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Survey of existing use of space assets by European polar operators, including recommendations for improved coordination

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1. INTRODUCTION

1.1. Document Overview and Scope

This report (D3.3) is a component of EU-PolarNet work package 3 which encompasses Infrastructures, Facilities and Data. The task objective is to consider joint programming of infrastructure to enable bigger and more complex science projects.

Task 3.2 considers space technologies as part of the facilities, infrastructure and operations of European nations in the polar regions. The aim is to determine the best approach to wider and more coordinated use of space-based assets and facilities to support polar infrastructure and operations in delivering polar science.

We note that in the context of this task, support to polar operations is considered distinct from the direct use of space assets and data in polar science. Direct use of science data derived from space infrastructure is considered separately as part of the wider consideration of polar science and related data requirements. What is considered here are the space technologies which form part of the infrastructure and logistical support necessary to enable the scientific community to conduct the research.

Task 3.2 provides two formal deliverables as described in the EU PolarNet project proposal.

Table 1: Deliverables from EU-PolarNet Task 3.2

Task 3.2 Satellites, communication and remote sensing	
D3.3	Survey of existing use of space assets by European polar operators, including recommendations for improved coordination
D3.6	Gap analysis highlighting the technical and operational requirements of the European Polar Research Programme for satellite applications and identifying opportunities for improved linkages to ESA and other space agencies

In summary this report has the following aims:

- Summarise the current use of space assets to support polar operations by European polar programmes, highlighting the unique role of space technology for the polar regions.
- Identify space facilities and services which polar operators are reliant on.
- Address how to improve coordination of stakeholders in the European space program, including Galileo, Copernicus and the European Space Agency.
- Recommend approaches for wider and more coordinated access to space assets to support polar infrastructure and operations.

We also note that this report is not intended to exhaustively list every instance of use of space technologies in the context of polar operations. The intent is to summarise the main areas of use and provide some illustrative examples. This will set the scene for the next step, to identify gaps in current capabilities.

This report does not address the costs of space technologies being used and is not able to comment on their cost effectiveness. This would require a complete end-to-end cost benefit analysis which is not within the scope of this task.

The second deliverable (D3.6) will focus on highlighting the gaps in current space infrastructure and aim to set out a coordinated statement of requirements from the polar community. It will also present anticipated advances and future trends in space technologies that may have new application in the polar regions. This information will feed into the future evolution and implementation of the European space program and provide guidance to other stakeholders and providers of space infrastructure.

1.2. Layout of the Document

The document contains the following sections.
Section 1: Introduction, context and related information.
Section 2: Overview of polar context and its strategic importance.
Section 3: Summary of the various space assets discussed in the document.
Section 4: Description of the use of satellite communications in polar operations.
Section 5: Description of the use of satellite navigation in polar operations.
Section 6: Description of the use of satellite remote sensing in polar operations.
Section 7: Description of the use of other space technologies in polar operations.
Section 8: Summary of the facets of the current European space program and includes recommendations for improved coordination.
Section 9: Main conclusions at this stage of the task.

1.3. Reference Documents

Table 2: List of publications referenced Deliverable D3.3

EU Joint Communication "An integrated European Union policy for the Arctic"	http://eeas.europa.eu/archives/docs/arctic_region/docs/160427_joint-communication-an-integrated-european-union-policy-for-the-arctic_en.pdf
ESA Polaris Study	http://www.arcticobserving.org/images/pdf/Board_meetings/2016_Fairbanks/14_Final-Summary-Report_2016-04-22.pdf
Arctic Council Task Force - Telecommunications infrastructure in the Arctic: a circumpolar assessment	https://oaarchive.arctic-council.org/bitstream/handle/11374/1924/2017-04-28-ACS_Telecoms_REPORT_WEB-2.pdf?sequence=1
COMNAP Antarctic Roadmap Challenges report	https://www.comnap.aq/Projects/SiteAssets/SitePages/ARC/Antarctic_Roadmap_Challenges_Book_2016.pdf

1.4. Acronyms

Table 3: List of acronyms used in this document.

ADS-B	Automatic Dependent Surveillance – Broadcast
AIS	Automatic Identification System
ASPA	Antarctic Specially Protected Area
COMNAP	Council of Managers of National Antarctic Programs
COSPAS-SARSAT	Cosmicheskaya Sistyema Poiska Avariynich Sudov - Search and Rescue Satellite-Aided Tracking
EC	European Commission

EGNOS	European Geostationary Navigation Overlay Service
EGSA	European Global Navigation Satellite Systems Agency
EO	Earth Observation
EPIRB	Emergency Position-Indicating Radio Beacon
ESA	European Space Agency
EU	European Union
GCOS	Global Climate Observing System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IMO	International Maritime Organisation
JCB	Joint Board on Communication Satellite Programme
NWP	Numerical weather prediction
PB-EO	Programme Board for Earth Observation
PB-NAV	Programme Board on Satellite Navigation
POLARIS	Polar Operational Limit Assessment Risk Indexing System
RCC	Rescue Coordination Center
S-AIS	Satellite Automatic Identification System
SBAS	Space Based Augmentation Systems
SAR	Search and Rescue
SART	Search and Rescue Transponder

2. POLAR CONTEXT AND STRATEGIC IMPORTANCE

The focus of this report is the use of space technologies in support of European polar programs and operations. As noted in the COMNAP Antarctic Roadmap, the emergence of space-based technologies over the last six decades is a key technology enhancement which supports operations to enable science. The COMNAP ARC report went as far as to identify "new and improved satellite sensors, including appropriate coverage and availability" as one of the major cross cutting technology requirements for the Antarctic (see also Figure 1).
However, space technologies are expensive long term investments, funded by both the public and private sector to satisfy wide ranging public good, societal, policy and commercial needs. Space infrastructure is not exclusively dedicated to polar operations and it is worth understanding the context for justifying these investments. This is especially important when considering gaps in current capabilities and how they might be filled.
The polar regions are important for many reasons.

- They affect the entire planet due to their role in regulating and driving the global climate.
- They are experiencing significant change.
- There is growing global interest both politically and economically.
- New economic opportunities are driving increased attention and traffic.
- There is widespread public concern about the delicate and pristine environment.

For these reasons, it is vital to develop tools to model, understand and monitor the polar regions to better predict and mitigate the resulting global economic and environmental consequences. These models and monitoring strategies increasingly rely on data derived from and delivered by space infrastructure.

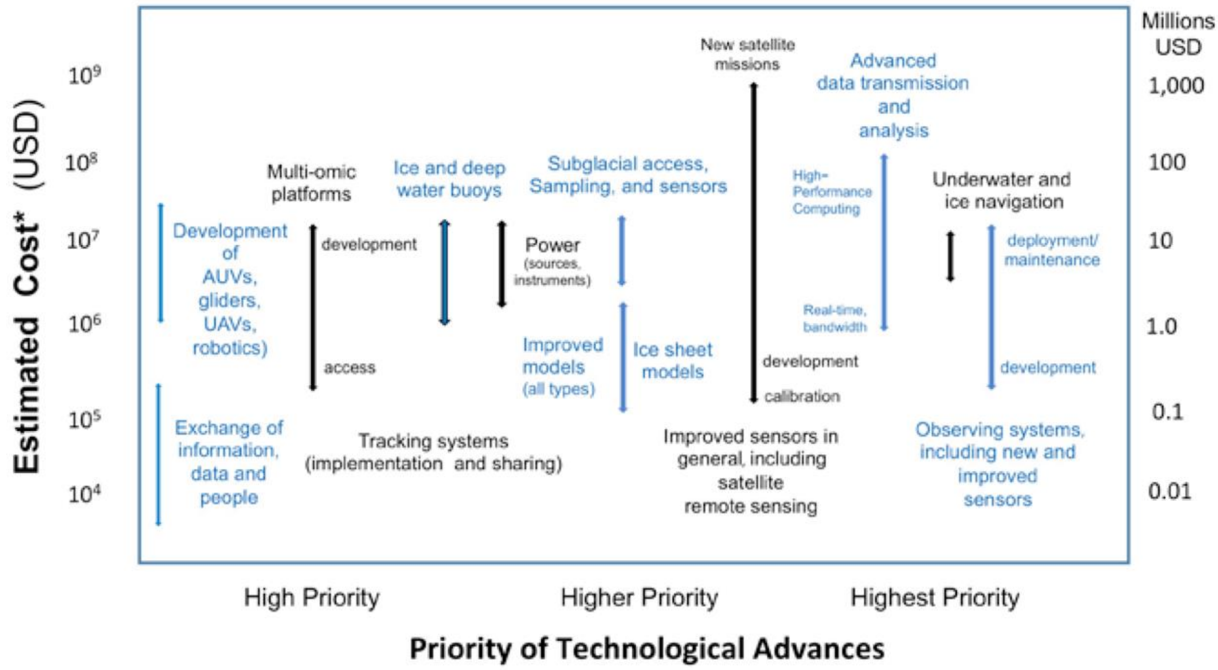

Figure 1: Summary of the qualitative estimates of the cost to develop high-priority technologies, including new satellite missions (taken from COMNAP Antarctic Roadmap Challenges report).

When considering the providers of these space infrastructure, it is acknowledged that supporting polar operations is one part of a very wide set of requirements. Understanding the basis for reliance on these infrastructures requires awareness of this wider setting. As highlighted by the COMNAP ARC report, development of satellite technologies and sensors is expected to occur outside of the Antarctic community.
This is not the place for a detailed analysis of the justification and drivers for all space assets mentioned in this report, but a short list of relevant factors is provided below (Table 4) for information.

Table 4: Drives for investment in space infrastructure.

Policy support	Information and data is required to develop local and national government policies. Monitoring is also required to scrutinize policy implementation and effectiveness.
Commercial activity	Space infrastructure underpins commercial services which can justify private sector investment in space infrastructure.
Economic development	Open access to space data and infrastructure is considered a driver of new innovative services and applications which will support economic growth.
Science research	Data and observations from space are frequently part of national, European and international research projects.
Societal needs	Open access to infrastructure such as satellite navigation systems and weather satellites provide benefits to the public.

3. CATEGORIES OF SPACE ASSETS

3.1. Satellite communications

Satellite communications refer to in orbit assets which provide voice and data radio communications capabilities via satellite transponders. They support communications links independent of ground infrastructure and are therefore well placed to provide telecommunications in the polar regions where populations and associated infrastructure density is low.

Geostationary satellite systems

Geostationary satellites are deployed to an orbit with an altitude of approximately 36,000km above the equator. This orbit means they remain in a fixed position over the Earth's surface as it rotates. At latitudes greater than 70 degrees (north and south), the very low incidence angle from the ground to the satellite means connectivity to the satellite becomes patchy or impossible due to the curvature of the Earth. As a result, geostationary telecommunications services are useable in the Arctic or Antarctic, but only to users at relatively low latitudes.
Where they are available, they provide broadband services over wide areas without the need for fixed infrastructure.

Example: Inmarsat Global Express

The Inmarsat Global Xpress satellite network comprises four Ka-band, high-speed mobile broadband communications satellites (see Figure 2 for their footprint). The network delivers VSAT services to maritime, aeronautical and users in other sectors. The satellites have a combination of fixed narrow spot beams that enable Inmarsat to deliver higher speeds through more compact terminals, plus steerable beams so additional capacity can be directed in real-time to where it is needed.

