NOAA Sea Ice Forecasting - Workshop Summary

19-21 September, 2011

Anchorage, Alaska

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I. Introduction

Early in her tenure as Under Secretary of Commerce for Oceans and Atmosphere, Dr. Jane Lubchenco initiated a NOAA-wide effort to determine how NOAA should best respond to the profound changes taking place in the Arctic. The result is the **NOAA Arctic Vision & Strategy** document[1] that contains six focused goals for near-term action. One of these goals is to **Forecast Sea Ice**, with the objective that "*accurate, quantitative, daily forecasts to decadal predictions of sea ice are provided to support safe operations and ecosystem stewardship*". This goal is of key importance because continued rapid loss of sea ice will be a major driver of significant Arctic system-wide changes with potential impacts at mid-latitudes. The most recent projections show that the Arctic Ocean could be nearly ice-free in summer before mid-century, affecting marine access, regional weather, ecosystem structures, and coastal communities. Some changes are already occurring, opening up newly sea ice-free areas north of Alaska in late summer and early fall. Improved sea ice forecasts at various scales are needed to reduce risk for operating in the Arctic and to improve social, ecosystem, and economic decision-making. Improved forecasts will require regular observation of Arctic atmosphere, ocean and sea ice; improved coupled atmosphere-ice-ocean models and process-level understanding; and development of services and information products for stakeholders.

An initial workshop on sea ice forecasting was held in May 2010 in Boulder, Colorado for NOAA and external experts to review current activities and exchange information. This workshop was a useful first step in identifying the key players and the current state of sea ice forecasting capabilities. The second workshop, held in Anchorage, Alaska on September 2011, with over 45 participants, went beyond information exchange and focused on identifying critical next steps for improving the state of sea ice analysis and forecasting. The workshop organizers will use the results of the 2011 workshop as the basis for an Implementation Plan that will identify actions NOAA could take over the next few years to improve its sea ice forecasting capability.

Projections show that the Arctic Ocean could be nearly ice-free in summer before mid-century, affecting marine access, regional weather, ecosystems, & coastal communities

The first day of the 2011 Sea Ice Forecasting workshop was devoted to reviewing the current forecast capabilities at three temporal scales: 1) the weather-scale; 2) the seasonal- to inter- annual scale; and 3) the decadal-scale. During the second day, break-out groups were formed to discuss four themes: 1) user and stakeholder needs; 2) current state of predictability at each scale; 3) current state of in situ observations and unmet needs; and 4) current state of satellite observations and needed improvements. After review of these four thematic discussions, plenary discussions were held on requirements for observations and model improvements. On the final day, two breakout groups were formed to develop specific recommendations and priorities for improving sea ice forecasting at the weather- and seasonal-scales. The resulting recommended near-term actions from the workshop are presented in the following sections. See Appendices for a detailed Workshop Agenda, Participant List, Available Workshop Materials, and an Acronym List.

[1] *Available at http://www.arctic.noaa.gov*

II. Definition of the Scales for Forecast Activities

Stakeholders and customers are increasingly asking for detailed, regional, sea ice information and forecasts to make informed decisions on the short-, medium-, and long-term time scales. For example;

- Coastal storm impact-based decision support requires real-time, regional and local forecast products and information of where ice is and how it's moving, including land-fast ice break-up and fracture information.
- Maritime traffic through the Bering Strait and Chukchi Sea within the US Exclusive Economic Zone (EEZ) has risen with the growth in ecotourism, ore and petroleum transport, and support shipping. The need for short-term weather, sea ice and marine forecasts and services are expanding along with the traffic that continues to grow.
- Daily and weekly forecasts for operations, fuel, durable goods, and food re-suppliers for rural Alaska require information to make decisions 10 to 12 days in advance for delivery of goods and supplies from west coast ports.
- High temporal and spatial resolution sea ice analysis, ocean circulation, and forecasts and other critical decision and scientific support are needed to understand how oil, and other contaminants behave and are transported through icy waters and what the effects are on the environment and ecosystems.
- Longer-term and downscaled forecasts, especially on the seasonal scale, are needed by resource, ecosystem, community and transportations managers for a variety of critical planning purposes.

Workshop participants considered sea ice forecasting in three distinct scales:

- ***Weather scale (1 hour - 20 days)***
- ***Seasonal to inter-annual scale (21 days - 3 years)***
- ***Decadal scale (3 years - 30 years)***

In response to these growing needs, workshop participants were asked to consider sea ice forecasting in three time frames: weather-scale (1 hour to 20 days); seasonal- to inter-annual scale (21 days to 3 years); and decadal-scale (3 years to 30 years). The scales are based both on the types user communities needs and the methods for making forecasts (e.g. current conditions versus future projections). For each scale, the workshop working groups discussed the current state of the science and recommended priorities and actions in the following categories; in situ and satellite observations, model advancements and predictability, and key forecast products and stakeholder communities and needs.

Providing improved and expanded sea ice forecasts and information across all of these scales and needs will ultimately require improvements in sea ice, ocean, and atmospheric observations, modeling with data assimilation, increased model resolution and model verification, and working with partners, resource managers, forecasters, and stakeholders to develop sea ice forecasts, products, and information.

