A report from JCAR to inform the ICARP IV Process

Topic Area 2: Observing, Reconstructing, and Predicting Future Climate Dynamics and Ecosystem Responses

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Japan Consortium for Arctic Environmental Research (JCAR) published "Long-term Plan for Arctic Environmental Research (JCAR, 2024a)" with its Executive Summary (JCAR, 2024b) that includes research priorities from the viewpoints of Japanese Arctic research communities. Herein, we discuss topics related to the observation, reconstruction, and prediction of future climate dynamics and ecosystem responses based on the Executive Summary (JCAR, 2024b), towards which the Japanese research communities can implement priority studies in the next decade.

The main areas of research in the atmospheric sciences include understanding of processes connecting different time scales from weather to climate, interactions among the elements of the Arctic and those from outside the Arctic, and coupling between the troposphere and stratosphere and can be studied through integrating observations, modeling, and data assimilation. The climate system has a hierarchical structure comprising complex, interconnected processes at various spatiotemporal scales. Thus, a climate prediction is required to incorporate all relevant processes. Otherwise, numerical models for climate predictions must be strategically selected for various applications. For short-term future forecasts, the initialization technique is vital and requires the establishment of an appropriate assimilation method. For long-term future projections, reproducing current climate states is also important. Because air–ice–sea coupled systems must be satisfactorily represented in models, the sea-ice thickness should be continuously monitored to assimilate as a crucial dataset. As the climate varies internally and in response to external forcing, studies on the mechanisms of internal climate variability, forced response, and modulation of internal variability with changes in the mean climate state with a focus on Arctic regions are needed for predicting the future climate dynamics better.

Many aspects of the climate interaction between the Arctic and extra-Arctic (e.g., sub-Arctic and mid-latitude) regions remain unknown. Scientifically understanding such teleconnections is one of the essential factors for understanding current climate variability and predicting its future; additionally, this is further important in investigating the cause of extreme events in and out of the Arctic region and obtaining their future perspective. Research priorities on climate teleconnection are to understand its mechanism between the Arctic and extra-Arctic regions, sustaining mechanisms for modes of natural climate variability and their modulations under global warming, and identifying the link between specific extreme events and global-scale climate teleconnections.

Furthermore, clouds and their physical processes, greenhouse gases, and aerosols are important research topics. Recently, Japan launched a second-generation global imager (SGLI), which enables the observation of atmospheric parameters related to clouds and aerosols as well as geophysical parameters on the ground surface (snow and ice, vegetation, and ocean areas). Moreover, to promote the future Arctic research, it is highly desirable to introduce dedicated aircraft for earth observations and establish a system to operate aircrafts. In the past few years, most research on the middle and upper atmosphere and geospace has been led by Japanese researchers as part of an international joint research project, along with starting new satellite observations ("Arase": Exploration of energization and Radiation in Geospace) and large radar observations (EISCAT_3D radar). It is important to establish a global radar network that includes Japan’s large atmospheric radar plus the EISCAT_3D radar, which will provide an extremely strong research base for global atmospheric environment research.

As for ocean sciences, Arctic Atlantification and Pacification are emerging topics that characterize Arctic environmental and ecosystem changes not only in the Atlantic and Pacific gateway regions but also in the central Arctic Ocean. International collaborations are necessary to conduct large-scale ocean observations that connect the Atlantic and Pacific gateways with central Arctic, such as the Synoptic Arctic Survey (SAS), and to obtain baseline data on a decadal timescale. Interannual monitoring of marine environmental and ecosystem changes in priority areas, such as biological hotspots interspersed throughout the pan-Arctic, also require internationally coordinated observations using multiple vessels at different times of the year, such as the Pacific-, Atlantic-, and Siberian-Arctic Distributed Biological Observatories (DBOs). At present, Japan is building a new icebreaker capable of transecting the Arctic ice zones, which will largely contribute to the pan-Arctic international collaborative studies (SAS and DBOs). Furthermore, the icebreaker is to be equipped with a fish-finding echo sounder with advanced onboard instruments capable of withstanding extreme low-temperature conditions; thus, it will contribute to scientific surveys related to the central Arctic Ocean fisheries agreement. To advance Japanese Arctic research in the future, it is necessary to establish a system that can deploy in situ observations (including on ice), manned observation stations, and unmanned observations (AUVs, drones, etc.) using the icebreaker as a platform and to expand observations across the Arctic Ocean by including organized collaboration with other countries.

