EU-PolarNet White Paper No. 5

Advancing operational informatics[1] for Polar Regions

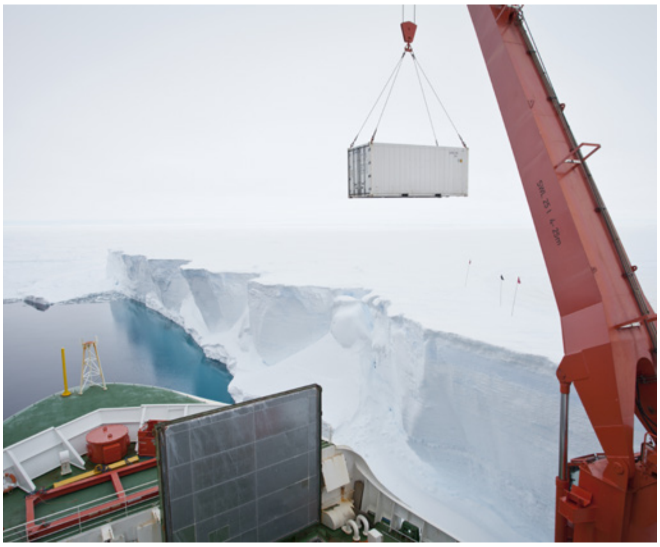
Wind generator at the Neumayer Station III in Antarctica *(Photo: Alfred Wegener Institute / Thomas Steuer)*

Motivation and background

The Polar Regions are characterised by low levels of communication technology, stemming from poor connectivity of ground-based systems to mobile and satellite platforms. Anyone who has worked in the Polar Regions will testify to the slow and expensive download rates, and the inability to exchange information efficiently between users. This makes the use of novel, innovative and emerging digital technologies impossible to utilise fully in the high latitudes.

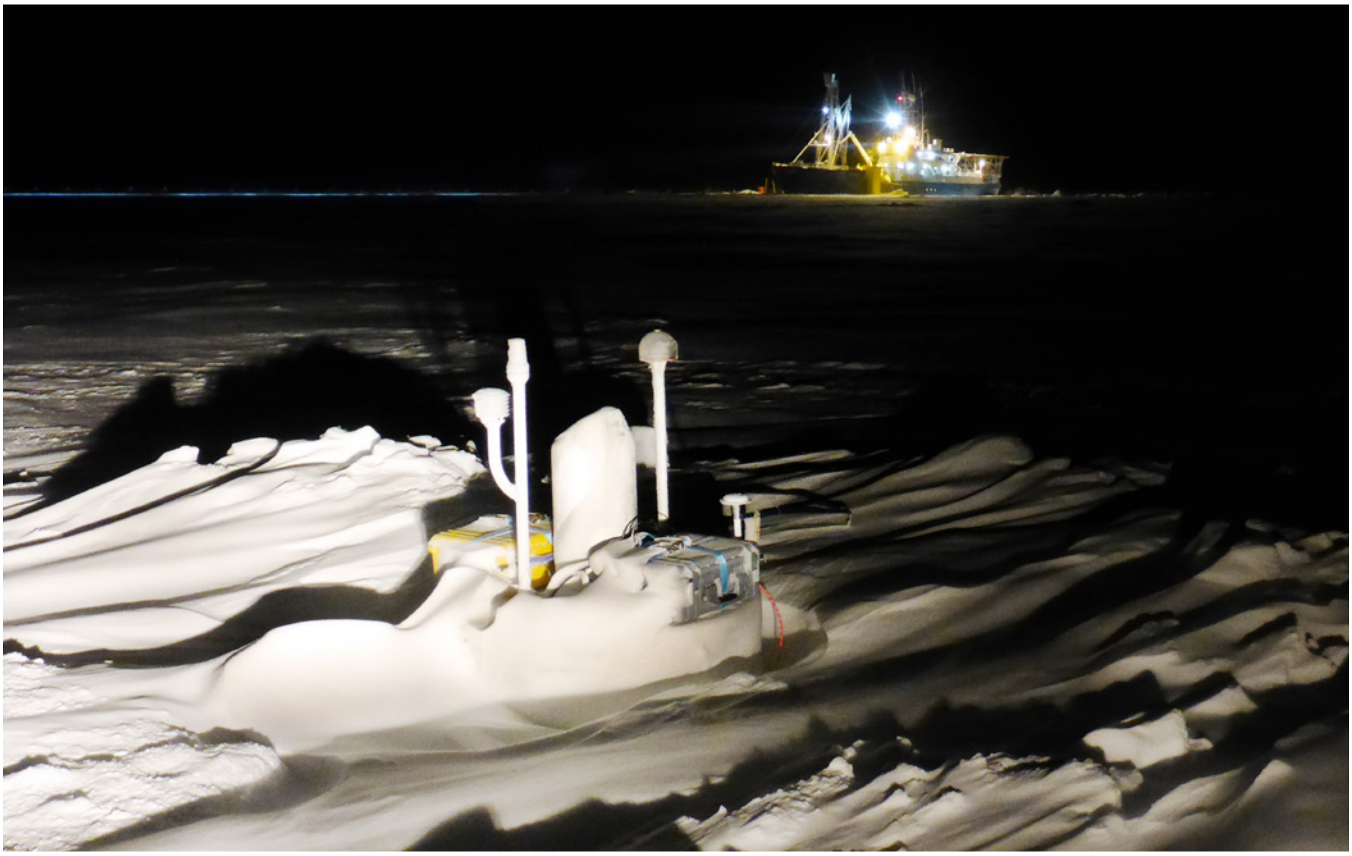
Many parts of the world have experienced a 'data revolution' advancing areas of scientific research, business and industry, education and societal well-being in numerous exciting ways. However, as recognised by the Joint Statement of Ministers (on the first White House Arctic Science Ministerial; 28 September 2016, Washington, DC, USA) **"many areas of the Arctic are data-sparse, and in some parts the paucity of observations is compounded by the lack of universal access to data. These shortfalls hinder scientific progress, the development of value-added products and services, and the formulation of innovative strategies for managing social and environmental changes in the Arctic and beyond."**