III. Key Findings for NOAA Sea Ice Forecasting on the Weather-Scale

There was a sense of urgency among those interested in forecasting at the weather-scale given that user demands are growing much faster than the capability of the forecasters and modelers. While weather and ocean/wave models outside the marginal ice zone in the Arctic have improved in the past few years, at present, there is no operational sea ice forecasting capability to support decision-makers. For example, the U.S. currently has no capability in place to predict ice on the 3-5 day time scale. This led the workshop participants to agree on one overarching weather-scale goal **--develop a coupled ice-ocean-atmosphere forecast model capability**. This model would ideally be developed with prescribed meteorological forcing, in high spatial and temporal resolution, to improve delivery of sea ice extent, concentration, thickness, and timing forecasts including forecasts of changes in land-fast ice and leads along shore or adjacent to land-fast ice. Model output should have a measure of uncertainty or probability so that users can perform their own risk analyses. Deterministic output is also required for accurate marine and coastal storm surge forecasts. Outputs from a coupled model should include growth and development of ice in the Marginal Ice Zone (MIZ), ice trajectory, and location and strength of shore-fast ice. Forecasts of fog, visibility, and ceiling, plus freezing spray information should also be improved.

Workshop participants agreed on one overarching weather scale goal --*develop a coupled ice-ocean-atmosphere forecast model capability*

Improving forecasts is intrinsically tied to additional requirements for enhanced in situ and satellite observations of the ocean, atmosphere, and sea ice. For example, in situ observations are critical for understanding the processes that influence ice melt and growth. A large fraction of the Arctic sea ice melt in summer and all of the thermodynamic growth in winter occurs at the ice-ocean interface. Improving forecasts of sea ice, on all but the shortest time periods, requires parallel improvement in general weather forecasts, especially wind forecasts as wind speed and direction are key drivers of ice dynamics at this scale –hence, wind observations are needed.

There is a need for improvement in storm surge prediction, which requires better ice, tides, circulation and bathymetry information. Accurate depiction and prediction of ocean state and circulation are critical for forecasters, operators in the Arctic, and our understanding of the changing Arctic-wide system. Detailed knowledge of the ocean stratification (temperature and density versus depth) is critical to understanding the temporal evolution of the sea ice mass. A modest number of in situ platforms that directly measure sea ice thickness, bottom and top ice ablation, surface air temperature, ocean temperature in the upper mixed layer, and other key variables are needed to support model-based forecasts.

Because sea ice covers such a large area and is constantly shifting due to winds and currents, commitments and improvements to satellite-based observations are important for observing large-scale characteristics of sea ice. Under favorable weather conditions or with the proper sensors, satellites can identify the presence of sea ice above a certain threshold (approximately > 15% coverage), provide rudimentary information on ice thickness (with significant uncertainty with present technology), detect leads, and identify changes in albedo due to melt ponds or other surface characteristics.

The group agreed that a coupled modeling effort of the scope needed should ideally be developed across NOAA (NWS, ESRL, NESDIS, GLERL), with external partners (NASA, Navy, BOEM, Environment Canada, Army Corps of Engineers, industry, WMO), and include input from stakeholders from the outset. Workshop attendees also stressed the idea of developing metrics to quantify not only forecast improvements but also the impacts on customers, stakeholders and their economies, safety, and decision-making.

A. Actions to Implement Sea Ice Forecasting on the Weather-Scale

In support of the longer-term overarching coupled ice-ocean-atmosphere model concept, the workshop participants identified key near-term actions that provide a pathway towards achieving this goal. Concepts such as observation enhancements and transitions, model development and improvements, interagency and international cooperation, product development and testbed implementation were discussed -- the following list of key, near-term actions was developed.

1. Observations and Data

- Support, enhance, and optimize key Arctic observations and systems:
    - Ensure that all relevant real-time data are placed on GTS in a timely fashion. Ingest existing research buoy observations into the MADIS to ensure maximum availability. Work with NWS/NBDC to capture buoy data in a common operating environment.
    - Enable incorporation of local sea ice observations into forecasts through a Cooperative Observer Certification Program for sea ice.
    - Aggregate and centralize real-time access to already existing atmospheric, oceanic and ice information via a common integration platform like AWIPS.
    - Exploit 'Ships of Opportunity' for obtaining much needed environmental information (e.g. bathymetry for bottom charts on shelves and near coastlines).
    - Initiate a NOAA plus partners 'Sea Ice Forecasting' standing coordination body to provide guidance on enhancing and optimizing observations, products, and interagency activities (e.g. developing buoy and mooring deployment plans that specify deployment plans by buoy type, sensors, data file structures, logistics plans, and agency coordination possibilities, etc.)
    - Evaluate R&D on techniques for getting sea ice information, especially thickness data, transmitted in real-time.

2. Models and Testbeds

- Support a workshop, or a series of workshops, focused on identifying and developing the coupled modeling approach and identifying the critical observational requirements.
- Accelerate the development and improve the capabilities and skill of the CFS model for the Arctic, including both improved sea ice representations and atmospheric circulation predictions.
- Improve models through Data Assimilation:
    - Attend CIS data assimilation workshop in Ottawa (December 12-14, 2011). Sponsor a follow-up workshop to continue to explore data assimilation studies with ONR and Environment Canada.
    - Evaluate R&D on techniques for getting sea ice thickness data, from all platform types, transmitted in real-time and made available to support model initialization.

