EU-PolarNet
connecting science with society

White Paper on European Polar

INFRASTRUCTURE ACCESS AND INTEROPERABILITY

Including an infrastructure implementation plan for the European Polar Research Programme

The French-Italian Station
of Concordia in Antarctica.
Photo: Thibaut Vergoz, IPEV.


2
GRT

1. European polar infrastructures: A landscape needing improved coordination

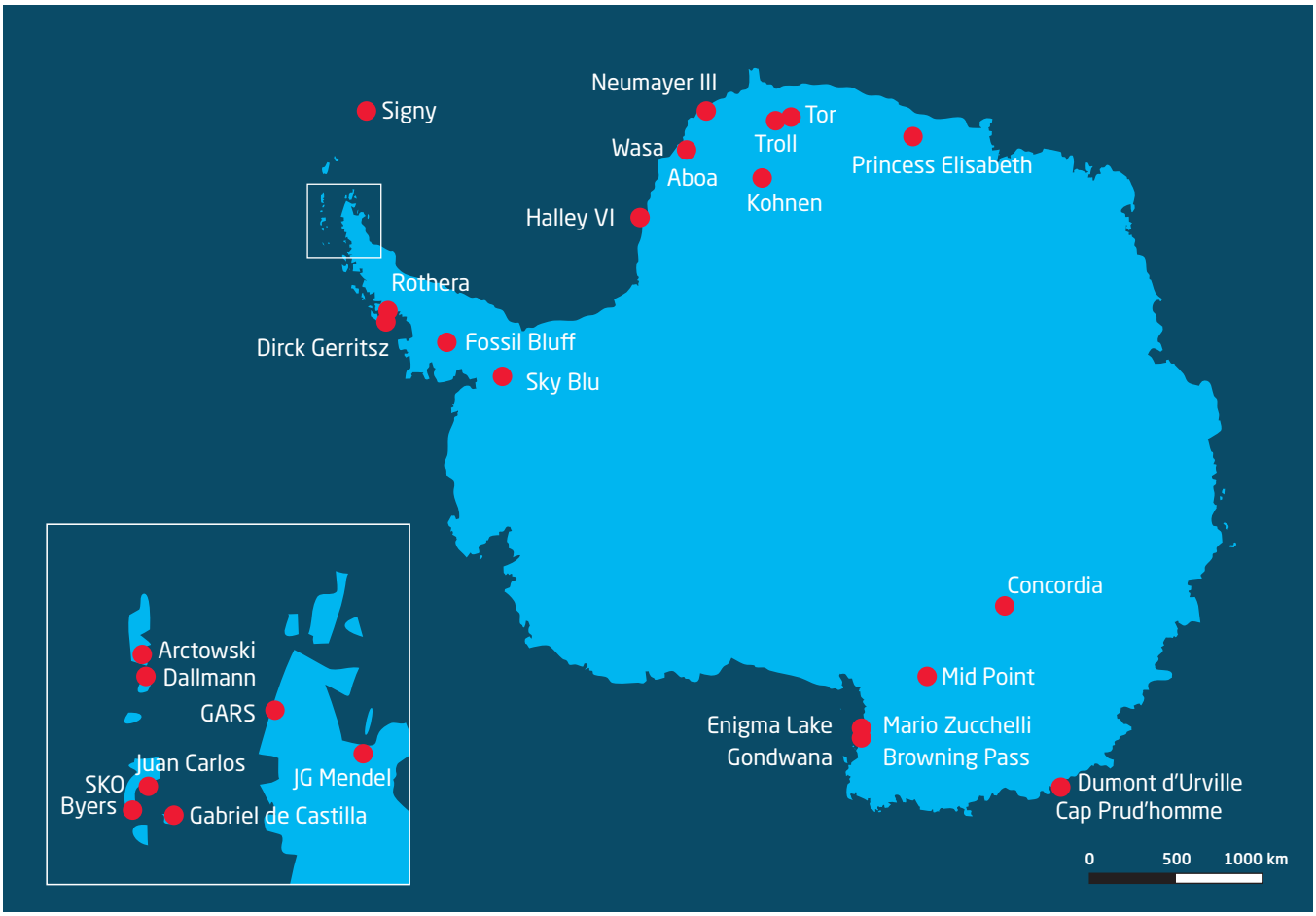

Figure 1. European research stations in the Antarctic.

European nations operate world-class research infrastructures in the Arctic and Antarctic, which result from a long history of polar research and significant investments made by national polar programmes. The European Polar Infrastructure Catalogue (D3.2, see Appendix I), which EU-PolarNet has compiled, identified 32 European stations in the Antarctic (Fig. 1) and on the Sub-Antarctic Islands and 32 stations in the Arctic (Fig. 2), with 2 icebreakers, 14 ice-strengthened research vessels and an aircraft fleet operating at both poles. These infrastructures are of extreme scientific value. They are either strategically located or their mobile capabilities provide them with unique capacities. European infrastructures are based over a large geographical breadth, providing a critical network and a valuable asset for the European Research Area.

