Seventh Framework Programme FP7-SPACE-2010-1
Stimulating the development of downstream GMES services

Grant agreement for: Collaborative Project. Small- or medium scale focused research project
Project acronym: **SIDARUS**
Project title: Sea Ice Downstream services for Arctic and Antarctic Users and Stakeholders

Grant agreement no. 262922
Start date of project: 01.01.11
Duration: 36 months
Project coordinator: Nansen Environmental and Remote Sensing Center, Bergen, Norway

D2.3: Report/ Data from summer experiments 2011-2012

Due date of deliverable: 31.12.2012

Actual submission date: 04.03.2013

Organization name of lead contractor for this deliverable: AWI

Project co-funded by the European Commission within the Seventh Framework Programme, Theme 6 SPACE		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group specified by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

ISSUE	DATE	CHANGE RECORDS	AUTHOR
0	21/12/2012	First version	S. Schwegmann, S. Hendricks, contributions from M. Zygmuntowska and S. Sandven
1	25/01/2013	Second Version	Mohamed Babiker
2	11/02/2013	Final version	with contribution from Till Wagner (UCAM)

SIDARUS CONSORTIUM

Participant no.	Participant organisation name	Short name	Country
1 (Coordinator)	Nansen Environmental and Remote Sensing Center	NERSC	NO
2	Alfred-Wegener-Institut für Polar-und Meeresforschung	AWI	DE
3	Collecte Localisation Satellites SA	CLS	FR
4	University of Bremen, Institute of Environmental Physics	UB	DE
5	The Chancellor, Masters and Scholars of the University of Cambridge	UCAM	UK
6	Norwegian Meteorological Institute, Norwegian Ice Service	Met.no	NO
7	Scientific foundation Nansen International Environmental and Remote Sensing Centre	NIERSC	RU
8	B.I. Stepanov Institute of Physics of the National Academy of Sciences of Belarus	IPNASB	BR

Table of Contents

List of Figures

List of Tables

SUMMARY

The goal of WP2.3 is to plan and implement new field experiments that provide airborne and in-situ sea ice thickness measurements from the Arctic. To fulfill this goal, several experiments with ice-going vessels as well as aircraft campaigns were performed during the period spring 2011 through summer 2012. Data are in the post-processing phase but some were already made publically available via the PANGAEA database for integration and validation in WP8.

(Leader: AWI, contribution from UCAM, NERSC)

1 Introduction

The goal of WP2.3 is to plan and implement new field experiments that provide airborne and in-situ sea ice thickness measurements from the Arctic. Therefore, a variety of sea ice data were collected during several expeditions to the Arctic Ocean, either with ice-going vessels or by airborne campaigns of the Alfred Wegener Institute (AWI). After the campaigns, all data underlie reprocessing and quality-controlling processes and are converted into a uniform file format. Some data from the AWI summer experiments are already freely available from the PANGAEA (http://www.pangaea.de/) database.

There are three types of data sets available from the ship-based campaigns:

1. Airborne electromagnetic (EM) total (sea ice + snow) thickness
2. Ground measurements of sea ice thickness
3. Visual observations of key sea ice parameters in combination with meteorological conditions

In some occasions, measurements from two or all three methods were performed coincidently. These datasets have been collected during field campaigns lead by scientists of the Alfred Wegener Institute (AWI). From the airborne campaigns, sea ice thickness data from helicopter surveys are available from the spring 2011 campaign.

In addition, to the AWI campaigns, the Nansen Environmental and Remote Sensing Center (NERSC) performed an expedition to the Fram Strait in August 2012 in order to measure in-situ sea ice properties. These measurements includes EM-31 surveys, ice drilling, ice cores and snow depth profiles and aim to investigate the sea ice thickness and snow depth distribution of distinct ice floes as well as to investigate physical sea ice properties and the relation between sea ice freeboard and sea ice thickness.

2 Data sources

2.1 (AWI) Airborne EM sea ice thickness

Airborne EM sea ice thickness measurements have been performed by the AWI during several campaigns. Measurements are based on an electromagnetic induction sensor, the so-called EM-Bird, which is towed underneath an aircraft (helicopter or airplane) in a height of 40 to 50 ft above the sea ice surface. This method allows individual sea ice thickness profiles with a length of 200 km (helicopter) and up to 500 km (airplane). A sketch of the aircraft-EM-Bird system is shown in Figure 2.1.

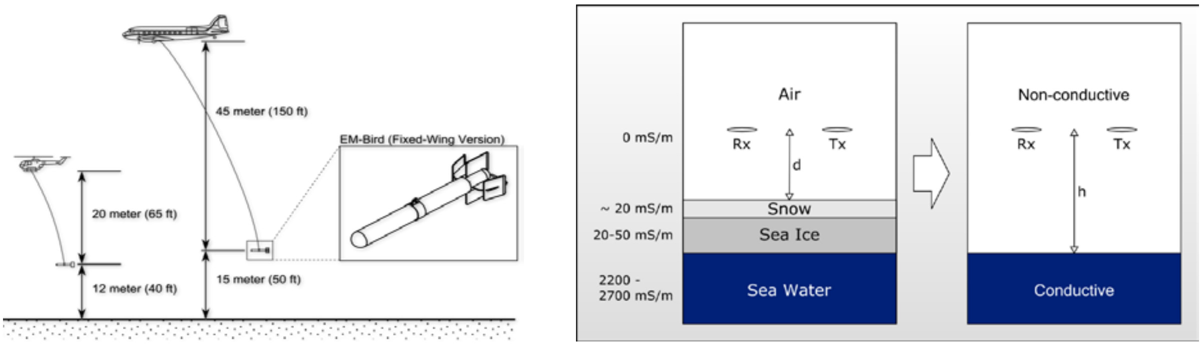

Figure 2-1:a) Airborne EM sea ice thickness measuring setup with helicopters and fixed-wing airplanes. b) Principle of Airborne EM sea ice thickness retrieval. The EM response is used to estimate distance of the sensor platform to the ice-water interface and a laser altimeter is used to measure the distance to the top ice or snow surface. The electrical conductivity of the sea ice/snow layer is neglected.

