Integrated Arctic Observation System

Research and Innovation Action under EC Horizon2020
Grant Agreement no. 727890

Project coordinator:
Nansen Environmental and Remote Sensing Center, Norway

Deliverable 6.24

Use of drones for sea ice observations

Start date of project:	01 December 2016	Duration:	63 months
Due date of deliverable:	31 October 2021	Actual submission date:	15 November 2021
Lead beneficiary for preparing the deliverable:		NORCE	
Person-months used to produce deliverable:		3 PM	

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Version	DATE	CHANGE RECORDS	LEAD AUTHOR
1.0	20/01/2020	First draft	TRL
1.0	28/10/2021	Complete draft	RST
1.1	29/10/2021	Final version	TRL
1.2	31/10/2021	Technical review and formatting	K Lygre
1.3	2/11/2021	Final review	T Hamre
1.4	15/11/2021	Submitted	Stein Sandven

Approval	Date:	Sign. Stein Sandven
X	15 November 2021	Coordinator

USED PERSON-MONTHS FOR THIS DELIVERABLE					
No	***Beneficiary***	***PM***	***No***	***Beneficiary***	***PM***
1	NERSC		**24**	TDUE	
2	UiB		**25**	GINR	
3	IMR		**26**	UNEXE	
4	MISU		**27**	NIVA	
5	AWI		**28**	CNRS	
6	IOPAN		**29**	U Helsinki	
7	DTU		**30**	GFZ	
8	AU		**31**	ARMINE	
9	GEUS		**32**	IGPAN	
10	FMI		**33**	U SLASKI	
11	UNIS		**34**	BSC	
12	NORDECO		**35**	DNV GL	
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14	USFD		**37**	NIERSC	
15	NUIM		**38**	WHOI	
16	IFREMER		**39**	SIO	
17	MPG		**40**	UAF	
18	EUROGOOS		**41**	U Laval	
19	EUROCEAN		**42**	ONC	
20	UPM		**43**	NMEFC	
21	UB		**44**	RADI	
22	UHAM		**45**	KOPRI	
23	NORUT	***3***	**46**	NIPR	
			47	PRIC	

DISSEMINATION LEVEL		
PU	Public, fully open	X
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EXECUTIVE SUMMARY

During the CAATEX KV Svalbard cruise 14/8–9/9, 2019 to the North Pole, NORCE operated a fixed-wing unmanned aircraft system (UAS), which was used to collect high-precision optical imagery, providing information about ice morphology and sea-ice properties. Furthermore, NORCE operated an ultra-wideband radar system on a multirotor UAS platform in collaboration with UiT and CIRFA. The radar, which can detect layers in the snow and ice, was operated along selected profiles where also snow and ice samples were collected (Norwegian Polar Institute).

In addition, NORCE operated an imaging radar on board KV Svalbard. The radar system, which was mainly operated during the periods where the vessel was stationary in the ice, provided information about ice drift and ice conditions. The main objective of the experiment was to collect observations of sea ice drift and ice coverage and type, at different positions along the route up to 90°N. In addition to the science data collection, the potential of using a high-resolution imaging Ku-band radar for navigation in ice-infested waters was also demonstrated. During the cruise, CIRFA tasked high-resolution Radarsat-2 satellite SAR scenes which were used during the cruise for navigation. NORCE also participated in daily processing and interpretation of satellite SAR imagery from Sentinel-1, which was instrumental in the navigational decision-making process.

This combination of data was collected to develop a real-time ice navigation support system. The campaign was co-financed by the Research Council of Norway (RCN) projects ARCEx, CAATEX and CIRFA in addition to the INTAROS Horizon2020 project and the RESICE project funded by the Norwegian Ministry of Climate and Environment. The results formed the foundation for the Project Digital Arctic Shipping, a bilateral Norway-China project on developing a drone and satellite-based ice navigation support system. Key stakeholders will be ship operators wanting to use the northern sea routes for transport between the far east and Europe as well as expedition cruise operators and fishing vessels operating close to the ice edge.

