Ice Information Services:
Socio-Economic Benefits and Earth Observation Requirements

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The Group on Earth Observation (GEO)
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Ice Information Services

INTRODUCTION

Ice – sea ice, icebergs, and ice covered lakes and rivers – affects large regions of economic, environmental, and social importance. In recent years, the uniqueness of the Earth's ice-affected regions and their importance to the world is being increasingly recognized. They are considered vital and valuable for a variety of reasons:

Ice affects large regions of economic, environmental, and social importance.

- Marine Transport – Marine trade is a vital part of world economies, and it is increasing. Sea ice is a serious obstacle in the North, and icebergs affect marine transport even in temperate waters (the Titanic disaster occurred at about the same latitude as Boston). A single iceberg report can cause tens of thousands of square miles of ocean to be declared unsafe for shipping transit.
- Weather and Climate Change – As a key component of the world's weather and climate system, knowledge of current and changing ice conditions is critical to the prediction of weather and climate events.
- Natural Resources – Ice-affected regions are rich in resources such as oil and gas, minerals, timber, and fish, but their production is often impeded by ice.
- Environment – Ice-affected ecosystems are adapted to, and depend upon, ice. They are increasingly under threat from climate change, resource exploitation, marine traffic, and human habitation.
- Habitation – The North is home to an increasing population that must cope with a hostile icescape and adapt to changing environmental conditions.

OPERATIONAL ICE INFORMATION:

- Enables year-round operations of critical shipping ports such as:
  - Montreal/Quebec City
  - Helsinki
  - Boston/New York
  - St. Petersburg
- Supports icebreaking operations for 3,500 ships through Baltic waters; delivering 32 million tons of cargo to and from Finnish ports alone;
- Helps ensure the safe & efficient transit of 1,500 ships across the Gulf of St. Lawrence, Canada;
- Provides logistics and safety support to offshore structures, in the Bohai Bay, Barents, Kara, and Caspian Seas, Sakhalin Island, and Grand Banks;
- Provides strategic and tactical ice information for sovereignty and national defence interests;
- Assists trans-Atlantic shipping by helping to prevent a recurrence of the 1912 TITANIC disaster where over 1,500 lives were lost.

Many stakeholders – mariners, scientists, the resource industry, and northern residents – need ice information. They are assisted in understanding and coping with ice by the world's national ice services. These organizations are represented by the International Ice Charting Working Group (IICWG), which is composed of the ice services and research institutes from 11 countries and the International Ice Patrol. They

Many stakeholders depend on the national ice services to understand and cope with ice.

share an interest in the analysis and forecasting of ice conditions for safety at sea, economic development, and environmental protection.

The operational ice services provided by the IICWG member organizations are based, to a great extent, on information from Earth Observation (EO) satellites. Earth Observation is a powerful tool for ice monitoring. Because of the extent, harshness, and isolation of ice-affected regions, Earth Observation is often the only cost effective and technically feasible means of obtaining information. Also, modern sensors can provide types of information that are not available from any other source.

The national ice services depend on Earth Observation.

Because of its dependence on Earth Observation information, the IICWG supports the objectives of the Group on Earth Observation (GEO) and Global Monitoring for Environment and Security (GMES) to define and ensure the availability of future Earth Observation missions.

The IICWG supports the objectives of GEO and GMES to ensure the availability of Earth Observation information.

GEO is an intergovernmental working group, created during the 2003 Earth Observation Summit in Washington DC. The Summit participants affirmed the need for timely, quality, long-term, global information as a basis for sound decision making. GEO has been given responsibility for producing a ten-year program to co-ordinate space and ground based global monitoring systems, to be known as the Global Earth Observation System of Systems (GEOSS). The aim of GEOSS is to maximize the effectiveness of Earth Observation by minimizing data gaps, building capacity and exchanging information as fully and quickly as possible.

GMES is a joint initiative of the European Commission and the European Space Agency, designed to establish a European capacity for the provision and use of operational information for Global Monitoring of Environment and Security. There are currently two projects under GMES that are concerned with ice and iceberg monitoring, The Northern View and ICEMON. The IICWG is participating in both of these projects.

SHIP NAVIGATION

The use of ice information by ships provides major benefits to ship operators:

- Increased safety for ships and personnel by either avoiding ice altogether or by choosing a route through the ice that is within the capabilities of the vessel.
- Reduced transit times by permitting the most direct route, concomitant with safety. Savings of up to $3,000 per ship per day have been estimated.
- Better ship designs that increase safety, increase environmental operating conditions, and decrease operating costs.
- Reduced danger to the environment from ship accidents, especially from oil tankers.

The IICWG seeks to ensure that plans for future Earth Observation missions provide for the continuity of data on which the ice services, and their clients, depend. The IICWG would like to contribute to the work of

GEO and GMES by assisting the definition of user requirements and the identification of socio-economic benefits of Earth Observation for ice information.

ICE INFORMATION USERS

Ice information is required by a wide spectrum of users operating in ice-affected regions over a wide range of latitudes:

The SAR sensors on the European Space Agency's ENVISAT satellite and the Canadian Space Agency's RADARSAT satellite are excellent tools for observing ice.

- Marine transportation operators and regulators – to support the viability, safety, and efficiency of wintertime shipping at mid-latitudes, and to ship resources in and out of the North;
- Meteorological organizations – for improved prediction of severe weather events and climate change scenarios;
- Search and rescue organizations – dedicated to the mitigation of loss of life or property due to accidents, pollution events, or other hazardous conditions;
- Resource developers – for oil and gas, timber, minerals, and fish;
- Policy-makers in Circumpolar nations – to better understand and monitor the polar region in order to protect the environment from the direct impact of development activities, and the indirect impact of climate change;
- Marine Engineers – for the design of safe structures and vessels to withstand ice conditions; and
- Residents in ice-affected regions – to maintain a high quality of life and safety in the conduct of their day-to-day activities.