The EM-Bird carries a pair of transmitter and receiver coils. The transmitter coils emit an electromagnetic (EM) field that penetrates through the sea ice and induces eddy currents in the saline sea water, which induced a secondary EM field. The receiver coil records this secondary EM-field and the distance between the sea ice-water-interface and the EM-bird is estimated by an empirical relation connecting the phase and strength of the transmitted and received EM fields. The accuracy above level ice amounts to 0.1 m, while thicknesses of deformed sea ice (pressure ridges) can be underestimated between 50% and 80%. The underestimation depends on the footprint of the measurements, the salinity of the sea water and water inclusions in pressure ridges (*Haas et al.*, 2009; *Haas and Jochmann*, 2003).

A laser altimeter measures the distance between the EM-bird and the sea ice or snow surface. The difference between both heights corresponds to the total (sea ice + snow) thickness of the ice cover. A more detailed description of the EM-bird system and measurement principle is given in *Haas et al.* (2009).

2.2 (AWI, NERSC) In-situ sea ice and snow thickness

During field experiments with ice-going vessels, sea ice thickness data were collected from EM-ground surveys. The acquisition of ground EM ice thickness data (hand-held EM device) follows the principle of the airborne dataset. These data bring the possibility to validate and evaluate airborne sea ice thickness measurements, when both surveys have been performed concurrently. EM-ground measurements indeed suffer from basically the same inaccuracies as the airborne EM measurements, but they have a higher spatial resolution.

Ice drilling offers in addition the possibility to obtain very accurate measurements of sea ice thickness, freeboard (sea ice above sea level) and draft (sea ice underneath sea level) and allows therefore to calculate relationships between those three parameters.

Additionally to ice thickness measurements, snow thicknesses were measured during ground surveys using a ruler stick.

2.3 (AWI) Sea ice surface roughness

The surface elevation or, more precisely, the surface roughness of sea ice is obtained from laser altimeters, which measure the distance to the sea ice with an accuracy of about ± 3 cm (*Haas*, 1998). To eliminate noise caused by aircraft height variations, a filtering method after *Hibler III* (1972) is applied to the data. The subtraction of the aircraft height alterations from the measured signal results in the surface roughness of the sea ice.

2.4 (AWI, NERSC) Ice coring

Sea ice physical properties are investigated by measurements of sea ice temperature, salinity and density. For this, ice cores are taken and analyzed.

3 Collected data from spring/summer experiments

3.1 Ship campaigns

During summer 2011 and summer 2012, AWI carried out expeditions to the Arctic Ocean with the RV Polarstern. A variety of data was collected and some of the data sets are already available from PANGAEA.

Figure 3.1 shows the cruise track of RV Polarstern during the TransArc campaign in summer 2011. The blue triangles show the helicopter surveys carried out using the EM-Bird for measurements of total sea ice thicknesses. Each triangle-leg corresponds to a length of 40 nautical miles (74.2 km). In total, the 16 flights result in profile data of more than 2500 km. In addition, laser altimetry and geolocated aerial photography were performed during these surveys.

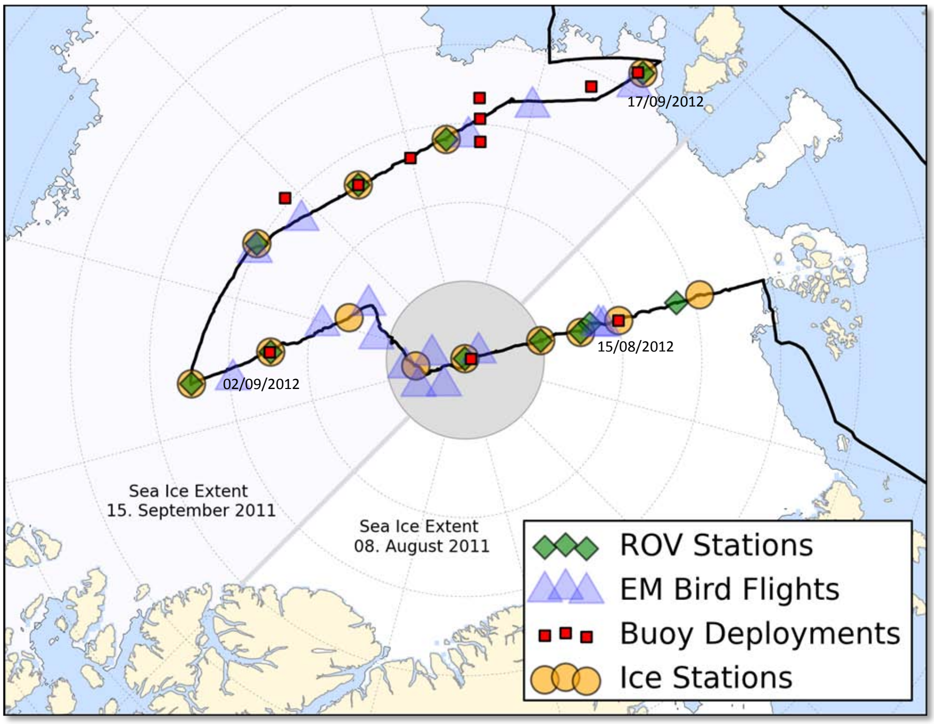

Figure 3-1: Cruise track of the Polarstern expedition TransArc (ARK-XXVI/3, 2011) to the Arctic Ocean. Symbols indicate kind of measurement performed along the cruise track. Source: Schauer (2012)

During ice stations, EM31 measurements were performed in order to investigate the small scale regional sea ice thickness distribution. In addition, sea ice buoys were deployed on several occasions during the expedition in order to measure ice displacements beyond the cruise.

