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CliC Arctic Sea Ice Working Group Workshop Report on

Arctic surface-based sea-ice observations:
Integrated protocols and coordinated data acquisition

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NOTE

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CliC Arctic Sea Ice Working Group

Arctic Surface Based Sea-Ice Observations: Integrated Protocols and Coordinated Data Acquisition

Norwegian Polar Institute
Tromsø, Norway
26-27 January, 2009



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Hajo Eicken, Nalan Koc, and Kazu Tateyama were not present at the photo session.
Photo: Ann K. Balto, NPI.

Table of Contents

Overview	1
Extended Abstracts	3
Overview of key parameters recommended by past workshops.....	
<i>Don Perovich</i>	4
Intercomparability and standardization of remote-sensing data sets.....	
<i>Walt Meier</i>	6
Arctic Sea Ice Workshop: Report on Antarctic efforts on ship-based observations.....	
<i>Tony Worby</i>	8
Overview of standard Russian sea-ice field measurements.....	
<i>Alexander Makhstas</i>	11
Sea-ice field measurements: Observation protocols and best practices – Potential resources and coordination.....	
<i>Hajo Eicken</i>	15
ESA-CliC collaboration.....	
<i>Daqing Yang</i>	18
Establishing a community-based sea-ice observing network in the Arctic.....	
<i>Shari Gaerhard</i>	23
Data acquisition, management and dissemination.....	
<i>Florence Fetterer</i>	27
Break-Out Session Summaries	28
Summary of Break-Out Session 1a: Key Parameters - Modeling.....	29
Summary of Break Out Session 1b: Key Parameters - Remote Sensing.....	31
Summary of Break-Out Session 2a: Standardization - Observations while on moving: ships, aircrafts, submarines.....	34
Summary of Break-Out Session 2b: Standardization - On-ice measurements.....	36
Summary of Break-Out Session 3a: Coordination and Implementation - North America Sector.....	40
Summary of Break-Out Session 3b: Coordination and Implementation - Eurasian Sector.....	43
Appendices	45
1. Report on <i>IcePlan.org</i>	46
2. Agenda.....	47
3. List of Participants.....	50
4. List of Acronyms.....	53

Overview

The Arctic Sea-Ice Working Group in the context of CliC

The Climate and the Cryosphere (CliC) program is a core project of the World Climate Research Programme (WCRP) and as such directly concerned with the science and observation of the Arctic sea-ice cover as an important component of the global cryosphere and the climate system (Allison *et al.*, 2001). Given recent observations of substantial reductions in the thickness and extent of the Arctic ice cover (Rothrock and Zhang, 2005; Serreze *et al.*, 2007; Lindsay *et al.*, 2009), and considering the need to coordinate ground-based observations as part of the emerging Arctic sea-ice observing network at a pan-Arctic level (Gascard *et al.*, 2008; Murray *et al.*, 2009), the CliC Arctic Sea-Ice Working Group was implemented in 2008 to help with this goal. Specifically, it is meant to address the following core goals of CliC: (i) enhancing observation and monitoring of the cryosphere in support of process studies, model evaluation and change detection, (ii) improving understanding of cryosphere physical processes and feedbacks, and ultimately (iii) improving representation of cryospheric processes in models (Allison *et al.*, 2001).

These long-term goals of the group will be achieved through a combination of workshops, collaborative efforts leading to online resources and white papers and joint publications. The present Workshop on Observation Integration is the first one of these efforts and meant to establish linkages within the international Arctic sea-ice research community, representing a broad mix of countries (32 representatives from 13 attended the meeting) and disciplines, including field-based research groups, remote-sensing experts, modelers and data managers, as well as a few key representatives of stakeholder groups such as local communities, industry and others. In organizing this meeting, we are building on a long tradition of international collaboration and joint efforts, ranging from such highly successful programs as the International Arctic Buoy Program (IABP) to joint scientific expeditions and field work. It is hoped that the efforts of this working group can be of help in the design, implementation and consolidation of the nascent Arctic Observing System and point the way for further integration at the pan-Arctic level.

Short summaries of the workshop were given by Perovich *et al.* (2009) and Perovich and Gerland (2009).

Workshop goals

The main goals of the workshop include the following:

1. Identify the key variables – in order of priority – that need to be captured as part of an Arctic sea-ice observing network aiming to address the overarching goals of cryospheric observing programs;
2. Assess the current status of ground-based and airborne sea-ice observation programs in the Arctic;
3. Identify necessary next steps to improve coordination of measurement programs, intercomparability and standardization of observations, data management and transfer of information to modeling and remote-sensing communities as well as key stakeholder groups;
4. Take first steps in developing an agenda for the group and building a network for exchange among Arctic sea-ice researchers.

Workshop process and expected outcomes

In addition to presentations providing an overview of key issues and summarizing workshop results (see detailed workshop program), the meeting was organized into three break-out sessions: identification of key variables/parameters to be obtained from measurements, standardization of observation protocols and development of best practices, and implementation of coordinated observing efforts. The key variables/parameters break-out session gathered in three sub-groups (modeling, field observations and remote sensing). The standardization break-out session distinguished between observations from moving platforms, on-ice measurements and remote sensing and modeling. Finally, coordination and implementation was divided up into three geographic regions (North American, Eurasian and High Arctic sectors). The key results and recommendations from these break-out groups are part of this summary report. Workshop outcomes are summarized in detail in this report, but fall into the following categories:

1. Creation of a draft set of key variables/parameters and prioritization deemed important in the context of Arctic observing system measurements of sea ice; this list is to be refined and updated through further working group efforts; brief survey of present status of the observing system and important observational gaps;
2. Development of a strategy to improve intercomparability and standardization of measurements, tying into existing standardization efforts such as through WMO Sea Ice Nomenclature and other working groups; the main outcome expected from this effort is an initial outline of how to move towards implementation of best practices across the entire range of observations that are part of an observing network;
3. Summary of field activities planned for 2009 and 2010 for each active country as a basis for joint planning and improved coordination of measurement campaigns;
4. Establishment of a rough outline of further working group activities and milestones.

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Extended Abstracts

Overview of key parameters recommended by past workshops

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The Arctic sea-ice cover is diminishing. Over the past decades the ice extent at the end of summer in September has declined markedly, the amount of perennial ice has decreased, and the ice has thinned. These changes are important to a wide range of issues and impact a varied group of stakeholders from Arctic communities to policy makers to marine transportation to resource extraction. First observing and then understanding the ongoing sea ice changes are critical in determining how to respond to the changes.

There are four central measurement issues in observing change: i) what parameters to measure; ii) what tools to use to measure those parameters; iii) what spatial scale to measure; and iv) how often to measure. These issues have been discussed by sea-ice researchers for many years. The design of a measurement plan depends on the hypotheses to be tested or the questions to be answered. The questions that are being addressed today range from the scientific to the societal, from examining sea ice as an indicator of climate change to examining the ice as a platform for human activity. Table 1 summarizes sea ice and snow parameters that have already been identified as important and are often measured. The first section of Table 1 lists the basic sea ice and snow parameters that define the amount of sea ice, and are of great interest. Parameters under other headings are more detailed and are measured in conjunction with specific efforts examining such topics as ice motion; ice growth and melt; ice physical, mechanical, or electromagnetic properties; and the sea-ice ecosystem.

There are numerous tools available to measure sea-ice parameters, some of which are shown in Figure 1. There is a wealth of archived data from earlier research that can be readily accessed. Satellites, aircraft, ships, and submarines can provide large-scale survey information on the ice cover. There is an extensive array of satellite sensors and products including visible and near infrared photographs, active and passive microwaves, laser and radar altimeters, and thermal imagers. Process studies can be conducted from ice camps and ships, while land-based observatories can provide detailed information on local ice conditions. Autonomous stations include ice-tethered platforms, moorings, and drifters; all provide *in situ* data, without the logistical difficulties of a field campaign.

Observations are made over spatial scales ranging from a few meters to several kilometers to a region to the entire Arctic Ocean and surrounding seas. Temporal periods of interest vary from seconds to days to seasons to years to decades. As always, the hypotheses and questions dictate the spatial and temporal scales of interest. For example, process-oriented studies typically are smaller in spatial scale and last for weeks to months to a year. Climate change issues require pan-Arctic observations made over time periods of years to decades.

A challenge for this workshop is to develop, standardize, and implement observation and measurement protocols for Arctic sea ice in coastal, seasonal, and perennial ice zones. The needs of different stakeholders must be considered as we work to standardize observations and strive to integrate observations and models.

Table 1: Standard snow and ice parameters that are often measured.

Basic sea ice and snow	Supplemental sea ice and snow	Thermodynamics
Ice thickness Ice extent Ice area Ice concentration Snow depth	Snow depth distribution Snow density Snow stratigraphy Snow grain size Ice thickness distribution Ice age Ice type Ice roughness Melt pond coverage Pond size and depth	Ice growth Ice surface melt Ice bottom melt Onset of summer melt Onset of fall freeze up
Dynamics	Physical Properties	Electromagnetic Properties
Ice motion Ice velocity Ice deformation Ice stress Ice strength	Ice salinity Ice temperature Ice density Sediments + biology Inclusion size distribution	Albedo Extinction coefficient Backscatter Emissivity

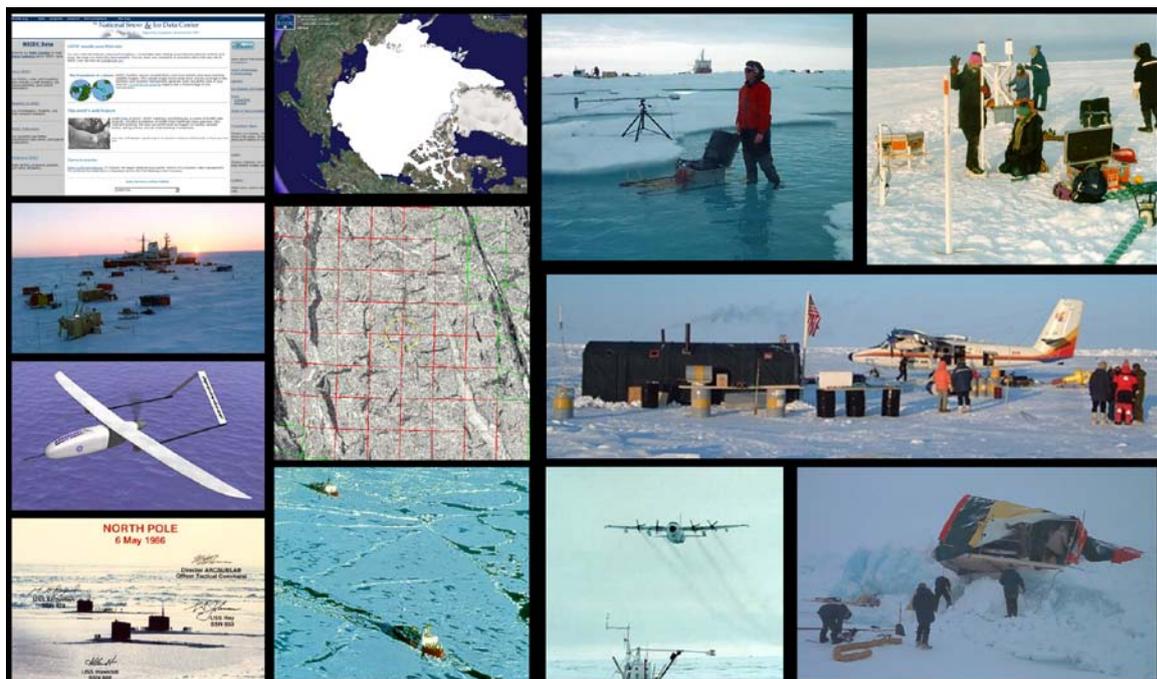


Figure 1: Tools to measure sea-ice parameters. These include satellites, aircraft, ice camps, ships, submarines, autonomous measuring systems, and land-based observatories.

Intercomparability and standardization of remote-sensing data sets

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Thanks to passive microwave satellite sensors, sea-ice extent and area is one of the longest and most complete climate records, now with a greater than thirty year time series. However, does this time series satisfy the level of a climate data record? The U.S. National Research Council defines a Climate Data Record (CDR) as:

“A time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change” - NRC Report on Climate Data Records from Environmental Satellites, 2004.

By this definition, the passive microwave sea-ice time series does appear to qualify as a CDR. However, important components of a satellite-derived CDR also include: (1) the best possible intersensor calibration, (2) detailed data quality information (e.g., grid-cell level error estimates), and (3) high-quality metadata.