Ice is an important indicator of climate change, and observations show that Arctic ice is decreasing in both thickness and extent. Over the next 20 years, the volume of Arctic sea ice is predicted to decrease a further 40%, and the lateral extent of sea ice to be reduced by at least 20% in summer. Climate models indicate the summertime disappearance of the Arctic ice by 2050 is possible.

The need for ice information is increasing because of climate change and increasing economic activity.

These changes have important implications for activity in ice-affected regions. Melting of the Greenland glaciers may result in an increased number of icebergs in the trans-Atlantic shipping lanes. Farther north, the opportunities for marine transport will increase substantially. Within five years, the Northern Sea Route will be open to non-ice-strengthened vessels for at least two months each summer. Within 5-10 years, the

Northwest Passage may be navigable by non-ice-strengthened vessels for at least one month each year, and the Sea of Okhotsk and the Sea of Japan may remain ice free.

It is clear that economic development in ice-affected regions is proceeding at an accelerating rate. Significant resources – oil and gas, metals and minerals, and even diamonds – are being discovered and extracted. Northern communities are obtaining political and economic independence, and working to ensure that they grow and prosper, while maintaining traditional values and lifestyles. Nations are also taking a greater interest in asserting their right to manage and develop their northern territories.

All of this development requires information to support the design and construction of specialized structures, such as ships and offshore oil platforms, which will provide the necessary levels of performance and safety in the harsh ice environment.

In summary, the increase in marine traffic through ice-affected regions, the recognition of the environmental significance of ice, the continuing development of resources in ice-affected regions, and the growing population of the North, mean that the importance of ice information will continue to rise.

The following graphic shows the regions, the ice extent, key shipping routes, and the countries with active ice services. The accompanying table on the following page describes ice affected regions in both polar and mid-latitudes.

Countries with National Ice Services, Ice-affected Areas, and Major Marine Transport Routes

Ice-affected regions can be identified by broad geo-economic areas that are defined by their natural characteristics and type of human activity. The use of ice information varies by region and application.

Area	Ice Conditions	Human Activity	Issues
Baltic Sea	Sea ice exists from October to June, covering, on average, half of the Baltic Sea.	Heavy marine traffic assisted by ship routing and icebreakers.	Ship damage. Marine pollution from vessels.
St. Lawrence / Great Lakes	Sea and lake ice from December to May.	Heavy marine traffic assisted by ship routing and icebreakers. Shipping season interrupted by ice	Ship damage. Marine pollution from vessels.
North West Atlantic / Labrador	Icebergs are common from February to August.	Heavy marine traffic. Most ships avoid areas of known ice. Offshore oil operations. Fishing.	Safety of marine traffic from sea ice and icebergs. Environmental risk from offshore oil operations.
North West Passage	Frozen over for most of the year. Minimum ice extent in September.	Local marine traffic during the summer. Hunting and tourism activity at the ice edge.	Potential for this route to open due to climate change with a resulting increase in marine pollution from vessels. Safety of people at the ice edge.
Northern Sea Route	The winter season extends from November to May. The western half is navigable year-round, the eastern half for 3-4 months in the summer.	Shortest route between Europe and the Far East. Passage currently requires icebreaker support. The area includes many navigated rivers and inland waterways connected to the ocean.	Potential for this route to open further due to climate change with a resulting increase in marine pollution from vessels.
Barents Sea / Svalbard	Ice often blocks the west coast and occasionally the north eastern coast. Icebergs can be present. The ports of Murmansk and Vard remain ice-free year round.	Marine traffic. Fishing.	Entry or exit from the Northern Sea Route.
Greenland / Iceland	Access to the east coast of Greenland is only possible from August to October with icebreaker support. Icelandic waters are generally ice-free, except for the north coast. Icebergs are common.	Fishing.	Entry or exit from the Northwest Passage.
Antarctica	Icebergs are of greater number and size compared to the Arctic. Freeze-up begins in March, with the maximum extent in September.	Limited marine traffic. Scientific research.	Decrease in ice extent and volume due to climate change. Oil and mineral exploration and fishing grounds investigation could increase.
Arctic Basin	Currently ice covered year-round.	Very limited scientific research.	Decrease in ice extent and volume due to climate change.
Northern Pacific	Local seasonal ice cover in Gulf of Alaska, Bering Sea, Sea of Okhotsk, Bohai Bay, and Sea of Japan.	Fishing. Offshore oil operations. Marine traffic.	Diverse and remote offshore and shipping activities in seasonal ice. Safety of people at the ice edge.

ICE INFORMATION SOCIO-ECONOMIC BENEFITS

Ice information provides benefits to industry, governments, citizens, and society in a number of ways – either directly, or as an important contributor to improved weather and climate prediction.

Ice information provides benefits to industry, governments, citizens, and society.

- Reduction of risk to life and property – Ice information allows better decisions to be made that reduce the likelihood of accidents and disasters.
- Increase in economic activity – Ice information allows economic activity to proceed where it might otherwise be too costly or dangerous.
- Reduction of operating costs – Ice information increases efficiency or decreases the cost of economic activity.
- Protection of the Environment – Ice information allows us to understand and mitigate the environmental impact of human activities.
- Contribution to scientific knowledge and policy development – Ice information increases our knowledge of the physical and ecological sciences in ice-affected regions and supports sound, science-based policy development.
- Improvement in quality of life – Ice information allows residents and visitors to ice affected regions to pursue activities on and around the ice more safely and effectively.

The national ice services have been established primarily to support marine transport operations, and the benefits of that application alone have been sufficient for governments to justify their continued operation. The ice information products to support the broader benefit areas are often the same as those used for operations, or may be derived from the same observations and analysis infrastructure at low incremental cost. The benefit areas are inter-related and frequently cascade from one area to the next.

Ice information provides safety, economic, environmental, knowledge, and quality of life benefits.

