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Online Sea-Ice Knowledge and Data Platform <www.meereisportal.de>

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Abstract: The combination of multi-disciplinary sea ice science and the rising demand of society for up-to-date information and user customized products on climate change emphasis the need for addressing the challenges posed by environmental change in the Polar Regions by means of creating new ways of communication.
The new knowledge platform "meereisportal.de" is a contribution to the cross-linking of scientifically qualified information on climate change and focuses deliberately on the theme: "sea ice" in both Polar Regions. With "meereisportal.de" the science opens to changing societal demands and goes new ways of communication between science and society. "meereisportal.de" is the first comprehensive German speaking knowledge platform on sea ice that went online 2013. It was developed in the frame of the Helmholtz Climate Initiative, Regional Climate Change (REKLIM) as a joint project of the University of Bremen (Institute of Environmental Physics) and the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research under the management of the Helmholtz Regional Climate Office for Polar Regions and Sea Level change. This paper describes the concept and the development of the knowledge platform, different usage examples and user-specific products. Moreover, an outlook on the planned activities in the future will be given.

Zusammenfassung: Die Kombination der zunehmend multi-disziplinären Meereisforschung und die steigende Nachfrage der Gesellschaft nach aktuellen Informationen und benutzerorientierten Produkten zum Thema Klimawandel erfordert neue Wege der Wissenskommunikation, um den Herausforderungen der zunehmenden Umweltveränderungen, insbesondere in den Polarregionen, zu begegnen.
Die neue Wissensplattform "meereisportal.de" ist ein Beitrag zum Vernetzen von wissenschaftlich qualifizierten Fachinformationen zum Thema Klimawandel und fokussiert dabei bewusst auf ein Thema: "Meereis" in beiden Polargebieten. Mit "meereisportal.de" öffnet sich die Wissenschaft gegenüber sich verändernden gesellschaftlichen Anforderungen und geht neue Wege der Kommunikation zwischen Wissenschaft und Gesellschaft. "meereisportal.de" ist 2013 als erste umfassende, deutschsprachige Wissensplattform rund um das Thema Meereis in der Arktis und Antarktis online gegangen. Sie wurde im Rahmen des Helmholtz-Verbundes Regionale Klimaveränderungen (REKLIM) als Gemeinschaftsprojekt der Universität Bremen (Institut für Umweltphysik) und des Alfred-Wegener-Institutes, Helmholtz-Zentrum für Polar- und Meeresforschung unter der Federführung des regionalen Helmholtz Klimabüros für Polargebiete und Meeresspiegelanstieg entwickelt. Dieser Beitrag beschreibt die Entstehung, das Konzept und die Entwicklung der Wissensplattform, verschiedene Anwendungsbeispiele sowie nutzerspezifische Produkte. Darüber hinaus wird ein Ausblick über die in Zukunft geplanten Aktivitäten gegeben.

INTRODUCTION

Stopping or at least slowing down climate change with its far-reaching and regionally varying consequences for humanity and nature is one of the great challenges of the 21st century. The Earth is undergoing profound climate change. Particularly, the Polar Regions are very sensitive to even slight climate changes. They play a paramount role for the global climate system. Whether we are able to adapt in time to the imminent changes will largely depend on whether the results from research and science are communicated and processed to an adequate degree and, hence, will be useful for government, economy and society in decision-making. Therefore, the importance of knowledge transfer of research results has grown in recent decades. Research institutes are obliged to disseminate their research results and knowledge to society and enter into a dialogue with society.

The need for the development of "meereisportal.de" was driven by various aspects, which will be shortly addressed in the following. The increasing interest of society to benefit from research results leads to the pressure to transfer research results into application and to interact directly with its users, as there is a big agreement that citizens get easy access to the results of research they have paid tax for. Policies and measures that mobilise these intellectual assets for a use through a broader access can accelerate scientific breakthroughs, increase innovation, and promote economic growth. That's why it is of growing importance to ensure that results of public-funded scientific research are made available to and useful for the public, industry, and the scientific community (Scott 2000).

Therefore, for example the European science policy as well as that of national governments has more and more set priorities for research to serve the requirements of society and have set increasingly ambitious targets for public research funding bodies in terms of the impact or application of their research. Communicating and interacting with the public about research outcomes presents a novel type of challenge and is of vital importance. However, it is clear that the landscape of scientific research communication is being transformed as the web gains increasing influence and alters how we interact with information. However, in facing urgent global issues like climate change, researchers cannot continue to share their findings only with their colleagues and scientific community through peer-reviewed scientific journals.

While the purpose of restricted-access, peer-reviewed journals is to ensure scientific quality and to communicate research outcomes to peers, the goal of open access, web-based dissemination is also to promote widespread public debate and to increase the speed of research feedback. Both, the restrict-

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ed-access and the open access are legitimate approaches and can co-exist effectively. Consequently, one major objective has to be to encourage scientists not to limit themselves to journals, but to engage with the public via other channels (BARETT et al. 2014).

Another important point to be taken into account is that 'the public' is not a homogeneous population; rather it encompasses numerous sub-groups such as policy makers, researchers, journalists, environmentalists and many others. Each of these groups forms a distinct audience, looking for information that answers their questions and concerns with an appropriate level of detail. For this reason it is necessary that information fits the expectations, needs, interests, and knowledge background of these various potential user groups. Different users will require knowledge presented and visualised in different ways. Briefly this means: getting the right knowledge, in the right form, in the right place, to the right person, at the right time. There are many ways to channel information of scientific research results. Among these, the Internet plays a major role in contributing to improve public awareness (BREYER et al. 2007). The advantage of web-based methods compared with conventional communications channels is a huge opportunity to share the outcomes of scientific research more extensively and quickly across the entire society.

Sea ice was chosen for implementation of these communication and dialogue processes described above because it plays an important role in the climate system and so far mostly English based web platforms with focus on sea ice exist. Furthermore, information in German is scattered on webpages of various research institutes (Tab. 1). For example, the portal of the University of Bremen provides daily updated hemispherical and regional maps of sea-ice concentration and an archive of this data since 2002 when the satellites sensor AMSR-E became operational. The portal is in English and gives little background information beyond the map explanations. Considering language barriers, this fact prevents a considerable group from the access to information and data products. As a consequence science-based tailored information, customized products and services on sea ice are hardly asked for and various possible important target groups are not reached. For this reason, the public perception about sea ice, its variability and its role in the climate system is rather incomplete.

Platform Language	Responsible institutions	Target group	Services
nside.org English	[1]NSIDC, USA	scientists, public	NSIDC manages and distributes scientific data, creates tools for data access, supports data users, performs scientific research, and educates the public about the cryosphere.
fram-data.awi.de English	[2]AWI, Germany	scientists	The content displayed in this webpage consists mainly of validated track lines, publications and reports from EPIC repository and primary data from PANGAEA-Data Publisher for Earth & Environmental Science.
iup.uni-bremen.de:8084/amsr2 English	[3]IUP, Germany	scientists	Provides daily updated hemispherical and regional maps and an archive starting with the sensor AMSR-E in 2002.
icdc.zmaw.de/daten/cryosphere.html English / German	Universität Hamburg, Germany	scientists, public	Extensive data collection on various data products but only very small background information.
aoos.org/ice-atlas English	[4]AOOS, USA	scientists, public	AOOS represents a network of critical ocean and coastal observations, data and information products that aid our understanding of the status of Alaska's marine ecosystem and allow stakeholders to make better decisions about their use of the marine environment.
seaiceatlas.snap.uaf.edu English	[4]AOOS, [5]ACCAP, [6]SNAP, USA	scientists, public	Simultaneously view multiple sources of historical sea ice data from the oceans surrounding northern Alaska.
climate4you.com English	Ole Humlum, Depart. of Geosciences, University of Oslo, Norway	scientists, public	Main emphasis of this web site is to provide the interested reader with data and other information on meteorology and climate. No large back-ground information. Data from various data sources.
seaice.dk English	Technical University of Denmark, DTU space, Denmark	operators, ice services, scientists	An Internet based distribution system for ice, weather and ocean information. The system provides near real time access to a large variety of data about the polar environment in a standard user environment.
Imb.erdc.dren.mil/newdata.htm English	[7]CRREL, USA	scientists	All data from active and past Sea Ice Mass-Balance Buoys.
Driftnoise.com/data-portal.html English	Drift & Noise Polar Services GmbH Germany	public, scientists, stakeholders, operators	Open Data Portal with service oriented near real time sea-ice concentration maps.
cpom.ucl.ac.uk/csopr/seaice.html English	Centre for Polar Observation and Modelling at [8]UCL, U.K.	scientists, stakeholders, operators	Near real time Arctic sea ice thickness processed at UCL from CryoSat's SAR mode data.

