et al. (2015) *Seasonal Changes of Arctic Sea Ice Physical Properties Observed During N-ICE2015: An Overview.* Fall Meeting of the American Geophysical Union, San Francisco, USA, December 2015.

Hu, D., **Doulgeris, A.P.**, Qiu, X. (2015) *An unsupervised method for equivalent number of looks estimation in complex SAR scenes.* IGARSS Milan, Italy, 26-31 July 2015.

Johansson, M, Brekke, C., Spreen, G., King, J. (2015) *Newly formed sea ice in Fram Strait leads monitored by X-, C- and L-band SAR.* ALOS-2 Symposium, Akihabara, Tokyo, Japan, 17 Nov 2015.

Johnsen, H. (2015) *Sentinel-1A Ocean Data - experiences, challenges, opportunities.* SOLab workshop, St. Petersburg, Russia, 22-24 June 2015.

Johnsen, H. (2015) *Ocean Currents and Sentinel 1.* Ocean Current Workshop, IFREMER, Brest, Germany, 2-3 Nov 2015.

Petrich, C. (2015) *ColdTech and oil in ice in Narvik.* Nordområdekonferansen 2015, Narvik, 17 Nov 2015.

Skrunes, S., Jones, C.E., Holt, B., Brekke, C. (2015) *Norwegian Oil-on-Water Exercise Campaign for Development of a Multi-Frequency SAR Slick Characterization Capability.* IGARSS Milan, Italy, 26-31July 2015.

Storvold, R. et al. (2015) *Arctic Science Remotely Piloted Aircraft Systems (RPAS) Operator's Handbook.* AMAP Oslo. http://hdl.handle.net/11374/1530.

2016

Peer-reviewed publications

Brekke, C., Jones, C. E., Skrunes, S., Holt, B., **Espeseth, M.M., Eltoft, T.** (2016) *Cross-Correlation Between Polarization Channels in SAR Imagery Over Oceanographic Features,* IEEE Geoscience and Remote Sensing Letters, 13 (7), 997-1001. DOI: 10.1109/LGRS.2016.2558543.

Eltoft, T. (2015) *Monitoring sea ice with space-borne synthetic aperture radar.* JAXA seminar 15 November 2015.

Espeseth, M.M., Brekke, C., Anfinsen, S.N. (2016) *Hybrid-Polarity and Reconstruction Methods for Sea Ice with L- and C-band SAR.* IEEE Geoscience and Remote Sensing Letters, 13 (3), 467-471. DOI: 10.1109/LGRS.2016.2519824.

Fors, A.S., **Brekke, C., Doulgeris, A.P., Eltoft, T.**, Renner, A., **Gerland, S.** (2016) *Late-summer sea ice segmentation with multi-polarisation SAR features in C and X band.* The Cryosphere, 10 (1), 401-415. DOI: 10.5194/tc-10-401-2016.

Fors, A.S., **Brekke, C., Gerland, S., Doulgeris, A.P.**, Beckers, J.F. (2016) *Late Summer Arctic Sea Ice Surface Roughness Signatures in C-band SAR Data.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 9 (3), 1199-1215. DOI: 10.1109/JSTARS.2015.2504384.

Hollands, T., Dierking, W. (2016) *Dynamics of the Terra Nova Bay Polynya: The potential of multi-sensor satellite observations.* Remote Sensing of Environment, 187 (2016), 30–48. DOI: 10.1016/j.rse.2016.10.003.

Jones, C., Dagestad, K.-F., Breivik, Ø., Holt, B., **Röhrs, J., Christensen, K., Espeseth, M., Brekke, C., Skrunes, S.** (2016) *Measurement and Modeling of Oil Slick Transport.* Journal of Geophysical Research – Oceans. 121 (10), 7759-7775. DOI: 10.1002/2016JC012113.

Marino, A., **Dierking, W.**, Wesche, C. (2016) *A Depolarization Ratio Anomaly Detector to Identify Icebergs in Sea Ice Using Dual-Polarization SAR Images,* IEEE Transactions on Geoscience and Remote Sensing, 54 (9), 5602-5615 . DOI: 10.1109/TGRS.2016.2569450.

Skrunes, S., Brekke, C., Jones, C., Holt, B. (2016) *A Multisensor Comparison of Experimental Oil Spills in Polarimetric SAR for High Wind Conditions,* Journal of Selected Topics in Applied Earth Observation and Remote Sensing, 9 (11), 4948-4961. DOI: 10.1109/JSTARS.2016.2565063.

Other publications

Akbari, V., Brekke, C., Doulgeris, A.P., Storvold, R., Sivertsen, A. (2016) *Quad-Polarimetric SAR for Detection and Characterization of Icebergs.* Paper and talk (# 731). Living Planet Symposium, Prague, Czech Republic, May 2016.

Blix, K., Eltoft, T. (2016) *Ocean Color Remote Sensing of the Marginal Ice Zone in the Arctic.* Poster presentation at The Colour and Light in the Ocean from Earth Observation (CLEO) conference, Frascati, Italy, 6-8 September 2016.

Brekke, C., Jones, C.E., Breivik, Ø., **Skrunes, S.**, Holt, B., **Christensen, K.** (2016) *NORSE2015 – Characterizing Experimental Oil Spills by Multi-polarization Synthetic Aperture Radar.* Poster (#1400). Living Planet Symposium, Prague, Czech Republic, May 2016.

Dierking, W. et al. (2016) *Selected European Studies On Sea Ice Classification And Drift Retrieval As Basis For Collaborative Projects During Dragon 4, Dragon 3 Final Results & Dragon 4 Kick-Off Symposium, Wuhan,* China, 4 July 2016 – 8 July 2016.

Eltoft, T. (2016) *Integrated Remote Sensing in Arctic operational services.* Break out session: Maritime Arctic Services, Arctic Circle Assembly, Reykjavik.

Eltoft, T., Brekke, C., Johnsen, H., Storvold, R., Gerland, S., Dierking, W., Pedersen, J. P. (2016) *CIRFA – Centre for Integrated Remote Sensing and Forecasting for Arctic Operations, a new Centre for Research-based innovation hosted by UiT-the Arctic University of Norway.* White paper. Arctic Observing Summit 2016, Fairbanks, AK, USA, March 2016. 7 pages.

Espeseth, M.M., Skrunes, S., Brekke, C., Salberg, A.-B., **Jones, C.E.** (2016) *Oil spill characterization in the hybrid-polarity SAR domain using log-cumulants.* Presentation 10004-42 at SPIE Remote Sensing, 26-28 September, Edinburgh, U.K.

Gerland, S. et al. (2016) *Seasonal thickness changes of Arctic sea ice north of Svalbard and implications for satellite remote sensing, ecosystem, and environmental management.* AGU Fall Meeting 12 – 16 December 2016.

Hansen, E., Borge, J., Høyland, K.V. (2016) *Effects of the observational footprint on the ice thickness distribution.* 23rd IAHR International Symposium on Ice Ann Arbor, Michigan USA, May 31 - June 3, 2016.

Johansson, M., Brekke, C., Spreen, G., King, J.A., **Gerland, S.** (2016) *Newly Formed Sea Ice in Arctic Leads Monitored by Cand L-Band SAR.* Paper and talk (#1932). Living Planet Symposium, Prague, Czech Republic, May 2016.

Johansson, A.M., Singha, S., King, J., **Doulgeris, A.P., Gerland, S.**, Spreen, G., Ressel, R., Busche, T. (2016) *Investigating Monostatic TS-X DRA acquisitions and Near-coincident C and L– band Fully Polarimetric SAR for Arctic Sea Ice Characterization.* TSM/TDM science team meeting 2016.

Johnsen, H., Nilsen, V., Engen, G., Mouche, A., Collard, F. (2016) *Ocean Doppler Anomaly and Ocean Surface Current from Sentinel 1 Tops Mode.* Paper and talk (#2972). IGARSS Beijing, China, 10-15 July 2016.

Jones, C.E., Brekke, C., Breivik, Ø., Holt, B., **Skrunes, S., Espeseth, M.** (2016) *NORSE2015 - A Focused Experiment On Oil Emulsion Characterization Using PolSAR During the 2015 Norwegian Oil-On-Water Exercise.* AGU Oceans February 2016.

Jones, C.E., Espeseth, M.M., Holt, B.M., **Brekke, C. Skrunes, S.** (2016) *Characterization and discrimination of evolving mineral and plant oil slicks based on L-band synthetic aperture radar (SAR).* SPIE Remote Sensing, 26-28 September, Edinburgh, U.K.

Lauknes et al. (2016) *High-Resolution Mapping of Sea Ice, Icebergs and Growlers in Kongsfjorden, Svalbard, using Ground Based Radar, Satellite, and UAV.* Poster presentation at AGU Fall Meeting 2016, San Francisco, USA, December 2016.

Meyer et al. (2016) *@OceanSeaIceNPI: Positive Practice of Science Outreach via Social Media.* Oral presentation at AGU Fall Meeting 2016, San Francisco, USA, December 2016.

Negrel, J. et al. (2016) *Observing Arctic fjord ice from in situ to satellite. Examples of the Kongsfjorden 2016 spring campaign.* Poster presentation at the Nordic Branch Meeting of the International Glaciological Society. Tromsø, Norway.

Negrel, J., et al. (2016) *In situ validation of segmented SAR satellite scenes of young Arctic thin landfast sea ice.* Poster presentation at AGU Fall Meeting 2016, San Francisco, USA, December 2016.

Rösel, A., King, J., **Gerland, S., Wagner, P.M., Doulgeris, A.P.** (2016) *Sea ice and snow in the Arctic Ocean north of Svalbard during N-ICE2015.* Poster (#1850). Living Planet Symposium, Prague, Czech Republic, May 2016.

Skrunes, S., Jones, C.E., Brekke, C., Holt, B., **Espeseth, M.M.** (2016) *On the Effect of Imaging Geometry on Multipolarization SAR Features for Oil Spill Observation.* Paper and talk (# 1439). Living Planet Symposium, Prague, Czech Republic, May 2016.

Skrunes, S., Brekke, C., Eltoft, T. (2016) *The Applicability of TerraSAR-X Dual-Polarization Data for Oil Spill Observation.* TerraSAR-X/TanDEM-X Science Team Meeting 2016; 17 - 20 October 2016.

2017

Peer-reviewed publications

Akbari V., Brekke, C. (2017) *Iceberg detection in open and ice-infested waters using C-band polarimetric synthetic aperture radar,* IEEE Trans. Geosci. Remote Sens., 5 (12), 1-15, 2017. DOI: 10.1109/TGRS.2017.2748394.

Assmy, P. et al. (2017) *Leads in Arctic pack ice enable early phytoplankton blooms below snow-covered sea ice.* Scientific Reports 7, Article number: 40850 (2017) DOI: 10.1038/srep40850

Dierking, W., Lang, O., Busche, T. (2017) *Sea ice local surface topography from single-pass satellite InSAR measurements: a feasibility study.* The Cryosphere, 11, 1967-1985. doi: 10.5194/tc-2017-40.

Espeseth, M. M., Brekke, C., Johansson, A.M. (2017) *Assessment of RISAT-1 and Radarsat-2 for sea ice observations from a hybrid-polarity perspective.* Remote Sensing, 2017, 9(11), 1088; doi: 10.3390/rs9111088.

Espeseth, M.M., Skrunes, S., Jones, C.E., Brekke, C., Holt, B., **Doulgeris A.P.** (2017) *Analysis of Evolving Oil Spills in Full-Polarimetric and Hybrid-Polarity SAR.* IEEE Transactions on Geoscience and Remote Sensing. pp. 1-21. doi: 10.1109/TGRS.2017.2690001.

Griebel, J., **Dierking, W.** (2017) *A Method to Improve High-Resolution Sea Ice Drift Retrievals in the Presence of Deformation Zones.* Remote Sensing 2017, 9, 718. doi:10.3390/rs9070718.

Johansson, M., Brekke, C., Spreen, G., King, J. (2017) *X-, C-, and L-band SAR signatures of newly formed sea ice in Arctic leads during winter and spring.* Remote Sensing of Environment. Remote Sensing of Environment, Vol 204, pages 162-180, year 2018. doi: 10.1016/j.rse.2017.10.032

Johansson, M., King, J., Doulgeris, A.P., Gerland, S., Singha, S., Spreen, G., Busche, T. (2017) *Combined observations of Arctic sea ice with near-coincident co-located X-band, C-band, and L-band SAR satellite remote sensing and helicopter-borne measurements.* Journal of Geophysical Research – Oceans 2016; Volume 122. ISSN 2169-9275.s DOI: 10.1002/2016JC012273.

Kræmer, T., Johnsen, H., Brekke, C., Engen, G. (2017) *Comparing SAR based short time-lag cross-correlation and Doppler derived sea ice drift velocities.* IEEE Transactions on Geoscience and Remote Sensing 56(4),1898-1908. doi: 10.1109/TGRS.2017.2769222.

Linow, S., **Dierking, W.** (2017) *Object-Based Detection of Linear Kinematic Features in Sea Ice.* Remote Sensing 2017, 9(5), 493. DOI: 10.3390/rs9050493.

