EU-PolarNet
connecting science with society

Summary of the EU-PolarNet White Papers

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Preamble by the EU-PolarNet coordinator

The Polar Regions are unique realms of planet Earth, they fascinate us with their remoteness, harsh and beautiful landscapes, and their highly adapted wildlife. They are essential for our climate and the weather patterns we are used to. They are sentinels of climate change, human expansion and the hunt for new resources, but also for peaceful international cooperation in Earth system research and nature protection. Since the advent of the Framework Programme in the 1980s, EU researchers have made tremendous strides in polar research, such as:

- improving understanding of polar climate processes and developing techniques to provide robust projections of change at the poles and across the global climate system;
- understanding the structure and function of polar ecosystems and how life has adapted to survive in extreme environments; and
- mapping the transport and accumulation of pollutants in e.g. food webs, and helping communities plan for the future.

Today, EU members operate world-class research infrastructures in both the Arctic and Antarctic, they have prominent leadership roles in many fields of polar research, and comprise an integrated and effective research community.
In coming years, there is need and potential to deliver even more facts and information by developing co-designed research programmes using interdisciplinary methodologies that encourage real-world problem-oriented approaches enhancing societal impacts.
In the recent Joint Communication to the European Parliament and the Council 'An integrated European Union policy for the Arctic ', the European Commission and the High Representative noted that the EU is committed to the Arctic and will engage with the region in three priority areas, as follows:

- climate change and safeguarding the Arctic environment;
- promoting sustainable development of the region; and
- supporting international cooperation on Arctic issues.

They also indicated that, under Horizon2020, the EU expects to maintain funding to Arctic research, which has amounted to around 200 million Euro over the last decade.

Antje Boetius, Director of the Alfred Wegener Institute *(Photo: Kerstin Rolfes)*

The five white papers introduced here are a product of the EU-PolarNet; a project funded under H2020 for five years, involving a consortium covering a vast range of European expertise in both Antarctic and Arctic Research. EU-PolarNet includes natural and social scientists, providers of polar logistics and infrastructures, and key stakeholders. EU-PolarNet works with the European Commission on many aspects related to the Polar Regions, identifying and developing, most often jointly with stakeholders, the research needs and opportunities that are of high societal relevance to Europe. These activities will contribute to the development of an Integrated Polar Research Programme, which will be presented to the European Commission in 2020.

The white papers represent an important step towards developing this programme. In them we identify research topics of most relevance to society and timeliness for their delivery, for further consideration in the appropriate panels and boards.

Prof Dr Antje Boetius
Director of the Alfred Wegener Institute
Helmholtz Centre for Polar and Marine Research

Research on Arctic sea ice in Greenland *(Photo: ICE-ARC / British Antarctic Survey)*

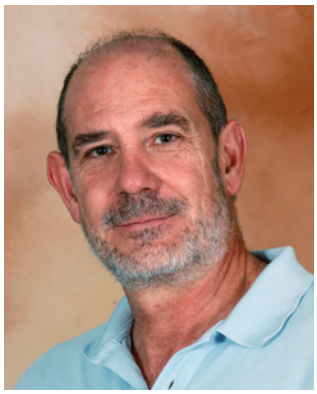
Foreword by the chairs

With rapid environmental change in recent decades, nowhere is climate change more evident and far reaching than in the Polar Regions. With communities and ecosystems subject to multiple environmental, climatic, cultural and economic stresses, the Polar Regions truly represent the sentinel of climate change. Already now, changes in the Polar Regions are changing the lives of polar residents, and are affecting the well-being of many polar communities. Furthermore, the state of the polar systems has far reaching effects on atmosphere, ocean and land including the change of weather pattern in Europe.

At both poles dramatic physical changes, such as the loss of ice cover and opening of ice-free areas on both land and sea, are well-documented and have become emblems of climate change. However, other subtle changes are also becoming apparent that may disrupt established (infra)structures, patterns and practices in ecosystems, communities and economic sectors. These recently identified changes may lead to major modifications in global ecosystem functioning and services. Across the Arctic, many diverse human communities will need to respond in order to navigate the profound changes in the ecosystem services on which they currently rely. Lives and livelihoods will undoubtedly be affected. In both Polar Regions, our ability to draw benefits safely and sustainably from natural resources, and to preserve and conserve the natural capital, their unique biodiversity and wilderness are at stake.

The changes occurring in the Polar Regions are, however, not just regional in impact. From north and south, changes near the poles exert a far wider influence on the global system. European weather is influenced by Arctic sea ice, and recent patterns of unusual weather, and occasional extreme events, have their genesis in a changing Arctic and Antarctic. Ice lost from Antarctica and Greenland contributes to rising global sea-levels that are being felt on coastlines around the world, increasing the risk to European coastal communities, assets and natural systems. Furthermore, the influence of the Polar Regions is not limited to physical and biological systems. Historically, the impact of competition for polar resources has had wide geo-strategic and socio-economic impacts, and may lead to significant political challenges in coming decades

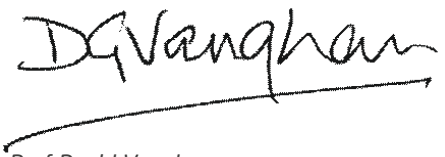
David Vaughan, Director of Science, British Antarctic Survey



Antonio Quesada, Executive secretary of the Spanish Polar Committee

European researchers contribute significantly to understanding the consequences of climate change in the Polar Regions, and help developing specific strategies to mitigate and adapt to these changes. In its Arctic policy[1] the EU states that a safe, stable, sustainable and prosperous Arctic is important not just for the region itself, but for the European Union (EU) and the world.