To show some results of this campaign, Figure 3.2 displays data from TransArc compared to data obtained during the summer expedition in 2007. The distributions of total sea ice thickness are quite similar and show the same modal thickness in both years. Further preliminary results and a complete description of the expedition can be found in Schauer (2012).

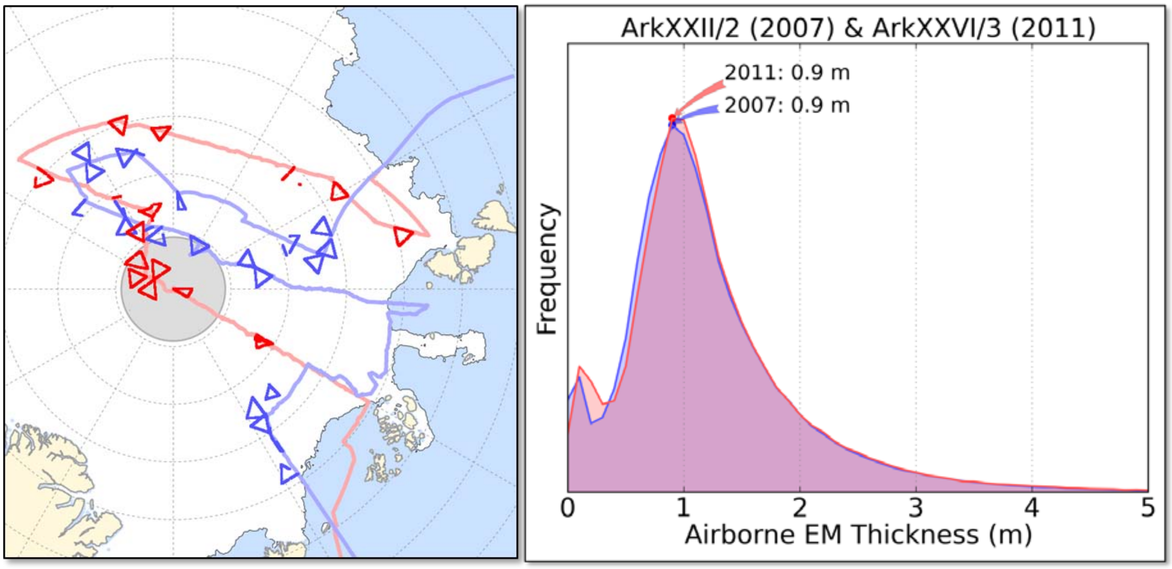

Figure 3-2: a) Cruise tracks of RV Polarstern and flight tracks with EM-Bird (triangles) for 2007 (blue) and 2011 (red). B) Distribution of total sea ice thickness for both years. After Schauer (2012).

Figure 3.3 shows the cruise track of RV Polarstern during the IceArc campaign in summer 2012. In total, in-situ data were obtained during 9 sea ice stations. In addition, different buoys where deployed in order to investigate the sea ice displacements and other physical properties also beyond the cruise.

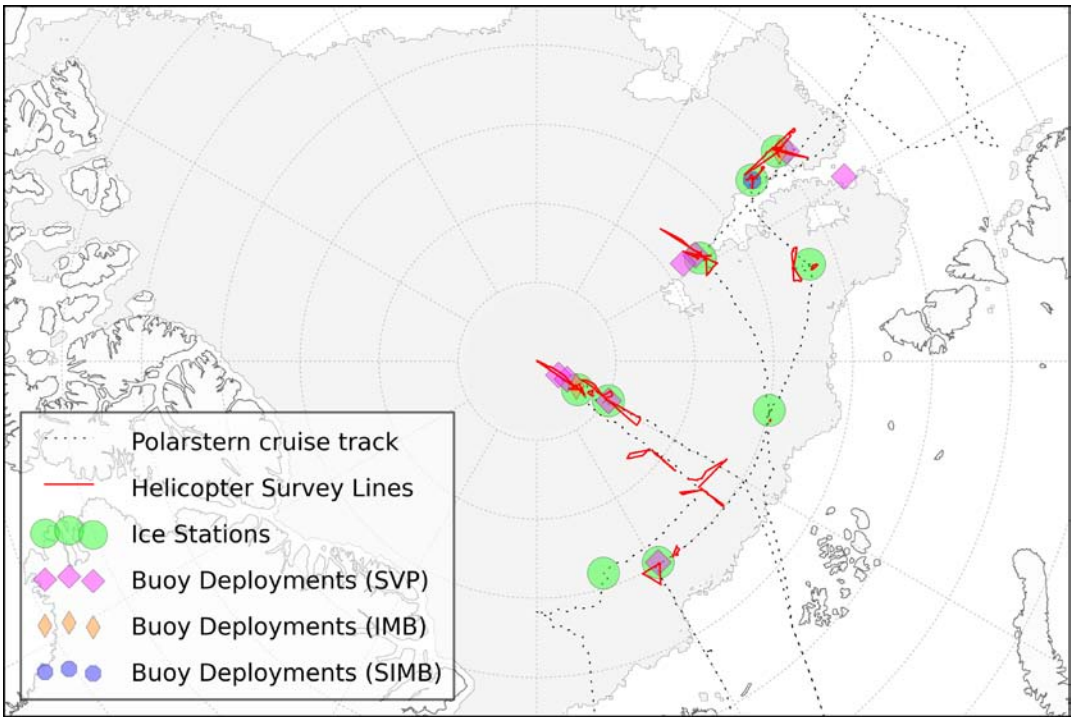

Figure 3-3: Cruise track of the Polarstern expedition IceArc (ARK-XXVII/3, 2012) to the Arctic Ocean. Symbols indicate kind of measurement performed along the cruise track.