The European Polar Research Programme (EPRP), created by EU-PolarNet, delineates the future strategy lines for European polar research. It has been developed by an encompassing consultation process involving scientists and polar stakeholders. The EPRP clearly identifies the urgent need to improve coordination among national polar programmes, align operations, implement, or further develop access schemes and foster interopera-

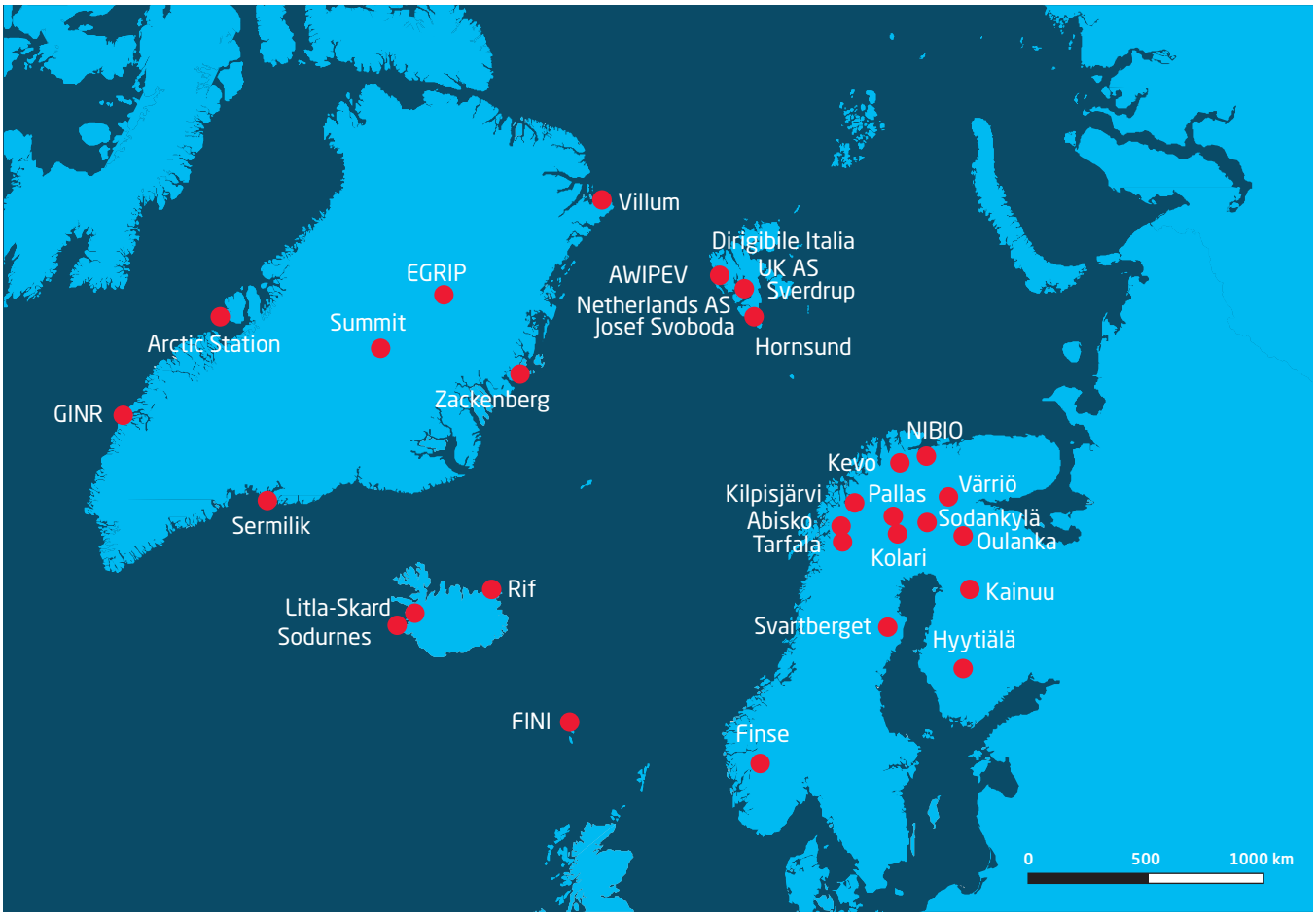

Figure 2. European research stations in the Arctic.

bility of infrastructure and data. This complex endeavour needs to account for the key characteristics of the individual infrastructures and priorities of national research programmes to secure stronger research collaboration and foster scientific impacts. As a result, it will optimise the operational costs and environmental footprint by reducing any possible overlap or duplication of efforts. This more efficient use of resources will also lead to harmonised actions developing more balanced cross-disciplinary observations and science. Improved coordination will also enable better interaction with industry and the private sector, as well as their engagement, boosting research and society interactions. Improved coordination and integration will facilitate connectivity with global networks and systems in and beyond Europe, strengthening sustainable infrastructure development and innovation.

This white paper builds upon EU-PolarNet's experience in bridging scientific and societal needs. It is the infrastructure and logistics response to the research needs addressed in the European Polar Research Programme and shall pave the way for stronger and interconnected European actions at the poles and for a common European voice in Polar organisations and fora.

