CANADIAN ICE SERVICE DIGITAL ARCHIVE – REGIONAL CHARTS:

HISTORY, ACCURACY, AND CAVEATS

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REVISION HISTORY

March 2000	• Original document (English only) “Documentation for the Canadian Ice Service Digital Sea Ice Database” written by Ballicater Consulting Ltd..
June 2005	• Section 3.6 “Items to Keep in Mind when Performing Statistical Ice Analysis of Ice Charts” added as well as other minor edits and updates by CIS. • Title changed to “The Canadian Ice Service Digital Charts Database - History of Data and Procedures Used in The Preparation of Regional Ice Charts”. • Document was also translated in French.
September 2006	• Minor changes to reflect new dataset name “CISDA – Regional Charts” and formatted for CIS Digital Archive Series. • CIS URL updated in Bibliography section.

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The original document titled “Documentation for the Canadian Ice Service Digital Sea Ice Database” was prepared as a contract report by Greg Crocker of Ballicater Consulting Ltd. for the Canadian Ice Service under the scientific authority of Tom Carrieres (Canadian Ice Service). The original document has been cited elsewhere as “Crocker and Carrieres, 2001”.

Acknowledgment must be given to Greg Crocker of Ballicater Consulting Ltd. for the entirety of the research and subsequent document. The current document would not exist were it not for the focussed efforts of Mr. Crocker.

In addition to this document, three companion documents were also prepared by Ballicater Consulting Ltd. for the Canadian Ice Service and include:

> Crocker, G. 2000. The Canadian Ice Service digital sea ice database: assessment of trends in the Gulf of St. Lawrence and Beaufort Sea regions. Contract report for Canadian Ice Service, Environment Canada, Ballicater Consulting Ltd. Report Number 00-04, 145 pp.
>
> Crocker, G. 2001. Factors influencing ice climate trends in the CIS database. Contract report for Canadian Ice Service, Environment Canada, Ballicater Consulting Ltd. Report Number 01-02, 55 pp.
>
> Crocker, G. 2002. Analysis of sea ice climate trends in Canadian waters. Contract report for Canadian Ice Service, Environment Canada, Ballicater Consulting Ltd Report Number 01-04, 119 pp.

Credit must also be given to Katherine Wilson and Steve McCourt of CIS for the changes required to bring this document in its final state.

Canadian Ice Service, September 2006.

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EXECUTIVE SUMMARY

The Canadian Ice Service, Environment Canada, has developed a digital database of sea ice information from its weekly regional ice charts. The digital database contains regional charts for the East Coast (1968 – 1998), Hudson Bay (1971 – 1998), Eastern Arctic (1968 – 1998), and Western Arctic (1968 – 1998).

The charts incorporate information from many different sources and do not rely exclusively on a single sensor. They are very detailed and have a higher spatial resolution than many other sources of ice information. The knowledge and experience of the ice forecasters also plays an important in producing a high quality product. This experience is applied to the interpretation of remote and surface observations, bridging information gaps, identifying any problems or errors, and interpreting the available information in a geophysical context.

The procedures used to produce the regional charts and the ice information available, have changed considerably over this period. It is believed that the charts produced in recent years are more reliable and more accurate than those produced in the 1960's and 1970's. The purpose of this report is to document the data and procedures used to develop the regional ice charts for the different regions, and for the time period covered in the digital database. In a subsequent CIS report, ice regime systems have been delineated and quality indices for each region have been assessed. Please see the documentation, CISADS No. 3 "CISDA – Regional Charts: Canadian Ice Service Ice Regime Regions (CISIRR) and Sub-regions with Associated Data Quality Indices".

A limitation of the dataset is its relatively short length. While 30-years is typical for many climate parameterizations, the decadal-scale cycles present in the ice signal, and the relatively high natural variability, make it difficult to extract patterns and trends. It should be noted that any comments or conclusions in this report do not constitute an unqualified endorsement of the CIS database for ice climate studies. The applicability of the database to a specific problem, and the quality of the results, will depend on the specific parameters used, the geographic location, the scale (both spatial and temporal), and the methodology used. If due care is taken to assess the reliability of the selected ice parameters *and regions*, then the Canadian Ice Service Digital Archive will be a valuable source of information for climate change studies. This report, the CISIRR report and discussions with CIS personnel can serve as valuable information sources in the assessment process.

The database is currently updated in near-real-time and efforts being made to extend it by adding digitizing CIS Historical Charts (and other historical chart information).

The database is maintained by the Canadian Ice Service and is available free of charge on CD or from the web to the scientific community. The data is stored as GIS polygon files or 0.25 degree Gridded data (see report CISADS No. 2: "CISDA – Regional Charts: Working With the Gridded Data, in NetCDF and Text Formats").

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1. INTRODUCTION

The Canadian Ice Service, Environment Canada, has developed a digital database of sea ice information from its weekly regional ice charts. The data is originally contained in a Geographic Information System (GIS). The digital data base contains regional charts for the East Coast (1968 – 1998), Hudson Bay (1971 – 1998), Eastern Arctic (1968 – 1998), and Western Arctic (1968 – 1998). The hard copy charts are at 1:4 million scale and were produced from the daily ice charts which contain slightly more detailed information (1:2 million scale). The maps are in the Lambert projection, based on the Clarke 1866 spheroid and NAD27 datum. The central meridian is 100° W, and the latitude of the projection origin is 40° N. More detailed information on the map projection is contained in the database.

Each digital chart contains all of the information contained in the 'egg code', split into individual fields for each egg attribute. The database also contains grid-point data, and pre-calculated statistics derived from the ice charts. These include minimum, maximum and median ice frequencies on three different grid spacings.

The database has many applications. These include: studies of global change where information on temporal variations in ice conditions is required, and engineering studies requiring statistical information on ice conditions. In order to properly assess the significance of any such analyses, it is important that the user be able to assess the accuracy of the ice information. Accuracy is a difficult parameter to quantify, particularly when such a wide variety of data sources have been used and much of the chart information is based on the judgement and experience of the forecaster. These issues are discussed in sections 2 and 3. The accuracy of the information is dependant on the region, and the specific location on the chart. It has also changed significantly over the 30-year period covered by the database. For these reasons it was important to document the chart preparation procedures. This required a review of available literature on operational procedures, and interviews with key personnel presently, or formerly, involved in chart preparation. This information is presented in Section 2. Additional information on the day-today preparation of the ice charts in contained in the Ice Operations Handbook. This information has not been repeated here, but can provide insights into the operational limitations of the charts, and should be referenced when making accuracy assessments.

2. DATABASE DOCUMENTATION

2.1 Regional Ice Charts 1968 – Present

The digital regional ice charts for the East Coast, Eastern Arctic, and Western Arctic cover the period 1968 – Present. The database for Hudson Bay includes the 1971 – present seasons only. The regional charts are 1:4 million scale, and cover sea surface areas of between 1.2 and 2.2 million km^2. Monthly winter charts in the Eastern and Western Arctic did not begin until 1980. These were based on available Infrared satellite imagery and information collected during the Arctic 'round robin' reconnaissance flights. Prior to 1980 there are no winter charts for the Arctic. Annual 'round-robin' flights were made from 1968 (and earlier) until RADARSAT data became available in 1996. These flights were designed to generate a single snapshot of conditions across the Arctic, with emphasis on the presence of multi-year ice. The round-robins were conducted in May until about 1978 when the advent of aerial SLAR permitted reconnaissance in darkness. Subsequent round-robins were usually conducted in February.

Until 1983, ice information was recorded using the 'Ratio Code'. This differed slightly from the 'Egg Code' used from 1983 to the present. In the database, the ratio code information has been converted to egg code format. The significant differences between the ratio and egg codes are described in Appendix A.

2.2 Brief Chronology of Data Acquisition and Chart Preparation Procedures

Figures 2.1a, b, and c illustrate the key changes in chart preparation procedures, and observational information that have occurred over the period 1968 – present. This figure is meant to provide a quick reference for changes that may affect chart accuracy. More detailed descriptions of the changes noted in the figure are provided in Sections 2.3 through 2.6. Ice operations moved from Halifax to Ottawa in 1971, but this is not expected to have had any immediate impact on procedures or chart reliability.

The first significant advancement over the original manual chart drawing process occurred in about 1975 when photo-facsimile technology was introduced for the first time. This allowed the field maps drawn by ice observers to be directly transmitted to the Ice Centre as images. Prior to this the maps were coded, and sent by telex. Once they were received at the Ice Centre they were decoded and the information was plotted manually on the daily chart. Around 1979, the epidiascope was first used for overlaying maps and imagery. This was a projection device that allowed imagery from one source to be projected onto a hard copy chart. Scale adjustments could be made to match the two images, but there was no ‘stretch’ capability to account for different map projections. In 1989 the IDIAS (Ice Data Integration and Analysis System) system was installed. This allowed digital data assimilation and mapping, and eliminated many of the uncertainties introduced by manual chart preparation. The ISIS system, installed in 1995, was significantly better for operational map preparation than the earlier IDIAS system.

Surface observation techniques have not changed in the past 30 years, but the number of ice reports received at CIS declined significantly over that period.