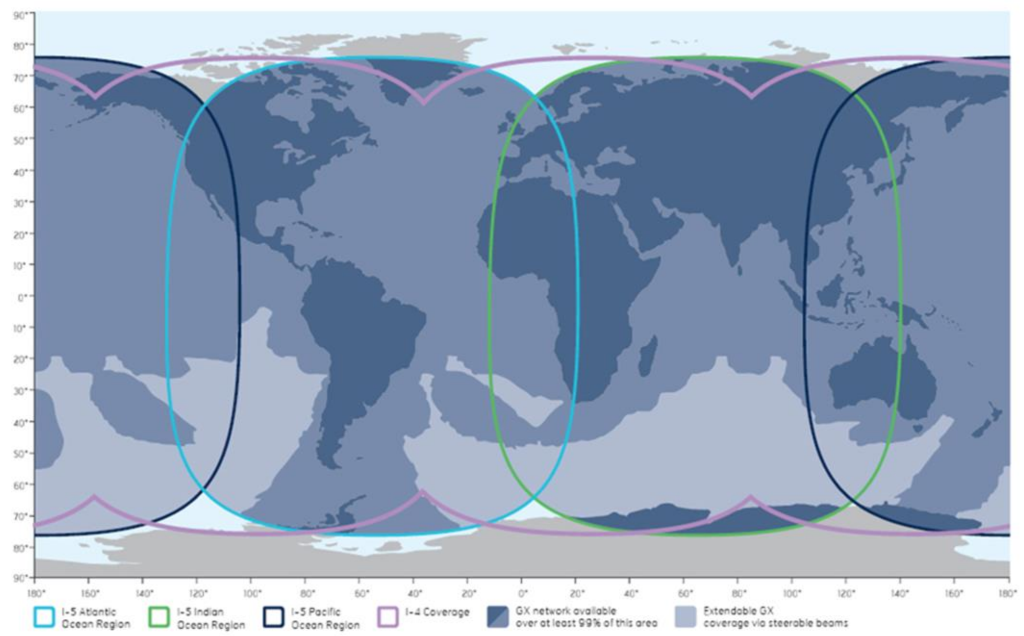

Figure 2: Coverage of Inmarsat Global Xpress footprints extending to the edges of both polar regions.

Further information is available at http://www.inmarsat.com/service/global-xpress/.

Low and medium earth orbit systems

At higher-latitudes, low and medium-earth orbit satellite services provide voice and data capabilities. Since the orbits of these satellites cross the poles, they are well placed to provide the necessary coverage. Currently the primary provider of these mobile satellite services is Iridium.

In the future, there are plans for new communication satellite networks to be deployed consisting of hundreds of satellites providing global coverage including the polar regions. OneWeb plans a constellation of up to 648 low-Earth Orbit (LEO) satellites, beginning with launches in late 2017. OneWeb is also expected to have the first satellites to enable high throughput broadband at higher latitudes.

Example: Iridium Next

Iridium Next (see Figure 3) is the replacement for the current constellation of Iridium communication satellites. The network will consist of 66 satellites, plus in orbit and on ground spares. Data rates up to 128kb/s are currently available, increasing to 512kb/s when the full constellation is ready in 2018. Support for legacy phones and devices will continue at data rates of the first-generation satellites. In addition, the Iridium Next satellites will include the AIREON payload providing ADS-B air traffic surveillance services.

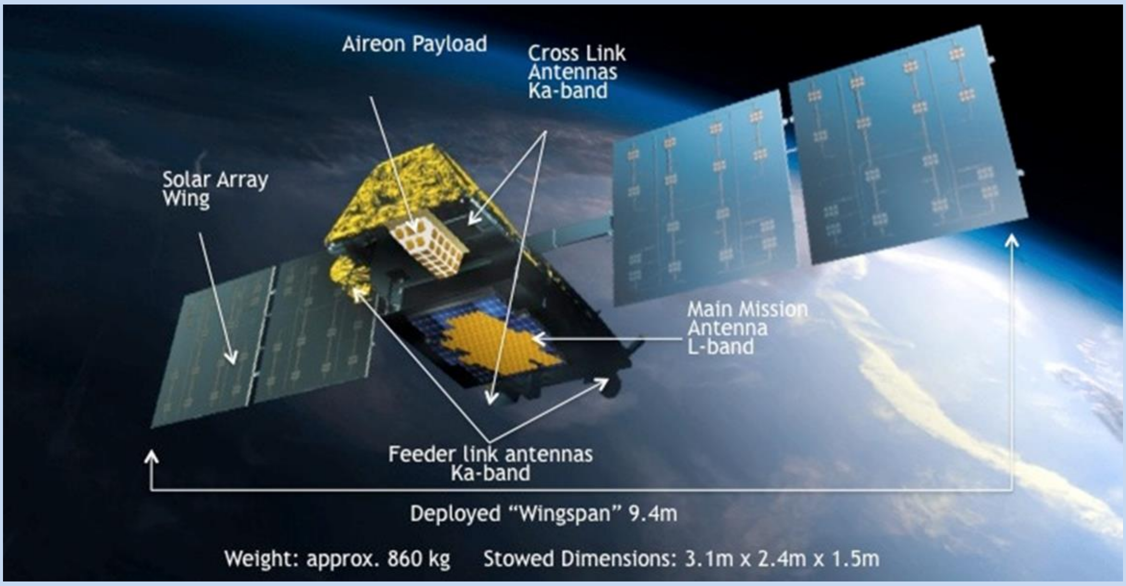

Figure 3: Depiction of an Iridium Next satellite.

Further information is available at https://www.iridium.com/network/iridiumnext.

3.2. Satellite navigation

Global Navigation Satellite Services (GNSS) use satellites to enable earth receivers to determine their location to a high level of precision (within metres or centimetres). GNSS receivers are found in a very large range of equipment from personnel and wildlife trackers to ships and aircraft. In the polar regions, there are some limitations on the accuracy of position information due to ionospheric effects, but they still have wide application as the best option for providing position information to support safe navigation and providing accurate timing information.

Currently two GNSS systems are operational:

- U.S. Global Positioning System (GPS)
- Russia's GLONASS system

In addition, two systems are currently under development:

- European Union's Galileo system (full operations planned for 2019)
- Chinese BeiDou Navigation Satellite System (full operations planned for 2020)

Example: European Galileo System

The European Galileo GNSS network will consist of 30 satellites in orbit (Figure 4) and is scheduled to be fully operational in 2020. The system will provide several levels of service including open access and a higher-precision encrypted commercial service. The inclination of the orbits was designed to ensure good coverage at polar latitudes, which are poorly served by the GPS network. Galileo is autonomous but also interoperable with existing GNSS systems. The satellites will also carry MESOSAR transponders providing a new search and rescue capability as an upgrade of the global Cospas-Sarsat system.

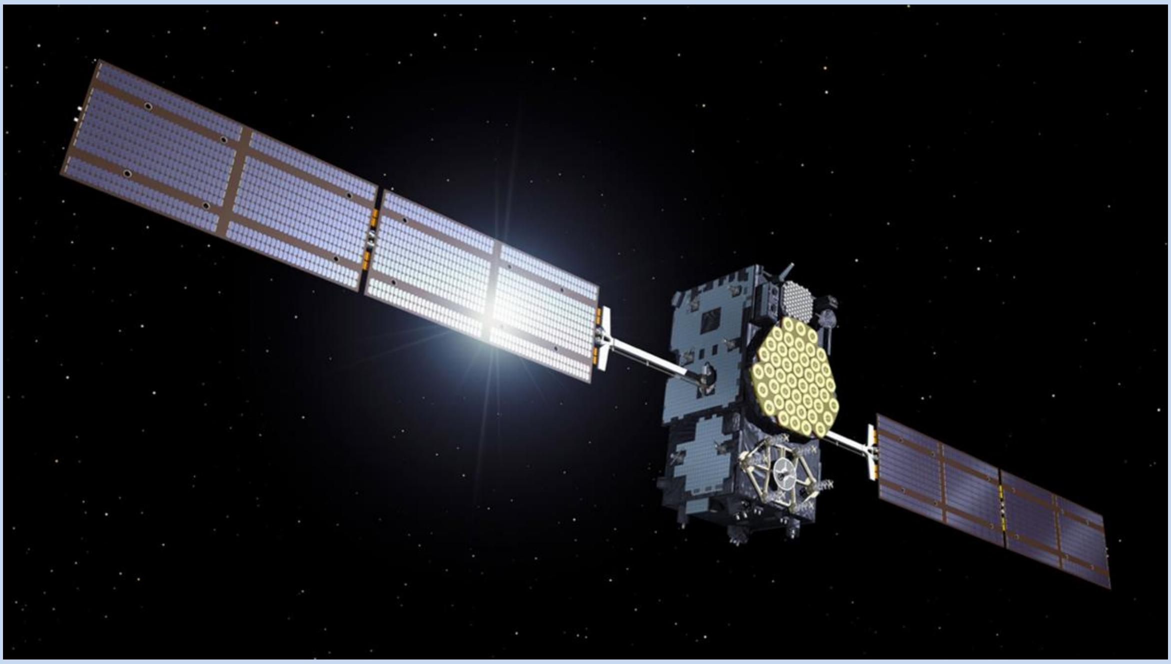

Figure 4: Depiction of a Galileo GNSS satellite in orbit.

Further information is available at http://ec.europa.eu/growth/sectors/space/galileo.

3.3. Earth observation satellite imaging

Earth observation or remote sensing satellites are designed to carry instruments which collect data about the Earth surface and atmosphere. This information is generally used for purposes such as meteorology, environmental monitoring and surveying, but the range of applications for these data is very extensive.

Remote sensing satellites have a unique capability in the polar regions, being the only source of integrated, year-round, synoptic region-wide measurements of many types of data. Due to the harsh environment, vast areas and polar winter, collection of data would otherwise be prohibitively expensive or logistically impossible.

Satellite remote sensing will continue to expand with new sensors and improved coverage. Satellites are provided by government and commercial operators, with a range of access options from free and open to fully commercial models.

Example: European Copernicus System

The European Sentinel satellites (Figure 5) form the space segment of the European Copernicus information services. In combination with in situ measurements and models, they will deliver up to date global information. The Sentinel series provide a range of different observations and measurements as described below. The satellites are considered operational and continuity of the satellite series is planned for years to come.

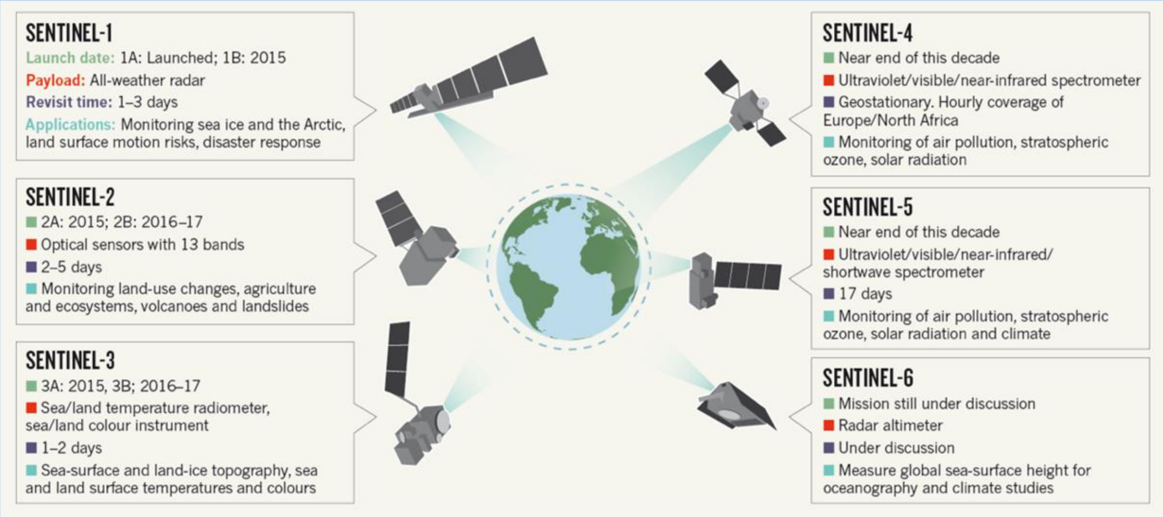

Figure 5: Copernicus series of Sentinel satellites.