2. Access and interoperability: Two priorities to be addressed by Europe

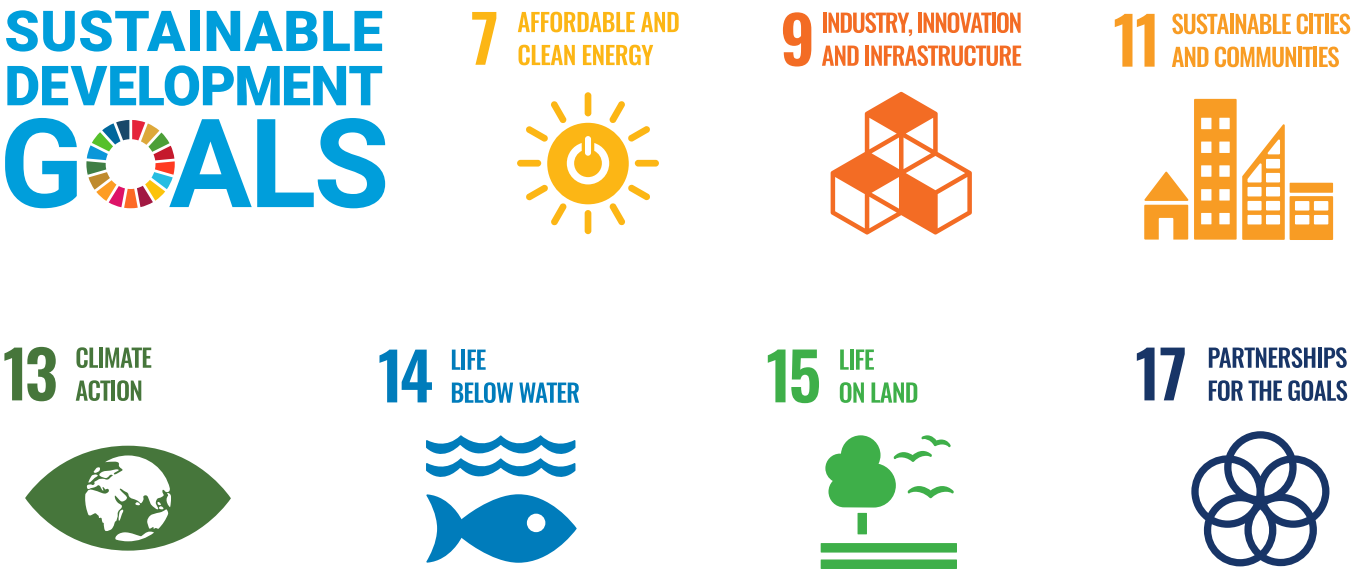

Figure 3. UN Sustainable Development Goals related to the improvement of the access and interoperability of the European polar infrastructures.

Polar research involves **multinational, complex and energy intensive infrastructure, logistically and safety challenging operations, and sustained observations in nearly inaccessible areas.** Minimising the environmental impacts of such activities by facilitating access, improving interoperability, maximising efficiency and standardisation across programmes will contribute to the UN Sustainable Development Goals (SDGs, Fig. 3) and to the EU Green Deal[1]. In this regard, the reduction of the environmental footprint and future-proof logistics implementation will be the major added-values for EU public funding. Existing European coordination organisations such as the European Polar Board (EPB), which brings together Arctic and Antarctic operators, research institutes and funding agencies, can be key to develop and implement a European model for interoperability, while striving to align European and national policies. This gives the chance for Europe to lead internationally with a flagship interoperable infrastructure network.

Promoting Trans-National Access (TNA) for all European researchers to world-class polar infrastructures is instrumental to addressing bigger and more complex science problems and to close important knowledge gaps in the Polar Regions. Especially, early-career scientists and scientists from countries where such facilities are lacking will benefit from the possibility of easy access to polar infrastructures. TNA and sharing of infrastructures are cornerstones for the success of the EPRP. Improving TNA fosters **international cooperation** and allows for resource **optimisation, maximising the degree of utilising infrastructure** capacities, **limiting duplication** of efforts, achieving an international **leveraging of funding**, while also **freeing resources** for science and **reducing the environmental footprint.**

[1] EC COM/2019/640: "The European Green Deal"

Any improvement in interoperability aims to standardise processes, products, and systems for optimising their use. In the polar research landscape, interoperability optimisation extends to data, instruments, and observation protocols, as well as research stations, vessels and aircraft, cross-cutting projects and research activities. Better interoperability makes infrastructure more useful for science, improves the research processes and facilitates logistic deployment for persons and goods. European polar research is framed within different types of research programmes and historically has shown limited interoperability in observations, data, and infrastructures. The EU-PolarNet work package 3 on infrastructure, facilities and data was implemented to improve this situation. It provided an overview of data and data infrastructures (D3.1 see Appendix I), space assets (D3.3), and commercial infrastructures relevant to support logistic research activities (D3.4). EU-PolarNet performed a gap analysis for data (D3.5) and satellite applications (D3.6) and published recommendations on how to significantly improve open access to data, interconnection and interoperability (D3.8) and on how to better coordinate access to space assets and facilities to support polar infrastructure and operations (D3.6). As pointed out by this work, while some of these issues are being tackled by international organisations, this is often within distinct research fields, and polar research still lacks true interoperability in most contexts. This needs to be addressed urgently. This is particularly true if we consider observations and observation protocols. Excelling in interoperability of European polar research infrastructure must acknowledge and address the complex scientific issues of an interlinked Earth System, addressing Arctic and Antarctic issues, and linking marine, terrestrial, cryospheric, atmospheric and social issues. Key issues for advancing research are improving the capacity for observations, better instrumentation, and operational protocols, improving data reusability, standardisation, quality control and data encoding, while moving from individual observations to networks addressing both large scale scientific and monitoring questions.