Tab. 1: Selection of sea ice related websites. The websites portrayed are exemplary and do not claim to be complete. The used acronyms of the institutes represent: [1]NSIDC = National Snow and Ice Data Center; [2]AWI = Alfred Wegener Institute, Helmholtz Centre for Polar and Marin Research; [3]IUP = Institut für Umweltphysik, Universität Bremen; [4]AOOS = Alaska Ocean Observing System; [5]ACCAP = Alaska Center for Climate Assessment and Policy; [6]SNAP = Scenarios Network for Alaska and Arctic Planning; [7]CRREL = Cold Regions Research and Engineering Laboratory; [8]University College London.

Tab. 1: Exemplarische Auswahl einiger meereisbezogener Websites. Die Tabelle erhebt keinen Anspruch auf Vollständigkeit. Die verwendeten Abkürzungen der Institute bedeuten: [1]NSIDC = National Snow and Ice Data Center; [2]AWI = Alfred Wegener Institut Helmholtz Zentrum für Polar- und Meeresforschung; [3]IUP = Institut für Umweltphysik, Universität Bremen; [4]AOOS = Alaska Ocean Observing System; [5]ACCAP = Alaska Center for Climate Assessment and Policy; [6]SNAP = Scenarios Network for Alaska and Arctic Planning; [7]CRREL = Cold Regions Research and Engineering Laboratory; [8]University College London.

These constraints led to the idea to create a German web platform about sea ice to meet the abovementioned demands and requests. “meereisportal.de” is the first comprehensive German online knowledge and data platform on sea ice. The knowledge platform is designed as an open portal and aims to bundle expertise around sea ice, especially utilising mainly the expertise of German research institutes. However, all research institutions from every country can use the platform as multiplier for their sea ice related data and research results. At the same time, we aim to provide updated links to ongoing international research activities and datasets.

Before going into the detailed description of the concept and idea, the implementation and finally the current application of “meereisportal.de”, the following paragraphs of this paper give a short introduction about the importance and role of sea ice in the climate system.

THE ROLE OF SEA ICE IN THE CLIMATE SYSTEM

Sea ice in the Arctic and Antarctica covers approximately seven percent of our planet’s surface, which is equivalent to the size to Europe. From a climate perspective, it serves as both, an indicator and an amplifier of climate change. Sea ice is a barrier, limiting the exchange of heat, moisture, and momentum between the atmosphere and the ocean, and in addition it hosts a rich marine ecosystem. Changes in ice cover affect a wide range of human activities from hunting and fishing, shipping and resource extraction.

Sea ice is a naturally occurring material with an intricate and highly variable structure; it consists of gas bubbles, ice platelets, brine pockets, brine channels, and crystals of various sizes and orientations, all of which exert large effects on the transport of solar radiation within sea ice. Furthermore, sea ice phenomena cover broad scales in time and space. Despite its relatively small volume compared to ocean and atmosphere, sea ice plays an important role in the Earth’s climate system. Sea ice is sensitive to global climate change, and in turn it is a driver and amplifier of climate change. Sea ice represents a thin blanket covering the ocean surface, which controls, but is also controlled by, the fluxes of heat, moisture and momentum across the ocean-atmosphere interface.

Sea ice reflects solar radiation due to its high albedo and is, therefore, an important element determining the Earth’s radiation budget. Furthermore, changes in sea-ice thickness and/or extent interact with dynamical processes in the atmosphere and the ocean, related to changes in atmospheric wind and temperature fields, ocean currents and heat storage as well as to thermodynamic and radiative processes connected with water vapor, cloud and aerosol feedbacks. In spite of the apparent extreme conditions it also provides a habitat for living organisms. Consequently, sea ice research spans many scientific disciplines including, among others, geophysics, glaciology, chemistry and numerous branches of biology.

The sea-ice cover in both hemispheres is characterized by large seasonal variability, with an Arctic extent maximum of approximately 15 million km^2 in March and to some 6 million km^2 in September. In the Antarctic, the sea ice cover varies from 17 million km^2 in September to 3 million km^2 in February. Sea ice exhibits a high spatial variability of different surface types, floe sizes, and snow and ice thicknesses.

Due to a number of feedbacks, sea-ice extent is a sensitive indicator of climate. Because sea ice is relatively thin, its vulnerability and sensitivity to small perturbations in the state of ocean and atmosphere is high.

Shifts in Arctic sea-ice indicate regional and global climate change. In recent years, Arctic sea ice retreated in summer extensively, leading to large areas of thin first-year ice during the subsequent freeze up season, an ice type that is more vulnerable to melting in the next summer (Stroeve et al. 2012). Sea-ice extent shows decreasing trends in all months and in almost all regions in the Arctic with the exception of the Bering Sea during winter (Perovich et al. 2014). The September average trend (Fig. 1b), representing the annual sea ice minimum extent, is now -13.3 % per decade relative to the 1981–2010 average. The trend for the annual winter maximum during March is smaller (-2.6 % per decade), but is still decreasing at a statistically significant rate (Fig. 1a). A complete demise of Arctic sea ice in summer during coming decades is projected around 2060, while some models predict this event as early as 2040 (Overland & Wang 2013).

In contrast to the sea-ice decline in the Arctic, Antarctic sea ice has undergone a spatial redistribution. Since the start of regular satellite observations in 1979, total Antarctic sea ice has increased by about 1.5 % per decade. Whether the increase is a sign of sustained change is uncertain because ice extents vary considerably from year to year around Antarctica. Antarctic climate is influenced by, among other factors, changes in radiative forcing and Pacific climate variability. It is likely that the gradual warming of the North and tropical Atlantic Ocean is contributing to climate change in Antarctica (Li et al. 2014). There are also indications that the Antarctic sea ice cover is slowly extending due to an intensification of the polar vortex caused by intensified interactions between troposphere and stratosphere (Fan et al. 2014).

The temperature gradient from the Tropics to the Polar Regions has a strong influence on the wind systems, their variability and ocean currents. It is one of the main drivers of the global atmospheric circulation. Strong warming in the Arctic has the potential to impact, e.g., storm tracks, patterns of precipitation and the frequency and severity of cold-air outbreaks in middle latitudes. Arctic processes can feed back on the global climate system. Disturbances in the wintertime Arctic sea-ice and snow cover may induce perturbations in the zonal and meridional planetary wave train from the Tropics over the Mid-Latitudes into the Arctic (Dethloff et al. 2006, Jaiser et al. 2012).

Beside physical changes of sea ice, also the ecosystem in Polar Regions is largely affected by sea-ice changes. Observations support the hypothesis that the current sea-ice thinning and increasing melt-pond cover may be enhancing under-ice productivity and ice-algae export to the benthos, with ecological consequences ranging from the surface ocean to the deep sea (Boetius et al. 2013).

In addition to its role in global climate change, the Arctic is receiving enhanced attention for economic reasons. Among these is the fact that large amounts of oil and gas are deposited

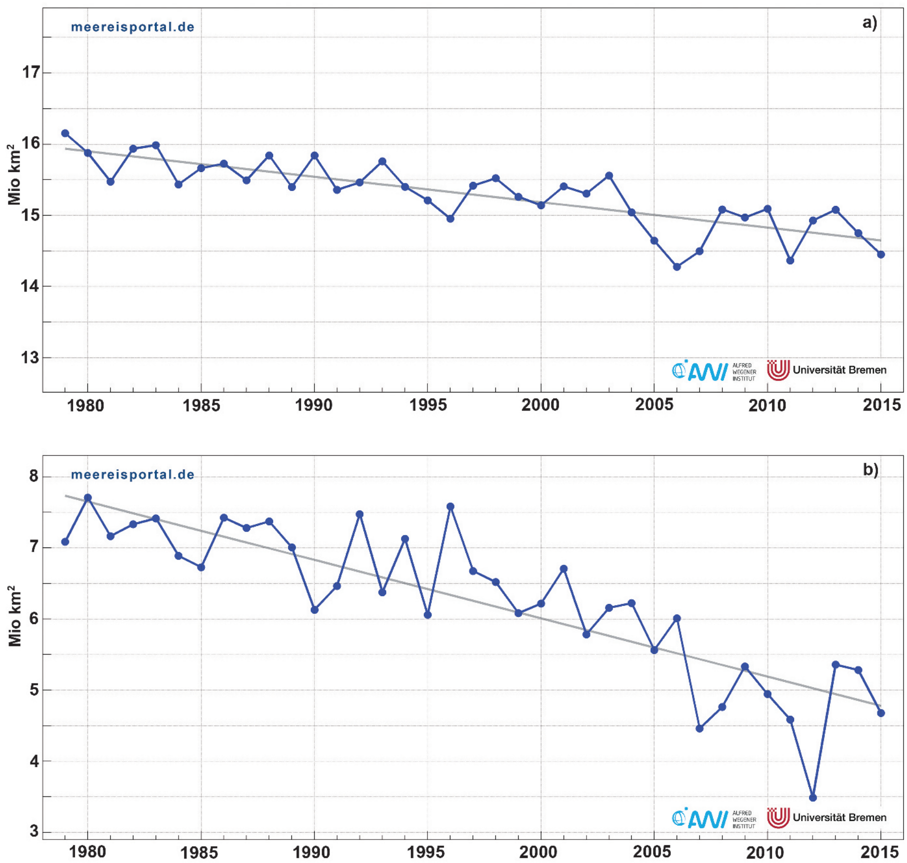


Fig. 1: Trend of Arctic sea ice minimum in March (a) and sea ice maximum in September (b) derived from satellite observations 1979–2015.