Rösel, A., King, J., **Doulgeris, A.P.**, Wagner, P., **Johansson, A.M., Gerland, S.** (2017) *Can we extend local sea-ice measurements to satellite scale? An example from the N-ICE2015 expedition.* Annals of Glaciology 59 (76) pp. 163-172. doi. org/10.1017/aog.2017.37.

Saïd, F., **Johnsen, H.**, Nouguier, F., Engen, G., Chapron, B. (2017) *Onto a skewness approach to the generalized curvature ocean surface scattering model.* IEEE Transactions on Geoscience and Remote Sensing; 55 (10) s.5843-5853. doi: 10.1109/TGRS.2017.2715986.

Sperrevik, A.K., Röhrs, J., Christensen, K.H. (2017) *Impact of data assimilation on Eulerian versus Lagrangian estimates of upper ocean transport.* J. Geophys. Res. Oceans, 122,doi: 10.1002/2016JC012640.

Staneva, J., Alari, V., Breivik, Ø., Bidlot, R., Mogensen, K. (2017) *Effects of wave-induced forcing on a circulation model of the North Sea.* Ocean Dynamics (2017) 67: 81. DOI: 10.1007/s10236-016-1009-0.

Yitayew, T.G., Ferro-Famil, L., Eltoft, T., Tebaldini, S. (2017) *Lake and Fjord Ice Imaging Using a Multifrequency Ground-Based Tomographic SAR System.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (Volume: PP, Issue: 99). Page(s): 1 – 12. DOI: 10.1109/JSTARS.2017.2718998.

Yitayew, T.G., Ferro-Famil, L., Eltoft, T., Tebaldini, S. (2017) *Tomographic Imaging of Fjord Ice Using a Very High Resolution Ground-Based SAR System.* IEEE Transactions on Geoscience and Remote Sensing 55 (2). DOI: 10.1109/TGRS.2016.2613900.

Other publications

Akbari, V., Brekke, C., Johansson, M. (2017) *Iceberg Detection in Open Water and Sea Ice using C-Band Radar Polarimetry.* Oral presentation at 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS2017), Fort Worth, Texas, USA, July 23-28, 2017.

Arienzo, A., Eltoft, T. (2017) *Investigations of polarimetric surface scattering models for oceanic slick characterization.* POLinSAR 2017 Workshop, 23-27 January, ESA-ESRIN, Frascati, Italy.

Blix, K., Eltoft, T. (2017) *Monitoring primary productivity through Chlorophyll-a content estimation in the Arctic.* Poster presentations at the Arctic Frontiers 2017, White Space – Blue Future, Tromso, Norway, 22-27 January, 2017.

Blix, K., Eltoft, T. (2017) *An alternative Chl-a content retrieval algorithm for MERIS/ OLCI.* Sentinel 3 Validation Team Meeting; 2017-02-15 – 2017-02-17.

Boccia, V., De Witte, E., Roselló, J., Tossaint, M., Donlon, C.J., Scipal, K., Burbidge, G., **Johnsen, H., Engen, G.** (2017) *A multi-static SAR mission concept enhancing Sentinel-1 capability in surface current dynamics retrieval.* SPIE Remote Sensing 2017, 11-14 Sep., Warsaw, Poland.

Brekke, C., Skrunes, S., Espeseth, M. (2017) *Oil spill dispersion in full-polarimetric and hybrid-polarity SAR.* Oral presentation at 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS2017), Fort Worth, Texas, USA, July 23-28, 2017.

Brekke, C. (2017) *CIRFA Centre for Integrated Remote Sensing and Forecasting for Arctic Operation.* Presentation for EASAC – the European Academies' Science Advisory Council, 2. February 2017.

Brekke, C. (2017) *Fjernmaling og modellering av oljesol – pa apen sjo og i is.* Oral presentation at Beredskapsforum, Oslo, 4 April.

Cristea, A.; Doulgeris, A.P.; Eltoft, T. (2017) *A filtering framework for SAR data based on non-Gaussian statistics and pixel clustering.* SPIE Remote Sensing 2017; 2017-09-11 – 2017-09-14.

Dierking, W. (2017) *Using Interferometric SAR for Retrieval of Sea Ice Topography.* 18th Meeting of the International Ice Charting Working Group (IICWG), September 25-29, 2017 – Hobart, Tasmania, Australia.

Dierking, W. (2017) *Dragon Sea Ice Remote Sensing – Preparation of Future Activities.* Presentation at the ESA-MOST Dragon 4 Symposium, June 24-30, 2017 – Copenhagen.

Doulgeris, A.P., Hu, D. (2017) *Speeding up non-gaussian polsar image analysis.* Oral presentation at 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS2017), Fort Worth, Texas, USA, July 23-28, 2017.

Doulgeris, A.P., Scambos, T., Tiampo, K. (2017) *Arctic Sea Ice Structure and Texture over Four Decades Using Landsat Archive Data.* AGU Fall Meeting; 11-15 December 2017.

Eltoft, T. (2017) *Integrated Remote Sensing for environmental monitoring in Arctic operations.* Arctic Science Week; 12-15 December 2017.

Espeseth, M.M., Brekke, C., Johansson, A.M. (2017) *Real and Simulated Hybrid-Polarity Versus Full-Polarimetric Sar Data For Sea Ice Observation.* POLinSAR 2017 Workshop, 23-27 January, ESA-ESRIN, Frascati, Italy.

Gerland, S. (2017) *Physical processes of Arctic sea ice: Plans within the MOSAiC project, with emphasis on Norwegian partners.* Oral presentation at Arctic Frontiers 2017 side event on MOSAiC project. Tromso, Norway, January 2017.

Gerland, S., Divine, D., Doulgeris, A.P., Haas, C., Hendricks, S., **Hughes, N., Johansson, A.M.**, Kaleschke, L., King, J. **Negrel, J.**, Rösel, A., Spreen, G. (2017) *Possibilities and challenges with sea ice satellite product validation with in situ and airborne observations.* Oral presentation at Polar Ice, Polar Climate, Polar Change, Remote sensing and modeling advances in understanding the cryosphere. Boulder, Colorado, USA, 14–19 August 2017.

Gerland, S., M.A. Granskog, P. Assmy, P. Duarte, S.R. Hudson, **N. Hughes**, L.H. Smedsrud, G. Spreen, A. Sundfjord, and H. Steen (2017) *N-ICE2015: Observational study on drifting Arctic sea ice north of Svalbard from winter to summer.* International Conference on Arctic Science: Bringing Knowledge to Action. Reston, VA, USA, April 2017.

Gerland, S., M.A. Granskog, P. Assmy, P. Duarte, S.R. Hudson, **N. Hughes**, L.H. Smedsrud, G. Spreen, A. Sundfjord, and H. Steen (2017) *N-ICE2015: Observational study on drifting Arctic sea ice north of Svalbard from winter to summer.* Poster. Arctic Science Summit Week 2017, Science Conference, Prague, Czech Republic, April 2017.

Granskog, M., P. Assmy, P. Duarte, **S. Gerland**, S.R. Hudson, **N. Hughes**, L.H. Smedsrud, G. Spreen, A. Sundfjord, and H. Steen (2017) *N-ICE2015: Observational study on drifting Arctic sea ice north of Svalbard from winter to summer.* Poster. Arctic Science Summit Week 2017, MOSAiC Workshop, Prague, Czech Republic, April 2017.

Hann, R., Wenz, A.W., Gryte, K., **Johansen, T.A.** (2017) *Impact of Atmospheric Icing on UAV Aerodynamic Performance.* Workshop on Research, Education and Development of Unmanned Aerial Systems (RED-UAS), Linkoping, 2017. Sweden, 2017, pp. 66-71, doi: 10.1109/RED-UAS.2017.8101645.

Johansen, H. (2017) *Doppler Shift Retrievals from Sentinel – Status and Way Forward.* Oral presentation at Copernicus S-1 Quality Working Group Meeting, 10 – 11 May at ESRIN/ESA.

Johansson, M., Brekke, C., Spreen, G. (2017) *Multi-frequency polarimetric SAR signatures of lead sea ice and oil spills.* Poster presentation at 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS2017), Fort Worth, Texas, USA, July 23-28, 2017.

Johansson, M., Brekke, C., Spreen, G. (2017) *Sea ice lead identification using remote sensing.* Oral presentation, Arctic Frontiers Conference, Tromsø, Norway, January 2017.

Johnsen, H., Engen, G. (2017) *Doppler shifts retrieval from Sentinel 1 - Status and Way Forward.* GlobCurrent Workshop, 21-23 March 2017, ESA/ESRIN, Frascati, Italy, March 2017.

Negrel, J., Gerland, S., Doulgeris, A.P., Lauknes, T.R., Rouyet, L. (2017) *On the potential of GPS tracking of fjord ice features for remote-sensing validation.* Svalbard Science Conference; 2017- 11-06 – 2017-11-08.

Negrel, J., Gerland, S., Doulgeris, A.P., Lauknes, T.R., Rouyet, L. (2017) *On the potential of GPS tracking of fjord ice features for remote sensing validation.* Poster presentation at Polar Ice, Polar Climate, Polar Change, Remote sensing and modeling advances in understanding the cryosphere. Boulder, Colorado, USA, 14–19 August 2017.

Negrel J., Gerland S., Doulgeris A.P., Rösel A., **Akbari, V., Lohse J., Johansson A.M., Dierking W.** (2017) *In situ validation of remotely-sensed Arctic sea ice identification.* Poster, Arctic Frontiers Conference, Tromsø, Norway, January 2017.

Negrel, J., Wagner P.M., **Gerland, S., Doulgeris, A.P.**, Rösel A., King J.A., **Johansson A.M.**, Spreen G., **Hughes N.,** (2017) *Validation of quad-pol sea ice classification maps from N-ICE2015 expedition dataset.* Poster presentation at Polar Ice, Polar Climate, Polar Change, Remote sensing and modeling advances in understanding the cryosphere. Boulder, Colorado, USA, 14–19 August 2017.

O'Sadnick, M., Petrich, C., Brekke, C., Skardhamar, J. (2017) *Examination of sea ice cover in Norwegian fjords.* Poster presentation at Arctic Change 2017 conference in Quebec, December 11-15, 2017.

O'Sadnick, M., Petrich, C. (2017) *MOSIDEO/CIRFA Experiments on Behavior and Detection of Oil in Ice.* Arctic Change 2017 conference in Quebec, December 11-15, 2017.

O'Sadnick, M., Petrich, C., Dang, N. P. (2017) *The Entrainment and Migration of Crude Oil in Sea Ice, the Use of Vegetable Oil as a Substitute, and Other Lessons from Laboratory Experiments.* Proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions 2017.

O'Sadnick, M., Petrich, C., Dale, L. (2017) *Recent ice conditions in North-Norwegian Porsangerfjorden.* Proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions 2017.

Petrich, C. (2017) *MOSIDEO/CIRFA Experiments on Behavior and Detection of Oil in Ice.* EGU General Assembly 2017, Vienna, Austria, 23–28 April 2017.

Rösel A., King, J., **Doulgeris, A.P.**, Wagner, P.M., **Johansson A.M., Gerland S.** (2017) *Can we extent local sea-ice measurements to satellite scale? An example from the N-ICE2015 expedition.* Poster presentation at Polar Ice, Polar Climate, Polar Change, Remote sensing and modeling advances in understanding the cryosphere. Boulder, Colorado, USA, 14–19 August 2017**.**

Skarbø, R., Løset, S. (2017) *Ice Intelligence Retrieval by Remote Sensing – Possibilities and Challenges in an Operational Setting.* Proceedings of the 24th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC), 11 June 11-16, 2017, Busan.

Skrunes, S., Brekke, C., Espeseth, M. (2017) *Assessment of the Risat-1 FRS-2 mode for oil spill observation.* Oral presentation at 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS2017), Fort Worth, Texas, USA, July 23-28, 2017.

Storvold, R., et al. (2017) *Integrating drones into the Arctic Observing System.* 7th EASN International Conference on "Innovation in European Aeronautics Research", 26-29 September 2017, Warszaw, Poland.

Storvold, R. (2017) *Efficient and innovative use of drones for scientific data collection in the Arctic*, Svalbard Science Conference, Oslo, November 6-8th, 2017.

Yitayew, T. G., Doulgeris, A. P., Eltoft, T., Dierking, W., Brekke, C., Rösel, A. (2017) *Sea ice segmentation using TanDEM-X pursuit monostatic and alternating bistatic modes.* Oral presentation at 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS2017), Fort Worth, Texas, USA, July 23-28, 2017.

Zhao, Z., Lang, W., **Doulgeris, A.P.**, Chen, L. (2017) *Improved LLM methods using linear regression.* Oral presentation at 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS2017), Fort Worth, Texas, USA, July 23-28, 2017.

2018

Peer-reviewed publications

Akbari, V., Brekke, C. (2018) *Iceberg detection in open and ice-infested waters using C-band polarimetric synthetic aperture radar*. IEEE Transactions on Geoscience and Remote Sensing 2018, 56(1), 407-421.