The following tables summarize the major benefits provided by ice information and relate them to the preliminary benefit areas defined by the GEO User Requirements and Outreach Subgroup.

The major benefits provided by ice information

	Marine Transport	Resource Exploitation	Environmental Monitoring	Regional Development
Risk to life and property	Increased safety for ships and offshore platforms. Support for Search and Rescue operations.	Increased safety for fishing vessels and offshore oil platforms.		Improved flood warnings and mitigation. Improved ice edge and coverage information.
Economic activity	Year-round operation of ports.	Development in areas that would not otherwise be possible.	Mitigation of pollution risk due to icebergs and heavy ice.	Increased economic activity for northern communities.
Operating costs	Decreased transit costs and time. More effective tasking of icebreakers.	Decreased operating costs for fishing vessels and offshore oil platforms.	Improved weather forecasts for marine and land weather-sensitive industries.	Decreased costs of living for northern communities.
Environment	Decreased marine pollution from marine accidents.	Decreased marine pollution from offshore oil platform accidents.	Improved understanding of polar ecosystems and environment. Improved understanding of climate change.	Decreased impacts of human activity.
Knowledge	Better ship design.	Better offshore oil platform design. Better resource exploitation policies.	Increased knowledge of the polar environment. Better environmental policies.	Better regional development policies.
Quality of life		Sustainable resources for increased economic benefits.	Protects the environment.	Permits people to live where and how they choose.

The benefits of ice information include many of the preliminary benefit areas defined by the GEO User Requirements and Outreach Subgroup

	Marine Transport	Resource Exploitation	Environmental Monitoring	Regional Development
Reducing loss of life and property from natural and human-induced disasters	❄	❄	❄	❄
Understanding environmental factors affecting human health and well being			❄	❄
Improving management of energy resources		❄		❄
Understanding, assessing, predicting, mitigating and adapting to climate variability and change			❄	❄
Improving water resource management through better understanding of the water cycle			❄	❄
Improving weather information, forecasting and warning	❄	❄	❄	❄
Improving the management and protection of terrestrial, coastal and marine ecosystems	❄	❄	❄	❄
Understanding, monitoring and conserving biodiversity			❄	

ICE INFORMATION REQUIREMENTS

A wide variety of user requirement inventories for ice information have been developed to support different benefit areas. The key features of ice user requirements are:

- The ice parameters to be measured,
- The spatial scale of the observations, and
- The frequency of the observation.

In addition, the time between an observation and the delivery of a useful information product to the user is an important characteristic, particularly for operational users. Because ice conditions can be highly dynamic (ice drift can be up to 50km/day), users engaged in operations in or around ice require information with fast turnaround (1-6 hours) and on a regular and reliable basis (every 6-24 hours, every day). Typically, users of this information are transport ships, ferries, icebreakers, national coast guards, fishing vessels, offshore oil and gas companies, and meteorological forecast operations. The Near-Real-Time (NRT) requirement of these users has significant implications for the revisit capabilities of observation systems, and the speed and robustness of the reception, processing, and delivery infrastructure.

ICE EDGE

The diversity of wildlife at the ice-edge is an important resource for northern communities and has a major cultural and economic significance. Knowledge of the location and structure of the ice-edge is needed for navigation and safety in the area. The traditional knowledge that formerly allowed local inhabitants to navigate safely and effectively in the icescape seems to be becoming less reliable, possibly due to climate change. Arctic communities are now using satellite images to complement traditional knowledge.

Another significant group consists of users that require access to an archive of imagery, observations, and derived ice products. There is a wide range of applications for time series of consistent, objective sea ice measurements - from calculating ice statistics for defining the best location and design of a wharf, to large-scale global change climate studies.

Both user groups have identified access to data, including data sharing among multiple users, as a key factor in maximizing the quality of ice information that may be derived from Earth Observation.

The table on the following page summarizes the observational requirements for three key user areas:

- Near-Real-Time Marine Operations,
- Regional Numerical Weather Forecasting, and
- Climate Monitoring and Science.

Observational Requirements for Key Ice Features
(Optimum Future Value/ Current Threshold Value)

Parameters	Marine Operations	Weather Forecasting Regional NWP	Climate Monitoring and Science
Ice Extent: Ice Edge Accuracy (absolute)	- ± 50m-100m / 750m	5km / 50km -	15km / 50km -
Ice Concentration Accuracy Ice Concentration Range	±1/10 / ±2/10 1/10 - 10/10	5% / 50% 5% - 100%	5% / 50% 5% - 100%
Ice Stage of Development (probability of typing correctly) Ice Stage of Development or Thickness	70% Distinguish new, young, first-year and multi-year ice i.e. 10cm / 30-50cm	- 50cm / 100cm	- 50cm / 100cm
Fast Ice Boundary Forms of Floating ice (floe type)	Same as for ice edge 10m / 50-100 m	Same as for ice edge -	Same as for ice edge -
Leads/Polynas	25m / 250m width	-	1% / 10% of ice area
State of Decay - % meltponds	10% / 50%	10% / -	5% / 25%
Sea Ice Topography - Ridge Height	1m / 2m	2m / -	-
Ice Motion Accuracy Ice Motion Range	± 1km/day 0-50 km/day	-	± 1km/day 0-50 km/day
Icebergs – max. waterline dimension	25m / -	-	-
River Ice Extent: River Ice Edge Accuracy (absolute)	3-10 meters .3 km	- -	- -
River Ice Concentration Accuracy River Ice Concentration Range	< 5% / 20% 5% - 100%	- -	- -
Timeliness	< 1 hr / 3-6 hr	< 1 hr / 3-6 hours	-
Sampling Frequency	24 hr / 48 hr	1 day / 7 days	3 days / 7-30 days
Geographic Coverage	North of 30° north and south of 45° south	North of 30° north and south of 45° south	North of 30° north and south of 45° south

Adapted from:

- CEOS Ice Hazards Report, 2001
- WMO Satellite Observational Requirements
- WCRP Satellite Observational Requirements
- GMES - Northern View
  - Data Needs and Availability Prospectus
  - Global User Needs Directory
  - Core User Needs Dossier
- GMES - ICEMON
  - Data Needs and Availability Prospectus
  - Global User Needs Directory
  - Core User Needs Dossier

ICE INFORMATION PRODUCTION

Ice information is provided by the national meteorological and oceanographic services of nations conducting activities in ice-affected waters.

