9.5 TEMPORAL AND REGIONAL VARIATIONS OF SEA ICE THICKNESS IN THE ROSS SEA DURING 1995 AND 1998

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1. INTRODUCTION

Sea ice is an integral component of the polar climate system. The high albedo surface reflects solar radiation while its porous interior insulates between the atmosphere and the ocean. The formation processes of sea ice involves salt rejection to the water underneath leading to densification of water, overturning, and contributions to deep ocean convection and the thermohaline circulation. Such interconnectivity at the boundary layer makes sea ice a sensitive indicator of climate change. These roles, along with the vast expanse of sea ice cover (~6% of the earth's surface), emphasize the importance of sea ice in the global climate system.

In the Arctic, research examining the satellite passive-microwave data found an overall decreasing trend of 2.8% per decade in sea ice extent and area over the last 20 years (Parkinson et al. 1999). In addition, research using a long record of declassified submarine data reveals a marked reduction of 40% in sea ice thickness over the past three decades, which establishes a significant climate-scale trend (Rothrock et al. 1999). No similar climatology currently exist to examine Antarctic sea ice thickness, hence similar changes in the southern hemisphere may be going unnoticed (Worby and Ackley 2000, Geiger et al. 2000).

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A National Science Foundation (NSF) project is near completion with researchers at the University of Delaware, the Cold Regions Research and Engineering Laboratory, the Australian Antarctic Division, the National Ice Center (NIC) and Clarkson University to evaluate the NIC weekly ice charts against in situ sea ice thickness observations. The goal is to ascertain their quality for use in monitoring sea ice thickness and mass balance changes in the Southern Ocean with an initial project in the Ross Sea. This paper focuses on the comparison results between NIC charts and ship observations in 1995 and 1998 including sea ice extent, thickness variability, and monthly thickness distribution.

2. HOURLY SHIP OBSERVATIONS AND WEEKLY NIC CHARTS

Two datasets are used in this study to investigate sea ice extent and thickness. The first is acquired from the Scientific Committee on Antarctic Research (SCAR) that has established the Antarctic Sea Ice Processes and Climate (ASPeCt) program to compile and standardize an extensive archive of ship observations. The ASPeCt program has identified data collected during more than 80 voyages resulting in over 20,000 individual records of Antarctic sea ice conditions since 1980. Sea ice thickness is estimated as both an ice type thickness range and an estimated thickness (to within 10 cm accuracy). A trained ice observer estimates the ice thickness as the ice turns sideways along a ship's hull using a ball of known diameter hung over the ship's side (Worby 1999).