The EU-PolarNet white papers will give the EU and national research agencies guidance, which research themes are of high importance to advance in the understanding of the ongoing change not only in the Arctic but in both Polar Regions.



Prof David Vaughan
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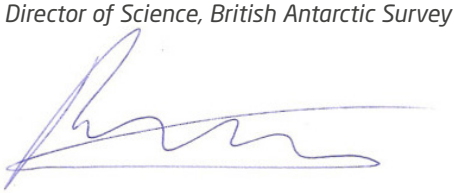

Prof Antonio Quesada
Executive secretary of the Spanish Polar Committee

[1]https://eeas.europa.eu/arctic-policy/eu-arctic-policy_en

The EU-PolarNet White Papers

The following white papers were developed by a specially selected team of EU and overseas experts from diverse areas of polar research. These experts were challenged to identify polar research topics with a clear societal relevance and a specific importance for Europe that could make them suitable for future EU support. These topics will, if adopted, further enhance EU research excellence, increase efficient use of European resources and expertise, and lead to a step change in data availability, access and interoperability. They will further increase the scale of polar research cooperation in Europe and, by including non-EU partners, will improve global cooperation. Each of the topics employs a strongly interdisciplinary approach to deliver benefits in the complex and multi-faceted real-world of policy issues. Some of the white papers describe approaches that step outside traditional disciplinary boundaries, offering a transformational or even 'post-disciplinary' approach. Each is designed to deliver tangible benefits to problems that arise in the Polar Regions from the complex interactions of a changing physical environment, stressed ecosystems, complex issues of sovereignty and governance, and layered cultural and social structures.

White Paper development

The EU-PolarNet white papers presented here were developed after preparatory work conducted in two stages.
First, an assessment of existing prioritised objectives, as expressed in published documents describing international, national and institutional policies and strategies of polar research identified ten priority as follows:

1. Polar climate system
2. Cryosphere
3. Palaeoclimate and palaeoenvironment
4. Polar biology, ecology and biodiversity
5. Human impacts
6. Solid Earth and its interactions
7. Sustainable management of resources
8. People, society and culture
9. Human health and wellbeing
10. Astronomy, astrophysics and space

Second, an online survey in 2017 allowed the identification of a public perspective on key polar research priorities. In this process, over 550 responses were obtained, representing institutions, companies, communities and individuals. The answers were categorised and sorted, and provided the basic foundations upon which the white papers were built.

In September 2017, armed with the results of these two preparatory exercises, EU-PolarNet convened a team of 50 experts from 16 countries to identify key needs, and debate and draft the white papers presented here. This team drew participants from many areas of polar research, including:

- Climate, atmospheric, oceanographic, cryospheric and geological sciences;
- Social, historical and cultural research;
- International policy development, environmental regulation, resource management and governance;
- Behavioural, ecosystem and evolutionary biology; and
- Satellite, communications, instrument and autonomous technologies.

These researchers were complemented by representatives from business and Arctic communities. Following a specially prepared methodology, involving several stages of refinement, the teams identified the topics and began the preparation of what has become the EU-PolarNet white papers. Interactions between experts from different knowledge areas were facilitated, promoting cross-fertilisation and co-creation from the beginning. As a consequence, the white papers presented here are the result of an interdisciplinary effort aimed at finding synergies focused on societal challenges.

The EU-PolarNet Consortium wishes to gratefully acknowledge this team of invited experts, whose generous contribution of their time and expertise was essential for the success of the workshop and its outcomes.

The breadth of expertise available within the workshop team, the retreat-style approach and the 'safe-house' method for debate, allowed topics identified in the white papers to benefit from a truly interdisciplinary collaboration. The topics themselves are issue-focused, and their implementation could prove to be transformational in polar research.

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The Arctic and Antarctic: Similar, not identical

The Polar Regions share many real and apparent similarities. Both are cold, icy, and sparsely populated (if at all); and both are considered remote, except perhaps by the people who live there! However, the Polar Regions are also profoundly different geographically, politically and biologically. It is important to acknowledge and understand these differences.

Geographic connectivity

While there is connectivity between the Arctic areas and northern latitudes via both land and sea, a strong Antarctic Circumpolar Current system impedes the exchange between the Antarctic and the Southern Ocean with the rest of the world. Despite their differences, both Polar Regions act as sentinels of climate change, and represent natural laboratories capable of providing extremely valuable insights into physical, biological and ecological processes at lower latitudes. For example, the relative simplicity of polar ecosystem structures, and rapidity of the changes to which they are being exposed, make them ideal places to investigate the fundamentals of ecosystem vulnerability and resilience.

Governance and human presence

While the Arctic Ocean is itself an international area, the lands that encircle it are the territory of eight Arctic Countries that cooperate under the auspices of the Arctic Council (AC). The Arctic regions are home to indigenous populations whose presence dates back thousands of years. The Antarctic is a continent under international governance through the Antarctic Treaty System (ATS). Parts of Antarctica have been subject to transient human presence for almost 200 years, but only in the past 65 years has human presence been substantial.