The increasing activity in ice-affected waters has led to a growing requirement for ice information services. The regular provision of ice information is an integral part of the operational programmes of national meteorological and oceanographic services of nations that conduct activities in ice-affected seas. The national ice services have a long history of international cooperation, and numerous regional and international organizations exist to share information and resources.

COUNTRIES WITH NATIONAL ICE SERVICES

- Argentina
- Australia
- Canada
- China
- Denmark
- Estonia
- Finland
- Germany
- Greenland
- Iceland
- Japan
- Latvia
- Lithuania
- Netherlands
- Norway
- Poland
- Russia
- Sweden
- United States

INTERNATIONAL ICE ORGANIZATIONS

- International Ice Charting Working Group
- International Ice Patrol
- Expert Team on Sea Ice of the World Meteorological Organization and the Intergovernmental Oceanographic Commission
- Baltic Sea Ice Meeting
- North American Ice Service

The majority of ice services concentrate on sea ice and weather information to support marine transport. In addition, icebergs are monitored by the International Ice Patrol, and additionally by Argentina, Canada, Denmark, and the United States. Lake ice is of interest to Canada and the United States, and river ice is actively monitored in Canada, the United States, the Netherlands, and Russia.

Examples of near-real-time ice information products include ice charts, bulletins, images, weather maps, and direct consultation services on current or near-term ice conditions. The analysis of archived ice observations is used to create non-real-time products such as climatological atlases of ice conditions, statistics on the presence of ice and the occurrence of extreme ice events, and the long-term record of changing ice conditions.

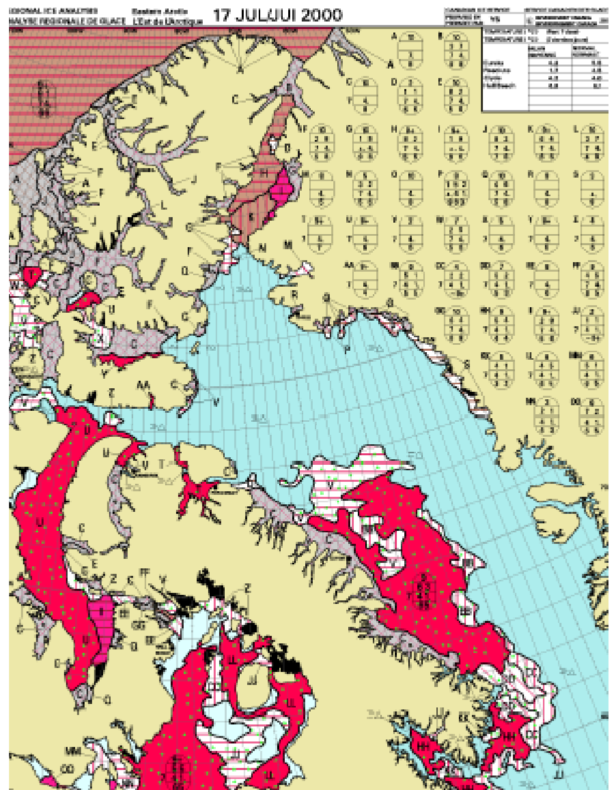
Ice information is produced using computer models and expert analysis to combine data from satellites, ships, aircraft, and in-situ sensors.

Ice products are created by combining data from satellites, aerial and shipboard observations, and in-situ sensors, using computer models and expert analysis. The different data sources each have their advantages and disadvantages. Information from vessels and weather stations is specific, but sparse. Visual and airborne radar surveys are detailed, but expensive, provide only limited coverage, and are frequently restricted by adverse weather conditions. Satellites, while not as detailed or specific as other sources, provide the best means of observing large areas in remote and hostile conditions.

Satellites provide the best means of observing large areas in adverse conditions.

Satellites cannot completely replace other information sources, but they provide observations over a wider geographical area, at much lower cost and in much less time than aircraft alone. As a result, ice information is more accurate and costs less to produce using satellites. For example, it is estimated that the Canadian Ice Service is saving CDN$7.7 million per year by using satellites to reduce the use of aircraft for strategic ice reconnaissance.

A variety of Earth Observation sensors are used to map ice conditions. Visible-Infrared sensors at moderate-resolution (e.g. NOAA-AVHRR, METEOR) have been used extensively because of their easy accessibility, low cost, and frequent coverage. However, clouds, fog, relatively poor resolution (e.g. 1km), and polar darkenss limit the use of this type of sensor to fully meet operational ice mapping requirements, particularly in cloud- and fog-prone marginal ice zones.



An Example Sea Ice Chart

Microwave sensors offer the advantage of all-weather observation independent of solar illumination and are used extensively for both near-real-time and archive applications. Passive microwave radiometers (e.g, ESMR, SSM/I, AMSR/E) have poor resolution (e.g. 12km-25km), but provide a global, long-term record of observations well suited to climate change monitoring. Passive microwave data, and more recently active microwave scatterometers, are used in near-real-time for daily ice edge, ice concentration, and large-scale ice motion products.

Wide-swath, C-band Synthetic Aperture Radar (SAR – e.g. RADARSAT, ENVISAT ASAR) are now considered the preferred sensor for detailed regional ice mapping because of the their high resolution and high information content on ice concentration, ice type, and ice topography. The ground segment to support near-real-time operations has been implemented in several regions, but data accessibility and cost are still perceived as barriers to broader operational use. The current 400km-500km wide-swath capability provides good revisit frequency at high latitudes, but does not allow for daily coverage in the active mid-latitude shipping areas.

