UK Arctic Ocean and Coastal Research for IPY5

Knowledge Gaps, Ambitions and Capabilities

Arctic Office
NATURAL ENVIRONMENT RESEARCH COUNCIL

This document was produced with input from individuals representing more than 30 different Higher Education Institutes, Research Centres, government agencies and NGOs from across the UK. A 2-day workshop was held 11-12 June 2025 at the National Oceanography Centre in Southampton, where the ideas and content of this document were established. A questionnaire was also widely circulated and open to all.

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Credit – Joe Laurance

Contents

Executive Summary 1

A Changing Arctic 4

Why We Need to Act Now 5

UK Strengths and Capabilities 6

Key Knowledge Gaps for IPY5 8

- 1: Arctic Ocean Climate 10
- 2: Arctic Ocean Ecosystems and Biodiversity 12
- 3: Global Environmental Impacts of a Changing Arctic Ocean 14
- 4: Hazards and Resilience 16
- 5: Impact of Direct Human Activity in the Arctic 18

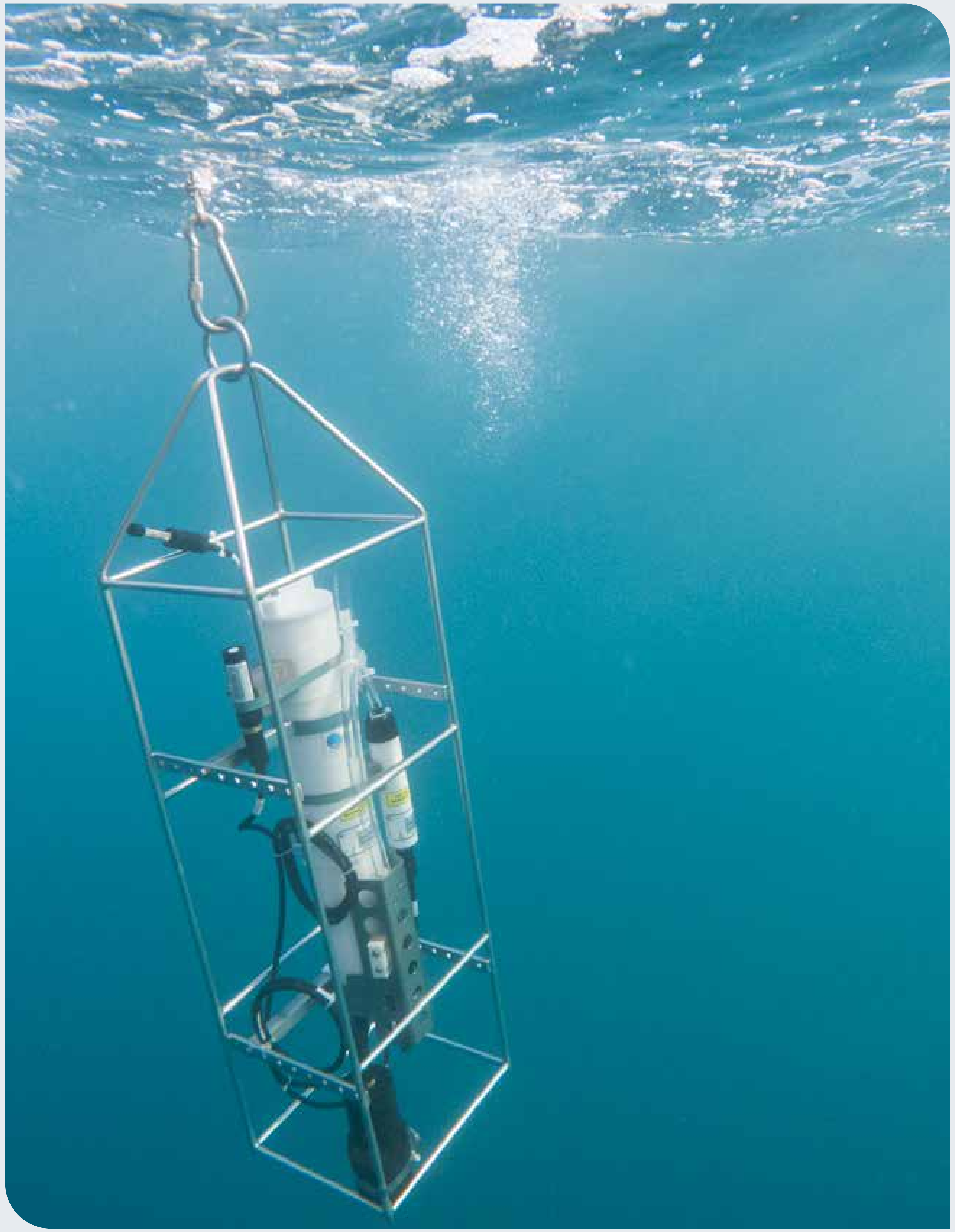
Socio-Economic Impacts, Adaptation and Governance in a Changing Arctic 20

Partnerships and Collaboration 22

References 24

Acronyms 25

Workshop and Report Contributions 26



Credit – Iain Rudkin

Executive Summary

The Challenge

The Arctic is warming at least three times faster than the global average. This is driving rapid loss of sea-ice, glaciers and permafrost, and the unique environments and marine ecosystems that support the livelihoods of local Arctic communities. These changes do not stay in the Arctic; they threaten our global climate, weather and shared biodiversity. As sea-ice is lost, the Arctic will become increasingly accessible.

This is opening up economic opportunities, including shipping, resource and mineral extraction, fishing, tourism and communications. An expanding ocean economy and human footprint however pose risks to the environment, ecosystems and the health, wellbeing and cultural practices of Arctic communities.

