

**STEERING GROUP FOR THE WMO PROJECT
GLOBAL DIGITAL SEA ICE DATA BANK (GDSIDB)**

Eighth Session

Canadian Ice Service/Environment Canada
Ottawa, Canada, 30 April – 1 May 2000

FINAL REPORT

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NOTE

The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariats of the Intergovernmental Oceanographic Commission (of UNESCO), and the World Meteorological Organization concerning the legal status of any country, territory, city or area, or of its authorities, or concerning the delimitation of its frontiers or boundaries.

GENERAL SUMMARY OF THE WORK OF THE MEETING

1. ORGANIZATION OF THE MEETING

1.1 Opening

1.1.1 The 8th session of the Steering Group for the Global Digital Sea Ice Data Bank (GDSIDB) was opened at 9:30 on Sunday, 30 April 2000 in the conference room of the Canadian Ice Service Building, Ottawa by the acting Director of the Canadian Ice Service, Bruce Ramsay. Mr Ramsay welcomed participants of the session. He then called on the WMO representative M. Krasnoperov to address the session.

1.1.2 Mr Mikhail Krasnoperov also welcomed all participants to the meeting on behalf of the Secretary-General of WMO, Prof. G.O.P. Obasi. He expressed the sincere appreciation of WMO to CIS and in particular to the local organizers of the session, Bruce Ramsay and Lyn Arsenault for hosting the meeting and providing such excellent facilities.

1.1.3 The list of participants in the session is given in Annex I.

1.2. Election of the chairman

1.2.1 Prof. Roger Barry was elected chairman of the meeting.

1.3 Adoption of the agenda

1.3.1 The meeting adopted its agenda on the basis of the provisional agenda, together with Roger Barry's proposal to include a discussion on the recommended structure of POSSIR as a WG of JCOMM.

1.3.2 The agenda is given in Annex II.

1.4 Working arrangements

1.4.1 It was agreed that the working hours should be from 09h 30 to 13h 00 and from 14h 00 to 17h 00 for the first day (30 April) and from 09h 00 to 13h 00 and from 14h 00 to 16h 00 for the second day (1 May) of the session.

2. GDSIDB ACTIVITIES

2.1 Reports of the GDSIDB centres (NSIDC, AARI)

2.1.1 The meeting was presented with reports by experts from AARI (Russia) and NSIDC (USA) on the status of the GDSIDB centres activities during the intersessional period, including contributions of sea ice data sets to the bank from Argentina, BSIM, Canada, Russia and USA.

2.1.2 The co-chairman of the steering group, Roger Barry, noted in his presentation (Annex III) that the bank is an unfunded activity at NSIDC. Therefore, funds are not available for the acquisition of additional data, or for work at NSIDC with the data. However his centre archives contributions to the data bank, and seeks funding sources for publishing data. In 1997, funds were obtained to convert Russian contributions to the data bank to a gridded format (EASE-Grid) favoured by researchers. These data and documentation are available through NSIDC on-line catalogue, which is accessible through NSIDC's web site (<http://www-nsidc.colorado.edu>). The data set was released in January 1997. From February 1997 through June 1998, 138 unique hosts visited the ftp site for the data. The number of unique hosts is roughly equivalent to the number of users of the data. A complete data set, including all years and documentation, is 46 Mbytes. Users can download just a part of the data set if desired. The meeting was informed also that in April 2000, NSIDC received SIGRID data for 1999 from the Japanese Meteorological Agency (JMA).

NSIDC plans to publish all Japanese GDSIDB data in 2000, if resources become available. The publication during 2000 of the US/Russian Environmental Working Group (EWG) Sea Ice Atlas will contain U.S. National Ice Centre data in SIGRID and other formats. This will replace the CD-ROM of SIGRID data from NIC that NSIDC formerly distributed.

2.1.3 The meeting noted the information provided by the AARI expert Vasily Smolyanitsky (Annex IV) that during the intersessional period AARI activities as one of the GDSIDB centres was performed according to the work plan for 1998-2000. A sea ice data set for 1950-1992 was prepared by AARI within the joint USA-Russian project "Arctic Sea Ice Atlas on CD-ROM", at the same time NIC prepared weekly data sets for 1972-1994 in the revised version of SIGRID format. The meeting noted with interest contributions made by Argentina, BSIM countries, Canada, Denmark and Japan to AARI GDSIDB centre. At the beginning of 1999 the Argentine Navy Hydrographic Service started to submit weekly sea ice coastal observations for the Weddell and Bellingshausen Seas (all in .dbf format). The information is available on-line (<ftp://aari.nw.ru/pub/incoming/gdsidb/>) along with the description and format used. During the intersessional period a number of reports and data selections were prepared and provided on request to WCP. Special web pages containing extensive information on the GDSIDB project were prepared at the AARI web-site (http://www.aari.nw.ru/gdsidb_2.html) and mirrored at DMI web-site (<http://www.dmi.dk/pub/>). Access of users is logged. In general there are 3-4 users per day coming from outside to the GDSIDB pages.

2.2 Reports by the representatives of national sea-ice services

2.2.1 The session reviewed national reports from Australia, Argentina, Canada, China, Denmark, Germany, Iceland, Japan, Sweden and USA. These reports are given in Annex V.

2.2.2 The meeting was informed that the CIS Ice Chart Digitization project, initiated in 1996, to digitize weekly regional ice charts for East Coast, Hudson Bay, Eastern Arctic and Western is now completed and a number of years for each region have been digitized in ArclInfo format (Annex V, p. 1). Also, as planned at the last 7th session of the SG for the GDSIDB, all items of the Working Plan concerning Canadian activities have been implemented. The participants in the session were informed that the Web versions of the Ice Atlases for all regions have been placed on the web; these can be accessed by connecting directly to: http://www.cis.ec.gc.ca/cia/climate_products/cis_ice_atlas/intro_e.htm. Future activities of the CIS includes other ice chart collection to be digitized and will include the collection of historical ice charts (1959-1974) and regional charts of ice of the Great Lakes from 1994 may also be digitized.

2.2.3 The meeting reviewed the information on sea ice monitoring and forecasting in China prepared by the National Research Centre for Marine Environment Forecast (Annex V, p. 2). The meeting noted that in the Bohai Sea water freezing and ice drifting have seasonal effects on winter navigation, oil field exploitation etc. Since 1969 sea ice monitoring and forecasting have played an important role in avoiding and reducing ice damage. Data acquisition is from conventional observation and coastal stations, ship survey, aircraft reconnaissance, satellite imagery and other sources. Ice temperature, thickness and type are obtained from aerial remote sensing and aerial survey of sea ice is provided as one of the operational observations from January to February. The operational flight routes cover the Liaodong Gulf, the Bohai Gulf and the Laizhou Bay of the Bohai Sea and the northern coast of the Yellow Sea. Radar imagery from Bayuquan coastal station and real-time ice data at the platform JZ-20-2 are provided daily. Visible and infra-red satellite imagery from NOAA (AVHRR) and visible imagery from GMS are used for the monitoring and forecasting of sea ice in the Bohai Sea and the northern part of the Yellow Sea. Sea Ice monitoring data and forecasting products are sent to users daily.

2.2.4 The meeting was informed on the sea ice activities around the Baltic Sea within the Baltic Sea Ice Meeting (BSIM) cooperation, and in particular, sea ice activities provided by the Swedish Meteorological and Hydrological Institute (SMHI) (Annex V, p. 3). Today BSIM includes Denmark,

Estonia, Finland, Germany, Latvia, Lithuania, Netherlands, Norway, Poland, Russia and Sweden¹. Every country has its own sea ice service responsible for their coast and the waters outside. Ice information is daily exchanged by the sea ice services. Ice charts for the open seas are produced and transmitted by Finland, Russia, Estonia, Germany and Sweden. The Swedish ice chart covers the whole of the Baltic sea including the Belts, Kattegat, Skagerrak and the German Bight. Swedish ice charts are re-transmitted on radio facsimile by Offenbach/Pinneberg in Germany². Together with NOAA-satellite images ERS-1 SAR images were used in 1992-1994, ERS-2 during 1997 and Radarsat in 1998-2000 by Finland and Sweden. The Baltic Sea Ice Data Bank for the whole Baltic region in the Basis format for the years 1960-1979 has been delivered for the GDSIDB in December 1998. The Basis format data have been kindly converted to SIGRID format by the AARI expert Vasily Smolyanitsky. Plans have been introduced to digitize the Swedish ice charts for the lacking years 1980-1998 in grid format. From the year 1999 the Swedish ice charts are in grid format. A very simple grid is used. The main ice information is ice concentration, ice thickness and topography.

2.2.5 The meeting reviewed information on sea ice activities in Germany (Annex V, p. 4). The sea ice service at the Bundesamt für Seeschifffahrt und Hydrographie (BSH) is mainly responsible for the south-western Baltic and the Belts to Kattegat, furthermore German Bight and the German inland and rivers. Ice reports in Baltic Sea Ice Code (BSIC), are daily issued in clear text in German/English. Ice charts are produced when ice occurs at sea and transmitted by fax, e-mail and Internet. A digital ice database from 1940 has been developed since 1982 for the German waters but not in SIGRID format. Since 1996 the ICEMAP-system is used for digital ice chart construction. An ice statistical report for the Rügen and Gedser area has been published.

2.2.6 The meeting was provided with information on sea ice activities in the USA carried out by the National Ice Centre. At present, the National Ice Centre (NIC) is considering a paradigm shift, from production of pictures of sea ice conditions to true digital sea ice charts. This will be accomplished with the design and implementation of a new image processing / GIS ice charting system. Through the US/Russian initiative, NIC has completed quality control and redigitizing of 1972-1994 Arctic wide (northward of 45°N) data set. The 1972-1994 weekly charts are available at the NIC website (<http://www.natice.noaa.gov>). The EWG Arctic Sea Ice CD-ROM will be available in about July. The CD-ROM will contain:

- 1972-1994 merged monthly Climatology charts
 - 24 charts of median concentration and probability of occurrence of ice
- 1972-1994 weekly Arctic (northward of 45°N) charts
 - weekly charts in gridded format (SIGRID)
 - weekly complete ice charts, including all available attributes, in GIS format (.e00)
 - climatological statistics derived from NIC charts (ERIM-generated)

These data present approximately 40% of NIC's data holdings. NIC has submitted a proposal to NOAA (in April 2000) to address some items, e.g.:

- 1973-1994 Antarctic has been translated from SIGRID into ArcInfo coverage, but is awaiting quality control;
- 1995-1996 Arctic, 1995-1997 Antarctic
 - data exist in various formats
 - need to convert to common format and undergo quality check
- 1996-present Arctic, 1998-present Antarctic
 - available from NIC web-site or NSIDC
 - planned release of annual CD-ROMs

If the NOAA proposal is approved, NIC will have a complete 28 years Arctic and Antarctic data set.

¹ The next 20th BSIM meeting will be held in Riga 25-29 September 2000.

² The customer can also receive the ice chart on fax, e-mail and Internet (key is needed).

2.2.7 The meeting further reviewed sea ice activities by the Danish Meteorological Institute (DMI) (Annex V, p. 5). The major developments provided by the DMI are the following:

- satellite images which constitute now the major source of ice information
- since June 1998 a new ice charting system has been used
- since March 1999 DMI has been using RADARSAT images operationally
- since January 1999 all ice analyses and charts are in digital form - ice attributes are stored in SIGRID code.

The meeting noted on sources of information used by DMI to prepare sea ice products such as weekly charts of sea ice conditions and charts for navigation in sea ice areas. The 1st of April 2000 marked the end of the first year where the sea ice conditions around Greenland were monitored and charted operationally for navigational purposes using, almost entirely, a combination of high and low resolution satellite images. The dominant source of information was 500 RADARSAT ScanSAR Wide scenes, which were transferred to DMI from receiving stations in Canada, Scotland and Norway, supplemented with data from NOAA AVHRR and DMSP SSM/I. The majority of ice charts were produced from visual interpretation of satellite images yet air reconnaissance is still needed as a supplement and backup in the Cape farewell region during the summer months due to the complex and difficult ice situation. The expert from DMI, H.S. Anderssen, advised the meeting that currently no funds are available to digitize historical data for the Greenland waters and Northern Atlantic.

2.2.8 The meeting noted a report on sea ice activities provided by the Japan Meteorological Agency (Annex V, p. 6) including the new system for the flow of sea ice data, analysis and archiving. It was informed that JMA gives announcements about sea ice condition surround Japan from every December through next May, mainly for the Sea of Okhotsk. Sea ice extent and its compactness for the whole of the Sea of Okhotsk are analyzed every day, mainly using images of the geostationary meteorological satellite (GMS) and the NOAA satellites. Automated classification using NOAA images was developed recently, and is examined with the sea ice vector calculation using GMS images and the utilization of passive microwave observations. All five-day analyses are archived in the BITMAP images, which are transformed to the SIGRID-II format and sent annually to the Global Digital Sea Ice Data Bank. Results of analyses and forecasts are issued twice per week as a "Sea Ice Information" bulletin by meteorological radio facsimile.

2.2.9 The meeting reviewed sea ice activities of the Argentine Navy Hydrographic Service (Annex V, p. 7). The Argentine Navy Hydrographic Service (SHN) continues with the national programme of sea ice and iceberg observations from coastal stations and ships. This programme is a cooperative effort with the SHN, the National Antarctic Direction (DNA) and the Antarctic Command of the Argentine Army. The service is the only agency in South America supporting ice navigation. Six permanent Antarctic near-shore stations make two observations per week on a routine basis, year round. Ship reports are issued every six hours, mostly during the melting season in the Weddell and Bellingshausen seas. Those observations are based on NIC coded messages: IILL for shore stations and IISS for ship reports. As there are no trained personnel, selected crew members of each ship and coastal station are trained through a two week course at the end of each year, in the use of those codes and in the nature and physics of sea ice and icebergs. IILL and IISS messages are transmitted to the U.S. National Ice Centre (NIC) in real time. The same messages are sent to the Arctic and Antarctic Research Institute (AARI) and to the USA National Snow and Ice Data Centre (NSIDC) after quality control. New software, called "SIMAR", has been developed at the SHN in order to get accurate sea ice observations. This programme based on a simple computer, gives the observer a comprehensive on-line set of 36 QC of variable ranges, characters and physical cross-checks. This software also includes options for management and archiving of sea ice and meteorological data.

2.2.10 The meeting was informed of activities in the Icelandic waters provided by the Icelandic Meteorological Office (Annex V, p. 8). The sea ice service at the Icelandic Meteorological Office is in charge of obtaining and providing information on sea ice close to, or covering, fishing grounds in the Denmark Strait and the Iceland Sea. Sea ice is a common feature in these areas. On the other hand,

sea ice covering sailing routes close to the coasts of Iceland is a rather infrequent occurrence and difficult to predict. However, due to economic consequences, monitoring, providing information, and issuing warnings is considered to be quite important. A combination of oceanographic and meteorological effects result in different amounts of sea ice, disturbing sea transport and at times affecting access to harbors. Besides a variable amount of advected sea ice being brought from north with the East Greenland Current and different ocean surface conditions locally, prevailing south-westerly and westerly winds due to atmospheric blocking situations over the North Atlantic are the main reasons for sea ice approaching the coasts of Iceland.

2.3 Report by the chairman of the Baltic Sea Ice Meetings (BSIM)

2.3.1 The meeting was presented with an overview of the status of existing sea ice observing systems among BSIM countries including activities carried by these countries on digitizing of sea ice charts to be submitted to the GDSIDB. At present Baltic sea ice data from the Baltic Sea Ice Data Bank for the period winter 1960/61 – winter 1978/1979 and based on both SMHI (odd years) and FIMR sea ice charts, were successfully transformed from BASIS into SIGRID format and submitted to GDSIDB. Similar procedure is planned for implementation for data in simplified BASIS format covering the subsequent period 1979/80 – 1997/98.

Further, the meeting considered the agenda item of the next forthcoming 20th Baltic Sea Ice Meeting (BSIM) to be held in Riga 25-29 September, 2000 (Annex VI).

2.4. Submission of new sea-ice data to the GDSIDB

2.4.1 Participants discussed the current list of GDSIDB holdings (Annex IV) and agreed upon proposed new submissions of sea ice data sets to the GDSIDB (Annex VII, p.2.1). In response to the request of the 7th session of the SG for the GDSIDB to prepare a status report on sea ice information from the Black, Azov and Caspian seas, Vasily Smolyanitsky, presenting comprehensive information on that subject (Annex VIII), noted possible ways to digitize historical sea ice charts for these seas.

2.5. Proposals for standard sea-ice nomenclature for sea-ice decay reporting

2.5.1 Bruce Ramsay provided a report on the “Arctic Sea Ice Regime Shipping System” [AIRSS]. Actual ice conditions including the presence of decayed ice and ridges are used to determine whether a ship can enter a given zone. Research is being undertaken to identify ice decay from radar back scatter and other data (Annex IX). Proposals for nomenclature for coding sea ice decay will be presented at the next SG session.

2.6 Technical discussions

2.6.1 Vasily Smolyanitsky presented the web-pages of the GDSIDB. Participants endorsed the scope and content of the web site and commended AARI on their initiative. It was decided that the web should maintain the links to real data and to track users through a registration system. Members of the GDSIDB were invited to suggest web-enhancements during May - July 2000. The address of the web pages is:- http://www.aari.nw.ru/gdsidb/gdsidb_2.html .

2.6.2 There was discussion of the issue of data formats preferred by the agencies producing ice information and by the users. Operational and research users having different requirements, it was agreed that an ad hoc sub-group of technical experts from AARI, CIS, DMI, NIC and NSIDC would meet during the ice workshop to discuss possible strategies to address the issue. A report of the ad-hoc group is included as Annex X.

2.7 JCOMM POSSIR

2.7.1 The meeting was presented with information on the establishment of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) in 1999. Participants

in the session were informed that major efforts have been made over the past 30 years to enhance cooperation and interaction between WMO and IOC, and to lay the foundations for eventual operational oceanography. To day there is a very high level of cooperation and coordination between the two organizations, with many joint programmes. The high point to date in this cooperation was the establishment of JCOMM, to serve as the intergovernmental coordination and regulatory mechanism for all the operational marine-related activities of both organisations. JCOMM replaces the former CMM and IGOSS and becomes the formal reporting and coordinating mechanism for, iner alia, sea ice activities. To address these issues, a small joint WMO/IOC expert meeting took place in the WMO Secretariat in December 1999. The 12 participants included polar region experts representing national ice services, observational programmes and climate and oceanographic research programmes. The primary objective of the meeting was to undertake a through review of existing activities of WMO and IOC in polar regions, leading to the development of proposals to JCOMM and GOOS for the enhanced, integrated development of operational ocean observing , data management and services systems in such regions, as well as appropriate institutional arrangements for their international coordination. Among others the meeting proposed to establish a JCOMM Working Group on Polar Seas and other Sea Ice regions (POSSIR), and provided draft terms of reference for the group. It also made a number of specific and practical recommendations to GOOS, JCOMM and other bodies, designated to better coordinate and enhance polar region observations, data management and services (Annex XI). The participants reviewed the proposed terms of reference of POSSIR. The meeting recommended that JCOMM establish a WG on Oceanography and Marine Meteorology of Ice Covered Seas (OMIS) and a WG on Sea Ice (WGSi). The terms of reference of OMIS would constitute numbers 1, 2, 3, 6, 7 and 8 of the proposed POSSIR (Annex XI) and number 4 and 5 would constitute the terms of reference the former CMM Sub Group on Sea Ice. Revised numbers 4, 5 and 7 will be:

- (4) To provide support for the development, implementation, maintenance and operation of the GDSIDB;
- (5) To recommend and promote appropriate QC, error analysis and archiving mechanisms;
- (7) To assist in development of guides, manuals, software exchange and specialized training for sea ice observations and data.

The meeting recommends these proposals be considered at the JCOMM Second Transition planning Meeting to be held in Paris in June this year.

2.8 Aspects of CLIC and ASPeCT projects

2.8.1 A report on the WCRP Climate and Cryosphere (CLIC) Project was presented by Roger Barry (Annex XII). The meeting noted that the CLIC Initial Science and Co-ordination Plan outlines research and co-ordination initiatives required to fully integrate studies of the impact and response of the cryosphere, and the use of cryospheric indicators for climate change detection, within the World Climate Research Programme (WCRP). The scientific strategy for a CLIC project is similar in each of the areas of interaction: a combination of measurement, observation, monitoring and analysis, field process studies and modelling at a range of time and space scales. A CLIC modelling strategy must address improved parameterization in models of the direct interactions between all components of the cryosphere, the atmosphere, and the ocean. A broad observational framework for CLIC is provided by the WMO meteorological and hydrological networks; the International Arctic Buoy Programme (IABP); elements of GCOS/GTOS/GOOS relating to the cryosphere; and continuing the International Programme for Antarctic buoys (IPAB) and for sea-ice thickness in the Arctic and in the Antarctic (ASITP and AnSITP). These projects will contribute to the CLIC. The development of a plan for CLIC data and their management will build directly on the experience of the ACSYS Data Management and Information Panel and the development of the Arctic Precipitation Data Archive as well as other WCRP programmes. The cryosphere is of interest to many diverse scientific organizations. CLIC will develop an implementation plan that is complementary to other initiatives and draws on expertise of other organizations. There are a variety of gaps in ongoing programmes and the need for co-ordination between the proposed CLIC and the other activities to achieve a global perspective of cryosphere research. In particular other WCRP and WMO programme components, IGBP, SCAR, SCOR and IASC projects need to be considered. The WCRP International Programme for Antarctic Buoys and the Antarctic Sea-ice Thickness Project are at present supervised by the ACSYS Scientific Steering Group. These projects will become part of CLIC. Similarly, ACSYS/CLIC is well represented in relevant WMO activities; for example, the Global Digital Sea-ice Data Bank within the joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology, and the Solid Precipitation Measurement Intercomparison within the Commission for Instruments and Methods of Observation. Options for establishing linkages with these programmes include joint participation on steering committees and science conferences; establishing links between project offices; co-sponsorship of projects with joint funding support; and full integration of international coordinated activities as subprojects of WCRP/CLIC. The particular mode(s) that CLIC should adopt has not been determined, but options will be considered by the joint ACSYS/CLIC SSG at its first meeting.

2.8.2 The meeting noted with interest and appreciation that Australia for first time participated in the session and presented a report on Antarctic Sea-Ice Processes and Climate (ASPeCt) (Annex XIII). The ASPeCt is a programme of multi-disciplinary Antarctic sea ice zone research within the SCAR Global Change Programme. ASPeCt will specifically address key identified deficiencies in our understanding and data from the sea ice zone. The programme is designed to complement and to contribute to the other international programmes in this region and will build on existing and proposed research programmes, and the shipping activities of National Antarctic operators, and will also include a component of data-rescue of valuable historical sea ice zone information. The overall aim of ASPeCt is to understand and model the role of Antarctic sea ice in the coupled atmosphere-ice-ocean system. This requires an understanding of key processes, and the determination of physical, chemical, and biological properties of the sea ice zone. These are addressed by the following objectives:

- (i) To establish the distribution of the basic physical properties of sea ice that are important to air-sea interaction and to biological processes within the Antarctic sea-ice zone (ice and snow cover thickness distributions; structural, chemical and thermal properties of the snow and ice; upper ocean hydrography; floe size and lead distribution). These data are required to derive forcing and validation fields for climate models and to determine factors controlling the biology and ecology of the sea ice-associated biota.
- (ii) To understand the key sea-ice zone processes necessary for improved parameterization of these processes in coupled models.

2.8.3 The session further noted the developments underway with regard to the forthcoming EWG Arctic Meteorology and Climate Atlas. The expert from NSIDC, Florence Fetterer reported that the Atlas provides new data for a data-sparse region of the earth, and presents new and existing data products in formats that are easy to use for climate research. The main contributors of the Atlas, as well as data sets, are from the AARI, NSIDC, the NOAA National Climatic Data Center, the USA National Center for Atmospheric Research, and the University of Washington. This Atlas complements the EWG oceanographic and sea ice atlases and contributes to a comprehensive interpretation of the Arctic climate system. Scientific applications foreseen for these data include: investigation of evidence for climatic change over the four decades from 1951 through 1990; examination of inter annual variability of climate in the coastal zone and in the central Arctic; and regional study of air mass transformation from open water to ice-covered ocean. A summary of included data sets is given in Annex IV. It is expected that the Atlas will be finalized by mid-2000. A draft copy of the Atlas is accessible at NSIDC by URL. The Atlas CD ROM will be released in June 2000

3. WORK PLAN FOR THE NEXT INTERSESSIONAL PERIOD

3.1 Participants of the meeting endorsed the continuation of the SG for the GDSIDB activities (Annex VII) and proposed the following additions for future activities:

- (1) Consideration of data format by the ad hoc group (Annex X);
- (2) Discussion of JCOMM recommendations on POSSIR by attendees at the IICWG workshop in Reykjavik October 2000;
- (3) Development of a new data submissions plan (Annex VII, p.2.1);
- (4) Possible preparation of CD of GDSIDB data sets (by AARI, NSIDC and CIS) under the auspices of WMO.

4. SEA ICE PUBLICATION AND GUIDANCE MATERIALS

4.1 Under this agenda item, the session was informed that the new version of the WMO-574 publication "Sea Ice Information Services in the World" was issued by WMO Secretariat in April 2000. Participants were also informed on the status of preparation of an English version of the "Handbook on Sea Ice analysis and forecast", which is planned to be published by the end 2000.

5. DATE AND PLACE OF THE NEXT SESSION.

5.1 The meeting was pleased to receive the tentative offer from the Argentine Hydrographic Service to host the 9th session of the Subgroup for GDSIDB in Buenos Aires, Argentina in October 2002.

6. CLOSURE OF THE SESSION

6.1 The 8th session of the Steering Group for the GDSIDB was closed at noon, Monday, 1 May 2000.

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GROUP PHOTO OF PARTICIPANTS



From left to right: Manuel H. Picasso (Argentina), Dr Henric S. Anderssen (Denmark), Takanori Matsumoto (Japan), Florence Fetterer (USA), Dr Anthony Worby (Australia), Torbjorn Gratstrom (Sweden), Cheril Bertoia (USA), Prof. Wu Huiding (China), Jan-Eric Lundqvist (Sweden), Dr Thor Edward Jakobsson (Iceland), Bruce Ramsay (Canada), Mikhail N. Krasnoperov (WMO Secretariat), Prof. Roger G. Barry (USA), Vasily M. Smolyanitsky (Russian Federation).