    - Assimilate multi-satellite derived polar wind products into weather prediction models.
- Create a testbed environment that focuses on two areas: Bering Sea during winter/spring and Beaufort/Chukchi Seas during summer/fall. The testbed setting should provide an environment for researchers and forecasters to work in tandem to test different models, different model parameterizations, model physics, observations impacts, etc. and provide a collaborative atmosphere for discussions of products, observations, etc.
    - Compare the WRF model, developed at UAF with focus on ocean surface winds, to the NWS WRF operational model currently used for the Bering and Chukchi Seas.
    - Test experimental 5 km Navy model, with addition of local observations, in Chukchi/Beaufort area for NWS Ice Desk.
    - Continue to work with GOES-R high-latitude satellite ‘Proving Ground’ efforts.
    - Assess improved sea ice thickness outputs in NCEP CFSv3.
    - Explore icosahedral model sea ice development and testing using the FIM.

3. Products and Partners

- Deliver a real-time, satellite-derived ice leads product for distribution through NWS, NIC.
- Determine the roles, responsibilities, and spatial extent for NWS and NIC forecasts on the 4-14 day time scale.
- Develop a coordinated interface between the AOOS Sea Ice Atlas and NODC Arctic Atlas.
- Continue Arctic-ERMA development for oil spill and ecosystem response/management.
- Evolve the SIWO through enhanced collaboration with SEARCH and other agency and stakeholder partners to improve Spring/Summer 2012 product.
- Develop a data-sharing agreement to use CryoSat-2 for ice thickness.
- Continue to foster partnerships with NSF, NASA, Environment Canada, National Ice Center, North American Ice Service, BOEM, Shell, ConocoPhillips, Statoil and others through MOU’s/annexes.
- Support the needs of sea ice forecasts for ecosystem assessment and habitat management -- provide detailed information about sea ice floe size, shape, and state and depth of snow cover on that ice floe for marine mammals that use ice floes for habitat.

IV. Key findings for NOAA Sea Ice Forecasting on the Seasonal-Scale

A summer seasonal forecast is an important need. On a seasonal scale, sea ice impacts shipping, resource exploration, marine mammal habitat, coastal erosion, and regional weather, and provides evidence of longer-term climate change.

Workshop participants agreed that the Sea Ice Outlook (SIO) activity should continue as the experimental summer sea ice minimum forecast synthesis and dissemination mechanism. The U.S. should develop a plan to convert the SIO implementation from an informal ‘group of the willing’ to a formal program that includes improved cooperation with SEARCH and continues to encourage broad participation, including researchers from the U.K., Sweden, Canada, Germany, and operational ice centers.

The Sea Ice Outlook should continue on an international basis and be strengthened and expanded

The SIO effort should consider adding a 'fall freeze-up' prediction product to bracket the shipping season and continue to work toward sea ice distribution information in the Outlook. The ability to forecast the position of the ice edge, not only the total ice area, was considered as a critical enhancement to provide more value to users.

The Workshop participants concluded that the Sea Ice Outlook activity should be formalized with at least two dedicated groups running sea ice models, encouragement of continued atmosphere-ocean-sea ice climate modeling at NCEP and GFDL, and exploration of empirical methods. Research is needed to understand why the Arctic appears to be at a new-normal climate state. Improving forecasts will depend on providing improved coverage of sea ice data through enhancements to sea ice buoys, aircraft reconnaissance, and satellite products. Any new NOAA forecast product will depend on an improved observational base. Delivery of data in real time is important for delivery of nowcasts as well as forecasts on seasonal to annual time scales.

A. Actions to Improve Seasonal-Scale Sea Ice Forecasts

- Support model development for use in the Sea Ice Outlook, particularly focusing on how to assimilate sea ice information and produce meteorological forecast ensembles. The current work of Zhang (Univ. Washington) and Wang (NOAA/GLERL) provide examples of how this might be done. Analyses to determine cause for different ensemble projections is needed and should be supported.
- Improve coverage of sea ice observations through increased numbers of sea ice buoys, more frequent aircraft reconnaissance, and improved satellite products, especially for late spring (initialization), late summer (ocean) and early autumn (verification).
- Explore current Arctic climate and sea ice conditions to determine if the Arctic is truly in a new climate state ('new normal') over the last five years. What are the changes in initial ice conditions (distribution and thickness) and changing winds over this time period?
- Continue sea ice model development and evaluation in coupled atmosphere-ocean models at NCEP (through support for improving the representation and evaluation of Arctic processes in fully couple global seasonal forecast models like the CFS and CFSv2) and GFDL. Evaluate seasonal atmospheric projections and ensemble ranges.
- Consider empirical methods based on 'new normal' data. The current work of Arbetter (CRREL/NIC) and the Canadian Ice Service are examples of what needs to be done.
- Develop milestones and metrics to guide and evaluate the needed work, including comparison of methods.

Both enhanced models and an improved observational base are needed to support sea ice forecast improvements

V. Key findings for NOAA Sea Ice Forecasting on the Decadal-Scale

Sea ice is a major climate change indicator as there may be a nearly sea-ice free summer sometime before mid-century; changes are occurring now and are faster than projected by climate models. Sea ice is transitioning from old, thick ice to mostly mobile first-year ice. Not only will this impact regional shipping, exploration, and ecosystems but increased ocean heat in newly sea ice-free areas may impact subarctic climates.

Comprehensive Atmosphere-Ocean General Circulation Models (AOGCMs) comprise the major objective tool to account for the complex interaction of processes that determine future climate change. The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) is in current production with NOAA contributions, and final results will be available in late 2013 and 2014.

