Sea Ice Modeling and Observing

Workshop Report

5 – 7 June 2013 Tromsø, Norway

Executive Summary

The sea ice covers of the polar oceans are a critical element of the global system. With support from the Research Council of Norway, CliC, the International Arctic Science Committee (IASC) and the Scientific Committee on Antarctic Research (SCAR), 48 researchers from 13 countries, including 10 early career scientists, met from June 5-7, 2013 in Tromso, Norway to discuss the next steps in better integrating sea ice observations and modeling. The group included field experimentalists, remote sensing specialists, and sea ice and climate modelers. The workshop featured overview presentations on sea ice observations, models, remote sensing, and data archiving plus ample time for group discussions. Five 7-9 person teams consisting of scientists from a mixture of areas of expertise were assembled to develop a list of key gaps of knowledge within sea ice observations and models. Targeted activities that could close some of these gaps were proposed with separate short (6 months to a year), medium (1-2 years), and long (3 years or more) term goals. A common theme from these projects was the need for standardization of sea ice observation data from the Arctic, developing and implementing a standardized, computerized ship-based ice observation protocols and creating an online center for summarizing ongoing field activities. The combination of ASPeCt and IceWatch efforts will help create an ongoing inventory of sea ice and sea ice related datasets for both Arctic and Antarctic

This meeting identified key areas where we need to improve our understanding of sea ice properties and processes and enhance our ability to model sea ice on different spatial and temporal scales. There are important issues with sea ice dynamics and thermodynamics that the proposed activities will address. We need to improve our understanding of sea ice rheologies and ice drift and deformation mechanisms which significantly contribute to sea ice thickness errors in models. Another principal factor that will help us accurately detect sea ice is implementing a better parameterization/understanding of snow processes for sea ice in both poles. It was agreed that we should update the Warren climatology for the Arctic (1999), and build a climatology for the Antarctic through a comprehensive data trawling exercise to parameterize snow processes on sea ice. In addition, participants pointed to a need to integrate surface-based and airborne observations with modeling activities and remote sensing. Team members with modeling backgrounds will help identify priorities and types of observations of greatest utility in understanding and predicting changes in the Arctic and Antarctic sea ice cover.

The participants identified the importance of collaboration in moving forward in sea ice science, including international partnerships and interdisciplinary studies. We are planning research activities that integrate modeling, in situ field observations, and remote sensing data. Results from these efforts will be shared through easily accessible data archives.

Those interested in participating in further activities resulting from the workshop should contact any of the authors of this meeting report.

Report compiled by Penny Wagner

Table of Content

Introduction

The sea ice modeling and observing workshop, held in Tromsø on the 5th - 7th June brought together Arctic and Antarctic sea ice researchers to define priority research areas for the coming years. The 48 participants included specialists working on sea-ice modeling, observations, remote sensing and forecasting.

Prior to this event the CliC Arctic Sea Ice working group held three workshops (2009-2011), bringing together mainly leading Arctic sea ice researchers to develop, standardize and implement measurement protocols and to integrate observation and modeling networks for the Arctic. One of the goals of this new workshop was to better establish ties with the SCAR/CliC Sponsored ASPeCt (Antarctic Sea Ice Processes and Climate) working group. Bringing both of the CliC sea-ice activities together creates an international platform for discussing the progress made in Arctic and Antarctic sea-ice research, identifying weaknesses in knowledge and methods used in observations, data processing, model validation and calibration to concentrate on perspective avenues of improving all aspects of sea-ice research.

The workshop had the following goals:

- establish optimal linkages between international groups involved in sea ice modeling, observations, data assimilation, prediction and service provision;
- finding avenues for future research efforts that are most productive for addressing the gaps in knowledge and weaknesses in our ability to observe sea ice, generate sea-ice data products and strengthen sea-ice modeling capabilities; and
- outline observational needs for sea-ice models, building on past assessments including those of the CliC Arctic Sea Ice Working Group..

The workshop began with a warm welcome to Tromsø by the Norwegian Polar Institute's Research Director, Nalân Koç and Sea Ice and Ocean Section Leader Sebastian Gerland and an introduction to the workshop from Don Perovich, Chair of the organizing committee. The first plenary session set the stage by considering different needs within the community. Introductory talks from experts in different areas summarized the current state of affairs and possible gaps in knowledge that the breakout groups might address. These presentations can be downloaded from the workshop website: http://www.climate-cryosphere.org/meetings/seaice2013/downloads. The plenary talks were followed by three breakout sessions targeted at; identifying gaps in understanding, how to fill the gaps, and data archiving and accessibility. The charge to the breakout groups was to consider where the gaps in knowledge lay, and how best these might be addressed in future research efforts. The breakout groups were asked to come up with "specific, actionable connections", solid plans of action that would bring together researchers from different disciplines to address the gaps in knowledge as a 'targeted activity'. The plans discussed were to define where each study would take place, who could be involved and the anticipated accomplishments. These breakout sessions were followed by a final plenary session focusing on strengthening international and bi-polar collaboration to address the outcomes presented by the various groups.
The following outcomes are presented in this report:

- a review of the current state of sea ice research, gaps and advances in sea-ice observations, modeling, data assimilation and prediction;
- action items with identified potential partners on how to coordinate overlapping interests, close gaps in knowledge, and enhance networking between groups; and
- a compendium of sea-ice issues to be discussed with the wider climate community.

The organizing committee consisted of:
- Don Perovich, Thayer School of Engineering, Dartmouth College, USA - Chair
- Hajo Eicken, University of Alaska - Fairbanks, USA
- Sebastian Gerland, Norwegian Polar Institute, Norway
- Marcel Nicolaus, Alfred Wegener Institute for Polar and Marine Research, Germany
- Penny Wagner, University of Delaware, USA
- Jeremy Wilkinson, Scottish Marine Institute/British Antarctic Survey, UK
- Jenny Baeseman, Climate and Cryosphere, Norway

Funding for the workshop was provided for by the Climate and Cryosphere Project, the Research Council of Norway, the International Arctic Science Committee (IASC) and the Scientific Committee on Antarctic Research (SCAR).

The Current State of Sea Ice Research

The first plenary session consisted of eight plenary talks covering large-scale and regional modeling issues, Arctic and Antarctic field observation efforts, remote sensing capabilities, and data archiving. These overview talks provided a common background for the workshop participants and discussion topics for the breakout sessions.

Large Scale Modeling Needs

- Alexandra Jahn (National Center for Atmospheric Research, USA)

Observations of sea ice are used in several ways for large-scale sea ice models: for model and parameterization development, for climate simulation skill evaluation and model testing, for model intercomparisons (CMIP3/5), and for model weighting. While in situ observations are needed for model development and parameterization development, large-scale gridded long-term (>10 years) observations are needed for all other purposes. Currently sea ice extent is the most widely used quantitative metric to evaluate model skill and to discriminate between models. Sea ice thickness from ICESat is a new quantitative variable that has started to be used more frequently, and which provides many added benefits to sea ice extent alone. In the future we hope to use many more sea ice variables for quantitative model development and evaluation purposes.

Several datasets are highly desired by modelers, including snow thickness on sea ice, derivatives of sea ice variables (e.g. sea ice formation and melt rates in addition to thickness), ocean-ice and ice-atmosphere fluxes, and ice volume fluxes through gates. Other gridded sea ice datasets like sea ice age and velocity already exist but are underutilized because of difficulties with the definition of variables in observations and models, difficulties because of the grids the data is on, and/or the availability of the datasets. This highlights the important roles of data availability and data documentation, which are crucial for data to be used for model evaluation and development. The NCAR Climate Data guide (https://climatedataguide.ucar.edu/) is one place where observers can document data suitable for climate model comparisons and can highlight the key strengths and limitations of the dataset. While new sea ice datasets are always welcome, better documentation and the improved availability of already existing data sets could help a lot to improve large-scale sea ice models. In the future we hope to be able to use more quantitative metrics for model development and evaluation, rather than relying primarily on sea ice extent metrics and expert judgment for the other sea ice parameters.

Regional approaches for Arctic sea ice modeling

- Klaus Dethloff (Alfred Wegener Institute for Polar and Marine Research, Germany) with contributions from A. Rinke and W. Dorn

The coupled regional climate model (RCM) HIRHAM-NAOSIM has been used to investigate atmosphere-sea ice feedbacks between September sea-ice anomalies in the Arctic and atmospheric conditions in the following autumn and winter. A six-member ensemble of RCM simulations forced by NCEP reanalysis data over the period 1949-2008 is analyzed.

The results indicate that negative Arctic sea-ice anomalies are associated with increased heat and moisture fluxes, decreased static stability, increased lower-tropospheric moisture, modified baroclinicity and changed synoptic activity and atmospheric large-scale circulation. The circulation changes in the following winter are connected with cold winter temperatures over Northern Eurasian land areas.

Internally generated climate variability connected with uncertain initial boundary conditions in the ocean and sea ice fields cause significant uncertainty in the simulated circulation changes due to coupled sea ice-atmosphere interactions. The simulated atmospheric feedback patterns depend strongly on the position and strength of the regional sea-ice anomalies and on the analyzed time period. The strongest atmospheric feedbacks are related to sea-ice anomalies in the Beaufort Sea.

The improved description of sea ice is a coupled problem and needs improvement in all subsystem models including atmosphere, ocean, sea ice and frozen land and the understanding of feedbacks in a coupled model setup. Sea ice thickness measurements are especially important for evaluating the performance of coupled regional climate models of the Arctic.

Stakeholder Needs

- Nick Hughes (Norwegian Ice Service/ Norwegian Meteorological Institute, Norway)

The Norwegian Ice Service supplies information to and represents a wide range of different users of sea ice information, as well as being an end user of that information itself. These data includes many different Earth observation data, ground truth from in situ observations, and forecast models. With the increase in economic activity in the polar regions, there has been a demand from marine users for more detailed and timely provision of sea ice information. Some of these users are also stakeholders, and can help provide additional data that otherwise might not be acquired. Therefore the Ice Service has been active in assessing these stakeholder needs through the use of questionnaires and user feedback.

Seasonal to Interannual Forecasting Needs: Towards an International Sea Ice Prediction Research Network

- Hajo Eicken (University of Alaska Fairbanks, USA) with contributions by J. Stroeve, C. Bitz, J. Overland, M. Wang, A. Tivy, L. Hamilton, H. Wiggins, J. Hutchings

The reduction in Arctic sea ice volume by roughly 75% since 1979 and the associated decreases in summer minimum ice extent raise important questions about the fate of the Arctic summer ice cover. Seasonal to interannual scale predictions of sea ice distribution and extent link needed improvements in our understanding of the state and evolution of the ice pack to urgent questions raised by different ice users and stakeholders impacted by recent change. Here, we provide a brief update on activities that build on the Study of Environmental Arctic Change (SEARCH) Sea Ice Outlook (SIO), an international, collaborative effort at synthesizing seasonal predictions and observations of the September mean ice extent at the pan-Arctic and regional scale.

Building on the SIO and through support by a different US agencies and international programs, we are working towards the establishment of an international sea ice prediction research network. The main objectives of this network are to (1) coordinate and evaluate predictions, (2) integrate, assess and guide observations, (3) synthesize predictions and observations, and (4) disseminate predictions and engage key stakeholders. The network is led by Julienne Stroeve at the National Snow and Ice Data Center and Cecilia Bitz at the University of Washington, with contributions by the co-authors of this presentation (see above). The presentation highlights the next steps and potential engagement by the sea-ice research community.

Arctic Sea Ice Observing Network and Field Campaigns

- Jeremy Wilkinson (Scottish Marine Institute/British Antarctic Survey, UK)

The scale and speed of Arctic change in recent times have been remarkable, most notably in the removal of almost half the summer Arctic sea ice cover. These changes in the Arctic marine environment are leading to greater access and an increase of economic activities, such as fisheries, shipping, tourism and oil and mineral exploration. The environmental, socio-economic, and geopolitical consequences associated with these changes yield new opportunities, amidst potential conflicts and risks for human activities right across the Arctic and the globe.

Because changes in the Arctic sea ice cover have occurred over a handful of years our current knowledge of the Arctic stems largely from observations in a multi-year ice setting, rather than the thinner Arctic sea ice that we find today. In order to keep abreast, understand, and predict the rapid changes in the sea ice environment there is a substantial need to build science capacity in sea ice research. It is important to remember that sea ice change is a function of atmosphere and ocean processes, all of which influence ecosystem function. Therefore in many respects a multi-disciplinary approach is needed.

An essential component of sea ice research is Arctic field campaigns, and the long-term deployment of autonomous instrumentation. However these campaigns are logistically difficult and expensive to perform and no single nation has the sovereignty, expertise, or knowledge, to individually tackle these challenges head on; a truly international and integrated scientific effort is needed. This is especially true as the issues associated with Arctic change transcend national boundaries and science disciplines. In this presentation we give an overview of scientific value behind the establishment of a multi-disciplinary Arctic sea ice observing system AND more dedicated interdisciplinary field programmes. Whilst significant international collaboration is occurring within polar science we identify a need for better international integration with respect to the sharing of technology, data and logistics. The stakes are high as Arctic sea ice change has substantial implications for humanity, ecosystem function and global climate.

Antarctic Sea Ice Observing and Field Campaigns

- Steve Ackley (University of Texas at San Antonio, USA)

Antarctic sea ice, unlike the Arctic, has not been traversed routinely by nuclear submarines with upward looking sonar to measure ice thickness. Therefore, the principal methods to obtain ice thicknesses on smaller (floe) scales have been by ice drilling or the use of hand-held EMI profilers. On the large scale, ASPeCt visual observations, conducted by observers on the bridges of icebreakers, have provided, over thirty years, a method to see the regional-scale ice thickness variations and have provided the only records at the circumpolar scale through the late twentieth century. Recent efforts on ice thickness have tried to use the laser altimeters from the ICESat 1 satellite from 2003-2009 and more recently from airborne lidar such as flown on the NASA IceBridge flights from 2009 until present. Since altimeters only measure topside elevation of the snow cover on sea ice, recent field campaigns have focused on providing the correlation between top elevation and ice thickness in an effort to convert altimetric elevation measurements into a usable estimate of the ice thickness. The Antarctic and Arctic conversion algorithms differ principally because of the deeper snow and flooding of the snow ice interface ("negative ice freeboard") that is widespread in the Antarctic sea ice zone.

Ice mass balance buoys in the limited deployments conducted in the Antarctic have shown how the flooded interface develops, from snow accumulations during winter, redistribution of snow cover in the high wind environment, and through melting of the ice cover from below during summer conditions. The snow environment and the rapidly changing air temperatures due to the oceanic environment cause high frequency fluctuations in the thermal regime of the ice cover and has been linked to rapid fluid flow changes resulting in a behavior of Antarctic sea ice coined as a "biogeochemical reactor".

Planned field campaigns will focus on understanding the unique role of Antarctic polynyas in sea ice production and water mass transformation, and providing Calibration/Validation for present airborne lidar elevation conversions to ice thickness and the anticipated launch of the satellite laser altimeter on ICESat 2 in 2016. Buoy deployments in association with ship experiments will provide needed information on ice dynamics as well as seasonal development of ice thickness and internal structures.

Remote Sensing Capabilities for Sea Ice

- Leif Toudal Pedersen (Danish Meteorological Institute, Denmark)

Remote sensing of sea ice starts with a measurement of electromagnetic radiation. This EM measurement subsequently needs to be associated with the ice/snow quantity we want to measure and the translation is typically performed by some kind of algorithm that is built around a number of assumptions about the relationship between ice/snow properties and the electromagnetic radiation. Due to this indirect nature of remote sensing measurements it is important to be aware of the assumptions that were made for constructing the algorithm, and it is thus evident that remote sensing measurements are associated with uncertainties not only related with noise in the actual measurements but also with flaws in the assumptions. It is therefore important to continue to evaluate algorithms and quantify the uncertainties in remote sensing measurements, and as our knowledge of the ice/snow interaction with EM radiation increases we can potentially reduce these uncertainties.

A sea ice concentration algorithm evaluation has been performed in ESA's Climate Change where more that 20 algorithms were compare. Comparisons were made using data from different satellite sensors, under different sea ice conditions, sensitivities to the atmosphere, snow, and ice type and both in the northern and the southern hemisphere were investigated.

The validation dataset consisted of brightness temperature data at 0%, 15%, 85% and 100% reference ice concentration. Due to ice concentration thresholds and due to an overestimate by some algorithms of ice concentration near 100 %, we used a 0% and 100% ice concentration dataset to build 'artificial' data at 15% and 85%.

The main comparisons were performed based on the standard deviation of how well each algorithm performed relative to the reference dataset. All comparisons were done without weather filters. The best performance (lowest standard deviation) at 15% concentration was by algorithms that included the 19V polarization.

However, algorithms using the higher frequencies at 90 GHz and 37 GHz were more noisy at low concentrations, thus requiring the use of weather filters. Biases for some algorithms (especially NT2) were found at 10-15% but most were small on the order of under 2%. Larger biases corresponds to an over estimation of sea ice concentration, and a 10% overestimation at 100% followed by a cut off at 100 means effectively that concentrations above 90% will be set to 100.

Based on the reference dataset the conclusion is that passive microwave concentration and real varıabılıty on real ice concentrations over 95% didn’t show a significant correlation. Concentration in the center of the pack in the Arctic did not go below 98% in the reference data and PMR variability was related mostly to ice/snow surface properties, not in ice concentration.

Some questions arise on how we include the uncertainty when assimilating the data into models. It is important to understand that a Gaussian error distribution with a standard deviation of 5% has only about 2/3 of the data within 5% of the correct value, the remaining 1/3 will be further away. Last can we identify those points where we have these errors, and thus add flags to the data? We need to establish a lower and an upper bound that shows these analyses at 68% confidence level with a 5% or 10% error so the modelers can use this information in their models. We will also need to create a range threshold for different seasons.