Amid this transformation, sustained investment in Arctic marine science, equitably and respectfully paired with Indigenous Knowledge has never been more critical. Long-term interdisciplinary ocean observations and advanced modelling provide essential understanding and prediction of Arctic Ocean and ecosystem changes and impacts.

Co-developed research – that clarifies the mechanisms of Arctic change and their implications – turns uncertainty into actionable knowledge, enabling local communities, governments, and industry to plan, adapt, and reduce risk.

Meeting this challenge demands integrated environmental, social and political science approaches. The 5th International Polar Year 2032-33 provides the platform from which this can be achieved.

Decisions made and actions taken this decade will shape global climate, geopolitical stability, biodiversity, and human wellbeing for generations to come.

Critical Knowledge Gaps

UK marine scientists, representing more than 30 institutions across higher education, research centres, government agencies and NGOs, have identified five interconnected marine focused research themes and priority questions that require immediate attention during the 5th International Polar Year 2032-33.

1) Arctic Ocean Climate. When will the Arctic Ocean become sea-ice free?

2) Arctic Ocean Ecosystems and Biodiversity. How will multiple interacting stressors alter species distribution, biodiversity and ecosystem functions in a rapidly changing Arctic?

3) Global Environmental Impacts of a Changing Arctic Ocean. How will a rapidly warming, increasingly ice-free Arctic Ocean reshape global climate stability and carbon sequestration?

4) Hazards and Resilience. Can we develop early warning systems that consider the complex interactions between multiple natural and human hazards in the Arctic?

5) Impact of Direct Human Activity in the Arctic. Which Arctic environments and ecosystems are most vulnerable to increasing human activities and can governance frameworks minimise the impacts?

Socio-Economic Impacts, Adaptation and Governance

Understanding socio-economic impacts, adaptation, and governance in a changing Arctic underpins all themes and requires truly interdisciplinary approaches that integrate physical, ecological, social and political sciences. All opportunities to conduct research through co-creation with Indigenous partnerships and respectful collaboration with Indigenous Knowledge systems should be pursued.

UK Strengths, Capabilities and Innovative Approaches

Despite not being an Arctic nation, the UK possesses world-class capabilities to address these challenges through two polar-capable research vessels, advanced autonomous platforms, cutting-edge modelling, Machine Learning/Artificial Intelligence and Digital Twin expertise, and strong international partnerships.

As an Arctic Council Observer with established research infrastructure in Svalbard, the UK is uniquely positioned to contribute to targeted Arctic science while advancing national interests in climate security, geopolitical stability, and sustainable economic development.

There are five sets of approaches, that cut across all the research themes, that the UK marine community identified as being crucial to addressing the knowledge gaps:

1 Sustained Arctic observation

Leverage the UK's autonomous platforms, novel sensors, ice-capable research vessels, remote sensing, and international collaborations to support year-round, high-frequency, multi-disciplinary, long-term observations of the Arctic Ocean and coastal zones, sea ice, biodiversity and ecosystems.

2 Integrated observational and modelling systems

Advance coupling of ocean, ice, atmosphere, land, and ecosystem models; improve downscaling of model projections from global to local scales; and progress data assimilation from autonomous and fixed platforms, to enable higher-resolution, more robust future climate projections, improved short-term forecasting and near-real-time monitoring.

3 Application of Artificial Intelligence and digital technologies.

Exploit UK expertise in Artificial Intelligence, Machine Learning, Big Data, and Digital Twins to improve parameterisation of missing processes in models, synthesize and upscale complex datasets, develop hybrid physical/Artificial Intelligence-based forecasting systems, and enhance ecosystem and hazard prediction capabilities.

4 Addressing data scarcity and accessibility

Develop innovative approaches to overcome the lack of long-term Arctic data (e.g., space-for-time substitution) and support development of open, interoperable Arctic data systems and observatories to improve accessibility and utility of observations.

5 Transdisciplinary and co-developed approaches

Increase integration of environmental, ecological, social, economic, and legal research, with emphasis on climate and hazard resilience (e.g., Arctic infrastructure, communities), and strengthen co-development of knowledge with Indigenous Rightsholders, NGOs, industry, and the public.

The Opportunity

The 5th International Polar Year 2032-33 presents a once-in-a-generation opportunity to catalyse coordinated, high-impact research that strengthens global partnerships and ensures UK science contributes meaningfully to understanding and responding to a rapidly changing Arctic.

Through enhanced international collaboration, world-leading science and technology expertise and Indigenous partnership, the UK can help safeguard Arctic ecosystems, support sustainable development, and maintain global climate stability. The consequences of inaction far outweigh the costs of coordinated science to inform robust and effective action.

Credit - Elena Garcia-Martin

A Changing Arctic

The Arctic is warming at least three times faster than the global average. This is driving a cascade of rapid and unprecedented environmental and socio-economic changes that are set to reshape climate, ecosystems, societal health, safety and economic stability, and governance structures both within and beyond the Arctic.

The most striking changes include accelerating glacier, ice-sheet and sea-ice loss, with earlier melting and later freezing. This is taking place alongside permafrost collapse, increasing river discharge, warming and freshening of ocean surface waters and spreading of warm sub-surface Atlantic water into the Arctic Ocean basin.

Important sea-ice habitats are disappearing. Changes in nutrient and carbon cycles are affecting marine ecosystems and food webs, and natural hazards are becoming more frequent and severe.

In parallel, as the Arctic Ocean becomes more accessible, its ocean economy potential will grow, and through resource extraction (food, energy, mining), tourism, new shipping and communication links, the human footprint in the Arctic will continue to increase, creating both threats and opportunities.