A. Actions to Implement Decadal-Scale Products

- Analyze results from the models for IPCC AR5 (called CMIP5, the latest version of the Coupled Model Intercomparison Project), now becoming available. Emphasis should be on the models' ability to capture natural variability of the atmosphere-ocean-ice system, thereby assessing the suitability of models for probabilistic predictions over decadal timescales.
- Support continued improvements in sea ice parameterizations and specialized analyses of Arctic climate in AOGCMs at GFDL and other centers.
- AOGCMs have coarse spatial resolution and are often difficult to interpret on small regional scales. This limitation is important for ice conditions near complex coastlines. NOAA and its partners should continue to evaluate downscaling methods and results, especially for Alaska, using statistics and regional modeling.

VI. Workshop Presentation Summaries

A. Summary of Weather-Scale Presentations

Activity in the Arctic continues to increase at a rapid pace and the interest is not limited to countries bordering the Arctic. In fact, there are a number of governments and commercial entities who currently, or plan to, exploit the Arctic for shorter shipping lanes, food, and the extraction of minerals, oil, and natural gas. Unlike the lower latitudes, there is little observational data in the Arctic. In addition, numerical modeling of the atmosphere and ocean has been demonstrated to be less accurate than in lower latitudes. This leads to inevitable gaps in NOAA's ability to provide critical decision-making information to customers and stakeholders.

Ongoing activities in the Arctic are proceeding with limited available forecast capabilities. In other words, choices regarding infrastructure, ecosystem impacts, as well as, day-to-day operations are being made without the appropriate capabilities needed to make the best-possible decision. For instance, Red Dog Mine near Kotzebue, Alaska (the world's largest zinc mine) is limited to shipping ore during periods that are ice-free. Currently, shipping begins late and is curtailed early to minimize the risk of an ore ship encountering sea ice. Accurate sea ice forecasts would allow better supply chain management of the shipping and improve navigation safety (Fig. 1). There is a similar narrative for offshore oil and gas exploration and production activities.

Both drilling ships and "jack-up" rigs used by the oil industry are highly sensitive to sea ice. Due to these concerns, drilling is planned based on climatology --and the climatology is highly conservative. Improved weather-scale sea ice forecasting capability would lead to improved risk analysis and decision-making for safe and efficient operations.

One of the more significant problems faced by forecasters in Alaska is the relationship between arctic sea ice and storm surges. The presence of significant shore-fast sea ice is known to act as a buffer, somewhat protecting coastal areas from the effects of waves and surge with coastal storms. With diminished shore-fast sea ice during the winter and spring sea-storm season, forecasters now need tools to assess the impact of slush ice and drifting young ice during coastal storm events.

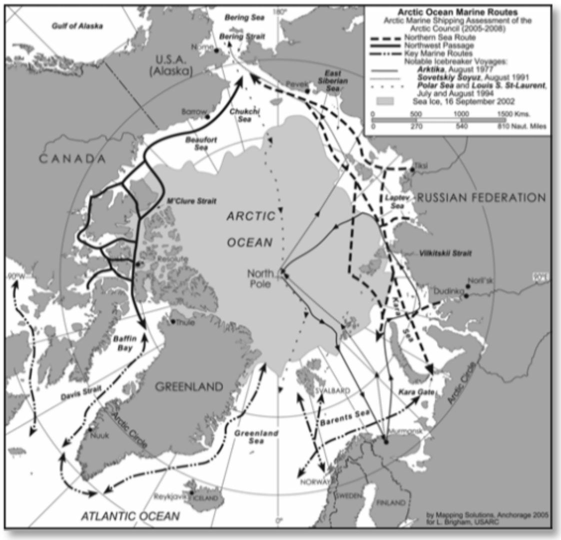


Figure 1. Possible Arctic Ocean marine routes.

Other critical decision support issues are further complicated by gaps in our sea ice forecasting capabilities. First and foremost is the lack of understanding of how oil, and other contaminants, behaves in the Arctic. Whether an oil spill results from a wrecked ship or a fault with an oil well, NOAA needs to be better equipped to provide scientific support regarding the behavior and transport of petroleum in cold water and ice, including high temporal and spatial resolution sea ice analysis, ocean circulation, and forecasts. Implicit in this discussion are the ecosystem impacts and the relationship between the physical ocean, ice, and atmospheric parameters to the biosphere.

Workshop participants agreed that there was a strong need for stakeholder input to ensure the science and technology was focused on creating actionable information. Stakeholder involvement includes other agencies as well as those in the private sector, such as the oil and gas industry. The involvement should not be limited to gathering requirements, but should include meaningful, ongoing collaboration. Metrics should be developed to measure the impacts on our customers and stakeholders and their economies, safety, decisions, etc. which is a step beyond merely measuring forecast accuracy. Finally, workshop participants agreed this issue is bigger than just Alaska –sea ice forecasting is a North American issue.

B. Summary of Seasonal-Scale Presentations

The state of sea ice at the end of summer (August through October) is a principal concern, especially north of Alaska, as the Chukchi and Beaufort Seas are major areas of summer sea ice retreat. This is the season where current sea ice conditions substantially depart from previous sea ice extents and sea ice is expected to continue to decrease and thin. In every September since 2007, sea ice extents have lower values that those before 2007. While there has been a downward trend in sea ice extent since 1979, the last five years (2007-2011) all have values at or below the long term trend line (Fig. 2). New, extensive sea ice-free areas improve access for shipping and resource exploration. Open ocean areas allow for increased wave activity and shore erosion, increased storms, and increased marine safety concerns. Sustained open water with additional ocean heat storage will impact regional climate over adjacent land areas and lead to shifts in marine ecosystems and harvestable living marine ecosystems.

