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Arctic in Rapid Transition: Priorities for the future of marine and coastal research in the Arctic

Werner Kirstin [1, 2, *], Fritz Michael [3, 4], Morata Nathalie [5, 6], Keil Kathrin [7], Pavlov Alexey [8], Peeken Ilka [9], Nikolopoulos Anna [10], Findlay Helen S. [11], Kedra Monika [12], Majaneva Sanna [13], Renner Angelika [14], Hendricks Stefan [9], Jacquot Mathilde [15], Nicolaus Marcel [9], O'Regan Matt [16], Sampei Makoto [17], Wegner Carolyn [18]

[1] Ohio State Univ, Byrd Polar & Climate Res Ctr, Columbus, OH 43210 USA.
[2] Korea Polar Res Inst, Inchon 21990, South Korea.
[3] Helmholtz Ctr Polar & Marine Res, Alfred Wegener Inst, D-14473 Potsdam, Germany.
[4] Univ Utrecht, Utrecht, Netherlands.
[5] Univ Brest, CNRS, LEMAR, Ifremer,IRD, Rue Dumont DUrville, F-29280 Plouzane, France.
[6] Akvaplan Niva, Fram Ctr Climate & Environm, Tromso, Norway.
[7] Inst Adv Sustainabil Studies, D-14467 Potsdam, Germany.
[8] Norwegian Polar Res Inst, Fram Ctr, N-9296 Tromso, Norway.
[9] Helmholtz Ctr Polar & Marine Res, Alfred Wegener Inst, D-27570 Bremerhaven, Germany.
[10] AquaBiota Water Res, S-11550 Stockholm, Sweden.
[11] Plymouth Marine Lab, Plymouth PL1 3DH, Devon, England.
[12] Polish Acad Sci, Inst Oceanol, PL-81712 Sopot, Poland.
[13] Linnaeus Univ, S-39182 Kalmar, Sweden.
[14] Inst Marine Res, N-9294 Tromso, Norway.
[15] Univ Bretagne Occidentale, F-29238 Brest, France.
[16] Stockholm Univ, Dept Geol Sci, S-10691 Stockholm, Sweden.
[17] Hiroshima Univ, Grad Sch Biosphere Sci, Higashihiroshima, Japan.
[18] GEOMAR Helmholtz Ctr Ocean Res, D-24148 Kiel, Germany.

* Corresponding author : Kirstin Werner, email address : werner.192@osu.edu

Abstract :

Understanding and responding to the rapidly occurring environmental changes in the Arctic over the past few decades require new approaches in science. This includes improved collaborations within the scientific community but also enhanced dialogue between scientists and societal stakeholders, especially with Arctic communities. As a contribution to the Third International Conference on Arctic Research Planning (ICARPIII), the Arctic in Rapid Transition (ART) network held an international workshop in France, in October 2014, in order to discuss high-priority requirements for future Arctic marine and coastal research from an early-career scientists (ECS) perspective. The discussion encompassed a variety of research fields, including topics of oceanographic conditions, sea-ice monitoring, marine biodiversity, land-ocean interactions, and geological reconstructions, as well as law and governance issues. Participants of the workshop strongly agreed on the need to enhance interdisciplinarity in order to collect comprehensive knowledge about the modern and past Arctic Ocean's geo-ecological dynamics. Such knowledge enables improved predictions of Arctic developments and provides the basis for elaborate decision-making on future actions under plausible environmental and climate scenarios in the high northern latitudes. Priority research sheets resulting from the workshop's discussions were distributed during the ICARPIII meetings in April 2015 in Japan, and are publicly available online.

Keywords : Early career scientists, Climate change, Interdisciplinary, New methodologies, Future research priorities

1. INTRODUCTION

The Arctic Ocean is currently responding to the significant global atmospheric warming by dramatic pan-Arctic sea-ice loss (Steele et al., 2008; Serreze et al., 2009; Polyakov et al., 2010, Meier et al., 2014). Strong reduction in areal ice coverage (ca. 16% per decade) is accompanied by a decrease in winter sea-ice thickness by nearly 50% over the 1980-2008 period, shifting from a multi-year to a largely seasonal and much thinner ice cover (Kwok & Rothrock, 2009; Comiso, 2012; Parkinson & Comiso, 2013). Resultant increase of open water leads to further oceanic uptake of atmospheric heat which contributes to amplified warming (Kellogg, 1975; Parkinson & Comiso, 2013). Thawing permafrost and increasing coastal erosion mobilize substantial amounts of organic matter, which could be converted into greenhouse gases thereby enhancing global warming (Schuur et al., 2015). Some projections suggest that the Arctic Ocean may become seasonally ice-free as early as 2040 (Wang & Overland, 2009). As a consequence, destinational and trans-Arctic maritime transportation opportunities allowing for easier offshore explorations and exploitation of living and non-living resources such as natural oil and gas (e.g., Gautier et al., 2009; Dodds, 2010; Stephenson et al., 2011) will induce high risks for further anthropogenic harmful impacts on the Arctic Ocean's vulnerable natural ecosystem. Therefore, a modern holistic scientific approach is needed to understand the Arctic system: how it worked in the past, how it looks today, how it is changing, and what it will be like in the future. Providing reliable projections of future consequences is essential for protection-oriented operation and sustainable use of natural resources by all Arctic states, but also by stakeholders, policy makers and land-use managers from beyond the Arctic region, and not least Arctic inhabitants including indigenous communities.