Credit - Jo Hopkins

Why We Need to Act Now

Changes in the Arctic are already affecting populations worldwide through modifications to our climate and weather patterns and threats to our shared biodiversity. Further, the Arctic is the largest regional land-ice contributor to global sea level rise.

Thanks in part to statements made in the IPCC 6th Assessment Report (IPCC, 2023a,b), multiple environmental change and impact reports (e.g., ACIA, 2005; Elshout et al., 2023; AMAP, 2024) and relevant UN Decades (e.g., Ocean Science for Sustainable Development, Ecosystem Restoration, Indigenous Languages, Cryospheric Sciences and Biodiversity) the attention of policy makers and governments worldwide is increasingly being focused on the Arctic.

The 5th International Polar Year has been brought forward by 25 years, reflecting the unprecedented speed at which Arctic change is negatively impacting ecosystems, economies, the rights and livelihoods of Indigenous Peoples, and human wellbeing within and beyond the Arctic.

The Arctic Ocean may be remote, but its impact is global. The Arctic is the upper limb of the Atlantic Meridional Overturning Circulation (AMOC), a major global and regional climate regulation process. Via its connections to the subpolar North Atlantic, the Arctic Ocean plays a role in setting European and UK weather patterns, including disruptive storms and extreme events. Beyond the UK and Europe, Arctic sea-ice and ocean change may lead to more extreme rainfall and shifts in monsoon systems, heatwaves and droughts. The Arctic Ocean is also a supplier of nutrients and carbon to the subpolar North Atlantic, which may influence primary production, carbon uptake and storage, food webs and fisheries.

The Arctic Ocean is a resource. It provides food through both commercial fishing and Indigenous hunting and the sea-ice is a means of transport and communication for local communities. Loss of ice and its associated ecosystems poses significant disruption for Indigenous communities with risk of displacement, food, economic and cultural insecurity alongside unanticipated health and social challenges.

As the Arctic becomes more accessible, its ocean economy will continue to grow. This presents both opportunities and threats. Emerging opportunities relate to shipping and communications, geoengineering, tourism, renewable energy, fisheries and resource extraction. The accompanying challenges are associated with access to new resources, maritime safety, environmental degradation, pollution and geopolitical uncertainty.

We must act now to mitigate and adapt to a changing climate and build resilience, safeguard the health and wellbeing of populations living within and beyond the Arctic, enable sustainable growth of the ocean economy whilst also protecting marine ecosystem services.

UK Strengths and Capabilities

Whilst the UK is not an Arctic nation, it is an active Observer within the Arctic Council and fully engaged in IASC (the International Arctic Science Committee). The UK's Arctic Policy Framework (2023) sets out the wider economic, security and diplomatic motivations for maintaining a strong presence in Arctic research and technology.

The UK possesses both established and emerging technologies, infrastructure and expertise to address critical knowledge gaps, in partnership with international collaborators across the Arctic regions.

The upcoming 5th International Polar Year 2032-33 presents an opportunity to catalyse coordinated, high-impact research efforts, strengthen global partnerships, and ensure that UK science contributes meaningfully to understanding and responding to rapid Arctic change.

Technological & Infrastructure Strengths

The UK possess two global-class and polar-capable research vessels (RRS Discovery and RRS Sir David Attenborough), a permanent research station in Ny-Ålesund, Svalbard, and advanced fleets of autonomous and robotic platforms.

We have expertise in winter and under-ice monitoring and operations and development of novel sensors (e.g., lab-on-chip, in-situ eDNA samplers) for use on moorings and autonomous platforms.

Credit - National Oceanography Centre

Credit – Iain Rudkin

The UK is a significant partner in global programmes (e.g., ARGO, ice-tethered profilers, marine mammal tagging, long-term Arctic observatories). Researchers based in the UK are developing advanced ocean-ice-atmosphere and ecosystem models, at local-regional and global scales, for both short-term forecasting and centennial climate projections.

Scientific & Data Capabilities

The UK is an international research leader in observational and experimental Arctic Ocean research (e.g., Arctic Ocean circulation and mixing, ocean acidification, ice dynamics, Arctic biogeochemistry, polar ecology and taxonomy, genomics, metabolomics) as well as digital tools (Artifcial Intelligence/ Machine Learning, Digital Twins), statistical and numerical modelling (Ocean and sea-ice models, Earth system models of varying resolution and complexity).

The UK hosts large data centres (e.g., BODC, UK PDC) supporting FAIR/CARE data principles and global platforms (e.g., GBIF). Figures produced last year showed that Arctic researchers in the UK have the highest global field weighted citation impact for their publications (Aksnes et al., 2023).

Environmental Protection and Science Diplomacy

With significant expertise in environmental impact assessments, marine engineering and the net-zero agenda (e.g through the Future Marine Research Infrastructure programme), the UK has a role to play in supporting sustainable, low/no carbon economic growth of both Arctic and non-Arctic nations and ensuring that Arctic biodiversity and its ecosystem services are protected.

The UK has a strategic interest in contributing to Arctic science not only for environmental reasons, but also to engage constructively in the region's evolving geopolitical landscape.