Between ice stations, 21 helicopter surveys were carried out, which resulted in more than 3500 km of total sea ice thickness profile data.

During both campaigns, general sea ice conditions such as ice and snow thickness, floe size distribution and melt pond fraction were observed on a regular basis by visual observations from the ships bridge. These observations were combined with meteorological conditions and follow the Arctic Ship-based Sea Ice Standardization Tool (ASSIST).

Table 3.1 shows the sea ice thickness data gained by different methods during both campaigns, which can be downloaded from the PANGAEA database (://www.pangaea.de/) with full metadata and file format description. Data files contain information on the measurement date and time, the position and the ice thickness.

	AEM	*In-situ*	*Visual observation*
TransArc (2011)	*Hendricks et al. (2012)* *:10.1594/PANGAEA.778654* - *doi:10.1594/PANGAEA.778669*	*Hendricks et al. (2012)* *doi:10.1594/PANGAEA.778745* – :10.1594/PANGAEA.778760	*Nicolaus et al. (2012), :10.1029/2012GL053738*
IceArc (2012)		*Hendricks & Krumpen (2012)* ://doi.pangaea.de/10.1594/PANGAEA.804451 - ://doi.pangaea.de/10.1594/PANGAEA.804456	*Hendricks et al. (2012)* *://doi.pangaea.de/10.1594/PANGAEA.803221*

Table 3.3-1: Data obtained during TransArc and IceArc and available from the PANGAEA data base.

During August 2012, also NERSC performed a ship based expedition to the Arctic, where in-situ measurements were carried out on individual ice floes in the Fram Strait (Figure 3.4). The geographical positions of the observed ice floes and the kind of measurements carried out are listed in Table 3.2. Data from this expedition are planned to be made freely available within the framework of PRODEX.

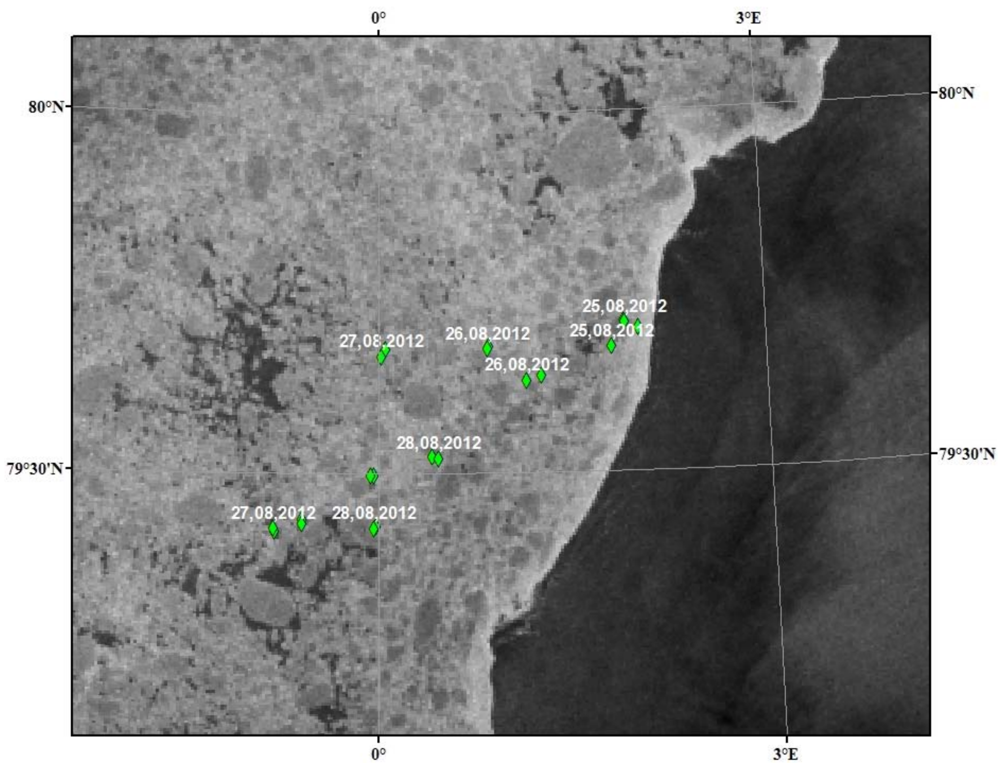

Figure 3-4 Radarsat2 image acquired on the 25/08/2012 (Fram Strait) over lied by ice station location

Station ID	Date	Position		Collected data			comment
		Lon	Lat	Drill holes	EM	Ice core	
KVS25082012_1	25.08.2012	2.022	79.699	x	x	-	Deployment of wave buoy, hydrophone and weather mast
KVS25082012_2	25.08.2012	1.909	79.708	x	-	-	Deployment of AITP
KVS26082012_1	26.08.2012	1.259	79.635	x	x	x	
KVS26082012_2	26.08.2012	0.857	79.675	x	x	x	
KVS27082012_1	27.08.2012	0.059	79.673	x	x	x	
KVS27082012_2	27.08.2012	-0.029	79.498	x	x	x	
KVS27082012_3	27.08.2012	-0.776	79.421	x	x	-	
KVS28082012_1	28.08.2012	-0.574	79.437	x	x	x	
KVS28082012_2	28.08.2012	-0.030	79.425	x	-	x	
KVS28082012_3	28.08.2012	0.461	79.522	x	x	-	

Table 3.3-2: Position of ice floes and overview of the collected sea ice data obtained during KV Svalbard expedition to the Fram Strait in 2012.

.

3.2 Aircraft campaigns

AWI performs aircraft expeditions to the Arctic Ocean on a regular basis. In spring 2011, airborne sea ice thickness and surface roughness data were obtained during the PAMARCMIP campaign over sea ice in the Lincoln, Beaufort and Chukchi Seas. Figure 3.4 shows a map with flight tracks (red) performed during this campaign as well as histograms of the sea ice thickness distribution for the individual regions. Both, flight tracks and sea ice thickness distributions are compared to data obtained during PAMARCMIP 2009 (blue).

