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ARICE: Arctic Research Icebreaker Consortium:

A strategy for meeting the needs for marine-based research in the Arctic

Deliverable 8.11

Impact evaluation report

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Submission of Deliverable

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Contents

Abstract

The assessment of the impact of ARICE is essential to understand how the strategies developed by the project and its outcomes have affected the Arctic research scene. The results are framed within three main dimensions: science, policy, and industry.

In this deliverable, we focus on results, events and activities that provide numbers and narratives to support the fulfilment of the impacts related to the Work Programme and other impacts.

1. Introduction: Tackling complex scenarios: from outputs of actions to impacts on the system

European Research Infrastructures (RI) are framed in long-term strategic processes to address scientific advances. Scientific results can contribute to provide solutions in tackling societal challenges at large, especially when their global dimension cannot successfully be approached by a single country.

Single projects or initiatives are designed and implemented to achieve some objectives usually framed within a wider vision. In Europe, the role of research recently focused on two main political goals: the Green Deal and Digitalisation. These two main goals are in some sense a simplification of the well-known UN SDGs addressing the global transformation we are facing, driven mainly by the climate change and the economy dynamics.

ARICE will develop strategies and activities to ensure the optimal use of the existing polar research vessels at a European and international level, working towards an International Arctic Research Icebreaker Consortium that will share and jointly fund operational ship time.

The activities and results of ARICE are framed within three main dimensions: science, policy, and industry.

In fact, ARICE selected excellent scientific proposal and provided ship time to develop research campaigns in the Arctic. This will result in advances in science and a cross-border structuring of the scientific community.

ARICE has addressed challenges at regional level that are well linked to the global challenges: climate change, maritime transport, natural resources exploitation. For the Arctic, these are recognised to be priorities for the impacts on the geo-political scenario. We can therefore frame the activities of ARICE in a science diplomacy context too, not only for the scientific results aiming at providing solutions but also as a platform for enabling the dialogue between countries and a bridge between the different communities.

The identification of the impacts of the results from a project, or an initiative, must be approached taking into account some considerations, as follows.

The challenges we are facing address interconnected aspects and actions that increase the complexity of the system. ARICE is dealing with the marine environment, economy, policy, with a diversity of involved stakeholders. The dynamics of this complex system is difficult to be controlled and predicted in the long-term. For this reason, it is quite impossible to attribute an impact of a single action on the overall scenario and better indeed to speak about a contribution to the process of a network of agents that points towards the goals.

When identifying the impacts of ARICE we will therefore focus on those results, events, activities that

will provide numbers and narratives to support the fulfilment of the objectives described in the contract with the EU Commission. This evaluation process aiming at identifying the impacts of the project is useful for the accountability to taxpayers, to support the policy/economy (through the identification of priorities, tech transfer etc.), and the internal awareness/learning of capacities and barriers (e.g. harmonisation, logistics, efficiency etc.).

2. The evaluation of the expected impacts from ARICE

ARICE is expected to impact accordingly to the above mentioned three main dimensions: science, policy, industry.

In this context, it is expected to provide outputs in the following aspects that, in turn, can indirectly induce a structural transformation of the system constituted by scientists, decision-makers, end-users and producers:

- The increase in ship-time availability for research in the high Arctic
- The improvement of the observation capacities in the Arctic Ocean
- The establishment of a common access procedure to international PRVs
- The education of new generations of polar professionals
- The reinforcement of partnership of research organisations with industry

The approach to the evaluation of the impacts has been described in deliverable D8.11 and is based on **quality,** i.e. through the analysis of activities and events within a fit-to-purpose narrative, and **quantity**, i.e. numbers. The consortium has selected indicators that are considered transparent, appropriate, reliable, credible, applicable, and understandable. In other terms, these indicators are **satisficing** (satisfying and sufficient), also for some aspects usually less tangible (e.g. alignment of national research programmes, enhanced cooperation, access to services, etc.).

In the following, we list the indicators that have been identified to evaluate the impacts within the three dimensions:

Science: Transnational Access, training, data access, networking.

Support to economy: identification of priorities, technological transfer, engagement of industrial partners.

Support to policy: identification of priorities, networking.

3. Contribution to impacts related to the work programme and other impacts of ARICE

3.1. Access to the infrastructure and interdisciplinary cooperation

"Researchers will have wider, simplified, and more efficient access to the best research infrastructures they require to conduct their research, irrespective of location. They benefit from an increased focus on user needs".

Icebreakers are very costly infrastructures, traditionally accessible to researchers from the icebreaker's country through their national funding system.

ARICE gave the possibility of access, for the first time, to a unique set of international world-class icebreakers (Figure 1) and provided a simplified and efficient access to in the ice-covered Arctic Ocean to all European (and international to a certain extent) researchers. This opportunity was offered independently on the nationality of the researchers (as long as the PI and the majority of the users were based in a country other than the country where the icebreaker was based), and the selection of proposals was based solely on scientific excellence and with particular attention to researchers from countries that do not own icebreakers.

Figure 1: ARICE participant icebreakers.

A single-entry portal, unique evaluation system accepted by all ARICE vessel operators and their institutions, simplified the access to these infrastructures.

Additionally, the planned "programme of ships and platforms of opportunity" with the maritime industry has allowed European researchers to access industry vessels to deploy sensors or other devices, which will significantly improve the researchers' capacities for widely spread observations in the Arctic Ocean.

In the following, we report numbers and figures to describe some aspects that can highlight the results of ARICE in terms of access to the infrastructures.

ARICE calls for ship-time proposals and implemented research projects onboard Research Icebreakers funded by the EC.

ARICE has offered access to six international icebreakers in the Central Arctic, Fram Strait, Barents Sea and Beaufort and Chukchi Seas in two calls for ship-time proposals.

A total of 19 proposals were submitted, involving 121 scientists from 20 countries (Figure 2).

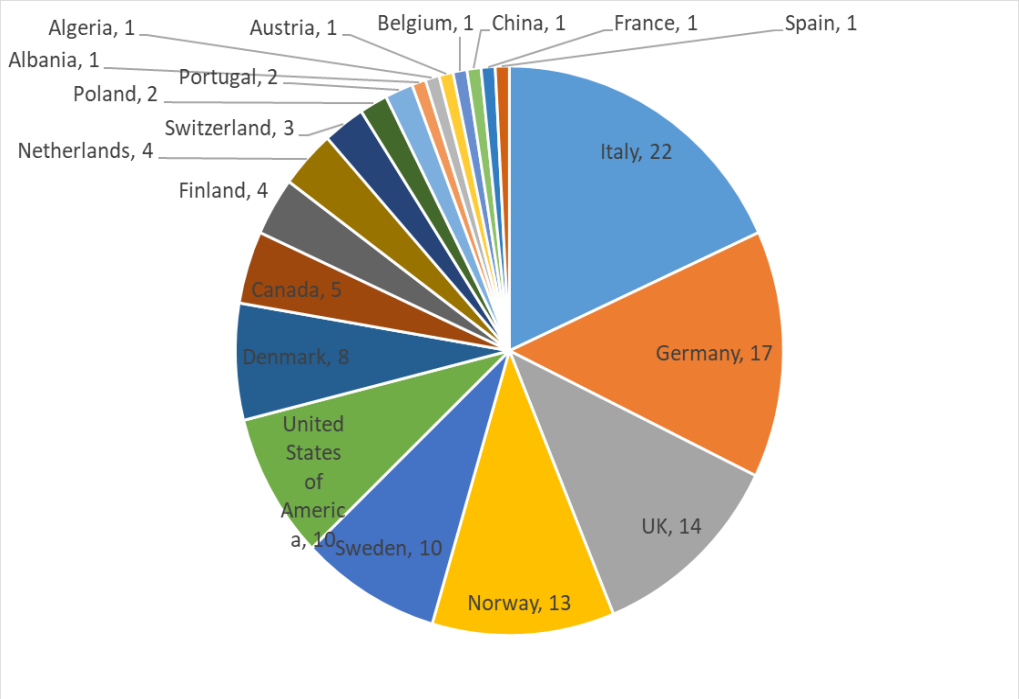

Figure 2: Nationality distribution of researchers involved in the proposals submitted to the two ARICE calls.

The evaluation system used in ARICE (Figure 3), was developed by the EU funded project EUROFLEETS(1), and implemented along in EUROFLEETS(1), EUROFLEETS2 and EUROFLEETS+ projects, as well as in ARICE.

This evaluation system has proved to be very efficient in ensuring that only excellent proposals are implemented on board the vessels.