AGENDA

1. OPENING OF THE MEETING
 - 1.1 Opening
 - 1.2 Election of the chairman
 - 1.3 Adoption of the agenda
 - 1.4 Working arrangements
 2. GDSIDB ACTIVITIES
 - 2.1 Reports of the GDSIDB centres: NSIDC, AARI
 - 2.2 Reports by the representatives of national sea-ice services (Argentina, Canada, China, Denmark, Germany, Iceland, Japan, USA)
 - 2.3 Report by the chairman of the Baltic Sea Ice Meetings (BSIM)
 - 2.4 Submission of new sea-ice data to the GDSIDB
 - 2.5 Proposals for standard sea-ice nomenclature for ice decay, reporting processes and other possible items (Canada, Germany)
 - 2.6 Technical discussions
 - 2.7 JCOMM/PSSIR
 - 2.8 Aspects of CLIC and ASPECT
 3. WORK PLAN FOR THE NEXT INTERSESSIONAL PERIOD
 4. SEA-ICE PUBLICATION AND GUIDANCE MATERIALS
 5. DATE AND PLACE OF THE NEXT SESSION
 6. CLOSURE OF THE SESSION
-

NSIDC's participation in the Global Digital Sea Ice Data Bank (GDSIDB)

AARI and NSIDC maintain the GDSIDB; a collection of data in SIGRID format from nations participating in a WMO-sanctioned Subgroup on Sea Ice. Contributions include data from Canada, Japan, and Baltic states, as well as from the US (National Ice Center) and Russia (AARI). The GDSIDB is an un-funded activity at NSIDC; therefore funds are not available for the acquisition of additional data., or for work at NSIDC with the data. However we archive contributions to the data bank, and seek funding sources for publishing data. In 1997, funds were obtained to convert Russian contributions to the data bank to a gridded format (EASE-Grid) favored by researchers. These data and documentation are available through NSIDC's on-line catalogue, which is accessible through NSIDC's web site (<http://nsidc.org>). The data set was released in January of 1997. From February 1997 through June 1998, 138 unique hosts visited the ftp site for the data. The number of unique hosts is roughly equivalent to the number of users of the data. (A complete data set, including all years and documentation, is 46 Mbytes. Users can download just a part of the data set if desired). The table below contains information on the current status of NSIDC's GDSIDB holdings.

NSIDC WDC for Glaciology summary of GDSIDB data holdings

Originating Nation	Data at NSIDC	Area Covered	Available from NSIDC?
Canada (CIS)	1950-1980	Hudson Bay, Canadian Arctic, Gulf of Newfoundland	Not yet
Japan (JMA)	1971-1999	Sea of Okhotsk	Not yet
Russia (AARI)	1953-1990	Arctic	Yes
Baltic Sea Ice	1960-1979	Baltic Sea	Not yet
Meeting countries			
United States (NIC)	1972-1994	Arctic and Antarctic	Yes

In April, 2000, NSIDC received SIGRID data for 1999 from the Japanese Meteorological Agency. NSIDC plans to publish all Japanese GDSIDB data in 2000, if resources become available. We look forward to the publication of the EWG Sea Ice Atlas, which will contain U.S. National Ice Center data in SIGRID and other formats. This will replace the CD-ROM of SIGRID data from NIC that NSIDC currently distributes.

AARI's participation in the Global Digital Sea Ice Data Bank (GDSIDB)

During the intersessional period activity was performed according to the work plan for 1998-2000. Following progress should be noted:

1. Technique Development

1.1 New version of SIGRID into GRID translating software was prepared at AARI. Software provides possibilities:

- conversion from SIGRID into geographical rectangular grid;
- conversion from SIGRID into user-defined grid of voluntary form (specified by the input file containing pairs of geographical coordinates);
- processing result grids either in ASCII, BINARY grid format or in ARCINFO style (.dat + .inf);
- interface and specification of parameters is provided in the form of .in ASCII-file and (by choice) via command-line;
- software is available on-line on GDSIDB AARI web-site in the form of Fortran-90 codes and .exe file (for Win32 environment).

2. Data Exchange

2.1 Information prepared and submitted to the Bank according to Schedule for sea ice data transfer to GDSIDB centers

Summary of GDSIDB holdings stored at AARI and contributions during the intersessional period are given in tables 4.1 and 4.2 respectively.

2.1.1 Within the project joint USA-Russian "Arctic Sea Ice Atlas on CD-ROM" AARI prepared and submitted to exchange (by the end of 1999) SIGRID format material for 1950-1992 period. Material includes new or revised and updated version of data for 1953-1990 period and new material for 1950-1952 and 1991-1992 periods. Grand total is 1993 SIGRID format 10-days period (with temporal gaps) sea ice conditions charts covering separately Western and Eastern sectors of Russian Arctic.

2.1.2 Within the project "Arctic Sea Ice Atlas on CD-ROM" NIC prepared and submitted for users the revised version of SIGRID weekly period material for 1972-1994 period, grand total is 1200 sea ice conditions charts (covering the whole Arctic region). Material is duplicated in ArcInfo style.

2.1.3 JMA has submitted the next parts of sea ice conditions total concentration charts for the Sea of Okhotsk in SIGRID-2 format for periods winter 1997/1998 and 1998/1999.

2.1.4 Canadian Ice service provided 30' latitude by 1 degree longitude resolution sea ice conditions weekly material in SIGRID format for the Canadian Arctic, Hudson Bay and St. Lawrence Gulf for period 1959 (1962, 1968) –1982 (1983, 1998). Material needs some syntax correction of the header. Also, as the initial material is stored in ArcInfo vector format, resolution can be improved to 15'.

2.1.5 DMI submitted samples of data for Western Greenland waters for yearly 1990's period.

2.1.6 Within cooperation with BSIM Basis-format material was converted into 15' SIGRID format and submitted to GDSIDB by November 1998. Conversion software implements some assumptions, as BASIS code does not coincide with SIGRID one. Data set for the Baltic Sea covers period 1961-1979 with 4-5 days interval without temporal or spatial gaps.

2.1.7 From the beginning of 1999 Argentine Navy Hydrographic Service ANHS started to submit sea ice coastal observation for the Weddell and Bellingshausen Seas on regular scale with weekly interval in .dbf format. Information is ftp'ed to AARI web-server and is available on-line (<ftp://aari.nw.ru/pub/incoming/gdsidb/>) along with the description of material and format used.

2.1.8 No information was received yet from the South-Western Baltic waters from the German Federal Maritime and Hydrographic service, for Icelandic waters from the Icelandic Meteorological Office and the Bohai Sea from the State Oceanic Administration, China.

2.2 Technical assistance.

2.2.1. SG experts from AARI and NSIDC continued to provide assistance for incorporation of ice information in formats other than SIGRID, namely BASIS, EASE-grid, provided that adequate documentation and access software are attached. See items 1 and 2.1.6.

2.2.2 During intersessional period a number of consultations were provided both on national (Russian) level) and international level.

2.2.3. Special web-pages containing extensive information on GDSIDB project were prepared at AARI web-site (http://www.aari.nw.ru/gdsidb_2.html) and mirrored at DMI web-site (<http://www.dmi.dk/pub/>). In general the user can find:

- list of participants and links to their Internet resources;
- samples of SIGRID and SIGRID-2 format data;
- description of SIGRID, SIGRID-2 and draft CONTOUR-2 formats in .html and .pdf;
- graphic material representing temporal series of sea ice total concentration and thickness of level ice values for different regions (Arctic, Antarctic, Baltic sea, Sea of Okhotsk, Greenland Sea) and climatic statistics;
- glossaries of sea-ice terms.

Access of users is logged. In general there are 3-4 users per day coming outside to GDSIDB pages.

3. Modification of formats for data exchange

Descriptions of CONTOUR-2, SIGRID and SIGRID-2 formats in .html and .pdf forms were published (by the beginning of 2000) at AARI GDSIDB web-pages for discussions and considerations. Further discussions and work on CONTOUR-2 format is anticipated in connection with IICWG activity.

4. Use, validation and intercomparison of GDSIDB data

4.1 Climatic statistics for decade, WMO (1961-1990) and 1950-1992 period were assessed using AARI SIGRID data for 1950-1992 period and published in the form of graphical replicas at AARI GDSIDB web-site. Partly this activity was carried out within preparation of the joint USA-Russian "Arctic Sea Ice Atlas on CD-ROM".

4.2 A draft version of blended AARI – J. Walsh sea ice total concentration dataset for 1950-1992 was prepared by the end of 1999. Dataset will be made available in the nearest future via AARI-web-page.

4.3 During 1998-2000 period a number of reports and data selections were prepared and provided to WCP.

5. Future activity

A report describing status of sea ice data for the Caspian, Black Seas was prepared and submitted to WMO Secretariat by autumn 1999.

6. Other activities

Within the activity of the former SGSI a revised and updated version of the WMO-574 was prepared and submitted to WMO Secretariat. Draft is available on-line in .html and .pdf versions at AARI GDSIDB web-site.

AARI summary of GDSIDB data holdings (by April 2000)

Area Covered	Time interval	Originator	Format	Notes
Arctic	1950-1992, every 10 days	Russian Federation, Arctic and Antarctic Research Institute	SIGRID, EASE GRID	Discontinuous in time and space
Arctic Antarctic	1972-1994, 1973-1994, every 7 days	US National Ice Center	SIGRID, EASE GRID ¹⁾	Preliminary revised and corrected version.
Sea of Okhotsk	1971-1999, every 5 days	Japan Meteorological Agency	SIGRID, SIGRID-2, EASE GRID ¹⁾	Total concentration only-
Baltic Sea	1960-1979, every 3-4 days	Baltic Sea Ice Meetings, jointly SMHI and FIMR	SIGRID, Baltic Sea Ice Code, EASE GRID ¹⁾	Land mask different from NIC
Gulf of Newfoundland Hudson Bay Eastern Arctic	1962-1982 1962-1983 1959-1980 all every 7 days	Canadian Ice Service	SIGRID, 60 ' resolution	Starting point not included
Canadian Eastern Seaboard Eastern Arctic Western Arctic Hudson Bay	1968 to 1998 1968 to 1998 1968 to 1998 1971 to 1998		SIGRID, 15 ' resolution ArclInfo .e00 format in WMO-code	High resolution raster SIGRID and vector ArclInfo sea ice data
Local waters near Greenland	1990 (sample)	Danish Meteorological Institute	In original gridded format (.xls table)	-
Weddell and Bellingshausen Seas	1998- to present moment	Argentine Navy Hydrographic Service	Point observations in NIC-code in .db format	-

Contributions to GDSIDB data holdings during September 1998 – April 2000

Institute	Region	Time interval	Notes
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¹⁾ Conversion from SIGRID into EASE-grid carried out by the AARI part of GDSIDB.

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1.	Arctic and Antarctic Research Institute	Arctic	1950-1952 1953-1966 (extended) 1991-1992	SIGRID, 10-days period, discontinuous in time and space
2.	US National Ice Center	reprocessed Arctic reprocessed Antarctic	1972 –1994 1973 –1994	SIGRID, 7-days period, Preliminary version
3.	Japan Meteorological Agency	Sea of Okhotsk	Winters 1997/1998, 1998/1999	SIGRID-2
4.	Baltic Sea Ice Meetings, jointly SMHI and FIMR	Baltic Sea	1960-1979	3-4 days period, SIGRID; Baltic Sea Ice Code
5.	Canadian Ice Service	Gulf of Newfoundland Hudson Bay Arctic Canadian Eastern Seaboard Eastern Arctic Western Arctic Hudson Bay	1962-1982 1962-1983 1959-1980 1968 to 1998 1968 to 1998 1968 to 1998 1971 to 1998	SIGRID, 60' resolution, 7-days period, submitted in October'99 SIGRID, 15 ' resolution, 7-days period, ArInfo .e00 format in WMO-code, submitted in May'2000
6.	Danish Meteorological Institute	Local areas near Greenland	1990 (sample)	In original gridded format
7.	Argentinean Navy Hydrographic Service	Weddell and Bellingshausen Seas	1998- to present moment	Point observations in NIC-code in .db format

ANNEX V

REPORTS BY THE REPRESENTATIVES OF NATIONAL SEA-ICE SERVICES

Report of the Canadian Ice Service

The Canadian Ice Service Ice Chart Digitization project initiated in 1996 to digitize CIS Weekly Regional Ice Charts for East Coast, Hudson Bay, Eastern Arctic and Western is now completed.

The following years for each region have been digitized in ArcInfo format:

Canadian Eastern Seaboard	1968 to 1998
Eastern Arctic	1968 to 1998
Western Arctic	1968 to 1998
Hudson Bay	1971 to 1998

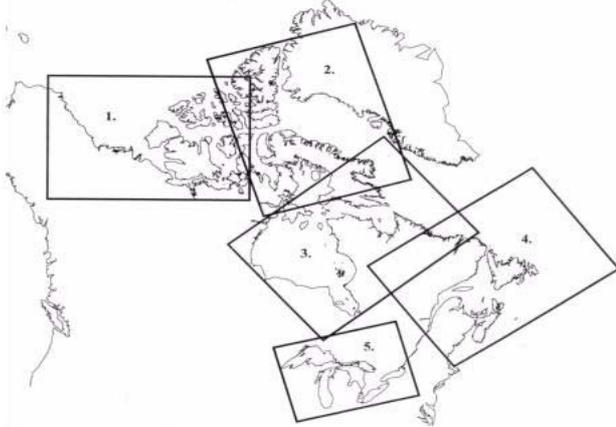
Also, as planned at the last GDSIDB meeting:

- the data has been converted to a standard topological ArcInfo format and is now available on CD-ROM
- a grid point database of 15min resolution has been created
- a fine grid SIGRID format dataset has been created and is now available on CD-ROM; this is to replace the coarser grid resolution dataset previously provided to GDSIDB
- several climate products have been developed using the ArcInfo files; these products were used for a number of climate projects
- a draft version of the updated Canadian Eastern Seaboard Ice Atlas has been produced using data from 1968 to 1998; the final version expected in the fall will use data from 1971 to 2000.
- Web versions of the Ice Atlases for all regions have been placed on the web; these can be accessed by selecting Climatic Ice Atlas under products on the CIS web (www.cis.ec.gc.ca) or by connecting directly to the following:
http://www.cis.ec.gc.ca/cia/climate_products/cis_ice_atlas/intro_e.htm

Future activities will include the following:

- automatic update of the digital database; charts are being produced operationally in digital format and will be converted to our standard topological ArcInfo format
- updated ice atlases for all the regions will be published starting with the Canadian Eastern Seaboard due for the fall 2000
- New Products will be added to the Web version of the atlases
- Other ice chart collections will be digitized; these will include the collection of Historical Ice Charts (1959 to 1974); regional charts of the Great Lakes from 1994 may also be digitized as a joint effort between CIS and GLERL.
- A new project has been initiated to make all digital Regional Ice Charts available on the Web via CEONET; this system will also provide climate analysis functions.

 **Regional Chart Extent**



 Environment Canada  Environnement Canada

 **Current Status**

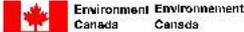
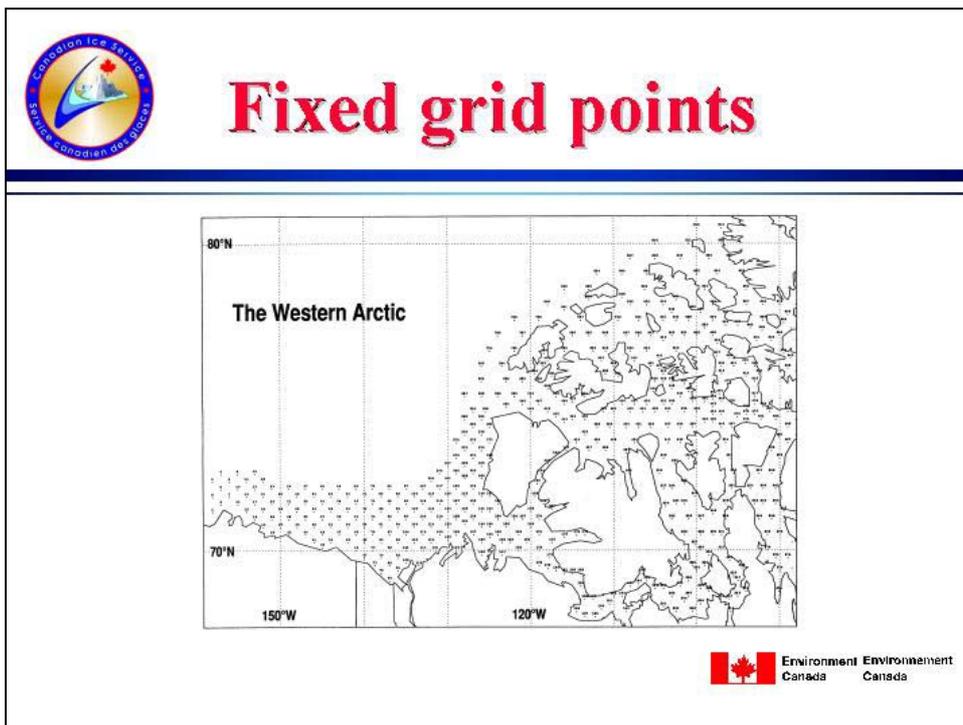
- Digitization completed
- Conversion to Standard ArcInfo completed
- Grid Point extraction completed
- SIGRID fine resolution completed
- Climate products for various projects
- Ice Atlases updates underway
- Soft Atlas on the Web

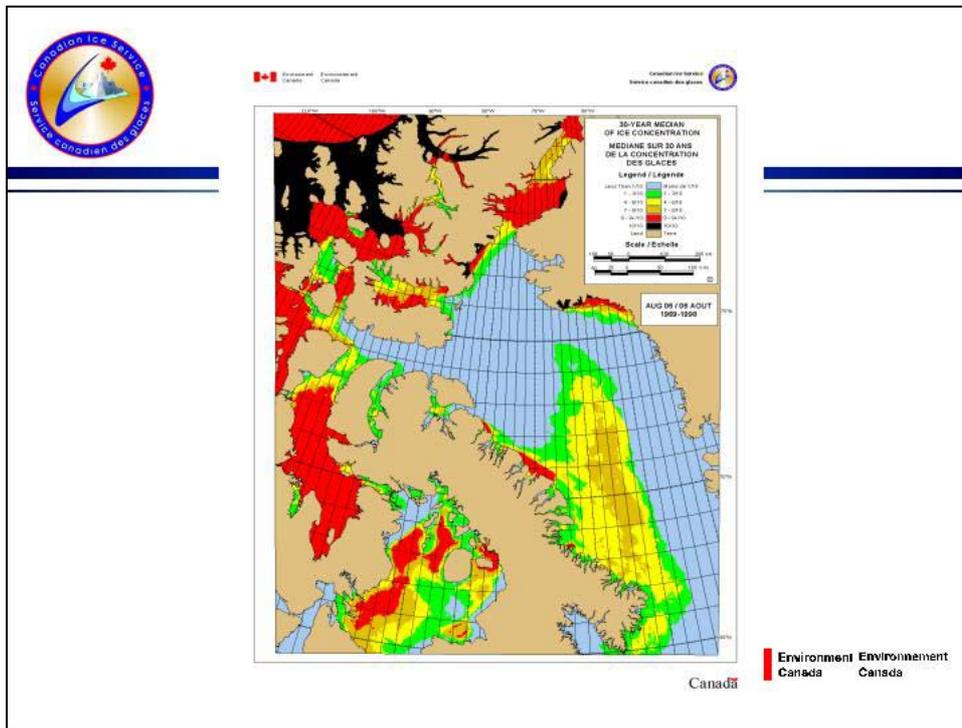
 Environment Canada  Environnement Canada



Regional Charts Status

Region	Years of data	Digitized
Eastern Coast	since 1968	1968-1998
Hudson Bay	since 1971	1971-1998
Eastern Arctic	since 1968	1968-1998
Western Arctic	since 1968	1968-1998



Climatic Ice Atlas - Atlas Climatique des glaces

CANADIAN ICE SERVICE CLIMATIC ICE ATLAS
SERVICES GLACIERS CLIMATIQUES ATLAS CLIMATIQUE DES GLACES

[Http://www.cis.ec.gc.ca](http://www.cis.ec.gc.ca)

Sea Ice Monitoring and Forecasting in China

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ABSTRACT

In the Bohai Sea of China, seawater freezing and ice drifting have substantial effects on winter navigation, oil field exploitation etc. Since 1969, sea ice monitoring and forecasting have played an important role in avoiding and reducing ice damages. Data acquisition is from conventional observation at shore stations, ship survey, aircraft reconnaissance, satellite imagery and other sources. Ice temperature, thickness and type are obtained from aerial remote sensing and aerial survey of sea ice is provided as one of the operational observations during January to February. The operational flight routes cover the Liaodong Gulf, the Bohai Gulf and the Laizhou Bay of the Bohai Sea and the northern coast of the Yellow Sea. Radar imagery from Bayuquan shore station and real-time ice data at the platform JZ-20-2 are daily provided. The visible and infrared satellite imagery from NOAA (AVHRR) and the visible imagery from GMS is used for the monitoring and forecasting of sea ice in the Bohai Sea and the northern Yellow Sea. The imagery from RADARSAT and ERS was used for studying.

The long-term seasonal outlook is prepared using the statistical method to estimate hierarchy of ice conditions of the Bohai Sea and the northern Yellow Sea in the next winter. The ten-day forecast and outlook up to one month are also made by the empirical-statistical schemes. A sea ice model is coupled with an oceanic model and linked to an atmospheric model for numerical ice prediction of the Bohai Sea. The sea ice monitoring data and forecasting products have been daily sent to users.

INTRODUCTION

The ice in the Bohai Sea and the northern Yellow Sea is first-year ice and relatively thin. Ice growth and decay are governed by the cold air from the north and the warm current from the open sea, and the drift is governed by winds and tidal currents. Temporal variation of ice condition is very complex in the Bohai Sea. The ice condition clearly changes from year to year with winter climate. Ice only covers at most 15% of the water surface during the warmest winter, while it covers more than 80% during the coldest winter. Seawater freezing and ice drifting have substantial effects on winter navigation and oil exploration operations. The oil platforms have been destroyed by sea ice during severe winters. Since 1969, empirical-statistical schemes have been used for forecasting the date of freeze up, ice thickness, ice coverage, etc. in National Research Center for Marine Environmental Forecasts (NRCMEF) of China (Zhang, 1986). More recently, a three-level dynamic-thermodynamic ice model has been linked to a numerical weather prediction model for operational forecast (Wu and Lepparanta, 1990; Wu et al., 1998). The daily numerical sea ice forecast outputs are sent to National Marine Forecasting Station (NMFS) of State Ocean Administration (SOA), China Offshore Oil Bohai Corporation (COOBC) and other users. This paper outlines sea ice monitoring and forecasting in China.

ICE CONDITIONS AND CLIMATE

The Bohai Sea and the northern Yellow Sea belong to the middle-latitude monsoon climate zone with cold and dry winters. In winter, the prevailing wind direction is bias northerly controlled by the Asia continental high pressure, very often accompanied by cold spell. The air temperature abruptly drops together with strong wind up to 25~28m/s as cold air passes, in particular the cold wave attacks. The continental type of variation of air temperature is predominant in the Bohai Sea. The lowest temperature occurs in January, then February. The Mean air temperature in January is between -4.0° and -8.0° , with a minimum of -28° . The tidal current velocity is generally in the order of 1 to 2 knot. The ice motion is dominated by the tidal current and wind. The ice drift trajectories in the Liaodong Gulf clearly show that the ice drifts back and forth along the long axis of the tidal ellipse.

In the Bohai Sea, ice formation begins in the north during mid-November to early-December and then extends southward. The decay of the ice cover begins in the south during mid-February to mid-March. The length of the ice period is more than 3 months. The ice conditions in the Bohai Sea and the northern Yellow Sea changes from year to year with winter climate. Ice only cover below 15% of water surface during the warmest winter, while it covers more than 80% during the coldest winter. The Bohai Sea has been almost entirely covered by ice 3 times during this century, i.e. January-February 1936, January-February 1947, and February-March 1969. Table 1 shows the length of the ice period and the date of freezing and breakup in the Bohai Sea and the northern Yellow Sea.

Table.1 The average date and range of freezing and breakup in the Bohai Sea and the northern Yellow Sea

Area	Station	Freezing date	Breakup date	Period (day)
Northern Yellow Sea	Daludao	28 Nov.(9 Nov.~ 18 Nov.)	19 Mar.(8 Mar.~ 4 Apr.)	112(147;96)
	Xiaochangshan	3 Jan. (28 Dec.~ -)	27 Feb.(- ~ 9 Mar.)	56(64;0)
Liaodong Gulf	Changxing Island	31 Dec.(11 Dec.~26 Dec.)	18 Mar. (6 Mar.~ 4 Apr.)	79(112;46)
	Huludao	1 Dec.(17 Nov.~18 Dec.)	16 Mar. (6 Mar.~30 Mar.)	107(124;82)
	Bayuquan	17 Nov.(3 Nov.~ 1 Dec.)	24 Mar. (10 Mar.~ 7 Apr.)	129(149;114)
	Qinghuangdao	26 Nov.(10 Nov.~13 Dec.)	10 Mar. (1 Mar.~24 Mar.)	105(124;85)
Bohai Gulf	Tanggu	20 Dec.(8 Dec.~ 2 Jan.)	22 Feb (16 Jan.~ 4 Apr.)	63(109;34)
Laizhou Bay	Longkou	27 Dec.(7 Dec. ~ -)	27 Feb. (- ~ 7 Mar.)	62(97;0)

The ice conditions have been classified as 5 grades corresponding to the ice thickness and extent based on the observed data and historical records in the Bohai Sea and the northern Yellow Sea. A time series of ice conditions and the mean air temperature of Dalian for January and February from 1952 to 1999 have been shown in Fig.1. The original data of the temperature are available four times per day (00, 06, 12, and 18GMT). The earlier studies have confirmed that the temperature of Dalian is a fair indicator for the Bohai Sea climate background, and there is a good negative correlation between the ice covered area and the temperature. The correlation coefficient is over 70%.

