KEPLER

KEY ENVIRONMENTAL MONITORING
FOR POLAR LATITUDES AND EUROPEAN READINESS

Best practice guide for Earth Observation information use by research vessels and stations

Co-funded by the Horizon 2020 programme of the European union

www.kepler-polar.eu

@KeplerEU www.facebook.com/KeplerEU #EUPolarCluster

Table of Contents

1. Objective

Earth Observation (EO) data is generally utilised in some way by research vessels and terrestrial research stations. But with so many EO-based products and sensors around it can be confusing and difficult to get the most out of EO whilst performing fieldwork. This is true for the operators of research vessels and research stations, as well as the scientists that frequent them.

> ***To excel in an environment, you must be able to understand and predict how that environment will evolve over different time scales. Access to the most recent EO products provides timely information that enables us to understand and operate efficiently and effectively in the Arctic, both today and in the future.***

Without the seamless access to satellite products, model output and other observational measurements, it is not possible to provide the situational awareness that field-based research scientists need to perform their research in the Arctic. At present, there are no set guidelines or acquisition policy for the use of EO information on research vessels or stations. The knowledge of how these systems work, and how to get the best out of near-real time EO products whilst in the field, has been acquired by a relatively small number of experienced users, or by people who can tap into the knowledge-base that is held by these users. Furthermore, disseminating near-real time EO information and products to remote field stations and vessels, in a timely and efficient manner, via satellite communication networks, can be challenging and expensive. Thus, knowledge of the advantages and limitations of the communication satellites in your area of operation is a key part of the successful use of EO within field operations in the Arctic. This document will not directly address the different types of EO products and their applicability to support research or activities on the field, that can be found in the KELPER deliverable 3.3: Research Gaps of Arctic Space-based Monitoring.

The aim of this manuscript is to ensure researchers that participate in science performed from research stations (such as those within the EU INTERACT network: *https://eu-interact.org*) or ice-strengthened research vessels (such as those within the EU ARICE network: *https://arice.eu*) have the tools at their disposal to ensure that they are using best practice when accessing EO data whilst in the field. To do this we have captured the knowledge of experienced users to ensure we have a better understanding of the challenges involved, but more importantly we provide a route to overcome these challenges so that we ensure the latest EO data are regularly retrieved and used by scientific field parties right across the Arctic. This will lead to an increased up-take of EO data and products, thus providing enhanced and timely knowledge of the Arctic Environment. By doing so, the safety for Arctic operations is improved, and we ensure knowledge-based decisions are made that benefit both the scientists and the operators of the vessels and stations.

This we believe can be achieved through a ***Best practice guide for EO information use by research vessels and stations.*** We hope that this best practice guide will continue to be updated beyond the lifetime of KEPLER. It should be a document that people can continuously add to, and by doing so we shall ensure that it is always up to date, and has the latest links and information within it.

2. Background

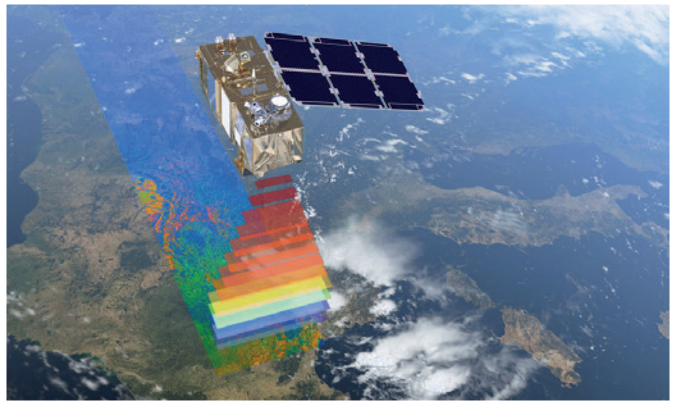
Our ability to understand the environment around us is directly connected to our ability to accurately observe and predict how this environment will evolve in the future; from hours, to weeks, to years. When an environment changes beyond what is considered normal our predictive capability on different timescales is substantially diminished. The changes we have witnessed in the Arctic suggest that is presently outside these normal boundaries. Take sea ice for example, satellite observations over an extended period of time have clearly shown a reduction in sea ice extent in all seasons (Stroeve et al,. 2012; Meier et al., 2014), changes to sea ice motion (Spreen et al., 2011), a dramatic decrease in concentration and extent of multi-year ice (Comiso, 2012), and an expansion of the marginal ice zone (Strong and Rigor, 2013). These unprecedented changes in sea ice properties affect our ability to perform field-based research in the ice-infested seas of the Arctic.

For over a century scientists from all disciplines have performed their research in the remote regions of the Arctic. This research is performed in all spheres (on the ocean, the land, in the atmosphere and the cryosphere), and in all seasons. However, the combination of natural variability and climate-forced changes in the Arctic system make it particularly challenging to predict the ice and weather conditions. (Wilkinson et al., 2017). Moreover, Indigenous Peoples and local Arctic communities often comment that the seasons and weather is not what it used to be. Therefore, it is essential for research-based activities, ocean-based and land-based, that scientists have access to the latest and most appropriate information regarding their surrounding environment. This information must be up-to-date, in a format that is easy to understand, be easily incorporated into a user's computer system (or similar), and in a compressed form that can overcome the communication/bandwidth limitations that exist in the high Arctic.

Accurate knowledge of the Arctic environment is essential to ensure sustainable and efficient use of scientific resources, and to ensure the safe and efficient use of the limited time scientists are in the field. It is therefore important that researchers in remote field sites need to have access to the latest EO observations and products, both land and marine, in order to better understand the environment around them, and more importantly how that environment may change in the coming hours and days.