Aerial reconnaissance capabilities benefited from two types of technological innovations. The first was improvements to navigation systems, first with the introduction of GPS systems in the mid-1980’s. The second technology to revolutionize aerial reconnaissance was airborne SLAR and SAR. These systems allowed ice information to be obtained day or night (of particular benefit in the Arctic in winter) and in poor visibility. This greatly increased the daily coverage areas, and reduced the requirements for now-casting.

Satellite information was available as far back as 1968, but was generally not used in operations because of its poor quality and the fact that images had to be sent by mail. This delay of several days made the imagery useful only in cases where there were no other information sources. The introduction of facsimile technology allowed satellite images to be received the same day, but the quality of the faxed images was initially very poor. When digital image transmission became available around 1989, satellite imagery became more important in daily chart production. The most significant event in the 30-year period of chart preparation occurred in 1996 when RADARSAT data became available. The high resolution, areal coverage, repeat coverage, and fast data transmission rates available with RADARSAT make it a key data source. A chart indicating the availability of different sensors is given in Appendix B. Appendix C provides summary information on the sensor specifications.

Figure 2.1a. Regional Ice Chart Chronology: 1968 - 1977

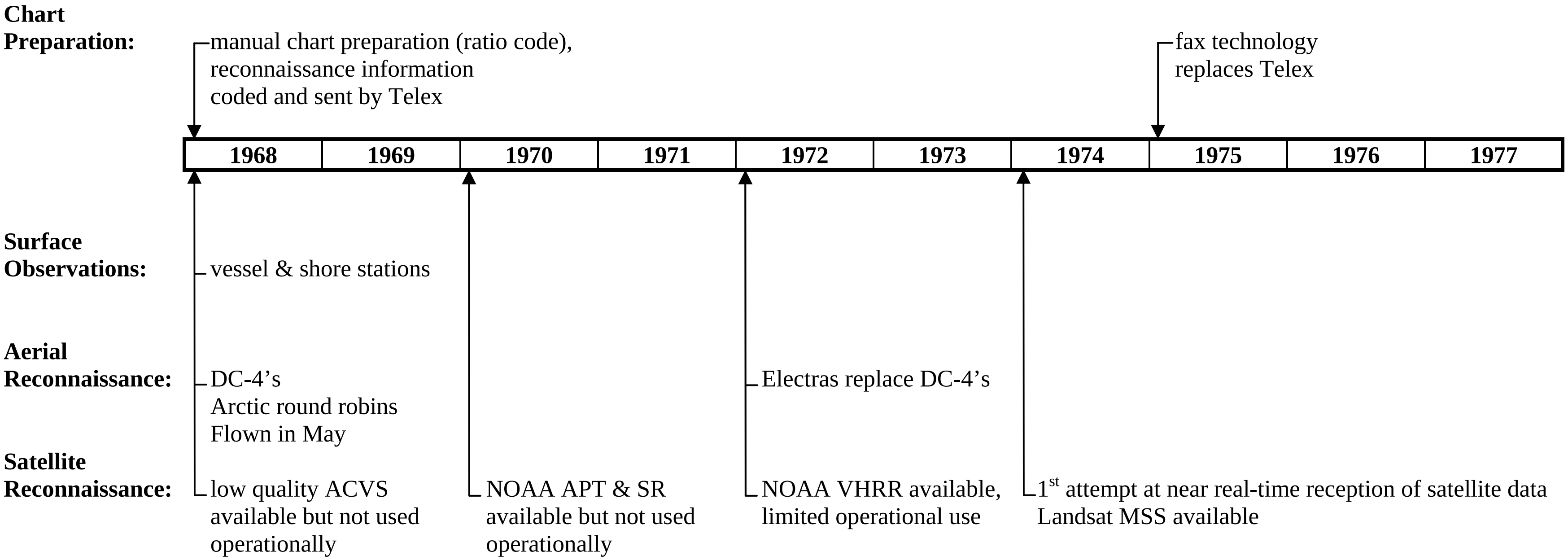


Chart Preparation:

1968: manual chart preparation (ratio code), reconnaissance information coded and sent by Telex

1975: fax technology replaces Telex

Surface Observations:

1968: vessel & shore stations

Aerial Reconnaissance:

1968: DC-4's Arctic round robins Flown in May

1972: Electras replace DC-4's

Satellite Reconnaissance:

1968: low quality ACVS available but not used operationally

1970: NOAA APT & SR available but not used operationally

1972: NOAA VHRR available, limited operational use

1974: 1st attempt at near real-time reception of satellite data Landsat MSS available

Figure 2.1b. Regional Ice Chart Chronology: 1978 - 1987

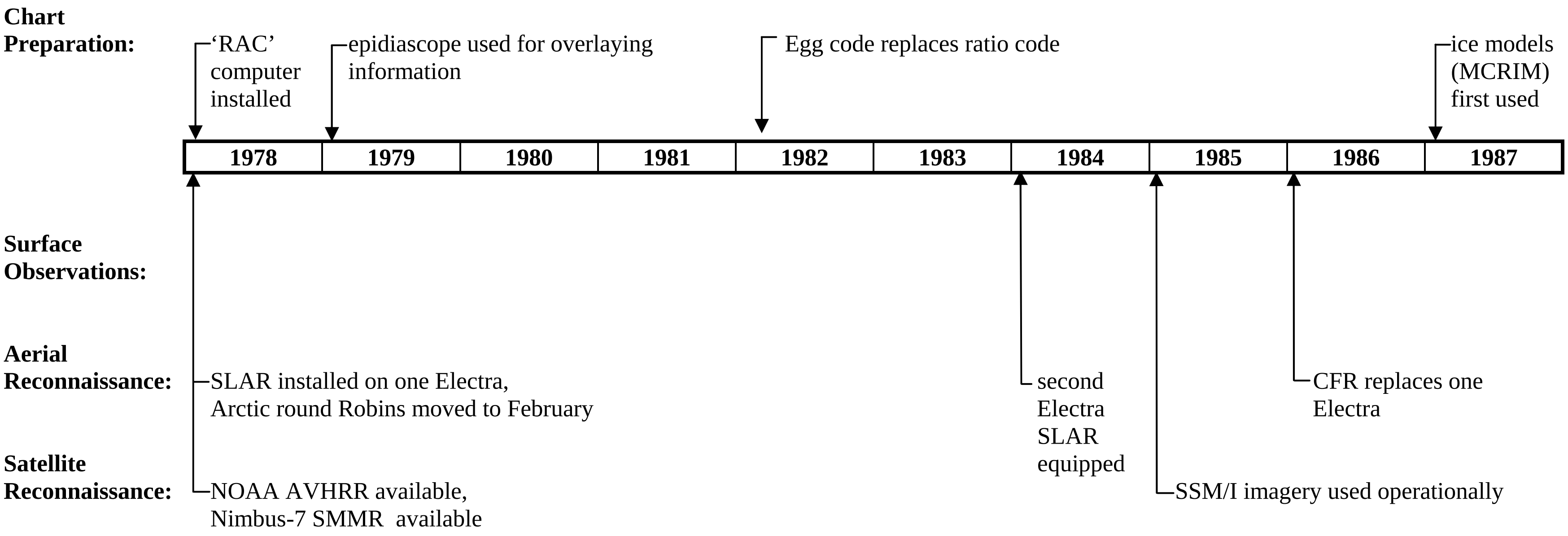
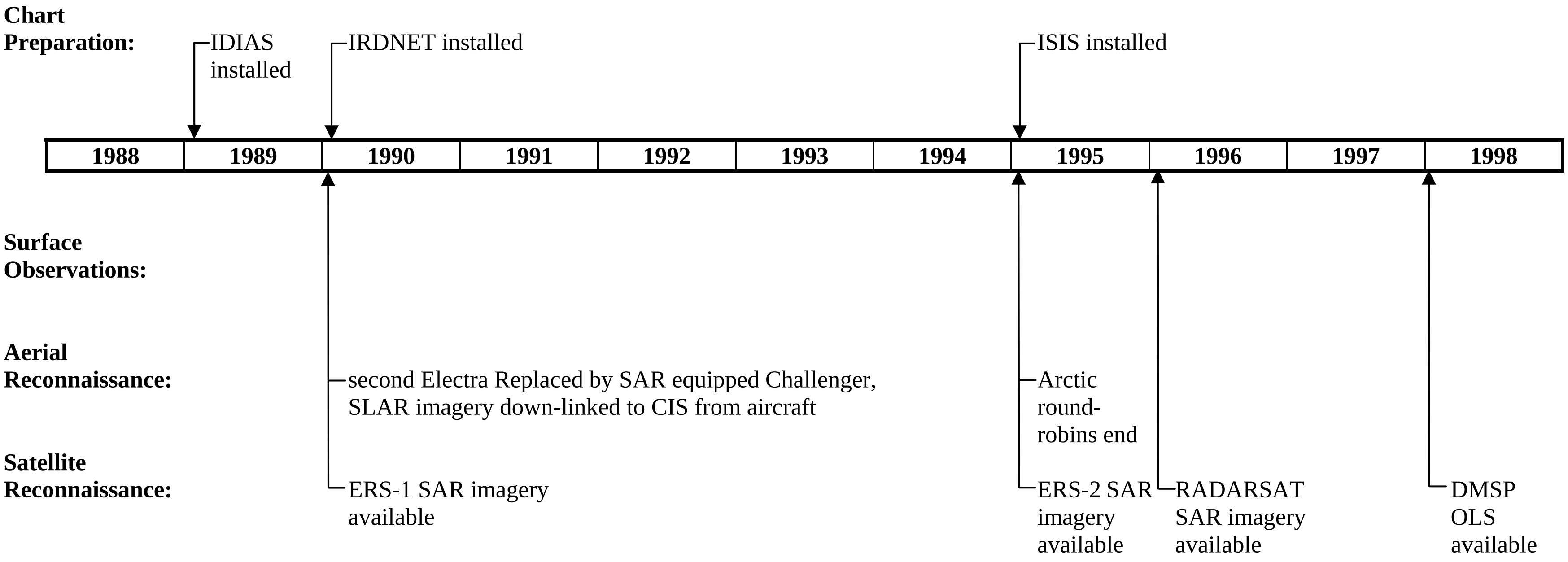


Figure 2.1c. Regional Ice Chart Chronology: 1988 - 1998



2.3 Surface Observations

1968

Numerous reports were received from shore stations (eg. lighthouses) and Coast Guard and other vessels. Landfast ice thickness and snow cover was reported at several coastal weather stations on a weekly basis.