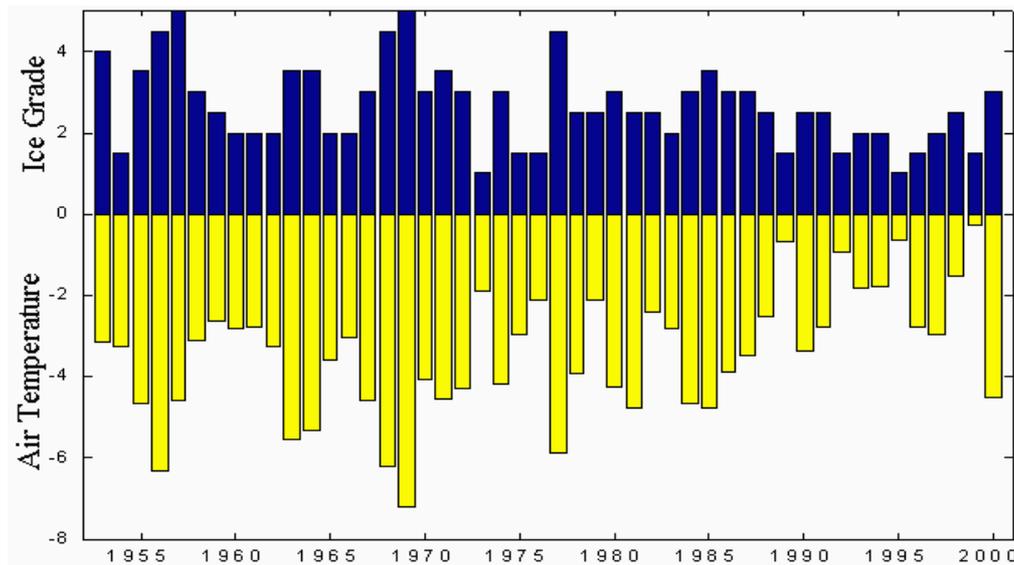


Fig.1 Annual ice grade in the Bohai Sea (upper) and mean air temperature (°C) of Dalian from January through February (lower) (1952/53~1999/2000)

OBSERVATION AND MONITORING

Ice data acquisition includes conventional observation at shore stations, ship survey, aircraft reconnaissance and satellite imagery. Sea ice type, thickness, compactness and temperature are routinely measured according to "The Specification for Offshore Observation" (SSA, 1994) at 11 shore stations along the Bohai Sea and the northern Yellow Sea. Icebreakers are used for observations of sea ice edge, thickness and types according to "The Specification for Oceanographic Survey" (SSA, 1991). The ice temperature, thickness and types have also been obtained from airborne remote sensing since 1985 (Du, et al., 1990). The air and shipping routes cover Liaodong Gulf, Bohai Gulf and Laizhou Bay of the Bohai Sea and the northern coast of the Yellow Sea. The helicopter reconnaissance flight is managed by COOBC for special missions. The sea ice radar imagery from Bayuquan shore-based radar station of SOA have been interpreted and digitized for monitoring inshore ice and ice in harbor, and real-time ice data at the platform JZ-20-2 located at $40^{\circ} 27' N$ and $121^{\circ} 17' E$ in the Liaodong Gulf were used for verifying forecast and modifying the initial ice fields of model forecast. The visible and infrared satellite imagery from NOAA (AVHRR) and the visible imagery from GMS are received by NRCMEF and National Satellite Meteorological Center. They are used for monitoring and forecasting sea ice in the Bohai Sea and the northern Yellow Sea (Huang, et al., 1992). The routine satellite remote sensing data opened up possibilities for operational numerical sea ice prediction. The satellite-borne SAR data from RADARSAT, ERS-1 and JERS-1 were used for study on operational possibility for monitoring sea ice in the Bohai Sea by NRCMEF and CCRS (Canadian Center of Remote Sensing) according to their joint project (Liu, et al. 1998). Figure 2 shows that SAR image with high resolution clearly displays the texture of sea ice field and improves sea ice monitoring and accuracy of the initial ice fields.

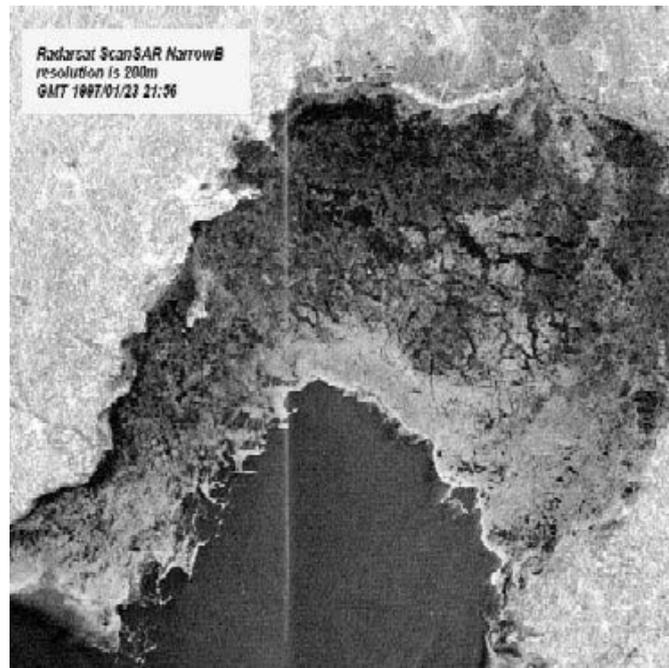


Figure2 Radarsat ScanSAR image of Liaodong Bay on January23 21:56 1997 GMT, Res=200m. Quicklook ice image from ftp site of CCRS (after Liu, et al., 1998).

FORECASTING

In NMEFC, empirical-statistical schemes have been traditionally used for operational ice forecast based on analyses of meteorological and oceanic data and ice conditions. For example, some statistical relations between ice conditions and evolution of meteorological and oceanic elements have been formed. Empirical relations between the ice situation and the evolution of the synoptic situation and variation of the circulation index have been studied, and the results are used for the tendency forecasts for freezing and ice breakup. Some statistical formulas have been proposed and used for forecasting the date of freezing, ice thickness, ice coverage, etc. The long-range seasonal outlook is prepared using the statistical methods to estimate hierarchy of ice conditions of the Bohai Sea and the northern Yellow Sea in the next winter. A 10-day forecast and outlook up to one month are also made by the empirical-statistical schemes.

Exploratory drilling and planning for production and transportation for oil and gas in the Bohai Sea during winter have raised great demand for numerical forecast of sea ice. A dynamic-thermodynamic ice model with three levels for simulating the ice growth, decay and drift in the Bohai Sea is presented on the basis of a review of the climate and ice conditions in the Bohai Sea and the earlier sea ice modeling studies (Hibler, 1979; WMO/TD,1989,etc.). Both dynamic and thermodynamic processes are incorporated in the model (Wu and Lepparanta, 1990; Wu et al, 1997). The ice model was coupled with a tidal current model for simulating the ice-tide interaction (Zhang et al. 1994). The sea surface temperature is obtained from the initial sea temperature assuming persistence. In order to model not only the dynamic process but also thermodynamic process of the ice-ocean interaction, Blumberg-Mellor ocean model is used instead of the tidal current model for coupling with the ice model (Blumberg and Mellor, 1987). The coupled model has been used for forecast tests since the winter of 1996/1997 and reasonable forecast results have been got (Li et al, 1998).

In order to develop an operational numerical ice prediction system for the Bohai Sea, the ice model has been linked to a numerical weather prediction model of NRCMEF for the 3-day sea ice forecast of the Bohai Sea and the northern Yellow Sea during the

winters since 1990 (Wu et al., 1998). The output of T106L19 model from National Meteorological Center of China (NMCC) and the products of T213L30 from Japan Meteorological Agency (JMA) and an atmospheric boundary layer (ABL) model are used for the 5-day and 7-day sea-ice forecasts. Figure 3 shows the flow chart of the numerical sea ice forecast system for the Bohai Sea and the northern Yellow Sea. The sea ice forecasting products, which contain fields of ice thickness, compactness and velocity, and ice edge, parameters of ice ridge and local estimate of ice thickness and tracks of ice floes near drilling platforms, are sent to COOBC and other users.

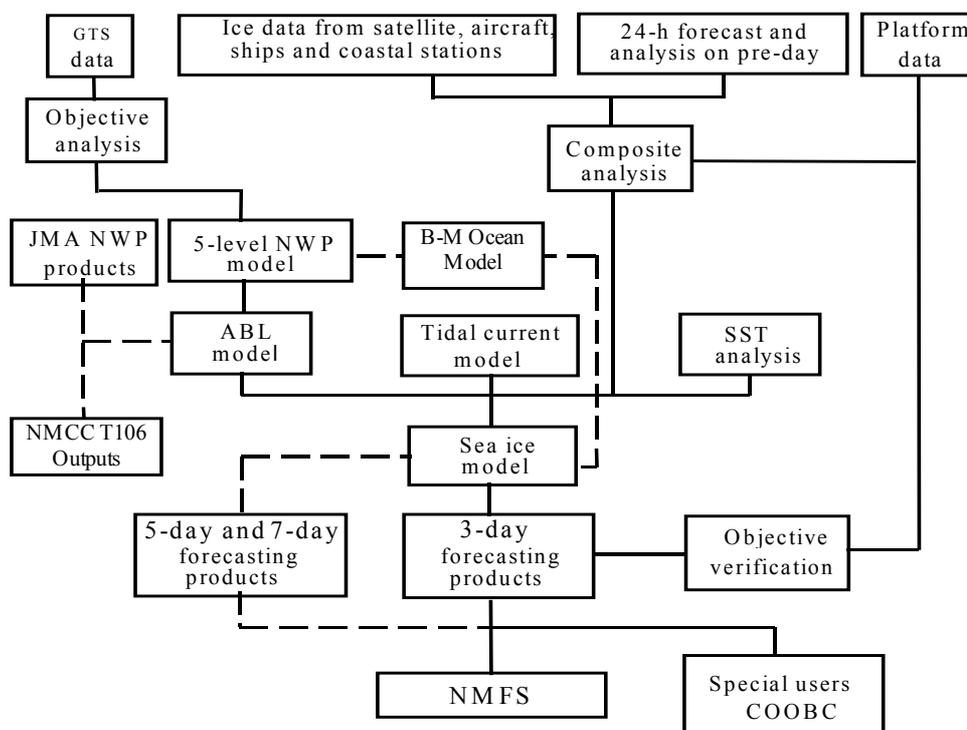


Fig. 3 Flow chart for the numerical sea ice forecasts in the Bohai Sea

SEA ICE SERVICE

The routine ice information from NOAA satellite imagery, which is useful for large scale monitoring and forecasting of sea ice, is used as a base for data analysis and integration and is supplemented with the aerial reconnaissance, ship survey, shore observations and others. The ice information from the composite analyses and the forecasts in the form of chart, code and plain language is issued to users. Major users of sea ice information are COOBC and companies for shipping, coastal and harbor activities. Plain-language ice information and 10-day outlook of ice condition in the Bohai Sea and the northern Yellow Sea with images are prepared by NRCMEF and are disseminated from CCTV and radio at each 10-day during winter.

The 10-day forecast and outlook up to one month are mailed and transmitted by facsimile per 10-day and month, and the long-range ice condition outlook of the next winter is mailed and transmitted by facsimile in the October of each year from NRCMEF. The 1-5 day numerical sea ice forecast charts, covering the Bohai Sea and the northern Yellow Sea, are daily transmitted by facsimile and computer network to the Group of Sea Ice Management (GSIM) of COOBC and other units. The coded output of ice concentration, thickness and velocity at grid points in tenths of degrees of latitude and longitude at 12-hour intervals up to 120 hour and the analyzed fields are transmitted daily by computer network as well.

The sea ice disaster warning system for marine oil/gas production and navigation is requested over the Bohai Sea, where offshore activities are seriously influenced by sea ice in winter. The sea ice warning system offers the marine oil production and navigation companies a safe guard against sea ice accidents in winter, while lots of oil/gas wells were set up rapidly year by year in the Bohai Sea. The Group of Sea Ice Management was organized. The annual meeting on sea ice prevention is held at the end of October or the beginning of November, which assigns task of sea ice prevention and works out an emergent measure as well as defines its goal for major project on ice prevention. According to types and longevity of structure, structures in service are divided into five safety catalogs by the capability of structures against sea ice. The warning level of severe ice condition for various structures and operations is established. Major project and dangerous structures are determined.

A sea ice management system was designed according to the mutual relations of sea ice conditions, structure features, interaction between ice and structure and other factors. Database of oil/gas, platform/facility, sea ice, structure states and warning and decision knowledge is included in the system (Zhang, et al. 1998). The information from monitoring and forecasting is compared with the warning level of severe ice condition and the safety catalogs of structures. When the ice condition reaches or exceeds the warning level, warning of severe ice condition is broadcast immediately and emergent measures are carried out at the same time. A safe and efficient winter offshore production should be achieved in the light of the sea ice management system.

CONCLUSIONS

The area of the Bohai Sea and its coastal region are one of the important economical areas in China but is the frozen sea with the lowest latitude in the world. Freezing of sea and drifting of the ice have a profound effect on navigation, oil field exploration, etc during winter. Observation and forecast of sea ice have been developed progressively since 1969, and a preliminary monitoring system of sea ice and transmitting network have been set up. The ice data from conventional observations at shore stations, ship survey, aircraft reconnaissance, satellite imagery and others are integrated and used for forecasting. Empirical-statistical schemes have been traditionally used for the 10-day and the 30-day forecasts, and the long-range seasonal outlook of sea ice. The ice model and the coupled ice-ocean model have been developed and used for numerical sea ice forecasts up to 7-day ahead. All forecasted products are transmitted daily by facsimile and computer network to users. The monitoring and warning system for sea ice management has great effect on the safe and efficient winter marine operation.

Exploratory drilling and planning for production and transportation for oil and gas in the Bohai Sea during winter have raised great demand for improving monitoring, forecasting and services of sea ice. More routine ice observations have to be carried out at stations and ships to further enhance the analyzed charts from the satellite imagery. The improvement in operational forecasting and monitoring is expected to come with the high-resolution satellite remote sensing data. The test of SAR data from RADARSAT and other satellites for monitoring sea ice in the Bohai Sea has shown the possibility of operational application. The accuracy of ice forecast could be also improved with an improvement of the atmospheric forecasts.

ACKNOWLEDGEMENTS

This work was supported by the Natural Science Foundation of China under contracts No. 49876003, 59739170 and 79976007, the National Scientific and Technical Project 818-06-04 and the "Ninth Five-year" National Project of 96-908-02-03.

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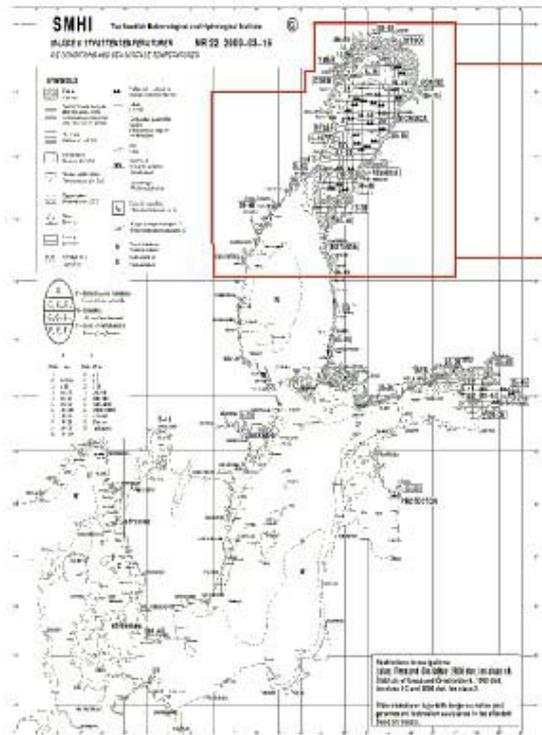
Zhang Q., H. Ding and J. Xu, 1998. Software of sea ice management system for winter oil/gas production in north Bohai Sea, In: *Ice In Surface Waters*, Shen, Ed., 269-273, Balkema, Rotterdam.

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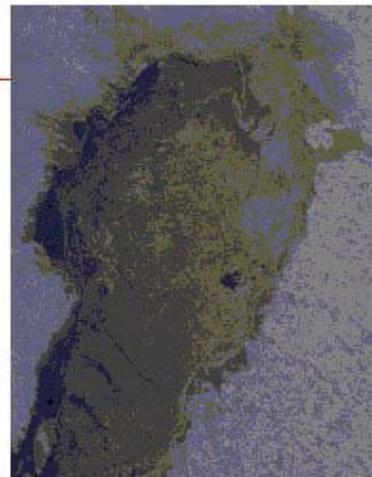
Zhang, Z. and H. Wu, 1994. Numerical study on tides and tidal drift of sea ice in the ice-covered Bohai Sea. In: *Sea Ice: Observation & Modelling*, (Yu, Z., C.L. Tang, R.H. Preller and H. Wu, Eds.), China Ocean Press, Beijing, 34-46.

Sea ice activities, provided by the Swedish Meteorological and Hydrological Institute

Swedish ice service

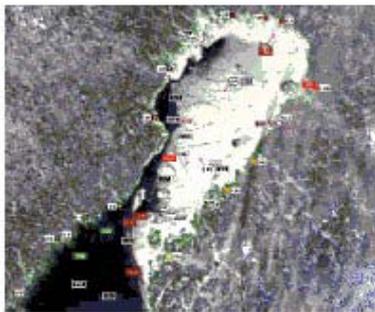


NOAA 14 Channel 1, 4 and 5
16 March 2000 at 12.28 UTC.



Radarsat image retrieved
16 March 2000 at 05.19 UTC.

Traffic situation 16 March 2000



Presentation onboard Swedish/Finnish icebreaker including location of individual merchant ships and ice breakers.



Swedish Meteorological and Hydrological Institute
ice@smhi.se

Figure V-3.1 Example products to support ice navigation during winter 2000.

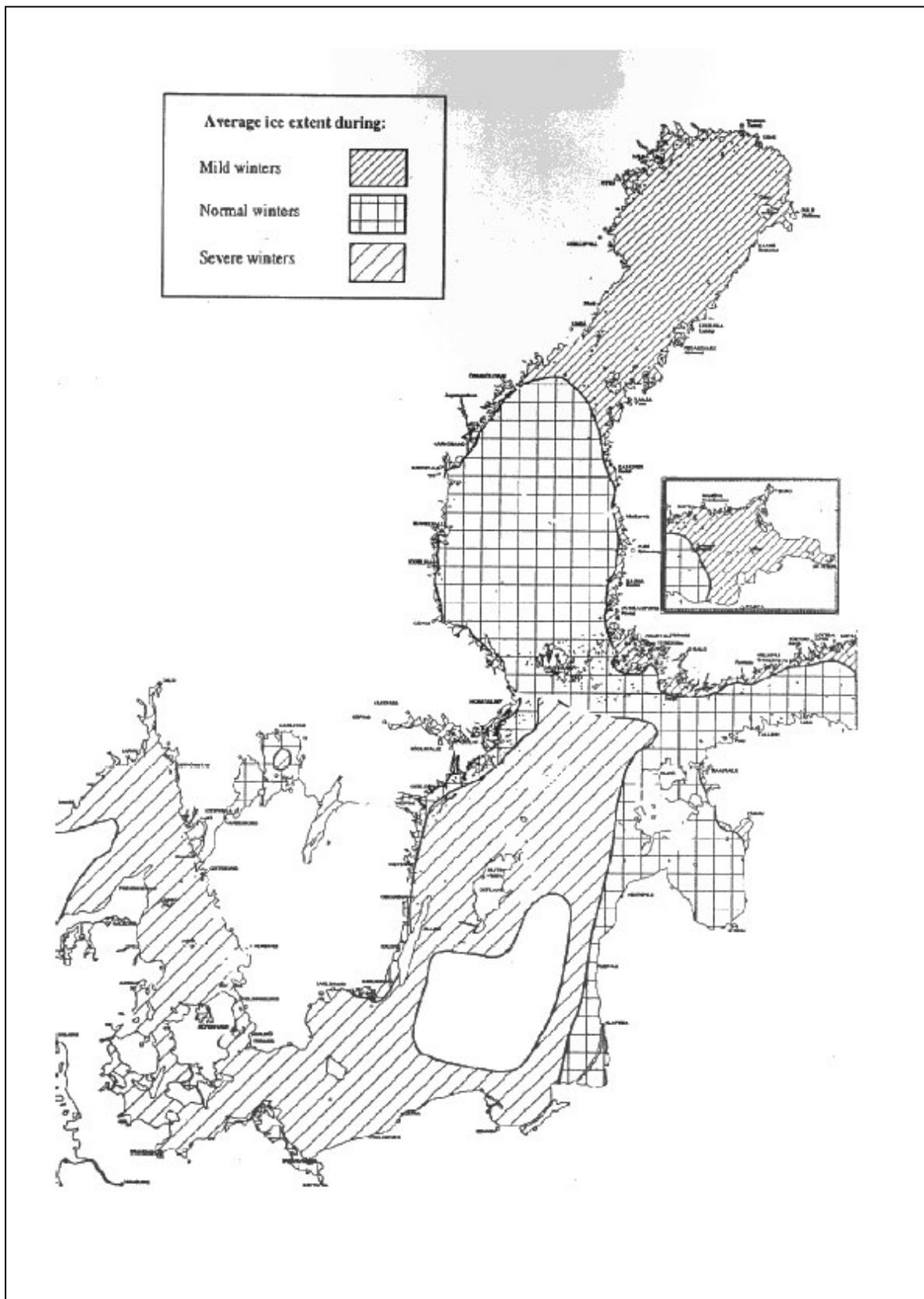
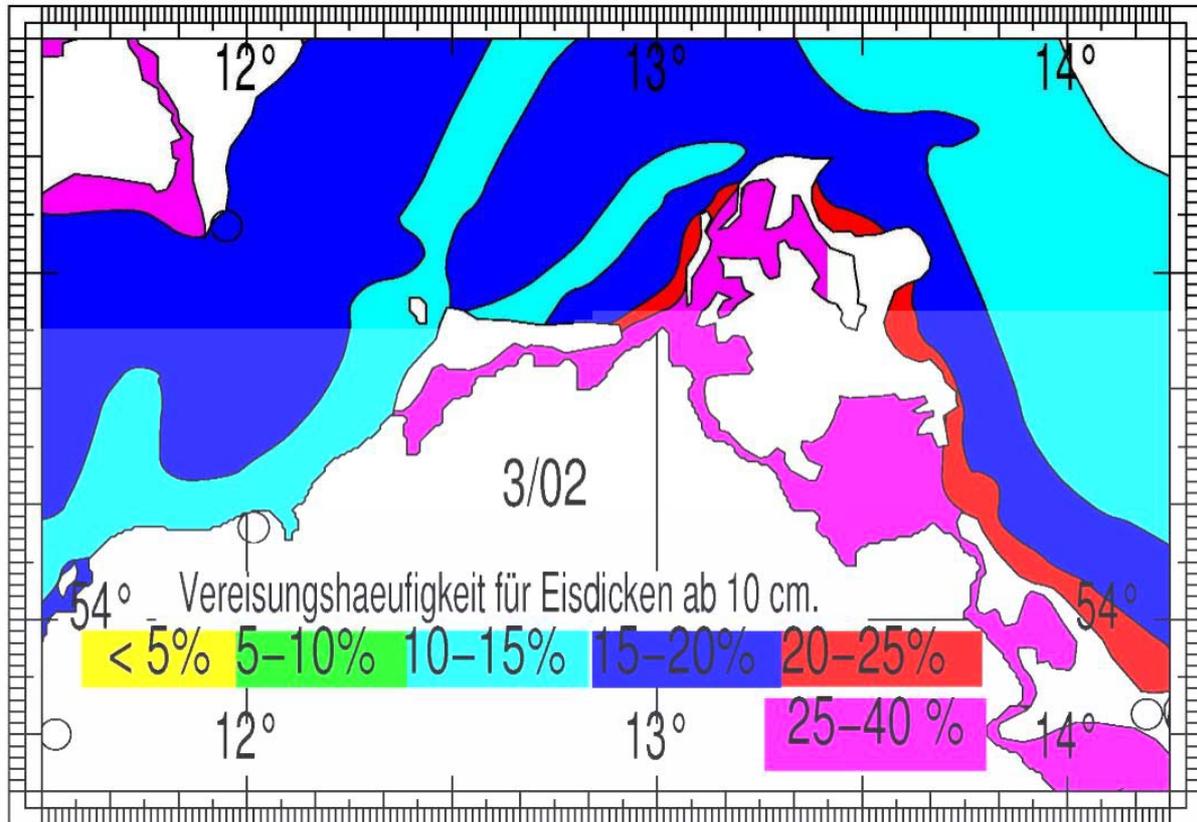


Figure V-3.1 Types of Baltic ice extent during mild, normal and severe winters.

Example of sea ice products, provided by the Bundesamt für Seeschifffahrt und Hydrographie (Germany)



Sea ice activities provided by the Danish Meteorological Institute

Major Developments

- ☛ *Satellite images constitute now the major source of ice information*
- ☛ *Since June 1998 a new ice charting system has been used*
- ☛ *Since March 1999 DMI has been using RADARSAT images operationally*
- ☛ *Since January 1999 all ice analyses and charts are in digital form - ice attributes are stored in SIGRID code*

MAY 2000 WMO/CIWG WMO/CIWG OTTAWA, CANADA

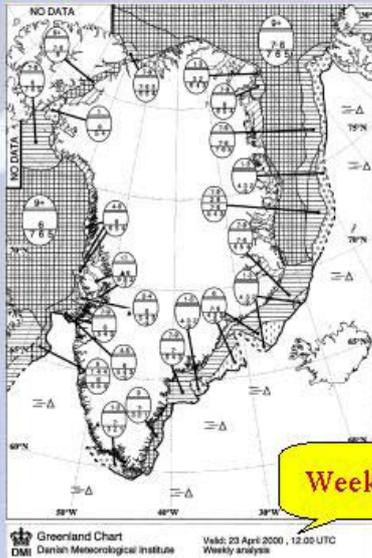
Sources of Information

- DMSP SSM/I
- Reconnaissance
- Meteorological Information
- NOAA AVHRR
- RADARSAT

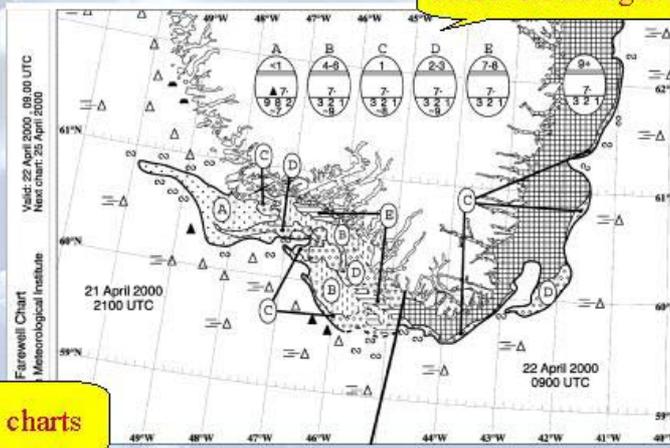
MAY 2000 WMO/CIWG WMO/CIWG OTTAWA, CANADA



The Products



MAY 2000



Charts for navigation

Weekly charts

WMO/CIWG

WMO/CIWG OTTAWA, CANADA

Sea Ice Operation and Sea Ice Data Archive of the Japan Meteorological Agency

1. Data Flow of Sea Ice in JMA

The Japan Meteorological Agency (JMA) conducts the analysis and forecast for the seas around Japan, the sea of Okhotsk and adjacent Seas. The outline of the flow of information related with our work is shown in Figure 1. For our analysis, we mainly use the visible image of GMS-5, visible and infrared images of NOAA, and the results of the aircraft observation by the Self- defense Force. JMA will conduct sea ice analysis using satellite data for just 30 years at this June. In addition, JMA uses the results of coastal visual observation conducted along the Okhotsk coast of Hokkaido (one of the main island of Japan located in the northern part) , the radar observation of Hokkaido University and voluntary ship observation. On Tuesday and Friday, all sea area is classified into sea ice area and open sea (cloud area is removed) by using several daily analysis in order to issue 'Sea Ice Information', attached with forecast prepared by considering meteorological and oceanographic condition around ice area. And the next day (Wednesday and Saturday), this analysis is used for numerical sea ice forecasting, whose model is operated in the southern part of the Sea of Okhotsk. "Sea Ice Condition Chart" (Figure.2) and "Ice Condition Forecast Chart" (Figure.3) are disseminated via radio facsimile.

2. Analysis and Archive of Sea Ice Data (Figure 4)

The Sea Ice Condition Data are archived in our system by Windows' bitmap file and Grid Point Value (GPV) data. And by means of GPV data, JMA has made the 5 day analysis data since December 1970. To make 5 day analysis data, the nearer 6 days' data around the standard date (5th, 10th, 15th, 20th, 25th at every month and the last day of every month from November to July) are used to eliminate cloud area.

These 5-day analysis data are converted to the SIGRID-2 formatted data, and sent to World Data Center -A, B.