Protection and conservation

In the Arctic, it is important to build development pathways that protect ecosystems while optimising the sustainable use of resources (especially those that are renewable) for the benefit of local communities and humanity in general. In the Antarctic, the imperative lies primarily in protection and conservation in accordance with the ATS, which among other things supports peaceful use of the area for science; other forms of international cooperation through commercial activities like tourism and fishing may occur.

Given these differences, a question arises as to whether benefits will arise from a fully 'Integrated' Polar Research Programme. To this question our expert teams have responded positively, citing key areas where north-south divergence of research communities and programmes has led to incomplete exploitation of potential north-south synergies and efficiencies. For example:

- There is a strong likelihood that, with atmospheric and ocean warming glaciological conditions, key parts of Antarctica over the coming century will resemble Greenland as it is today. Process studies undertaken in Greenland could thus improve projections of ice-loss from Antarctica and consequently of global sea-level rise.

- The ecosystem approach enshrined in the international agreements that manage Southern Ocean fisheries may provide a sustainable and equitable framework for the protection of the Arctic Ocean as sea ice retreats and new fishing grounds become available.

- Tourism is now a global phenomenon and is well established in the Polar Regions. The management and conservation issues that the remote and wild places on our planet face and the benefits that tourism brings are universal and apply equally to both Polar Regions.

Our White Papers seek to maximise synergies and cooperation between Arctic and Antarctic research communities by identifying research topics which are important to investigate in both Polar Regions.

Summary of the
EU-PolarNet White Papers
White Paper No. 1

The coupled polar climate system:
Global context, predictability and regional impacts

Glacier front, Alpefjord, Northeast Greenland National Park *(Photo: Peter Prokosch)*

The Polar Regions are intimately coupled to the global climate and can be considered climatologically unique. Events and changes that occur in the polar areas have consequences that can be felt around the world. Their influence is transmitted through many pathways, such as atmospheric and ocean circulation changes and global sea level rise, or release of ancient carbon from thawing Arctic permafrost, which can accelerate global climate change.

With the recent realisation that anthropogenic climate change affects the Polar Regions more severely than other regions on Earth, the study of the polar climate system and its role within the global climate system is an international science priority. In order to assess local impacts and support the choice of adaptation pathways, research in this area requires innovative technologies to perform measurements under harsh and cold conditions and should involve researchers from diverse disciplines as well as stakeholders.

Knowledge gaps and research needs

In order to act on climate change and adapt to its effects, we need to understand the polar climate system in a global context, the limits of what Earth system models can predict, as well as the regional impacts and adaptation pathways in response to polar climate change. These actions will require an integrated programme that supports community-based decision-making, building on the best possible evidence and understanding of the coupled climate system.

The coupled polar climate system in a global context

Current Earth System Models (ESMs) have been developed for the mid-latitudes where most people live, and their representation of polar processes is incomplete. Important polar components (e.g. ice-sheets, glaciers, permafrost, snow, sea-ice, seasonally-frozen rivers and lakes) are either poorly represented or are passive rather than interactive (coupled) components. This means that the associated feedbacks are also poorly represented, and this negatively impacts the quality of projections produced. Future research to improve the understanding of the interactions between the polar components and ensure that these currently passive polar components become active (fully-coupled) components in future regional and ESMs is therefore of high priority.

Limitations of the predictability of the polar climate system

Society requires reliable predictions in order to meet the challenges communities and ecosystems will face under a warming world with significantly less snow and ice. Improving predictability of climate change and its effects, including both risks and

Penguins observing a measurement tower in Antarctica *(Photo: Alfred-Wegener-Institut / Alfred-Wegener-Institut / Stefan Hendricks)*

opportunities, in the Polar Regions will not only help local inhabitants, but through teleconnections via atmospheric and oceanic circulation, it will also improve predictability at lower latitudes. Understanding and expanding the limits to which we can robustly predict future changes in the Polar Regions is therefore of high societal relevance. It is important to understand how rapid the changes will be and whether these changes will be gradual or sudden.

Regional impacts and adaptation pathways in response to polar climate change

By identifying regional environmental sensitivity and risk vulnerability in the Polar Regions and beyond, communities and business sectors can be provided with the information they need to prepare and adapt to the challenges and opportunities presented by climate and environmental change. Local communities should participate in defining their requirements to inform their adaptation plans. They may require projections of storm occurrences, sea-ice thinning, fast-ice retreat, glacier retreat, snow melt season, river flooding, permafrost thaw, vegetation browning and drought, ecosystem health at scales affecting people's lives and activities.

To deliver on these requirements and transfer physical model results into policy tools, new methods have to be developed, by integrating socio-economic variables and community-based knowledge, such as hazard and risk assessment and mapping at regional and local scales applied in different key geographical settings.