The solution to this widely-acknowledged problem is an internationally-agreed effort to introduce effective data and information systems to the Polar Regions (e.g. taking an informatics approach). The benefits would be three fold. **First,** for science, access to data offers opportunities to widen our observation pool and to link such observations to numerical models of natural processes. There is also opportunity to form intelligent systems, allowing information to be gathered autonomously and effectively as needed, and exchanged with users across short timescales. The outcome will be a step-change in our ability to understand the physical and natural changes occurring in the Polar Regions. **Second**, for business and industry, data systems will aid navigation of ships, allow marine resources to be tracked and measured, and form shared records on which regulation on important extractive industries can be formed. Access to data is linked to economic growth and jobs throughout the world, and the Polar Regions are no different. **Third**, for society, the benefits are also significant in terms of avoidance and mitigating both natural and man-made disasters, education healthcare, and



Research vessel Polarstern resupplying the research station Neumayer Station III in Antarctica *(Photo: Alfred Wegener Institute / Thomas Steuer)*

[1]Definition: "Informatics studies the representation, processing and communication of information in natural and engineered systems. It has computational, cognitive and social aspects." (University of Edinburgh, School of Informatics 2017).



Norwegian Research vessel „Lance" and IAOOS buoy in the Arctic Ocean (Photo: Michel Calzas, CNRS)

a better understanding of the manner in which changes in Polar Regions impact weather and climate over Europe (teleconnections).

While informatics has grown to the benefit of many regions of the world, the Polar Regions have been left behind. A concerted understanding on how to remedy this problem is critical to science, society and business and is overdue.

In this White Paper, we detail the research needs of operational levels of informatics in Polar Regions, and how scientific discovery will be a major beneficiary. We also discuss how the approach will improve societal well-being and lead to business opportunities and economic growth.

The challenge is significant, however. For example, it is unclear how operational informatics is best implemented in the Polar Regions, and what the cost/return of investments would be. Similarly to the Arctic Science Ministerial (2016), we are convinced, however, that having access to data and information would lead to substantial benefits to research, society and business.

As a first step toward enhanced informatics in Polar Regions, **we recommend the EU commission a formal scoping study** of the problem, pulling expertise in informatics together with knowledge of polar conditions and existing operations systems. Only then can we fully understand how the Polar Regions problems with information access and sharing can be understood, planned and implemented.