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1. Introduction

NORCE together with UiT Arctic University of Norway, Met.no and Norwegian Polar Institute (NPI) took part in the NERSC led CAATEX cruise with *KV Svalbard*. The scientific goal of NORCE during this cruise was to collect sea-ice data using drones to develop a real-time operational sea-ice navigation support system combining, sea-ice data from drones with ship-based radar and satellite data. The data would be combined by a NORCE developed situational awareness system (NLive) fusing data in real-time and visualizing it for the navigators. This ambitious scope was made possible through combining efforts through the RCN projects ARCEx, CAATEX and CIRFA in addition to the INTAROS Horizon2020 project and the RESICE project. Particular sea-ice properties of interest were ice ridges, leads, snow depth on ice and ice-ridge heights.

2. Data Collection Systems

As part of the CAATEX cruise, we operated different Unmanned Aircraft Systems (UAS) and radar systems, described in this section.

Parrot Disco fixed-wing drone

We operated two Parrot Disco fixed-wing drones. The Parrot Disco has a wingspan of 1.15 m and the low weight of 750 gram provides an endurance up to 45 minutes. The system has auto takeoff and landing. One of the Parrot Disco systems carried a nadir-looking optical camera with an onboard GPS receiver. Both platforms had a nose-camera for navigational purposes.


Figure 1. Left: Parrot Disco fixed-wing drone. Right: NORCE Fox multirotor drone.

NORCE 'Fox' multi rotor drone

The unmanned aerial vehicle (UAV) used to carry the ultra-wideband snow sounder (UWiBaSS) is a purpose-built X8 multicopter called 'Fox'. The 'Fox' can lift a maximum payload of 25 kg. Each of the eight motors (U11, 120KV) has a maximum rated thrust of 12.3 kg using 27" propellers. For navigation and control, a 'Cube Black' running ArduCopter is used. An SF11 laser rangefinder, accurately measures the distance to the ground. It is set up with a 'Here+' real-time kinematic (RTK) global positioning system (GPS) providing much more accurate position estimates than regular GPS. The positioning system has relative and absolute accuracy below 10 cm and 1 m respectively, in single-channel mode, given the distance to the base station is less than 20 km. This also provides autonomous flights that have been tested at above ground altitudes as low as 1 m.

Gamma Portable Radar Interferometer (GPRI)

The Gamma Portable Radar Interferometer (GPRI) is a frequency-modulated continuous-wave (FM-CW) interferometric real aperture radar operating in the frequency range of 17.1–17.3 GHz (Werner et al., 2012). The three real aperture antennas are mounted on a rigid 1-meterhigh tower mounted on a precision rotational scanner (Figure 2). The radar image is built up line by line by azimuthally rotating the antennas about the vertical axis. The two receiving antennas are separated vertically forming a spatial interferometer useful for measurement of height information. The spatial resolution is 0.75 m in range and 7 m in azimuth at 1 km (12.6 m at 1 NM) distance. By rotating the antenna tower, images are formed at second to minute intervals.

The phase difference of the images received by the two receiving antennas can be used to precisely measure the elevation of the targets (Strozzi, 2012). Because two images are created simultaneously, an elevation model of the entire scene, can be created; there are no atmospheric artifacts; and there is no need to separate motion from topography. The expected standard deviation in height is on the order of 0.4 m at 500 m distance, and 1.5 m at 1 NM distance. It is also well demonstrated that the GPRI radar can detect ice floes and icebergs, and to monitor their dynamics over time (Voytenko et al., 2015).