The passive microwave record has limited intersensor calibration. Unfortunately, much of this is due to limited overlaps of satellite missions. Nonetheless, there are opportunities to improve the intersensor calibration. For example, basing the calibration off of the most recent, highest-quality sensor would be better than the current approach of using the oldest sensor.

Data quality is a significant omission in the present passive microwave sea-ice record. Currently, there is no error or data quality field that accompany the data. There are only general error estimates, based on limited validation, but no grid-cell level error fields.

Metadata is also severely lacking and needs to be enhanced to conform to the latest standards. This is essential for long-term preservation. Metadata should include all necessary information to completely reprocess the data record.

Another factor with the passive microwave sea-ice record is that there are myriad algorithms archived and commonly used. The two most widely-used are the NASA Team and Bootstrap, but there are several others. Ideally, a CDR is a single, authoritative record for a given parameter, though it may be based on a fusion of various estimates. While the various algorithms each have good internal consistency, there is a wide discrepancy between algorithm products. Total ice extent and area can vary by 500,000 square kilometers – up to 10% of the total ice cover – depending on the algorithm.

The National Snow and Ice Data Center and the ESA Satellite Application Facility, Ocean and Sea Ice (OSISAF) project have collaborated on a project to reprocess SMMR and SSM/I brightness temperature and sea-ice products. OSISAF has led the project with NSIDC aiding in processing of SMMR data. The project will yield many new improvements, including preserving the source swath brightness temperature data, running sea-ice algorithms on the swath data instead of daily gridded averages, using a hybrid combined algorithm, and using daily-derived tiepoints (calibration coefficients for pure ice or water surface types). NSIDC is undertaking a related project to enhance its sea-ice products toward a CDR-level product.

In addition to sea-ice extent, concentration, and area fields, there are several other potential passive microwave sea-ice products that could be further developed, including: sea-ice motion/drift, sea-ice age, melt onset and freeze-up.

Other sensors are providing new sea-ice data products. These include ICESat-derived freeboard, thickness, and volume. The ESA Cryosat-2, scheduled to be launched in late 2009, will provide similar data. Field observations of ice thickness as ground truth are needed for validation of the satellite ice thickness estimates. Finally, there are numerous other *in situ* data, from autonomous instruments (e.g., buoys) to field data that could be incorporated into sea-ice climate records.

In combining various sources together, it is essential to account for different spatial and temporal scales. For example, passive microwave data has a spatial resolution on the order of 10 km, while *in situ* measurements are point measurements. It is crucial to consider these effects in light of the wide spatial and temporal range of sea-ice features – from large floes many kilometers across that are relatively stable over many days or weeks to leads or ridges that may be on the order 10 m wide and develop over the course of a few hours. Small-scale surface properties, such as snow cover, frost flowers are also important, both to the physical environment and to the signal observed by remote sensing instruments.

The Integrated Global Observing Strategy Partners (IGOS-P) Cryosphere Theme Report made several recommendations for future observing requirements that are important to consider. Some of the key recommendations are listed below:

- Continuity of PM records – reanalysis/reprocessing, algorithm validation, fused algorithms
- Access to SAR products
- Continuity and coordination of altimeter missions – improved methods for sea ice
- International collaboration on field campaigns, for maximum benefit to satellite validation
- New technologies – UAVs, AUVs, airborne lidars, *etc.*
- Recovery of historical records – extend timeseries
- Coordination with biology, chemistry, ecosystem research
- Coordination with modeling – data formats and projections, emissivity/backscatter models, data assimilation
- Continue to meet operational requirements of ice services

Arctic Sea Ice Workshop: Report on Antarctic efforts on ship-based observations

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The Antarctic Sea-Ice Processes and Climate program was formed in 1997 under the auspices of SCAR. The goal of ASPeCt was to promote multi-disciplinary sea-ice research to address deficiencies in our understanding of Antarctic sea ice processes, to improve the understanding of sea ice in the climate system, and to assist with the planning and coordination of field campaigns by national programs.

One of the key successes of ASPeCt has been the implementation of a ship-based sea-ice observing program, which has harnessed the efforts of hundreds of ice observers aboard many different icebreakers, to produce a quality controlled, standard format data base from 1980 – 2005. With funding from SCAR, and in-kind support from the Australian Antarctic Division, ASPeCt undertook an extensive data rescue program, identifying many historical voyages which collected information on sea ice en route to coastal stations, or during science voyages. These data sets contained varying levels of detail and were in many different formats, often using codes to refer to particular characteristics of the ice. Most were in analogue format, including old ice charts kept in filing cabinets and basements, and those that were digitised used a range of software products, some of which are now obsolete.

In establishing the sea-ice observation program, there were a number of key challenges:

1. Devising a standard procedure and format for recording sea-ice data from vessels. Many national programs, or ship's crew, had devised their own method of estimating and recording the details of the sea ice. In 1985 Dr Ian Allison from the AAD adapted a new format based on that used by officers on Norwegian ships, but which recorded multiple ice types using the WMO nomenclature. This was refined throughout the late 1980s and early 1990s, and trialled by sea-ice scientists from a number of countries, before being adopted by ASPeCt. It was important to ensure we had international buy-in before asking people to adopt the procedure as standard protocol.
2. To train ice observers and to implement an observing network. It was acknowledged that "junk in equals junk out" when it comes to statistics and therefore deemed important to ensure that high quality observations were made. To facilitate this a training CD-ROM was compiled by ASPeCt that provided a step-by-step tutorial to making observations, and basic software to enter and quality control the observations.
3. To establish a repository of data for new observations, and for the historical data that had been digitised and quality controlled. This was established at the Australian Antarctic Division, where individual data files can be downloaded from the Australian Antarctic Data Centre. The ASPeCt website: www.aspect.aq hosts the full data archive and derived statistics that can be easily downloaded. An online tool to grid the data to suit different model grids is being developed and will be available in 2010.

The observation protocols have been described in detail in a number of reports and scientific papers, so are not covered in detail here. To summarize, the observations include time, latitude and longitude, total ice concentration, and the concentration, ice type, thickness, floe size, topography and snow cover type and thickness for the dominant ice thickness classes present at the time of observation. Observations are conducted hourly and are filtered with a 6 nautical mile filter to ensure that the data processing is not weighted towards observations

in thicker ice when the ship is moving slowly. More details can be found in Worby *et al.* (1999) and Worby *et al.* (2008), including circumpolar maps showing mean annual ice and snow thickness, and season changes in the ice thickness distribution in different regions of the Antarctic.

Now that the program is well established, there are a new set of challenges:

1. Keeping the program current - promoting observing programs each year in particular to those areas where there are fewer observations. It is also important to keep the software current so that it runs on new operating systems and to make this available. This requires significant resources and is admittedly behind at the time of writing this report.
2. Ongoing financial support, or in-kind support to tackle software upgrades mentioned above, and to keep the summary statistics updated as new data are added. Ongoing support for additional data rescue would also be handy. There are log books with valuable data right back to the 1950s, but it was not possible with the first round of funding to examine anything prior to 1980. These data would be a valuable addition to the archive.

The ASPeCt data set provides some wonderful opportunities, in particular for ground-truthing satellite data and assessment of model output. It has provided very valuable insights into the circumpolar distribution of sea ice and the thickness distribution of sea ice in Antarctica. There is additional scope for adding aircraft-based observations, ground-truthed with *in situ* measurements, as well as incorporating ice chart data from centres such as the North American Ice Centre. As there is no “one” perfect method of measuring sea-ice thickness it is important to assess each data set on its merit to determine whether it is compatible with ship-based observations, and where possible to use complementary data sets to fill the gaps in the ship-based product.

A number of the lessons learnt in the Antarctic would help guide the development of a similar observing system for Arctic sea ice. However, a number of key challenges must be met:

1. There must be a champion. Somebody in the community must be prepared to step up and develop a program, in consultation with the community, attract funding, and be prepared to dedicate the time to establishing an observing program. Ideally, this should be somebody that will benefit professionally from doing the work and will therefore provide continuity for the foreseeable future.
2. It is important to attract funding, find a “home” within an international program, such as CliC, and develop the necessary tools for observing, quality controlling and storing the data.

3. The Arctic sea ice has a number of features that are very different to the Antarctic. While the Antarctic observing protocols could provide a solid footing for an Arctic program it will be necessary to tailor the observations for Arctic conditions. There may be limitations to Arctic observing that only an experienced Arctic sea-ice scientist would be aware of. It will be important to engage with the community closely to develop appropriate tools that capture the Arctic sea-ice environment.

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Overview of standard Russian sea-ice field measurements

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Field investigations of sea ice in Polar Regions are executed in several different ways: in stationary conditions on drifting stations or short ice stations, during expeditions on research vessels and planes, and/or as accompanying observations from commercial vessels. Reviews of sea-ice observation methods on Russian drifting stations and ice aerial reconnaissance are addressed by Frolov *et al* (2005), Romanov *et al* (1997) and Konstantinov & Grachev (2000).

Complex sea-ice observations taken while on drifting stations, includes:

- Regular registration of drifting station position and estimation of ice floe drift velocity
- Study of sea-ice cover deformation in different spatial scales and rotation of ice floes
- Investigations of structure and texture of sea ice
- Measurements of ice temperature, salinity, and density in different depths
- Study of sea-ice strength
- Investigations of optical, acoustical, and electrical characteristics of sea ice
- Study of sea-ice morphology

The main method for investigating sea-ice morphological and physical characteristics on drifting stations is through the use of polygons. Between the 1950s and 1970s many efforts and publications were devoted to optimizing the design and organization of such polygons. It was determined (*Buzuev, 1968*) that structure function of sea-ice thickness distribution for multiyear ice floe is characterized by rather quick saturation. Researchers found that a route of approximately 150 m with 10 – 15 sample sites is optimal for estimating mean sea-ice thickness with root-sum-square uncertainty of 25 cm.

For more detailed studies triangular polygons are used. These polygons are equal lengths on all sides with usually 10 meters between sample sites. This type of polygon can be seen in Figure 1, and was used on drifting station “North Pole – 33” from 2004 – 2005 (Kuznetsov, personal communication). At this station, ice cores were sampled every 10 days and sea-ice thickness, temperature and salinity at different depths were measured. Results were stored in EXCEL tables. An example of the seasonal variability of ice thickness can be seen in Figure 2.

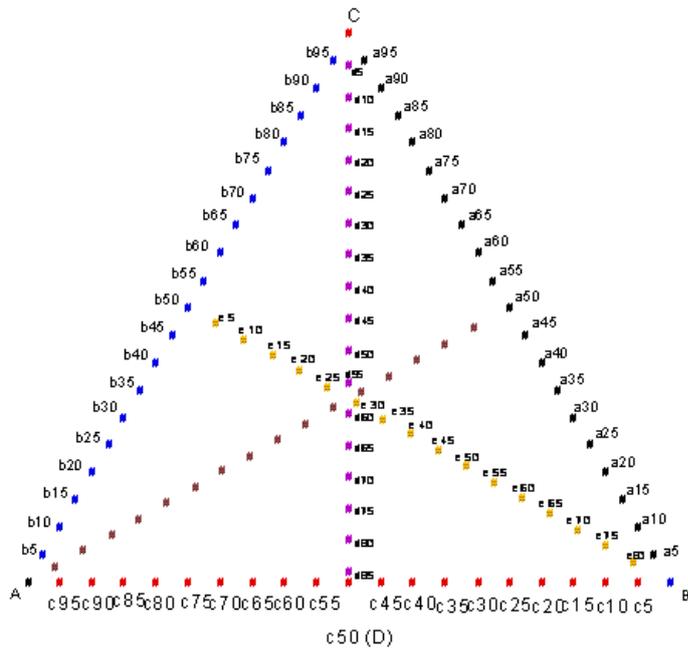


Figure 1: Polygon for studying sea-ice properties on drifting station “North Pole – 33”.