As an international, integrative and multidisciplinary network of early career scientists (ECS) working in the Arctic, the Arctic in Rapid Transition (ART; https://sites.google.com/a/alaska.edu/arctic-in-rapid-transition/) initiative has succeeded in triggering a discussion on how such an approach in Arctic sciences may look like hereby integrating various interdisciplinary concepts and processes (Figure 1). ART was founded in 2009 in order to establish a long-term pan-Arctic research network for ECS who study the changes and feedbacks among all physical and biogeochemical components of the Arctic Ocean and their ultimate impacts on biological productivity (Frey et al., 2010; Wegner et al., 2011; Forest et al., 2013; Kędra et al., 2015b). In 2013, ART became an official network of the International Arctic Science Committee (IASC). The workshop *Integrating spatial and temporal scales in the changing Arctic System: towards future research priorities* (ISTAS; http://istas.sciencesconf.org/) jointly organized by ART, the Association of Polar Early Career Scientists (APECS; http://www.apecs.is/), and the European Institute for Marine Studies (IUEM; http://www-iuem.univ-brest.fr) took place 21-24 October 2014 at the IUEM in Plouzané, France. Scientists from 13 different countries representing multiple fields of Arctic research and various career stages met in order to discuss priorities of future Arctic research in parallel and plenary sessions. Seven documents were produced following the ISTAS discussion, identifying future Arctic research directions in specifically *Arctic Oceanography*, *Physical Processes in Sea Ice*, *Arctic Land-Ocean Interactions*, *Arctic Biodiversity*, *Paleoceanographic Time Series from the Arctic Ocean*, *Proxy Calibration and Validation*, and as a new component for the ART network *Law in the Arctic*. These documents were a contribution to the Third International Conference on Arctic Research Planning (ICARP III) that took place in Toyama, Japan in April 2015.

In this paper, we introduce future Arctic research priorities identified during the second ART workshop ISTAS by ECS - the upcoming generation in Arctic research. After a note on methods, future research priorities structured along the lines of the ART priority sheets addressing different Arctic research fields are discussed. The paper concludes with a discussion of ideas as to what early career researchers need from, but more importantly what they can offer to, the Arctic scientific community in terms of addressing the challenges ahead for Arctic research. With this note, we aim for an enhanced dialogue between scientists but also for discussions beyond the research realm, such as promoted through ICARP and related meetings, involving various external parties concerned with Arctic-related issues.

2. METHODS

Following the philosophy of ART and APECS, the ISTAS workshop emphasized the active involvement and training of the next generation of Arctic scientists that will become future leaders in Arctic research within the next decades. The main objective of this interdisciplinary and international workshop was to congregate Arctic scientists from different areas of expertise and various career stages in order to discuss future research priorities for the Arctic Ocean. In total, 76 participants including 24 graduate students, 19 post-docs and 33 senior scientists from 13 countries (France, Russia, USA, Canada, Finland, Sweden, Spain, Germany, Poland, Norway, United Kingdom, China, and Estonia) attended the workshop representing various disciplines of Arctic sciences including biological and physical oceanography, sea ice, marine biodiversity, land-ocean interactions, paleo-reconstruction and biological archives, as well as law and economics (Figure 2).

The workshop was a mix of open plenary lectures providing overviews within different fields of natural as well as social sciences, and parallel sessions for presentations of the participant's current research. The natural variability in Arctic marine geo-ecosystems was reviewed over various spatial and temporal scales in order to better understand the changing Arctic marine system as a whole. Through plenary lectures open to the public, invited speakers provided overviews of their respective field of research, presenting latest findings, challenges, and points of view on future Arctic research directions. A plenary presentation about Arctic sustainability and resources followed by a discussion about multidisciplinarity provided insights into inter- and transdisciplinary research approaches with the aim of purposefully integrating Arctic natural and social sciences.

The material from all the presentations fed into discussions on future Arctic research priorities during the second half of the workshop. The final outcome of ISTAS was a series of short documents that highlight future research priorities for Arctic sciences including marine, cryosphere, atmosphere, terrestrial, and socio-economic research fields. These documents were termed *Priority Sheets*.

Post-workshop activities included several steps such as (i) the synthesis and writing of priority sheets by topical groups which were also open for additional experts to join, (ii) post-workshop feedbacks by topical peers, invited specialists, and the ART Advisory Board, (iii) synthesis of input provided by the ART Executive Committee, and (iv) feedback by the wider scientific community after finalization of the priority sheets. In April 2015, the ART future research priorities were first presented and distributed during the ART session *Arctic in Rapid Transition - future research directions from the perspective of early career scientists* (session chair: Makoto Sampei) at the Arctic Science Summit Week 2015 (ASSW 2015) in Toyama, Japan. Part of the ASSW 2015 were the Fourth International Symposium on the Arctic Research (ISAR-4) and the Third International Conference on the Arctic Research Planning (ICARP III). The venue of ASSW 2015 thus provided the appropriate platform to further disseminate and discuss the priority sheets during informal meetings, poster sessions and social gatherings (Majaneva et al., 2015a; Morata et al., 2015; Wegner et al., 2015b). The priority sheets were published online (https://sites.google.com/a/alaska.edu/arctic-in-rapid-transition/background-information/publications/art-priority-sheets) and archived at the German National Library of Science and Technology (http://www.tib-hannover.de/en/).

3. FUTURE RESEARCH PRIORITIES

Below, we introduce future Arctic research priorities as identified by participants during the ISTAS workshop.

3.1. From Microphysics to Large-Scale Dynamics: Sea ice in the Arctic Ocean

While the recent retreat of Arctic sea ice is well documented (Meier et al., 2014), there are still significant knowledge gaps concerning the understanding of internal processes of sea ice and its drivers of change leading to substantial uncertainties also in long-term climate model projections and seasonal forecasting (Tietsche et al., 2014; Serreze and Stroeve, 2015). To tackle these uncertainties, a synergy between numerical and observational studies of the complex ocean-ice-atmosphere-biosphere system on varying spatial and temporal scales is crucial (Figure 2). Improving the reliability of projections of Arctic sea ice is a major priority for the Arctic research community due to the socio-economic relevance of sea ice for the living conditions of Arctic inhabitants, and especially indigenous peoples, its relevance for marine trade, tourism, and exploration of marine resources, and not the least for its role in the Arctic environmental system (Meier et al., 2014).