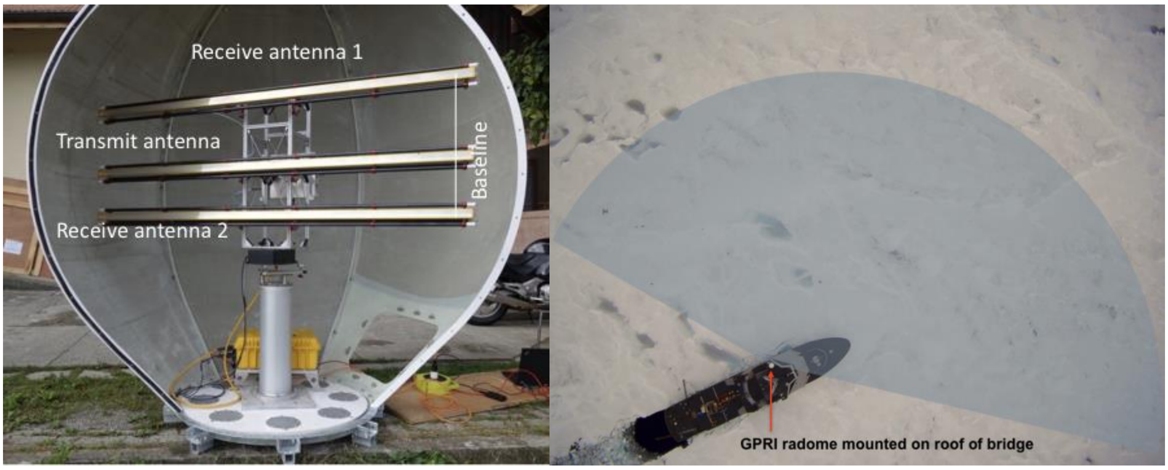

Figure 2. Left: The GPRI radar system consists of three rotating antennas, mounted inside a protective radome. The spatial baseline between the antennas provide sensitivity to topography. Right: The radome was mounted on the bridge roof on the forward port side. The shaded field shows the field of view of the radar. Note that the radar operated up to a distance of ca. 4 km in range.

UWiBaSS drone mounted radar

The ultra-wide band snow sounder (UWiBaSS) is a ground penetrating radar system developed for drone mounted operations. The radar system was designed with focus on low payload weight to fulfill UAV mounting and high range resolution requirements for snow measurements, contributing to the relatively new field of UAV mounted instrumentation. The UWiBaSS will enable autonomous, drone-based measurements of snow-cover over large and hard-to-reach regions. The radar transmits a 6 GHz bandwidth pseudo noise signal that can penetrate dry and wet snow as well as resolving thing layer in the snow stratigraphy.

Figure 3. UWiBaSS mounted under CryoCopter FOX

3. Experiments carried out during CAATEX/INTAROS cruise

GPRI Ku-band radar observations

The GPRI Ku-band radar system was installed in a protective radome on the port side of the bridge, see Figure 2. During the cruise, we operated the radar system under different vessel operating conditions:

- stationary in ice;
- under way open waters;
- under way in ice infested waters.

Due to mechanical stresses, the radar is not capable of operation during heavy seas or when the vessel is breaking ice. During transits in ice, the radar antennas were secured on the bridge roof. The radar was operated with a temporal sampling between 1 and 5 minutes, covering a sector of almost 180°. A total of 2447 radar images were collected at 17 different locations, see Figure 4. Figure 5 and Figure 6 shows examples of radar images captured while in the ice.

Fixed-wing drone operations

The fixed-wing drone was operated at 8 different ice stations. All operation was carried out from the ice. At a few locations the local conditions did not permit flying due to strong wind and/or icing conditions. The drone was operated in a controlled pattern, and all the acquired images have been combined by using structure-from-motion (SfM) to produce an orthomosaic, see Figure 6 for an example.