Abb. 1: Entwicklung des arktischen Meereisminimums im März (a) und Meereismaximum im September (b) aus Satellitenmessungen von 1979–2015.

in high Northern Latitudes. Other economic sectors depending on the sea-ice cover are transportation, fisheries and extraction of mineral resources. The potential for resource development and associated potential ecosystem risks is of increasing concern to the Arctic nations and to all concerned about the region's fragile environments (Gautier et al. 2009). Activities in the Polar Regions, e.g., research or economic planning strongly depends on a timely provision of accurate sea-ice data. Thus, there is an increasing need to provide various real time sea-ice data. Furthermore, stakeholders from different fields have a growing interest in expert commented sea-ice assessments. Consequently, sea ice becomes an increasing focus in the general public.

IDEA, REALIZATION AND CONCEPT OF "meereisportal.de"

The combination of multi-disciplinary sea-ice science and the rising demand of society for up-to-date information and user customized products emphasis the need for addressing the challenges posed by environmental change in the Polar Regions by means of creating new ways of communication. Therefore, research institutes are obliged to disseminate their scientific results and knowledge and enter into a dialogue with society. Disseminating and facilitating access to science-based information is a necessity to enable the public to make informed decisions. To provide information in this sense means process it appropriately to make it attractive and accessible to the intended audience. Accordingly, the development of "meereisportal.de" was governed by the following guiding principles:

- Simplicity, comprehensibility, and professional presentation.
- Topics and themes addressed through various approaches.
- Credibility by means of independence and reliability.
- User-friendliness, clear navigation.
- Differentiated access, depending on knowledge and experience.

In 2013 "meereisportal.de" was the first comprehensive German speaking knowledge platform on sea ice that went online. It was developed under the lead of the Helmholtz Regional Climate Office for Polar Regions and Sea Level Rise as a joint project of the University of Bremen (Institute of Environmental Physics) and the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research within the frame of the Helmholtz Climate Initiative, Regional Climate Change (REKLIM).

The website delivers popularised information for the general public as well as scientific data meant primarily for the more expert readers and scientists. It also provides for various permanent tools allowing interaction with its visitors. Content is displayed using a web-based platform, based on a Typo 3 Content Management System. First results indicate a high level of interest from the general public and from experts, showing that the content of this website can contribute by communicating science-based information to improve awareness and understanding of sea ice related research. The principle concept of the new knowledge platform is based on three pillars:

(i) background information;
(ii) map and data archive and
(iii) expert knowledge.

The first pillar of the new knowledge platform is primarily providing comprehensive and understandable information about sea ice in German. This part of the website provides popularised information for the general public. Questions like *“How does sea ice form?”, “How is it explored?”* or *“Which role does it play in the Earth’s climate system?”* are answered here. All topics are described in various levels of detail. Particular emphasis is given to the description of new measurement methods, addressing general overview information up to detailed expert knowledge. This part also contains insight into latest research topics, project and methods. This is the main entrance door to the scientific results of sea-ice research for non-specialists.

The second pillar constitutes the extensive map and data archive. There are currently more than 10,000 graphically edited sea-ice maps of the past fourteen years and the associated datasets for processing available for download. Furthermore, this portal provides the first maps worldwide about sea-ice thickness as data products of the European Space Agency (ESA) satellite CryoSat-2. In addition to that, datasets of snow and thermistor buoys for the Arctic and Antarctic are found in the data portal. This part of the portal is presented in English in order to make contents also easy accessible to the international scientific community. Accordingly, the English version of “meereisportal.de” is directly accessible through the second domain name “seaiceportal.de”.

The third pillar of “meereisportal.de” represents the outstanding expert knowledge of the partner institutions for different subject areas of sea-ice. This constitutes the main foundation of the platform and feeds into all parts of the portal. Consequentially, there are different essential quality features for the platform such as the accompanying assessments and evaluation of the sea-ice measurements, which are performed directly by the experts. These experts are also available to answer questions. Additionally, the direct connection to actual scientific questions guarantees a high level of competence and relevance of the topics represented on “meereisportal.de”, where sea-ice physicists, oceanographers and sea-ice modellers discuss and explain sea ice research from various points of view.

The portal is complemented by appealing reports on sea-ice expeditions, which are performed by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research. Initial ideas about this have already been realised. So far, several expeditions of the research icebreaker RV “Polarstern” in both Polar Regions have been documented on “meereisportal.de” through photographs, reports, blogs and background information and are thus available for the general public.

IMPLEMENTATION EXAMPLES

Sea ice maps and products

Continuous and areal observations of the Arctic (Antarctic) sea ice requires satellite observation – *in situ* or airborne sensors do not allow observing the sea ice cover daily and monitor the seasonal variation between 6 and 15 million km^2 (3 and 17 million km^2) as average values between 1979 and 2014. Among the various types of satellite sensors, passive microwave instruments offer the advantage of being able to observe also during the (polar) night and not being hampered by clouds. Spaceborne passive microwave sensors on polar orbits belong to the most important tools for global sea-ice observations as they have been observing the complete Earth surface daily for over 30 years. A series of different sensors was involved in these observations, mainly the Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR, 1978–1987), the Defense Meteorological Satellite Program (DMSP)-F8, -F11 and -F13 Special Sensor Microwave/Imagers (SSM/Is, 1987–2003) and the DMSP-F17 Special Sensor Microwave Imager/Sounder (SSMIS, since 2003). The sensors with the highest resolution are the AMSR (Advanced Microwave Scanning Radiometer) instruments, namely AMSR-E (2002-2011) on AQUA and AMSR2 since 2012. In the data portal, sea-ice concentration maps starting from 2002 are available; in addition, monthly mean areal extent is provided from 1979 (Fig. 1 & 2).

All these instruments observe at a set of several microwave frequencies where the atmosphere is nearly transparent. The resolution on ground varies with frequency, e.g., for the AMSR instruments the resolution varies from 5 to 50 km as the frequency varies from 89 to 7 GHz. From the set of microwave observations of a given surface area, the sea-ice concentration, that is the percentage of the surface area covered by sea ice, is determined with so-called retrieval algorithms. The sea-ice concentrations are determined based on the difference between the vertically and horizontally polarised brightness temperatures at 89 GHz of the retrieved signal, called polarization difference. It is high with values around 47 K for open water (ice concentration 0), and low with values around 11.7 K for closed sea-ice cover (ice concentration 100 %). For values in between these range, intermediate sea ice-concentration are retrieved (Spreen et al. 2008). Various algorithms have been suggested over the years, and their results agree within about 5 %, which is among the best precisions of global time series of geophysical parameters. Most of the algorithms use the observations near 19 and 37 GHz. However, on “meereisportal.de” the ASI algorithm (Spreen et al. 2008) based on the 89 GHz observations of AMSR2 are used which offer a higher spatial resolution (5 × 5 km^2).

However, at 89 GHz the atmospheric influence from water vapor and clouds is higher than at 18 and 37 GHz which requires careful “weather filtering” based on other, lower frequency channels of the same sensor and validation of the retrieved sea-ice concentrations (Spreen et al. 2008). Figure 2 shows as an example of the obtained sea-ice-concentration map. Over the ocean, the colour represents the sea-ice concentration. According to the scale, 0 % ice concentration (open water) is represented in blue. As the ice concentration increases, the colour code changes gradually to lighter blue (50 % ice concentration) and then through blue tones to white, which corresponds to 100 % ice concentration (i.e., closed ice cover). Intermediate ice concentrations only occur near the ice edge, especially in those parts pointing towards the Siberian coast. In the inner ice pack, the ice cover is practically everywhere closed (100 %, white). The map shows the ice concentration on 16 September 2012, the day of the smallest ice extent ever observed (3.3 million km^2) in the satellite era since 1972. For comparison, the coloured lines show three more sea-ice extent contours, in blue the contour of the second-lowest sea-ice minimum of September 2007 with 4.3 million km^2, in green the average minimum extent of the years 1979–1983