Societal impact

Understanding the polar processes and improving predictability through truly coupled climate models in a global context will benefit the people, policy, ecosystem management, and businesses well beyond the Polar Regions. A better understanding of the following changes will allow decision makers to create mitigation and adaptation pathways for:

- **Changes in the occurrence of extreme weather events,** as a result of changes in sea ice cover and in ocean circulation in response to increased freshwater supply from melting ice sheets, glaciers and river run-off.
- **Changes in the composition** of the atmosphere induced by modifications in the exchanges of trace gases and particles with the land and the ocean. This has effects on precipitation and air quality.
- **Changes in the ecosystems on land and in the ocean,** with consequences for fisheries and natural resources and changing distribution/availability of subsistence species.
- **Further decline of the sea ice cover** as a result of increased global warming, with consequences for Polar ecosystems, Arctic communities and economic activities.
- **Global sea level rise** as a result of melting of the ice sheets and ice caps, with risks to coastal communities and ecosystems.
- **Increase of natural hazards** from lakes and river flooding, with impact on hydropower potential and river services.
- **Changes in landscape due to permafrost degradation** with key hazard implications such as damage to infrastructure, increased coastal erosion and contaminants release.
- **Hazards to people living in and visiting the Polar Regions** such as accidents on thinning ice and thawing permafrost; and to both humans and animals: spread of diseases, harmful algal blooms, and degradation of potable water.

Inuit hunter traveling by snow scooter on melting sea ice, Pond Inlet, Canada *(Photo: Peter Prokosch)*

The way forward

The development of coupled climate models as well as techniques for model-downscaling to produce climate change projections on a local scale is advancing rapidly. These advances mean there are real opportunities to provide the information polar stakeholders and local communities need to develop effective adaptation strategies. At the same time, the accelerating impacts of climate change call for urgent action in the following areas:

- **Increased policy and public awareness** of thresholds of abrupt change and hazards as a result of climate change effects, via educational and outreach programmes.
- **Coordination of existing data** into common databases, integrating different data among disciplines at different temporal and spatial scales, promoting interoperability of data.
- **Implementation and clustered use of infrastructures** with supercomputing capabilities.
- **Strengthening the polar observation infrastructure** through joint networks and standardised measurement
- **Achieving a more accurate understanding of the coupled Polar climate system** through intensive new measurement campaigns and data collection field work as well as careful analysis and integration of existing data, via EU projects funded by new coordinated calls.

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Summary of the
EU-PolarNet White Papers

White Paper No. 2

Footprints on changing polar ecosystems

Processes, threats, responses and opportunities for future generations

Arctic Fox *(Alopex Lagopus)*, Lena Delta *(Photo: Peter Prokosch)*

Expedition Cruise tourists experience autumn colors on the West-coast of Greenland *(Photo: Peter Prokosch)*

Around the world, human activities are increasingly causing profound and observable changes to ecosystems, through local activities such as fishing and land-use change, and remotely through climate change, ocean acidification and transport of pollutants. Although they are sparsely-populated and remote, some of the clearest human 'footprints' are seen in the ecosystems of the Polar Regions, where they have largely unknown consequences.

Today, we have an unique opportunity to build a knowledge base to provide sound science-based advice that will underpin decision-making and minimise these 'footprints' and their consequences for future generations.

The EU has recently acknowledged the need to carry out more research in Polar Regions, as the rate of change in polar biological systems has increased substantially in recent decades and is likely to continue on the same trajectory in the future. Such changes will have major consequences at different scales for ecosystems and societies, also causing elevated costs and irreversible problems for European nations. Direct and indirect effects of these perturbations of climate patterns and ecosystem services, among others, will hugely impact Europe. Despite differences between the Arctic and Antarctic, for example the extent of human population in the area, many issues regarding the two Polar Regions can be similarly addressed.

Knowledge gaps and research needs

The oft-heard saying "What happens at the poles does not stay at the poles" summarises that any changes in polar areas have pronounced effects on lower latitudes through a variety of feedback mechanisms. There is general consensus that climate targets set by the Paris Agreement in 2016 are strict and require immediate, qualified joint actions and adaptation at all scales: local, regional and international. In addition to strong and accurate forecasting abilities that are needed to ensure adaptation to forthcoming climatic and environmental changes, there is an urgent need to strengthen the existing long-term monitoring programmes and implement additional ones, combat the threat of extinction of native species and conduct further research on invasive species. It is of high priority to ensure a sound stewardship of the Polar Regions for a balanced and sustainable future. The international aspect of research should enable solutions that transcend the local and national governance levels and coordinate them to address questions of global relevance.

Major gaps in knowledge on the diversity of polar ecosystems could be filled by wide-ranging surveying and monitoring of the Polar Regions to deliver standardised, high-quality data on a range of essential biodiversity variables, and key reference sites that can be maintained long enough to provide an indication of changes and trends. There is a need to develop a set of genuine ecological indicators to identify and quantify thresholds of change and the risks to polar ecosystems. State of the art, innovative technologies will help to minimise cost and impact, and to maximise scientific value. Involvement of indigenous and local

Loss of Ice in Greenland; Icebergs in Disco Bay *(Photo: Peter Prokosch)*

Penguins and researchers in Antarctica *(Photo: Alfred-Wegener-Institut / Stefan Hendricks)*

communities will mobilise the local knowledge and improve the collection of data.

This improved knowledge of polar ecosystems, together with a robust toolbox of ecological indicators and new modelling approaches, will enable more accurate future scenarios and predictions, which will be crucial in formulating effective scientific advice for management and policy-making, both regionally and globally.