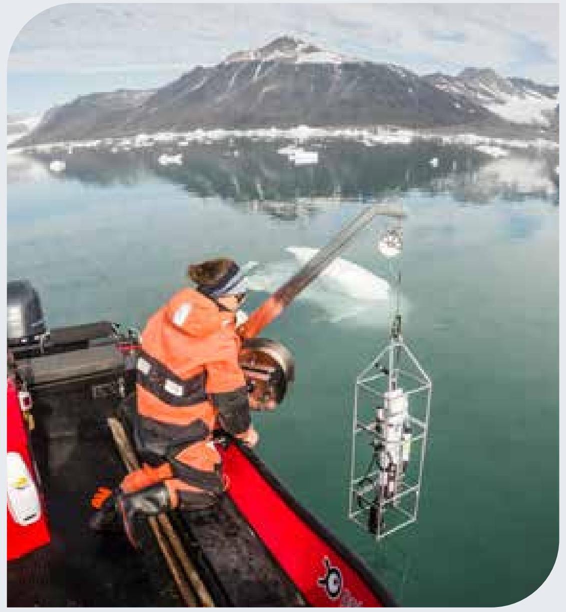
By supporting collaborative research and science diplomacy, the UK can help inform international and supra-national governance frameworks, future risk assessments, and policy development—while respecting Arctic nations sovereignty and Indigenous rights. Sharing scientific insights strengthens the UK's role as a trusted partner in shaping stable, ethical, and forward-looking Arctic policy.

Credit – Iain Rudkin

Key Knowledge Gaps for IPY5

Despite decades of international research efforts in the Arctic, including major contributions from the UK (e.g., the NERC funded Changing Arctic Ocean Programme) that have world leading scientific impact, owing to its remote location and challenging environmental and geopolitical operating conditions, critical knowledge gaps persist.

These undermine our ability to comprehensively understand, predict and effectively build resilience to, mitigate against and adapt to both current and future Arctic change.



Credits (Clockwise from top left) Daniel Jones, National Oceanography Centre, Iain Rudkin, Image copyright: Prof. Daniel Mayor (@Oceanplankton)

All components of the Arctic system, including the atmosphere, ocean, land, and ice, are inextricably interconnected. The pace and nature of physical changes in these environments drive and regulate the dynamics of the entire system.

Consultation with the UK marine science community yielded a broad range of ideas for future science priorities within **five interconnected marine themes**, all motivated by the need to understand the **socio-economic impacts, adaptation and governance issues** in a changing Arctic.

1) Arctic Ocean Climate
2) Arctic Ocean Ecosystems and Biodiversity
3) Global Environmental Impacts of a Changing Arctic
4) Hazards and Resilience
5) Impact of Direct Human Activity in the Arctic

Here we consider the marine environment to encompass the deep and coastal realms, from the sea-floor to the ocean surface, including the marine influenced areas of river, fjord and deltaic systems.

Within each theme, scientists from multiple marine science disciplines identified research gaps that are both societally important and pressing.

These challenges are highly interdisciplinary. They require a holistic approach underpinned by technological advances alongside capacity to reimagine scientific practice and push inquiry beyond established boundaries.

Collaboration across all research themes is therefore essential to understand risks and opportunities of the changing Arctic Ocean, develop effective adaptation strategies, sustainable economic pathways, and resilient governance frameworks.

Critically, all the knowledge gaps identified here must be addressed through co-creation and capacity building with Indigenous rightsholders and through respectful collaboration with Indigenous Knowledge, when and where available.

1: Arctic Ocean Climate

The knowledge gap

When will the Arctic Ocean become sea ice-free?

The ability to accurately predict the rapid rate of Arctic change is significantly limited by poor understanding of cryosphere-ocean-atmosphere interactions and feedbacks. Sea ice loss patterns and trajectories differ strongly across Arctic regions.

Knowledge gaps include understanding the sea-ice-ocean-atmosphere processes implicated in sea ice decline, changing ocean stratification, mixing and circulation, and the impacts of enhanced land-ocean exchanges driven by permafrost thaw and glacial melt that increases river runoff.

Why is it timely?

The Intergovernmental Panel on Climate Change (IPCC) reports that the Arctic could be ice-free in summer by mid-century (IPCC 2023b). Indeed, the impacts of ongoing rapid sea-ice loss are already being felt.

Sea ice regulates ocean-atmospheric exchange, alters local and remote ocean water properties via formation and melting, influences Earth's climate through ice-albedo feedbacks, helps regulate nutrient and carbon flow, supports diverse ecological habitats and Indigenous ways of life.

While satellite observations show rapid decline in sea-ice extent (~13% per decade in the month of September since the 1970s), the driving dynamics and feedbacks involved remain highly uncertain. The halocline currently protects sea-ice from deeper Atlantic heat, but if this halocline is disrupted and the heat is released ice-loss could accelerate dramatically. The negative consequences would ripple through all components of the Earth System.

There are discrepancies in future projections of Arctic sea-ice loss due to uncertainties in ocean processes and couplings with the atmosphere, cryosphere and land. For example, albedo and gas exchange, sea-ice properties, ocean mixing (e.g. wind, tides, internal waves), drivers of stratification (e.g. riverine input, sea-ice and glacial melt, atmospheric heat fluxes) and Arctic inflow and outflow properties.

Uncertainties are then amplified in projections of changes to ocean and atmosphere circulation, regime-shifts, ecosystem change and the threats associated with hazardous events such as storms, erosion and sea level rise - both local and remote.

Innovative approaches to address the challenge:

Observing

Support year-round, high-frequency observations of ocean temperature, salinity, turbulent mixing, currents, sea-ice and air-sea exchanges by leveraging the UK's autonomous platforms, remote and in-situ sensors, ice-capable research vessels and international collaboration opportunities (e.g., SAON, DBOs, SAS, NABOS, EU-PolarNet and POLARIN).

Modelling

Improve capability to model the Arctic Ocean through coupling of ocean, ice, atmosphere and land models at increasingly higher resolutions and making advances in data assimilation.

Artificial Intelligence

Combine Artificial Intelligence and Machine Learning approaches with physical models to improve parameterisation of key processes (e.g. mixing).