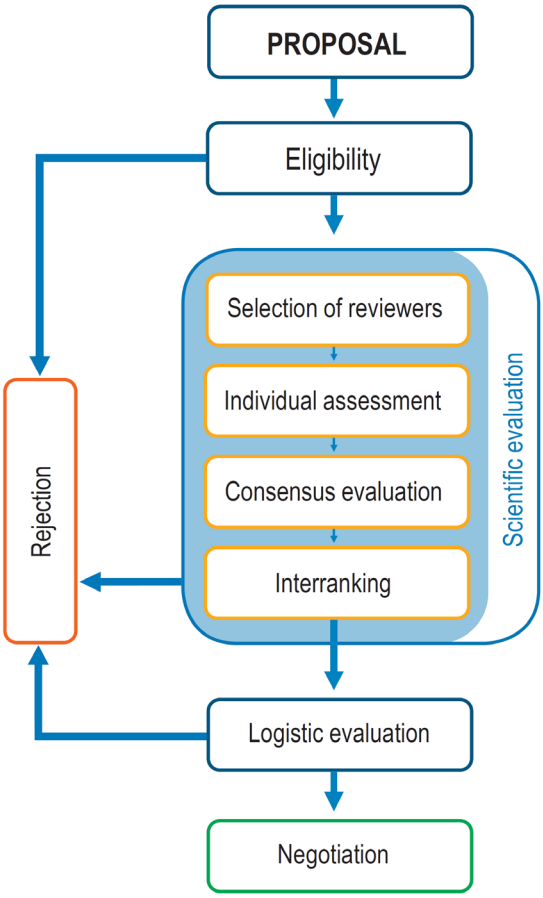

Figure 3: Pathway to proposal granting.

Each proposal was reviewed by at least three international external experts (Figure 4) recommended by the ARICE Scientific Evaluation Panel (the latter more than 50% external to ARICE, see ARICE Deliverable 4.6 Selection report of the ARICE Call for proposals).

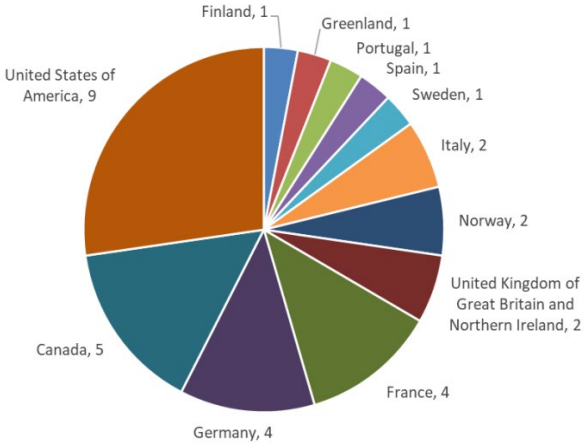

Figure 4: Nationality of the reviewers of the submitted proposals.

Granted cruises

Eight cruises have been granted and implemented (see table 1). In order to ensure transnational access to the infrastructures, the first eligibility criteria for the access to the icebreakers is that the Principal Investigator and the majority of users for each proposal are based in a country other than the country where the infrastructure is based.

Table 1: Name of the infrastructure, country and number of granted cruises on board of the 6 icebreakers coordinated by ARICE.

Name of the ice-breaker	Country	# granted proposals
IB Oden	Sweden	3
PRV Polarstern	Germany	1
RV Kronprins Haakon	Norway	1 (in two years)
MSV Fennica	Finland	0
RV Sikuliaq	USA	1
CCGS Amundsen	Canada	1

Overall, more than 90 researchers were involved in the granted proposals.

The cruise implementation – international cooperation and human dimension

More than 15 countries were involved in the implemented cruises (table 2 and 3, figure 5), an example of how the international cooperation is enhanced by polar expeditions.

Table 2: Project acronym, name and country of the icebreaker, country from consortium's partners, country of participants from countries not included in the consortium. EU countries are marked in bold. For a project description see https://arice-h2020.eu/arice-cruises/.

Name of the project	Vessel name and country	List of countries/nationalities in consortium	List of countries out of consortium/nationalities
DearICE	Polarstern, **DE**	**FI**, **NO**, **IT**, **SE**, US	**CZ**, **SL**, RU, CH
NOTAC2020	RV Kronprins Haakon, **NO**	**DE**, **DK**, **PL**, CA	BR, CN, **IR**
NOTAC2021	RV Kronprins Haakon, **NO**	US, **DK**, **DE**, **PL**, CA	RU, ZA, BR, CN, **IR**
PECABEAU	CCGS Amundsen, CA	**DE**, **SE, FR**, UK, CA	JP, **NL**
TRACE	IB Oden, **SE**	**DE**, UK	
VACAO	IB Oden, **SE**	**DE**, **SE**, **ES**	
PROMIS	IB Oden, **SE**	**UK**	
Go-WEST	RV Sikuliaq, US	**DE**, US	RU, **NL**, **BE**

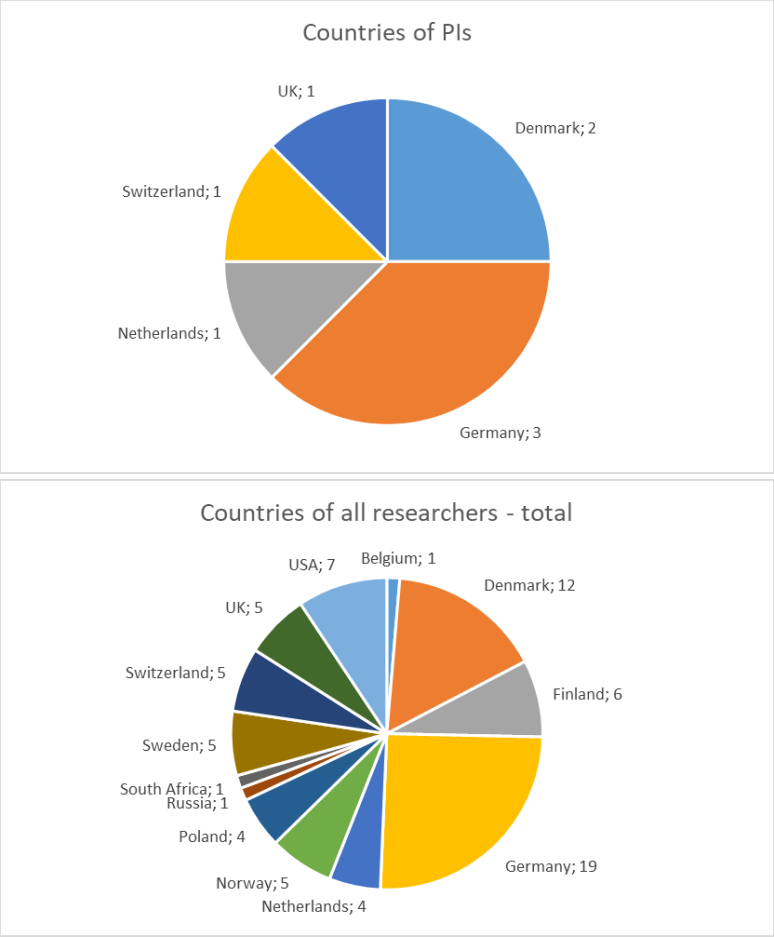

Figure 5: Nationalities of the PIs (above) and of all the researchers (below) involved in the cruises, including scientists in person and with remote access.

Table 3: Proposal acronym, # of researchers involved in the campaigns, distinguishing between gender, presence or remote participation and PI institution's nationality (note that NOTAC2020 took place only in remote access due to travel restrictions associated to COVID-19).

Accessing INFRA	Females	Females in remote	Males	Males in remote	# Researchers	PI Institution Nationality
DEARice	3	2	2	5	12	Switzerland (M)
NOTAC2020	0	2	0	5	7	Denmark (M)
NOTAC2021	4	5	1	2	12	Denmark (M)
PECABEAU	3	1	6	1	11	Netherlands (F)
TRACE	1	0	0	2	3	Germany (M)
VACAO	0	2	3	4	9	Germany (M)
PROMIS	2	0	0	0	2	UK (F)
Go-WEST	4	0	6	0	10	Germany (F)
Total	17	12	18	19	66	

The following numbers refer only to the researchers who participated in the implementation of the cruises and not in the analysis of the data collected on the cruises.

Assuming that any researcher on board of the cruises involved in average 6 other colleagues or technicians for the preparation, implementation and data analysis of the campaign, we estimate a total number of researchers and operative technicians in 600. An additional community constituted by the unsuccessful applicants and the reviewers is of the order of 100. Also considering the number of students and participants to the training courses in person or online (of the order of 1000), participants to workshops and conferences (of the order of 500), we estimate more than 2000 people were involved in ARICE at different levels, not including the public or experts accessing the ARICE website.

Days at sea

The total of 39 days funded by the transnational access activities in ARICE, have resulted in a total of 359 of access to the Arctic Ocean (table 4). This is mainly due to the participation of ARICE scientists (project DEARice) in MOSAiC, the largest polar expedition in history (https://mosaic-expedition.org) on board PRV Polarstern. The expedition took place over a full year in the central Arctic Ocean, and ARICE funded scientists were present in three of the 6 legs. In addition, in order to minimise transit days, the research cruises are implemented with different research groups onboard, promoting the multidisciplinarity and mutual collaboration. The sampling is usually intercalated between the different groups, allowing the successive preparation of samples and sampling devices, in a continuous work in well calculated shifts.

Table 4: Cruise acronym, ship-time (in days) granted by ARICE, actual time (in days) scientists spent on board[1].