Blix, K., Pàlffy, K., Tòth, V.R., **Eltoft, T.** (2018) *Remote Sensing of Water Quality Parameters over Lake Balaton by Using Sentinel-3 OLCI.* Water, *10*, 1428; https://doi.org/10.3390/w10101428.

Blix, K., Eltoft, T. (2018) *Evaluation of feature ranking and regression methods for oceanic chlorophyll-a estimation.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 11: 1403-1418; https://doi.org/10.1109/JSTARS.2018.2810704.

Blix, K., Eltoft, E. (2018) *Machine Learning Automatic Model Selection Algorithm for Oceanic Chlorophyll-a Content Retrieval.* Remote Sens. 10 (5), 775; doi: 10.3390/rs10050775.

Christensen, K.H., Sperrevik, A.K., Brostrom, G. (2018) *On the Variability in the Onset of the Norwegian Coastal Current.* J. Phys. Oceanogr. 48: 723-738. https://doi.org/10.1175/JPO-D-17-0117.1.

Christensen, K.H., Breivik, Ø., Dagestad, K.F., Röhrs, J., Ward, B. (2018) *Short Term Predictions of Oceanic Drift.* Oceanography; 31:59–67. https://doi.org/10.5670/oceanog.2018.310.

Dagestad, K.F., Röhrs, J., Breivik, Ø., Ådlandsvik, B. (2018) *OpenDrift v1.0: a generic framework for trajectory modelling.* Geosci. Model Dev. 11, 1405-1420. https://doi.org/10.5194/gmd-11-1405-2018.

Eltoft, T., Anfinsen, S. N., Doulgeris, A. P., Ferro-Famil, L. (2018) *Polarimetric SAR Modelling: Mellin Kind Statistics and Time-Frequency Analysis. I: Mathematical Models for Remote Sensing Image Processing.* Springer 2018. ISBN 978-3-319-66328-9. pp. 191-242.

Fritzner, S., Graversen, R., Wang, K., Christensen, K.H. (2018) Comparison between a multi-variate nudging method and the ensemble Kalman filter for sea-ice data assimilation. Journal of Glaciology. 2018;64(245):387-396. doi:10.1017/jog.2018.33.

Griebel, J., Dierking, W. (2018) *Impact of sea ice drift retrieval errors, discretization and grid type on calculations of sea ice deformation.* Remote Sensing 10 (393); doi:10:3390/rs1030393.

Fernández-Méndez M. et al. (2018) *Algal Hot Spots in a Changing Arctic Ocean: Sea-Ice Ridges and the Snow-Ice Interface.* Frontiers in Marine Science, 5(75). doi: 10.3389/fmars.2018.00075.

Hu, D., **Doulgeris, A.P**, Qiu, X., Lei, B. and Jin, Y. (2018) *A high-efficiency automatic U-distribution segmentation algorithm for PolSAR images*. IEEE Geoscience and Remote Sensing Letters, 16(5): 831-835.

Meyer, A. et al. (2018) *Science Outreach Using Socail Media: Oceanography from the Lab to the Public.* Oceanography: 31(2); https://doi.org/10.5670/oceanog.2018.212

Murashkin, D., Spreen, G., Huntemann, M., **Dierking, W.** (2018) *Method for detection of leads from Sentinel-1 SAR images.* Annals of Glaciology, 59: 124-136; doi:10.1017/aog.2018.6

Negrel, J., Gerland, S., Doulgeris, A.P., Lauknes, T.R., Rouyet, L. (2018) *On the Potential of hand-held GPS Tracking of Fjord Ice Features for Remote Sensing Validation.* Annals of Glaciology, 59 (76): 173-180; https://doi.org/10.1017/aog.2017.35.

O'Sadnick, M.O., C. Petrich, C., Kleven, Ø., **Brekke, C.**, Skarðhamar, J., Dang, N. (2018) *Observations of ice conditions and properties in Norwegian fjords during the winter of 2018 and implications for oil spill response.* 41st AMOP Technical Seminar on Environmental Contamination and Response, October 2-4, 2018. Victoria, BC Canada. 123-137. http://hdl.handle.net/11250/2640269.

Pavlov, A.K. et al. (2018) *Does your lab use social media? Sharing three years of experience in science communication.* Bulletin of The American Meteorological Society – (BAMS); 99:1135-1146; https://doi.org/10.1175/BAMS-D-17-0195.1.

Petrich, C. et al. (2018) An overview of the MOSIDEO/CIRFA experiments on behavior and detection of oil in ice. 41st AMOP Technical Seminar on Environmental Contamination and Response, October 2-4, 2018. Victoria, BC Canada. ISBN 978-0-660-04851-2, pp 112-122.

Röhrs, J., Dagestad, K.F., Asbjørnsen, H., Nordam, T., Skancke, J., **Jones, C.E., Brekke, C.** (2018) *The effect of vertical mixing on the horizontal drift of oil spills.* Ocean Science; https://doi.org/10.5194/os-2018-100

Rösel, A., King, J., **Doulgeris, A.P.**, Wagner, P.M., **Johansson, M.A., Gerland, S.** (2018) *Can we extend local sea-ice measurements to satellite scale? An example from the N-ICE2015 expedition.* Annals of Glaciology, 59: 163-172; https://doi.org/10.1017/aog.2017.37.

Sigernes, F., Syrjäsuo, M., **Storvold, R.**, Fortuna, J., Grøtte, E.M., Johansen, T.A. (2018) *Do it yourself hyperspectral imager handheld to airborne operations.* Opt. Express, 26: 6021-6035; https://doi.org/10.1364/OE.26.006021.

Singha S., **Johansson A.M., Hughes N.**, Munk Hvidegaard S.M., Skourup H. (2018) *Arctic Sea Ice Characterization using Spaceborne Fully Polarimetric L-, C- and X-band SAR with Validation by Airborne Measurements.* IEEE Transactions on Geoscience and Remote Sensing. 56: 3715-3734; doi: 10.1109/TGRS.2018.2809504.

Skrunes, S., Brekke, C., Jones, C.E., Espeseth, M. M., Holdt B. (2018) *Effect of Wind Direction and Incidence Angle on Polarimetric SAR Observations of Slicked and Unslicked Sea Surfaces.* Remote Sensing of Environment; 213: 73 – 91. https://doi.org/10.1016/j.rse.2018.05.001.

Xu X., Brekke C., Doulgeris, A.P., Melandsø, F**.** (2018) *Numerical Analysis of Microwave Scattering from Layered Sea Ice Based on the Finite Element Method.* Remote Sens. 10,1332; doi:10.3390/rs10091332.

Yitayew, T.G., Dierking, W., Divine, D.V., Eltoft, T., Ferro- Famil, L., Rösel, A., **Negrel, J.** (2018) *Validation of Sea-Ice Topographic Heights Derived From TanDEM-X Interferometric SAR Data With Results From Laser Profiler and Photogrammetry*. IEEE Transactions on Geoscience and Remote Sensing, 56; 6504-6520; https://doi.org/10.1109/TGRS.2018.2839590.

Other publications

Akbari, V., Lohse, J. P., Eltoft, T, Dierking, W. (2018) *Characterization and detection of icebergs in open water and sea ice using spaceborne fully polarimetric SAR.* Oral presentation at SeaSar 2018.

Akbari, V., Lauknes, T.R., Rouyet, L., **Negrel, J., Eltoft, T.** (2018) *Validation of SAR Iceberg Detection with Ground-Based Radar and GPS Measurements.* IEEE International Geoscience and Remote Sensing Symposium. IEEE conference proceedings 2018, 4623-4626.

Blix, K., Espeseth, M., Eltoft, T. (2018) *Machine Learning simulations of quad-polarimetric features from dual-polarimetric measurements over sea ice.* EUSAR 2018 - 12th European Conference on Synthetic Aperture Radar, Electronic proceedings, 661-665.

Brekke, C. (2018) *Applications of full-polarimetric SAR to monitoring newly formed sea ice, leads, and oil spills.* ESA Cryosphere Remote Sensing Training Course, 6 Dec 2018.

Cristea, A., Doulgeris, A.P. (2018) *Integrating incidence-angle dependence in the segmentation of UAVSAR images UiT.* Poster Presentation at SeaSar 2018.

Dierking, W. (2018) *Multi-frequency SAR Classification of Sea Ice and Plans for ESA`s Copernicus L-band SAR mission.* Oral presentation at the XIX meeting of the International Ice Charting Working Group (IICWG), Helsinki, September 24-28, 2018.

Doulgeris, A.P., Cristea, A. (2018) *Incorporating incidence angle variation into SAR image segmentation.* IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 8552-8555.

Eltoft, T., Anfinsen, S. N., Doulgeris, A., Ferro-Famil, L. (2018) *Polarimetric SAR Modelling: Mellin Kind Statistics and Time-Frequency Analysis.* I: Mathematical Models for Remote Sensing Image Processing. Springer 2018 ISBN 978-3-319-66328-9. 191-242.

Hann, R. (2018) *UAV Icing: Comparison of LEWICE and FENSAP-ICE for Ice Accretion and Performance Degradation.* 2018 Atmospheric and Space Environments Conference (AIAA), 2018-2861.

Hann, R. (2018) *Icing Protection Systems for Unmanned Aerial Vehicles in the Arctic.* Arctic Change, December 2018.

Ivonin, D., Ivanov, A., **Brekke, C., Skrunes, S.** (2018) *Oil Slick Characterization Using C-band and X-band Spaceborn SAR Images and Model Based Polarimetric Technique.* Oral presentation at SeaSar 2018.

Jenssen, R. O. R, Eckerstorfer, M, Jacobsen, S. K., **Storvold, R.** (2018) *Drone-mounted UWB radar system for measuring snowpack properties: Technical implementation, specifications and initial results.* InternationalbSnow Science Workshop; 2018-10-07 - 2018-10-12.

Johnsen, H. (2018) *Sentinel-1 WV OSW Validation.* Oral Presentation at SeaSAR 2018.

Johansson, M.A., Skrunes, S., Brekke, C., Johansson, J., Karlson, B. (2018) *Algae blooms in the Baltic Sea observed in overlapping synthetic aperture radar and optical images combined with in-situ data.* SeaSar 2018.

Jones, C., Espeseth, M., Holt, B., **Brekke, C.** (2018) *Measurement of Oil Slick Transport and Evolution in the Gulf of Mexico using L-band Synthetic Aperture Radar.* Electronic proceedings (EUSAR) 2018, 502-506.

Karlson, B. et al. (2018) *Harmful algal blooms in the Baltic Sea and in the Kattegat-Skagerrak area investigated using novel in situ and remote sensing methods.* 18th international conference on harmful algae – From ecosystems to socio-ecosystems.

Lohse, J., Doulgeris, A., Dierking, W. (2018) *Sea Ice Classification from SAR on varying Scales.* Poster at EGU 2018.

Marino, A., **Wolfgang, D., Halland I.S.** (2018) *Using Sentinel-1 dual polarization incoherent images to detect iceberg.* Oral presentation at SeaSar 2018.

Myrnes, M., Brekke, C., Ferro-Famil, L., Petrich, C. (2018) *Polarimetric analysis of oil contaminated laboratory grown saltwater ice imaged by a ground-based SAR.* Electronic proceedings (EUSAR). Volume 2018. ISSN 2197-4402, p. 657-660.

Nilsen, V., Engen, G., Johnsen, H. A. (2018) *Novel Approach to SAR wind Retrieval.* Oral presentation at SeaSar 2018.

Quigley, C.P. (2018) *Inferring the dielectric properties of oil slick using SAR.* Poster Presentation at SeaSar 2018.

Sivertsen, A., S. Solbø, S., Stødle, D., Arntzen, I.M., **Lauknes, T.R.** (2018) *Real-time and Autonomous Detection of Sea Ice and Growlers Using UAS.* Poster presentation at AGU Annual Meeting, Washington DC, USA, December 10-14th, 2018.

Skrunes, S., Johansson, M., Brekke, C. (2018) *Observing Oil Releases from Platforms Using Synthetic Aperture Radar,* Poster Presentation at SeaSar 2018.

Soldal, I.H., Korosov, A., Marino, A. (2018) *Automatic Iceberg Detection in the Barents Sea for Icebergs in Open Water, Fast Ice and Pack Ice.* Poster Presentation at SeaSar 2018.

Storvold. et. al. (2018) *Drones in environmental mapping and monitoring in polar regions*, Opening Keynote, 1st EARSEL UAS for mapping and monitoring workshop, Warszaw, Poland, 5-7 Sept 2018.

Storvold, R., Sivertsen, A., Solbø, S. A., Tøllefsen, A. (2018) *Use of Satellite Information to Optimize Drone Coverage, Navigation and Data Collection*, IICWG-XIX Meeting, Helsinki, Finland, September 24-28th, 2018.

2019

Peer-reviewed publications

Dagestad, K.-F., Röhrs, J. (2019) *Prediction of ocean Surface trajectories using satellite derived vs. modeled ocean currents.* Remote Sensing of Environment, 223, 130-142. https://doi.org/10.1016/j.rse.2019.01.001.