Major gaps and needs in current Arctic sea-ice physics research identified by the participants of the ART ISTAS workshop (Renner et al., 2015) include

- Improved representation of sea ice in global climate models and its impact on ocean-ice-atmosphere interactions by highly resolved sea-ice thickness and snow depths measurements on a pan-Arctic scale.
- Appropriate tools and techniques are required for up- and downscaling of numerical model output, in-situ and remotely sensed observations. Experience from other disciplines should be utilised to develop statistical tools and Arctic sea ice reanalyses.

- The surface state and properties of sea ice including the snow cover are poorly documented and understood. New and improved techniques are needed for in situ and remote observations as well as advanced model parameterisations.
- Spatio-temporal uncertainties and biases in data products from model outputs, remote-sensing products, and observational records should be quantified. It is vital to agree on standardized metrics and procedures for data collection and error assessments.
- Data recovery, building of new time-series data streams, and continuation of current time-series measurements, in particular for essential sea ice variables should be prioritized. Data should be made openly accessible.
- Reassess and evaluate established but old conceptual models of Arctic sea ice in light of new knowledge and developments. This requires funding for review work and increased collaborations between modellers and observationalists.

3.2. Holistic Arctic Oceanography: Atmosphere-ocean exchange, Biogeochemistry, and Physics

The very shallow continental shelves (0-200 m water depth) account for approximately half of the Arctic Ocean’s total area, with the central Arctic extending to over 5500 m in depth. Its vast continental shelf areas are heavily influenced by surrounding landmasses through river run-off and coastal erosion (Dittmar and Kattner, 2003, Stein, 2008). As a main area of deepwater formation, the Arctic is one of the major ”engines” of global ocean circulation (Aagaard et al., 1991). Due to large freshwater inputs and sea ice, it is also strongly stratified (Rudels et al., 1996). The Arctic Ocean’s complex oceanographic configuration is tightly linked to the atmosphere, the land, and the cryosphere (Figure 2). The physical dynamics not only drive important climate and global circulation features but also control biogeochemical cycles and ecosystem dynamics. The current and forecasted changes in Arctic sea-ice thickness and distribution, air and water temperatures, and water column stability result in measurable shifts in the properties and functioning of the ocean and its ecosystems. These include the exchange of heat and gases across the atmosphere-ocean interface, wind-driven circulation and mixing regimes, light and nutrient availability for primary production, food web dynamics, and export of material to the deep ocean (Findlay et al., 2015b; Katlein et al., 2015). In anticipation of these changes, extending our knowledge of Arctic oceanography and these complex changes has never been more urgent. Over the last decades there have been significant developments in Arctic oceanographic research, yet we still lack an in-depth understanding around some of the key environmental processes at varying spatial and temporal scales. Combining new technologies (i.e., autonomous platforms, satellites, evolving biological methods, isotope technologies, biomarkers and modelling), and bringing together oceanographic sub-disciplines, will be crucial to successfully understanding the Arctic Ocean as a coupled environmental system, and how it should be managed in the future.

In order to link plans for future societal use of the Arctic Ocean (e.g., for shipping and exploitation of living and non-living marine resources) with climate change, ecosystem and biogeochemical studies, we need to develop an interdisciplinary approach (Findlay et al., 2015a). This includes increasing our understanding of:

- The cycling of carbon and nutrients, including the terrestrial input and its role in ocean chemistry. Internal cycling (i.e., of primary production, export and carbon sequestration) as well as connections to the benthos and how microbes impact on these cycles need to be investigated.
- The ecosystem functioning, including how energy is transferred through trophic levels.
- The freshwater, including quantifying the freshwater budget and its potential to changing the oceanic chemical composition (i.e., salinity, alkalinity and pH). We need to understand how freshwater impacts the stability of the halocline and nutricline.

- The forming mechanisms, dynamics, and variability of the cold halocline, the exchange processes between the halocline and surrounding water masses, and the degree of influence by the halocline on the sea-ice characteristics and vertical exchanges of water properties and matter.

3.3. Linked through Permafrost: Land-Ocean Interactions in the Arctic

Most Arctic coasts are permafrost coasts. The permanently frozen ground extends below sea level on the shallow Arctic shelves as submarine permafrost. There is evidence in northern Alaska and the Laptev Sea area for recent acceleration in the rate of coastal erosion (e.g., Günther et al., 2015) related in parts to more open water and higher wave energy due to reduced sea-ice coverage, rising sea level, and more rapid thermal abrasion along coasts with high volumes of ground ice. Nearshore zones are transient zones for terrigenous matter, which arrives via coastal erosion, river discharge, and sea ice (e.g., Forbes, 2011). Recent flux estimates of sediment and organic carbon from coastal erosion into the Arctic Ocean are around 430 Tg (Tg = 10^{12} gram) sediment per year and 4.9-14.0 Tg organic carbon per year (Wegner et al., 2015a). Yet, the fate of terrestrial material, its contribution to greenhouse gas emissions and ocean acidification and impact on nearshore ecosystems is poorly understood. Currently, the climate debate outshines the many lines of consequences that accelerating coastal erosion bear to society with immediate impact on coastal infrastructure and cultural heritage.