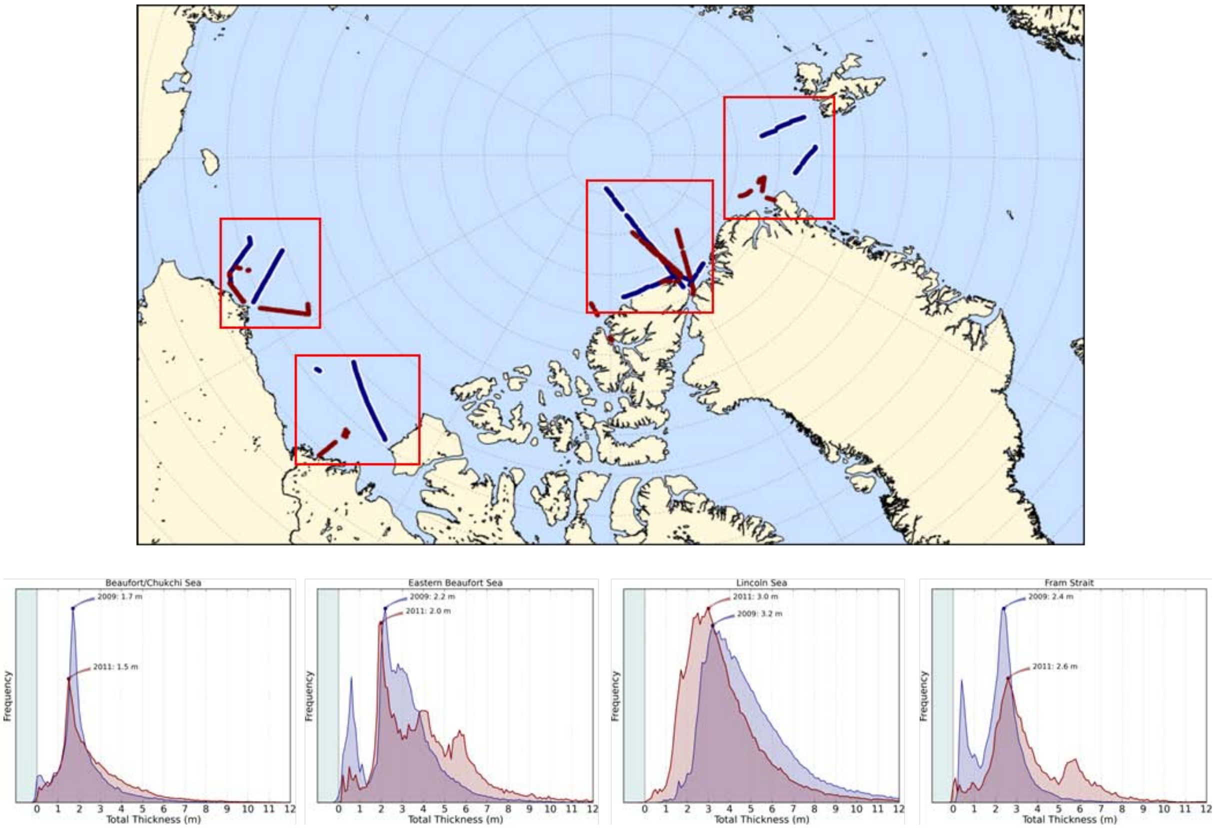

Figure 3-5 Map of flight surveys performed during PAMARCMIP 2009 (blue) and 2011 (red). Histograms show a comparison between the sea ice thickness distibution observed during both campaigns.

Data from this campaign are useful for cross validation of different measurement methods, since sea surface elevation for example has been measured by different sensors. In addition, they are of particular value for the validation of CryoSat sea ice freeboard retrievals, as some surveys were performed in conjunction with CryoSat over flights.

During spring 2012, AWI performed three more aircraft campaigns to the Arctic Ocean. Figure 3.5 maps the flight tracks of each campaign. During PAMARCMIP and SIZONet, sea ice thickness data were repeatedly sampled in the same regions as in 2009 and 2011. In addition, further data were obtained in the Laptev Sea. This campaign revealed that sea ice thicknesses were comparably low this year in spring. Due to wide areas of low sea ice thickness, this data set is of special value for the validation of SMOS based sea ice thicknesses, since SMOS can only resolve sea ice thicknesses of up to 50 cm.