There is evidence that changing conditions in the Pacific Arctic may lend more possibility for seasonal forecasts of September sea ice conditions from end of spring data. The current Sea Ice Outlook that projects September sea ice extent based on May data uses model, statistical and empirical projections from contributions by Arctic scientists and international Ice Centers (Fig. 3). For 2011, the median Outlook projection for September sea ice extent was 4.7 million square kilometers compared to a verifying value of 4.6 million square kilometers. Both models and empirical approaches are including recent trend and persistence information (www.arcus.org/search/seaiceoutlook).

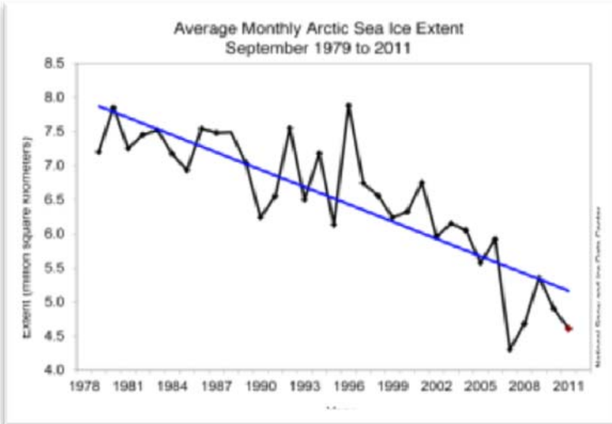


Figure 2. Monthly September ice extent for 1979 to 2011 shows a decline of 12.0% per decade.

Scientific studies of Drobot, Bitz, Lindsay, Holland, and associates (e.g. Blanchard-Wrigglesworth et al., 2011, *Journal of Climate*) show some weak predictability of summer sea ice conditions from spring or even previous October conditions based on regression and numerical model studies using data from the 1990s and early 2000s. One problem is the uncertainty of forecasting summer *weather* conditions. An important observation is that while the 2007 ice loss had much to do with supportive wind patterns in July and August, 2010 and 2011 show low sea ice extents at the beginning of the summer season that may provide some predictability of relatively low, end of summer sea ice extents, even for average summer wind conditions (Fig. 4).

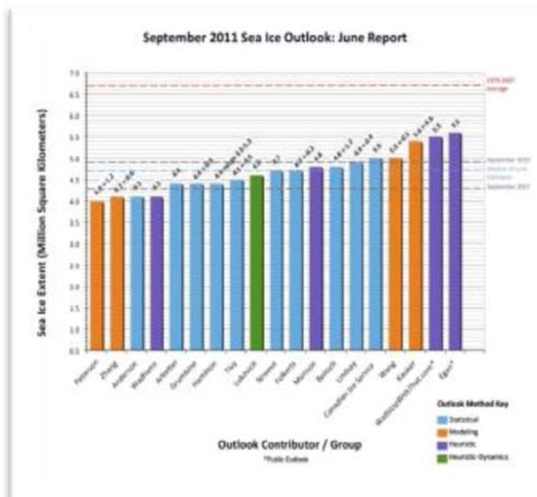
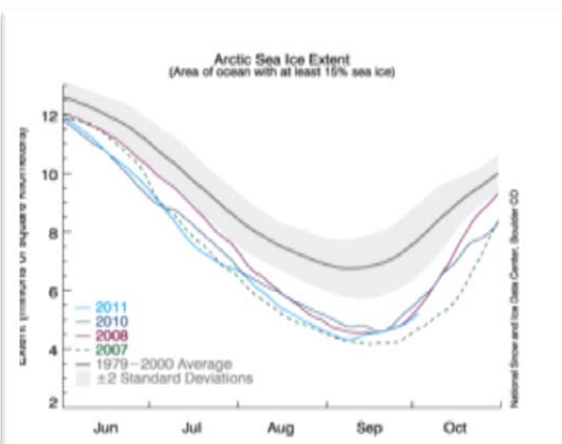


Figure 3. Distribution of individual Pan-Arctic Outlook values based on May data for September 2011 sea ice extent.



Major approaches for the Sea Ice Outlook include running high resolution sea ice/ocean models with hindcast weather data during winter to initialize the sea ice field and then an ensemble of previous years' summer wind fields to obtain a range of outlooks for September sea ice. Other approaches include probabilistic and empirical methods based on observed sea ice conditions. New options are evaluating and using available summer ensemble atmospheric predictions.

Figure 4. Daily Arctic sea ice extent as of October 1, 2011, with daily minimum ice extents for the previous 3 lowest years.

C. Summary of Decadal-Scale Presentations

1. Use of Climate Models

Complex atmosphere-ocean general circulation models are the primary tool for projecting future climate change while accounting for chaotic natural variability

At decadal time scales, forecasts are not based on initial conditions but on changes in external forcing, primarily human-caused increases in greenhouse gases. Comprehensive AOGCMs comprise the major objective tool to account for the complex interaction of processes that determine future climate change. The Intergovernmental Panel on Climate Change (IPCC) used the projections from about two dozen AOGCMs developed by 17 international modeling centers to form the basis for the results in their Fourth Assessment Report in 2007 (IPCC AR4). NOAA provided major evaluation of these model results. The IPCC Fifth Assessment Report is in current production and final results will be available in late 2013 and 2014. New model projections are becoming available and are archived as part of CMIP5.