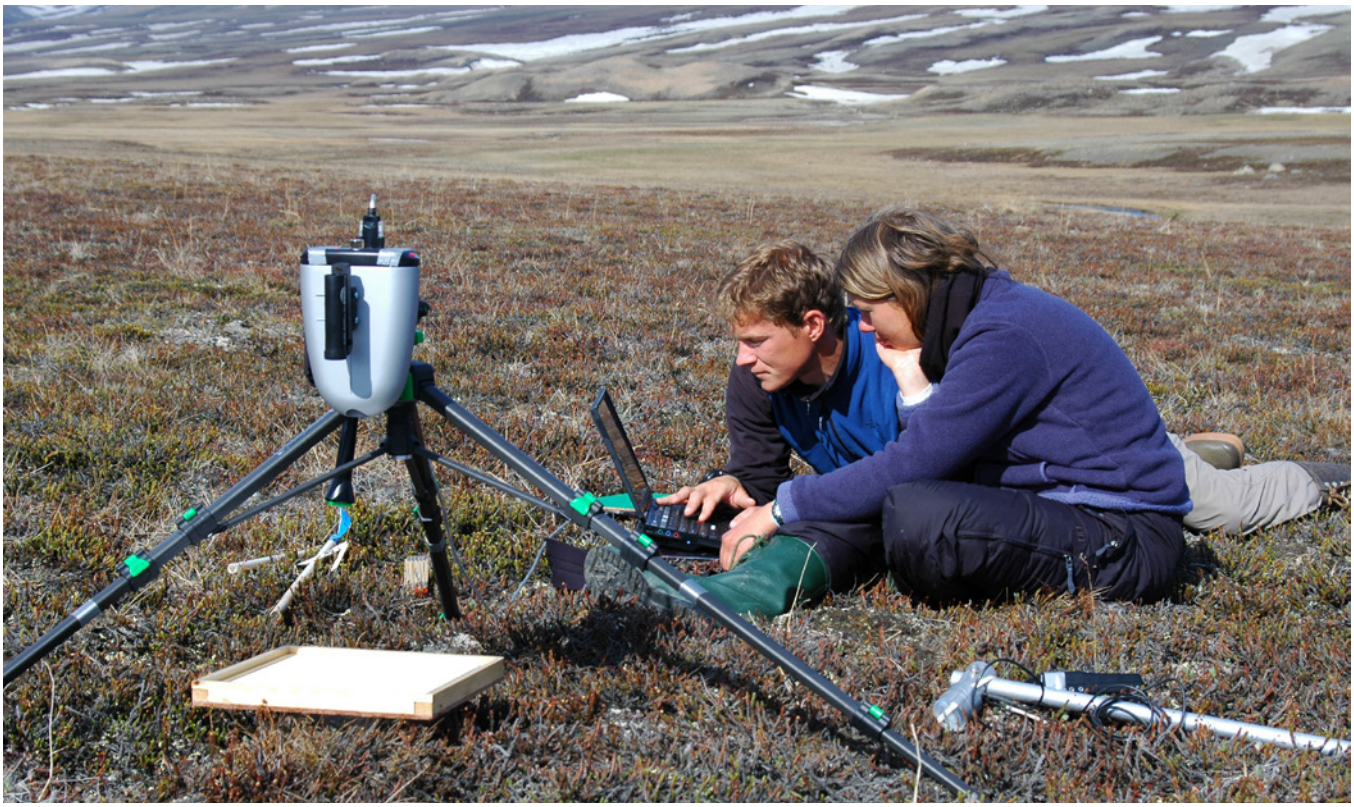

Figure 4. Field work in the Zackenberg Station area, Greenland. *Photo: Henning Thing, INTERACT.*

3. Good practice and achievements: Paving the way for a future coordinated and integrated European Polar Research Programme

Improving cooperation and coordination: the current situation

Cooperation is very well developed in polar research due to safety, logistical and budgetary necessities. Many national polar research programmes within Europe jointly operate and share expensive infrastructures (e.g. Concordia Station, AWIPEV Station) or are partners in multi-national infrastructure consortia such as the Svalbard Integrated Arctic Earth Observing System (SIOS) and the European Incoherent Scatter Scientific Association (EISCAT), both of which also include Asian partners. The international polar community has also shown an impressive willingness to work together in large-scale programmes such as the International Polar Year (IPY) or the MOSAiC expedition, sharing facilities, results, and data. These large international efforts usually coalesce around a grand challenge or complex issues that cannot be tackled by one country alone, and these generally are one-off initiatives. A good example of such grand challenge is the European project for ice coring in Antarctica (EPICA, Fig. 5), which involved 10 European nations and was awarded by the EC with the Descartes Prize for excellence in scientific collaboration.

In addition, several initiatives which aim to improve the cooperation of polar researchers and coordination of research infrastructures exist and are funded at European level, such as EU-PolarNet, the ESA Polar Science Cluster and the EU Polar Cluster. In addition, the EC funds projects (INTERACT and ARICE), which are explicitly dedicated to improving coordination, TNA and interoperability of European polar infrastructures.

At the international level, non-governmental and international scientific organisations like the International Arctic Science Committee (IASC), and the Scientific Committee on Antarctic Research (SCAR) do an outstanding job in encouraging and facilitating the cooperation in Arctic and Antarctic research. Managers and operators of national Antarctic (Council of Managers of National Antarctic Programs, COMNAP) or Arctic (Forum of Arctic Research Operators, FARO) programmes meet regularly to develop and promote best practice in managing the support of scientific research at both poles. Regional information and coordination hubs, such as ISAAFFIK for Greenland, DueSouth for the Southern Ocean, RiS for Svalbard or COMNAP´s groups have been implemented to facilitate logistical coordination and rationalise the use of resources.

Figure 5. The flagship European cooperative project EPICA for ice-coring in Antarctica. *Photo: PNRA, COMNAP.*

Initiatives like the Arctic Science Ministerial and the connected new Forum of Arctic Science Funders thrive to coordinate Arctic Research on a political level. In addition, the Roadmap for Arctic Observations and Data Systems (ROADS) process designed by SAON and acknowledged by the Arctic Observing Summit, will pave the way towards a development of interoperable technologies and data systems.

The Antarctic: Intense collaboration and bottom up coordination

Antarctic research and operations are framed within the Antarctic Treaty System and performed by national Antarctic programmes. This context is significantly different from the Arctic under a geopolitical context of Arctic nations surrounding the Arctic Ocean, where access is generally easier and frequently possible using commercial regular transportation lines.