Further information is available at http://ec.europa.eu/growth/sectors/space/copernicus.

3.4. Other space technologies for polar operators

Several other space assets, technologies and activities related to polar operations are worth consideration. Some relate to extensions of the main assets listed in this section, while others are related applications which are worth noting. A list is provided below and further description is given in section 7:

- Satellite AIS
- ADS-B
- GNSS augmentation
- Integrated space technology applications

4. USE OF SATELLITE COMMUNICATIONS FOR POLAR OPERATIONS

The importance of telecommunications for the polar regions cannot be overstated, supporting a wide range of activities in communities, science, navigation, emergency response and economic development.

A wide range of uses within the polar regions means there are multiple drivers for telecommunications capacity. Beyond direct support for polar operations other drivers include:

- the public and social needs of indigenous peoples and local communities, and
- supporting sustainable economic development and global connectivity.

Both requirements are expected to increase with forecasted growth in economic activity, traffic and population.

No single technology will meet all telecommunications needs in the polar regions, but satellite telecommunications are an important component to provide connectivity to vast areas with low population, little infrastructure and few service providers.

Currently, telecommunications capabilities at high latitudes is only possible with limited technologies, including VHF/HF radio and satellite voice/data services. This is partly due to severely limited connectivity due to reduced visibility of geostationary satellites at high latitudes and the lack of terrestrial infrastructure.

The use of satellite telecommunications as part of support to polar operations includes the uses described below (sections 4.1.-4.8.).

4.1. Science data

Space-based telecommunications are essential for polar science and environmental monitoring. Due to the limitations of terrestrial communications links, data collection from remote instrumentation is difficult. This applies equally to transmission of satellite data to scientists working in remote field locations. Given the ever-increasing volume of data required from science and environmental monitoring instruments, there is a severe limitation in the polar regions on this requirement.

Transmission of data from field instrumentation and to remote field works allows:

- Transfer and backup of data, minimizing the risk of data loss.
- Collection of data from remote instruments, wildlife, buoys, ice floats, and icebergs.
- Continual data transfers in real-time from remote locations as inputs to scientific and NWP computer model activities (e.g. Automatic Weather Stations).
- Input to Earth observation satellite calibration and validation activities.

The transmission of satellite data or sharing of other instrument data to scientists conducting field operations in remote locations allows:

- Access to data to inform scientific field programs, including optimal siting of deployed instrumentation.

Communication with colleagues to adjust plans in light of new circumstances or to troubleshoot issues with instrument operation.

Example: ARGOS system

The ARGOS system (Figure 6) is a satellite-based system operating since 1978, relaying environmental and scientific sensor and position data. It is primarily for uses related to environmental protection, awareness or study and protecting human life. These data are also vital for calibration and validation activities of satellite instruments.

Figure 6: Collection of data from instrumentation by the ARGOS satellite system.

Further information is available at http://www.argos-system.org/.

4.2. Field party safety

For all personnel conducting fieldwork or other operations in remote locations, reliable telecommunications provide the following benefits.

- Ability to submit regular status and position updates and communicate on all aspects of planning ongoing fieldwork. This may include adjusting schedules due to unforeseen events, reporting emergencies and planning rescue of personnel.
- Access to emergency telemedicine services (see section 4.8).
- Access to information services like weather, sea ice forecasts etc.

Example: Garmin InReach Explorer communications system

The Garmin InReach Explorer (Figure 7) is a handheld unit which supports 2-way text message communication and sharing/querying of position information. These functions work globally based on the Iridium satellite network. The system also provides weather forecast information for the current location and allows triggering of interactive SOS messaging in an emergency.

Figure 7: Handheld Garmin InReach units which provide satellite communication and position functions.

Further information is available at https://explore.garmin.com/en-GB/inreach/.

4.3. Satellite data relay

Satellite observations of the polar regions are vital for many purposes (*e.g.* environmental monitoring, meteorological observation, science data). In some cases there is inadequate downlink capacity to allow all data to be delivered to the satellite ground segment. To alleviate this bottleneck in-orbit data relay satellites can be employed to transmit data from the collecting satellite to the ground network via a geostationary communications satellite (See Figure 8).

Example: European Data Relay Satellite

The European Data Relay System (EDRS) is designed to transmit data between low earth orbiting satellites and the EDRS payloads in geostationary orbit using innovative laser communication technology. Composed of a hosted payload on a commercial telecom satellite and a dedicated satellite in geostationary orbit, EDRS will dramatically increase the speed of data transmission from satellites in lower orbits to users on the ground.

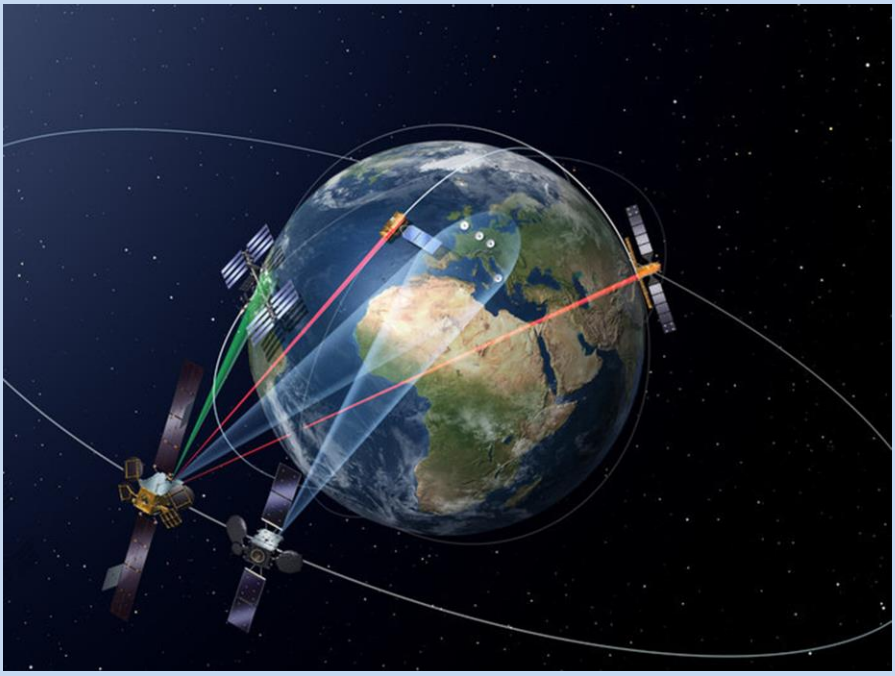

Figure 8: Depiction of the EDRS data relay satellite capability.

Further information is available at http://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/EDRS.

4.4. Shipping and maritime

Ship operations extend to all parts of the polar oceans for significant parts of the year. Some operations continue even through the polar winter, including science experiments where research vessels are purposefully beset in sea ice and drift with it.

The availability of telecommunications is essential for maritime safety and situational awareness. Polar research vessels use geostationary satellite links for telecommunications needs (email, Internet, phone, and fax). At higher latitudes where geostationary satellites have limited visibility, operators must switch to Iridium services.

In addition to general communications needs, polar vessels also have other important requirements as follow:

- Access to routing, hydrographic chart, meteorological, and oceanographic information services for safe and efficient navigation.
- Access to sea ice and iceberg information.

- Support for the IMO e-navigation strategy to promote safer navigation, including better ship-to-ship and ship-to-shore data exchange and communication.
- Safety information and situational awareness, SAR preparedness (see section 4.6).
- Environmental protection and incident management, e.g. oil spill preparedness.
- Regulatory and reporting requirements (e.g. IMO Polar Code).

Example: IMO Polar Code

The International Code for Ships Operating in Polar Waters (Polar Code, see Figure 9) supplements existing IMO regulations such as SOLAS, to increase safety of ships operation in polar waters. Polar Code addresses many aspects of ship operations, including limitations of communications at high latitudes together with guidance for working around these restrictions.

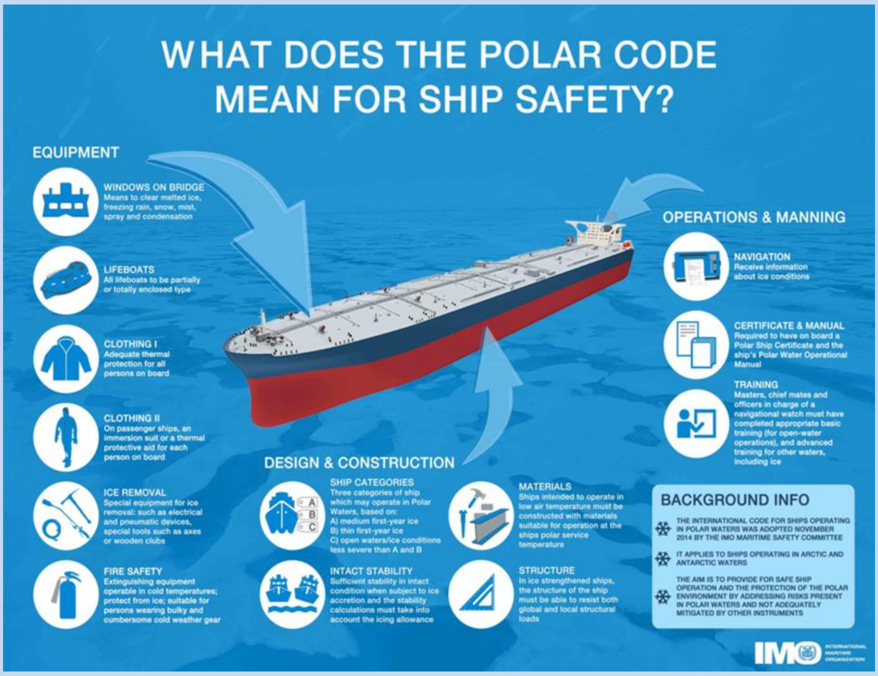

Figure 9: Summary graphic of IMO Polar Code requirements for ships operating in polar waters.

Further information is available at http://www.imo.org/en/MediaCentre/HotTopics/polar/Pages/default.aspx.

4.5. Aeronautical

Aircraft are a vital form of transport for passengers and cargo in all polar operations both in the Arctic and Antarctic. This covers a range of activities from support to science operations and some commercial air traffic. Three categories of aeronautical communications use are highlighted below:

- Operational communications for air traffic management. Managed by ICAO and including communication, navigation, surveillance and air traffic management (CNS/ATM) systems. These systems include exchange of information related to safety, navigation, technical, and administrative or legal matters and their updates.

As a complement to terrestrial datalinks (VHF/HF radio), satellite communication (e.g. via Iridium) will have an important role to play in ATM infrastructure, providing additional bandwidth plus coverage at sea and in remote areas such as the Arctic and Antarctic.
A more recent development has seen ADS-B (see section 7.2) receivers on board LEO-satellites to collect the position of planes in near real-time worldwide.

