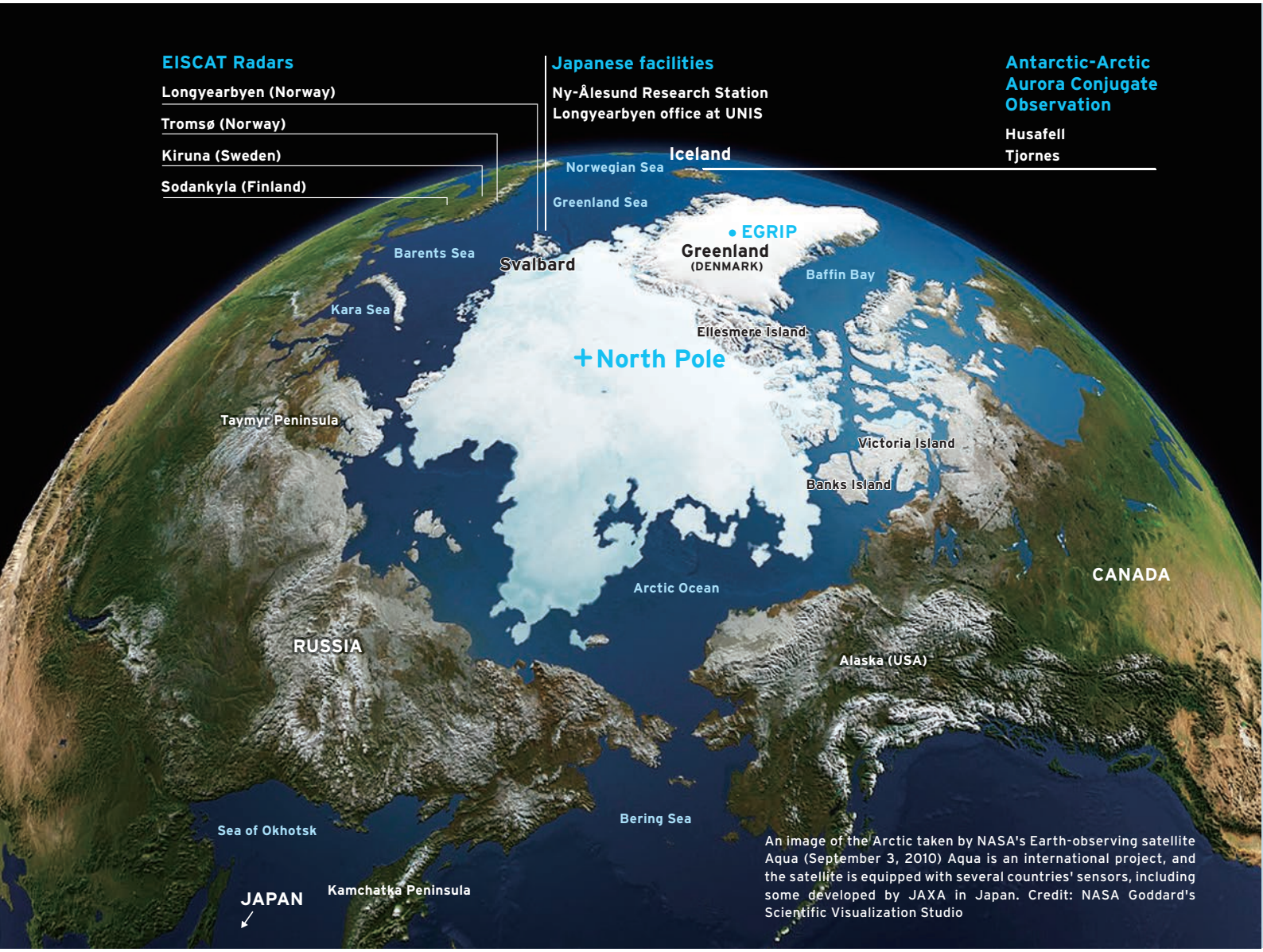
Arctic Research

NiPR
National Institute of Polar Research

Arctic climate is rapidly changing



An image of the Arctic taken by NASA's Earth-observing satellite Aqua (September 3, 2010) Aqua is an international project, and the satellite is equipped with several countries' sensors, including some developed by JAXA in Japan. Credit: NASA Goddard's Scientific Visualization Studio

The Arctic

As of January, 2018

The North Pole refers to a point at 90 degrees north, and the region above 66.5 degrees north latitude is generally called the Arctic Circle. There is no land at the North Pole. The Arctic Ocean, which is ringed by the Eurasian and North American continents and Greenland, covers an area of 14 million km^2, or about the same size as Antarctica. There are many inhabited settlements within the Arctic Circle, and the region has more vegetation than Antarctica. The Arctic sea ice extent in summer tends to shrink. It is about half of that in the 1980s.