Integrated observational and model systems

Through UK marine autonomy, remote and satellite sensor technologies, modelling and digital ocean expertise, support international efforts to develop broader, more integrated, long-term observational networks, data infrastructure and accessibility.

Credit – Rob Ovenden

Expected impacts

- New understanding on drivers and feedbacks of sea ice dynamics
- More robust, higher confidence regional projections of sea-ice loss, including improved understanding of circulation and connectivity changes and inflow/outflow properties
- Improved Pan-Arctic state estimates
- Enhanced local and global weather forecasts and global climate projections
- Greater exploitation and sharing of observational data across the international community

2: Arctic Ocean Ecosystems and Biodiversity

The knowledge gap

How will multiple interacting stressors alter species distribution, biodiversity and ecosystem functions in a rapidly changing Arctic?

Arising from a scarcity of measurements, there is limited skill to forecast the impacts of singular or multiple interacting stressors on species distribution, biomass and biodiversity, functional trait metrics, trophic linkages, ecosystem productivity and function, and species migration patterns. This limits our ability to assess vulnerability, conserve and manage the Arctic Ocean ecosystem.

Why is it timely?

Rapid warming, loss of sea ice habitats, ocean acidification alongside changes in circulation patterns, phenology, nutrient cycling and productivity are interacting to exert multiple and escalating stressors on marine life in the Arctic Ocean. It is highly likely that the biomass and biodiversity of Arctic ecosystems are being altered but the lack of long-term baseline data, especially in winter, means it is challenging to detect strong and directional ecosystem change. The rate of change alongside heterogeneity and strong phenology in the Arctic compared to other environments means understanding how changes in species distribution, biomass and biodiversity alter ecosystem function is even more challenging.

The lack of mechanistic understanding at the single species to ecosystem level further reduces our ability to predict and manage Arctic ecosystem change. The consequences will cascade through the entire marine food web, threatening key species and ecological services such as the provision of food, primary production and the biological carbon pump, blue carbon storage, and Indigenous practices.

Forecasting these multiple effects on single species or entire Arctic ecosystems is challenging with our current knowledge. Neither laboratory experiments, nor increased field sampling or numerical modelling alone can be used to easily build mechanistic understanding of species or ecosystem responses, or resolve the uncertainties in how an ecosystem responds to a changing climate.

This lack of knowledge increases the risk of missing early warning signals of population collapse or trophic disruptions, which could push ecosystems past tipping points and result in irreversible biodiversity loss. Therefore, there is an urgent need to reimagine how we study ecosystems in rapidly changing environments.

Innovative approaches to address the challenge:

Observing

Support year-round, high-frequency observations of species distribution, biodiversity and ecosystem function by leveraging the UK's autonomous platforms, remote and in-situ sensors, ice-capable research vessels and international collaboration opportunities (e.g., SAON, DBOs, SAS, NABOS, Hausgarten, Arctic GRO and GACS).

Modelling

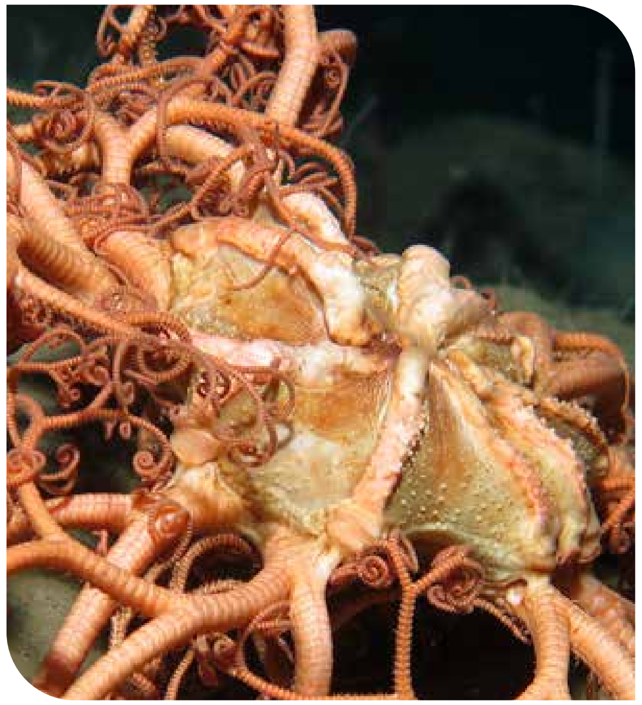
Improve our ability to forecast ecosystem responses to a changing climate by improved coupling and resolution of ocean, ice and land models and their associated ecosystem components.

Data scarcity and accessibility

Define new ways to overcome scarcity of long-term data in the Arctic, (e.g. by using space-for-time and short-term-for-long-term substitution) and bring together research and Indigenous communities to collect new data and digitise existing records.

Artificial Intelligence

Apply Artificial Intelligence and Machine Learning approaches to upscale experimental results and assess biodiversity.



Credit – Daniel Jones

Expected impacts

- Established baselines for biomass and biodiversity and connections to ecosystem function
- Identified, quantified, mapped and protected vulnerable species, habitats and carbon pathways
- Predictions of individual and ecosystem-level responses to environmental change
- Informed adaptive management strategies for long-term ecosystem sustainability

3: Global Environmental Impacts of a Changing Arctic Ocean

The knowledge gap

How will a rapidly warming, increasingly ice-free Arctic Ocean reshape global climate stability and carbon sequestration?

The ability to successfully assess the global impact of the Arctic is constrained by a lack of sustained, co-located biological, chemical and physical observations – especially at key inflow-outflow gateways and boundary currents – and the absence of high resolution, fully-integrated Earth system models. These limitations hinder the capacity to understand and predict the impacts of Arctic-driven change on global climate and weather systems, sea-level, marine primary production, natural and anthropogenic carbon sequestration.