This is not always the case, and access to the latest EO data and products, via research vessels and terrestrial stations, cannot always be depended upon. There is some emphasis on the researcher to ensure their needs are covered before embarking on Arctic field research. However, there seems to be no set guidelines or acquisition policy for the use of satellite-based information by vessels and stations, with each seemingly having their own protocols and procedures. This document attempts to capture the good practices and to collate them through a **Best practice guide for research vessels and stations.**

The report first discusses the different satellite communication issues regarding working in the Arctic, and especially the high Arctic. An important bottle-neck to overcome if one is to receive EO data in the field. The report then goes on to discuss some of the different products that are available, as well as some of the issues associated with transmitting EO data to field parties. Finally, we discuss a best-practice case study from a research cruise to the high Arctic Ocean.



Sentinel-2A ESA/NASA/STSCI

3. Communication in the high north

Outside the main population centres in the Arctic researchers are reliant on satellite communication systems[1]. Wikipedia defines satellite communications as '*an artificial satellite that relays and amplifies radio telecommunications signals via a transponder; it creates a communication channel between a source transmitter and a receiver at different locations on Earth.*'

Satellite communication systems generally fall under two categories

a) Geostationary and

b) Low-Earth-orbit.

We explain each below, as well as the advantages and limitations with these systems.

3.1 Geostationary communication satellite systems

Geostationary communication satellite systems are placed in orbit above the equator. They orbit at a height of 35,785 km above Earth's equator. This satellite's orbital period corresponds to that of the rotation of the Earth. The result being the apparent position of the satellite in the sky does not change (when viewed from Earth). This is a very important fact as it means that a ground station's antenna, from an Arctic research station for example, can be aimed permanently at the satellite, with no need to change its pointing direction.

Any research station or vessel within the footprint of the satellite can use the system for communications (voice and data). However, for a vessel it is slightly trickier as the vessel navigates through the ocean the antenna may not always be pointing in the right direction. The result being that communications may not always be available, despite being within the communication footprint. Although it is fair to say that omnidirectional antennas can solve this problem somewhat.

3.1.1 Advantages

The good news is that geostationary satellite systems have reasonable communication bandwidth. The result being that a researcher or operator can download/upload most of the things they need, even live streaming video is possible. Some of the main players in geostationary telecommunications are Inmarsat, Thuraya, and Intelsat. Each of these companies have different infrastructure needs (on the vessel or station), and different data/voice transmission costs. It is important to keep good records of what has been sent and received to ensure that these are within your budgeted costs.

3.1.2 Limitations

However, the nature of geostationary satellites means that there are severe limitations at the higher latitude regions of our planet (see fig 1a, 1b). This is because satellites are based around the Equator, and due to the curvature of the Earth there is limited coverage above 75° N, and no coverage above 80° N.

Figure 1a show the spatial coverage of the IMARSAT geostationary communication satellite system. Whilst Figure 1b shows a map of the Arctic region with a blue dotted line shows the location of the Arctic Circle, the 75° N latitude line (a solid blue line), and 80° N latitude line (in black). From Figure 1b we can see that most of the land within the Arctic is within range of geostationary satellites, (except the north of Greenland, Ellesmere Island, and Svalbard as well as sections of northern Siberia), but for the central Arctic Ocean no geostationary communication is possible.

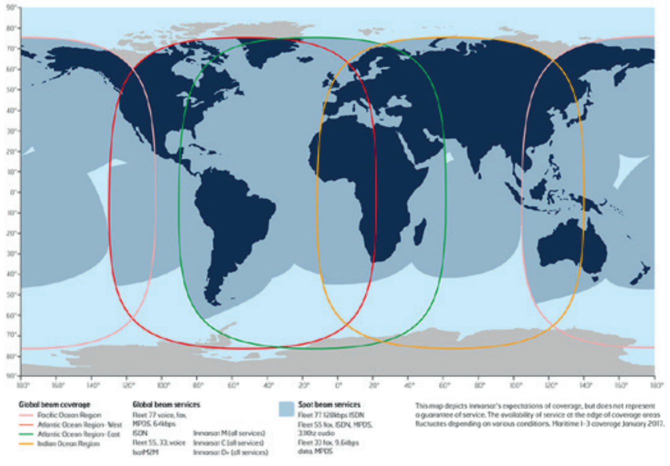


Figure 1a: Geographic coverage from the Inmarsat Marine I-3 system. Notice there is very limited coverage in the polar regions. *Inmarsat*

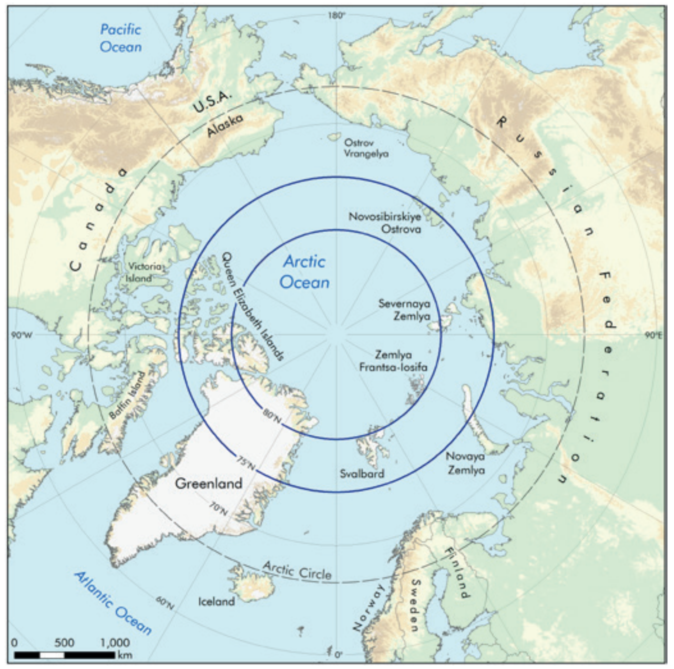


Figure 1b: Map of the Arctic region. Blue dotted line shows the location of the Arctic Circle. Solid blue line shows the 75 N latitude line where some geostationary communication is possible. Black line shows the 80N latitude line where no geostationary communication is possible. *Laura Gerrish, British Antarctic Survey*