We used the SMOS thin ice thickness to identify large areas of thin ice. All algorithms underestimate the concentration of thin ice. Ice thickness estimates greater than 20 cm is fine but under that they substantially underestimates concentration. More work on the different properties of thin pancake and congelation ice is necessary.

MODIS melt ponds fraction dataset was used to evaluate algorithm performance during Summer. All algorithms underestimate the concentration of ice with melt ponds practically by the area fraction of the ponds.

No one algorithm performed best under all circumstances, so algorithm selection remains a compromise based on the particular application.

Data Archiving, Accessibility, and Dissemination

- Øystein Godøy (Norwegian Meteorological Institute, Norway)

Data management: Why should we bother? Fundamental tasks of data management were briefly discussed in the context of some relevant frameworks, like IPY, INSPIRE, WMO Information System and GEOSS. Special emphasis was put on the Global Cryosphere Watch program, which utilize WMO Information System and the experience from IPY to establish interoperability between existing catalogues. Technological requirements were briefly evaluated with a cost cost-benefit perspective. Key conclusions drawn for the community represented at the workshop include the following:

The Polar science community has the opportunity to explore major advances related to data management and dissemination as a test-bed for interdisciplinary science and data exchange. Important prerequisites to take advantage of such opportunities include the need to (1) agree on standards, (2) follow standards wherever possible or develop new standards in cooperation with others, (3) develop or better yet contribute to existing controlled vocabularies, (4) document, publish and archive data. In moving towards these goals, four guiding principles may be of help. They include the need to prioritize activities, choose a technological framework based on the expected functionality and benefits extended to users, keep it simple and pursue pragmatic rather than dogmatic solutions.1

Current Gaps in Sea Ice Modeling and Observing Research

The first set of breakout groups were charged with identifying some of the current gaps in sea ice modeling and observing research that are needed to better understand sea ice variability in both the Arctic and Antarctic. The following is a combined list of these identified gaps from the groups.

Models:

- **Importance of variables and parameters:** Do we know if there are variables that have a bigger impact on predictability than others? A result of the last CliC Arctic Sea Ice Workshop was a short note identifying many of these and what is needed. One of the main parameters that still needs to be addressed more effectively is sea ice thickness – needing more and better measurements as well as modeling testing under ideal conditions to improve physical prediction and under conditions more reflective of real world scenarios.

- **SEARCH Sea Ice Outlook Models:** Would the SEARCH outlook models have gotten the right ice distribution when forced with the 2012/2007 forcing? This is a very good effort at model intercomparisons that could be improved upon by integrating hindcast simulations with 2012/2007 forcings, which could better predict the sea ice distribution.

- **Level of uncertainty:** What level of uncertainty can models handle for initialization and/or assimilation? How can models be improved with regards to uncertainty? Model experiments that investigate the sensitivity of simulations to initial sea ice/ocean/atmosphere conditions need to be done.

- **Ice volume time series:** We have not yet been able to create a time series that illustrates historical trends in Arctic sea ice volume. We can potentially use the Pan-Arctic Ice Ocean Modeling and Assimilation System (PIOMAS) to convey what we know with the use of our compiled datasets. However, the following questions need to be resolved: How representative is this model for historical ice volume? How sensitive is this model to changes in the model physics/parameters. What would the ice volume time series tell us? Could we use it to understand how much was bottom melt and surface melt? Though we can evaluate comparisons between ice age and sea ice thickness, these comparisons are not robust enough to represent long-term ice volume.

- **Scale differences between observations and models and the separation of scales:** Scale differences between sea ice observations and models have been difficult to accurately coordinate because various data collections require several scales in which to measure. We need to evaluate a hierarchy of models from process models to global scale models, including weather forecast models and observations at different scales. Through this we can determine how many data points we need to represent one grid or how one data point represents time & space? Modelers need to know how well these point measurements represent an area in order to do data simulations. Some questions to be answered are the following: Do these two uncertainties fall into the same category? What small-scale processes have a big impact on large scale processes? Do we need to downscale or upscale our observations? What physical relationships are valid at the scale of any model?

- **Wave-ice interaction:** Ocean and wind forcings are significant drivers of sea ice movement. Some unknown gaps that need to be resolved are: What do we want to predict? What oceanographic information is necessary for this purpose? Do we evaluate this interaction on a decadal time scale or a regional to basin spatial scale? What is the impact of wave action on broken floes?

Data products:

- **Errors:** We need to understand the errors in different products, whether they are in situ and airborne observational products (i.e. EM-31, ship observations, sea ice profiles...etc.) or from remote sensing (passive microwave geophysical caveats, algorithms, and active microwave) to determine what this really means for their use in validation studies or to drive models.

- **Ice thickness data:** There is a significant need for timely sea ice thickness data when assigning initial conditions for sea ice predictions. A suggestion was to implement a combined satellite sea ice product (March, start of melt season) at a 20 km resolution or lower product. This could be illustrated by providing a PDF of ice thickness in each grid cell in the combined satellite product. Further validations can be compared with ground observations, airborne observations (EMI and Lidar), the optical SMOS product, active microwave products, CryoSat 2, and altimeter data.

- **Microwave properties with melt-out and freeze up sea ice**: A specific gap with observing sea ice conditions is attributed with geophysical caveats in how the sensors detect sea ice during the melt onset and freeze up from active or passive microwaves. We need to understand the transition between freeze and thaw signal between microwave/observed data versus how it is being represented in models.

- **Floe size distribution:** The sea ice floe size is known to have a large contribution to lateral melt. We know that MODIS and SAR can detect floe size down to 100m but there is no automated method to detect them. Though it is technically possible, it would be a very complex classification. The question then arises "How important is the floe size distribution in models? The suggestion was to test in models first to see the investment of time and money before committing to the study.

Measurements:

- **Buoy placement:** To understand spatial variability, should we place buoys on a grid with spacing ~250km (Arctic buoy program goal) or should they be placed in a closely spaced grid (like a "five dice" array at ~20km spacing) for ice deformation, marginal ice zone formation etc? We need to determine a methodology for buoy deployment. Should it be deployed repeatedly in the same place or should there be a specific distribution that would optimize measurements in areas that we need specific sea ice information?

- **Sea ice thickness and snow depth:** Little is known about what happens to snow on sea ice in both polar regions. Some suggestions to study this problem further consist of the following:
    - Use data from snow buoys being developed by AWI.
    - We need to coordinate more actual measurements, i.e., from aircraft with, e.g., snow radar with other ongoing or field campaigns
    - There is a crucial need for coincident mapping of the snow elevation, ice surface elevation, and ice thickness and a plan to implement these measurements regularly in field campaigns.

- **Real time ice thickness**: There is a lack of real time sea ice thickness measurements. Those who are collecting the data need to be conscious of the need to get that data to the modeling community as quickly as possible. We can use the Global Cryosphere Watch to try to put in place a network to share data under WMO, WCRP.

- **Measurement of ridges**: Ridges are especially unknown when assessing sea ice conditions because our remotely sensed data (i.e. microwaves, airborne electromagnetics...etc.) do not include parameters that can resolve this problem on a large scale. The following suggestions to map the ridges are as follows:
    - Ridge retrieval from SAR - Though it is available, it isn't accurate.
    - We can use lidar (scanning lidar) data resolve the ridges but not the keel depth.
    - We need to determine the timescale related to consolidation of ridges. Internal ice stress field and snow cover are the main fuel guzzlers of a ship trying to navigate in the Arctic.

- **Need autonomous atmospheric profiling measurements over the Arctic Ocean**: We can potentially use technology from lidar buoys. Should also explore the potential role of routine dropsonde observations from unmanned aircraft.

  Standardize Measurements: There is no definition of standard parameters for sea ice data collection in the Arctic. Additionally in the Antarctic we haven't included every parameter. A further problem is that we need to understand errors in each instrument since each measurement has different errors. Drilling is the highest precision measurement for ice thickness but is not practical on a large scale.

- **Lead openings and polynyas**: We need to understand the distribution of leads at the marginal ice zone and pack ice and identify their spatiotemporal scales to monitor the evolution is different seasons; important for ocean/ice/atmosphere exchange and heat budget; particularly need more observations year-round but particularly in winter.

- **Ice Roughness and Drift:** Ice roughness and drift measurements are difficult to measure based on the scale of which they are being measured. Some suggestions are as follows:
  - Airborne lidar surveys at key locations to map ice roughness.
  - Drift from: SAR, satellite passive microwave; element tracking; buoy tracking
  - Need to combine satellite products: SAR: e.g. Radarsat-1/2, Envisat ASAR, and/or TerraSAR-X. We could merge the base product or combine the derived ice drift product

- **Measurements on grid cell of climate model:** We need to establish a plan to organize grid cell measurements for model and satellite verification, create better measuring technologies, and have more wide spread usage of new technologies, for example: airborne electromagnetic ice thickness sensors, underwater vehicles (both AUVs and Gliders under ice), etc. Some important details to determine include the grid size, density of measurements in time and space within the grid, and how these vary as a function of parameter or other conditions.

Geophysics:

- **Heat budget or mass balance:** We do not have a clear understanding of its influence.

- **First year ice processes:** Relative to multi-year ice, little is known about important processes in first-year sea ice, and particularly the interactions among the sea-ice, the atmosphere, and the ocean. A year-long interdisciplinary field campaign is needed to explore atmosphere-ice-ocean interactions in an ice cover that is predominantly first year ice. This deficit is in part due to challenges associated with making measurements in a thin ice environment. While first-year ice should be the focus of many activities, it will be one particular focus of the inter-disciplinary MOSAiC project (2018-2019), which will observe sea-ice related processes over at least a full annual cycle in the central Arctic. Use the framework of SHEBA to plan for MOSAIC 2018/19 to evaluate these processes. SHEBA information on sea ice processes > 10 years old, when multi-year ice was still prevalent in the Arctic. Therefore, we need to update our data due to dominance of first-year ice.

- **Snow on ice:** There is a need to look at the sensitivity of models to the density/conductivity. Current snow on sea ice climatology is > 10 years old, dating back to when multi-year ice was still prevalent in the Arctic. Therefore, we need to update our data due to dominance of first-year ice. The following effort was suggested: Determine the spatial gap by understanding the snow spatial distribution measurements in sea ice, especially in underrepresented sectors like Russian, European sector, and first year ice. We need newer pan-Arctic understanding of snow distributions.

- **Energy Fluxes into the ice: Atmosphere and Ocean:** There are gaps for measuring fluxes and their spatial distributions. The following concerns need will need to be evaluated:
  - Vertical storage and mixing processes in the upper ocean: What is the fate of stored solar heat during fall freeze up? Where is the heat stored? How does it influence the timing/extent/physics of autumn freeze up?
  - Seasonality of meteorology relative to other features that lead to freeze up.
  - Atmospheric fluxes and ice-atmosphere boundary layer dynamics are generally a major gap. We have few observations and generally lack capabilities to measure the needed fluxes over thin ice, or to measure these fluxes autonomously in sea-ice environments.
  - How much ice can be grown in a parcel of open Arctic Ocean water, given our current understanding of fluxes, heat storage, mixing, etc.?
  - Our understanding of the role clouds play in the surface energy balance is limited. In large part this is due to the scarcity of cloud measurements over the sea-ice (limited to the SHEBA year, a few short campaigns, and satellite measurements). Important questions related to the clouds involve their source of moisture, energy, and aerosols; the processes by which cloud phase is partitioned; the role clouds play in vertical exchange and mixing processes; linkages with precipitation efficiency; their impact on atmospheric and surface radiative budgets. Clouds are a particular challenge for models due to low model resolution that is unable to capture the scale at which cloud processes occur and the complexity of a 3-phase water system with many interdependent feedbacks.
  - Storm activity**:** These contribute to very strong processes, promote mixing, and greater dynamics. Are more observations of strong vs. weak processes able to be measured by buoys and do we need these observations?
  - Oceanic heat flux and salt flux - Need for parameterization

- **Drift & deformation**: We are still unclear about the cause of the speed up in ice drift. The answer to this question is potentially found by studying thinner and looser ice pack which drifts faster (i.e., this is not dependent on changes in atmospheric forcing). The quality of ice drift and thickness observations affects the ability to measure ice mass export and can explain ~30% of this exchange. The following questions need to be answered and resolved:
  - Why does thin ice drift faster? Are there potential changes in roughness and deformation that alter the ocean and atmosphere drag and may play a role?

- Is the production of thick ice by sea ice deformation important for mass balance and thickness distribution?
- Are location of convergent/divergent ice regimes and location of leads/ridges important for shipping/resource extraction and short term model forecasts?

- **Ice roughness and changes due to change in ice regime:** There is the general question of how young and old ice differ in terms of roughness (top of ice, top of snow cover, underside of ice). This is also a question of scales on which roughness is measured and which processes are affected. Additionally, what is the sensitivity of roughness parameters in models?

- **Floe size:** Understand the distribution of ice floe size for heat fluxes and wind forcings at the marginal ice zone and perennial ice pack and dynamic processes, which create divergence or convergence of pack ice versus aggregations of individual floes.

- **Stress and strains on fast ice:** Coastal processes and ice-use by stakeholders require improved understanding of landfast ice dynamics. In particular, stresses resulting from atmospheric and oceanic forcing or ice-ice interaction and their translation into specific strains need to be measured and predicted. At the same time, changes in ice stability related to accommodation of strain impact landfast ice extent and atmosphere ocean interaction. Coupled ice / ocean models have begun to simulate such processes but are lacking fundamental data for improved representation of physical processes and model validation. Please contact Jeremy Wilkinson for further details.
- **Understanding the differences between the characteristics of sea ice in the Arctic verses the Antarctic**: Multi vs. first year ice conditions are different with both poles. The Antarctic has granular ice and flooding with many other different mechanical properties. There are also coastal pressure zones, but the rest is more divergent than the Arctic. Additionally, there are different temperature profiles because the top surface of sea ice can be flooded as it is pushed down below the sea level due to snow cover. Last, in the Antarctic there is pancake ice but it may also be beginning to be observed in the Arctic in the Beaufort and Chukchi Seas. The Arctic sea ice also includes melt-ponds in summer not generally seen on Antarctic sea ice. Another problem is that models do not use a category to include 'Multiyear ice', but rather have an age tracer for each grid box.

- **Ice density in time & space**: Buoyancy changes (density) can be induced by brine drainage driven by temperature. This topic also has influence on the ability of satellite sensors to characterize sea-ice properties such as thickness.

- **Evolution of melt ponds:** There is a huge gap of knowledge about sea ice conditions with melt ponds. The following suggestions were discussed:
  - A focus on rheology and contribution of level ice and ice deformation is necessary to answer some of the questions related to melt pond sizes and distributions.
  - Key linkages exist with snow cover/distribution, ice deformation, energy budget, etc. but processes behind those links need to be explored further.

- Use of MODIS and TerraSAR X to study melt pond fraction from space, also recently declassified high resolution satellite imagery.
    - A need for ground truthing for better satellite estimates of pond fraction.

- **Gaps specific to Antarctica:** Some points of interest need to be specifically directed towards understanding Antarctic sea ice processes:
    - Why are the models not producing the trends that we have seen in terms of ice increase in one sector and ice decrease in another?
    - Freshening from under ice shelves may lead to enhanced ice. This mechanism is not currently included in the models.
    - Regional models include ice shelves & ocean interactions, but global climate models do not have this component.
    - Do we have enough data to validate models? In some areas we do not because Antarctic models are not specifically tuned to Antarctic conditions. A reason for this is that Antarctic cruises yielding model validation data are fewer than done in the Arctic.

Funding

- The discussions emphasized the importance of an international collaborative approach. However, the nationally based funding structure creates a barrier to planning and conducting these studies.

Proposed Targeted Activities

Five breakout groups were established to determine specific gaps in knowledge from the sea ice observation and modeling community. The following are initial suggestions of potential targeted activities, motivation/need for doing them, and potential collaborators and action items where there was time to develop them. The Breakout group chairs were asked to lead the integration of related activities and inclusion of additional potential partners and participants.

BLUE GROUP

Moderator: Alexandra Jahn, Reporter Penelope Wagner

Activity 1: Blended sea ice thickness dataset for spring and fall 2007 and 2012

Motivation: Create a blended dataset of ice thickness data and snow thickness and for model initialization and evaluation for spring and fall of two years (2007 and 2012) and evaluate the differences between different products.

What: We will create a Sea Ice Thickness (SIT) data product combining different satellite data sources that can be used to compare the differences between the data sources, easily compared with validation datasets, and utilized by modelers. Preliminary efforts will evaluate the parameters with the use of mode, standard deviation, PDF.

Who: Nick Hughes (Met.No), Julianne Stroeve (NSIDC), Susanne Hanson (DMI), Penny Wagner (Delaware), Gina Henderson (USNA)

Details:

- Spatial Resolution: Data gridded on NSIDC EASE grid, 10 km resolution
- Temporal Resolution: Daily if possible, otherwise weekly.
- Input data sources:

- Optical thin ice - Key and Haefliger implementations from AVHRR and MODIS. 1981 onwards.
- PMW thin ice - SMOS, but any SMMR/SSMI/AMSR?
- Radar altimetry thick ice - ERS, Envisat, and Cryosat. 1991 onward.
- Laser altimetry thick ice - ICESAT. 2004 -2009
- Snow depth and density - Warren climatology, Ron Kwok, Thorsten Markus AMSR
- Investigate methods of best blending of component products and have blended component ready by mid-2015.