While the timing of climate events has uncertainty due to natural variability and structural differences among models, continued increase in greenhouse gases is a major source of modeled future loss of sea ice

Sea ice is impacted by increases in greenhouse gases, often termed "external forcing," and internal or unforced variability, which are changes in wind and temperature fields due to the chaotic nature of atmospheric general circulation. One complication in the Arctic is that external forcing and internal variability can reinforce each other, such as in 2007 which created a major summer sea ice minimum. It is known that if climate models are run several times with slightly different initial conditions - called ensemble members - the trajectory of day-to-day and indeed year-to-year evolution will have different timing of events, even though the underlying statistical character of the model climate is similar for each run. This internal variability is a feature of the real climate system, and users of climate projections must recognize its importance. The timing of sea ice loss in single AOGCMs varies among ensemble members because the timing in internal variability, extremes, and their interaction with the global warming external forcing varies for different ensemble members. Since on decadal time scales the timing of internal variability events cannot be predicted, the normal procedure for climate projections is to average several ensemble members together to give an expected value for sea ice changes due to external forcing alone, and note the range of ensemble members as a measure of uncertainty in the timing of events. If models simulate internal variability realistically, their output can provide probabilities of sea ice changes of a particular sign and magnitude over a prescribed timeframe. Figure 5 (red line) suggests increased loss of sea ice in the 21st century, but there is a range of possible trends due to the uncertainty of internal variability.

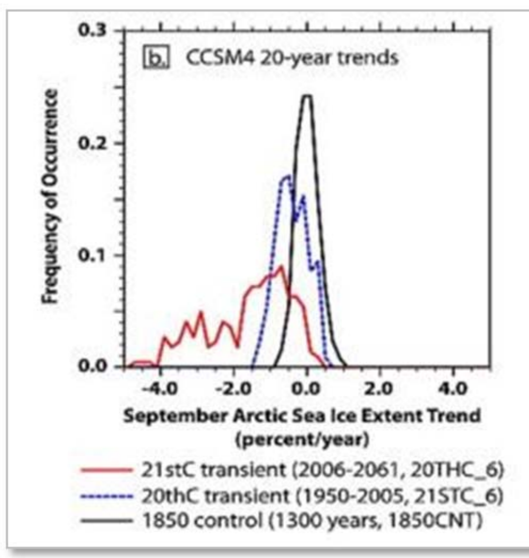


Figure 5. Range of potential sea ice loss trends for the 20th and 21st centuries --*after Kay et al., 2011 GRL.*

In addition to uncertainty due to the influence of internal variability, there are two other sources of model uncertainty. A second source of uncertainty arises from the range in plausible emissions scenarios. Emissions scenarios are developed based on assumptions for future development of humankind and associated energy needs and sources; for each scenario, estimates are made for greenhouse gases and aerosol concentrations, which are then used to drive the AOGCMs in the form of external forcing specified in the CMIP5 models. Because the residence time of carbon in the atmospheric system is on the order of centuries, climate projections for the next few decades are relatively insensitive to the precise details of which future emissions scenarios are used, as the impacts of the scenarios are rather similar before mid-21st century. For the second half of the 21st century, however, and especially by 2100, the choice of the emission scenario becomes the major source of uncertainty in climate projections. The third source of uncertainty is termed structural uncertainty. Different numerical approximations of the model equations, including spatial resolution, introduce part of the structural uncertainty. Sub-grid scale processes must be parameterized in all models; these parameterizations by necessity are simplifications of complex processes and require tuning. Results from multiple models have the advantage of sampling structural uncertainty.

2. Climate Model Downscaling for Alaska

The Scenarios Network for Alaska Planning (SNAP) program at the University of Alaska is an example of downscaling global climate model output to the local scale, in this case for terrestrial locations of Alaskan communities. The activity consists of the following steps: (1) identification of the best-performing CMIP3 global models that best capture Alaska's present-day climate, including its seasonal cycle, (2) definition of a high-resolution (2 km or 0.8 km) baseline climatology, based on products from the Parameter Regression on Independent Slopes Model (PRISM), and (3) superposition of the changes projected for future time-slices by the best-performing global climate models. This approach, known as the Delta method, resolves the topography and coastline at the 2 km or 0.8 km resolution of the baseline climatology, but the superimposed changes are at the coarse resolution (~200 km) of the global models. To date, the downscaling by the Delta method has been done for temperature and precipitation, on a calendar-month basis, for decadal time slices and the IPCC A2, A1B and B2 scenarios. An example is shown in Fig. 6 which depicts downscaled temperatures for January 2070-2090 relative to the 1961-1990 baseline climatology. In addition to spatial maps, the products accessible online (www.snap.uaf.edu) include seasonal bar graphs illustrating the various scenarios of temperature and precipitation for 353 specific communities in Alaska. Derived fields of evapotranspiration and soil (permafrost) temperature have also been produced. Needed next steps include 1) extensions to the offshore regions and 2) identification of extreme events by the use of quantile-mapping of daily distributions, using methodologies such as Bias Correction Spatial Disaggregation.