Potential impacts of increasing erosion on primary production need to be identified. This is important not only to comprehensively assess Arctic carbon and nutrient cycles but also to secure food for Arctic indigenous coastal communities (Fritz et al., 2015b). To achieve a holistic understanding of Arctic permafrost land-ocean interactions in future interdisciplinary research we recommend to:

- Address past, modern and future dynamics of Arctic coastal erosion, and the related biogeochemical fluxes and implications for climate change by developing conceptual models for erosion on geological timescales and empirical models for future scenarios.
- Develop an understanding of submarine permafrost dynamics on Arctic continental shelves regarding aggradation and degradation.
- Track the linkages between the Arctic Ocean and the terrestrial hydrological cycle with special emphasis on lateral water and material fluxes.
- Quantify the impacts of environmental change on Arctic local communities, on ecosystem services, and socioeconomic dynamics.

3.4. Arctic Marine Biodiversity: from Individuals to Pan-Arctic

The disproportionally fast warming of the Arctic together with massive reduction of sea ice thickness and extent (Wang & Overland 2009; Duarte et al. 2012; Parkinson and Comiso 2013) will affect all levels of marine biodiversity from taxonomic and genetic to functional, physiological and community diversity (Moline et al. 2008; Cheung et al. 2009; Bluhm et al. 2011; Philippart et al. 2011). Shifts in biodiversity can directly and indirectly change species interactions and ecosystem processes resulting in large cascading changes with implications for the entire Arctic ecosystem (Slagstad et al. 2011; Wassman et al. 2011; Ji & Varpe 2013; Post et al. 2013; Kędra et al. 2015a) and thus for ecosystem services (e.g., food production in the form of fisheries but also the cultural heritage of hunting practices as well as tourism). As current observations and predictions suggest an ice-free Arctic summer likely to occur within the next few decades (Cavalieri & Parkinson 2012) possible effects of Arctic biodiversity are of critical concern.

Projected increasing human presence in a changing Arctic requires good knowledge of marine biodiversity on multiple temporal scales, ranging from seasonal and interannual to decadal; and spatial scales, ranging from local through regional to pan-Arctic. Also the integration and connections between these various scales is important taking into consideration all biological levels varying from genetics to organisms and populations. Importantly, we need to elaborate the resilience, plasticity, and adaptation capacity of Arctic marine species and the response of the (changing) Arctic biodiversity to multiple and cumulative pressures (Majaneva et al., 2015b). To achieve this, we suggest to:

- Increase biodiversity knowledge on spatial scales, especially in deep sea and sympagic ecosystems and on a pan-Arctic scale.
- Expand biodiversity knowledge on temporal scales, with special focus on the dark/winter season and building multidecadal time series.
- Improve biodiversity knowledge on microbial communities and benthic ecosystems including molecular approaches.
- Integrate functional and physiological diversity with taxonomic and genetic diversity regarding biological traits as well as cold and dark adaptation.
- Develop indicators for response(s) to environmental pressures and changes.

3.5. Looking Back: Paleo-Oceanographic Time Series from Arctic Sediments

Marine sediment cores hold essential environmental information beyond the period of historical and observational data acquisition. Reconstructing past climatic and oceanographic changes in the Arctic Ocean significantly contributes to our understanding of long-term feedback mechanisms and their relationships to global environmental changes. In particular, Arctic climate excursions during the present (Holocene) and earlier interglacials are crucial references for recent and future climate changes (Kinnard et al., 2011). Comparatively poorly constrained age models of sediment cores obtained from the Arctic Ocean's abyssal region and a lack of temporal resolution in slowly deposited sediments are still fundamental challenges in Arctic marine geology (Backman et al., 2004). Overcoming these obstacles will be a key research priority in the near future, and can be met by the acquisition of sediment records from high sedimentation areas, marginal settings, and through the application of advanced seafloor drilling technologies (O'Regan et al., 2015). Future geological approaches in the Arctic Ocean may thus focus on:

- An improved chronological control of Arctic sedimentary records in order to correlate geological features of the Arctic Ocean to the global ocean system.
- High-resolution sedimentary records retrieved from Arctic shelves and margins.
- Seeking analogues in Arctic geologic history to present and future climate warming.
- The integration of marine and terrestrial datasets to reconstruct past land-ocean linkages (see 3.3).
- Acoustic mapping of seabed and shallow sub-seabed combined with chronological and proxy data.
- The utilization of ground-truthing technologies.

3.6. Geological Climate Indicators: 'Ground-truthing' Proxies with Modern Data

A further challenge in marine geology is the understanding and calibration of climate indicators to reliably reconstruct environmental parameters from Arctic Ocean sediments. Indirect or proxy climate indicators ('proxies') provide knowledge on environmental conditions in the past Arctic Ocean (e.g., Müller et al., 2009; Stein et al., 2012; de Vernal et al., 2013). They include fossilized benthic or planktic organisms, preserved biomarkers, organic matter, but also lithic particles transported either by sea ice, glacial ice, or ocean currents. 'Ground-truthing' proxies with modern data, e.g., comparing the distribution and conditions of microfossils in relation to environmental factors is crucial for reconstructions of past environmental conditions from sediment cores such as sea surface temperatures and salinity or sea-ice cover (e.g., Husum and Hald, 2012; Ho et al., 2014; Pados and Spielhagen, 2014). Uncertainties often arise from imperfect knowledge of the detailed response of a proxy to its environment. Novel proxies but also existing proxy calibrations are not yet sufficiently elaborated in the Arctic Ocean due to temporal and/or spatial biases. Improved proxy-to-environment calibrations are thus needed to understand how different aspects of the Arctic changed in the past, and will potentially change in the future (Werner et al., 2015). Close collaboration between geoscientists, oceanographers, biologists, and modellers is needed in order to focus on key aspects of proxy calibration studies in the Arctic Ocean (Figure 1). These include:

- The evaluation and calibration of existing proxies for a quantitative assessment of past environmental conditions (e.g., temperature, salinity, sea ice).
- The development of novel proxies (e.g., for stratification, ocean acidification) by adopting reliable methods to track present-day changes in water mass properties.
- The assessment of seasonal cycles in Arctic Ocean productivity and nutrient cycling to distinguish between annual and seasonal signals of microfossil records.
- The quantitative assessment of organic and inorganic matter fluxes to the sea floor, and potential impact of sea ice and ocean currents on particle transport and accumulation.