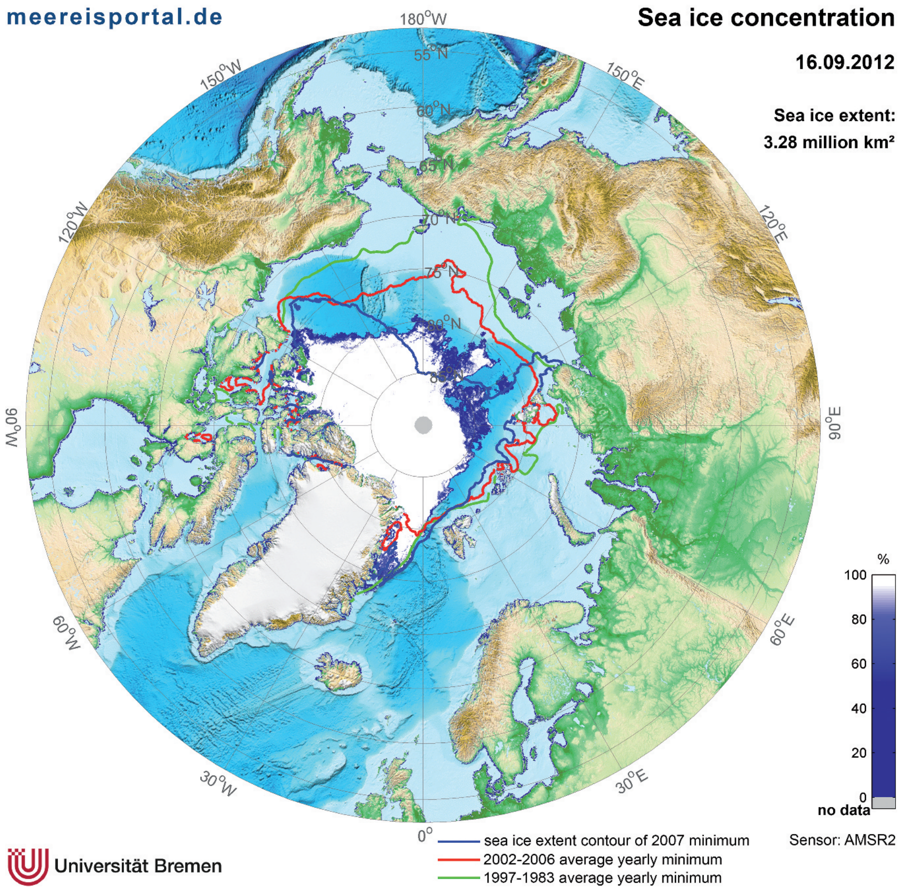


Fig. 2: Example map: sea-ice concentration of the historic minimum on 16 September 2012. Blue line: sea-ice extent contour of 2007 minimum; red: 2002–2006 average yearly minimum; green: 1997–1983 average yearly minimum. (Source contour lines: http://www.iup.uni-bremen.de: 8084/amsr2/; algorithm: SPREEN et al. 2008).

Abb. 2: Beispielkarte des historischen Meereisminimums am 16. September 2012; blau: Meereisminimum 2007; rot: mittleres jährliches Minimum von 2002–2006; grün: mittleres jährliches Minimum von 1997-1983 (Quelle: Linien: http://www.iup.uni-bremen.de:8084/amsr2/; Algorithmus: SPREEN et al. 2008).

and in red the average mean from 2002–2006: the extent of the yearly sea-ice minimum in September has reduced to less than 50 % from 1980 to 2012. The sea-ice concentration maps can be downloaded either as png-images as shown in the portal, or as original hdf5-files suitable for further processing by the users in the context of their specific applications. The files contain maps of the sea-ice concentration in percent. They use a polar stereographic projection with equal area at 70° latitude. The geographical coordinates of the pixels are given in separate files to be found at the data portal of "meereisportal.de". The data can also be found in more data formats (pdf, geotiff) on the pages of the cooperating portal of the University of Bremen (www.iup.uni-bremen.de:8084/ amsr2).

The most important applications of the maps are strategic planning of ship routing, especially for cruise ships and research vessels going to less frequented waters. Moreover, in combination with maps of earlier microwave sensors, various types of time series can be investigated. Figure 3 shows as an example of the daily Arctic sea-ice extent since 1972 together with the yearly maxima and minima. The horizontal line shows that all minima of 2007 and later were lower than all minima before: although the sea ice-minima of 2013 and 2014 were clearly higher than the historic minimum of 2012, the Arctic is still in a state of low sea ice.

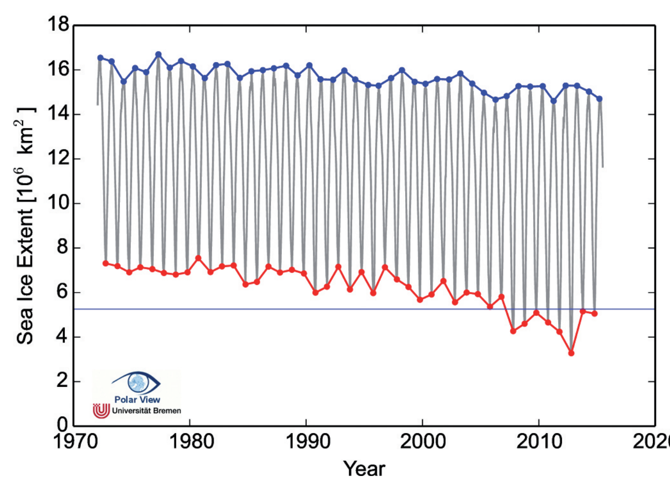


Fig. 3: Arctic sea ice extent 1972–2015. Data from various sensors combined according to iup.uni-bremen.de:8084/amsr2. Connected blue dots: winter sea-ice maximum values; connected red dots: summer minimum sea-ice extent values. The horizontal red line shows that all minima of 2007 and later were lower than all minima before.

Abb. 3: Arktische Meereisausdehnung von 1972-2015. Die Daten stammen von verschiedenen Sensoren die entsprechend iup.uni-bremen.de:8084/amsr2 kombiniert wurden. Die verbundenen blauen Punkte kennzeichnen das Wintermeereismaximum während die roten Punkte das Sommermeereisminimum kennzeichnen. Die horizontale rote Linie zeigt, dass alle Minima von 2007 und später niedriger sind als alle Minima davor.

Buoys data and maps

One main service of "meereisportal.de" is the near real-time access to measurements from autonomous platforms that measure sea-ice and sea-ice related parameters. Although these platforms are mostly not floating, but are deployed on sea ice (ice tethered), we use the common expression of "buoys" for them. The portal provides complete datasets of all buoys (beside metadata and latest position), including all measured data of the operating sensors of the different buoys. Datasets are updated daily for all active, still reporting, buoys. Past buoys, which do not report data any more, are archived in the portal and also transferred into the Pangaea data publishing and archiving system ›http://www.pangaea.de‹. This is of particular interest, because the data get a digital object identifier (DOI) and a publication abstract, allowing proper citation of the dataset.

Currently, "meereisportal.de" processes measurements from five different types of buoys/autonomous platforms (Fig. 4). Here we describe the standard configuration of these buoys, while single units may have slightly different specifications or sampling intervals:

- Snow Depth Buoys (MetOcean, Canada) measure snow depth at four points, air temperature at 1.5 m height, body temperature, and barometric pressure in hourly intervals (Fig. 4a).
- Thermistor String Buoys (SRSL, Scotland) consist of a thermistor chain with 256 elements with 2 cm spacing on a 5 m long chain to measure air, snow, sea ice, and water temperatures as well as thermal conductivity through an internal heating mode (Hoppmann et al. 2015). Temperature profiles are measured and transmitted every three hours, heating mode data daily (Fig. 4b).
- Surface Velocity Profilers (SVP) and CALIBS (Compact Air-Launch Ice Buoys) both from MetOcean, Canada measure surface temperature and barometric pressure. Their main difference is the buoy design (Fig. 4c).
- Ice Beacons (MetOcean, Canada) measure water tempera–ture and conductivity in 5 and 10 m depth (Fig. 4d).
- CALIBS (Compact Air-Launch Ice Buoys) may be launched by air drop from planes, while SPVs are deployed manually on the ice. Depending on the exact purpose and design, SVPs differ in size and specifications, e.g., may have a drogue or not (Fig. 4e).

Beyond these key scientific parameters, all buoys transmit their geographic position and timestamps based on internal GPS receivers, as well as additional control parameters, like battery voltage and satellite transmission duration, to monitor the status of the buoy and satellite connection with every recording. Data transmission is realised through the Iridium telecommunication system for all units, except CALIBS, which transfer their data though the Argos system.

The backbone of the buoy data processing and archiving is a database of metadata. These metadata include information on:

1) the buoy owner (institute, contact person, project);
2) the buoy deployment (expedition, sea ice and snow conditions, co-location with other buoys, additional measurements and observations);
3) connections to buoy networks (see below);
4) the sensors on the buoy and their individual reporting times;
5) photos of the buoy;
6) additional information and comments.