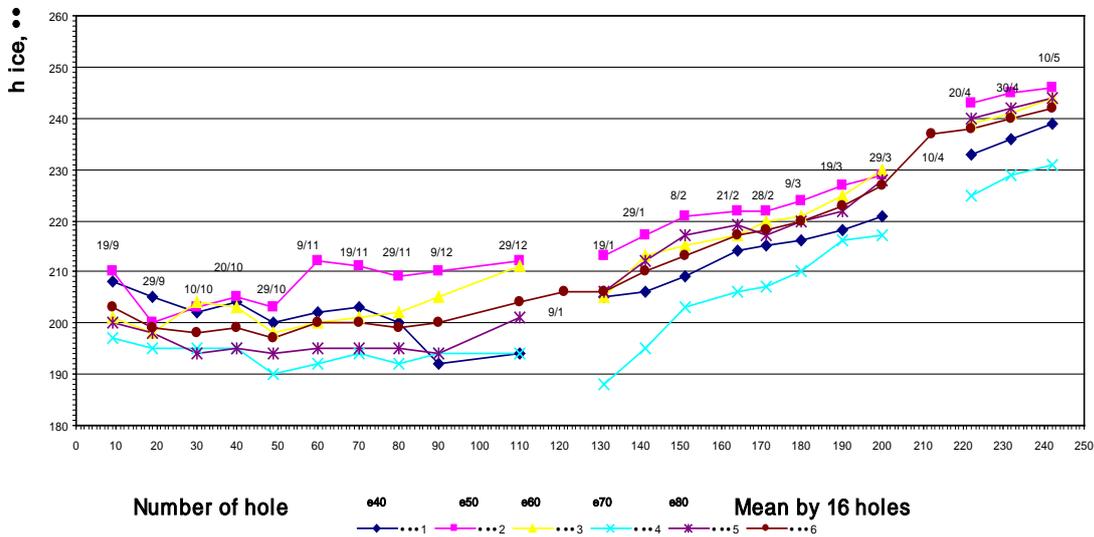


Figure 2: Example of temporal variability of sea-ice thickness from 5 points (drifting station North Pole - 33).

The standard procedure for sea-ice observations from ships is described in “International symbolism for sea-ice maps and nomenclature of sea ice” (1984, ed. Krutskih) (Refer to Figure 3 for example of an ice map). Recently a new method for measuring sea-ice thickness from ships was developed at AARI by Frolov *et al.* (2007).

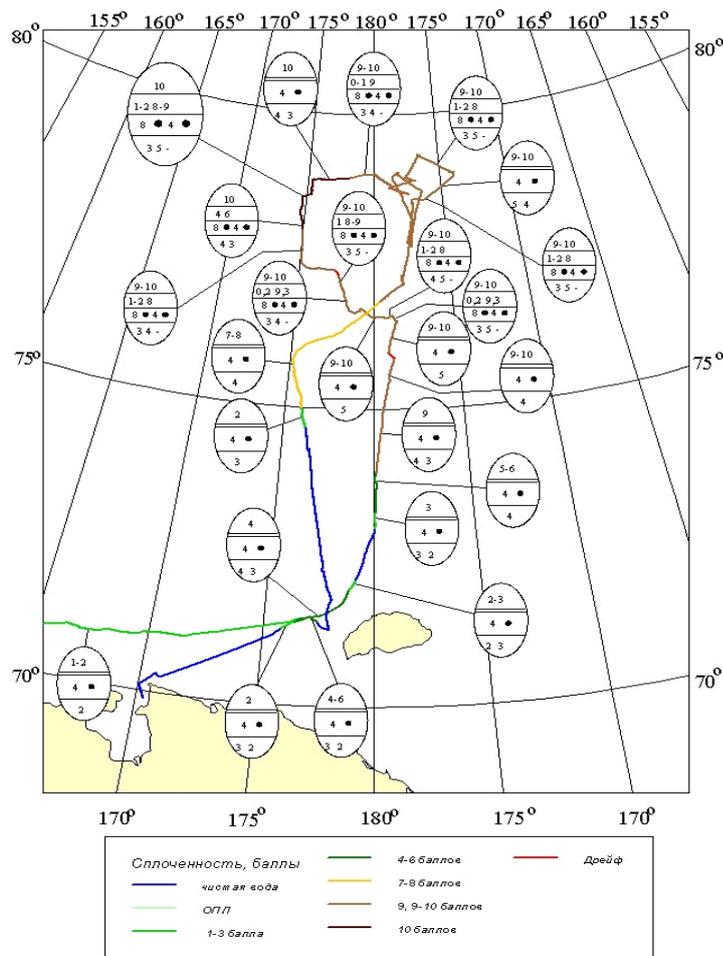


Figure 3: Example of an ice map, prepared from visual observations during an icebreaker’s winter expedition north of Wrangell Island.

In the seventies, AARI developed a simple method for estimating sea-ice thickness from directly on board the icebreakers. Ice thickness was visually estimated by using a ruler mounted on board a ship and observing the thickness of rotating fragments of ice floes while vessels moved by (Refer to Figure 4a). The error for this method was estimated 10% of real ice thickness. Since 2004 digital cameras have been used to record the thickness of ice fragments below the ruler, and special software was developed to process the vast amount of images recorded (10^3 - 10^4 images during a cruise). Refer to Figure 4b) and Table 1 to see the comparison of first year ice, old ice and mean flat sea-ice thicknesses, obtained during cruises of the nuclear icebreaker “Sibir” in May 1987, and nuclear icebreaker “Yamal” in May 2006 (Frolov *et al.* 2009). Recent decrease of sea-ice thickness in the same region is evident.

a)



b)

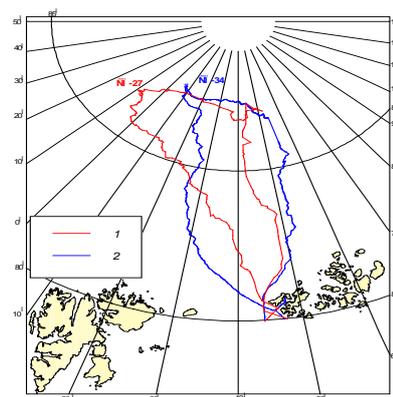


Figure 4: TV image of ruler installed on the board of icebreakers (a) and routes of icebreakers “Sibir” (1) and “Yamal” (2)(b).

Table 1: Characteristics of sea-ice cover on routes of the icebreakers “Sibir” (1987) and “Yamal” (2006).

Type of ice	1987		2006	
	Quantity, %	Ice thickness, cm	Quantity, %	Ice thickness, cm
First- year	64	138	87	123
Old ice	36	256	13	240
Mean		180.5		138

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Sea-ice field measurements: Observation protocols and best practices – Potential resources and coordination

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Introduction and motivation

A key aspect of a coordinated measurement approach aimed at quantifying Arctic sea-ice variability and assessing the role of cryospheric change in the climate system, is the need for intercomparable, standardized measurements. Consider for example, the measurement of ice thickness, a key variable underlying much of the discussion of recently observed Arctic change. Three commonly employed approaches in obtaining modern records of ice thickness over large areas are actually not measuring ice thickness *per se*, as defined, e.g., in the schematic shown in Fig. 1. Instead, these approaches are determining another observable quantity, such as the elevation of the snow or ice surface above sealevel (laser altimeter measurements), the draft of sea ice (submarine sonar measurements) or its apparent conductivity (electromagnetic induction techniques). Extracting intercomparable ice thickness data from such observations requires that the following three conditions are met:

- The measured variable is defined in a unique, quantifiable fashion. For example, some studies may use freeboard (often defined as the elevation of the solid ice surface above sealevel) and surface elevation (often defined as the total elevation of sea ice and overlying snow cover above sealevel) interchangeably. Such issues are also important in the context of data management and standard vocabularies (Refer to contribution by Florence Fetterer)
- The measurement methodology has to be established to the extent that measurement errors can be quantified and any potential dependence on different sampling rates or sampling volumes can be corrected for. For example, laser altimeter measurements of surface elevation may have a very different footprint than submarine sonar measurements, requiring correction for direct intercomparison. This in turn may result in a need for development of a protocol of how to approach such corrections
- For measurements that require further processing to derive the variable in question through a model or parameterization (*i.e.*, inversion of raw data), intercomparability requires the development of a standard protocol or shared model and/or quantification of errors or biases inherent in the derived variables

Meeting such demands typically requires the development of some systematic, common approach to data acquisition and processing. For example, this has been achieved for ship-based ice observations where a standard nomenclature has been established by a World Meteorological Organization working group ([WMO, 1985](#)) and where groups such as the Antarctic Sea Ice Processes and Climate ([ASPeCt](#)) working group has developed a standardized ice observation approach (Refer to contribution by Tony Worby). The purpose of Arctic Sea Ice Working Group is not to duplicate any such ongoing efforts but rather to enhance information exchange between such activities and the broader scientific community, in particular in areas where advances in measurement techniques have created the need for development of common, best practices.

Potential approaches towards improved intercomparability

In the context of this workshop, we recognize four different approaches aimed at improving intercomparability of measurements made, e.g. in the context of an observing network.

- Definition of standard variables and establishment of a standardized protocol: This would for example apply to measurements of seawater salinity, with a standard seawater equation of state and associated standard approaches towards measurements of salinity in the field
- Standardization through certified organizations: Such efforts include the current development of a common set of engineering standards for Arctic Offshore Oil and Gas Development under the auspices of the International Organization for Standardization (ISO)
- Development of common tools that improve intercomparability: This can be achieved through the widespread use of the same type of sensor or measurement system that brings about technology-driven convergence of measurement approaches, e.g., in the use of certain types of ice mass balance buoys commonly deployed in the Arctic. Development of software products that are employed by many practitioners to aid with data acquisition can play a similar role, such as the ASPeCt ice observation software (see contribution by Tony Worby to this report)
- Promotion of “best practices”: This is in some ways the most modest but ultimately also most practical approach to involve broader segments of the scientific community and achieve convergence towards a common protocol in a reasonable amount of time. This is recognized, e.g., in industrial applications where best practices may often precede the development of actual industrial norms or standards

Towards the development of best practices as a realistic goal and first step in standardization

Having identified development of best practices as a near-term goal within the reach, what are promising approaches to move towards this end? Naturally, approaches within the different sub-disciplines represented at the workshop may vary. However, two potentially promising approaches are of particular relevance in the context of this group. First, education and training in the Arctic sea-ice research community is highly collaborative, with international field courses or field schools (such as the IPY Sea Ice Summer School held in Svalbard in 2007, or the University of Alaska Fairbanks/Hokkaido University International Sea Ice Field Course held in Barrow in 2008) commonly attended by a significant fraction of graduate students in the field. Such courses provide excellent opportunities for intercomparison and convergence of best practices for a number of different field methods.

Second, and more importantly, a review and evaluation of different measurement approaches with potential recommendations can go a long way towards development of best practices within the research community. As a starting point, an international group of experts in the field have contributed to a “Handbook of Sea Ice Field Research Techniques” (Eicken *et al.*, 2009). While only a modest first step, this effort aims to provide a baseline from which discussions, reviews and revisions of methodology can emanate, ultimately leading to increased intercomparability of measurements. The handbook covers a broad range of field measurements, including geophysical and biogeochemical approaches and includes a

multimedia DVD with resources and videos of field measurements to provide further guidance.

In the context of the group's long-term goals, we see value in such a handbook as the foundation of a dialog among practitioners in the field that could then lead to a more technical focused document aimed to promote increased intercomparability and standardization – where applicable. Such future discourse may take the form of a collaborative, internet-based effort (Wiki) that facilitates co-evolution and parsing of different approaches.

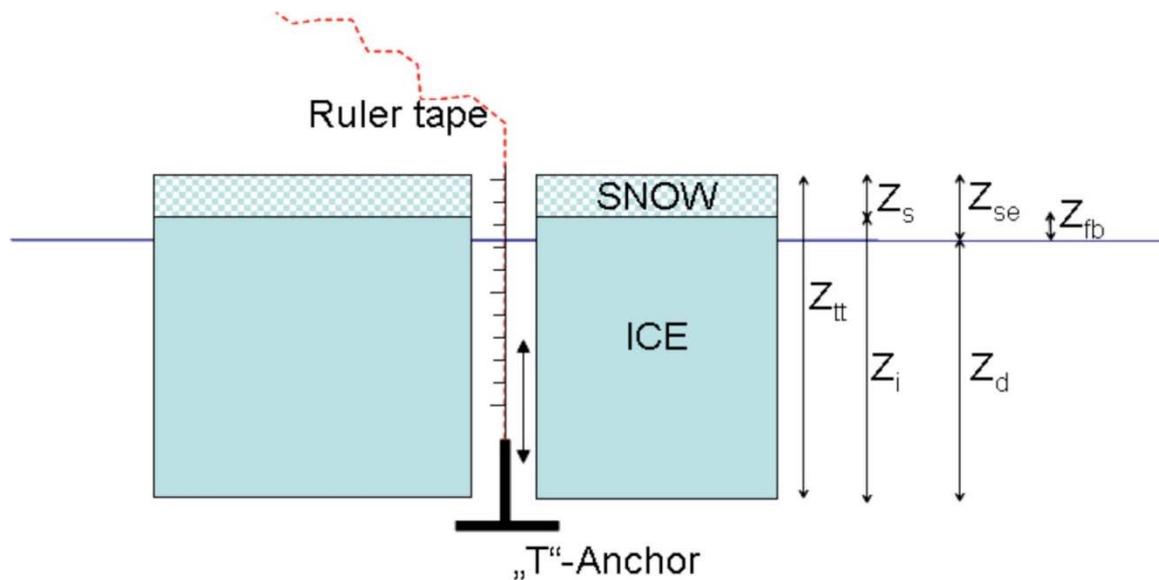


Figure 1: Definition of different variables related to sea-ice thickness (z_i), including total thickness (z_{tt}), snow depth (z_s), surface elevation (z_{se}), and freeboard (z_{fb}). Also shown is direct measurement of these variables in a single drill hole (Figure from Haas and Druckenmiller, 2009).