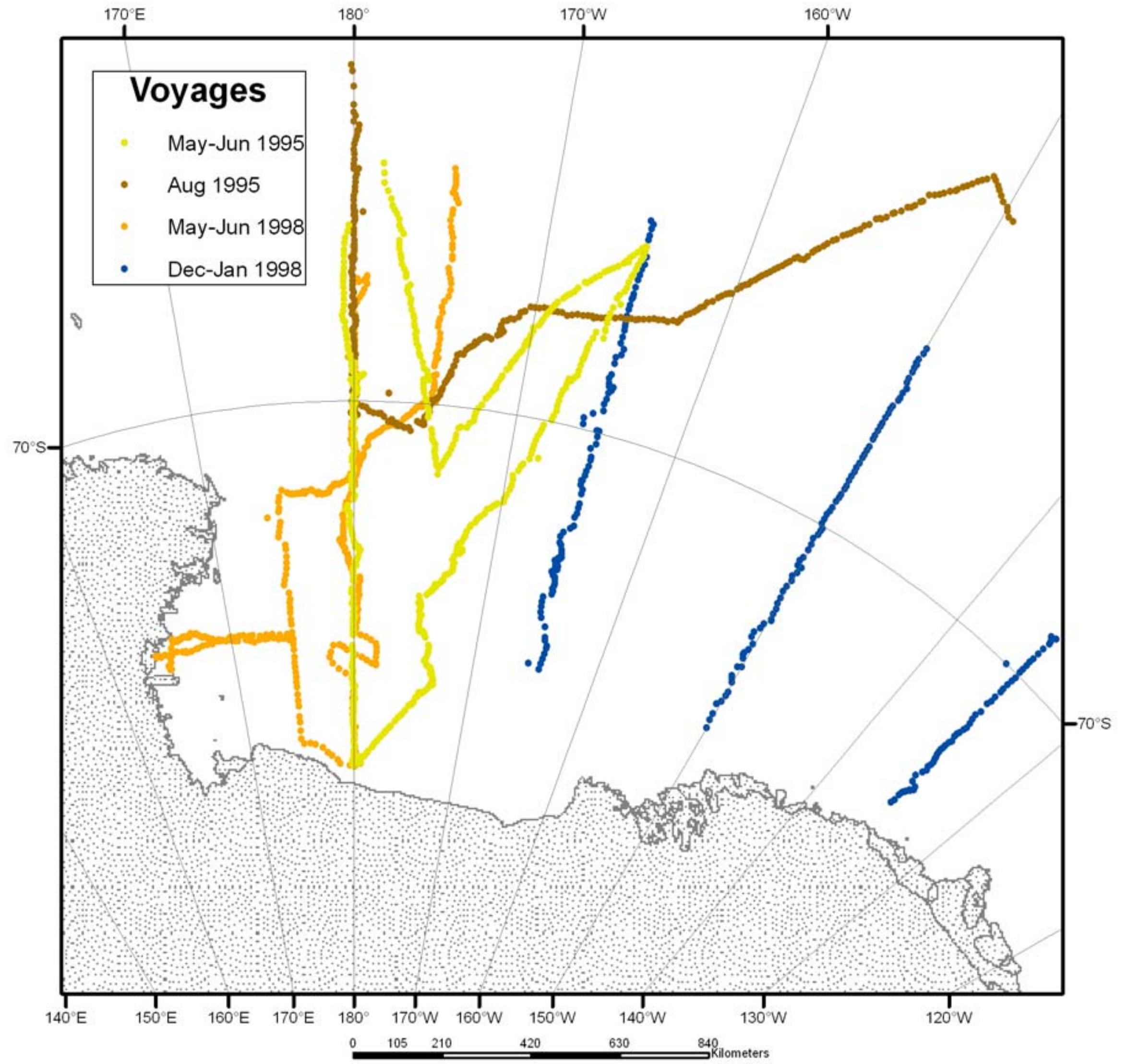

Figure 1. Ship observations shown for five separate voyages in the Ross Sea during 1995 and 2000.

The second dataset is obtained from the NIC that has operationally produced weekly ice charts for the Southern Ocean since the early 1970's. These charts are produced by trained sea ice analysts, who discern sea ice concentration and stage of development information using satellite imagery (NIC et al. 1996). The NIC charts are produced weekly, reporting average ice conditions integrated from data typically collected over a 3 to 5 day period. The NIC ice charts incorporate discrete polygons to characterize regions of homogenous sea ice conditions with information on sea ice concentration and stage of development in accordance with the World Meteorological Organization protocols (WMO 1970).

Four research cruises are chosen for this comparison based on their location and the weekly NIC charts. These include ship voyages from May/June 1995, August 1995, May/June 1998, and December 1998/January 1999 (Figure 1). Figure 2 displays the ship (point) observations during the May/June 1998 voyage with 30 May to 5 June 1998 observations highlighted in yellow coincident with the shown NIC chart.