To understand changes in the Arctic land surface, continuing the long-term observations of terrestrial ecosystems and permafrost in Russia and Alaska by Japanese scientists with international collaborations is necessary. International programs, such as Terrestrial Multidisciplinary distributed Observatories for the Study of Arctic Connections (T-MOSAiC), are essential to connect observations on continents in concentric circles in the longitude direction, and sustainable north-south transects in the latitude direction are also needed. Further development and improvement of polar observation systems are required to complement the information from remote sensing data. Further, it is necessary to promote analysis of wide-area environmental changes through the use of data from multiple satellites, including those equipped with optical and microwave sensors. Natural ecosystems and permafrost processes are interconnected to events of various spatiotemporal scales; hence, they need to be understood using land-surface and ecosystem models constructed at appropriate spatiotemporal scales. In addition, it is necessary to establish a database containing information from land area research and combine it with social, cultural, and economic analyses. Occurrences of land disasters, such as Eurasian and North American wildfires, should be analyzed in depth by combining in situ and satellite observations.

Snow and ice are key components of the Arctic environment. The PALSAR series of Japan, a leading L-band synthetic aperture radar, enables the observations of changes in snow and ice using parameters such as flow rates in glaciers and ice sheets and land subsidence caused by permafrost thawing. Observations of snow and ice using microwave radiometers began in the 1970s, and the AMSR series developed by Japan has been the leading satellite in the world for sea-ice observations since 2002. The melting of snowpacks is primarily controlled by air temperature, solar radiation, and surface albedo. Therefore, quantitative evaluations of surface albedo and its dependence on the snow grain size and light-absorbing impurity concentration are issues for the future studies. To evaluate the impact of impurities on melting, quantification of organic and inorganic materials in snow/ice and their impact on surface albedo are crucial. Particularly in the field of glacial microbes, Japanese researchers are assuming leading roles in the in situ observations and numerical modeling.

Mass loss in the Greenland ice sheets and Arctic glaciers is a dominant factor in the sea level rise in the 21st century. Under the framework of Japanese Arctic research programs (GRENE, ArCS and ArCS II), the long-term monitoring of climatic conditions and in situ studies on ice-sheet surface processes have been performed in northwestern Greenland since 2012. The programs also perform monitoring of glacier mass balance and studies on glacier–ocean interactions in the same area in collaboration with local communities in the Qaanaaq region as well as with international researchers. To accurately understand the mass loss in snow and ice in the Arctic and its global and social consequences, it is important to strengthen the synergy among long-term field observations, satellite remote sensing, and numerical modeling. The efforts for investigating Greenland ice sheets and glaciers using in situ and satellite observations should be applied to sea-ice studies. Sea ice is one of the principal factors that characterize the Arctic climate. Additionally, it is important for the ecosystem and existence of living organisms in the Arctic region and directly impacts human activities, such as ship navigation and fishery. Therefore, sea-ice prediction studies have gained special interest among the various aspects of the Arctic climate research. Knowledge of physical processes, such as waves, snow on sea ice, representation of leads and polynyas and fluxes from there is vital for efficient sea-ice predictions. Feedback between physical and ecosystem processes associated with sea ice could be essential for earth system modeling.

The improved reconstruction of the Northern Hemisphere ice-sheet evolution and reconstruction of the past sea-ice distribution is important to understand the Arctic climate system. Because the Arctic region (land and sea) is rapidly changing, paleoenvironmental analyses with high temporal resolution focused on the near past are greatly needed. Furthermore, it is necessary to plan sampling in the estuaries of large rivers where high sedimentation rates can be expected. Ice core studies have been conducted in the last four decades using several ice cores drilled from the Greenland ice sheet and other Arctic glaciers to reconstruct past climate and atmospheric conditions. Future ice core studies need to propose new processes and mechanisms using new analytical techniques and numerical simulations of Earth's environmental systems and/or to contribute to certain geo-engineering studies. To elucidate polar amplification mechanisms throughout the Earth's history from the process level to climate system point of view, continuous supporting of the international activities of model–model and model–data comparisons is needed.

Japanese researchers can also play a leading role in strategically promoting solid Earth science research in the Artic in this decade. In addition, since the themes listed below can be expected to make a significant contribution from the Japanese research community, the research system for these issues should be established over the next decade.

- Geology: From the early Earth and early life to the Paleozoic Caledonian orogeny, as well as basement rock specimens collected from beneath the Greenland ice sheet will be the main focus as Japan’s strengths in geochronology and isotope geochemistry.

- Marine geophysics: Understanding Cretaceous igneous activity, continental breakup, and seafloor spreading processes is important. Observation programs based on new research vessels in the Arctic and the active use of underwater robot technologies for unmanned exploration and rock sampling are indispensable for understanding the abovementioned topics.

- Geodesy: Monitoring ice-sheet mass balance in global warming urgently requires satellite-based analysis of regional crustal deformation and development of an absolute gravimeter network and high-resolution numerical modeling to reconstruct these observables.

Submitted together with
JCAR (2024b): Executive Summary of Long-term Plan for Arctic Environmental Research.

References:

Japan Consortium for Arctic Environmental Research (2024a). Long-term Plan for Arctic Environmental Research. [in Japanese]

Japan Consortium for Arctic Environmental Research (2024b). Executive Summary of Long-term Plan for Arctic Environmental Research. https://www.jcar.org/e/longterm/