1969 – 1994

A gradual reduction in the number of reporting shore stations occurred over this period. Many of the early shore reports came from lighthouse keepers, who were gradually phased out. Other information came from meteorological stations where weekly landfast ice thickness were made. This information was particularly useful in estimating the stage of development.

1995 – 1998

The rate closures increased rapidly after a program review in 1995. The number of manned stations and the number of remaining stations reporting ice thickness was reduced to near zero.

2.4 Aerial Reconnaissance

1968

Visual aerial Reconnaissance with performed with two Kenting DC-4s (CF-KAC and CF- KAE). One aircraft was normally based in Summerside, PEI, from late December to early January until break-up (normally April), and covered the Gulf of St. Lawrence region. This aircraft then returned to Montreal for maintenance and was subsequently stationed in the western Arctic (Inuvik) for the northern ice season (June to October). The second aircraft was based in Gander and covered the east coast region from late December or early January until June (typically). It was then moved to Iqaluit (Frobisher Bay) to cover the eastern Arctic region from July until October. Ice observations along the Labrador coast were made en route.

In addition, one aircraft performed the Arctic ‘round robin’ observations in the high Arctic every May. A complete map of ice conditions along the main summer shipping routes was produced.

At this time both aircraft were flying approximately 1100 hours per year and, weather permitting, were flying approximately two out of three days. The maximum flying altitude was 3500 to 4000 feet, which permitted visual observations approximately 15 miles out each side of the aircraft. With an average speed of about 200kts (365 km/hr), this corresponded to a potential coverage area (not accounting for visibility) of approximately 2.2 million square kilometres per aircraft per year. The flights out of Gander focussed on ice edge position. The flights out of Summerside focussed on the main shipping routes. The Arctic flights focussed on the presence and location of multi-year ice along shipping routes.

The DC-4's were equipped with standard aviation weather radars that allowed some estimation of the range to significant ice features such as ice edges in front of the aircraft.

Vessel-based CCG helicopters also assisted in ice reconnaissance but were restricted to close range because of VFR limitations and lack of any navigation system. As a result these observations were most often limited to the main shipping routes.

1969 - 1971

No significant changes.

1972

The two DC-4's were replaced by two Lockheed (L-188C) Electras (CF-NAY and CF-NAZ). The Electras could use their Bendix aviation weather radars to detect the position of ice edges in poor visibility. They were also equipped with 'Brutus' submarine detection radar systems with a 360° field of view. These radars were effective for detecting ice edges at closer range.

1973 - 1977

No significant changes.

1978

A Motorola AN/APS-94DX Side Looking Airborne radar (SLAR) was installed on one of the Lockheed Electra aircraft (CF-NAZ renamed CF-NDZ). During the period from 1978 until 1984, when the second aircraft was equipped with a SLAR, the Electras were regularly switched between regions so that no specific region received significantly more SLAR coverage than another. The SLAR equipped aircraft was also used for occasional flights outside its designated region. For example, if the SLAR equipped aircraft was based in Summerside (covering the Gulf region), it would occasionally perform surveys in the east coast region.

The introduction of SLAR was a major advance in reconnaissance technology. It allowed surveillance of regions in darkness and under a cloud cover. It also allowed much larger areas to be surveyed because of the large (100km) swath width. The increased swath width resulted in a 6 fold increase in the nominal areal coverage. The real increase in coverage area was even larger than this because the survey areas were not limited by poor visibility. Although the SLAR imagery was distorted and often difficult to interpret, its introduction led to an immediate improvement in information on ice edges and concentration. This is likely to have improved the quality of the charts.

1979 - 1983

No significant changes.

1984

The second Electra (CF-NAY) was equipped with a Motorola AN/APS-94DX SLAR. With both aircraft SLAR-equipped weather and darkness limitations were greatly reduced.

1985

No significant changes.

1986

One Lockheed Electra (CF-NAY) was replaced by the deHavilland Series 150 DHC-7 (Dash-7, call sign C-GCFR). This aircraft was equipped with a CAL Corp. SLAR-100. This was later upgraded to a SLAR-200. The SLAR was normally operated with a 100km swath width out each side of the aircraft. In this mode the ground resolutions was approximately 25m at near range and 300m at far range.

The Dash-7 was equipped with a GPS navigation system.

1987 – 1988

No significant changes.

1989

CCG helicopters were equipped with GPS navigation at about this time.

1990

The remaining Lockheed Electra (CF-NDZ) was replaced by the Intera Challenger. This aircraft was equipped with an X-band Synthetic Aperture Radar (SAR). The ground resolution of this system under normal operation was 30m, and it had a swath width of 50 km. SAR and SLAR data were received in near-real time at CIS through IRDNET. The data was block averaged and transmitted to CIS at a 100m resolution. The ground resolution of the SAR was constant with range from the flight path. This was an advantage over the SLAR systems where the resolution decreased significantly with range.

1991 - 1994

No significant changes.

1995

Flights with the SAR-equipped Challenger ended in the winter of 1995. Some additional flights were contracted out to Aries Aviation who flew a Cessna Conquest equipped with a single-sided SAR with a 100km swath width. These flights filled the gap that occurred when the Challenger SAR contract ended before RADARSAT data became available. The Arctic round robins ended in February, 1995.

1996 - 1998

No significant changes.

2.5 Satellite Reconnaissance

1968

Low quality visual camera systems such as AVCS (Advance Vidicon Camera System) and APT (Advanced Picture Transmission) imagery was received at Ice Forecasting Central in Halifax. The poor quality of the imagery limited its use for the operational program. Higher quality images were received via mail, but the delayed arrival meant it was used primarily for climatological purposes and the historical charts.

1969

No significant changes.

1970

The NOAA-1 satellite was launched in 1970. This platform contained an APT (Automatic Picture Transmission) system which operated in the visible spectrum, and a Scanning Radiometer (SR) with visible and thermal IR channels. Initially this information was received by mail, limiting its usefulness to areas for which there was no other information.

1971

No significant changes.

1972

LANDSAT 1 was launched with a 4 channel multi-spectral scanner (MSS). This was an excellent source of more detailed info, but the imagery was available only by mail. The LANDSAT MSS had a swath width of 185km and resolution of 79m. The first NOAA VHRR was available from NOAA-2. This provided much better resolution than earlier sensors, but was also received by mail, and was (and still is) severely limited by cloud cover. VHRR had a swath width of about 2600 km and resolution of about 1.1 to 1.9km.

Higher resolution satellite imagery helped to define the regional ice coverage. However, the delay in reception meant that its primary uses were for climatology (for example the historicals), and for updating ice conditions in regions for which there was no other information.

1973

No significant changes.

1974

The first attempt at near real-time reception of satellite imagery was made in the summer of 1974. Selected LANDSAT MSS and NOAA VHRR images were relayed from Prince Albert Saskatchewan over the telephone line. Most of the facsimile copies were of poor quality and the amount of imagery that could be transmitted was limited.

The facsimile technology at this time was relatively primitive and probably did not result in significant improvements to the quality of the charts.

1975

Photo-facsimile was used on a routine basis for acquiring satellite data. This improved the quality of data substantially, but there were frequent equipment problems.

At this time the introduction and steady improvement in the quality and reliability of photo-facsimile technology began to increase the timeliness and overall usefulness of satellite imagery. As a result, the overall quality of the charts probably began to improve, particularly with respect to the regional ice extent.

1976 - 1978

No significant changes.

1978

NIMBUS-7 Scanning Multi-channel Microwave Radiometer (SMMR) became available. This sensor had a resolution of 20 – 80km and swath width of 783 km and was used primarily for ice edge detection.

NOAA AVHRR imagery became available. The AVHRR sensor had typical ground resolutions of 1.1 to 2.5km.

1979 - 1984

No significant changes.

1985

LANDSAT-4 was used for accurate ice edge detection. NOAA-5 and NOAA-7 AVHRR data was acquired from Toronto within 1 to 2 hours after satellite pass. NIMBUS-7 was used for ice edge detection.

Special Sensor Microwave Imager (SSM/I) imagery was first used on a regular basis for daily chart production. The 19 and 37 GHz data was used, and had a nominal resolution of 25km.