Activity 2: Model prediction study with the SEARCH Sea ice outlook models
Motivation: This study is motivated by the question what kind of error is acceptable for the observational ice thickness initial conditions for the models currently used in the sea ice outlook. To answer this question we plan to first plan to assess the skill of the models in hindcasts and then to investigate the impact of changes in the initial ice conditions, to supplement the existing studies that have explored other aspects of seasonal sea ice predictability.
What: Assess how well the models participating in the sea ice outlook can simulate the September sea ice extent and concentration in hindcast mode for 2012 and how models respond to changes in initial ice thickness fields for 2012 (to assess how much uncertainty is acceptable for model initial ice thickness data)
Who: SEARCH Sea ice outlook modelers. Experiment outline drafted by Alexandra Jahn (NCAR), reviewed by sea ice prediction community (Celia Bitz (UW), others)

Action items:
Activity 1: Blended sea ice dataset
- Write document detailing data format (NetCDF) and identifying input data sources. October 2013.
- Create test data files for March/April 2007 and 2012. Have it finished by the start of 2014 melt season.
- Use test data files for SEARCH Hindcast model runs.
- Validate against Icebridge and other observations.

Activity 2: Model Prediction:
- Re-run 2012 predictions as hindcasts in same model setup as used for the Sea Ice Outlook predictions but now with the 2012 reanalysis.
  Outcome: How close do the different models get to September ice extent with 2012 forcing (pattern and extent)?
- Vary the initial ice thickness conditions by +/- 10 or 20% (exact number to be determined) and force with same 2012 reanalysis as before. Repeat for snow thickness (+/- 20%). How much of a difference does this make for the September extent and concentration field?
  Outcome: How much precision do we need in the observed ice thickness conditions for the sea ice predictions for fall?
- Use the new blended ice thickness product to initialize model hindcast ice thickness for 2007 & 2012 and see how it changes results. Then compare the blended ice thickness product for September with the model simulations for September.
  Outcome: How much does using this product improve the simulations?

ORANGE GROUP

Moderator: Matt Shupe, Reporter Angelika Renner

Activity 1: Fall Freeze Up Study

Motivation:

The large area of open water inside the Arctic Ocean freezes up every autumn, this areas is increasing in spatial extent, and there is a lack of observations and understanding of this process.

What: This activity aims to answer the question: when will autumn freeze up occur? Focus is on air-ice-ocean interactions, the impact of energy fluxes through the system, the fate of the solar heat input into the upper ocean during the Arctic summer, and its impact on the autumn ice formation.

Who: Steve Ackley, Ted Maksym, Matthew Shupe, Leif Pedersen, Lars H. Smedsrud, Angelika Renner, Øystein Godøy, Don Perovich, Hajo Eicken, Jens Ehn w/ Dave Barber

Activity 2: Analyzed sea ice drift and deformation dataset

Motivation: Drift and deformation observations are generally not used for evaluating global climate models, and are needed for regional model studies.

What: Drift and deformation are essential to correctly simulate Arctic sea ice in a physically correct way, and would explain much of today's model errors.

Who: Leif Pederson, Øystein Godøy, Pierre Rampal, Sylvain Bouillon, Jeremy Wilkinson, Lars H. Smedsrud, Jenny Hutchings, Gunnar Spreen, Justin Beckers

Activity 3: Ice drift /deformation process studies for high-resolution model development

Motivation: Currently developed new sea ice rheologies for high resolution models are expected to considerably improve ice models but require evaluation using suitable ice drift and deformation observations.

What: Moving past the viscous-plastic/elasto-visco-plastic rheologies, which are still widely used in climate models but not always appropriate for resolutions < 50 km, we need to improve our understanding of high frequency variability in the forcing of the ice (e.g. through tides or inertial oscillations), variability of drag coefficients, and deformation processes on 1-50km scales.

Who: Leif Pederson, Øystein Godøy, Pierre Rampal, Jeremy Wilkinson, Lars H. Smedsrud, Justin Beckers, Rune Storvold

Action Items:

Activity 1: Title

- The project will include three parts: Observations from field campaign(s); Coordination with remote sensing activities; and Modelling on different scales (climate/regional/process). The field campaigns and remote sensing data acquisition should take place in various locations to develop a generalized knowledge of freeze up processes in different conditions (e.g. open ocean vs. shelf seas). The first field campaign with potential data gathering is in 2015 in the Chukchi Sea (Steve Ackley, ONR MIZ and Sea State projects). Variables to measure include ice thickness & topography on 50km scales, photography, snow measurements, oceanic and atmospheric fluxes (radiative & turbulent), buoy arrays, boundary layer profiling, clouds and other atmospheric properties that might be relevant. The project would be of general interest to the sea ice physics community as process study, but also highly relevant to stakeholders such as shipping or exploration companies. Two possible planned drift experiments will hopefully contribute to this, the MOSAiC project in the central Arctic / transpolar drift (Matthew Shupe; 2018-2020), and the Lance project north of Svalbard (Lars H. Smedsrud; 2014/2015).

Activity 2: Title

- We proposed to develop a merged, concise sea ice drift dataset which combines currently available datasets from different sensors, algorithms and regions. To achieve this, a thorough intercomparison of the available products needs to be conducted addressing different scales from small to basin wide and short-term (sub-daily) to climate scales. There is also a need for better evaluation datasets to help the intercomparison. An observational testbed dataset would need a buoy array of about 12 buoys where position buoys would be sufficient. Potential field campaigns to tag along include Barents Sea 2014 (U. Hamburg), 2015 Lance (NPI, Nick Hughes & Gunnar Spreen), 2018 MOSAIC (Matthew Shupe), Beaufort MIZ Break-up study (Jeremy Wilkinson).

Activity 3: Title

- The observational base would be formed by >20 drift buoys, including several IMBs covering a range of ice types. Spatial variability should be covered both in the ocean (AUVs), on the ice (helicopter/airplane surveys) and in the atmosphere (UAS), all at scales that can resolve roughness at the desired resolution. Gridded patterns should be applied. Observations need to take place in different seasons to capture e.g. different roughness characteristics during melt/freeze. This project could be coordinated with activity 3 and with studies into surface energy budgets, snow properties, etc. MOSAiC activity will include this type of measurement over a full annual cycle in evolving ice conditions.

RED GROUP

Moderator: Marilyn Raphael, Reporter Jennifer King

Activity 1: Snow and Sea ice

Motivation: It was felt that there was significant value in a tightly focused research programme (bi-polar) that concentrates on one important area of research, and hitting that topic hard!

What: A better parameterization/ understanding of snow processes on sea ice; this would lead to significant benefits to both the modeling and satellite communities.

Who: Potentially Matthew Sturm (UAF), Don Perovich

Details: In many ways snow on sea ice is the elephant in the room. Snow on sea ice influences the albedo of the ice, the size and volume of melt ponds, the growth rate and/or melt rate of sea ice, and when it blows or falls into the ocean it can either add to the freshening and stability of the upper water column or provide additional nucleation points for frazil ice production. Furthermore, given the large open ocean region we presently have in the Arctic in summer the increased air moisture content of the atmosphere may result in heavier snowfalls early in the freeze-up season. This in turn could influence the growth rates of young sea ice. Moreover because the relationship of between freeboard and ice thickness is very much controlled by the depth and density of the snow these properties are needed for accurate satellite derived sea ice thickness measurements. Unfortunately observations of snow properties and their temporal and spatial distribution are incredibility difficult to perform, and as a result snow is not well parameterized in coupled models This is especially so for the depth, density and conductivity of the snowpack. This program aims to address these shortfalls through a data retrieval program, coupled to a focused observation and modeling effort.

Action Items:
Activity 1: Sea Ice Climatology for the Arctic and Antarctic

- Climatology: Update the Warren climatology for the Arctic (1999), and if possible build a climatology for the Antarctic through a comprehensive data trawling exercise. For the Antarctic, data sources are the ASPeCt ship observations data set, and the Ice Thickness data sets obtained from drilling profiles, both at the Australian Antarctic Division Data Center. IceBridge Snow Radar data, once calibrated and validated, will also provide a data source in both the Arctic and Antarctic.
- Field programme: both autonomous systems and dedicated on-ice field campaigns, linked to model parameterizations and satellite/airborne algorithm validation/development.

YELLOW GROUP
Moderator: Danny Feltham, Reporter Gina Hendersen
Near-term activities
Activity #1: Virtual fieldwork showcase studies using Obs4MIPS
Motivation: Obs4MIPS is an effort to provide modeling groups with a limited collection of well established and documented data sets that have den organized according to the CMIP5 model output requirements. We need to find datasets that would be useful for Obs4Mips and do the initial documentation.
Who: Walt Meier (NSIDC/Goddard), Gina Henderson (US Naval Academy), others?

Activity #2: Inventory of datasets, both Arctic and Antarctic
Motivation: Create an inventory of sea ice and sea ice related datasets for both Arctic and Antarctic regions.
Who: Øystein Godoy, others?

Activity #3: Icebridge project
Motivation: Propose to NASA that the polar and sea ice community needs sea ice flight data (weave pattern over a square/grid-box area as opposed to regular flight lines).
Who: IceBridge Sea Ice Science team, Jackie Richter-Menge, Jeremy Wilkinson, others?

Activity #4: Modeling studies
Motivation: Using data for validation/forcing, identify new things that may impact/improve model simulations of sea ice and related fields.
Who: Annette Rinke, Danny Feltham, Greg Flato, Vladimir Kattsov, Alexandra Jahn

Activity #5: Southern Ocean Sea Ice workshop to assess shortfalls of representation of modeling efforts in this Hemisphere.
Motivation: Why is the Antarctic region so poorly simulated? How much is down to physics versus the atmosphere? Where are the sources of error in the coupled model? Sources of error include; too much ice on the same area or concentration being too high. Not enough ice in places.

What: Workshop will focus on southern ocean sea ice representation in climate models and associated shortcomings. Participants will also include atmospheric and ocean modeling community representatives.
Who: Petra Heil, Marilyn Raphael and Steve Ackley will develop workshop concept and send to Jenny B for follow up.

Action Items:
Activity 1: Dataset mining
- Find datasets that would be useful for Obs4Mips and do the initial documentation.
- Data may need to be reformatted/repackaged to conform to the Obs4MIPS criteria/rules.
- Passive microwave sea ice concentration data initial test case for Obs4MIPS. Lead W. Meier.

Activity 2: Global Cryosphere Watch
- Global cryosphere watch working along those lines. Of particular interested was data availability and near term needs for southern ocean SAR data, such as Radarsat-2.
- How can the Southern Ocean community find out definitively what is available for this region?
- Utilize the WMO Polar Spacetask group to get support for satellite data acquisition, also look at GCW and WDAC efforts, eg. Radarsat

Activity 3: Ground truth spatial distribution of ice thickness and snow depth
- Weave pattern provides a spatial distribution of ice thickness and snow depth over a grid cell area (e.g., 40 km x 40 km) that will be particularly valuable for model (and satellite) validation; transects over sea ice done to date do not capture the full variability over a grid cell.
- Make recommendation to this effect that could potentially influence next year's flight paths. Also propose a framework of Ice Mass Balance buoys to compliment this new IceBridge collection (Jeremy Wilkinson), ONR MIZ Buoy programme in Spring 2014, followed by IceBridge flights.

Activity 4: Physics models
- Areas to focus on, relating to new elements of the model physics in particular, include: floe size distribution, drag coefficients and melt ponds.
- What geographical regions are the models particularly sensitive? Pick regions of where to improve the model physics first.
- Where are these physical representation improvements going to make the most impact?
- Use data/observations to assess key geographical regions. Deliverables include; new physics of floe size, drag coefficients, melt ponds
- Develop a sea ice forum/modeling group
- Collate field observations already available from a similar area. Bringing together everything needed to validate models. (Perhaps by Meier)

Activity 5: Details -- this workshop will include:
- A plan to address shortfalls of southern ocean ice representation
- 1-2 day workshop during/after the next SCAR meeting next year in Auckland.

- A register for all upcoming field campaigns
- Identifying motivating factors for getting it right
- Bottom water story
- Precipitation in the winter will influence ice mass balance, freshwater input
- Teleconnections and implications with Australian weather & climate

Mid-range activities:
Activity #1: Icebridge project Plus
Motivation: Stemming from the recommendation to NASA's IceBridge campaign in the near-term section above that altered/added flight lines (in weave pattern) to cover a model grid box-type area instead of isolated transect lines, which resulted in measurement of; snow thickness, ice thickness, surface topography, and floe size distribution. This will provide the justification for the long-range actions (the Plus part of Icebridge Plus).
Who: ?? Icebridge people, international dimension via MB buoys (IMBs)

Action Items:
- Propose Ice Mass Balance buoys (IMBs) to measure basal versus surface melt.
- Measurement of coincident fluxes on the sub-grid cell scale will be critical to this research.
- Compare the atmospheric pattern with reanalysis, targeting correlation versus causality.
- Synthesis of these datasets submitted into the Obs4MIPS framework.

Long-range activities:
Activity #1: MOSAIC grid box type study
Motivation: This MOSAIC grid box field study will focus on processes associated with/on first year ice. Deliverables include everything! Instrument the heck out of a region to understand the sub-grid scale variability/scaling problem. Variables will include those normally collected during a SHEBA type study, but for a 40 x 40km field area. The new element here is the spatial scale at which collection is occurring! The virtual near-term study (outlined above) will have identified the critical new variable to be collected. Exercising/fine tuning and potential testing of new observational technologies, including ground-truthing satellite products will be incorporated.

Who: Matthew Shupe (U. Colorado / NOAA) is contact for MOSAiC project. Others that are closely engaged in the current design (who were part of the workshop) include: Sebastian Gerland, Don Perovich, Jinping Zhao, Klaus Dethloff

GREEN GROUP

Moderator: Jinping Zhao, Reporter Alice Orlich
Activity 1: **Identifying the relationship between ice floe characteristics and sea ice thermodynamics and geophysics.**
Motivation: The thinning sea ice cover in the Arctic is resulting in an increasingly dynamic ice environment with ice fracturing and break-up occurring throughout winter. A result is the creation of smaller ice floes, which alters the ice pack's response to wind, waves, and ocean currents. Ice floe size affects a number of processes and properties that are important for sea ice thermodynamics, e.g.: 1)

snow distribution and retention on sea ice, 2) mechanisms of new ice formation in areas between floes, 3) ice floe deformation, 4) lateral melting, 5) surface melting, horizontal drainage and melt pond formation, 6) water column stability, 7) variability on the radiation field in and under the sea ice, 8) ice strength/survivability. Therefore, this activity links closely with at least the following activities: fall freeze-up study (orange group), snow on sea ice (red group), Icebridge, MOSAIC and modeling studies (yellow group).
Who: Jinping Zhao (OUC), Jens Ehn (U. Manitoba), Sebastian Gerland (NPI), Alice Orlich (UAF), Adrienne Tivy (NRC-CNRC), Baek-Min Kim (KOPRI), Mikko Lensu (FMI), Torbjørn Eltoft (UIT), Sylvin Bouillon (NERSC), others TBD
Details: Development of an observation program focused on floe characteristics such as size, distribution, composition, and condition. The data collected will contribute to improved models and remote sensing accuracy. Observations will also include lead creation, development, size and orientation to better represent and characterize divergence and convergence events, estimate ocean/ice/atmosphere heat and chemical exchange; deformation events and features; bottom, surface and lateral melting; and new ice formation.

Action Items:

- Field Campaigns: Field campaign(s) in drifting sea ice that encompass the seasonal cycle, supplemented with autonomous devices. Observations must include a combination of in-situ field observations, aerial surveys and satellite remote sensing. Recommend that the specific observations are included in the ASSIST software for optimum data capture from underway ships. Develop processing to orthorectify digital still and video imagery from handcams, ship, helicopter, and UAS webcams.
- Where: Ideally, the marginal ice zone and perennial ice zone will be studied. Potential field campaigns and locations could include: 1) Central Arctic as a part of, e.g., the Arctic Ocean Drift Study (CCGS Amundsen), MOSAiC project (Polarstern), ICE project onboard R/V Lance; 2) Baffin Bay onboard CCGS Amundsen; 3) Hudson Bay onboard CCGS Amundsen; Barneo and Russian drifting stations?

International and 'Bi-Polar' Collaborations: The Road Map Ahead

The final section of the workshop was an open discussion on where to take things from here, how to continue the discussions and collaborations started during the workshop and bring them forward to tangible outcomes.

Upcoming Opportunities to Meet / Move Things Forward

Arctic Observing Summit - April 2014, Helsinki, Finland
Hajo Eicken to develop a white paper on specific objectives resulting from this meeting

IGS Hobart - March 2014, Hobart, Tasmania
A joint CliC Arctic Sea Ice Working Group / ASPeCt workshop on spatial variability and design for observing campaigns; best practices and standard methods (including

core variables) guidance and protocols on ice sampling and protocols will be developed by Hajo Eiken and a representative from the ASPeCt group.

Gordon Polar Marine Science, March 2015, to be determined in either Italy or Ventura CA USA
Steve Ackley to discuss with Paul Wassmann, the conference chair, ways to integrate topics from this workshop into potential sessions at the conference.

Conference Suggestions
Sessions on targeted activities could be proposed and special journal issues or review papers produced as a result. A general poster on CliC sea ice activities should be produced for people to present at conferences, meetings, or other events of opportunity.

Involvement of Russian sea ice researchers
A concerted effort needs to be made to involve Russian researchers these targeted activities. One potential mechanism could be to organize a follow up workshop at AARI in St. Petersburg or another location. Alexander Makshtas could potentially be asked help lead this effort. APECS could also be consulted to engage early career sea ice researchers from Russia.