Eltoft, T., Doulgeris, A.P. (2019) *Model-based polarimetric decomposition with higher order statistics.* IEEE Geoscience and Remote Sensing Letters, 16, 992-996. DOI: 10.1109/LGRS.2018.2889682.

Fritzner, S., Graversen, R., Christensen, K. H., Rostosky, P., **Wang, K.** (2019) *Impact of assimilating sea ice concentration, sea ice thickness and snow depth in a coupled ocean–sea ice modelling system*, The Cryosphere, 13, 491–509, https://doi.org/10.5194/tc-13-491-2019.

Graham, R.M. et al. (2019) *Winter storms accelerate the demise of sea ice in the Atlantic Sector of the Arctic Ocean.* Scientific Reports, 9(9222), 1-16. DOI:10.1038/s41598-019-45574-5.

Halland-Soldal, I., Dierking, W., Korosov, A., Marino, A. (2019) *Automatic detection of small icebergs in fast ice using satellite wide-swath SAR images*, Remote Sensing 11, 806, doi:10.3390/rs11070806.

Hann, R., Borup, K.T., Zolich, A.P., Sørensen, K.L., Vestad, H. N., Steinert, M., **Johansen, T.A.** (2019) *Experimental Investigations of an Icing Protection System for UAVs.* SAE technical paper series 2019; Volume 2019-June. https://doi.org/10.4271/2019-01-2038.

Hann, R. (2019) *UAV Icing: Ice Accretion Experiments and Validation*. SAE technical paper series 2019; Volume 2019-June.

Jenssen, R.O.J., Jacobsen, S.K., Eckerstorfer, M. (2019) *Drone-Mounted Ultrawideband Radar for Retrieval of Snowpack Properties.* IEEE Transactions on Instrumentation and Measurement 2019; 69(1), 221-23: https://doi.org/10.1109/TIM.2019.2893043.

Johansson, M., Malnes, E., **Gerland, S., Cristea, A., Doulgeris, A.P.**, Divine, D.V., Pavlova, O., **Lauknes, T.R.** (2019) *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, https://doi.org/10.1017/aog.2019.52.

Johansson, M., Espeseth, M., Brekke, C., Skrunes, S. (2019) *Separation and characterisation of mineral oil slicks and newly formed sea ice in L-band synthetic aperture radar.* IEEE International Geoscience and Remote Sensing Symposium proceedings, 3253-3256.

Johnsen, H., Engen, G., Nilsen, V. (2019) *A Novel Approach to SAR Ocean Wind Retrieval.* IEEE Transactions on Geoscience and Remote Sensing. 57(19), 6986-6995.

Lohse, J., Doulgeris, A.P., Dierking W. (2019) *An Optimal Decision-Tree Design Strategy and Its Application to Sea Ice Classification from SAR Imagery,* Remote Sensing 11(13), 1574, https://doi.org/10.3390/rs11131574.

Nilsen, V., Engen, G., Johnsen, H. (2019) *A Novel Approach to SAR Wind Retrieval.* IEEE Transactions on Geoscience and Remote Sensing, 57(9): 6986-6995, doi: 10.1109/TGRS.2019.2909838.

Monteban D., **Johnsen H.**, Lubbad R. (2019) *Spatiotemporal observations of wave dispersion within sea ice using Sentinel-1 SAR TOPS mode*, Journal of Geophysical Research (JGR) – Ocean, 124(12), 8522-8537, https://doi.org/10.1029/2019JC015311.

Oggier, M., Eicken, H., Wilkinson, J., **Petrich, C., O'Sadnick, M.** (2019) *Crude oil migration in sea-ice: Laboratory studies of constraints on oil mobilization and seasonal evolution*. Cold Regions Science and Technology, 174, 102924. https://doi.org/10.1016/j.coldregions.2019.102924.

Olsen, L.M. et al. (2019) *A red tide in the pack ice of the Arctic Ocean,* Scientific Reports 9 (9536), DOI:10.1038/s41598-019-45935-0.

Pavlova, O., **Gerland, S.**, H. Hop (2019) *Changes in sea ice extent and thickness in Kongsfjorden, Svalbard (2003-2016)*. In Hop, H., Wiencke, C. (eds.): The ecosystem of Kongsfjorden, Svalbard. Advances in Polar Ecology, 2, 105-136, Springer Nature Switzerland AG. DOI: 10.1007/978-3-319-46425-1_4.

Petrich, C. et al. (2019) *Mosideo/CIRFA tank experiments on behavior and detection of oil in ice.* Proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions, 2019-June. 1-11.

Petrich, C., O'Sadnick, M., Kleven, Ø., Sæther, I. V. (2019) *A low-cost coastal buoy for ice and metocean measurements.* Proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions, 2019-June.

Röhrs, J., Dagestad, K.-F., Asbjørnsen, H., Nordam, T., Skancke, J., **Jones, C. E., Brekke, C.** (2019) V*ertical mixing and horizontal drift of oil spills: simulations with the opensource oil spill model OpenOil.* EGU General Assembly 2019.

Singha, S., **Johansson, M., Doulgeris, A. P.** (2019) *Towards operational sea ice type retrieval using L-band Synthetic aperture radar.* IEEE International Geoscience and Remote Sensing Symposium proceedings 2019, 4226-4229.

Skrunes, S., Johansson, M.A., Brekke, C. (2019) *Synthetic Aperture Radar Remote Sensing of Operational Platform Produced Water Releases.* Remote Sensing, 11 (23). doi:10.3390/rs11232882.

Verfuss, U.K. et al. (2019) *A review of unmanned vehicles for the detection and monitoring of marine fauna*; Marine Pollution Bulletin, 140, 17-29. doi.org/10.1016/j.marpolbul.2019.01.009.

Other publications

Blix, K. (2019) *Machine Learning for Monitoring Arctic Waters by using Sentinel 3 OLCI.* Oral presentation at the 5th Sentinel 3 Validation Team meeting, Frascati, ESA-ESRIN.

Blix, K. (2019) *Machine Learning for Remote Sensing Complex Waters.* Poster presentation at the International Ocean Colour Science (IOCS) Meeting 2019, Busan, South Korea, 2019-04-09-2019-04-12.

Blix, K., Eltoft, T. (2019) A generalized Chlorophyll-A estimation model for complexity-diverse Arctic waters. IGARSS 2019.

Blix, K., Eltoft, T. (2019) *Machine Learning Remote Sensing for Ecosystem Monitoring in the Arctic.* Oral presentation at Arctic Frontiers 2019.

Brekke, C., Jones, C.E. (2019) *SAR Imaging of Oil Spills in Open Water – Interpretation and Information Retrieval Techniques.* Oral presentation at the 6th Scotland Norway Waves and Marine Hydrodynamics Symposium; 2019-05-08 – 2019-05-10.

Christensen, K.H., Kristensen, N.M., **Brændshøi, J.**, Batrak, Y., Samuelsen, E.M., Kristiansen, J., **Breivik, L.A**. (2019) *Weather and ocean forecasting for increased prepardness in the Arctic.* Oral presentation Arctic Frontiers 2019.

Cristea, A., Doulgeris, A.P. (2019) *Incidence angle in narrowswath Quad-polarimetric SAR images.* Oral presentation at Polinsar 2019.

Divine, D. et al. (2019) Satellite-based SAR versus visual direct observations: an intercomparison of the two techniques for sea ice observations in Kongsfjorden. Svalbard science conference 2019.

Espeseth, M., Skrunes, S., Brekke, C., Johansson, A.M. (2019) *The Impact of Additive Noise on Polarimetric Radarsat-2 Data Covering Oil Slicks.* IGARSS 2019.

Fajt, N., Hann, R. (2019). *The Influence of Meteorological Conditions on the Icing Performance Penalties on a UAV Airfoil.* European Conference for Aeronautics and Space Sciences 2019.

Fritzner, S., Graversen, R., Christensen, K., Wang, K. (2019) *Assimilation of high-resolution ice charts in a coupled ocean-sea-ice model.* IGARSS 2019.

Granskog, M. et al. (2019): *Role of winter storms on the evolution of sea ice in the Atlantic sector of the Arctic.* Oral presentation at IGS – Sea Ice Symposium 2019.

Hann, R. (2019). *UAV Icing: Comparison of LEWICE and FENSAP-ICE for Anti-Icing Loads. I: AIAA Scitech 2019 Forum.* American Institute of Aeronautics and Astronautics (AIAA 2019-1286), https://doi.org/10.2514/6.2019-1286.

Hann, R., Hodson, A., Jonassen, M. O. (2019) Glacier Mapping and Wind Estimation with UAVs on Svalbard. Svalbard Science Conference.

Itkin, P., Oikkonen, A, Spreen, G., Korosov, A. (2019) *Bridging temporal and spatial scales of sea ice deformation.* Oral presentation at IGS 2019.

Itkin, P., Rampal, P., Òlason, E., Williams, T. (2019) *Is it really getting younger? Sea ice type and age in a model simulation and satellite remote sensing Products:* Oral Presentation at IGS 2019.

Johansson, M., Doulgeris, A.P., Brekke, C. (2019) *Investigating the occurrence of newly formed sea ice in the Barents Sea using archived Sentinel-1 SAR data.* Poster presentation at IGS 2019.

Johansson, M. Espeseth, M., Brekke, C., Skrunes, S. (2019) *Separation and characterisation of mineral oil slicks and newly formed sea ice in L-band synthetic aperture radar.* IEEE International Geoscience and Remote Sensing Symposium proceedings 2019.

Johansson, M., Gerland, S., Cristea, A., Malnes, E., **Doulgeris, A.P., Divine, D.**, Pavlova, O., **Lauknes, T.R.** (2019) *Sea ice and open water classification using historical multi-sensor synthetic aperture radar satellite datasets, applied to two Svalbard fjords*: Oral presentation at IGS - Sea Ice Symposium 2019.

Johansson, M., Malnes, E., **Gerland, S.**, Vickers, H., **Lauknes, T.R., Doulgeris, A., Cristea, A., Divine, D**. (2019) *28 years of fjord ice coverage in Kongsfjorden, Svalbard, observed by satellite radar*. Oral presentation at Arctic Frontiers 2019.

Lohse, J., Doulgeris, A.P., Dierking, W. (2019) *Ice Type Mapping from Sentinel-1 Considering Surface-Type Dependent Effect of Incidence Angle.* Poster presentation at IGS - Sea Ice Symposium 2019.

Lohse, J., Doulgeris, A.P., Dierking, W. (2019) *New Strategies for Automated Sea Ice Classification at CIRFA.* International Ice Charting Working Group Meeting.

Marci, D., Marinoni, A., Gamba, P. (2019) *Mapping mineral abundances on the moon Surface using CHANGÈ-1 IIM data*. IGARSS 2019.

Marinoni, A., Espeseth, M., Gamba, P., **Brekke, C., Eltoft, T.** (2019) *Assessment of Polarimetric variability by Distance Geometry for Enhanced Classification of Oil Slicks Using SAR*. IEEE International Geoscience and Remote Sensing Symposium proceedings 2019.

Marinoni, A., Johansson, M., Espeseth, M., Brekke, C. (2019) *Multidimensional distance geometry analysis for classification of PolSAR images in Arctic scenarios.* Oral presentation at Polinsar 2019.

Oikkonen, A., Haapala, J., **Itkin, P.** (2019) *The impact of waves on sea-ice deformation.* Poster presentation at IGS – Sea Ice Symposium 2019.

O'Sadnick, M., Petrich, C., Kleven, Ø., **Brekke, C.** Skardhamar, J. (2019) *Changes in sea-ice coverage in Norwegian fjords since 2002 and relationship to climatic, oceanographic and topographic variables.* Poster presentation at IGS - Sea Ice Symposium 2019.

O'Sadnick, M., Petrich, C., Kleven, Ø., **Brekke, C.** Skardhamar, J. (2019). *Cold and dry vs warm and wet: how two winters of differing weather impacted sea-ice conditions and properties in seven northern Norwegian fjords. IGS* - Sea Ice Symposium 2019.

O`Sadnick, M., Petrich, C., Dang, N., Kleven, Ø., **Brekke, C.**, Skardhamar, J. (2019) *The importance of sea ice properties in assessing the risks present in coastal regions of the Arctic.* EGU General Assembly, Vienna, Austria, 7-12 April, 2019.

Petrich, C., O'Sadnick, M., Brekke, C., Myrnes, M., Maus, S., Salomon, M.L., Woelk, S., Grydeland, T., Jenssen, R.O.R., Eicken, H., Oggier, M., **Ferro-Famil, L.**, Harkati, L., Rebane, O., Reimer, N. (2019) *Mosideo/cirfa tank experiments on behavior and detection of oil in ice.* Proceedings – International Conference on Port and Ocean Engineering under Arctic Conditions 2019 ; Volum 2019-June. s.1-11.

Petrich, C. (2019) The color of ice. Poster presentation at IGS - Sea Ice Symposium 2019.

Petrich, C., O'Sadnick, M., Brekke, C., Myrnes, M., Maus, S., Salomon, M., Woelk, S., Grydeland, T., Jenssen, R.O. (2019) *Joint MOSIDEO/CIRFA tank experiments on behavior and detection of oil in ice.* Poster presentation at IGARSS 2019.