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ESA-CliC collaboration

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Background

The CliC Project was established in March 2000 by the *World Climate Research Programme* to stimulate, support, and coordinate research into the processes by which the cryosphere interacts with the rest of the climate system. The CliC project's principal goal is to assess and quantify the impacts that climate variability and change have on components of the cryosphere and its overall stability, and the consequences of these impacts for the climate system. To attain its goal, CliC develops and coordinates national and international activities related to cryosphere and climate. This includes organizing conferences, workshops, scientific experiments, and model comparison studies, as well as collaboration with other groups of climate and cryosphere research, including the space agencies.

In the last few years, the European Space Agency's (ESA) Earth Observation (EO) programs have supported CliC activities and interests via its EO missions, dedicated development projects (e.g., the Data User Element's GlobIce, GlobGlacier, GlobSnow, Permafrost) and exploitation activities (e.g., ESA contribution to the IPY). Recently, ESA launched a new program, the Climate Change Initiative, dedicated to develop and implement Essential Climatic Variables (ECVs) relevant to ESA missions, which will deliver critical information products to the CliC community. In addition, a new element dedicated to support scientific activities, Support To Science Element (STSE), has been launched in 2008, and as a part of STSE, several projects addressing CliC areas of interest have already been launched (SnowRadiance, IceSARConstellation with more in preparation (NorthHydrology, SMOSIce). ESA has established long-term partnerships with major international scientific programs, such as the WCRP and IGBP. These partnerships will benefit ESA, and particularly the international projects to better address the scientific questions and priorities.

CliC recent development and achievement

CliC project encourages and promotes research into the cryosphere and its interactions with the global climate system. CliC was on the ICARP II Scientific Steering Committee and organized the development of two ICARP science plans. CliC generated strong input from the climate research community to the International Polar Year and will lead in establishing a Global Cryosphere Watch (a WMO initiative) as an IPY legacy. CliC also currently collaborates as members of the Initiating Group of the Sustaining Arctic Observing Networks (SAON).

CliC has a leading role in coordinating and promoting cryospheric research worldwide. With strong support from many space agencies, including ESA, CliC led the development of a Cryosphere Observing System concept (CryOS): a sustained, robust observing system for the cryosphere. The Integrated Global Observing Strategy (IGOS) published the IGOS-Cryo Theme Report in 2007; the report articulates the requirements in cryospheric observations, data and products, and recommends on their development and maintenance. The implementation of the Theme largely depends on the involvement of major space agencies,

CliC is ready to work closely with them to implement some of the recommendations of the IGOS-Cryo report.

CliC-ESA collaboration and benefit

CliC has directly collaborated in the past with ESA missions. CliC was involved in the supporting CryoSat-1 mission and has continuing interest in future missions, such as Cryosat-2 and the concept of COLD Regions Hydrology High-Resolution Observatory (CoReH2O) as these missions will fill data gaps and provide critical products for global cryosphere investigations. Furthermore, ESA EO existing data and products are valuable to CliC research projects.

The newly established STSE provides an exciting opportunity for global earth science research, including the cryosphere, and CliC will participate and contribute to this new program to the full extent possible. CliC interacts with many national and international organizations and its worldwide scientific focus makes it a valuable partner for organizations with regional and global interests.

CliC partnership with ESA Earth Observation Programs can directly contribute and benefit to CliC objective - to improve understanding and prediction of the changing global cryosphere, and to provide the essential science for sound decision-making and policy development. CliC-ESA partnership will also benefit ESA Earth Observation Programs. It will stimulate research to address the major science challenges outlined in the “Changing Earth”. It will establish an important communication and feedback mechanism between ESA and the earth science research community. Furthermore, a partnership will, and, enhance the exploration and application of existing and new ESA EO data and products for CliC regional and global research activities over various cold regions around the globe.

Major cryosphere challenge and priority

For the establishment of a strategic partnership between CliC and ESA, the CliC project has developed a Scientific Requirements Document. This document, based on the CliC Science Plan and the IGOS-Cryo documents identifies and describes major scientific questions and challenges for the CliC community. It also relates CliC research priorities with the ESA Earth Science challenges (as defined in the report Changing Planet) and the multi-mission strategy. Major challenges and priorities for CliC and cryosphere research include:

A. Global Snowfall and Solid Precipitation

Major problems remain in accurately measuring snowfall in the cold regions. Gauge undercatch of snowfall can be as high as 50-70% in windy and cold conditions. Due to lack of the European Global Precipitation Mission (EGPM) component, the current Global Precipitation Measurement (GPM) design may not adequately measure solid precipitation in the polar regions. CliC Project has rich experience in developing regional snowfall datasets, bias corrections of the gauge data, assessment of new technologies for snowfall measurement, and validation of remote sensing precipitation data over the cold regions. CliC has defined the accuracies and requirements for solid precipitation measurements by surface and space techniques in the IGOP-Cryo document. Development of accurate regional and global snowfall datasets and products is the top priority for the CliC Project.

B. Global Snow Cover

Improvement of snow-cover observation systems and data is important for CliC. Key requirements include:

- Development of surface-based snow-observation networks at a regional level to address the needs for improved consistency in observation methods and reporting standards and for improved exchange of data.
- Improvement of satellite observations, including development/validation of satellite remote sensing techniques, validation of existing products, support of new systems (i.e. the concept of European Global Precipitation Mission (E-GPM)/CGPM and CloudSat for solid precipitation), and support of algorithm development to more effectively use existing data sources, such as SAR and other microwave observations for SWE and snow depth determinations.
- Improvement of integrated multi-sensor data fusion and regional/global analysis systems that blend snow observations from all sources, including new techniques for merging *in situ* measurements and satellite retrievals through targeted field projects in various environments.
- Improvement of new snow observing system to use observations from all relevant sources in coherent, consistent high-resolution analyses of snow-cover extent, snow depth, SWE, snow wetness, and albedo.

C. Arctic and Antarctic Sea Ice

Sea ice is a key component of the cryosphere system. Predicting the future of Arctic and Antarctic sea ice is a high priority for CliC. The recent dramatic changes in the Arctic are well documented, while changes in the Antarctic are less clear. Satellite data do not yet provide reliable information on sea-ice thickness in either hemisphere. Climate models suggest that Arctic sea-ice thickness will change more rapidly than extent, with the total volume projected to decrease at approximately double the rate of ice thickness. It is possible that changes in Antarctic sea-ice thickness are currently going unnoticed due to lack of long-term record. To address these deficiencies, a concerted effort is required to improve both observational and predictive capabilities of sea ice. CliC needs to generate and facilitate:

- Improved capability to measure sea-ice thickness on a regional scale, for development of long-term monitoring programs and calibration and validation of Cryosat-2 and other remotely sensed data.
- Information on the structure and volume of ice, in sea-ice ridges in the Antarctic, and the effects of basal melt on the ice thickness distribution.
- Improved parameterisation of sea ice in climate models, with particular effort on understanding how the thickness distribution and age of the ice cover changes into the future, to allow improved estimates of sea-ice response to global warming.
- Improved understanding of snow processes on sea ice, particularly in the context of improving the interpretation of airborne and space-borne laser and radar altimetry data.
- Maintenance and expansion of existing networks to monitor sea-ice drift and regional changes in fast ice properties.

D. Ice Masses and Sea Level Change

This is a major Theme in the CliC Project. CliC leads the WCRP cross cut research to address sea-level rise and associated uncertainty, through WCRP project collaboration in global water budget, including land water storage change (GEWEX) and ocean thermal expansion (CLIVAR) under a warming climate. The main tasks of this theme include estimations of the mass balance of the Antarctic and Greenland ice sheets, glaciers and their contribution to sea-level change. It is also necessary to develop an enhanced capability to estimate past, and predict future, ice sheet and glaciers changes. This research is a new focus for the WCRP and CliC; it aims to generate and facilitate:

- Improved long-term ice-sheet, ice-cap, and glacier-monitoring systems, inventory of related database to assess the mass balance change and its uncertainties, including mass balance records for a selection of large glaciers and ice caps representative of different climatic regions.
- Realistic representation (model and observational) of spatial and temporal variability of surface mass budget in areas, which are sensitive to sea-level change.
- Records of continuous ice velocities for a selection of sensitive regions to determine the dynamic response of ice sheets to climate perturbation on seasonal and longer time-scales.

Assessment of the Greenland and West Antarctic ice sheet stability and vulnerability to climate change (including snow accumulation variation), and sudden and potentially irreversible changes.

E. River and Lake Ice in Northern Regions

Lake and river ice is a dynamic element in the northern hydrology system. River and lake ice changes over seasons. The dates of freeze up and break up are useful indicator of climate change and variation. Ice is a seasonal storage of water over the winter. To determine this storage amount, ice extent and thickness data are necessary. Ice thickness can reach up to 3-4 meters in the northern regions. Ice break-up in the arctic watersheds is closely associated with the spring peak floods. River and lake ice conditions change due to climate warming in the cold regions. There are long-term observations of river and lake ice in the northern regions. The observations network is declining in recent decades. Satellite data such as MERIS, MODIS and SAR can provide ice information for large rivers and lakes. There is a need to develop algorithms to produce consistent ice data and products. Due to lack of data and information, most LSM models used for the high latitude regions do not have a river ice component. This creates uncertainty in simulation of river streamflow particularly in the spring season. The generation of river and lake ice data and info will greatly benefit climate and hydrology analyses in the high latitudes, enabling models to consider ice processes, such as seasonal storage, ice break-up, ice damming and snowmelt peak flood simulation. CliC is currently working with the several northern countries (i.e. Canada, USA, Russia, and the Nordic countries) to compile a river ice dataset for the arctic regions as a whole; this dataset, once completed in the near future, will be very useful for validation of remote sensing ice data and products.

CliC's specific interests in freshwater ice include:

- Develop composite lake-ice product from the combination of optical (e.g., Envisat MERIS, MODIS Aqua and Terra data) and SAR data, and validate the MODIS 500-m and other snow products for lake ice applications.
- Use SAR data to develop operational methods for mapping of ice cover and areas of open water on rivers and lakes, and to identify areas of floating and grounded ice.
- Examine the potential of passive and active microwave data to map ice cover (concentration and extent), open water, ice thickness, and snow depth on ice on large lakes.
- Establish a set of lake and river experimental sites for remote sensing algorithm development and validation, including comparison of surface-based observations of freeze-up and break-up with satellite derived time series, such as the AVHRR data during 1970s-1980s.
- Explore multi-sensor data fusion and numerical model output of lake and river ice, so as to improve estimates of ice parameters and for ice forecasting.

Summary

Many important cryospheric research issues have been identified in the CliC Science Requirement Document. ESA and CliC will organize a community consultation workshop to discuss this document and to examine the feasibility of various potential projects. The outcomes and recommendations of the workshop will be useful for ESA to develop the STSE projects in collaboration with CliC.

CliC believes that collaboration with ESA will benefit its regional and global projects and goals. CliC is very pleased to increase its collaboration with the ESA Earth Observation Programs through its participation in the STSE projects, and Data User Element (DUE) and the new Climate Change Initiative (CCI). CliC is ready to contribute and work more closely with ESA to develop a multi-mission observing strategy for the cryosphere.

Establishing a community-based sea-ice observing network in the Arctic

Shari Gearheard, National Snow and Ice Data Center, University of Colorado, Boulder, USA

Both Arctic residents and scientists are well aware of the importance of sea ice. Arctic sea ice plays a critical role in local, regional, and global climates and provides a home and habitat for a variety of Arctic animals. For Arctic residents, it is a means to travel and to harvest food, and it is a source of cultural well-being and personal identity.

Over the past decade or so, many projects have documented local knowledge of sea ice. Some have focused on sea ice change, others on terminology, mapping, and use of sea ice. Very little research has included the systematic monitoring of sea ice at the local level, although some projects have employed the use of diaries, daily observations (survey forms), and there have been a few projects that include local use of scientific monitoring stations.

The research that has been done that includes local knowledge of sea ice and local monitoring of sea ice has been very valuable. Further development of the methods used, and coordination between efforts, is needed. In some cases, local methods for observing sea ice, both quantitatively and qualitatively, have been highly developed. A system for supporting these programs over the long term, and coordinating observation programs across different communities and Arctic regions, could provide valuable data regarding the characteristics, dynamics, and changes in the sea ice at the local level over time and space. These data could complement the sea-ice data obtained at other scales and via other methods, such as remotely sensed data. They could also complement other meteorological data and traditional knowledge, as well as studies about human vulnerability and adaptive capacity to sea-ice change.