Planned drifting stations and sea ice cruises

A key recommendation from the group was co-ordination of research efforts with regard to drift stations and sea ice cruises. Planned activities include:

- ONR DRI (U.S. Office of Naval Research Directed Research Initiative) study (2013-17): Sea state & boundary layer physics in the Arctic. Fall freeze up in Chukchi Sea field experiment in Oct 2015. This project has a big theoretical component directed to wave-ice interaction with international collaborations.
- U.S. Office of Naval Research Initiative: A multi disciplinary program aimed at understanding what is happening in the Beaufort Sea. Autonomous platform program. Flux buoys, etc woods hole- gliders. Lots of ice physics, ice mass balance buoys. Aim to cover all possibilities. Assets go out in March until break up in the summer. Remote sensing component to get size distribution. Floe size from high resolution SAR. & high resolution visible imagery. Within ice camp ground truthing will happen & ice bridge will fly over this line. 5 dice array of ice mass buoys repeated at 100km. Also linked up with the Koreans.
- Norwegian Polar Institute: Proposal to have RV Lance frozen in North of Svalbard - snapshots from earlier expeditions show area is interesting
- Chinese plans for ice drift: Big projects. Laptev Sea fieldwork & observations. Have an independent drifting station in 2015, depending on the ice, also hope to collaborate with MOSAiC.
- Canadian ice program 2015: drift stations planned up towards Siberian Russia then go with transpolar drift ending east or west of Greenland depending on ice conditions. Amundsen has a fixed schedule & will do its regular cruses.
- MOSAiC: central Arctic drifting observatory. Starting in East Siberian Sea with brand new ice & following the life span of sea ice. Ice profiles, deformation. Upper ocean turbulence and state. Atmospheric fluxes and processes. Spatial domain, grid box scale. Integrated hierarchy of modeling activities. Would welcome guidance on what the current modeling needs are throughout the process. This

internal program is in its formative stages working on writing a science plan. This will be an International project using international participation and infrastructure.

Other planned projects of interest

- UK (NERC) funded project on the economic impact of an ice-free arctic. Integrated look at change in the arctic. One work package is observations. Effect on shipping routes, what does this mean for transfer of goods.
- ACCESS (builds on the European DAMOCLES project) ACCESS is a European Project supported within the Ocean of Tomorrow call of the European Commission Seventh Framework Programme. Its main objective is to assess climatic change impacts on marine transportation (including tourism), fisheries, marine mammals and the extraction of oil and gas in the Arctic Ocean. ACCESS is also focusing on Arctic governance and strategic policy
- A key question with regard to sharing data from the different programmes was: What can we do to garner better Russian participations?

Ice Plan

Ice Plan (see www.iceplan.org) is a web site designed to display present and future sea ice activity in the Arctic. It presents information on field campaigns including location, type (icebreaker, ice camp), and point of contact. Jennifer Hutchings led the development and testing of this program. The next step is to find the resources to make the site fully operational It has been commented by various field researchers that the program has value and should be maintained. In particular it is a convenient site to learn about what, when, where, how and who is working in your Arctic area of interest. It is also a great site to link up people, campaigns and names with where data and reports might be acquired, which is a step towards ensuring data is well utilized and not lost.

A solution for the large cost of running Ice Plan is to utilize the simple web form database entry that was developed by the International Arctic Research Center. This form could be used to integrate Ice Plan into online ice dedicated social networks. It is anticipated that this approach, and drawing upon the enthusiasm of young researchers in the APECS network, national representatives in the CliC working groups, and ad-hoc mailing lists we can more effectively populate Ice Plan with the data that everyone wants to find.

Hutchings discussed technology transfer with Baeseman. It is agreed that Hutchings, Baeseman and King will be in touch to develop this concept further.

Ice Watch

Since the last CliC Arctic Sea Ice Working Group meeting in Boulder in October 2011, we have made considerable progress on standardization of ship based visual observations of sea ice in the Arctic. At the Fall AGU meeting in San Francisco, December 2011, a small ad-hoc group gathered to discuss this standardization. They were constrained by the need to be backward compatible with ASPeCt convention and to meet WMO standards. This meeting led to a small reorganization of the form adjusting the topography coding, making data entry more intuitive, and adding melt pond characteristics.

Jennifer Hutchings, UAF, found funding to build a new multi-platform web browser interface for data entry in Spring 2012, which followed the agreed upon coding system. We are now referring to the Arctic ship observation program as "Ice Watch" and the tool we build is called the Arctic Shipbourne Sea Ice Standardization

Tool (ASSIST). This system was tested in summer 2012, with observers on US, Canada, Germany, Norway, South Korean, Swedish, Greenpeace and Russian ships participating. The majority of observers were performing academic research programs, however one participant was from industry. It is our intention to expand Ice Watch to increased industry participation in the future. We are also working on integrating the ASSIST data archive with ice charts produced by various national ice analysis groups.

In order to be successful in bringing ASSIST data into operation use there is a need for the data to strictly follow WMO standards in particular SIGRID-3. It was noted by Hutchings that the agreed upon melt pond code did not fully characterize stage of melt. This is a very important characterization for navigators in the Arctic. To address this Hutchings proposed adding additional information about thaw holes through melt ponds, and whether ice is dried or rotten. These observation fields, with information on how to make the observations, will be added to the next release of ASSIST. Please see the attached tables for information about the agreed up standard observation codes, and backward compatibility with ASPeCt.

During the meeting representatives of ASPeCt and ASSIST met. It was agreed that the ASSIST team will provide ASPeCt with their code. ASSIST and ASPeCt will maintain the same observation protocol in the future, and ASPeCt will move to use the ASSIST CSV output in their data archive at the Australian Antarctic Division. If needed Hutchings will provide some support to convert between spreadsheet styles of ASSIST and ASPeCt. Global sea ice users will be encouraged to use the most recent distribution of ASSIST. We discussed forming a joint ASPeCt/CliC (under the Arctic Sea Ice Working Group) working group to provide continuity and support for the Ice Watch program in both hemispheres. Members of this group were identified as Hutchings, Heil, Orlich, and Weissling. We agreed we would like representation from Europe, Asia (probably China) and Russia in the group. This is a small group of experts interested in maintaining the Ice Watch program. The purpose of the group will be to maintain continuity in the program and facilitate technology transfer and seamless integration into current infrastructure and research programs. (*see below for followup post meeting discussion)*.

In Summer 2013 we release a new version of ASSIST, the Arctic ice observations data base (housed at the International Arctic Research Center, UAF), a near-real time data interface and Ice Watch website. We anticipate an interesting season with exceptional coverage of ice observations throughout the Arctic. See apendix xxx for more information.

Finally all Ice Watch observers are encouraged to submit comments to the Ice Watch team. We are also interested in talking to individual groups about how to include old data collections in the Arctic Ice Watch archive. At the moment we are planning on collecting the data in the format it is in with detailed information about the format.

POST MEETING: Formation of the ice observations technical group. See next page for details.

Technical Committee on Integrating In-Situ Sea Ice Observations

(A Joint sub-group formed under the CliC Arctic Sea Ice Working Group and the SCAR/CliC Antarctic Sea Ice Processes and Climate (ASPeCt) Group of Specialists)

Shipboard and on-ice sea ice observations are routinely collected during expeditions to ice covered seas. This data, if well managed, is of value to operational sea ice services, industry, researchers, and environmental planners. We recognize a need to share resources between groups working in all sea ice regions to support collection and archival of standardized, quality controlled data.

Our goals are to facilitate:
1) standardization of observational methods;
2) archival of data collected;
3) near-real time transference of data to users; and
4) rescue and integration of historical data collections.

These goals may be accomplished through the following objectives:
a) development of a comprehensive Arctic/Antarctic observation system that can be adjusted to the local conditions;
b) design of robust equipment and software to facilitate standardized and autonomous observations;
c) development of novel observation methods, providing data follow WMO or accepted standards.
d) exchange technical information on hardware and software between institutes and nations to best leverage limited funding availability; and
e) provide expert development of technical and training material to broaden participation in sea ice watches with sufficient standardization and quality control.

Initial Membership: Jenny Hutchings (OSU), Petra Heil (AAD), Blake Weissling (UTSA), Alice Orlich (UAF), Marcel Nicolaus(AWI) and Stephen Ackley (UTSA). Other members are welcome to join, or may be asked to join, based on their interest and expertise in contributing to the objectives of the Technical Committee.

Summary of Sea Ice Researcher Survey

To help set the stage for the workshop, the organizing committee developed an 11-question on-line survey, distributed to the attendees and other scientists in sea ice research prior to the workshop. The survey asked six questions about impediments to sea ice prediction, modeling uncertainties, key sea ice questions, and the variables that need to be observed. There were also five questions about data archiving and accessibility. There were 59 respondents to the survey from both workshop attendees and the sea ice community. Here we summarize the responses to the 11 survey questions.

Key questions and uncertainties:

Question 1. What is the biggest impediment to improved sea ice prediction? The most common response was that there was a lack of something. This included a lack of data for model initialization, forcing, and evaluation; a lack of understanding of first year sea ice properties and processes; a lack of ice thickness and snow depth observations; a lack of data on atmosphere and ocean forcing; and a lack of completeness of sea ice rheologies.

Question 2. What is the largest modeling uncertainty? There was a wide variety of answers to this question including different approaches to modeling and different processes to model. One uncertainty was the lack of knowing how much complexity is needed. The impact of a paucity of observational data on modeling uncertainty was stated. Deficiencies in the treatment of several processes and properties were identified as creating modeling uncertainty including feedback processes, snow cover evolution, cloud simulation, ice dynamics, the surface heat budget, the ocean heat flux, radiation fluxes, albedo, melt ponds, flooding, ridging. Finally, one response said that it depends on what you are trying to model.

Question 3. What is the key sea ice question that needs to be addressed? Responses to the key question centered on prediction and changing conditions. A central theme was improving short term sea ice forecasting and longer-term sea ice prediction on regional and basin scales. Understanding the reasons for differences in Arctic and Antarctic predictions is important. Other concerns were on determining the relative contributions of dynamics and thermodynamics to Arctic sea ice loss, as well as the anthropogenic and natural cycle contributions. The impact of changes in the sea ice physical system to the ecosystem must also be addressed.

Question 4. What observations are needed to address questions 1 through 4? The most common response was sea ice thickness, sea ice thickness, sea ice thickness. More generally, increased data from autonomous stations, time series observations from long-term drift stations, and continued remote sensing were seen to be essential. Also noted was the need for a central repository for routine Arctic sea ice observations similar to what is being done in the Antarctic.

Question 5. What are the most important variables that need to be observed whenever possible in a standardized way? Many responses discussed the importance of conducting an ice watch on all cruises, with the observed variables based on the ASPeCt protocols. The primary parameters to observe are ice concentration, ice thickness, snow depth, pond fraction, and floe size. These parameters will be measured for the primary, secondary, and tertiary ice types present on an hourly or bi-hourly schedule. Photographs of ice conditions should also be taken in conjunction with the observations.

Question 6. What sea ice field experiments are you aware of in the next few years? The answers to this question showed that there are many sea ice field experiments planned for the next few years and ii) the information about these field experiments is compartmentalized and not widely known. The answers demonstrate the need for a central clearinghouse of planning field experiments. Such a clearinghouse would greatly facilitate collaborative, international, interdisciplinary research.

Data dissemination and availability:

Question 7. Where is your observational data stored? Select as many as applicable from formal archive, personal website, on my computer, in my lab notebook, and publications. The good news is that 72% of the respondents stored their data at multiple locations. The bad news is only 54% use a formal data archive. The most common locations for data storage is "on my computer" and "in my lab notebook," neither of which are searchable on-line. This creates a significant problem for data accessibility.

Question 8. Where do you look for data? Select as many as applicable from formal archive, personal website, contact people directly, and publications. Over 90% of the respondents look for data in multiple locations. The most common location searched is personal websites (87%), followed by formal data archives (76%). Many people (69%) just contact other researchers directly.

Question 9. If you answered 'Formal Data Archives' in either of the above questions, please indicate which archives. Survey respondents listed 31 different data archives and accessed several archives to satisfy their data needs. The most frequently mentioned archive was the National Snow and Ice Data Center. Other data archives with several responses are Antarctic Sea Ice Properties and Climate (ASPeCt), ECMWF reanalysis, and NCEP reanalysis.

Question 10. Finding the data I need is very easy, easy, slightly difficult, difficult, and extremely difficult. The responses were distributed symmetrically around slightly difficult (50%). 27% of the respondents said finding data is easy and 19% said it is difficult Only one person said finding data was very easy and only one found it extremely difficult.

Question 11. If finding data is a challenge for you, what would make it easier? Several people stated the need for one stop data shopping through a central web site providing updated inventories of all the distributed data archives. Formal protocols for data and metadata were also deemed important. It was suggested that data sharing be encouraged by formal referencing of datasets in publications and by requiring that all data be shared.

CliC Arctic Sea Ice Working Group Data Policy

During the workshop, quite a bit of the discussion focused on the generation, acquisition, sharing, archival and management of data. It was decided that a data policy should be developed for both the Arctic Sea Ice Working Group and ASPeCt. Reviewing a number relevant national and international data policies, the workshop participants decided to endorse and expand the IASC Data Policy, which in turn builds on the IPY Data Policy. Key elements of the CliC Arctic Sea Ice Working Group Data Policy that extend the IASC document include the following:

(1) Observational data, including operational data, should be fully, freely and openly made available on the shortest feasible timescale, i.e., without application of embargo periods.
(2) The substantial effort necessary to acquire, process, share and archive datasets should always be acknowledged by data users through full citation of data, including referencing of unique identifiers, specifically digital object identifiers (DOI).
(3) Long-term accessibility and preservation should be ensured by submission of data and associated metadata to one or several data centers with a track record of data stewardship.

The complete data policy is included as Appendix 3 in this report.

Workshop Conclusions

It is important to understand the properties and processes of sea ice in the polar oceans. This understanding can be used to improve models and our ability to predict the future state of these ice covers. This workshop identified current observation and model shortcomings and priority research areas including i) data gaps in snow depth, ice thickness, and ice volume; ii) uncertainties in ice rheology and energy balance; iii) knowledge of atmosphere and ocean forcing; iv) difficulties in spatial and temporal scaling; and v) archiving and accessing data.

Several targeted activities have been identified to address these issues. Team leads and members have been identified for many of these activities and plans have been made to move them forward. We believe that progress in observing, understanding, and predicting sea ice in the polar oceans will be made through international collaboration and an interdisciplinary approach integrating field observations, model results, remote sensing data, and easily accessible archived data.

Appendixes:

1. Workshop Agenda
2. Participants list
3. CliC Arctic Sea Ice Working Group Data Policy
4. Sea Ice Researcher Survey Direct Comments
5. ONR DRI Sea State Project Summary
6. ASSIST Protocol

Appendix 1: Workshop Agenda

All presentations will be in the Ny-Ålesund room (2011), 2nd Floor, Fram Centre, unless otherwise noted.

Wednesday, 5 June 2013

Time	Agenda Item
08:30 - 09:00	**Registration and Coffee Social**
09:00 - 09:20	**Welcome and Introductions** - Nalân Koç (Norwegian Polar Institute, Norway) - Sebastian Gerland (Norwegian Polar Institute, Norway) - Don Perovich (Dartmouth College, USA)
09:20 - 09:40	**Large Scale Modeling Needs** - Alexandra Jahn (National Center for Atmospheric Research, USA)
09:40 - 10:00	**Regional Modeling Needs** - Klaus Dethloff (Alfred Wegener Institute for Polar and Marine Research, Germany)
10:00 - 10:20	**Stakeholder Needs** - Nick Hughes (Norwegian Ice Service/ Norwegian Meteorological Institute, Norway)
10:20 - 10:40	**Sea Ice Outlook Results and Seasonal to Interannual Ice Forecasting Needs** - Hajo Eicken (University of Alaska Fairbanks, USA)
10:40 - 11:00	**Coffee Break and Poster Viewing**
11:00 - 11:30	**Arctic Sea Ice Observing Network and Field Campaigns** - Jeremy Wilkinson (British Antarctic Survey, UK)
11:30 - 12:00	**Antarctic Sea Ice Observing and Field Campaigns** - Steve Ackley (University of Texas at San Antonio, USA)
12:00 - 12:20	**Remote Sensing Capabilities for Sea Ice** - Leif Toudal Pedersen (Danish Meteorological Institute, Denmark)
12:20 - 12:40	**Data Archiving, Accessibility, and Dissemination** - Øystein Godøy (Norwegian Meteorological Institute, Norway)
12:40 - 13:45	**Group Photo followed by Lunch at Arktika and Poster Viewing**
13:45 - 14:00	**Introduction to Breakout Session 1: What are the Key Gaps in Understanding?**
14:00 - 16:30	**Breakout Group Work** *(break as needed)* ◆ *Red group: Ny-Ålesund (2nd floor, 2011)* ◆ *Orange group: Tre Kroner (5th floor, 5010-5012)* ◆ *Yellow group: Barentsburg (2nd Floor, 2012)* ◆ *Blue group: Sarkofagen (5th floor, 5093)* ◆ *Green group: Pyramiden (2nd floor, 2013)*
16:30 - 17:00	**Breakout Group Reports to Plenary**
19:00 - 22:00	**Workshop Dinner at Maritime School**

Workshop Sponsors

Workshop Agenda, Continued

Thursday, 6 June 2013

Time	Agenda Item
09:00 - 09:15	**Progress So Far and Today's Expectations**
09:15 - 09:30	**Introduction to Breakout Session 2:** **How Do We Fill the Gaps**
09:30 - 11:30	**Breakout Group Work** *(break as needed)* ◆ *Red group: Ny-Ålesund (2^{nd} floor, 2011)* ◆ *Orange group: Tre Kroner (5^{th} floor, 5010-5012)* ◆ *Yellow group: Barentsburg (2^{nd} Floor, 2012)* ◆ *Blue group: Sarkofagen (5^{th} floor, 5093)* ◆ *Green group: Pyramiden (2^{nd} floor, 2013)*
11:30 - 12:30	**Breakout Group Reports to Plenary**
12:30 - 13:30	**Lunch at Arktika and Poster Viewing**
13:30 - 13:40	**Introduction to Breakout Session 3:** **Data Archiving and Accessibility**
13:40 - 15:30	**Breakout Group Work** *(break as needed)* ◆ *Red group: Ny-Ålesund (2^{nd} floor, 2011)* ◆ *Orange group: Tre Kroner (5^{th} floor, 5010-5012)* ◆ *Yellow group: Barentsburg (2^{nd} Floor, 2012)* ◆ *Blue group: Sarkofagen (5^{th} floor, 5093)* ◆ *Green group: Pyramiden (2^{nd} floor, 2013)*
15:30 - 16:00	**Breakout Group Reports to Plenary**
16:00 - 16:30	**IcePlan and IceWatch – Tools for Enhancing International Collaboration** - Jenny Hutchings (University of Alaska Fairbanks, USA)
16:30 - 19:30	**Poster Session with Barbecue**