Importantly, almost all Arctic land masses are situated at a latitude less than 80° N, which means that most of the EU INTERACT research stations have access to geostationary communication satellite systems (assuming they have the necessary infrastructure in place). It should be noted also that even within the coverage area, local conditions such as trees and/or mountains in the line of sight to the satellite may still prevent or reduce the quality/bandwidth of communication. This can for example be the case for ships operating in fjords surrounded by high mountains or for research stations situated in thick forests. However, research vessels in the central Arctic Ocean are too far north and must rely on other communications systems, namely Low Earth Orbit satellite communication systems.

[1] A good summary of communication issues in the Arctic, entitled: *Telecommunications Infrastructure in the Arctic; A Circumpolar Assessment* by the Arctic Council can be found here: https://oaarchive.arctic-council.org/handle/11374/1924

3.2 Low-Earth-orbit communication satellite systems

Low Earth Orbit satellite systems, or LEOs, generally orbit between 160 km to 2,000 km above the Earth's surface, which corresponds to an orbit period of about 90 minutes. Due to their closer proximity to the Earth LEOs are less expensive to launch and they do not require as high signal strength as the Geostationary satellites. However, their low orbit means their footprint is much smaller than that of the Geostationary systems, thus limiting their effectiveness as a communication satellite system. To get around this limitation and to ensure global coverage they are launched in larger numbers, and have procedures that allow them to communicate together. This ensures that they have excellent satellite visibility and service coverage in the polar regions, and also means very little infrastructure is needed to use the system. For example, the Iridium communication system has a constellation that consists of around 66 active satellites in orbit. These satellites communicate with neighbouring satellites using inter-satellite links, thus ensuring full global coverage. See Figure 2.

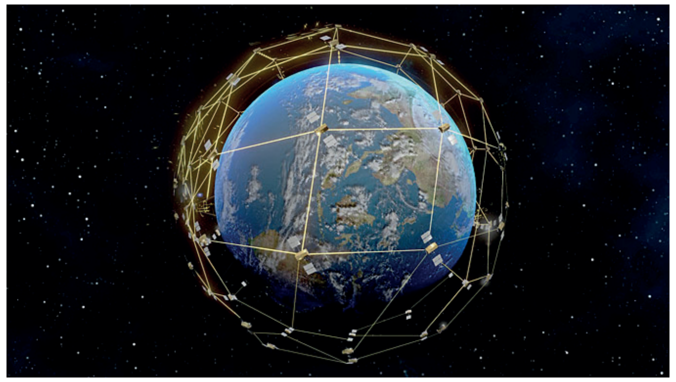


Figure 2: Example showing the global coverage of the Iridium satellite system. *Iridium*

The Iridium satellite communications service was launched almost 20 years ago, and it is presently the "go to" service for transmitting data and voice to and from the high Arctic. Since it became operational it has revolutionized data and voice transfer from the high-latitude regions, but the bandwidth is severely limited, around 1300bps. Which limits what you can transmit, for example video streaming is not possible.

There is a new generation of Iridium satellites, known as *Certus* that has the potential to further revolutionize data transmissions from the high Arctic. At present documentation for the *Certus* system is referencing speeds of up to 704k bps for their Broadband service and 88k bps for their Midband service. These speeds are significantly faster than anything that has come before. It could be a game changer for Arctic communications and may even allow for basic live video streaming. Skype, for example, requires a minimum of 128k bps for video streaming and screen sharing, well within the bandwidth of their Broadband service.

Other LEO possibilities include:

- GoNets (Russian): See https://en.wikipedia.org/wiki/Gonets
- Globalstar (US): See https://en.wikipedia.org/wiki/Globalstar
- Orbcomm (US): See https://en.wikipedia.org/wiki/Orbcomm

The state of play for LEO satellite communications is currently fluid, with a number of new providers engaged in raising funding to support their entry into the marketplace. New services–including OneWeb and Starlink constellations – are on the horizon and look promising, although their Arctic coverage is potentially limited due to orbit inclination. A recent successful example was the test of very high bandwidth communications with the MOSAiC expedition by the Canadian start-up Kepler Communications. Other potential players include SpaceX Starlink. A good review of the current status can be found in Jones et al, 2019[2] "*Closing the Arctic Infrastructure Gap: Existing and Emerging Space-based Solutions*".

3.2.1 Advantages

The advantages of the LEOs, especially the Iridium system, is that it is easy to set up and use. For example, Iridium phones (which differ from normal cell- or smart-phones), with data transmission capability, are relatively inexpensive, and there are numerous suppliers of appropriate SIM cards, as well as many different data/voice plans that can be tailored to your needs. There is coverage over the entire Arctic so there is confidence that you can communicate when in the field, albeit at a cost.