Future Polar research in the EU should thus address three main objectives:

- **Improve the understanding of the current structure and functioning** of polar ecosystems, and how they will change under predicted environmental pressures
- **Identify the most relevant ecological indicators** to evaluate risks to the polar ecosystems and services they provide, locally and to lower latitudes, and evaluate the impact of management options
- **Provide relevant and timely scientific advice to decision-makers** to allow sustainable management of the polar areas under a changing climate, including concepts for nature conservation

Characterisation of these three intertwined steps will help to compile, process and provide the necessary ecological science to complement the research in other areas, for example in the coupled climate system, as highlighted in White Paper 1.

Societal impact

The audience for the results from the proposed research programme include European and national policy-makers, their advisors and funding agencies, European Commission, academia and national research bodies.

The societal relevance of the topics outlined in this summary touches upon several UN Sustainable Development Goals that are relevant in the European context. These topics include: filling in the gaps in the knowledge on ecosystem structure and function (SDG 13), conservation, restoration and sustainable use of ecosystems and their services (SDG 14 and SDG15), involvement of local communities in the generation of knowledge and resource management (SDG 12), education and capacity building for innovative solutions in ecosystem management (SDG4 and SDG9), ecosystem health as a determinant of resilient and sustainable communities, and human health and wellbeing (SDG 3, SDG 6 and SDG 11).

The way forward

Polar Regions provide a natural focus for strengthening international collaboration, and the EU has the capacity and the responsibility to lead such large-scale, multidisciplinary, collaborative research efforts. Europe's role in the leadership in polar science, its coordination and logistics capabilities can be sustained well into the future by:

- **Publishing coordinated calls for seed funding** to initiate the implementation of the research outlined in this white paper at long-term observation sites, especially at remote places in Polar Regions. For example, coordination and standardisation of monitoring protocols need to be developed and resources need to be allocated to the design and implementation of standardised data management, to ensure interoperability and making the best use of existing and accumulating data sets. In addition to programmes focusing on either the Arctic or the Antarctic, explicitly bipolar approaches should be encouraged and funded.
- **Leading concerted international actions** (involving EU countries and countries worldwide) to establish a coordinated research programme and to provide science-based and scenario-based advice to international decision makers.
- **Supporting capacity building,** promoting excellence at the level of universities and research institutes, to create and establish world-leading scientists in polar biology and ecosystems.
- **Nurturing public education and outreach** initiatives to demonstrate the relevance of polar biology in the global ecosystems.

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Summary of the
EU-PolarNet White Papers

White Paper No. 3

Managing human impacts, resource use and conservation of the Polar Regions

Research vessel in the Arctic Ocean *(Photo: Alfred-Wegener-Institut / Mario Hoppmann)*

Once seen as distant and isolated, the Polar Regions are rapidly coming to be understood as a crucial intersection where the consequences of historical and recent societal policies and resource management decisions are becoming apparent. It is clear that policies and decisions may feed back on people and communities in ways both anticipated and unexpected. Recognising this, it becomes imperative to strengthen both the scientific and the policy understanding of the Polar Regions, and in particular, how human interaction with polar environments can benefit people and societies, and how human activities can be pursued while still protecting and conserving these regions. This implies an urgent requirement for greatly increased and more integrated knowledge regarding the interplay between human activities and natural systems. This will incorporate key elements often identified under the banner of resilience and social-ecological systems.

Gaps in knowledge and research needs

Increased human activities at both poles are generating local impacts. In the Arctic, these come from increased tourism, transport and activities aimed at securing both finite and renewable natural resources. In the Antarctic, these impacts arise from increased human presence through expanding tourism, and the establishment of research stations and infrastructure is amplifying pressures.

Yet, many of the most powerful and ubiquitous drivers or stressors are generated by human activities taking place outside of the Polar Regions - or being guided from outside the regions. One critical effect is that the links between damage-causing activities and their social and ecological consequences are blurred not only by time, but by geographical distance. This distance between cause and effect adds to the challenges of understanding the causal relationships and sequences. This kind of knowledge integration requires a "systems approach" that examines the phenomena of interest in the system of which it is a part.

Within the broader context of trans-disciplinary, systems-oriented science, we offer a few concrete examples of areas where additional research promises insights that can help inform more effective policy and management decisions and their implementation:

- **The direct and indirect impacts of human presence:** In both Polar Regions, increasing tourism is generating environmental impacts from the effects of expanding and more persistent human presence. In the Antarctic, the expansion of scientific research is similarly generating new pressures, and in the Arctic, reductions in sea ice promise to open new sea routes that must be managed to ensure that networks of marine protected areas are preserved and protected. In all instances, both the lack and the construction of infrastructure for long-term and transient human presence present challenges.
- **Choices about resource use, conservation and related impacts:** Intensified competition between securing/using natural resources and conservation of sensitive ecosystems requires the development of more informative indicators of interactions between social and ecological systems, and of the human policy and management systems. These dynamics differ significantly between renewable resources and non-renewables (only in the Arctic), where not only impacts of resource extraction must be understood and managed, but also the impacts of using those resources in the intended manner (as with fossil fuels). Further, conservation also concerns protecting intrinsic values that once lost, cannot be replaced.
- **Linking knowledge and decision making:** While understanding impacts from individual drivers is important,

social-ecological systems drivers are more accurately characterised as part of a set of cascading interactions. Some drivers generate impacts through an accumulation of effects, making research to understand cumulative impacts especially urgent. Similarly, there is a need to better understand the social responses to ecosystem changes that have their origins in impacts of human activities. Finally, management regimes for sensitive areas such as Marine Protected Area networks and Ecosystem Based Management represent paradigm shifts, but greater understanding is required to adequately implement the systemic change they envision.