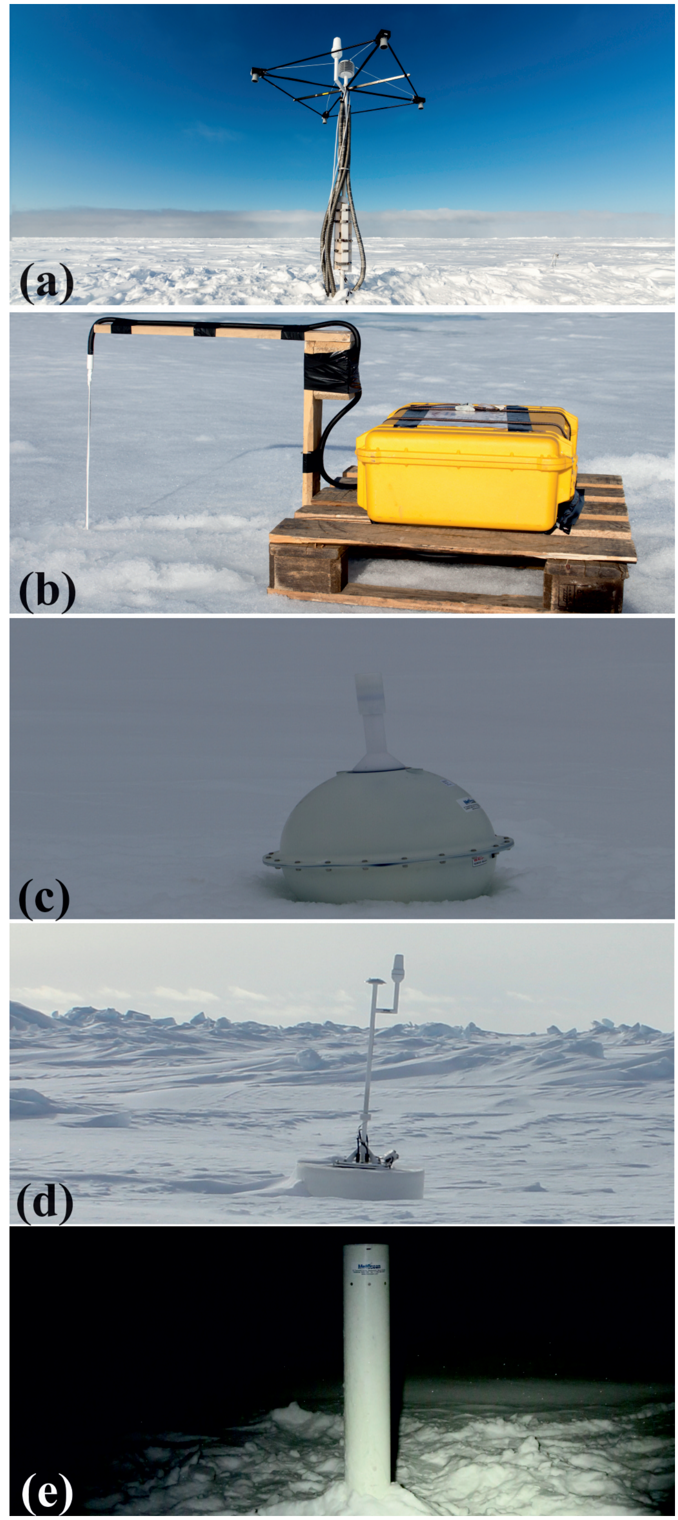


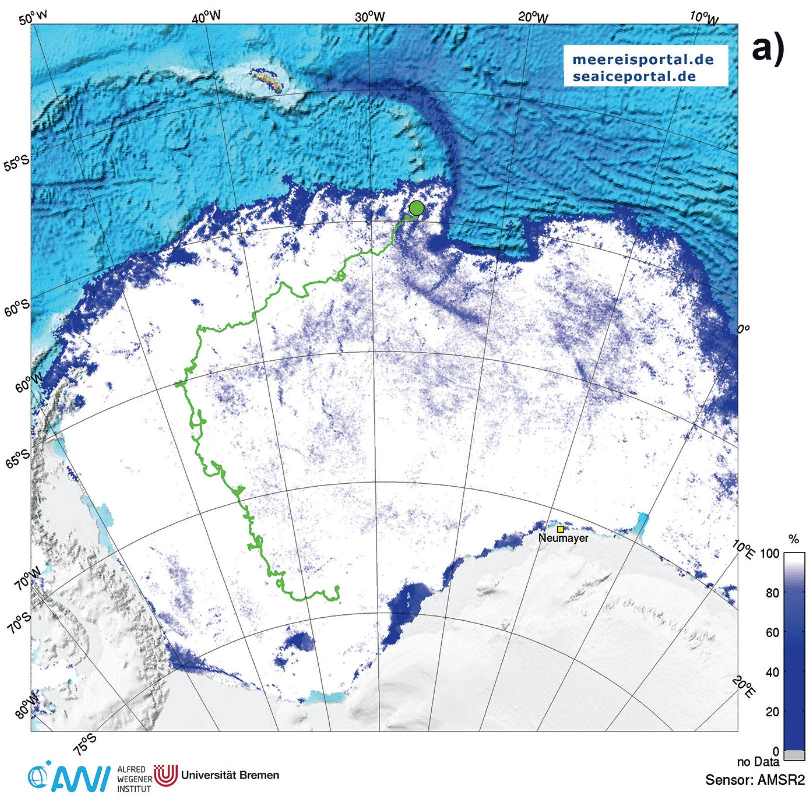
Fig. 4: Photographs of different buoy types; (a): Snow depth buoy; (b): Thermistor string buoy; (c): Surface Velocity Profiler, SVP; (d): Ice Beacon; (e): CALIBS (Compact Air-Launch Ice Buoys).

Abb. 4: Fotos verschiedener Bojentypen; (a): Schneeboje, (b): Thermistorboje, (c): Surface Velocity Profiler, SVP; (d): Ice Beacon; (e): CALIBS (Compact Air-Launch Ice Buoys).

In addition, the output of this database controls various processing routines (mostly Matlab scripts). The processing includes data retrieval from the data provider (currently JouBeh, Canada, and SRSL, UK), merging of individual datasets, processing into final physical quantities (e.g., from distance measurements into snow depth), plotting of data and maps. Pre-processed data plots and maps as well as pre-processed datasets are available from the "meereisportal.de" website. Data tables and figures use a consistent naming of all buoys, based on the year of deployment (e.g., 2014), the buoy type (S for Snow Depth Buoys, T for thermistor string buoys, C for CALIBS, B for Ice Beacons, P for SVPs), and a running number per buoy type. Buoy 2014S11 is the eleventh Snow Depth Buoy in the system that was deployed in 2014.

The platform "meereisportal.de" reports position and temperature data into the Global Telecommunication System (GTS), since December 2014. The International Arctic Buoy Program (IABP, http://iabp.apl.washington.edu/) receives all buoy data and necessary metadata since August 2012. Data forwarding to GTS and IABP is coordinated in collaboration with the respective buoy owner.

Figure 5 shows an example of a drift and data plot for Snow Depth Buoy 2014S11. The buoy was deployed in the Weddell Sea, Antarctic, on 29 January 2014 and reported data until 02