Longyearbyen, the biggest town on the island of Spitsbergen in the Svalbard Archipelago, is accessible by commercial air service. The standard route from Japan begins in Narita and includes layovers in Oslo and Tromsø, Norway. The total flight time is about 16 hours.

Polar bear

The polar bear is largest land-based carnivore on the earth. They can grow up to 2 - 2.5 m in length, and males can weigh between 250 and 600 kg, while females can weigh between 150 and 300 kg. Living primarily on the islands of Canada, polar bears can also be found in Greenland, Alaska and Russia in a ring around the Arctic Ocean. The current polar bear population is estimated at 22,000 to 31,000. They live mainly on sea ice and feed chiefly on seals. For this reason, they are considered marine mammals instead of terrestrial ones. Polar bears have been listed in the Red List of Threatened Species (IUCN) since 2006.

Reduction of Arctic ice

Accelerating reduction in sea ice extent, diminishing glaciers, and melting and disintegration of Greenland Ice Sheet are strong concerns not only in terms of Arctic climate change but also global environmental change. Arctic sea ice and snow cover are important components of the Arctic climate system that drives polar amplification through ice-albedo feedback. Sea ice is a fragile component affected by the warming climate, and changes in it transfer anomalous conditions to various areas of the environment, including oceanic processes, marine ecosystem, atmospheric processes, and terrestrial conditions.

The Arctic Ocean is surrounded by the Eurasian Continent, North American Continent, Greenland, and many Arctic islands. It is thus connected directly to human activities in the Arctic countries, and is often the setting for international economic activities.

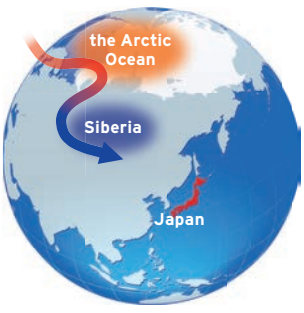
One of the Arctic's important influences on the global environment is sea level rise is accelerated by melting of Greenland Ice Sheet. Recent evaluation shows a strong relationship between Greenland ice disintegration and sea level rise. We started observation on Greenland Ice Sheet to focus the system of Ice Sheet mass change.

Arctic connection to middle latitudes

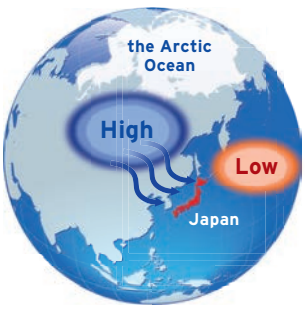
Mid-high latitude atmospheric circulations pass over continents and sub-arctic seas. Circum-Arctic atmospheric circulation is affected by land-sea distribution. The Arctic amplification is a leading mode of atmospheric circulation in the high-middle latitudes in the northern hemisphere. Arctic circulation patterns influence the weather of many countries, including Japan. This phenomenon often determines colder winter anomalies with snow cover and cold air outbursts from Siberia. Anomalous weather influences also terrestrial and marine ecosystems. Observations of snow and ice are substantial for Arctic Climate research.

Arctic amplification and extreme weather conditions

Weather in Japan, which lies between the Arctic and the tropics, can be affected by climate change in the Arctic region. In recent years, sea-ice loss and warmer air from the south have caused extremely high temperatures in the Arctic Ocean, with rainfall occurring even in mid-winter. This condition has coincided with severe winter weather in the mid-latitudes including Japan, Europe and North America. It has been speculated that this "Warm Arctic, Cold Continents" trend pattern is due to sea-ice loss and mid-latitude oceanic changes. Other theories have been advanced as well. At present there are insufficient observation data to scientifically substantiate any of the theories. Continuous observation and data collection are therefore indispensable.



Meandering westerlies are involved in the "Warm Arctic, Cold Continents" trend pattern.



Cold air flows into Japan from the Eurasian continent under a western-high and eastern-low pressure pattern.