The table on the next page links the major ice information categories to the types of available Earth Observation sensors and their capabilities.

Earth Observation Sensor Capabilities for Various Ice Types

Information Requirement	Sensor Type	Capability
Sea Ice	Synthetic Aperture Radar (SAR)	The high spatial resolution of SAR sensors, wide swath modes, and the ability to detect most of the features of interest to the ice community (especially C-band SAR) make them the most suitable and preferred sensor for regional sea ice mapping and monitoring. A wide swath imaging mode provides daily coverage at high latitudes is suitable to support operations and science requirements. Revisit frequency at mid-latitudes provides coverage only once 2-3 days, and does not fully support operational requirements
	Visible-infrared	Geostationary satellites have high temporal resolution (15min.-30min.), at low-resolution (5km-25km), and with high geometric distortion at high latitudes Polar orbiting satellites' visible, infrared, and thermal channels are used for mapping sea ice, and the thermal channel measures sea surface temperature. Multiple satellites, frequent revisit, near real-time access, and low cost for reception make them a basic part of ice monitoring operations. However, their relatively coarse spatial resolution and inability to see ice through frequent cloud cover are significant constraints.
	Passive Microwave	Simultaneous imaging at multiple frequencies and polarizations enable automated discrimination between ice types and very wide swaths provide twice-a-day coverage at high latitudes. However, their coarse spatial resolution (12km-25km) limits their use to support tactical operations, and their use near coastlines and regions surrounded by land. The latter includes the regions with the highest shipping activity, such as the Baltic Sea. Integrated ice edge and sea-surface wind products are a useful strategic-scale product.
	Scatterometers	Scatterometers can be used to map sea ice extent and ice motion at a scale similar to the passive microwave data. However, the coarse spatial resolution places utility constraints similar to passive microwave sensors. Integrated ice edge and sea surface wind products are a useful strategic-scale product.
	Altimeters	The major sea-ice parameters measured with laser altimeter are surface elevation, surface roughness, and reflectivity. Recent work with satellite radar-altimeter data indicates the possibility of estimating sea-ice freeboard, a proxy indicator for sea ice thickness. Operationalization of advanced sensor technology and near-real-time access to data may add another tool for ice services in the future.
Icebergs	Synthetic Aperture Radar (SAR)	SAR is the most suitable satellite sensor for smaller icebergs because of the higher spatial resolution. The success of detection decreases with increased sea state because of increased background sea clutter. The ability to distinguish an iceberg from a ship is a critical requirement for any microwave sensor.
	Visible-infrared	Very large icebergs (in the order of 10 km in length), such as those calved off Antarctica, are detectable using polar orbiting visible infrared sensors.
	Altimeters	The laser altimeter on ICESat may also have some application for iceberg detection.
Lake and River Ice	Synthetic Aperture Radar (SAR)	SAR is the optimal sensor class because it has a higher spatial resolution and is able to image through cloud and in darkness. The latter characteristic is important for episodic events such as river and lake ice break-up.
	Visible-infrared	Mapping ice on lakes and rivers requires a finer spatial resolution than for most sea ice mapping applications because of the small size of some lakes and narrow river channels. On larger lakes and rivers, like the Great Lakes and St. Lawrence River, polar orbiting visible infrared sensors provide useful information on the ice cover.
Sea Surface Information	Synthetic Aperture Radar (SAR)	SAR is capable of providing wave direction and wave spectra to augment surface measurements.
	Visible-infrared	Sensors with thermal channels (AVHRR for example) can provide sea surface temperature. Wind speed can be inferred from cloud motion by geostationary satellites.
	Passive Microwave	Passive microwave is capable of measuring surface wind speed and sea surface temperature.
	Scatterometers	Scatterometers are widely used for deriving wind speed and direction over open oceans
	Altimeters	Altimeters can provide wave height.

Sensor Type	Polar Visible / Infrared								Geostationary Visible / Infrared					
SATELLITE														
Name	NOAA	DMSP	ENVISAT	ENVISAT	MetOp	Meteor	TERRA/AQUA	NPP	GOES E/W	Meteosat 7	Meteosat 8+	INSAT	MTSAT1R	FY 2
Status		F12-16	Mar 02	Mar 02	2005		Dec 99 May 02	2006	2001 1997	1997	2004	1999/ 2003	2004	2000
SENSOR														
Name	AVHRR	OLS	AATSR	MERIS	AVHRR		MODIS	VIIRS	I-M	VISSR	SEVIRI	VHRR	VISSR+	VISSR
Spatial Resolution (m)	1100 & 4000	550 & 2700	1000	300 or 1200 No IR	1100 & 1100	1400 & 3000	250-1000	375-750	1000 to 4000	2250 and 5000	1400 and 4800	2000 & 8000	1250 & 5000	1250 & 5000
Revisit Time (days)	~0.25	~0.25	6	3	~0.25	1	1-2	4 hr (2 sat)	30 min	30 min	15 min	30 min	15 min	30 min
Swath Width (km)	2600-3000	2600-3000	512	1150	3000	3000	2330	3000	3000	3000	3000	3000	3000	3000
Country of Origin	USA	USA	EU	EU	EU	Russia	USA	USA	USA	EU	EU	India	Japan	China
FEATURE														
Total Ice Conc'n	◎	◎	◎	◎	◎	◎	●	●	•	•	•	•	•	•
Location Ice Edge	◎	◎	◎	◎	◎	◎	●	●	◎	◎	◎	◎	◎	◎
Ice Type	◎	◎	◎	◎	◎	◎	●	●	•	•	•	•	•	•
Ice Thickness	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Floe Size	•	•	•	•	•	•	◎	◎						
Ice Topography														
Landfast Ice	•	•	•	◎	•	•	◎	◎						
Leads/Polynyas	•	•	•	◎	•	•	◎	◎						
Pressure / Kinematics	◎	◎	◎	◎	◎	◎	◎	◎	•	•	•	•	•	•
Icebergs														
Deterioration / Decay														
Snow cover / Depth														
River Ice Conc'n														
River Ice Thickness														
Lake Ice Conc'n	•	•	•	•	•	•	•	•						
Lake Ice Thickness	•	•	•	•	•	•	•	•						
Surface Temp	●	●	●		●	●	●	●	◎	◎	◎	◎	◎	◎
Wave Height Spectra														
Currents														
Surface Winds									•	•	•	•	•	•

