Operational polar ice forecasting

USS Honolulu in Arctic pack ice (Photo: Arctic Submarine Laboratory)

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Introduction

The Arctic is one of the most hostile operational environments in the world. Free drifting icebergs, shifting boundaries of pack ice, 24-hour darkness, sub-zero temperatures, icing on ship's equipment and superstructures, and a lack of dependable logistical support can make Arctic operations extremely dangerous for ships, aircraft, and submarines. Given these hostile operating conditions, real-time information and accurate forecasts can mean the difference between mission success and major equipment damage.

Despite the difficulty of operations in this environment, numerous vessels transit the Arctic regularly and the volume of traffic is likely to increase in the near future because of diminishing ice cover. Canada, Denmark, the Russian Federation, the USA and other Arctic bordering nations have a presence in the Arctic.

Scientists have conducted extensive research in the Arctic for the past several decades, but more recently, oil and gas interests have spurred increased Arctic exploration. Recently, a team of over 300 scientists confirmed unprecedented changes occurring north of the Arctic Circle. The Arctic Climate Impact Assessment (ACIA) released in November 2004 describes these changes including a 3 per cent per decade northerly retreat of the ice edge or extent at the end of the summer season (Figure 1).

As the Arctic becomes increasingly accessible with diminishing ice, large reserves of oil and gas are simultaneously being discovered, adding to the Arctic's strategic and economic value. A combination of commercial and scientific interests makes knowledge of current Arctic conditions critical to support operations.

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Arctic conditions and operational requirements

Arctic conditions are highly variable and thus difficult to predict. The ice and snow that cover the cold Arctic Ocean area vary on decadal, interannual, seasonal and even short time-scales, such as days to weeks. This variability in the sea-ice cover is due to a combination of dynamic and thermodynamic effects. Surface stresses on the top and bottom of the ice cause the movement of sea ice as

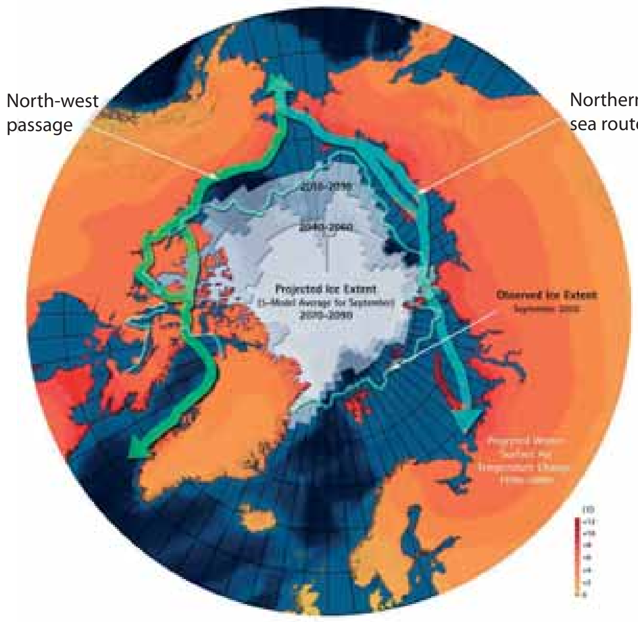

Figure 1 — Projected ice extent for 2010-2090 (Arctic Climate Impact Assessment, 2004)

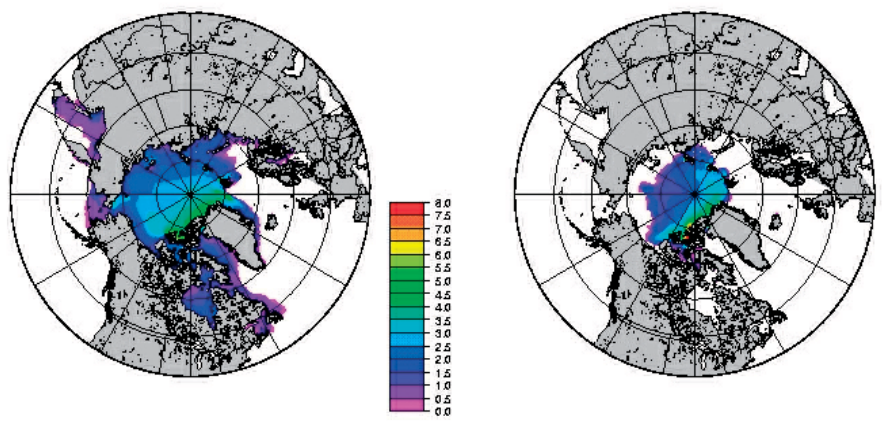

Figure 2 — Typical (a) winter and (b) summer ice-thickness (m) forecast from the Polar Ice Prediction System (PIPS 2.0).

well as the deformation of the ice, building ridges and generating areas of open water. Heating and cooling from the atmosphere and ocean in combination with the ice motion are largely responsible for the growth and decay of sea ice.