Why is it timely?

The Arctic is undergoing profound environmental changes, including accelerating sea-ice loss, glacier and ice sheet melt, and increasing freshwater export from both rivers and ice (IPCC, 2019; IPCC, 2023b). Yet, the cascading global consequences of these changes remain poorly quantified.

Uncertainties persist around how changing Arctic heat, freshwater, nutrient and carbon exports, combined with modified air-sea gas and heat fluxes, influence large-scale oceanic systems such as the Atlantic Meridional Overturning Circulation (AMOC), and the North Atlantic Subpolar Gyre (SPG). Both play crucial roles in regulating global ocean heat transport, marine primary productivity and atmospheric carbon sequestration and are therefore central to global climate stability.

Via ocean-atmosphere linkages, the AMOC and SPG are actors in controlling regional weather patterns and extremes, including over Europe, and the subsequent feedback of these processes to the Arctic.

Further, global and regional sea level rise which threatens coastal areas worldwide and amplifies coastal flooding and erosion hazards, are also linked to Arctic change. Nutrient availability, marine primary productivity, food webs and hence fisheries across the Subpolar North Atlantic – including around the UK – are linked to the SPG and its connection to the Arctic.

Accelerating climate change is pushing the system into environmental states not previously observed. Against the backdrop of a weakening AMOC, projections of the SPG and AMOC potentially approaching tipping points and Arctic nutrient fluxes already being modified, the interactions between Arctic change and downstream effects on global climate, regional weather extremes, sea-level rise and global biogeochemical cycles require urgent and more integrated investigation.

Credit – British Antarctic Survey

Innovative approaches to address the challenge:

Modelling

Advance Earth system modelling by better coupling the physical, chemical and biological components of the ocean, atmosphere, land and ice.

Observing

Support sustained and expanded near-real time observations of the Arctic Ocean and marine ecosystems, notably at key Arctic connection points to the Atlantic and Pacific Oceans, by leveraging UK's autonomous platforms, sensors, ice-capable research vessels, remote sensing and digital ocean technologies.

Artificial Intelligence

Improve Artificial Intelligence and Machine Learning tools to synthesize complex, interdisciplinary datasets and improve warnings of sudden climate and ecosystem regime shifts.

Expected impacts

- More robust global and regional climate projections of the impacts of Arctic change
- Early and more reliable detection of ocean and climate tipping points
- Improved forecasting of and preparedness for extreme weather events
- More robust and timely adaptive strategies for climate resilience, marine resource management and coastal protection

4: Hazards and Resilience

The knowledge gap

Can we develop early warning systems that consider the complex interactions between multiple natural and human hazards in the Arctic?

There is insufficient understanding of compound and cascading hazardous events and extremes in the Arctic. We do not know how, when and where natural (e.g., permafrost-thaw, marine heatwaves, landslides and tsunamis, coastal flooding and erosion, wind and wave storms, ice-dynamics) and human-induced (e.g., infrastructure failure, oil and gas leaks, pollution) hazards and extremes pose risks to communities, ecosystems and maritime operations, singularly or as a series of compound or cascading events.

Why is it timely?

The rapidly changing Arctic is increasingly exposed to a complex interplay of natural (including climate-induced), and human-driven hazards (e.g., due to increasing human activities).

Increasing areas of open water, whilst easier to access, remain littered with drifting ice-hazards to ships and infrastructure. Increased frequency and severity of storm events hampers maritime activities and places lives at risk. Sea-level rise, permafrost-thaw and stormier seas together accelerate coastal flooding and erosion and increase the risk of landslides and tsunamis.

These hazards and extreme events increase the risks of infrastructure failure, oil and gas leaks and pollution. Marine heat waves in the Arctic are projected to intensify, threatening marine ecosystems and coastal communities.

The speed at which these changes are occurring has outpaced development of our ability to observe, predict and understand their impacts, especially when they occur as compound and cascading events. This has left countries unable to provide adequate operational forecasts and early-warnings, make suitable risk assessments or mount effective emergency responses.

Systems are not resilient or responsive enough in the face of increasing risk and uncertainty, leading to loss of life and cultural practices, infrastructure failure, and irreversible environmental degradation.

Understanding, and preparing for Arctic hazards is therefore not only critical for Arctic nations but also for global political and economic stability, development and resilience.

Innovative approaches to address the challenge:

Integrated modelling and observations

Leverage UK modelling capabilities, expertise in near-real time data transfer from autonomy and fixed platforms, and data assimilation experience to support integration and expansion of observational and model systems such that they are capable of near-real time weather forecasting and hazard assessment, particularly in coastal areas.