3. Problems about Data Archive (Figure 5)

The analyzed data are archived in the window's bitmap formatted file. The reasons why the format is adopted are as follows:

First, by this file format, the analysis by the satellite is easily reflected on the analyzed chart.

Second, the system for analyzing the sea ice is easily constructed on PC.

But, file of this format is easy to append the new analysis on the charts, and mistakes are often took place. Preventing this error, the sea ice data are also archived in a GPV format that is difficult to change.

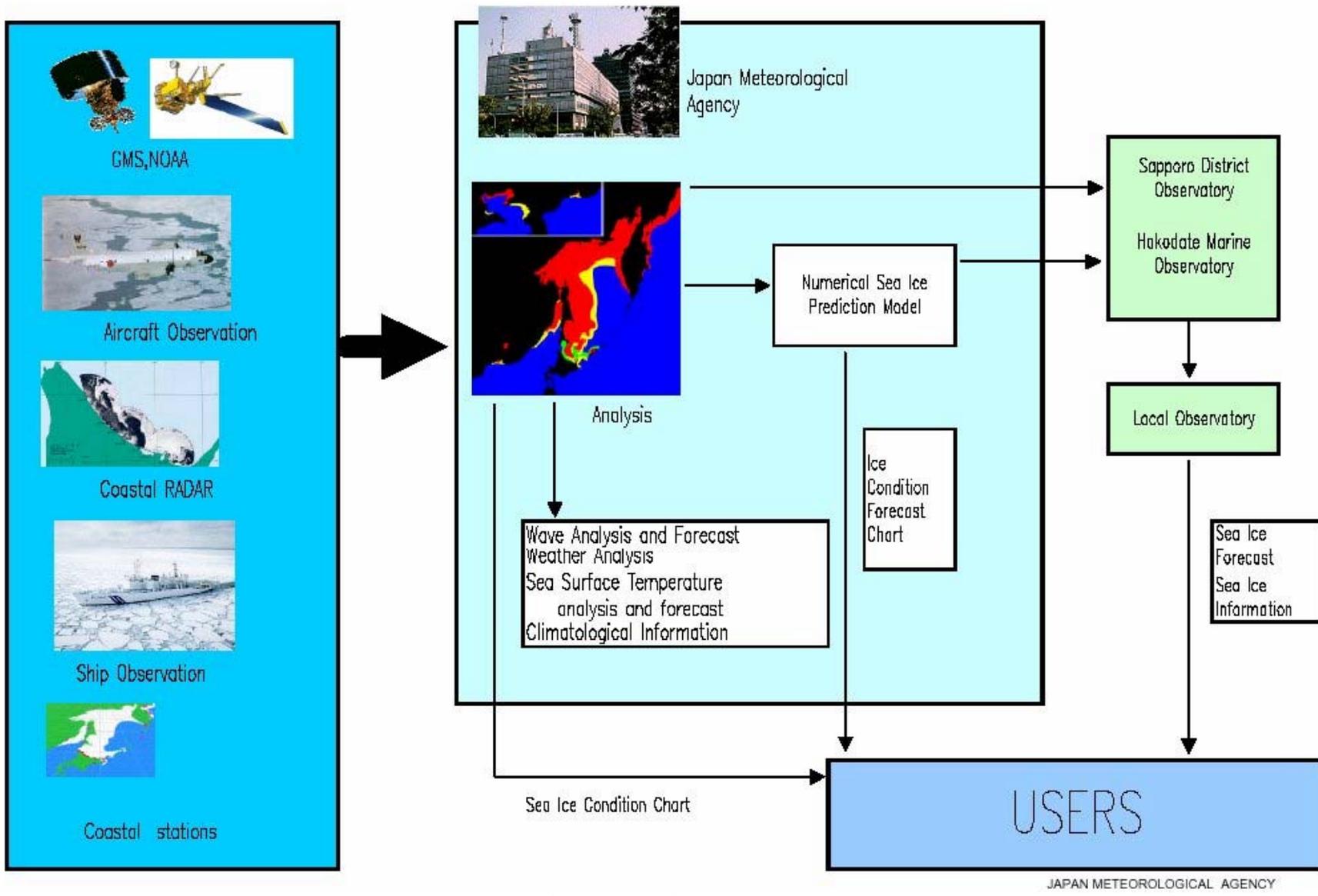


Figure 1. Data Flow of Sea Ice in Japan Meteorological Agency

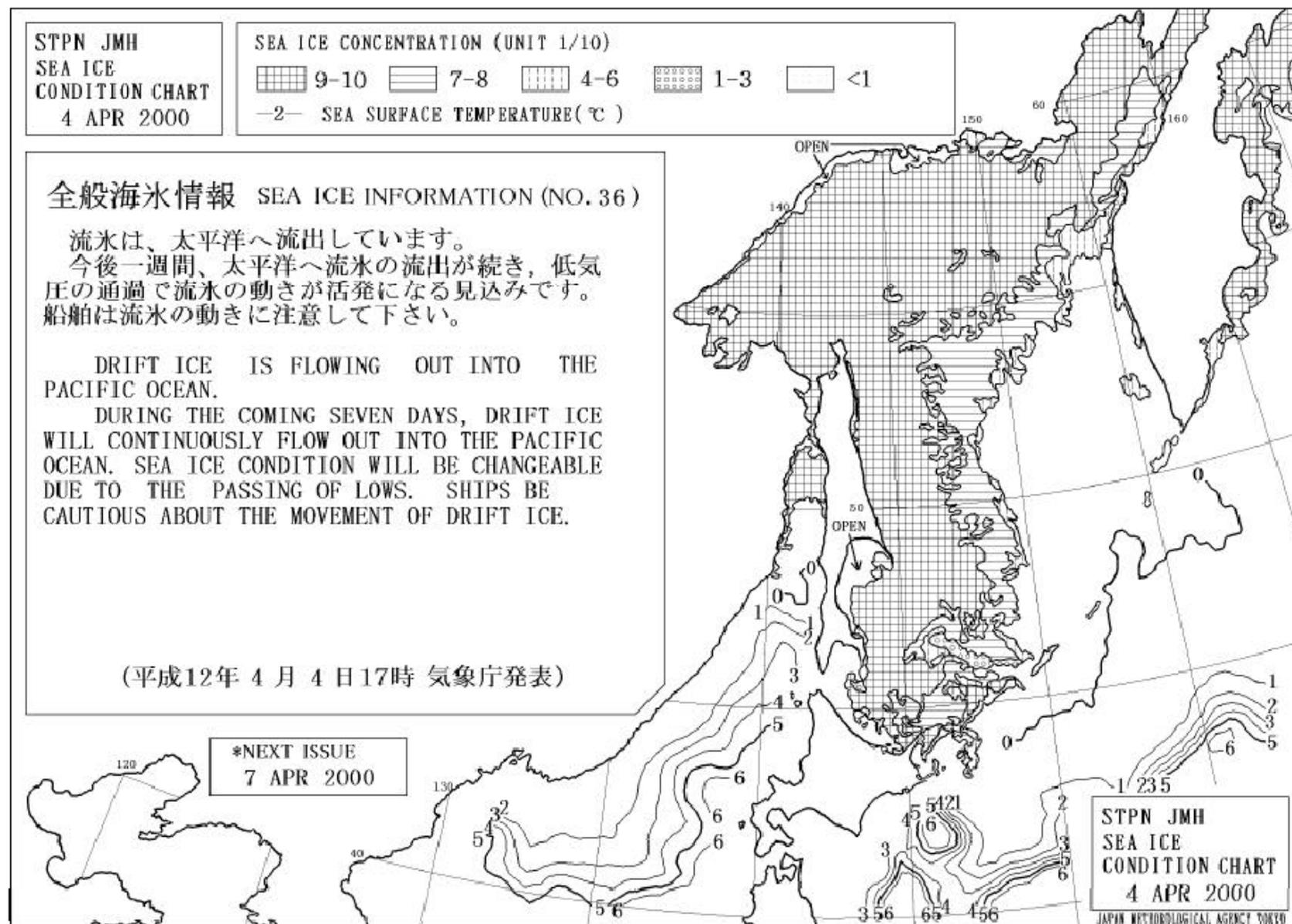


Figure 2. Sea Ice conditions chart

FI0H04 JMH	ICE CONCENTRATION
ICE CONDITION	▨9-10/10 ▨7-8/10
FORECAST CHART	▨4-6/10 ▨1-3/10
FOR 2000.4 .7 (00Z)	
INITIAL 2000.4 .5 (00Z)	

FI0H16 JMH	ICE CONCENTRATION
ICE CONDITION	▨9-10/10 ▨7-8/10
FORECAST CHART	▨4-6/10 ▨1-3/10
FOR 2000.4 .12(00Z)	
INITIAL 2000.4 .5 (00Z)	

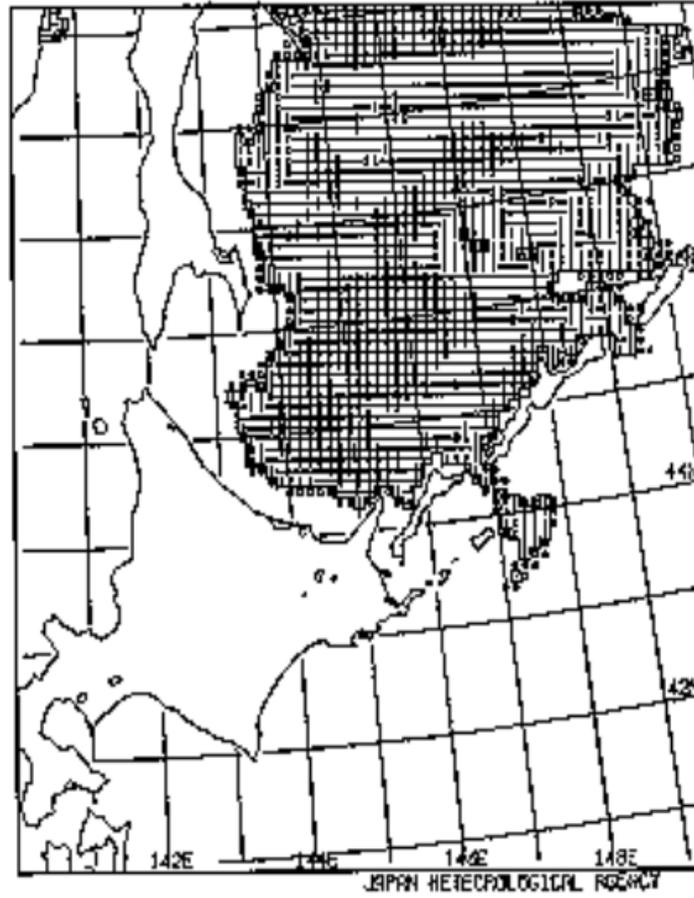
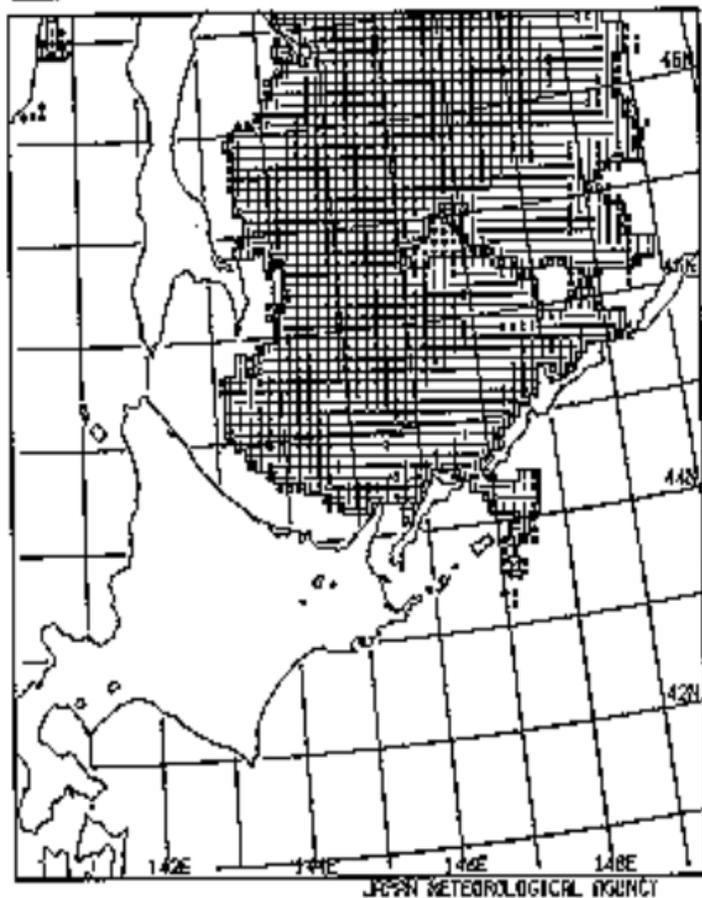
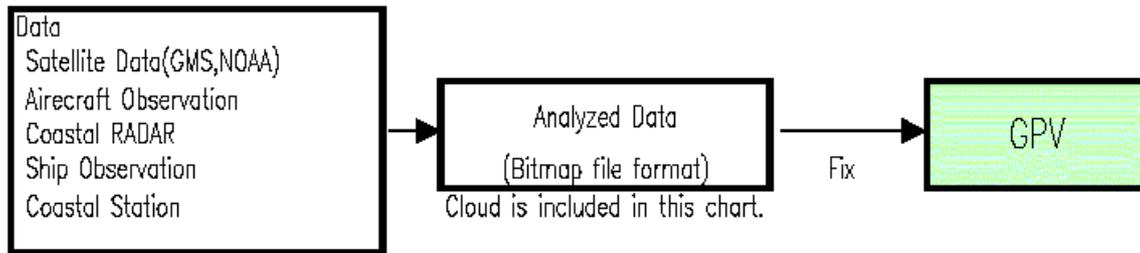


Figure 3. Ice condition forecast chart.

Daily Analysis

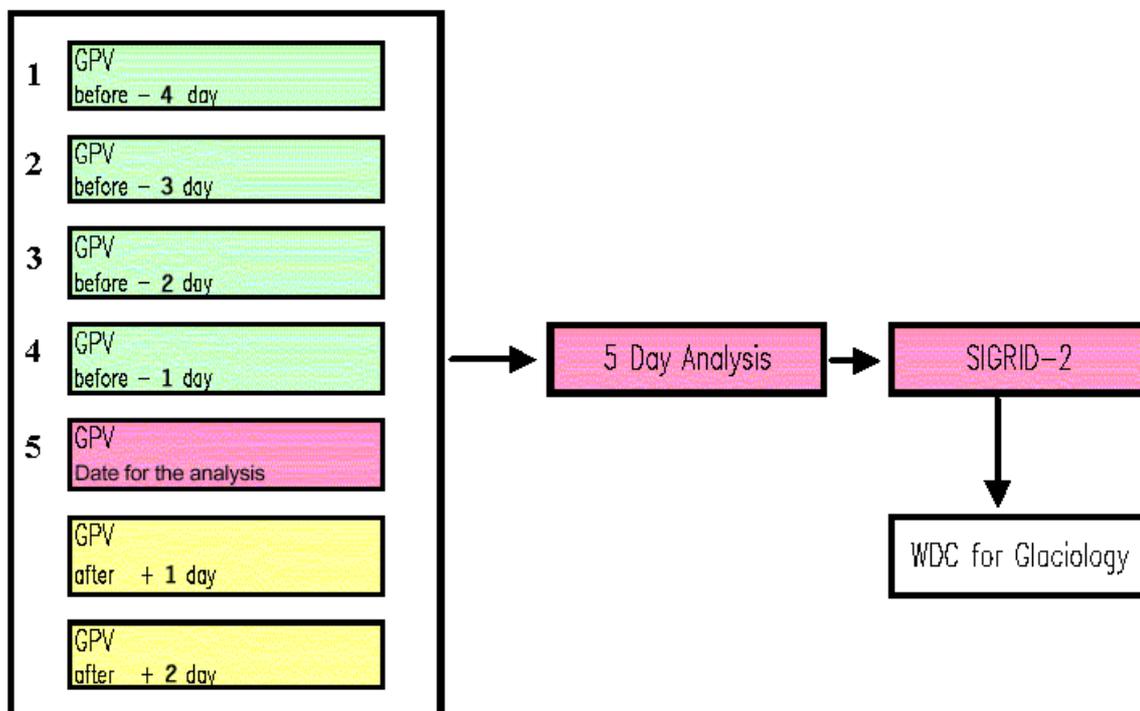


5 Day Analysis

In our daily analysis data, cloud area is included.

7 days analysis are used to eliminate the cloud area.

Analysis Date are 5th, 10th, 15th, 20th, 25th and the last day of every month in sea ice season.



Order of analysis chart composition for eliminating the cloud : 1->2->3->4->5

Figure 4. Analysis and archive of sea ice data.

Bitmap file Characteristics

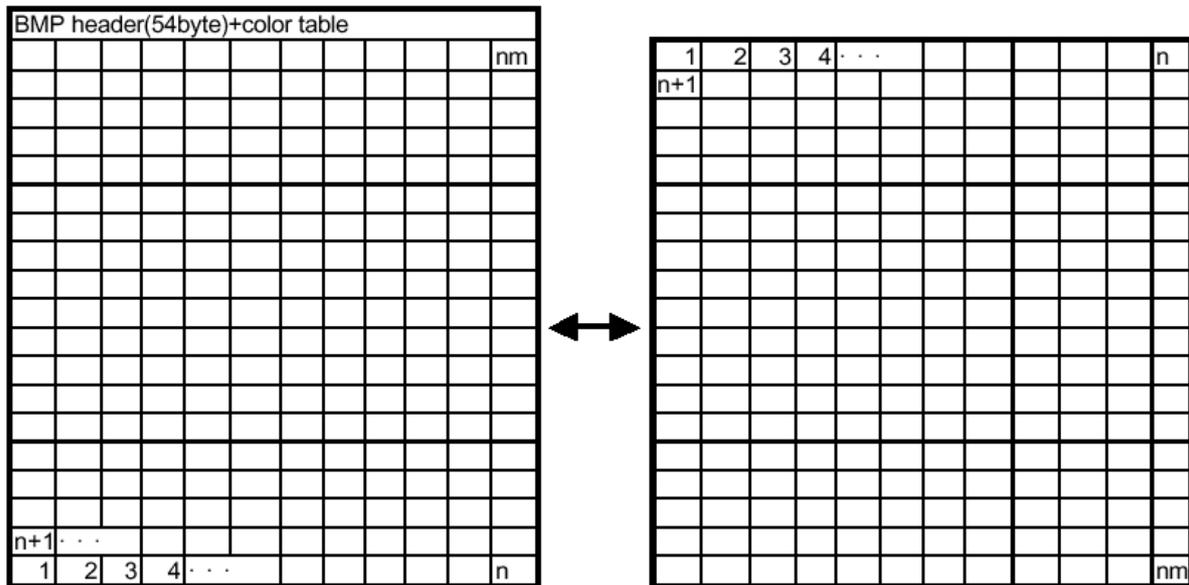
One to one correspondence between BMP file and GPV file

BMP file has header area.

In this area, there are definition of width of column and line,
1 pixel's byte length, etc.

Bitmap File Format

GPV file



The Bitmap Formatted file's Characteristics

Advantages

Extracted Ice characteristics are easily reflected on the analyzed chart.

Analyzing system is easily constructed.

Shortcomings

Easily append the incorrect analysis.

Figure 5. Advantages and shortcomings of using bitmap formatted files for archiving sea ice products

Pages 23-31 not available electronically.

Sea ice incidents in Icelandic waters and their monitoring

ABSTRACT

Sea ice monitoring of Icelandic waters as well as archiving of sea ice observation data is looked after by the Icelandic Meteorological Office. Icelandic waters are defined as the economic zone around Iceland, extending outwards to a 200 nautical miles distance from the coast or to the midline between Iceland and Greenland in the Denmark Strait. The variability of sea ice extent in Icelandic waters is displayed by examples of sea ice charts, based on sea ice reconnaissance flights of the Icelandic Coast Guard and supplemented by ship reports and other available information. Recent and planned research projects dealing with physical processes in this complicated meteorological and oceanographic area and further north are mentioned.

Introduction

Annual extension of sea ice in the vicinity of Iceland fluctuates between open sea across the Denmark Strait in late summer to sea ice in the Strait in late winter covering the ocean at the coast of East Greenland half way towards Iceland. Much of the sea ice is advected by the East Greenland Current from the Arctic Ocean and the Northern Greenland Sea but considerable amount forms during winter along the coasts of Greenland further south. Besides variable amount being brought south by the East Greenland Current, year-to-year fluctuations in surface ocean conditions in the Denmark Strait and the Iceland Sea give rise to different sea ice extent in Icelandic waters. However, the final cause at present times resulting in sea ice reaching as far east as sailing routes around Northwest and North Iceland, and even to the coasts, is the effect of prevailing winds, i.e. the atmospheric pressure configuration over the North Atlantic. In earlier centuries of colder climate, with more extensive sea ice in the Greenland Sea, Icelandic coasts were visited by sea ice more frequently.

Sea ice in the Denmark Strait (Greenland Sound)

Figure 1 displays a rather normal extent of sea ice in the Denmark Strait in June, soon after maximum extent in late May. The chart resulted from an expedition in June 1982 on board the Soviet icebreaker "Otto Schmidt" with Icelandic participation. Meteorological and oceanographic observations were made in the marginal sea ice zone between Iceland and Greenland. The broken line in Figure 1 displays the general position of the sea ice edge during the expedition. The encircled points show the locations of oceanographic stations. During middle of June, the month of the cruise, the sea ice is normally on retreat but still extensive.

Figure 3 displays in detail the characteristics of part of the sea ice edge investigated during the cruise, described by the international sea ice symbols, at that time newly adopted, see Figure 2. The sea ice amount was still quite large after the gradual accumulation through the winter months. The sea ice in the southern part of the area investigated was in general characterized by thick ice. However, the overall panorama during the cruise was surprisingly variable in terms of concentration, stage of development, floe size and other ice features. Figure 4 indicates position changes of the ice edge in the Denmark Strait in June 1982. The eastward movement of the ice edge was associated with moderate winds from south, southwest and west.



Figure 1. Sea ice edge in the Denmark Strait in June 1982

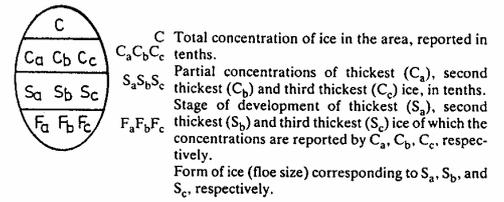
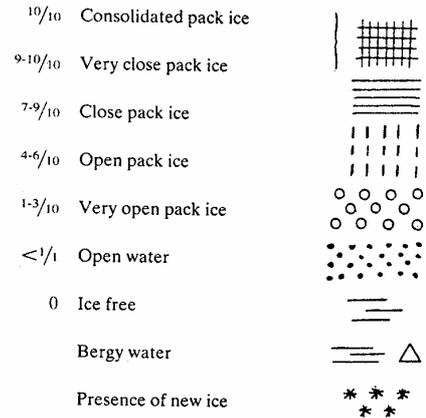


Figure 2. Sea ice symbols used in Figure 3

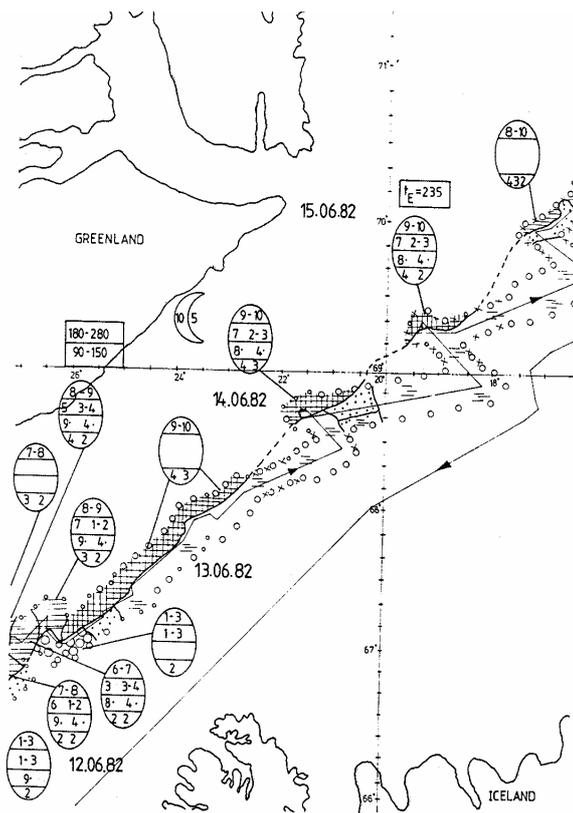


Figure 3. Characteristics of the sea ice edge in Figure 1

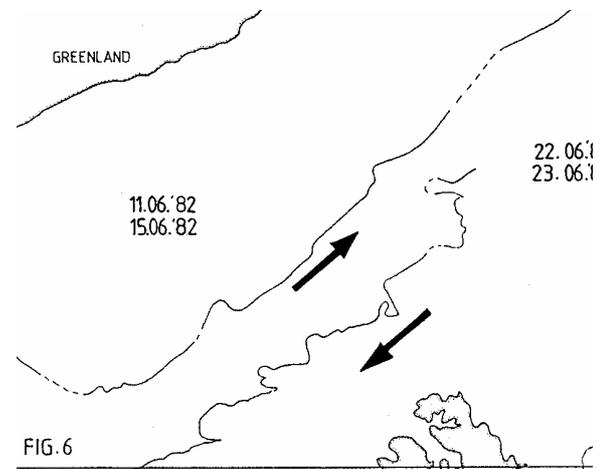


Figure 4. Movement of sea ice edge in June 1982

Examples of sea ice incidents

Sea ice off the Icelandic coasts has been recorded for centuries, first by remarks in annals and diaries kept by farmers and officials, but in more regular manner during the last couple of centuries. In an effort to find a measure of variability from one year to another, an index was developed indicating the severity of sea ice incident during a particular year at the coasts of Iceland. The index refers both to the extent of the Icelandic coastline being visited by sea ice and number of weeks with recorded sea ice during the year.

Figure 5 shows the sea ice index during most of 20th century. During the first two decades heavy sea ice was quite common at the coasts of Iceland, but in the twenties a drastic change occurred. Sea ice at the coasts of Iceland became an uncommon characteristic and almost forgotten phenomena around the middle of the century. An abrupt change occurred in the mid-sixties.

Figure 6 shows the distribution of sea ice at the northern coast of Iceland in February 1965. Heavy sea ice distribution occurred almost each year in the following, but since 1980 widespread and long lasting sea ice off Iceland took place at rather irregular intervals. Figure 7 displays a mid-summer sea ice distribution in 1984, showing the effect of prevailing southwesterly and westerly winds due to dominating blocking high pressure area over the North Atlantic. Finally, in Figure 8 a more recent mid-winter incident in March 1988 is shown, demonstrating a combined effect of above average sea ice extent in the Greenland Sea in the weeks before and atmospheric pressure configuration favouring westerly winds.