On a basin scale, Arctic variability is seen as ice thinning in some regions while growing in others. This variability is often represented by a see-saw effect when one part of the Arctic basin experiences a "mild" ice year, while another part has an increase in ice extent and thickness (Preller *et al.*, 2002). However, during the past two decades, decreases in ice extent have been observed throughout the periphery of the Arctic Ocean (ACIA, 2004).

The thinnest sea ice and largest amount of open water in the Arctic appear from June to September. Ice begins to grow in the fall and builds to a maximum thickness in the late winter and early spring, March-April (Figure 2). Many of the marginal seas, such as the Barents and Greenland Seas are nearly ice-free in the summer. Other marginal seas, such as the Bering Sea and the Sea of Okhotsk, are completely ice-free in the summer.

Viewing the Arctic from an operational perspective requires focus on highly variable parameters such as: knowledge of ice extent, coverage, thickness and movement in small and defined areas. To a submarine or surface ship, knowing the location of divergent motions that produce open water and regions of strong convergent motion is also critical. Awareness of ridging or folding of the ice along with the locations of small and large cracks in the ice and open pools of water (referred to as fractures, leads and polynyas) is additionally required for traversing the Arctic. Because of these specific needs, forecasting tools, observations and ice charting must either be developed specifically to match operational requirements or modified to suit these specialized needs.

Status of Arctic observations and forecasting capabilities

The real-time tools available to provide information on ice conditions operationally are limited. To obtain an accurate "nowcast" or present snapshot of the Arctic requires a combination of *in situ* observations and satellite imagery. As an "Action Group" of the WMO's Data Buoy Cooperation Panel (DBCP), the International Arctic Buoy Programme has been a cornerstone of these operations since 1979. During this time, an array of buoys has collected and transmitted data on air temperature, pressure and position in the Arctic (http://iabp.apl.washington.edu). Newly engineered buoys are capable of measuring ice thickness as well as collecting oceanographic data. This observational array of information is growing through international cooperation and provides high temporal resolution, *in situ* observations, which complement the high spatial resolution of remotely sensed imagery.

Ice-charting agencies rely most heavily upon real-time satellite observations from many different sources such as the US National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), Canada's RADARSAT and Europe's ENVISAT. Satellite observations are used daily by operational centres such as the US National Ice Center (NIC) to provide a picture of current ice conditions in both the Arctic and Antarctic.

Unfortunately, satellite observations and buoy data are not enough to give full coverage of the ice conditions. Often, satellite coverage is incomplete, as in the case of commercial Synthetic Aperture Radar (SAR) observations. In the case of visible imagery, clouds and precipitation degrade the image, thus causing gaps that must be fillied in by the analyst using computer-generated models and algorithm ouputs as guidance.

Ice models are designed to fill these gaps and make up for the deficiencies in both satellite imagery and observational data. Generated on large-scale super computers, models use an analysis or initial state of the ice field

before generating a "forecast" (future guess of ice conditions). These analyses can be combined over the past several days to compile a history or "hindcast" of ice motion and other information. Thus, the ice extent and partial concentrations of various stages (proxies for thickness) of ice can be estimated by starting at the last known analysis and then projecting the probable state of the ice field forward in time using the "hindcast" data. Without this model guidance, the analyst would be left to estimating the state of the ice in the gaps by generating ice motion manually, which would be a tedious and almost impossible task.

The Naval Research Laboratory (NRL) has been developing sea ice forecast systems tailored to fit the needs of their Navy customers. The existing forecast system currently in operational use is the Polar Ice Prediction System (PIPS 2.0). PIPS 2.0 provides forecasts in all sea-ice-covered areas in the northern hemisphere (down to 30°N latitude). The horizontal grid resolution of the PIPS 2.0 model is 0.28° and ranges from 17 to 34 km. Figure 3 shows the PIPS 2.0 grid (red dots) plotted at every fourth grid point. PIPS 2.0 uses the Hibler dynamic/thermodynamic ice model (Hibler, 1979) coupled to the Bryan and Cox ocean model (Cox, 1984).

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Figure 3 — Polar Ice Prediction System (PIPS 2.0) model domain and grid: every fourth point is plotted.