1987 - 1989

No significant changes.

1990

ERS-1 C-band SAR became available. The data was averaged to 100m x 100m resolution and received 4 to 6 hours after a satellite pass.

1991

No significant changes.

1992

The ‘Special Sensor Microwave Imager’ (SSM/I) was used for identifying old ice, but had a very coarse (25km) resolution.

1993 - 1994

No significant changes.

1995

ERS-2 C-band SAR data became available.

1996

RADARSAT C-band SAR became available. RADARSAT images are received daily, with repeat coverage every 2 to 3 days on the east coast and almost daily in the high Arctic. Most images are obtained in ScanSAR Wide mode and have a swath width of 500km, a pixel spacing of 50m, and ground resolution of 100 × 100m. The data is then 2x2 block averaged to reduce speckle in visual interpretation methods. Approximately 3500 frames are received per year. The repeat coverage depends on latitude. For the high latitudes (east and west Arctic) repeat coverage is obtained every one to two days. Further south (Gulf and east coast) repeat coverage is typically three days.

RADARSAT SAR imagery provides relatively high resolution, all weather, day or night information on ice extent and concentration, and some indication of stage of development. RADARSAT imagery resulted in a significant increase in confidence in the ice charts.

1997

No significant changes.

1998

DMSP (Defence Meteorological Satellite Program) Operational Linescan System (OLS) became available. This visible and IR sensor has a 3000km swath width and 2.7km resolution (0.55km in fine mode).

2.6 Chart Preparation

Since 1968 (and earlier) the Canadian Ice Service has produced daily sea ice charts for ice covered waters in Canada. These charts cover several geographic regions at a scale of 1:2 million. The daily charts are produced with all information available at the time, which may include satellite imagery, aerial reconnaissance, and surface observations. This information is augmented with information from previous charts, now-casting, and the general knowledge of ice conditions and moments possessed by the ice forecasters. The daily charts must be completed and disseminated on a strict schedule. These deadlines are not always compatible with the timing of reconnaissance information or the workload of the forecasters.

The regional ice charts contained in the digital database are produced once per week from the daily ice charts. The regional charts cover larger geographic areas (East Coast, Hudson Bay, Eastern Arctic, Western Arctic) and are at a 1:4 million scale. Because the deadline for completion of regional ice charts is less restrictive than for the daily charts, all information sources can normally be included. However, the larger scale of the regional charts means that some of the detail available on the daily charts cannot be included. Prior to 1974 both regional and 'historical' ice charts were produced. The historical ice charts were produced at the end of the ice season and benefited from the availability of reconnaissance information gather shortly after the chart date. The historical charts are believed to be more accurate than the regional ice charts, but to date have not been included in the database.

1968

In addition to the daily ice charts that were used to produce the regional charts, weekly 'historical' charts were produced on set 7 day (or occasionally 8 day) intervals. They were produced at the end of the season specifically for climatological purposes. This allowed for additional data and continuity checking, increased satellite use (because the time delay was not important). The 'northern historicals' were produced for the summer months only. The 'southern historicals' were produced all year round. Both historical and regional ice charts were produced until 1974 when the historicals were discontinued. The historical charts contain better information on the start and end of the ice season than the regionals because the latter were often not produced until the ice season was underway. To date the information contained in the historical charts has not been directly incorporated into the database.

The regional charts have always been at a scale of 1:4 million. The daily charts from which they were derived were at 1:2 million scale.

1969 – 1978

No significant changes.

1979

The epidiascope was used to overlay maps and imagery of different scales. The epidiascope was a projection system that allowed one image to be projected onto another. The projected image could be magnified to match the hard copy but could not be stretched to correct for different map projections. As a result, images in the wrong projection could have significant errors. These errors were particularly difficult to correct away from land. The epidiascope also resulted in some degradation of image quality. The projected images could become blurred and some of the dynamic range was lost. Overall, the epidiascope allowed slightly more accurate transfer of ice information than the strictly manual techniques used previously.

1980 – 1982

No significant Changes.

1983

The switch to the egg code allowed for more detailed reporting of ice conditions. This did not necessarily lead to an immediate improvement in the charts because the accuracy was limited by the quality of the input data. More likely, it allowed for the accuracy of the charts to improve gradually over time as the reconnaissance technology improved. The significant differences between the ratio and egg codes are described in Appendix A.

1984 – 1988

No significant changes.

1987

Dynamic ice forecasting models (eg. MCRIM) were introduced. These could be used as tools for assisting with now-casting.

1988

No significant changes.

1989

The introduction of IDIAS allowed folly digital data presentation and chart preparation. This was a significant advancement over earlier techniques because it allowed all data to be superimposed on the same chart projection. This eliminated errors resulting from transcribing information from one projection or scale to another. It was particularly good for determining ice edge positions and boundaries between polygons. However, the IDIAS system was slow and somewhat difficult to work with, and it was used primarily as a tool for viewing data, rather than producing the charts.

1990

The IRDNET (Ice Reconnaissance Data Network) was installed. This allowed the digital data collected during reconnaissance flights to be transmitted in near real time to the Ice Centre.

1991- 1994

No significant change.

1995

ISIS (Ice Service Integrated System) was installed. This fully integrated GIS-based system replaced the older IDIAS system. ISIS has a better and easier to use operation interface and is much less prone to breakdowns. These qualities lead to a general improvement in the quality of the charts.

2.7 Data Availability and Now-casting Requirements

Interpreting the reliability of the regional chart information requires some knowledge of the relative proportions of the charts that were compiled from the different information sources. For, example, a chart that was based largely on a three day now-cast will be less reliable than one that was produced from a recent (same day) RADARSAT image. Data availability changes from region to region, year to year, and chart to chart. General regional and annual trends are described in Tables 2.1 (East Coast) and 2.2 (Arctic). These tables indicate the proportion of the chart covered by various data sources, and the proportion that needed to be now-cast on the day the regional charts were produced. They also provide an estimate of the typical now-cast duration for those areas requiring now-casting. The East Coast charts include the Gulf of St. Lawrence, northern Grand Banks, north east Newfoundland coast, and Labrador Sea. The estimates provided are averages for the entire chart, but it is expected that the now-casting requirements for the Gulf of St. Lawrence were less than in other areas due to more surface observations and more aerial coverage per unit area.

The Arctic regions (Eastern Arctic, Western Arctic, Hudson Bay) are grouped together in Table 2.2. The eastern and western Arctic are virtually identical, while Hudson Bay received very little aerial reconnaissance during the winter season.

Solid arrows indicate that the quantity was relatively stable in intervening years. Dashed arrows indicate that values increased or decreased in an approximately linear manner. In many cases the coverage sums exceed 100%, indicating that some areas on the charts were covered by more than one data source.

Surface observations have played a small role in overall chart production in all regions. The number of observations and therefore the proportion of the charts covered by surface observations has decreased steadily over the 30 year period. It should be noted, however, that surface observations are still an important source of verification for the remote observations. Their importance in overall chart preparation is therefore greater than might be inferred merely from the coverage area indicated here.

Aerial reconnaissance increased as navigation and radar systems became available, then decreased in the mid-1990’s when the availability of RADARSAT data reduced the reliance on aerial observations. Aerial coverage over the Arctic regions is less than on the east coast because the same resources were spread out over a much larger geographic area. Table 2.3 summarizes the area of sea surface, and the maximum and minimum ice extents in each region. For comparison, one 6-hour reconnaissance flight with SLAR would cover approximately 0.44 million km^2. Prior to the introduction of SLAR, the visual coverage for the same 6-hour flight would be approximately 0.06 million km^2 (assuming good visibility throughout).

Satellite observations were available as early as 1968, but were of limited use operationally until the introduction of facsimile technology in the mid-1970’s. The next significant event in terms of satellite coverage occurred in 1996 when RADARSAT became operational. Satellite coverage in the Arctic regions tends to be greater than on the east coast because of the polar orbits, and less cloud cover.

The now-cast requirements have undergone a very significant decline over the 30-year period. In 1968 between 85% and 95% of a regional chart was filled in through now-casting. By 1996, this had reduced to approximately 20%. The now-cast duration decreased in a similar fashion as more observational data became available. In the Arctic, the typical now-cast period was reduced from 14 days to 1 day. On the east coast the reduction was from about 7 days to about 1 day. These reductions may represent the most significant increase in the accuracy of the regional chart information through time.

Table 2.1 Proportion of Regional charts covered by observational information and now-casts: East Coast Region.

YEAR	SURFACE (%)	AERIAL (%)	SATELLITE (%)	NOW-CAST[1] (%)	NOW-CAST PERIOD[2] (days)
1968	5	15	5	85	7
1969	↓	↓	↓	↓	↓
1970	↓	↓	↓	↓	↓
1971	↓	↓	↓	↓	↓
1972	↓	↓	↓	↓	↓
1973	↓	↓	↓	↓	↓
1974	↓	↓		↓	↓
1975	↓	↓	10	↓	↓
1976	↓	↓	↓	↓	↓
1977	↓				
1978	↓	30	40	50	4
1979	↓	↓	↓	↓	↓
1980	↓	↓	↓	↓	↓
1981	↓	↓	↓	↓	↓
1982	↓	↓	↓	↓	↓
1983	↓		↓	↓	
1984	↓	40	↓	↓	3
1985	↓	↓	↓	↓	↓
1986	↓	↓	↓	↓	↓
1987	↓	↓	↓	↓	↓
1988	↓	↓	↓	↓	↓
1989	↓	↓			
1990	↓	↓	45	40	2
1991	↓	↓	↓	↓	↓
1992	↓	↓	↓	↓	↓
1993	↓	↓	↓	↓	↓
1994	↓	↓	↓	↓	↓
1995	↓				
1996	↓	20	75	20	1
1997	↓	↓	↓	↓	↓
1998	2				

1. For now-casts > 1 day.
2. Typical now-cast duration.

Table 2.2 Proportion of Regional charts covered by observational information and now-casts: Arctic Regions.