- Communications during SAR and incident response. Aircraft are very likely to be involved in any incident response with the polar regions, providing vital surveillance and rescue capabilities. The response to any aeronautical incident is coordinated by the aeronautical rescue coordination center (ARCC) which covers the incident location. In both polar regions satellite communications are vital for notification of incidents and during the response phase due to the limitations of terrestrial links.
- Data communications. Although at an early stage, it is possible to interface directly with data provided by the aircraft or onboard instrumentation via satellite communications links. This might include flight data information and onboard instrumentation.

4.6. Search and rescue (SAR)

Telecommunications are vital when operators require urgent response and outside assistance. This includes SAR events where life and/or infrastructure is at risk (e.g. a ship sinking), but also environmental protection e.g. pollution prevention and oil spill response.
This is necessary not only to raise the alarm but also to maintain communications with the body coordinating the rescue. There are likely to be multiple entities involved in SAR operations and all will need to share information to maintain a common operating picture as the basis for coordinated decision making.

Example: Common Operating Picture for SAR

The ESA ArcticSat study considered the use of multiple space technologies to respond to a SAR incident in the Arctic. A view of the components of a Common Operating Picture to support decision making was developed. As shown below (Figure 10), the simulated event north of Svalbard involved numerous entities (ships, aircraft, incident command centers), but the satellite communication link is clearly a vital part of any such system to allow information to be shared and synchronized between the incident location and the rescue coordination efforts.

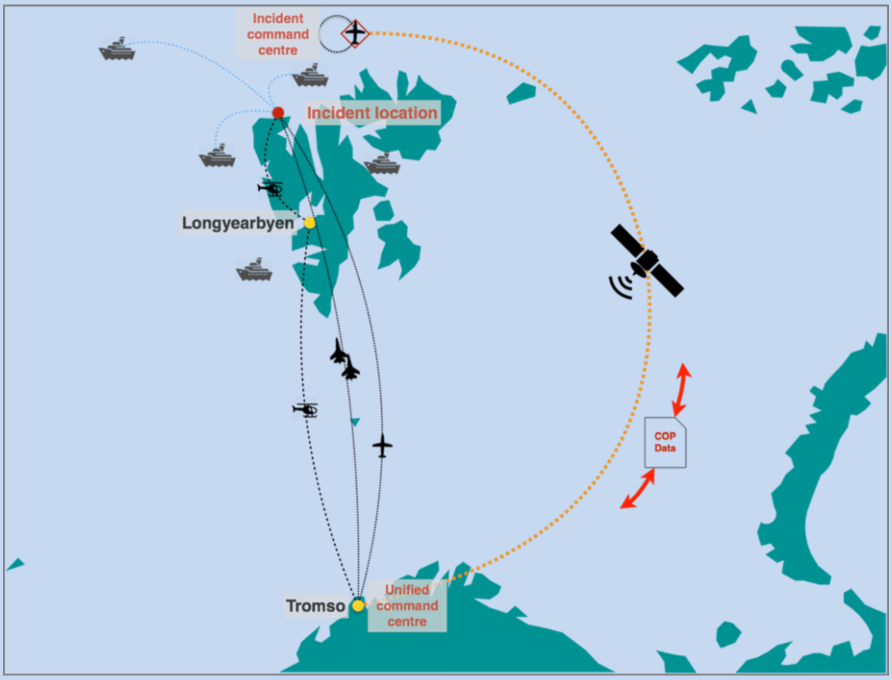

Figure 10: Diagrammatic of a simulated common operating picture in a SAR event taken from the ESA ArcticSat study.

Further information is available at https://artes-apps.esa.int/projects/arcticsat.

The initial notification of an incident is likely to be via voice communication or activation of a transmitter (e.g. EPIRB, SART or COSPAS-SARSAT transmitter).

Example: COSPAS-SARSAT

COSPAS-SARSAT terminals are radio transmitters activated by persons, aircraft or vessels in distress. The alert information is then forwarded on to the responsible authority so they can take appropriate action (see Figure 11 for an overview). The system uses a network of satellites which provide global coverage, consisting of five satellites in polar low-altitude Earth orbit (LEOSARs), nine satellites in geostationary Earth orbit (GEOSARs), and over 30 more recent satellites in medium-altitude Earth orbit (MEOSARs). MEOSAR receivers are located on navigation satellites including GLONASS, GPS and GALILEO.

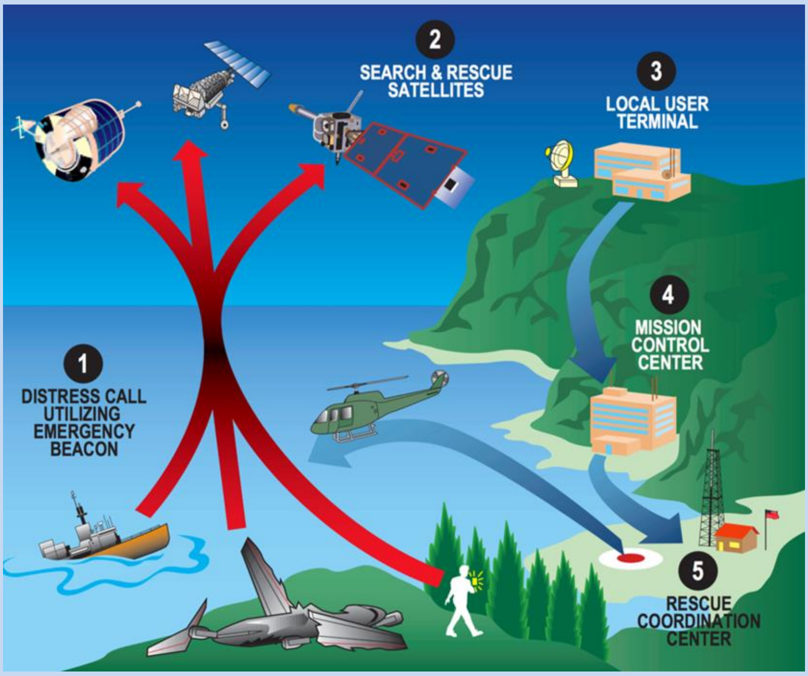

Figure 11: Diagrammatic of the COSPAS-SARSAT system (courtesy of NASA).

Further information is available at http://www.cospas-sarsat.int/.

In most polar SAR and incident response scenarios, especially in maritime events, there will be a reliance on satellite communications. While initial bandwidth requirements are small (initial notification and messaging), the bandwidth requirements increase during the incident as more entities are involved and more data is required to maintain an up-to-date common operating picture. This increase in required bandwidth may be limited by the capabilities of currently available Iridium data links.

Example: Global Maritime Distress and Safety System

The GMDSS is an international system using terrestrial, ship-radio and satellite systems to notify authorities in an emergency. The system also alerts vessels near the incident and provides improved means of locating survivors. Equipment to operate with the GMDSS network is required on all maritime vessels more than 2,000 tons. The system considers 4 areas of coverage based on range of shore based radio and Inmarsat satellites (Figure 12), with the polar regions falling into Sea Area A4. Since Inmarsat cannot be relied on to provide GMDSS at higher latitudes, IMO is working to expand GMDSS to include Iridium satellites.

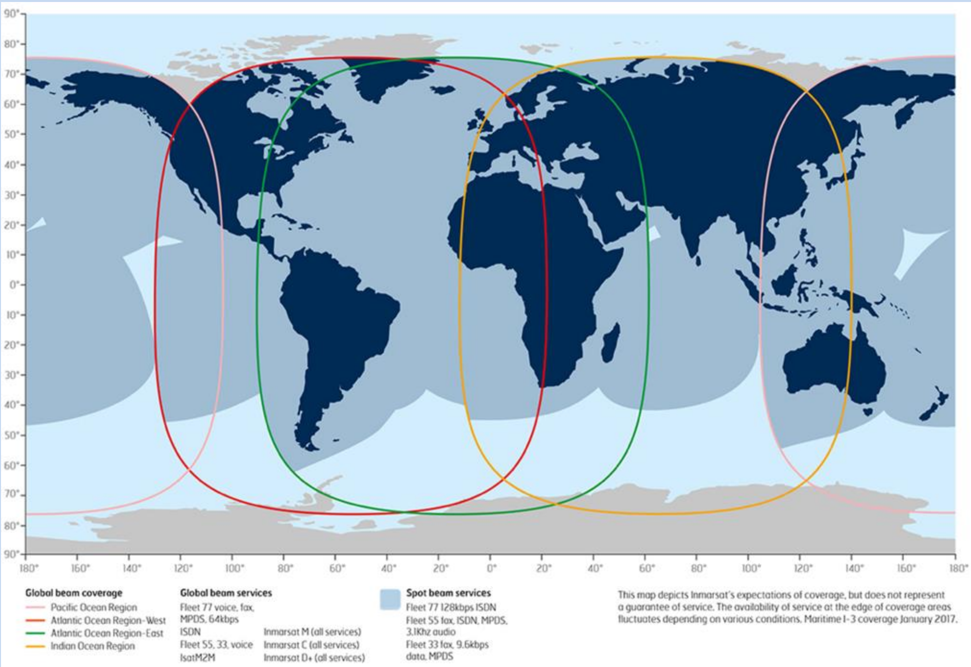

Figure 12: Diagrammatic of Inmarsat coverage, showing limited coverage of sea area 4 (the polar regions).

Further information is available at http://www.imo.org/en/OurWork/Safety/RadioCommunicationsAndSearchAndRescue/Radiocommunications/Pages/Introduction-history.aspx.

4.7. Remote polar stations and temporary field camps

Communications between remote stations in the polar regions use a combination of telecommunications methods. These are required to maintain connectivity in the local area of operations (close to stations and with field parties deployed at greater distances) and global connectivity to host nations (potentially on the other side of the globe).

Communications links are necessary to:

- Plan and execute field operations and travel, including regular situation reports
- Relay information and data to/from field parties, including weather information and updated plans
- Communicate in the event of an emergency

- Maintain communications with host organisation/company and maintain supply chain logistics

Local area communications traditionally use HF/VHF radio links, but increasingly also use satellite phones (e.g. Iridium) for voice and low volume data transmission. Inter-continental communications now routinely use satellite communications. Most year-round Antarctic stations are located on the edge of the continent where they retain some visibility of geostationary satellites.

4.8. Emergency telemedicine

Medical expertise may not be immediately available for workers in remote polar field sites, on stations or on ships. In the event of an emergency where immediate medical expertise is required, telemedicine services can deliver critical care.

Modern telemedicine (which uses video and advanced health monitoring systems) is generally difficult to provide without access to broadband communications. Its use is therefore limited in many situations currently, but use will expand as communications systems improve.

5. USE OF SATELLITE NAVIGATION FOR POLAR OPERATIONS

The use of GNSS services has wide application in the polar regions where position, navigation and timing information is required. While the accuracy of position information is affected by ionospheric variability, there are space based augmentation systems (SBAS) which are available for parts of the polar regions to improve the accuracy and integrity of GNSS data.

5.1. General navigation and position

Travel in the polar regions, whether overland, by ship or by aircraft, requires navigation systems. These are especially important where there is little infrastructure, the terrain can be featureless, weather conditions can lead to very poor visibility, and detailed maps are often unavailable. In these circumstances, there is an increasing use and reliance on GNSS systems for navigation and route following.

GNSS equipped vehicles, vessels and aircraft can be used to locate position on satellite images and available digital maps. Navigation through or over ice is a good example of this, whereby satellite imagery provides details of ice conditions, and GNSS provides real-time positions to allow vessels and field parties to navigate through hazardous ice conditions.

