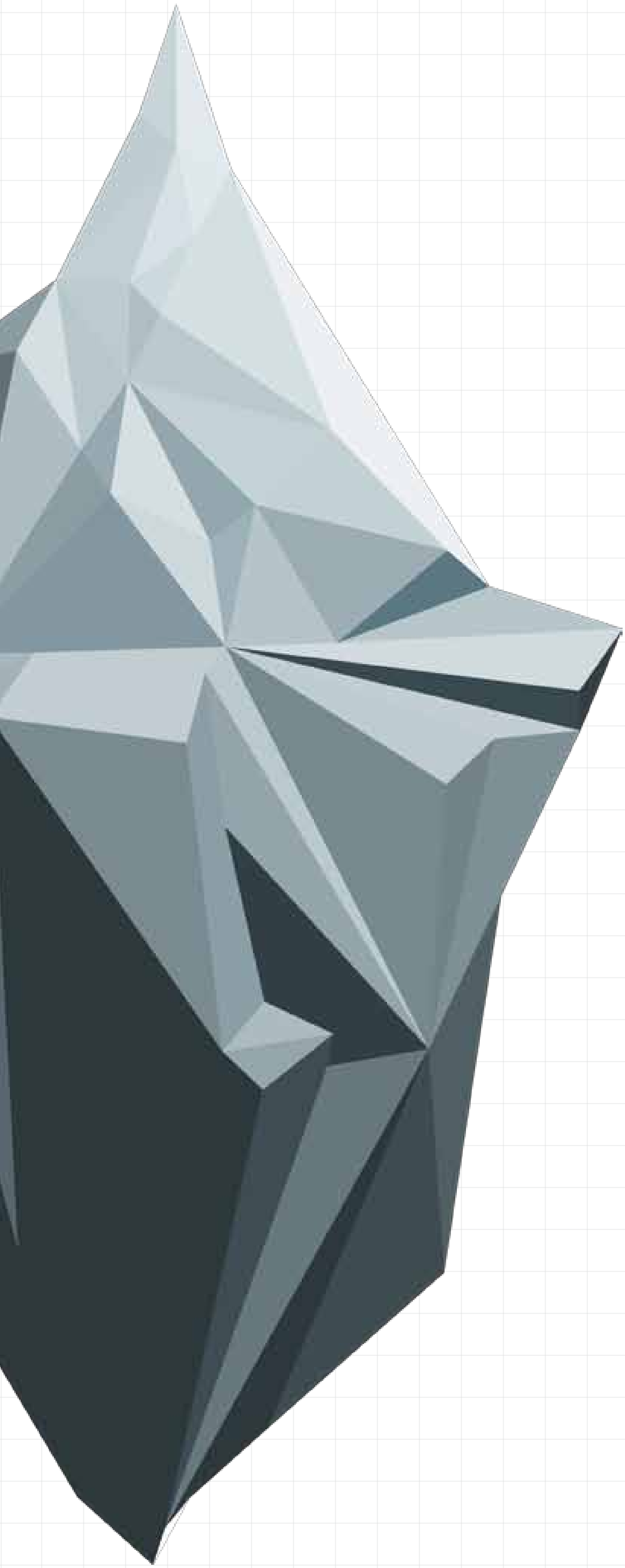

The Future of Arctic Ice

An Indo-Pacific Connect

A SYNOPSIS OF SaGAA 7
RECOMMENDATIONS FOR ACTION

The Report has been compiled from the proceedings of SaGAA 7 Conference, held on 27-28 April 2023 at New Delhi. The speakers of SaGAA 7 are cited in this document and provide for the findings of this Report in a thematic chapterization.

The biographies of speakers are available at: https://www.saghaa.org/sagaa7.php
The abstracts of the presentations are available at: https://www.saghaa.org/sagaa7.php
The programme schedule is available at: https://www.saghaa.org/sagaa7.php
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Recordings of the Conference can be accessed at GnYTV on Youtube.

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डॉ० जितेन्द्र सिंह
राज्य मंत्री (स्वतंत्र प्रभार),
विज्ञान एवं प्रौधोगिकी मंत्रालय;
राज्य मंत्री (स्वतंत्र प्रभार) पृथ्वी विज्ञान मंत्रालय;
राज्य मंत्री, प्रधान मंत्री कार्यालय;
राज्य मंत्री कार्मिक, लोक शिकायत एवं पेंशन मंत्रालय;
राज्य मंत्री परमाणु ऊर्जा विभाग तथा
राज्य मंत्री अंतरिक्ष विभाग
भारत सरकार

सत्यमेव जयते

Dr. JITENDRA SINGH
Minister of State (Independent Charge)
of the Ministry of Science and Technology;
Minister of State (Independent Charge)
of the Ministry of Earth Sciences;
Minister of State in the Prime Minister's Office;
Minister of State in the Ministry of Personnel,
Public Grievances and Pensions;
Minister of State in the Department of Atomic Energy and
Minister of State in the Department of Space
Government of India

MESSAGE

The unprecedented increase in natural hazards in recent years, the retreating of almost all the glaciers world over, and depleting Arctic sea ice are indications of the worsening scenario of global climate change. Antarctica, the storehouse of millions of year-old ice, is reeling under this impact. The warming climate is resulting in a ten-fold increase in the loss of ice shelves around the continent, which provide a much-needed buttress to the continental ice and reduce the latter's slide to the Southern Ocean.

Indian scientists have been working relentlessly in both the Arctic and Antarctic Polar Regions for several decades in tandem with the international community to decipher the complex land-sea-ice interaction in the coupled system. A robust model that establishes the teleconnections between Polar Regions and the Indian Summer Monsoon is underway and will usher in an era of nuanced understanding in monsoon sciences.

The enactment of the Indian Antarctic Act- 2022 and the issuance of the document on Arctic Policy and the Deep Ocean Mission recently demonstrates India's priority for protecting the fragile environment of the Polar Regions and the oceans surrounding it. India has a large pool of scientists engaged in research in various scientific domains in Polar Regions. I am happy to note that several members from various institutes are assembling shortly in New Delhi to discuss the scientific and geopolitical issues about the Arctic and the Antarctic, as also the impact on the Indo-Pacific Region as a consequence of the likelihood of opening the Northern Sea Route.

I wish the Conference great success.

(Dr. Jitendra Singh)
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The strength of SaGAA lies in the high-level experts who work in distant glaciers and mountains of the Arctic, Antarctic and the Himalaya, and contribute freely to the SaGAA forum; Chandratal, Himalaya.

Preface

India's augmented scientific capacity places an indelible mark on the polar realms, proving to the world that we can easily engage in cutting-edge science. Global changes are likely to affect our populous coasts, our icy mountains, and more–not to mention the need to be in the reckoning in these distant realms. Science does not happen in isolation; as far as the Polar Regions are concerned, an understanding of science is the ticket to an exclusive close-knit club.

It is against this backdrop that a one-of-a-kind platform for the Polar Regions, SaGAA (an acronym for Science and Geopolitics of the Arctic and the Antarctic) was conceived in 2011 that would not only talk about science but also geopolitics to assist India in building robust policies dedicated to the Poles. The mandate of SaGAA is to not only involve policy makers and scientists but also to reach out to civil society and open our arms to scholars from universities to interest them in future polar research endeavours.

Today SaGAA is India's only think tank that has been working on Polar and cryospheric issues for over a decade and a half now. Here is a brief summary of our work. SaGAA has organized seven conferences to date, with over 2400 persons spanning over a hundred organizations from India and abroad working in scientific, policy bodies, think tanks and industry and attending the event, in-person. The strength of SaGAA, therefore, lies in what we call the 'SaGAA people' – the high-level experts. Prominent persons assiduously attend and share our vision, contributing emphatically and freely to the discourse. The success of SaGAA, therefore, is what it draws from its myriad stakeholders, providing a body of recommendations that serves as a well-informed illuminated path. SaGAA has showcased more than 278 presentations, 47 on the Arctic and 77 on the Antarctic (124 in all), 68 on the Indian Himalayan Region, 32 on policy matters and 56 on allied areas of oceans, monsoons and adaptations. We have published five issues of G'nY, an environment and development magazine, on the Polar discourse, and have also brought into the global knowledge commons three books by reputed publishers and contributed to policy interventions, such as India's Arctic Policy.

SaGAA is an observer in UK Parliament's Polar APPG and invitee in events such as the Arctic Circle and many other well-accepted platforms such as ICWA, IIC, NMF, SAMA, Sushma Swaraj Institute of Foreign Relations, SCAR-APECS, UGC, and NIAS where Members of SaGAA have delivered talks on polar issues.

SaGAA interfaces two extremely diverse subject areas into one. Scientists, for instance, can unwittingly project their subject bias, while geopoliticians are fairly disinterested in science, analysing global relations in relative isolation as far as the Polar science agenda is concerned. The bringing together of the two is, therefore, unique and unparalleled in India. This convergence in SaGAA is imperative to better India's future endeavours in the Polar Regions.

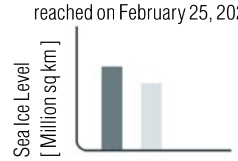
SaGAA plays an important role in the area of policy and consolidation of science and technology developments in the Arctic and Antarctic. SaGAA sustains itself through the support of MoES and its subsidiary institutes, NSCS, DST and MEA. While it is important to recognize its status as an independent think-tank for providing a platform for frank and free discussions on Polar issues, it is also necessary to keep this platform robust through long-term institutional support.

Changing Poles

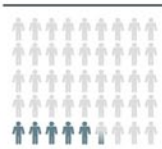
Climate change is altering the physical and living environment of the Poles, but opening up opportunities too.

ARCTIC

Sea ice around Antarctica reached its lowest extent on February 21, 2023, at 1.79 million sq km. That is 0.13 million sq km below the previous record-low reached on February 25, 2022.



In the recent low Antarctic Sea ice records, the sea level pressure pattern anomalies contributed to the maximum sea ice recession in the Ross Sea, western Weddell Sea, and the Indian Ocean while advancing in the Bellingshausen Sea.



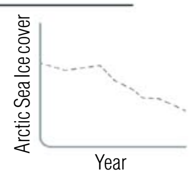
Antarctica is one of the major contributor to future sea level rise, and by the year 2100 almost 12% of India's population would be impacted significantly from the sea level rise.

The Arctic Sea ice has thinned, with loss of multiyear sea ice amounting to nearly 90% loss of five-year-old ice.

The Arctic holds an estimated 90 billion barrels (13%) of undiscovered oil and 30% of undiscovered natural gas.

Between 1979 and 2018 the rate of reduction in Arctic Sea ice is 12.8 ± 2.3% per decade during the month of September.

The trends in the Arctic sea ice cover in March show the decline of about 2.6% per decade.

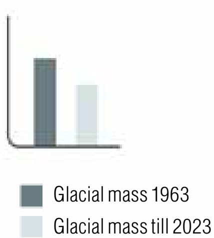


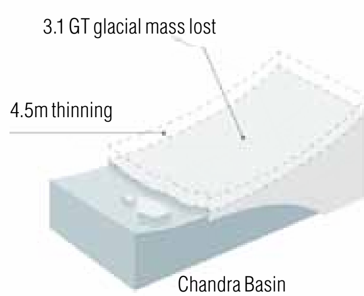
ANTARCTIC

Himalayan Environment

Climate change is causing the Himalayan glaciers to melt, its rainfall patterns to change and its weather conditions to become unpredictable.

25 per cent of the glacial mass has been lost in Kashmir Himalayas during the last 60 years.

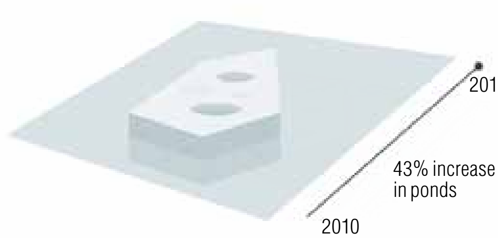




Chandra Basin has lost 3.1 Giga tonnes of its glacial mass with thinning of 4.5 m during the last seven years.

Proglacial lake dynamics in Tenbawa Kangse (1988-2022)
Total area of Tenbawa Kangse proglacial lake between 1998-2022 has increased by 170%. Its total volume increased from 1.36 in 1988 to 5.59 $m^3 \times 10^6$ in 2022.

Gangotri Glacier, Uttarakhand
Ponds on the Gangotri glacier represent an overall growth of 43% during 2000–2018. Rising rates of surface and air temperatures and total annual precipitation near the supra-glacial ponds from previous to recent decades are leading to significant pond growth observed in the recent decade (2010–2018).

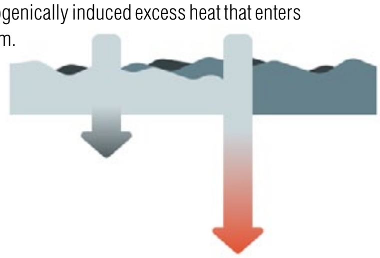


Oceans in Flux

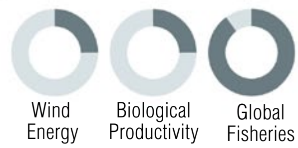
Variations in ocean temperatures brought about by climate change are leading to unprecedented alterations.

Oceans are the driving force for the Indian monsoon and the origin for disasters such as cyclones, tsunami, storm surges and sea-level rise.

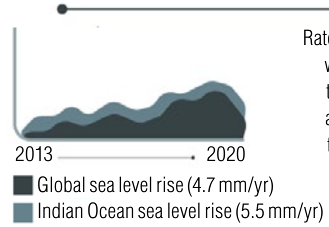
Oceans absorb about 30% of carbon dioxide and 90% of the anthropogenically induced excess heat that enters the earth system.



OCEAN ECONOMY

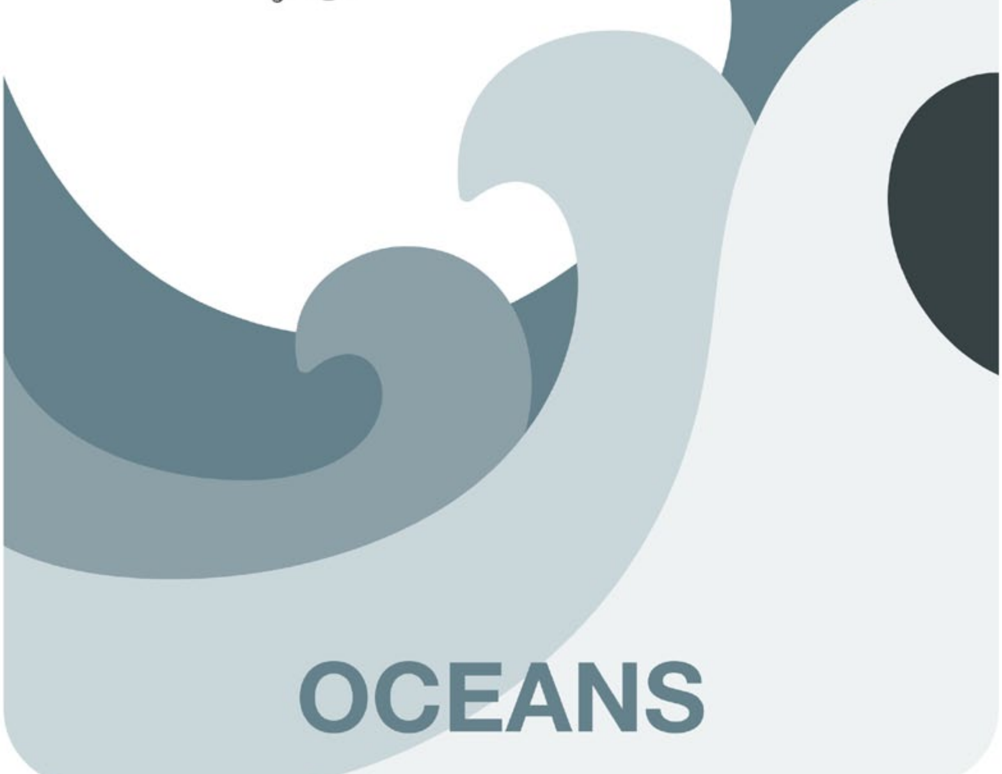


Ocean economy supplies 90% of global fisheries, 25% of global biological productivity along with 25% of world energy supplies.



Rate of sea level rise was 4.7 mm/yr in the world oceans and 5.5 mm/yr in the Indian Ocean 2013 to 2020.

50% of the oxygen we breathe comes from oceanic phytoplankton.



Continued warming of the atmosphere results in continued loss of ice in all forms, whether in Arctic, Antarctic or the Himalaya; Formation of new ponds and lakes; Nordenskiold, Svalbard, Norway.

Summary

Science is making it abundantly clear, confirming that global warming leads to more frequent and intense extreme weather events, droughts, and tropical cyclones, not to mention continued warming of the ocean and the atmosphere due to the current rates of human-led greenhouse emissions and continued loss of ice in all forms, whether in Arctic, Antarctic or the Himalaya. However, not all regions of the world are warming at the same rate. With the Polar regions experiencing accelerated warming compared to the oceans and equatorial regions, urgent action is required to reduce greenhouse gas emissions and mitigate the effects of climate change. Raising awareness and engaging in multiple platforms is essential to encourage faster climate action.

The Arctic is melting more rapidly than other Polar realms. It raises concerns about the cryospheric regions' fragile ecosystem and the potential for conflict over territory and resources. Science shows that melting Arctic ice can lead to monsoon extremes, cloud bursts and hydrological disasters, resulting in homelessness and migration in the Indian sub-continent.

The Himalayan region has a multi-hazard profile, including earthquakes, landslides, flash floods, avalanches, and glacial lake outburst floods (GLOFs). These hazards are often interlinked and exacerbated by population density, steep slopes, fragile ecosystems, and anthropogenic activities. A holistic and integrated approach involving various stakeholders, from governments to local communities, is needed to help manage such hazards. Developing an early warning system for earthquakes, GLOFs, and impact forecasting for flash floods is essential. Flash floods in the Himalaya are frequent along steep sloped arid, and semi-arid regions, with low vegetation cover and high soil erosion

rates. They can be predicted and monitored using various methods, and mitigation measures can be implemented to reduce the risks. However, there are multiple challenges to impact forecasting and early warning systems.

The cryosphere is an area occupied by snow, ice, glaciers and permafrost and is a sensitive tool to slightest perturbation in the climate systems. The melting of permafrost in the Arctic has serious consequences in terms of release of methane and pathogens. Since, data on the permafrost in the Himalaya is limited, there is a need to enhance efforts to identify and map permafrost in these regions. There is a need for advancement in technological solutions in the cryosphere in order to predict future climatic changes. Advancement in cryosphere monitoring includes both space borne and air borne monitoring techniques that use multispectral information of the electromagnetic spectrum. Technologies such as SAR and LiDAR are considered to be the game changers. Apart from remote sensing, multi-model ensemble approaches are also required to provide valuable insights into the ongoing changes in sea ice dynamics, highlighting the vulnerability and potential consequences of Arctic and Antarctic sea ice loss in the coming decades.

The Ministry of Earth Sciences (MoES) unveiled India's Arctic Policy in March 2022. The Policy document is buttressed by six pillars of scientific research and cooperation, environmental protection, economic and human development, transportation and connectivity, governance and international cooperation, and national capacity building in the Arctic. With science as the bedrock, the aims and objectives of India's Arctic policy are well aligned with the global Arctic needs. Science is the most critical objective of India's Arctic involvement, focusing on microphysical and microbiological processes, permafrost, atmospheric instruments, Indian monsoon and Arctic climatic variability and more. India is engaging on Arctic issues through institutional collaborations, prioritization of activities, points of contact in key ministries, interaction with think tanks, and consultative mechanisms with Asian observers. India's socioeconomic and cultural involvement in the Arctic includes enhancing international cooperation, industry and policy persons' interactions, celebrations of International Yoga Day on June 21 in the Arctic nations such as Russia, Denmark and Finland, and increasing awareness about the Arctic issues within the country. These multidimensional efforts should be sustained with a people centric multi-stakeholder approach, more engagement, and capacity building in shipping, scientific observation, and Arctic education.

India's concerns are also well-directed towards the Antarctic, especially since the Antarctic Treaty of 1961, created to isolate Antarctica for preservation. The Treaty has been under doubt regarding its effectiveness and there is a call at various fora for the spirit of the Treaty to be reworked to better address contemporary geopolitical concerns. Significant concerns about the future of the Antarctic Treaty include changes in geopolitical power dynamics, increasing human involvement, and the possibility of certain member nations altering the provisions of the Treaty. There are also concerns about the governance system of the Antarctic Treaty System, which may pose a risk to the functionality of the Antarctic governance model. To address these concerns, scholars suggest a move towards inclusiveness. However, there are currently no indications that any party will seek a review of the Treaty. The prohibition on mineral resource activities in Antarctica can only be removed if a binding legal regime on Antarctic mineral resource activities is in force. Overall, the future of the Antarctic Treaty remains to be determined in light of changing global geopolitics and increasing human involvement.

From being the cornerstone of the Blue Economy with a diverse set of opportunities in terms of living and non-living resources to providing multiple ecosystem services such as regulation of monsoon, global biological productivity, driving regional and global climate systems, oceans play a significant role in supporting the planet's systems. Oceans cover 75 per cent of earth, offering a 'sea-of-opportunities' but also a 'sea-of-challenges' due to climate change and anthropogenic exploitative/extractive activities. India's large coastline of 7500 km can be utilised for the production of hydrogen energy due to the ready availability of oceanic water, apart from wind energy.

The challenges around oceans can be categorized into knowledge-solution, infrastructural, foundational and governance challenges. The knowledge-solution challenge highlights gaps in understanding the nature of different challenges to the oceans. The infrastructural challenge focuses on the need for ocean observing systems and digital solutions to address ocean-related risks and hazards such as sea level rise, algal blooms, storms, tsunamis, cyclones and other disasters impacting the coasts and other regions.

Furthermore, the governance challenge around oceans is based on the ambiguity and conflicting nature of international laws and treaties that govern the part of oceans beyond national jurisdiction. Strategically and economically important global maritime routes such as the Suez/Strait of Malacca and the NSR are realigning in the backdrop of climate change. UNCLOS, being an important legal international instrument, can address some of the maritime security challenges. However, the issues related to energy exploration, trade and transportation require a more focused attention.

The role of youth in polar studies in a nation with the youngest demographic dividend in the world needs to be bolstered, as this generation is more likely to bear the consequences of climate change. They must be encouraged to pursue careers in climate and environmental science and learn to understand the policy ramifications of their work, shifting from conventional careers in various academic fields. Emerging academic fields such as climate accounting, sustainability management accounting, sustainable finance, ecosystem accounting, zero emission economy and others are providing new platforms to the youth interested in careers in climate change. In India, Polar knowledge goals are being integrated at the elementary, higher studies and at the professional level.

India's Arctic involvement needs to set a new course with a multi-stakeholder approach, expanding its outreach to more institutions, think tanks, universities and the private sector; Spitsbergen, Svalbard, Norway.

PHOTO COURTESY: KIMBERLEY CASEY

Recommendations

Policy Recommendations

Every chapter in this Report concludes with specific recommendations. They include advice for the policy makers of India's Arctic Policy and advice for India's role in mitigating climate change in Polar areas, including the Himalaya, advice for India as a stakeholder in the fate of the Antarctic Treaty, advice for working towards the engagement of youth and capacity building in Polar knowledge goals, advice for people centric climate change solutions, advice for working on maritime security, energy exploration as well as advice for working towards developing India's energy transition policy. This section is a distilled synopsis of all recommendations in order of their significance to India.

PR 1: India's Arctic involvement needs expansion at the domestic level. The six pillars of India's Arctic Policy must strengthen its multi-stakeholder approach and expand its outreach to more institutions, think tanks, universities and the private sector. India needs to heighten international engagement, creating a more proactive role for the Asian Observers of the Arctic Council and strengthening its foray through increased participation. International outreach through membership in the Arctic Economic Council needs to be sought. MoES and MEA need to calibrate India's efforts.

PR 2: Arctic living is congruent with the sustainability ideas of Mission LiFE, an India-led global mass movement encouraging individual and community action to protect and preserve the environment. Best practices from India, therefore, must be shared and assisting in satellite/digital medical services and engaging with far-flung communities may be a few such ideas. MoES, MoH&FW and AYUSH may work towards such integrations.

PR 3: India can build collaborations in strategic areas of oceanic routes in the Arctic waters and contribute officer-grade workforce for hydrography or satellite-based communications for ships on the Arctic routes. The Northern Sea Route is likely to become commercially important in the coming years, and India's involvement can help better ties with several nations in the region. The NSR is likely to become commercially viable in the coming years, and India's involvement needs to be enhanced to help develop multi-stakeholder collaborations with several nations in the region. MEA, MoPSW and MoPN need to review and take action.

PR 4: India needs to build a policy environment where sustainable energy transition models are a key adaptation measure for cryospheric regions. India needs policies to attract foreign investment in the geothermal or hydrogen fuel industry, best suited for the Himalayan region and its cold deserts. Therefore, a transitional-energy policy, aided by knowledge of geothermal and hydrogen utilization, should be popularized with capacity building through training and short courses in site-specific demonstration projects. MNRE, MoP and MoES need to take a lead.

PR 5: Antarctic governance requires democratization, revisiting the resilience of the Antarctic Treaty System. India and other like-minded nations must ensure that the existing Antarctic Treaty, built and strengthened over 60 years, continues to inspire the international legal regime and keeps Antarctica safe and pristine for future generations. As the Treaty was constructed on hope and trust, the Antarctic Treaty Consultative Meetings (ATCM), held annually, bear a significant role in channelling Member States' opinions and upholding the preamble of the Treaty, which says that Antarctica will never become a site of discord. India needs to work towards bolstering the environment of trust in its interactions while hosting the ATCM in 2024, which will be held in Kochi, Kerala. MoES and MEA need to work towards making ATS more inclusive and democratic.

PR 6: An innovative research ecosystem for India's youth needs to be ensured to provide strategic roadmaps in Polar studies at the primary and higher research levels. The culmination of the UGC Arctic courses and an introduction to the subject in NCERT textbooks are needed. Emerging courses in climate studies such as sustainability accounting, ecosystem accounting, zero-emission economy, sustainable finance, innovation and technology should be mainstreamed in India's academic institutions. Indian universities, institutes, and think tanks need to gain memberships in the UArctic, helping lead global linkages in research. Regular conferences, seminars and workshops are mandated to provide the requisite environment for dissemination, assimilation and query among the Indian intelligentsia. Mentoring research at the early stages, including new areas of research such as climate accounting and incentivizing it with recognition can drive significant improvements at the government sector, and at the institutional levels. MoES in tandem with MoE and UGC can build a cohesive platform for a Polar study ecosystem in India.

PR7: There are many countries, scientists and industries who lobby to promote sea bed mining. The UNCLOS needs to have an authority to declare any commercial mining as illegal or disprove it, in case a country intends to go for mining. There needs to be a moratorium on deep seabed mining.

Research Recommendations

Research recommendations are made throughout this Report at the end of each chapter. They include advice for India's scientific community working on Polar sciences, more specifically cryospheric research to synergize with the broader perspectives on oceans, disaster management and early warning systems, and energy transition. This part is a succinct synopsis of every recommendation in the report in order of their importance to India.

RR1: The Himalayan region is suffering the consequences of climate change and needs enhanced investments, institutional support, and state-of-the-art monitoring networks and satellite-based observations to better predictions. Increasing the number of observational platforms is required to avoid site-specific bias in the data. Early warning systems in the Himalayan regions are critical in disaster preparedness. To effectively provide early earthquake warnings and save lives, it is essential to have a sufficient number of seismological stations and a quick response time, which can be improved by networking and involving local agencies. In order to improve impact forecasting for potential disaster zones, there is a need for more comprehensive and standardized monitoring methods, which can be enhanced through new technologies such as UAVs and remote sensing. Besides, close scientific coordination among various science and research organizations such as MoES, MoS, MoM (GSI) and DST is needed for better preparedness against disasters.

RR2: Data on permafrost in the Himalaya is limited. There is a need to initiate a long-term programme for such areas and collecting depth profile data to map the extent of permafrost, especially in Lahaul and Spiti districts of Himachal Pradesh and Ladakh region. Research efforts may be guided through MoES, DST, MoS and MoM (GSI).

RR3: Development of newer instruments capable of measuring subtle variations in ocean observations for effective forecasting, date assessment, ocean and atmospheric modelling are needed. Innovative technologies for mapping of groundwater, subsurface aquifers, and their depths with spatial resolutions is also required. A self-propelled track based seabed mining system is imperative to address the challenges of variable ocean dynamics. MoES, DSIR and MoS can develop actionable mechanisms to take it forward.

RR4: There is a need to focus on assessing the performance, accuracy, and penetration depth capacity of new altimeters for measuring glaciers, comparing them with existing technologies like LiDAR and microwave altimeters. There is also a potential of integrating explicit load balancing (ELB) synthetic aperture radar, such as NISAR, with the proposed altimeter technology. Feasibility and benefits of advanced altimeter in future technological usage needs to ascertained. Also, space based observations need to be supplemented by field checks and ground surveys. MoES, MoS and MoD (DRDO) may work in tandem towards new instrumentation needs.

RR5: Newer technologies must be developed to stop pollutants from reaching the oceans. Research on bio-plastic should be done to develop sustainable alternatives. C ost-effective technologies is needed for carbon capture and sequestration. Also, restriction on the construction along vulnerable coastal areas and preparing for planned relocation can help adapt to sea level changes. MoES, MoEF&CC and MoH need to fashion actionable mechanisms.

RR6: As the grounding line of Antarctica measures approximately 62,000 km, which is larger than the earth's circumference of 40,000 km, there is a need for heightened international collaboration for monitoring it. This entails creating and merging various regional initiatives to generate uninterrupted data. There is also a need to deploy drones to monitor the sea ice dynamics closely. MoS, MoES and MoM (GSI) may come together to develop new collaborations.

RR7: Research based on human ingenuity for cost-effective and efficient climate solutions are needed to address the climatic concerns that can lead to a sustainable transition in the model of economies worldwide. Relevant research infrastructure must be created in the domain of energy alternatives, sustainable utilization of oceanic and other hydrological resources, and identification of new resources. MNRE, MoP, MoF, MoWR and MoES need to take a lead.

Contents

The melting of the Arctic ice caps poses a risk of triggering 19 climate tipping points, which can dramatically change the natural climate systems; Thinning sea ice, Canadian Arctic.

PHOTO COURTESY: ROXANNE DESGAGNÉS/UNSPLASH

1. Setting the Context

1.1 Context

SaGAA-LIGHTS has been working towards bringing scientists, policy makers, academia and industry together since 2009 to facilitate a comprehensive dialogue on diverse concerns and opportunities in the face of constantly changing climatic and geopolitical contexts. India has made significant contributions to this cause, whether it be in matters related to the global commons on the high seas or in the remote, frozen lands of Antarctica. The following sections provide a brief overview of the thematic areas that the forum aims to address through the SaGAA 7 Conference and this Report.

1.2 Climate Change: Impact on the Poles

The impact of climate change has become a serious concern in recent years, and the Sixth Assessment Report of the IPCC, 2021 confirms that global warming is leading to more frequent and intense extreme weather events, droughts, and tropical cyclones. The average global temperature has already surpassed the limit of 1.2°C set in the Paris Accord of 2015, and the Report clearly identifies anthropogenic activities as the primary cause of global warming. However, policy makers have been slow to respond to the extensive warnings of the scientific community, with climate discussions complicated by the inclusion of other interests, business opportunities, and economic constraints. It is therefore crucial to raise awareness and engage in multiple platforms to encourage faster climate action.

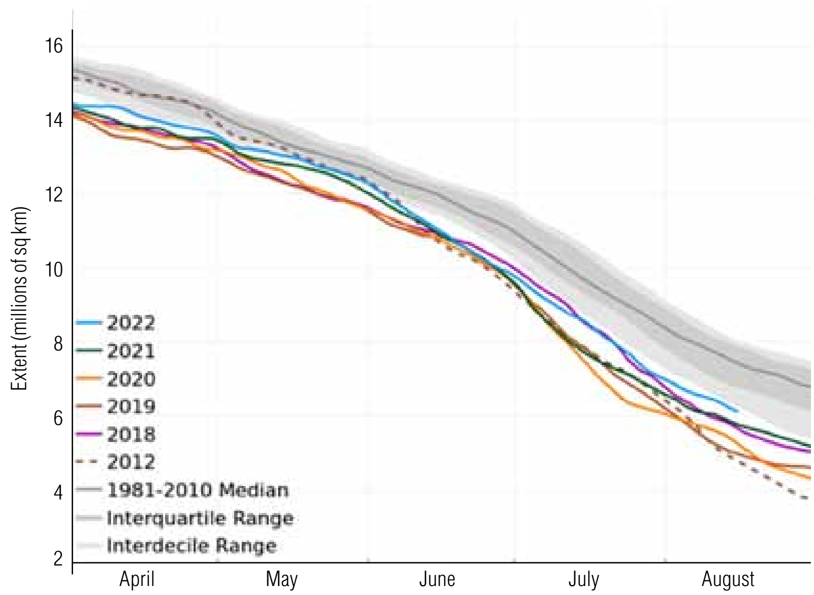
The Arctic, Antarctic, and Himalayan cryosphere are particularly vulnerable to the impact of climate change, with their rapidly changing conditions a cause for concern. In the Arctic, temperatures have risen twice as fast as the global average in the past 50 years (NASA, 2021), leading to the melting of sea ice and a decline in Arctic sea ice extent by an average of 12.8 per cent every decade since satellite records began in 1979 (NSIDC, 2021) (Fig. 1.1). Similarly, warming trends have been observed in the Antarctic, particularly in the West Antarctic Peninsula, where temperatures have increased by 2.5°C over the past 50 years (Turner et al., 2016). This warming has resulted in significant ice mass loss, primarily from the melting of ice shelves, which has the potential to contribute to sea level rise (Rignot et al., 2019). In the Himalayan cryosphere, warming has resulted in the retreat of glaciers that are a critical source of water for millions of people living downstream. Studies suggest that Himalayan glaciers have lost over 15 per cent of their volume since the 1970s, with the rate of loss accelerating in recent years (Mukherjee et al., 2020).

sea level rise
Himalayan cryosphere

Not all regions of the world are warming at the same rate, with the Polar regions experiencing accelerated warming compared to the oceans and equatorial regions, making it difficult to obtain a clear picture. The Arctic, which is the focus of the SaGAA 7 Conference, has warmed nearly four times faster than the global average in the last four decades (Retanen et al., 2022). However, the observed warming trend in the Arctic, Antarctic, and Himalayan cryosphere underscores the urgent need to reduce greenhouse gas emissions and mitigate the effects of climate change.

In conclusion, the current warming trend and its impact on the Arctic, Antarctic, and Himalayan cryosphere are major concerns, with potential impacts on sea level rise, water

Fig. 1.1: Arctic sea ice extent (area of ocean with at least 15 per cent sea ice)



The graph shows Arctic sea ice extent along with daily ice extent data for four previous years and the record low year (as of August 16, 2022).

Source: National Snow and Ice Data Center, University of Colorado Boulder

action
awareness

scarcity, and the planet's ecosystems. Urgent action is required to reduce greenhouse gas emissions and mitigate the effects of climate change. It is important to raise awareness and engage in multiple platforms to encourage faster climate action.

Senior scientists, policy makers and academics such as Dr M Ravichandran, Dr Shailesh Nayak, HE Ambassador Hans Jacob Frydenlund, Shri Sanjay Verma, Ambassador Pankaj Saran, Dr R Krishnan, Dr K J Ramesh, Dr R P Singh, Dr Bhaswati Das, Er Sonam Wangchuk, Dr Monica Singhania, addressed these concerns at SaGAA 7, highlighting challenges along with suggesting recommendations.

1.3 The Arctic

The Arctic region, once largely unknown and uninhabitable, is seeing a heightened research effort from multiple countries, resulting in a better understanding of its climatology, oceanography, ecology, glaciology, anthropology, and exploration geology. The Arctic is experiencing a warming trend, which is causing significant alterations in sea ice, snow coverage, and frozen ground. The Arctic is melting more rapidly than other Polar regions resulting in temperature spikes and fluctuations that are becoming more frequent and prolonged.

resource extraction
melting permafrost

The melting of Arctic sea ice is opening up opportunities for resource extraction, shipping, and tourism. Still, it also raises concerns about the impact on the region's fragile ecosystem, particularly indigenous communities, and the potential for conflict over territory and resources. The loss of sea ice and changes in ocean currents are affecting the migration patterns of marine mammals and fish, making it difficult for indigenous hunters to access traditional fishing grounds. Additionally, the melting permafrost and changing weather patterns are affecting traditional hunting and gathering practices, damaging infrastructure, such as homes and roads, and threatening food security and cultural heritage.

Polar vortex

The collapse of the Polar vortex, which typically shields the Arctic from warm equatorial air masses, during extreme heat waves or cold snaps, may be responsible for the enhanced warming of the region. The intensity of the Polar vortex is determined by the temperature contrast between the Arctic and the Tropics, but this difference is decreasing because of the Arctic's rapid warming.

albedo

The melting of the Arctic ice caps poses a risk of triggering 19 climate tipping points, which are dramatic changes in the natural climate systems. The ripple effects of this melting is felt around the globe, including the albedo effect, sea level rise, extreme weather conditions, thawing permafrost, and a threat to biodiversity and the economy. The albedo effect refers to the reflective ability of any surface, which determines the earth's terrestrial or outgoing radiation. Thick ice and clouds have a high albedo, reflecting back most of the sun's rays, while barren surfaces and open seas have a low albedo, meaning they absorb the majority of incoming heat. The loss of glaciers and snow contributes to maintaining the earth's delicate solar insolation balance. Sea level rise is also a significant outcome of melting Arctic ice caps, causing flooding in coastal areas and posing a high risk of land loss for island nations such as Indonesia, the Caribbean, Polynesia, and the Indian Ocean islands.

flooding

1.3.1 India and the Arctic Connections

The Indian monsoon is closely linked to the Arctic glaciers, and the Arctic oscillation plays a role in driving the monsoon and melting Arctic ice (Chowdhury, 2021). The melting of Arctic ice due to global warming can affect the land-sea temperature differences, leading to monsoon extremes that may cause hydrological disasters, homelessness, and migration in India (Rai, 2021).

Arctic oscillation
monsoon extreme

India's investment in scientific research in the Arctic includes the establishment of a research base in Svalbard, Norway, for conducting research on climate change, oceanography, and glaciology. India has also collaborated with Russia and Norway on scientific research projects in the Arctic (Bhatia and Bhattacharya, 2021).

India's Arctic connection is not only scientific but also political. India became an Observer at the Arctic Council in 2013, enabling it to observe and contribute to the Council's work on sustainable development and environmental protection. India's participation in the Council could facilitate collaborations with member nations in Polar sciences, biotechnology, and earth sciences (Bhatia and Bhattacharya, 2021). India's collaboration with Russia includes joint oil and gas projects, access to the Northern Sea Route for trade, and the development of oil fields (Ministry of External Affairs, 2021).

Northern sea route

India sees potential in Arctic tourism and has been exploring opportunities in recent years, attracting travellers seeking to experience the unique landscapes and wildlife of the region (Ministry of External Affairs, 2021). However, India's pursuit of energy security through hydrocarbon exploration in the Arctic region may pose a challenge to its commitments to the Paris Agreement and the Kigali Amendment (Bhatia and Bhattacharya, 2021).

Arctic tourism
hydrocarbon exploitation

Speakers who addressed Arctic endeavours at SaGAA 7 were Dr Anand Jain, Dr Sarat C Tripathy, Dr Paul Dodd, Mr Hjalti Omar Agustsson, Rear Admiral Monty Khanna, Dr R P Pradhan, Cmde Sujeet Samaddar and, Shri Sanjay Baveja.

1.4 The Himalaya

The IHR is an essential source of water for millions of people, but it is vulnerable to various disasters, including GLOFs, landslides, cloud bursts, and avalanches. The retreat of the Himalayan glaciers, caused by climate change, poses a severe threat to the stability of water resources and the lives of those living in the foothills. There is an urgent need for a robust early warning system that can identify and assess hazardous glacial lakes and landslide-prone areas, monitor changes, establish early warning systems, and

early warning systems

pollution
cleaner fuels

implement mitigation measures to reduce risk. The Indian government has taken steps to reduce pollution, such as promoting cleaner fuels, electric vehicles, and waste processing plants, but more needs to be done. The impact of climate change in the Himalaya is challenging to monitor, but countries like Bhutan, Nepal, and India have initiated programmes such as the National Action Plan for Adaptation to Climate Change (Bhutan) and the National Communication on Climate Change Mitigation and Adaptation (India) to address this issue.

Scientist who spoke on Himalaya at SaGAA 7 include Dr Santonu Goswami, Dr O P Mishra, Dr Miriam Jackson, Dr Vimal Singh, Dr S A Romshoo, Dr Parmanand Sharma, Dr Aparna Shukla, Dr Manasi Debnath, Dr Nisha Mendiratta, Dr V M Tiwari and, Dr Rajeev Mehajan.

1.5 The Antarctic

alarming rate

Antarctica, the southernmost continent on earth, is facing the consequences of global warming. Ice shelves in the deeper south of Antarctica are losing volume at an alarming rate, with an increase from 25 cu km per year during 1993-2003 to 310 cu km per year during 2003-2013 (Paolo et al., 2015). Although ice sheet thinning has been observed in West Antarctica and on the Antarctic Peninsula, the same has not been observed around East Antarctica (Pritchard, 2009). In fact, some parts of the East Antarctic ice sheet have been thickening, particularly deep in the interior (Davis et al., 2005). Nevertheless, the overall melting of ice sheets observed is significant, and the effects of global warming in Antarctica cannot be ignored. This is similar to the situation observed in the Karakoram Himalayas.

commercial mining

Antarctica is divided into sections by overlapping territorial claims from seven nations, including Argentina, Australia, Chile, France, New Zealand, Norway, and the United Kingdom, which are currently in abeyance. India ratified the conservation of Antarctic Marine Protected Areas in October 2021 to prevent over fishing of krill at CCAMLR, but this effort was vetoed by China and Russia in 2022 (The Hindu, 2022). It is worth noting that India does not participate in fishing for krill. While commercial mining has never been the focus in Antarctica due to a moratorium until 2048, the situation is different in the Arctic, where nations hold sovereign rights to the icy high-north realms, and exploration has almost always been part of the national plan of most of the Arctic nations.

1.5.1 The Antarctic Treaty

scientific preserve

The Antarctic Treaty, signed in 1961, has been hailed as a successful Treaty that has helped to maintain Antarctica as a scientific preserve. The Treaty allows for freedom of scientific investigation while banning any military activity. This has made it a model for treaties related to oceans and space. Despite the Antarctic region being rich in resources, the Treaty has helped keep the moratorium on mining and exploration activities intact. However, the relationship between science and politics in the frozen realms of the

Antarctic and Arctic is complex, with science often being the strategic front (Chaturvedi, 2014).

Scientific activities have played a significant role in supporting the political engagement of Antarctic Parties with the continent. The seven states that maintain territorial claims in Antarctica all operate research stations within their own zones, while non-claimant states have used scientific activities and expeditions to challenge the territorial claims. Science has also provided the motive and means to negotiate and adopt the Antarctic Treaty. Despite the challenges posed by the Cold War, the Treaty has been successful in developing an effective and enduring regime for Antarctica (Chaturvedi, 2014).

Antarctic Treaty

The Antarctic Treaty of 1959 has developed into a complex governance system called the ATS, which addresses important issues such as tourism regulation, biological prospecting, and climate change. The ATS has become more complicated due to the diverse membership and growing governance agenda. This requires a focus on the changing role of Antarctic Science and a critical examination of existing power dynamics. The Treaty was created to promote peace and scientific cooperation in Antarctica, but security concerns continue to influence the laws and policies governing the region (Hemmings and Rothwell, 2012).

The Indian Antarctic Act, 2022 has been enacted to provide for national measures towards the protection of the Antarctic environment and regulation of activities in the region (Ministry of Law and Justice, 2022). An Antarctic Governance and Environmental Protection Committee is proposed, to be headed by the Secretary, MoES. It will be bestowed with functions such as granting permits for activities including an Indian expedition, vessel or aircraft registered in India to enter Antarctica and will ensure the compliance of international laws for the protection of Antarctic environment. The Act includes measures such as environmental impact assessment, permit for expedition being contingent upon a waste management plan, prohibition of activities such as disposal of radioactive wastes in the pristine continent, etc. (Ibid.). It also specifies the offences and penalties for the contravention of the Act's provisions.

1.5.2 Antarctica: From Commercial Interest to Global Knowledge

Antarctica has long been a subject of international interest due to its rich mineral resources. In the 1970s, the idea of a minerals regime in Antarctica was considered unlikely and unfeasible due to economic, technological, and geopolitical constraints. However, by the 1980s, with the growth of the global population and the intensification of the oil crisis, the potential for commercial activity in Antarctica became more appealing (Liu, 2010).

mineral negotiations

As the prospect of commercial activity in Antarctica increased, India, Brazil, China, and Uruguay formed a lobby to promote the interests of third-world countries in mineral negotiations. However, the ATS member states faced dilemmas regarding the reconciliation of the legal status quo with equitable plans for mineral resource development. Despite this, the ATS member states reiterated that their respective positions on territorial claims in Antarctica could not be compromised (Liu, 2010).

CRAMRA

In 1988, the CRAMRA was opened for signature. It prescribed tough procedures for exploration and development, including provisions related to environmental protection. However, the prospects of CRAMRA dimmed when the Australian government refused to sign it in 1989, citing environmental conservation concerns. Australia instead sought international support for a comprehensive environmental protection convention and an Antarctic Wilderness Park. This decision was supported by France, leading to the eventual collapse of CRAMRA (Hemmings, 2011).

permanent hostage
natural reserve

The crisis of consensus in the ATS exposed the dubious and disputed ownership crisis of a continent with abundant resources. The ATS had made the pursuit of science and scientific knowledge a 'permanent hostage' to the colonial legacy of territorial claims and counter-claims (Liu, 2010). The inability to resolve territorial claims in Antarctica continued to hinder the development of regulations for commercial activities in the region. However, the US decision to sign the Protocol on Environmental Protection to the Antarctic Treaty in 1991 restored dialogic politics and consensual diplomacy to the ATS and reaffirmed the state and status of Antarctica as a global knowledge commons. This protocol aimed to protect Antarctica's environment and designated the continent as a natural reserve dedicated to peace and science (Hemmings, 2012).

The emergence of the Greenpeace movement and other environmental groups played a significant role in opposing mining in Antarctica. This led to the emergence of a new non-state contributor and claimant to knowledge production, value addition, and representational practices in the ATS, eventually becoming the ASOC (Treaty Secretariat, 2017).

1.5.3 Protection of Antarctic Environment

CEP
research integrity

The Protocol on Environmental Protection to the Antarctic, established in 1991, designates the Antarctic as a protected area for peace and scientific research. It prohibits mining activities except for scientific purposes and is monitored by the CEP. New scientific advancements and the rise of bioprospecting pose challenges to the Antarctic's environmental and research integrity. The Antarctic regime needs to continuously adapt to address these challenges.

Speakers who addressed Antarctic endeavours are Dr Avinash Kumar, Dr Waliur Rahaman, Dr Sandip R Oza, Ms Tiina Jortikka-laitinen, Dr Koteshwar Rao, Dr N C Pant, Dr Sanjay Chaturvedi, Dr Rasik Ravindra, Dr Rahul Mohan, Dr Kenichi Matsuoka.

1.6 The Deep Ocean Mission

India initiated the Deep Ocean Mission in 2018 with the objective of investigating and utilising the extensive resources within its 2.2 million sq km EEZ in the deep ocean. Led by the MoES, this comprehensive endeavour aims to explore the ocean's depths, comprehend its impact on climate change, and gather crucial data for disaster management and early warning systems. The Deep Ocean Mission encompasses the development of advanced technologies for extracting both living and non-living resources from the deep ocean. With a revised budget of INR 6.5 billion, the programme is currently in progress and has enabled India to acquire underwater mining capability. By deploying manned titanium submersible vehicles, India has joined the ranks of esteemed nations such as the USA, Russia, Japan, France, and China, opening avenues for collaboration with countries in the high-north and advancing exploration initiatives (MoES, 2018; MoES, 2023).

EEZ

1.6.1 Matsya 6000

The Matsya 6000 is a manned submersible vehicle currently being developed with the support of NIOT, ISRO, IITM, and DRDO. It has been designed to accommodate three people and can reach depths of up to 6,000 m. Equipped with advanced scientific sensors and tools, it promises to enhance our understanding of the deep ocean.

6000m

1.6.2 Samundrayaan

In October, 2022, India launched its first manned deep ocean mission-Samundrayaan, putting it in the company of nations such as the USA, Russia, Japan, France, and China which have also developed underwater vehicles for subsea activities. Samundrayaan is designed to explore the deep ocean and investigate non-living resources like poly-metallic manganese nodules, gas hydrates, hydrothermal sulphides, and cobalt crusts that are found at depths ranging from 1,000 to 5,500 m. This cutting-edge technology holds great promise for deep sea exploration.

mineral resource

1.6.3 Blue Economy

Oceans are home to 97 per cent of the earth's water and play a crucial role in sustaining the environment by absorbing 30 per cent of global carbon emissions. They are not only a valuable source of economic development, contributing 3-5 per cent to global GDP and facilitating about 80 per cent of global trade (Indian Ocean Rim Association, 2017), but they also support the livelihoods of approximately 3 billion people living near coastal regions (Ghosh and Sridharan, 2023). Recognising the significance of oceanic waters for environmental, economic, and security purposes, nations are increasingly focusing on the protection and conservation of oceans through sustainable practices.

global carbon emission
conservation

The concept of the blue economy, introduced by Prof Gunter Pauli at United Nations

University, Japan in 1994 (Trainings, 2017), envisions an economic model that conserves and sustainably utilises marine and freshwater resources. This model gained further attention during the Rio Earth Summit of 2012, where Small Island Developing States emphasised the need to bridge the gap between the green and blue economy. In response, institutions like the UNEP drafted the report 'Green economy in a blue world', recognising the blue economy as a crucial component of sustainable developmental growth (UN Economic and Social Council and Sustainable Development Solutions Network, 2014).

UNEP

International legal frameworks have played a significant role in shaping practices related to the blue economy. For instance, the World Trade Organisation's Agreement on Fisheries Subsidies in 2022 prohibited subsidies for illegal, unreported, and unregulated fishing. Additionally, the Kunming-Montreal Global Biodiversity Framework, established in December 2022, has fostered consensus among marine nations in preserving oceanic and freshwater resources through biodiversity conservation. Furthermore, the UNCLOS concluded on March 3, 2023, known as the High Seas Treaty or BBNJ, is regarded as a milestone in extending marine life protection and promoting sustainable development in areas beyond national jurisdiction.

biodiversity framework

UNCLOS BBNJ

India, with its extensive coastline and EEZ spanning over 2.02 million sq km, possesses significant potential for the development of its blue economy. However, this development carries geopolitical implications due to the Indian Ocean's critical strategic and economic importance. India's maritime interests are intricately linked to national security, energy security, and trade. Active participation in regional organisations like the IORA and the IONS demonstrates India's commitment to promoting cooperation and security in the region.

IORA IONS

To support its blue economy, India has been focusing on the enhancement of maritime infrastructure, including ports, shipbuilding, and offshore industries. This increased maritime capability has bolstered India's strategic influence in the Indian Ocean region, enabling the provision of logistical support to other countries in the area. Collaborative efforts with countries such as Japan, the United States, and Australia further contribute to maintaining security and stability in the region.

Speakers who addressed India's Deep Ocean Mission included Dr M V Ramana Murthy, Dr Jenson George, Dr Avinash Kumar, Dr T Srinivasa, Dr M A Atmanand, Dr S Rajan, Captain Sarabjeet S Parmer, Dr G Latha, Dr M Ravichandran, Dr Satheesh Shenoi, Dr Tanu Jindal, and Dr Swapna Panickal.

1.7 Northern Sea Route and the Indo-Pacific Region

Throughout human history, nations have always been intrigued by opportunities for resource exploration. The unfrozen Arctic region, which makes up one-sixth of the world's landmass, is currently experiencing what is known as the 'Cold Rush' (Briggs,

cold rush

2021). As a result, there is a geopolitical competition between various nations, including China which has claimed to be a 'near Arctic' state. This competition is likely to bring about a range of challenges at multiple levels.

near-Arctic

The Arctic region offers vast volumes of unexplored resources, including fossil fuels such as petroleum oil, natural gas, and gas condensates, as well as base metals, rare earth elements deposits, and gemstones (Boyd et al., 2016). However for these resources to be sustainable, they must be commercially and environmentally viable, as well as easily accessible and transportable.

Arctic region

The Russian plan to establish a year-round navigation system in the NSR by the 2030s could greatly benefit exploration efforts in the Arctic region leading to a significant increase in marine traffic, which would require the development of infrastructure such as ports, railways, roads, and pipelines. Areas such as Murmansk, Novaya Zemlya, Taymyr Peninsula, and Yamal Peninsula in Russia are likely to see significant development in this regard. The development of this route could also have broader strategic implications, as it would provide a shorter and more economical alternative to the existing Indian and Pacific Ocean marine traffic routes.

navigation system
NSR

Bypassing the chokepoints such as Malacca, Suez, and Panama, this new route could save 10-15 days in travel time. This would have far-reaching consequences, beyond just cargo transportation. However, the Arctic region is sparsely populated and faces multiple stressors, presenting unique governance challenges. India has ratified all major treaties, including the UNCLOS and is actively involved with international bodies working on the Arctic. India's new Arctic Policy, released in 2022, focuses on six key areas: science and research, environmental protection, economic and human development, transportation and connectivity, governance and international cooperation, and national capacity building for involvement. India's continued interest in the Arctic region is therefore assured, and a calibrated approach is necessary to fully understand the region's changing potential. By focusing on these key areas and working collaboratively with other Arctic nations, India can contribute to the sustainable development of the Arctic region while ensuring its own strategic interests.

choke points

Arctic Policy

Speakers who addressed Northern Sea Route and the Indo-Pacific Region are Major General B K Sharma, Dr M Sudhakar, Cmde Debesh Lahari, Dr R Srikanth, Dr Sulagna Chattopadhyay, Dr R P Pradhan, and Dr Stuti Baneerjee.

1.8 Clean Energy

Hydrogen and geothermal energy are two promising sources of clean energy that could help address the urgent need to reduce greenhouse gas emissions and mitigate the impacts of climate change. Hydrogen, when produced using renewable sources such as solar or wind power, can be used as a fuel for vehicles, power generation, and heating. It produces no greenhouse gas emissions when burned and can be stored for long periods

Hydrogen
geothermal

of time. Geothermal energy, on the other hand, involves harnessing heat from the earth's core to generate electricity or provide heating and cooling for buildings. It is a reliable and consistent source of energy that can operate round the clock without interruption. The urgency for these forms of energy production is clear as the world continues to rely heavily on fossil fuels and faces the consequences of climate change. Switching to clean energy sources like hydrogen and geothermal is essential to reduce greenhouse gas emissions and ensure a sustainable future for generations to come.

Speakers who addressed clean energy include Dr Dilawar Singh and Ms Kunzes Dolma.

1.9 Conclusion

The significant and widespread changes that are taking place in the Polar regions have created a pressing need for ongoing research to enhance our comprehension of local, regional, and global processes. These changes extend beyond man-made geographical boundaries, necessitating the involvement of multiple nations and communities on a global scale, each with their own set of interests and constraints. As a result, it is crucial to establish an interface between science and geopolitics in the Arctic and Antarctic. Although there are several fora for sharing scientific or geopolitical findings, an interface between them is rare. The principles that govern the Polar regions are based on science but also require the involvement of multiple countries and communities. Therefore, it is necessary to hold discussions on platforms such as SaGAA, where various interdisciplinary issues can be discussed.

The influence of topographic parameters coupled with increasing surface temperatures and anthropogenic activity are melting the Himalayan glaciers; Khumbu glacier with debris cover, Nepal.

PHOTO COURTESY: WILFRIED HAEBERLI

2. Predicting Future Pathways: Permafrost, Sea ice and Glaciers

The chapter discusses the impacts of climate change on the cryosphere, which includes the earth's glaciers, ice sheets, permafrost, and sea-ice. The melting of these components of the cryosphere is caused by the rise in global temperatures and the subsequent increase in greenhouse gas emissions. The melting of the Arctic sea ice will have a severe impact on the Arctic environment, including its biodiversity and habitat, which will affect the livelihood of the indigenous population. Moreover, the loss of multiyear sea ice is contributing to Arctic amplification, leading to a significant increase in surface air temperature. This chapter also highlights the teleconnections between Arctic sea-ice and regional monsoons and how the melting of ice can affect the ocean circulation. The changes in temperature gradient between mid-latitudes and the Polar region can cause weather extremes such as heat waves. Finally, it discusses the impacts of climate change on permafrost, which contains almost twice the amount of carbon than the atmosphere. The thawing of permafrost releases carbon along with methane, another greenhouse gas, into the atmosphere, contributing to further rise in global temperatures.

2.1 Introduction

Climate change is no longer a myth or mere speculation. It is impacting lives and livelihoods in all spheres be it onshore or offshore, mountainous, coastal areas or plains. The cryosphere and oceans support unique habitats and are interconnected with other components of the climate system through global exchange of water, energy and carbon dioxide (Krishnan, 2023). Around 10 per cent of earth's land area is covered by glaciers or ice sheets which are sensitive to climate change processes. The projected responses of the cryosphere to the global warming and climate change, accelerated by the human induced greenhouse gas emissions, has led to widespread shrinking of the cryosphere, with mass loss from ice sheets and glaciers, vanishing sea ice in Arctic both in extent and thickness, melting of ice sheets in Greenland, West and Peninsular Antarctica and the high mountain glaciers of Himalaya. The permafrost in the Arctic, highland of Tibet and Himalaya and elsewhere in the cold regions of the earth is thawing due to this rise in temperature.

mass loss

2.2 Arctic Sea ice

The Arctic occupies an area of about 40 million sq km that is three times larger than Europe and represents about eight per cent of the earth, housing four million people. The rise in the global temperatures and consequent melting of Arctic sea-ice will adversely impact the Arctic environment including the biodiversity and the habitat, impacting the livelihood of the population, especially the indigenous people that constitute about 15 per cent of the population.

2.2.1 Impact of Global Warming on Sea ice

The spatial pattern of the warming of the surface temperatures is not uniform. Some regions, such as the Arctic, are warming at alarming rates, nearly four times higher than the global average. The temperature in 2022 was almost 1.2 degrees warmer than the pre-industrial climate. With the increase in the greenhouse gases, Arctic sea-ice is projected to further decrease.

greenhouse gas

Arctic sea-ice extent has recorded a decreasing trend for all months of the year. The extreme warming of the Arctic has been well recognized more so after the year 2000. The rate of warming is much higher and this is leading to increased melting of sea-ice as also the ice sheets of Greenland where extreme melting was only observed in the years 2019 and 2021. The trends in the Arctic sea-ice cover in March show a decline of about 2.6 per cent per decade. The month of September, which is the end of summer season in the northern hemisphere, records minimum sea ice. Between 1979 and 2018, the rate of reduction is 12.8 ± 2.3 per cent per decade during this month. The Arctic sea-ice has thinned, with loss of multiyear sea ice amounting to nearly 90 per cent loss of five-year-old ice. The loss of sea ice contributes to the Arctic amplification with surface air temperature increasing by more than double the global average over the last two decades. The model (SSP 245) predicts the future projection of melting, under medium median emission scenario, to reach about 15 per cent. Models capture that under these scenarios the Arctic may be sea ice free by 2050 unless emissions are brought down considerably with grave consequences (Krishnan, 2023).

Arctic sea ice extent

emission

2.2.2 Teleconnections

regional monsoon
teleconnection
pattern
thermohaline
circulation

Arctic sea-ice can influence the regional monsoons through the teleconnection patterns. The melting of ice influences the ocean circulation. The contrast in the dense cold water columns of North Atlantic and the warm fresh water of lower latitudes establishes a density gradient which results in thermohaline circulation or overturning of the waters. With increased melting of the sea-ice, more fresh water will be introduced in the North Atlantic altering the tropospheric temperatures and weakening the thermohaline circulation. This in turn would affect the Indian summer monsoon adversely.

Arctic vortex
heat wave
radiative forcing

As the temperature increases and the Arctic ice melts, the Arctic vortex can break down and the Polar jet stream can weaken. The changes in the temperature gradient between the mid latitude and the Polar region can produce meanders in the jet stream, which can also influence the mid latitude and lead to weather extremes like heat waves as witnessed during the Russian heat wave in 2010 (Krishnan, 2023). The experiments have confirmed that when we increase long wave radiative forcing, the extent of the sea-ice decreases and with further increase in the radiative forcing the meandering starts. The assessment is that even the Gulf Stream will weaken.

2.3 Permafrost

Permafrost is defined as a frozen surface below the land which is typically frozen for about two years or more. It may occur in a continuous, discontinuous, sporadic or isolated form in nature. It is spread over in the Northern hemisphere for more than 20 million sq km. When it comes to the Himalayas, it has the largest area of mountain permafrost in the world.

loss of the permafrost

The loss of the permafrost in the Arctic and other cold and high mountain regions of the world such as Tibet and Hindukush Himalaya, as also in other areas, is driven by rise in surface air temperature, globalisation, infrastructure development, migration and tourism. The Permafrost temperatures have increased to record high levels when observed for the period from 1980s onwards to the present including the recent increase by 0.29°C ± 0.12°C (IPCC AR 6) from the year 2007 to 2016.

soil carbon

Arctic and boreal permafrost contain 1460–1600 Gt organic carbon, almost twice the carbon in the atmosphere. Preliminary computer analyses suggest that permafrost could produce carbon equal to about 15 per cent of today's emissions caused by human activities. Permafrost thaw and glacier retreat have decreased the stability of high mountain slopes with disruption in infrastructure (Goswami, 2023). Globally the permafrost has about 1,700 pentagram of carbon which is equal to about 1/4 of the total soil carbon. The soil carbon which gets frozen and trapped in the permafrost can be released on thawing. It warms the local climate, impacts the overall global climate and can have disastrous effects on roads, constructions and other infrastructures.

The studies on the permafrost areas in Himalaya have yet to gain momentum. However, some areas such as Lahaul and Spiti district in Himachal Pradesh and Tso Kar in Ladakh have been identified for detailed studies by Indian scientists where subsidence has been calculated in centimetres by using interferometry. The models suggest that southwest and northward monsoon rains and extreme events are likely to increase in Ladakh. This will cause permanent loss to the permafrost.

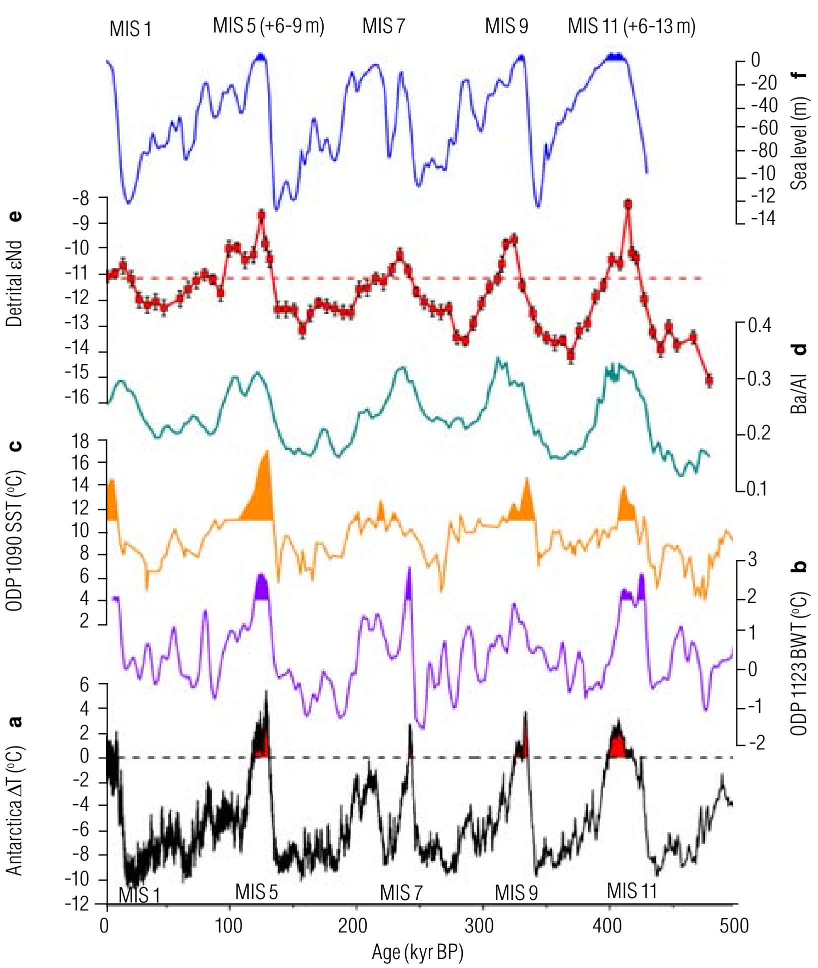
subsidence

2.4 The Antarctic Scenario

Antarctica is a unique continent, dominated by an ice sheet. With 98 per cent of the continent covered by permanent ice that accounts for 30 x 106 cu km of the ice. Antarctica is also the storehouse of 70 per cent of the earth's fresh water locked in its vast expanse of ice. The global rise in temperatures and climate change have also touched Antarctica which displays variable melt rates in different parts. The West Antarctica and Antarctic Peninsula are the worst affected, while the east Antarctic ice sheet has also

ice sheet

Fig. 2.1: Pliocene Greenhouse



Source: Rahaman, 2023

temporal variation
negative mass balance

started showing a negative mass balance (Kumar, 2023a). The Antarctic Sea ice expansion and recession are asymmetric with regional and temporal variation. While the sea ice was exhibiting a positive trend till 2015, the satellite data for subsequent years reveal that the years 2016, 2020, 2022 and 2023 have seen the lowest growth in Antarctic sea ice. The sea ice in the months of January and February in the Ross Sea Region too has recorded a drastic decline. The extent being 43 per cent lower than the mean extent of the previous years. The low sea ice significantly impacts the stability of the Antarctic ice shelves.

2.4.1 West Antarctic Ice sheet

risk
Pliocene

The West Antarctic Ice sheet is undergoing rapid mass loss currently and may collapse at some point of time with catastrophic consequences. A peep into the geological time scale when the CO_2 was very high along with high SST and atmospheric temperatures hints what we can expect with similar conditions in the present scenario. In one of the reconstructions for the last interglacial period in the Pliocene at 5.3 to 2.6 million years, CO_2 was 400 to 450 ppm and SST was two to three degree higher, and West Antarctica was completely free of ice. This particular interval is considered to be the best analogue for our near future climate. Two of the major glaciers in West Antarctica are undergoing rapid mass loss and most of the consequent rise in sea level, at approximately one cm per decade, is coming from the melting of land ice and glaciers of West Antarctica (Rahaman, 2023) leaving the coastal habitats worldwide, including India, at risk. The isotopic analyses of the sediments retrieved from this part have revealed a dynamic ice sheet situation in warm Pliocene to icehouse conditions in Pleistocene (Fig. 2.1).

2.4.2 Biogeochemical Changes

nutrient dynamics
carbon pump

The interaction of ice-ocean-atmosphere and ice-free high latitude ocean waters, have opened up new fields of research to understand the biogeochemical processes taking place under the climate change scenario. The Antarctic Sea ice is a substrate for algal growth that influences nutrient dynamics and water column stratification. Sea-ice melting gives rise to phytoplankton bloom which in turn controls the CO_2 draw-down as part of the carbon pump (George, 2023). A steadier mooring system has been set up in the sea ice with temperature sensors at 2 cm interval across the sea-ice.

2.5 The Himalaya

freshwater
discharge regime
glacial lakes

The glaciers all over the world are losing mass and the Himalaya is no exception when it comes to the impact of global warming and climate change on the cryosphere. The Himalaya stores the largest number of mountain glaciers with varying geometry that serve millions of people downstream as the source of freshwater for drinking and agriculture. Decline in the glacier mass eventually alters the local and regional hydrology by changing the discharge regime and also increasing the number and area of glacial lakes.

Though the direct field measurements of the glacier mass balance over Himalaya are limited, studies have shown that Himalaya has lost the ice mass in all its eastern, central and western sectors.

2.5.1 Kashmir Himalaya

Field studies coupled with remote sensing data in Jammu, Kashmir and Ladakh for over more than 12,000 glaciers occupying 19,727 sq km area, have revealed thinning during the period from 2000 to 2012 (Romshoo, 2023). During the last six decades glaciers have lost almost 25 per cent of the mass in the Upper Indus Basin. By the end of this century, the loss would amount to almost 47 to 67 per cent under these scenarios. The glaciers have receded and thinned with maximum thinning in the Pir Panjal Range and minimum in the Karakoram Range.

Indus Basin
Pir Panjal Range

2.5.2 Western Himalaya

The excessive melting of the glaciers in Chandra basin of Himachal Pradesh has resulted in an increase of the mean annual discharge by about 50 per cent during the last five decades (Sharma, 2023b). For example, in the Bhaga basin of Himachal Pradesh, glaciers have lost a huge ice mass equivalent -1.06 ± 0.3 m w.e/year. The rise in the melting and consequent spring runoff has changed the hydrological behaviour due to availability of water earlier on in the basin. The runoff, when constrained by moraines, gets stored in the form of glacial lakes and adds to the further ice loss due to calving. Glacial lakes in Samudra Tapu and Gepang Gath glaciers have shown 20 to 25 times expansion over the last five decades.

Chandra basin
Bhaga basin

2.5.3 Sikkim Himalaya

Compared to western Himalaya, the Sikkim Himalaya in eastern parts of the range present a different scenario due to being in different climatic and topographic zones. The glacier area loss in Sikkim ranges from 20 per cent to 30 per cent at different basins (Debnath, 2023). The exceptional and high recession has produced a number of glacial lakes which show 8 to 35 per cent of lake area expansion.

topographic zones
glacial lakes

The influence of topographic parameters coupled with increasing surface temperatures, low precipitation and anthropogenic activity are the main causes for the loss of glaciers. The debris cover or debris free glacier responds differently to the ablation, with clean glaciers suffering more loss than the others (Shukla, 2023). The melting glaciers have significant impact on water resources of Himalayan Rivers due to change in glacier basin hydrology, downstream water budget, impact on hydropower plants due to variation in discharge, flash flood (GLOF) and sedimentation.

Himalayan rivers
water budget
hydropower

2.6 Recommendations

i. Most of the models on Arctic sea-ice, especially the scenarios of the ER6 September Arctic ice, capture the free fall of sea-ice and predict that the Arctic will be free of sea ice by 2050. It is only in the low emission scenarios in the SSP 119 and 126 that the Arctic can be saved from the Arctic free ice condition (Krishnan, 2023).

ii. We need to advance capabilities in climate and earth system modelling and prediction systems, advance impact assessments, development of adaptation strategies to mitigate risk and for policy making, improve early warning systems and more importantly advance scientific research academic collaborations to complement and enhance in house R&D capabilities minimum climatologically (Krishnan, 2023).

iii. The data on permafrost area in Himalaya is constrained. There is a strong need to initiate a long term programme for mapping of such areas and collection of data on depth profile and extent of permafrost, especially in Lahaul and Spiti district of Himachal Pradesh and Ladakh region (Goswami, 2023).

iv. More glaciers in Himalaya need to be monitored for ice mass loss, recession and formation of glacial lakes. Space based observations need to be supplemented by field checks and ground surveys (Rahaman, 2023).

Collecting information about specific regions of interest such as ice shelves; Antarctica.

PHOTO COURTESY: TOM KALIRAI

3. Monitoring the Cryosphere: Emerging Methods

It is crucial of monitoring the cryosphere, which is frozen water on earth, in order to understand the impact of climate change. Space-based and airborne monitoring technologies are being used to collect data on the cryosphere, and various instruments such as multispectral sensors, spectrometers, LIDAR, microwave radiometers, and synthetic aperture radars are used for measuring different properties of the cryosphere. The chapter highlights the advancements in monitoring the Antarctic ice sheet using remote sensing techniques, including satellite altimetry, satellite imagery analysis, and ice velocity measurement. The data collected through these technologies are vital for understanding the changes occurring in the cryosphere and developing strategies to mitigate the effects of climate change.

3.1 Introduction

The term 'cryosphere' comes from the Greek word, 'krios,' which means cold. There are places on earth that are so cold that water is frozen solid. These areas of snow or ice, which are subject to temperatures below 0°C (32°F) for at least part of the year, compose the cryosphere. Monitoring changes in the cryosphere is crucial for understanding the earth's climate and predicting future changes (Singh, 2023b). In today's day and age there have been many advancements in cryosphere monitoring. Space-based monitoring offers a unique perspective, allowing for global coverage and long-term observations. Satellites equipped with sensors that measure different properties of the cryosphere, such as temperature, reflectivity, and thickness, are used to monitor changes in the cryosphere. For example, altimeters on satellites can measure the height of ice sheets and glaciers, while microwave radiometers can detect changes in snow depth. Space-based monitoring has shown that the cryosphere is rapidly changing, with significant declines in sea ice extent, glacier volume, and ice sheet mass. These changes have implications for sea level rise, changes in ocean circulation patterns, and impacts on ecosystems. Continued space-based monitoring of the cryosphere is critical for understanding the impacts of climate change and developing strategies to mitigate its effects. The development of new technologies, such as improved sensors and data processing techniques, will further enhance our ability to monitor and understand the cryosphere (Singh, 2023b).

sea ice extent

ice sheet mass

Not only space but also airborne observations are emerging technologies for cryosphere monitoring. Airborne monitoring, which involves flying aircraft over the cryosphere to collect data, can provide higher-resolution measurements than satellites and can be useful for validating satellite data. It can also provide more detailed information about specific regions of interest, such as glaciers or ice shelves (Matsuoka, 2023).

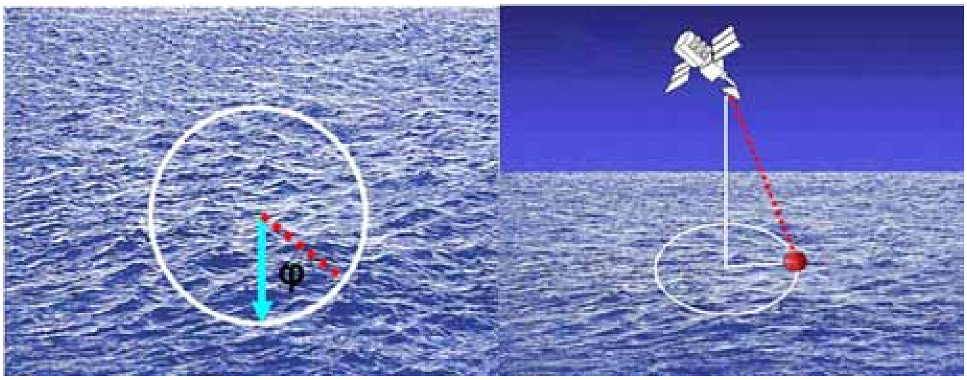
airborne monitoring

3.2 Advancement in Monitoring the Cryosphere

To measure the cryosphere, instruments such as the multispectral imaging sensor, spectrometer, LIDAR inoptical region, passive microwave radiometer, synthetic aperture radars and Scatterometer in microwave region are needed (Singh, 2023b). Many of these instruments developed indigenously in India, are being used in the field of cryosphere. To measure the cryosphere, three regions: optical, thermal, and microwave are used. Reflectance, brightness, temperature, or backscattering coefficient are measured depending on the spectral window, and then the problem is inverted to retrieve the property of surface. There are several challenges in this study, including measuring snow and its melt to model the hydrological process, monitoring glaciers, assessing hazards, and understanding the connection between monsoons and other climate indicators.

assessing hazards

Fig. 3.1: Pencil-beam scatterometer



Source: Oza, 2023

radar systems

Optical remote sensing has matured into a powerful and proven technology that allows an understanding of how glaciers are melting. However, this technology has limitations, particularly in case of snow and cloud cover. Therefore, radar systems need to be deployed to penetrate surfaces and detect buried lakes. The microwave region is particularly important for hydrology, and the SAR technology allows the measurement of amplitude and phase, which helps to determine velocities, mass balances, and more.

3.3 Advancement in Monitoring the Antarctic Ice Sheet

global sea-level rise
ice sheet
surface height

Antarctica's ice sheet is a significant contributor to global sea-level rise. Remote sensing techniques are crucial to monitor the changes occurring over the ice sheet and provide data for scientific research. One such method is the estimation of ice sheet mass balance through changes in elevation (Oza, 2023). This technique uses satellite altimetry data to determine the variations in the surface height of the ice sheet, which, when combined with other data, provides an estimate of the ice sheet mass balance. Another important aspect is the assessment of variations in ice surface melt processes. This involves using satellite imagery to identify and analyse meltwater ponds and streams on the ice surface. The retrieval and analysis of ice velocity over ice sheets and shelves is also crucial to the understanding of ice sheet dynamics.

Indian earth
observation missions
TRISHNA

Several on-board Indian earth observation missions, including SARAL-AltiKa Altimeter, EOS-06 Oceansat-3 (OCM & SCAT), RISAT-1/1A (C-band SAR), and Resourcesat (LISS-III, LISS-IV, AWiFS) series, are used to monitor changes in Antarctica's ice sheet (Oza, 2023). These missions provide high-quality data for scientists to analyse and study changes occurring over the ice sheet. In the future, the NISAR, L&S band SAR and TRISHNA, multi-band thermal missions will be launched, providing even more data for research (Ibid.). The monitoring of land ice feature changes over and around ice margins is essential to understanding the dynamics of the ice sheet and its impact on global sea-level rise. Overall, remote sensing techniques, along with data from on-board and future earth observation missions, are vital tools for monitoring and understanding changes occurring over Antarctica's ice sheet.

surface melting pattern
Antarctic

The Pencil-beam scatterometer (Fig. 3.1) instrument is an essential tool used to study the surface melting pattern of the Antarctic Ice Sheet. It consists of two off-nadir beams known as the inner and outer beams. These beams are created using two offset feeds and a parabolic reflector that is mechanically spun around the yaw axis of the satellite (Oza, 2023). The instrument provides a high level of accuracy and precision in measuring the surface characteristics of the ice sheet. The inner and outer beams of the scatterometer instrument are used to obtain measurements from each point in the inner swath twice, and similarly twice from the outer beam. This provides a comprehensive dataset that can be used to analyse the melting pattern of the Antarctic ice sheet. The instrument is particularly useful for studying the effects of climate change on the ice sheet, as it can detect even small changes in surface melting. The pencil-beam scatterometer instrument is a significant advancement in the field of Antarctic research and is helping to improve our understanding of one of the most important natural features on our planet.

3.4 Sea Ice Dynamics in the Arctic Using a Multi-model Ensemble Approach

With recent technological advancements, the data gathered from instrumentation, remote sensing, etc. can be aptly utilized for sea ice dynamics. Today there are multi-model approaches available for examining the sea ice and oceans. The sea ice and ocean parameters in the Greenland Sea and Barents Sea regions have been examined using the CMIP6 multi-model ensemble mean data spanning from 1850 to 2100 (Pant, 2023b).

instrumentation

CMIP6

The analysis reveals a concerning trend of significant sea ice area decline exceeding 60 per cent and a substantial increase in sea surface temperature of approximately 3° C during the winter months, specifically in March, compared to present conditions. Furthermore, there is a noticeable decline in sea ice concentration across the entire Arctic domain during both summer and winter months. By September 2050, the spatial mean value of sea ice concentration reaches zero, emphasising the diminishing nature of Arctic sea ice. Notably, during the high summer months, particularly September, there is considerable variability of over 30 per cent in sea ice concentration observed in the East Siberian Sea, Laptev Sea, Beaufort Sea, and Greenland Sea regions (Pant, 2023b). These findings provide valuable insights into the ongoing changes in sea ice dynamics, highlighting the vulnerability and potential consequences of Arctic sea ice loss in the coming decades.

decline
Arctic sea-ice
concentration

3.5 Challenges

Like any technology, optical technology has limitations, particularly when dealing with cryospheric regions that often have cloud cover. Clouds can pose a significant obstacle for optical observations. Similarly, SAR technologies also have drawbacks, such as limited revisiting capability and the inability to provide daily observations. To overcome these limitations, microwave radiometers are utilized in the cryosphere. These radiometers have the advantage of daily observation power. Depending on the frequency used, they can provide valuable information about snow depth, snow amount, water equivalence, and more. Different frequencies have different properties, with some are able to penetrate the snow, others are sensitive to water content. Promising frequencies for cryosphere measurements include 18 and 36 GHz. By employing microwave radiometers at these frequencies, researchers can gather crucial data and enhance their understanding of the cryosphere's characteristics and dynamics (Singh, 2023b).

cloud cover
revisiting capability
frequencies

The measurement of bed elevation cannot be accurately done through satellite imagery, which poses a significant challenge. Although satellite data can be helpful, it cannot be relied upon solely without better topography information to address issues related to sea levels. Despite the significant investment made in satellite technology, it may not be sufficient to answer important questions about the earth's surface (Matsuoka, 2023).

3.6 Recommendations

i. Continuity and a greater focus on technology is needed to measure elevation using interferometry or altimeters (Singh, 2023b).

ii. Wide swath altimetry with interferometry capability is needed for improved monitoring of cryosphere (Singh, 2023b).

iii. Systematic use of LiDAR and microwave altimeters can be game changers in terms of understanding the properties and penetration depth (Singh, 2023b) and therefore needs greater focus.

iv. NISAR, a type of ELB synthetic aperture radar, is expected to impact future technology (Oza, 2023) and should be built into the research environment.

v. A larger number of international consortium needs to be formed to conduct airborne geophysical surveys of the Antarctic ice sheet using specialised aircraft to provide accurate topography data for understanding and addressing issues related to sea level changes (Matsuoka, 2023).

Flash floods are rapid and destructive flooding events can occur within a few minutes or hours after a heavy rainfall; Teesta, Sikkim.

4. Disaster Preparedness through Early Warning Systems

Natural disasters such as earthquakes, glacial lake outburst floods (GLOFs), and flash floods are common occurrences in the Himalayas and have had a significant impact on the lives and livelihoods of the people in the region. This chapter specifically examines the three key disasters in the Himalayas, their impact, and the development of early warning systems for disaster preparedness. There is a compelling demand for early warning systems to prepare for such disasters, and build robust monitoring and mitigation techniques. Challenges in developing warning systems for earthquakes, GLOFs, and flash floods are also briefly discussed, and recommendations for the development of early warning systems are provided. The chapter emphasizes the importance of understanding these natural disasters and their impacts in order to improve disaster preparedness in the Himalayas.

4.1 Introduction

The Himalaya presents a complex and diverse set of multi-hazard facets. The region is prone to earthquakes, landslides, flash floods, avalanches and GLOFs. The frequency and intensity of these hazards are compounded by a range of factors including population density, steep slopes, fragile ecosystem and anthropogenic activities. Earthquakes are the most frequent and potentially catastrophic hazards in this region. In addition, these hazards are often interlinked with one triggering the other. For example, earthquakes can trigger landslides, which can block rivers and cause floods. Climate change is exacerbating many of these hazards, with rising temperatures causing glaciers to melt and changing precipitation patterns leading to more intense rainfall and snowfall events. Therefore, managing the multi-hazard facets of the Himalayas is a complex challenge that requires a holistic and integrated approach involving a range of stakeholders from governments to local communities.

The Himalayan region has experienced many major earthquakes throughout history, with some reaching magnitudes of 8 to 8.5. These earthquakes can generate a massive amount of energy and cause tremendous damage to nearby cities. Hence, it is crucial to develop an early warning system to help mitigate the impact of earthquakes (Mishra, 2023). NCS is the nodal agency of the Government of India for monitoring earthquake activity in the country. Predicting earthquakes is currently not possible as the physics of earthquakes is not yet fully understood. Therefore, the development of an early warning system for earthquakes is necessary for all earthquake-prone regions of the world (Mishra, 2023).

early warning system

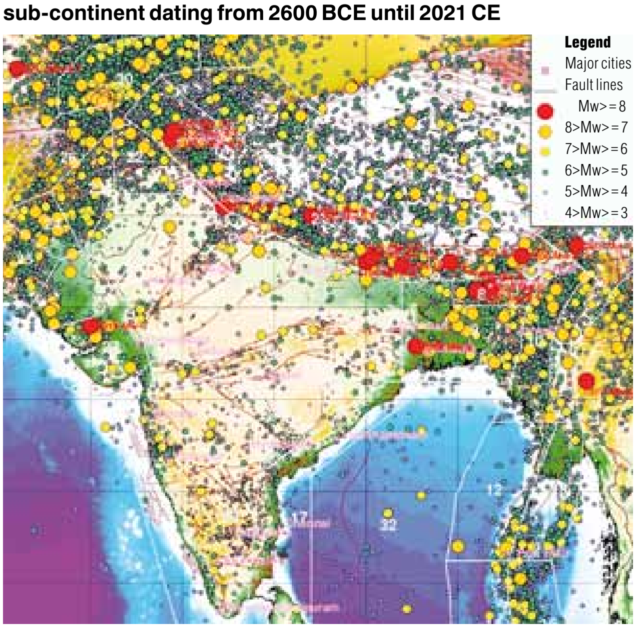
GLOFs are a serious threat to the Himalayan region and downstream areas. The expansion or formation of new lakes in the cryospheric regions is turning areas more hazardous and the impact is likely to exacerbate in the coming years (Meloth, 2023). ICIMOD is an organisation studying and working on issues related to high mountain areas, particularly in the Hindukush Himalayan region. ICIMOD conducts research, develops solutions, and provides policy advice to governments and local communities. By collaborating with local communities, ICIMOD looks for applications that meet the needs of those living in the region (Jackson, 2023).

Hindukush Himalayan region
local communities

Flash floods are another common natural disaster in the Himalaya, particularly during the monsoon season (June to September) when heavy rainfall can trigger sudden and intense flooding in mountainous regions. Flash floods can be particularly devastating in the Himalayas due to the steep terrain, high population density, and vulnerability of the communities that live there. Therefore, the impact forecasting system for flash floods is a critical tool in mitigating disasters and making informed decisions for communities and governments. Early warning systems focus on providing information about the location

flash floods
vulnerability

Fig. 4.1: Distribution of different seismic events across the Indian sub-continent dating from 2600 BCE until 2021 CE



Source: Mishra, 2023

Map not to scale

and magnitude of an event, while impact forecasting provides estimates of the potential consequences of an event. This information helps decision makers determine which areas require the most attention and resources (Singh, 2023c).

4.2 Understanding Natural Disasters in Himalayas and its Monitoring

4.2.1 Earthquakes

risk mitigation strategies potential impact

The seismic activity in the Himalayan region is characterised by a total of 68,342 events dating from 2600 BCE until 2021 CE (Fig. 4.1). Among these 28,425 were main shocks with a magnitude greater than three on the moment magnitude scale. Furthermore, the region has experienced a total of 26 main shocks with a magnitude greater than eight, indicating the occurrence of extremely powerful earthquakes. These statistics highlight the significant seismicity of the area and emphasise the need for appropriate disaster preparedness measures and risk mitigation strategies to mitigate the potential impact of seismic events on the local population and infrastructure.

network seismological stations

The seismic monitoring network of NCS has undergone significant development in recent years. In 2014, it comprised 84 stations, of which 38 were analog (Fig. 4.2). By 2018, the network had been upgraded to include 115 seismological stations with broadband and strong motion recorders, and V-SAT connectivity. This has allowed for improved detection capabilities of earthquakes of magnitude 3.0 and above in most parts of the country. The network was further strengthened in December 2022, with the addition of 37 new stations, bringing the total number of stations to 152, and enhancing the network's operational capabilities. The NCS has proposed to add 100 new stations to the network over the next three years (2023-2026).

4.2.2 Glacier Lake Outburst Floods (GLOFs)

preparedness risk assessment dissemination

Early warning systems for risks in high mountain areas typically involve a four-step approach that includes risk assessment, monitoring, information dissemination, and preparedness (Jackson, 2023). The first step, risk assessment, involves identifying potential hazards and evaluating the likelihood and potential impact of each. The second step, monitoring, involves continuously monitoring key indicators to detect any changes or developments that could pose a threat. The third step, information dissemination, involves sharing relevant information with those who need it, such as the public, emergency responders, and decision-makers. Finally, preparedness involves taking actions to mitigate the potential impact of a threat and having plans in place to respond effectively if necessary. Together, these four steps can help organizations and communities stay informed, prepared, and ready to respond to potential threats.

The process of assessing hazards associated with a lake involves two important steps, namely standardization and prioritization (Jackson, 2023). The first step is to standardize hazard assessment by considering various physical conditions such as the state of the lake, the moraine dam, and the features around the lake. The assessment should be comprehensive and include all relevant indicators, and appropriate weights should be assigned to each indicator. The outcome of this step is a list of PDGLs that need to be evaluated for risk. The second step involves assessing the downstream socio-economic risks that may be associated with each PDGL. This assessment can be achieved by examining the downstream impacts caused by exposure to potential hazards. Based on this analysis, the PDGLs can be categorized according to their level of risk. The aim of this step is to prioritize the PDGLs based on their level of risk, thereby allowing decision-makers to focus their resources and attention on the most critical areas. Overall, the standardization and prioritization process are essential steps in the management of hazards associated with lakes. By following these processes, stakeholders can better understand the risks and make informed decisions about how to mitigate them. This approach can help to ensure the safety and well-being of communities that are located downstream from potentially dangerous geological locations (Jackson, 2023).

geological locations
socio-economic risks
hazards

GLOFs can occur when water trapped by a glacier or moraine is released suddenly (Jackson, 2023). Early warning systems are crucial in preventing or mitigating the impact of GLOFs, but they can be challenging to implement in areas where the water body and area affected by a flood are transboundary, i.e., on different sides of a border.

moraine
regional cooperation

4.2.3 Flash floods Impact Forecasting

Flash floods are rapid and destructive flooding events can occur within a few minutes or hours after a heavy rainfall. They are caused by intense rainfall or the sudden melting of snow or ice, which can overwhelm the capacity of rivers, streams, or drainage systems. Flash floods are characterised by their unpredictability, high velocity, and destructive power,

unpredictability

Fig. 4.2: National seismological network

Source: Mishra, 2023

Map not to scale

impermeable surfaces
urbanization

which can result in the loss of human lives and damage to infrastructure and property. Flash floods are highly prevalent in the Himalayan regions, most common in arid and semi-arid regions with steep slopes, low vegetation cover, and high soil erosion rates (Fig. 4.3). The severity and frequency of flash floods are also influenced by climate change, land use changes, and urbanization. For example, the increased use of impermeable surfaces such as concrete and asphalt in urban areas can reduce the amount of water that can be absorbed by the soil, leading to an increase in runoff and flash floods.

infrastructure
damage

Flash floods are highly dangerous due to their speed and force, and can cause significant damage to infrastructure and property. They can also cause soil erosion, landslides, and damage to crops and livestock. In addition, flash floods can pose a significant risk to human life, as they can trap people in their vehicles or homes and can result in drowning, electrocution, or injury from floating debris.

rainfall forecasting
flood control structure

Flash floods can be predicted and monitored using various methods such as rainfall forecasting, river flow modelling, and satellite imaging (Fig. 4.4). However, the effectiveness of these methods depends on the availability of accurate and timely data, and the capacity of local authorities to respond quickly to flood events. To reduce the risk of flash floods, mitigation measures such as the construction of flood control structures, land use planning, and early warning systems can be implemented.

4.3 Mitigating Natural Disasters: Advancements in Early Warning Systems

4.3.1 Earthquake Early Warning

critical facilities
nuclear plants

Earthquake early warning systems have been developed to alert people of impending earthquakes. The concept was first introduced in America in 1868 by Cooper, who noted earthquake occurrences and predicted future ones. In Japan, Nakamura conducted research on the shaking mechanism to develop early warning systems. However, there is a blind zone where people are not able to be alerted to ground motion that has already started, and the accuracy of these warning systems is not always guaranteed. Early warning systems are crucial for industrial purposes as they provide the opportunity to shut down critical facilities, such as nuclear plants, and for people to take safer positions. The MoES in India is working to develop a regional early warning system using local sensors and shorter warning periods. However, there are challenges, including the lack of medical facilities and the need for accurate estimation of the main cracks of the CAV.

surface wave
epicenter

Earthquake early warning systems are designed to send notifications through communication channels before the arrival of destructive seismic waves, such as the S-wave or surface wave. The time it takes for shaking to reach the alert area can vary from seconds to minutes, depending on the distance from the epicenter. This response time can be maximized by minimizing delays in data processing, communication, and delivery of earthquake early warnings. Therefore, the farther a location is from the epicenter, the greater the potential warning time. The effectiveness of an earthquake early warning system relies on the ability to reduce delays in the various stages of information processing and dissemination, ultimately allowing for more time for individuals to take protective action.

minimising delay protective action

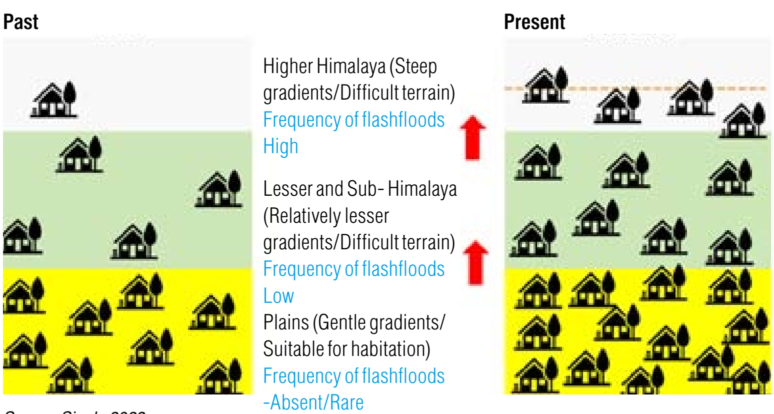
The IIT, Roorkee has also developed an early warning system with support from the MoES, but the recent (November 2022 and January 2023) Nepal earthquake highlighted the need for improved systems. The PPA regional earthquake early warning system for the safety of important structures involving nuclear, thermal, hydroelectric power plants; gas and electric supply network, and the transportation systems postpile strainmeter early warning system proposed by the NCS uses spectral kernel frequency estimation to determine earthquake strength. The computational circuit uses real-time mode and the suspect propagation path to determine areas of potential damage.

regional earthquake early warning system

4.3.2 GLOF Early Warning

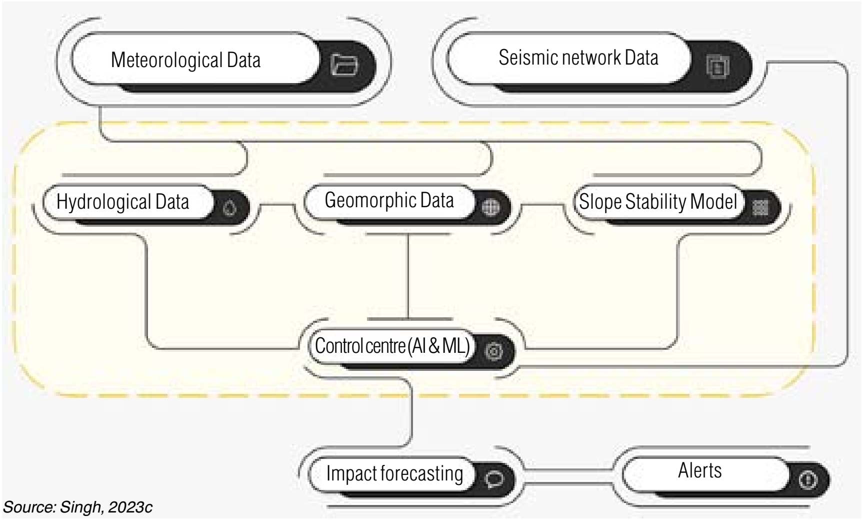
India, Bhutan, Nepal, and other countries in the Himalayan region face significant risks from GLOFs. To mitigate these, several projects have been implemented, including

Fig. 4.3: Himalayan Scenario



Source: Singh, 2023c

Fig. 4.4: Flowchart demonstrating Impact Forecasting Modelling



Source: Singh, 2023c

Thorthormi Tsho
Imja
Tsho Rolpa
PunatsangChhu
PhoChhu

the Thorthormi Tsho, Imja, and Tsho Rolpa glacial lake risk mitigation projects. The Thorthormi Tsho project was carried out between 2008 and 2012 with a budget of USD 4.23 million and co-financing from the Royal Government of Bhutan. It involved lowering the lake level by 5 m and installing a comprehensive early warning system in the PhoChhu and PunatsangChhu valleys. The project identified 31 vulnerable communities that benefited from the mitigation measures.

automatic sirens

The Imja glacial lake risk mitigation project was implemented at an altitude of 5,004 m in Nepal. It involved the installation of sensors and automated early warning sirens linked with a dynamic mass SMS alert system polygon. The project benefits over 71,000 vulnerable people living in 27 settlements. The ICIMOD provided technical support in the project's design. The Tsho Rolpa glacial lake risk mitigation project was implemented in Dolakha, Nepal, at an altitude of 4,580 m. It involved siphoning water to lower the lake level and excavating a three meter wide channel to lower the lake level further. The project also installed an early warning system with 19 automatic sirens in 18 villages, which was upgraded in 2015.

These glacial lake risk mitigation projects have been crucial in reducing the risk of GLOFs in the Himalayan region. By lowering lake levels and installing early warning systems, these projects have helped protect vulnerable communities and infrastructure from the devastating effects of these floods.

4.3.3 Flash Flood Impact Forecasting in Himalayas

Kedarnath
impact forecasting
decision making
preparations

In the past, early warning systems have provided information about impending disasters, but often without an accurate assessment of the potential impact. For example, during the Kedarnath disaster in India, the IMD issued warnings about heavy rainfall in the area, but the warnings did not provide information about the potential consequences of the rainfall. As a result, many people in the area stayed in their hotel rooms, believing that they were safe, but were later swept away in the disaster. Impact forecasting takes into account the potential consequences of an event, such as the number of people likely to be affected, the extent of the damage, and the resources required for recovery. This information helps decision-makers prioritize their response efforts and allocate resources accordingly. For example, if impact forecasting predicts that a particular area is likely to be hit hard by a disaster, decision-makers can allocate more resources to that area to ensure that the necessary preparations are in place.

In recent years, there have been significant advancements in impact forecasting technology. For example, the use of artificial intelligence and machine learning can help predict the potential consequences of a disaster based on historical data and real-time information. Additionally, new debris flow detection technologies using seismic approaches have been developed to detect potential landslides and other disasters before they occur.

4.4 Challenges

Despite the advancements there are several challenges in developing early warning systems. The challenge faced in earthquake early warning systems is the response time, or lead time, which is crucial for saving lives. The time it takes for seismic waves to travel to different locations can vary greatly, with a minimum of six seconds to reach Dehradun and 66 seconds to reach Delhi. Even a fraction of a second can be important for safety, so it is essential to develop the technology to predict earthquakes. This requires leveraging advancements to understand the predictability of earthquakes based on valid principles in physics. There are many tectonic processes that contribute to earthquakes, and the history of the seismo-tectonic zone provides a long term early warning for understanding where to live and what to do in case of an earthquake. It is important to take advantage of this information for earthquake warning and develop a system similar to monsoon, storm, cyclone, and tsunami warning. An early warning system for earthquakes is an urgent need, as there are many tectonic deformations in the Himalayan range and surrounding areas that have the likelihood to generating significant earthquakes.

seismic waves
seismo-tectonic zone

The NCS is monitoring earthquakes across the range of 0 to 40 ° N and 60 to 100 ° E, with 152 seismological stations across the country and are continuously increasing the number of stations to understand earthquake records and behaviour, and are analyzing seismograms to provide earthquake parameter warnings. However, providing this information to the public quickly enough is the challenge, as earthquakes can destroy in a matter of minutes (Mishra, 2023).

seismological stations

The earthquake early warning system currently in place is more of a post earthquake disaster phase early warning, providing information on the latter phase arrivals of seismic waves such as shear and surface waves. The warning system involves creating shaking maps to understand the maximum and minimum areas impacted by the earthquake. It is crucial to determine which disastrous phase is going to hit where and at what time to provide adequate warnings. Challenges in developing an early warning system include making the network dense enough to provide accurate information and avoiding false alarms that could cause chaos. Himachal Pradesh has been selected as a testing ground for the early warning system, and it is hoped that significant progress will be made within 2023-2024.

testing ground

In the case of glaciers, there is the lack of continuous mass balance series data, which is crucial in understanding glacier behaviour. Accurately predicting the effect of a disaster still poses a challenge. For instance, monitoring a large number of potential disaster zones can be difficult, and not all areas may be monitored equally. Additionally, the accuracy of impact forecasting is often limited by the availability of historical data and real-time information. Hence, impact forecasting is an essential tool in mitigating disasters and making informed decisions for communities and governments. While there have been significant advancements in impact forecasting technology in recent years, there are still challenges to accurately predicting the impact of a disaster. By improving monitoring and collaboration

mass balance
potential disaster zones
mitigating disasters

between different agencies and organisations, there is a potential to continue to improve the ability to predict and prepare for disasters.

4.5 Recommendations

Despite encountering numerous obstacles when it comes to impact forecasting and developing an early warning system, following recommendations can be adopted for disaster preparedness and enhancing our early warning systems.

i. Earthquake early warning systems require sufficient response time and increased number of seismological stations (Mishra, 2023).

ii. Providing earthquake parameter warnings quickly is essential to save lives, which may be enhanced through networking and involvement of local agencies (Mishra, 2023).

iii. More comprehensive and standardised monitoring of potential disaster zones is needed for improved impact forecasting (Jackson, 2023).

iv. New technologies like UAVs and remote sensing can be used for data collection in potential disaster zones (Singh, 2023c).

v. Improvement in modelling efforts required, especially for cryospheric changes (Ravichandran, 2023a).

vi. Need to generate more knowledge to gain a better understanding of cryospheric changes and their potential impacts (Ravichandran, 2023a).

vii. Effective adaptive and mitigation strategy required to mitigate risks and uncertainties (Ravichandran, 2023a).

viiii. There is a need to building regional , transboundary and global cooperation to address the problem of GLOF (Jackson, 2023).

One-fourth of the global heat uptake occurs through heat transport pathways in the Indian Ocean and the lack of deep convection and ventilation in the region leads to oxygen minimum zones, impacting marine life; Lombok, Indonesia.

PHOTO COURTESY: LOMBOK

5. Analyzing Challenges around the Oceans

Oceans cover 75 per cent of the planet, cohesively connecting different continents. The significance of understanding and managing oceans for a sustainable economy and adaptation is increasing. There are obstacles in knowledge-solution gaps, infrastructural, foundational and governance-related challenges around the seas and oceans that need to be bridged in order to attain the outcomes for the Ocean Decade delineated in the United Nations decade of Ocean Science for Sustainable Development (2021-2030).

5.1 Introduction

Oceans worldwide play a crucial role in the sustenance of different ecosystems. Covering 75 per cent of the earth, they connect the other parts of the planet with the two poles into a coherent whole and provide diverse ecosystem services that ensure people's livelihood (Kumar, 2023b). The ecosystem services of oceans comprise a significant amount of oxygen-producing phytoplankton, a key to the existence of all life forms. Phytoplankton also serves as an indicator of oceanic warming (Tripathy, 2023).

While on one side, oceans drive the Indian monsoon, on the other, the ocean economy supply chains contribute to national and global GDPs. It supplies 90 per cent of global fisheries, 25 per cent of global biological productivity, and 25 per cent of world energy (Kumar, 2023b). In recent years the ocean economy model's orientation has shifted, and the sustainability aspect has been added, compositely known as the blue economy (Ibid.).

While the Indian Ocean plays a crucial role in meeting societal needs, it conflictingly exposes the coastal population to extreme weather events, climate change and sea-level rise. The Ocean also plays a significant role in the global climate system, as one-fourth of the global heat uptake occurs through heat transport pathways in the Indian Ocean. The region's lack of deep convection and ventilation leads to OMZs and impacts marine life. The Madden-Julian Oscillation, Indian Ocean dipole and teleconnections with other oceans and Poles influence the region's weather patterns. Operational drivers for the Indian Ocean include improving surface fluxes, ocean data assimilation systems, and sub-S2S forecasting (Kumar, 2023b). The oceanic territory is largely unexplored and mandates observations, which poses a challenge as it demands the development of innovative solutions.

OMZs

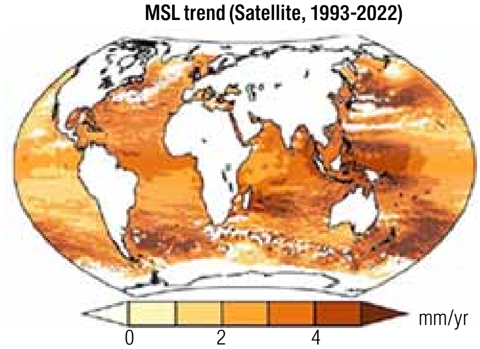
oceanic territory

5.2 Objectives and Challenges around the Oceans

The United Nations Decade of Ocean Science for Sustainable Development (2021-2030) aims to achieve the goal of 'science required to ensure the ocean we desire'. This initiative provides a platform for various stakeholders to collaborate on designing and implementing research. It offers practical solutions to support the objectives of the 2030 agenda for a healthy ocean. The United Nations Decade of Ocean Science for Sustainable Development emphasises the significance of capacity building, promoting ocean literacy,

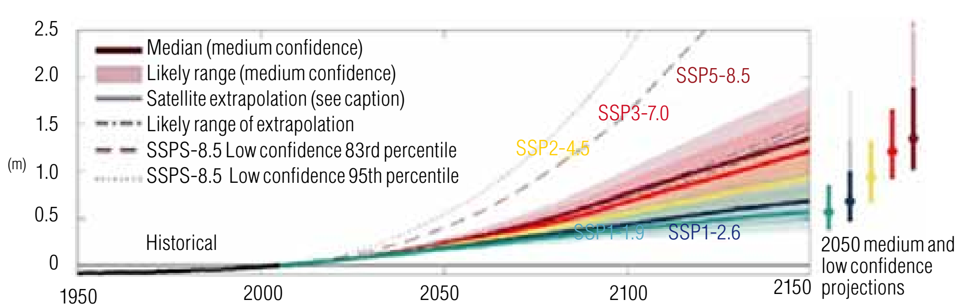
2030
ocean literacy

Fig. 5.1: Trends in global sea level taken from AVISO data and sea level projections



Source: Swapna, 2023

Fig. 5.2: Projected mean sea level rise under different scenarios



Sea levels along the entire Indian coast are rising faster than the global average: WMO report 2022. Rate of sea-level rise was 4.7 mm/yr (global) and 5.5 mm/yr (IO), 2013 to 2020

Source: Swapna, 2023

and eliminating obstacles to achieving gender, generational, and geographic diversity. The challenges around Oceans can be categorised into three broad pillars: knowledge and solution, infrastructural and foundational (Kumar, 2023b).

5.2.1 Knowledge-Solution Challenges

marine resources

The knowledge solution challenge highlights the information gap and the associated solutions for oceanic ecosystems. For instance, knowledge about marine pollution, threats to coastal ecosystems, environmental and climatic variables, sustainable utilization of marine resources, etc. needs to be augmented. Also, understanding the relationship between ocean-climate interactions and their dynamic impacts on oceans and surrounding ecosystems needs to be developed. The impact of various stressors on the ocean ecosystems to develop strategies for monitoring, protecting, and restoring the ecosystem and biodiversity needs to be understood.

5.2.2 Infrastructural Challenges

harmful algal blooms
sea level rise
Greenland ice sheet

Infrastructural challenges include ocean-related risks/ hazards and the need for ocean observation and digital representation to address these hazards. Ocean-related risks and hazards such as rise in sea level, harmful algal blooms, destructive storms and unpredictability require significant investment and development of relevant technologies. Out of all the potential hazards, the threat of sea level rise ranks topmost, impacting communities adversely, particularly those living along the coasts. A rise in global temperatures, the consequent melting of glaciers, and the thermal expansion of seawater are causing sea levels to rise. For instance, the Arctic is warming, causing the Greenland ice sheet to melt at an accelerated rate. Glaciers cover a tenth of the planet's land surface, a significant part of which lies in Greenland. The melting Greenland ice sheet can contribute to 24.5 per cent of the sea level rise (Swapna, 2023). Also, oceans absorb 93 per cent of the sun's heat, leading to the thermal expansion of oceanic water (Shenoi, 2023). This expansion increases the volume of overall water, leading to a rise in sea levels. Effective strategies can holistically address rising sea levels and require an intense understanding of such and more underlying mechanisms.

Furthermore, the variability in the global rate of change in sea levels needs to be understood in greater detail. For instance, sea levels in the Indian Ocean have been rising at a rate of 5.5 mm per year from 2013-2020 compared to the global rise of 4.7 mm per year (Fig. 5.1 and 5.2). The Indian Ocean region, therefore, faces a faster sea-level rise, well above the global average (Swapna, 2023) and poses a considerable challenge for India and its coastal communities.