Petrich, C., O'Sadnick, M.E., Brekke, C., Myrnes, M., Maus, S., Salomon, M.L., Woelk, S., Grydeland, T., **Jenssen, R.R.**, Eicken, H., Oggier, M., **Ferro-Famil, L.**, Harkati, L., Rebane, O., Reimer, N. (2019). Joint MOSIDEO/CIRFA tank experiments on behavior and detection of oil in ice. IGS - Sea Ice Symposium 2019.

Petrich, C., Langhorne, P., Eicken, H. (2019) *Desalination of sea ice in a fluid dynamics model.* Poster presentation at IGS - Sea Ice Symposium 2019.

Petrich, C., O`Sadnick, M., Kleven, Ø. and Sæther, I. (2019) *Acquiring sea ice data under high probability of loss of equipment*: Oral presentation at IGS - Sea ice symposium 2019.

Petrich, C., O'Sadnick, M., Kleven, Ø. (2019). *Acquiring data under high probability of loss of equipment.* EGU General Assembly 2019.

Petrich, C., O'Sadnick, M., Kleven, Ø., Sæther, I. (2019) *A low-cost coastal buoy for ice and metocean measurements.* International Conference on Port and Ocean Engineering under Arctic Conditions 2019. Poster presentation at IGARSS 2019.

Petrich, C., O'Sadnick, M., Kleven, Ø., Sæther, I**.** (2019). A low-cost coastal buoy for ice and metocean measurements. In proceedings - International Conference on Port and Ocean Engineering under Arctic Conditions 2019

Quigley, C.P., Eltoft, T. (2019) *Retrieval of the dielectric properties of oil slick using SAR via a Polarimetric Two-Scale Model.* Oral presentation at Polinsar 2019.

Röhrs, J., Dagestad, K.F., Asbjørnsen, H., Nordam, T., Skancke, J., **Jones, C.E., Brekke, C.** (2019) *Vertical mixing and horizontal drift of oil spills: simulations with the open source oil spill model OpenOil.* EGU General Assembly, Vienna, Austria, 7-12 April.

Semmling, M., **Divine, D., Gerland, S.**, Wickert, J., Schuh, H. (2019) *Estimation of sea-ice concentration using signals of a global navigation satellite system:* Poster presentation IGS – Sea Ice Symposium 2019.

Singha, S., **Johansson, M., Doulgeris A.P**. (2019) *Towards operational sea ice type retrieval using L-band synthetic aperture radar*. IGARSS 2019.

Singha, S., **Johansson, M., Doulgeris A.P**. (2019) *Arctic Sea Ice Classification Using ALOS-2 Palsar-2 L-Band SAR Images*. Oral presentation at ESA Living Planet Symposium 2019.

Winter, A., **Hann, R**., Wenz, A., Wolfgang, A, Gryte, K., **Johansen, T.A.** (2019). *Stability of a Flying Wing UAV in Icing Conditions*. European Conference for Aeronautics and Space Sciences 2019.

Yitayew, T.G., Dierking, W., Divine, D., Eltoft, T., Negrel, J. (2019) *Sea ice topographic height retrieval from Tandem-X interferometric SAR data*. Oral presentation IGARSS 2019.

2020

Peer-reviewed publications

Asim, M., Brekke, C., Mahmood, A., **Eltoft, T.**, Reigstad, M. (2020) *Ocean Color Net (OCN) for the Barents Sea*. IEEE International Geoscience and Remote Sensing Symposium proceedings 5881-5884.

Bianchi, F. M., **Espeseth, M.**, Borch, N.T. (2020) *Large-Scale Detection and Categorization of Oil Spills from SAR Images with Deep Learning. Remote Sensing*. https://doi.org/10.3390/rs12142260.

Blix, K., Espeseth, M., Eltoft, T. (2020) *Comparison of Machine Learning Methods for Predicting Quad-Polarimetric Parameters from Dual-Polarimetric SAR Data*. IEEE International Geoscience and Remote Sensing Symposium proceedings. https://doi.org/10.1109/igarss.2018.8518747.

Blix, K. (2020) *Machine Learning Classification, Feature Ranking and Regression for Water Quality Parameters Retrieval in Various Optical Water Types from Hyper-Spectral Observations*. IEEE International Geoscience and Remote Sensing Symposium proceedings.

Blix, K., Espeseth, M., Eltoft, T. (2020) *Machine Learning for Arctic Sea Ice Physical Properties Estimation Using Dual-Polarimetric SAR Data*. IEEE Transactions on Geoscience and Remote Sensing 2020. doi: 10.1109/TGRS.2020.3022461

Brekke, C., Jones, C.E. (2020) *SAR Oil Spill Imaging, Interpretation and Information Retrieval Techniques*. In: Iodice, Di Martino. Maritime Surveillance with Synthetic Aperture Radar. The Institution of Engineering and Technology p. 227-267.

Brekke, C., Espeseth, M., Dagestad, K., 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 (JGR): Oceans. https://doi.org/https://doi.org/10.1029/2020JC016499.

Breivik, Ø., Christensen, K. H. (2020) A combined stokes drift profile under swell and wind sea. Journal of Physical Oceanography. https://doi.org/10.1175/JPO-D-20-0087.1.

Chlaily, S., Mura, M. D., Chanussot, J., Jutten, C., Gamba, P., **Marinoni, A.** (2020) *Capacity and Limits of Multimodal Remote Sensing: Theoretical Aspects and Automatic Information Theory-Based Image Selection*. IEEE Transactions on Geoscience and Remote Sensing. https://doi.org/10.1109/TGRS.2020.3014138.

Cristea, A., Johansson, M., Filimonova, N. A., Ivonin, D., **Hughes, N., Doulgeris, A. P.** (2020) *Towards automatic detection of dark features in the Barents Sea using synthetic aperture radar*. IEEE International Geoscience and Remote Sensing Symposium proceedings. https://doi.org/10.1109/IGARSS39084.2020.9323749.

Cristea, A., Van Houtte, J., **Doulgeris, A. P.** (2020) *Integrating Incidence Angle Dependencies Into the Clustering-Based Segmentation of SAR Images*. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. https://doi.org/10.1109/JSTARS.2020.2993067.

Dierking, W. F. O., Stern, H. L., Hutchings, J. K. (2020) *Estimating statistical errors in retrievals of ice velocity and deformation parameters from satellite images and buoy arrays*. The Cryosphere. https://doi.org/10.5194/tc-14-2999-2020.

Espeseth, M., Brekke, C., Jones, C. E., Holt, B., Freeman, A. (2020) *The Impact of System Noise in Polarimetric SAR Imagery on Oil Spill Observations*. IEEE Transactions on Geoscience and Remote Sensing. https://doi.org/10.1109/TGRS.2019.2961684

Espeseth, M., Jones, C., Holt, B., **Brekke, C., Skrunes, S.** (2020) *Oil-Spill-Response-Oriented Information Products Derived From a Rapid-Repeat Time Series of SAR Images*. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. https://doi.org/10.1109/jstars.2020.3003686

Espeseth, M.M., Jones, C.E., Holt, B., **Brekke, C., Skrunes, S.** (2020) *Quantitative measurements of oil slick evolution using a time series of SAR images*. J. Selected Topics in Applied Earth Obs. Remote Sens., 13, 10.1109/JSTARS.2020.3003686.

Fritzner, S. M., 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 (JGR): Oceans. https://doi.org/10.1029/2020JC016277.

Gerland, S., Pavlova, O., **Divine, D., Negrel, J.**, Dahlke, S., **Johansson, M.**, Maturilli, M., Semmling, M. (2020) *Long-term monitoring of landfast sea ice extent and thickness in Kongsfjorden, and related applications (FastIce)*. In: Van den Heuvel et al. (eds): SESS Report 2019, Svalbard Integrated Arctic Earth Observing System, Longyearbyen, pp. 160 - 167. Svalbard Integrated Arctic Earth Observing System, Longyearbyen 2020. ISBN 978-82-691528-6-9.

Hann, R., Hearst, R. J., Sætran, L. R., Bracchi, T. (2020) *Experimental and numerical icing penalties of an S826 airfoil at low Reynolds numbers*. Aerospace. https://doi.org/10.3390/aerospace7040046.

Hovenburg, A. R., Andrade, F., **Hann, R.**, Rodin, C. D., **Johansen, T. A.** (2020) *Long range path planning using an aircraft performance model for battery powered sUAS equipped with icing protection system*. IEEE Journal on Miniaturization for Air and Space Systems. https://doi.org/10.1109/JMASS.2020.3003833

Ivonin, D., **Brekke, C., Skrunes, S.**, Ivanov, A., Kozhelupova, N. (2020) *Mineral Oil Slicks Identification Using Dual Co-polarized Radarsat-2 and TerraSAR-X SAR Imagery*. Remote Sensing. https://doi.org/10.3390/rs12071061.

Jenssen, R. R., Jacobsen, S. K. (2020) *Drone-Mounted UWB Snow Radar: Technical Improvements and Field Results*. Journal Electromagnetic Waves and Applications. https://doi.org/10.1080/09205071.2020.1799871.

Johansson, M., Malnes, E., **Gerland, S., Cristea, A., Doulgeris, A. P., Divine, D. V.**, Pavlova, O., **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. https://doi.org/10.1017/aog.2019.52.

Johansson, M., Espeseth, M., Brekke, C., Holt, B. (2020) *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. https://doi.org/10.1109/JSTARS.2020.3017278.

Lohse, J., Doulgeris, A. P., Dierking, W. (2020) *Mapping sea-ice types from Sentinel-1 considering the surface-type dependent effect of incidence angle*. Annals of Glaciology. https://doi.org/10.1017/aog.2020.45.

Moiseev, A., Johnsen, H., Hansen, M. W., Johannessen, J. A. (2020) *Evaluation of Radial Ocean Surface Currents Derived From Sentinel-1 IW Doppler Shift Using Coastal Radar and Lagrangian Surface Drifter Observations*. Journal of Geophysical Research (JGR): Space Physics. https://doi.org/10.1029/2019JC015743.

Moiseev, A., Johnsen, H., Johannessen, J. A., Collard, F., Guitton, G. (2020) *On removal of sea state contribution to Sentinel-1 Doppler shift for retrieving reliable ocean surface current*. Journal of Geophysical Research (JGR): Oceans. https://doi.org/10.1029/2020JC016288.

Negrel, J., Divine, D. V., Gerland, S. (2020) *Impact of Arctic sea ice floe-scale anisotropy on airborne electromagnetic surveys.* Annals of Glaciology. https://doi.org/10.1017/aog.2020.61

O'Sadnick, M. E., Petrich, C., Brekke, C., Skardhamar, J. (2020) *Ice extent in sub-arctic fjords and coastal areas from 2001 to 2019 analyzed from MODIS imagery. Annals of Glaciology.* https://doi.org/10.1017/aog.2020.34.

Quigley, C., Brekke, C., Eltoft, T. (2020) *Comparison Between Dielectric Inversion Results From Synthetic Aperture Radar Co- and Quad-Polarimetric Data via a Polarimetric Two-Scale Model.* IEEE Transactions on Geoscience and Remote Sensing. https://doi.org/10.1109/TGRS.2020.3038366.

Quigley, C., Brekke, C., Eltoft, T. (2020) *Retrieval of Marine Surface Slick Dielectric Properties From Radarsat-2 Data via a Polarimetric Two-Scale Model.* IEEE Transactions on Geoscience and Remote Sensing. https://doi.org/10.1109/TGRS.2020.2973724.

Singha, S., **Johansson, 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. https://doi.org/10.1109/TGRS.2020.3035029.

Strand, K. O., **Breivik, Ø.**, Pedersen, G., Vikebø, F. B., Sundby, S., **Christensen, K. H.** (2020) *Long-Term Statistics of Observed Bubble Depth Versus Modeled Wave Dissipation.* Journal of Geophysical Research (JGR): Space Physics. https://doi.org/10.1029/2019JC015906.

Sutherland, G., Soontiens, N., Davidson, F., Smith, G. C., Bernier, N., Blanken, H., Schillinger, D., Marcotte, G., **Röhrs, J., Dagestad, KF, Christensen, KH, Breivik, Ø.** (2020) *Evaluating the leeway coefficient of ocean drifters using operational marine environmental prediction systems.* Journal of Atmospheric and Oceanic Technology. https://doi.org/10.1175/JTECH-D-20-0013.1.

Other publications

Blix, K. (2020) *Innovative Technologies for Monitoring Arctic Waters with Upcoming Sensors.* Arctic Frontiers Conference 2020.

Brekke, C., Jones, C. E. (2020) *SAR oil spill imaging, interpretation and information retrieval techniques.* Institution of Engineering and Technology (IET). https://doi.org/https://doi.org/10.1049/SBRA521E_ch9

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

Gerland, S., Pavlova, O., **Divine, D. V., Negrel, J.**, Dahlke, S., **Johansson, M.** (2020) *Long-term monitoring of landfast sea ice extent and thickness in Kongsfjorden, and related applications (FastIce)* In: Van den Heuvel et al. (eds): SESS report 2019, Svalbard Integrated Arctic Earth Observing System, Longyearbyen, pp. 160 – 167.