Friday, 7 June 2013

Time	Agenda Item
09:00 - 09:05	**Progress So Far and Today's Expectations**
09:05 – 11:00	**International and 'Bi-Polar' Collaboration – Plenary Discussion**
11:00 - 11:20	**Coffee Break**
11:20 - 12:20	**Final Plenary Discussion**
12:20 - 12:30	**Workshop Wrap-up and Next Steps**
12:30 - 13:30	**Lunch at Arktika and Departure**
13:30 - 17:00	*CliC Arctic Sea Ice Working Group and Workshop Organizers Meeting*

Appendix 2: Participant List

Name	Institution / Affiliation	Email Address
Steve Ackley	University of Texas at San Antonio, USA	stephen.ackley@utsa.edu
Jenny Baeseman	Climate and Cryosphere Project Office, Norway	jbaeseman@gmail.com
Antoine Barthélemy	Université catholique de Louvain, Belgium	antoine.barthelemy@uclouvain.be
Justin Beckers	University of Alberta, Canada	justinbeckers@gmail.com
Sylvain Bouillon	Nansen Environmental & Remote Sensing Center, Norway	sylvain.bouillon@nersc.no
Klaus Dethloff	Alfred Wegener Institute, Germany	klaus.dethloff@awi.de
Dmitry Divine	Norwegian Polar Institute, Norway	divine@npolar.no
Martin Doble	Villefranche Oceanographic Laboratory, France	martin.doble@obs-vlfr.fr
Jens Ehn	University of Manitoba, Canada	jens_ehn@umanitoba.ca
Hajo Eicken	University of Alaska Fairbanks, USA	hajo.eicken@gi.alaska.edu
Torbjørn Eltoft	University of Tromsø, Norway	torbjorn.eltoft@uit.no
Danny Feltham	University of Reading, UK	d.l.feltham@reading.ac.uk
Sebastian Gerland	Norwegian Polar Institute, Norway	Sebastian.Gerland@npolar.no
Øystein Godøy	Norwegian Meteorological Institute, Norway	oystein.godoy@met.no
Mats Granskog	Norwegian Polar Institute, Norway	mats.granskog@npolar.no
Susanne Hanson	Danish Meteorological Institute, Denmark	sha@dmi.dk
Petra Heil	Australian Antarctic Division, Australia	petra.heil@utas.edu.au
Gina Henderson	U.S. Naval Academy, USA	ghenders@usna.edu
Thomas Hollands	Alfred Wegener Institute, Germany	thomas.hollands@awi.de
Stephen Hudson	Norwegian Polar Institute, Norway	hudson@npolar.no
Nick Hughes	Norwegian Ice Service, Norway	Nick.Hughes@met.no
Jenny Hutchings	University of Alaska Fairbanks, USA	jenny@iarc.uaf.edu
Elina Jaatinen	Finnish Meteorological Institute, Finland	elina.jaatinen@iki.fi
Alexandra Jahn	National Center for Atmospheric Research, USA	ajahn@ucar.edu
Frank Kauker	Alfred Wegener Institute, Germany	Frank.Kauker@awi.de
Tarmo Kiik	University of Tartu, Estonia	tarmo.kiik@gmail.com
Baek-Min Kim	Korea Polar Research Institute, South Korea	bmkim@kopri.re.kr
Jennifer King	University of Sheffield, United Kingdom	arctic_jen@yahoo.co.uk
Mikko Lensu	Finnish Meteorological Institute, Finland	mikko.lensu@fmi.fi
Walter Meier	National Snow and Ice Data Center, USA	walt@nsidc.org
Alice Orlich	University of Alaska Fairbanks, USA	aorlich@arthur.iarc.uaf.edu
Leif Toudal Pedersen	Danish Meteorological Institute, Denmark	ltp@dmi.dk
Don Perovich	Dartmouth College, USA	jonesperovich@myfairpoint.net
Pierre Rampal	Nansen Environmental & Remote Sensing Center, Norway	rampal@nersc.no
Marilyn Raphael	University of California - Los Angeles, USA	raphael@geog.ucla.edu
Angelika Renner	Norwegian Polar Institute, Norway	angelika.renner@npolar.no
Matthew Shupe	University of Colorado, USA	Matthew.Shupe@noaa.gov
Lars H Smedsrud	University of Bergen, Norway	lars.smedsrud@uni.no
Gunnar Spreen	Norwegian Polar Institute, Norway	Gunnar.Spreen@npolar.no
Rune Storvold	Northern Research Institute, Norway	Rune.Storvold@norut.no
Julienne Stroeve	National Snow And Ice Data Center, USA	stroeve@kryos.colorado.edu
Erki Tammiksaar	University of Tartu, Estonia	erki.tammiksaar@emu.ee
Adrienne Tivy	National Research Council of Canada, Canada	adrienne.tivy@nrc-cnrc.gc.ca
Penelope Wagner	University of Delaware, USA	penelope@udel.edu
Jeremy Wilkinson	British Antarctic Survey, United Kingdom	Jeremy.Wilkinson@sams.ac.uk
Jinping Zhao	Ocean University of China, China	jpzhao@ouc.edu.cn
Heidi Isaksen	Climate and Cryosphere Project Office, Norway	heidi@climate-cryosphere.org

Appendix 3

Climate and Cryosphere (CliC) Arctic Sea Ice Working Group Data Policy

- Last revision 9 August 2013

The CliC Arctic Sea Ice Working Group fully endorses the International Arctic Science Committee's (IASC) data policy (Statement of Principles and Practices for Arctic Data Management, April 16, 2013; http://www.iasc.info/home/iasc/data; retrieved June 6, 2013) and recommends it be broadly applied to all sea ice data collected in the Arctic.

Moreover, building on and extending the IASC data policy, the CliC Arctic Sea Ice Working Group includes the following guidelines, which are seen as particularly relevant to internationally coordinated, collaborative research activities that help advance polar environmental science:

- Observational data, including operational data, should be fully, freely and openly made available on the shortest feasible timescale, i.e., without application of embargo periods.
- Metadata is essential to ensure data discovery and effective data use.
- The substantial effort necessary to acquire, process, share and archive datasets should always be acknowledged by data users through full citation of data, including referencing of unique identifiers, specifically digital object identifiers (DOI).
- Long-term accessibility and preservation should be ensured by submission of data and associated metadata to one or several data centers with a track record of data stewardship.

The Working Group notes that by adhering to this data policy the international sea ice research community creates a foundation for a highly collaborative and productive research environment that fosters activities addressing urgent science questions arising from rapid Arctic environmental change.

The Working Group encourages free and unrestricted release of remote sensing datasets by national and international space agencies and commercial data providers for locations and time periods that are linked to surface-based or airborne observation campaigns conducted in adherence to this Data Policy. Such observational data can substantially enhance the value of remote sensing data, which in turn benefits the remote sensing data provider and in turn provides further justification of free and open data access.

Appendix 4: Sea Ice Researcher Survey Individual Comments

58 responses

View all responses

Summary

1. In your opinion, what is the biggest impediment to improved sea ice prediction?

weather forecasting Knowledge of ice physical properties and processes in ice while ice forming or melting. Mechanical deformation of ice and formation of ice ridges. 1-2 years: Winds are poorly predicted in global climate models so sea ice advection is biased. 2 years: High sensitivity of sea ice makes it sensitive to heat flux biases in ocean and atmosphere From an austral perspective I think the biggest impediment is lack of observation. There are too few datapoints to reliably predict ice conditions. The spatial resolution of most products which do not cause a very smooth predictions. However, it is interesting to see, that works of Gunnar Spreen show e.g. the formation of Linear Kinematic Features. Another aspect is the limited availability of high resolution forcing data for models and the small amount of high resolution ground truth data - here satellite data has probably somehow to close the gap (Problem: either high resolution and sparse or low resolution with a good coverage) field observations of drift and thickness, including deformed ice floe size and ice concentration at the local scale (1 km) understanding of breakup and the dynamics of the marginal ice zone Lack of sea ice & snow thickness data & lack of in situ observations at the ice edge during active ice formation & melt non-linear ocean-ice-atmosphere phenomena In dynamic models (climate models), sea ice simulation need to be treated differently in the Northern and Southern Hemisphere since the physical environments are quite different in the two poles. One sea ice model applying to both hemispheres (particularly heavily turned to the Arctic sea ice) will not generate correct Antarctic sea ice. For stochastic predictions, updated sea ice thickness data and ice motion data would greatly help improve the sea ice seasonal forecast. Nor enough knowledge of local weather conditions, radiation fluxes and sea water temperature. Albedo of snow/ice surface is also important. Simulating relationships between sea ice and large-scale atmospheric and oceanic circulation processes realistically. I'm not sure its the biggest impediment, but an importnat problem is that the observational record is too short to test models against (I know: they alreday do badly against the short record, but even so...) Lack of sea ice thickness data to be compared with the models. Lack of detailed, interdisciplinary, process-level observations in the sea-ice of the central Arctic (1) Few coupled atmosphere-ocean-sea ice models are used. (2) Lots of models are not accurate enough in simulating some fundamental processes (cf. point 2). (3) Large uncertainties in atmosphere reanalyses/operational analyses/forecasts used to force non-fully coupled sea ice predictions. (4) Lack of observations for prediction initialization of the full sea ice-ocean states (sea ice thickness, snow depth, deep ocean) and/or verification of predictions. My work concentrates on understanding physical and mechanical properties of sea ice (macroscopically and microscopically) and failure processes during interaction with offshore and marine structures. We need to understand spatial and temporal variations. For this, we need DATA. The lack of publically available RAW DATA is the biggest impediment. This concerns level ice, icebergs and ice ridges. natural variability of the weather. There are large limits on the predictability of sea ice...or any other seasonal prediction. From my opinion, one of the biggest problems might be that individual physical processes related to growth and decay are still unclear. For example, ridging and rafting processes which are critical to the ice growth in the seasonal sea ice zones are not fully understood. Besides wave-ice interaction which plays an important role in melting processes remains to be clarified. Study its physical properties on micro and meso scales Predicting the atmospheric forcing on sea ice. 1. Uncertainties of Atmospheric predictions, i.e. imperfection of atmospheric forcing 2. Shortcomings of used sea ice rheologies Lack of funding for model development as research. The situation is quite different for the Arctic & the Antarctic. For the Arctic, it could be improving models (especially drift and deformation & melt ponds) For the Antarctic, forcing uncertainties from ocean and atmosphere, including freshwater supply & precipitation, are major issues. Contribution of deformed ice to the sea ice mass balance is unknown. It depends on the timescale: For timescale of a few days, it is the initial conditions of the ice cover, and especially to know where it is highly damaged. For seasonal and decadal timescale, it is the feedbacks coming from interactions with the atmosphere and ocean. Insufficient in situ data for cal/val. Big data gaps exist, spatially and temporally. Lack ofseaonal observation data of ice, boundary layer above and under sea ice. Satellite era observations are not sufficiently long to quantify the sensitivity of sea ice to global temperature. Paleo-Records have insufficient coverage and are not compiled for periods usually used by climate models (eg PMIP) such as the LGM and mid holocene. Initializing sea ice thickness How to run weather ensembles for the future Lack of good quality synoptic real-time thickness data. Unknown weather conditions during summer; unknown ice thickness at onset of summer; non-linear feedbacks involving melt ponds and leads Model deficiencies and lack of ocean climatology and observations Ocean heat content Sea ice thermodynamics Sea ice dynamics Inability to produce seasonal weather forecasts Inability of satellites to detect sea ice thickness correctly, especially in areas with high snowfall, like most of the Southern Ocean. Two things: 1) Lag of repeat (or better sustained) observations at high spatial and temporal resolution. 2) Lag of understanding of all processes and scales affecting the sea ice state. Sufficient observations to assimilate into models and to test models. Radiative Transfer in Sea ice, Depends on the time scale of the prediction. For sea ice forecasting (days to weeks) in the Southern Ocean it would be high resolution atmospheric model forcing and to a lesser extent high resolution ocean data. I haven't thought so much about longer term predictions but I presume they would be tackled using probabilities and that would require a large number of simulations. Sea ice changes are strongly related to the atmosphere and the ocean. A better representation of the interactions between the sea ice, ocean and atmosphere is thus needed and the efforts to my point of view should deal with the three medias together, not just sea ice. Reproducibility of the sea-ice thickness. Different problems in the Arctic and Antarctic. Arctic-With the loss of multiyear ice, we need to know whether the first-year ice will continue to thin or whether the "new normal" is a relatively stable first year ice thickness. Increased winter dynamics of thinner ice may also increase ice thickness through ridging activity. Antarctic-Lack of knowledge on ice thickness distribution and its variability under climate change. It seems that the climate models that incorporate sea ice are tuned with lower resolution satellite data due to their high temporal resolution and global coverage. However, the errors are higher than what is desirable and increase with extended forecasts. The obstacle we face is that we are currently unable to automate higher resolution data to reflect real-time conditions. I think sea ice observations are good to validate the data but it is necessary to use large-scale satellite data for large scale sea ice predictions I have no good answer. The lack of: 1) Detailed knowledge of sea ice volume over decadial time scales. 2) Salinity and thermal variations in the polar ocean 3) Interaction and influence of major natural driven quasi oscillations. funding Cloud simulation Lack of verification measures applied to short range (few days) models. Surface radiative and turbulent heat fluxes are poorly known. These are extremely dependent on the atmospheric moisture errors, vertical moisture profile (and water phaze), wind errors (although assimilated in many models), sea ice thickness errors ... This depends on the time period for prediction: At a short time scale. Data initialization. We have very little observational data and poor representation of sea ice from Passive Microwave. At longer time scales, the sea ice forcing is poorly characterized. Realistic and accurate measurementd Initialization for the prediction, especially for the sea ice thickness, and model biases in surface fluxes. Real-time observations of sea ice thickness Lack of good sea ice thickness data for model calibration. Lack of long-term observation and insurficient knowledge for changing micro-physics of sea ice Lack of spatially complete, readily available and timely observations of ice thickness, for the validation and initialisation of models.