YEAR	SURFACE (%)	AERIAL (%)	SATELLITE (%)	NOW-CAST[1] (%)	NOW-CAST PERIOD[2] (days)
1968	2	5	5	95	14
1969					
1970					
1971					
1972					
1973					
1974					
1975			15	85	
1976					
1977					
1978		10	50	60	7
1979					
1980					
1981					
1982					
1983					
1984		15			
1985					
1986					
1987					
1988					
1989					
1990			55	50	5
1991					
1992					
1993					
1994					
1995					
1996		5	80	20	1
1997					
1998	1				

3. For now-casts > 1 day.
4. Typical now-cast duration.

Table 2.3. Approximate sea surface areas and ice extents on the regional ice charts.

Region	**Sea Surface Area (million km^2)**	**Maximum Sea Ice Extent (million km^2)**	**Minimum Sea Ice Extent (million km^2)**
East Coast	2.2	0.6[†]	0.0
Hudson Bay	1.8	1.8	0.7[♦]
Eastern Arctic	1.4	1.4	0.7[*]
Western Arctic	1.2	1.2	0.9*

[†] February 26th.

[♦] July 15th.

* August 15th.

3. ACCURACY

3.1 Overview

Accuracy can be defined as the degree of correspondence between information on a chart and the actual conditions on the surface.

The ice charts are thematic maps, and the accuracy of the information at any specific point in space (and time) is a function of the positional accuracy, attribute accuracy (the accuracy of the interpreted ice characteristics), and temporal accuracy. Errors can be introduced at all stages of the chart preparation process. Both positional and thematic information are subject to three main types of errors:

- Observational errors,
- Mapping errors, and
- Now-casting errors.

Observation errors are associated with sensor performance, platform stability, and viewing conditions. Personal errors can be introduced by the limitations of human observers who must estimate distances and lengths, and mentally integrate varied ice characteristics over large areas in relatively little time. Instrument errors can result from sensor system limitations and calibration.

Mapping errors are more varied and in many cases more difficult to quantify. Thapa and Bossler (1992) described many of the errors that can be introduced in the mapping process. Those most relevant to ice chart preparation are:

- Compilation and drawing error,
- Error due to generalization,
- Error due to deformation of materials,
- Errors in digitization, and
- Data transmission errors.

These error sources are described in detail in Section 3.3.

In addition to the mapping error sources described above, there are a number of non-quantitative errors that affect chart accuracy. These include errors due to mislabelling, misclassification, and erroneous feature coding. These types of ‘gross’ errors are virtually impossible to quantify.

Now-casting errors can have a significant influence on chart accuracy. Because ice is dynamic, information collected many hours or days in the past cannot be expected to represent present conditions. To fill in areas of the charts for which there is no up-to-date information, the forecaster must use past ice and meteorological conditions, along with her/his judgement and experience, to predict present ice position and characteristics. Regardless of the forecaster’s skill, and the availability of predictive tools such as computer models, this process will introduce an error in chart information.

Total error is very difficult if not impossible to assess because the functional relationships among the various errors are not known (Thapa and Bossler, 1992). If the error sources are independent and a linear relationship exists between total error and the individual component errors, then total error (E_{total}) can be computed as the square root of the sum of the squares of the individual errors,

$$E_{total} = \left[e_1^2 + e_2^2 + e_3^2 + \cdots + e_n^2\right]^{\frac{1}{2}},$$

where e_1, e_2, … are the ‘n’ individual errors contributing to the total.

3.2 Observation Accuracy

The many sources of ice information used to compile the charts have varying accuracy limitations. In many cases the accuracy of the information coming from a specific sensor varies considerably with distance from the target, or with the nature of the ice feature being observed. This makes it very difficult to make general statements about observation accuracy, but in view of the importance of accuracy to proper use and interpretation of the database, some approximate, quantitative estimates have been developed. These are compiled in Table 3.1. These quasi-quantitative accuracy estimates were developed during group discussions among CIS personnel who are (or have in the past) been using the observation sources for chart preparation.

The first column in Table 3.1 lists the primary sources of operational ice information. In some cases the specifications of the sensors or the data formats changed with time, so several different accuracy estimates are provided for a single data source. The second column contains the positional accuracy estimates in units of kilometres. These values represent ‘typical’ accuracy ranges. That is, the accuracy under normal operation, when observing typical ice conditions at typical distances from the sensor platform. The reported position is typically within the listed values. For example, a positional accuracy value of 4km indicates the true position is likely to be within 4km (± 2km).

It is clear from the wide variations in positional accuracy that the overall accuracy of the resulting chart will be highly dependent on the proportion of the chart derived from each data source. Changes in data coverage through time for satellite, aircraft and surface observations are described in Section 2.7.

The third column in Table 3.1 contains ‘typical’ accuracy estimates for total ice concentration. Again the estimates vary considerably, and the overall accuracy of the chart will depend on the relative usage of the different data sources.

The stage of development information (column 4) is much more difficult to quantify. The stage of development classifications used in the egg code cover widely ranging thickness bins. For example, grey-white ice ranges in thickness from 15 to 30cm, while first year ice (the next higher thickness category) includes ice between 30 and 200cm thick. As a result it is not meaningful to estimate accuracy in terms of a fixed thickness range. Instead, the accuracy estimates indicate a level of confidence with respect to the reported stage of development code. For example, a value of 75% indicates that using a specific sensor, the stage of development could be correctly identified 3 out of 4 times. These values are very broad averages, again representing typical operating conditions, and averaged over all regions.

Stage of development becomes more difficult to determine with increasing distance. Surface observations tend to be more reliable than aerial, which are turn more reliable than satellite data. Also, some stages of development are much easier to identify than others. In general, sub-categories of ‘first-year’ ice are almost impossible to distinguish from the remote sensing data. This is why the first-year ice stage of development category is so large. Thin ice types, and multi-year versus first-year distinctions are more reliable. The values quoted in column 4 represent averaged estimates over all stage of development classifications. It should be noted that the ice information reported on the charts is for level ice, deformed ice such and ridges and rafted ice are ignored.

The final column in Table 3.1 gives the confidence in the floe size categories. As noted, these values indicate confidence in the ability to correctly classify floe size *above the sensor floe size resolution*. These values are also averages over all conditions and all regions.

Table 3.1 Typical estimated observation accuracy for the principal sources of ice information[1].

SOURCE	POSITION (km)	TOTAL CONC.[4] (tenths)	STAGE OF DEVEL. (% confidence)	FLOE SIZE[5] (% confidence)
RADARSAT	1	0.5	75	90
ERS-1 / ERS-2	0.5	1	65	90
NOAA AVHRR (digital)	4	2	55	75
NOAA AVHRR (pre-digital)	40	4	55	75
NOAA VHRR	40	2	55	75
SSM/I	25	4	NA	75
LANDSAT	1	1	75	90
Aircraft SLAR (GPS nav.)	1	1	50	90
Aircraft SLAR (INS nav.)	4	1	50	90
Aircraft SAR	0.5	0.5	80	95
Aircraft Visual[2] (GPS nav.)	1	1	85	95
Aircraft Visual (INS nav.)	4	1	85	95
Helicopter Visual (GPS)	1	1	85	95
Helicopter Visual (pre-GPS)	2	1	85	95
Shore[2]	1	4	85	80
Ship (GPS)	1	2	85	90
Ship[3] (pre-GPS)	4	2	85	90

1. All estimates indicate the range of values or confidence. For example, a positional accuracy of 4 km indicates the position is typically within 4 km (± 2 km).
2. Visual observations are strongly influenced by range. Near to the flight path or shore station, observations are more accurate than at large distances from the observer.
3. The positional accuracy of ship reports decreases with increasing distance from the coast.
4. The accuracy of total concentration estimates made from satellite data is highly dependent on the concentration. Many sensors, including RADARSAT are poor at showing low ice concentrations. Concentration data from SSM/I imagery has been shown to systematically miss low concentrations of ice (< 3/10^{ths}).
5. The accuracy of floe size information is highly dependent on the floe sizes. Small floes cannot be resolved on satellite imagery. Therefore the estimates in this column indicate "ability to determine floe size above the sensor resolution".

3.3 Mapping Accuracy

Inaccuracies in chart information can also occur during the chart production process. In this discussion, ‘gross errors’ arising from mistakes in decoding or transferring data are ignored. Examples of gross errors might include reading 5 tenths concentration from a satellite image but inadvertently writing 8 tenths on the egg, or reading stage of development 7 (thin first-year ice) from the aerial reconnaissance chart, but writing 7. (old ice) on the egg. Gross errors are often extremely difficult to detect. In the absence of gross errors, errors in the mapping process are limited to positional information.