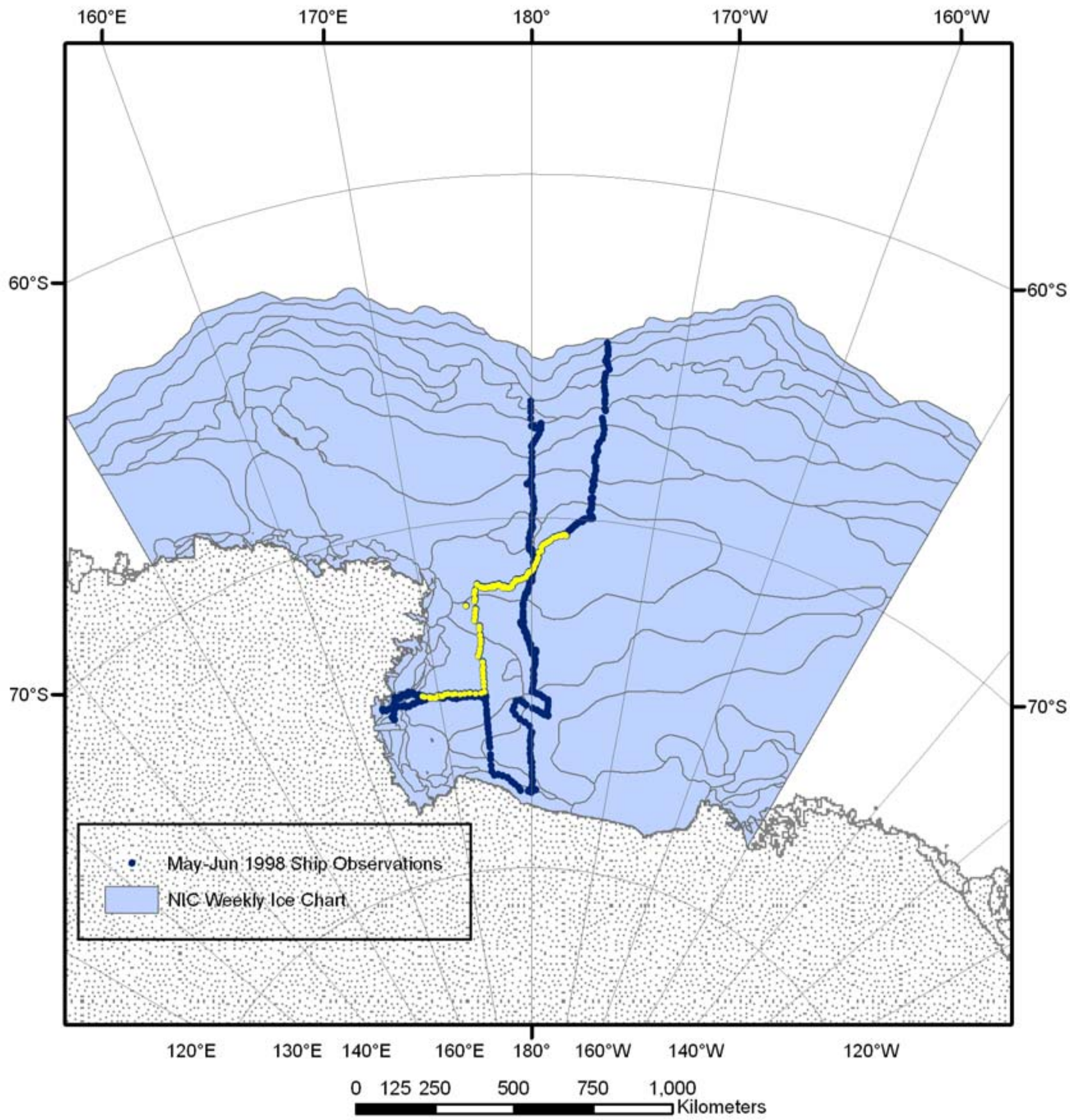

Figure 2. Ship observations (points) during the May/June 1998 voyage are shown overlayed on weekly NIC ice chart polygons. Yellow dots represent coincident ship observations from 30 May to 5 June 1998.