Accessing INFRA	**Ship time granted (in days)**	**On board participants**	**Actual cruise length in days**
DEARice	7	5	210
NOTAC(1)	4	0 (Remote Access)	20
NOTAC(2)	4	5	20
PECABEAU	11	9	28
TRACE	7	1	56
VACAO		3	
PROMIS		2	
Go-WEST	7	10	25
Total	39 days	35	**359 days of access**

[1] Note that time spent on board is actual working time. Since the moment mobilisation occurs, the scientific teams install their equipment and laboratories. Once data acquisition starts, usually spread in different stations along the way, the team uses the time between stations to analyse and or process the samples/data collected.

"Closer interactions between a large number of researchers active in and around a number of infrastructures, cross-disciplinary fertilisations and a wider sharing of information, knowledge and technologies across fields and between academia and industry".

In the framework of the cruises and other activities implemented by ARICE (see also next paragraphs), the project has fulfilled the expected impact to facilitate a wide range of interactions among the different communities. A common vision and joint actions constitute in fact an extremely useful support to the national and international initiatives encouraging cross-disciplinary Arctic research.

The proposals submitted for funding involved a variety of disciplines and applications (see figure 6). All different disciplines of Arctic marine-based science have been involved. The participants to the granted cruises showed an equal sharing of expertise between biology/genetics, physics/oceanography and technology.

In order to maximise the use of the ship-time in the Arctic Ocean, the ARICE proposals were implemented in expeditions together with other scientific teams, ensuring the best use of these infrastructures. This, in fact, facilitates the cross-fertilisation among the different groups, while new networks and collaborations are established.

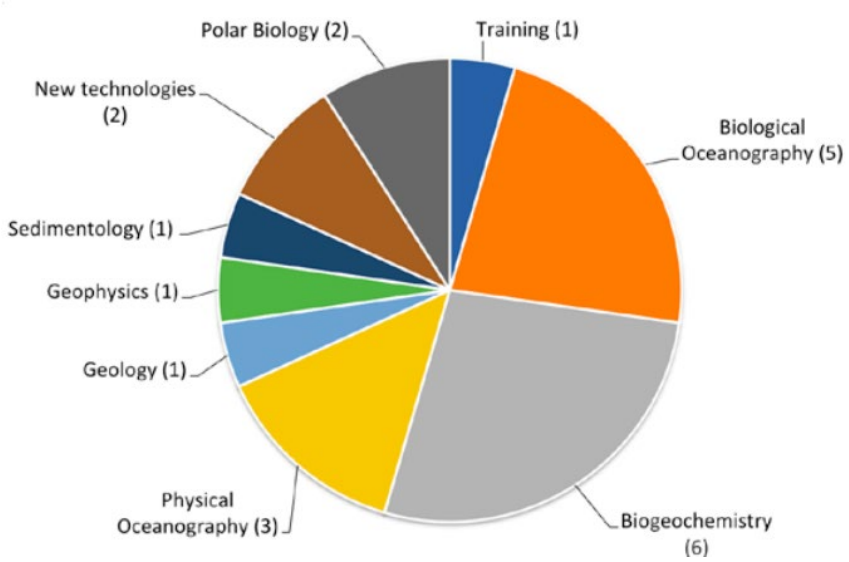

Figure 6: Scientific disciplines of the proposals submitted to ARICE.

Moreover, data and results from the ARICE cruises and activities have been disseminated to a wide audience, providing a unique opportunity for an integration of competences and interests in the Arctic.

Networking and cooperation at scientific level also beyond the consortium

ARICE established a fruitful dialogue with other projects and initiatives such as the established networks of vessel operators ERVO and IRSO (European Research Vessel Operators and International Research Ship Operators, respectively), but as well FARO (Forum of Arctic Research Operators), EuroGOOS, the EPB (European Polar Board) and the EU Polar Cluster projects such as EU-PolarNet 2,

INTERACT, ARCSAR, EXTREME EARTH, INTAROS and KEPLER. The cooperation has ranged from co-organisation of sessions at international conferences (Arctic Circle 2019, ASSW2021, online workshops and informative booths at (e.g.) AGU in December 2019 in Washington DC, and the SMM maritime fair in Hamburg, in September 2022. The cooperation between ARICE, FARO, INTERACT and the EPB has led to the organisation of a conference in Brussels on the 27th of October entitled "The Future of Research Infrastructure in the Arctic" (https://arice-h2020.eu/the-future-of-research-infrastructure-in-the-arctic/).
In the wider context of global activities in the Arctic, ARICE also contributed to Large Scale International (and multidisciplinary) Initiatives, such as within the MOSAiC Expedition with the DEARice project (with 210 days of ARICE scientists on board 3 legs) and the Synoptic Arctic Survey (58 days with three ARICE projects taking place simultaneously) (table 4).

Ships and platforms of opportunity

The fruitful cooperation developed with the industry operating in the Arctic as result of the established dialogue with industry, has led to the implementation of a Ships and Platforms of Opportunity Programme in collaboration with the Polar Expedition Ship state-of-the-art icebreaker (PC2 Class) "Le Commandant Charcot" operated by PONANT (France). The vessel is equipped with scientific laboratories and facilities and has offered through ARICE to host up to four scientists to participate in their regular cruises to perform scientific projects. The access to "Le commandant Charcot" is offered by PONANT free of charge.

Three calls for proposals have been opened in collaboration with PONANT. At the time of writing this deliverable the first call for proposals resulted in the granting of 10 research projects that have been implemented in the summer of 2022 giving access to 38 scientists (see Table 5), some of them over several consecutive legs.

The second call for proposals, for projects to be implemented in 2023 and beyond, has resulted in 15 proposals recommended for implementation. Logistical evaluation is still ongoing.

A third call for proposals is at the moment of writing this deliverable open for applications.

See also https://arice-h2020.eu/science-industry-cooperation/

Figure 7: The cruise icebreaker (Commandant Charcot) from Ponant.

Table 5: Proposals implemented on board Le Commandant Charcot in the Arctic Ocean.

Lead Institution, Country code	**TITLE**	**Number of participants /days at sea**
University of Calgary, CA	Underway Measurements of Essential Marine Biogeochemical Variables in the Arctic	2 participants / 6 days at sea (23/06/2022 to 28/06/2022) 2 participants / 11 days at sea (28/06/2022 to 08/07/2022)
Laval University, CA	NANOPLARCTIC	2 participants / 13 days at sea (22/05/22 to 03/06/22) 2 participants / 16 days at sea (07/08/2022 to 22/08/2022)
AWI, DE	Arctic and Antarctic Sea Ice – Thickness variability and change, ice loads and navigability.	2 participants / 16 days at sea (08/07/2022 to 23/07/2022)

GEOMAR, DE	GOOD-OARS-IMDOS	4 participants / 13 days at sea (03/06/22 to 15/06/2022) 4 participants / 9 days at sea (15/06/2022 to 23/06/2022) 2 participants / 5 days at sea (23/06/2022 to 28/06/22) 2 participants / 11 days at sea (28/06/2022 to 08/07/2022)
Oregon State University, USA	Under-ice phytoplankton distribution and diversity across poles	2 participants / 16 days at sea (08/07/22 to 23/07/22) 3 participants / 16 days at sea (22/08/22 to 06/09/22)
Duke University, USA	NITRARC	2 participants / 25 days at sea (07/09/22 to 01/10/22)
LEGOS/OMP, FR	Drone Experiment for Sea Ice Retrieval (DESIR)	2 participants / 16 days at sea (08/07/22 to 23/07/22)
AWI, DE	Response of harmful dinoflagellates to climate change (ReHaDiCC)	2 participants / 12 days at sea (03/06/22 to 15/06/22)
CNR, IT	Monitor Radiation and Clouds Characteristics over Arctic Ocean (MoRaCCA)	3 participants. / N/A. Installation of sensors during stopover. NB: To date, sensors are still on board and collecting data.
UiT The Arctic University of Norway, NO	ECOTIP	2 participants / 12 days at sea (10/05/22 to 22/05/22)

3.2. Harmonisation/optimisation

"Operators of related infrastructures develop synergies and complementary capabilities, leading to improved and harmonised services. There is less duplication of services, leading to an improved use of resources across Europe. Economies of scale and saving of resources are also realised due to ***common development and the optimisation of operations".***

Coordination of the Polar fleet

ARICE implemented a regular dialogue with PRV operators to improve the coordination of the icebreakers with ice strengthened/ice-classified vessels.

Nine operators were involved in this process, from Sweden, Germany, Norway, Canada, USA, UK, Finland, Denmark, Spain. Four meetings have been organised and implemented with vessel operators at the International Research Vessel Operators (IRSO) meetings, European Research Vessel Operators (ERVO) to discuss the benefits of a coordinated fleet and the way to achieve this. In addition, other discussion and planning webinars took place, e.g. to introduce software developed for managing marine facilities (Marine Facilities Planning) to the operator's community.

The networking activities with PRV operators have allowed to identify some technical challenges to be tackled. One of the needs was the information sharing - especially during the earlier stages of the cruise planning process – that would reduce duplication of efforts, increasing efficiency and effectiveness geographical coverage too. In order to facilitate the sharing without added workload, ARICE organised a webinar with one software provider that many operators use in the planning of their activities. The focus in the workshop was on the existing and potential future possibilities to use this software in the sharing of specific parts of the information that the operators already collected.