Community-based sea-ice observations have a number of distinct advantages, for example:

- *Expert observers*
Many Arctic residents, in particular indigenous people and long time residents, are sea-ice experts. Their expertise is gained from a life time of living off the land and sea ice and acquiring knowledge passed down to them from older hunters and elders. Their extensive knowledge provides important baseline information for assessing sea-ice characteristics and changes.
- *Year-round observers*
Since community-based observations are done by local residents, the observations can be consistent and year-round. Scientific research is often only conducted in summer months and/or limited to short visits. Year-round, consistent data provides more complete data sets.
- *Locally relevant and useful information*
Community-based observation programs can provide the best advice on where to make observations. Often residents can suggest locations that are of importance for local travel and activity, or where there seem to have been changes, or no change. Knowledge of the local/regional sea ice and its use provides critical information on where to locate observation and monitoring activity so that the information gathered provides results that are useful for local application (e.g. hazard warnings, changes in animal habitat, *etc*).

- *Complements satellite and other scales of observation data*
Local observations are made at a scale that is often not captured by scientific methods, such as remote sensing. Community-based observations can help provide data at these local scales and also aid in ground-truthing other data, like those from satellites.
- *Local training and job opportunities (jobs in sea-ice monitoring)*
Many communities in the Arctic are seeking economic development opportunities. With the increase of research in the North, many people see an opportunity for training and new jobs in science. Sea-ice monitoring can be one way to provide needed jobs to people in remote northern communities and at the same time creating quality data sets to be used locally and by collaborating scientists and other communities.
- *Observing can be combined with sea-ice travel and hunting*
Sea-ice monitoring is a natural fit for many northern residents, especially hunters, in terms of aligning with activities and interests they already have. Hunters are already travelling the sea ice, often on a daily basis, so combining these activities with regular stops at a sea-ice monitoring station is a good fit. The income earned in such a job as a sea-ice monitor provides needed income to support hunting by paying for gas, ammunition, equipment, and other supplies. By being able to afford hunting, the hunter is then able to be on the sea ice regularly and observing, so the activities are complimentary.
- *Cost effective, while at same time producing robust data*
By having locally-based sea-ice observers and researchers, science projects can save enormously in travel and maintenance costs. Arctic travel is extremely expensive. By cutting down the number of trips, or completely eliminating the need to travel, funds are freed up for other purposes such as data analysis, data management, student support, more or better equipment, and more. With a local observer available to check equipment at all times, small repairs can be made as opposed to large repairs or replacements if the equipment cannot be checked regularly. This also helps prevent large gaps in the data if a piece of equipment breaks and the monitoring has to stop and wait for a researcher to travel to the location and maintain the station.



Figure 1: *Sea-ice monitors Teema Qillaq (left) and Lasalie Joasasie (right) install ice monitoring stations near their community of Clyde River, Nunavut, at the start of the sea-ice season. Teema's son, Ken, helps out (photo: Shari Gearheard, 2008).*

The above benefits focus on a quantitative approach to sea-ice monitoring, but there are many benefits to a qualitative approach as well, and both together can be beneficial to understanding the sea ice environment. For example, regular sea-ice monitoring using quantitative measurements can be complimented by daily logs of a hunter, monitor, or resident who is travelling or simply watching the sea ice from town. The logs can document the start of freeze up and break up and detail the different processes that occur during each sea-ice phase. This information can help enormously in interpreting the quantitative information and can only be done by a person who is in the location full-time.

An example of community-based sea-ice monitoring can be found in the *Siku-Inuit-Hila* project, a collaborative project between the University of Colorado, the Inuit Circumpolar Council-Greenland, and the communities of Clyde River Nunavut, Qaanaaq Greenland, and Barrow Alaska. The project developed a methodology for local sea-ice monitoring and the common protocol is used in all three communities in the project, creating a small monitoring

network (see http://www.nsidc.org/pubs/special/nsidc_special_report_14.pdf). The network monitors sea-ice thickness, sea-ice temperature, snow thickness and snow temperature, and combines these data with qualitative observations and photographs made by the local monitors and other local experts, along with available weather data.

The methodology was developed with local sea-ice monitors who tested the methods over several seasons and provided feedback. The resulting techniques and protocol, provided in an available step-by-step handbook (see weblink above) helps address those elements needed for successful observations in remote communities, including:

- Ease of operation
- Cost effectiveness
- Ease of construction and maintenance in remote locations
- Minimal technical equipment; use of locally available materials
- Robust data

More communities in Canada, Alaska, and Greenland are expressing great interest in developing a local sea-ice monitoring network. There are several components to developing a strong network, including:

- Ensure that the network works with local, regional, national, and international organizations to support local observers
- Strive for long-term funding; monitoring necessitates long term observations
- Provide quality training; involve youth and elders and incorporate local knowledge in the development and implementation of the monitoring techniques and network
- Implement a common protocol
- Facilitated by a common protocol, share data and compare results across communities
- Mechanism to develop data products to be used in the communities and in collaborative research
- Create partnerships with other observing networks (e.g. other scientific programs)
- Develop strong data management
- Develop strong communication network

The next steps in developing a local sea-ice monitoring network in the Arctic is for local communities to start communicating and seeking opportunities to work together. This is already happening. Organizations and initiatives like CliC have an opportunity to support and work with a local network by sharing information, methods, and forming collaborative projects that can link different scales of observation and monitoring. As well, CliC and other initiatives can continue to include local sea-ice knowledge and monitoring as part of their discussions and begin to form cooperative programs.

For more information please contact members of the Siku-Inuit-Hila project:

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Data acquisition, management and dissemination

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Once acquired, sea-ice observations should be managed in a way that preserves the data over the long term, and facilitates sharing the data so that a wide community can benefit now and in the future. To do this, data need to be described well with metadata and, often additional documentation. Large programs like the European DAMOCLES or the NSF funded component of the Arctic Observing Network may have a data management component to assist with this, but often, it is up to the investigator to document data and find a suitable long-term archive for it.

Metadata is a structured summary of information about the data; the brief “who, what, where, when and why” of the collection of data. Catalogs of metadata like the NASA Global Change Master Directory (GCMD) make it possible to, for instance, use a search engine to find data online. Metadata authoring tools may be included in some GIS and other data analysis packages or exist as standalone tools. The GCMD docBUILDER is one good choice. It is available both online and as an offline tool that can be used in the field. The European Sea Search program for marine data management offers guidelines for writing documentation (<http://www.sea-search.net/guidelines-practices/guidel05.htm>), as does the IPY Data and Information Service (http://ipydis.org/data/data_documentation_template.html).

Data collections can and should be cited like reference papers. This credits those responsible for the intellectual effort required to collect and organize the data, and properly associates a research result with the data that were used. Metadata should include enough information to create a citation for the data. “How to Cite a Data Set” (<http://ipydis.org/data/citations.html>) has more information.

Using a standard format and standard content for data files is helpful. Format and content can be determined by a task force from the community that authors and uses the data files in question. CLiC and similar coordination groups can play an important role in developing these standards.

Data and documentation should be placed in a secure archive. Opportunities to archive data may be available with a relevant World Data Center (list at <http://www.ngdc.noaa.gov/wdc/>), or with a national data center (e.g., one of the NOAA data centers in the U.S.).

Sea-ice observations from field experiments are research data with relatively high overhead costs when it comes to managing them as data sets. They vary considerably and do not offer the economy of scale of remote sensing data, for instance. But they are critical to polar research and must be broadly accessible and usable to realize full value. Researchers and data managers need to work closely together to establish protocols for describing observations with metadata, and standard file formats and contents for sea-ice observations.

Break-Out Session Summaries

1. Key Parameters
 - a. Modeling
 - b. Remote Sensing
2. Standardization
 - a. Observations while on moving: Ships, aircrafts, submarines
 - b. On-ice Measurements
3. Coordination and Implementation
 - a. North America Sector
 - b. Eurasian Sector

Summary of Break-Out Session 1a: Key Parameters - Modeling

Rapporteur: Ralf Döscher, Swedish Meteorological and Hydrological Institute, Sweden

Running a model

Observational needs for modeling sea ice are not limited to sea-ice parameters, but also requires knowledge of:

- Forcing fields
 - Of atmospheric ocean conditions and mechanisms of interaction
- Initial conditions
 - For short term forecast, seasonal, decadal, climate scenarios

Model development

Direct sea-ice information is needed for model development. In addition to standard parameters (thickness, concentration, albedo, salinity, temperature *etc.*), specific need is currently seen in observations supporting development of parameterizations for:

- Processes determining surface albedo
 - Surface temperature, albedo, salinity, melt pond ratio, *etc.*
- Lateral/vertical melting/freezing
 - Heat flux in leads, mixing in leads and close to leads, wind over leads, melting/freezing rates, lateral and vertical
- Melting processes (esp. in ridges)
- Fast ice behavior (important for impact studies)
- Rheology improvements: representation of ridging/new ice formation
 - Ridge height and patterns, stresses
- Salinity effects, interaction with ocean
 - T/S in and underneath the ice

Validation

Validation of models builds on comparison of simulated fields with observations. Meaningful validation parameters depend on the purpose and domain of the model. Coarsely resolved global model domains require integrative observations such as sea-ice extent, overall volume and export. In addition, Arctic-wide model domains and global model domains of intermediate resolution require regional distribution patterns. Point-to-point comparisons are generally not meaningful due to locally different patterns. Regional/local process studies and 1D studies can greatly benefit from local observation arrays.

Re-analysis

(Re)analysis is an important tool for integrating observations of all kinds into a single grid in a dynamically consistent way. The results allow for various analyses and represent major products for model validation. An important need for data assimilation is knowledge of observational uncertainties. These are required by the assimilation procedure. If the observer cannot provide error estimates, the data assimilator must guess the error.

Communication between observation and modeling

Use of observational data by modelers is often prevented by distributed data archives that are difficult to access, and have non-standardized data formats. Data availability should be increased by standardization of data.

Models should be increasingly used to optimize observation networks based on model sensitivities.

Key Messages and Recommendations

- CliC might want to establish communication tools such as a web page linking relevant data sources to help improve communication and data access
- Introduction and better utilization of standard observations should be explored
 - E.g. automatic observations, bridge logs, visual records (cameras), ship-of-opportunity efforts which enable repeated tracks.
- Creation of combined gridded data sets, collecting information from different locations into one map. This may include even no-data flags if necessary and quality flags if possible. Such combined data sets will stimulate use of observation data by modelers

Summary of Break Out Session 1b: Key Parameters - Remote Sensing

Rapporteur: *Walter N. Meier, National Snow and Ice Data Center, Boulder, USA*

Continuity of satellite remote sensing measurements

The group first discussed continuity of satellite remote sensing measurements, particularly (1) passive microwave (PM), (2) altimetry, and (3) SAR. For passive microwave, there was broad agreement that there was high confidence in continuity for the foreseeable future with DMSP and NPOESS. There was some concern that these satellites are too operationally focused and there may not be enough attention paid to climate record concerns. There was also discussion of the JAXA AMSR2 sensor to be launched on GCOM-W in 2011. This would provide continuity of the higher spatial resolution AMSR-E, but only if AMSR-E remains operational until then. This brought up the need for long overlap periods (at least one year) to provide quality intersensor calibration to assure a consistent passive microwave time series.

In regards to altimetry, Cryosat-2 to be launched later in 2009 will provide continuity with ICESat, but there may not be much if any overlap opportunity. This is a lost opportunity to take complementary measurements from the different sensor types (radar vs. laser) as well as the chance to directly intercalibrate the two. ICESat-2 is still in the planning stages at NASA, but it is a top priority and seems likely to be launched. Another potentially useful NASA satellite is DESDynI, also a laser altimeter. Its mission will likely be more focused on vegetation applications, but it may be useful for sea ice. These missions are on track to launch in 2014 or 2015.

Continuity of SAR sensors was considered a very high priority because of their importance for both fine-scale research of sea-ice properties and support of operations. This is particularly important because of the lack of non-commercial access to Radarsat-2 data. There are many other SAR systems coming in the future, so there should be good coverage, but coordination would be most useful to get as much as possible from the sensors, particularly in terms of the complementary properties of L-band and C-band sensors. NIC in particular is seeing useful information in the ALOS L-band SAR, features not seen in C-band. There are also potential conflicts between wide-scan mode (100-150 m) most useful for operations and fine-beam (15 m) needed for field campaigns, ground validation, and other high-resolution research applications. Good coordination should remove most conflicts.