Societal Relevance

An effective data and information system in the Polar Regions will improve interoperability and exploitation of distributed datasets allowing enhanced services and information systems for society, industry and science. The following Business and Society sectors will benefit substantially from the development of such a system in the following ways:

Business

Informatics will assist the Business Community of the Polar Regions through enabling: (1) Project assessment and feasibility studies (economics, risks, environmental evaluations, operational considerations etc.); (2) Business opportunities in implementing these services; (3) Commercial services based on research-driven informatics systems (e.g. Copernicus); (4) Trade and supply chain management; (5) Organisations overseeing adherence to standards and regulations; and (6) Safe and responsible tourism (e.g., NW Passage, Arctic and Antarctic Cruises).

Society

For society, the benefits of informatics are also significant to areas such as: (1) Regional development; (2) Community development (communications between communities); (3) Standards and permitting (international, regulations, sustainable management of resources); (4) Educational services (across the full spectrum of delivery - schools, universities, distance learning, professional training etc.); (5) Cultural exchanges - connect EU and Arctic residents; (6) Disaster preparedness and early warning systems; (7) Search and rescue operations; (8) Navigation and logistical services; (9) Capacity, capability and efficiency in public management; (10) Security issues (such as border control); (11) Health services (basic, emergency, epidemiology); (12) Urban and infrastructure planning; and (13) Safeguarding subsistence resources (reindeer herders, artisanal fisheries, etc.).

Global Sustainability Goals

Research in enhanced informatics in the Polar Regions is aligned with the seventeen UN Sustainable Development Goals (SDGs) in a variety of ways. A table summarizing these links is given below. We draw attention to the following SDGs, where we think particularly strong positive impacts exist:

Research Needs

Our strategy is to recommend, facilitate and promote research that can deliver operational levels of informatics. In doing so, the outcomes will support the development of four other WPs (Climate and Cryosphere (WP#1), People and Societal Issues (WP#4), Polar biology (WP#2), and Natural Resources (WP#4)) to reach their specific goals.

The development of polar informatics will address current limitations in collection, integration, processing and communication of information. Importantly it will build on developments in relevant domains including new communications networks, data management, cloud-computing and information visualisation. The development of informatics tailored to the specific needs

Sustainable Development Goal	Explanation	Relevance to the Polar Regions
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	The Polar Regions, should be a major recipient of progress in SDG9, and much of this White Paper is a consequence of the present-day lack in infrastructure
11 SUSTAINABLE CITIES AND COMMUNITIES	Make cities and human settlements inclusive, safe, resilient and sustainable	There are numerous cities in the Polar Regions, and because of the harsh environments surrounding them, there is an urgent need to consider ways to make them safer and more resilient, as well as sustainable
13 CLIMATE ACTION	Take urgent action to combat climate change and its impacts	The Polar Regions are seeing some of the greatest impacts of climate change on the planet – through polar amplification of atmospheric warming and through the melting of ice
14 LIFE BELOW WATER	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	The oceans are a major source of food and income for the Polar regions, and their sustainable use and management is key to future prosperity.
15 LIFE ON LAND	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Polar regions land use change needs to be managed sustainably, if we are to maintain ecosystems and their natural services
17 PARTNERSHIPS FOR THE GOALS	Strengthen the means of implementation and revitalize the global partnership for sustainable development	The Polar Regions are very much an international space, where collaboration is both natural and essential or tackling the major problems that exist, such as access to data and information.

3 GOOD HEALTH AND WELL-BEING · 4 QUALITY EDUCATION · 8 DECENT WORK AND ECONOMIC GROWTH · 10 REDUCED INEQUALITIES · 16 PEACE, JUSTICE AND STRONG INSTITUTIONS

By establishing an infrastructure for informatics in the Polar Regions, and delivering on the above SDGs, we assert that there would be significant benefits to commercial, industrial and public services. This is manifested in further SDG progress in health, education, economic growth, reduced inequality justice.

Electromagnetic (EM) induction sounding for ice thickness measurements is a technique that can achieve long profiles of some kilometer length. The accuracy and robustness of the EM method has been evaluated by comparing coincident drill-hole and EM measurements. *Photo: Alfred Wegener Institute / Stefan Hendricks*

of the Polar Regions requires a coordinated research effort. This will address relevant aspects specific to the Polar Regions including limited communications capabilities, the harsh and remote environment, and limited in situ observations. The result should be a better connected information network, providing tools for easier exploitation of information by all stakeholders in the Polar Regions.

Subtopic 1: Communication systems

Key Message 1. Polar Regions are data poor and lack communication infrastructure for reliable and effective data sharing for research, services and societal needs.