3.7. Arctic Law and Governance

Over the last years, research in Arctic law and governance has seen a large array of studies (for an overview see Arctic Governance Project, http://www.arcticgovernance.org), which highlights the increasing importance of the Arctic against the background of the significant climatic and environmental changes occurring in the North. Arctic law and governance has a crucial role in making sense of the natural processes and their rapid changes for subsequent societal implications, encompassing social, cultural, political and economic processes and developments. Law and governance are hereby not only means to study and describe such processes and developments but also actively shape, influence and decide what we make of the changing Arctic climate and environment for societies within and outside the Arctic region.

Academic studies in Arctic law and governance have been focusing on a variety of topics over the last few years including, amongst others:

- Institutions, regimes and forums dealing with Arctic governance on various scales,
- Gaps in Arctic regulations and necessary reforms (e.g., Koivurova and Molenaar, 2010),
- Questions of sovereignty and sovereign rights, e.g. concerning extended continental shelves in the Arctic Ocean especially among the five Arctic states who border the Arctic Ocean (e.g., Elferink et al., 2001), and
- Questions of cooperation and conflict (e.g., Keil, 2014, 2015) as well as security questions, ranging from traditional, military issues of security to a more comprehensive understanding of security including human and environmental security (e.g., Young, 2011).

While these approaches provide highly relevant inputs to our understanding of Arctic law and governance processes, systems, and actors, a lot remains to be done in terms of topics we need to address and how we are going about studying, understanding and making sense of those topics mentioned above (Beurier et al., 2015; Keil, 2016 This could be done by:

- Systematic discussion about the meaning of who and what qualifies as "Arctic" or "non-Arctic" against the background of the region's history and the current process of globalization. We need studies on different scales of governance and how these interact to provide a regional-sensitive outlook taking into account the social, political, economic, environmental, and climatic circumstances in different Arctic regions,
- A transdisciplinary understanding of Arctic law and governance with regard to an increasing number of actors in Arctic governance,

- A better understanding of the Arctic as a case in the sense of detecting larger law and governance processes and developments,
- Implementation of laws and regulations, including connected legal and political difficulties and challenges. This should focus on areas of high relevance given increasing human activities in the region, including environmental pollution in the Arctic, threats to Arctic biodiversity, and impacts from new or increasing activities such as shipping and resource development. This needs to include the consideration of existing institutions but also the usefulness and viability of new forms of governance such as a *Regional Sea Convention* for the Arctic.

4. DISCUSSION

Drawing upon the multiple research needs as outlined above, it becomes clear that Arctic research faces many challenges and requires scientists, in addition to pure scientific efforts, to open up to many different cross-disciplinary activities. For reaching a full-scale understanding of the Arctic, scientists need to increase their utilization of collaborative methods and activities which combine the classical, but often logistically challenging, field experiments with autonomous efforts (e.g, glider data) and large-scale products (e.g., remote sensing data and numerical models). Also, less traditional ways in communication and interaction (e.g., social networks) as well as interrelations with coastal communities are needed to cover all aspects and concerns about the change of the Arctic.

However, the major precondition to enable a future holistic understanding of Arctic systems is to ensure long-term and stable funding for the next generation of Arctic scientists (see chapter 4.2.).

4.1. Cooperation and Communication across Disciplines

Appropriately addressing these many interactive research needs requires close communication and collaboration amongst the members of the international scientific community, but also outreaching activities involving societal stakeholders and representatives of various groups with Arctic-related interests. State-of-the-art, borderless and year-round access to both marine and terrestrial study areas, research stations and vessels as well as deployment of novel technologies and infrastructures are key prerequisites to allow for providing answers to research questions such as those outlined. To all these activities, the Arctic coastal communities need to be included. Local stress in the communities potentially caused by changes in sea ice, resource development and increasing ship traffic may also limit scientific activities around coastal communities e.g., during the traditional hunt period.

Cross-discipline collaborations involving various research fields is challenging also within the scientific community. In order to conduct interdisciplinary collaborations we need to understand at least the basics of the respective other disciplines, including the main principles and questions each discipline addresses and which uncertainties and challenges researchers in this discipline are confronted with. Endowed with such a basic understanding, we will be able to identify possible synergies across our fields and opportunities for complementing each other's work (Figure 1).

Communication but also willingness to delve into completely foreign areas is thus key for interdisciplinary work to succeed, especially since methodologies, data and research results are often not easily comparable. As one example, while some research fields aim more towards generating specific results on dedicated temporal and spatial scales, others aim more towards the generalizing their findings. Integrating these two very different approaches can be difficult but a holistic understanding of Arctic systems needs both perspectives. Efforts needed here include the translation of specialized research outcomes into more general debates of Arctic studies. In other words, specific case studies need to be embedded into the broader scope that they are a part of. This would provide a fruitful basis for discussion among researchers of various disciplines. In short, cross-discipline collaboration requires scientists to put their specific results into a larger perspective in order to trigger communication amongst different groups.