2. In your opinion, what is the largest modeling uncertainty?

Consideration of additional state parameters characterizing sea ice structure in different space scales including sea ice salinity,porosity, snow thickness, melwater on ice, slush, sizes of floes, consolidation of ridged ice, concentration, MIZ structure, land fast ice boundaries. The influence of ice porosity, brine content and melt ponds on thermodynamic processes. Accounting of ice ridges in mass, momentum and energy balance. (a) sea ice drift (in ice forecasts to facilitate operations in sea ice-covered waters), including deformed ice, floe size -- in particular during the transition period of breakup and new ice formation. (b) Weather At ice forecasting, the location of ice and motion of the ice has a large uncertainty and there is no uncertainty even provided in the initialization conditions. In Climate models: the physics to force ice conditions is poorly understood and characterized. higher complexity leads to larger uncertanty the cricual unknown aspect : when to stop the complexity Deposition and evolution of snow on sea ice. (all models) 1. There is not one answer. This depends on the questions you want to answer by modeling 2. see question 1. for ice-ocean modeling and forecast 3. for fully coupled, i.e. climate models, atmospheric dynamics, i.e. energy, moisture etc. fluxes towards the Polar Regions seem to be the largest uncertainties I'm not really qualified to answer this question - but I'd say the largest uncertainty is ice volume in the antarctic, and therefore ice-ocean interactions and feedbacks. in ice-ocean modelling: the choice for the realistic drag coefficients for the respective region as well as the quantification of ice stress and the inertia of ice under the influence of changing wind conditions and if I'm correct the fact that many models Lack of spatial and process resolution Ice thickness (spatial and temporal) distributions; likely a key uncertainty in all models sea ice model in general: ice concentration, thickness, opening rates, shear. SNOW thickness!!!! ==> Precipitation uncertainty in atm models... Atm models: Clouds, precip Ocean models: Mixed layer temp, sal... Ice thickness likely impost the largest uncertainty in statistical forecast models because of lacking observational data. Sea ice models in general: parameterization of thickness redistribution. 1) Understanding how increased open water area influences cloud (and fog) cover. models currently do not track uncertainties in their code. It takes too much computational time. The inputs have uncertainties and are tagged with bulk uncertainties, but uncertainties need to be applied for each and every value at each point to be really effective. Biggest one still remains THICKNESS Treatment of clouds and of feedback processes. Dynamical process on the ice with small scale. Arctic - Sensitivity of melt ponds area / depth to changing sea ice Link between drift, deformation and mechanical redistribution Future response of ocean and feedback on sea ice Antarctic - snow processes, atmospheric & ocean forcings. Specific physics (linked to snow, deformation, ocean-ice interactions). ice thickness data are much required to improve ocean-ice models Ice-ocean modelling: Ocean heat content and stratification Sea ice thickness sea ice dynamics representation Epistemic uncertainty. Too limited data to make reliable inferences. Propagated measurement errors from remote sensing products are only reported as bulk numbers based on a few sampled cal/val studies. The models need to have a "uncertainty run" scenario. It will run slower and take quite some coding to implement, but should be considered as much a standard as a control run in terms of sensitivity tests. Sea ice thickness, snow cover on ice and boundary layer knowledge above and under sea ice. Accuracy of weather condition over Ocean. Ice-Ocean modeling- Insufficient parameterization of processes, e.g. melt ponds in the Arctic, pancake ice formation and role of polynyas in ice production in the Antarctic. Failure to capture observed Antarctic sea ice trends over last 30-50yrs (i.e., models show negative trends, observations show positive trends) (Forecast (> 2 weeks) and climate models) Lack of knowledge on sea ice rheology (the shape/roughness of the ice derived from thickness measurement) is the most uncertain parameter and that is affecting the parameterisations used for wind and ocean drag.. ice dynamics related to lack of reliable weather forecasting data. (1) Sea ice modeling: (1a) representation of surface albedo (e.g. lack of explicit melt ponds), (1b) improper snow formulation over sea ice, (1c) formulation of ice thickness distribution (and lack of in some models...), (1d) sea ice dynamics. (2) Sea ice-ocean coupling: flaws in ice-ocean coupling (water, salt fluxes, conservation). (3) Air-sea ice/ocean coupling: turbulent fluxes (heat, momentum) formulation atmosphere boundary layer in the polar regions (over sea ice...). In the model I've been using (CICE4) I think the largest uncertainties are to do with the northern hemisphere bias of the model. How many of the parametrizations have been tested with Southern Ocean measurements? Not very many as far as I can tell. Once this has been done there remains the issue of a global implementation which naturally simulates both hemispheres. clouds and radiation Coupled air-sea-ice model intercomponent flux biases. The representation of sea ice dynamics in sea ice models is very poor and does not help in reproducing the sea ice motion and deformation deduced from remote sensing observations. For ice-ocean coupled model, the main uncertainty is arisen from dynamic forcing and thermadynamic parameters of ocean and sea ice. I mostly work with ice-structure interaction models an the biggest problme here is the lack of simultaneous measurements of ice forces, ice characteristic and structural response Don't know In climate models, the largest uncertainty is in ice behavior and parameterization - especially considering that sea ice behaves differently at the different poles. In ice-ocean models, the largest uncertainty coincides with the largest uncertainty in real data - ice thickness, and other ice parameters. Estimates of the surface freshwater fluxes (including meltwater from Antarctic and Greenland ice sheet) are not good enough to drive ice-ocean models and not well simulated by coupled climate models. High resolution reanalysis, well validated in polar regions would help in ice-ocean modeling and would provide a good target for climate models. In a more general way, the internal variability of climate models is generally not good and observations are too short to estimate precisely models skill at decadal timescales. cloud simulation in coupled models. Both for ice-ocean modeling and climate models, one of the biggest uncertainties might be thickness redistribution processes in the interior region and interaction with ocean waves in the marginal ice zone. The largest modeling uncertainty in my opinion is ice-ocean models because we haven't been able to accurately depict volume and sea ice thickness which governs how the ice will change in the summer. However, I am unsure about some of the other errors associated with climate models to have a good opinion on that. It depends New ice formation (frazil ice, grease ice, pancake ice) that will provide a negative feedback representation of energy fluxes throug the ice ice forecast models: Modeling of deformation of ice and pressure in ice. Snow on top of ice climate models: Deformed ice, ice ridges, Regarding ice-ocean modeling and climate models, reproduction and parameterization of sea ice production and melting is the largest modeling uncertainty. For example, all the present climate models could not reproduce the AABW formation: deep convection occurs in the open ocean in the models, while in reality dense shelf water caused by high ice production is ventilated from the continental margins to be AABW. Driving of the thermohaline circulation is the key role of sea ice through its production/melting. -scale dependence and anisotropy (Sea ice mechanical properties) -surface and ice-ocean interface topography and microstructure (ice-ocean-armosphere interaction, remote sensing) Climate models - understanding the spread of predicted future Arctic ice decline. Also understanding why models do not capture observed decreased in Antarctic ice extent. In climate models, multidecadal variability tends to be too large. In ice forecast models, initial sea-ice analysis and atmospheric forcing are often uncertain, in the Antarctic in particular. In general, many sea-ice related parameterisations, such as shortwave, ice-ocean energy and momentum exchange and internal stress fields. Partly the parameterisation related uncertainty in the Antarctic is due to the fact that the parameterisations are often based on Arctic observations. Errors in heat fluxes at air-water, air-ice, and water-ice interfaces. ice-ocean modeling: sea ice dynamics (rheology, air-sea ice drag, ocean-sea ice drag), melt ponds. ice forecast models: good initial conditions for the sea ice cover itself (leads and ridges maps mainly), initial conditions for sea ice model in the Marginal Ice Zone (distribution of floes size) climate models: sub-grid scale parameterization of fractures and leads, melt ponds Marginal ice zone, both extent and location (where will the ice retreat). Also whether there will be any outliers or rogue floes. (any forecast involving sea ice) Future weather, in particular the winds.

3. In your opinion, what is the key sea ice question that needs to be addressed?

need to better understand what is driving the loss of ice in the Beaufort/Chukchi seas as old ice that is transported into the region by the Beaufort Gyre tends to melt out before recirculating back to the central Arctic. this region seems to be key to the future evolution of the ice cover. Where is the international funding to support the science? Is the acceleration of sea ice loss in the last decade from natural variability, short-term forcing, or larger positive feedbacks than in global climate models? What is the influence of using a realistic sea ice deformation in coupled sea ice-ocean-atmospher models? What are the length scales and the lag in the response of sea ice to various forcing types? What are the cyclic variations are what are the changes due to climate change? are there cycles? are there bigger cycles we don't know about, because we only relatively recently started observing from space? Why is Antarctic sea ice not melting back ? The location and thickness of the ice. Modelers don't even have that correct. In order to apply the sea ice data, it needs to be correct not just on a hemispheric scale as a whole, but particularly along the margins and at higher resolutions. How can the sea ice community prepare for the upcoming climate shift especially in terms of moving away from reliance on generalized global trend analysis and focusing on more infrastructure-critical processes at the small scale where human impacts will be felt directly. What accuracies are needed in the data sets, imagery, and models to assure sufficient data quality to address these issues? How can we standardize sea ice observations that could be easily implemented for each cruise? With this, how can we improve how we validate remotely sensed data to depict true sea ice conditions? What causes the rapid sea ice decline? 1) How wil a reduce winter ice are and an increasing amount of annual freezing influence the thermohaline circulation? 2) Prediction for the time to when the Asian side up to 88 degrees will be ice free in the late summer months and annual duration of the ice free times. 1. Further understanding of sea ice production in coastal polynyas and its prediction, because it is the key of the thermohaline circulation and its possible change in the future, as mentioned above. 2. Interaction of sea-ice, ocean, and fast-ice and their roles on thermohaline circulation and biogeochemical cycles. A good example is Mertz Glacier Tongue, whose calving in 2010 has greatly affected the sea ice production, subsequently AABW (Tamura et al., 2012) and biogeochemical cycles (Shadwick et al., 2013). Another example is a newly-found AABW formation area, off Cape Darnley, where extremely high ice production occurs leeside of the grounded iceberg tongue (Ohshima et al., 2013). 3. Evaluation of air-ice-ocean drag dependent on various ice conditions. According to Helmer et al. (2012), change of the drag coefficient has the potential to cause the drastic change of ocean current and thereby dramatic collapse of ice shelf. Recent reduction of sea ice in the Arctic ocean might enhance the ocean circulation through the increase of the drag. References Tamura et al., 2012, Nature Communications, 3:826. Shadwick et al., 2013, Geophysical Research Letters Ohshima et al., 2013, Nature Geoscience, 6, 235-240. Hellmer et al., 2012, Nature, 485, 225-228. Why Antarctic sea ice extent is increasing in the face of the warming world? We need to understand how differently pack ice physical properties evolve as the ice pack changes, e.g. from perennial ice to seasonal ice. This means accurately capturing the derivatives in time and space. Sea ice ridges and how their formation, areal concentration and size will change in the future due to the climate change. How climate change affects to the dynamics of sea ice. Sea ice predictability in the future: (1) Sources of predictability of the winter ice edge in the MIZ while an ice-free summer Arctic ocean (ocean, atmosphere...). (2) Sea ice as a source of predictability for Eurasian/North American weather. Light transmittance, radiative transfer What physical processes are responsible for surface flux errors? How do we resolve known problems in remotely sensed microwave and altimetry assessments of sea ice that lead to indirect derivations of ice thickness, snow depth, slush presence and thickness, freeboard, etc.? Understand of dynamics, such as ridging and rafting, based on the observation, and its interactions with both atmosphere and ocean. Predicting future sea ice variability and trends with changing precipitation and ocean stratification See 1-2. Why is Antarctic sea ice showing the trends and spatial patterns it is, what controls that? How will the shift to a predominantly first year ice cover impact atmosphere-ice-ocean interactions? Hos does massive loss of sea ice affect climate globally? what are the respective contribution of thermodynamical versus dynamical processes in the observed decline? what are floe size, ice concentration, ice pressure field, and what is the characteristic of deformed features present? What is the contribution in recent changes of the forcing compared to internal varaibility, and among this varaibility, what is the one fraction that is generated in polar regions and what is the fraction that is driven by teleconnections with lower latitudes? To answer this question, a good estimate of the natural varaibility of the system at decadal time scale is required as well as a good representation of this variability by models. (1) sea ice quick melting in summertime related with the interaction of sea ice and upper ocean (2) relationship of low ice concentration with cloud in certain seasons. (3) the contribution of sea ice drifting on sea ice retreat How roles of sea-ice related physical processes change in changing climate when ice becomes less and thinner. What, exactly, to users need from small incremental improvements in seasonal forecasts. What exactly needs to be predicted and why? How would a small improvement in the uncertainty help, if at all? I doubt either users or predictors have realistically addresses this question. Sea ice thickness distribution all over the Arctic Energy budgets for first year sea-ice If we consider the sea ice material, I think that a better understanding of the thermo-mechanical processes during deformation would be crucial. A better fundamental understanding of how forces (or stresses are functions of time, temperature and size is the most important issue Evolution of ice thickness distribution on a few days time scales. Snow-sea ice interaction should also be addressed. Can we improve climate models by parameterizing sea ice differently at each pole? evolution of sea ice cover in arctic and antarctic Are there key missing physical processes in current climate models which limit the ability to predict the future state of the sea ice. How to make a sea ice model that performs well on the few day time scale with the least bias on annual integrations. Cumulative impacts of hydroelectric projects in Hudson Bay on winter Sea Ice dynamics In the short term in the Southern Ocean I think we need to know if total ice volume is increasing with the small increase in area. In the longer term for ecologists it will be important to know what future climate scenarios the ice obligate species (e.g. weddell seals) will be able to survive, i.e. what climatic conditions will make the Southern Ocean ice free in summer. Is the ice predictable on local-to-regional scales for seasonal or longer-range forecasts. What is the sensitivity of sea ice to changes in global temperature. Simulating clouds at high latitudes to improve the surface radiation balance. how to observe various sea ice features with the remote sensing, with the best spatial resolution possible When will the summer ice go away, what else from me... How has the change from a predominantly multi-year (perennial) ice to a first-year (seasonal) ice cover in the Arctic affected model predictions - are model parameterisations based on experiments such as SHEBA still valid? Why is the increase in sea ice extent around the Antarctic occurring? Is this due to a more widely scattered, thinner ice cover or is Antarctic sea ice maintaining it's thickness? Icebergs - is the climatology for these changing in the areas where these could affect increasing maritime activity (Barents Sea, West Greenland, Antarctic

Peninsula)? The regional scale ice thickness distributions and how they vary with external driving (including secular change from global warming). The influence of swell and storm waves on sea ice can influence significant changes of ice conditions in few hours. This effect is very important for the Arctic Seas, but in case of shrinking of ice coverage in the Arctic could be important forthe whole Arctic. Seasonal change of complete ice, atmosphere, ocean growth/decay observation. Future fate of Antarctic sea ice. Balance between thermodynamic and dynamic causes for changes in sea ice both in the Arctic and Antarctic What is the volume of Antarctic sea ice? and is it changing? Physical properties and microstructure

4. In your opinion, what observations are needed to address issues 1 - 3?

More timely and more extensive observations of ice thickness, snow depth, and perhaps ocean heat content. ground observations: ice thickness, including pressure ridges and their degree of consolidation, of ice concentration and floe size See 1. All of them. And more of them. Measurements of short-term forcing. field measurements and additional buoys combined with satellite data from various sensors to "upscale" the small number of field observations as good as possible in order gain a kind of truth to assess the performance of different models. Due to the dynamics of sea ice, it would be helpful for the linkage of the datasets to coordinate the field measurements with the acquisition of the satellite data more systematically. Mainly, we need accurate satellite observations of sea ice thickness, especially around Antarctica. Paleo sea ice observations to extend the record, but in order to achieve this, we need many more observations of the components that determine the proxy record: DMS production (MSA in ice cores), blowing snow over sea ice (sea salt in ice cores), phtoplankton assemblages in ice, open water and sediment traps, biomarker production in sea ice,.... More and better cloud fraction observation. More and better long and short wave radiation observations. Improved and more frequent satellite-based observations of ice and snow thickness. Improved and more frequent satellite-based observations of ice advection (e.g. ASAR). Improved observations of heat and other fluxed associated with latent heat polynyas and other areas of open water. Also better numerical models. Studies on sea deformation processes, ice ridges and deformed ice. Ice model development for climate models Sea ice thickness observations for SAR, active microwave, and lidar data. Ocean observations Thickness of sea ice Snow on ice (thickness, density etc) Year-around in-situ observation on sea ice, at multi stations. More frequent, near-real time sea ice thickness observations that can be used to further improve satellite remote sensing based techniques such as altimetry (thicker ice) and passive microwave interferometry/thermal optical (thinner ice), and image based sea ice type classification. On icebergs: Better use of existing SAR image archives to derive iceberg climatologies. We need a lot more integrated in situ measurements. The sea ice is not the same material it used to be because of its warmer, thinner composition. Many of the model assumptions are now ill-constrained relative the ice conditions of today. Microwave sensors can't see many of the new properties because there is so much more wet ice over longer periods of time. As for deformation processes, to realize the monitoring of ice thickness ddistribution by satellite sensors, in-situ validation measurements are needed. As for wave-ice interaction, the concurrent field measurements of wave energy and floe distribution are important. As for snow-sea ice interaction, long term monitoring observations about the morphological change together with satellite sensors are needed. Large scale oceanographic deployments, community based monitoring programs throughout Hudson Bay and James Bay Full seasonal time series of sea ice & snow thickness evolution, of ice-ocean interactions before, during and after freeze & melt onset, met/ocean obs within the sea ice zone Validated global ice conc at reasonably high spatio-temp sampling. Ice and snow thickness data (REAL!) at decent spatio-temp sampling frequency. Ice stress. Accurate estimates of surface salinity (as a way to estimate the strength of the freshwater cycle) and as long time series as possible of ice extent (through retrieval and calibration of early data) ice thickness Wide-area and routine sea-ice observations for understanding the dynamics of ice with small scale. In addition, the development of new algorithm for measurement of sea-ice thickness is indispensable. Application of data assimilation of ice is also useful, I think. Better sources (multisensor + observational data) to initialize models and more research in understanding how to initialize longer time scale models. Expand ice thickness observational bases through new technologies for in situ measurements and for satellite observations. 1. aerial (close range) remote sensing over sea ice, in particular using swath-mapping altimeters (eg liDAR) in conjunction with imagery and other sensors. 2. smaller-scale on-ice surveys coincident with (1), combining terrestrial laser scanners, underwater observations (multibeam sonar on UAVs), drill hole measurements and rigorous spatial data collection. Clearly that is a huge task - so at least the surface (drill hole, TLS, spatial survey) data should be collected as a calibration exercise for airborne altimetry. 3. satellite altimetry, using the data collected in (1) and (2) as validation exercises. 4. as many ship-based observations (eg ASPeCt program) as possible. Cloud observations 1) Next gereation IceSat and Cryosat satellites in an operational modus. 2) increasing buyos in and under ice. 3) Reall time monitoring of moorings in the Frams strait and north of Svalbard, Greeland and north east Canada Ice thickness as noted in 1. How is the ice melting - relative importance of surface vs basal melting Long-term and year-round observations of ice and snow thickness change and processes affecting the sea ice mass balance (including ocean and atmosphere forcing). For sea ice forecast, observation of sea ice deformation may indicate where the ice cover is damaged and fractured. For climate model, analysing the observations allows scientists to identify the key properties of the ice cover dynamical behaviour. Field data on ice processes, including time series from drifting stations in both the Antarctic and Arctic. Continuing development of satellite remote sensing which must have CAL/VAL SHIP field experiments (Not Aircraft alone!) on high resolution radar, radar and laser altimetry, passive microwave, etc.. Buoys, of a variety of types such as

Ice Mass Balance, the "O" buoys, Ocean heat (UpTempo), as well as Surface Velocity, Pressure and Temperature.   Ice thickness from satellites and stress fields in the ice pack. Also, observations on ocean surface waves interacting with ice are of importance.   (1) Sea ice thickness (with PDFs). (2) Snow over sea ice. (3) Atmosphere profiles. (4) Ocean under sea ice.   Sea ice thickness, surface meteorological fields, atmospheric profiles, and subsurface temperature.   One needs to be able to measure deformation and forces for sea ice of different sizes, different temperatures and different time scales. But the measurements needs to be carried out within the proper theoretical framework, or else no progress will be made.   Compilation of historical and paleo ice records. More paleo observations IP25 in sediment etc.   continuous, hemispheric wide observation of 1. sea ice area 2. thickness 3. drift 4. snow cover and melt ponds   1. Increased radiosonde network in the Arctic 2. Increased buoy network in the Arctic 3. detailed in situ study of the BC region   Continuation and enhancement of satellite observations, particularly for AMSR and ICESat/Cryosat. Since AMSR-E/AMSR2, from which ice concentration, drift, detection of thin-ice (polynya) can be obtained, has been the life line of sea ice investigation, succeeding of AMSR2 without a gap will be very important. For obtaining sea ice thickness and volume globally, enhancement of ICESat/Cryosat-like observation would be indispensable with supplementary observations by airplane. Moorings of Ice profiling Sonar (IPS) or Upward Looking Sonar (ULS) are needed to validate the above satellite observations.   We need both large-scale (remote sensing) observations and detailed in situ case studies that complement each other.   scatterometers, SAR, passive microwave satellite measurements   Thickness - both Arctic and in Antarctica. Process studies in polynyas on new ice formation during winter.   Sea ice thickness   More of them! Both in quantity and concentration   3-d microstructure Surface and interface Deformation events on small (1-100 m) and microscale   Colocated comprehensive interdisciplinary observations. These need to be in the sea-ice, ocean, and atmosphere together   Much more observations for the Antarctic (sea ice, atm, ocean) Met and ocean data for the Arctic + melt ponds + drift / deformation   More "boots on the ice" in situ observations of sea ice to assess, calibrate, and validate RS observations.   - local high resolution images to retrieve cracks and leads maps (SAR for example, L-band) - local airbone pictures of the Marginal Ice zone - Satellite observations allowing to retrieve basin-wide maps of leads - more Ice Mass balance buoys within the Arctic sea ice pack region - tons (:) !) of small drifting buoys, both in within the central Arctic and in the Marginal Ice Zone.   in situ joint with airborne and satellite missions (all scales)   1. A comprehensive, interdisciplinary field experiment, jointly planned by observers, modelers, and remote sensers, to explore atmosphere-ice-ocean processes in the new Arctic. 2. A central repository for routine sea ice observations (concentration, pond fraction, thickness, snow depth) made during field campaigns.   (1) More long-term, multiple parameter and automatic sea ice based observations. (2) Fine designed field experiment for sea ice micro-physics (3) Long-term submarine up-looking sonar measurement for large area sea ice thickness   Field observations of energy fluxes, ice thickness, temperature and salinity, weather conditions, waves and under ice currents. Sattelite observations of sea ice structure with high resolution. Monitoring of ice drift with high temporal resolution.