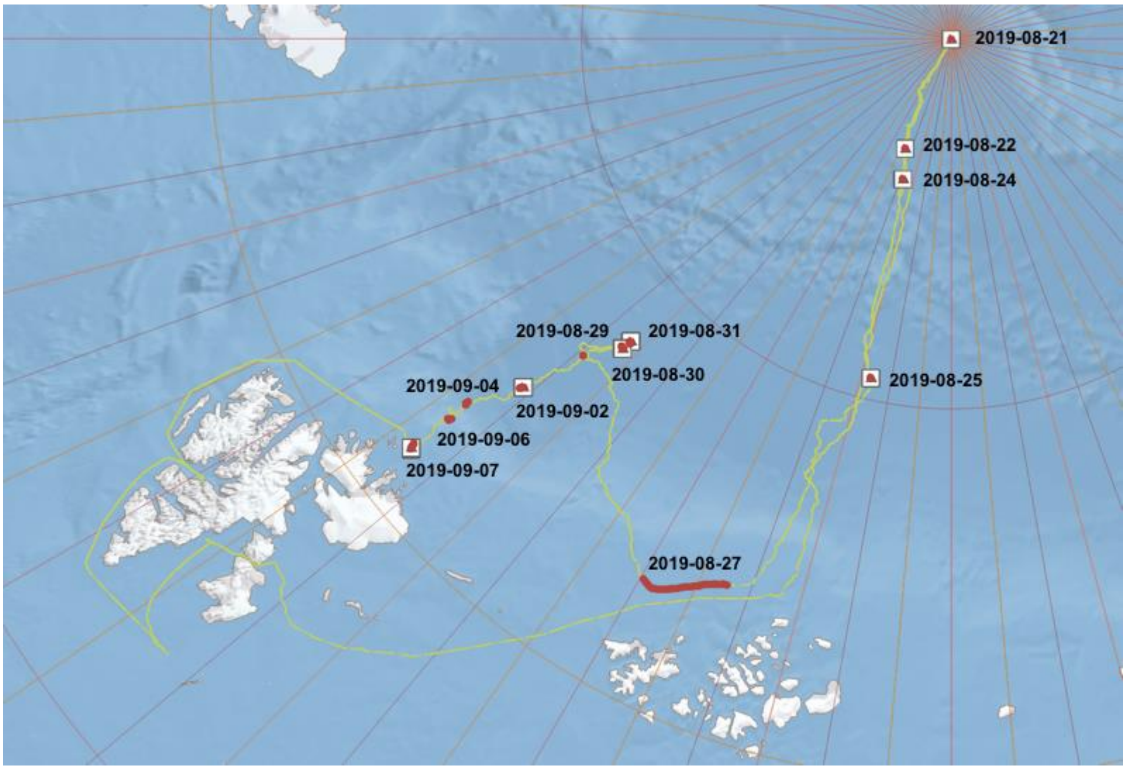

Figure 4. The figure shows the sailing route of KV Svalbard (green), locations of ice stations with UAS operations (white squares) and areas with GPRI radar operations (red).

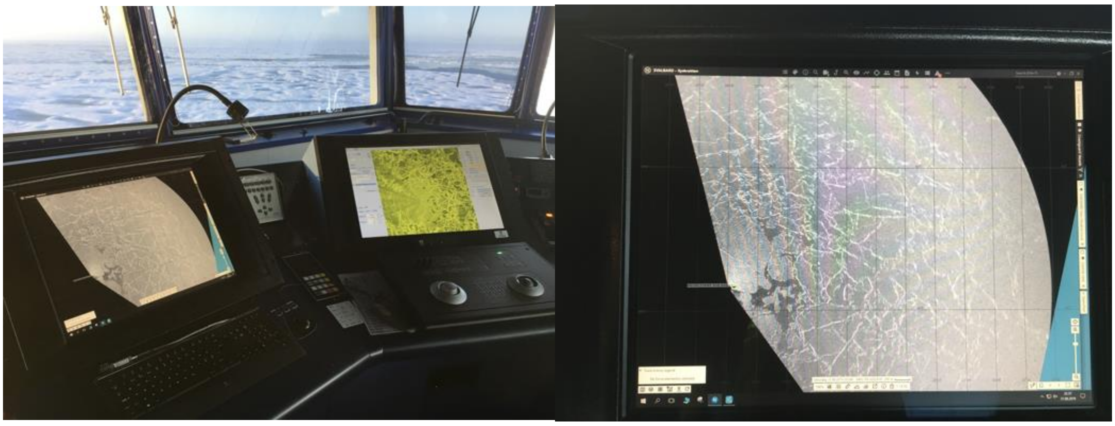

Figure 5. Left: The radar images from the GPRI Ku-band radar was integrated into the navigational system of the vessel (left monitor) to allow comparison with the traditional ship radar (right monitor). Right: a closeup of the GPRI radar visualization. Ridges are highly visible.