3.2.2 Limitations

The limitations of the LEOs, especially Iridium, centre around the limited bandwidth and high data/voice-transmission costs. The combination of the two means that there can be substantial costs involved in moving large files, including raw EO imagery, over the network. In our experience, there are also issues around drop-outs or lost calls. This means communication can be lost without warning, and will need to be restarted, which can be a frustrating and costly process. This is a very relevant and real problem for the transmission large satellite images, and needs consideration of proper transfer methods to resume transfer.

3.3 Summary

Communications solutions for the Arctic are almost entirely delivered by commercial providers. Meaning coverage is always tensioned against commercial revenue. This is unlike both GNSS and EO where there are many free-to-air options available with a wider public good mandate.

Communication in remote areas of the Arctic can be a challenge, and rarely are communications available that correspond to anything that we are used to at lower latitudes, or within cities and towns. But solutions do exist, through either Geostationary or Low Earth Orbit satellite systems. It is important to know which system you have access to, what are the limitations and advantages of this system, how to use this system, what the data transmission rates are, and importantly what the transmission cost involved will be. Having the answers to these questions will produce a better understanding of what communication is possible to the field team, and how to best transmit much needed EO information to field parties and to platform operators. However, the satellite communication sector is changing fast and we need to keep abreast of opportunities that arise. Furthermore, we need to ensure that we have a good understanding of the advantages and limitations for pan-Arctic communication of each service that comes on-line.

A short note on maritime safety and satellite communication. Previously maritime safety information broadcasting for the Global Maritime Distress and Safety System (GMDSS) of the Joint WMO-IOC Commission for Oceanography and Marine Meteorology (JCOMM) was the sole preserve of Inmarsat (geostationary satellite system), which was itself set up in 1979 as a non-profit intergovernmental organization at the behest of the UN's International Maritime Organization (IMO). However, it was evident that Arctic coverage was lacking, and after prolonged talks and negotiations Iridium (LEO satellite system) has recently added as an authorized GMDSS service provider (Iridium, 2020[3]).

[2] https://aerospace.org/sites/default/files/2019-10/Jones_ClosingArcticGap_10172019.pdf

[3] http://investor.iridium.com/2020-01-13-Iridium-is-Now-Formally-Authorized-to-Provide-GMDSS-Service

4. EO products

There are a wide range of EO products that are freely available from different space agencies and associated organisations. Exactly which products are routinely used by a particular researcher, vessel or station varies depending on their expertise, needs and location. It is beyond the scope of this document to provide links to all the various products available, however, Work Package 2 (WP2) of KEPLER provided an inventory of the products currently available in the two most relevant Copernicus Services for the polar regions: (1) Copernicus Land Monitoring Service (CLMS) and (2) Copernicus Marine Environment Monitoring Service (CMEMS). The results can be found in the KEPLER deliverable reports D2.1 '*Final report on ways to improve the description of the changing Polar Regions in the Copernicus Land Monitoring Service*' and D2.2 '*Final report on ways to improve the description of the changing Polar Regions in the Copernicus Marine Environment Monitoring Service*'. These results were built upon within WP3 and the reader is also referred to deliverable D3.3. '*Research gaps of space-based Arctic monitoring*'.

It is worth noting that not all products can be passively obtained from EO vendors, some products need to be ordered ahead of their acquisition date, such as dedicated SAR imagery and commercial high-resolution optical satellite imagery. These products usually have on minimum order-window before the image is acquired, i.e. three days prior to acquisition. In some instances, ordering images closer to the acquired date could incur significant extra costs.

The following table is an example of some Marine, Terrestrial and Cryospheric products that are presently available from CLMS and CMEMS[4]. This table (derived from D3.3) is not meant to be a comprehensive list, and the reader is encouraged to visit the appropriate space agencies and associated organisations to ensure they have access to the EO data at the right spatial and temporal coverage and that the format and file size is appropriate. Please be aware that not all products mentioned in Table 1 (right) are from satellite observations, some are the outputs from model simulations.

Theme	Variable available from CMEMS
Sea Ice	Sea ice concentration
	Sea ice thickness
	Sea ice drift
	Sea ice Temperature
	Sea ice Type
	Sea ice Age
	Sea ice Albedo
	Snow depths
Cross-disciplinary	Iceberg Density
Physical Ocean	Sea surface temperatures
	Sea surface salinity
	Sea surface height
	Surface currents
Sea state	Significant wave Spectra heights, periods and direction
	Surface Stress (Wind)
Biogeochemical Ocean	Oxygen
	Ocean Colour
	Chl profiles
	Nutrients (NO_2, NO_3, NH_4, PO_4, Si, Fe)
	Zooplankton
	Phytoplankton (PHYC+PP)
	Attenuation Coefficient (KD)

Theme	Variable available from CLMS
Cryosphere	Snow cover extent
	Snow water equivalent
	Lake Ice Extent (Baltic)
	Snow melt
	Snow depth
	Snow avalanche
Energy	Surface albedo
	Land Surface Temperature
	Top of Canopy Reflectance

Table 1: Details some variables presently available at the Copernicus Marine Environment Monitoring Service and the Copernicus Land Monitoring Service (from KEPLER D3.3).

4.1 EO Formatting Challenges

Due to differences in activities, training and background knowledge, there is no guarantee that everyone can understand the EO data that has been sent. Furthermore, the wide range of EO products that are available may have different formats and spatial and temporal resolution, and some data products developed for researchers may not be suitable for all users. It is therefore important when coordinating the two-way data flow with a field team, it's critical that the users of EO data in the field are adept in understanding how to use varying data products on offer. This means they will already have knowledge or will be trained to interpret attributes from different derived products and sensors all of which may be at multiple temporal and spatial scales. However, not all researchers will be proficient in using the different data formats available or understanding geophysical caveats associated with remotely sensed products. Thus, the EO products selected for use should be coordinated between the field team and Logistics Providers, based on their expertise, prior to any field activity.