Extracting evidence of global climate change from the Arctic atmosphere and ice

Human activities' effect on climate change

We have continually monitored greenhouse gases, such as carbon dioxide and methane, in the Arctic atmosphere since 1991. For more accurate prediction of the climate of the future, we need to know more precisely about the current variability of these gases.

Actually greenhouse gases are increasing by human activities, and thus it is believed that the current global warming is caused by the increase of greenhouse gases. However, atmospheric constituents produced by human activities do not always contribute solely to global warming. Aerosol is one of such constituents.

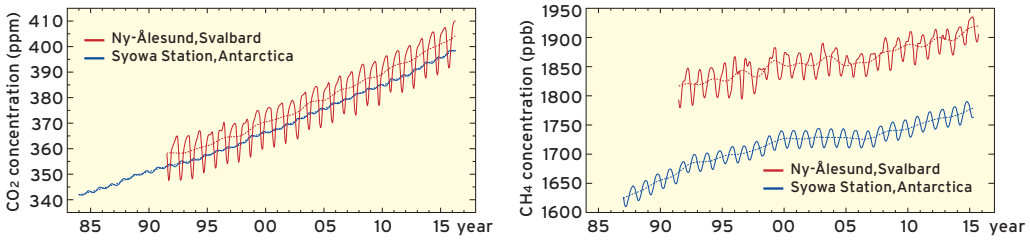
Aerosol consists of liquid-and/or solid-state particulate matters suspended in the atmosphere. Aerosol particles come from not only natural sources but also anthropogenic materials. Aerosol has two important effects in the global climate: a direct effect by reflecting incoming solar radiation, and an indirect effect by modulating cloud reflectance. In general, aerosol has a cooling effect in the atmosphere.

Long-term monitoring of greenhouse gases, aerosols and clouds are essential for elucidating their effects on climate change. Atmospheric observation in the Arctic has just begun in this sense.

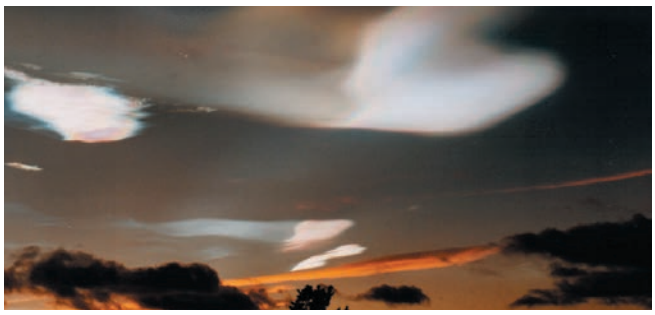
Sky-radiometer for monitoring aerosol optical properties at Ny-Ålesund

Increasing concentrations of greenhouse gases

Monitoring of atmospheric minor constituents has continued in Ny-Ålesund since 1991. In the Arctic region, CO_2 and CH_4 concentrations show clear seasonal cycles under the influence of forests and wetlands in the northern hemisphere. Also seen are secular increases of concentrations in the Arctic and Antarctic regions.



CO_2 (left) and CH_4 (right) concentrations observed at Ny-Ålesund and Syowa Station.



The key role of PSCs in ozone hole formation

Polar stratospheric clouds (PSCs) have been frequently observed in the Arctic as well as Antarctic. PSCs are formed in the stratosphere at an altitude of 15-25 km, which are much higher than usual tropospheric clouds at an altitude of 0-10 km. Although water vapor is very scarce in the stratosphere, it freezes in the very low temperature and creates PSCs. The increase of greenhouse gases is thought to cause stratospheric cooling as well as tropospheric warming. The stratospheric cooling aids in the formation of PSCs. Chemical reactions on the surface of PSCs are thought to promote ozone depletion.

Greenland Ice Sheet: A frozen archive of past climates and environments

An immense ice sheet covers most of Greenland. In recent years, there have been concerns about increased ice loss from the Greenland Ice Sheet and the resultant rise in sea levels. The increase in ice loss is believed to be caused by increased melting and accelerated flow of ice into the ocean, but the specific mechanisms involved have not been identified.

Japan is a member of the East Greenland Ice-core Project (EGRIP) being carried out at the onset of the North East Greenland Ice Stream (NEGIS), Greenland's largest ice stream. Ice core drilling and analysis will allow us to understand ice flow within the NEGIS. It will also provide an opportunity to reconstruct past climates and environments up to the middle of the last glacial period- (50,000 – 60,000 years ago).