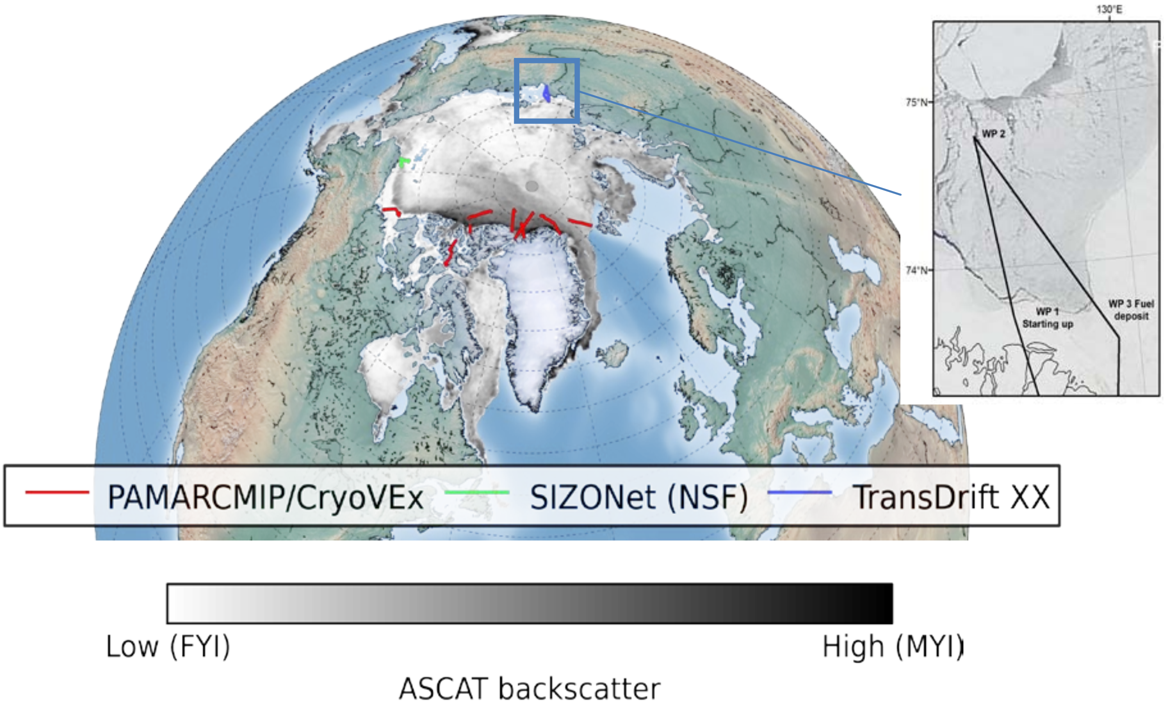

Figure 3-6: Flight tracks of AWI spring campaigns 2012.

However, data from these campaigns are still in the processing phase or are not approved yet and are therefore not freely available at the moment.

3.3 Cruise with Arctic Sunrise

The Polar Ocean Physics Group (UCAM) performed sea ice thickness and sea ice morphology measurements in the marginal ice zone aboard the MV Arctic Sunrise during two cruises in September 2011 and July 2012.

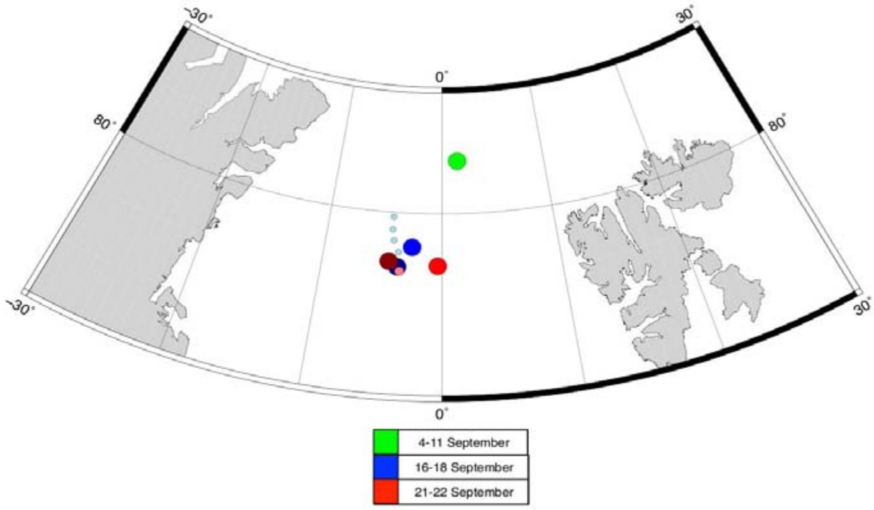

Figure 3-7 Location of ice stations in Fram Strait, (MV Arctic Sunrise, Sept 2011)

In addition to thickness measurements via drill holes, a main focus of the trips was to gather high resolution data of deformed sea ice morphology that is aimed to provide new insights into the physical processes underlying sea ice mechanics and dynamics. In order to achieve these goals we performed a variety of observations, including ice core sampling, snow depth measurements, aerial imagery and 3D laser scanning.

Table 3-3 Overview of ice stations and measurements taken Sept 2011 in Fram Strait aboard the MV Arctic Sunrise

Date	Floe	Lat/Lon	Scanner	Drill Data	Imagery	Survey Data	Snowdepths	Cores
03/09	1	80°42.9' N, 2°25.5' E	8	23 (ALine)	√	27 (random)	30 (ALine)	1
04/09 05/09	2[a]	80°43.1' N, 2°17.0' E	11	12 (ALine) 11 (BLine) 12 (CLine)	√	78 (ALine+) [b] 108 (BLine+Peri)	31(ALine) 61 (‖ ALine) 114 (→Survey)	2
09/09 - 11/09	3[c]	80°52.1' N, 1°27.7' E	6	22 (ALine)	-	279(ALine+Peri) [d] 1012 (Grid)	16 (ALine) 14 (random)	-
15/09	4	79°38.3' N, 2°02.6' E	12	11(ALine) 11(BLine) 8 (CLine) 11 (DLine)	√	-	no signif. snow	1
16/09	5A 5B 5C 5D 5E	79°26.4' N 2°31.8' W	2 1 1 1 2	8 (5m int.) 6 (") 6 (") 5 (") 5 (")	√	-	-	-
17/09 18/09	6	79°16.5' N, 3°28.3' W	24	11 (ALine) 22 (BLine) 18 (CLine)	√	-	no signif. snow	3
17/09	7A[e] 7B 7C 7D	79°23.9' N, 3°47.3' W 79°32.5' N, 4°08.0' W 79°43.4' N, 4°18.2' W 79°55.4' N, 4°17.5' W	-	10 (5m int.) 11 (") 10 (") 4 (")	√	-	-	-
18/09	8	79°06.3' N, 3°42.8' W	3	9 (5m int.)	-	-	no signif. snow	1
21/09	9	79°8.2' N, 0°20.4' W	3	103 (6 Lines)	√	110 (6 Lines)	110 (6 Lines)	1
22/09	10	79°11.4' N, 4°27.4' W	3 (hi-res)	12 (ALine)	-	16 (ALine)	16 (ALine)	-

During the first cruise (Sept 2011), a total of 17 ice floes were surveyed. The final data set includes 77 panoramic 3D laser scans, ca. 350 ice thickness measurements (drill holes) and several thousand aerial images. 3 sets of observations were conducted, with 3-10 floes at each site. The floes measured were chosen to give a representative picture of the of the local ice conditions - with exception of floes 3 and 6 which were selected for their intricate topographies. The locations of the ice stations are shown in figure 3.7. An overview of the measurements taken at each station is provided in table 3.8.