The sea ice index graph during this century is an indication of interesting climate changes on decadal time scales. However, changes of sea ice distribution in Icelandic waters on smaller time scales, down to a few days, and even from one hour to another, are important as sea ice affects human activities on fishery grounds, sailing routes and in the most serious scenarios can threaten access to harbours in northern Iceland. Due to its irregular, almost erratic, behavior, sea ice around Iceland is an important natural feature, which has to be watched and studied.

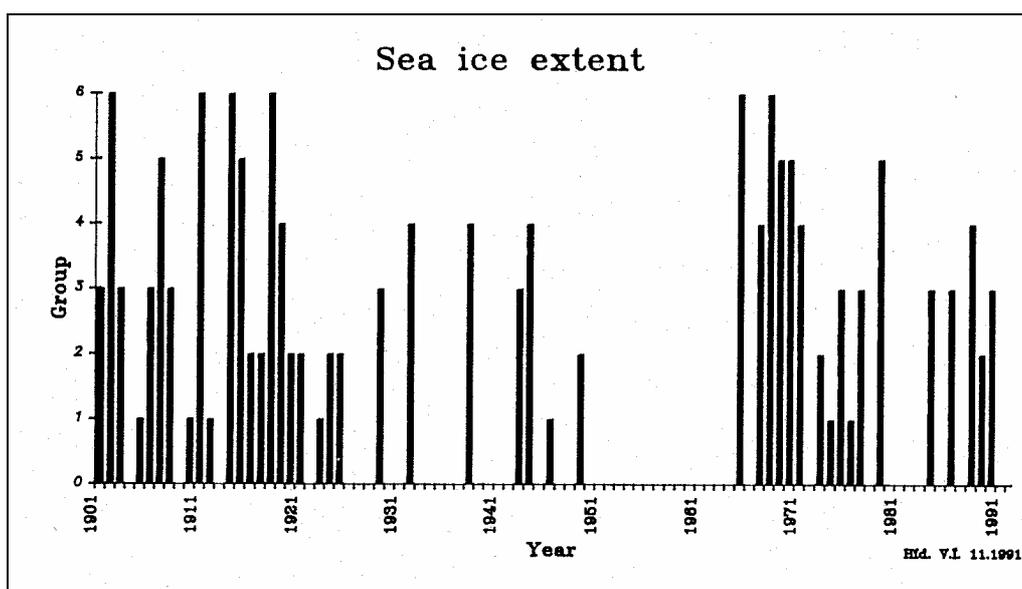


Figure 5: Sea ice index indicating sea ice incidents at the coasts of Iceland

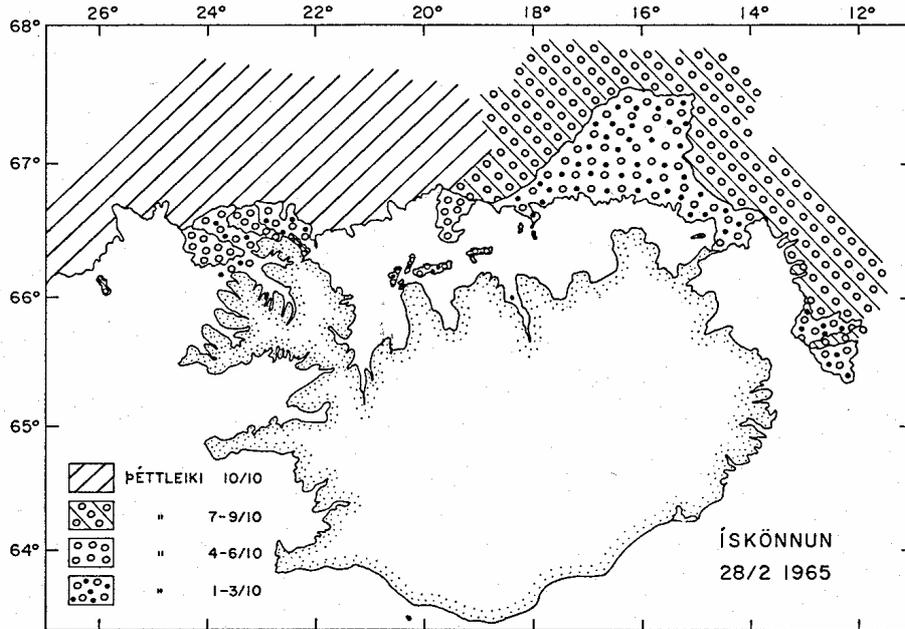


Figure 6. Extreme sea ice conditions off Iceland in February 1965

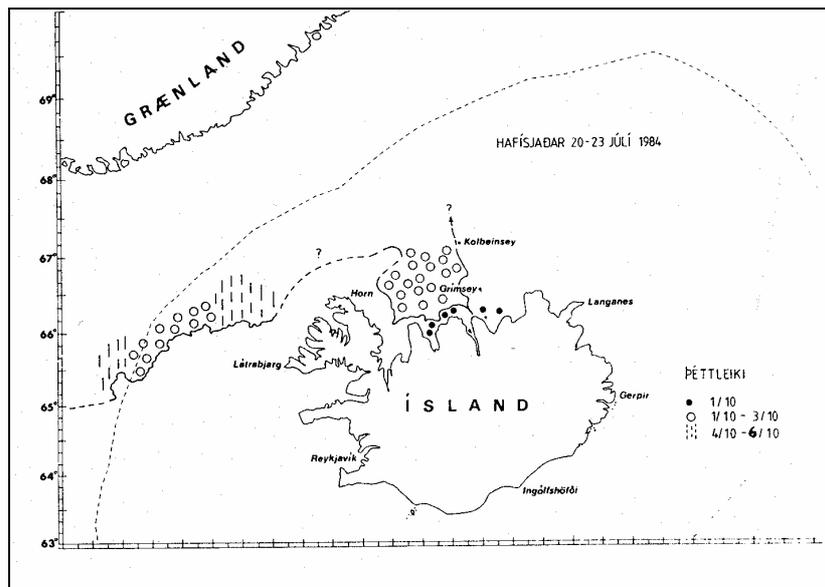


Figure 7. Sea ice north of Iceland during summer due to a blocking high

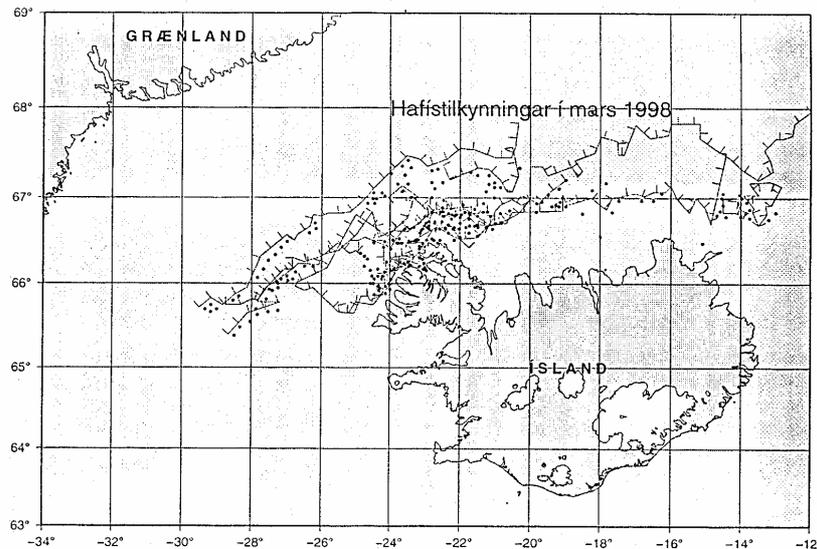


Figure 8. Serious sea ice conditions northwest off Iceland in late winter

Scientific projects and integrated monitoring systems

In addition to conventional sea ice service based on flow of data from ships and airplanes and archiving of obtained information, the Icelandic Meteorological Office has participated in European and Nordic research projects in the North Atlantic where international cooperation results in increased knowledge of the physical processes involved in variable sea ice amount on many scales. The Greenland Sea Project (GSP) and the European Sub-polar Ocean Programmes, (ESOP-1 and ESOP-2), have contributed to improved understanding of the northern seas and a series of Nordic research projects for the Sub-Arctic have concentrated on analysis of meteorological and oceanographic observation time series around the North Atlantic. Useful experience in the fields of remote sensing, sea ice modelling etc. has been gained.

More on the practical, operational side a three-year European project in the field of information society technology commenced recently, called "Integrated weather, sea ice and ocean service system" (IWICOS). Six institutions and a private company in the Nordic countries will work together on the design of a cooperating platform of marine services in the North Atlantic and along the Northern Sea Route in the Arctic Ocean. Closer cooperation between different organizations will improve service and safety at sea.

Final remarks

Despite indications of decreasing sea ice amount in the Arctic, the East Greenland Current, the main current leaving the Arctic, will continue to bring sea ice long distances south along the coasts of Greenland. Conditions for local sea ice formation en-route will also persist. Helped by atmospheric variability sea ice in Icelandic waters will still in the years to come be of concern for seafarers, be they onboard small sailing boats, fishing boats or big tank ships or cruise liners.

Draft Agenda of the next forthcoming 20th Baltic Sea Ice Meeting

**BSIM-20 Riga, 25-29 Sept. 2000
Draft AGENDA**

- 1. Opening of the Meeting**
- 2. Organization of the Meeting**
 - 2.1 Election of the chairmen
 - 2.2 Adoption of the agenda
 - 2.3 Working arrangements
- 3. Sea ice observation techniques and exchange procedures**
 - 3.1 Baltic Sea countries
 - 3.2 Other countries/areas
 - 3.3 Exchange procedures (GTS, Telefax, E-Mail, Internet)
 - 3.4 Harmonization: Requirements and possibilities
- 4. Baltic Sea Ice Code**
 - 4.1 Experiences and possible need for further development
- 5. Review of the WMO/JCOMM sea ice activities**
- 6. Digitizing of sea ice charts for the period from 1960/61**
 - 6.1 Status
 - 6.2 Future activities
- 7. International System for Sea Ice Symbols**
 - 7.1 Experiences
 - 7.2 WMO Sea Ice Nomenclature, Symbols and Codes
- 8. Ice charts**
 - 8.1 New satellite related ice charts
 - 8.2 New production techniques and products
 - 8.3 Transmission techniques
 - 8.4 Joint production
- 9. Remote Sensing**
 - 9.1 ESA data politics
 - 9.2 RadarSat and ENVISAT data utilization
- 10. Reports of the Icebreaking Services (co-operation with Ice Services, requirements)**
- 11. Baltic sea ice climate**
 - 11.1 Classification of ice seasons
 - 11.2 International activities
- 12. International Affairs and Events** (workshops, projects, cooperation, working groups as IICWG)
- 13. Other questions**
- 14. Adoption of the Draft Report**
- 15. Date and place of the next Meeting**
- 16. Closing of the Meeting**

Work Plan for Cooperation between the members of the Steering Group on the WMO Project Global Digital Sea-Ice Data Bank for May 2000 - October 2002

1. Technique Development

The experts from the GDSIDB centers will to continue make available data browsers, translating and other necessary software for processing data in SIGRID, ArcInfo and EASE-grid formats

2. Data Exchange.

2.1 Anticipated data sets to be contributed by GDSIDB members, on a schedule dictated by available resources, during the intersessional period 2000 – 2002.

	Institute	Region	Time interval	Exchange date (notes)
1.	AARI	Antarctic	1971-1990 (10-days period)	When the data are available for WDC-B
2.	Argentinean Navy Hydrographic Service	Weddell and Bellingshausen Seas	App. 1982 to 1990, point observations Current observations	June 1999 Point observations in NIC-code in .db format, submitted with weekly interval to NSIDC and AARI ftp-servers
3.	Australia, within the ASPeCT project	Antarctic, en-route and pointal observations	1980-1997	In WMO code
4.	BSIM (jointly SMHI and FIMR)	Baltic Sea	1980 – 1998, 3-4 days interval 1999 - 2000	SIGRID By 2002, exchange formats will be determined by ad-hoc group
5.	CIS	Canadian Arctic	1999- ongoing data forward in time	Exchange formats will be determined by ad-hoc group
6.	China, State Oceanic Administration	Bohai Sea	1968 – up to present 1952/53 – up to present	0,1° by 0.1° grid, total and partial concentrations and stages of development maximum annual extent to be submitted before the next meeting

7.	DMI	Greenland waters	March 1999 – March 2000	December 2000, exchange formats will be determined by ad-hoc group
8.	Germany, Federal Maritime and Hydrographic service (BSH),	Baltic Sea (south of 56°N and to the west of 14 20')	1960-1982 and updates	to be determined
9.	Icelandic Meteorologica l Office	Icelandic waters	to be determined	to be determined
10.	JMA	Sea of Okhotsk	ongoing data forward in time	Once a year in SIGRID-2 format
11.	NIC	Arctic and Antarctic	1972 –1994 1973 –1994, 7-days period	Final version is anticipated by mid-2000 in SIGRID, EASE-GRID and ArcInfo e00-format
		Arctic Antarctic	1995 – 1996 1995 – 1997	need to be converted to standard format and undergo QC before submission
		Arctic Antarctic	1996 - till present 1998 – till present	ArcInfo e00-format, available on-line via NIC web-site, exchange formats will be determined by ad-hoc group

2.2 Technical assistance.

2.2.1 SG experts from AARI and NSIDC centers of GDSIDB will continue to provide assistance for incorporation of ice information in formats other than SIGRID (EASE-grid, Contour etc.) provided that adequate documentation and access software are attached.

2.2.2 NSIDC and AARI will continue to provide guidance on preparation of metadata and other necessary documentation accompanying data submitted or to be submitted to GDSIDB.

2.2.3. NSIDC and AARI centers of GDSIDB will develop web-links to complementary meteorological and oceanographic data sources.

3. Modification of formats for data exchange

3.1 The ad-hoc working group on data formats will continue to assess the feasibility of implementation of new formats for ice mapped information international exchange (see ANNEX X).

3.2 NSIDC and AARI, together with the experts from operational centers, will prepare a report on the given activity for the next IICWG meeting in October 2000, Iceland

4. Use, validation and intercomparison of GDSIDB data

4.1 Experts from SG will continue joint activity on development of blended sea ice data sets and sea ice climate estimates from the GDSIDB data.

4.2 SG members will endeavor to establish linkages with the other programs and projects concerning the development of climate estimates, validation and intercomparison of GDSIDB data

5. Future activity

5.1 GDSIDB SG experts will participate in preparation and discussions of JCOMM recommendations on POSSIR at the IICWG workshop in Reykjavik October 2000 and in further JCOMM connected activity.

5.2 Experts of GDSIDB SG (mainly from AARI, NSIDC and CIS) will cooperate in development of possible "CD of GDSIDB data sets" under the auspices of WMO.

Possibilities of incorporating sea ice information from Black, Azov and Caspian seas into GDSIDB

The Black, Azov and Caspian seas are the seas with seasonal ice cover. Northern Caspian sea ice conditions are compatible with those for eastern and northern Baltic; moreover during severe ice winters southward drifting pack was a real threat and a source of damage to oil and gas structures located in the Central part of the Sea and designed regardless of ice factor. Ice conditions on the Black Sea are milder and are compatible with the Sea of Japan and the northern part of the Yellow Sea. Azov Sea has intermediate ice conditions. Ice cover on those areas is the integral part of the global ice sheet, and no doubt has information containing climatic signals thus interesting to the modelers apart to its influence on coastal activities and navigation.

The Seas were thoroughly studied by the former USSR and now Russia Rosgidromet institutions in meteorological and oceanographic respect, including sea ice, a number of monographs, climatic atlases, manuals on ice navigation support etc being published. As most of the studies were carried out using initial and derived data on paper or digital data in original formats no end-user digital databases on sea ice were developed. Possibilities to construct such databases are reviewed below. As a source of information following publication of the State Oceanographic Institute - "Gidrometeorologicheskie usloviya shel'fovoi zony morei SSSR" [Hydrometeorological Conditions of the shelf zone of the seas of USSR], vol.2 – Caspian Sea, vol.3 – Sea of Azov and vol.4 – Black Sea (Gidrometeoizdat, Leningrad, 1986) - was used.

Caspian Sea

In ice respect Caspian Sea was divided into Northern, Middle and Southern parts. Annual probability of ice formation is equal to 100% for the area in northern part bordered by the 3 m isobathe and lessens to 4% for the southern part. In a whole, process of ice formation does not exceed shelf area bordered by 200 m isobathe. Spatial distribution of probability of ice formation (occurrence) is given on attached figure. The greatest ice thickness are observed in the shallow areas of the northern part where fast ice can be in average 35-45 cm thick and up to 70-90 cm for the severe winters. Rafted ice can be up to 100-150 cm thick and the height of hummocks can be 3-6 m or more. Usually ice season for the northern part covers the period from November till March or for definite years can be by 1 month earlier or later. Greater ice extent is observed during the years of activation of air pressure Polar Maximum, lesser extent – during the years of latitudinal transfer of air masses.

Initial sea ice information includes coastal stationary ice observations, ice reconnaissance and shipborne observations as well as data from various Atlases, manuals and other publications. Initial data were archived mainly at Russian institutions and partly at Azerbaijan meteorological service.

Hydrological stationary observations cover the period from 1923 to the present time. Regardless of political aspect the natural phenomenon – level alterations of the Caspian Sea led to successive closure of a number of stations in the northern part of the Sea. Some of the stations were moved to more representative locations. By the beginning of 90s ice observations in the northern part were being conducted at 5 stations. As for the whole Caspian Sea area again only 5 stations have duration of observation more than 50 years, while others have less duration.

Open sea ice conditions can be reconstructed using shipborne observations and air reconnaissance flights conducted from 1927 up to beginning of 90s. Authors of the used publication do not specify exactly the year when en-route observations were compiled into the chart but it can be assumed the same year as for the Arctic – 1933. In the northern part for the time before and during the WWII air reconnaissance flights were conducted simultaneously with the reconnaissance of seals locations over rather small areas and irregularly during winter period. In the northern part flights became more regular after WWII and from 1959 had being conducted on regular scale and not less than 1 time per 10 days along fixed standard routes. Along the western coast of the Middle part regular flights were conducted only during extreme ice seasons (1949/50, 1953/54, 1968/69, 1971/72).

Summarizing, perspective electronic database on the ice of Caspian Sea may contain stationary observations from at least 5 stations with duration of observation period of several decades and a set of two-three hundreds of ice conditions charts for the period of 40-45 years. Climatic charts from the cited publication and as well as other Atlases can be also incorporated into the database.

Black Sea

Only a minor part of the Black Sea is covered by ice in the winter period. Even during most severe winters not more than 5% of the sea area is ice covered, and in average – from 0.5% to 1,5%. Spatial distribution of probability of ice formation (occurrence) is given on the attached figure. Northwestern part of the Sea is featured by the lowest December to February air temperature and has the greatest ice extent. Estuaries of Bug-Dnepr and Dnestr rivers are covered by ice every year, the same is for coastal waters in the vicinity of the port of Odessa. During severe winters fast ice propagates along the western coast to the south of Konstanza port and for most severe cases pack drifts up even to and into the Bosfor strait. Due to counter clockwise circulation formation of ice along the northeastern coasts of Black Sea is to less extent and is restricted by the areas from the port of Novorossiisk to Feodosia port. Usually ice formation starts by the mid December. For the most severe winters duration of ice season is about 130 days for the northwestern part and about 85 days for the northeastern part. In mild conditions duration of ice season is about 40 days and in those cases ice does not appear in some places in the northwestern part and does not appear at all within the northeastern part. In springtime ice usually disappears in March, in severe conditions by the beginning of April.

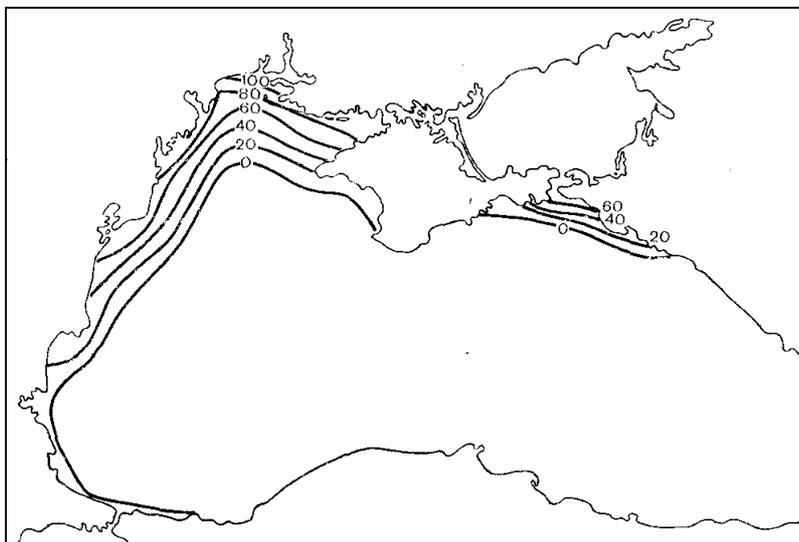
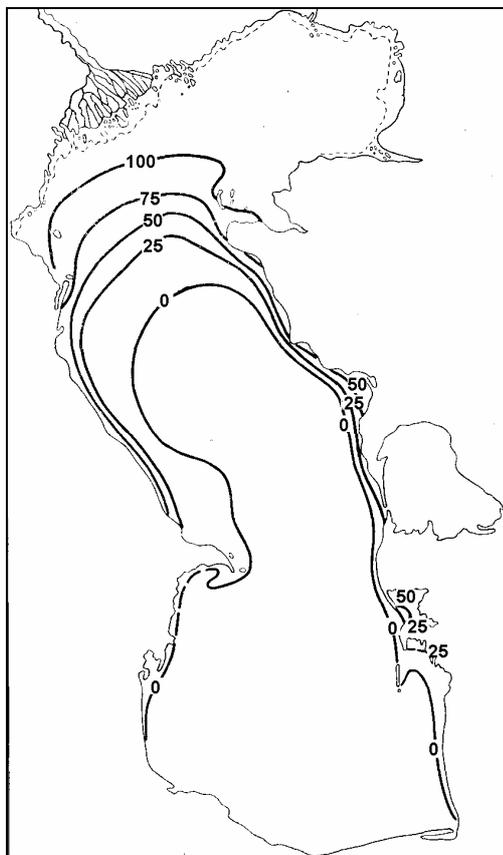
Initial ice information includes coastal stationary ice observations, ice reconnaissance and shipborne observations as well as other published data. Initial data were archived at Russian institutions and at Ukrainian meteorological service.

Ice stationary observations were being conducted at 33 stations and cover the period from 1900 to present time but mainly from mid 20s to 70s, which makes duration of observation period equal to 50 years. However, historical data for such prominent locations as Bosfor etc can be available from the beginning of the 19th century.

Opposite to Caspian Sea air reconnaissance flights were conducted on irregular basis and mostly during severe winter conditions within the northwestern part. Cited publication gives the period from 1949 to early 90s.

Summarizing, perspective electronic database on the ice of Black Sea may contain a valuable set of stationary observations from at least 33 stations with duration from several decades to more than a century and a set of episodically conducted ice conditions charts.

More valuable is the incorporation of the climatic charts for different types of winter conditions (mild-average-severe etc) from the cited publication drawn by the experts on the basis of coastal, shipborne and aircraft observations as well as charts from the other Atlases.



Probability of ice formation (occurrence) for the areas of Caspian and Black Seas, %.

Sea of Azov

The Sea of Azov is a shallow sea with mean depth equal to 7 m and with a low salinity. That, together with the complexity of coastline facilitates ice formation during wintertime. Every year significant part of the sea is covered by ice (i.e. with probability of 100%) and only seldom the central and southern parts of the sea are free of ice. Dates of ice formation and destruction can vary by 2-3 months from year to year. During intermediate type of winter conditions ice is firstly formed by the end of November – beginning of December at the corners of northeastern and eastern bays. After a month fast ice gradually propagates along the coasts and drifting ice appears in the southwestern part and begins to move through the Strait of Kerch into the Black Sea. By mid February the whole sea can be covered by fast and consolidated ice with the thicknesses of 30-40 cm and up to 60-80 cm in the northeastern corner. Breakup and destruction of ice occur in March-April. Mean duration of ice period is 4,5 month. Since the sea area is greatly influenced both by the high air pressure located to the north and northeast and by the cyclones propagating from the west and southwest ice conditions of the sea are featured by a high variability, i.e. in some cases very fast ice formation and propagation, several breakups and consolidations of pack during winter, and as a result, high concentration of hummocks.

Initial ice information includes ice reconnaissance, shipborne and coastal stationary ice observations as well as other published data and is archived at Russian institutions and at Ukrainian meteorological service.

According to the cited publication the most significant source of information on ice distribution was air reconnaissance flights for the period from 1949 up to beginning of 90s. During intermediate and severe winters flights were conducted on a regular scale and not less than 1 time per 10 days period along fixed routes. During mild winters flights were conducted irregularly.

Shipborne observations are available from 1927. Coastal stationary ice observations are available for not less than 11 stations, three of which cover the period from 1893 and other 5 from 1916-1918 and 1924-1926.

Summarizing, perspective electronic database on the ice of the Sea of Azov may contain a detailed set of air reconnaissance observations covering the period of 41-42 years blended with a set of shipborne observations starting from 20s. Stationary observations from at least 11 stations with duration from several decades to about a century may be also incorporated into the database as well as a set of climatic charts for different types of winter from the cited publication.

Sea Ice Ablation

A discussion document for the creation of new WMO categories of sea ice decay

Draft

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Why change the WMO categorizations of sea ice decay

Both mariners and meteorologists have been interested in the fact that climate variability and change may result in significant alterations in the polar regions of the planet. Within the context of this discussion document, we are interested in producing a definition of the thermodynamic states of the snow/sea ice system as we move from winter to summer conditions for both the Arctic and Antarctic. The existing WMO definitions of sea ice decay are based on visual observations of the ice state (particularly from the bridge of a ship). For the most part they do not consider the geophysical changes occurring within the snow cover on the sea ice and they do not include microwave remote sensing as an 'observational tool' to assess the thermodynamic evolution of the snow/sea ice system. In what follows we propose a series of ablation states, describe in some detail the physical and thermodynamic conditions occurring within each of these states then conclude with a pair of summary tables which describe the physical, thermodynamic and visual conditions of each state (Table 1), followed by the associated microwave scattering (Table 2).

Physical Properties of Sea Ice

Sea ice is an important component of the Earth's Cryosphere and is more appropriately considered as a multiphase alloy rather than a single-phase purer ice form such as snow or lake ice. Once ice has formed, the relationships between ice, liquid brine, and solid salts are governed by the thermodynamic structure within the snow and sea ice volume (Weeks and Ackley, 1986; Figure 1). This relationship is fundamental to relating the microwave scattering and thermodynamic state of a seasonally varying snow covered sea ice volume.