Estimates of positional errors associated with different components of the mapping process are given in Table 3.2. Compilation and drawing errors are those associated with combining graphical information from different sources and at different scales, and physically drawing feature boundaries on a common base map. After the introduction of the IDIAS system in 1989, and ISIS in 1995 most of these errors were greatly reduced. However, they can never be completely eliminated because all mapping systems have inherent resolution limitations.

Error due to generalization occurs in both the data acquisition and data analysis stages of the chart preparation process. Thickness, concentration, and floe size vary on different spatial scales. The need to define predominant characteristics over relatively large regions introduces a potential error in the information at any point within the larger polygon (even if the predominant characteristics are correctly identified).

Deformation of materials refers to the stretch of the paper sheets on which the charts were prepared prior to the introduction of digital systems. This error is a function of changes in the temperature and humidity in the office at the time the chart was being prepared. Paper can deform by up to 1.6% over normal ranges of temperature and humidity (Maling, 1989). At a scale of 1:4 million, this can result in a positional error of several kilometres. This source of error should not be a factor for digital maps.

Digitization or scanning of imagery can introduce errors. The magnitude of the error is dependent on the size of the feature, the skill of the operator, the complexity of the feature, the resolution of the scanner/digitizer, and the density of features (Thapa and Bossler, 1992).

Significant errors could also be introduced in data transmission. Again these errors were virtually eliminated once the completely digital mapping and chart preparation software systems were installed. When field charts and satellite images were faxed to the Ice Centre, significant positional inaccuracies resulted from image distortion and loss of resolution. Before fax technology was used, accuracy limitations arose from the requirement for coding of the field charts. Each position along an ice edge or polygon had to be measured, coded, typed onto a tape, and sent by telex to the Ice Centre where they were decoded and plotted. This process limited the number of points that could be used to define a polygon, and therefore the accuracy of the boundaries. Early fax systems were poor quality and introduced gross errors whereby numbers were illegible or easily misread.

TABLE 3.2 Estimated positional errors associated with various components of the chart preparation process.

SOURCE	POSITION (km)
Compilation & Drawing (digital)	2
Compilation & Drawing (epidiascope)	10
Compilation & Drawing (manual)	15
Generalization	2
Deformation of materials (paper)	3
Digitization	2
Data transmission (digital)	0
Data transmission (fax)	10
Data transmission (code)	10

3.4 Now-casting Accuracy

Areas of a chart for which there was no current ice information were filled in using ‘now-casting’. This involved using measured or forecast meteorological and oceanographic conditions, model predictions (where available), and the experience and judgement of the forecaster, to move and change ice conditions from the previous day’s chart (some of which may have been now-cast from earlier charts). Clearly, the longer the now-cast period, the larger the error is likely to be. Now-casting requirements have typically been greatest in the Eastern and Western Arctic because the reconnaissance efforts have been spread out over these very large geographic areas. Ice charts for Hudson Bay also contain a large amount of now-cast information. Fortunately, ice conditions in these regions are relatively easy to now-cast during much of the winter (see below). Now-casting requirements in these regions were greatly reduced when RADARSAT imagery became available. The polar orbit of this satellite gives the smallest repeat coverage intervals at high latitudes.

The Gulf of St. Lawrence region contains the least amount of now-cast information because it is a relatively small (it can be almost completely covered in one day by aerial reconnaissance), and there is frequently supplemental information available from Coast Guard helicopters and merchant shipping.

Some geographical regions are more difficult to now-cast than others. For example, the ice conditions in Hudson Bay are very stable once a first-year ice cover has developed. Because there is very little change from one day to the next, now-casting is relatively easy. Portions of the central Arctic also have stable ice conditions during the late winter. Ice on the east coast is much more difficult to now-cast because it is unconfined and very dynamic.

Table 3.3 provides estimates of now-cast accuracy for each ice characteristic as a function of now-cast period. These are again rough estimates representing typical conditions, averaged over all regions, and were developed during group discussions with ice forecast personnel. In all cases the accuracy is expected to decrease with increasing duration. The stage of development accuracy is listed as being constant because this characteristic changes very slowly once the ice has reached the first-year stage (about 30cm). The accuracy of all other ice characteristics is expected to decrease approximately linearly with time, with the positional information being subject to the greatest relative error.

Table 3.3 Typical estimated now-cast accuracy for a range of now-cast duration.

SOURCE	POSITION (km)	TOTAL CONC. (tenths)	STAGE OF DEVEL. (% confidence) [1]	FLOE SIZE (% confidence) [1]
6-12 hour (temporal adjustment)	5	1	95	95
24 hour (no data for 1 day)	10	2	95	90
> 48 hour (no data for 2+ days)	25	3	95	85

1. The accuracy estimates indicate the level of confidence with respect to the reported stage of development and floe size codes associated with the now-cast (ie. assuming the initial values were correct). For example, a value of 95% indicates that changes in the stage of development are correct 19 times out of 20 over the now-cast period.

3.5 Ice Characteristics

3.5.1 Introduction

The sources of error discussed above can affect all of the ice characteristics on the charts. The ice charts contain information on sea ice:

- Position (ice edges and polygon boundaries),
- Concentration,
- Stage of development, and
- Floe sizes.

The accuracy of each ice characteristic is controlled by several factors and has changed through time as reconnaissance, reporting, and chart preparation techniques have evolved. The main factors limiting the accuracy of each ice characteristic are discussed below.

3.5.2 Position

The accuracy of the ice edges and polygon boundaries on the ice charts is limited by many factors. The first limiting factor is the accuracy of the positioning system on the vessel, aircraft or satellite platform. Current platforms have highly accurate GPS systems and can determine their position at any time to within about 100m or less. However, the DC-4 and Electra aircraft used in earlier reconnaissance efforts were equipped with much less accurate inertial and beacon-based (Omega) systems. These were typically accurate to within a few kilometres. Positional errors will be smaller where there is more information, such as near to shore (which can be used for reference) and in the main shipping lanes in the Gulf of St. Lawrence.

In addition to these limitations, the ice observer must make judgements as to the spatial position of ice features. This error is difficult to quantify, and would increase with distance from the flight track. In the absence of radar information these errors were likely to be ± 10% (1 to 2km at long range). This would be very much a function of the experience of the observer. Once airborne SLAR was available this source of error was greatly reduced, and was probably comparable to the range resolution of the SLAR or SAR system (~300m). Helicopter observations are still made without the benefit of SLAR, and therefore are subject to the judgement of the ice observers.

Another source of positional inaccuracy results from the fact that most ice is dynamic and changes position continuously through time. The regional ice charts represent a ‘snap-shot’ of ice conditions at 1800 UTC on specific day. Since not all of the data used to produce a chart is collected at the same time, changes in position between ‘data takes’ will limit positional accuracy. For example, if the sea ice is drifting at a rate of 10km/day, data collected 6 hours before the time specified on the ice chart would be offset by 2.5km. Even during a long aerial reconnaissance flight the ice can move several kilometres. Forecasters attempt to compensate for temporal differences by adjusting positions slightly, knowing the conditions and the time the data were acquired. This is a type of short-term now-casting. The magnitude of this error will be a function of the data collection schedule and the rate of ice movement. Landfast ice (and possibly high ice concentrations in constricted channels) would not be a strongly influenced by these limitations.

Coding and decoding ice messages can limit the positional accuracy of the charts by limiting resolution of the information that can reasonably be coded and decoded. This is not a factor in the current chart production procedure, but probably played a role in the late 1960’s and early 1970’s when flight messages were coded and sent by Telex. Since the latitude and longitude of each ice edge and polygon had to be coded and put onto a teletype tape, the number of points that could be transmitted was limited. This in turn limited the resolution of the ice edge and polygon boundary positions on the resulting ice charts.

Similarly, the graphical scale of the ice charts limits their positional accuracy. The regional charts used to create the database are at 1:4 million scale. At this scale the width of the lines defining the ice edges and polygon boundaries is approximately 1km. Since the accuracy cannot be greater than the resolution, this introduces a limit on the positional accuracy of the ice information to ± 0.5km.

One of the most significant limitations to positional accuracy results from the requirement to ‘now-cast’ ice conditions in regions where current observations are not available. Now-casting involves taking all relevant ice and meteorological information and using judgement and experience to extrapolate conditions into regions where recent observations are unavailable. Now-casting is aided by numerical ice growth and decay models (which can indicate changes in stage of development), and ice drift models (which indicate movements). However, an experienced forecaster can often outperform numerical models. As the length of time for which there is no data increases, the accuracy of the now-cast decreases. This was a much more significant problem before satellite and airborne radars because darkness and cloud cover could obscure the ice cover for many days a time. The finite number of flying hours available also meant that even in good weather some areas would not be surveyed for several days. Since the availability of RADARSAT imagery, the now-casting requirements have been greatly reduced.

The position and extent of landfast ice is more accurate than drift ice because it is relatively stable through time. This reduces the effects of data gaps. However, it is subject to the same resolution limitations. Also, the positional accuracy of the polygon boundaries is subject to more uncertainty than the ice edges. Although ice edges can be diffuse, it is generally simpler to select representative position when the distinction is between ice and no ice, than it is when a boundary between different ice types must be defined.