Artificial Intelligence

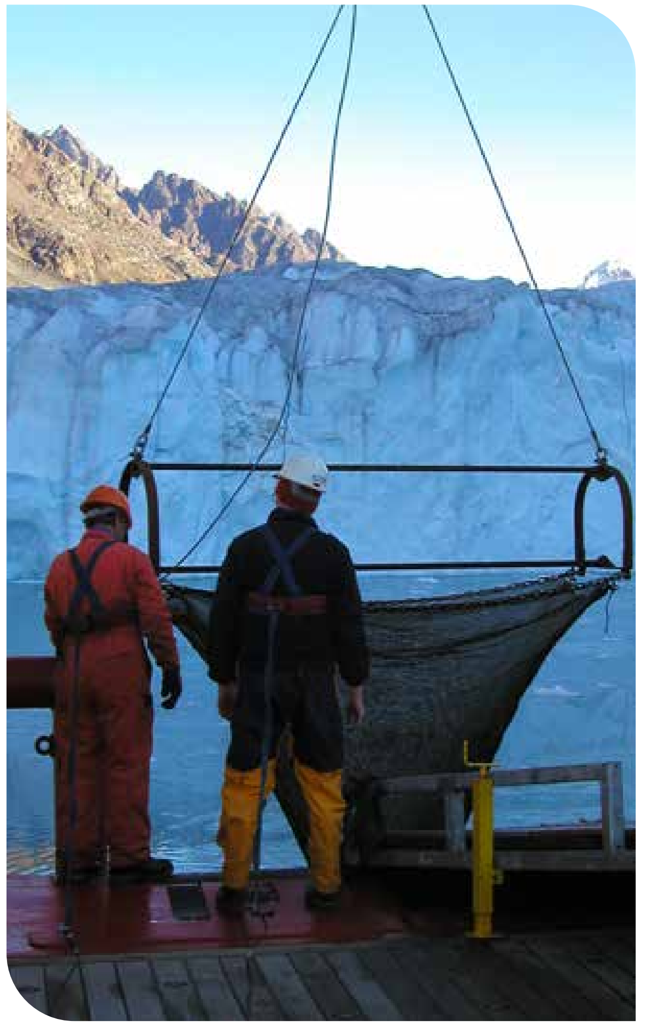
Develop physical, Artificial Intelligence-based forecasting and hybrid systems tailored to Arctic conditions, and integrated hazard modelling frameworks, including compound event simulators.

Transdisciplinary research

Increase transdisciplinary approaches and the integration of environmental, social and economic modelling to better define resilience in specific Arctic contexts, e.g., the resilience of Arctic infrastructure (pipelines, ports, research stations) and the preparedness of remote communities to multi-hazard exposure.

Sustained observing systems

Invest in long-term coastal and ocean hazard observatories and open, interoperable Arctic data systems.



Credit - Daniel Jones

Expected impacts

- Fit-for purpose early warning systems for single or multi-hazard events
- Policy-aligned research to support risk assessment, resilience planning, and international cooperation

5: Impact of Direct Human Activity in the Arctic

The knowledge gap

Which Arctic environments and ecosystems are most vulnerable to increasing human activities and can governance frameworks minimise the impacts?

There is insufficient understanding of ecosystem-level responses to human activity, including shipping, tourism, defence activities, mineral exploitation, fishing, pollution and invasive species, with serious consequences for conservation and management of Arctic ecosystems and the underpinning environments and resources.

Why is it timely?

Declining ice cover is making the Arctic Ocean more accessible to human activities—commercial, geopolitical, military, research, tourism, and fishing—resulting in environmental stressors such as ship strikes, infrastructure footprints, pollution (plastic, chemical, atmospheric, sound, and light), and invasive species.

These multiple stressors interact with and compound the impact of climate change with direct effects on Arctic communities and ecosystems.

There is a pressing need to address the negative effects on biogeochemical cycles and ecosystem health, structure and function, which can lead to species loss and ecosystem collapse.

It is important to know the hotspot regions that are most vulnerable in order to make the necessary policy changes to reduce human impacts on Arctic environments on the local scale; for example, by managing shipping around individual communities or migration routes.

At the broader scale, by contributing to policy and regulatory guidelines through the FCDO-led UK Arctic Policy, the Arctic Council and its Working Groups.

Innovative approaches to address the challenge:

Multidisciplinary Observing

Leverage use of the UK's autonomous platforms, novel sensors, research vessels, remote sensing expertise and international networks, including contributions from NGOs, industry and citizen science to make co-located, multi-disciplinary observations of stressors and impacts.

Artificial Intelligence

Integrate Artificial Intelligence into data analysis and reporting alongside support of Digital Twins.

Transdisciplinary and co-developed Research

Align physical and ecological research with social sciences, humanities, law, policy and co-production of research with Indigenous Rightsholders (via e.g., ICARP-IV Indigenous Peoples' Coordination Group, Arctic Council Working Groups).

Expected impacts

- Pressures, activities and impacts that are absent from existing regulatory frameworks (e.g., Driver, Activities, Pressures, and Impact on Ecosystem Services, DAPSIR) are identified and filled
- Regions and ecosystems most sensitive to environmental impact now and in the future protected
- Thresholds of the impact of multiple stressors on organisms and ecosystems are defined and accounted for in regulatory guidance

Credit – Daniel Jones

Socio-Economic Impacts, Adaptation and Governance in a Changing Arctic

How will Arctic change and expansion of the ocean economy impact coastal communities and Indigenous Peoples, human wellbeing, and sustainable development?

Whilst progress is being made, we require more interdisciplinary approaches that integrate physical, biogeochemical, ecological, and socio-economic research, to quantify the effects of accelerating Arctic change and economic development on society, health, economy, and governance. Otherwise, there is a risk of weakening inclusive decision-making, undermining resilience and heightening geopolitical tension.

Why is it timely

The accelerating pace of climate change and economic development in the Arctic (e.g., resource extraction, tourism, shipping, fishing, geoengineering) has uncertain impacts on future community resilience and employment, and may drive large demographic shifts and trigger socio-economic tipping points.

In this context, it is critical to understand how these changes will impact the preservation of coastal livelihoods, food, energy, data and communication security, health education, as well as cultural heritage and identity.

There is also an urgent need to value (e.g., via natural capital, blue finance, carbon credit) and better manage Arctic ecosystem services.

How can a diverse and equitable blue economy be realised, that sustains livelihoods and works towards the UN Sustainable Development Goals?