Sensor Type	Passive Microwave			RAR	SAR				
SATELLITE					C-band			L-band	X-band
Name	DMSP	DMSP	EOS AQUA	Okean	Radarsat-1	Radarsat-2	ENVISAT	ALOS	TERRASAR-X
Status	F13-15	F16 Nov 03	May 02		June 95	2006	Mar 02	2004	2006
SENSOR									
Name	SSM/I	SSM/IS	AMSR-E	SLAR	SAR	SAR	ASAR	PALSAR	SAR
Spatial Resolution (m)	30-70 km	30-70 km	6x4 km 75x43 km	1500-2000	10 to 100	3 to 100	30 to 150	100	1-16
Revisit Time (days)	~0.25	~0.25			~3 to ~5	~3 to ~5	3	3	11
Swath Width (km)	1400	1707	1445	450	20-500	20-500	100-400	350	100
Country of Origin	USA	USA	USA / Japan	Russia	Canada	Canada	EU	Japan	EU
FEATURE									
Total Ice Conc'n	◎	◎	●	◎	●	●	●	◎	◎
Location Ice Edge	◎	◎	◎	◎	●	●	●	◎	◎
Ice Type	◎	◎	◎	◎	●	●	●	◎	◎
Ice Thickness	•	•	•	•	•	•	•	•	•
Floe Size				•	●	●	●	◎	◎
Ice Topography				•	•	•	•	•	•
Landfast Ice				◎	●	●	●	◎	◎
Leads/Polynyas				◎	●	●	●	◎	◎
Pressure / Kinematics	•	•	•	◎	●	●	●	◎	◎
Icebergs					•	•	•	•	•
Deterioration / Decay	•	•	•	●	●	●	●	◎	◎
Snow cover / Depth	•	•	•						
River Ice Conc'n					●	●	●	◎	◎
River Ice Thickness					•	•	•	•	•
Lake Ice Conc'n					●	●	●	◎	◎
Lake Ice Thickness					•	•	•	•	•
Surface Temp	◎	◎	◎						
Wave Height Spectra					◎	◎	◎	◎	◎
Currents					•	•	•	•	•
Surface Winds	◎	◎	◎		•	•	•	•	•

Sensor Type	Scaterometer		Altimeter		
SATELLITE					
Name	QUIKSCAT	MetOp	CRYOSAT	ENVISAT	ICESAT
Status	June 99	2005	Nov 04	Mar 02	Jan 04
SENSOR					
Name	SEAWINDS	ASCAT	SIRAL	RA-2	GLAS
Spatial Resolution (m)	25000	25000		400-8000	70 m?
Revisit Time (days)	~1	~1	369 30 dy sub	35 3/17 sub	8
Swath Width (km)	1800	2x550			
Country of Origin	USA	EU	EU	EU	USA
FEATURE					
Total Ice Conc'n	◎	◎			
Location Ice Edge	◎	◎	•	•	•
Ice Type	◎	◎			
Ice Thickness			•	•	•
Floe Size					
Ice Topography			•		•
Landfast Ice					
Leads/Polynyas					
Pressure / Kinematics	◎	◎			
Icebergs					
Deterioration / Decay					
Snow cover / Depth					
River Ice Conc'n					
River Ice Thickness					
Lake Ice Conc'n					
Lake Ice Thickness					
Surface Temp					
Wave Height Spectra	●	●	◎	◎	◎
Currents			•	•	•
Surface Winds	●	●			

LEGEND

	Does not meet threshold requirement	◎	Meets requirements most of the time (70%+)
•	Incremental benefit over threshold, but alternatives exist	●	Satisfies requirement (85%+)

ACRONYMS

AATSR	Advanced Along Track Scanning Radiometer
AMSR	Advanced Microwave Scanning Radiometer
ALOS	Advanced Land Observing Satellite
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced Scatterometer
AVHRR	Advanced Very High Resolution Radiometer
DMSP	Defense Meteorological Satellite Program
EOS	Earth Observing System
GLAS	Geoscience Laser Altimeter System
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP	NPOES Preparatory Project Mission
OLS	Operational Linescan System
PALSAR	Phased Array L-band SAR
RA-2	Radar Altimeter 2
RAR	Real Aperture Radar
SAR	Synthetic Aperture Radar
SIRAL	SAR/Inteferometric Radar Altimeter
SSM/I	Special Sensor Microwave Imager
SSM/IS	Special Sensor Microwave Imager-Sounder
VHRR	Very High Resolution Radiometer
VIIRS	Visible/Infrared Imager/Radiometer Suite
VISSR	Visible Infrared Spin-Span Radiometer

This table shows the capability of existing and near-future satellite sensors to provide information relevant to ice service operations. The larger the bubble in the cell, the better it meets the requirement. Satellite sensors used by the ice services are operated by a number of nations around the world. Polar orbiting visible/infrared sensors are an important source of data because of their frequent revisit, moderate spatial resolution, and low cost. Geostationary visible/infrared sensors are important for meteorological analysis. Microwave sensors' capability to image through most clouds and in the dark provides a reliable source of data for ice monitoring. The Synthetic Aperture Radar's high spatial resolution and sensitivity to sea ice features make it the most suitable sensor for sea ice mapping. Scatterometers provide useful information on ocean state and winds, as well as coarse mapping of some sea ice features. Ice thickness and topography can be inferred using altimeters for hemispheric scale analysis.