Societal impact

There is an urgency to develop the knowledge needed to manage ourselves in our relationship to nature, with special attention to the Polar Regions. Deeper insight is needed to be able to more successfully cooperate with each other in balancing increasing resource needs and sometimes competing social goals with stewardship of the ecosystems that constitute our life support systems. Recognising international agreements and their stated ambitions, one intention of this white paper is to emphasise the importance of the conservation of the Polar Regions for humanity and future generations for their intrinsic value. A further intention is to highlight the need for sustainable resource utilisation in light of human needs, and in the context of rapidly changing environments. A third goal - one that applies specifically to the Arctic - is to emphasise the importance of organising resource and economic development in ways that accrue to the benefit of the people of the region, and in particular those whose livelihoods have been disturbed and disrupted by human impacts from activities taking place or directed from far away.

The way forward

It is important to acknowledge that integrative efforts outlined in this white paper are already being pursued in specific projects and particular settings, and these efforts can help point the way. What is needed now is to replicate, scale up, and add missing components to these efforts to accelerate the process of better integration of knowledge, and better integration of knowledge

Tourism in Antarctica *(Photo: Peter Prokosch)*

with practice, that is needed to respond effectively to the pace and breadth of change seen in the polar regions. We suggest to:

- **Engage iteratively with policy makers** with a focus on the existing and likely future threats to polar ecosystems and communities.
- **Identify available data sources for environmental and social variables** that are needed to assess systemic impacts upon Arctic and Antarctic environments.
- Identify gaps in knowledge and initiate or enhance monitoring activities to strengthen future predictions of environmental impacts and trends in Polar Regions.
- At policy-relevant spatial scales, **integrate available environmental and societal knowledge** to model likely future scenarios.
- **Use topic areas involving resource conservation and use** (land use, tourism, transport, fishing, resource extraction) as focal areas for research on strengthening knowledge integration that can be incorporated into strengthened regulatory and management practices.

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Port of Murmansk, Russia *(Photo: Peter Prokosch)*

Summary of the
EU-PolarNet White Papers
White Paper No. 4

The road to the desired states of social-ecological systems in the Polar Regions

Reindeer herd (Rangifer Tarandus) in Finnmark, Norway *(Photo: Lawrence Hislop)*

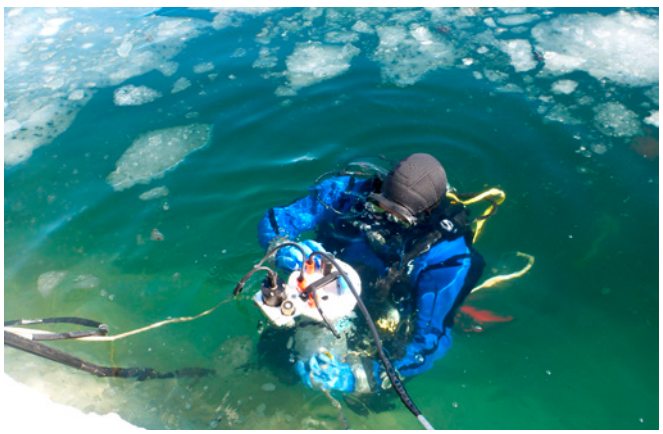
The future development of social-ecological systems of the Polar Regions depends on our ambition and capacity to cope with changes and to navigate towards a sustainable future. The sustainable development goals of the UN were designed primarily for areas of the world in the lower latitudes, and are thus rather ill-suited to the Polar Regions. In order to be able to make effective and strategic decisions with regard to our socio-ecological futures, this white paper addresses the most fundamental needs for any societally-relevant research for the Polar Regions: the identification of what the different Arctic and Antarctic stakeholders see as the desired future states of the Polar Regions and the assessment and proactive development of pathways that allow us to come as close as possible as reaching those desired states.

Gaps in knowledge and research needs

Gaps in knowledge relate to the components of the desired states of the social-ecological systems in the Polar Regions, as much as to the type and extent of climatic changes and changes in human activity in these regions. It follows that there are also gaps in knowledge in relation to the actions that would be required to ensure that developments move in the direction of the desired states. Even when we have increased knowledge of the desired directions of governance, we still need to understand which instruments (governmental, intergovernmental, self-regulatory, and other instruments, or a mix thereof) offer the best chance of success.

To enable positive change, we need to understand the outcomes different stakeholders and right-holders want to achieve, keeping in mind that resilient and sustainable ecosystems are needed to support these futures both in the Arctic and the Antarctic. This means that we need to:

- **Identify and agree the desired future states** envisioned by stakeholders and 'right-holders' for the Polar Regions and develop a suite of polar indicators, which are appropriate to assessing a progress towards the desired future states;



Diving for marine observations in Antarctica *(Photo: CNRS/Michel Calzas)*

Heading out for seal hunting *(Photo: Lawrence Hislop)*

Kangaamiut, West-Greenland *(Photo: Peter Prokosch)*

- **Create guidelines for sustainable monitoring** and regular assessments that enable us to assess our progress towards the desired states; and
- **Provide guidance on optimal pathways** towards the desired states ensuring a just transition.