Credit – Elena Garcia Martin

Innovative approaches to address the challenge

Co-producing knowledge with Indigenous and local partners and incorporating intergenerational, youth and gender perspectives is essential to bridging natural and social sciences so that the risks and opportunities posed to livelihoods, health, education and cultural integrity can be addressed.

Through innovative science communication, participatory research using novel methods and expertise in ocean ecosystem service valuation and capacity building, the UK is well placed to support the development of actionable solutions, ensuring that Arctic research delivers tangible benefits to society and nature both within and beyond the region. Suggested collaborative areas for research and dialogue include:

Governance, policy, and international relations:

- Co-developing Arctic governance and policy, recognising science diplomacy as an essential tool and respecting Arctic sovereignty.
- Contributing to future planning (e.g. narrative scenarios), risk assessments and adaptation pathways developed in parternship with Arctic stakeholders, with full consideration of legal and ethical issues.
- Providing robust scientific advice to UK policy on the Arctic.

Cumulative, cascading, cross-scale and cross-sectoral impacts:

- Understanding local and regional linkages between socio-economic and ecological changes and the global societal impact of Arctic change (e.g., on food systems, migration, markets and economic costs).
- Identifying potential socio-oceanographic tipping points and abrupt changes.

Research enabling communication, engagement, and capacity building:

- Co-development of novel methods of interdisciplinary and participatory research (e.g., Narrative Foresight, interdisciplinary storylines, stakeholder personalisation), enabling co-production of knowledge and supporting decision-making at local, regional and global levels.
- Undertaking multi-disciplinary science communication with e.g., the arts and humanities, to amplify a broad range of voices and engage Arctic residents, policy makers and funding bodies.
- Explore novel methods of engaging and supporting early career and local researchers and underrepresented groups in Arctic research.

Partnerships and Collaboration

Whilst the UK has significant opportunities to advance Arctic Ocean research, the science community recognises the urgent need to strengthen the way Arctic research is designed, coordinated, and delivered.

Credit – Johan Faust

Credit – Elena Garcia Martin

Credit – Jo Hopkins

International cooperation will be key. The UK is well-positioned to contribute and lead through active roles in global initiatives such as the Decade of the Cryosphere, EU PolarNet and Horizon Europe. Opportunities to strengthen and financially support partnerships with both Arctic (Canada, USA, Norway, Denmark (via Greenland), Finland, Iceland, Sweden) and non-Arctic nations (e.g., Germany, Japan, Korea) should continually be explored.

Expanding participation in observational networks and programmes (e.g., SAS, SAON, DBOs. NABOS, ITPs, ArORA) and strengthening ties with Arctic communities through for example Arctic Council Working Groups and ICARP-IV Indigenous Peoples' Coordination Group, would ensure sustained and ethically grounded research efforts.

Interdisciplinary and trans-disciplinary research is essential. Closer alignment of physical and ecological marine science research with social sciences, humanities, law, and policy, together with strengthened collaborations and co-design with non-academic stakeholders and local Arctic communities is essential.

All components of the Arctic system are inextricably interconnected. Whilst the focus of the research questions presented here is on the marine environment it is imperative that marine, terrestrial, cryosphere and atmospheric researchers identify and collaboratively tackle the interdisciplinary challenges.

Leveraging synergies between Antarctic and Arctic science – with the UK having great strength in both – and promoting knowledge exchange between polar regions, will further enhance our understanding of Arctic change and the planetary scale feedbacks.

Credit – British Antarctic Survey

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Acronyms

ACIA	Arctic Climate Impact Assessment
AMAP	Arctic Monitoring and Assessment Programme
AMOC	Atlantic Meridional Overturning Circulation
Arctic GRO	Arctic Great Rivers Observatory
ARGO	Array for Real-time Geostrophic Oceanography
ArORA	The Arctic Ocean Regional Alliance
BODC	British Oceanographic Data Centre
DAPSIR	Drivers, Activities, Pressures, and Impact on Ecosystem Services
DBO	Distributed Biological Observatory
eDNA	Environmental DNA
EU-PolarNet	EU Polar Network
FAIR/CARE	Findable, Accessible, Interoperable, Reusable / Collective Benefit, Authority to Control, Responsibility, Ethics
FCDO	Foreign, Commonwealth & Development Office
FMRI	Future Marine Research Infrastructure
GACS	Global Alliance of Continuous Plankton Recorder Surveys
GBIF	Global Biodiversity Information Facility
IASC	International Arctic Science Committee
ICARP	International Conference on Arctic Research Planning
ITP	Ice-Tethered Profilers
NABOS	Nansen and Amundsen Basins Observational System
POLARIN	Polar Research Infrastructure Network
SAON	Sustaining Arctic Observing Networks
SAS	Synoptic Arctic Survey
SPG	Sub Polar Gyre
UK PDC	UK Polar Data Centre

Workshop and Report Contributions

The following institutions were involved in the workshop and in shaping the content of this report:

- Bangor University
- British Antarctic Survey
- Durham University
- ECOWAS Commission
- Heriot Watt University
- Marine Biological Association
- National Oceanography Centre
- NERC Arctic Office
- Plymouth Marine Laboratory
- Scottish Association for Marine Science
- The Alan Turing Institute
- UK Centre for Hydrology and Ecology
- UK Foreign, Commonwealth and Development Office
- UK Met Office
- University College London
- University of Aberdeen
- University of Bath
- University of Birmingham
- University of East Anglia
- University of Edinburgh
- University of Edinburgh
- University of Exeter
- University of Liverpool
- University of Oxford
- University of Plymouth
- University of Portsmouth
- University of Reading
- University of Southampton
- University of Stirling
- University of Strathclyde
- World Wide Fund for Nature

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