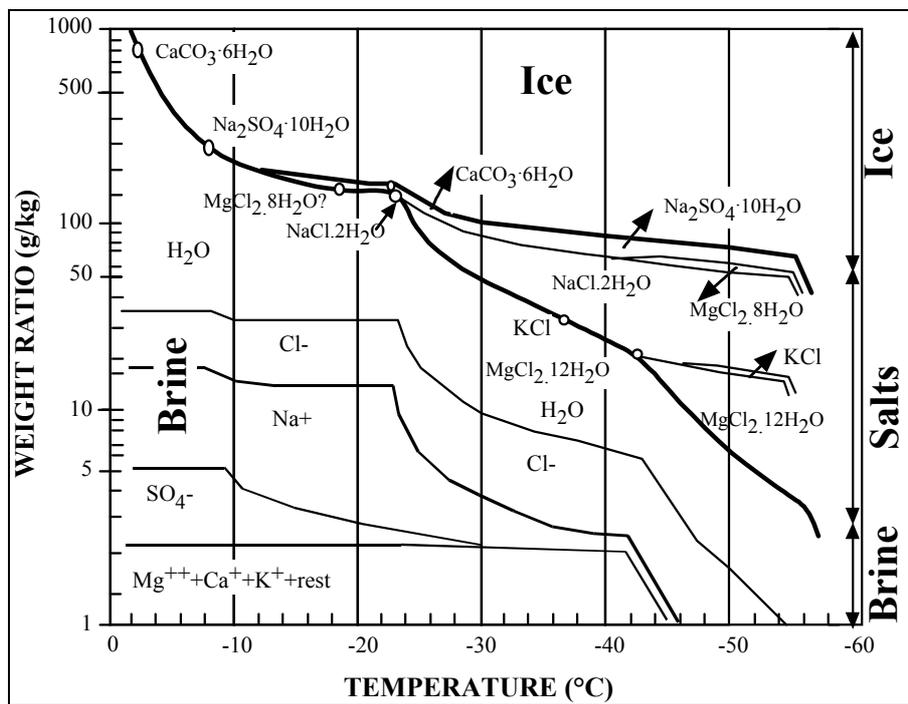


Figure 1 Phase diagram of sea ice showing the relationships between ice in solid phase, brine, and solid salts.

The interpretation of these phase relationships relative to the thermodynamics of the icescape is a continuous function of the atmospheric temperature³. For simplicity we have adopted a categorical structure within which to compartmentalize the salient theory. If we consider average conditions of the snow thermodynamic properties we can identify several regimes based on the principal processes operating within the snow/sea ice system. Although the thermodynamic evolution of the system is inherently continuous we partition the system into a series of discrete ablation states: freeze-up, winter; ablation 1 (very early melt); ablation 2 (sustained snow melt); ablation 3 (saturated snow); ablation 4 (melt pond formation); ablation 5 (drainage of ponds) and ablation 6 (rotten ice). This process is variable in both space and time and thus requires measurement by direct observation or through remote sensing with a calibrated synthetic aperture radar (SAR). Spatial and temporal variability is considerable both within and between each of these thermodynamic states. This single fact is cited as a primary motivator for determining remote sensing estimates of the thermodynamic state of the sea ice rather than relying on climatologies of these conditions. It is also a strong motivator for development of the Arctic Ice Regime Shipping System (AIRSS) structure rather than using the more static Zone/Date system.

In what follows we provide a detailed overview of the physical properties of the snow and sea ice over a range spanning the mm to km scale within the framework of the thermodynamic regimes described in Figure 2.

³For simplicity we consider the ocean temperature to be a constant -1.8°C. This is a reasonable simplification for most icescape conditions of interest in this report but the reader is cautioned that notable exceptions occur (such as in sensible heat polynyas).

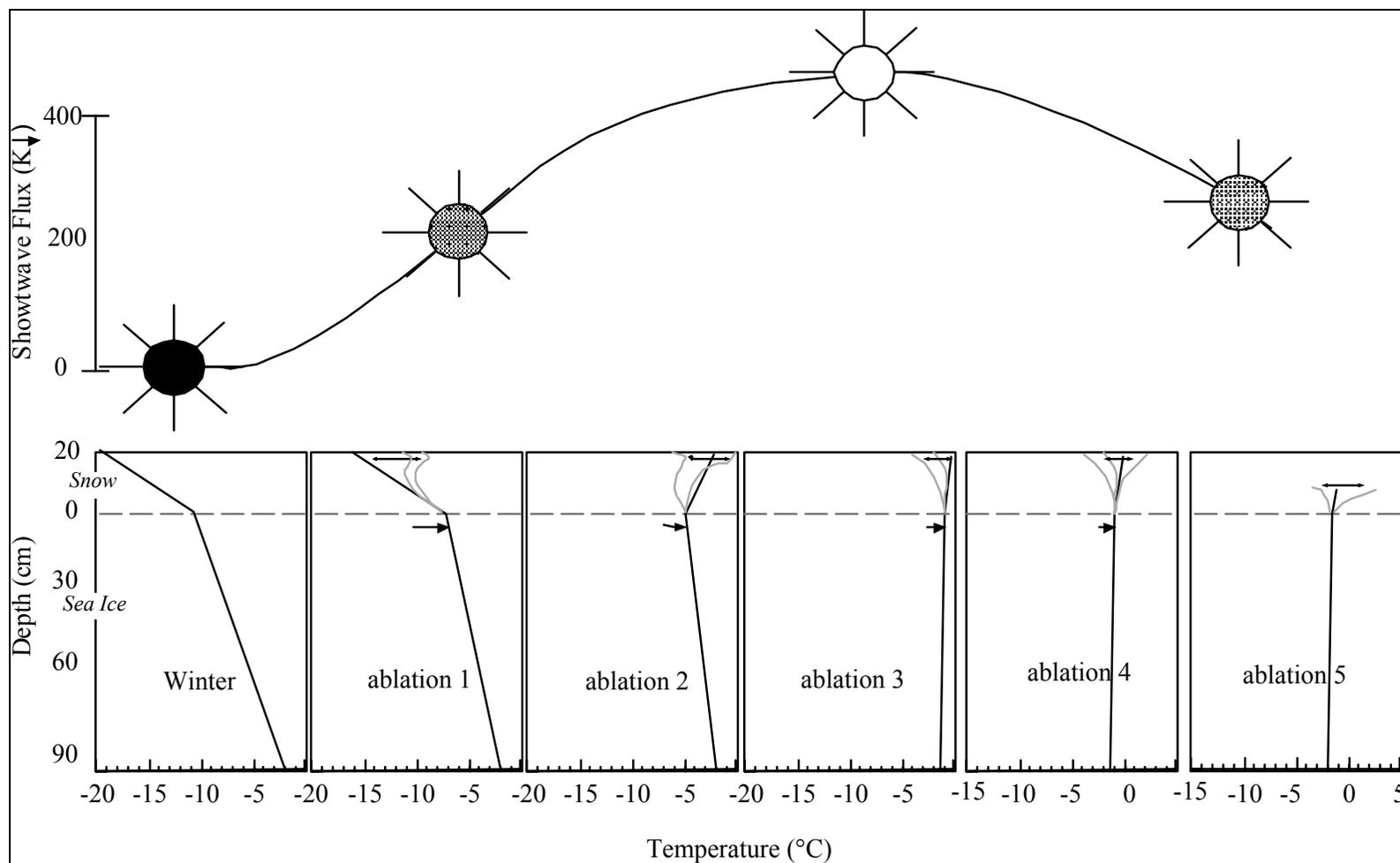


Figure 2. Categorical structures of the general thermodynamic regimes representing the transition from freeze-up, winter and into the proposed ablation states 1-6. for landfast first-year sea ice in the Canadian Arctic. Temperature profiles are summarized from 7 years of measured in situ temperature profiles. The available shortwave energy is denoted in summary above the thermodynamic profiles.

Ablation State 1

Ablation state 1 is a transitional period where water in liquid phase occurs within the snow cover for a portion of the diurnal cycle. This period coincides with large snow grain growth within the snow cover. Metamorphic processes include kinetic energy (wind induced metamorphosis) and radiant energy. Radiant energy provides for development of ice lenses and ice layers within the snow pack (Miller, 1981). Kinetic processes cause metamorphosis from a faceted hexagonal snow flake with inter crystal pore spaces consisting primarily of air, to a more rounded grain state (Colbeck, 1982). This can cause density changes from light newly fallen snow ($\sim 0.05 \text{ g}\cdot\text{cm}^{-3}$) to very dense crystal snow layers ($\sim 0.5 \text{ g}\cdot\text{cm}^{-3}$).

Coinciding with the return of solar irradiance, as a significant component of the surface energy balance, there is an increased forcing from the atmosphere onto the snow surface. Although the downwelling part of the shortwave flux can be very high early in this seasonal regime ($\sim 300 \text{ W}\cdot\text{m}^{-2}$) the surface albedo is also high ($>85\%$) resulting in a fairly small diurnal surplus of heat at the surface. The earth-sun geometry creates a diurnal pattern to the shortwave flux, which sets up a diurnal temperature wave within the snow volume (Figure 2). Variability in the thermodynamics within this regime can also be caused under atmospheric forcing events illustrating both high longwave fluxes (presence of low-level thick stratus cloud cover) and the advection of warm air masses over the snow/ice system.

The shortwave flux is transmitted across the snow/air interface and is absorbed within the first few cm of the snow surface. This penetration creates a sub surface maximum in the temperature profile due to the fact that the radiative exchanges dominate over the conductive exchanges within the surface layer of the snow volume. Increasing atmospheric temperatures during the day cause an increase in the surface most portion of the snow layer with reduced amplitudes at greater depth. This process is termed the thermal diffusivity of the snow and is defined as the rate at which the surface induced temperature wave can travel within the snow volume.

Note that the thermal diffusivity is directly proportional to the thermal conductivity (i.e., as the snow becomes more conductive to thermal energy the thermal diffusivity increases). Typically, new snow has a thermal diffusivity of about 0.1 (low thermal conductivity and a good insulator). Old snow with larger snow grains has a higher thermal conductivity (0.42) and as a result a higher thermal diffusivity (0.40). The heat capacity of the snow is defined as the ability of the ice/snow mixtures (bulk snow properties) to retain heat and is expressed as the amount of heat gained or lost for a particular change in temperature. The heat capacity of the snow layer on sea ice can be calculated by modeling the partial fractions of ice, air, water, and brine as constituent components of the snow volume. Researchers have explicit definitions for heat capacity computations for ice, air and water but little is known about the structural distribution of brine within the basal layer of the snow volume and consequently this parameter is poorly defined in thermodynamic snow layer models.

The most significant aspect of the early melt period to snow thermodynamics are rapid changes to the geophysics of the snow volume. Because of the oscillations in the temperature profile (Figure 2), the early melt stage represents a rapid growth period for snow grains throughout the snow layer. Under strong negative temperature gradients (like the winter regime or cold atmospheric temperatures in the early melt regime) a process of kinetic growth dominates the snow metamorphism. Sublimation of snow grains next to the

ice surface (basal layer of the snow volume) occurs and the resulting vapor travels along the vapor pressure gradient (i.e. along the temperature gradient) upwards toward the snow/air interface. The vapor travels through pore spaces within the interstices of the snow grains and is deposited onto the top parts of grains creating an isotropically aligned layer of large grains (Figure 3). The process of temperature gradient metamorphism occurs through this period and can create substantial increases in kinetic growth grains (sizes up to several cm in length).

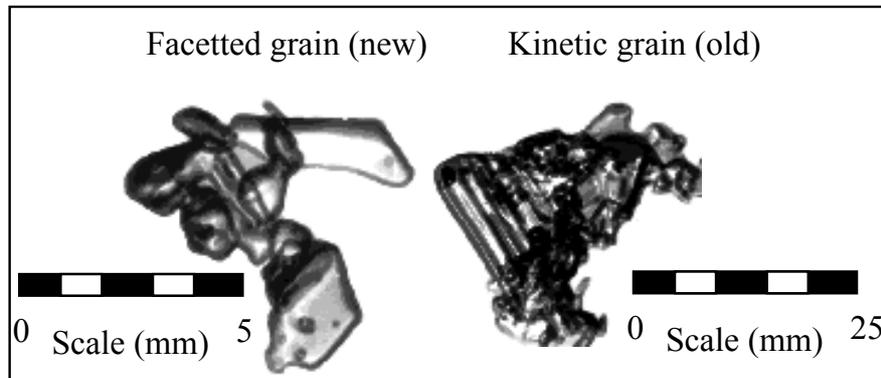


Figure 3 Typical new (Faceted) and old (Kinetic) snow grains which result from the metamorphic processes described in the text.

During this state there is a slight increase in the brine volumes of the sea ice because of the increased temperature within the volume. The magnitude of the increase in the ice volume temperature is controlled by the atmospheric temperature and the thickness of the snow cover and sea ice. Brine pockets within the sea ice begin to grow but in general remain discrete thus making the sea ice mechanically strong. Visually this ice type appears like a winter snow covered sea ice.

Ablation State 2

Once water in liquid phase occurs throughout the diurnal cycle (usually at bulk percentages of about 2 percent water by volume) and the ice surface becomes damp at the snow-ice interface, we categorize the period as Ablation State 2. In this state water is held within the interstices of adjacent snow grains (termed the Pendular Regime). Polycrystalline aggregates form locally at the snow base and superimposed ice layers sometimes form on first-year ice (Holt and Digby, 1985).

Once the surface temperature increases and the thermodynamic regime begins to oscillate (Figure 2) there is a tendency for snow metamorphism to be dominated by equitemperature processes. Equitemperature metamorphosis occurs when the temperature gradient is relatively equal over the given volume of snow. Under this process smaller grains connect together and there is a tendency for small faceted grains to grow together into a state, which minimizes the surface tension of the snow grain. In nature this minimum is found as a sphere or circle thus resulting in a tendency for rounded grains to occur under this metamorphic process. In dry snow, grain growth occurs slowly, but with the addition of small amounts of water (2-5 percent water by volume) grain growth increases markedly (Colbeck, 1982).

There is a feedback mechanism operating within this system at the time of the ablation state 1 regime. As basal layer grains enlarge (primarily as a result of kinetic growth processes) and as the mid pack grains grow under equitemperature regimes there are corresponding changes in the thermal diffusivity, heat capacity and thermal conductivity of

the snow layer. Although this feedback mechanism has not been extensively studied there is sufficient information to piece together the primary components of the process:

- Grains enlarge thereby reducing the amount of air in the volume. Less air means that the thermal conductivity will increase from a very low value of 0.1 towards that of very dense snow (0.42).
- Since the thermal conductivity is directly proportional to the thermal diffusivity we can expect the temperature waves to penetrate faster and further into the snow volume.
- This increase in thermal diffusivity tends to enhance the metamorphic processes - both those of equitemperature (warming during the day) and temperature gradient (cooling at night) thereby enhancing the overall rate of grain growth.

During this state there is a continued increase in the brine volumes of the sea ice because of the increased temperature within the volume. In general the rate of sea ice brine volume expansion increases over this period (relative to ablation state 1) due to the reduced albedo of the snow volume. Much of the energy gained in the snow layer is lost due to phase changes deeper into the sea ice volume. This leads to formation of freshwater ice layers within both the snow layer and in the upper surface of the sea ice. Brine pockets enlarge to such a size that some may begin to interconnect. This significantly reduces the mechanical strength of the sea ice. It is possible for the system to revert to winter thermodynamic and geophysical conditions any time during the period up to and including Ablation State 2. This is usually caused by advection of cold air into the region or increase in the short-wave albedo of the surface due to new snow deposition.

Ablation State 3

When sufficient water by volume is accumulated within the snow cover the pore spaces will become filled with water (this is termed the funicular regime, Colbeck, 1982). This transition occurs at approximately 7 percent water by volume (note – you can make a snow ball at about 5 percent by volume). During this period liquid is drained from the saturated snow resulting in a gradient of water volume with a surface minimum and basal maximum. Tightly packed grain clusters occur after the liquid has drained. Colbeck (1982) reports that grain clusters under these conditions are typically two to four crystal arrangements (Figure 4). These multi-crystal forms can also form aggregates of several hundred crystals, often called polycrystalline aggregates.

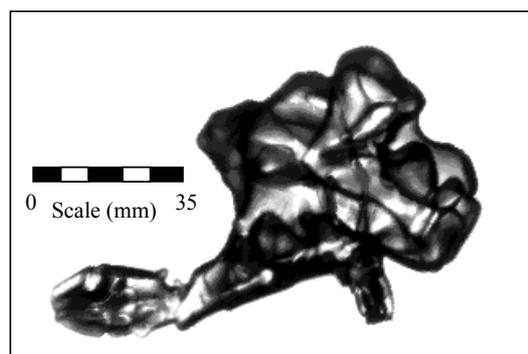


Figure 4. Example of a polymorphic grain structure typical of late season snow covers on sea ice.

During this state, the brine volume within the sea ice volume begins to increase, due to the increased short-wave penetration into the snow cover (reduced snow albedo). The brine volume relationships are well understood and can be modeled using heat conduction equations. Over this period salinity at the sea ice surface decrease rapidly as freshwater infiltrates into the rapidly growing brine drainage channels within the sea ice. The spatial

distribution of these surface salinity are heterogeneous, probably due to the non-uniform distribution of brine drainage channels (Wakatsuchi. and Kawamura, 1987). The average surface temperature is near freezing and, generally, we consider that the system cannot return to its winter state. The reason for this is that the grains are sufficiently large that advection of cold air into the region will create a transitory phase change to solid then a rapid return to these ablation conditions whenever sufficient solar illumination occurs (due to the very low surface albedo).

Ablation State 4

From Ablation State 3 there is a preferential snow melt process whereby shallower inter drift patches melt first. This is because the shallower snow cover generally results in larger snow grains, created during cold season temperature gradient metamorphosis (i.e., thinner snow cover results in a stronger temperature gradient and more kinetic grain growth). The drifts themselves are preserved longer to eventually become the snow patches evident on melt pounded sea ice surfaces (Figure 5 and 6).

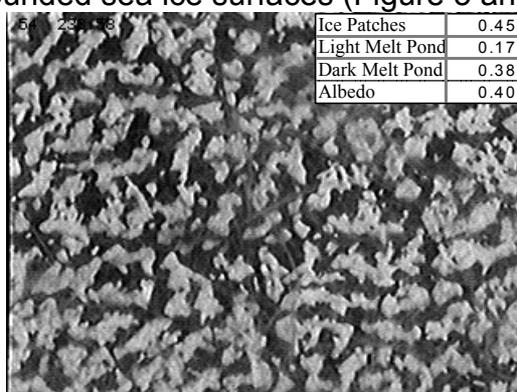


Figure 5 Typical melt pounded first-year sea ice surface measured with aerial video then digitized into a microcomputer for morphological measurements of pond sizes and structure (adapted from Barber and Yackel, 1999)

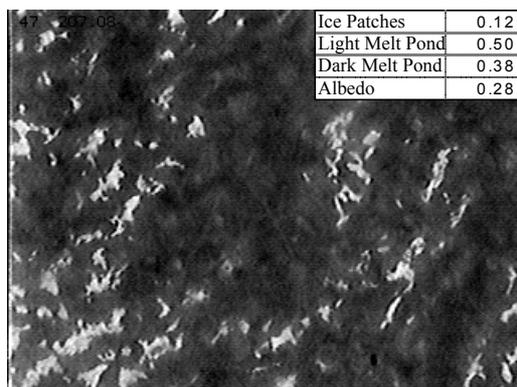


Figure 6 High concentration of flooded first-year sea ice measured with aerial video then digitized into a microcomputer for morphological measurements of pond sizes and structure (adapted from Barber and Yackel, 1999)

The development of drainage networks begins primarily through seal holes (Figure 1.9), cracks, and leads (Figure 1.10). Statistical characteristics of these features are highly variable in both space and time. Results show that the size and percent cover of both pounded surfaces and residual snow patches vary according to: the type of sea ice; the timing of consolidation; and the pattern of snow distribution prior to melt (Barber and Yackel, 1999).

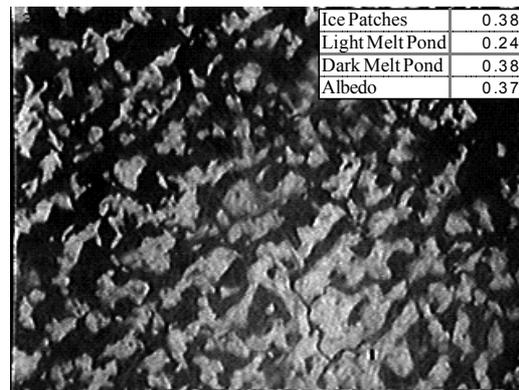


Figure 7. Typical example of a sea hole drainage feature and its effect (increased snow patch concentrations) on the local area drainage of first-year sea ice (adapted from Barber and Yackel, 1997)

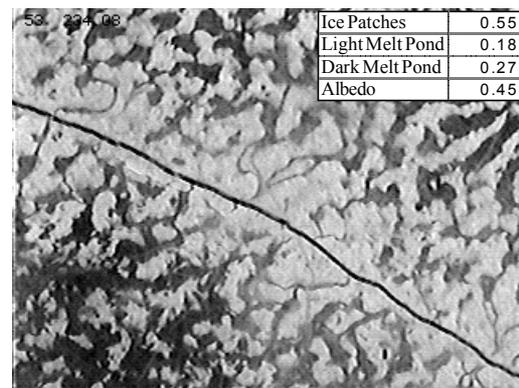
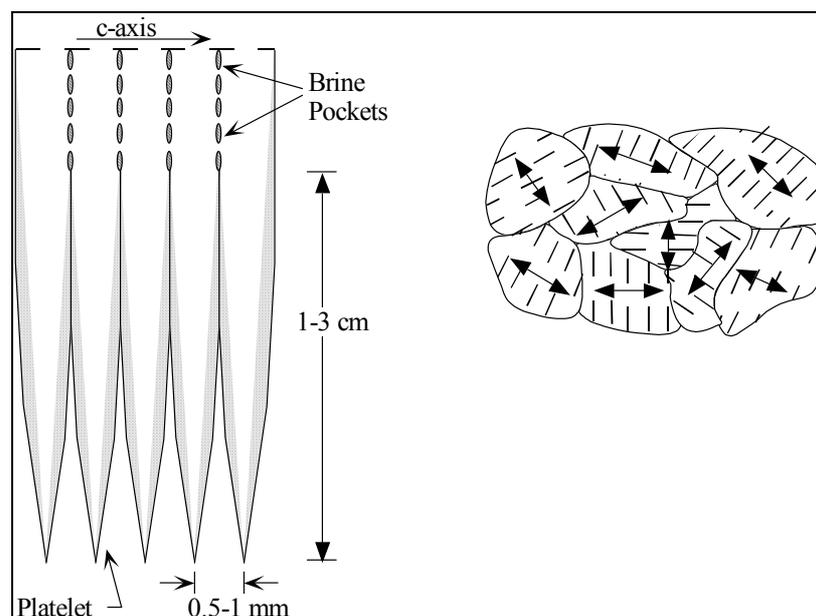


Figure 8. Typical example of a crack drainage feature causing pond water drainage (increased snow patch concentrations) for first-year sea ice (adapted from Barber and Yackel, 1997)

The bulk salinity of the sea ice and the basal layer of snow on first-year sea ice, both decrease within ablation state 4. The processes, which lead to this rapid desalination are however poorly understood. We do know that brine is held within the interstices of the ice grains in both frazil and columnar sea ice grains. At cold temperatures these brine pockets are 'pinched' off by increasing the size of the ice grains (Figure 9).



Adapted from Ackley, (1996)

Figure 9. Schematic of the brine constriction in growing sea ice

As the temperature increases in ablation state 4 the brine pockets enlarge as a function of the phase relationships within sea ice (Figure 1). Practically speaking this means that once the ice reaches a temperature above -7°C there is a rapid increase in the brine volume within sea ice. It has been estimated (from a variety of sources) that the increase in brine volume accomplishes little in the desalination until brine volumes exceed 5 percent by volume. After this point the brine pockets align linearly (generally along the boundaries of adjacent columnar grains). These brine pockets form tubes, which join to larger features to create brine drainage channels. Once brine channels are re-established then brine drainage occurs rapidly. Fresh melt water from the melting snow pack can enhance this brine drainage mechanism thereby increasing the desalination process over both first-year and multiyear forms of sea ice. Desalination is highly variable spatially and temporally with average conditions showing a curvilinear decrease with time (Figure 10).

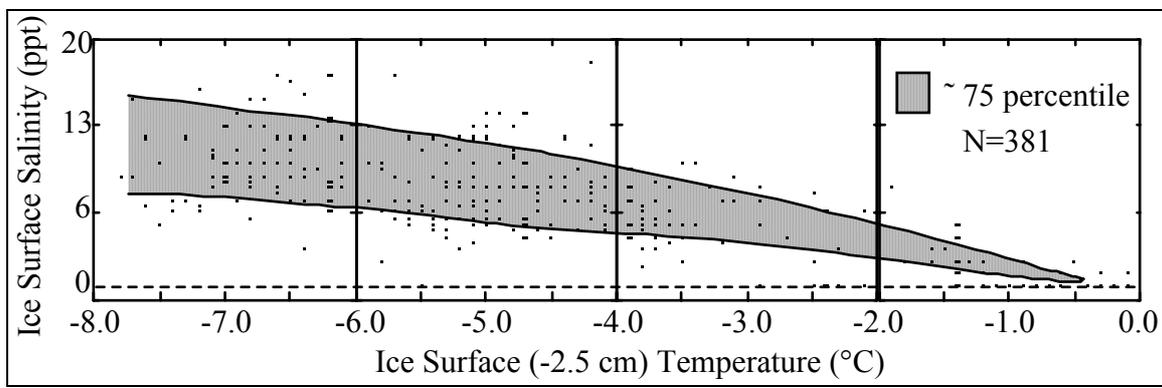


Figure 10. Sea ice surface salinity (-2.5 cm) relative to ice surface temperatures (-2.5 cm) obtained from the snow pit sampling conducted during field projects in 1990 and 1991 in the Canadian Archipelago. The approximate 75th percentile ranges of the variables within a particular temperature range are shaded.

Ablation State 5

This state is typified by the drainage of the melt ponds through the opening of the brine drainage channels within the sea ice. Short-wave energy is found to be a significant factor in sub-ice ablation through the enhanced short-wave flux through open leads, cracks and holes (Maykut and Perovich, 1987). Mechanical and thermodynamic ablation can also be attributed to the freshwater runoff and flushing through the sea ice (Moritz and Perovich, 1996). Dynamic processes play a large role in breakup and can either retard or delay the timing of a purely 'thermodynamically' driven breakup. Observations have shown that the ponding on the ice surface occurs so long as the brine drainage networks within the ice allow less gravity drainage than is created by new freshwater inputs from the melt of surrounding snow patches. Once the ice warms to an isothermal state and the brine drainage networks are fully coupled, rapid drainage occurs (e.g., within hours). It also appears that melt ponds on sea ice are generally freshwater at the beginning of the melt period. Once the ice has fully drained (i.e., drainage networks are fully dilated) then melt ponds can reform but they are generally saline. The assumption here is that once the ice is sufficiently porous the freeboard of the ocean surface is actually above the level of the old melt pond, thereby creating a saline surface pond.

Ablation State 6

Once ice break-up occurs, pans of sea ice can exist for extended periods of time as decayed ice. This type of ice has fully formed brine drainage channels and is mechanically weak. The melt ponds on the surface are dominated by brine pond types with only isolated occurrences of freshwater ponds. This is due to the fact that the sea ice freeboard is beneath that of the ocean level, thus with brine drainage channels fully dilated sea water can occur as ponds with the low areas of the sea ice. This ice can last through the summer season and become second year or multiyear forms in the next year.