Communication methods are limited, costly, and often unreliable in Polar Regions. Providing high-speed, low-cost, and reliable communications to Polar Regions will open the door for innovation and economic development. The ability to exchange information and data will enable rapid advancement of polar science, thereby adding value to existing and planned polar and climate research initiatives and permitting truly ground-breaking research to be undertaken in the future. Real-time access to data and information will increase situational awareness in general and promote safer maritime navigation and 'Safety of Life at Sea' (SOLAS), and general economic development through more accurate and timely assessments of environmental conditions and human impacts. High-speed, affordable communications will benefit all Arctic residents through access to information and education (from pre-K to university and professional development) and will decrease response times during emergencies (disease/medical, weather-related extremes, oil spills, etc.). Improved communications will also promote health and well-being of Arctic residents through developments such as tele-medicine and cross-cultural exchange.

Research is needed to adapt existing communications technology, and to implement and evaluate emerging technology, with the goal of establishing a polar communication network that:

- Can withstand harsh and variable environmental conditions;
- Is accessible (affordable, scalable, and user-friendly);
- Minimizes impact or damage to polar ecosystems and heritage sites (low footprint, green tech);
- Provides high speed/bandwidth in all polar locations (not only in population centres or high-density shipping lanes); and
- Enables links to be made between measurements from all components of earth and climate systems: atmosphere, ice, land and ocean.

Linking observations with models, and information interoperability (Subtopics 2 and 3), will have a much greater stakeholder impact if the communication problem is solved. Stakeholder activities in Polar Regions are increasing and we must put a communication system in place that can handle current and future needs.

One area of interest with a large degree of overlap in science, industry and society that will benefit from communication capabilities is surveying and mapping, as vast areas of the poles do not have modern accurate maps and hydrographic charts. Accurate maps and charts will aid in navigation of both ships and aircraft and high-resolution bathymetry is critical to improve coupled models. Improved communications, complemented by advances in sensors and models, and interoperable data standards, will enable the type of rapid mapping that is required in the context of climate change. Raw field data can be processed in real-time using cloud-computing services.

Global Navigation Satellite System (GNSS) augmentation services need to be developed, and a polar network of Continuously Operating Reference Stations (CORs) should be expanded. Increased communication capabilities will also allow ships to receive important weather-related and sea-ice information, and also to transmit environmental data to scientists and Joint Rescue Coordination Centres (JRCCs). Finally, communication capabilities, in addition to providing societal benefits like healthcare and education, will allow citizens to participate in research initiatives.

Research on board of Polar6 aircraft near Rothera Station, Antarctic Peninsula (*Photo: Alfred Wegener Institute, R. Ricker)*

We are aware of ongoing subsea telecommunication (fibre optic) cable projects in the Arctic – such as the Quintillion Project (cable from NE Asia to Alaska and onwards to Europe along the Northwest Passage) and Arctic Connect (cable from NE Asia to Russia and onwards to Europe along the Northeast Passage). The Quintillion Project is already providing for the first time broadband Internet services to Alaskan Arctic communities ranging from Nome to Prudhoe Bay. Further developments along these lines are welcome and should be planned in an integrated, inter-connected manner.

Subtopic 2: Linking observations and models

Key Message 2: We must address the deficiency of observations in Polar Regions and the inability to assimilate existing and future observations into Earth System models and weather and climate prediction.

Compared to most other parts of the globe, there is very limited collection of in situ observations from the Polar Regions. The deficiency of polar in situ data limits the development and accuracy of earth system, climate, and weather models. The lack of observations is, in part, due to the vast, remote and harsh environment, which makes collection from the ground, ships and aircraft both logistically and financially prohibitive.

The situation would be improved by the deployment of many more sensors and instrument platforms. However, developments are required in several aspects, listed below, to tailor them to the polar environment:

- Sensor 'ruggedisation' to cope with low temperatures, harsh and variable conditions;
- New battery technologies and power options to allow long-term autonomous operation;
- Low cost, miniaturised technologies allowing deployment of large numbers of sensors; and
- Transferring to biodegradable components or developing options for instrument recovery to minimise the environmental impact.

In addition, new sensors will need to include advances in communication technologies data compression and transmission. Developments should consider the creation of smart sensor networks (with variable sampling rates and AI-based autonomous tasking) and integration with expanding polar communications networks (including new satellite communications and fibre-optic options). These advances should allow increasing volumes of data, required in real-time from the polar land surface, ocean and under ice.