The net effect of these accuracy limitations may be a function of the how the data is used. For general ice climatology the effect of random errors will be small. It is believed that all of the factors contributing to uncertainty in the ice position are random.

3.5.3 Concentration

Total ice concentration and partial concentrations of each ice type are provided for each polygon. Both the ratio code and egg code allow concentrations to be reported in tenths. Concentrations are relatively easy to observe visually, and a number of the remote sensing tools have been shown to provide accurate total concentration data. In general the coarser the resolution of the imagery, the poorer the partial concentration data will be. An important systematic error can be introduced in the data when satellite sensors are used to estimate concentration. Some sensors, including RADARSAT do not show low concentrations. Areas of small floes of 3 tenths or less can appear as open water. If supporting information is not available, this will lead to underestimates of ice at low concentrations. Since the recent charts rely more heavily on satellite imagery, it is possible that the accuracy of the ice concentration data has decreased.

The accuracy of the partial concentration estimates is also a function of the ability of the observer/forecaster to distinguish between different ice types (see below). If the stage of development is not correct, then the concentration for that ice type will not be correct. Since concentration is so dependant on image interpretation, the accuracy of the concentration information on the charts is likely to vary between observer/forecasters and it is possible that some systematic errors exist. This is difficult to quantify, but it is likely to be small because any systematic bias introduced by a single observer/forecasted will tend to be offset by others.

Now-casting introduces an additional uncertainty in the concentration data. Where observations are not available the forecaster must project past conditions into the present. On a large scale these now-casts are probably quite accurate because the total surface coverage of ice in a region does not change rapidly. Exceptions to this are in conditions of extreme ridge-building and rafting, rapid decay, or when new ice is forming. However, even if the total surface area covered by ice does not change significantly, the local distribution of floes and therefore the local concentrations, can change dramatically in short periods of time. This is more likely to occur on the east coast where the ice largely unconfined. The effect of these changes on the accuracy of the concentration information is dependant on the scale of the charts. The daily charts, which are at a smaller scale, are more prone to now-casting errors than the larger scale regional charts contained in the database. At 1:4 million scale, the regional charts describe average conditions in polygons that are typically larger than 3000km^2. At this scale local variations in concentration can not be reported, and the average conditions in each polygon are relatively insensitive to such variations. As the length of the now-cast increases the accuracy will decay. Again this suggests that the concentration data from the early ice charts is less accurate that the charts being produced today, since there were longer periods without observations.

3.5.4 Stage of Development

The stage of development is one of the most difficult parameters to observe. There are currently no sensors in operational use that can distinguish ice thickness to the resolution contained in the egg code. It is usually possible to distinguish multi-year ice from first year ice, and thinner forms of first-year ice (less than about 30cm in thickness) from thicker first-year ice. Beyond these broad classifications, the accuracy of the thickness information is heavily reliant on the aerial and surface observations. When there is no snowcover, the different forms of thin ice (less than about 30cm in thickness) can be readily distinguished by the trained observer. Thicker first year ice can also be identified, but becomes more difficult to classify as the thickness increases due to the presence of snow and the less pronounced colour changes. Multi-year ice is also readily identified visually by its roughness and the presence of snow free, bluish ice. Ship-based observations are probably the most accurate in terms if stage of development because the observer is close to the ice, and can often observe the ice floes on edge as the vessel transits through the ice. This suggests that the thickness information might be more accurate near to the main shipping lanes.

A general result of these interpretation limitations is that the greatest uncertainty lies in the ‘first-year ice’ classifications (30 – 200cm). In this range, peripheral information must be relied upon to improve the thickness estimates. Ice growth is one of the more easily predicted characteristics and both historical information and simple freezing-degree-day growth models can be employed. In regions where the ice is very dynamic these models become less effective because the ice can move between areas with different growth conditions.

The most significant effect of now-casting on the stage of development data occurs when the ice is first forming. In the absence of observations it is difficult to predict formation, and now-casts are subject to considerable error. Once the ice has formed, but is still thin, its growth is predictable using freezing-degree-day data and errors should be small. Once the ice has thickened, it is more difficult to predict its stage of development, but the growth is slow and the errors introduced by now-casting should again be small.

Prior to 1983 the ice information was presented using the ratio code. This coding system allowed less detail in the stage of development information than the egg code that has been used since 1983. For example, the ratio code contains a single category for first-year ice (30 – 200cm), whereas the egg code contains four different first-year ice sub-categories. In situations where there is detailed thickness information available, the ratio code data (pre-1983) would be less accurate. This probably did not result in an immediate increase in accuracy in 1983, but permitted a gradual improvement as detection technology improved.

Stage of development information is more susceptible to systematic error because it is much more difficult to observe, and there is much less surface verification.

3.5.5 Floe Size

Floe size, like concentration, is relatively easy to estimate if sufficiently detailed imagery or visual observations are available. Visual observations made from aircraft can resolve objects down to several metres in length, and floe size estimates from these sources are probably quite accurate. Airborne SLAR is also a useful tool for measuring floe sizes, and can supplement or replace (in cases of poor visibility) visual observations. The resolution of the SLAR systems ranges from 25m at near range to 300m at far range. The usefulness of satellite sensors for measuring floe size depends on the resolution of the sensor. High-resolution sensors such as LANDSAT MMS, ERS-1, ERS-2 and RADARSAT SAR are much more valuable than low-resolution sensors such as AVHRR.

Since only one representative floe size can be given for any single ice type, an attempt is made to provide the ‘predominant’ floe size value. This requires further skill on the part of the observer/forecaster, particularly if the floe size distribution is highly skewed. Because of the resolution limitations on the various information sources, floe sizes in the egg code are normally reported as medium (100 – 500m) or larger. This produces compatibility between the egg code and ratio code in that there was no provision in the ratio code to report floe sizes if they were less than 100m. However, it could lead to some interpretation problems since floes reported as ‘medium’ are actually ‘medium or less’.

Now-casting does not have a significant effect on the floe size information unless the now-cast period is quite large. This is because floe sizes generally do not change quickly. Exceptions to this rule are near to ice edges where wave action can rapidly reduce the size of floes within several kilometres of the open ocean, and during cold calm spells when floes can bond together to make larger conglomerates.

Chart scale is also less important to the accuracy of the floe size information than it is for other ice characteristics. Average floe size is a relatively stable parameter both spatially and temporally. Therefore positional errors and scale limitations will not have a significant effect on the accuracy of the information.

The floe size information, like ice concentration, is probably free of systematic errors with one exception. As mentioned above, floe sizes are only reported if they are medium or larger (this is a specified characteristic of the ratio code, and the accepted operational practice with the egg code). Therefore, there is a bias in the data toward large floes.

3.6 Items to Keep in Mind when Performing Statistical Ice Analysis of Ice Charts

In addition to the general statements about data quality made above, some specific characteristics of the database are important for assessing its potential for statistical analyses. Quality-assurance has taken place at various stages through time from chart production to post chart review and finally to chart digitization which increased the overall quality by correcting human errors found on the original ice charts.

The chart database has been used successfully for numerous ice statistics such as sea ice atlases and can be applied to climatological studies in Canadian waters. (A Bibliography of atlases, reports and papers which have used the database is available on request). During such endeavors, the following considerations should be kept in mind when performing any analysis using the dataset.

- The dataset for the most part consists of weekly observations through an active ice season, but missing charts do exist and increase in frequency towards both the beginning and end of the active season.
- Monthly ice charts in the winter for the East Arctic, West Arctic, and Hudson Bay began regular production in 1980.

- Trace amounts of ice have been reported throughout the dataset, but a decrease in the number of traces per polygon is seen in 1982 as the “ratio code,” which allowed for multiple traces per polygon was replaced with the “egg code,” which allows for only 1 trace of “thick” ice and 1 trace of “thin” ice.

- The encoding of areas of “fast ice” has not always been consistent for the East Arctic and West Arctic particularly during the “ratio code” years and makes it difficult to differentiate between “fast ice” and “drift ice.”

- Up to and including 1996, charts in adjacent regions were not produced on the same day and this can result in differences in areas where charts of different regions overlap

- Some inconsistencies have been noted in the continuity of amounts of old ice (multi-year/second-year/old) from the end of a summer melt season to the beginning of the next season. This may be reasonable in areas where ice motion still occurs during the winter season i.e. the Beaufort Sea yet unreasonable in areas where little or no ice motion occurs i.e. the Canadian Arctic Archipelago.

- Some inconsistencies have been noted in the differentiation between multi-year and second-year ice. It is recommended that studies involving multi-year ice should consider multi-year, second-year, and old ice as one ice type.

- Areas of “no data” exist in the dataset. Sometimes these areas can be large and their impact on statistics may need to be considered.

- The use of “multiple codes” has been noted to affect statistics particularly that of old ice. A “multiple code” is an area on a chart where two or more ice codes were placed with no line of delineation between them. Upon digitization, an approximate mid-point between multiple codes was drawn. In general, the impact will be minimal due to the similarities in ice conditions between the codes. However, it has been noted to affect areas of low concentrations of old ice most notably in Baffin Bay.