Downscaling of global models is critical for providing useful information for decision-makers

An alternative to empirical (statistical) downscaling is dynamical downscaling, which consists of the implementation of high resolution modeling – usually with a regional climate model – over the region of interest. Dynamical downscaling offers some advantages in areas such as offshore seas, where historical records of high-resolution observational data are not available for use in statistical downscaling. Offshore regions affected by sea ice are prime examples of areas for which some sort of downscaling (either statistical or dynamical) will be needed if climate models are to provide useful decadal-scale predictive information. There is room for novel approaches involving the use of high-resolution sea ice/ocean models in conjunction with the atmospheric output from global or regional climate models.

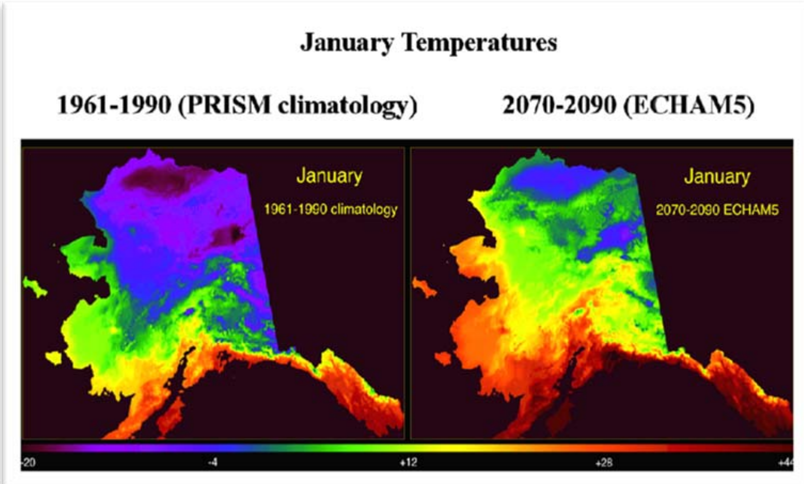


Figure 6. Comparison of late 20th century and future conditions downscaled for Alaska.

VII. NOAA Plans for Action in Response to the Workshop

This report describes the results from the September 2011 NOAA workshop on sea ice forecasting. It presents views from a number of experts on the current state of sea ice forecasting as well as recommendations for improving sea ice forecast capabilities. The report has been reviewed by workshop participants and is an accurate reflection of the discussions held at the workshop.

The next step in the process is to prepare NOAA to take action on the workshop recommendations. This will require a **Sea Ice Forecasting Implementation Plan** that describes specific steps to be taken, assigns responsibilities, and estimates a time line and resources required to address the recommendations. It is intended to focus the implementation plan on FY2012 through FY2014 and to identify actions that may be taken within current resource constraints. The plan may also identify high priority actions for future years that may require additional resources for completion. To the extent possible, the implementation plan will identify actions that may be taken by external partners that could prove mutually beneficial and enhance activities of all parties involved. The intention is to present the draft implementation plan to NOAA leadership in 2012 for their consideration and potential action.

A NOAA Sea Ice Forecasting Implementation Plan will be developed that describes specific steps, assigns responsibilities, and estimates a timeline and resources required to address recommendations

VIII. Appendices

A. Workshop Agenda

September 19, 2011

0830 – Registration – collect small fee to cover coffee and snacks

0900 – Opening and Introductions – John Calder

0915 – Welcoming Remarks/Local Logistics – Frank Kelly

0930 – Review of workshop purpose and structure– John Calder

0945 – Summary presentation on current status of sea ice forecasting at "weather" scales – Carven Scott

1100 – Technical presentations related to sea ice forecasting at "weather" scales - Carven Scott

Carven Scott - Groundwork for Decision Support
Gary Hufford - Remote sensing of sea ice
Aimee Fish - Arctic Observations
Kathleen Cole - Current Alaska Ice Products/Services
Chris Szorc - Current NIC Ice Products/Services
Tom Carrieres - Current CIS Ice Products/Services
Rick Allard - NRL Ice Modeling
Darlene Langlois - CIS Ice Modeling

1330 – Summary presentation on current status of sea ice forecasting at seasonal scales – Jim Overland

Review of current forecast products
Review of tools and types of data used to produce current products
Overview of Sea Ice Outlook

1415 – Short (10 minutes) presentations by:

Climate Prediction Center – Wangqui Wang
Great Lakes Forecast System – Jia Wang
Model-based projections – Jinlun Zhang
Seasonal prediction algorithms - Adrienne Tivy
Sea Ice Forecasting – Synergies and collaboration with SEARCH – Hajo Eicken

1600 – Review of current status of sea ice forecasting at interannual to decadal scales – John Walsh

Review of current forecast products
Review of tools and types of data used to produce current products
Discussion of metrics used to evaluate skill

1630 – Presentations by:

IPCC model evaluation – Jim Overland, IARC representative

September 20, 2011

0900 – Break-out groups set #1

a. Focus on user and stakeholder needs for data products, forecasts/predictions, communications, etc., – Leader, Sarah Trainor
b. Focus on current state of predictability at each scale, uncertainties, metrics, and also on current status of models and improvements needed – Leader, Adrienne Tivy

1100 – Break-out groups set #2

c. Current status of in situ observations and unmet needs, technologies – Leader, Andrey Proshutinsky
d. Current status of satellite products, uncertainties, improvements needed – Leader, Jeff Key

1330 – Summary reports from 4 break-out groups

1500 - Discussion of summary reports

1600 – Summary and discussion of requirements for model improvements needed for sea ice forecasts – Leader, Ron Lindsay