The formation of interdisciplinary master programs during the last few decades, in parallel to an increasing societal awareness of cross-disciplinarity in previously rather conservatively-taught, descriptive science courses (e.g., geography, physics, chemistry), indicates that sciences have opened to more interdisciplinary viewpoints (e.g., Newell, 2001). Having benefited from this new perception in sciences at university level, the upcoming generation of Arctic scientists is most aware of interdependencies between all different parts of the complex Arctic system including natural as well as socio-economic processes. Integrated studies of coupled human and natural systems have elucidated new and complex patterns that otherwise would have not been identified (Liu et al., 2007). Allowing ECS to collaborate early with other researchers and help forming interdisciplinary pathways by organizations such as IASC, APECS, and ART enables a rapid transfer of early career experience into established circles of Arctic research.

Fieldwork and other research activities jointly carried out by multidisciplinary groups are another important aspect of stronger collaboration and communication. In order to provide satisfying conditions to each working group, different needs have to be identified to provide individual sampling and data monitoring after standardized protocols. Well-organized logistics and a thought-through chronological protocol of individual fieldwork procedures need to be determined to avoid interferences between the groups. That said, interdisciplinary work always requires high flexibility from all different parties and a strong willingness to compromise in order to reach common goals of the joint research program. As an example of collaboration and communication through fieldwork the ART-initiated expedition TRANSSIZ is briefly described in section 4.1.1.

4.1.1. The TRANSSIZ Cruise – Example for Interdisciplinary Research in the Arctic Ocean

The RV *Polarstern* expedition PS92, *Transitions in the Arctic Seasonal Sea Ice Zone* (TRANSSIZ) was planned and organized by the ART network as an interdisciplinary field campaign of international early career scientists with various research backgrounds. The cruise took place from 19 May to 28 June 2015 (Figure 3) and involved a young and interdisciplinary team of 51 scientists from 11 countries (Peeken, 2016).

Following the research questions outlined in the ART Science Plan (Wegner et al., 2010) and the key points of Arctic research identified in the ART priority sheets (see chapter 3), the TRANSSIZ cruise aimed at conducting ecological and biogeochemical early-spring process studies within the marginal ice zone close to the major gateway of Atlantic Water entering the Arctic Ocean. Key to the program were process studies carried out during eight sea-ice stations between 81° 11' N, 19° 8' E and 81° 54' N, 9° 44' E (for details see Peeken, 2016). By comparing data from the Barents Sea shelf across the shelf break and into the deep basin, results from the TRANSSIZ cruise will allow for an improved understanding of the ecosystem functioning and biogeochemical cycles during the transition from spring to summer, and how it compares to geological time scales.

4.2. Transdisciplinary Efforts

Next to stronger collaboration within the scientific community, researchers have to engage more strongly in transdisciplinary efforts, i.e., in enabling and facilitating dialogues about scientific processes and findings with the larger society but also with coastal communities. Trandisciplinarity differs from interdisciplinarity in the sense that it reaches out to stakeholders beyond academia, and aims to engage them throughout the research process. This is crucial in order to ensure the translation of scientific findings into social processes like political and individual decision-making, law-making etc., but also to ensure societal legitimacy of scientific work, which requires societal actors to understand and to feel included and concerned by researchers' efforts. This also includes improving the public's general knowledge about e.g., globally relevant teleconnections from the Arctic such as sea-level rise that may eventually affect their own personal living conditions. In this context, Arctic indigenous peoples playing a particular role due to their special legal rights (Fritz et al., 2015a; Larsen & Fondahl, 2015) have to be seriously involved. Finally, scientists increasingly view themselves as part of the stakeholder world interested in, affected by and affecting Arctic research. Not least, the scientific community is part and parcel of societal processes by co-deciding what will be studied in the first place and which aspects are highlighted or omitted.

While efforts have been made to communicate between science, politics and society through scientific advisory bodies such as the European Polar Board, the Arctic Council, or the Intergovernmental Panel on Climate Change, these communication lines are often hampered by the relative closeness of these groups. Also limited resources in terms of money, time and human resources in order to participate in such exchange and communication efforts play a crucial role, not least among Arctic indigenous peoples. Also, ECS are only very rarely represented in meetings where recommendations to stakeholders and decision-makers are discussed.

However, ECS have been strongly involved with reaching out to the general public since the International Polar Year 2007–2008 (Salmon et al., 2011). The ICARP III process provided an opportunity especially also for ECS to get actively involved in transdisciplinary efforts to communicate the global importance of the Arctic to policy-makers and the broader public (Fritz et al., 2015a). The ART network has thus produced the priority sheets aiming at actively contributing to ICARP III related consulting and decision-making processes from an early career perspective (IASC, 2016). As an example, the priority sheets were used in the discussion and formation of the recent UK Natural Environment Research Council call:

Changing Arctic Ocean: Implications for marine biology & biogeochemistry. The scoping group used the documents to provide evidence to the UK Science and Innovation Strategy Board to persuade them to fund Arctic Ocean research (David Thomas, chair of scoping group, pers. comm.) and they were also cited in the call Announcement of Opportunity (http://www.nerc.ac.uk/research/funded/programmes/arcticocean/news/ao-outline/ao/).

Involvement of ECS as well as societal actors early on in the research process will ensure the success of transdisciplinary efforts for addressing the various Arctic research tasks as outlined above and to ensure their positive influence on long-term Arctic sustainable development (Chabay et al., under review).