Ships may also have a requirement to hold position in circumstances where there is no mooring option or if they need to hold position close to another ship or platform. This is possible for ships equipped with dynamic position (DP) capability. Dynamic positioning is a computer-controlled system to automatically maintain a vessel's position and heading by using its own propellers and thrusters. The position information for DP systems is derived from GNSS systems.

GNSS position information is also vital for safety application in the polar regions. Field workers in remote locations increasingly make use of personnel trackers (e.g. InReach Explorer) or have access to emergency beacons (e.g. EPIRB) which are triggered in an emergency. The position information included as part of the tracking service or contained in an emergency distress signal is often derived from an integrated GNSS receiver.

Example: Ship navigation in sea ice

The ability to accurately plot a ship position in relation to maps or satellite imagery allows for optimised navigational decisions based on the current conditions. The example below (Figure 13) shows the planned route for the British Antarctic Survey ship RRS Ernest Shackleton transiting through sea ice in the southern Weddell Sea. Up to date ship position from onboard GNSS receivers allow detailed routing decisions based on the near-real-time satellite imagery which shows the current sea ice conditions.

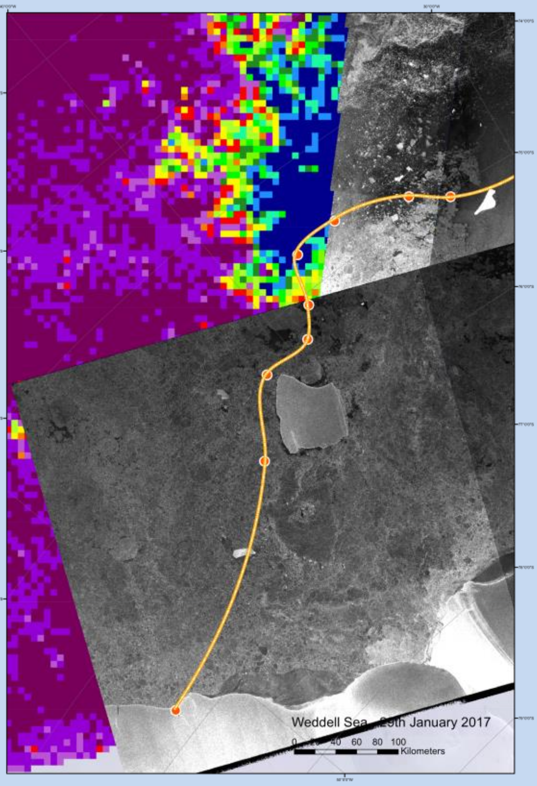

Figure 13:.Ship navigation through sea ice in the Weddell Sea. Sea ice conditions are visible in both satellite radar imagery (from Sentinel1) and sea ice concentration data (from University of Bremen).

Further information is available at www.polarview.aq.

5.2. Timing informaton

GNSS systems are principally based on timing information from precise clocks. Increasingly many modern systems use GNSS timing as an integral method to synchronise their operation. While the impact in the polar regions may not be immediately apparent, this reliance will increase as this source of timing information is incorporated into power grids, mobile communication networks and other sensor networks.

5.3. Sensor data for EO validation

In situ or mobile sensors combined with GNSS receivers allow collection and potentially real-time feedback of ground information that can be used to validate remotely sensed information in a satellite image. For example, a field technician equipped with a GNSS locator can provide information on land and vegetation classes to support supervised classification of EO imagery.

5.4. GNSS reflectometry

GNSS reflectometry involves making measurements from the reflections from the Earth of navigation signals from satellite navigation systems. Payloads can be included on EO satellites to measure reflected GNSS signals. This technique has been used in studies of parameters including ocean wave motion and wind speed, sea ice, snow cover and soil moisture.

6. USE OF SATELLITE REMOTE SENSING IN OPERATIONAL ACTIVITIES

Data of the polar regions has been collected from satellite for almost 40 years. These observations play an important role in polar science, but also in supporting polar operations and infrastructure in many diverse ways.
Current uses of remote sensing are summarised below (sections 6.1. to 6.9.).

6.1. Environmental impact assessment

Environmental impact assessments (EIAs) are a prerequisite to the development of any major infrastructure project in the polar regions. Such infrastructure might include development of a new polar research station, runway or harbor.
Regulators consider many factors when assessing the environmental impacts of projects and information may be required on the following:

- physical and meteorological environment
- soil, soil productivity and vegetation
- wetlands, water quality and quantity
- fish, wildlife, and their habitat
- species at risk or species of special status and related habitat
- heritage resources
- traditional land and resource use
- human health, aesthetics and noise

A variety of satellite remote sensing instruments can provide data on many of these factors.

6.2. Monitoring human impact

Given the public perception of the polar regions as pristine environments, there is an ongoing need to monitor the potential impact of human presence and activities. This is specifically important for specially protected and managed areas (e.g. Antarctic specially protected areas - see http://www.ats.aq/e/ep_protected.htm).
Long term monitoring of stations and visited areas, especially high-intensity sites, can help detect and mitigate the effects of human presence including introduction of alien species. Given the remote location and other difficulties in visiting these locations, using satellite imagery makes regular monitoring significantly more efficient.

Example: Monitoring ASPA vegetation

One potential impact of human presence is damage to indigenous vegetation and the introduction of non-native species. High resolution multispectral satellite imagery is used to establish a baseline of vegetation extent and monitor for changes. The future availability of hyperspectral satellite data should allow for more detailed surveys of vegetation types to be performed. Moe Island, shown below (Figure 14), is one of 39 protected areas in the Antarctic which are regularly monitored for changes in vegetation cover.

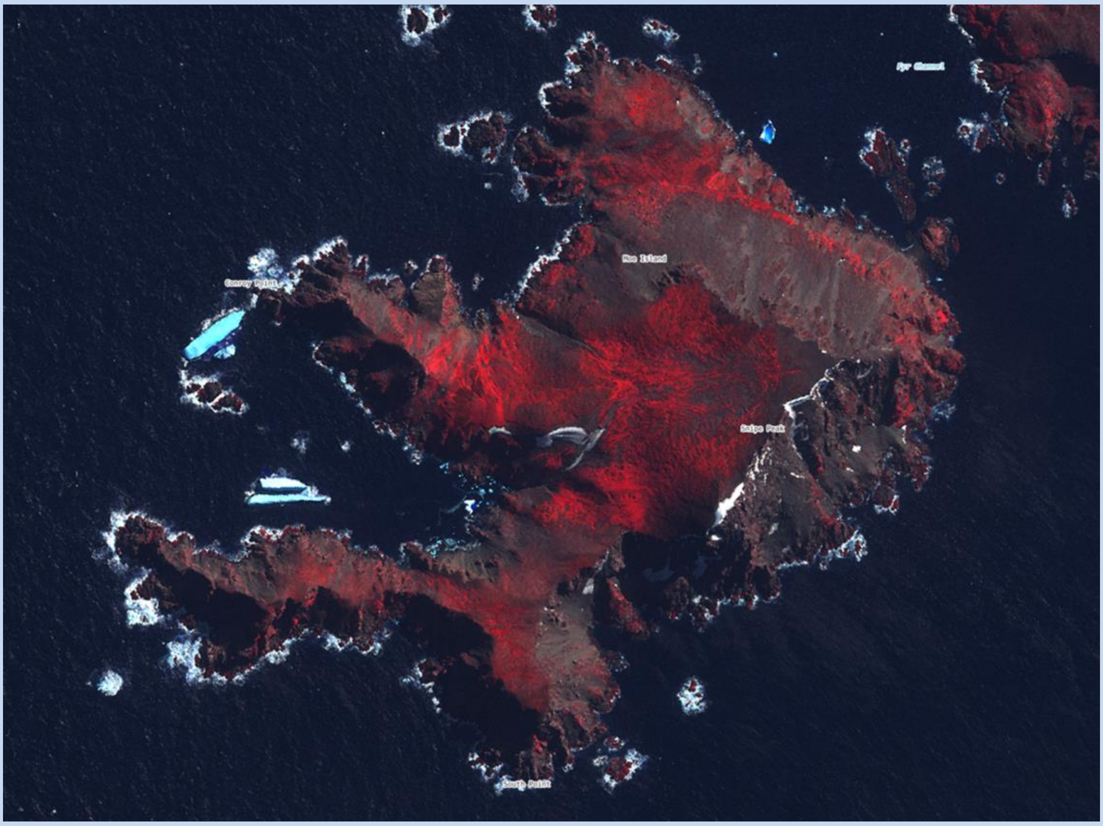

Figure 14: High resolution satellite imagery used to monitor vegetation cover on Moe Island ASPA.

Further information is available at http://www.ats.aq/e/ep_protected.htm.

6.3. Engineering design - siting buildings & offshore infrastructure

The design of ships, stations and other facilities for the polar regions must consider the unique environmental characteristics and challenges of operations in the Arctic and Antarctica. Designers and architects need information about factors such as weather, temperature, permafrost, surface topography, sea ice and icebergs. Statistics on many of these parameters can be derived from satellite data, *e.g.* wind speed from meteorological satellites, wave height from satellite altimeter data, iceberg occurrence frequency and size distribution from synthetic aperture radar imagery.

Siting of science instruments and experiments also requires detailed information about surface conditions and options for power generation before selecting a suitable site. Relevant factors include surface slope and aspect, prevailing wind direction and speed, cloud and temperature records.

Satellite imagery also provides regular monitoring of dynamic polar environments where infrastructure is located. Such situations include developing fractures in ice shelves and surface deformation caused by permafrost.

Example: Elevation data for infrastructure site planning

Surface elevation and slope for infrastructure planning require detailed digital elevation models of remote locations. The use of photogrammetric methods with high-resolution stereo satellite imagery has made routine generation of DEMs (Figure 15) with cell spacing of ~2m possible without the need for expensive aircraft operations.

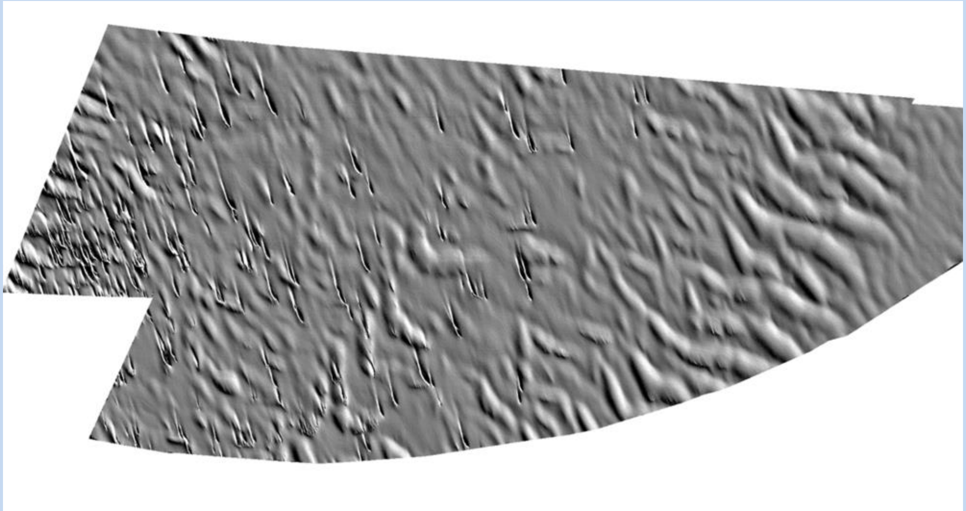

Figure 15: DEM of part of the Antarctic Brunt Ice Shelf used for site selection when relocating the UK Halley VI Research Station.