By carefully investigating the climate and environment of the early Holocene (current interglacial), which is believed to have been 3°C warmer than the present, it will be possible to estimate the potential decline of the Greenland Ice Sheet in a warmer earth and the impact of such a decline on sea-level rise, as well as predict climate and environmental changes. Ice core analysis will also allow us to assess the possibility of the kind of extreme climate change that occurred in the last glacial period. It is known that there were more than 20 times of abrupt temperature rises by 10°C in just a few decades during the last glacial period.

EGRIP field facility for ice core processing. The white column lying on the table is an ice core.

EGRIP: An international deep ice coring project

EGRIP is a deep ice coring project in East Greenland being carried about by 12 nations including Denmark, Germany, Japan, Norway, the United States, France, Switzerland. Coring began in 2015 and will be continued to the bedrock at a depth of about 2,600 meters. Samples cut from the ice core are distributed to scientists in participating countries for various investigations (stable isotopes of water, greenhouse gases, black carbon, dust, etc.). The results of the analyses will tell us about the climate and environment during the Holocene warm period, which is believed to have been approximately 3°C warmer than the present, as well as the abrupt climate changes in the last glacial period.

EGRIP camp. Researchers from all over the world work together, utilizing the latest technologies to conduct ice core drilling and analyses.

We are studying Arctic ecosystem and its response to climate change

After glaciers retreated, a few plants invade the retreated area.
Vegetation developed over time and animals show up there.

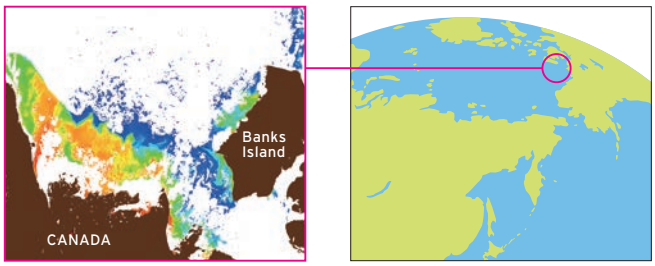
Saxifraga oppositifolia

Salix polaris

Silene acaulis

Plants living in the Arctic

Arctic flora comprises more than 900 vascular plant species, of which two thirds would be endemic species. There are over 100 vascular species in Spitsbergen Island, Svalbard, where NIPR's Arctic station is situated.



Ocean colour satellite image in the coast of Arctic Ocean. A high chlorophyll concentration was observed (>10 mgm^{-3}, orange colored area) by satellite on June 25, 2011.

Phytoplankton in the Arctic Ocean

The Arctic coastal area is one of the most productive phytoplankton regions in the world. Sea ice melt starts from June in the Arctic Ocean. At this time, strong sunlight suddenly penetrates the surface ocean, causing a rapid increase in phytoplankton (called "blooming"). Much of the phytoplankton is grazed upon by zooplankton, and the remainder sinks to the bottom as organic particles. The zooplankton is then preyed upon by pelagic fish and whales, and the particles are consumed by macro fauna in the seafloor. The magnitude of phytoplankton blooming is an important element of the Arctic Ocean ecosystem.

Arctic terrestrial ecosystem's response to climate change

Current climate change predictions indicate that warming will be more pronounced at high latitudes in the Northern Hemisphere. The Arctic terrestrial ecosystem is believed to be extremely susceptible to climate change, and major ecological impacts are expected to appear rapidly. Responses of the ecosystem carbon cycle to climate change are of crucial importance, because of the large carbon stock in Arctic soils and possible feedback effect on global atmospheric CO_2. However, because of the diverse responses of ecosystem components to climate change, overall response of the ecosystem carbon cycle to climate change is difficult to predict. We are investigating the contribution of each ecosystem component to carbon flow, and the response of the components to environmental parameters, as prerequisites for predicting response of the Arctic terrestrial ecosystem to climate change.

Possibility of change: marine ecosystem

Next, we focused on the Arctic marine ecosystem. We studied the long-term changes of coccolithophores (one of the phytoplankton taxa) in the Bering Sea. We found that the coccolithophores drastically increased from the late 1990s due to sea surface water warming. However, the concentration decreased from the late 2000s due to rapid cooling. Thus, climate variability directly affected the ecosystem in the Bering Sea.