A step-change in the availability of polar in situ or remote observations will also require improvements in the methods to assimilate these data into earth system climate and weather forecast models. New research efforts are required to improve operational assimilation and quality control methods, addressing both in situ and remote sensing (satellites, aircraft, drones etc.) observations.

Furthermore, even the most advanced models use parameterisations of unresolved, sub-grid-scale processes. Examples include small-scale turbulence and ice-ocean interactions. Studies have noted that critical climate processes, like deep-water formation, exhibit strong sensitivity to the type of parameterisations employed. Observations in key regions, and of critical processes, will enable better models with increased ability to predict processes, events and their impacts.

Subtopic 3: Information and interoperability

Key Message 3: Interoperability and exploitation of distributed data will provide useful information in a collective sense for science, society, industry and operations in Polar Regions.

The aforementioned advancements in data collection and earth systems modelling will provide more value to EU stakeholders if they are easily accessible and useable. The breadth and scope of data collection initiatives and platforms means data will be delivered by an increasing number of distributed repositories. It is essential that open interoperable standards are developed and promoted to ensure these data can be contributed by, and are accessible to, the largest possible audience.

A key aspect will be development of two-way communications links to allow community-based observations to be contributed to and shared (e.g. mobile phone sensor networks). Development of standards must happen in close collaboration with existing initiatives and established data management approaches (IASC Arctic Data Committee and SCAR Standing Committee on Antarctic Data Management). Further development of cloud-based data exploitation platforms is also required. These are currently under development in some sectors (e.g., EC DIAS system), but need to be promoted and extended for the Polar Regions. These technologies provide access to data, software tools, virtual development environments and computer processing resources in an online cloud infrastructure. This has a key benefit of democratising access to both big data and high performance computing resources required to develop and deliver information and information services. Effort is required to ensure these platforms are developed according to specific data requirements, software tools and access needs of the social and scientific polar communities who will benefit from them.

The integration of data and improved communications bandwidth should be considered the basis to develop new data mining, information extraction and visualisation tools. These will increase the value of available data, making them more easily understood and delivering easily digested material for wide syndication. A focused effort should consider appropriate tools and visualisation options for the Polar Regions, including real-time visualisation applications from remote devices.

Relevant Cooperation Partners

To deliver informatics infrastructure, it is important to work alongside a number of organisations to ensure fit for purpose and value for money.

In the Arctic, it is important to recognise the contribution and assets linked to the Arctic states – Russia, USA, Canada, the Nor-

Sector	Stakeholder	Reasoning (position, influence, impacts, etc.)
Logistics	Arctic Council Nations, First Nations	Proximity, assets, people
	IASC, ATCM, COMNAP, SCAR	Multi-national discussion and planning
	ESA	Assets and platforms
Science community	IASC; SCAR; ATCM	Means to engage the scientific community with long-term planning of infrastructure
	CCAMLR; COMNAP;	
	FARO; ISO	
Industry and business	Arctic Economic Council; World Economic Forum;	Offering investment and financing
	investment and finance sector; insurance industry;	
	fishing; shipping (IMO, Polar Code, ISO, classification societies;	Matching regulations and planning
	tourism (e.g., IAATO, AECO);	
	extractive industries (mining, oil-gas exploitation);	
	aviation and space sector	
Public	Arctic regional governments, coastal and local authorities	Beneficiaries of enhanced informatics, allowing long-term planning and growth
	EU citizens	Improved access to education, health and environmental prediction

dic Countries, as well as the First Nations – in fully implementing the recommendations in this white paper. We also see a major engagement with China, Japan and South Korea in developing the ideas outlined here.

For the Antarctic, the role of the ATCM will be critical to engaging multiple nations in a collective effort. Additionally, COMNAP has a significant role to play. The SCAR Horizon Scan based COMNAP ARC initiative identified "new and improved satellite sensors, including appropriate coverage and availability" as one of the major cross cutting technology requirements for the Antarctic.
For both Polar Regions, space technologies will play a very important role in delivering operational informatics. This will require dedicated activity and cooperation from the European Space Programme delivered by the EC and ESA.

The following three stakeholder groups will benefit from improved operational informatics in the Polar Regions.