4.3. Request for Money, Mentors, and Material

As ECS we need the support from the existing Arctic science community to profit from their resources and experience. This especially includes ensuring stable career prospects by providing a more consistent funding base to support ECS activities. This involves financial support for long-term contracts but also mentoring and advising with regard to both scientific expertise and career management (see also Majaneva et al., in review, this issue), the latter potentially preparing ECS also for alternative pathways e.g., in governmental and private sectors. Funding systems also need to adapt to the new requirements of Arctic research as outlined above, i.e., to provide for incentives and structures to conduct inter- and transdisciplinary research. Given the limited experience with difficulties of planning and conducting large-scale research projects, funding programmes need to adjust for example in terms of longer funding periods, better opportunities for follow-up funding, better coordination between national funding agencies to facilitate cross-border projects, and reducing administrative burdens to allow (especially early career) researchers to invest the majority of their time and resources into research.

Further, funding programs need to provide resources to research projects, which not necessarily solely focus on the collection of new data, but on combining and making new sense of existing data sources but from an interdisciplinary perspective. Institutes and funding agencies are still mostly organized along disciplinary lines. It is thus often difficult to raise funds for e.g., a physicist and a biologist from the same funding source. Finally, while many funding calls nowadays call for the engagement of societal stakeholders in the research process, the temporal and material resources are seldom sufficiently provided for such an endeavour, since engagement with stakeholders often requires the establishment of close relationships and trust in order for a transdisciplinary process to work. These are by nature time- and resource-intensive processes, and also require (early career) researchers being able to spend sufficient amounts of time on a project.

Collaboration with industries may offer a source of additional funding. If doing so, scientific projects, however, need to be kept independently from any industrial interest in the sense of preventing business interest from guiding (or in the worst case distorting) research processes and outcomes. But learning about the practical needs of companies, e.g., in the form of internships, enhances dialogue between business and science hereby preparing for mutual initiatives shaping the Arctic's future.

5. CONCLUDING REMARKS

Developing priorities for future Arctic marine and coastal sciences was one of the major goals since ART was established in 2009 during the ART Initiation workshop in Fairbanks, Alaska. With the priority sheets now at hand, we invite the Arctic scientific community to suggest additional priority sheets about topics that have not yet been covered and to provide ideas as to how these can be incorporated in science-society discussions about Arctic change and challenges. As a contribution to the ICARP III process, we hope that these research priorities for future directions of Arctic sciences will be taken into consideration by national and international funding calls, research programs and projects in close consultation with non-scientific parties and ECS.

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Figure captions

Figure 1. Interdisciplinary Arctic research: Integration of concepts and processes. The house design (slightly modified after Renner et al., 2015) illustrates different levels of key elements that need to be maintained and build up to allow successful and sustainable interdisciplinary research in the coming decades. Research needs are to be based on discipline-specific existing knowledge, data sets and methods that have to be continued and developed further. Excellent research across disciplines will allow to connect the various approaches, and to establish new and to extend existing connections. Bridges over temporal and spatial scales, enhanced communication, and personal links are key requirements for this interaction. Finally, this will lead to advances in our process understanding, including innovative concepts and ideas in Arctic sciences.

Figure 2. Feedbacks and interactions between various components of the Arctic system with arrows indicating various linkages (after Renner et al., 2015).

Figure 3. Participants of the TRANSSIZ expedition in front of the German research icebreaker RV Polarstern (Photo: Ilias Nasis).

Figure 1

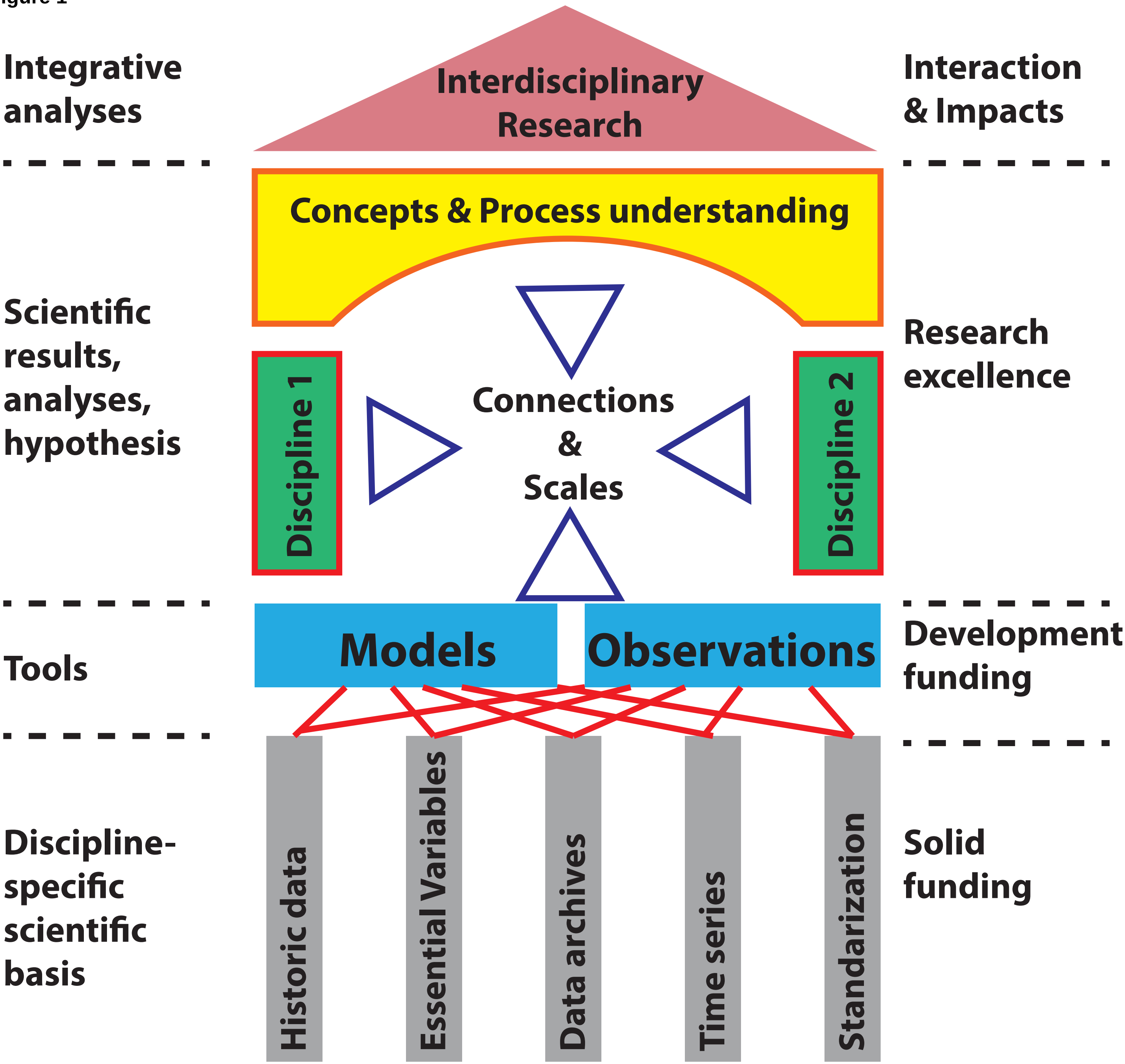
Integrative analyses
Interdisciplinary Research
Interaction & Impacts
Concepts & Process understanding
Scientific results, analyses, hypothesis
Discipline 1
Connections & Scales
Discipline 2
Research excellence
Tools
Models
Observations
Development funding
Discipline-specific scientific basis
Historic data
Essential Variables
Data archives
Time series
Standarization
Solid funding