Understanding how Arctic predators interact with the environment

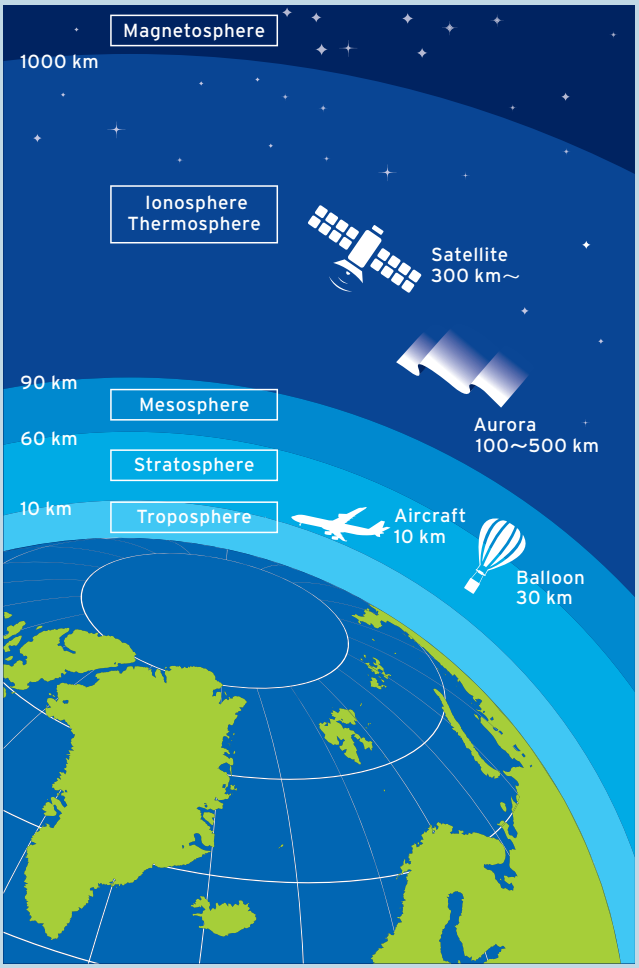
We have been conducting field research to understand how top predators in the Arctic Ocean (such as polar bears, bearded seals, and Greenland sharks) interact with the environment. This research has been made possible by our development of tiny animal-attached tags that record various parameters (e.g., depth, acceleration, and position) at a minute scale.

Development of swimming skill in bearded seal pups

Seals are major top predators and play important ecological roles in the Arctic Ocean. They are born on land or ice and must acquire the diving and swimming skills required to forage and avoid predators during their early lives. We recorded the depth, swim speed, and acceleration of bearded seal pups (aged 0-17 days) by using animal-attached tags in Svalbard, Norway. The results showed that these animals rapidly increase their swim speed and distance using a stroke cycle with age, with older pups incorporating more stroke-and-glide swimming.

A bearded seal on the ice

Quest for climate change mechanism through the Arctic upper-middle atmospheric observations



Transition between Earth and Space: The upper and middle atmosphere

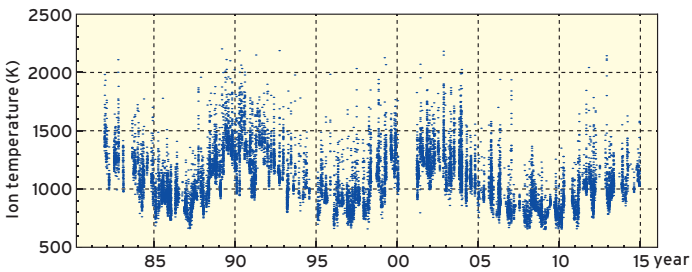
The mesosphere, thermosphere and ionosphere spreading over the troposphere and stratosphere are invisible shields protecting all life on the Earth from harsh electromagnetic radiation and high-energy particles from the Sun. Recent studies made it clear that these regions are playing an important role in global circulation and climate change with upward disturbances from the lower atmosphere/ground and downward energy input from space. The National Institute of Polar Research (NIPR) is intensively promoting observations and research in these regions in collaboration with foreign and domestic research institutes.