Figure 3.9 shows two 3D laser scans of deformed ice floes in the marginal ice zone. To obtain insight into statistical properties of the marginal ice zone, such as floe size distribution and spacing, a large set of digital aerial images was collected during a number of helicopter flights. The individual images can be mosaicked to yield large scale images of the surveyed areas (see figure 3.10) for a small sample mosaic.

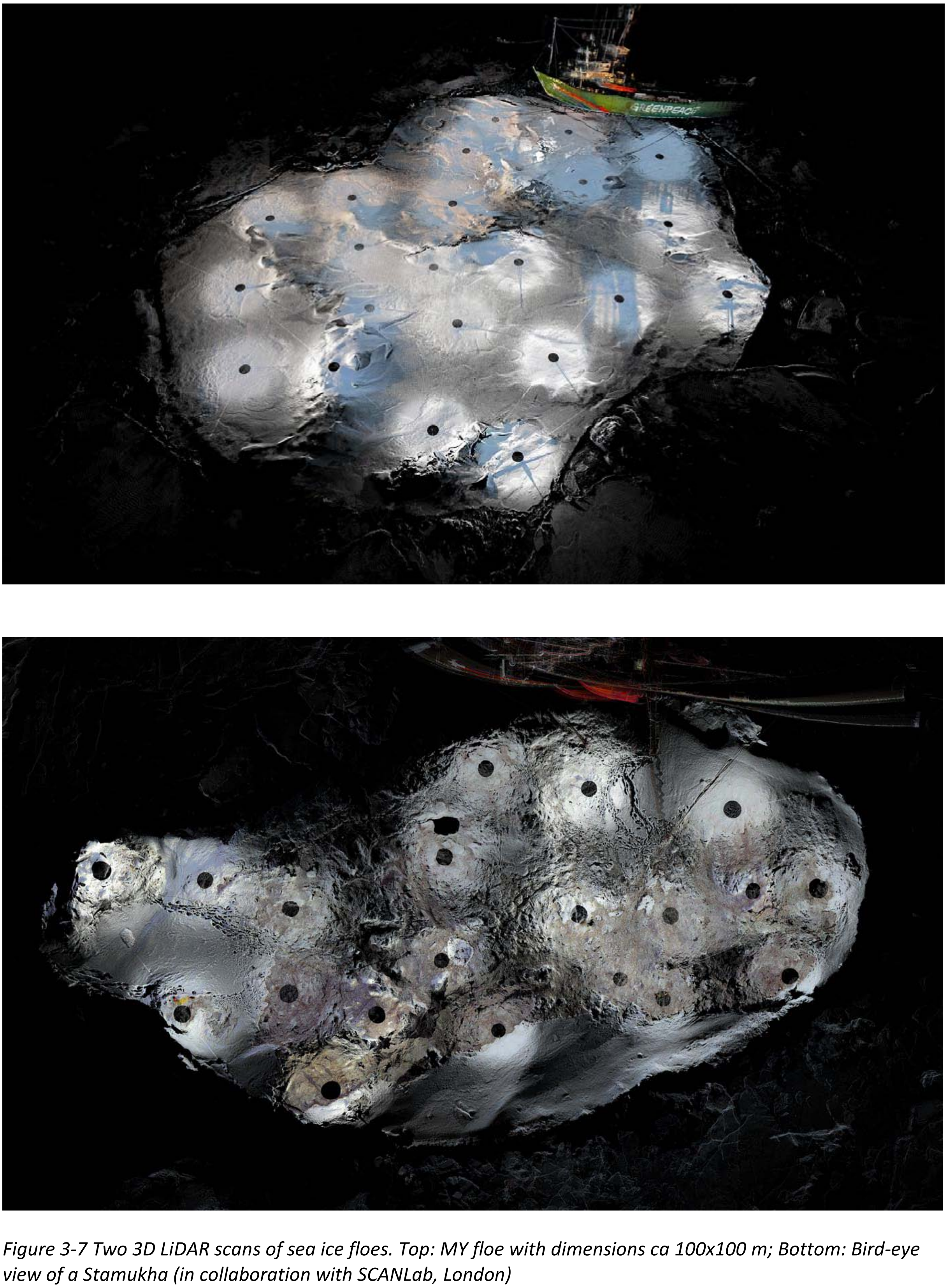

Figure 3-7 Two 3D LiDAR scans of sea ice floes. Top: MY floe with dimensions ca 100x100 m; Bottom: Bird-eye view of a Stamukha (in collaboration with SCANLab, London)

The 2012 field operation to measure simultaneously the surface and underside topography of pressure ridges was carried out between July 9 and 21, again using MV "Arctic Sunrise". DAMTP personnel were Prof Peter Wadhams (chief scientist), postdoc John Fletcher and graduate students Till Wagner and Nick Toberg. The underside was profiled by a SeaBed AUV of Woods Hole Oceanographic Institution, which was operated by Dr Hanu Singh and two assistants. The surface topography was obtained in high resolution by Scan LAB personnel.

The ship started from Longyearbyen, where the AUV was calibrated and tested, on July 10, and sailed to meet the ice edge in Fram Strait at a location (79° 32'N, 0° 40'E) corresponding to a Radarsat quadpol retrieval expected on July 14 and ordered by the Norwegian Meteorological Institute (Nick Hughes) as part of their participation.. The ship was in 50% concentration first-year (FY) and multi-year (MY) floes when it reached this position.