Figure 2

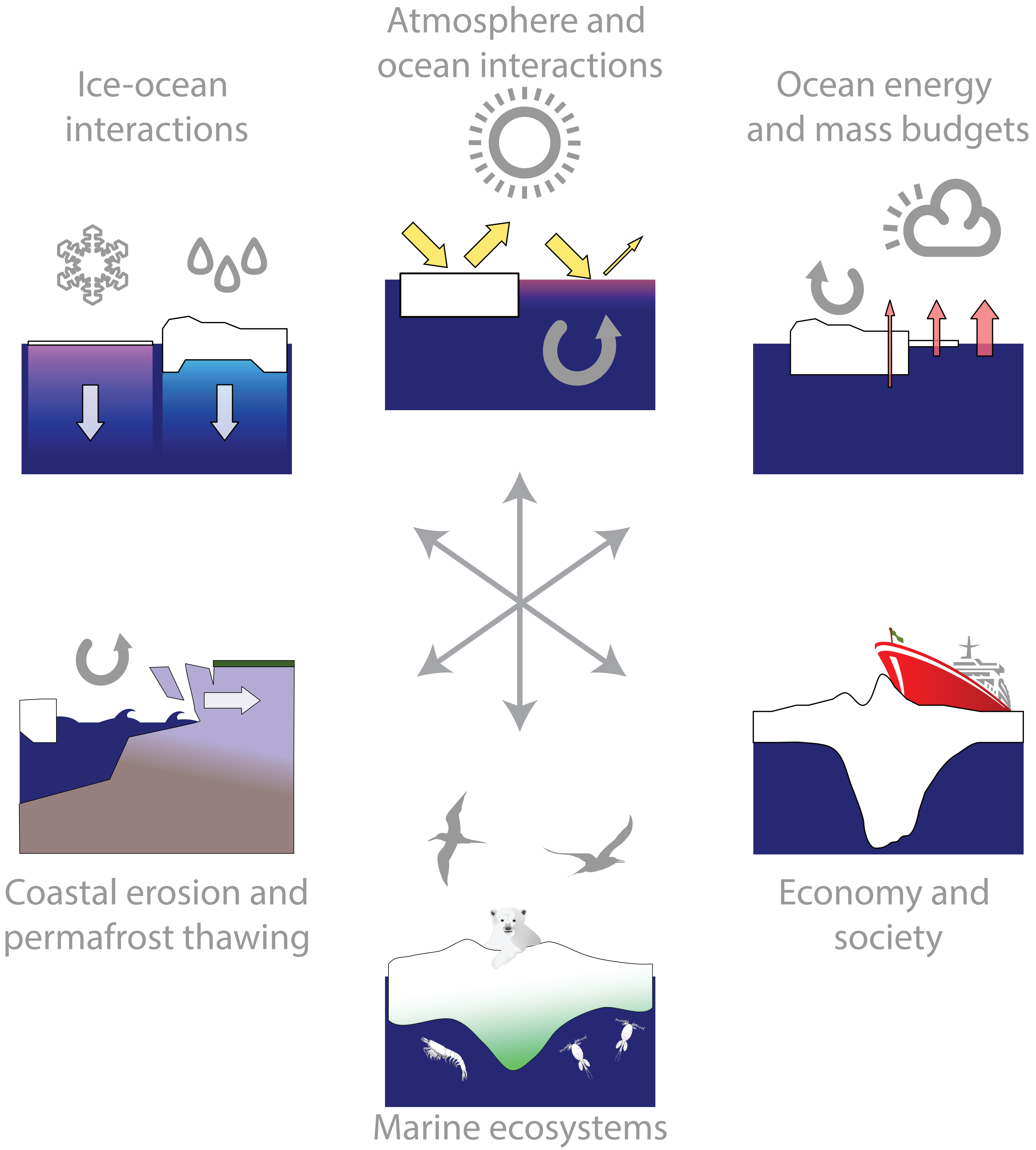
Atmosphere and ocean interactions
Ice-ocean interactions
Ocean energy and mass budgets
Coastal erosion and permafrost thawing
Economy and society
Marine ecosystems

Figure 3

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