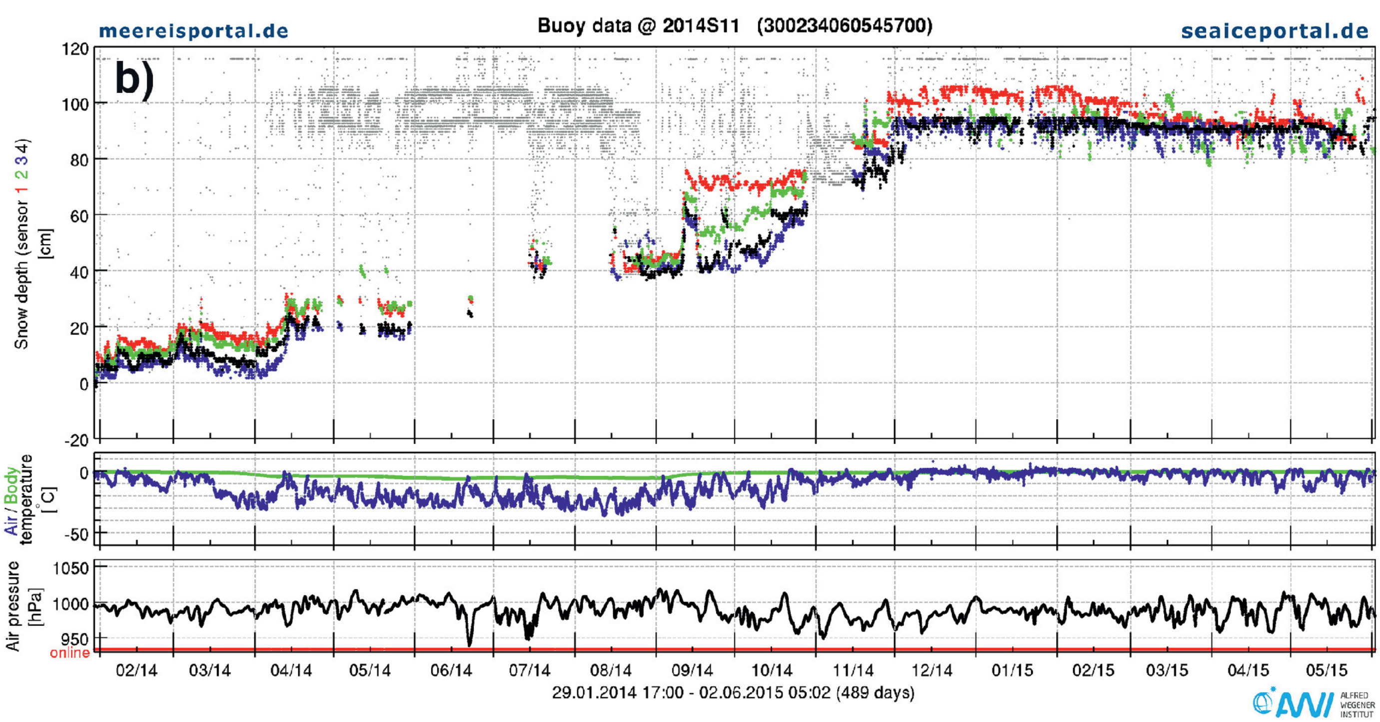


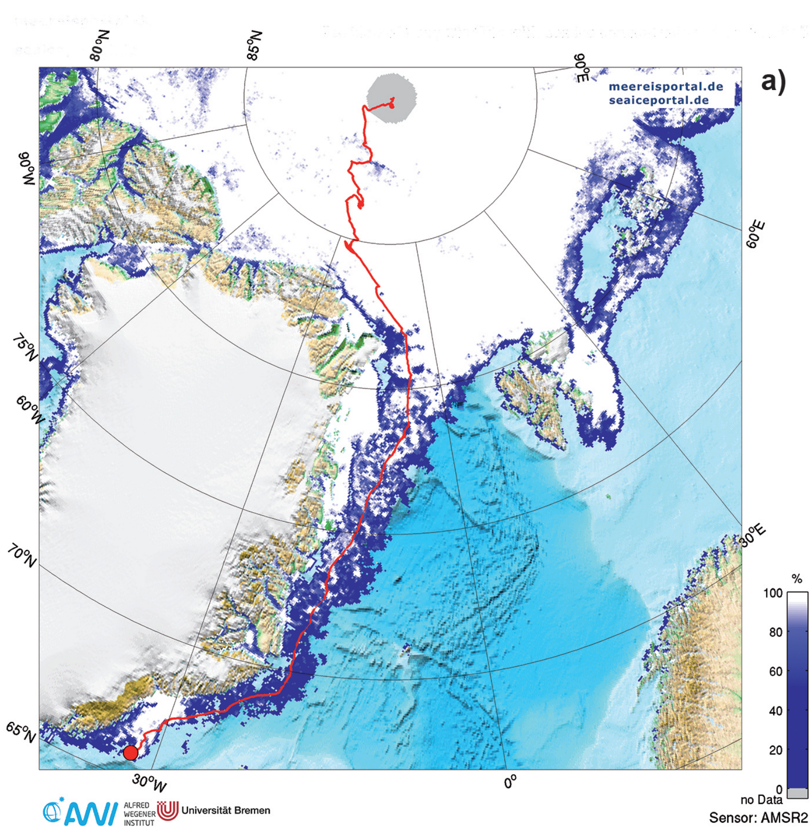
Fig. 5: (a) Drift trajectory and (b) measured parameters of the snow depth buoy 2014S11, which drifted in the Weddell Sea from 29 January 2014 to 02 June 2015. Snow depth is shown for all four sonic pingers individually. In addition, barometric (air) pressure as well as 1.5 m air temperature and the body temperature of snow and sea ice are shown.

Abb. 5: Drifttrajektorie (a) und gemessene Parameter (b) der Schneeboje 2014S11, die im Weddellmeer vom 29. Januar 2014 bis 2. Juni 2015 gedriftet ist. Die Schneedicke wird individuell an vier verschiedenen Ultraschallsensoren gemessen und dargestellt. Darüber hinaus werden gezeigt: barometrischer Luftdruck, Lufttemperatur in 1,5 m Höhe und die Schnee- und Oberflächentemperatur.

June 2015, when it (most likely) drowned in the marginal ice zone (Fig. 5a). In the meanwhile, snow depth has increased from below 10 to over 80 cm. Different snow fall events characterise the increase of snow depth, while also a slight decrease over the austral summer 2014/15 is visible (Fig. 5b). All four sonic sensors are shown and indicate the small-scale variability of snow depth in the area around the buoy (approximately 4 m^2) as well as uncertainties in the measurements. Grey dots show reported observations that got filtered during data processing and are removed from the final data set. In addition, air and body temperature show the seasonal cycle with air temperatures as low as -30 °C, while the body (snow and surface ice) temperature only drops to -15 °C. Air pressure is recorded along over the entire observation period of 489 days.

An example of Thermistor String Buoy 2014T14 is shown in Figure 6. This buoy was deployed close to the North Pole on 26 August 2014 (Fig. 6a). The buoy reported temperature and heating profiles through the entire Arctic winter 2014/15 (Fig. 6b). An automatic conversion of temperature profiles into sea-ice thickness is not possible yet, but different projects are currently working on methods that will allow time-series calculation of sea-ice thickness in the near future.

Different to the two very long lifetimes of the exemplary buoys from Figures 5 and 6, other buoys have much shorter lifetimes and periods of data transmission. Figure 7 shows the lifetimes of all snow depth (Fig. 7a) and thermistor string buoys (Fig. 7b) that are currently registered in "meereisportal.de". Average lifetime of snow depth buoys and thermistor string buoys are currently (status 24 November 2015) 200 and 153 days, respectively. Lifetimes on Antarctic sea ice are generally longer (snow buoys: 323 days, thermistor string buoys: 260 days) then on Arctic sea ice (snow buoys: 116 days, thermistor string buoys: 84 days), but this statistic is still weak due to the limited number of buoys (Arctic: 32 buoys, Antarctic: 28 buoys). The exact reason of buoy failure is often unknown. However, some reasons may be derived



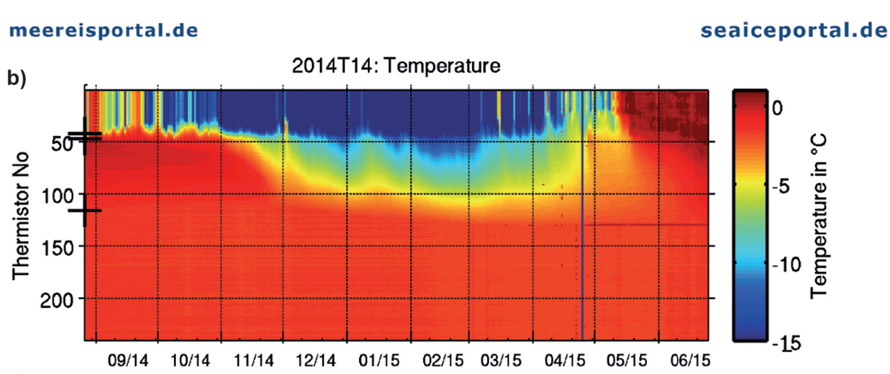


Fig. 6: (a) Drift trajectory and (b) measured sea ice temperatures of the thermistor string (mass balance) buoy 2014T14, which was deployed on 26 August 2014 close to the North Pole and drifted along the coast of Greenland until it stopped reporting after 265 days on 18 May 2015.

Abb. 6: Drifttrajektorie (a) und gemessene Meereistemperatur (b) der Thermisterboje (Massenbilanz) 2014T14, die am 26.08.214 nahe des Nordpols eingesetzt wurde. Sie driftete entland der Küste Grönlands und die Übertragung stoppte die Übertragung nach 265 Tagen am 18. Mai 2015.