5. What are the most important variables that need to be observed whenever possible in a standardized way?

ice velocity, ice thickness, ice concentration, ice strength, drag coefficients between ice and atmosphere and ice and ocean, etc. Sea ice thickness. salinity, temperature, current velocity, ice thickness and extent, polynya size, floe edge location, wildlife entrapment surveys 1. Sea ice elevation. Freeboard is misleading - without additional terms (eg snow, ice, ...) so here I'll say 'elevation' meaning the height of the topmost surface visible from, say, an airplane. 2. Sea ice draft. 3. in-situ sea ice composition. For example if a drill hole or ice coring study was performed, it would be neat to stick a mini-borehole logger down each hole and record in-situ sea ice composition, or at least the thickness of solid vs non-solid layers. 4. Sea ice density (for solid parts) 5. snow thickness on sea ice (can you tell yet I'm working on sea ice thickness modelling from altimetry?) spatial ice thickness distributions, spatial distribution of ice ridges, ice drift patterns, iceberg drift patterns, iceberg size distributions, evolution of iceberg size as function of time Ice thickness, concentration, albedo Atmosphere and ocean characteristics Surface heat flux, and thickness again. Variables in the ASPeCt obs list lower atm and upper ocean state variables ice stength (time series) (1) Sea ice thickness (2) Sea ice concentration (3) Snow depth (4) Sea ice drift (velocity) (5) Sea ice surface albedo Not the most importnat, but we need blowing snow observations over sea ice to confirm or negate a hypothesis. thickness and its distribution over multiple scales. motion and material deformation over multiple scales momentum and stress transfer properties growing biological changes that may be impacting the material properties of ice. Ice drift velocity and deformations, ice thickness and compactness, floe sizes and melt pond sizes, geometrical characteristics of ice ridges (sail and keel heights, length, spatial orientation, macro-porosity and consolidated layer thickness), vertical profiles of ice temperature and salinity, Reynolds drag stresses on the ice surface and bottom, turbulent heat fluxes and radiation balance. Attenuation and spectral characteristics of waves propagating below the ice. Velocities of under ice sea currents and characteristics of tides. Standarization not that important. Interoperability and calibration is important. Ice type (stage of development) Ice age (including id'ing multiyear ice vs old/rotten ice) Ice thickness. Ice thickness distribution. Ice divergence/convergence/motion Ice concentration (and extent) Ice concentration, pond fraction, ice thickness, snow depth, ice age standardization is needed (and will be difficult) to measure and report porosity and consolidation of pressure ridges. Currently, they are highly dependent on the person performing the measurement. ice thickness. snow depth. ocean heat Use of ASPeCt and Ice Watch protocols from ships which have ice thickness, type, concentration, snow depth, floe size, ice roughness. These can be easily supplemented with digital photography (EISCAM system) on any ship of opportunity (i.e. "whenever possible").. sea ice thickness, sea ice edge. For the latter, there is a wild variety of approaches, from the 'last icecube' (if any ice at all can be seen, ice edge extends out to there) to some moderately high concentration conditions. Ice thickness, concentration and velocity. Then perhaps thermodynamic fluxes and roughness at air-ice and ice-ocean interfaces. concentration, thickness, ice velocity Cloud amounts, snowfall and upper ocean heat content. sea ice thickness, snow depth and very important snow layers Ice Concentrations, Ice Thickness, Ice Motions, Snow Depth, Salinity, and Ice Albedo. Forces and deformations on the larger level. A precise characterization of the substructure (brine and gas size and shape) and further the permeability for different types of sea ice (warm, cold and intermediate) ice concentration especially in summer months ice volume (thickness) ice motion/deformation ice age Ocean hydrography Sea ice thickness (draft or freeboard) Sea ice density Snow thickness Snow density Ice concentration, type, thickness; snow cover thickness. Ice and snow thickness. Ice advection. for sea ice it is thickness, area, drift, deformation, strength, temperature (see the CICE model all these variables apply. The problem is an integrated one not a cherry picking event. Heat flux variables: Radiative, turbulent, conductive heat fluxes ice thickness ice thickness transmitted solar radiation through sea ice optical thickness of atmosphere Ice thickness, ice concentration, ice ridge size and ice ridge density. Ridge orientation/direction Sea ice type, thickness, and sea ice concentration in order for it to be easier to infer overall sea ice conditions when reviewing ship-based observations. ice concentration, ice thickness, snow depth, ice types. Thickness of ice and snow, ice compatctness. Sea ice thickness Ice concentration, ice thickness, ice velocity, ocean salinity and temperature, mixed layer depth We have a lot of data on sea ice motion and deformation but a very few on leads and ridges width distribution. salinity, temperature, thickness, growth velocity Initial growth time series of variables Ice concentration, surface morphology ice thickness, ice concentration, snow thickness, ice motion Ice and snow morphology in dependence of ocean and atmosphere conditions (incl. drift); standardized not as important as representative, meso-scale (i.e. a few drill-holes don't really help) Sea ice and snow thickness (all polar venturing ships should have a digital camera set-up from which stereo imaging can retrieve ice thickness while underway) Thickness distribution and floe size distribution.

6. What sea ice field experiments are you aware of for the next few years?

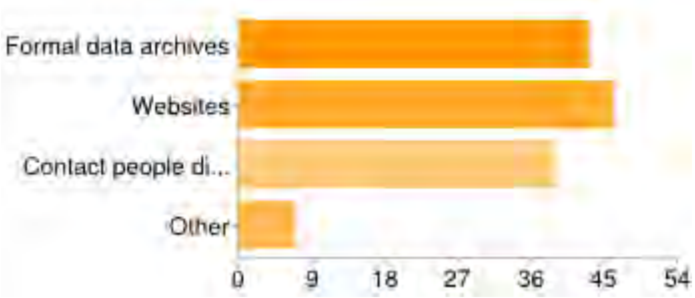
under ice / in ice / on ice heat flux measurements (like SHEBA) ArcticNet in the Beaufort Sea (summer 2011, CCGS Amundsen). iAOOS (LOCEAN, France, April 2013, Central Arctic): beacons on sea ice. The Polarstern Weddell sea expedition - I'm not aware of any others. Monitoring of sea ice characteristics and strength, waves, sea currents and tides in Svalbard fjords and North-West Barents Sea. Oden AT Research Cruise 2013, Studies of sea ice for engineering purposes. CryoVEx 2014

CryoSat validation project, ESA, March/April 2014, airborne and ground based measurements of snow and ice thickness and morphology and snow properties.Coordinated with CryoSat and IceBridge overfligths AODS : David Barber, Igor Polyakov, in 2015 MOSAiC: Par Olesen, Klaus Dethloff, in 2017 Polarstern ANT-XXIX-6 and 7 (Jun - Aug and Aug - Nov 2013): WEddell Sea: Check with AWI folks for details Antarctic Fast-ice Network: Various locations, ice and snow thickness and freeboard. Marcel Nicolaus-June 2013-Weddell Sea-Polarstern. Transect with ice stations in the Weddell Sea. (based at AWI). Stephen Ackley-Sept--Oct 2015-Chukchi Sea-Sikuliag. Ice measurements with AUV, EMI, lidar, waves and wave-ice interaction and air-ice-ocean measurements by other groups (Wadhams/Doble, Guest/Fairall, Thompson) None (only proposals). Norut Narvik, spring, Barents Sea, ColdTech project, pressure ridges and mechanical sea ice properties MOSAiC 2013 Polarstern in Weddell sea: blowing snow, snowpack salinity and blowability, sea salt aersool sizes and concentrations. We would be looking for other platforms to repeat this. A lot, sorry but have't got the time to detail Office of Naval Research, S. Ackley (PI) - Fall 2015, Arctic Chukchi, ice breaker cruise, combination sea ice/oceanographic investigation of autumn sea ice advance. none funded that I know of yet. I have no idea so far. None Mooring observations of IPS, ADCP, CT in the Arctic coastal polynya (Chukchi Sea Coastal Polynya) by cooperation of Hokkaido University (Fukamachi & Ohshima) and University of Alaska (Eicken and Mahoney) since 2009, and in the Antarctic coastal polynya (Cape Darnley Polynya) by Japanese Antarctic Research Expedition (Fukamachi & Ohshima) since 2010, to investigate the high ice production process and the associated dense water formation and to validate thin-ice/ice-production algorithm of AMSR-E/AMSR2 and SSM/I. met.no/NPI - Sea ice thickness and observations from Hopen island (SE Svalbard) Other activities waiting on funding decisions. MOSAiC Ocean Drifting Project Ice camp of China in summer cruise in 2014 and 2016 I am not aware of any at the moment. I don't know of any (except for my plans to go to the Antarctic). None specific. Office of Naval Research Marginal Ice Zone experiment - deployment of autonomous vehicles and buoys - 2014 Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) - ice camp - 2017 We are working on that. Will get back to you once the funding is confirmed. None. FP7 ICE project. Jeremy Wilkinson, Sea ice dynamics and thermodynamics 1. NPI, summer (Aug/Sep) every year, Fram Strait, RV Lance, full sea ice program including helicopter ice thickness and topography observations 2. NPI, winter to summer 2015 (Jan-Jul), two drifts from North of Svalbard to Fram Strait, RV Lance, full sea ice program including helicopter ice thickness and topography observations Myself: microstructure, tomography (not yet funded) Others: not aware of truly novel approaches to the meso and microscale, but i think there will be some... ARCTIC ONR DRI marginal ice zone experiment (2013-14) and sea state experiment (2015) SCICEX, BROMEX 2 I've not been following the effort going into field experiments but will be doing in the future. I am a global climate modeller so not many. Australian Antarctic Division will measure Antarctic sea-ice stresses, Petra Heil is the contact person. Guy Williams from University of Tasmania plans to do under ice measurements. Prof Peter Wadhams 2014/2015 Arctic Ocean Measurement of ocean wave propagation in marginal ice zone Not aware of any specific ones. Biology - ice - ocean, May - June 2014, Chukchi Sea, USCG Icebreaker Healy, investigate impact of diminished sea ice on primary productivity.

7. Where is your observation data available?

Formal Data Archive	**24**	32%
Personal Website (i.e., not part of a formal data center)	**12**	16%
On my computer, in my lab notebook	**30**	40%
Other	**9**	12%

8. Where do you look for data?



Formal data archives	**43**	32%
Websites	**46**	34%
Contact people directly	**39**	29%
Other	**7**	5%

9. If you answered 'Formal Data Archives' in either of the above questions, please indicate which archives.

NSIDC Chinese Polar Data Center https://data.aad.gov.au/ RGPS GlobIce OSI-SAF NSIDC www.pangaea.de www.aoncadis.org NSIDC and NCEP.

Antarctic Glaciological Data Center (AGDC) at NSIDC USAP Antarctic Data Coordination Center at Lamont ACADIS NSIDC (Boulder, USA) APL (Seattle, USA) cryosphere.gsfc.nasa.gov nsidc NSIDC sea ice data IARC/JAXA IJIS data and expectin Arctic Data archiving System (NIPR, Japan) Mainly NSIDC Image data archives of the space agencies, IFEMER, OSISAF, University of Bremen, IABP, IPAB NSIDC Australian Antarctic Data Center USAP (Lamont-Doherty Geol Observatory) Reanalysis Data from NCEP, ECMWF http://arctic-roos.org/observations /satellite-data/sea-ice/ice-area-and-extent-in-arctic http://nsidc.org/arcticseaicenews/ NSIDC, Pangea NSIDC, JAXA ASPeCt data archive: http://aspect.antarctica.gov.au/data National Snow and Ice Data Center (NSIDC): http://nsidc.org CRREL Ice mass balance buoy data: http://imb.crrel.usace.army.mil /buoysum.htm PCMDI, NCAR, NSIDC, NCDC, etc NSIDC CERSAT/Ifremer mostly NSIDC NSIDC NCDC Bob's Data Warehouse and Bait Shop NSIDC, ECMWF, NSIDC, NCEP/NOAA, other NASA DAACs National Snow and Ice Data Center Earth Cube National Climate Data Center NSIDC OSISAF ESA Uni-Bremen NASA ECMWF DMI - GTS IFREMER ITP and IMB data sites National Ice Center, National Snow and Ice Data Center, PolarData, National Climate Data Center, NOAA CLASS, Arctic Collabrative Environment (ACE) HadISST, NSIDC, UCAR and ECMWF. http://nsidc.org/data/docs/daac/nsidc0051_gsfc_seaice.gd.html ASPECT for Antarctic sea ice. NSIDC ESA NASA Ice thickness climate data record (Lindsay) For example, I have used the data from IABP, NSIDC, NOAA. A-CADIS DOE ARM archive NOAA archive NSIDC NASA/NOAA CLASS and LAADS ESA MDA (Radarsat-2) NSIDC primarily.

10. Finding the data I need is:

Very easy	**1**	2%
Easy	**15**	27%
Slightly difficult	**28**	51%
Difficult	**10**	18%
Extremely Difficult	**1**	2%

11. If finding data is a challenge for you, what would make it easier to

find what you want/need?

The data we require often is difficult to transition into an operational environment. It is a constant effort to ensure we can obtain the data needed to chart sea ice. Forecast models are very limited for operational requirements needed to navigate in and around sea ice. We rarely can use them do to poor characterization that have for determining mesoscale features. One stop shopping Laws, implemented in all countries in which Arctic industrial exploration is carried out, that instruct corporations to share data they collect openly on the web. This should be a contractual requirement. Perhaps they could get some tax deductions in return. The point is that much data is collected by corporations, but this is not shared. Also, academic researchers don't always collect the really relevant and useful data; they often collect data they think is important, and perhaps important for their research focus, but in the grand scheme of things: not really important. Not sure. I've generally found what I need but it sometimes has taken a bit of effort. better meta data protocols and formal referencing of data archives in publications as per Mark Parson's efforts at NSIDC My work need a long time in the archives to look trough hundreds of files Graphical descriptions (sample plots) I have two answers for Question 10: Remote sensing data: Very easy Field observations: Difficult Finding remote sensing data is very easy due to the cataloguing systems that are available from the different data suppliers (NASA/NOAA, ESA, etc). Finding field observation data is difficult and you really have to know if an activity took place and who was the principal investigator. Then there is the question of whether they are willing to let you use what they have. The data that I need but don't have/produce is things like thickness, which is very hard to get in near real time (my time frame of concern). A standardized format for documentation adopted by formal data centers and strongly encouraged for others which includes: -- field(s) -- resolution (if gridded product) -- level of processing (raw, quicklook, final) -- duration -- error estimate Would be nice if we could all agree on a file format (eg netcdf, hdf). Would be even nicer if data centers could be given funds to reformat existing data (but see number 4) Better access to proprietary data sources and reports I do not necessarily think that finding data is difficult, but I feel sometimes data format is different in each data set. The sample program (Fortran and C) for reading data is helpful. Develop a centralized archive of sea ice observations for global analyses of sea ice concentration and sea ice thickness, as well as in situ observations. If those who were recording sea ice observations always input their data into the same data archive to keep it public. Finding data on sea ice area cover is easy. All other data is difficult, I havn't looked for Ice Mass Balance bouy data though. Having a list of possible data sites somewhere Personal researchers network More script based data retrieval tools would be great, so data retrieval could be automated instead of browsing websites. Integrated data approach finding system of item. area, time A web based archive of historical and paleo ice records would be useful. It is relatively easy to find coarse global data for the offshore regions in the different archives, but technical problem occur if the area of interest is close to the coast. Field work data which could be linked with satellite data is difficult to find. A geodatabase of field work data or high resolution satellite data products could be helpful where you could search if some experiments were undertaken in a certain region and/or at a certain time with data description, perhaps data download or at least reference and contact person. It is not so much the lack of archives, but more the lack of data which makes them difficult to find. For the Antarctic, SOOS is putting together a Data System which will probably combine/link the various national and international archives, may make it easier? More uniform archival and metadata It's the lack of data that makes it a challenge more than anything. With advances in technology, hopefully there will be an increase in situ buoy (floating, freeze-in, ice-moored, bottom-moored) observations, particularly for the Antarctic sea ice zone, that are automatically archived in a central data holding. World sea ice database, i would contribute we need to consider having a central data portal that links to all the data available. Internet web site giving an updated inventory of datasets with assessment of quality (strengths/weaknesses). https://climatedataguide.ucar.edu/ is a good example.