Another challenge can be attributed to the use of data in non-standard format. What is considered standard format for one type of user may not be appropriate for all users. This issue is further described in the KEPLER deliverable D1.4. For example, researchers or intermediate users can generally use NetCDF or GeoTIFF formats, whereas ship operators or those working in indigenous communities prefer easily accessible data formats, such as geolocated jpg or png.

[4] A couple of comments regarding some of the Copernicus services for polar regions:
1) Please be aware that a lot of the datasets from CMEMS are model forecasts and not EO in the normal sense of EO.
2) Furthermore, CMEMS is an upstream service provider that is designed to deliver a large volume and variety of data to so-called downstream service providers. The data formats delivered by CMEMS are typically not meant for or useful for low bandwidth communication. You may need to use (or are supposed to use) a downstream provider to resolve these issues.

Additionally, the use of EO data formats from a stable processing location differs from what is necessary or suitable in the field. The operational space in the field is often different to the research space. For example, some ships rely on an Electronic Chart Display and Information System (ECDIS) for nautical navigation, which adheres to International Maritime Organization (IMO) regulations, and is different to operational ice charts (IHO, 2012). In this case, a NNetCDF format is not appropriate. The data needs to be converted into another format (i.e. S-100) for operational use within the vessel's navigation system. If these issues are not resolved prior to the cruise, it creates added steps that often lead to unnecessary delays. It can also introduce the possibility of error in the conversion, thus making the data ineffective.

4.2. Improving Preparedness

Perhaps the most critical component for the successful use of EO data and products during a field-based research campaign in the Arctic is the need for good lines of communication; both internal and external to the Research Team. This next section describes the internal discussions and documentation that precedes a field programme, and the two-way dialogue that should occur between the Logistics Provider and the Research Team to ensure a successful, safe and fruitful field campaign for all involved.

4.2.1 Internal Communication within the Research Team

Internally, a Field Manual (or similar) should be written by the Research Team to summarise all the information needed to streamline operations in the field, and to ensure all participants are aware of the logistic plans, health and safety, research operations, as well as the communication, accommodation, and transportation schedules. The Manual should have a dedicated section on EO which the following areas such as:

1. The Point of Contact for EO data transmission
2. State what EO data is needed, when it is needed, and at what spatial and temporal resolution;
3. Provide technical capabilities on how will it should be transmitted;
4. Provide the maximum file limit and the protocols in place to ensure the maximum limit (and available budget) is not exceeded; and
5. State the format that is required for the EO product to be most useful to the Research Team and Logistics Provider.

It is also worth establishing and communicating the schedule for when each EO product will become available, so everyone knows when to expect new files to be transmitted. This can include access to the acquisition plans of relevant satellites during the voyage or field campaign. Furthermore, it is important to agree beforehand on any costs and procedures for changes to the agreed schedule, such as including any costs associated with the acquisition of a new dedicated image.

4.2.2 What EO, modelling and forecast products are needed

It is essential to have a good understanding of what EO, modelling and forecast products are necessary to fulfil the needs of the research programme. It is also necessary to understand which of these products, if any, are routinely obtained by the research station or vessel (see Section 5.2).

The Arctic weather can be severe, and therefore an up-to-date understanding of the weather near your research location is essential. Daily access to the latest weather forecasts is mandatory for any field programme. Access to these forecasts is needed for 'on the fly' planning as Arctic field campaigns are very weather dependent. Ideally, 12 hr, 24 hr, 48 hr and 72 hr forecasts should be available daily. If the Logistics Provider does not supply these, then alternative plans should be made, e.g., to have them sent via the satellite communication service provided by the Logistics Provider, or one you have supplied yourself. Some sources for Arctic weather information include:

- https://www.windy.com
- https://www.yr.no (for Norway)
- https://www.wetterzentrale.de

Understanding the surrounding environment and predicting how it will change on the scale of hours to days is a key part of a successful research programme. This can be best achieved by supplementing weather forecasts with near-real time EO products of the region of interest. EO products that are available (see Section 3: EO Products), and only a small fraction of these will be relevant to any field research programme. For example, the dynamic nature of the sea ice pack means that a research vessel moving through ice-covered seas needs access to real-time information on the sea ice conditions. Sea ice based EO products normally used to make all types of strategic decisions include: ice charts from a relevant Ice Service[5], passive microwave ice concentration maps, visible satellite imagery (limited by cloud cover and polar night) and SAR (Synthetic Aperture Radar) satellite imagery (can see through cloud cover and the polar night) of the region the ship is moving through, or will move through. In addition, satellite derived data products, e.g. sea ice motion and thickness information, can also be useful for near-real time route planning for vessels.

Normally there is not a single EO product that provides an ideal solution, but the solution is normally achieved through the blending of several EO products, reinforcing the need to consider tools and formats to support integrated visualisation of all information products. For example, by using a suite of satellite products a ship can more efficiently navigate through or around the sea ice, and thus better achieve the research objectives of that expedition. Please refer to KEPLER deliverable D1.4: '*Overall Assessment of Stakeholder Needs, on how EO data needs regarding scales vary with users and activity*'.