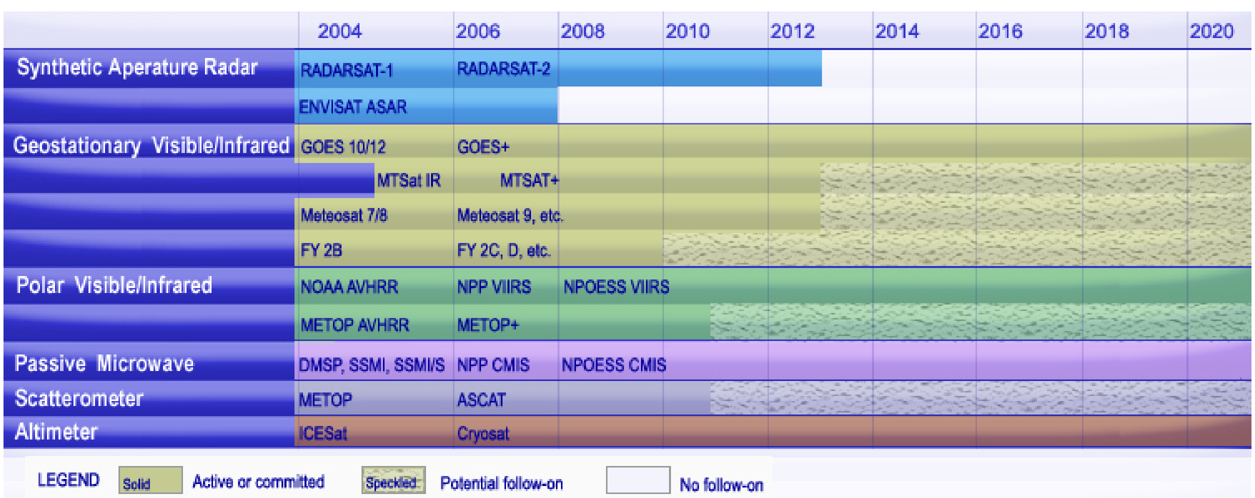
ICE SERVICES AND THE FUTURE OF EARTH OBSERVATION

The ice services are leaders in the operational adoption of EO technology and are critically reliant on EO systems to support their users. The benefits of ice information cannot be realized without the continued availability and reliability of such systems.

The table below summarizes currently planned EO missions of key interest to the ice community. It is believed the plans for meteorological satellites (e.g. NPOESS, METOP) will continue to meet the requirements for visible-infrared and coarse-resolution microwave data for several decades. Follow-on scatterometer missions would be desirable for the broader community of marine users, though not considered operationally critical for ice. The development of future operational missions for ice thickness and topography would be of interest if the current experimental missions demonstrate operational promise.

For SAR, the current and planned systems provide short-term redundancy of wide-swath coverage, but a gap in data continuity exists beyond 2012. Wide-swath C-band SAR is considered a critical data source, so the lack of firm follow-on missions is of great concern. In order to meet revisit and reliability requirements, a scenario of two or more wide-swath (500km-1000km) SARs at 100m-200m resolution, or equivalent, would be desirable to provide daily global ice mapping capability. Improved near-real-time processing and delivery, and improved opportunities for data sharing among ice services, are also of high interest.

The IICWG strongly supports cooperation among nations in defining future EO systems and requests that the requirements of the operational ice services be recognized and considered by GEO and GMES in the 10-year implementation plan for GEOSS. The socio-economic benefits of ice information are numerous and are already being realized. Meeting the requirements of the ice services in future missions will help ensure continuing benefits, and the realization of even more.



There is international commitment to ensure data continuity for geostationary and polar orbiting visible/infrared, passive microwave, and altimeter data. Although SAR is the most suitable sensor for sea ice mapping, its future is less certain.

TYPES OF ICE

Sea ice – Sea ice is formed from the freezing of seawater. Offshore, drift ice is dynamic, being moved by winds and currents. Near the shore, 'fast ice' forms early in the season and remains stationary. In the late winter, sea ice typically covers about 14 to 16 million square kilometers in the Arctic and 17 to 20 million square kilometers in the Antarctic. Sea ice impacts climate in may ways: its high albedo affects the planet's heat budget; its thermal insulation controls heat and mass fluxes between the atmosphere and the polar oceans, and its role in destabilizing the water column through brine rejection drives deep convection. Sea ice restricts the routes and seasons for marine vessels. Multi year ice and ice ridges in particular can create serious impediments to navigation. The ice edge is a region of intense biological activity: nutrient rich water feeds a food chain of plankton, fish, and the many polar animals that depend upon the sea ice for their habitat.

Icebergs – Icebergs are formed from the 'calving' of pieces of glacier into the sea. The majority of the icebergs in the North Atlantic come from about 100 glaciers along the Greenland coast. About 40,000 medium to large sized icebergs calve annually in Greenland, and about 400-800 take up to three years to transit into the shipping lanes. They can travel as far south as Philadelphia. The average iceberg in the Grand Banks is one to two hundred thousand tonnes and is about the size of 15-story building. Icebergs can also be found throughout the Arctic Ocean including the Barents Sea and Greenland Seas. Icebergs in the Antarctic originate from Antarctic ice shelves. They are far more abundant and much larger than Arctic icebergs – 93% of the world's mass of icebergs is found surrounding Antarctica. Icebergs often 'ground' on the seabed where this scouring impacts the ecosystem of the ocean floor and can destroy communications cable, pipelines and other logistical infrastructure. Icebergs are serious threats to navigation – the Titanic disaster resulted in numerous changes to marine practices. Icebergs are also an ongoing concern for offshore oil platforms requiring expensive design, ongoing monitoring, and occasional interception

Lake and river ice – The build-up or break-up of river ice can impact infrastructure and people upstream and downstream if water backs up as a result of an ice jam. A sudden break-up of river ice can threaten the safety of lives and property. The break-up of ice is usually short in duration and detection must be monitored regularly and reported quickly when it does occur. When a lake freezes over and is sufficiently thick to support a load, ice roads are built to connect some northern communities or to access remote locations of importance to local populations. Weather forecast models use the dates when lakes freeze over or when they become ice-free as thermodynamic model inputs. Scientists are also using these dates as an indicator of climate change.