1645 - Summary and discussion of requirements for observational improvements needed for sea ice forecasts – Leader, Jackie Richter-Menge

1730 – Adjourn for the day

September 21, 2011

0830 – Break out groups set #3

e. Focus on developing specific recommendations and priorities for improving sea ice forecasting at "weather" scales – Leader Carven Scott
f. Focus on developing specific recommendations and priorities for improving sea ice forecasting at seasonal scales – Leader Jim Overland

1030 – Summary reports from 2 breakout groups

1100 – Discussion of summary reports

11:30 - Approach for preparation of Implementation Plan – Janet Intrieri

1230 – Adjourn workshop; special presentation by Marty Kress on PEOPLE-ACE

B. Registered Workshop Participants

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C. Workshop Materials Available on www.arctic.noaa.gov

Workshop on Sea Ice Analysis and Forecasting

- Introduction - Sea Ice Analysis and Forecasting: Rationale, Objective, Organization

Weather-Scale

- Arctic Cap Nowcast/Forecast System - Rick Allard, Pam Posey, Joe Metzger, Alan Wallcraft, David Hebert, Ruth Preller- Naval Research Laboratory; O. M. Smedstad – QinetiQ North America; M.W. Phelps – Jacobs Engineering
- National / Naval Ice Center (NIC) - Christopher Szorc, Senior Ice Analyst/Forecaster
- Overview of Ice Modelling Projects - Tom Carrieres, Canadian Ice Service
- Products and Services at the Canadian Ice Service - Darlene Langlois, Canadian Ice Service
- NWS Alaska Sea Ice Program - Kathleen Cole, Sea Ice Program Leader, National Weather Service, Anchorage, Alaska [PPT format, didn't convert properly to PDF]
- Sea Ice Damage Kotzebue May 2011
- NWS Alaska Region Satellite Data Capture System

Seasonal-Scale

- Sea Ice Outlook - Jim Overland, NOAA PMEL
- Numerical Ensemble Seasonal Forecast of Arctic Sea Ice - Jinlun Zhang, PSC/APL/UW
- Seasonal Prediction Algorithms: Statistical Methods in Seasonal Sea Ice Forecasting - Adrienne Tivy
- Seasonal sea ice forecast from NCEP CFSv2 - Wanqui Wang, NCEP
- Charting a new seasonal outlook for the National Ice Center (NIC) - Todd Arbetter, Pablo Clemente-Cólon, Sean Helfrich, Christopher Szorc, Ignatius Rigor, Son Nghiem
- Presentation for International Arctic Buoy Programme: Buoys and NSIDC Ice Concentration & associated Arctic Domain Awareness Video YouTube video (or as .mov movie) - Ignatius Rigor
- Sea Ice in the NCEP Forecast System - Xingren Wu, EMC/NCEP and IMSG, and Robert Grumbine EMC/NCEP
- Synergies & Collaboration with SEARCH - Hajo Eicken, Chair, SEARCH Science Steering Committee

Decadal- and Longer-Scale

- Sea ice predictability: Interannual to decadal - John Walsh, International Arctic Research Center, University of Alaska, Fairbanks
- Reduction of Uncertainties in Arctic Sea Ice Prediction - From Decadal to Century Scales through Climate Sensitivity Constraint - Xiangdong Zhang, International Arctic Research Center, University of Alaska Fairbanks

D. Acronym List

AOGCM – Atmosphere-Ocean General Circulation Model

AOOS – Alaska Ocean Observing System

AR5 – IPCC Fifth Assessment Report

AWIPS – Advance Weather Interactive Processing System (NOAA/NWS)

BCSD – Bias Correction Spatial Disaggregation

BOEM – Bureau of Ocean Energy Management

CFS – Climate Forecast Model (NOAA/NWS/NCEP)

CIS – Canadian Ice Service

CMIP – Coupled Model Intercomparison Project

CPC – Climate Prediction Center (NOAA/NWS)

CRREL – Cold Regions Research and Engineering Laboratory (U.S. Army)

EEZ – U.S. Exclusive Economic Zone

ERMA – Environmental Response Management Application

ESRL – Earth System Research Laboratory (NOAA/OAR)

FIM – Flow-following, finite Icosahedral Model

GFDL – Geophysical Fluid Dynamics Laboratory (NOAA/OAR)

GLERL – Great Lakes Environmental Research Laboratory (NOAA/OAR)

GTS – Global Telecommunications System

IPCC – Intergovernmental Panel on Climate Change

MADIS – Meteorological Assimilation Data Ingest System

MIZ – Marginal Ice Zone

MOU – Memorandum of Understanding

NBDC – National Buoy Data Center (NOAA)

NCEP – National Center for Environmental Prediction (NOAA/NWS)

NESDIS – National Environmental Satellite Data and Information Service (NOAA)

NIC – National Ice Center

NOAA – National Oceanic and Atmospheric Administration

NODC – National Ocean Data Center (NOAA/NESDIS)

NSIDC – National Snow and Ice Data Center

NWS – National Weather Service (NOAA)

OAR – Office of Oceanic and Atmospheric Research (NOAA/OAR)

ONR – Office of Naval Research

SEARCH – Study of Environmental Arctic Change

SIO – Sea Ice Outlook

SIWO – Sea Ice Walrus Outlook

SNAP – Scenarios Network for Alaska Planning

WRF – Weather Research Forecast Model