The Navy Operational Global Atmospheric Prediction System (NOGAPS) (Hogan and Rosmond, 1991) provides atmospheric wind stresses. Fluxes to the ice model and ocean forcing come from a fully coupled ocean model. The forecast products from PIPS 2.0 include ice drift, ice thickness and ice concentration. These products are disseminated daily from the operational centre to the National Ice Center for use by the ice analyst. Along with these existing products, PIPS 2.0 has the capability to forecast ocean currents, ocean temperature and salinity.

In real-time forecasting, unexpected problems (such as computer downtime or cloudy days for imagery) could cause serious problems if the analyst were dependent on only one source of information. At most of the operational centres, ice-forecasting systems (e.g. PIPS 2.0) are the only objective input for locating the ice edge and concentration boundaries when SAR or clear and daylight visible imagery (Advanced Very High Resolution Radiometer (AVHRR), Operational Line-Scan (OLS), etc.) is not available. For this reason, the computer-generated forecast helps the analyst determine where the ice has moved over a period of time and thus estimates the ice edge/location. With the variety of information (ice forecasts, satellite data, observations etc.) the analyst is not dependent on one particular data source to produce an ice edge chart.

International collaboration and ice charting

Real-time sea-ice observations, analyses and forecasts are now available from ice centres around the world (Canada, Denmark, Finland, Iceland, Japan, Norway, Russian Federation, Sweden and the USA). These centres are usually responsible for providing information on ice conditions near their own coastlines (e.g. the Russian Federation in the Arctic Shelf Sea, Finland, Germany and Sweden in the Baltic) and supply the user with products ranging from harbours and bays to tactical routeing of ice-breakers. Forecasting is critical to all agencies with an operational Arctic interest.

Given the global interest in the Arctic, international collaboration is key to maintaining the best operational Arctic information possible. The International Ice Charting Working Group (IICWG) was formed in October 1999 to promote operational cooperation between the world's ice centres on all matters concerning sea-ice products and icebergs (http://nsidc.org/noaa/iicwg/). This Group strives to maintain ice charting as well as to share remote-sensing and forecasting information. Members of the IICWG are partnering to promote cooperation in

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mutual areas of interest and to reduce redundancy.

The Canadian Ice Service and the US National Ice Center, under the auspices of the North American Ice Service, have formed such a partnership to provide forecasts for US and Canadian waters, including the Great Lakes. This type of collaborations promotes consistency between the ice-charting agencies and are critical for sharing scientific knowledge.

Future trends in ice forecasting

Scientists and modellers are currently validating the newest short- and long-range ice-forecast models. Increased knowledge of the correlation between the winter Arctic Oscillation (AO) and summer sea-ice extent has been documented and is being incorporated into new seasonal forecasts (Rigor *et al.,* 2000; Rigor and Wallace, 2004). Resolving small-scale features such as fractures, small polynyas and the formation of ridges is another area of current research (Gow and Tucker, 1990; Kwok *et al*., 2003). This work will enable ice services to improve short- and long-range forecasts.

Understanding sea-ice dynamics and thermodynamics, as well as observing ice conditions, are all critical to improving the quality of operational models and forecasts. New ice models such as the Los Alamos Sea Ice Model (CICE) (Bitz and Lipscomb, 1999; Hunke and Dukowicz, 1997) have synthesized the technology of the last 10 years. In addition, ocean models have advanced over the past decade into fully global ocean models (Chassignet *et al*., 2003), capable of predicting ocean currents, temperature and salinity with greater accuracy (Rhodes *et al*., 2002). These improved ocean products will, in turn, be used as input into sea-ice forecasting systems.

An additional critical factor in the improvement of ice modelling and forecast capabilities is computer technology. Computer codes now make use of multiple processors and can perform more extensive computations in operationally acceptable time periods. With all of these recent improvements, a more sophisticated ice and ocean model, together with assimilating improved real-time satellite imagery, will be able to produce a more realistic ice condition for the polar regions.

Conclusions

The Arctic has been, and will continue to be, a region of strategic and operational interest. Given the potential energy resources available in the Arctic and reports of diminishing ice, the Arctic remains economically important. However, the harsh conditions in this environment make operators heavily reliant upon accurate ice information to protect life and equipment. Ice-charting agencies must use all resources available to create an accurate snapshot of the Arctic, including the use of *in situ* observational and remotely sensed data.

Given the limitations of both of these, operational ice-forecasting systems are critical components of ice-chart creation. It is vital that international cooperation and ongoing scientific research continue to contribute to operational forecasting capability. This work will make major strides toward making the Arctic a safer place in support of global strategic, economic, and scientific interests.

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