The introduction of a management system for enhanced access and interoperability of European and international research Icebreakers has provided a coherent and more cost-effective use of these infrastructures. Before ARICE, national polar research strategies were mainly non-homogeneously designed and developed: joint planning has improved the data coverage from the Arctic Ocean, providing a more comprehensive overview of the changing Arctic Ocean and better data for modelling and prediction.

The dialogue with the polar vessel operators has led to a willingness to continue the cooperation and networking in the future, in order to improve the services, the vessels offer to the scientific community. The first steps are done towards the creation of a consortium of Polar Research Vessel Operators in the Arctic Ocean.

Research proposals: Single access point and joint evaluation system

Before ARICE, access to research icebreakers was limited to the national application systems for scientists based at a country operating those icebreakers, and for those willing to join foreign expeditions to personal contacts. ARICE has standardised the use of a single entry-point /joint evaluation system, to manage the ship-time proposals. This process has been accepted by the operators of the ARICE vessels, with a structured link with other initiatives aiming at coordinating marine infrastructures (e.g. Eurofleets, Eurofleets2, Eurofleets+).

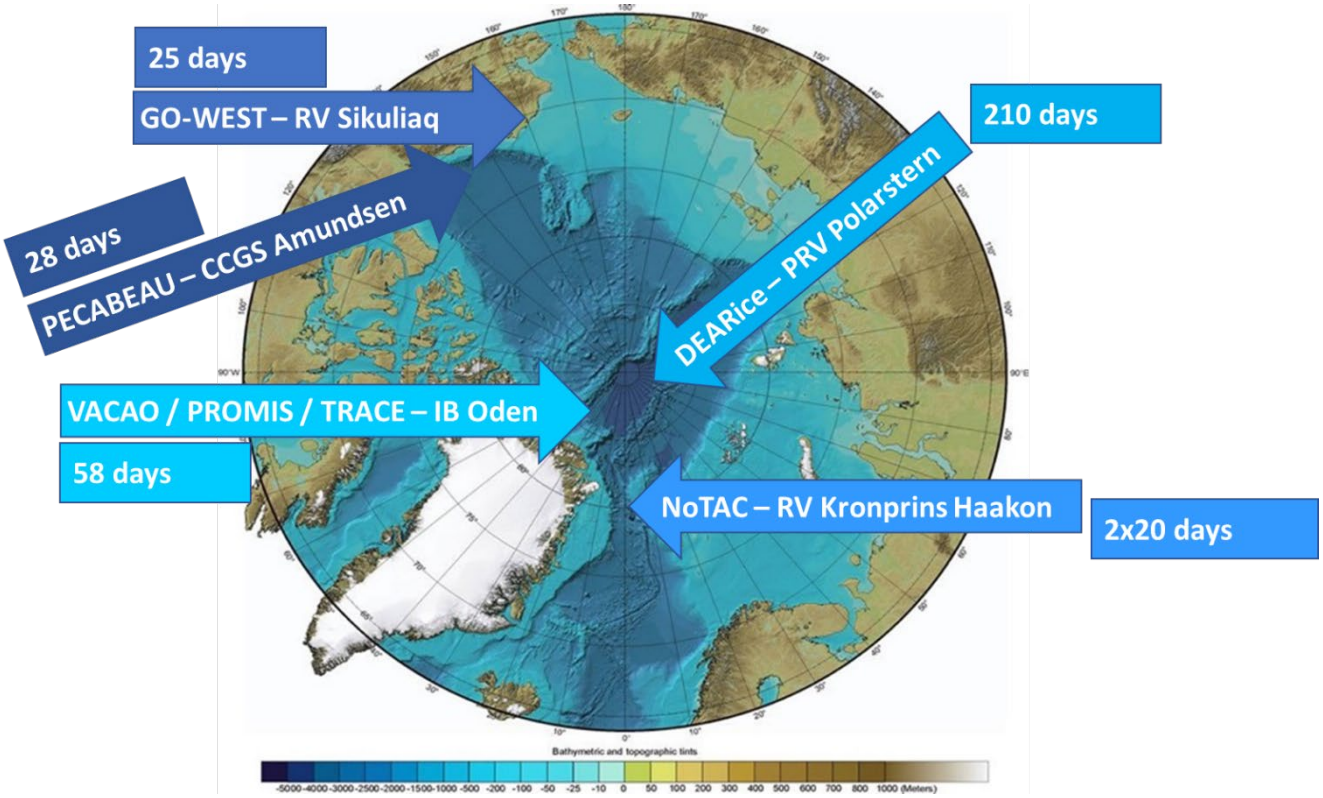

Figure 8: Geographical coverage of the funded cruises.

The 3D Virtual Icebreaker – a tool to improve the efficiency of pre-cruise preparation

The 3D Virtual Icebreaker platform https://vessels.arice-h2020.eu/ gathers information from all the ARICE Icebreakers and provides advanced functionalities such as an interactive map with real-time ship positions and layers, interactive 3D model of the Icebreakers with their scientific equipment, a 360° photo virtual tour, a map with present and past cruises of the ships, a multimedia section as well as an educational and informative video section.

3D models of ships and several instruments as well as virtual tours based on state of art technologies help to bring several user categories more "near" these research ships. The platform, through the virtual tour even provides a tool to measure with accuracy the space and distances, enabling researchers and operators to better plan and implement the instrumental setup even in remote, increasing efficiency and effectiveness of the cruises.

The portal is planned to act in the future as a collector of all the other ARICE data management resources.

Figure 9: The 3D icebreaker entry portal.

Figure 10: The 3D model for Laura Bassi and description of points of interest.

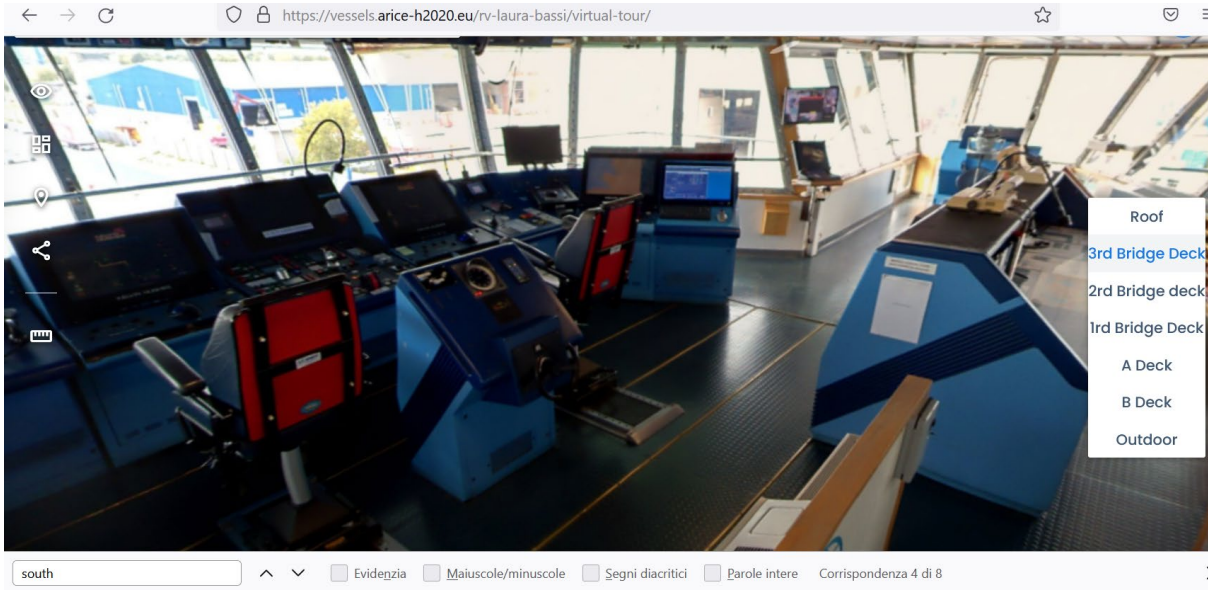

Figure 11: Screenshot from the web interface of the virtual tour for the 3D-icebraker.

"Optimising European Polar research capacities and the use of European resources"

The collaboration of infrastructure operators in implementing multidisciplinary and international cruises with transnational access component, together with the contribution from industry as shown in the "ships and platforms of opportunity programme" has substantially increased the capacities of European researchers to reach beyond the extent of the European Polar vessels' capacity.

"Innovation is fostered through a reinforced partnership of research organisations with industry."

Innovation is considered a relevant aspect in addressing the challenges in the Arctic, especially for those opportunities that could be offered when climate change will enable new economic routes to be open.

Dialogue with industry

ARICE reinforced the dialogue with industry, demonstrating the value for a more structured science community interaction with this community, stimulating the involvement of industry representatives in appropriate Arctic research and science planning bodies.

ARICE constituted an **Industry Liaison Panel**, with representatives from more than 20 Associations, 85 companies and individuals. A diversity of industrial sectors has been involved: shipping, shipbuilding, oil and gas, tourism, fishing, aquaculture.