Antarctica is rich in examples of international collaboration in science and logistics. These are mostly based on bi- or multilateral agreements between countries or on ad-hoc planning framed within COMNAP. Tackling the cooperation schemes is almost as large and complex as the number of players, with varying architectures involving European and other national programmes. Currently, no overarching strategy to improve collaboration among European countries exists, neither in science nor in logistics. Thus, sharing of Antarctic research stations or vessels and TNA to these assets is determined only by individual nations under bi- or multilateral agreements. Better coordination and support for TNA is needed to allow all European polar researchers to perform research in the Antarctic and to further a coherent and efficient use of European polar infrastructure resources. In addition, the creation of a European logistical hub in Argentina or Chile in support of European operations in the Antarctic Peninsula area, would promote and facilitate coordination while reducing logistic costs.

3.2

Access to infrastructure: Examples of success

World-leading European polar research is not possible without access to excellent infrastructures such as research stations, research vessels and aircraft for all European researchers. Facilitating scientific excellence-driven TNA to Polar infrastructures has therefore been an important goal of the European Commission within the last Framework Programmes (e.g. INTERACT, ARICE). The experience gained within these projects and their success stories must be recognised as pillars supporting the implementation of the future European Polar Research Programme. Currently, the European-funded TNA projects are only directed to the Arctic and there is a strong need to extend them to the Antarctic building upon successful examples and new actions.

Among the advantages of existing TNA schemes, are the significant research impacts achievable with light bureaucratic procedures and flexible funding, especially when compared to national access programmes. Common access procedures implemented through joint calls for proposals and mutually agreed and accepted evaluation procedures facilitate the access for European users to these nationally owned research marine and terrestrial infrastructures. The TNA schemes further offer excellent opportunities for advanced training and post-graduate education (e.g. INTERACT). The following examples of successful projects providing TNA or sharing of infrastructures give an overview about the different means of funding and implementing access to polar infrastructures.

Access to Arctic infrastructures:

INTERACT (International Network for Terrestrial Research and Monitoring in the Arctic) is a circumarctic network of currently 88 terrestrial field stations in northern Europe, Russia, US, Canada, Greenland, Iceland, the Faroe Islands and Scotland as well as stations in boreal and northern alpine areas. INTERACT is offering access in three different modalities: TNA to 53 research stations, Remote Access to 33 stations and Virtual Access to 32 stations. Together, the stations in INTERACT host thousands of scientists from around the world who work on projects within the fields of glaciology, permafrost, climate, ecology, biodiversity, biogeochemical cycling and human dimension. The INTERACT stations also host and facilitate many international single-discipline networks and aid training by hosting summer schools. INTERACT is funded by the EC since 2011.

Figure 6. MOSAiC crew replacement operations under the COVID-19 pandemic in Svalbard. *Photo: Leonard Mager.*

Figure 7. Ny-Ålesund research facilities in Svalbard. *Photo: Giuseppe Pellegrino, INTERACT.*

ARICE (Arctic Research Icebreaker Consortium) offers TNA to six international High Arctic research icebreakers to a wider community of researchers, including those who cannot benefit from such capacities at the national level. ARICE also collaborates with the maritime industry operating in the Arctic on a "programme of ships and platforms of opportunity". ARICE´s overall goal is to improve Arctic marine capacities of Europe by better coordination and sharing of vessels (Fig. 6). ARICE has been funded since January 2018.

SIOS (Svalbard Integrated Arctic Earth Observing System) facilitates access to the full breadth of research infrastructure on Svalbard (Fig. 7) that has been made available to SIOS by its members. SIOS offers access opportunities through regular strategic SIOS calls since 2017. Subsequent calls for access are opened each summer and are linked to the research priorities identified in the SESS (State of Environmental Science in Svalbard) report. The SIOS infrastructures are owned and operated by SIOS members, which are national research institutes and the access programme is funded by the members and host contribution from the Research Council of Norway.

Access to Antarctic infrastructures:

Access to Antarctic infrastructures differs significantly from the Arctic since multi-national funded TNA programmes are not in place. Bottom-up cooperation between national polar programmes on a need-based bi-lateral level is the most frequent way of accessing research infrastructures in the Antarctic, which limits their international use. Examples of international cooperation include:

EUROFLEETS+, which is providing TNA to 27 state-of-the-art research vessels from European and international partners is offering access to research vessels operating in the Pacific part of the Southern Ocean and the Ross Sea (Antarctica). EUROFLEETS has been funded since 2009 by the EC.

CONCORDIA station (Fig. 8) is an example for a successful bilaterally shared research station in Antarctica. Framed by a governmental agreement, it is jointly funded, staffed, and operated by the Italian Antarctic Programme (PNRA) and the French Polar Institute (IPEV). Concordia does not yet have a TNA programme, although some European researchers could get access in the past through French or Italian projects. However, the Italian

Figure 9. Spanish Antarctic Station Gabriel de Castilla. *Photo: Rafael Abella, COMNAP*

and French governments are willing to consider widening the access to researchers from other European nations in the future, building up on the successful partnership already in place with the ESA since 2006 for biomedical studies at this remote station. Concordia hosts and supports the EU-funded Beyond EPICA project, aiming to drill the oldest ice-core in Antarctica by providing its infrastructure and logistics, a much more economical solution than to rely on an autonomous drilling camp.

COMNAP's Antarctic Peninsula efficiency task force.

The Antarctic Peninsula has over 40 research stations operated by different countries (e.g. Fig. 9), offering vast opportunities for sharing logistical efforts. The COMNAP task force noted that bilateral cooperation for movement of personnel and equipment between one country's station and another is working well. It developed a point-based bartering system, like that used by the Ocean Facilities Exchange Group (OFEG) to share logistics (flights, containers, and ship-time) without involving financial transactions between nations. The task force was working for the first time throughout the 2018-2019 Antarctic field season, and consists of members from Chile, Korea, Poland, Spain and Turkey, having developed from a bottom-up initiative with the activities being funded by the national polar programmes. The bartering system could be extended to other regional groups in Antarctica.