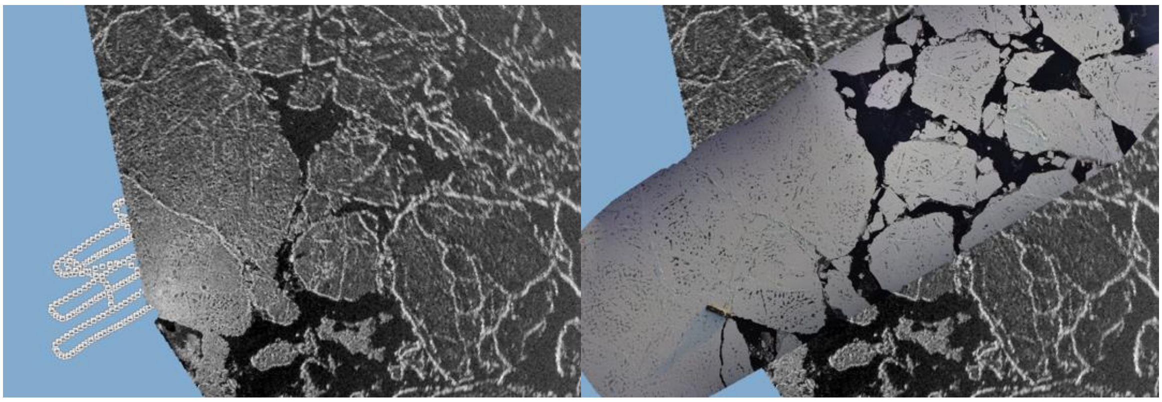

Figure 6. Left: A GPRI Ku-band radar image from 31.08.2019. Right: On top of the radar image is shown an orthomosaic produced by the fixed-wing UAS platform.

4. UWIBASS operations

The UWiBaSS was operated at each ice station except two, where the weather did not permit drone operations. At the remaining ice stations, the UWiBaSS was flown in 100–300 m transects where in situ freeboard, snow and ice thickness was collected in 20 m intervals.

Preliminary results from the UWiBaSS measurements show the detection of the increase in salinity which might be used to identify sea ice types. We will now look at an example dataset from ice station 4.

The salinity profile in Figure 7 shows that the ice starts to become saline at approximately 30 cm. The detected interface in the radar image (Figure 8) is varying between 10 and 40 cm. Based on the assessment from the ice experts working on the ice, this ice type was classified as second year ice. On second year ice we can expect to have a layer of ice with little to no salinity at the top and a sharp increase in salinity further down the ice. The thickness of the low salinity ice is expected to vary as seen in the radar image. This leads us to believe that the radar is measuring the thickness of second year ice, but not the thickness of first year ice, and therefore, not the total ice thickness.

There was no significant snow cover to measure during the campaign. However, the UWiBaSS have previously been verified as a snow measurement sensor in (Jenssen et. al, 2019). The ability to measure snow cover as well as the thickness of second (and most probably multiyear) ice could be used to identify different ice types and map composite ice sheets.

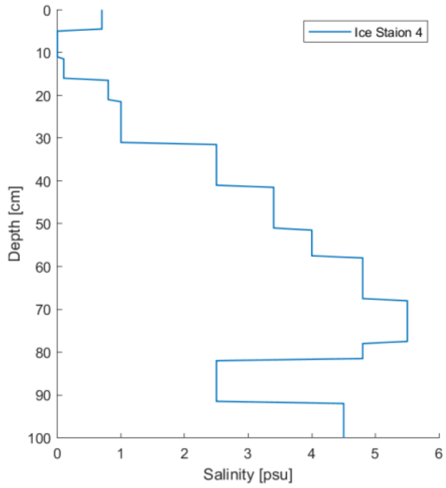

Figure 7. Ice Station 4. In situ salinity profile taken at approximately the center of the transect.