The most up-to-date products have the maximum value to a field party. Generally, the time-window associated with these products is usually less than 24 hours from collection. Forecasts, such as weather predictions, are valuable out to about 5 days, as this advanced knowledge will allow for significant weather events (that could affect operations) to be identified and ensure preparations can be made in advance. Figure 3 captures the time-period associated with the tactical planning for forecasts (Tactical Future) and near-real time data such as satellite observations that have been collected (Tactical past).

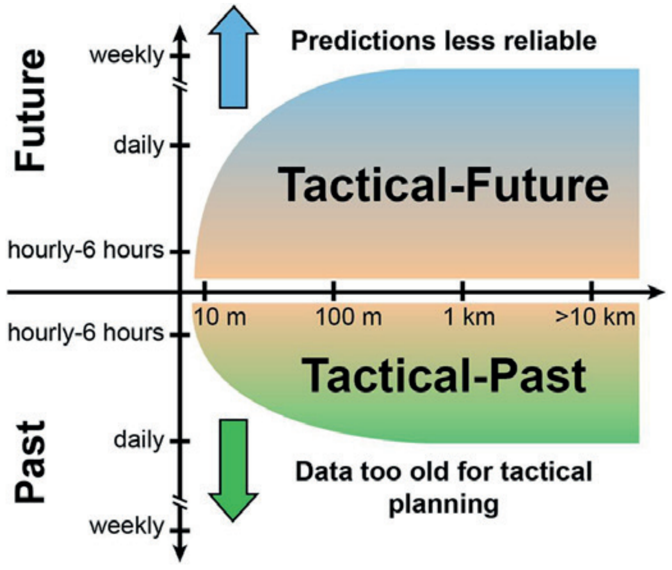


Figure 3: Schematic showing the timeline associated with the usefulness of EO, modelling and forecast products. The older the product the less useful it becomes for tactical planning. *Rainville, Luc et al, 2020 Improving Situational Awareness in the Arctic Ocean. Frontiers in Marine Science, 7. https://doi.org/10.3389/fmars.2020.581139*

[5] Ice charts are a product of the various National Ice Services. These services cover the entire Arctic region and it is worth contacting the ice service that is local to your research area for access to their latest ice charts

4.3 External Communication with the logistics providers

Several months before the field program begins, the team should open the communication channels with representatives of the research station or research vessel. Semi-regular phone calls (and associated email traffic and meetings) are needed for establishing needs, priorities, operating procedures, satellite communication needs and procedures, and so on. This two-way flow of information is critical as it allows the Logistics Provider to understand better the aims and objectives of the field programme, and it provides the Research Team with an understanding of characteristics and operating procedure of that particular research vessel or station. Examples of questions, and information, that should be established prior to the trip include:

- Map out the cruise track or terrestrial fieldwork region/s and agree on number and type of products needed;
- Establish what products are available based on spatial, temporal need, and if they fall within budgetary requirements;
- Identify any supporting data relevant to the activity that may need to be specially ordered and transmitted;
- Establish who can/will interpret the EO information in the field and ensure the appropriate software is available;
- Agree on data transmission file limits and timing for all data that will be used, including identifying areas of potentially poor data coverage or problematic data acquisition;
- Establish contingency plan for changes in field plans and data transmission issues
- Understand the vessel or land stations capabilities to receive and transmit specific data formats. If working with vessels, there is a need to address whether or not alternative data formats are available that may be easier for ships to ingest into their navigational software (i.e. ECDIS systems).
- Ensure that transmitted EO data has geolocation information embedded within the product.

Importantly, by going through this procedure it allows the Research Team to better understand what EO products and weather information they will have regular access to from the Logistics Provider, and what additional EO products and information they should organise themselves (within the operating framework of the Logistics Provider). Any additional EO products obtained should, where possible, also be made available to the Logistics Providers as well. This should be discussed during the semi-regular phone calls and meetings. During these discussions, it is important to consider end user licence agreements for satellite imagery and information products. The following sections describe some of the issues to consider when coordinating data exchanges between researchers and Logistics Providers.

Nick Hughes (KV Svalbard)

5. Transmitting EO products to and from Field Parties

As mentioned above (Section 5.2) the Research Team and the Logistics Provider should, have identified any additional EO products beyond those that are regularly obtained by the Provider. In addition, there should be a comprehensive understanding how these additional EO products can be transmitted to the research vessel or station in a timely fashion.

5.1 Earth Observation latency

There will always be a delay from when EO data is acquired by a satellite, to when it becomes available to the end-user. This delay is generally measured in hours, but in some instances, there may be reasons why the product can only become available on a longer timeframe. For real-time planning during a field campaign, the longer the delay, the less valuable the product becomes (see Section 4.2.2). Each EO product will have gone through several refinement and quality control processes before being released to the end-user. It is worthwhile having a rudimentary understanding of the timelines that underlies when a product is collected (i.e. the predicted overpass by the satellite), to when it becomes available to the end-user. By better understanding this process the latency between retrieval, availability and subsequent transmission to the vessel or station can be minimised. If timing is critical, automatic routines can be written to routinely check and pull appropriate EO products from dedicated EO websites. In fact, some services provide automatic email notification of new data over an area of interest defined by the user. These EO products then can be transferred to a local site (normally run by the Research Team's institute) from where they can be transferred to the research vessel or station.

It is also worth considering satellite imagery that might be received directly from a local receiving station (on a ship or at a research station) through a VSAT / DARTCOM like system. These options can provide lower resolution optical imagery, subject to cloud cover, in almost real-time. They also have the advantage of (a) very low latency and (b) bypassing the communication bandwidth limitations experienced at high latitudes.