The first floe selected, floe 1, was a large, long MY floe carrying a classic triangular ridge, a low rolling hummock and a lot of rubble. The ship was moored to the floe, the laser scanning operation carried out as well as several cores and lines of thickness holes drilled, in order to obtain optimal co-registration between laser and AUV.

Floe 2, in the same vicinity, was a **stamukha**, a very old isolated pressure ridge, covered in dirt and of considerable draft (28 m), which is a feature of the shelf seas north of Siberia. They are ridges which run aground and remain fast to the seabed thropugh a summer when all the ice around them melts, leaving the stamukha as a grounded isolated island. It may remain for a number of years at a given site before lifting off through melt and joining the Arctic circulation, to emerge through Fram Strait as a real rarity. To our knowledge no stamukha has been studied before in this intense way, and once again we were able to obtain AUV multibeam mosaics of the underside and laser scans of the topside.

Floe 3, on July 16, had a well developed ridge complex on one edge of a very large (2 km) floe. The first AUV transit was successful, but a second mosaic resulted in the vehicle being carried into the centre of the floe through not having sufficient power to stem a strong relative current under the floe. The AUV was lost and could not be recovered despite a day of searching; it was insured by WHOI.

Floe 4 was mapped only on the upper surface by the laser, with drilled and cored holes. It was overflown at low level by the Polar 5 aircraft of Alfred Wegener Institute on July 18, equipped with e-m sounder. Finally, floe 5, a thick FY floe with well-defined linear ridges, was profiled by laser.

The 3D sonar multibeam maps obtained in July 2012, in combination with the coincident surface maps from 3D laser scanning, provide the first 3D top and bottom imaging achieved for Arctic sea ice.

The data for both trips has so far only been partially processed and is not freely available yet.

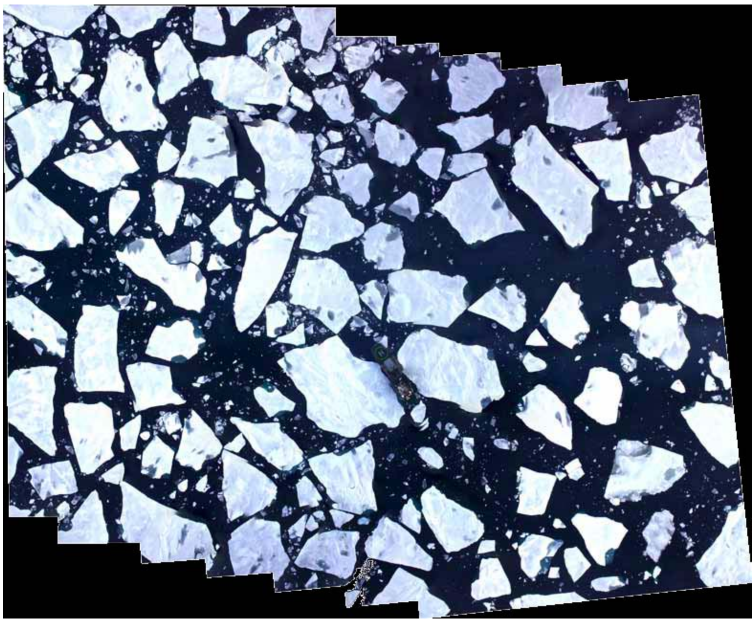

Figure 3-8: Digital imagery mosaic consisting of 10 individual photographs. The Arctic Sunrise can be seen in the centre of the image.

4 Bibliography and further literature

Haas, C., Evaluation of ship-based electromagnetic-inductive thickness measurements of summer sea-ice in the Bellingshausen and Amundsen Seas, Antarctica, *Cold Regions Science and Technology, 27* , pp. 1-16, 1998

Haas, C. and P. Jochmann, Continuous EM and ULS thickness profiling in support of ice force measurements, Proceedings of the 17th International Conference on Port and Ocean Engeneering under Arctic Conditions POAC ´03, Department of Civil and Transport Engeneering, Norwegian University of Science and Technology NTNU, Trondheim, Norway, 2, pp. 849 – 856, 2003

Haas, C., J. Lobach, S. Hendricks, L. Rabenstein and A. Pfaffling, Helicopter-borne measurements of sea ice thickness, using a small and lightweight, digital EM system, *Journal of Applied Geophysics, 67*, (3), pp. 234–241, 2009.

Hendricks, S.; Hunkeler, P.; Ricker, R.; Nicolaus, M.; Hoppmann, M.; Katlein, C., Ground-based electromagnetic (EM) and drill-hole ice and snow thickness measurements during POLARSTERN cruise ARK-XXVI/3 (TransArc) in 2011, 2012

Hendricks, S.; Hunkeler, P.; Ricker, R.; Nicolaus, M.; Hoppmann, M.; Katlein, C., Helicopter-borne sea ice thickness measurements during POLARSTERN campaign ARK-XXVI/3 (TransArc) in the Arctic Ocean, 2012

Hendricks, S.; Nicolaus, M.; Schwegmann, S., Sea ice conditions during POLARSTERN cruise ARK-XXVII/3 (IceArc) in 2012, 2012

Hibler III, W. D., Removal of aircraft altitude variation from laser profiles of the Arctic pack ice, *Journal of Geophysical Research, 77*, No. 36, pp. 7190–7195, 1972.

Nicolaus, M.; Katlein, C.; Maslanik, J. A.; Hendricks, S., Sea ice conditions during the POLARSTERN cruise ARK-XXVI/3 (TransArc) in 2011, 2012

Schauer, U., The Expedition of the Research Vessel "Polarstern" to the Arctic in 2011 (ARK-XXVI/3 - TransArc), Berichte zur Polar- und Meeresforschung, 649, 2012, ://hdl.handle.net/10013/epic.39934

END OF DOCUMENT