Gerland, S., Divine, D. V., Fransson, A., Granskog, M.; Pavlova, O., Chierici, M. (2020) *Svalbard fjord environments with land-fast sea ice as arenas for climate research, monitoring, remote sensing validation, and dedicated process studies.* 25th IAHR International Symposium on Ice: https://www.iahr.org/library/info?pid=8505

Gerland, S., Divine, D. V., Dierking, W. F. O., Doulgeris, A. P., Eltoft, T., Johansson, M. (2020) *Use of in situ and airborne Arctic sea ice surveys for SAR satellite remote sensing application improvements.* 2020 ESA European Polar Science Week.

Hann, R. (2020) *Opportunities and Challenges for Unmanned Aerial Vehicles (UAVs) in the Arctic.* SIOS Polar Night Week.

Khachatrian, E., Chlaily, S., Eltoft, T., Marinoni, A. (2020) *Unsupervised Information Selection In Multimodal Sea Ice Remote Sensing.* I: Proceedings of the 25th International Symposium on ice. Trondheim, Norway, 23-25 November 2020. The International Association for Hydro-Environment Engineering and Research (IAHR). ISBN 978-82-7598-120-0. pp 208-217.

Khaleghian, S., Ullah, H., Kræmer, T., Everett, A., Kiærbech, Å., Pedersen, J. (2020) *Automatic sea ice classification using Synthetic aperture radar data analysis by deep learning.* PHI-Week: Earth Observation and AI for Operational Sea Ice Charting.

Khaleghian, S., Kræmer, T., Everett, A., Kiærbech, Å., Hughes, N., Eltoft, T., Marinoni, A. (2020) *Deep learning for enhanced sea ice understanding.* Arctic Frontiers.

Marinoni, A., Chlaily, S., Jutten, C. (2020) *Addressing Reliability Of Multimodal Remote Sensing To Enhance Multisensor Data Fusion And Transfer Learning.* IGARSS International Geoscience and Remote Sensing Symposium 2020.

Moiseev, A., Johnsen, H., Johannessen, J. A. (2020) *Retrieving ocean surface currents from the Sentinel-1 Doppler Shift observations: A case study of the Norwegian coastal current.* IGARSS International Geoscience and Remote Sensing Symposium 2020.

Narum, E. F. L., **Hann, R., Johansen, T. A.** (2020) *Optimal Mission Planning for Fixed-Wing UAVs with Electro-Thermal Icing Protection and Hybrid-Electric Power Systems.* IEEE https://doi.org/10.1109/ICUAS48674.2020.9214054

O'Sadnick, M., Petrich, C.; Kleven, Ø., Skardhamar, J., **Brekke, C.** (2020) *Ice Formation in Norwegian Fjords – Findings from the 2018 - 2019 Field Season.* IAHR International Symposium on Ice. Trondheim, 23-25 November 2020.

Petrich, C., Sæther, I. V., Dang, N. P., Kleven, Ø., **O'Sadnick, M.** (2020) *A Note on Remote Temperature Measurements with DS18B20 Digital Sensors.* IAHR International Symposium on Ice. Trondheim, 23-25 November 2020.

2021

Peer-reviewed publications

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

Blix, K., Ruescas, A. B., Johnson, J. E., Camps-Valls, G. (2021) *Learning Relevant Features of Optical Water Types.* IEEE Geoscience and Remote Sensing Letters 2021:19.

Glissenaar, I. A., **Landy, J.**, Petty, A., Kurtz, N., Stroeve, J. (2021): *Impacts of snow data and processing methods on the interpretation of long-term changes in Baffin Bay early spring sea ice thickness.* The Cryosphere 2021. doi: 10.5194/tc-15-4909-2021.

Campbell, K. et al. (2021) *Monitoring a changing Arctic: Recent advancements in the study of sea ice microbial communities.* Ambio 2021 (51) 318-332.

Hann, R., Enache, A., Nielsen, M.C., Stovner, B. N. Van Beeck, J., Johansen, T. A, Borup, K. T. (2021) *Experimental Heat Loads for Electrothermal Anti-Icing and De-Icing on UAVs.* Aerospace 2021. doi: 10.3390/aerospace8030083.

Hann, R., Johansen, T. A. (2021) *UAV icing: the influence of airspeed and chord length on performance degradation.* Aircraft Engineering and Aerospace Technology 2021. ISSN: 0002-2667.

Heorton, H., Tsamados, M., Armitage, T., Ridout, A., **Landy, J. C.** (2021) *Cryosat-2 significant wave height in polar oceans derived using a semi-analytical model of synthetic aperture radar 2011-2019.* Remote Sensing 2021. doi: doi.org/10.3390/rs13204166.

Johansson, M., Skrunes, S., Brekke, C., Isaksen, H. (2021) *Multi-mission remote sensing of low concentration produced water slicks.* Electronic proceedings (EUSAR) 2021, 249-254.

Jenssen, R.-O. R., Jacobsen, S. K. (2021) *Measurement of snow water equivalent using drone-mounted ultra-wide-band radar.* Remote Sensing 2021. doi: 10.3390/rs13132610.

Khachatrian, E., Chlaily, S., Eltoft, T., Dierking, W. F. O., Dinessen, F., **Marinoni, A.** (2021) *Automatic Selection of Relevant Attributes for Multi-Sensor Remote Sensing Analysis: A Case Study on Sea Ice Classification.* IEEE Journal of Selected Topics in Applied

Earth Observations and Remote Sensing 2021. doi: 10.1109/JSTARS.2021.3099398.

Khachatrian, E., Chlaily, S., Eltoft, T., Gamba, P., **Marinoni, A.** (2021) *Unsupervised Band Selection for Hyperspectral Datasets by Double Graph Laplacian Diagonalization.* IEEE International Geoscience and Remote Sensing Symposium proceedings 2021, 4007-4010.

Khaleghian, S., Ullah, H., Kræmer, T., Eltoft, T., Marinoni, A. (2021) *Deep Semisupervised Teacher–Student Model Based on Label Propagation for Sea Ice Classification.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2021. doi: 10.1109/JSTARS.2021.3119485.

Khaleghian, S., Ullah, H., Kræmer, T., Hughes, N., Eltoft, T., Marinoni, A. (2021): *Sea Ice Classification of SAR Imagery Based on Convolution Neural Networks.* Remote Sensing 2021. doi: 10.3390/rs13091734.

Lohse, J., Doulgeris, A. P., Dierking, W. (2021) *Incident Angle Dependence of Sentinel-1 Texture Features for Sea Ice Classification.* Remote Sensing 2021. doi: 10.3390/rs13040552.

Landy, J., Bouffard, J., Wilson, C., Rynders, S., Aksenov, Y. Tsamados, M. (2021) *Improved Arctic Sea Ice Freeboard Retrieval From Satellite Altimetry Using Optimized Sea Surface Decorrelation Scales.* Journal of Geophysical Research (JGR): Oceans 2021: 126(12).

Mallett, R., Stroeve, J. C., Tsamados, M., **Landy, J. C.**, Willatt, R., Nandan, V., Liston, G. (2021) *Faster decline and higher variability in the sea ice thickness of the marginal Arctic seas when accounting for dynamic snow cover.* The Cryosphere 2021. doi: 10.5194/tc-15-2429-2021.

Moiseev, A., Johannessen, J. A., Johnsen H. (2021) *Towards retrieving reliable ocean surface currents in the coastal zone from the Sentinel-1 Doppler shift observations*. Journal of Geophysical Research: Oceans, 127, e2021JC018201. https://doi.org/10.1029/2021JC018201.

Röhrs, J., Sutherland, G., Jeans, G., Bedington, M-, **Sperrevik, A. K., Dagestad, K.-F., Gusdal, Y.,** Mauritzen, C., Dale, A. Lacase, J. H. (2021) *Surface currents in operational oceanography: Key applications, mechanisms, and methods.* Journal of operational oceanography. doi: 10.1080/1755876X.2021.1903221.

Singha, S., **Johansson, M., Doulgeris, A. P.** (2021) *Robustness of SAR Sea Ice Type classification across incidence angles and seasons at L-band.* IEEE Transactions on Geoscience and Remote Sensing 2021. doi: 10.1109/TGRS.2020.3035029.

Singha, S., **Johansson, M.**, Spreen, G., Howell, S., Shin-ichi, S., Davidson, M. (2021) **Year-around C- and L-band observation around the MOSAiC ice floe with high spatial and temporal resolution.** IEEE International Geoscience and Remote Sensing Symposium proceedings, 5509-5512.

Staneva, J., Ricker, M., Alvarez, R. C., Breivik, Ø., Schrum, C. (2021) *Effects of wave-induced processes in a coupled wave-ocean model on particle transport simulations.* Water 13(4).

Tollinger, M., Graversen, R., Johnsen, H. (2021) *High-resolution polar low winds obtained from unsupervised SAR wind retrieval.* Remote Sensing 2021. doi: 10.3390/rs13224655.

Zhou, X., Min, C., Yang, Y., **Landy, J. C.**, Mu, L., Yang, Q. (2021) *Revisiting Trans-Arctic Maritime Navigability in 2011–2016 from the Perspective of Sea Ice Thickness.* Remote Sensing 2021. doi: 10.3390/rs13142766.

Other publications

Eltoft, T. (2021) *Can Transfer Learning Solve Remote Sensing Challenges in Ocean Colour?* PHI-Week: Earth Observation and AI for Operational Sea Ice Charting.

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

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

Eltoft, T. (2021) *Deep Learning Challenges in Sea Ice Classification.* AIDingArctic. 2021.

Eltoft, T., Johansson, M., Doulgeris, A. p., Singha, S., **Itkin, P., Blix, K.** (2021) *Advancing information extraction on Arctic sea ice using a multi-sensor and multi-temporal integrated approach.* The Joint PI Meeting of JAXA Earth Observation Missions. 2021.

Færch, L., Dierking, W., Doulgeris, A. P. (2021) *Iceberg Detections with SAR at C- and L-band.* 22nd Meeting of the International Ice Charting Working Group. 2021.

Færch, L., Kræmer, T., Dierking, W., Doulgeris, A. P., Hughes, N. (2021) *Evaluation of iceberg detection limits from remote sensing data-An investigation around Negribreen.* Online conference on remote sensing in Svalbard. 2021.

Gerland, S., Divine, D., Pavlova, O., Fransson, A., Assmy, P., Chierici, M., Eronen-Rasimus, E., Hoppe, C., **Johansson, M.** (2021) *Seasonal sea ice scenarios in recent years for Kongsfjorden, Svalbard, and related physical, biological and biogeochemical properties and processes.* Svalbard Science Conference. 2021.

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

Johansson, M., Eltoft, T., Singha, S., **Itkin, P.,** Spreen, G., Howell, S.,Shin-ichi, S., Davidson, M. (2021) *L- and C-band Synthetic Aperture Radar data analysis from the yearlong MOSAiC expedition.* Joint PI Meeting of JAXA Earth Observation Missions.

Johansson, M., Skrunes, S., Brekke, C., Isaksen, H. (2021) *Multi-mission remote sensing of low concentration produced water slicks.* EUSAR 2021: 13th European Conference on Synthetic Aperture Radar.

Khachatrian, E., Chlaily, S., Eltoft, T., Gamba, P., **Marinoni, A.** (2021) *Unsupervised Band Selection for Hyperspectral Datasets by Double Graph Laplacian Diagonalization.* IEEE International Geoscience and Remote Sensing Symposium proceedings.

Khachatrian, E., Chlaily, S., Eltoft, T., Marinoni, A. (2021) *Selecting principal attributes in multimodal remote sensing for sea ice characterization.* I: EUSAR 2021: 13th European Conference on Synthetic Aperture Radar.

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

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

Singha, S., **Johansson, M.,** Spreen, G., Howell, S., Shin-ichi, S., Davidson, M. (2021) *Year-around C- and L-band observation around the MOSAiC ice floe with high spatial and temporal resolution.* IEEE International Geoscience and Remote Sensing Symposium proceedings 2021.

2022

Peer-reviewed publications

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

Campbell, K. et al. (2022) *Net heterotrophy in High Arctic first-year and multi-year spring sea ice*. Elementa: Science of the Anthropocene 2022, 10(1).

Cristea, A., Johansson, M., Doulgeris, A., Brekke, C. (2022) *Automatic detection of low-backscatter targets in the Arctic using wide swath sentinel-1 imagery.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2022, 15: 8870-8883.

Dawson, G., **Landy, J.,** Tsamados, M., Komarov, A. S., Howell, S., Heorten, H., Krumpen, T. (2022) *A 10-year record of Arctic summer sea ice freeboard from CryoSat-2.* Remote Sensing of Environment 2022, 268.

Elyouncha, A., Eriksson, L. E. B., **Johnsen, H.** (2022) *Direct Comparison of Sea Surface Velocity Estimated From Sentinel-1 and TanDEM-X SAR Data.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 15, pp. 2425-2436, 2022, doi: 10.1109/JSTARS.2022.3158190.