Societal impact

The research proposed in this white paper has direct links to, and contributes to, improving governance in the Polar Regions as it will clarify the range of interests, perspectives and values of different stakeholders, including policy-makers, highlighting areas of common interest and areas of divergence. Thus, it will allow a more targeted approach towards sustainable development and building of resilience in the Arctic, and effective integrated environmental management and informed decision-making in the Antarctic. In particular, it will assist European governments in their efforts to define sustainable polar policies, contributing to the future stability and sustainability of a strong and relevant European community, particularly with regard to (a) climate-change adaptation and mitigation, and (b) reducing potential discord in both Polar Regions, thus contributing to stable polar governance.

The way forward

Regarding the SDGs' indicators for the Polar Regions, a scoping study could be dedicated specifically to an:

- **Examination of the existing SDGs indicators' framework** and to determine which indicators, if any, apply to the Arctic/Antarctic/or both;
- **Examination of other indicators,** more appropriate to the Polar Regions, that have been used/proposed in social science projects (e.g. Arctic Social Indicators, Arctic Human Development Report, ECONOR - The Economy of the North) and may be more appropriate for the Polar Regions. In addition, it will be important to draw on natural scientific research, indigenous and local knowledge, and other stakeholders' perspectives at this stage;
- **Assessment of existing data** that might inform the scoring of the indicators identified in 1 and 2. Such data may be stored in various forms, locations and institutions; its identification is an important starting point to indicate the current state of knowledge about Polar Social-Ecological Systems. This data, might form a natural starting point for a more ambitious and substantial programme of work.

Remnants of a village, Siberia *(Photo: Peter Prokosch)*

Finally, it is important to establish a relationship with non-Polar stakeholders, for example, partners involved in the work with the implementation of UN's Agenda 2030, and specifically, the SDG indicators. This relationship will add global verification and relevance to our endeavour and will ensure that we reap the maximum value from it.

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Summary of the
EU-PolarNet White Papers

White Paper No. 5

Advancing operational informatics[1] for Polar Regions

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

A 'data revolution' has advanced areas of scientific research, business and industry, education and societal well-being in many parts of the world. Polar Regions, however, are characterised by low standards of communication technology and, 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, taking an informatics approach. This will benefit:

- **Science,** by allowing better access to data and observations, improving linkages between observations and models, and serving as a basis for intelligent information systems;
- **Business and industry,** by allowing access to data systems that can aid navigation, tracking marine resources, and forming a basis for resource management and regulation; and
- **Society,** by enabling knowledge systems that can provide better avoidance and mitigating measures, education, healthcare, and better understanding of the role that Polar Regions have impacting weather and climate over Europe.

[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).

The result should be a better connected information network, providing tools for easier exploitation of information by all stakeholders in the Polar Regions.

Gaps in knowledge and research needs

The establishment of state-of-the-art operational levels of informatics in Polar Regions requires research that addresses current limitations in collection, integration, processing and communication of information. 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 of the Polar Regions requires a coordinated research effort addressing the current limitations in communications capabilities, the harsh and remote environment, and limited in situ observations. Research is needed within the following domains:

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

- **Communication systems.** Polar Regions are data poor and lack communication infrastructure for reliable and effective data sharing for research, services and societal needs;
- **Linking observations and models.** 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; and
- **Information and interoperability.** Interoperability and exploitation of distributed data will provide useful information in a collective sense for science, society, industry and operations in Polar Regions.

Societal impact

Scientific discovery will be a major beneficiary from investment in the research needs of operational informatics, but this investment will also improve societal well-being and lead to business opportunities and economic growth.

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 business and society. Informatics will assist the business community of the Polar Regions in many areas such as enabling project assessment and feasibility studies, business opportunities in implementing these services, commercial services based on research-driven informatics systems, trade and supply chain management, adherence to standards and regulations, and safe and responsible tourism.

For society, the benefits of informatics are also significant to areas such as regional development, community development, development of standards and regulations, educational services, cultural exchange, disaster preparedness and early warning systems, search and rescue operations, navigation and logistical services, public management, security issues, health services, urban and infrastructure planning, and safeguarding subsistence resources.

Research in enhanced informatics in the Polar Regions is also aligned with a number of the UN Sustainable Development Goals (SDGs) and will have positive impacts on developing sustainable industrialisation and societies in the Polar Regions, combating climate change, assuring sustainable use of the polar oceans and protecting biodiversity.

The way forward

As a major contributor to polar research over the past decades, building on polar research funding under H2020 and the EU space programmes, Europe has the capacity, expertise and links to other Polar Nations to lead this initiative. Through its existing strengths in polar research, Europe is ideally placed with a strong core infrastructure, academic and industrial expertise, partnerships and economic strength, to form an informatics system tailored to the requirements of the Polar Regions that will lead to advances in our understanding of processes and change in these remote and challenging environments.