Figure 16: Coverage of the ArcticDEM elevation dataset.

The US Polar Geospatial Center have produced a high quality digital surface model of the Arctic. The ArcticDEM dataset (Figure 16) is constructed from in-track, high-resolution imagery acquired by the DigitalGlobe constellation of optical imaging satellites.
Further information is available at https://www.pgc.umn.edu/data/arcticdem/.

6.4. Overland travel

Detailed route planning is required for a range of operational activities in the Arctic and Antarctic, including science and research field operations. Access to field locations can often be a critical limiting factor to conducting science or other polar operations.

Planning of travel by vehicles on land requires analysis of information about crevassing, fractures in ice shelves, permafrost conditions and the state of winter roads over frozen lakes and rivers. Detailed information about historical and forecast weather conditions for the operational period are also critical factors. Many of these parameters are derived from Earth observation and meteorological satellites.

Example: Crevasse assessment for overland travel

Crevasses pose significant risks for overland travel on glaciated areas of the Arctic and Antarctic. Field parties often need to access remote locations via overland routes or land aircraft on unfamiliar surfaces. In these circumstances assessing the area for crevasses is essential to assess the level of risk, determine safe areas to work and plan safe travel routes.

High resolution visible and radar satellite imagery (see Figure 17) often allows the surface expression of crevasses to be identified more clearly than when viewed from ground level. While not all crevasses are visible due to snow cover, these types of imagery provide an excellent way to assess areas which would be very dangerous to field parties.

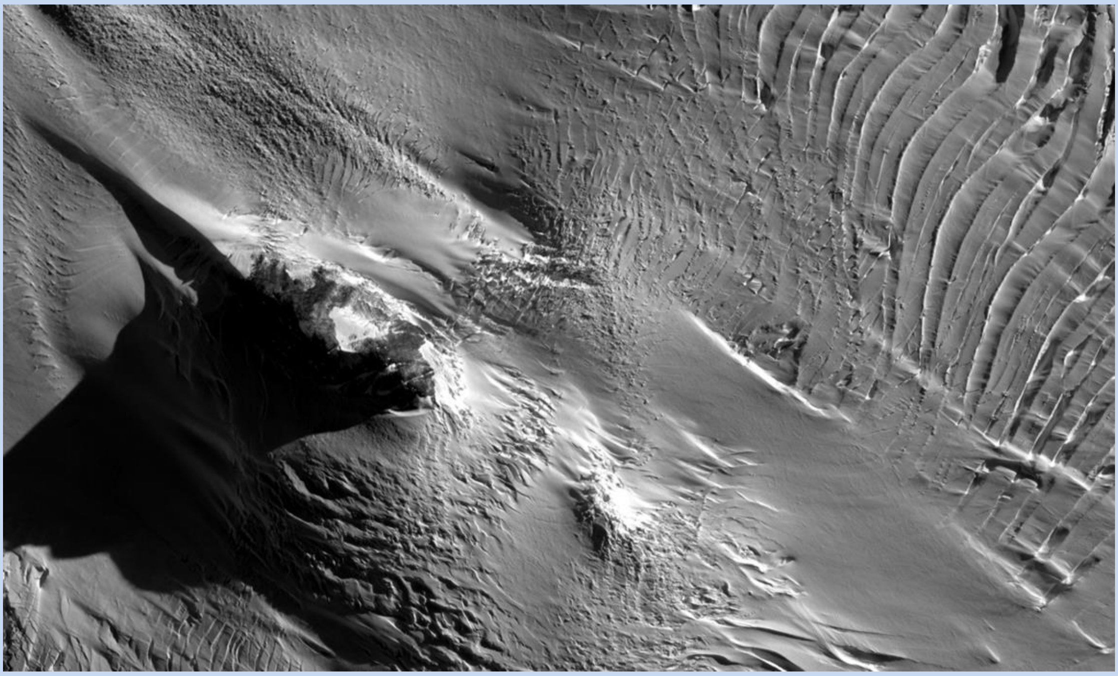

Figure 17: A Digital Globe WorldView2 optical satellite image of Dorrel Rock (near Mt Murphy, Antarctica), clearly showing areas of significant crevassing which makes the area very dangerous for overland travel.

Further information about Digital Globe satellite imagery is available at www.digitalglobe.com/.

6.5. Ship navigation and operations

Planning of safe and efficient routes by ship to and through the polar waters is principally focused on assessment of weather, sea ice and iceberg conditions. This is a high priority for operators due to the costs of operating ships. Good routing means efficient use of available ship time, maximising scheduling, and less time transiting sea ice reduces hull maintenance costs.

Avoidance of sea ice and icebergs also reduces the risk of damage to vessels and consequential injury to persons on-board or oil spill incident should the hull be damaged.

Analysis of historical data covering the proposed route and time window of the operation can provide key information to help plan the optimum routing. Many of these parameters are derived from Earth observation and meteorological satellites.

Up to date information on the current sea ice and weather conditions is primarily derived from satellite data and associated forecast models. Satellite imagery, especially synthetic aperture radar data, is especially effective in the polar regions given the ability to provide data regardless of cloud cover and independent of sunlight. These data are used to identify areas of sea ice and ice bergs, construct ice charts and derive information about sea ice drift.

6.6. Risk management

The dramatic environmental changes taking place in the polar regions are increasing risks for operations in both the Arctic and Antarctica. For example, melting permafrost is increasing the risk of damage to roads and other infrastructure, climate change is predicted to increase the frequency of extreme weather events and melting ice sheets will lead to an increase in iceberg density.

Risk management systems are developed and implemented by polar operators to take these risks into account for their location and activities. Tracking and mitigating the risks requires good information about likelihood of occurrence and severity.

Due to their wide area coverage and regular monitoring capability, satellite observation systems are well placed to provide the required information more easily and efficiently than other sources.

Example: POLARIS risk assessment for IMO Polar Code

New IMO regulations, referred to as Polar Code, require ships to access a range of weather and environmental information, and utilise a risk assessment methodology for determining the limitations of operation in ice. The POLARIS system (see Figure 18) evaluates the risk posed to a ship in ice based on the ships assigned ice class and sea ice information which can be derived from ice charts.

The production of ice charts by the National Ice Centres is based on interpretation of satellite imagry by expert ice analysts. The ice centres are mandated to provide charts of Arctic national waters and the Southern Ocean in support of safe shipping. They are one of the largest users of satellite imagery in the polar regions.

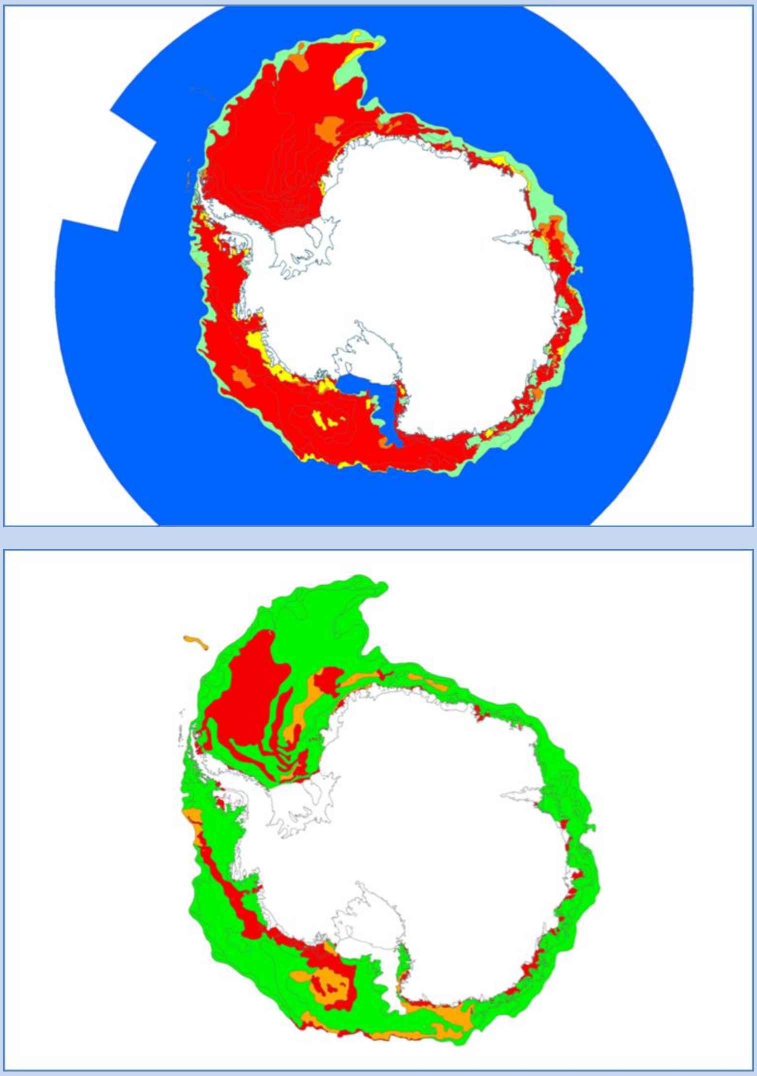

Figure 18: An ice chart of the Southern Ocean (top) includes information about the sea ice concentration and stage of development. The POLARIS system translates this into a risk map (bottom) showing areas where the ship can operate (green), proceed with caution (amber) and cannot operate (red).

Further information is available at http://www.imo.org/en/MediaCentre/hottopics/polar/Pages/default.aspx.

Example: Monitoring river ice breakup

The development of ice covers on large rivers can result in ice jamming and flooding of large areas. The severity and economic impact of floods related to ice jams is exacerbated by the danger of post-flooding freeze-up. Decision makers require up-to-date information in riverine ice development to identify and mitigate potential hazards. Key parameters required to assess the danger of flooding include location, extent and structure of the ice field. However, a systematic determination of these parameters is difficult to achieve using conventional, field-based methods, especially in remote areas. EO is an ideal tool to collect information on river ice repeatedly and consistently throughout the ice season. Satellite-based river ice monitoring services provide information of location, extent and changes of ice covers to stakeholders.

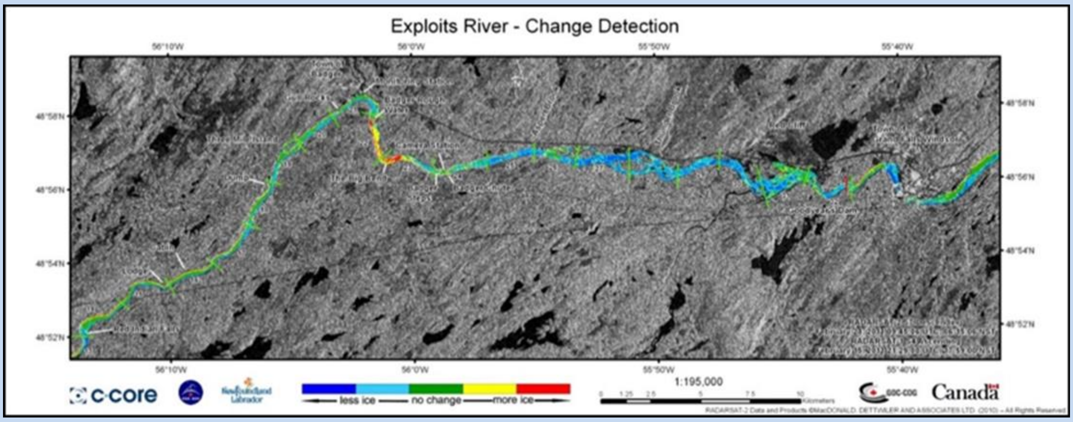

Figure 19: Open lead in Exploits River ice cover (top) and map of change detection in the Exploits River derived from satellite synthetic aperture radar imagery.