EISCAT Radar: The most powerful facility for sounding the upper atmosphere

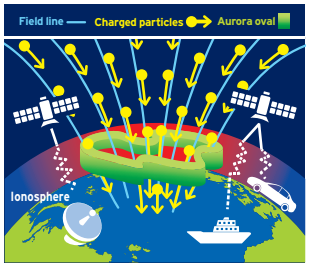
The European Incoherent Scatter (EISCAT) radar is one of the most powerful facilities for sounding the

Long-term variations of the polar upper atmosphere

The temperature of the upper atmosphere is affected by variations in solar EUV and X-ray radiation. The thermospheric temperature under high solar activities (1989 - 1992 and 2000 - 2003) is about 500 K higher than that under low solar activities. The temperature and density in the upper atmosphere are also influenced by the lower atmosphere and electromagnetic and particle energies from the magnetosphere. The EISCAT radar has continued to obtain upper atmospheric parameters since 1981, and contributed to study on long-term variations of the upper atmosphere in the polar regions.



Time variation of ion temperature at an altitude of 300km over 34years as measured with the EISCAT Tromsø UHF radar



Modern infrastructure affected by space weather

"Space Weather" affecting our daily lives

Auroras are excited by charged particles coming from the solar wind and the Earth's magnetosphere which finally collide with the polar atmosphere. We can see bright and active auroras when solar activity is particularly high. Solar activity has a strong influence on not only auroral activity but also the upper atmosphere. Severe magnetic storms frequently cause satellite malfunctions and large induced currents in the ground-level power grid. In order to reduce these risks, "space weather" is being studied to improve numerical model through real-time monitoring of solar activity. The polar upper atmosphere, where many commercial satellites are orbiting, is considered as a part of the humanosphere. Science data from EISCAT radars are fully utilized for maintaining and monitoring the humanosphere.

upper atmosphere. It enables us to measure precisely density, temperature and velocity in the atmosphere from an altitude of 60 km up to higher than 1,000 km by analyzing integrated faint radar signals scattered from electrons in the upper atmosphere. Affiliated in the EISCAT Scientific association as the representative of Japan since 1996, NIPR has contributed to cutting edge research using EISCAT radars.

The EISCAT radars are deployed in Tromsø (Norway), Kiruna (Sweden), Sodankyla (Finland) and Longyearbyen (Svalbard). The EISCAT_3D project, which aims major upgrade of the existing EISCAT mainland radars with cutting-edge multi-static phased array is now in progress.


EISCAT Svalbard radar

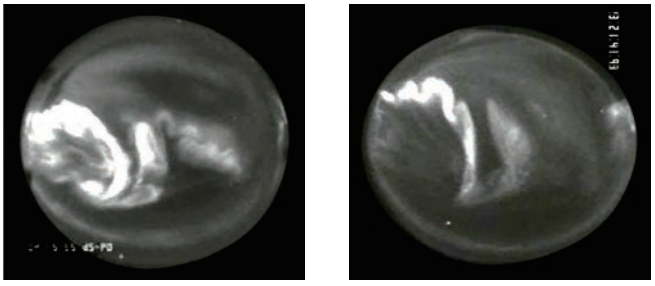

Left top: Tromsø optical observation facility / Right top: Longyearbyen optical observation facility / Left below: Iceland optical instruments Right below: Longyearbyen meteor radar

Integrated ground-based observation of the Arctic upper atmosphere

NIPR has made integrated ground-based observations based on EISCAT radars in Svalbard and northern Scandinavia, including meteor radars and aurora/airglow imagers to study the mesosphere, lower thermosphere and upper atmosphere. With the unique merit of the geomagnetic conjugate relationship between Syowa Station and Iceland, NIPR has contributed to conjugate auroral study with integrated observations using riometers, magnetometers and optical aurora instruments.

Conjugate observation of auroras

Auroras are commonly observed within the "aurora oval", a doughnut-shaped area in both polar regions. Aurora particles are thought to precipitate into the polar regions along geomagnetic field lines. If this is the case, is it possible to observe mirror-image auroras in both polar regions? In order to answer this question, NIPR has conducted simultaneous auroral observations in Iceland and Syowa Station, Antarctica, which are tied by the same geomagnetic field line. It has been found that the patterns of slow and steady auroras are similar each other, but the conjugacy becomes poor for bright and active auroras in both hemispheres.


Conjugate aurora pictures in Iceland(Left) and Syowa Station(Right) at same time

International collaborations in the Arctic sciences for a sustainable earth environment

Ny-Ålesund is an international research village.