Science (research) community

The whole scientific community will benefit greatly from increased communication abilities, expanded in situ sensor networks allowing continuous real-time monitoring, and enhanced modelling and data sharing to advance our currently limited understanding of the polar environments and the numerous changes taking place there due to climate change (as mentioned, stakeholders include: IASC; SCAR; CCAMLR; COMNAP; FARO; Arctic Council; ATCM; Arctic Council research agreement; ISO; and others).

Industry and business

It is generally agreed the main driver of near-future socio-economic development in the Arctic region is natural resource exploitation. But it is very important to focus also on local and regional value-creation and development that will benefit local people and the Arctic regions themselves (boost regional economic development and job creation as well as healthcare and well-being). Increased communication networks, observations, and information availability is essential for innovative industrial development and investments, regional planning and feasibility studies, environmental impact assessments, transportation and logistics systems, and for all infrastructure development in general (stakeholder include: Arctic Economic Council; World Economic Forum; investment and finance sector; insurance industry; fishing; shipping (IMO, Polar Code, ISO, classification societies; tourism (e.g., IAATO, AECO); extractive industries (mining, oil-gas exploitation); aviation and space sector; and many others).

Public

Governmental bodies such as Arctic regional governments, coastal and local authorities, will benefit from enhanced communication networks and information sharing for their decision-making, governance and urban and regional planning. Enhanced informatics will improve the formulation of local and national policy, plus the monitoring of policy implementation and effectiveness. EU citizens and organizations tasked with weather prediction and response to extreme events (storms, floods, etc.) will benefit from an improved understanding of the changing polar en-

Nothern lights above the Arctic Ocean *(Photo: Alfred Wegener Institute / Stefan Hendricks)*

vironments and access to improved environmental information services, e.g. national weather services. Changes in polar environmental conditions can affect the lives of EU citizens through teleconnections, but a full understanding of the range and scope of the problem requires the approach proposed here.

Enabling Capacities and Resources

The EU has the capacity, expertise and links to Polar Nations to lead this initiative. Through its existing strengths in polar research, Europe is ideally placed (with its core infrastructure, academic and industrial expertise, partnerships and economic strength) to form a bespoke (tailored to the needs of the Polar Regions, primarily) informatics system that will lead to advances in our understanding of processes and change in these remote and challenging environments.

The EU is a major contributor to polar research. Over the past decades the EU efforts have been devoted to improve Arctic observation and monitoring programmes as well as to fund numerous research projects to better understand the Arctic and the ongoing change (e.g. INTAROS; APPLICATE, Blue Action, Nunataryuk all funded in H2020), but Arctic systems, their functions and possible responses to various drivers are still largely unknown due to a lack of proper communication and informatics technology.

EU space programmes are also supporting research in the Polar Regions. The operational infrastructure and services of Copernicus will provide input to polar research activities, including weather monitoring, monitoring of climate variables and ice thickness, and improved ocean modelling. The development of polar informatics to better address the current limitations in collection, integration, processing and communication of information will add value to these Copernicus services.

We also have to acknowledge important data management initiatives related to both poles, which will strongly benefit from better communication and data collection and which already are working on interoperability standards, like the Sustaining Arctic Observing Networks (SAON), the "International Polar Data Forum", the Arctic Data Committee (ADC), and the Standing Committee on Antarctic Data Management (SCADM).

The way forward and key action areas

The development of operational informatics will be of considerable cost. **To prepare the ground for such work, we believe a formal EU scoping study is needed.** Such an investigation will draw together expertise in informatics and technology, who may have no previous connections to polar research with those who have experience in polar research and activities. It should involve researchers, technicians, industry and stakeholders. The study should include an implementation plan, a cost analysis, an environmental evaluation and an economic impact assessment. The scoping study, in line with the subtopics described in this white paper, should have following attributes that would lead to a prioritisation of efforts to maximise returns on investments.

1. Identify existing and required communications systems and standards that would best connect Polar Regions to each other and with external agencies.
2. Consider how best to link measurements of the natural environment with models, allowing better forecasting and prediction capabilities.
3. Study how informatics in the Polar Regions can enable interaction and interoperability of measurements.

It is probable that a single study is best suited, as integration across the subtopics is a necessity. It is also essential to engage with stakeholders identified in this white paper.

The scoping study should form a time-frame over which advances can be developed, their financial requirements (including installation and maintenance) and likely benefits in short, medium and long term.

The scientific drivers demand that the scoping study should consider both Polar Regions, but not necessarily in the same manner as they have different needs, stakeholders and constituencies.

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