Further information is available at http://www.polarview.org/services/river-ice-monitoring/.

6.7. Emergency response

Emergency response in both polar regions is coordinated by joint rescue coordination centers, maritime rescue coordination centers, and aeronautical rescue coordination centers. These entities coordinate a response, but an actual emergency response requires assets to be deployed to the incident site. These can be formal SAR responders or assets opportunistically close to the incident.

The response time might be considerable and it is essential that the responding assets and the RCC have access to current conditions at the incident site to ensure an appropriate response and minimize the risk to responders.

Relevant information provided by remote sensing satellites includes:

- Weather conditions including wind speed and direction
- Sea state including wave height (if offshore)
- Presence of sea ice and icebergs (If offshore)
- Surface conditions and routes for responding assets (if onshore)
- Oil spill detection and movement (if offshore)

Example: Support to the Akademik Shokalskiy

The Akademik Shokalskiy ship became stuck in ice during December 2013. The response was coordinated by the Australian RCC, with several ships responding to evacuate passengers and help the ship escape from the sea ice. Good information about the changing sea ice conditions was obtained from satellite imagery (see Figure 20) and shared with the RCC and all of the responding vessels.

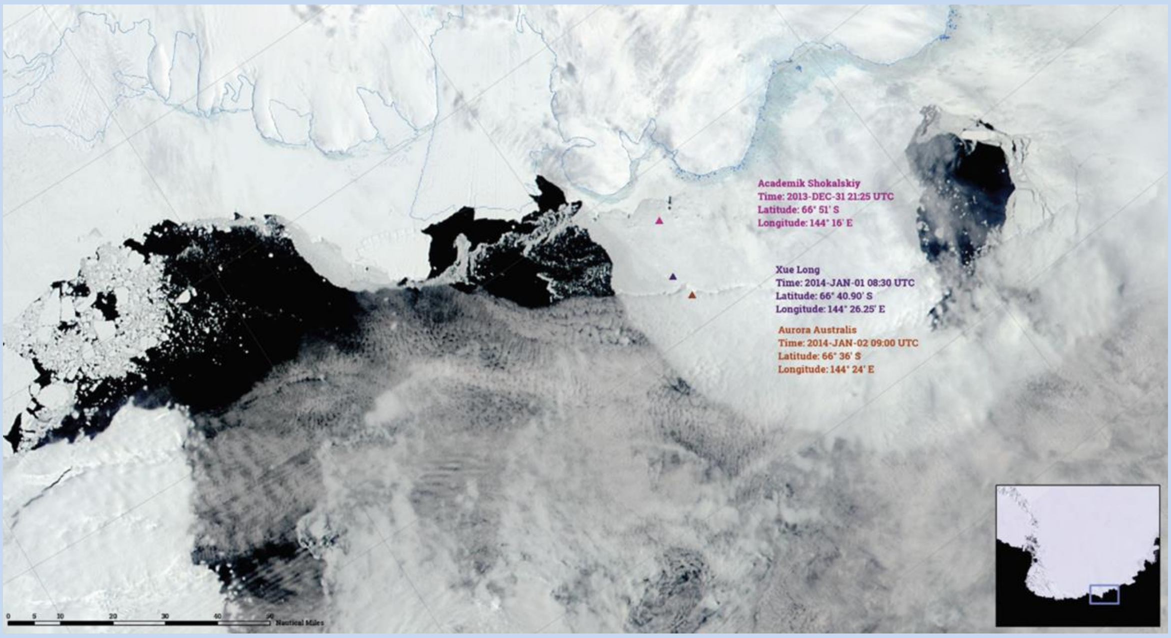

Figure 20: Showing sea ice conditions from MODIS satellite imagery (provided by NASA) and the position of the Akademik Shokalskiy and other vessels responding to the incident.

Further information is available at http://www.bbc.co.uk/news/world-asia-25573096.

6.8. Weather forecasting – reliant on regular satellite imagery and data

Weather forecasting includes observing current weather conditions (i.e. initial condition) using in situ sensors, ocean buoys, weather balloons and satellite sensors. Based on this initial state, a forecast is generated using numerical weather prediction (NWP) model forecasting.
Satellite observations of these initial conditions are vital in the polar regions where data from other sources is scarce. Required observations for NWP from satellite include clouds, sea ice, ocean surface parameters and winds, atmospheric and ocean chemistry, melt ponds on sea ice etc.

6.9. Climate change adaptation

The European Commission describes climate change adaptation as follows: "Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimise the damage they can cause, or taking advantage of opportunities that may arise." (European Commission, 2015). Adaptation measure will include establishing new laws and standards, changes in food sources, population relocation, improving transportation infrastructure and enhanced SAR capabilities.
In response to the requirements identified in the second assessment of the adequacy of observing systems for climate in 2003, the GCOS program developed an implementation plan to develop the global observing system for climate (GCOS, 2004). Specific references to information parameters from remote sensing, required for climate change adaptation operations include (but are not limited to):

- Aerosol
- Forest biomass
- Ocean colour
- Sea ice coverage.
- Albedo
- Cloud properties
- Elevation data
- Elevation models
- Earth radiation budget

7. USE OF OTHER SPACE TECHNOLOGIES

7.1. SatAIS

As part of Safety of Life At Sea (SOLAS) regulations, the IMO added Automatic Identification Systems (AIS) to the shipboard navigational carriage requirement for a number of ship categories. AIS was conceived mainly as a collision avoidance system and is based on regular VHF transmission and reception of short binary messages containing information about the ship's identity and includes its position, speed and course.
AIS is primarily a ground based system, meaning AIS information can only be received if the vessel is within range (typically 10's of km) of a shore based receiving station. Placing an AIS receiver on a satellite is an alternative way of addressing the wide area surveillance requirement (see Figure 21).

In recent years, work has been undertaken by several government and commercial entities to deploy S-AIS receivers for satellite-based ship information and tracking. As a result, several current and planned AIS-capable missions are operational or pending. Orbcomm, exactEarth and Spire are notable examples of commercial S-AIS surveillance service providers.

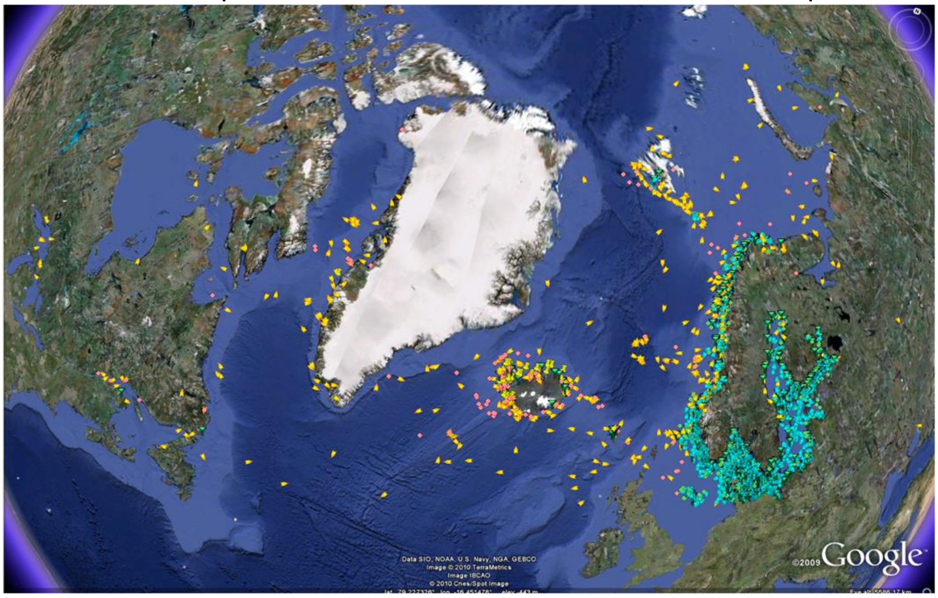

Figure 21: AIS data in green and Sat-AIS data in yellow provided courtesy of the Norwegian AISSAT-1 9satellite (Kongsberg Seatex AS).

Shipboard Global Maritime Distress Safety System (GMDSS) installations include one or more search and rescue locating devices, used to locate a survival craft or distressed vessel. This device can be an AIS-SART, which sends updated position reports using a standard Automatic Identification System (AIS) report.

7.2. ADS-B

Automatic Dependent Surveillance – Broadcast is a surveillance technology in which an aircraft determines its position via satellite navigation and periodically broadcasts it, enabling it to be tracked. The information can be received by air traffic control ground stations as a replacement for secondary radar. It can also be received by other aircraft to provide situational awareness and allow self-separation.

The limitation in the polar regions is the need to be in range of a ground station. It can also be received via low-Earth orbit satellites to collect the position of planes in near real-time worldwide. This has clear benefits for air traffic management and flight following for aircraft operators in the polar regions.

7.3. GNSS Augmentation

Currently GNSS augmentation systems (SBAS) such as EGNOS are widely used globally where satellite navigation is used in safety critical situations. The service reports on the reliability and accuracy of their positioning data and publishes corrections. Use of these services in the polar regions has two major limitations.

SBAS services are delivered by geostationary satellites which have limited visibility at high latitudes. Therefore, delivery of the published corrections is difficult, making access impossible for many users.

A major source of GNSS errors in the polar regions is the ionosphere. Published corrections are derived from ionospheric models which are often inaccurate in the polar regions due to a lack of observations to incorporate into the model. The new dual frequency of the Galileo service will go some way to address these quality issues.
Therefore, there is a limitation on the use of GNSS services for safety critical services which would require an augmentation service. To correct this situation both the delivery and quality of the augmentation service will need to be addressed.

7.4. Integrated Applications

Frequently greatest advantage is gained from space technologies when an integrated approach is used, rather than considering them independently.

- Examples of options for integrated use of space assets in the polar regions might include:
  - Combined sea ice information from EO imagery with ship location from GNSS to support ship navigation in sea ice.
  - EO imagery and S-AIS position data for ship surveillance and fisheries monitoring in marine protected areas.
  - GNSS, EO and sat comms to establish a common operating picture in support of search and rescue emergency response.

ESA have a specific program called ARTES Integrated Applications Promotion (IAP) which aims to develop operational services through the integration of different space assets. This programme has included a few polar focused projects including the ArcticSat project (https://artes-apps.esa.int/projects/arcticsat).

8. SPACE ASSETS AND THE EUROPEAN SPACE PROGRAM

The preceding sections have described many uses of space assets by polar operators. These applications use satellites and space infrastructure provided by public and private sector organisations, which can be free to access or require payment. It is beyond the scope of this report to supply detail on the providers and access options for all space infrastructure used by polar operators. But it is within scope to consider the breadth of the European space programme and how polar requirements are coordinated and communicated within it.

8.1. Overview of European space programme

Given the very high costs of developing, building and launching satellites, these developments are generally beyond the resources of single organisations. Many countries are also not able to invest in a national space program. European nations have decided that it is optimal to pool resources, both financial and expertise, to develop joint space assets based on their common requirements.
Both the European Union and the European Space Agency have space policies and activities which are relevant in this context.