CSA is planning for a Radarsat constellation. It is currently planned as a fully-government operated system, but there is pressure to be at least partially commercial. The overwhelming recommendation is that future systems should be completely government to allow open access to government agencies, researchers, and operational centers. ESA has already adopted this principle for its satellite sensor systems, including the Sentinel-1 SAR. Other future SAR systems are the TerraSAR X-band and the Italian Cosmo SkyNET.

Climate data records

Next, the discussion moved on to climate data records. Not only do we need good continuity and coverage, but there is the need to assure long-term consistency of measurements, thorough documentation of methods for any future reprocessing efforts, and long-term data

stewardship to assure the survival of data into the future. These issues are only just starting to be addressed. NOAA has started a Science Data Stewardship program and there is a sea-ice program funded. ESA is funding a EUMETSAT Satellite Application Facility Ocean and Sea Ice (OSISAF) project to do a full reanalysis of the passive microwave sea-ice record. That project is moving forward and data should become available sometime later in 2009. As mentioned above, a long-period of sensor overlap is needed for the best intersensor calibration. Historically these periods have been relatively short (less than six months); at least one year is really needed. Use of higher quality, newer sensors, such as AMSR-E, can be useful if they can be integrated with the SMMR-SSM/I record in a consistent manner.

Another issue for a sea-ice climate data record is which algorithm or suite of algorithms is best to use. To date, NASA Team and Bootstrap have been most widely used, but both have deficiencies. A combination of algorithms may be best. OSISAF has settled on a combination of the Bootstrap frequency more for low concentration regions and the Bristol algorithm in high concentration regions; it also includes the potential to use a high-frequency algorithm in high concentration regions when it is available.

A final issue in regards to climate data records is the tension between operational and climate needs. Operations need lots of data quickly but do not necessarily have the resources to save data and quality-check it for consistency. Operational data could be very useful if information saved, but often it isn't. NIC is now saving info on source data for the polygons in their charts, which is a big step forward. This is also a concern for the U.S. NPOESS missions that will combine operational and climate applications on the same platform. It is important that information important to the creation of climate data records not be lost.

Uncertainty in Satellite Measurement

There are many uncertainties in satellite measurements and ground validation data can help resolve some of these ambiguities. First and foremost is snow cover. Snow thickness and density is a key unknown in determining sea-ice thickness from altimetry. Snow properties also can have significant effects on passive and active microwave systems. The effects on the sea-ice emission can vary depending on whether seasonal or perennial ice is present. Snow cover is also an important parameter in its own right because of its contribution to the hydrological cycle. A key recommendation is to increase the number of ground measurements of snow cover over the ice, perhaps through automated snow depth monitors, e.g., at drifting stations or from autonomous buoys. There are still other issues, such as snow-ice formation – is it snow or should it be considered part of the ice thickness. This is more of an issue in the Antarctic, but it may become more of an issue in the Arctic as the ice thins. It was also noted that indigenous peoples may be able to contribute useful observations of snow (and ice) conditions. There are some future satellite sensors that could help unravel some of the snow cover uncertainties. These are the ESA CORE H2O and SMOS (an L-band radiometer). Both are not focused on sea-ice applications but there could be useful data from these data.

Thin ice growth information is also a key gap in understanding. Such ice is difficult to measure accurately with microwave sensors or altimeters. Buoys are not placed on thin ice because of the precarious conditions. One suggestion is to develop and place seasonal ice mass balance buoys. These would start out floating in the ocean, and then would be frozen in as thin ice forms. They would include thermister strings to measure temperature profiles. One question raised is whether the presence of the buoy would affect the growth of the ice?

Non-satellite sensors were also recognized as providing very useful information. Airborne or helicopter-borne EMI has been shown to be able to obtain good ice thickness measurements. A regular schedule of flights over key areas could be possible. AUVs have great potential, though their generally smaller size limits the type of sensors that can be flown (*i.e.*, radiometers and SARs are generally too big for most). The GlobalHawk is one platform big enough to carry any type of sensor, but cost is high. AUVs have also run into roadblocks in the U.S. due to Federal Aviation Administration restrictions. There was the suggestion to look into “aircrafts of opportunity” – putting small devices (e.g., cameras) onto planes, including commercial aircraft. This seems like a great idea but logistically would be very hard to get started and there could be political concerns about where images would be taken. One thing that is necessary is a standardization of protocols and measurement and data collection standards so that observations can be easily combined.

Current and Upcoming missions discussed during the session

- Cosmo SkyNet (Italian)
- Envisat
- ESA Sentinel-1, 2012
- ICESat-2, 2014-2015
- DESDyn1
- Cryosat-2, late 2009
- Radarsat constellation
- GCOM-W AMSR2, 2011-2012
- NPOESS – 2015?
- ALOS follow-on?
- Argentinian L-band?
- German X-band?

Key Messages and Recommendations:

- Continuity of PM observations must be maintained – there is pretty solid plans through at least 2020, but currently based on operational/defense satellites, not optimal for climate. Intersensor calibration is extremely important during sensor transitions.
- Radar/laser altimeter continuity should be maintained if possible – it would be good to have overlap, between Cryosat-2 and ICESat-2, though it seems unlikely at this point.
- SAR continuity is essential, to both research and operations – C-band good continuity, but lots of value from L-band – combined C-band and L-band.
- Sub-satellite observations are valuable to connect scales between ground measurements and satellite measurements.
- Snow cover is the largest uncertainty and better knowledge of snow depth and snow properties is crucial for understanding PM and SAR signal, and altimetry measurements. More *in situ* measurements of snow cover are desperately needed.
- Thin ice regions are lacking in ground validation and have considerable uncertainties for satellite sensors.
- Climate data records and the issue of research vs. operations needs to be considered so that conflicting needs and priorities can be resolved. It is essential that long-term consistency is maintained for high-quality climate records. NOAA and EUMETSAT projects should be encouraged to be continued

Summary of Break-Out Session 2a: Standardization - Observations while on moving: ships, aircrafts, submarines

Rapporteur: Martin Doble, Laboratoire d'Océanographie de Villefranche, France

Discussing the development of measurement protocols including field experiments, opportunistic observations and intercomparability of different types: Observations while moving: Ships, aircraft and submarines

Ships observations

Standardization is a problem, even between professional ice services, since their charts are often aimed at different user groups – e.g. the charted ice edge will differ markedly if your users are looking for ice (in which case a 'sure' edge is required) or avoiding it (a 'sure not to be any ice' edge required). US and Canadian ice services are a good example of this.

Ice observations from ships have developed independently, with crews now routinely following their own protocols. It was suggested that a *post-hoc* standardization, as done by the ASPeCt group in the Antarctic, might be a more realistic goal than, say, getting the U.S. Coastguard to adopt AWI protocols, or *vice versa*. Standardization could likely be achieved on tourist ships in the Arctic, however, since there are less existing practices in place on such vessels.

Incorporating new measurements into the observations will offer an easier path to standardization: for example, there is a strong need for biological observations of ice-algal loading under floes and a standardized "colour stick" – with a range of greens and browns to compare with the underside of floes turned over by the ice-breaker should be distributed.

Sonar

Intercomparisons of upward-looking sonar (ULS) instruments were examined in previous workshops: at ACSYS/Monterey in 1997, at NSIDC in 2000 and at NPI/CliC in 2002. Studies highlighted many problems, arising from both instrument differences (primarily beam width and sampling interval) and environmental parameters (*i.e.* establishing the zero-reference with varying sound speed profiles and atmospheric pressure).

The simplest and most effective method to achieve standardization between instruments is to measure the same ice simultaneously with the available hardware, and investigators have been encouraged to co-locate ULSs from different manufacturers on the same mooring. There have also been recent efforts to profile the same area surrounding ice camps with U.S. and U.K. submarines (e.g. at the APLIS 2007 camp) which are expected to improve the situation in this regard.

Photography (aerial or other)

The big problem in dealing with photographic datasets is data reduction and processing. Datasets rapidly grow too many gigabytes and getting inter-comparable quantitative data from the images is far from trivial. Transfer to and storage of the raw data in a central location is unrealistic and undesirable, given the sizes involved. Ideally, investigators would

use a standard image processing package to reduce the data to tabular form (fractional coverage of ice type), and efforts are underway as part of the ASPeCt programme to develop and supply such a product to the community

Other photographic platforms include the “IceCam” – a type of self-contained ferrybox system developed at SAMS, which also measured its GPS position and mounting parameters (tilt *etc*) to geometrically calibrate the oblique images obtained, once the height of the mounting is known. At the time (2002) the camera sensor had insufficient dynamic range to allow ice surfaces to be well-distinguished in the same frame as dark open water, but with the advances in sensor technology, this might be usefully revisited now. The box would be relatively low-cost (c. \$2500) and could be distributed to ships-of-opportunity to provide a standardized, low cost solution.

In all cases, a calibration line should be performed to check geometry (both lens and look angle).

Aircraft

Principal ice thickness measurements from airborne platforms are scanning laser profilometer (ice+snow freeboard), electromagnetic induction (ice+snow thickness) and radar, whose reflection horizon can be the ice-snow interface or within the snow cover, depending on the snow and radar properties. These different parameters already present difficulties in comparing derived ice thickness, since they rely on assumptions about snow thickness, snow density, ice density and isostatic balance. The instruments also have rather different footprints, for instance 1m for the scanning laser and around 30m for the electromagnetic method (HEM). The HEM also ‘sees’ any seawater included in the pore spaces of deformed regions.

The way forward in understanding the response of these instruments is to perform simultaneous measurements along tightly controlled lines. This work is ongoing as part of both the Cryosat calibration-validation project and the EU DAMOCLES project.

Mention was also made of the potential for UAVs (unmanned aerial vehicles) to measure albedo and other radiative parameters.

Key Messages and Recommendations:

- Comments on other topics
- Possible Comments on Pictures - Ideally, investigators would use a standard image processing package to reduce the data to tabular form (fractional coverage of ice type). Efforts are underway as part of the ASPeCt programme to develop and supply such a product to the community. Advances in sensor technology might allow researchers to revisit the issue of camera sensors having insufficient dynamic range to allow ice surfaces to be well-distinguished in the same frame as dark open water.
- Potential for UAVs (unmanned aerial vehicles) to measure albedo and other radiative parameters.

Summary of Break-Out Session 2b: Standardization - On-ice measurements

Rapporteur: Jenny Hutchings, University of Alaska, Fairbanks, USA

In this working group we discussed what on-ice observations need to be standardized, and which could be routinely taken at ice stations and camps. Later in the discussion we touched on the role of autonomous *in-situ* observations and buoy deployments.

It was quickly identified that there is a great need to standardize particular observations for which sampling methodology is mature. As priorities for *in-situ* measurements are often dictated by the length of on-ice time available, we focused our discussion on the key observations we desire, that are most useful to the broadest interested, for ice stations of 1 hour, 4 hours and a month. This naturally led to prioritization of a set of standard observations that should be recorded at all field stations.

As researchers have differing interests, the set of measurements identified were necessarily small. We could aim for standard measurements to be taken at all Arctic field sites (including very short term stations). In which case, the burden on the observer must be small. We also discussed that the measurement set may be taken by a non-expert sea-ice field observer, such as an “adventurer” or volunteer. Hence the measurements at the top of our priority list (to be taken if only one hour is available), can be achieved with a small amount of training and equipment. It is important to prioritize and standardize, measurements for non-sea ice people who could be encouraged to provide data. Note that these measurements will depend on season.

Standard reporting forms should be provided and we should strive for them to be widely used. We recommend these are included in Hajo’s field manual, and should be readily accessible to all who plan field activities. These forms could be the back-bone for a standardization effort, and will ease compilation of pan-Arctic observations in a central database. The issue of “how do we choose where to measure” was brought up. Often this is outside of the control of the ice observer, and we must recognize this in the reporting of standard observations.

Key questions:

1. Is there a set of key measurements that could easily be done, and currently may be missed?
2. Are there measurements that are taken in widely different ways by different people?
3. How far does one need to walk to characterize an ice floe?
4. Can we come up with set of standardized measurements for length of time available?”

Key Measurements to Standardize

We identified that it is important to prioritize and standardize, for the lay person, a set of measurements that should be performed at a short ice station. Experienced ice observers should perform a standard sub-set of observations, but can also pick from a larger list of standardized observations.

Time Frame: One Hour

**Observer's name*¹

**Position*: Latitude, Longitude and Time

**Temperature*: Air, Surface and Snow-Ice interface

**Visual Observations* of the station site

Scale of ice floe station is on, Stage of melt, Ice type, Topography. Encourage photographic panoramas of field site

Wider field observations

- Ice Concentration, Ridge Density, Melt Ponds. It is highly recommended that bridge based visual observations (as per ASPeCt or modified ASPeCt / WMO convention) are taken at the location of the ice station.