ARICE addressed the science-industry dialogue in the Arctic participating in many **events** such as at the Sustainable Ocean Summit (Hong Kong 2018), Investing in Oceans Future (Paris 2019), Arctic Circle Assembly (Reykjavik 2019), Ocean Vision 2030 (online 2020), Science day at Le Commandant Charcot (Le Havre 2022), SMM maritime conference (Hamburg 2022) - the latest, organised in close cooperation with EU-PolarNet 2, included a panel discussion with industry representatives.

During the workshops organised by the consortium (Workshop "Industry-Science Cooperation for Safe and Sustainable Arctic Operations" on 20 November 2019 in Paris and ARICE Project Meeting: "Industry-Science Cooperation for Safe and Sustainable Arctic Operations" on 8 December 2020 online) the number of participants were more than 80, with a share of 70% and 50% from industrial representatives respectively.

In most of those meetings, information and ideas have been shared to pave the way for a long-term cooperation to frame scientific and economic sectors in the Arctic. The integration of information from research and merchant vessels has been considered fundamental and measurement capabilities, data collection and transmission have been provided in guidelines for the support to the "**programme for ships and platform opportunity**".

Figure 12: Screenshots and pictures of some meetings where industry played a joint role with ARICE.

"Enhanced innovation capacity"

Identification of new technology for sustainable operations in Arctic waters

The harsh conditions of the Arctic provide an ideal benchmark for developing and improving technology for extreme environments like space or the deep-sea. The Arctic is highly sensitive to human influence and hence innovation in reducing the footprint of the humans living and working in these areas, including research and industry, is of high importance. This ranges from improving alternative energies to reducing the noise impact of vessels working and crewing in the polar marine areas. ARICE worked with the maritime industry to identify **new technologies** for sustainable operations in the harsh Arctic environment.

A special attention has been focused on Autonomous Unmanned Vehicles (AUVs), whose impact and limitations for the use in the Arctic have been investigated. In general, *automation, miniaturisation, communication capacity and endurance, use of artificial intelligence* emerged as the relevant aspects. Battery life and reliability have been identified as key factors for technology development. Communication links and weather services have been identified as key factors for the support to the activities in the Arctic.

In this context, specific technological standards and tools that require research and innovation for their development with short-medium term transfer time to market include, have been proposed, amongst others:

• Standard ship interfaces based on Data Distribution Standard (DDS)

• Automatic instruments for data acquisition, e.g. of sea ice and snow variables of interest or atmospheric variables as radiation and cloudiness

• High bandwidth communications and cloud-based services for near real-time, high-resolution transfer, storage and analysis of data

• AI-based methodologies for automatic classification of ice properties from satellite images

"New market opportunities to strengthen competitiveness and growth of companies".

The design and development of the above tools are expected to open new markets for major system architecture and software companies as well as for SMEs developing apps for instrument and data management.

Ship specific route optimisation in ice covered waters: Based on the above mentioned technological achievements, an ice routing service to optimise travel time and CO2 emission while taking into account the risk related to harsh ice conditions could be developed.

In terms of research priorities to increase the sustainability of economic operations at sea in Arctic and provide market opportunities, measurable results for the science-industry cooperation have been listed as follows:

- In the short term: standard ship interfaces based on DDS, automatic instruments, high bandwidth communication.
- In the long term: methods for environmental assessment, end-to-end ecosystem models, operational risk maps.

The details of this are provided in public available documents as the deliverables from the Work Packages 6 and 2.

3.3. Human Capacity Building

"A new generation of researchers is educated that is ready to optimally exploit all the essential tools for their research."

One of the main objectives of ARICE was to educate a new generation of researchers. ARICE also included dedicated training for technical personnel on devices used for research in ice-covered waters.

This objective was achieved through different initiatives.

The MOSAiC School

ARICE and APECS enabled a unique in-person training opportunity on an icebreaking research vessel in the Central Arctic: **the MOSAiC School**, a "summer" school in the frame of the MOSAiC Expedition held from 16th September to 28th of October 2019 onboard the Russian Research Vessel Akademik Fedorov. The aim of the summer school was to provide the opportunity for practical hands-on and in-depth learning, as well as active exchange with peers and lecturers. Twenty selected early career scientists (MSc. and PhD students) from 11 countries participated in the training programme (Figure 13). The RV Akademik Fedorov accompanied the RV Polarstern into the central Arctic sea ice where the RV Polarstern spend a year drifting with the sea ice to study the coupled Arctic climate system.

Figure 13: Participants to the MOSAiC summer school. Flags of their countries and main scientific disciplines are also shown.

This in-person training included lectures, practical exercises and workshops, as well as fieldwork training on the Arctic sea ice. Lectures onboard RV Akademik Fedorov covered all aspects of interdisciplinary research during MOSAiC, as well as training in science communication. The MOSAiC School 2019 received additional support by the International Arctic Science Committee (IASC), Climate and Cryosphere (CliC) and Year of Polar Prediction (YOPP).

A total of 255 applications from 35 countries were received (Figure 14). More than 2/3 of the applicants were female and the selection of the successful candidates reflected the ratio of applicants. 30 junior and senior reviewers were involved.

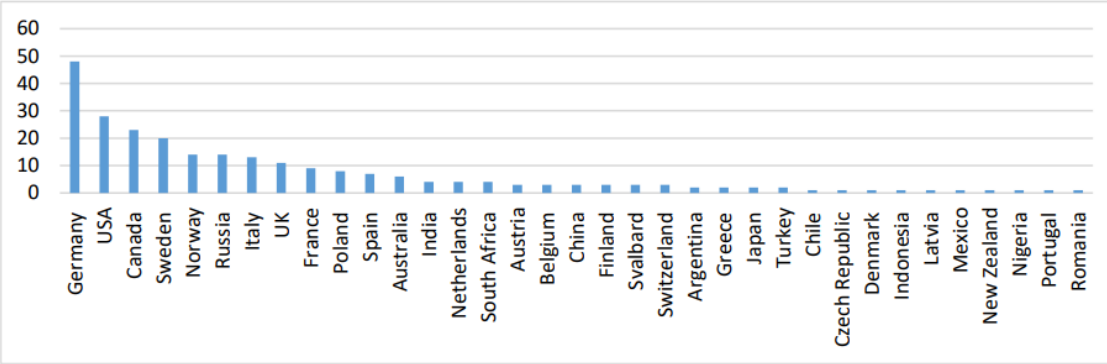

Figure 13: Country distribution of the applications to the MOSAiC summer school.

Prior to the MOSAiC School the participants recorded short video clips to present their research background, which are available on the ARICE website (Frostbite videos). To pass their experience to the public, the participants acted as MOSAiC Ambassadors and produced a variety of outreach products and activities. The Ambassador's projects can be found on the MOSAiC Ambassador webpage. The outreach projects included photo exhibitions, school visits, blogs, public talks and other products.

Online Technical Training

Within the framework of ARICE, APECS organised an "Online Technical Training Programme for early career researchers and professionals" from 30 March to 14 April 2021. The objective of this training was to convey an insider's view of technical operations on research icebreakers, provide a platform for interactive knowledge exchange and maximise the practical experience possible using the online meeting format. Six modules were developed, covering a wide spectrum of operational, scientific and technological topics. The technical training was advertised through the ARICE, APECS and World Ocean Council outreach channels including websites and social media. 984 registrations in total were received and participation was generally between 30-50 % of registrants, depending on the module.

A survey for information was distributed to the participants: they were mainly junior/early career scientists or engineers; they came from all continents with the majority indicating the European Union (EU) as their current residence. The gender balance of the attendees was approximately 50-50.

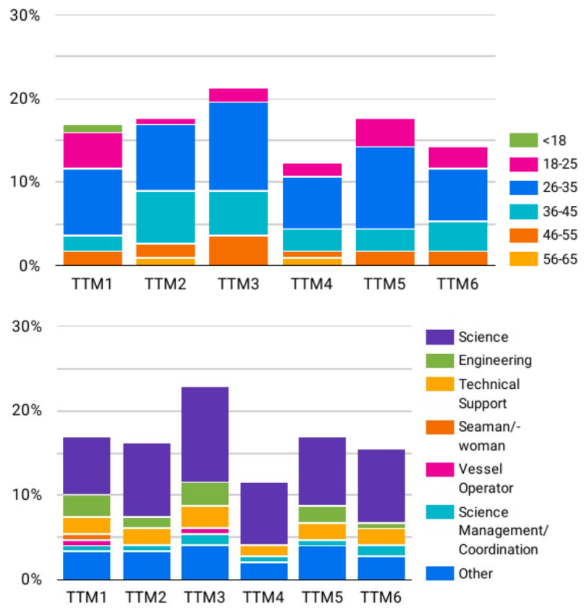

Figure 15: Age and professional background of attendees to the 6 Training Modules.

ARICE-APECS Webinars

In addition to the MOSAiC summer school and technical training, APECS hosted 12 webinars as part of ARICE. The webinars covered topics on career development and soft skill training as well as all seven scientific cruises funded by ARICE until the beginning of 2022. The webinars were held in the period from February 2019 to February 2022 with a total duration of 14 hours. The webinars were announced though the APECS and ARICE website and social media channels as well as via the Cryolist mailing list and within the networks of the speaker. A total of 1.128 people registered for the webinars and 528 participated during the live sessions. Based on the registrations, participants attending the webinar were joining from all continents, predominantly from Europe and countries within the EU (Figure 16). The ratio of registrants to participants for each webinar ranged between 31-64 %. The recordings of the ARICE webinar series on the APECS Vimeo channel have 14,230 impressions and have been viewed 797 times so far (data as of 10 October 2022), underlining the value of this resource for early career scientists and professionals, as well as to the wider polar community.