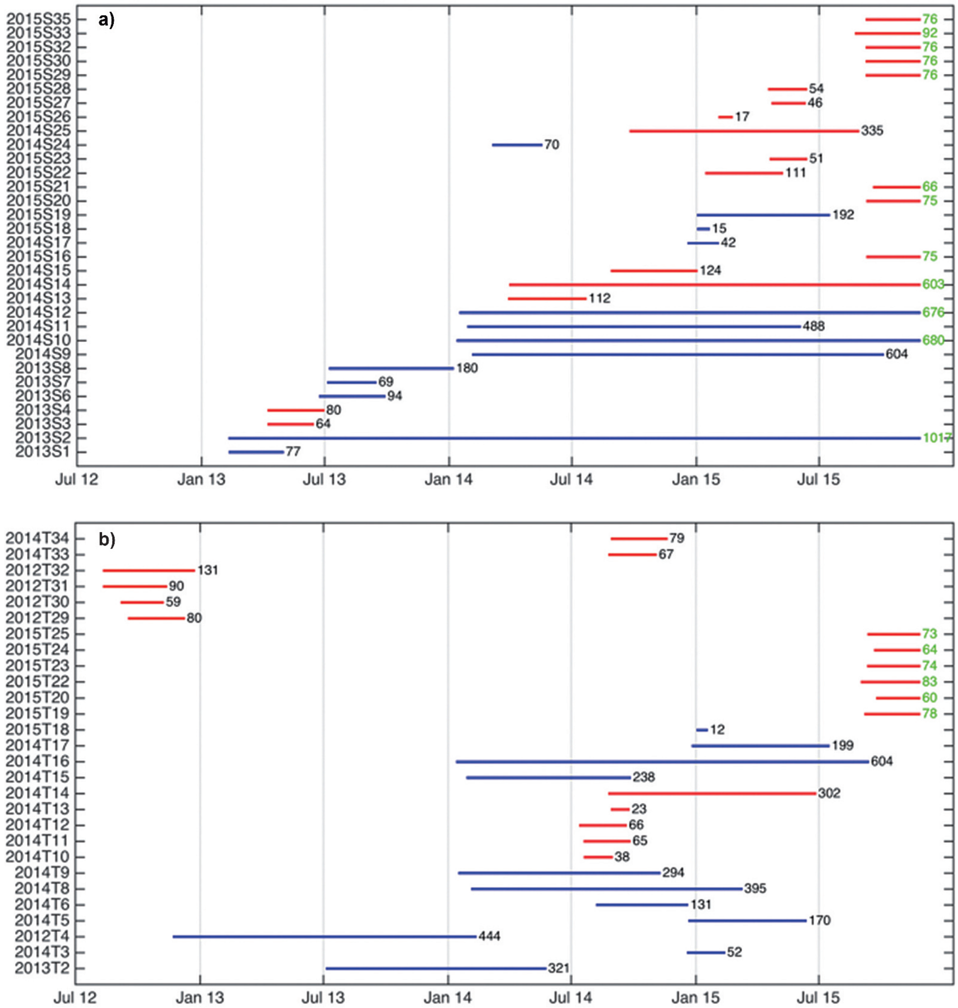


Fig. 7: Lifetimes of (a) all 32 snow depth and (b) all 28 thermistor string buoys recorded in "meereisportal.de" (status 24 November 2015). Numbers give the life time in days, while green numbers indicate buoys that were still transmitting. Blue (red) bars indicate Antarctic (Arctic) buoys, respectively.

Abb. 7: Lebenszeit aller (a) 32 Schneebojen und (b) 28 Thermistorbojen, die in "meereisportal.de" dokumentiert werden (Status 24. November 2015). Die Zahlen geben die Lebenszeit in Tagen an, während grüne Zahlen Bojen anzeigen, bei denen die Datenübertragung noch besteht. Blaue (rote) Balken stehen für antarktische (arktische) Bojen.

from the datasets themselves or in connection with sea-ice concentration data. Some snow depth buoys seem to have strongly tilted or even fallen over (e.g., 2013 S4; not depicted here, for details see website). This may be derived from the sudden spread of the measurements of single sensors. In this and similar cases, the buoy continued to send data, but not the entire suite of possible parameters is useful over the entire lifetime. However, the dataset may still be used for drift studies. Other buoys have simply melted out of the ice. In this case, the buoy does not send any data from one to the next moment and sea-ice concentration shows a position in the marginal ice zone (e.g., 2015 S22; not depicted here, for details see website). For the Thermistor String Buoys, the thermistor chain itself is the weakest element, causing most failures, while these units also report their position much longer (e.g., 2014 T9; not depicted here for details see website). Drifting buoys (SVP and CALIB) without masts or chains are the most robust systems.

CryoSat data product

The estimation of sea-ice thickness using data from the satellite radar altimeter mission CryoSat-2 of the European Space Agency (ESA) is a field of active research and developing processing schemes. Preliminary products, mainly monthly gridded fields of Arctic sea-ice thickness, are nevertheless of interest for model evaluation (STROEVE et al. 2014) and forecast initialisation. These products are based on a processing chain that has been developed at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research with the aim to investigate and evaluate optimal strategies for sea-ice thickness retrieval, using high resolution radar altimeters with the ultimate goal of quantifying the global sea-ice volume budget.

The underlying principle of CryoSat-2 sea-ice thickness retrieval is the estimation of freeboard, the height of the sea-ice surface above the local sea level and its conversion into thickness using isostatic principles. Freeboard values are obtained by means of differential radar range measurements between the elevation of the sea level over leads between floes and the elevation of the ice surface (Fig. 8). Main research question and reason for evolving processing schemes is the interpretation of radar echoes of CryoSat-2's synthetic aperture radar altimeter over rough and snow covered ice surfaces (RICKER et al. 2015). In addition, several auxiliary input parameters such as snow depth or snow and ice density cannot be measured on a relevant scale for CryoSat-2 sea-ice thickness retrieval and must be substituted by assumptions or parametrisations. It is therefore imperative for the scientific usability of data products to include an inventory of all parameter fields used with uncertainty estimations when possible. A detailed overview of the underlying assumptions and processing steps is available in a user guide (HENDRICKS et al. 2013) or in the scientific literature (RICKER et al. 2014).

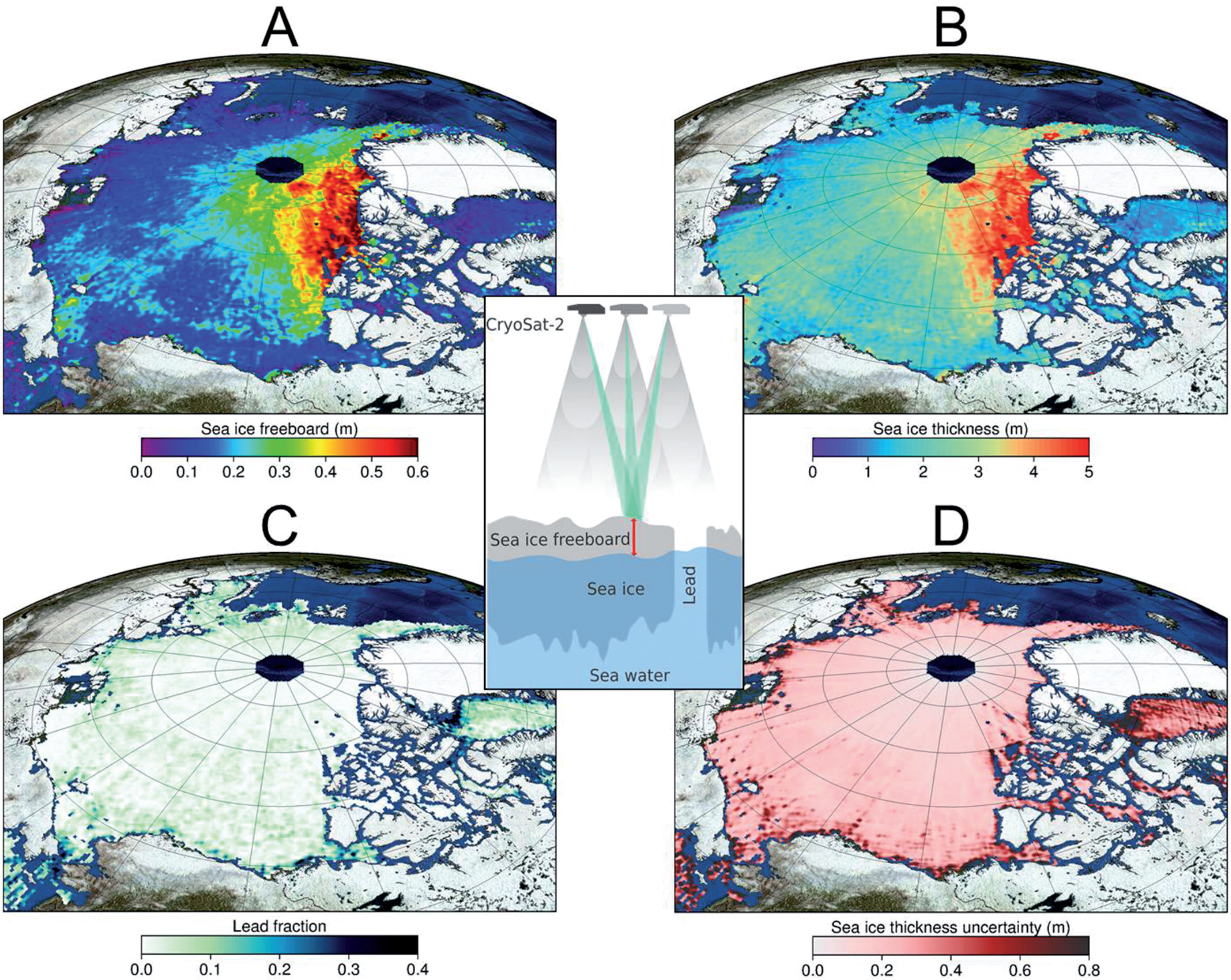


Fig. 8: Exemplary sea-ice parameters of the CryoSat-2 Arctic sea-ice data product. A: sea-ice freeboard, the height of ice floes above sea level, B: sea-ice thickness, derived from freeboard with the assumption of a snow climatology. C: The fraction of identified leads between sea-ice floes, whose elevation is used to obtain freeboard from the CryoSat-2 range measurements. D: The geographical distribution of sea-ice thickness uncertainty. The sketch in the middle of the figure demonstrates the principal behind CryoSat-2 sea-ice measurements.