Guo, W., Itkin, P., Lohse, J., Johansson, M., Doulgeris, A. (2022) *Cross-platform classification of level and deformed sea ice considering per-class incident angle dependency of backscatter intensity.* The Cryosphere 2022, 16(1):237-257.

Howell, S., Babb, D. G., **Landy, J.,** Brady, M. (2022) *Multi-Year Sea Ice Conditions in the Northwest Passage: 1968–2020.* Atmosphere-Ocean 2022.

Itkin, P., Divine, D., Steer, A., **Jenssen, R.-O. R.** (2022): *On the shoulders of giants.* Fram Forum 2022.

Khachatrian, E., Sandalyuk, N. V. (2022): *On the Exploitation of Multimodal Remote Sensing Data Combination for Mesoscale/ Submesoscale Eddy Detection in the Marginal Ice Zone.* IEEE Geoscience and Remote Sensing Letters 2022, 19.

Landy, J., Dawson, G., Tsamados, M., Bushuk, M., Stroeve, J. C., Howell, S., Krumpen, T., Babb, D. G., Komarov, A. S., Heorton, H., Belter, H. J., Aksenov, Y. (2022) *A year-round satellite sea-ice thickness record from CryoSat-2.* Nature 2022, 609(7927): 517-522.

Liu, M., Shi, Q., **Marinoni, A.,** He, D., Liu, X., Zhang, L. (2022) *Super-Resolution-Based Change Detection Network with Stacked Attention Module for Images with Different Resolutions.* IEEE Transactions on Geoscience and Remote Sensing 2022, 60.

Mallett, R., Stroeve, J. C., Tsamados, M. Willatt, R., Newman, T., Nandan, V., **Landy, J., Itkin, P.,** Oggier, M., Jaggi, M., Perovich, D. (2022) *Sub-kilometre scale distribution of snow depth on Arctic sea ice from Soviet drifting stations.* Journal of Glaciology 2022, 68(271): 1014-1026.

O'Sadnick, M., Petrich, C., Brekke, C., Skardhamar, J., Kleven, Ø. (2022) *Ice conditions in northern Norwegian fjords: Observations and measurements from three winter seasons,* 2017–2020. Cold Regions Science and Technology 2022: 204,1-20.

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

Rabault, J. et al. (2022) *OpenMetBuoy-v2021: An Easy-to-Build, Affordable, Customizable, Open-Source Instrument for Oceanographic Measurements of Drift and Waves in Sea Ice and the Open Ocean.* Geosciences 2022, 12(3).

Ratha, D., Marinoni, A., Eltoft, T. (2022) *A Generalized Geodesic Distance-Based Approach for Analysis of SAR Observations Across Polarimetric Modes.* IEEE Transactions on Geoscience and Remote Sensing 2022, 61.

Ratha, D., Johansson, M., Marinoni, A., Eltoft, T. (2022) *Performance Analysis of Roll-Invariant PolSAR Parameters from C-band images with Regard to Sea Ice Type Separation.* Electronic proceedings (EUSAR) 2022.

Taelman, C., Chlaily, S., Khachatrian, E., Van Der Sommen, F., **Marinoni, A.** (2022) *On the Exploitation of Heterophily in Graph-Based Multimodal Remote Sensing Data Analysis.* CEUR Workshop Proceedings 2022.

Other publications

Cristea, A., Johansson, M., Doulgeris, A. (2022) *Automatic detection of newly formed sea ice and lookalikes in the Barents Sea using Wide-Swath Synthetic Aperture Radar*. ESA Living Planet Symposium.

Dierking, W., Schneider, A., Eltoft, T., Gerland, S. (Eds.) (2022) CIRFA Cruise 2022. Cruise Report. UiT, Department of Physics and Technology. 123 pp. doi:10.5281/zenodo.7314066.

Farch, L., Dierking, W., Doulgeris, A., Hughes, N. (2022) A comparison of Backscatter Intensity of Icebergs in C- and L-band SAR Imagery. EGU General Assembly.

Farch, L., Dierking, W. (2022) *Comparison of CFAR algorithms for detection of icebergs in SAR imagery*. 2022 DRAGON 5 mid-term results symposium.

Gerland, S., Divine, D., Granskog, M., **Itkin, P., Johansson, M.,** Steer, A., **Cristea, A.,** Jaggi, M., Schneebeli, M. (2022) *Coordinated SAR satellite observations, airborne and ground surveys over Arctic sea ice and snow for different seasons*. Living Planet Symposium.

Johansson, M., Dierking, W. (2022): *POLSAR/Multifrequency Theme 3: Sea ice and ocean*. Second Workshop on International Coordination for Spaceborne Synthetic Aperture Radar.

Johansson, M., Lohse, J. (2022): *Arctic sea ice monitoring using synthetic aperture radar satellite imagery at C- and L-band frequency.* Arctic Science Summit Week.

Johansson, M., Singha, S., Spreen, G., Howell, S., Sobue, S., Davidson, M. (2022) *Fully polarimetric L- and C-band Synthetic Aperture Radar data analysis from the yearlong MOSAiC expedition.* ESA Living Planet Symposium.

Johansson, M. (2022): *Disaster Assessment Using Synthetic Aperture Radar: Part 3 – Oil Spill Detection.* NASA Arset Lecture Series.

Lohse, J., Dierking, W., Johansson, M., Doulgeris, A., Taelman, C. (2022): *Towards combining C-and L-band SAR imagery for operational sea ice type classification.* Living Planet Symposium; 2022-05-23 - 2022-05-27

Lohse, J., Eltoft, T., Khaleghian, S., Wang, Q. (2022) *Sea ice classification methodologies developed in CIRFA*. Arctic Science Summit Week.

Lohse, J., Dierking, W. (2022) *Towards combining C- and L-band SAR imagery for automated sea ice classification.* International Ice Charting Working Group Meeting.

Marinoni, A. (2022) *Multimodal AI for climate change adaptation and mitigation.* Norway-Singapore science week.

Quigley, C., Johansson, M., Jones, C. E. (2022) *An alternative approach for calculating the SAR damping ratio of verified oil slicks.* IEEE International Geoscience and Remote Sensing Symposium.

Quigley, C., Johansson, M., Serov, P., **de Aguiar, V.,** Winsborrow, M., Mattingsdal, R., Stetzler, M. (2022) *Satellite detection and drift estimates of naturally occurring oil seeps in the Barents Sea.* Arctic Science Summit Week.

Steer, A., Cristea, A., Divine, D., Gerland, S. (2022) *Filling in gaps: fusing high resolution imagery products from remotely piloted aircraft (RPA) and on-ground measurements to understand the spatial distribution of sea ice morphological features at sub-floe scale.* Living Planet Symposium.

Taelman, C., Lohse, J., Khachatrian, E., Marinoni, A., Cremers, S. (2022) *Semi-automated classification of sea ice types using C- and L-band SAR data.* Living Planet Symposium.

Wang, Q., Doulgeris, A. P., Eltoft, T. (2022) *Physics-Aware Training Data to Improve Machine Learning for Sea Ice Classification from Sentinel-1 SAR Scenes.* IEEE International Geoscience and Remote Sensing Symposium.

2023

Peer-reviewed publications

Chlaily, S., Ratha, D., Lozou, P., Marinoni, A. (2023) *On Measures of Uncertainty in Classification*. IEEE Transactions on Signal Processing 2023: 71. 3710-3725.

Dawson, G. J., **Landy, J. C.** (2023) *Comparing elevation and backscatter retrievals from CryoSat-2 and ICESat-2 over Arctic summer sea ice.* The Cryosphere 2023: 17(9). 4165-4178.

de Rijke T. C., **Landy, J. C.**, Mallett, R., Willatt, R., Tsamados, M., King, J. (2023) *Airborne Investigation of Quasi-Specular Ku-Band Radar Scattering for Satellite Altimetry Over Snow-Covered Arctic Sea Ice*. IEEE Transactions on Geoscience and Remote Sensing 2023: 61.

Demchev, D., Eriksson, L. E. B., Hildeman, A., **Dierking, W.** (2023) *Alignment of Multifrequency SAR Images Acquired over Sea Ice Using Drift Compensation.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 16: 7393-7402.

Eltoft, T., Johansson, M., Lohse, J., Ferro-Famil, L. (2023) *Analysis of Time Series of Polarimetric Sea Ice Signatures Observed In Fast Ice in the Belgica Bank Area.* IEEE International Geoscience and Remote Sensing Symposium proceedings 2023: 176-178.

Færch, L., Dierking, W. F. O., Hughes, N, Doulgeris, A. P. (2023) *A comparison of constant false alarm rate object detection algorithms for iceberg identification in L- and C-band SAR imagery of the Labrador Sea.* The Cryosphere 2023: 17(12). 5335-5355.

Laurent, F.F., Boutet, F, Avrillon, S, **Dierking, W., Eltoft, T., Itkin, P., Johansson, M., Landy, J., Lohse, J.** (2023) *Overview of Ground-Based Radar Measurements of Snow-Covered Sea-Ice Led During the 2022 CIRFA Arctic Cruise*. IEEE International Geoscience and Remote Sensing Symposium proceedings 2023, 64-66.

Glissenaar, I. A., **Landy, J. C.**, Babb, D.G., Dawson, G. J., Howell, S.E.L. (2023) *A long-term proxy for sea ice thickness in the Canadian Arctic: 1996-2020*. The Cryosphere 2023: 17(8). 3269-3289.

Guo, W., Itkin, P., Singha, S., **Doulgeris, A. P., Johansson, M.**, Spreen, G. (2023) *Sea ice classification of TerraSAR-X ScanSAR images for the MOSAiC expedition incorporating per-class incidence angle dependency of image texture.* The Cryosphere 2023: 17(3). 1279-1297.

Idzanovic, M., Rikardsen, E., Röhrs, J. (2023) *Forecast uncertainty and ensemble spread in surface currents from a regional ocean model.* Frontiers in Marine Science 2023: 10.

Iversen, S. C., Sperrevik, A. K., Goux, O. (2023) *Improving sea surface temperature in a regional ocean model through refined sea surface temperature assimilation.* Ocean Science 2023: 19(3). 729-744.

Jones, C.E. (2023) *An automated algorithm for calculating the ocean contrast in support of oil spill response.* Marine Pollution Bulletin, 191, Art. no. 114952. https://doi.org/10.1016/j.marpolbul.2023.114952.

Khachatrian, E., Dierking, W., Chlaily, S., Eltoft, T., Dinessen, F., **Hughes, N., Marinoni, A.** (2023) *SAR and Passive Microwave Fusion Scheme: A Test Case on Sentinel-1/AMSR-2 for Sea Ice Classification.* Geophysical Research Letters 2023: 50(4). 1-7.

Khachatrian, E., Sandalyuk, N. V., **Lozou, P.** (2023) *Eddy Detection in the Marginal Ice Zone with Sentinel-1 Data Using YOLO v5.* Remote Sensing 2023: 15(9).

Lohse, J., Taelman, C., Everett, A., **Hughes, N.** (2023): *Automated Sentinel-1 ice type mapping and in-situ validation during the CIRFA-22 cruise.* Manuscript in review with Annals of Glaciology.

Martins de Aguiar, V. C., Röhrs, J., Johansson, M., Eltoft, T. (2023) *Assessing ocean ensemble drift predictions by comparison with observed oil slicks.* Frontiers in Marine Science 2023: 10. 1-15.

Nandan, Vishnu et al. (2023) *Wind redistribution of snow impacts the Ka- and Ku-band radar signatures of Arctic sea ice.* The Cryosphere 2023: 17(6). 2211-2229.

Negrel, J., Divine, D., **Gerland, S.** (2023) *Spline-based helicopter movement filter for sea ice surface topography estimation from airborne laser range finder*. Zenodo 2023.

O'Sadnick, M., Petrich, C., Skardhamar, J. (2023) *Tracking changes in the fjord environment over a winter season using ice bulk salinity and 18O.* Cold Regions Science and Technology 2023: 208.

Quigley, C. P., Johansson, M., Jones, C. E. (2023) *An Investigation on the Damping Ratio of Marine Oil Slicks in Synthetic Aperture Radar Imagery.* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 2023: 16. 5488-5501.

Quigley, C., Johansson, M., Jones, C. E., Garcia, Ó., Monaldo, F. (2023) *A Comparison Between Oil-to-water Volumetric Fractions Derived From L-Band Synthetic Aperture Radar Imagery and in-situ Samples.* IEEE International Geoscience and Remote Sensing Symposium proceedings 2023.

Rabault, J. et al. (2023) *A dataset of direct observations of sea ice drift and waves in ice.* Scientific Data 2023: 10.

Röhrs, J. et al. (2023) *Barents-2.5km v2.0: an operational data-assimilative coupled ocean and sea ice ensemble prediction model for the Barents Sea and Svalbard.* Geoscientific Model Development 2023: 16(18). 5401-5426.