REFERENCES

Barber, D., M. Manore, T. Agnew, H. Welch, E. Soulis, and E. LeDrew (1992), Science Issues Relating to Marine Aspects of the Cryosphere: Implications for Remote Sensing. Cdn J. of R.S., vol 18, No. 1. pp. 46-54.

Bertoia, C. and J. Falkingham, F.Fetterer (1998), Polar SAR Data for Operational Sea Ice Mapping, in R. Kwok and C. Tsatsoulis (Eds.). Recent Advances in the Analysis of SAR Data of the Polar Oceans, Springer Verlag: Berlin, pp. 201-234.

Bertoia,C., Michael Manore, Henrik Steen Andersen, Chris O'Connors, Keld Q. Hansen, Craig Evanego (To be published 2004), "Synthetic Aperture Radar Marine User's Manual", National Oceanic and Atmospheric Administration, Center for Satellite Application and Research, NOAA/NESDIS, C.R. Jackson and J.R. Apel, editors, Washington, D.C., USA.

CEOS (2001), "Ice Hazards", Final Report of the CEOS Disaster Management Support Group.

Duchoissois, G. and G. Sommeria (2003), WRCP Satellite Working Group Report on Update of Space Mission Requirements for WCRP.

European Environment Agency (2004), "Arctic Environment: European Perspectives".

Goss Gilroy Inc. (2001) "Economic Benefits from the Utilisation of RADARSAT-1 for Surveillance of Ice Conditions in Canada".

ICEMON (2004) "C10 - Data Sources Inventory", prepared under the GMES Service Element for the European Space Agency.

ICEMON (2004) "U1 - Global User Needs Directory", prepared under the GMES Service Element for the European Space Agency.

ICEMON (2004) "U5 - Core User Needs Dossier", prepared under the GMES Service Element for the European Space Agency.

ICEMON (2004), "C12 - Data Needs and Availability Prospectus", prepared under the GMES Service Element for the European Space Agency.

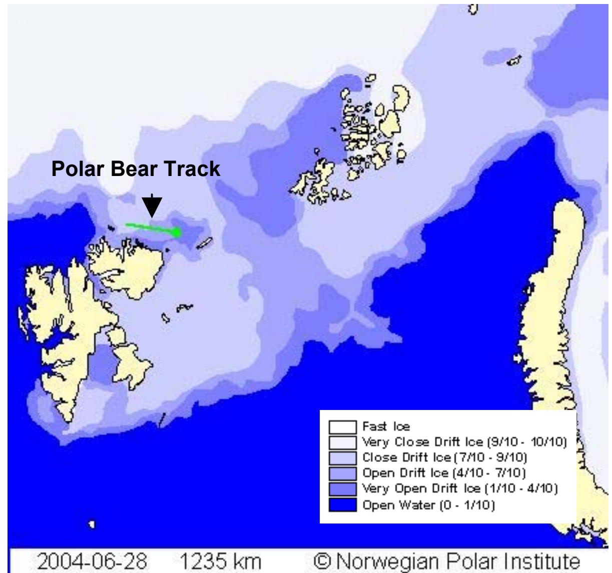
ICEMON (2004), "C2 - Cost Benefit Analysis", prepared under the GMES Service Element for the European Space Agency.

ICEMON (2004), "S2 - Methods Compendium", prepared under the GMES Service Element for the European Space Agency.

ICEMON (2004), "U2 - Key User Segment Profiles", prepared under the GMES Service Element for the European Space Agency.

National Ice Center (2004), "Table on Observational Requirements for Ice Hazards", received via e-mail from Paul Seymour.

Nelson, C and J.D. Cunningham (2003), "The National Polar-Orbiting Operational Environmental Satellite System Future US Environmental Observing". IGARSS Proc.



POLAR BEARS

Scientists worry that receding sea ice areas will adversely affect polar animals, particularly polar bears. Polar bears need sea ice to access their food, and to move from hunting grounds to their denning or summer resting areas. The Norwegian Polar Institute is using sea ice information and the movements of polar bears to help understand the relationship between ice extent and bear health.

Northern View (2004) "C2 - Cost Benefit Analysis", prepared under the GMES Service Element for the European Space Agency.

Northern View (2004), "C10 - Data Sources Inventory", prepared under the GMES Service Element for the European Space Agency.

Northern View (2004), "C12 - Data Needs and Availability Prospectus", prepared under the GMES Service Element for the European Space Agency.

Northern View (2004), "U5 - Core User Needs Dossier", prepared under the GMES Service Element for the European Space Agency.

Northern View Global (2004), "U1 - Global User Needs Directory", prepared under the GMES Service Element for the European Space Agency.

Ramsay, B., T. Hirose, M. Manore, J. Falkingham, R. Gale, D. Barber, M. Shokr, B. Danielowicz, B. Gorman, and C. Livingstone (1993), "Potential of RADARSAT for Sea Ice Applications". Cdn. J. of R.S., Vol. 19, No. 4. pp. 352-362.

Sandven, S., H. Gronvall, A. Seina, H.H. Valeur, M. Nizovsky, H. Steen Andersen, VEJ Haugen (1998), "Operational Sea Ice Monitoring by Satellites in Europe". Final Report. OSIMS Report No. 4. European Commission Environment and Climate Programme 1994-1998.

WCRP Satellite Observational Requirements - http://alto-stratus.wmo.ch/sat/stations/SatSystem.html

WMO Satellite Observational Requirements - http://alto-stratus.wmo.ch/sat/stations/SatSystem.html