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

As a first step towards enhanced informatics in Polar Regions, a formal scoping study of the problem is needed, pulling expertise in informatics and technology together with knowledge of polar conditions, research and operations systems. It should involve researchers, technicians, industry and stakeholders of relevance for the Arctic and the Antarctic, and include the most important international organisations and networks. The study should include an implementation plan, a cost analysis, an environmental evaluation and an economic impact assessment, and should:

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

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Capacities and cooperation partners needed for implementation

There is a large potential for capacity building in Europe for studying the Polar Regions, which draws on European-funded scientific and monitoring projects, operational stations and vessels in both Polar Regions and existing supercomputing facilities. Nevertheless, the research and development necessary to significantly advance the understanding of the polar systems will require enhanced measurement infrastructures in the Polar Regions, new advanced technologies to carry out measurements under harsh and cold conditions as well as supercomputing facilities and sustained comprehensive databases. Furthermore, integrated research yielding effective solutions will need strong international circumpolar and interdisciplinary collaboration. Significant efforts and resources need to be devoted to build capacity for creating and maintaining an effective research infrastructure and a better coordination of these assets. Capacity building should also be aimed at public education and outreach, to communicate that the processes occurring in polar areas have a significant impact on Europe and the rest of the world.

Answering the full scale of research questions needed to understand the changes in the Polar Regions is beyond the capabilities of any one nation acting individually. Bi- and multilateral cooperation with partners outside of Europe is needed to meet the depth and geographic scale of these challenges. In the Arctic, it is important to recognise the contribution and infrastructures linked to the Arctic states – Russia, USA, Canada, the Nordic Countries, as well as the First Nations – in fully implementing the recommendations of the white papers. However, significant benefit would be achieved through engagement with IASC as it includes all countries engaged in Arctic research and in all areas of the Arctic region. For the Antarctic, the role of the ATCM and SCAR will be critical to engaging multiple nations in a collective effort. Additionally, COMNAP has a significant role to play.

The research needed could benefit from co-designed programmes based on international cooperation, coordination of observational strategies and monitoring stations, sharing data acquisition programmes and the built-in interoperability of databases and supercomputing resources. For both Polar Regions, space technologies will continue to play a crucially important role in data collection. This will require dedicated activity and cooperation from the European Space Programme delivered by the EC and ESA. Coordinated sampling and assessment has the potential to minimise costs, both financial and environmental, while increasing the usefulness of the obtained parameters. The involvement of local communities in sampling and monitoring, supported by modern technologies, has the potential to mobilise and involve traditional knowledge and raise awareness. A well-designed data management plan is necessary and the collected data should be deposited to an openly accessible public repository.

The outputs of the research recommended in the white papers will address many different stakeholders and right-holders such as indigenous people, the public and private sectors (e.g. oil and gas, fishing, shipping, tourism and port industries, insurance sectors) as well as local governments and communities. These stakeholders and right-holders in the Arctic and Antarctic need to be included at an early stage of the proposed research as it fundamentally draws on their perspectives, motivations and values. In addition, there are many other relevant cooperation partners at all levels local, regional and international including: research and coordination organisations and other scientific communities; intergovernmental organisations, such as the Antarctic Treaty System (ATS) and Arctic Council (AC); and non-governmental and private organisations.

Outlook

The process used to develop the White Papers allowed and encouraged independent development of ideas by each of the writing teams. Nevertheless, clear common threads have emerged. Independently, three of the five working groups highlighted an urgent requirement to develop standardised metrics, or 'indicators', of change for the Polar Regions. While each team developed a specific focus relevant to their expertise and subject area, there is a common realisation that while some established long-term measurements, especially those relating to parameters in the physical environment, show clear, rapid and profound changes (e.g., the 30-year satellite record of ice loss in the Arctic and in Antarctic), there are many aspects of change in the Polar Regions for which measurements are sparse, poorly standardised and too short in duration to allow us to discriminate trends from variability. This is particularly true for ecosystems and socio-cultural change.

Similarly, the standardised metrics of change established elsewhere around the world are often wholly inappropriate for application to the Polar Regions. For example, a specific issue identified in White Paper 4 is that the indicators adopted to monitor progress towards the UN Sustainable Development Goals are poorly-adapted, and arguably require special interpretation or even modification to be applicable to either the Arctic or Antarctic.

The White Papers highlight indicators that are particularly pertinent to the subject area, as follows:

- **White Paper No. 2** (Footprints on Changing Polar Ecosystems) advocates 'Ecological Indicators' that will allow the assessment of ecosystem health and change;
- **White Paper No. 3** (Managing resource use, conservation, and human impacts of the Polar Regions) recommends both the requirement of indicators of effective management and governance, and indicators of social-ecological resilience. Furthermore, it highlights the potential of Natural Capital Accounts as one method of measuring and valuating resource stocks and flows where human activity draws on ecosystems services; and
- **White Paper No. 4** (The Road to the Desired States of Social-ecological Systems in the Polar Regions) advocates indicators to measure the state of Arctic and Antarctic social-ecological systems.

Finally, while White Papers Nos. 2, 3 and 4 each demonstrate the requirement for specific indicators to be selected, developed and maintained, there is also the potential that a collaborative, interdisciplinary effort to develop such indicators would provide a more coherent and comprehensive result. Such a result could strengthen the capacity to effectively measure and monitor the state, magnitude and rate of change of the Polar Regions their mutual connection and, with the low latitude change and most importantly, the social, cultural, commercial and ecological interactions with the physical environment.

Imprint

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Research in Hornsund, Svalbard *(Photo: Witold Kaszkin)*

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