There are conditions that egg codes do not completely capture. Pablo Clemente-Colon gave the example of nilas over rotten ice. Do we need to account for such phenomena in a standard visual observation protocol for the Arctic? Observations of the ridge, and lead density and orientation is useful to the operational community, as well as researchers studying ice mechanics. It would be good to include these observations

Weather

- Standard weather observations should be recorded. Ideally a ship platform will be reporting to the AVOS (Automated Voluntary Observation System). Such measurements should be encouraged for all field campaigns

Ice Thickness

If drill-hole measurements are taken, they should follow a standard reporting protocol with ice thickness, snow thickness and freeboard uniformly defined across observers. It is important to define zero on the measurement scale. *i.e.* is zero the top, bottom or sea level? A diagram on the standard data form would be helpful for

Thickness Transects, the length of the transects and ice type transect occurs over should be reported. It should be noted if the transect was constrained to a single floe or particular ice type, due to summer melt conditions, or whether the observer was unimpeded in their travel along the transect. An experienced ice observer can take a 1km transect with EM-31 within an hour. Should an EM-31 be considered standard kit for a professional ice observer? It would be good to formalize distance between ice and snow thickness measurements along transects

Time Frame: Four Hours

**All measurements required for a one hour station*

**Snow Properties*: Thickness and Density. It was suggested that rather than using a density tube, it is simpler to measure the mass of snow within a pre-defined area that can be cut out of the snow pack

Ice Cores: This group thinks that we should attempt to standardize ice coring protocols, recognizing that there are several methods commonly employed. Depending on the parameters of interest (physical, chemical or biological properties) there may be several different methods commonly used to get at the same information. It was suggested that standardizations should be provided for each common methodology. There are so many variations on how to drill and cut a core, we feel it may not be possible to tackle standardizing this.

¹ An asterisk (*) is placed by observations that we believe must be reported

- To represent small scale variability it should be encouraged to take 3 cores close to each other, at 10cm spacing. It is important to standardize how to measure the distance between cores.
- We identified that cores of thin ice are especially needed.
- *Albedo*: Don Perovich reports that there is a pretty standard set of protocols used for albedo measurements.
- *Ridge Transects*: Measure on both sides of the ridge!
- Newer Measurements, such as permeability and density, have not been standardized. Perhaps these should not yet be standardized, as the methodology is an active research topic. We recommend this data should be reported with lots of meta-data, documenting comprehensively how the measurements were taken.

Time Frame: One Month

At such a station it possible to characterize the ice and snow pack in detail. We recommend that a detailed survey of snow (which may take a week) be performed at such stations. Snow is one of the key uncertainties in remote sensing of the ice pack, and much more data is required.

Intensive surveys will allow us to address length scale issues. Alexander Makshatas mentioned that there is work performed by AARI looking at the issue of decorrelation length scales for ice thickness that could help define standard transect lengths and placement.

Some measurements that could be considered standard at a long station are:

- *Ablation Stakes*
- *Ridge Surveys*
- *Ice Cores* (weekly)
- WMO Weather observations, autonomous weather station
- *Thermistor String*
- *Melt Ponds*: Note temporal evolution of a few
- *Autonomous camera*, or scheduled photographs from a fixed location (a high vista point)
- *Buoys* should be deployed to track the station after it is vacated

Time Requirements

Time series should be taken, and the temporal spacing of observations should be tailored to season, and may need to be flexible to capture specific short time scale events. For example, ice thickness surveys may happen at regular intervals, but also be taken after a storm event to resolve dynamic evolution of the ice pack. Measurement frequency should be stepped up to resolve melting events. Measurement interval must be tailored to observation. For example the snow depth and ice thickness fields evolve on different time scales. Ice cores may need to be taken more frequently than once a week to resolve seasonal transitions.

Some measurements require highly trained and skilled observers. For example, estimating ridge porosity and taking ice cores. Other measurements are intensive and may take much of the ice station time, such as snow and ice thickness surveys. However, this information is vital, and such surveys should be highly encouraged.

Buoy Deployments

There was a workshop in 2004, Andrey Proshuntinsky's Ice Tethered Profiler Workshop, that discussed this topic in great detail. Recommendations for clustered buoy deployments, and data that should be collected, were outlined in the workshop report. The recommendations, for a suite of sensors, for autonomous buoy stations that came out of this workshop is good for the perennial ice zone. However, there is a great need for seasonal ice buoys, and as these are in development standardization of their deployment has not yet been discussed.

We suggest that buoy deployments should be accompanied by standard *in-situ* observations, and a larger sub-set of observations (such as ice thickness and snow information) may be appropriate to identify ice state at deployment.

Reporting

Reporting after the ice station could be standardized, and we should consider a standard way to store data. Simply agreeing on a standard file format, header, *etc*, would be enormously valuable. Standardized reporting forms would assist in building archive software and protocols.

Proper terms should be agreed upon and used. A standard reference would be required, and could build upon documents that are already available (e.g. WMO ice classification in four languages dating from the 1970s).

Reporting must be accompanied with reliability reports.

Where to put the data (archive it) is a big problem, since most national archives or World Data Centers are not funded to accept data unless arranged in advance.

Key Messages and Recommendations

- Standard reporting forms should be provided and we should strive for them to be widely used. We recommend these are included in Hajo's field manual, and should be readily accessible to all who plan field activities
- We suggest that buoy deployments should be accompanied by standard *in-situ* observations, and a larger sub-set of observations (such as ice thickness and snow information) may be appropriate to identify ice state at deployment.
- This group identified forms as a high priority for enabling standardization. Standard report forms give people a checklist of measurements to take. The forms should include standardized comments such as:
 - How quickly are clouds changing?
 - Did water gush out of the core?
- A second high priority was to standardize a small set of measurements that are taken at all sites, that a lay-person could report. These may be the measurements listed as essential to report at a one hour ice station

Summary of Break-Out Session 3a: Coordination and Implementation - North America Sector

Rapporteurs: *Florence Fetterer, National Snow and Ice Data Center, University of Colorado, Boulder, USA and Tony Worby, Australian Antarctic Division and ACE CRC, Hobart, Australia*

Coordinating ice observations can take place at several levels. It was noted that last summer there were 7 icebreakers conducting research activities in the Arctic and none knew what the others were doing. Most simply, sharing information can result in coordination. Knowing what science cruises are being planned, with what observations, well in advance of a cruise may help other researchers plan complementary observations. Sharing information in near real time can be especially valuable. The Web site that provides real time information from the North Pole Environmental Observatory, for example, was used by USGS investigators planning acquisition of high resolution imagery – an unanticipated but valuable use of the Web site information. A current example is the system used by the Polarstern to share logs, cruise tracks, and other information (<http://www.awi.de/en/infrastructure/ships/polarstern/>): this could be emulated.

A higher level of coordination is what could be termed opportunistic planning. That is, if information about upcoming field experiments or cruises is shared with enough detail, and early enough, this may facilitate sharing resources. An outside investigator may approach a field program with an offer of adding to that program's data collection in exchange for deploying an instrument, for example. A specific example would be to approach Healy cruise planners about installing a camera to observe surface melt conditions, if it is suggested that this would be valuable by the shared planned cruise track.

The highest level of coordination that this group discussed is joint experiment planning. It is important to plan for incorporating standard observations, acquired and reported in a standard way. This requires significant effort not only in the coordination of activities, but also in bringing the science community to agree on what to measure and how to measure it; in other words, identifying baseline measurements, standardizing measurement and analysis techniques, and coordinating data management. Ice mass balance buoys (IMBs) and Upward Looking Sonars (ULS) were discussed as two valuable measurement techniques for which there is no coordinated network; however it was agreed that the establishment of the Sustained Arctic Observing Network (SAON) would help facilitate such coordination. It was hoped SAON would also help to overcome some of the geopolitical issues that have resulted in significant data gaps on the Eurasian side of the Arctic basin.

The group discussed ideas for implementing some of the goals related to coordinating and standardizing sea-ice observations that had been identified in earlier breakout groups and talks.

Key Messages and Recommendations

- Share information needed to coordinate ice observations using Web services. This includes planning for standardized observations, and sharing information related to coming or in progress field expeditions. We envision a Web site or wiki that posts or links to this information, or creates the information when it is not available to link to

elsewhere. One model would be to have a coordinator for each country provide information for the CliC project office to host.

- Standardize sea-ice observations. Here we refer to standardizing content: that is, those collecting snow measurements on sea ice, for instance, would have a standard list of observations to make. (The On Ice Observations working group report should be referenced). Related to this is determining the measurement accuracy required for different purposes, and the importance of meta data (such as the type of sonar instrument, data quality, etc.). It was agreed that coordinated ice camps are the best way to measure and monitor surface conditions.
- Standardize data file format. Among other benefits, this will make it easier to share data. This can simply be a recommendation for storing data in ASCII files with a standard header record and data structure, though some types of observations may be easier to standardize using a file type other than ASCII. NetCDF with CF extensions, a self-describing format, is advantageous. However, requiring netCDF or other complicated formats can be burdensome to scientists in the field, and we do not extend the recommendation to “standardize formats” beyond prescribing a simple header and data structure for types of observations.
- Encourage data release and data sharing. Individual investigators and agencies should be encouraged to release data that could be compiled into valuable data sets. One example discussed was Canadian submarine data from the Arctic.

A number of key issues and parameters were discussed as having priority for the sea-ice community, including:

- Transition of the Arctic sea-ice environment from predominantly multi-year ice, to a more seasonal regime of predominantly first-year ice. This will affect the temperature and salinity profiles of the ice and consequently ice strength and kinematics.
- Importance of designing field programs in conjunction with modelers and the remote sensing community, to ensure optimal model and product development.
- Black carbon
- Snow processes, particularly in a changing environment. Snow thickness and snow density are very important parameters, particularly for knowing the surface albedo, for calculating ice thickness from satellite-derived altimetry measurements of freeboard, and for validating remotely-sensed snow thickness products.
- How does the ice thickness distribution respond to melt? In particular, how is the ice mass balance changing? What is the block size and porosity of ridges and is it changing?
- Standardized ice definitions for melting ice.

To implement recommendations for standardization, we suggest that CliC approach experts who can be sea-ice variable protocol leads. The leads would draft forms for reporting the following types of observations with standard content and format. These could be developed by the leads with community input using a wiki, and published online as a supplement to the recently published *Field Techniques for Sea Ice Research* (ISBN 978-1-6022230-59-0). At some point it may be desirable to engage WMO JCOMM² Expert Team on Sea Ice. WMO involvement provides international endorsement and can formalize protocols.

² JCOMM’s vision includes “...the development and recommendation of appropriate technical standards and procedures for a fully integrated marine observing, data management and services system.”

We had the following suggestions for experts who could be contacted to serve as sea-ice variable protocol leads.

Ship observations – Hajo Eicken (Jenny Hutchings offered to provide a student to assist)

Optics – Don Perovich

Snow on ice – Marcel Nicolaus

Ice cores and thickness – Dirk Notz

Meteorology – Peter Guest

EM induction – Stefan Hendricks

Summary of Break-Out Session 3b: Coordination and Implementation - Eurasian Sector

Rapporteurs: *Alexander Makshtas, Arctic and Antarctic Research Institute, St. Petersburg, Russia* and *Sebastian Gerland, Norwegian Polar Institute, Tromsø, Norway*

Tasks and Sources of information

There are various sources of information that support coordination of observations of Arctic sea ice, and the implementation of coordinated activities. The new website <http://iceplan.org>, maintained by Jenny Hutchings includes updated overviews and summaries from most countries that conduct active field research in the entire marine Arctic, not only in the Eurasian sector.

Other websites that also contribute to better information on what activities are planned and are going on are the ASCI website (www.asci-ipy.de; mainly ships; U. Schauer, AWI), the EASO website (www.ipyeaso.aari.ru; AARI, St. Petersburg), and the SAON activity (<http://saon.arcticportal.org/>). It was also mentioned that calibration and validation fieldwork campaigns are going to be carried out in the context of the planned launch of the ESA CryoSat satellite in early 2010 (www.esa.int/esaLP/LPcryosat.html).

Among other important contact points for fieldwork information and coordination in the Eurasian sector of the Arctic are Rene Forsberg, (DTU Space, National Space Institute, Denmark) for air logistics, and the FARO (forum of Arctic research operators, under IASC) and CEON (www.ceon.utep.edu/; contact: Craig Tweedie) for land-based observations.