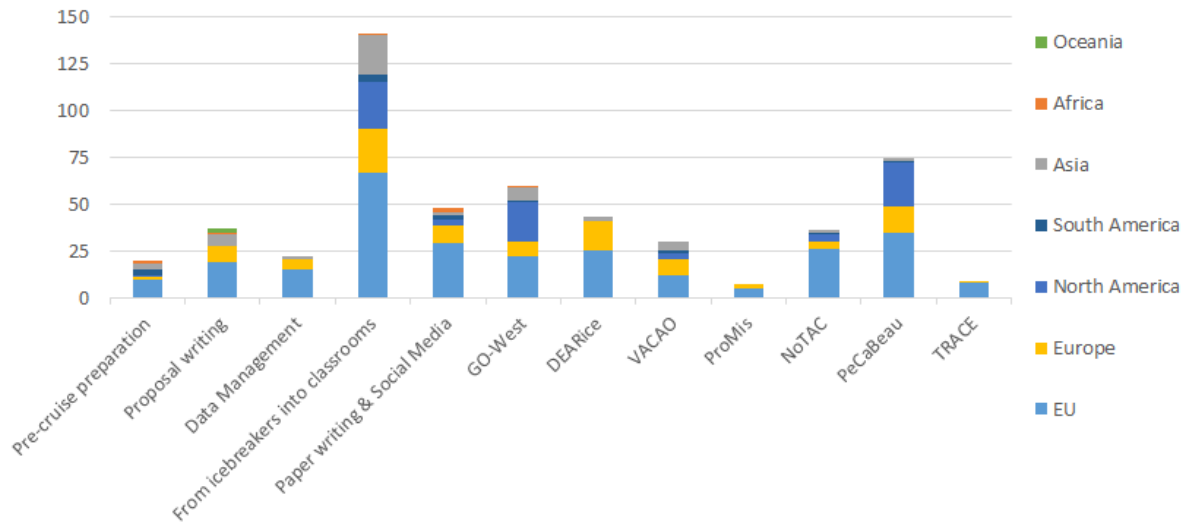

Figure 16: Webinar participants by continent (with a distinction between EU and non-EU countries for Europe).

In summary, through the three ARICE funded training formats Mosaic School, Online Technical Training, and webinars, over 600 people were involved directly or during the live sessions. In addition, a wider audience was reached as a result of the MOSAiC Ambassador projects, and the recordings of the technical training and webinars have been watched by more than 500 viewers by the time this deliverable was written. By combining face-to-face and online training activities, ARICE had a substantial impact on a broad range of people with diverse backgrounds, from different continents and at various career stages.

3.4. Access to data and data management

"The integration of major scientific equipment or sets of instruments and of know-based resources (collections, archives, structured scientific information, data infrastructures, etc.) leads to ***a better management of the continuous flow of data collected or produced by these facilities and resources****."*

Data from the Arctic Ocean is in fact considered a valuable and indispensable asset, thus increasingly needed to quantify, and evaluate the impact at environmental, economic, and political levels. In this context, ground-based data from the areas covered for large part of the year by ice, in particular the central part of Arctic Ocean, are very scarce, and even Earth observations are limited due to technical barriers (e.g. cloud coverage, latitudinal limits of satellite coverage, etc.), so that icebreaker-based research is crucial to fill this gap.

Relevance and impact of data collected by icebreakers are increasing as a consequence of the increasing importance of the Arctic region not only for the influence on climate changes at global scale (i.e. change in sea level and atmospheric and marine large scale circulation) but on a variety of opportunities that changes at regional and local scale (i.e. sea ice reduction and melting glaciers) can provide (e.g. Arctic is estimated to hold as much as 30% of the world's unused resources and Trans-Arctic shipping is becoming a real possibility).

Contribution to data management and access to data in agreement with FAIR principles

ARICE contributed to obtain a better picture of the Arctic by the implementation of different cruises in this area. Moreover, ARICE has built a bridge between the historical approach to sampling (mainly based on the Cruise Summary Report) and the modern offer/access to data. Increase of data fairness being accomplished through a metadata catalogue and direct access to data based on a map-viewer platform, both allow a better management of the continuous flow of data collected or produced within ice-breakers' cruises and legacy.

ARICE addressed the data issue in all its compartments and stages, from collection, extraction, and analysis to integration. The impact of the ARICE activities can be identified in a minimisation of data bias and improvement of the overall efficiency, contributing therefore to the Arctic Data Infrastructure efficiency and interoperability. ARICE activities will also bring more information and data from polar research ships to the European Marine Observation and Data Network (EMODnet), the main portal at European level through which information and observations of the sea are freely available as interoperable data layers and data products.

ARICE approached the data issue within two main lines of activities: a) **understanding the data ecosystem** and b) **structuring the process** for data management from icebreakers in agreement with FAIR principles.

Understanding the data ecosystem

Through a consultation and discussion with operators, scientists and representatives from the industrial sector, ARICE identified who are the potential stakeholders (those who create the data, set their rules and requirements, and those who use them). This also allowed us to describe the current data management systems of data providers, including the actual data centres and repositories. More than 40 data repositories and aggregators have been identified, managed at either governmental or private levels, providing services for data storage, processing and retrieval. Main national data centres provide interfaces for data quality control, discovery and access. In practice, at the moment a robust way of transferring data from research vessels to the data storage and final users is present.

Nevertheless, the diversity and fragmentation of information provided by the different online platforms result in a difficulty reported by the users when accessing and analysing the data.

Structuring data management: The ARICE Data management system and the 3D Virtual Icebreaker

ARICE identified EMODnet (European Marine Observation and Data Network) as the most appropriate platform to interact for making the retrieval and use of the data from the icebreakers efficient and effective. Constituted by DG MARE in 2008, EMODnet is currently the most accessed and usable interface for marine data at EU and global level. In 2016, EMODnet completed its central portal and ingestion facilities and provided a unique opportunity to bridge data providers and users. A MoU between ARICE and EMODnet was established to define the scope of the cooperation between them.

ARICE has created a **metadata catalogue** and a **data visualisation tool** (Figures 17 and 18), the second in cooperation with EMODnet. Thanks to this cooperation, icebreaker data will enrich the databases

of EMODnet, contributing significantly to improve the services currently offered and the ultimate goal is to provide a future integrated view of the Arctic. In the frame of this cooperation, harmonisation and common standards have been promoted.

A third tool devoted to cruise report (cruise summary report and full cruise report database) following standards from the SEADatanet initiative is currently under development in close cooperation with IFREMER (Figure 19).

To implement efficient discovery functionalities compliant with FAIR principles and facilitating machine-to-machine (M2M) interaction, the ARICE Data Management System (DMS) integrates the open-source application GeoNetwork, which provides powerful functions such as metadata editing and searching, as well
as an interactive web map viewer. Both the metadata catalogue that the mapviewer tool based on Geoserver can be reached through ARICE web site (https://arice-h2020.eu/data-tools/).

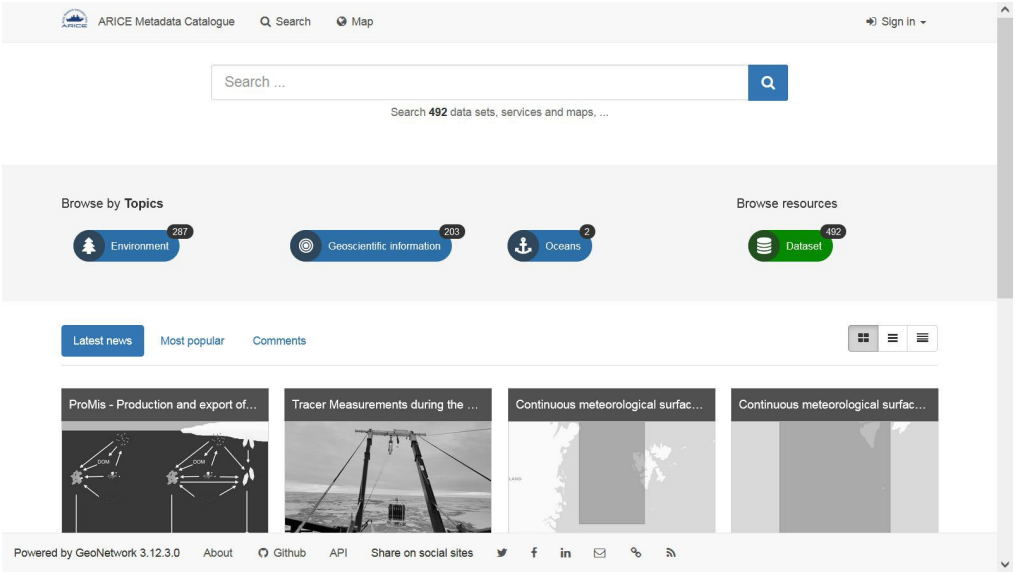

Figure 17: The home page of the metadata catalogue.