Figure 8. The French-Italian Station of Concordia in Dome C in the interior of Antarctica. *Photo: Thibaut Vergoz.*

3.3

Good practice in interoperability

The Polar research infrastructure landscape includes many regional, national, and international organisations covering various aspects of polar research support. These range from logistical and operational challenges, to observations in remote areas and the application of FAIR data management principles. Mutually agreed standards are an essential step to achieve good interoperability on all levels. In addition, good and accessible guidance on how to apply these standards are key for their success. Several examples of good practice in improving interoperability exist which are relevant reference cases for the implementation of the EPRP. The following examples show different levels of engagements to improve interoperability:

The **World Meteorological Organization** (WMO) is a well-established intergovernmental organisation dedicated to international cooperation and coordination on the state and behaviour of the Earth's atmosphere, its interaction with the land and oceans, the resulting weather and climate regimes, and the resulting distribution of water resources. It is an excellent example of a top-down body that enforces global standards to drive measurements through standardised protocols, quality control, and real-time exchange of information necessary for public services.

Sustaining Arctic Observing Networks (SAON) is an international organisation under the scope of IASC and the Arctic Council created to strengthen multinational engagement in coordination of pan-Arctic observing networks. It recognises, in particular, the complexity of Arctic observing and infrastructure stakeholders and intents to involve Arctic and non-Arctic countries and Indigenous People, through facilitating activities and promoting increased cooperation. SAON hosts the joint SAON/IASC Arctic Data Committee (ADC) and the Committee on Observations and Networks (CON) being of special relevance to promote better interoperability in e.g. data management principles. Through the collaboration with the SCAR Standing Committee on Antarctic Data Management (SCADM), the joint SAON/IASC ADC a polar perspective of data interoperability is ensured.

The **European Polar Infrastructure Database and Catalogue** (Fig. 10) has been implemented in 2019 by EU-PolarNet and the EPB, in collaboration with COMNAP, INTERACT and EUROFLEETS. It includes the first European-wide survey of Polar stations, vessels and aircraft and an easily updatable online database with the characteristics of the infrastructure, associated to a query enabling WebGIS for visualisation purposes. This database is an excellent baseline for research and logistics planning and is currently being improved under the EPB with the aim of enhancing functionality for coordination and interoperability.

Figure 10. The European Polar Infrastructure web-accessible database. *Background Photo: BullRun, Adobe Stock*

Figure 11: AWI aircraft for Polar research. *Photo: AWI.*

Containerised laboratories based on standard shipping containers are used for a long time in polar research and are a practical model to improve interoperability. A good example is the Dirck Gerritsz Labs (Fig. 12) implemented by the Dutch Research Council (NWO), the Royal Netherlands Institute for Sea Research (NIOZ) and the British Antarctic Survey (BAS) at Rothera Research Station on the Antarctic Peninsula. The concept is to modify and instrument existing standard shipping containers, which are easily transported by different vessels and to install them in docking stations providing structural support, water, and power supply. This reduced cost and low impact approach allows for high flexibility for research and logistics, including upgrades and mobility of infrastructure.

Figure 12. Dirck Gerritsz containerized labs in Rothera Research Station (Adelaide Island, Antarctic Peninsula). *Photo: Tristan Biggs.*

4. An implementation plan for European Polar infrastructures: key recommendations

4.1

Improving infrastructure coordination

Better coordination and integration of infrastructures are key for strengthening European observing and modelling capacities, identified as two essential pillars of the future European Polar Research Programme, and for responding timely to emerging and new societal and environmental challenges. It will also contribute to identifying further indicators for sustainable development in the Polar Regions, which, when properly addressed, will positively affect the wellbeing and quality of life of peoples and the state of Polar ecosystems. Strategic investments in better coordination and integration of infrastructures will improve evidence-based decision-making processes.

Better sharing of infrastructures, logistics and operational procedures will serve large polar programmes and will scale-up smaller ones, maximising the technological capabilities to fill research gaps and reducing the environmental footprint in Polar Regions. The paradigm should be building long-term capacities to support sustained observations and research based on shared principles. Launching large-scale research initiatives will be facilitated by building upon existing and new essential infrastructures, and by enhancing the cooperation with the private sector (tourism, extractive industry, logistical and technological companies), as well as with Indigenous Peoples, local communities, academia, policy-makers and local governmental bodies.

Coordination of infrastructures to support the implementation of the EPRP should be supported by a **continuously updated map of European infrastructures,** including national and NGO initiatives. This will allow identifying imbalances and limited integration of European infrastructure due to geopolitical issues or resource availability. It will also allow the encompassing monitoring of observation infrastructure programmes, promoting the implementation of sustainable observations on a long-term basis.

The **implementation of policies** aiming to secure open and free access to European polar infrastructure, samples and data is also an essential step for the implementation of the EPRP.

Key to advancing the coordination and cooperation of European polar infrastructures is easily discoverable and up to date information on national polar operations. The establishment of a **European Network of Polar Operations** that will collect and provide such information and develop a system to coordinate access to polar infrastructures would serve all European polar programmes.

A better coordination of European infrastructures should be linked to the existing European integrative actions and infrastructures on Earth Observation (ESA, COPERNICUS), life sciences (European Molecular Biology Organization (EMBO), European Molecular Biology Laboratory (EMBL) and research coordination (EU Polar Cluster, ESA Polar Science Cluster) to streamline decision-making.

More specifically, innovation on European infrastructure development should address:

- The significance of the current regional observing systems for a pan-Arctic/Antarctic observing system, including strengthening their capabilities through advanced systems of telecommunications and navigation,
- The current technical limitations for data collection and validation, especially in icy environments,
- The need for new observation infrastructures to overcome the geographical coverage imbalance on communications (e.g. satellite constellations) and in situ observing systems,
- The different degrees of maturity on data collection and integration across disciplines, by using enhanced supercomputing infrastructure.