Svalbard Treaty

In 1920, immediately after World War I, a multinational treaty was concluded regarding the administration of the Svalbard Archipelago. Under this treaty, Norway was granted full sovereignty over Svalbard, but the signatories were permitted to engage freely in activities on the islands. The main points of the treaty are as follows:

- Article 1: Norway has sovereignty over the Svalbard Archipelago.
- Article 2: Signatories to the treaty are granted the same fishing and hunting rights enjoyed by Norway in the Svalbard Archipelago.
- Article 3: The people of the signatory nations are granted the same rights as Norwegian nationals to access the Svalbard Archipelago and to stay and conduct activities there.
- Article 9: No country, including Norway, can establish military bases on the islands.

In accordance with this treaty, the Svalbard Archipelago has been opened to the scientists of the world as a base for polar research.

The R. Amundsen Monument welcomes visitors to Ny-Ålesund

Ny-Ålesund Research Station

Ny-Ålesund is located on the island of Spitsbergen in the Svalbard Archipelago, which is about 1,000 km north-northwest of Tromsø in northern Norway. The Rabben station, familiar to all Japanese researchers for about 30 years, has been replaced by the new research station (Terrestrial science building) being completed at the heart of the research village in April 2019. There are dedicated space for Japan (bed rooms, living room, observation room, dry laboratory, equipment room, storage) and some facilities shared with other countries in the new research station.

International collaborations

The Arctic region is undergoing a rapid change in climate, and the effects of this are evident in various regions and countries. Japan is working with Arctic countries to study this problem. Japan aims at contribution to Arctic research in the international partnerships with the Arctic community. The Arctic Environment Research Center (AERC) was established in June 1990 at the National Institute of Polar Research to promote sea ice study, oceanography, marine ecology, terrestrial ecology, atmospheric science, and upper atmospheric science.

The International Arctic Science Committee (IASC) has established in 1990 by eight Arctic countries. Japan joined IASC in 1991 when IASC invited the participation of countries contributing to Arctic study. IASC has five working groups (WG): Atmosphere WG, Cryosphere WG, Terrestrial WG, Marine WG and Social & Human WG. Japan sends personnel to IASC's WGs, the Forum of Arctic Operators (FARO), and Ny-Ålesund Science Managers Committee (NySMAC).

Japanese observatory in the Arctic

AERC manages an Arctic observatory called the Ny-Ålesund station and an office at the University Centre in Svalbard (UNIS) in Longyearbyen, Spitsbergen Island. Ny-Ålesund is a unique observation site that features an international observing system operated by 11 countries. Japan supports the international coordination of this system. AERC assists researchers visiting this area.

AERC also supports cooperative and international research at the research and/or observation facilities in other Arctic regions, such as Alaska, northern Canada, Russia, and Iceland.

Svalbard Integrated Arctic Earth Observing System (SIOS) project

In 2018, the SIOS project has officially started to strengthen monitoring and researches on global-scale climate changes in Svalbard Archipelago and surrounding sea areas by utilizing member countries' observation system more integratedly. NIPR has affiliated in the SIOS consortium as a founding member.

Two flagship projects encouraging the study on the Arctic – ArCS and J-ARC Net)

[ArCS: Arctic Challenge for Sustainability]
The Arctic research project, called ArCS, is a flagship project funded by the Ministry of Education, Culture, Sports, Science and Technology, which is carried out from September 2015 to March 2020. NIPR plays a core role in ArCS as the principal institute. The project aims to elucidate the changes in the climate and environment, clarify their effects on human society, and provide accurate projections and environmental assessments for internal and external stakeholders so that they can make appropriate decisions on the sustainable development of the Arctic region.
https://www.arcs-pro.jp/en/

[Japan Arctic Research Network Center (J-ARC Net)]
AERC is working with the Arctic Research Center at Hokkaido University and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) as partners of J-ARC Net. Established in April 2016, J-ARC Net seeks to strengthen interdisciplinary studies on the environment and human activity, as well as to find approaches for solving problems through the collaborative efforts of industry, government, and academia. AERC also provides facilities for researchers.
http://j-arcnet.arc.hokudai.ac.jp/?lang=en


Cassiope tetragona


Papaver radicatum


Vaccinium vitis-idaea


Polygonum viviparum


Melandrium apetalum


Dryas octopetala


Huperzia arctica


Splachnum ampullaceum


Eriophorum scheuchzeri

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