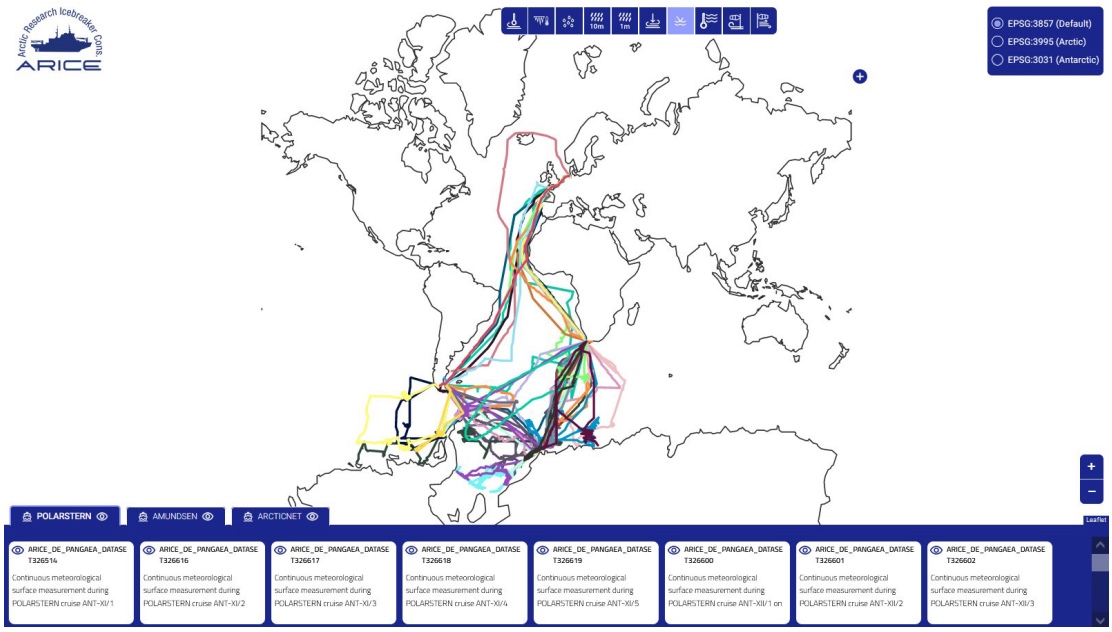

Figure 18: The Map viewer: several Polarstern data sets have been selected.

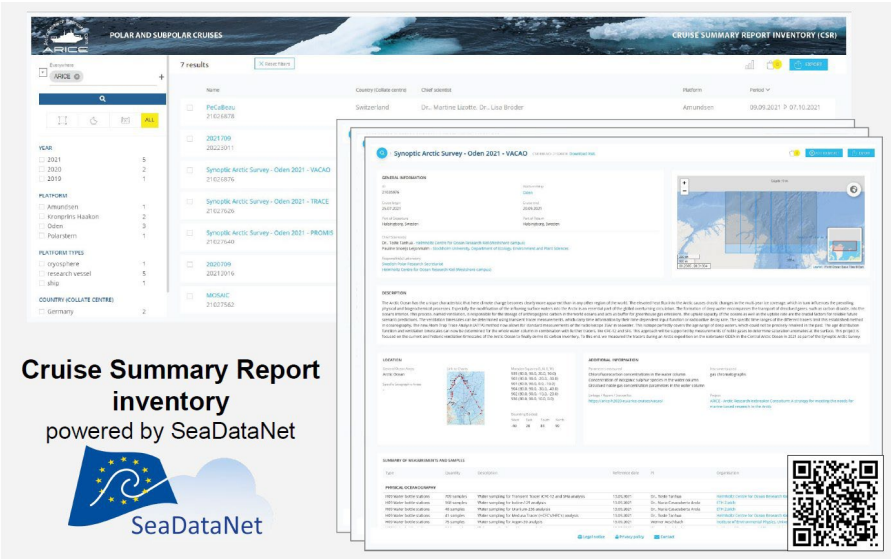

Figure 19: The home page of the Polar Cruise Summary Report.

3.5. Support to policy

"The integrated and harmonised access to resources at European level can facilitate the use beyond research and contribute to evidence-based policy making."

The Arctic Ocean is recognised as one of the key areas at geo-political level regarding the disruptive changes induced by climate changes and the consequent transformation of maritime traffic, natural resources exploitation and pollution.

The process of support to decisions can involve different activities, from policy briefings and recommendations to citizen engagement, from cross-national cooperation to an operational integration and harmonised access to information at European level. This in fact can facilitate the use beyond research through 1) an increased awareness of threats in the Arctic Ocean, 2) the understanding of the processes behind the coupling between humans and the natural environment, and 3) possible interventions to tackle the different challenges.

The deluge of data and news is nowadays asking for a renewed role of science in supporting policy decisions and the adoption of effective solutions. Often, scientists struggle in providing salient and responsible advice for the adoption of effective action. One of the main challenges is not only a lack of common terminology between different communities but different levels of descriptions of the reality. Diverse scientific domains or economic sectors can result in a proliferation of advice, often considered as based on opinions and not evidences.

In this context, ARICE coordinated and structured a dialogue between scientific disciplines, industrial stakeholders and different territorial capacities. In this sense, ARICE provided 1) a unique and coherent voice to address policy makers through a knowledge-based analysis of the problems and 2) a platform to develop cross-border research at EU level.

As an example to support to policy, ARICE contributed to two Arctic Science **Ministerials (ASM2 and ASM3)**, as the project contributes significantly to Strengthening, Integrating and Sustaining Arctic Observation, Facilitating Access to Arctic Data and Sharing Arctic Research Infrastructure. ARICE was highlighted in the most recent EU Arctic Policy as one of the core projects from the EU Polar Cluster.

"Implementing the European Union's policy for the Arctic"

By promoting and facilitating effective international scientific cooperation, through supporting transnational access to research infrastructure and open data resources, ARICE is contributing to improving political and economic links and maintaining good relations with key countries in the region.

"Science diplomacy and policy advice"

As future perspective and political framework, EU States affirmed in their recently published policy for the Arctic[2] that the EU should continue to promote and facilitate effective international scientific cooperation through supporting transnational access to research infrastructure and open data resources to improve political and economic links and maintain good relations with key countries in the region. ARICE fits perfectly to fulfil these objectives of the EU by offering transnational access to six world-class polar research vessels in the Arctic and to the data gathered on the ARICE cruises.

ARICE therefore contributed either as **science for diplomacy** in terms of integrating scientists and stakeholders from different EU and non-EU countries in a geo-political sensitive area, or as **science in diplomacy**, providing relevant advice to policy makers.

[2] Joint communication to the European Parliament and the Council: An integrated European Union policy for the Arctic, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52016JC0021&from=EN

"Advancing Europe's role in Arctic Research"

By contributing to the implementation of Large Scale international initatives and providing research opportunities outside the summer season, ARICE has contributed to delivering key data for understanding climate change.

"Citizen awareness"

Regarding the indirect influence on policy, the novel ARICE **outreach and dissemination strategies** (e.g. virtual 3D icebreaker, training of early career researchers, see previous paragraphs) are well positioned to indirectly inform decision makers on the status of the Arctic Ocean.

ARICE produced a wide variety of electronic material from training activities, such as:

- **FrostByte Videos:** 20x 1min-videos with 944 views to date. The Frostbite videos are short videos that explain a research topic, or research project in a short and simple way.

- **Lectures:** Six lectures recorded on-board during the MOSAIC School.

The materials generated by the MOSAIC School are available at https://arice-h2020.eu/training/mosaic-school-2019/

- **Webinars:** Twelve webinars were organised in soft-skills and on cruises granted by ARICE, with more than 500 people participating live and almost 800 people viewed the recordings so far. . Webinar participants came from all continents, but with 272 participants, the majority were based in EU countries. All webinars were recorded resulting in 14 hours of educational video material. https://arice-h2020.eu/training/webinars/

- **ARICE Technical training:** Six training modules were taught by experts in engineering, technical and scientific practitioners, covering topics of marine robotics, atmospheric measurements, mooring operations, laboratory work on a moving ship and best practices in technical science support. Over 200 views to date in total.

All materials are available in the ARICE website and the video platform Vimeo: https://arice-h2020.eu/training/arice-technical-training/

ARICE's website

ARICE has published a total of 12 newsletters that were distributed to the newsletter subscribers.

Since September 2021, when the new website was implemented[3], and until the time of writing this report (September 2022) 5000 visitors accessed the website, estimating a 30% share from non-experts

[3] Note that a full access to the first website of ARICE (www.arice.eu) was lost when the project partner in charge of public outreach left the consortium. Lost the full control of the project website, the project ARICE had to implement a new site (www.arice-h2020.eu).

in Arctic issues.