Figure 13. Field work in the vicinity of the Greenland Institute of Natural Resources Station. *Photo: Bula Larsen, INTERACT.*

Figure 14. Neumayer Station III in Antarctica. *Photo: Thomas Steuer, AWI.*

4.2.

Improving access to infrastructures

The EC has dedicated funding schemes to support the TNA to research infrastructures, such as Arctic research stations through INTERACT, research vessels through EUROFLEETS and Arctic research icebreakers through ARICE, and to research aircraft through EUFAR. These projects have been extremely successful in giving European researchers access to international world-class infrastructures and must be continued. Furthermore, initiatives to sustain these networks beyond the current EU funding should be supported.

Trans-National Access to the Antarctic infrastructures is based on individual agreements between national polar programmes and is so far limited. Except for EUROFLEETS+, which offers access to a few vessels operating in the Antarctic, no third-party funded projects exist until now, which provide TNA to Antarctic infrastructures. Accessing some regions in Antarctica or specific infrastructures is certainly challenging and expensive, while in other regions, such as the Antarctic Peninsula, TNA programmes could be more easily developed. Several European and international polar programmes are operating there and the development of common mechanisms to further TNA to infrastructures is highly recommended. It is important that such joint mechanisms become implemented, while also recognising the existing infrastructures as national assets contributing to a common European research goal. The European Polar Board, which includes all European polar operators, should take the lead on such pilot initiatives. Nevertheless, improved access to Polar infrastructures can in the long run only be properly addressed through financial and technical support to better coordinate operations and optimise resource use.

Besides access by individual research teams, Europe must promote the use and combination of infrastructures to answer **complex and key science questions,** which can only be addressed by joint efforts of several nations. An example is the international optimisation of marine infrastructure deployment.

Fostering the extension of **remote and virtual access** activities, including granting technical personnel, Indigenous and local communities to support science, is an important path to increase research, to reduce the ecological footprint, promote local employment and address health and safety issues. These new ways to promote data collection need further dissemination within the science community and much better interoperability (see Section 3).

Figure 15. Monitoring atmospheric pollution in Svalbard. *Photo: Marco Maggiore, INTERACT*

4.3
Improving interoperability

Improved interoperability is essential for a strong and future-proof European Polar Research Programme, where logistics serve science and observations efficiently, while fostering Europe's relevance in cutting-edge Polar research with low environmental impact.

More and better coordinated observations are the basis for the thorough and universal understanding of the fast-changing Polar Regions. The generated data will contribute to evaluate and improve models that will allow to correctly apply mitigation and adaptation policies. Remote and autonomous sensing is essential for data collection reducing the needs for human presence or allowing sampling inaccessible areas. Nevertheless, currently many sensors are not retrievable and have an environmental impact. New interoperable and standardised in situ observation technologies are needed to improve the spatial and temporal coverage of monitored key environmental and societal variables. These systems should be durable, minimise their end-of-life impact, including the use of materials that need to be truly biodegradable, biocompatible, or benign under the specific Polar environment. Miniaturisation, low power consumption, green energy and a focus on reusable instrumentation must be fostered, targeting also interoperable components. Real-time/near-real time data streaming is key for service-driven observations. Besides these technical improvements, a close interaction with research programmes is key to improve observation networks, as they are instrumental to identify observation gaps and needs across disciplines.

Fostering coordinated servicing of remote automatic stations by local and Indigenous technicians, as well as promoting cooperation with ships and platforms of opportunity of industry (D.3.4 – see Appendix I), should improve data collection. However, these should be pursued with care, using standard instruments and protocols, and aiming at reducing the ecological footprint. **Improving capacity building, training and mobility** of local and Indigenous technical and scientific personnel in Polar operations will open new paths for improved data collection and will support streamlining interoperability with a distributed network of local specialised personnel. This will support local employment and reduces the operational footprint. In remote sensing, the gap between the space and ground segments needs to be bridged, aiming to improve interoperability. To harmonise in situ observations and to making them suitable for integration with both remote sensing and Earth System Model approaches is of special importance. The FAIR data management principles must be widely applied, and respective policies should be implemented.

Figure 16. Heavy equipment transport in Juan Carlos I Station, Antarctic. *Photo: Gonçalo Vieira.*

Standardisation of infrastructure, instruments and protocols is essential to improve interoperability. Several activities towards better interoperability are being currently developed by different organisations (e.g. SAON/IASC ADC, WMO, SOOS[2]). The development of standard instrumentation to be deployed, i.e. in collaboration with commercial tour operators, as black box solutions, can be a way to promote interoperability (see the Norwegian Institute for Water Research (NIVA)'s FerryBox, Ships of Opportunity). To improve the use of data, the traceability chain to secure accuracy and homogeneity of observations is of prime relevance. Experience shows that standards are interpreted differently by each user, limiting interoperability. Hence, the development of high-quality training and guidance materials on instruments and observation protocols are highly recommended, allowing for a wider uptake of INSPIRE directives (see ENVRI-FAIR, EOSC[3]). The objectives should contribute to fostering the semantic web and linked data approaches, improving interoperability from instrumentation to data and its access. It is also essential to ensure a buy-in from the science community, which will translate into operational practice, linking field teams and organisations.