Röhrs, J., Halsne, T., Sutherland, G., **Dagestad, K.-F.**, Hole, L. R., Brostrøm, G., **Christensen, K. H.** (2023) *Current shear and turbulence during a near-inertial wave.* Frontiers in Marine Science 2023: 10.

Sandven, S., Spreen, G., Heygster, G., Girard-Ardhuin, F., Farrell, S. L., **Dierking, W.F.O.,** Allard, R. A. (2023) *Sea Ice Remote Sensing—Recent Developments in Methods and Climate Data Sets.* Surveys in Geophysics 2023: 44. 1653-1689.

Swirad, Z., **Johansson, M.**, Malnes, E. (2023) *Extent, duration and timing of the sea ice cover in Hornsund, Svalbard in 2014–2023.* The Cryosphere Discussions 2023.

Taelman, C., Lohse, J., Johansson, M., Olsen, S., Rabault, J., Eltoft, T. (2023) *In-situ drift and wave observations of sea ice, icebergs and open ocean in the Greenland Sea.* DataverseNO 2023.

Wang, Q., Lohse, J., Doulgeris, A. P., Eltoft, T. (2023) *Data Augmentation for SAR Sea Ice and Water Classification Based on Per-Class Backscatter Variation With Incidence Angle*. IEEE Transactions on Geoscience and Remote Sensing 2023: 61.

Other publications

Eltoft, T., Dierking, W. (2023) CIRFAEx. Research cruise to Belgica Bank, Northeast Coast of Greenland to Support the Development of ROSE-L and S1NG. Deliverable D3: Data processing, quality assessment, tools and campaign data analysis. Version 1.0. ESA CONTRACT RFP/3-17845/22/NL/FF/ab.

Eltoft, T., Ratha, D., Ferro-Famil, L. (2023) *Polarimetric Signatures for the Analysis of Fast Sea Ice in the Belgica Bank Area.* ESA Polinsar Biomass 2023.

Johansson, M. (2023) *ARSET - SAR for Detecting and Monitoring Floods, Sea Ice, and Subsidence from Groundwater Extraction Part 1.* NASA ARSET Lecture Series 2023.

Johansson, M. Karlsen, T., Scharien, R. K. (2023) *Improved Arctic sea ice classification and thickness mapping using a multi-sensor approach.* JAXA ALOS-2/-4 PI meeting.

Johansson, M. (2023) *Detection of oil spill from satellites in ice covered regions.* Arctic Frontiers.

Johansson, M., Jones, C. E. (2023) *The use of SAR images to aid harmful algae bloom monitoring in the Baltic Sea.* International Geoscience and remote sensing symposium.

Johansson, M., Singha, S., Scharien, R. K., Eltoft, T., Howell, S., Spreen, G. (2023) *Sea ice type separation using the polarization difference in high resolution C- and L-band SAR images.* International Symposium on Sea Ice 2023.

Karlsen, T., Johansson, M., Lohse, J., Dierking, W. (2023) *Arctic sea ice monitoring using C- and L-band SAR – how multi-frequency SAR can support a changing Arctic.* Arctic Frontiers.

Korosov, A., Johansson, M., Shuchman, R., Dierking, W., Kwok, R. (2023) *Plenary Presentation and Discussion Theme 4: Sea Ice Retrievals.* SeaSAR 2023.

Lohse, J., Taelman, C., Everett, A., Hughes, N. (2023) *Fully-automated navigation support for vessels in the Arctic: An application and validation example of ice type mapping during the CIRFA cruise 2022.* 11th International Workshop on Sea Ice Modelling, Assimilation, Observations, Predictions and Verification.

Marinoni, A., Chambon, Q., Plaza, A., Rottman, S., Shimoni, M., Hall, R. (2023) *On the robustness and reliability of target detection in remote sensing.* International Conference On Microwaves, Communications, Antennas, Biomedical Engineering & Electronic Systems.

Marinoni, A., Mercier, M., Shi, Q., Selvakumaran, S., Girolami, M. A. (2023) *Incorporating reliability in graph information propagation by fluid dynamics diffusion: a case of multimodal semisupervised deep learning.* IEEE International Conference on Acoustics, Speech and Signal Processing.

Meraoumia, I., Ratha, D., Dalsasso, E., Denis, L., Tupin, F., Marinoni, A. (2023) *Despeckling of dual-pol GRD Sentinel-1 images in extra-wide mode by deep learning.* IEEE International Geoscience and Remote Sensing Symposium 2023.

Rabault, J. et al. (2023) *Collecting Marginal Ice Zone ground truth observations: recent deployments, data use, and outstanding questions.* 11th International Workshop on Sea Ice Modelling, Assimilation, Observations, Predictions and Verification.

Ratha, D., Doulgeris, A. P., Marinoni, A., Eltoft, T. (2023) *On Importance of Off-Diagonal Elements in the Polarimetric Covariance Matrix: A Sea Ice Application Perspective.* ESA Polinsar Biomass 2023.

Rolland, I., Selvakumaran, S., Marinoni, A. (2023) *Remote Sensing Image Completion Using a Diffusion-Based Propagation Algorithm.* SPIE Remote sensing.

Swirad, Z., Johansson, M., Malnes, E. (2023) *Ice distribution in Hornsund fjord, Svalbard from Sentinel-1A/B (2014-2023).* Pangaea 2023.

Swirad, Z., Herman, A., Johansson, M., Rees, G., Moskalik, M. (2023) *Incorporating sea ice into a nearshore wind wave transformation model (Hornsund, Svalbard).* 11th International Workshop on Sea Ice Modelling, Assimilation, Observations, Predictions and Verification.

Swirad, Z., Johansson, M., Malnes, E. (2023): *High-resolution near-daily sea ice distribution in Hornsund, Svalbard in 2014-2023.* AGU 2023.

Swirad, Z., Moskalik, M., Herman, A., Johansson, M., Rees, G. (2023) *Sea ice, wind waves and coastal erosion in Hornsund, Svalbard.* EGU 2023.

Telegina, A., Dierking, W., Doulgeris, A. P., Demchev, D. (2023) *Methodology for prediction of ice conditions based on SAR mages and model sea ice drift data.* 11th International Workshop on Sea Ice Modelling, Assimilat.

Telegina, A., Doulgeris, A. P., Dierking, W., Demchev, D., Korosov, A. (2023) *Prediction of sea ice conditions using Sentinel 1 imagery and sea ice drift forecast. Methodology and accuracy assessment.* International Symposium on Sea Ice 2023.

Telegina, A., Doulgeris, A. P., Dierking, W., Korosov, A., Demchev, D. (2023) *Short term prediction of ice conditions: an integration of SAR Imagery and model derived sea ice drift data.* 24th Meeting of The International Ice Charting Working Group.

Wang, Q., Johansson, M., Lohse, J., Doulgeris, A. P., Eltoft, T. (2023) *The impact of input features in deep learning-based sea ice mapping.* SEASAR 2023 ESA workshop.

2024

Peer-reviewed publications

Færch, L., Dierking, W. F. O., Hughes, N, Doulgeris, A. P. *Mapping Icebergs in Sea ice: An Analysis of Seasonal SAR Backscatter at C- and L-band*. Manuscript in review with Remote Sensing of Environment.

Swirad, Z., **Johansson, M.**, Malnes, E. (2024): *Extent, duration and timing of the sea ice cover in Hornsund, Svalbard in 2014–2023.* The Cryosphere 2024.

Tollinger, M., Graversen, R.G. (2024) *Validation of a SAR-Only Wind-Vector Retrieval Against Shipborne In Situ Wind Observations in the European Arctic*. IEEE Transactions on Geoscience and Remote Sensing, 62, pp. 1-11, Art no. 4101611, doi: 10.1109/TGRS.2024.3349693.

Other publications

Swirad, Z., **Johansson, M.**, Malnes, E. (2024) *Sea ice present, extent and duration in Hornsund, Svalbard in 2014-2023.* Arctic Frontiers 2024.

de Aguiar, V., Idžanović, M., Röhrs, J., Johansson, M., Olsen, S. V., Rabault, J., Rikardsen, E., Rusin, J., Durán Moro, M., Dagestad, K.-F., Hope, G., Serov, P. (2024) *Drifter trajectories in the Fram Strait and Barents Sea.* https://doi.org/10.18710/EPB9AG, DataverseNO, V1.

Christian Zoelly, NPI

Financing through the lifetime of the center

1/3 Distribution of resources

This table contains information on amounts that were spent common center activities to enhance cohesiveness at the centre, internationalization, work package leader support, research equipment, the CIRFA-2022 expedition cruise, and personnel costs for the administrative coordinator.

Amounts are rounded estimates, in 1 000 NOK.

Type of activity	NOK
Research projects	198 642
Common center activities (annual meetings, dialogue meetings, board meetings, etc.)	3 120
Travel to conferences, workshops and meetings, travel affiliated staff to visit CIRFA	1 900
Young Scientist Forum	240
Internationalization (affiliated staff in Germany: Wolfgang Dierking, and the USA: Cathleen Jones; support for international students)	2 180
Work package leader (support for research stays, courses, etc)	1 963
WP 1	295
WP 2	321
WP 3	676
WP 4	150
WP 5	235
WP 6	155
WP 7	131
Research equipment, fieldwork/experiments, travel to fieldwork (all WP`s)	3 300
CIRFA-2022 expedition cruise - *RV Kronprins Håkon*	1 900
Travel mainland-Svalbard t/r inkl. overnatting/ mat/social for 33 participants	1 000
Cruise workshops (1 digital, 2 in person + social)	56
Administration (admin. coordinator)	5 500
Total	**219 801**

2/3 Summary sheet for the main categories of partners, in 1 000 NOK.

Contributor	Cash	In-kind	Total
Host		48 345	**48 345**
Research partners		26 176	**26 176**
Companies	39 400	9 879	**49 279**
Public partners			**0**
RCN	96 000		**96 000**
Sum	**135 400**	**84 400**	**219 801**

3/3 Statement of accounts for the complete period of centre financing, in 1 000 NOK.

Funding and cost summarised for the entire centre period (next page).

Wenkai Guo, UiT

Funding

	RCN	UiT	Aker BP	Aker Solution	Aranica	Vår Energi	Globesar	KSAT	Maritime Robotics	MET Norway
WP1	7 968	286	0	65	0	134	0	0	369	0
WP2	16 794	13 864	0	0	0	6 998	0	0	9	0
WP3	15 290	12 393	1 038	0	0	1 185	0	2 000	0	0
WP4	12 910	3 612	5 299	0	123	18	0	0	205	0
WP5	13 889	6 263	1 663	389	0	15	0	0	0	8 935
WP6	3 085	287	0	0	0	11	0	0	0	0
WP7	9 732	2 327	0	0	0	11	0	2 531	0	0
WP0	16 329	9 311	110	0	0	290	0	0	0	119
Sum	**96 000**	**48 345**	**8 110**	**455**	**123**	**8 663**	**0**	**4 531**	**584**	**9 054**

Costs

		UiT	Aker BP	Aker Solution	Aranica	Vår Energi	Globesar	KSAT	Maritime Robotics	MET Norway
WP1		327	0	65	0	134	0	0	369	0
WP2		30 688	0	0	0	105	0	0	9	0
WP3		26 287	0	0	0	78	0	0	0	0
WP4		3 691	0	0	123	18	0	0	205	0
WP5		11 069	0	389	0	15	0	0	0	20 764
WP6		624	0	0	0	11	0	0	0	486
WP7		12 619	0	0	0	11	0	2 531	0	0
WP0		30 816	110	0	0	290	0	0	0	907
Sum		**116 122**	**110**	**455**	**123**	**663**	**0**	**2 531**	**584**	**22 157**

Multi-consult	Nansen	Sintef Narvik	NORCE	NTNU	OMV	NPI	Spacetec	Equinor	Total E&P Norge AS
0	0	0	1 793	0	0	0	0	319	3 270
870	593	0	0	0	117	1 541	74	508	335
1 200	0	1 989	0	0	0	0	0	273	1 030
0	0	0	5 695	1 443	0	0	0	255	0
0	0	0	0	222	4 037	0	0	294	0
0	0	0	0	0	1 266	3 361	0	204	48
0	0	0	411	0	2 696	0	120	1 657	0
91	0	0	71	0	805	0	0	7 018	315
2 161	**593**	**1 989**	**7 970**	**1 666**	**8 922**	**4 902**	**194**	**10 532**	**5 001**

Multi-consult	Nansen	Sintef Narvik	NORCE	NTNU	OMV	NPI	Spacetec	Equinor	Total E&P Norge AS
0	0	0	12 990	0	0	0	0	319	0
870	3 804	0	0	0	117	5 193	74	508	335
0	0	9 661	0	0	0	0	0	273	101
0	0	0	20 300	4 970	0	0	0	255	0
0	0	0	0	3 178	0	0	0	294	0
0	0	511	0	0	0	6 379	0	204	48
0	0	0	3 846	0	0	0	120	359	0
91	0	0	533	0	805	276	0	316	315
962	**3 804**	**10 172**	**37 669**	**8 147**	**922**	**11 849**	**194**	**2 532**	**801**

10.5281/zenodo.10785642

Photo: Sebastian Gerland, NPI