- The European Union (EU) maintains a space program to help with implementing its societal, industrial and research activities. In this context, the EU Joint Communication "An integrated European Union policy for the Arctic" is one important driver in the polar context.

- The European Space Agency (ESA) is an intergovernmental organisation comprised of 22 member states. Its remit is to develop and implement Europe's space capability on behalf of its member states.

The EU and ESA have a common objective of developing space for the benefit of Europe and its citizens. Whilst the programs are separate and each institution has different competences, they have increased ties and cooperation in recent years. In the EO domain, it is generally the case that ESA are responsible for funding developing new technologies and capabilities, while the EU are responsible for funding longer term operation of EO satellite series once they are proven.

8.2. ESA Space Segment

ESA develop and operate many satellites (Figure 22), full details of which are available at https://earth.esa.int/web/guest/missions/esa-eo-missions. New satellites and capabilities are developed through the various ESA programmes which are driven by the requirements of the member states. If new space technology or infrastructure is required to meet polar operational needs, then the existing ESA framework is well placed to communicate those needs to ESA and identify how they might be addressed in the current or future program.

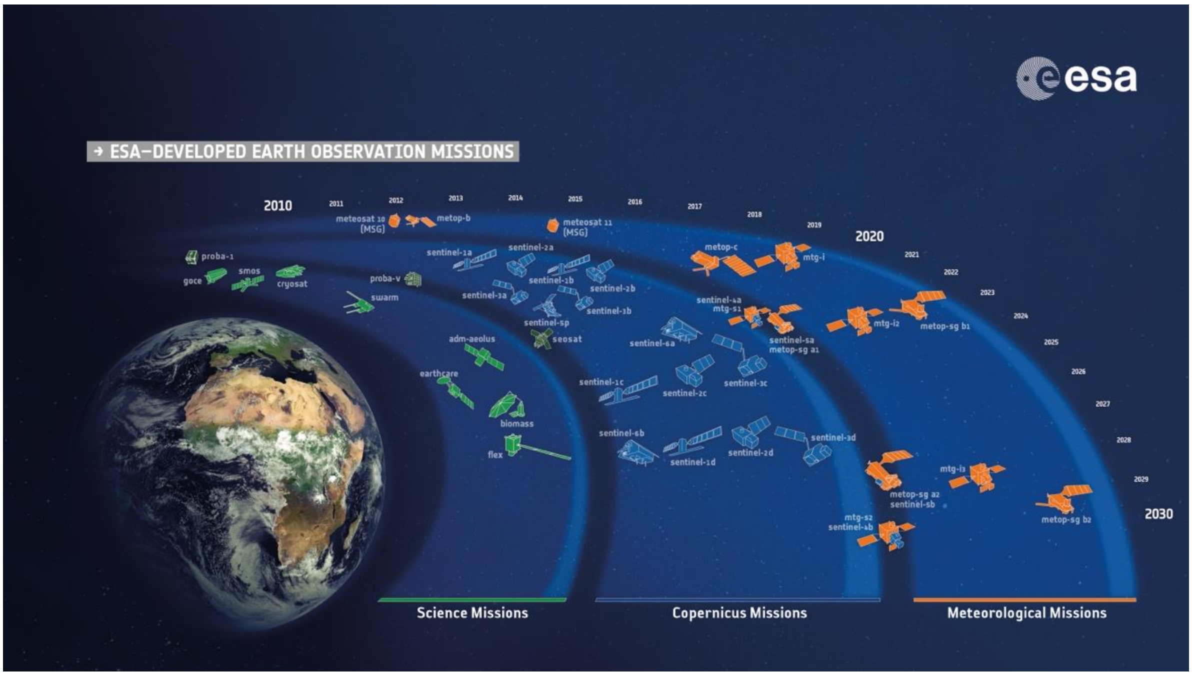

Figure 22: EO missions developed by ESA.

8.3. EU Space Program

The space segment of the EU space programme is currently comprised of two major components.

- Galileo – Satellite navigation system for positioning and timing information.
- Copernicus – Sentinel series of Earth observation satellites for environmental monitoring.

Satellite telecommunications are the largest users of satellites. The required space infrastructure is provided by industry who successfully operate commercial telephony and television services to the mass market. Given this, there is no EU funded satellite telecommunications infrastructure.

Example: Cryosat2

The Cryosat2 satellite is the first in the ESA Earth Explorer series. It is an synthetic aperture altimeter designed to measure the freeboard of sea ice in the Arctic. Using this data, it is possible to derive the thickness of sea ice and understand the changing volume of sea ice in the polar regions as opposed to just its extent. The satellite is also used to study ice sheets and ocean circulation. While Earth Explorer satellites are designed to answer specific science questions, more recently data from Cryosat2 has started to deliver operational products. These provide a more up to date picture of sea ice thickness (Figure 23) which is useful for ship operators planning routes in the Arctic and for input into oceanographic models.

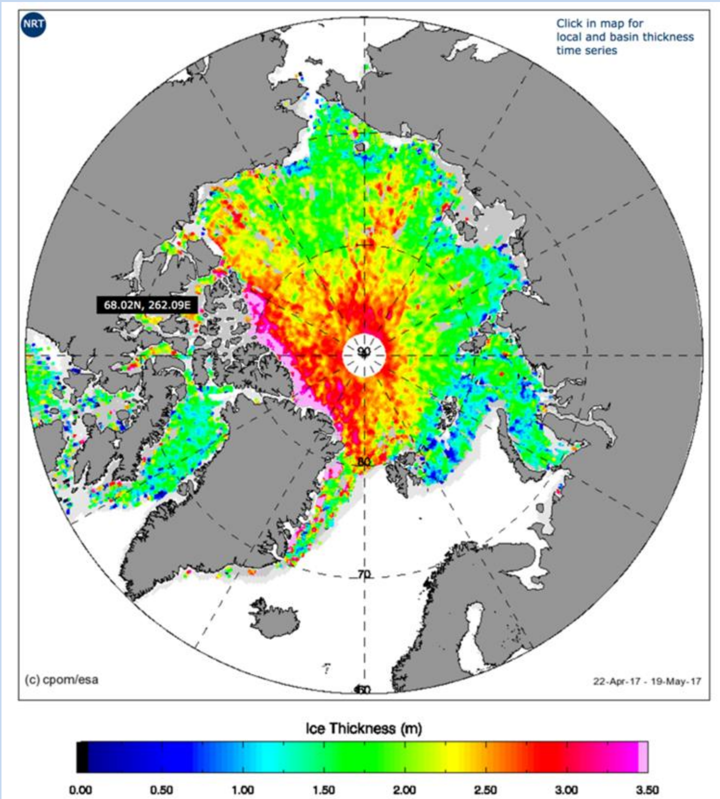

Figure 23: Sea ice thickness derived from Cryosat2 data. Provided courtesy of CPOM.

Further information is available at http://www.cpom.ucl.ac.uk/csopr/seaice.html.

8.4. Improving coordination for developing future space assets

This first part of this task (Task 3.2) is presented in this report and consists of surveying existing use of space assets by European polar operators. The task also includes recommending how coordination might be improved in this domain.
Considering this report, the next part of Task 3.2 will identify technical and operational gaps in current space infrastructure. This will result in a prioritized statement of requirements from European polar operators, documented in the second deliverable D3.6 (due end 2017).
Getting agreement on this statement of requirements and ensuring it is considered by the European space program will require improved coordination on two fronts.

- Coordination of European polar operators to agree on high priority needs from space infrastructure.
- Coordination between the European space program entities, specifically between ESA and EU.

As mentioned previously, several activities are already underway in the EU and ESA to identify potential polar-focused satellite missions. These are being conducted to inform what new satellite programs to fund and how the existing series of satellites will evolve in the next 1 to 2 decades. Two specific groups should be highlighted in this context.

- EU Copernicus Committee Task Force on polar observations
- ESA Space and Arctic Task Force and associated Concurrent Design Facility study

Both groups are aiming towards assessing user requirements against current capabilities and then proposing new mission concepts and instrument technologies. This EU-PolarNet study and output from other groups with related mandates (*e.g.* Polar Space Task Group - http://www.wmo.int/pages/prog/sat/pstg_en.php) should also be coordinated with the EU and ESA activities, to have a single view of requirements for polar operators, science, industry and government in Europe. In addition to publishing and circulating this report on use of current space technology, we suggest that the second deliverable (D3.6) should be presented to both ESA and EC polar task forces. D3.6 will provide a summary of the gaps in current capabilities where these is a requirement for European polar operators.
In addition to these higher level strategic activities, coordination in this domain still requires ongoing communication between the polar community and the space agencies, including ESA and national space entities who are responsible for financial contributions to ESA. It is essential that the polar community engages more fully with national space agencies to ensure their needs are represented in planning efforts. It is also recommended that more polar operators and scientists are included in advisory and expert groups for space activities, so they can speak up for the needs of the polar operational community.
Each national polar operator should be clear on the route to engaging with representatives to the ESA and EC space programs to actively communicate and represent their requirements where possible. This should be achieved through the established and appropriate national representation to ESA and EU space programs.
Details of ESA governance arrangements and where member states are represented are available at http://www.esa.int/About_Us/Law_at_ESA/ESA_s_organs_and_functioning. Representation relevant to this report includes the JCB (Joint Board on Communication Satellite Programme), PB-EO (Programme Board for Earth Observation) and PB-NAV (Programme Board on Satellite Navigation).

For the EU Copernicus programme, national representatives are chosen by member states for the Copernicus User Forum. This group is tasked with advising the Commission about the definition and validation of user requirements, and to the coordination of the Copernicus programme with its public-sector users. Further details, including names of member state representatives are available at: http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=2584.

The European Union's objectives and investments in satellite navigation is coordinated by the European Global Navigation Satellite Systems Agency (EGSA). The EGSA governance arrangements includes input from member state representatives from an Administrative Board and the European GNSS Programmes Committee. Further details including national points of contact are available at: https://www.gsa.europa.eu/gsa/governance.

9. CONCLUSIONS

A summary of the key points from this document are provided below.

- Space infrastructure, technologies and applications play an increasingly important role in supporting safe and efficient polar operations.
- Space technologies are frequently an ideal solution for observations and telecommunications in the polar regions where a lack of terrestrial infrastructure and harsh conditions make traditional options too expensive or logistically impossible.
- Satellite Earth observation has a unique role in the polar regions, providing the only source of consistent, repeatable, regional scale, calibrated, year-round data for science and operations observations.
- Improving bandwidth of satellite telecommunications at higher latitudes mean larger volumes of data, real time observations and connectivity to remote sensor networks are now possible. This leads to better inputs and outputs of NWP models.
- A wide range of space assets (telecommunications, navigation, Earth observation) are already in orbit or planned for launch in the coming years. The development cycle for space activities takes several years from concept to launch and it is necessary to consider new requirements as soon as possible.
- The European Union and European Space Agency have identified the polar regions as an important driver for new space requirements. Both institutions are conducting current studies to determine requirements for future polar satellite missions. EU-PolarNet should propose to present the outcomes of this task, especially the gap analysis (D3.6), in these fora to contribute to a coordinated approach.
- National polar operators should be proactive about sending national representatives to both the ESA and EC space programs to communicate and represent their requirements for space technologies and infrastructure with clarity and, where appropriate, urgency.
- This report has identified the current use of space technologies to support polar operations. The next phase of this task will identify the gaps in the currently available technology. These requirements should then be contributed to ongoing assessments of polar observation needs as a statement of requirement from European polar operators.