12. Please provide any additional comments that you think would be helpful in discussing the issues around sea ice research.

1. Making ice motion, ice thickness data available near real time would greatly help to improve the seasonal sea ice prediction. I think we need to make sure to follow only the topics listed for discussion in the breakout groups and include what types of actions items and expectations we want to come out of each one. I think it is important we make that very clear so that all participants can think about how they will do their part during these discussions. I would like to see more effort in processing available ice thickness measurements that are limited spatially and/or temporally into a homogeneous dataset to facilitate comparison with model data. Increased communication and collaboration are critical. Awareness between different groups of researchers. Some are in it due to industrial applications. Some just like to explore academic questions. Yet, the second group might hold information relevant for the first group. I think the future of sea ice physics research lies in collaboration with other spatial research fields, and use of innovative (and lightweight) tools. SIPEX2 was a great example of this - combining traditional sea ice research (snow pits, drill holes) with 'modern' survey methods - TLS, GPS, AUV, total station, aerial imagery, airborne LiDAR. Using these instruments even allows things to happen totally differently - for example why pick 100m of flat floe to drill holes in, or take ice cores in, or dig snowpits in, when you can now choose the most interesting parts, and locate the sampling sites very accurately with respect to aerial imagery, laser scanner topography or underwater sea ice draft data. It is not the easiest message to get across, and yes, in order to work this way resources need to be allocated to obtaining and deploying survey equipment. But I think the results are worthwhile. Hmm. I'm not so sure that was entirely useful - hope it helps!! We need more systematic observational programs There have been many sea ice researches by local or by large campaign. The recent changes are far dynamic and rapid than we are thinking based on the previous experience. And we are inviting new researchers.

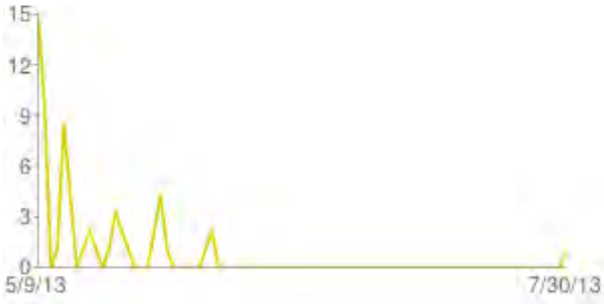
Thus we may need to do a kind of gap analysis specified for sea ice study and share problem, knowledge and future plans. The plan need not to be large, a compact and concrete aproach also improves the study. Arctic and Antarctic sea ice changes are huge target, coordination is important but the action can be done both by community and by individuals. Just as the information. Sea ice production and the heat- and salt-fluxes dataset in the Southern Ocean, Arctic Ocean, and Sea of Okhotsk are available from the following site. http://wwwod.lowtem.hokudai.ac.jp/polar-seaflux/ These dataset have been made from daily SSM/I and AMSR-E grid data with their thin-ice algorithm based on heat flux calculation with ERA-40, ERA-interim, and NCEP2 data. This is a small and spread out community. Efforts at coordinating (CliC, working groups) fall way short of being inclusive and extensive enough to reach everyone in the community. Communication is not good, despite listservs like cryolist and ArcticInfo. There is a gap between operations and basic/applied research, university and government, US and the rest of the world. Enhance dialogue between modellers and observationalists so that observationalists could address modellers needs and modellers could support planning of field expeditions. This questionnaire is great, but perhaps a workshop during e.g. an IUGG conference would be good too. Are you going to organise one? Lack of continuity? Many projects trying to address sea ice climate change issues. However these are short-term (3-4 years) and lack of long-term funding affects the effectiveness of these. No central data repository (like NSIDC) in Europe. Joint sea ice conference/forum of arctic engineers, ocean and atmosphere scientists,glaciologists and physicists that practically work with ice and sea ice be good to include weather forecasters in the meeting to better understand accuracy and needs to improve weather forecasting. Sea ice is an international study that requires international funding. Call for proposals from an international body would enhance the ability for scientists to participate in integrated teams at the international level. Corporations have global resources for global activities, why can't science? CLIC should offer a website for international calls for proposals and provide guidance for universities from around the world to compete for such funding opportunities. Governmental biases often inhibit scientists from engaging in critical international problems. International funding would remove this critical barrier. with respect to the current list of participants: give ice mechanics a voice! Why is NTNU not represented?

CliC has created a sea ice email list for people to share questions, field plans, ask for data, etc - much like Cryolist, but specifically for sea ice researchers. If you would like to sign up for this list, please enter your email address below.

ew428@cam.ac.uk nick.hughes@met.no Elena.Maksimovich@ifremer.fr hugues.goosse@uclouvain.be sean.helfrich@noaa.gov j.j.day@reading.ac.uk jo@1.k.u-tokyo.ac.jp xyuan@ldeo.columbia.edu jpzhao@ouc.edu.cn fmontiel@maths.otago.ac.nz petteri.uotila@csiro.au sonke.maus@gfi.uib.no Robert.Grumbine@noaa.gov rlindsay@uw.edu enomoto.hiroyuki@nipr.ac.jp

ckatlein@awi.de adam.d.steer@gmail.com ann.keen@metoffice.gov.uk
Erki.Tammiksaar@emu.ee matthieu.chevallier@meteo.fr
todd.e.arbetter@erdc.dren.mil mack@ccpo.odu.edu stephen.ackley@utsa.edu
donald.k.perovich@usace.army.mil haasc@yorku.ca cgeiger@udel.edu
Wanqiu.Wang@noaa.gov afrobert@nps.edu janne.p.valkonen@helsinki.fi
roger.stevens@uclouvain.be james.e.overland@noaa .gov ltp@dmi.dk
ohshima@lowtem.hokudai.ac.jp martin.vancoppenolle@locean-ipsl.upmc.fr
toyota@lowtem.hokudai.ac.jp penelope@udel.edu

Number of daily responses



Appendix 5

ONR DRI Sea State Project

- part of a targeted activity from Steve Ackley

Wave-Ice and Air-Ice-Ocean Interaction During the Chukchi Sea Ice Edge Advance.

The fastest Arctic sea ice changes are happening during the transitional seasons. For example, over 1979 to 2010, the sea ice retreat became 48 days earlier and the sea ice advance 42 days later in the greater Chukchi Sea region. A late autumn sea ice advance now often follows an early sea ice retreat. These seasonal sea ice trends are consistent with the expected seasonal feedbacks, e.g., an earlier spring break-up leads to increased solar ocean warming and accelerated sea ice retreat, while the additional solar heat gained by the ocean must be removed before sea ice can grow, slowing autumn sea ice advance. Further, an overall thinner, more seasonal Arctic sea ice cover (as observed) enhances the feedback: less latent energy is required to melt a thinner sea ice cover, thus making available more sensible energy to warm the ocean. Finally, the lengthening of the summer open water season also means a longer period of wind/wave forcing on the upper ocean, together with changes in upper ocean heat and freshwater content and possible increases in particulates due to increased sediment inputs in shallower shelf areas. Together, these changes affect subsequent freeze onset and sea ice formation processes.

To better understand these changes in upper ocean properties and effects on sea ice formation, we require difficult-to-obtain in situ time series observations, specifically during the summer-autumn transition. While most other field campaigns have focused on processes in the interior pack (e.g. SHEBA) or on air-ice-ocean interactions during spring-summer retreat (e.g., ICESCAPE, ONR 'MIZ' research initiative), none have focused on key processes, mechanisms and sensitivities operating at the ice edge during end-of-summer and begin-of-fall, i.e., when the upper ocean cools and freeze onset commences. This proposal aims to address this important yet poorly known physical system by proposing a multiplatform field campaign to capture the space/time evolution of air-ice-ocean interactions initiated during end-of-summer and begin-of-fall to assess in detail the controls on timing of ice-edge advance and new sea ice formation processes.

Our multiplatform approach includes autonomous underwater vehicles (e.g., glider, SeaBed-100) and floating ocean buoys (e.g. UpTempO) mapping upper ocean changes in space/time ahead and within the advancing ice edge, along with ancillary ice-tethered sensors and ice mass balance buoys to monitor ice-ocean interactions post ice edge advance. In addition, ship-based measurements include high frequency full water column hydrographic profiles, along with continuous surface measurements of sea ice growth (using LiDAR, EMI and digital stereo photography) at the advancing ice edge.

Using this suite of autonomous ocean vehicles and buoys and ship-based measurements, our objectives are to: (1) conduct a complete (the first) wave-ice interaction field experiment that adequately documents the relationship of pancake ice growth with a time/space varying wave field; (2) document the state of sea ice advance, i.e., rate of advance, sea ice properties and thickness evolution, and compare rates relative to presence/absence of waves and changing heat/freshwater content; (3) document the state of ocean-atmosphere-ice interactions before and during the autumn sea ice advance to assess seasonal changes in ocean heat/freshwater content and effects on ice-ocean interactions post ice formation; (4) provide the necessary data to allow ocean-atmosphere-ice interactions and pancake ice growth at the advancing ice edge, including waves, to be correctly parameterized in the next generations of ice-ocean coupled and wave prediction models; and (5) provide the necessary data to improve and refine remote sensing algorithms that aspire to describe sea ice morphology (signatures of brash, pancake ice and young congelation ice) during sea ice advance. Our proposed study site is the advancing ice edge in the greater Chukchi Sea to better understand processes driving the 42-day delay in sea ice advance, as well as leverage other studies conducted in that area in other seasons. Given the magnitude of Arctic sea ice changes, there is an immediate need to understand the mechanisms forcing these rapid sea ice changes, particularly during the summer-autumn transition given the dearth of in situ measurements currently available and our lack of understanding, and thus predictive capabilities, of newly evolving ice formation processes.

Main Tab			Sub-tab		Sub-tab		Sub-tab		Sub-tab		Sub-tab	
General												
	Primary Observer						Red - Compulsory fields in each observation data record					
	Additional Observers						Green - Fields that will be included in the next ASSIST distribution					
	Date	yyyymmdd					Blue - typos need fixing in ASSIST code					
	Hour	hh										
	Minute	mm										
	Latitude	dd mm ss or dd.ddd										
	Longitude	dd mm ss or dd.ddd										
	Ship Speed											
	Ship Heading											
	Ship Power											
			Primary/Secondary/Tertiary									
Ice			**Ice**		**Snow**		**Topography**		**Melt Ponds**		**Other**	
	Total Concentration	10ths	Partial Concentration	10ths	Snow Type	menu	Topography Type	menu	Concentration	10ths	algea	menu
	Open Water	menu	Ice Type	menu	Snow Thickness	cm	Concentration	10ths	Pattern	menu	sediment	menu
	Other		Thickness	cm			Ridge Height	m	Surface Type	menu	Dried	yes/no
	thick ice type	ice type menu	Floe Size	menu			Old	yes/no	Freeboard of pond	cm	Rotton	yes/no
	thin ice type	ice type menu					Consolidated	yes/no	Depth	cm		
							Snow Covered	yes/no	Bottom Type	menu		
Meteorology			**High/Medium/Low Cloud**									
	Visibility	menu	Cloud Type	menu								
	Weather	menu	Cloud Cover	1/8's								
	Total Cloud Cover	1/8's	Cloud Height	m								
	Wind Speed											
	Wind Direction											
	Air Temperature											
	Water Temperature											
	Humidity											
	Pressure											
Photos												
Comments												
	General comments	accessible from all tabs										
	Spare Box	To enter additional undefined observations										
	Spare Box	To enter additional undefined observations										
	Spare Box	To enter additional undefined observations										
	Fauna	text field										
	Fauna count	count										

ASSIST .csv Output Interpretation Guide

Observation	Open Water (OW)	Ice Type (*T)	Floe Size (*F)	Snow Type (*SY)	Topography Type (*Top)	MP Pattern (*MPP)	MP Surface Type (*MPT)	MP Bottom
Code Value I	0 :: No openings	10 :: Frazil	100 :: Pancakes	00 :: No snow observation	100 :: Level ice	1 :: Linked	1 :: Frozen	1 :: Solid
	1 :: Small cracks	11 :: Shuga	200 :: New sheet	01 :: No snow, ice or brash	200 :: Rafted Pancakes	2 :: Discrete	2 :: Open	2 :: Few thaw holes
	2 :: Very narrow breaks, <50	20 :: Nilas	300 :: Brash/Broken	02 :: Cold new snow, <1 day	300 :: Cemented Pancakes		3 :: Bottom up	3 :: All have thaw holes
	3 :: Narrow breaks, 50-200m	30 :: Pancakes	400 :: Cake, <20	03 :: Cold old snow	400 :: Rafting			
	4 :: Wide breaks, 200-500m	40 :: Young Grey Ice, .10-.15m	500 :: Small floes, 20-100m	04 :: Cold wind-packed snow	500 :: Ridges			
	5 :: Very wide breaks >500m	50 :: Young Grey Ice, .15-.30m	600 :: Medium floes, 100-50	05 :: New melting snow(wet)				
	6 :: Leads	60 :: First Year, <.70m	700 :: Large floes, 500-2000r	06 :: Old melting snow				
	7 :: Polynya	70 :: First Year, .70-1.2m	800 :: Vast floes, >2000m	07 :: Glaze				
	8 :: Water broken only by sc	80 :: First Year, >1.2m	900 :: Bergy floes	08 :: Melt slush				
	9 :: Open sea	75 :: Second Year	Small Cakes	09 :: Melt puddles				
	10 :: Strips and patches	85 :: Multiyear	Giant Floe > 10000m	10 :: Saturated snow				
		90 :: Brash		11 : Sastrugi				
		95 :: Fast Ice						

Observation	Algae (*A)	A Density	Sediment (*SD)	SD Density	Thick Ice Type (TH)	Thin(Other) Ice Type (OT)	Visibility (V)	Weather (WX)
Code Value I	0 :: 0%	??	0 :: 0%	??	10 :: Frazil	10 :: Frazil	90 :: <50m	000 :: Clouds not observable/observed
	1 :: <30%		1 :: <30%		11 :: Shuga	11 :: Shuga	91 :: 50-200m	001 :: Clouds dissolving or becoming less developed
	2 :: <60%		2 :: <60%		20 :: Nilas	20 :: Nilas	92 :: 200-500m	002 :: State of sky as a whole unchanged
	3 :: >60%		3 :: >60%		30 :: Pancakes	30 :: Pancakes	93 :: 500-1000m	003 :: Clouds forming or developing
					40 :: Young Grey Ice, .10-.15	40 :: Young Grey Ice, .10-.15	94 :: 1-2km	020 :: Drizzle not freezing or snow grains
					50 :: Young Grey Ice, .15-.30	50 :: Young Grey Ice, .15-.30	95 :: 2-4km	021 :: Rain not freezing or snow grains
					60 :: First Year, <.70m	60 :: First Year, <.70m	96 :: 4-10km	022 :: Snow not freezing or snow grains
					70 :: First Year, .70-1.2m	70 :: First Year, .70-1.2m	97 :: >10km	023 :: Rain and snow or ice pellets
					80 :: First Year, >1.2m	80 :: First Year, >1.2m		024 :: Drizzle or rain, freezing
					75 :: Second Year	75 :: Second Year		025 :: Showers of rain
					85 :: Multiyear	85 :: Multiyear		026 :: Showers of snow, or of rain and snow
					90 :: Brash	90 :: Brash		027 :: Showers of hail, or of rain and hail
					95 :: Fast Ice	95 :: Fast Ice		028 :: Fog in past hour, not at present
								036 :: Drifting snow below eye level, slight/moderate
								037 :: Drifting snow below eye level, heavy
								038 :: Blowing snow, above eye level, slight/moderate
								039 :: Blowing snow, above eye level, heavy
								041 :: Fog in patches
								042 :: Fog thinning in last hour, sky discernable
								043 :: Fog thinning in last hour, sky not discernable
								044 :: Fog unchanged in last hour, sky discernable
								045 :: Fog unchanged in last hour, sky not discernable
								046 :: Fog beginning/thickening in last hour, sky discernable

Observation	High Cloud Type (HY)	Medium Cloud Type (MY)	Low Cloud Type (LY)
Code Value I	CI :: Cirrus	AS :: Altostratus	ST :: Stratus
	CS :: Cirrostratus	AC :: AltoCumulus	SC :: Stratocumulus
	CC :: Cirrocumulus		CU :: Cumulus
			CN :: Cumulonimbus

* = P, S, or T if ice is Primary, Secondary or Tertiary

Topography

Ridging Codes for ASPeCt require combination of Topography type 500 with three binary flags: old; consolidated; and snow covered. We have also split out ridge height and cover to two separate fields

ASSIST	old	consolidated	snow covere	fraction	thickness	ASPeCt
500	no	no	no	x	y	5xy
500	no	no	yes	x	y	6xy
500	no	yes	yes	x	y	7xy
500	yes	no	no	x	y	8xy (not in ASPECT!)
500	yes	yes	no	x	y	8xy
500	yes	yes	yes	x	y	8xy

x	ASSIST	ASPECT
	0.5m	1 :: 0.5m
	1m	2 :: 1m
	1.5m	3 :: 1.5m
	2 - 2.5m	4 :: 2m
	3 - 3.5m	5 :: 3m
	4 - 4.5m	6 :: 4m
	> 5m	7 :: 5m

y is the Ridge fraction, in tenths, in ASSIST

Melt Ponds

All meltpond data in the Ice >> melt pond tab is extraneous to ASPeCt

Ice Type

ASSIST	ASPECT
75	85

Floe Size

ASSIST	ASPECT
small cake	400 :: Cake, <20
giant floe	800 :: Vast floes, >2000m