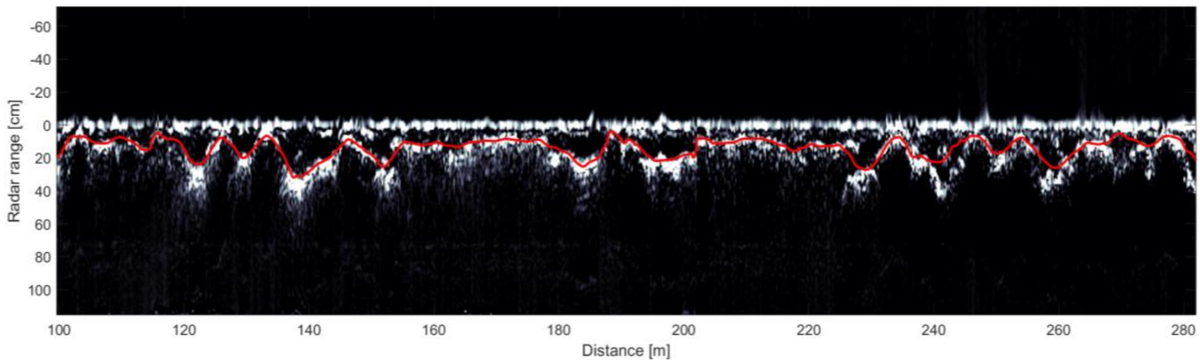

Figure 8. Ice station 4. Radar image showing the Air-Snow interface at 0 cm and a distinct interface at varying depth between 10 and 40 cm, marked with red line using a detection algorithm.

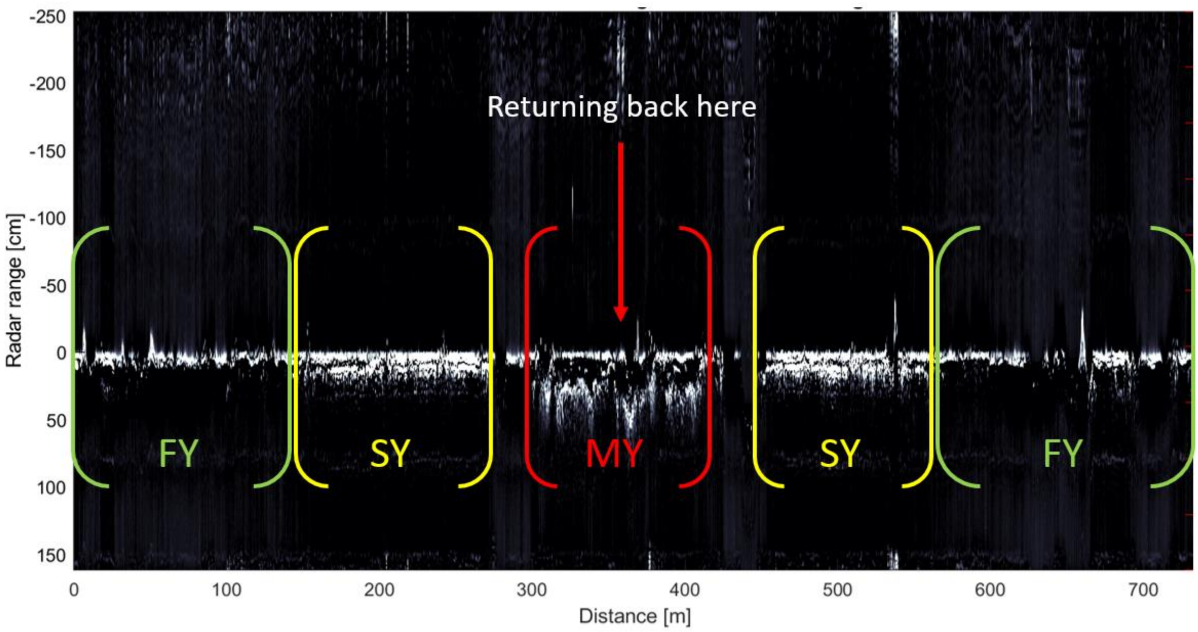

Figure 9. Ice station 7. Example of ice identification, with drone flying in transect back and forth. This interpretation needs more verification from sea ice experts, but three different regions is found.