Summary Descriptions

In what follows we summarize the physical, thermodynamic and visual (Table 1) characteristics of each of the ablation states. This is followed by the corresponding microwave scattering response of each state (Table 2).

Table 1 - Geophysical, thermodynamic and visible characteristics of the proposed sea ice ablation states.

Variable	Characteristics
Winter	Large temperature gradients occur within the snow and sea ice with little or no diurnal variation within the thermodynamics of the snow and ice volumes. This results in low brine volumes within the sea ice due to the constriction of the brine pockets from the encroaching ice crystals. Visually this ice appears as a dry snow, cold season ice volume.
Ablation 1	Large temperature gradients still occur within the snow and sea ice but there is now a significant diurnal variation within the diurnal cycling within the snow and ice volumes. This atmospheric forcing can now reach the sea ice volume and thereby begin to increase the volume of brine. This begins once the ice volume exceeds temperatures of about -7 °C. Visually this ice still appears as a dry snow cold season ice volume. Microwave RS data are required to identify this point in the ablation state process (see table 2).
Very early melt	
Ablation 2	In this state temperatures in the snow and sea ice are dominated by isothermal or positive gradients (in the snow). Water in liquid phase occurs throughout most of the diurnal cycle. The surface albedo is reduced considerably at this point. The surplus energy goes into increasing the temperature within the sea ice volume and there is a corresponding increase in the brine volume of the ice making the ice mechanically weaker than winter or ablation state 1. Visually this ice will appear as a snow covered ice surface with slight variations in the 'greyness' of the snow patches – particularly with snow patches being a darker grey than thicker snow patches. On site examination will see a significant decrease in the snow density and the snow will be sticky.
Sustained snow melt	

Ablation 3 Saturated snow	In this state temperatures in the snow and sea ice are dominated by isothermal gradients. Water in liquid phase occurs throughout the diurnal cycle. The surface albedo is reduced considerably at this point. The surplus energy goes into increasing the temperature within the sea ice volume and there is a corresponding increase in the brine volume of the ice making the ice mechanically weaker than preceding ablation states. Visually this ice will appear as a snow covered ice surface with slight variations in the 'greyness' of the snow patches – particularly with snow snow patches being a darker grey than thick patches. On site examination will see large snow grains in the upper layers and a saturated snow/water mixture in the basal layers.
Ablation 4 Pond formation	In this state, melt ponds form first in areas of low snow thickness with snow patches being retained from the thicker snow drift patterns. The aerielly averaged albedo reduces considerably due to the contributions from the melt ponds themselves. The surplus energy goes into increasing the temperature within the sea ice volume and there is a corresponding increase in the brine volume of the ice making for mechanically weak sea ice. Visually this ice will appear as dark patches of saturated snow through to well developed flooded surfaces of the sea ice. The snow patches will be white in colour and the ponds appearing grey through to blue (depending on how many bubble inclusions occur in the ice at the base of the pond). On site examination will show that the ponds are freshwater as are the snow patches (surface salinity has migrated lower into the sea ice through gravity drainage mechanisms).
Ablation 5 Pond drainage	In this state melt ponds will drain from the surface once the sea ice brine drainage mechanisms become fully dilated. This drainage can occur very rapidly (within hours). This is because the temperature will increase in the ice volume thereby increasing the brine volume until the channels become fully formed. Gravity drainage will flush the freshwater from the surface and the ponds may become replace with saline ocean water. Visually this ice will appear ponded one day and the next it will have a white porous drained surface. Cracks and holes may be evident but the surface is generally dry. On site examination will show that the surface is made up of white porous granular ice which is saline free (taste test).
Ablation 6 Rotten ice	Once the ice has broken up it can exist for several months as a form of rotted ice. This form of sea ice has fully opened brine drainage channels thus making the melt ponds mostly saline (except in areas where local melting can create new ponds). The ice appears darker in colour because it is saturated throughout with ocean water. This ice no longer has any appreciable mechanical strength.

Note - In the definition of the ablation states we have compartmentalized what is by definition a continuous process. The creation of a thermodynamically weak sea ice volume requires that the brine volume exceed about 5 percent by volume. At this point the brine drainage channels will begin to reform thus significantly reducing the mechanical strength of the sea ice. From field experiments it appears that this point of 5 percent by volume can occur anywhere in ablation state 3 or 4. The timing of this depends on the thermodynamic controls on the evolution of the snow/ice system and the historical conditions of the original ice formation (salinity and density). Once this point has been reach physical break-up then depends on the magnitude of atmospheric or oceanic forcing on the snow/sea ice system.

Microwave remote sensing has evolved to the point where we can now consider using the seasonal evolution of the scattering coefficient to estimate the thermodynamic state of snow covered sea ice (Table 2). Details of these thermodynamic-scattering relationships can be found elsewhere (Barber and Yackel, 1999; Barber et al. 1998; Barber et al. 1996). The microwave scattering coefficient at C-band follows a seasonal evolution, which is typified in Figure 11.

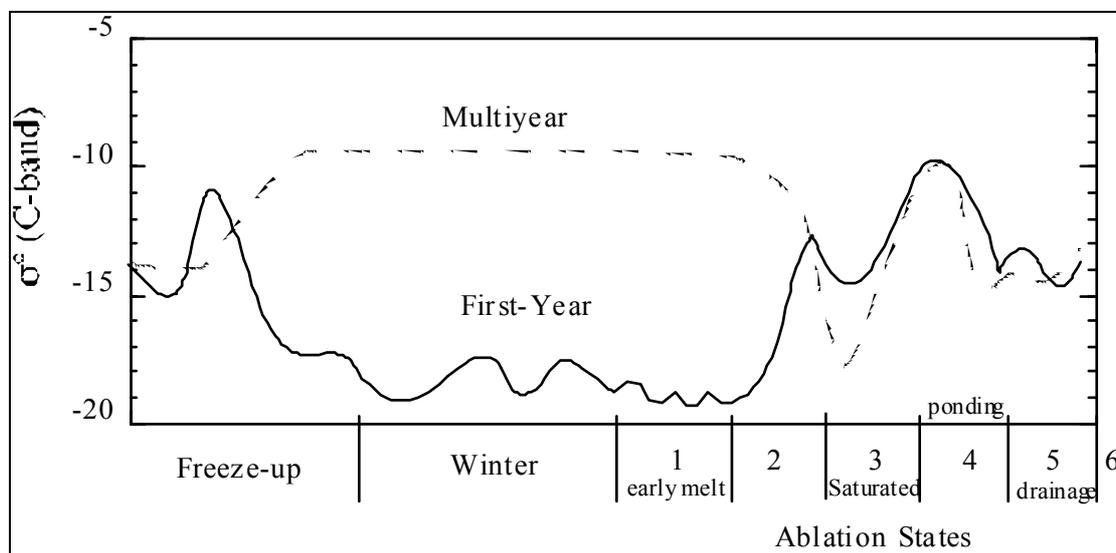


Figure 11. Seasonal evolution in scattering at 5.3GHz, as an average return for both VV and HH polarization.

Table 2 – Microwave scattering characteristics of the proposed sea ice ablation states.

Variable	Characteristics
Winter	Microwave remote sensing can distinguish first-year smooth from multiyear ice forms. Confusion can occur between rubble first-year and multiyear sea ice. Ridges are usually detectable.
Ablation 1 Very early melt	The temporal evolution of scattering (relative to the winter magnitudes for the same ice type) will show a distinct oscillation in scattering over a diurnal period. This oscillation is due to changes in temperature at the interface of the snow and sea ice. Multiyear signatures will be stable (relative to winter scattering) during this period.
Ablation 2 Sustained snow melt	The temporal evolution during this period is most effectively seen in the change in multiyear sea ice scattering. Once sufficient water is available in the snow pack (>~2 percent) there is a rapid reduction in the multiyear sea ice scattering (Figure 11). There is also a corresponding increase in scattering for smooth first-year sea ice due to an increase scattering coming from the enlarged, wet snow grains in the basal layer of the snow cover.

Ablation 3 Saturated snow	The temporal evolution of scattering during this period often shows a dip in scattering over first-year sea ice forms (Figure 11) and an increase in multiyear sea ice scattering. The first-year dip is not always apparent and may be due to differences in scattering from the snow surface. The multiyear scattering increase is most likely due to the removal of snow from the old hummocks and water drainage from these structures thereby returning a large volume scattering term to the total measured scattering.
Ablation 4 Pond formation	Once ponds form on the sea ice there is an oscillation of the scattering, which is both spatially and temporally variable. The scattering is dominated by specular return for smooth pond surfaces and volume scattering from the snow patches. For surfaces roughened by wind the scattering will increase dramatically due to the rough surface scattering from the pond surfaces. The larger the pond fraction the more variable the scattering will be due to the fact that the water surfaces (rough versus smooth) will dominate the scattering.
Ablation 5 Pond drainage	Microwave scattering during this period remains a research topic area.
Ablation 6 Rotten ice	Microwave scattering during this period remains a research topic area.

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Ad-hoc format group report

On the 3rd of May an ad-hoc format group including experts from AARI, CIS, DMI, NIC and NSIDC, held a discussion on the concept of the future format for submitting sea ice mapped information from the operational centers to the Bank.

The following proposals were drawn:

- to discuss which sea ice attributes should be included into the ice attributes text string;
- to use, or extend if necessary, existing SIGRID, SIGRID-2 or draft CONTOUR-2 formats as references for compilation of sea ice attribute text strings, including possible description of initial satellite or other sounder data, its quality, errors etc;
- NSIDC and AARI GDSIDC centers will provide each operational center with an Arctic-wide geographical grid(s) of points, possibly starting with the lowest reasonable resolution of 1 or 5 geographical minute; each operational center will perform a) "point to grid" extraction using the above grid(s) and b) polygon extraction (either in the form of ArcInfo .e00 or shape file), and will attach "SIGRID" text string in each centers' native format and submit output for further consideration to NSIDC and AARI;
- NSIDC and AARI, together with the experts from operational centers, will prepare a report on the given activity for the next IICWG meeting in October 2000, Iceland.

RECOMMENDATION TO JCOMM

The meeting recommends that JCOMM establish a JCOMM Working Group on Polar Seas and Other Sea Ice Regions (POSSIR)

The major task of POSSIR will be to promote and encourage the collection and exchange of marine meteorological, oceanographic and ice data and products in polar seas and other ice-covered seas, which are needed to support safe and efficient marine operations, to protect the environment and living marine resources, to understand the Earth's system and forecast its variability, and to assist with the development of the Global Ocean Observing System (GOOS) and the Global Climate Observing System (GCOS).

To meet this goal the following Terms of Reference are proposed:

1. To review and catalogue the products and services required by the user communities in polar and sea-ice areas;
2. To compile, catalogue and maintain a user requirements database for observational data for polar and ice services and products;
3. To review, coordinate and advise on observing systems to meet users needs in polar and sea-ice areas;
4. To review, coordinate and advise on data and information management (real-time, delayed-mode and historical) and exchange, recognizing in addition the need to:
 - a. review and propose amendments to formats, nomenclatures and procedures for sea-ice data and information exchange;
 - b. define terminology, coding and mapping standards for sea ice;
 - c. provide support for the implementation and operation of the Global Digital Sea-Ice Data Bank ^(*)
5. To recommend and promote appropriate quality control and data archiving mechanisms;
6. To encourage the application of numerical models;
7. To assist in building regional capacity through the development of guides, manuals and related documents, software exchange, specialized training and other appropriate means;
8. To develop and maintain linkages with relevant international governmental and non-governmental organizations and bodies.

^(*) There may also be special requirements for marine meteorological or oceanographic data, but those will not be unique to polar and other sea-ice areas and so will be addressed by other JCOMM programme areas. Special requirements for sea-ice are identified here because this is the only JCOMM group that will deal with this topic.

**CLIMATE AND CRYOSPHERE (CLIC) PROJECT
INITIAL SCIENCE AND CO-ORDINATION PLAN**
(Selections from the general document, 2 May 2000)

EXECUTIVE SUMMARY

The Climate and Cryosphere (CLIC) Initial Science and Co-ordination Plan, outlines research and co-ordination initiatives required to fully integrate studies of the impact and response of the cryosphere, and the use of cryospheric indicators for climate change detection, within the World Climate Research Programme (WCRP). The report has been prepared by the CLIC Task Group, which was established by the Joint Scientific Committee (JSC) for the WCRP in 1998, with input from many other climate scientists. It draws on the deliberations of an expert meeting on Cryospheric Processes and Climate in Cambridge, UK (February 1997) and meetings of the CLIC Task Group in Utrecht, the Netherlands (July 1998) and in Grenoble, France (August 1999).

The term "cryosphere" collectively describes the portions of the Earth's surface where water is in a solid form and includes sea-, lake-, and river-ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground (including permafrost)⁴. The cryosphere is an integral part of the global climate system with important linkages and feedback generated through its influence on surface energy and moisture fluxes, clouds, precipitation, hydrology, and atmospheric and oceanic circulation. The cryosphere plays a significant role in global climate, in climate model response to global change, and as an indicator of change in the climate system.

However, the impact and response of the entire cryosphere in the global climate system, and the use of cryospheric indicators for climate change detection, have not been fully covered within WCRP. There are notable gaps in present studies of cryospheric elements and in accurate and appropriate treatment of cryospheric processes in climate models.

In this report the cryosphere and the most important interactions are treated under the following headings:

- Interactions between the atmosphere, snow/ice and land
- Interactions between land ice and sea level
- Interactions between sea ice, oceans, and the atmosphere, and
- Cryospheric interactions with the atmosphere and the ocean on a global scale

The cryosphere is also considered as an indicator of climate variability and change.

Atmosphere-snow/ice-land interactions are concerned with the role of the terrestrial cryosphere⁵ within the climate system and with improved understanding of the processes, and of observational and predictive capabilities applicable over a range of time and space scales. Better understanding of the interactions and feedback of the land/cryosphere system and their adequate parameterization within climate and hydrological models are still needed. Specific issues include the interactions and feedback of terrestrial snow and ice in the current climate and their variability; in land surface processes; and in the hydrological cycle. Improved knowledge is required of the amount, distribution, and variability of solid precipitation on a regional and global scale, and its response to a changing climate. Seasonally-frozen ground and permafrost modulate water and energy

⁴ The discipline of glaciology encompasses the scientific study of snow, ice and glaciers.

⁵ Terrestrial cryosphere is defined as snow, lake- and river-ice, glaciers and frozen ground/permafrost.

fluxes, and the exchange of carbon, between the land and the atmosphere. How do changes of the seasonal thaw depth alter the land-atmosphere interaction, and what will be the response and feedback of permafrost to changes in the climate system? These issues require improved understanding of the processes and improved observational and modelling capabilities that describe the terrestrial cryosphere in the entire coupled atmosphere-land-ice-ocean climate system.

The primary issue regarding the role of the cryosphere on sea level is the past, present and future contribution of land ice to sea level change. We need to know how much of the sea level rise over the last 100 years can be explained by changes in land ice volume. In order to understand past sea level change and predict future change, it is essential to measure and explain the current state of balance of glaciers, ice caps and ice sheets, and especially to resolve the large present uncertainties in the mass budgets of the Greenland and Antarctic ice sheets. In spite of the fact that the current state of balance of ice sheets and ice caps is not well known, the sensitivity of the volume of ice stored in glaciers and ice sheets to climate change can and must be studied.

Over a considerable fraction of the high latitude global ocean surface sea ice forms a boundary between the atmosphere and the ocean, and considerably influences their interaction. The details and consequences of the role of sea ice in the global climate system are still poorly known. Improved knowledge is needed of the broad-scale time-varying distributions of the physical characteristics of sea ice, particularly ice thickness and the overlying snow-cover thickness, in both hemispheres, and the dominant processes of ice formation, modification, decay and transport which influence and determine ice thickness, composition and distribution. We do not know how accurate present model predictions of the sea ice responses to climate change are, since the representation of much of the physics is incomplete in many models, and it will be necessary to improve coupled models considerably to provide this predictive capability.

Key issues on the global scale are understanding the direct interactions between the cryosphere and atmosphere, correctly parameterizing the processes involved in models, and providing improved data sets to support these activities. In particular, improved interactive modelling of the atmosphere-cryosphere surface energy budget and surface hydrology, including fresh-water runoff, is required. Better formulations and data sets on surface albedo and its dependence on surface type, vegetative cover, underlying surface albedo, and surface temperature are also required, particularly in regions of ice and snow melt. Other important global issues are the impact of cryospheric anomalies on the atmosphere; and the sensitivity to variability and change of atmospheric moisture transport, which controls snow accumulation and thus the mass balance of ice sheets. Another important aspect of the cryosphere for global change concerns the ice-albedo feedback. A key question, given the impact this has on the high sensitivity of the Polar Regions to climate change, is how the atmosphere responds to and helps determine systematic changes in the ice and snow cover, and how these will influence the response to global warming. The cryosphere also has the potential for influencing the global ocean through changes in sea level; modulation of the thermohaline circulation, which affects meridional heat and fresh-water transport; and impacts on efficiency of carbon uptake and exchange. The key-underlying interactive processes and feedback between large-scale ocean circulation and the cryosphere must be better understood.

Because of its response to regional and global variations in the climate system, the cryosphere is not only an integrator of climate processes, but also a strong indicator of change. Cryospheric change indicators are particularly valuable in regions where

conventional observations are of short duration or completely lacking. Existing time series of the extent of sea ice, snow cover, and permafrost, and of glacier geometry and mass balance, should continue to be monitored for change. Records of past climatic variability at the multi-decadal and longer time-scales are available from historic and geomorphologic records of glacier fluctuations, borehole temperatures and ice cores. These data complement the existing instrumental records of temperature and precipitation and can improve both temporal and spatial coverage. The longer perspective can indicate how significant recent changes are in relation to natural variability.

The scientific strategy for a CLIC project is similar in each of the areas of interaction: a combination of measurement, observation, monitoring and analysis, field process studies and modelling at a range of time and space scales. A CLIC modelling strategy must address improved parameterization in models of the direct interactions between all components of the cryosphere, the atmosphere, and the ocean. It will need to do this at a variety of scales from the regional to global; and with a hierarchy of models ranging from those of individual processes to fully coupled climate models. It will also be essential to provide the improved data sets needed for validation of models and parameterization schemes.

A broad observational framework for CLIC is provided by the WMO meteorological and hydrological networks; the International Arctic Buoy Programme (IABP); elements of GCOS/GTOS/GOOS relating to the cryosphere; and continuing WCRP projects for Antarctic buoys (IPAB) and for sea-ice thickness in the Arctic and in the Antarctic (ASITP and AnSITP). Satellite remote sensing methods will be particularly important. They provide invaluable and often unique observational data for a range of climate and cryosphere studies, including: process-oriented studies; analyses of large-, regional-, and even global-scale spatio-temporal variability; monitoring and detection of climate change; and validation and/or assimilation data for numerical models. Numerous satellite-derived cryospheric data sets or products have already been developed, and more are under development or planned using data from present and near-future sensor systems. Several future techniques in remote sensing systems, data sets and methodologies for cryospheric studies may be realized within the coming decade. Potentially valuable new system includes ESA-CryoSat, with a goal to measure fluctuations in sea and land ice masses (thickness) at large space and time scales. Another is NASA's planned Geoscience Laser Altimeter (GLAS) which will provide valuable data to map sea and land ice elevations, and which may directly address the problem of the mass balance of the large ice sheets. These will complement the current and future systems including SSM/I, AMSR and SAR, which provide valuable information on our snow and ice resources.

The development of a plan for CLIC data and their management will build directly on the experience of the ACSYS Data Management and Information Panel and the development of the Arctic Precipitation Data Archive as well as other WCRP programmes. CLIC data requirements will necessitate the continuation of many ACSYS data collection and archiving activities and their expansion to encompass Antarctic and other cryospheric data needs. Complementary national and international programmes will be particularly important.

The cryosphere is of interest to many diverse scientific organisations. CLIC will develop an implementation plan that is complementary to other initiatives and draws on expertise of other organisations. There are a variety of gaps in ongoing programmes and the need for co-ordination between the proposed CLIC and the other activities to achieve a global perspective of cryosphere research. In particular other WCRP and WMO programme

components, IGBP, SCAR, SCOR and IASC projects need to be considered. Many of the broader global issues in CLIC are relevant to wider aspects of CLIVAR and GEWEX and it is critical that there are strong links between the programmes and that science initiatives within CLIC are co-ordinated with, and complementary to, those initiated or planned in CLIVAR and GEWEX.

The WCRP International Programme for Antarctic Buoys and the Antarctic Sea-ice Thickness Project are at present supervised by the ACSYS Scientific Steering Group. These projects will become part of CLIC. Similarly, ACSYS/CLIC is well represented in relevant WMO activities; for example, the Global Digital Sea-ice Data Bank within the joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology, and the Solid Precipitation Measurement Intercomparison within the Commission for Instruments and Methods of Observation. The Scientific Committee for Antarctic Research and the Scientific Committee for Ocean Research have a number of important Antarctic programmes and projects, and there are several relevant scientific unions and commissions within ICSU, especially the International Permafrost Association and the International Commission on Snow and Ice. Options for establishing linkages with these programmes include joint participation on steering committees and science conferences; establishing links between project offices; co-sponsorship of projects with joint funding support; and full integration of international co-ordinated activities as subprojects of WCRP/CLIC. The particular mode(s) that CLIC should adopt has not been determined, but options will be considered by the joint ACSYS/CLIC SSG at its first meeting.

BACKGROUND

The main goal of the World Climate Research Programme (WCRP) is to understand and predict -- to the extent possible -- climate variability and change, including human influences. In a stepwise approach, it has first tried to understand seasonal to inter-annual climate variability by mounting projects like the *Tropical Ocean/Global Atmosphere (TOGA)* project. This project brought the breakthrough to physically based seasonal climate predictions, especially for areas affected by the El Niño phenomenon. Within the *Global Energy and Water Cycle Experiment (GEWEX)*, our understanding of cloud/radiation interaction and land-surface processes was greatly enhanced. These are becoming more and more important for both weather forecasting and climate variability predictions. Progress in understanding decadal timescale climate variability and climate change projections, however, also needs observations of global ocean structure and circulation and tested ocean models. Therefore, WCRP launched the *World Ocean Circulation Experiment (WOCE)*, which has now entered into an analysis, interpretation, modelling and synthesis phase. The importance of the positive snow/ice albedo feedback which amplifies high latitude sensitivity to external forcing by the sun or an enhanced greenhouse effect, together with the opportunities for internationally co-ordinated Arctic research, stimulated the *Arctic Climate System Study (ACSYS)*. This project is concentrating first on establishing data sets on the Arctic Ocean circulation and sea-ice cover, the Arctic atmosphere and land surface hydrology of the Arctic Basin, and on improved sea-ice models for climate research.

However, the impact and response of the entire cryosphere and the associated interactions and feedback of its components within the global climate system, and the use of the cryosphere as an indicator of climate change, have not been fully covered within WCRP. Fully coupled atmosphere/ocean/land models for decadal timescale simulations and projections of climate change scenarios, as envisaged in the WCRP *Climate Variability and Predictability Study (CLIVAR)* need this input. Therefore, at the JSC-XVII in

Toulouse, France, March 1996 the Joint Scientific Committee (JSC) for WCRP charged ACSYS and CLIVAR with enhancing connections with other cryospheric activities outside WCRP, especially with SCAR-GLOCHANT, IASC-MAGICS and SCOR-iAnZone. In addition, in response to several external requests, the WCRP organized an expert meeting on Cryospheric Processes and Climate in Cambridge, UK, 3-5 February 1997 (WCRP, 1998b).

WCRP was also asked by experts representing climate-related activities in other international programmes, groups, and activities to initiate a broader cryospheric project without disrupting successful on-going studies (e.g., ACSYS). Therefore, at JSC-XVIII in March 1997 (Toronto, Canada) the JSC for WCRP invited the Conference on *WCRP: Achievements, Benefits and Challenges* (Geneva, August 1997) to consider the role of the cryosphere in climate, and to note the weaknesses and gaps in studies of cold climate processes. JSC-XVIII also instructed the 2nd ACSYS Science Conference on *Polar Processes and Global Climate* (Orcas Island, WA, USA, November 1997) to provide input and suggestions from the broader polar/cryosphere research community. The ACSYS Scientific Steering Group was also asked to prepare a comprehensive statement on the overall status of studies of cold climate processes for review by the JSC in March 1998.

The following were presented to JSC-XIX (Cape Town, South Africa, March 1998):

- 1) The WCRP 1997 Conference Statement calling for an enlarged WCRP activity with respect to cryosphere and climate;
- 2) the ACSYS Conference Statement voicing the desire of the broad scientific community for a comprehensive co-ordinated cryosphere and climate activity within WCRP; and,
- 3) the proposal from the 6th session of the ACSYS Scientific Steering Group (Seattle, WA, USA, November 1997).

A summary report on the first session of the CLIC Task Group was published as *WCRP Informal Report No.4/1999 (WCRP, 1999a)*. The first draft of the *CLIC Science and Co-ordination Plan* (SCP) developed by the Utrecht meeting was reviewed by the seventh session of the ACSYS Scientific Steering Group (Tokyo, Japan, November 1998). The revised draft was presented to JSC-XX (Kiel, Germany, March 1999) and the CLIC Task Group was asked to continue its work to map out a full CLIC science strategy and define other cryosphere-related scientific and observational programmes. At the JSC-XXI meeting in Tokyo, March 2000 the establishment of the CLIC Project within the WCRP and the formation of a combined ACSYS/CLIC SSG was approved. Co-ordination of CLIC with other relevant projects/programmes is an ongoing part of the project and is essential for success.

The initial science and co-ordination plan for the WCRP Cryosphere and Climate (CLIC) Project follows. The plan is seen as a "living document" that will continue to develop as our knowledge of processes and interactions of the cryosphere in the climate system increase. It will evolve as new data sources from satellite and in-situ sources become available, and as our hydrological and climate modelling of the climate system over a range of scales from basin-to-regional-to global improves.

GOALS AND KEY SCIENTIFIC QUESTIONS FOR CLIC

Four overarching goals that address major concerns for the WCRP can be identified. These are:

- 1) Improve understanding of the physical processes and feedback through which the cryosphere interacts within the climate system.

- 2) Improve the representation of cryospheric processes in models to reduce uncertainties in simulations of climate and predictions of climate change.
- 3) Assess and quantify the impacts of past and future climatic variability and change on components of the cryosphere and their consequences, particularly for global energy and water budgets, frozen ground conditions, sea level change, and the maintenance of polar sea-ice covers.
- 4) Enhance the observation and monitoring of the cryosphere in support of process studies, model evaluation, and change detection.

Specific questions that help define the primary tasks of CLIC are:

- (i) How stable is the global cryosphere?
 - How well do we understand and model the key processes involved in each cryospheric component of the climate system?
 - How do we best determine the rates of change in the cryospheric components?
 - What is the contribution of glaciers, ice caps and ice sheets to changes in global sea level on decadal-to-century time scales?
 - How can we reduce the current uncertainties in these estimates?
- (ii) What changes in frozen ground regimes can be anticipated on decadal-to-century time scales that would have major socio-economic consequences, either directly or through feedback on the climate system?
- (iii) What will be the annual magnitudes, rates of change, and patterns of seasonal redistribution in water supplies from snow-and ice-fed rivers under climate changes?
- (iv) What will be the nature of changes in sea-ice mass balance in both Polar Regions in response to climate change?
- (v) What is the likelihood of abrupt climate changes resulting from regime changes in ice shelf - ocean and sea ice - ocean interactions that impact the ocean thermohaline circulation?
- (vi) How do we monitor cryospheric components as indicators of change in the climate system?