5.2 Data Transmission

If the Logistics Provider confirms that bandwidth limitations do not exist, then additional EO products can be obtained through standard protocols such as email attachments, downloading from websites, or pulling the data from FTP sites. However, if limitations do exist then the provider may set limits on file sizes, or possibly the total amount of data that can be transmitted. In some cases, traffic-shaping solutions can allow prioritised transfer of EO information to avoid conflict with less important information over the same bandwidth. In the worst-case scenario, the researcher may have no other option than to set up their own satellite communication system. All options should be discussed thoroughly with the Logistics Provider. It is beyond the scope of this document to explain how to set up a dedicated satellite communication system. Although it is not as hard as it seems.

5.2.1 Method of delivery

Depending on the available means of communication, data can be delivered either by push or by notification and pulling. With the push method all relevant data is sent directly to the user based on pre-set requirements. As necessary data are made available, this method may require high communication bandwidth. For this reason, it is important to tailor what is pushed, and reduce data volumes by using limited areas of interest (AoI), reduce spatial resolution and select appropriate choices of file formats. With the notification/pull method, the user actively downloads relevant data products upon notification (usually by email) from the relevant information provider.

If there are bandwidth limitations, a compromise between the resolution of the EO product needed by the Researcher, and the size of file allowed to be received by the Logistic Provider is necessary. Three standard techniques to minimise file sizes are:

1. File compression: Minimise file sizes using compression software
2. EO resolution: Downgrading the resolution of the EO product to reduce file sizes
3. EO coverage: Reducing the area of the EO product will reduce file sizes.

For example, SAR images[6] are mainly used to assess sea ice conditions around a research vessel in the Arctic Ocean, but often they are too large to be sent over a bandwidth-limited communication system. The original SAR product may be 400 km wide and have a pixel resolution of 20 x 40 m (and be many megabytes in size). Even with the best compression software the original SAR image is most likely beyond bandwidth limitations. However, the Research Team may only need information regarding the ice condition up to 50 km around the ship. In this instance a 50 km x 50 km geo-located sub-image, centred around the vessel, may be an appropriate solution. If this is still too large to be sent then the image can be further trimmed, or the pixel resolution downgraded from its original 20 x 40 m to larger pixel size of 100 m x 100 m or more. By exploring these options an appropriate solution may be found. Such a solution may also include applying appropriate lossy data compression such as jpeg or the streaming of an image using a wavelet compression format such as jpeg2000[7].

Given the time needed to find an appropriate solution, it is important that acquisition plans are in place and tested well before a field programme begins. It is optimal if this solution can be automated with a script, where no user intervention is required, other than periodic quality control.

5.3 Data visualisation

It is beyond the scope of this document to go into the details of data visualisation, but it is worth making a few comments. It is important that any EO product sent to field-based researchers is in the appropriate format to be ingested by their geographic information system (GIS) software, such as ArcGIS, QGIS, GlobalMapper, etc. Moreover, these additional EO products can be very useful for the Logistics Provider, such as within the navigational software of a research vessel. Required data formats for data visualization will vary greatly, therefore, it is always useful to check that this is indeed the case, and if it is what format they prefer the EO product to be in.

5.4 Summary

This section has shown the importance of frequent communication between the Research Team and the Logistics Providers to ensure both teams have a good understanding of their respective needs. Part of this process is ensuring the Research Team relays to the Logistics Providers the EO products that are needed to fulfil their research objectives as well as for day-to-day tactical planning. Part of this process is understanding the communication bandwidth limitations that may exist, and to ensure solutions are in place, and well tested, before the field campaign begins. By doing so the full potential of both the Research Team and Logistic Providers is released to the benefit of scientific knowledge and research.

[6] https://sentinel.esa.int/web/sentinel/missions/sentinel-1/instrument-payload/resolution-swath

[7] This option requires an open internet connection, but it allows the full image to be accessible at full resolution, if required. It is achieved by only sending the part of the image required for the screen AOI at the screen resolution. This significantly reduces the total volume of data that needs to be transferred over the ship-shore bandwidth.

6. Good practice case study

There are numerous case studies that highlight good practice in the use of EO data on research vessels or at research stations. The one highlighted here is not meant to be the definitive practice, as processes can always be improved, but it was included to show the thought processes by the team that went into making the best use of EO data within the constraints of a research cruise to areas of the high Arctic. This case study forms part of a manuscript that is in preparation by Luc Rainville[8] and colleagues.

6.1 Stratified Ocean Dynamics of the Arctic programme

The Stratified Ocean Dynamics of the Arctic is a Departmental Research Initiative (SODA DRI[9]), funded by the US Office of Naval Research. The aim of SODA is to better understand how the changing Arctic sea ice environment impacts Arctic stratification and circulation, sea ice evolution, and the acoustic environment. SODA is a collaborative project involving over 25 principal investigators from more than a dozen US, European and international institutions (Science Plan, Lee et al., 2016[10]).

The 2018 research cruise, on-board *USCGC Healy*, was the first of a series of SODA cruises to the Beaufort Sea region in the late summer. The main objective of the 2018 cruise of was both sea ice and ocean based:

(a) Ocean: deployment of several gliders and three deep-water moorings;

(b) Sea ice: deployment of several robotic platforms on the sea ice itself.

Ideally, the Gliders and deep-water moorings should be deployed in open water, however the deployment region for these assets was fixed, and it had the potential to be ice covered. Difficulties can arise when sea ice in the region where gliders are being deployed, can cause substantial problems with the deployment of the mooring line. Therefore, understanding the local ice conditions (if any), and how the ice would evolve over the coming hours and days was essential for planning on when and how to deploy these assets. Thus, a combination of near-real time ice conditions, model sea ice drift scenarios, and weather forecasts were needed.