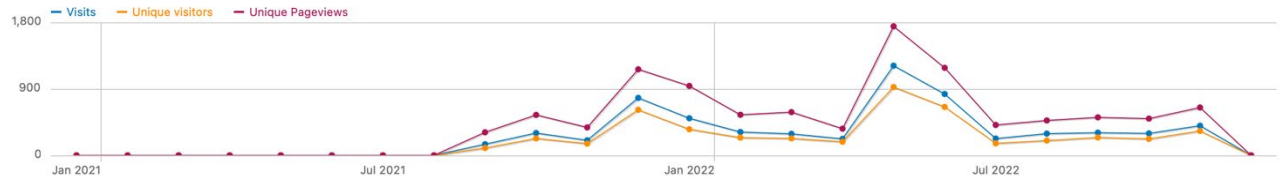

Figure 20: number of visits at the ARICE web pages over time from September 2021 until 17 November 2022.

ARICE contributed also to the **awareness of citizens** via a diversity of activities that engaged the general public. In particular, we refer to the following:

- The MOSAiC Ambassadors outreach projects included presentations at universities and high schools, media coverage in newspapers, radio and television broadcasts in several countries, as well as presence on social media, websites and podcasts, and many other activities. A quantitative measure of participation is difficult to determine.
- Participation at fairs such as the SMM in Hamburg in 2022, and the series of Sustainable Ocean Summit industry conferences.

Featured press articles

- Enhancing Voluntary Weather Observations from Ships in the Arctic. https://www.maritime-executive.com/editorials/enhancing-voluntary-weather-observations-from-ships-in-the-arctic
- Breaking the Ice with International Research Mobility. https://search.myresearchconnect.com/Documents/en-GB/expert-corner/Breaking_The_Ice.pdf
- Where Cruising Meets Science: Ponant's Luxe Icebreaker Doubles As A Science Lab, https://cruisepassenger.com.au/news/ponant-icebreaker-science-lab/

Publications from the ARICE consortium

- International access to research infrastructure in the Arctic. https://www.cambridge.org/core/journals/polar-record/article/international-access-to-research-infrastructure-in-the-arctic/B639D488877FDC7EDA862C451D06E5B2

Publications from ARICE Cruises

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10.48433/BzPM_0759_2022
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3. Cherkasheva, A., P Kowalczuk, R Manurov, M Zabłocka, 2022. Monitoring and parameterization of plankton dynamics in the European Sector of the Arctic Ocean. ESA Living Planet Symposium, Germany.
4. Cherkasheva, A., R Manurov, P Kowalczuk, 2022. Monitoring and parametrization of plankton dynamics in the European Sector of the Arctic Ocean. Ocean Optics XXV, Quy Nhon, Vietnam.
5. Flores, Hauke (2020), Possibilities for executing the Mapping Program: ARICE (GO-WEST 2019), Provisional Scientific Coordinating Group (PSCG) of the Agreement to Prevent Unregulated High Seas Fisheries in the Central Arctic Ocean, 12 Feb 202, Ispra, Italy
6. Gerke, L., Tanhua, T., Arck, Y., Aeschbach, W., Frank, N. Oberthaler, M., Wefing, A., Casacuberta, N. (2022): Ventilation and Anthropogenic Carbon in the Arctic Ocean (VACAO), The Future of Research Infrastructure in the Arctic Conference, Brussels, BE.
7. Haraguchi, L ; CA Stedmon, E Eronen-Rasimus, H Kartokaalio, RF Flynn, S Fawcett, R Gonçalves-Araujo, 2022. Fram Strait 2021: biological cycling of C and N. The Future of Research Infrastructure in the Arctic Conference, Brussels, BEL.
8. Kowalczuk, P. , A Makarewicz, J Meler, M Zabłocka, S Sagan, M Konik, M Darecki, CA Stedmon, MA Granskog, 2022. Variability of bio-optical properties in surface waters in northeast Greenland Shelf (Arctic Ocean) in late summer. The Future of Research Infrastructure in the Arctic Conference, Brussels, BEL.
9. Lin, G., J Qiao, R Gonçalves-Araujo, P Steier, PA Dodd, CA Stedmon, 2022. A closer look into the Fram Strait for tracing Atlantic waters in the Arctic Ocean using reprocessing-derived 236U and colored dissolved organic matter. The Future of Research Infrastructure in the Arctic Conference, Brussels, BEL.
10. Manurov, R., 2022. Modeling of phytoplankton primary production in the Greenland Sea using satellite data. ESA Living Planet Symposium, Germany.
11. Roberta Pirazzini, Henna-Reetta Hannula, David Brus, Ruzica Dadic, and Martin Scnheebeli, Drone-based sea ice albedo measurements and photogrammetry during the Arctic freeze-up in the MOSAiC expedition, EGU General Assembly, 2021
12. Ruzica Dadic (2021): Spatial variability of the sea ice surface (SSL/snow) during MOSAiC, The Virtual Atmosphere-Cryosphere-Ocean seminar series, 19-23 July 2021 (VACO-21)
13. Ruzica Dadic (April, 2021): The MOSAiC Expedition and the Importance of Snow on Sea Ice – University of Otago Geology Seminar
14. Ruzica Dadic (May 2022): Snow on Sea Ice during the MOSAiC Expedition, Glaciological Seminar – Laboratory of Hydraulics, Hydrology and Glaciology | ETH Zurich
15. Ruzica Dadic (May, 2021): The MOSAiC Expedition and the Importance of Snow on Sea Ice – Victoria University of Wellington, SGEES Seminar Series
16. Ruzica Dadic, Martin Schneebeli, Amy Macfarlane, Henna-Reetta Hannula, Roberta Pirazzini, Melinda Webster, Michael Gallagher, Marcel Nicolaus, Mario Hoppmann, Julia Regnery, Ola Persson, Henning Löwe, Huw Horgan, Lucille Gimenes, Matthias Jaggi, David Wagner, Linda Thielke, Gunnar Spreen, Julienne Stroeve,Polona Itkin, Evolution of the snow/surface layer during the sea-ice freeze-up phase on the MOSAiC expedition, IGS International Symposium on Snow, September 2022
17. Ruzica Dadic, Martin Schneebeli, Henna-Reeta Hannula, Amy Macfarlane, and Roberta Pirazzini, Physical properties and spatial distribution of the sea ice surface layer (SSL/snow) during the autumn phase of the MOSAiC expedition, EGU General Assembly, 2021
18. Ruzica Dadic, Martin Schneebeli, Henna-Reetta Hannula, Roberta Pirazzini, Amy Macfarlane,

Oliver Wigmore, Lauren Vargo, David Wagner, David Brus, Stefanie Arndt, Matthias Jaggi, Daniela Krampe, Michael Lehning, Julia Regnery, Gunnar Spreen, Julienne Stroeve : Evolution and spatial variability of small-scale surface roughness during MOSAiC. MOSAiC Science Conference, Potsdam, April 2022

19. Ruzica Dadic, Martin Schneebeli, Henna-Reetta Hannula, Roberta Pirazzini, Amy Macfarlane, Oliver Wigmore, Lauren Vargo, David Wagner, David Brus, Stefanie Arndt, Matthias Jaggi, Daniela Krampe, Michael Lehning, Julia Regnery, Gunnar Spreen, Julienne Stroeve : Evolution and spatial variability of small-scale surface roughness during MOSAiC. IGS International Symposium on Snow, September 2022
20. Zäncker, B., Bird, K., Harley, J., Krumpen, T., Cunliffe, M. (2022): Contrasting drivers of fungal diversity across sea ice habitats indicate impacts of climate change on the Arctic mycobiome, UK sea ice group meeting, Cambridge, UK
21. Zäncker, B., Bird, K., Harley, J., Krumpen, T., Cunliffe, M. (2022): Fungal communities across Greenland's shelf sea ice ecosystems and the wider Central Arctic Ocean, Challenger150 Conference, London, UK

4. List of ARICE deliverables that support the reported impact

- D1.4 -Identification report on contribution of a coordinated PRV fleet to fulfilling EU member states' research interests in the Arctic Ocean
- D1.5 - Report on the global present and future resources' investments in Arctic icebreaker capacity for research
- D1.7 - Recommendations from the joint scientific and operational workshop on implementation of shared European cruises
- D2.3 - Report on potential science – industry –priorities in research and observations
- D2.7 - Updated inventory of specific opportunities for technology transfer and innovation between the Arctic science community and industry
- D3.4 - Early career technicians and engineers training course report
- D3.7 - Summer School Final Report
- D3.9 - Training Assessment report (in preparation) (confidential, consortium only)
- D4.1 - Definition of the international shared evaluation system
- D4.6 - Selection report of the ARICE Call for proposals
- D4.9 - Report on cruise implementation, post cruise assessment and lessons learned (in preparation)
- D6.1 - Survey on underway and automatic data collection in the Arctic Ocean
- D6.2 - Recommendations for automatic environmental data collection of ice going vessels

- D6.3 - Guidelines for recommended technology, data collection and transmission systems for environmental data collection and management to support the "programme of ships and platforms of opportunity"
- D6.5 - Key technologies for an improvement of ship-based and autonomous measurements in the Arctic Ocean
- D6.7 - Assessment report of the "programme of ships and platforms of opportunity" for the Arctic Ocean (in preparation)
- D7.6 - Data Management System and documentation
- D7.8 - Report on performances and use of the ARICE system and compliance with standards
- D8.8 - Progress report on dissemination activities
- D8.12 - Progress report on dissemination activities (2) (in preparation)