- Concentration of “icebergs” 1/10 or greater is sometimes included in the total concentration. This should be considered for studies pertaining to sea ice only.
- The encoding of “9+” for total concentration can also affect values. Numerical attributes in the CIS Digital Archive considers this as 9.7/10 or 97% total ice cover. This differs from the sum of the partial concentrations, which in this case would be 10/10 or 100%. This applies for all regions and all years in the CIS Digital Archive.
- Changes in the digital base map can affect statistics, but their impact is considered minor.
- Changes in chart extents throughout the dataset can have a marked impact on values. Care must be taken to ensure a consistent area throughout the dataset for the analysis.

The CIS Digital Archive represents the best available source of detailed, high-resolution digital data for sea ice in Canadian waters. The dataset contains over 30 years of sea ice data and represents a compilation of numerous data sources. In its current state the CIS Digital Archive is of great value for statistical sea ice studies in Canadian and adjacent waters. It is planned to further improve the quality of the dataset through continuing quality control, and by addressing the issues above in future releases.

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REFERENCES AND BIBLIOGRAPHY

Anonymous, 1981. Interpreting Canadian Ice Charts (1967-1981), Internal Ice Centre Note.

http://www.ice-glaces.ec.gc.ca/App/WsvPageDsp.cfm?ID=175&Lang=eng (Ice Codes and Symbols).

http://www.ccrs.nrcan.gc.ca/ccrs/tekrd/satsens/sats/satliste.html (Satellite Information)

Maling, D., 1989. Measurements from Maps: Principles and Methods of Cartometry. Pergamon Press, Oxford, 577p.

MANIS, 1992. Manual of Ice Services, Environment Canada, Atmospheric Environment Service.

Massom, R. 1991. Satellite Remote Sensing of Polar Regions, Belhaven Press, London.

Mullane, T. 1980. Operational use of satellite imagery in the Canadian ice program, 6th Canadian Symposium on Remote sensing, Halifax, Nova Scotia, May 21-23, 1980.

Ramplee-Smith, C. and Hall, R. 1991. The Dash-7 Ice Reconnaissance Aircraft, Presented at the WMO Operational Ice Remote Sensing Workshop, Ottawa, 11 September, 1991.

Ramsay, B. 1985. Qualitative and quantitative interpretation of satellite imagery as related to sea ice analysis, AES Ice Centre Note, February, 1985.

Thapa, K., and Bossler, J. 1992. Accuracy of spatial data used in geographic information systems, Photogrammetric Engineering and Remote Sensing, 58(6): 835-841.

APPENDIX A: Key Differences between the Ratio and Egg Codes.

The significant differences between the egg code used from 1983 to the present and the ratio code used prior to 1983 are the amount of detail allowed in reporting the stage of development and floe size information. These differences are discussed below, along with an indication of their repercussions with respect to resolution and accuracy.

Stage of Development

The ‘egg’ code differs from the earlier ‘ratio’ in the amount of detail provided in the stage of development (thickness). The stage of development categories for both systems are given in Tables A1 and A2. The egg code provides for more detailed reporting in several thickness categories. These are,

- The egg code provides for separate reporting of new ice and nilas, which are combined in the ratio code,
- The egg code contains an additional ‘young ice’ category which includes grey ice and grey-white ice, but still allows for these ice types to be reported individually,
- The egg code has four development stages for first-year ice, while the ratio code has only one,
- The egg code has separate categories for ‘old ice’ and ‘multi-year’ ice (the ratio code includes multi-year ice only, and
- The egg code contains an ‘ice of land origin’ category.

Table A1. Ratio Coding for Sea Ice Stages of Development.

Description	**Thickness (cm)**
Nilas and new ice	0 – 10
Grey ice	10 – 15
Grey-white ice	15 – 30
First-year ice	30 – 200
Second-year ice	
Multi-year ice	

Table A2. Egg Coding for Sea Ice Stages of Development.

Description	Thickness (cm)	Code
New ice	<10	1
Nilas; ice rind	0 – 10	2
Young ice	10 – 30	3
Grey ice	10 – 15	4
Grey-white ice	15 – 30	5
First-year ice	30 – 200	6
Thin first-year ice	30 – 70	7
Thin first-year ice, first stage	30 – 50	8
Thin first-year ice, second stage	50 – 70	9
Medium first-year ice	70 – 120	1.
Thick first-year ice	120 – 200	4.
Old ice		7.
Second-year ice		8.
Multi-year ice		9.
Ice of land origin		.

Floe Size

The egg code provides 11 floe size categories (Table A3), but only codes 3 or larger (20 – 100m) are reported on the charts. The ratio code includes only the concentration in tenths of floes greater than 100m diameter, for each reported stage of development. Therefore, the charts produced using the ratio code (after 1982) contain more information on small floes.

Table A3. Egg Coding for Ice Floe Size.

Description	Width (m)	Code
Pancake ice		0
Small ice cake; Brash ice	< 2	1
Ice cake	2 – 20	2
Small floe	20 – 100	3
Medium floe	100 – 500	4
Big floe	500 – 2000	5
Vast floe	2000 – 10000	6
Giant floe	> 10000	7
Fast ice, growlers or floebergs		8
Icebergs		9
Undetermined or unknown		X

Repercussions

As a result of these differences between reporting procedures, the sea ice charts compiled after 1982 (using the egg code) are of a higher resolution. When detailed information was available this would result in charts that were also more accurate. However, a significant and sudden increase in accuracy after 1982 is not expected. The stage of development is often difficult to observe from airborne platforms, particularly when there is snow cover or the ice is thick. The accuracy of the charts is likely to be more strongly influenced by changes in remote sensing technologies than the reporting procedures. The exception may be the floe size data, which is easily observable from the air and significant improvement can be expected as a result of the more detailed reporting procedures after 1982.

APPENDIX B: Availability of Principal Data Sources

DATA SOURCE	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Satellite Sensor																															
SR			■	■	■	■	■	■	■	■	■	■																			
VHRR					■	■	■	■	■	■	■	■																			
MSS					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
AVHRR											■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
TM															■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SSM/I																				■	■	■	■	■	■	■	■	■	■	■	■
SAR[1]																							▪	▪	▪	▪	▪	▪	▪ ■	■	■
Airborne Sensor																															
Visual	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SLAR											■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SAR																							■	■	■	■	■	■			
Brutus Radar					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Weather Radar					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Surface Obs.																															
Visual	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

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[1] dashed line indicates ERS-1 and ERS-2, solid line indicates RADARSAT availability.

APPENDIX C: Specifications of Principal Sensors

SATELLITE SENSORS

SR – Scanning Radiometer

Wavelength: visible, thermal IR
Satellites: NOAA 1-5
Dates: January 1970 – March 1979
Ground Resolution: 3.2km – 8.0km
Swath Width: 2,900km

VHRR – Very High Resolution Radiometer

Wavelength: visible, thermal IR
Satellites: NOAA 2-5
Dates: October 1972 – March 1979
Ground Resolution: 1.0km – 1.9km
Swath Width: 2,580km

MSS – Multi Spectral Scanner

Wavelength: visible, near IR
Satellites: LANDSAT 1-7
Dates: July 1972 – present
Ground Resolution: ~80m
Swath Width: 185km

AVHRR – Advanced Very High Resolution Radiometer

Wavelength: visible, near IR, thermal IR
Satellites: TIROS-N, NOAA 6-11, NOAA ‘NEXT’
Dates: October 1978 – present
Ground Resolution: 1.1km
Swath Width: 2,580km

TM – Thematic Mapper

Wavelength: visible
Satellites: LANDSAT 4-7
Dates: July 1982 – present
Ground Resolution: 30m
Swath Width: 185km

SSM/I – Special Sensor Microwave Imager

Wavelength:	passive microwave
Satellites:	DMSP
Dates:	June 1987 - present
Ground Resolution:	25km
Swath Width:	1400km

SAR – Synthetic Aperture Radar

Wavelength:	C-band (5.3 GHz)
Satellites:	ERS-1, ERS-2, RADARSAT
Dates:	July 1991 – June 1996 (ERS-1), April (1995) – present (ERS-2), November 1995 – present (RADARSAT)
Ground Resolution:	30m (ERS-1, ERS-2), 9 to 100m (RADARSAT)
Swath Width:	80-100km (ERS-1, ERS-2), 45-500km (RADARSAT)

SMMR – Scanning Multichannel Microwave Radiometer

Wavelength:	passive microwave
Satellites:	NIMBUS-7
Dates:	October 1978 – July 1988
Ground Resolution:	approx. 20 - 80km
Swath Width:	783km

AIRBORNE SENORS

Visual

Wavelength:	Visible
Platforms:	DC-4, Lockheed Electra, Dash-7, Challenger, CCG helicopter, and others
Dates:	1968 - present
Ground Resolution:	typically 10 -100m
Swath Width:	typically 10 -30km

SLAR – Side-Looking Airborne Radar

Wavelength:	X-band
Platforms:	Lockheed Electra, Dash-7
Dates:	1978 - present
Ground Resolution:	50 – 300m
Swath Width:	100km

SAR – Synthetic Aperture Radar

Wavelength: X-band
Platforms: Challenger
Dates: 1990 - 1995
Ground Resolution: 30m, transmitted as average 100m pixels
Swath Width: 50km

SURFACE OBSERVATIONS

Wavelength: visible
Platforms: radio & DEW line stations, lighthouses, CCG, fishing & merchant marine vessels
Dates: 1968 - present
Ground Resolution: variable
Swath Width: variable