3. SEA ICE THICKNESS CALCULATIONS

Sea ice thickness is calculated for both the ship observations and the NIC ice chart data. The ship based observations catalog properties of ice for each of three partial ice categories from thickest to middle to thinnest ice type with estimates in attributes of ice concentration, thickness, type, topography, amount of ridged ice and ridge sail height, snow depth, and open water fraction. Estimates of sea ice thickness (cm) are calculated from the level ice (T_{Level}), ridged ice (T_{Ridge}), and snow thickness (T_{Snow}) which together are used to estimate the total thickness (T_{Ship}) by

$$T_{Ship} = T_{Level} + T_{Ridge} + T_{Snow} \quad (1)$$

in which

$$T_{Level} = \frac{C_1}{10} Z_1 + \frac{C_2}{10} Z_2 + \frac{C_3}{10} Z_3 \quad (2)$$

$$T_{Ridge} = \frac{C_1}{10}R_1 + \frac{C_2}{10}R_2 + \frac{C_3}{10}R_3 \quad (3)$$

$$R_i = (4.3 + 1.0)(0.5AS) \quad (4)$$

$$T_{Snow} = \frac{C_1}{10}Z_1 + \frac{C_2}{10}Z_2 + \frac{C_3}{10}Z_3 \quad (5)$$

where C_i represent the partial concentration for the thickest (i=1) to middle (i=2) to thinnest ice (i=3), Z is the thickness, the constant 4.3 represents the ratio of ice below sea level to ice above sea level in ridge areas based on drilled measurements, A is the percent area of ridging in the given ice category, and S is the sail height of the ridge (Worby 1999, Schellenberg 2002).

Each sea ice concentration and thickness estimate has an associated uncertainty. Following standard rules of error propagation, empirically determined uncertainties for sea ice concentration and thickness estimates are computed based on ship limitations (Schellenberg 2002 pp. 34).

Similarly, thickness estimates and their uncertainty are calculated from the weekly NIC ice charts. Stage of development is a quantifiable proxy whereby ice type is used to characterize a mean and range ice thickness and uncertainty, respectively.

Sea ice concentration (C_i) and this stage of development ice thickness proxy (S_i) are quantified by analysts from a suite of remotely sensed data for up to three categories of ice type from thickest (i=1), middle (i=2), and thinnest (i=3) ice within polygons of homogeneous surface sea ice conditions such that total NIC ice thickness (T_{NIC}) is determined following Schellenberg 2002), in which

$$T_{NIC} = \frac{C_1}{10}S_1 + \frac{C_2}{10}S_2 + \frac{C_3}{10}S_3 \quad (6)$$

4. COMPARISON BETWEEN NIC CHARTS AND SHIP OBSERVATIONS

An evaluation of sea ice thickness estimates calculated from the satellite-derived NIC ice charts is performed using a Geographic Information System (GIS) called ArcGIS Desktop ArcInfo developed by the Environmental Systems Research Institute (ESRI). The in situ point observations and NIC polygon datasets are spatially defined in their respective native geographic coordinate system and projection and then temporally and spatially merged into one coincident dataset of averaged ship observations concurrent with individual NIC polygons.

In general, the NIC ice chart thickness estimates correlate reasonably with in situ observations. A detailed graphical and statistical comparison is provided in Schellenberg (2002) and will be emphasized in more detail during our presentation. Discrepancies between the two datasets (Figure 3) provide insight into data set differences such as operational biases, thin ice not seen by satellites, and snow and ridge contributions to the total mass balance.

The comparison between ship and NIC thicknesses suggest the potential usefulness of the NIC data in developing a sea ice climatology, monitoring sea ice conditions in the Southern Ocean, and elucidating potential data integration strategies between these two operational data sets.

5. SEA ICE EXTENT AND THICKNESS

Using the NIC charts, sea ice extent, seasonal and interannual thickness distribution and mass balance (not shown) are derived for the Ross Sea. The NIC data resolves the seasonal cycle of sea ice thickness and extent with evident interannual variability between years. The areal coverage of sea ice the first week of June 1995 covers 2.82×10^6 km^2, while the first week of June in 1998 encompasses a slightly larger area of 3.0×10^6 km^2. In early June 1995, the geographic location of the ice edge extends northward to -61.5ºS in the eastern Ross Sea but only to -65ºS in the western portions of the Ross Sea. The ice edge is more spatially uniform extending from -65.5ºS to -65.75ºS in early June 1998. Although the areal extent of sea ice is greater in early June 1998 than 1995, there is a greater extent of thicker ice (≥70cm, light and dark pink) in 1995 (0.92×10^6 km^2) versus 1998 (0.63×10^6 km^2).