5. Further Development and Exploitation of Project Results

This field work was used as background for seeking further funding and in 2020 NERSC and NORCE got funding from RCN to further develop these results into an ice navigation support system through the project "Digital Arctic Shipping - New data products and visualisation services" (coordinated by NERSC). The project also formed the basis for additional development and field validation and testing campaigns in 2020, 2021 and a planned final demonstration based out of the Norwegian research ice breaker Kronprins Haakon in late spring 2022, where a full demonstration of real-time operational support will be conducted based on satellite data, drift modelling using the BarentsROMS 2.5 km ice drift model provided by the Norwegian Meteorological Institute, supporting drone mission planning and data collection to improve accuracy in sea-ice property mapping and forecasting in a common visualization environment available on a ship bridge. NORCE is further developing on board processing capabilities on the drones that will allow data reduction and real-time satellite transfer of data hence extending the range of coverage drones may use.

6. Contribution to the iAOS Roadmap

This work will contribute to the development of a future sustainable observing system by laying the foundation for collection of important climate variables by developing sensor systems for retrieval of sea-ice morphology and sea-ice properties like leads, ridges, snow on ice, and drift that can be carried by inexpensive drone systems. Drones used in the project has limited range but could be operated efficiently from ships. Ships of opportunity using the systems being developed for ice navigation would also be able to support science by sharing the data collected. As for dedicated time series generation of Essential Climate Variables (ECVs), needs could be met through use of larger long range drone systems, that still are orders of magnitude more fuel efficient than manned aircraft or ship-based operations that are used today. The challenge of airspace access for these systems are being solved through the European Union Aviation Safety Agency (EASA) common drone regulation that took effect in 2020 and that are currently being implemented in the member states. On board near real-time processing of data intensive sensors and transfer in NRT through satellite communication will support more dynamic and model driven observations in the future, reducing number of expensive measurement platform like drones by exploiting their agility to create a self-optimizing infrastructure where sensors are dynamically placed where they are most needed (reduce the model output uncertainty the most). Ultimately enabling coordinated use of drones the future Pan-Arctic integrated Sustained Arctic Observing System (SAOS)

7. Conclusion

The experiment has demonstrated a novel use of an imaging radar system combined with drone-based operations for increased real-time situational awareness in support of sea-ice navigation. Comparison between a traditional marine radar and the ship mounted interferometric imaging radar demonstrates clear potential for improved characterization of ice conditions, as well as the need for tight integration with timely satellite SAR observations. Furthermore, the drone mounted UWiBaSS radar could be used to provide valuable information about sea ice types, being important to supplement and validate satellite SAR imagery. The wide area coverage compared to manual measurements provides a better understanding of snow backscatter variability in SAR images. The collected scientific dataset, using these sensors, has a great value for validation of satellite-based ice classification and segmentation algorithms, as well as providing novel information about sea ice dynamics at high temporal and spatial scales in near real-time. The use of inexpensive fixed wing drone allows for accurate mapping of leads and ridges beyond visual and radar line-of-sight from the vessel. The joint use of satellite, drones, and ship-based radar systems, coupled with ice drift models, is important to increase the situational awareness for the navigators. The *nLive* visualization and dissemination platform is now in operational use for different projects, e.g. by the European Maritime Safety Agency (EMSA) who is using drones for operational pollution monitoring, and where nLive is used for visualisation and dissemination of data. Key stakeholders for further use of the system will be ship operators wanting to use the northern sea routes for transport between the far east and Europe as well as expedition cruise operators and fishing vessels operating close to the ice edge.

8. References

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This report is made under the project
Integrated Arctic Observation System (INTAROS)
funded by the European Commission Horizon 2020 program
Grant Agreement no. 727890.

Project partners: