Appendix I: Indian Arctic Programme

India's Arctic program aims to contribute to the development, consolidation, and dissemination of the current understanding of climate change, its impacts, and adaptations in the Norwegian Arctic, Svalbard. The Indian scientific endeavors in the Arctic realm commenced when a five-member scientific team visited Ny-Ålesund, Svalbard archipelago of Norway, during the summer of 2007.

Appendix II: Study area:

Svalbard: Ny-Ålesund, Broggerhalvoya, Kongsfjorden and Krossfjorden

Background

Ny-Ålesund, located at 79°N, is the world's northernmost year-round research base that provides unique access to a natural polar laboratory. As the Arctic is warming four times as fast as the rest of the globe, and the Svalbard region is warming fastest within the Arctic, Ny-Ålesund Research Station in the north-western part of Spitsbergen, Svalbard, is a unique platform for climate change studies, and is a key location for natural science research and environmental monitoring in the high Arctic. Though remote, it is easily accessible and offers extensive research infrastructure.

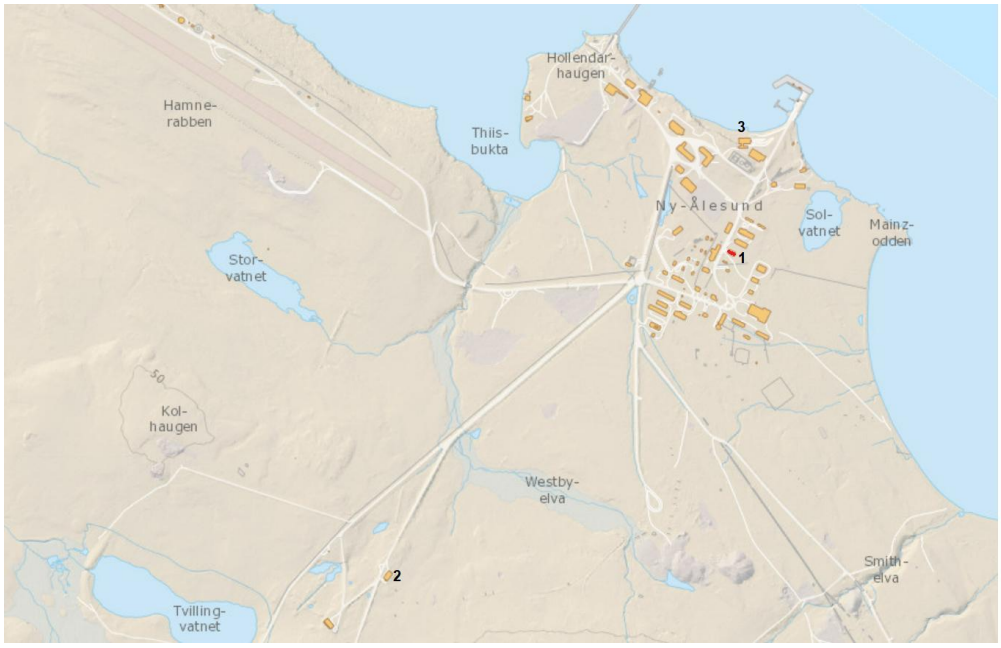
Svalbard: Svalbard (meaning "Cold Coast") archipelago, part of Norway, located in the Arctic Ocean well north of the Arctic Circle. The islands lie between longitude 10° and 35° E and latitude 74° and 81° N, about 580 miles (930 km) north of Tromsø, Norway. The archipelago is composed of nine main islands: Spitsbergen (formerly West Spitsbergen), North East Land, Edge Island, Barents Island, Prins Karls Foreland, Kvit Island (Gilles Land), Kong Karls Land (Wiche Islands), Bjørn (Bear) Island, and Hopen. The total area of Svalbard is 24,209 square miles (62,700 square km). Spitsbergen, with an area of 15,075 square miles, is the largest island of Svalbard.

Ny-Ålesund: Ny-Ålesund located at 79°N, is the world's northernmost year-round research base that provides unique access to a natural polar laboratory. India has a research station in Ny-Ålesund named 'Himadri'

Brøggerhalvøya: Brøggerhalvøya is a peninsula in Oscar II Land on the west coast of the island of Spitsbergen in Svalbard. It is 20 kilometers (12 mi) long and 10 kilometers (6.2 mi) wide and borders Kongsfjorden to the north and Forlandsundet to the west. Ny-Ålesund, the world's northernmost permanent settlement, is located on the peninsula.

Kongsfjorden: Kongsfjorden is an Arctic fjord located in the Svalbard archipelago. Its hydrography is influenced by the warm and saline Atlantic Water (AW) in the West Spitsbergen Current and the cold and fresh Polar Water circulating on the shelf. Ny-Ålesund, the research base, is located on the southern shore of Kongsfjorden.

Krossfjorden: Krossfjorden is a fjord adjacent to Kongsfjorden. Both fjords share a common mouth. However, Krossjorden is inside a protected nature park, and therefore special permissions may be required.



1- Himadri
2- Gruvabadat Atmospheric Laboratory
3- Marine Lab

Ny-Ålesund is situated on the southern shore of Kongsfjorden, one of the many deep and wide fjords on Spitsbergen's west coast. Its geographic position, varied topography, and prolific representation of bird, animal, and plant life make it ideal for research. The ice-capped interior is dotted with the pointed nunataks, which gave the island its name. The steep mountains along the coastal fringe are interspersed with glaciers, some of which terminate in the sea. The coastline (45 km around Broggerhalvoya) has a starflat (snow-free mid-June to September) with tundra, alluvial plain, and braided streams. Kongsfjorden is approximately 28 kilometers long.

Climate

A northern branch of the Gulf Stream produces a climate on Spitsbergen's west coast which is unusually "warm" for its extreme northerly position. The West is mostly free of sea ice during the summer months. The north and east have colder temperatures and are choked with fast or pack ice for most of the year.

Ny-Ålesund	78° 55'N 11° 56'E
Period of midnight sun	21 April to 21 August
Period of polar night	28 October to 14 February
Mean July temperature	+5.0°C
Mean February temp.	-14.0°C
Annual precipitation	371 mm

Reference: Ny Ålesund Safety Guide, 2nd Edition

Appendix III: Himadri and Gruvabadet Atmospheric Laboratory

HIMADRI - 'the abode of snow' is India's research station located at the International Arctic Research base, NyÅlesund, Svalbard. The station was inaugurated on the 1st July 2008. The station caters to the sustained interest of Indian researchers to pursue scientific studies in the Arctic. The 'Himadri' consists of office space, a preparatory laboratory, and accommodation for 8 researchers. The office space has computer systems and an internet facility. Bedding in the bedrooms is provided by Kings Bay AS.

Gruvebadat Atmospheric Laboratory is an atmospheric laboratory and observatory located midway between Ny-Ålesund, the Zeppelin observatory, and the Climate Change Tower. India has a dedicated portion of the lab to install its own instruments. Currently, the lab has a microwave radiometer profiler, micro rain radar, ceilometer, nephelometer, aethalometer, aerodynamic particle sizer, net radiometer, and sun photometer in operation.

Appendix IV: Facilities provided by Kings Bay AS

1. Marine Laboratory

The Kings Bay Marine Laboratory in Ny-Ålesund, owned and managed by Kings Bay AS, is the first common research infrastructure in Ny-Ålesund. It was officially opened 1 June 2005. It is the northernmost experimental laboratory for research in marine ecology, physiology, and biochemistry, as well as physical sciences like oceanography, marine geology, and ice physics. The laboratory is located right on a beach with easy access to boats. It contains smaller rooms with system-controlled experimental variables like air and seawater temperature. It is also appropriate for experiments under ambient conditions.

2. Veksthuset Laboratory

The terrestrial laboratory Veksthuset is located in the middle of Ny-Ålesund and includes dry and semi-wet lab facilities.

3. MS Teisten

MS Teisten is a small work boat operated by Kings Bay AS. The boat is 31 feet long and equipped to do smaller scientific operations, transportation, and survey in Kongsfjorden and

Krossfjorden. Safety equipment is available on board (life raft, life belts, and survival suits). For scientific work, the maximum number of passengers on board is restricted to four.

In the Polar winter, the MS Teisten availability is limited, and the boat can only cover the coastal area. The following map shows the region covered by the boat during the polar winter

Due to weather and rescue conditions, Boat MS Tiesten usually only operates in the marked region during the polar winter season.

Annexure V: Resource websites and links to know the study area and ongoing research

Research in Svalbard (RiS): https://www.researchinsvalbard.no/

The Research in Svalbard database (RiS) contains information about research and monitoring projects in Svalbard and surrounding waters. The portal is used by registered users to submit applications and reports to the Governor of Svalbard for research activities, and to book services at the Ny-Ålesund Research Station.

The portal contains the research strategy for Svalbard and Ny-Ålesund, which will help you make the proposal more suitable for the study area. The portal also contains guidelines for researchers coming to Svalbard and Ny-Ålesund Research Station, which will be useful both before and after the proposal is approved.

Svalbard Integrated Arctic Earth Observing System: https://www.sios-svalbard.org/

SIOS is a regional observing system for long-term measurements in and around Svalbard addressing Earth System Science questions. SIOS integrates the existing distributed observational infrastructure and generates added value for all partners beyond what their individual capacities can provide.

SIOS brings observations together into a coherent and integrated observational programme that will be sustained over a long period. Within SIOS, researchers can cooperate to access instruments, acquire data, and address questions that would not be practical or cost-effective for a single institution or nation alone.

NCPOR is a member institution of SIOS.

Appendix VI: Ongoing long-term projects in the Arctic

1. Long-term monitoring of Kongsfjorden for climate change studies

The Arctic Ocean once believed to be remote as well as pristine, is now one of the fastest warming regions, and the pace/magnitude of environmental change is greater in the Arctic than at any other location on Earth. Moreover, the ocean and sea ice in the Arctic are a crucial part of the global climate machinery, influencing atmospheric and oceanographic processes, and biogeochemical cycles beyond the Arctic region. Over the last several decades, there have been numerous scientific programs mounted in the Arctic. Nevertheless, there still exist critical knowledge gaps that need to be addressed on priority considering the fast pace of events that happen far north. The Arctic fjords, are vital systems in the Arctic hydrographical network and serve as pulse points to measure the cause and effect of environmental change, may it be fuelled by local disturbances or global processes. Considering the imperative need to monitor the fjords, Indian researchers have been conducting systematic measurements with respect to the hydrography of Kongsfjorden, an Arctic fjord since 2011. The Kongsfjorden located on the west coast of Svalbard that is directly influenced by intrusion of waters from the Arctic and Atlantic along with glacial melt. Preliminary assessment of hydrographical data

suggests that monitoring should be continued with higher temporal resolution. A comprehensive science plan has been prepared with identified long-term and short-term objectives that would yield a better understanding of the dynamics and functioning of the Arctic fjords from regional and global perspectives.

Long-term objectives:

1. The variability in the Arctic/Atlantic climate signal by understanding the interaction between the freshwater from the glacial run-off and Atlantic water from the west Spitsbergen current.
2. Climate-influenced variability in the food web structure and carbon dynamics.
3. Climate-modulated variability in the transport and fate of pollutants.
4. Arctic fjords as a highly sensitive indicator of environmental health.

Short-term objectives:

1. High-frequency fjord-atmospheric interactions and their impacts
2. Triggering mechanism for phytoplankton blooms, carbon sequestration, and mineralization.
3. Seasonal perspectives in food web structure.
4. Elemental biogeochemical cycles and processes.
5. Threshold limits of environmentally sensitive chemical moieties.
6. Functional taxonomic diversity of microbes

2. Precipitation, atmospheric aerosols, and its characterization, as well as the role of aerosols/precursor gases in direct radiative forcing over Arctic region at Ny-Ålesund

Precipitation in the form of snowfall and rainfall is an important part of the hydrological system and modulates the energy and water cycle, ecosystem and also has large socio-economic impacts. Though caused by regional processes mainly, knowledge of precipitation and its underlying processes, its high temporal and spatial variation, can provide important leads to global energy and water cycle studies. The freshwater input through precipitation in the glaciers and ice caps and its impact on their mass balance is an important issue to be addressed. Unlike the rest of the globe, polar precipitation is shallow and of low intensity, mostly dominated by solid precipitation. Small changes in the atmospheric parameters can significantly influence the precipitation process. Besides, under the rapid and most significant impacts of global warming that the Arctic is exhibiting, quantification of changes in precipitation rate and its underlying processes, and precipitation characteristics are some of the striking issues that are to be addressed for better and more accurate prediction of the future climate. In order to achieve this goal, a Micro Rain Radar was installed at Himadri, which collects precipitation characteristics at 1 minute intervals and will help to understand the high latitude precipitation characteristics. Combining this information with an accumulation rate will give the information of falling precipitation. The instrument is switched on for continuous data collection and can be accessed from NCPOR.

Fig.1: The geographic position of Ny- Ålesund (79°N, 12°E, 8 m amsl) in the Arctic (left panels), along with the atmospheric BC observatory at Gruvebadet (top-right) in Ny-Ålesund and the surrounding snow sampling locations at the bottom.

3. Aerosols projects

Atmospheric aerosols influence regional and global climate through direct and indirect processes. While polluted continental locations are more prone to drastic changes in anthropogenic activities, the far remote Arctic, Antarctic, and high altitude Himalayas are also not free from the dramatic influence of these suspended particulates, primarily through long-range transport from source regions outside these regions. The transport of aerosols from low latitude regions to the Arctic atmosphere and subsequent deposition in Arctic snow/ glaciers and ice sheets has been a major scientific concern in recent years. In addition, the Arctic is considered as a net sink for black carbon (deposition > emission). Viewed in the above backdrop, atmospheric aerosol measurements have been carried out at the Norwegian Arctic location Ny-Ålesund since 2010, emphasizing on scattering and absorption properties of aerosols, their physical dimensions (e.g., mass concentration, size distributions etc.), in addition to the columnar optical properties.

The impact of atmospheric warming due to the presence of BC on the regional climate and hydrological cycles is an increasing concern of scientific and social importance. At the same

time, the deposition of BC on highly reflecting surface (like snow or ice) exacerbate warming and glacier/snow melting due to the absorption of more sunlight, thus reducing the surface Albedo. Hence the field experiment initiated during the 2013-14 expeditions had simultaneous measurement of Black Carbon (BC or soot) aerosols both in the atmosphere and snow surface medium.

4. **Bacterial community dynamics in the Arctic ecosystem**

Global warming is affecting all regions of the world, especially the Arctic is warming at an alarming rate that is causing glacier melting as well as the decline in the sea-ice cover. The declining sea ice cover has led to the expansion of macroalgal beds with associated fauna, the release of trapped manmade particulates (microplastics), and increased stratification of the water column. The glacial input of sediments and terrigenous organic Carbon into the fjord and Open Ocean could potentially impact the biogeochemical processes. The pronounced seasonal variations in sunlight, glacier melt, and sea ice cover influence the downward export of biogenic matter. Besides, the intrusion of warm and saline Atlantic water and longer glacier melt periods are expected to affect the magnitude and composition of export fluxes in the high Arctic Fjords such as Kongsfjorden. However, the effects of these warming-induced variations on prokaryotic (bacteria and archaea) communities are not that well understood. Although some studies have examined bacterial community dynamics as a function of environmental variables to get a general conspectus on how Arctic bacterial communities will respond to these climate change-induced variations warrant further studies. Therefore, we intend to expand our knowledge of microbial community dynamics and their responses to climate change-induced variations, such as increased macroalgal biomass, and Atlantic water intrusion, to better understand their consequences on the climatic-feedback mechanism and biogeochemical cycles. The main objectives of this ongoing project are to 1) evaluate the impact of macroalgal forest on the water column and benthic processes in Kongsfjorden; 2) investigate the effect of kelp detritus on the prokaryotic community structure and metabolism, and 3) to estimate the rates of polysaccharide degradation on the biogenic particles within the macroalgal forests

5. **Environmental studies:**

- Monitoring emerging contaminants, toxic metals, and persistent organic pollutants in Kongsfjorden and lakes around Ny-Ålesund
- Investigating microplastic pollution in Kongsfjorden and Krossfjorden