On the other hand, the on-ice deployments of the robotic platforms required very different environmental conditions. They needed to be deployed well inside the ice edge, and ideally on thick multi-year ice (MYI) floes. This combination is most beneficial for the longevity of the robotic platforms. Therefore, the identification of the MYI floes (away from the ice edge), in certain key regions, were wanted in order to guide the ships to the location of these floes. Thus, near-real time ice conditions were required.

Many months before the cruise the SODA team established the needs and priorities of the cruise and wrote a comprehensive field manual. The key players in the success of receiving near-real EO information were identified. These were:

- The logistics providers of *USCGC Healy*: US Coast Guard
- Local sea ice charting providers: US National Ice Center (NIC)
- Satellite data providers: such as data from the ESA Sentinel 1 series

Key players of the SODA science team commenced semi-regular meetings with the US Coast Guard, and the National Ice Center. These discussions orientated around not only identifying the best EO products, but how to move these products and associated information from shore-to-ship and/or ship-to-shore. Especially when *USCGC Healy* moved out of range of the fast and efficient geostationary communication system, and into the much slower and bandwidth-limited LEO, Iridium, domain.

The solution arrived at was a bespoke shore-based FTP system from which both geo-located high-resolution images (for geostationary communication) and lower-resolution images (for Iridium communication) could be successfully obtained. Scripts were written to automatically put these images on the FTP site, and to create low resolution images from the higher resolution images for potential transfer via Iridium. All these images were in an agreed format, from which both science and ship's navigational software could digest.

The EO, weather and modelling information available to be transmitted to the ship included:

- NIC ice charts
- Pre-ordered Radarsat-2 images
- Sentinel-1 SAR images
- MODIS/VIIRS images
- Weather forecasts
- Model sea ice drift data from the Naval Research Lab's high resolution Global Ocean Forecasting System (GOFS).

Given the dynamic nature of sea ice, the importance of receiving EO images as soon possible after acquisition time cannot be overstated. In our case, all images were available within 12 hours of acquisition, with the fastest delivery being 0.3 hours. This system worked extremely well for all involved, (ship and science) and certainly aided the successful and safe deployment of all assets.

With this increased situational awareness regarding the local environmental conditions (through the transmission and use of appropriate EO, modelling and weather products) the captain and crew of *USCGC Healy* and SODA team were together able to successfully and efficiently fulfil all the objectives of the cruise. In some instances, this meant reshuffling the order of deployment operations. When this occurred, the decisions were based upon the knowledge gained from the different transmitted products.

Nick Hughes (KV Svalbard)

[8] Rainville, L et al., (in prep) *Improving Situational Awareness in the Arctic Ocean.*

[9] see http://www.apl.washington.edu/project/project.php?id=soda

[10] The Stratified Ocean Dynamics of the Arctic (SODA): Science and Experiment Plan can be obtained here: http://www.apl.washington.edu/research/downloads/publications/tr_1601.pdf

References

Comiso, J. C. (2012), Large decadal decline of the Arctic multiyear ice cover, J. Climate, 25, 1176– 1193.

IHO, 2012. Operational Procedures for the Organization and Management of the S-100 Geospatial Information Registry (Edition 1.1.0, November 2012)

Meier, W. N., G. Hovelsrud, B. van Oort, J. Key, K. Kovacs, C. Michel, M. Granskog, S. Gerland, D. Perovich, A. P. Makshtas, and J. Reist, 2014. Arctic sea ice in transformation: A review of recent observed changes and impacts on biology and human activity, Rev. Geophys., 41, doi:10.1002/2013RG000431.

Spreen, G., R. Kwok, and D. Menemenlis (2011), Trends in Arctic sea ice drift and role of wind forcing: 1992–2009, Geophys. Res. Lett., 38, L19501, doi:10.1029/2011GL048970.

Stroeve, J. C., V. Kattsov, A. Barrett, M. Serreze, T. Pavlova, M. Holland, and W. N.Meier (2012), Trends in Arctic sea ice extent from CMIP5, CMIP3 and observations, Geophys. Res. Lett., 39, L16502, doi:10.1029/2012GL052676.

Strong, C., and I. G. Rigor (2013), Arctic marginal ice zone trending wider in summer and narrower in winter, Geophys. Res. Lett., 40,.).

Wilkinson, J., C.J. Beegle-Krause, K. Evers, N. Hughes, A. Lewis, M. Reed, P. Wadhams (2017). Oil spill response capabilities and technologies for ice-covered arctic Marine waters: a review of recent developments and established practices Ambio, 46 (3), pp. 423-441, 10.1007/s13280-017-0958-y

Acknowledgements

This best practice guide has been strengthened through input by several experts in this field. We would like to thank Andrew Flemming (BAS), Nick Hughes (Met Norway), Roberto Saldo (DTU), and Leif Toudal (DTU). These experts sacrificed their valuable time to review and comment on the document. We would also like to thank the management team of KEPLER who have been very supportive during the writing of this document. Thank you all.

PARTNERS

CONTACT

For more information please contact either:

KEPLER Coordinator
Nick Hughes, Head of
the Ice Service at Met Norway
email nick.hughes@met.no

KEPLER Project Manager
Elaina Ford,
British Antarctic Survey
email elaina.ford@bas.ac.uk

KEPLER is a member of the EU Polar Cluster:
www.polarcluster.eu @EUPolarCluster

@KeplerEU www.facebook.com/KeplerEU

This project has received funding from the European Union's Horizon 2020 research and innovation under grant agreement No. 821984.

www.kepler-polar.eu