Logistics and operations will highly benefit from more interoperable systems. The European Polar Infrastructure Database (EPID) should be expanded to fully encompass facilities, instruments, and observations, including the needs for interoperability interfaces. It should cross-feed with - but not duplicate – existing initiatives, such as SAON-CON, improving the connection to SIOS, SOOS, WMO-OSCAR and continuing the cooperation with COMNAP, INTERACT, ARICE and EUROFLEETS. A better EPID would feed into a system involving new planning algorithms allowing to coordinate instruments, containerised laboratories and to align vessel operations (see ARICE and EUROFLEETS) accounting for activities in both Polar regions. The new system should be designed to account for science priorities and make best use of the interoperable and connected infrastructure, through coordinated operations. Lessons can be learned from the portals SOOS' DUE-South for the Southern Ocean and ISAAFFIK for Greenland, which aim at fostering cooperation and coordination by providing better information on ongoing operations.

[2] Southern Ocean Observing System.
[3] ENVRI-FAIR is the connection of the Cluster of Environmental Research Infrastructures (ENVRI) to the European Open Science Cloud (EOSC).

5. Conclusions and Outlook

Europe has a long tradition and strong reputation for world-class scientific research in the Polar Regions. This research is enabled and supported by significant and substantial scientific infrastructures, facilities and platforms operated by many European nations in both the Arctic and the Antarctic. Whilst there is already a degree of coordination and cooperation between European polar operators, there is a great potential for these resources to be used more coherently and effectively to deliver the highest quality research.

Since 2015, EU-PolarNet has brought polar operators, researchers and different stakeholders together to clearly identify the needs for infrastructure improvements in support of European Polar Research. As the outcome of this in-depth analysis, the following general recommendations have been identified:

- Coordination and cooperation among polar operators and stakeholders need to be fostered. Existing good practice from temporary projects or within bi- or multilateral agreements, must be enlarged into a consolidated framework that will serve Europe as a whole. This will contribute to promote better integration among existing initiatives, gain scale and boost impacts.
- Dedicated policies and investments are needed for improving access to polar infrastructure, samples, and data. Here, Trans-National Access programmes have shown to be an excellent model that should be strengthened and extended to both Polar Regions.
- Interoperability is a major challenge and needs a strong commitment, since it is key to maximise the efficiency of operations, shortening the path to the production of knowledge and applications. Investment must be done to improve interoperability at the level of observations, standardisation of infrastructure, as well as of logistics and shared operations.

Europe needs to urgently address these recommendations to allow for filling major knowledge gaps and emerging needs on Polar research and beyond. A solid strategy for Polar infrastructures is also essential for optimising the use of resources, avoiding fragmentation and duplication, consolidating existing capacities, while simultaneously reducing the ecological footprint, addressing the EU Green Deal and the UN SDGs.

Figure 17: Complex land supply logistics in interior Antarctica in the traverse to Concordia Station. *Photo: PNRA, COMNAP.*

Figure 18: Tethered ballon at Gruvebader lab, Dirigibili Italia Station, Svalbard. *Photo: Vittorio Tulli.*

Appendix I.

List of EU-PolarNet deliverables relevant to the White paper on European polar infrastructure access and interoperability, including an infrastructure implementation plan for the European Polar Research Programme.

EU-PolarNet D3.1:
Survey of the existing Polar Research data systems and infrastructures, including their architectures, standard/good practice baselines, policies and scopes.

EU-PolarNet D3.2:
European Polar Infrastructure Catalogue. Also accessible here together with the online European Polar Infrastructure Database.

EU-PolarNet D3.3:
Survey of existing use of space asset by European polar operators.

EU-PolarNet D3.4:
Survey of polar commercial infrastructure.

EU-PolarNet D3.5:
Data management recommendations for polar research data systems and infrastructures in Europe.

EU-PolarNet D3.6:
Gap analysis highlighting the technical and operational requirements of the European Polar Research Programme for satellite applications.

EU-PolarNet D3.8:
White paper on European polar data accessibility.

Authors

Gonçalo Vieira (IGOT-UL), Nicole Biebow (AWI), David Velázquez (AWI).

Contributors

in alphabetical order: Badhe, Renuka (EPB); Cabrita, Teresa (IGOT-UL); Chappellaz, Jérôme (IPEV); Godøy, Øystein (MetNorway); Houssais, Marie-Noëlle (CNRS); Ignatiuk, Darek (SIOS); Jennings Inger (SIOS); Johannessen, Johnny (NERSC); Lihavainen, Heikki (SIOS); Mateev, Dragomir (BAI); Nolan, Joseph (EPB); Ojeda, Miki (UTM); Rysgaard, Søren (AU); Savela, Hannele (UOULU); Schlarb-Ridley, Beatrix (UKRI-BAS); Schmidt Mikkelsen, Peter (AU); Vaikmae, Rein (TUT); Valentin, Christine (WOC); Vitale, Vito (ISP-CNR); Willmott, Verónica (AWI).

Imprint

EU-PolarNet is coordinated by the Alfred Wegener Institute
Alfred Wegener Institute
Helmholtz Centre for Polar and Marine Research
Am Handelshafen 12
27570 Bremerhaven
Tel.: +49 (0)471 4831-0 / Fax: +49 (0)471 4831-1149
info@awi.de
www.awi.de

Publisher: EU-PolarNet
info@eu-polarnet.eu
Tel.: +49 (0)471/4831-1011

Design: www.glinsmann-design.de
Cover Photo: The French-Italian Station of Concordia. Photo: Thibaut Vergoz, IPEV.

Funding: EU-PolarNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 652641.

Acknowledgements: INTERACT and COMNAP are thanked for their continued cooperation on data sharing for the European Infrastructure Database, which provided several pictures included in this publication.

EU-PolarNet
connecting science with society

info@eu-polarnet.eu
www.eu-polarnet.eu

Figure 19: Czech field camp in Eastern Antarctic Peninsula. *Photo: Mikova, COMNAP.*

EU-PolarNet has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 652641.