In this report we begin by discussing the links between the different cryospheric elements and other components of the physical climate system. For convenience, we treat the cryosphere and the most important interactions under the following headings:

- Interactions between the atmosphere, snow and land
- Interactions between land ice and sea level, and
- Interactions between sea ice, oceans, and the atmosphere

Then the role of the cryosphere in the global climate system is considered through its interactions with the atmosphere and the ocean on a global scale. A number of key questions and issues are discussed under each of these categories, followed by appropriate strategies to address them.

As part of the overall implementation of the CLIC science plan, a comprehensive strategy will need to be developed to address the science questions and associated issues identified above. Many of the strategies will in fact be common or could best be coordinated with those of the other components of CLIC. The Task Group has identified and documented some of the key needs related to observation, process studies and modelling at a range of scales at the Cambridge meeting of cryospheric experts (WCRP, 1998b) and at the Utrecht team meeting (WCRP, 1999a).

INFRASTRUCTURE FOR CLIC

The cryosphere is of scientific interest to many scientific organisations, with diverse scientific interests. Development of a scientific programme that is complementary to other initiatives and draws on expertise of other organisations will be necessary.

The Meeting of Experts on Cryosphere and Climate (WCRP, 1998b) identified various existing activities of relevance to the CLIC endeavour. It did not find any important overlaps; rather it recognised a variety of gaps in ongoing programmes (Grassl, 1999). These include information on sea-ice thickness and ice volume, sea-ice motion in the Southern Ocean, representative mass balance data for mountain glaciers and ice caps, altimetry data and mass balance data for the Greenland and Antarctic ice sheets. Comprehensive data are also lacking on the distribution of global snow depth and snow water equivalent, as well as on fresh-water ice conditions, that can potentially be derived by optimal blending of *in-situ* and satellite data. Information is also needed on trends in the extent of permafrost and seasonally frozen ground, in active layer thickness and permafrost temperatures. Further identified deficiencies exist in the parameterization of cryospheric processes in climate models and their validation and intercomparison.

There is a need for co-ordination between the proposed CLIC and the other activities, especially to achieve a global perspective of cryosphere research. There are three broad categories of polar and cryospheric programmes, agencies and organisations that need to be considered. These are other WCRP and WMO programme components, IGBP, SCAR, SCOR and IASC projects, and other climate-related activities of other groups.

The establishment of a Working Group on Polar Seas and Other Sea Ice Regions (POSSIR) has been proposed under the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). Its tasks would include the co-ordination of relevant operational polar observing systems. A JCOMM/GOOS Meeting of Experts on a Polar Regions Strategy in December 1999 took note of WCRP ACSYS, CLIC and the existing GDSIDB activities. If POSSIR is established, a formal linkage with CLIC will clearly be desirable.

In the case of WCRP programmes, it is critical that science initiatives within CLIC are co-ordinated with, and complementary to, those initiated or planned especially those of ACSYS and GEWEX. It may be appropriate to have one- or two-way representation or points of contact on steering groups and/or working groups, with agreed schedules for any deliverables that may be required (from ACSYS/CLIC to CLIVAR, for example). Current models for this include ACSYS - GEWEX, two-way, and CLIVAR-ACSYS one-way representation. In the case of ACSYS/CLIC - GCOS/TOPC, there is already good cryospheric representation on the latter, where glacier and permafrost monitoring networks have been proposed.

WCRP's International Programme for Antarctic Buoys (IPAB) and the WCRP Antarctic Sea Ice Thickness Project (AnSITP) are at present supervised by the ACSYS Scientific Steering Group. These Groups will become part of CLIC. Similarly, ACSYS/CLIC are well represented in relevant WMO activities, within JCOMM for the Global Digital Sea Ice Data Bank (GDSIDB), and within CIMO for the Solid Precipitation Measurement Intercomparison.

WCRP also has close co-operation with several IGBP components including Past Global Changes (PAGES) and Biospheric Aspects of the Hydrological Cycle (BAHC). PAGES addresses issues relating to climate change, including the response of ice sheets and sea level, principally on two time scales – around 2000 years, and 250,000 years (IGBP, 1998). A number of component activities relate to ice coring, but others in the terrestrial, marine and modelling realms are also important for CLIC. The BAHC project refers to the value of snowline monitoring and the importance of water balance in mountain catchments, some of which involve snow cover and glaciers (IGBP, 1997). The Mountain Agenda (1998) group has drawn attention to the critical role of mountains as “water towers for the twenty-first century”. WCRP and the Inter-American Institute (IAI) have agreed to co-operate in climate research and the IAI will consider supporting, within available resources, scientific activity and research in South and Central America relevant to WCRP (Inter-American Institute, 1999).

The Scientific Committee for Antarctic Research (SCAR) and the Scientific Committee for Ocean Research (SCOR) have a number of important Antarctic programmes and projects. These are well summarised by P. Clarkson (WCRP, 1998b, Appendix B.8) and E. Fahrbach (WCRP, 1998b, Appendix B.11). Close co-ordination between CLIC and some of these efforts will be needed.

There are several relevant scientific unions and commissions within ICSU. These include the International Permafrost Association (IPA), the International Commission on Snow and Ice (ICSI) and the International Association of Hydrological Sciences (IAHS). A link to planned ICSI model intercomparisons would be useful. ACSYS/CLIC is already represented in the IAHS and ICSI as well as on the Standing Committee on Data, Information and Communication of the IPA. Also under ICSU are the World Data Centers, which include WDCs for Glaciology in Boulder (USA) and Lanzhou (China), and the World Glacier Monitoring Service (WGMS) through the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

The International Arctic Science Committee (IASC) oversees several important science activities. These include the Mass Balance of Arctic Glaciers and Ice Sheets (MAGICS) (see J. Hagen in WCRP, 1998b, Appendix B.7), and the Barents Sea and Bering Sea Impact Studies (BASIS and BESIS), as described in the IASC Project Catalogue, 2000 (www.iasc.no/ProjectCatalogue/catalogue.htm).

CLIC might also become attractive for consortia of scientists co-operating at present in climate-related Arctic and Antarctic research activities like WAIS (West Antarctic Ice Sheet), FRISP (Filchner-Ronne Ice Shelf Programme), and EISMINT (European Ice-Sheet Modelling Initiative). The possibility of establishing a partnership for observations of global snow and ice, analogous to the recently established Partnership for Observations of Global Oceans (POGO) (see <http://igos.partners.org>) is an idea that might be explored via ICSI.

The next IPCC review includes cryospheric processes as a component of Working Group I. Working Group II specifically addresses many of the cryospheric impacts of climate change in the chapter Polar Regions. It is essential that CLIC interact in the presentation and identification of scientific issues, needs, and gaps.

STRATEGIES FOR COOPERATION

There are various options for establishing linkages with other WCRP and external programmes. These include:

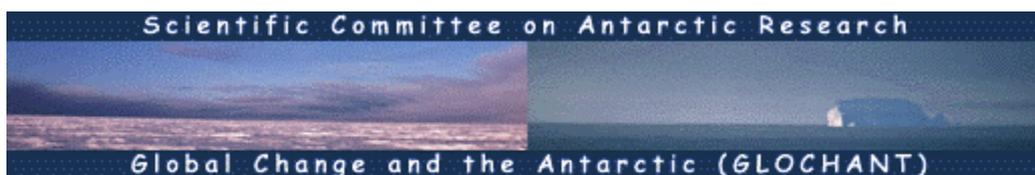
- (i) Participation of invited experts from related programmes to the ACSYS/CLIC SSG meetings and science conferences;
- (ii) establishing links between the IACPO Director and corresponding GEWEX and CLIVAR project office directors;
- (iii) letters of agreement from the parent bodies (such as SCAR, SCOR, IGBP) of specialist groups or projects to contribute to CLIC with invited experts representing these groups to attend ACSYS/CLIC SSG meetings;
- (iv) participation of CLIC representatives in other programmes, such as ASPeCt or IAnZone, or in their SSGs;
- (v) formal representation of other programmes on the CLIC SSG;
- (vi) co-sponsorship of the CLIC project by WCRP and other organizations like SCAR, with joint funding support; and,
- (vii) full integration of international co-ordinated activities as subprojects of WCRP CLIC.

Each option affords various benefits and may have certain drawbacks. The particular mode(s) that CLIC should adopt has not been determined, but options will be considered by the joint ACSYS/CLIC SSG at its first meeting.

TERMS OF REFERENCE OF THE CLIC TASK GROUP

The JSC-XIX 1998 endorsed the proposal of the ACSYS SSG-VI (WCRP Informal Report No. 8/1998) for a broader programme on cryosphere and climate in the WCRP. As a first step, a task group ("The WCRP Climate and Cryosphere Task Group" (CLIC)) was established to develop a science and co-ordination plan for presentation at the JSC-XXI (March 2000, Tokyo). The detailed responsibilities were set down as follows:

- (i) The Task Group is responsible to the JSC through the ACSYS Scientific Steering Group;
- (ii) The Task Group will develop a science and co-ordination plan for the WCRP Climate and Cryosphere (CLIC) project. The Group members will propose studies of cryospheric elements where there are notable gaps in present programmes. They will seek to enhance links between global and regional cryospheric studies and will ensure accurate and appropriate treatment in climate models of cryospheric processes and the interactions of the cryosphere with atmosphere, oceans and land surface. Preparation of the global and regional cryospheric data sets necessary for forcing and validating climate models and for diagnostic studies of the cryosphere's role in climate will be organized. The Task Group will interact with other WCRP efforts (in particular, GEWEX and CLIVAR) and they will establish appropriate co-ordination mechanisms with other projects that can contribute to WCRP research on climate and the cryosphere.
- (iii) The Task Group shall also set out the framework in which CLIC can be implemented in the WCRP (noting that ACSYS will be maintained as a distinct component of the WCRP until its agreed end date in 2003);
- (iv) A progress report shall be given to the 20th session of the Joint Science Committee (JSC-XX) in March 1999, and a draft science and co-ordination plan delivered for review at its 21st session in March 2000.



INTRODUCTION

ASPeCt is a programme of multi-disciplinary Antarctic sea ice zone research within the SCAR Global Change Programme. ASPeCt will specifically address key identified deficiencies in our understanding and data from the sea ice zone. The programme is designed to complement and to contribute to the other international programmes in this region and will build on existing and proposed research programmes, and the shipping activities of National Antarctic operators, and will also include a component of data-rescue of valuable historical sea ice zone information.

The overall aim of ASPeCt is to understand and model the role of Antarctic sea ice in the coupled atmosphere-ice-ocean system. This requires an understanding of key processes, and the determination of physical, chemical, and biological properties of the sea ice zone. These are addressed by objectives which are:

- I. To establish the distribution of the basic physical properties of sea ice that are important to air-sea interaction and to biological processes within the Antarctic sea-ice zone (ice and snow cover thickness distributions; structural, chemical and thermal properties of the snow and ice; upper ocean hydrography; floe size and lead distribution). These data are required to derive forcing and validation fields for climate models and to determine factors controlling the biology and ecology of the sea ice-associated biota.
- II. To understand the key sea-ice zone processes necessary for improved parameterization of these processes in coupled models.

BACKGROUND TO ASPeCt

The Antarctic sea ice zone remains one of the least known regions of the earth's surface. Apart from satellite derived data on ice extent and concentration, there are few reasonable climatological estimates of ice conditions that can be used for validation of numerical models. What limited information we have, mostly from the Weddell Sea, indicates that the ice characteristics and the dominant processes in the Antarctic are substantially different from those in the central Arctic. The Antarctic sea ice zone acts as a regional boundary between the Antarctic and sub Antarctic, an interface between the upper ocean and the lower atmosphere, and globally, as a region of important interactive physical and biogeochemical processes.

Uncertainties in, and the importance of, the role of sea ice in the climate system are highlighted in a US Global Change Program Report, Forum on Global Change Modeling. On the basis of studies of past climates, which provide evidence for polar amplification of

warming it is predicted that under any future global warming scenario, Northern Hemisphere sea ice will probably be reduced, but that projected changes and their timing in the Southern Hemisphere sea ice extent are less certain. Current coupled model studies of an increased carbon dioxide atmosphere are also essentially in conflict in their predicted Southern Hemisphere sea ice response. First simulations with a coupled model even suggested an expansion, but more likely thickening, of the ice cover in particular regions. Other model studies, using different parameterizations of both fluxes and sea ice processes suggest the opposite effect; that instead sea ice extent and thickness will both be drastically reduced in increased atmospheric carbon dioxide scenarios. Through ice-albedo feedback, these latter simulations also suggest that the sea ice retreat itself accounts for a significant fraction(40%) of the *global* atmospheric warming that will occur under CO₂ doubling, with of course very large increases in the regions more local to the present day ice cover. These projected changes are at present currently impossible to ascertain, because without knowledge of the Antarctic sea ice thickness distribution, it is difficult to provide compelling evidence if and when change occurs. Since the models currently give contradictory results, it suggests that the model parameterizations of sea ice physical processes are different and some, perhaps all, of the models are unrepresentative in some way in their depiction of the sea ice cover. Without present-day knowledge of the ice thickness distribution, models however cannot be verified, so we cannot even ascertain which model physics, if any, are correct.

The role of sea ice in the global climate system has been long recognized and included as a study component of major international weather and climate programmes such as the Polar Sub-Programme of the Global Atmospheric Research Programme, and the World Climate Research Programme. However several factors have restricted implementation of a co-ordinated Antarctic sea ice zone programme before the present. Many of the SCAR countries, tied also through the closely associated Council of Managers of National Antarctic Programmes (COMNAP), are already carrying out, and plan to continue, sea ice zone research in both physical and biological sciences within National programmes: substantial new information is now available, particularly from the Weddell Sea, Amundsen and Bellingshausen Seas, and the Indian Ocean sector. A number of sophisticated, ice-capable research vessels are now working in the Antarctic, and at the same time the increased number of nations working in the Antarctic has seen a growth in all types of shipping activity. And new remote sensing capabilities, particularly active radar systems, have greatly enhanced sea ice observation from space.

KEY SCIENTIFIC QUESTIONS

Key scientific questions which must be answered to meet the objectives are:

- (i) What are the broad-scale time-varying distributions of the ice and snow-cover thickness, ice composition and other physical characteristics in the Antarctic sea ice zone?
- (ii) What are the dominant processes of ice formation, modification, decay and transport which influence and determine ice-thickness, composition and distribution?
- (iii) What is the role of coastal polynyas in determining total ice production, heat salt and biogeochemical fluxes, and water mass modification?
- (iv) What are the processes that control the ice-water interactions at the ice-edge, and their seasonal changes?

IMPLEMENTATION STRATEGY

The ASPeCt programme will achieve its goals by co-operation within the SCAR community. Some components of this co-operation may involve multi-national process studies, but much will be achieved within individual National Programmes provided that there is a framework of co-ordination, and that common observational protocols are established. Where possible the programme will build on existing and proposed research programmes, and the shipping activities of National Antarctic operators. The implementation plan will include some components that can be undertaken as part of normal resupply voyages; for example a system of simple but quantified shipboard observations that provide statistical ice and snow thickness distributions. ASPeCt will also include a component of data-rescue of valuable historical sea ice zone information.

Elements of the ASPeCt programme addressing each key scientific questions will include the following:

(i) The broad-scale time-varying characteristics of the ice

Transects involving direct ice sampling by coring is the principal method for determining the dominant variations in growth, metamorphism and decay in various regions. Seasonal sampling is also necessary to determine the evolution of the ice cover. Preliminary work has suggested that in some regions these compositional changes can also vary interannually, and that repeated visits to some regions at the same season but different years can also establish how these changes are related to variability in forcing from the ocean and atmosphere.

Broad scale surveys are required to define a climatology of the time-varying state of the ice thickness distribution and snow cover; structural, chemical and thermal properties of the snow and ice; floe, lead and ridge distribution and upper ocean. A minimum requirement is for autumn, winter, spring and summer measurements along transects perpendicular to the Antarctic coast and spaced at intervals of about 15-30° of longitude. Ice-capable vessels used by an increasing number of national Antarctic programmes are capable of undertaking these surveys in all seasons.

It is not proposed that the surveys be undertaken in any one year, but that a composite climatological picture of the Antarctic sea ice zone be built up over a number of years. The surveys can be achieved by standardized ship-based observations along a series of systematic transects, building on ongoing national efforts (including re-supply voyages) and co-operating with other programmes with survey requirements such as EASIZ and APIS.

Observations during the transects will include both underway measurements and on-site sampling. Underway measurements includes hip-based area-wide estimates of ice conditions and of the ice and snow cover thicknesses (using standardized ASPeCt ice observation protocols), continuous meteorological and near surface oceanographic measurements, and a number of direct underway ice measurements, such as ice thickness and ridge height estimation with boom mounted altimeters and inductive electromagnetic devices. On-site sampling, proposed at least every half-degree of latitude along the transects, of ice and snow core characteristics; profiles of ice thickness, snow thickness, ice-snow interface temperature, etc.; and hydrographic measurements to at least the depth of the mixed layer.

A minimum requirement is to define a sea ice climatology for each of autumn, winter, spring and summer seasons along transects perpendicular to the Antarctic coast and

spaced at intervals of about 15-30° of longitude of the time-varying state of the main variables. These include:

- ice extent and concentration;
- ice and snow thickness distribution;
- ice drift and deformation;
- ice formation type; and
- floe size and ridging distribution.

(ii) The dominant processes of ice formation and modification determining ice-thickness, composition and distribution

(iii) The role of coastal polynyas

(iv) The processes at the ice-edge

Specific *in-situ* process studies are necessary to tackle these problems. In some cases these may be relatively simple and short and might be undertaken as components of the transect programme. In other cases specific multi-disciplinary, and possibly multi-ship, studies will be required.

A small number of selected coastal polynyas will be studied at different seasons in multi-disciplinary studies including elements of meteorology, oceanography, glaciology, marine biology, and remote sensing.

LINKS WITH OTHER INTERNATIONAL PROGRAMMES

While the major thrust of the ASPeCt programme is physical sea ice processes and ocean-atmosphere interaction in the sea-ice zone, it maintains strong links with programmes of ecological research in the sea ice zone, and in particular with SCAR EASIZ. As a SCAR programme, ASPeCt is focused towards the role of the unique regional environment of the Antarctic sea ice zone, but it is also closely linked to the overall international global change research agenda. Hence inter-disciplinary components of ASPeCt are designed to contribute to, and extend, international open ocean programmes such as [JGOFS](#)

The World Climate Research Programme (WCRP) emphasizes the physical climate system, and has established two programmes which use automatic observing systems to increase meteorological and sea ice related data from the Antarctic region: the International Programme for Antarctic Buoys (IPAB) and the Antarctic Ice Thickness Research Programme (AnITRP). Many elements of ASPeCt will also contribute to the objectives of the WCRP CLIVAR Programme a study of Climate Variability and Predictability, which involves investigations of atmosphere, ocean and land at a variety of timescales. ASPeCt plans are particularly relevant to the CLIVAR-DecGen component-programme, concerned with decadal to centennial climate variability and predictability. The ASPeCt programme will initiate implementation of parts of these a ice zone research requirements of CLIVAR, and will collaborate closely with IPAB, AnITRP, CLIVAR and other WCRP programmes to ensure the essential global integration of Antarctic regional research.

Planning of ASPeCt has been undertaken in parallel with that of the SCOR iAnZone programme. Three major experiments in the Southern Ocean have been completed or are underway under iAnZone auspices, the Ice Station Weddell (ISW) drift in 1992, the Antarctic Zone Flux Experiment (ANZFLUX) conducted in the eastern Weddell Sea in 1994 and oceanographic work (1997-99) in the confluence of the Weddell and Scotia Seas near

the Antarctic Peninsula on deep ocean ventilation (DOVETAIL). The theme for a fourth iAnZone experiment is convection: quantitatively determining the effect of Antarctic zone water mass modification on the global thermohaline circulation and establishing the basis of an observational system which allows improvement and validation the representation of Southern Ocean convection in large scale models.

THE ASPeCt SCIENTIFIC STEERING GROUP

ASPeCt is managed by a Scientific Steering Group (SSG), composed of scientists working in relevant fields. The SSG is responsible for the ASPeCt implementation plan, continually refining and updating the ASPeCt science plan, and promoting and co-ordinating ASPeCt activities. Members of the SSG are:

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LIST OF ACRONYMS AND ABBREVIATIONS

ACDP	Acoustic Doppler current profiler
ACSYS	Arctic Climate System Study (WCRP)
ACSYS-	SIOM Arctic Climate System Study, Sea Ice/Ocean Modelling Panel
AnITRP	Antarctic Ice Thickness Research Project (WCRP)
ANZFLUX	Antarctic Zone Flux experiment
APIS	Antarctic Pack-Ice Seals programme (SCAR)
ASPeCt	Antarctic Sea-Ice Processes, Ecosystems and Climate (SCAR-GLOCHANT)
AUV	Automatic Underwater Vehicle
BIOMASS	Biological Investigations of Marine Antarctic Systems and Stocks (SCAR)
BIOTAS	Biological Investigations of Terrestrial Antarctic Systems
CCCO	SCOR Committee on Climate Change and the Oceans
CLIVAR	Climate Variability and Prediction Research (WCRP)
COMNAP	Council of Managers of National Antarctic Programmes
EASIZ	Ecology of the Antarctic Sea-Ice Zone (SCAR-GoSSOE)
CTD	Conductivity Temperature Depth (probe)
DecCen	Decadal to Centennial climate variability and predictability (CLIVAR)
ECMWF	European Centre for Medium Range Weather Forecasts
ERS	Earth Resources Satellite, European Space Agency
GCOS	Global Climate Observing System
GLOBEC	Global Ocean Ecosystems Dynamics Research (IGBP)
GOOS	Global Ocean Observing System
GoSSOE	Group of Specialists on Southern Ocean Ecology (SCAR)
HNLC	High nutrient-low chlorophyll
HSSW	High Salinity Shelf Water
IANZone	International Coordination of Oceanographic Research within the Antarctic Zone
ICSU	International Council of Scientific Unions

IGBP	International Geosphere-Biosphere Programme
IOC	International Oceanographic Commission
IPAB	International Programme for Antarctic Buoys (WCRP)
IPCC	Intergovernmental Panel on Climate Change
ISW	Ice Shelf Water
JGOFS	Joint Global Ocean Flux Study (SCOR and IGBP)
JSC	Joint Scientific Committee for WCRP
MIZ	Marginal Ice Zone
ROV	Remote Observational Vehicle
SCAR	Scientific Committee on Antarctic Research
SSG	Scientific Steering Group
SSM/I	Special Sensor Microwave Imager, DMSP Satellite Program
SCOR	Scientific Committee on Oceanic Research
SO-JGOFS	Southern Ocean - JGOFS
TOGA	Tropical Ocean and Global Atmosphere Experiment (WCRP)
UNEP	United Nations Environment Programme
UV	Ultraviolet Radiation
WCRP	World Climate Research Programme
WG	Working Group
WMO	World Meteorological Organization
WMO-CAS	World Meteorological Organization, Commission on Atmospheric Sciences
WOCE	World Ocean Circulation Experiment (WCRP)
WSBW	Weddell Sea Bottom Water

The Arctic Climatology Project Arctic Meteorology and Climate Atlas

Technical Documentation

The Arctic Meteorology and Climate Atlas provides new data for a data-sparse region of the earth, and presents new and existing data products in formats that are easy to use for climate research. This Atlas compliments the Environmental Working Group's oceanographic and sea ice atlases and contributes to a comprehensive interpretation of the Arctic climate system. Scientific applications foreseen for these data include: investigation of evidence for climatic change over the four decades from 1951 through 1990; examination of inter annual variability of climate in the coastal zone and in the central Arctic; and regional study of air mass transformation from open water to ice-covered ocean.

Summary of Atlas Data Sets

1) Gridded Fields

Climatological monthly mean fields of meteorological parameters are provided in an easy-to-use format. Decadal mean fields for those parameters with sufficient data for a decadal analysis are included. These fields are based on the best available existing products improved, when possible, with new data obtained for this Atlas.

Browse files are gif-format images with a color bar and contours. These allow you to quickly visualize the content of the corresponding ASCII data files. The ASCII EASE-Grid format files have a cell size of 250 km. Technical documentation for the parameter of interest is provided to find complete information on data sources and methods of compiling these fields. The fields are:

- Two-meter air temperature. Included are monthly means, standard deviation, and coefficient of variation for 1980's and 1990's.
- Sea level pressure. Included are decadal monthly means for 1950's through 1990's; long-term monthly means for 1951 through 1990; long-term monthly means for 1961 through 1990 (the WMO period); and fields of anomaly, standard deviation, and coefficient of variation.
- Precipitation. Included are monthly mean fields for the period 1951 to 1990.
- Cloud. Included are decadal monthly mean fields of total and low cloud cover (in %) for 1952 through 1995; long-term monthly mean fields of total and low cloud cover (in %) for 1952 through 1995.
- Snow. Included are monthly mean snow depth fields on land for the period 1966 through 1982; monthly mean snow depth fields for the Arctic ocean for the period 1954 through 1991; monthly mean snow water equivalent fields for the Arctic ocean for the period 1954 through 1991.
- Global solar radiation. Included are climatological monthly means. In addition, the "Gridded Fields" section of the Atlas contains a climatology of direct, total (or global) and net radiation from Russian and other sources, compiled and scanned at AARI by M. S. Marshunova.

2) Coastal Stations

Monthly means of meteorological observation data from 65 Russian and 24 western coastal and island stations for a period that includes the early 1950's through 1990 are provided in uniformat files. The Russian station observations include two-meter air temperature, sea level pressure, total and low cloud amount, and relative humidity. The western station observations include sea level pressure, air temperature, and precipitation. After 1960, a moisture parameter (relative humidity or dew point temperature) is generally available. The HTML interface is provided to see the temporal coverage of each parameter at each station. The interface can also be used to browse the data by plotting parameters.

3) Floating Platforms

The data in this section of the Atlas, taken together, provide observations with better spatial and temporal coverage of the Arctic ocean than has generally been available in the past. These data are three or six hourly synoptic data, monthly means, or in the case of DARMS, once daily observations. Data are from:

- Russian "North Pole" drifting stations. Included are two-meter air temperature, sea level pressure, total and low cloud, surface temperature, and wind velocity, for years spanning 1938 to 1991.
- Western drifting stations The earliest data are from the Fram in 1893, and the latest are from the AIDJEX experiment in 1975 and 1976. Parameters vary but all stations include air temperature, pressure, wind, and humidity data.
- DARMS (Drifting Automatic Radiometeorological Stations). Included are wind, pressure and temperature data from 1958 through 1975.
- Ice patrol ships. Included are wind, pressure, air temperature, sea surface temperature, total cloud amount, low cloud amount, and relative humidity for voyages from 1952 through 1982.

To view the time coverage for any parameter from any station, and to see a plot of the individual station track, the Atlas HTML interface is provided. (These options are not available for DARMS data due to the large number of stations). The data are in uniformat files.