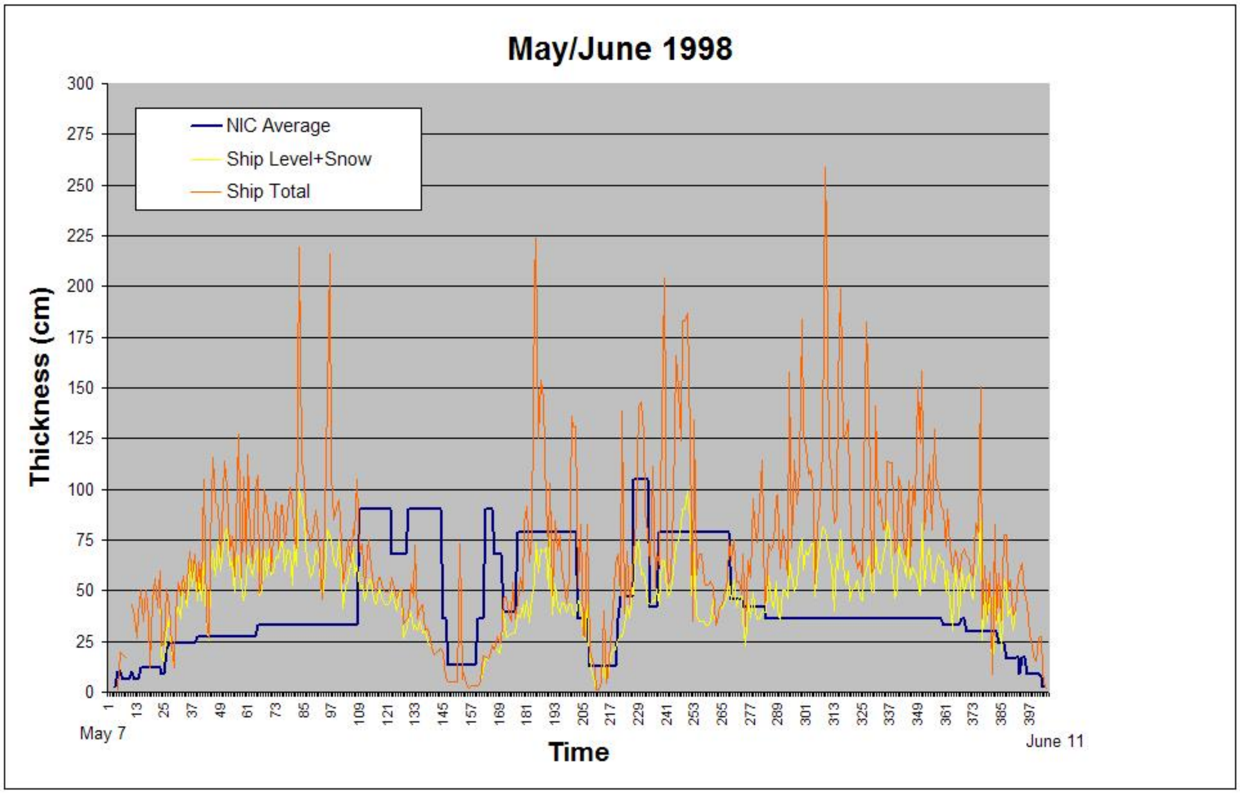

Figure 3. Time series comparison shown of the ship estimates of snow and level ice thickness (yellow line) and total ice thickness (snow+level+ridge) (orange line) in comparison to the NIC thickness (blue line) along a Ross Sea cruise track from 7 May to 11 June 11 1998.

These relationships do not occur in January of 1995 and 1998. The areal extent of sea ice during the last week of January 1995 is greater ($1.49x10^6$ km^2) than the same week in 1998 ($0.86x10^6$ km^2) which is dominated by sea ice of first-year thick and multi-year ice. In contrast, the distribution of sea ice in 1995 is distributed into a wider range of thickness from thin to multi-year ice.