It was pointed out that there is a lack of systematic overviews on non-scientific campaigns, for various reasons. Non-scientific campaigns include cruises for oil and gas exploration (and reconnaissance), trips of adventurers by ships, ski, boat and foot, tourist cruises and flights, and military activities such as submarine transects under the Arctic sea ice.

With better knowledge on planned non-scientific cruises, cooperating ship crews could be contacted and equipped with sea tutorials such as developed in the ASPeCt project (www.aspect.aq; contact: Tony Worby, Australian Antarctic Division, Hobart, Australia).

The CliC Arctic Sea Ice Working group can be contacted if information on field activities and contacts is needed.

Procedure of collaboration and data exchange

Means to improve possibilities of exchange of metadata and observational data were discussed. In the framework of the IPY, a new data policy was introduced, and it will make project data for 2007 to 2008 easier accessible (e.g. DAMOCLES data at met.no in Oslo). Better accessibility of observational data is also important for the climate modeling community. Modelers need also information on data uncertainties along with data and metadata. For most applications it is crucial that data are stored in consistent formats and that they are thoroughly documented.

This break-out group collected also a number of specific news and suggestion that will or would improve data accessibility and exchange possibilities:

The collocation of different autonomous logging sensors (e.g. IMBs (CRREL) and ocean buoys (JAMSTEC and WHOI)) that are placed in the Arctic Ocean would be an advantage.

Among specific tasks where the CliC Arctic Sea ice working group could help are to support publication and advertising of additional data from the DAMOCLES project work (e.g. POPS, ITPs, tiltmeters, IMB, ULS) as well as meteorological and oceanographical data (IABP, ARGOS, Ship based ice observation images.) There have been also recently made memoranda of understanding between DAMOCLES (EU) and SEARCH (NSF), and between DAMOCLES and PRIC (China).

Various meteorological and sea-ice data collected at Tiksi (Russia) since the 1930s are now available on the internet (www.aari.nw.ru, contact A. Makshtas, AARI, St. Petersburg, Russia).

It was also commented that for the Arctic sea-ice outlook initiative, which started in 2008, it would be beneficial if April sea-ice thickness data could be made available immediately after measurements, in order to improve model runs. A part of the observational data that are collected on Russian drifting stations, organized by AARI, are available in real time on AARI's website www.aari.nw.ru. This can give new possibilities for future joint studies.

Key Messages and Recommendations

- The new website <http://iceplan.org> can make a substantial improvement in international collaboration in the Arctic in the near future. It is suggested that the CliC Arctic sea ice working group supports and advertises for this activity.
- Availability of data and metadata are key for pan-Arctic work and data integration. The recent IPY brought this further, but it needs more work also in the years to come.
- As another example where the CliC Arctic sea ice group could give support is the work linked to the 2010 CryoSat-2 launch and connected calibration and validation activities. Here, the CliC Arctic Sea ice working group could possibly help in coordinating and enhancing activities beyond what is already planned.

Appendices

1. Appendix 1: Report on IcePlan.org
2. Appendix 2: Agenda
3. Appendix 3: List of Participants
4. Appendix 4: List of Acronyms

Appendix 1

Report on *IcePlan.org*

Arctic Sea-Ice Measurement Campaign Coordination

Jenny Hutchings, University of Alaska, Fairbanks, USA

Last January, the *CliC Arctic sea ice working group* met to discuss developing and implementing a protocol for Arctic surface-based sea-ice observations. Representatives from 12 nations reported to the group on planned field activities for 2009 and 2010. The discussion and possibilities for international collaboration that emerged highlighted a need for sea-ice researchers to share information about each others' field plans.

The workshop decided to find a way to report planned sea-ice field-work activities in an international forum accessible to anyone interested. This is how *IcePlan.org* was born. *IcePlan* is a website - jointly sponsored by the International Arctic Research Center at the University of Alaska Fairbanks and CliC - that aims to be a jumping-off point for researchers seeking information about planned Arctic sea-ice field work. If you are looking for people working on sea ice in a particular Northern-hemisphere region or season, *IcePlan* is worth a look.

While compiling information for the 2009 summer and winter field seasons, we found large regions of the Arctic where sea-ice information simply was not being collected. Most striking was the East Siberian Sea, a region that has undergone dramatic sea-ice reductions in the last few years. We also found that not all research ships travelling in the Arctic included a dedicated sea-ice program, and that several ships simply did not record visual sea-ice observations. There are opportunities waiting to be exploited for increasing the quantity and coverage of Arctic sea-ice field observations. It is hoped that *IcePlan* can bring these opportunities to our attention, while also informing us of the wealth of data being collected.

Community input indicates that the website is interesting and useful to many sea-ice researchers, thus encouraging us to maintain the site for future field seasons. With continued help and support of the sea-ice community, *IcePlan* will grow into a successful networking tool that will help to improve collaboration and coordination among sea-ice field campaigns. We ask you to provide information about planned sea-ice field activities and welcome input at anytime. Please submit information about your planned sea-ice field work to Jenny Hutchings (jenny@iarc.uaf.edu). <<http://iceplan.org>>

Appendix 2

Agenda

CliC Arctic Sea-Ice Working Group Workshop: “Arctic surface-based sea-ice observations: Integrated protocols and coordinated data acquisition”

Venue: Room “Tre Kroner”/5010-12, 5th floor. Norwegian Polar Institute, The Polar Environmental Centre, Hjalmar Johansens gate 14, 9296 Tromsø, Norway (phone switchboard +47 777 50 500).

Monday January 26, 2009

Morning session chair: Donald K. Perovich

Introduction and welcome

0900 – 0910 Local organizing committee (Sebastian Gerland)

0910 – 0920 Brief overview and welcome: The NPI and its research department (Kim Holmen)

0920 – 0930 CliC including brief overview of CliC Working Groups roles (Daqing Yang)

0930 – 0940 CliC Sea Ice Working Group, workshop goals and process (Hajo Eicken)

Key parameters

0940 – 1000 Overview of key parameters recommended by past workshops (Don Perovich)

1000 – 1130 Discussion in break-out groups. Topic: Identify priorities, platforms and gaps of key parameters

1130 – 1200 Summary of discussion groups (Rapporteur from each group)

1200 – 1245 Lunch

1245 Group picture (entrance area Polar Environmental Centre)

Afternoon session chair: Sebastian Gerland

Standardization of observation protocols and intercomparability of measurements

1300 – 1320 Intercomparability and standardization of remote-sensing data sets (Walt Meier)

1320 – 1340 Overview of Antarctic efforts on ship-based observations (Tony Worby)

1340 – 1400 Overview of standard Russian sea-ice field measurements (Alexander Makshtas)

1400 – 1420 Sea-ice field measurements handbook and best-practices (Hajo Eicken)

1420 – 1430 ESA-CliC collaboration (Daqing Yang)

1430 – 1450 Break

1450 – 1500 Directions for break-out groups

1500 – 1645 Break-out group discussions. Topic: Development of measurement protocols including field experiments, opportunistic observations, and intercomparability of different types.

1645 – 1730 Summary of discussions groups (Rapporteur from each group)

1900 Dinner at Restaurant “Sjøgata XII”, Tromsø

Appendix 2

Tuesday January 27, 2009

Morning session chair: Anthony Worby

0830 – 0845 Overview of day's activities (morning of second day)

Brief summaries of field activities planned for 2009 and 2010 (1-2 slides, <5 minutes):

0845 – 1000

Norway: Sebastian Gerland
Finland: Jaari Haapala
Sweden: Ralf Doescher
Denmark: Leif Toudal Pedersen
Germany: Dirk Notz
France and EU DAMOCLES project: Jean-Claude Gascard
UK: Martin Doble
Russia: Alexander Makshtas
Japan: Jun Inoue
China: Zhijun Li
Canada: John Yackel
US: Jenny Hutchings

1000 – 1030 Break

1030 – 1130 Break-out group discussion. Topic: Outline process to coordinate pan-Arctic observation activities with specifics on implementation

11:30 – 1230 Summary of discussion in break-out groups (Rapporteurs)

1230 – 1330 Lunch

Afternoon session chair: Hajo Eicken

Linking and integration

1330 – 1350 How to improve use of observations in remote sensing, modeling, and stakeholder planning. (Leif Toudal Pedersen)

1350 – 1410 Community-based observations and information exchange (Shari Gearheard by phone)

1410 – 1430 Data acquisition, management and dissemination (Florence Fetterer)

1430 – 1530 Final review and discussion

Outcomes & Products from the Workshop:

- (1) Workshop report with recommendations on: Measures needed to improve and sustain coordinated observations; approaches to improve intercomparability and standardization; role of data management in coordinated observations; next steps for CliC Sea Ice Working Group
- (2) Building a network of Arctic sea-ice researchers involved in measurement programs
- (3) Overview of 2009 and 2010 pan-Arctic measurement campaigns
- (4) Very rough draft document for standardized observation protocols

Appendix 2

Break-Out Group Structure for CliC Workshop on Arctic Sea Ice

Break-out 1 (Monday morning): Key parameters

Theme	Modeling	Field observations	Remote sensing
Rapporteur	Ralf Döscher	Anthony Worby	Walt Meier
Room	Sarkofagen	Tre kroner	Arctic Council

Break-out 2 (Monday afternoon): Standardization

Theme	Observations while moving: Ships, aircrafts, submarines	On-ice measurements	Remote sensing and modeling*
Rapporteur	Martin Doble	Jenny Hutchings	Leif Toudal Pedersen
Room	Sarkofagen	Tre kroner	Arctic Council

Break-out 3 (Tuesday morning): Coordination and Implementation

Theme	North American sector	Eurasian sector
Rapporteur	John Yackel	Alexander Makshtas
Room	Sarkofagen	Tre kroner

Location of meeting rooms:

Tre kroner (5010-12): 5th floor, main workshop meeting room

Sarkofagen (5093): 5th floor, from tre kroner towards west at the end of the corridor)

Arctic Council: 6th floor, from tre kroner one floor up (use staircase) and then via the long corridor towards west to the end of the (long and more narrow) corridor

*Summary not available.

Appendix 3

List of Participants

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Appendix 4

List of Acronyms

AARI Arctic and Antarctic Research Institute	IDL Interactive Data Language
ACSYS Arctic Climate System Study	IGOS-P Integrated Global Observing Strategy Partners
APLIS Applied Physics Laboratory Ice Station	IARC International Arctic Research Coordinating Committee
ARGOS Automatic Remote Geomagnetic Observatory System (French satellite-borne data relay and platform-location system)	IMB Ice-Mass Balance Buoy
ASCI Arctic Ship Coordination during IPY	IPY International Polar Year
ASPeCt Antarctic Sea-Ice Processes and Climate	ITPs Ice-Tethered Profiler
ASSW Arctic Science Summer Week	ISO International organization for Standardization
AUV Autonomous Unmanned Vehicle	JAMSTEC Japan Agency for Marine-Earth Science and Technology
AVOS Automated Voluntary Observation System	JCOMM Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology
AWI Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany	NASA National Aeronautics and Space Administration
CDO Climate Data Operators	NCO NetCDF Operators
CDR Climate Data Record	NetCDF Network Common Data Form
CliC Climate and Cryosphere (WCRP/SCAR/IASC)	NOAA National Oceanic and Atmospheric Administration
CRC Cooperative Research Centres	NPI Norwegian Polar Institute
CRREL Cold Regions Research and Engineering Laboratory	NPOESS National Polar-Orbiting Operational Environmental Satellite System
CSA Canadian Space Agency	NRC National Research Council
CVRT CryoSat Validation and Retrieval Team	NSIDC National Snow and Ice Data Center
DAMOCLES Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies	NSF National Science Foundation
DMSP Defense Meteorological Satellite Programme	OSISAF Ocean and Sea Ice Satellite Application Facility
EASO European Arctic Stratospheric Ozone Experiment	PM Passive Microwave
EM Electromagnetic Radiation	POPS Polar Oceans Profiling System
ESA European Space Agency	PRIC Polar Research Institute of China
EUMETSAT European Meteorological Satellite Organization	SAMS Stratospheric and Mesospheric Sounder
FARO Forum of Arctic research Operators	SAON Sustained Arctic Observing Network
GIS Geographic Information System	SAR Synthetic Aperture Radar
GCMD Global Change Master Directory	SEARCH Study of Environmental Arctic Change
GPS Global Positioning System	SMMR Scanning Multichannel Microwave Radiometer
HEM Electromagnetic Method	SSM/I Special Sensor Microwave Imager
IABP International Arctic Buoy Program	UAV Unmanned Aerial Vehicles
IASC International Arctic Science Committee	ULS Upward Looking Sonar
	US NIC United States National/Naval Ice Center
	WHOI Woods Hole Oceanographic Institution
	WMO World Meteorological Organization