Abb. 8: Exemplarische Meereis-Parameter aus dem CryoSat-2 Meereis-Produkt. A: Eis-Freibord, die Höhe der Meeresoberfläche über dem Meeresspiegel. B: Meereisdicke, abgeleitet aus Freibord unter Annahme einer Schneeklimatologie. C: Anteil der innerhalb der Eisfläche als offenes Wasser detektierten Messungen, deren Höhe genutzt wird, um das Freibord zu berechnen. D: Geographische Verteilung der Eisdicken-Unsicherheiten. Die Skizze in der Mitte der Abbildung beschreibt das Messprinzip von CryoSat-2.

Currently "meereisportal.de" hosts the Arctic CryoSat-2 sea-ice data product from spring 2011 to spring 2015 as gridded monthly means. Data from June to September are not shown because summer melt conditions strongly impact even prohibit reliable measurements (e.g., Ricker et al. 2014). An Antarctic CryoSat-2 sea-ice data product is under development and is planned to be included into "meereisporatal.de" in 2016 (Schwegmann et al. 2015). The data are available also during summer when the properties of the melting surface do not allow the retrieval of freeboard. Gridded fields on an Equal-Area Scalable Earth Grid (EASE2-Grid) with a 25 km resolution are available for a modified snow-depth climatology that is used in the processing as well as the density of ice and snow. In the future these fields shall be extended not only to recent monthly means but also with additional parameters such as the sea-surface height estimation. The height of the sea surface, that is a byproduct of the freeboard estimation, is usually described as the sum of mean sea-surface height and the anomaly of the actual sea surface relative to its mean value at the location of the individual record. The sea-surface anomaly is a valuable parameter since it may be used for sea-level budget estimations and Arctic wide measurements in ice-covered waters are sparse.

Changing baseline algorithm versions of the lower level data products at ESA and improvements in the sea-ice thickness retrieval are the reasons that the CryoSat-2 data product requires infrequent update. Subsequently, the data product on "meereisportal.de" will need to be updated as data and processing algorithms mature. Though CryoSat-2 data show a good agreement with independent validation data (Laxon et al. 2013) the sea-ice thickness grids should not be taken as an operational product. The intention is rather to distribute a science dataset that shall promote the use of CryoSat-2 data products over sea ice and enable tests and improvements of the processing chain by the wider scientific community.

EXAMPLES OF "meereisportal.de" DATA PRODUCTS, THEIR APPLICATIONS, AND SPECIFIC USER REQUESTS

The following paragraph shortly describes the variety usage of information, data and products based on "meereisportal.de". Since its start in 2013, these services are used and incorporated in various applications and in many ways. This encompasses the answer of question by an interested public as well as data input for scientific analysis. In Table 2 we compiled a brief overview of some example applications to demonstrate the capability and the potential of the website and its provided direct data access.

CONCLUSION AND OUTLOOK

The website "meereisportal.de" represents an example of the knowledge transfer process of science to different stake–holders, which could be scientists for specific data demand or the society in general, with respect to sea ice as an important climate indicator. The platform is maintained by institutional support from different departments and partners and is embedded in the frame of the Helmholtz Climate Initiative, Regional Climate Change (REKLIM). The platform "meereisportal.de" offers scientific qualified information focused on sea ice to a German audience. It provides comprehensive, high quality and up-to-date data and information. The portal aims at user specified and individually tailored information and services. Through the multilevel structure (breadth and depth) of the data and information portal and its user specified products "meereisportal.de" responds to the increasing demands of various user groups. Following this approach, knowledge relevant for the society is derived from scientific results and supports activities in the fields of information, education and decision-making. In recognition of its excellent service the platform "meereisportal.de" received an award in 2015 within the "Germany – Land of Ideas" initiative.

The platform "meereisportal.de" is intended as a lively platform, providing preprocessed data, expert assessment of the current sea-ice situation and information from different perspectives around the topic of sea ice. However, beyond this service and products "meereisportal.de" is intended to be used from the scientific community as a multiplier forum for their research results and data. The website "meereisportal.de" invites scientists to upload their data on the portal, providing successively a full range of all sea ice related data. As a next step, ice thickness information on thin ice from SMOS satellite measurements (Tian-Kunze et al. 2014), complementing CryoSat-2 information on thin sea ice between 50-100 cm, as well as ice drift information and its uncertainty for the period 2003–2007 (Sumata 2015) will be made available. In addition, an evaluation of the Coupled Model Intercomparison Project phase 5 (CMIP5) with respect to sea-ice variability and projections will be provided by University of Hamburg

Area of application	Service	Example description and according references
Education	Support data set usage, including the extraction of custom-made datasets on demand	Sub-sampling sea ice concentration data over longer time periods related to past expeditions are used in different Bachelor and PhD theses which are realized in close cooperation with various universities (e.g., University of Hamburg, Jade Hochschule), where "meereisportal.de" is directly involved in providing processed data. These studies comprise data analysis about ship routing in the Russian Arctic and the comparison of EM bird measurements of sea-ice thickness with sea-ice concentration data.
Scientific papers	Access to various sea ice related data and data products for further own processing	Data input of "meereisportal.de": Rutgers van der Loeff et al (2014) used sea-ice concentration data in order to relate their findings of gas transfer through sea ice with the ice conditions prior to and during their expedition. Mutsa Roca-Marti et al (pers. com. 2015) used sea-ice concentration data to illustrate the results on "carbon fluxes and export efficiency in the Central Arctic at different time scales during summer 2012". Buoy data have been used for sea-ice drift product validation (Lavergne pers. com. 2014). Sea ice concentration data were analysed for different sectors in order to determine the impact of oceanic ^{222}Rn emissions (Weller et al. 2014).
Expedition support	Support route planning, provide for expedition operation areas, custom-made datasets and products on demand	This includes both the statistical analysis of data prior to the expedition as well as routinely providing current daily sea-ice concentration maps for specific operational areas via E-Mail during the expedition. These activities effectively support the on-site station planning (e.g., three RV "Polarstern" expedition into the Weddell Sea have been supported). Another example is a touristic shipping company, which downloaded sea-ice maps of the Weddell Sea area to derive average conditions of the sea ice to support their expedition planning, focussing on routes along the potential sea-ice edge.
General public	Provide answers for questions or provide input for books, exhibitions etc., custom-made data products on demand	For example in Lemke & von Neuhoff (2014), a popular science book, historical expedition maps and modern sea-ice concentration maps were specially adopted for this publication. Furthermore, "meereisportal.de" provided a customized animation of sea-ice concentration evolution of the Antarctic and Arctic for an exhibition in the International Maritime Museum Hamburg.
Policy support	Contribute to policy processes	"meereisportal.de" was directly asked for a contribution to a "kleine parlamentarische Anfrage 18/5692" of the party fraction "Bündnis90/Die Grünen" about sea ice in summer 2015.

Tab. 2: Overview on application examples of "meereisportal.de" services.

Tab. 2: Exemplarischer Überblick über einige Anwendungen von "meereisportal.de".

(Dirk Notz pers. com), offering data and maps for a thorough comparison of observational and modelled data up to present day and an expert assessment of the potential future development of sea-ice evolution in the Artic and Antarctica.

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<http://meereisportal.de> Wissens und Datenplattform rund um das Thema Meereis; function tested on 01 March 2016.

<http://seaiceportal.de> Knowledge and data platform on the topic sea ice; function tested on 01 March 2016.

PANGAEA <http://www.pamgaea.de/> Data publisher for Earth & Environ– mental Science; funtion tested on 01 March 2016.

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