Regional monthly thickness distributions are calculated in 1995 (not shown) and 1998. During the 1998 annual cycle, the growth and melt seasons are resolved in percentages of open water and thin to thick ice types. In the decay season, the sea ice pack is largely distributed between open water and the thickest ice that has survived the melt season (1^{st} year medium/thick and multi-year ice), while July through September pack ice is distributed into the thinner ice categories as the growth season is reaching its maximum in September.

6. SUMMARY

This paper focuses on the temporal and spatial variability of sea ice extent and thickness in the Ross Sea during 1995 and 1998. Moreover, this analysis is being used to establish a framework for creating a Southern Hemisphere sea ice thickness climatology, and enabling the detection of any trends in the distribution of Antarctic sea ice thickness. Analysis of this type is underway for the 4-year time period from 1995 through 1998 and for the other regional seas in the Southern Ocean.

A GIS web site is also under development for online visualization and distribution of the in situ sea ice observations from the ASPECT program and satellite-derived NIC weekly ice charts. This GIS web application is being built using the new ESRI ArcGIS Server to display thickness estimates and their respective uncertainties, along with spatial and temporal queries to view and subset time periods and

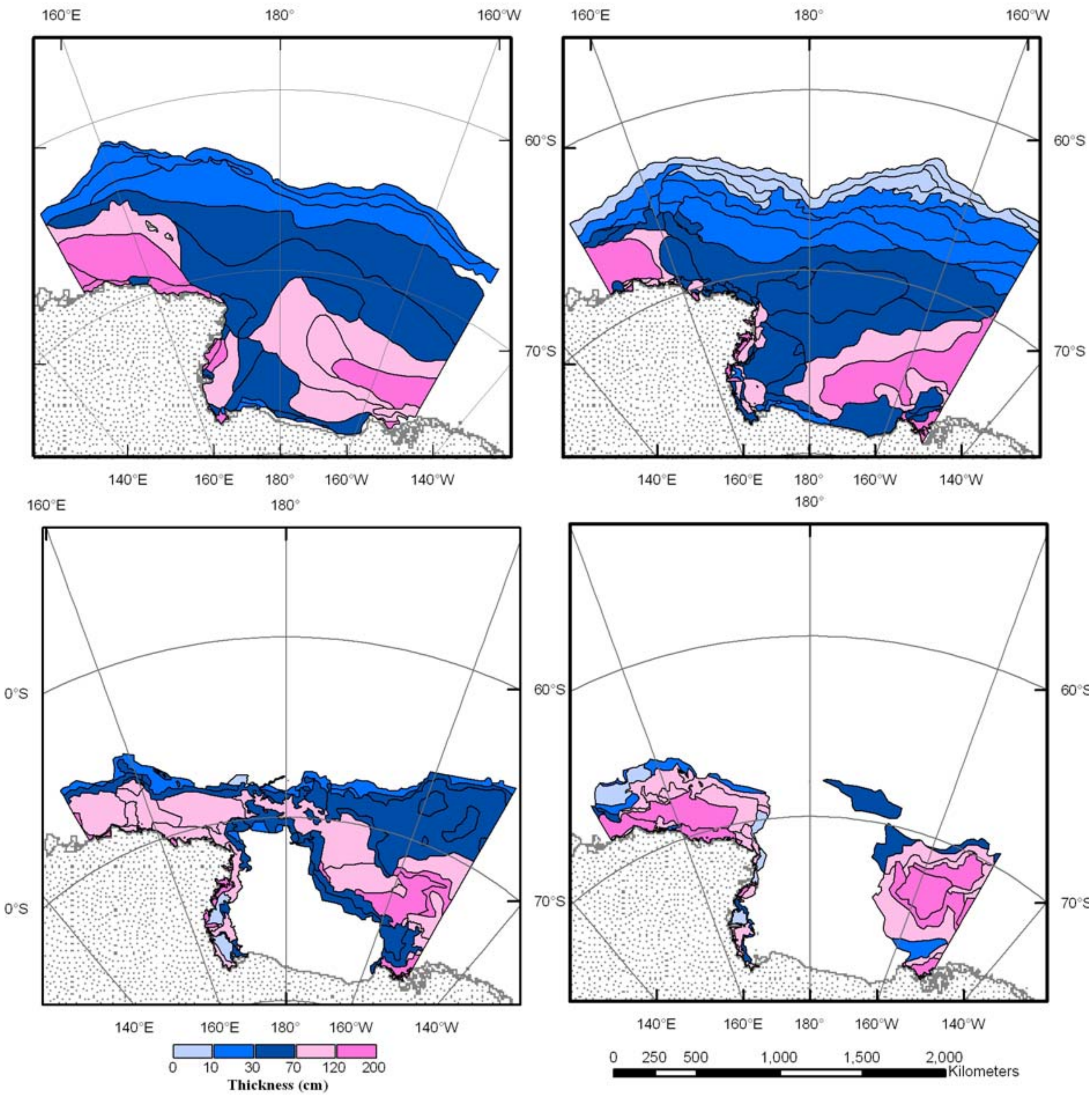

Figure 4. Sea ice thickness based on NIC analysis shown for the weeks of 1-8 June 1995 (upper left) 30 May - 5 June 1998 (upper right), 23-29 January 1999 (lower left), and 22-28 January 2000 (lower right).

geographic areas of interest. The goal is to serve the sea ice and climate modeling communities.

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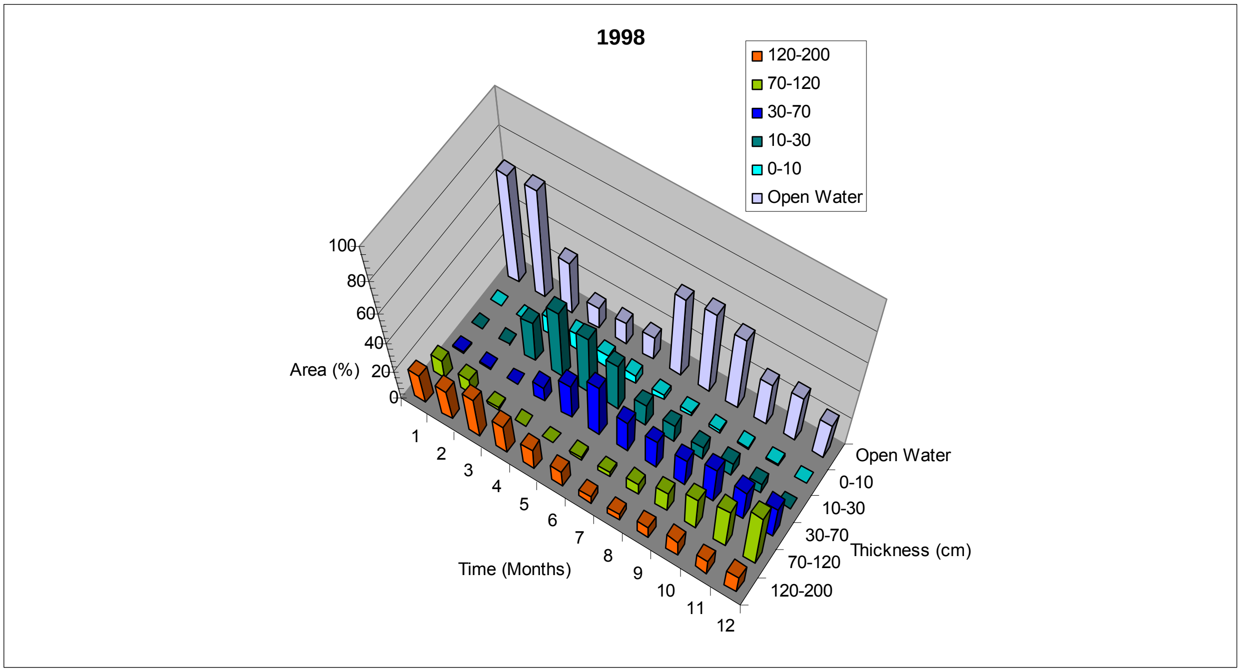

Figure 5. The monthly sea ice thickness distribution in 1998 is shown as a percentage of sea ice extent within the Ross Sea.

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