CISM
IITM-ESM

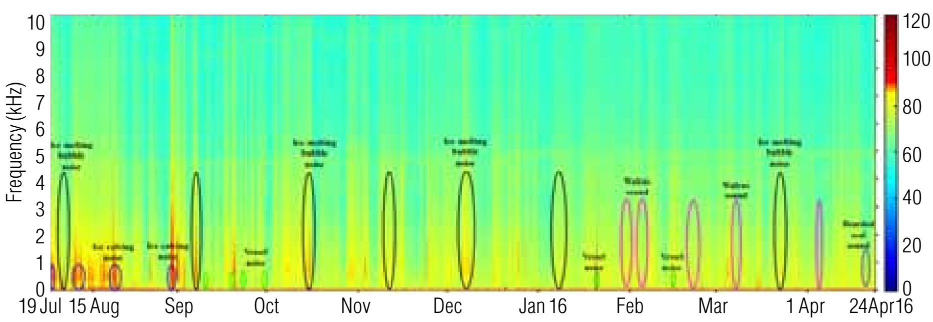
Various models, such as CISM and IITM-ESM, predict the current sea level rise and future scenarios (Swapna, 2023). As per the simulations done by the IITM model, the potential impact of Greenland ice melt will likely change the surface level of oceanic waters. For instance, freshwater inflow may impact the oceanic waters' thermohaline in the Atlantic, changing the temperature and salinity in deeper layers, over 2,000 m. The circulation pattern in that scenario would become slow, and with the further melting of glaciers, the global oceanic conveyor belt is predicted to be weakened by about 25 per cent (Swapna, 2023).

As per a new study, between 2000 and 2019, glaciers collectively lost 267 billion tonnes of ice annually (Ramesh, 2023). Assuming all the water from melting glaciers eventually reaches the ocean, its contribution to sea level rise can be estimated at 0.74 mm yearly. Furthermore, the 'thinning rate' of glaciers has also accelerated. On average, glaciers' annual 'thinning rate' was 36 cm in 2000 but increased to 69 cm by 2019 (Ibid.).

thinning rate

The geographical features or the landlocked nature of the Indian Ocean further enhance the rise in the sea level, with increased heat retention resulting in significantly rising

Fig. 5.3: Soundscape components and temporal patterns in the Kongsfjorden, Arctic Ocean



Source: Latha, 2023

Months

temperatures (Swapna, 2023). However, the drivers of sea-level rise are different for different regions. In the global sea level budget, 38 per cent of sea level rise is attributable to thermal expansion (Ibid.). With relevant infrastructure and technological solutions, these challenges may be addressed.

sea level budget

5.2.3 Foundational Challenges

Foundational challenges relate to capacity building in domains, such as technical skilling across all domains to move from the 'Ocean we have' to the 'Ocean we want'. Another aspect of achieving this vision is the behavioural, stemming from humanity's connection with the oceans. Both issues demand a fundamental change in the approach toward sustainable ocean use. Oceans are dynamic and offer a 'sea of opportunities' (Ravichandran, 2023b). However, with opportunities, there are 'sea of challenges' too (Shenoi, 2023). Climate change, plastic pollution and competing interests for marine resources present challenges with potentially dire consequences. The blue economy model will also likely have repercussions in the coming years (Shenoi, 2023).

sustainable ocean use
plastic pollution

Ocean observation and monitoring systems help understand trends. However, Acoustic recordings innovations

maintenance and deployment of the ocean observation and monitoring systems are complex due to their substantial power requirement (Latha, 2023). Acoustic recordings consisting of high-frequency samples at 50kHz, sampled autonomously every ten minutes for a year, require significant power (Fig. 5.3). This power requirement in the subsea provides scope for technical innovations.

forecasting warning systems

Robust observation, monitoring and forecasting and warning systems, relevant data sets, digital representation of the oceans and other efficient technologies need to be developed. It can facilitate understanding the current state of oceans, how they are changing, their potential impacts, and appropriate steps to adapt to these changes (Kumar, 2023b).

Capacity building policymakers

Capacity building and skilling the stakeholders–scientists, policymakers and civil society people to better manage the oceans and sustainable utilization of resources is the need of the hour. There is a lack of awareness among the public in terms of the influence of the ocean on climate change and vice versa. The youth must be motivated and enthused to undertake oceanic research and opt for ocean-based careers to achieve Sustainable Development Goal 14: 'conserve and sustainably use the oceans, seas and marine resources for sustainable development' (Atmanand, 2023).

5.2.4 Governance Challenges

treaties UNCLOS BBNJ

Various international laws and treaties govern the oceans. Being part of the global commons, the seabed, ocean floor and subsoil of the oceans are governed by UNCLOS with the clause that no state shall claim or exercise sovereignty or sovereign rights over any part of the area or its resources (Parmar, 2023). The ISA under the UNCLOS is entrusted with the seabed and sub-seabed areas beyond the national jurisdiction and authority over international waters. While the recently signed BBNJ Treaty, also under UNCLOS, envisions governing the high seas to protect biodiversity. It includes environmental impact assessment, marine protected areas, transfer of technology and capacity building, amongst others (Rajan, 2023).

The diverging and converging of such mechanisms lead to challenges to the governance of oceans with ambiguities and conflicting nature of the laws; the discordance between scientists and technologists on the one hand and legal brains on the other hand; and personal prejudices among the stakeholders against and for the law of the sea (Rajan, 2023). Additionally, nations vying for existing and potential resources is a matter of governance (Parmar, 2023).

ISA

The overlapping mandates of ISA and BBNJ may bring the authorities into conflict with each other (Rajan, 2023). Also, the effectiveness of BBNJ lies in its implementation, which depends on the subjective interpretation of nations (Parmar, 2023). However, the body has been paradoxically criticized and praised for its work (Rajan, 2023). Moreover, non-signatory countries of the UNCLOS are not bound by its regulations.

5.3 Ocean Decade Outcomes

It is important to promote clean, healthy, resilient, productive, predicted, safe and accessible oceans, whether it is in the coastal regions or beyond national jurisdiction (Meenakumari, 2023). The ocean decade outcomes aim to inspire and engage people to take action for ocean conservation. The programme addresses the growing concerns of marine pollution, plastic waste, and climate change impacts on the ocean's health and resilience. The outcomes also aim to promote sustainable and responsible use of ocean resources while protecting the ocean's biodiversity and ecosystems. Through collaborative efforts and innovative technologies, India will strive to create a more sustainable and prosperous future for the Indian Ocean region and the world.

accessible oceans
national jurisdiction
innovative technologies

5.4 Recommendations

In order to address the challenges around oceans and attain the ocean decade outcomes, the following recommendations are made:

i. The energy potential of oceans should be utilized through the OTEC technology with good scalability (Atmanand, 2023).

ii. India possesses a coastline stretching 7,500 km, with a capability to generate 140 GW of offshore wind energy. Measures should be taken to utilize this potential (Atmanand, 2023).

iii. Developing advanced instruments to measure small changes in ocean observations and making them globally accessible is crucial for tackling pressing issues like global warming and ocean acidification. These instruments can aid in forecasting, evaluating data, and creating models for the ocean and atmosphere (Atmanand, 2023).

iv. New technologies should be developed along with conventional methods to clean the beaches. Technologies like ocean-cleaning robots and other litter traps should be developed (Atmanand, 2023).

v. Research on bio-plastic should be done to develop a sustainable alternative to plastic pollutants (Atmanand, 2023).

vi. Cost-effective newer technologies should be developed for carbon capture and sequestration to capture them in deep earth and oceans (Atmanand, 2023).

vii. To address the lack of awareness about the influence of oceans on climate change, youngsters should be encouraged to take up an ocean-based career (Atmanand, 2023).

viii. The rate of sea level rise along the Indian Ocean was 5.5 mm/yr from 2013- 2020 (Swapna, 2023). Restricting construction along vulnerable areas and preparing the population for planned relocation should be arranged as an adaptation measure.

ix. For better ocean observations, autonomous recording systems of high sampling frequency with enhanced power capabilities that can work for more than one year are needed (Latha, 2023).

India's coastline can be used to produce wind energy, which can then generate green hydrogen that can have a transformative effect on the nation. Offshore wind farms, North Sea.

PHOTO COURTESY: HTTP://HARICHARANAM.BLOGSPOT.COM/

6. Innovating Technologies or Climate Change Solutions

The most poignant phenomenon that humanity is witnessing due to the rise in global temperature is climate change, which leads to changes in the cryosphere, weather, climatic patterns, and oceanic circulations, among others. The recent IPCC AR6 Report shows that the average global temperatures have risen by 1.1°C compared to pre-industrial levels. There are various implications of this rise on diverse ecosystems. The urgency and uncertainty attached to the phenomenon require climate solutions encompassing different domains. This chapter highlights innovative technologies employed or likely to be employed in the energy sector, assessment of hydrological and oceanic resources, solutions regarding climate-based disasters, and the challenges and opportunities to redress these concerns.

6.1 Introduction

The impact of climate change on ice and the cryosphere is alarming. According to the IPCC AR6 assessment and special report, anthropogenic factors influence the climate. Recent findings indicate that the temperature in 2022 was approximately 1.1 degrees warmer than the pre-industrial climate due to greenhouse gases (Krishnan, 2023). Gases, such as CO_2, methane, nitrous oxide, and HCFCs, trap heat, leading to an accelerated rate of warming. However, there is variability in the spatial warming pattern, resulting in a non-uniform surface temperature increase. As mentioned in the report, the Polar Arctic has experienced the most significant warming. Similarly, the Indian Ocean has witnessed the highest levels of sea level rise compared to other regions (Swapna, 2023).

Climatic solutions are necessary to address climatic concerns and facilitate a sustainable transition for global economies. It entails implementing measures in energy alternatives, sustainable utilisation of oceanic and hydrological resources, and identification of new resources. These advancements can enhance observations, data aggregation, modelling, and prediction.

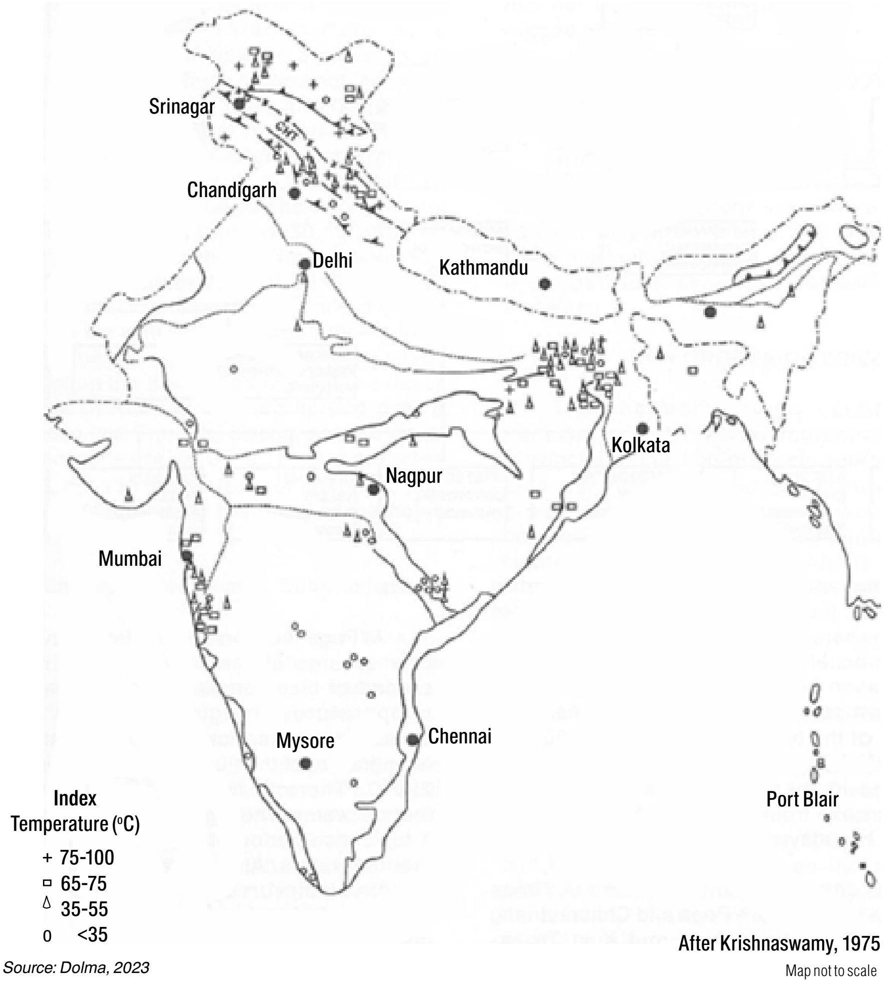
6.2 Clean Energy Solutions

6.2.1 Hydrogen Energy

Hydrogen, a high-density energy source, has the potential to emerge as a sustainable alternative to conventional energy sources. It is ten times more efficient than petrol or diesel (Singh, 2023a). Hydrogen can be extracted through electrolysis, splitting water into oxygen and hydrogen. The resulting hydrogen can be a high-density fuel, aligning with India's Net Zero 2070 vision. When renewable energy is used in electrolysis, the hydrogen is considered renewable.

Net Zero 2070 vision

Fig. 6.1: Geothermal in India



Source: Dolma, 2023

light fuel
liquefied

Hydrogen is a light fuel, eight times lighter than oxygen, increasing transportation costs. Therefore logistical challenges are associated with the supply chain of hydrogen energy. In order to transport the hydrogen from remote areas, it must be liquefied at -253°C and transferred to tankers (Singh, 2023a). Despite these challenges, there are economical ways to produce hydrogen. Scaling up hydrogen production is necessary to make it affordable and accessible. For example, caustic soda plants produce hydrogen as a byproduct (Atmanand, 2023). Situating a hydrogen plant near a caustic soda plant can provide a cost-effective option.

cost-effective

wind energy production
fertilizer industry

India's extensive coastline of 7500 km offers opportunities for hydrogen production from oceanic water (Singh, 2023a). The coastline can also be utilized for wind energy production, further enhancing the potential for generating green hydrogen. Producing hydrogen can have a transformative effect on the fertilizer industry, as hydrogen is a crucial component in ammonia production for urea. The transportation sector can also transition to sustainable practices by adopting green hydrogen. With zero emissions and high energy density, 1kg of hydrogen can provide a mileage of 116 km using existing technologies, with the potential for further improvement (up to 150 km) with technological advancements.

6.2.2 Geothermal Energy

geothermal heat pump
hydrothermal

Geothermal energy, harvested from beneath the ground, is a significant source of energy (Dolma, 2023). Its resources can be classified into three categories: geothermal heat pump, hydrothermal, and enhanced geothermal systems. Based on temperature, geothermal energy can be divided into low-temperature fields (below 190°C) and high-temperature fields (above 190°C). In India, most fields fall under the low-temperature category ranging from 75 to 80°C (Ibid.).

Flash steam plants

hydrothermal fluids

Various technologies are employed to extract geothermal energy, depending on the nature of the source. Flash steam plants, the most common type, utilize fluids exceeding 182°C (Dolma, 2023). These fluids are pumped from underground and undergo a pressure change, causing some fluid to transform into vapour rapidly. The vapour then drives a turbine, generating electricity. On the other hand, dry steam plants primarily utilize steam hydrothermal fluids, which are less common. The steam is directly sent to a turbine to generate electricity. Dry steam power plants have been in use since 1904, with the oldest plant located in Lardarello, Italy (Ibid). Steam technology is still used at northern California Geysers, the world's largest geothermal power source.

geothermal policy

Utilizing geothermal energy poses several challenges. In India, developing enhanced geothermal systems in low-temperature fields requires significant investment (Dolma, 2023). Moreover, the absence of a geothermal policy discourages foreign investment due to the need for stability and clarity in the sector.

India has implemented a demonstration project in Puga, Ladakh, and other potential geothermal sites, including Manikaran in Himachal Pradesh, Sohna in Haryana, and

Demchok in Ladakh (Dolma, 2023) (Fig. 6.1). With the increasing costs of coal and oil, geothermal energy offers a clean alternative, reducing dependence on imports. Additionally, it can support remote households and contribute to the development of resource parks, benefiting small businesses and attracting tourists.

clean alternative

6.2.3 Ocean Thermal Energy Conservation

India's Intended Nationally Determined Contributions aim to achieve a 500 GW installed energy capacity from non-fossil fuel sources by 2030. One potential alternative to traditional clean energy resources is OTEC, Ocean Thermal Energy Conversion. The technology harnesses the temperature difference between the ocean's surface and depths (Atmanand, 2023), converting it to energy. However, it is crucial to consider scalability when considering OTEC as a viable energy source in order to make it cost-effective.

non-fossil fuel
OTEC

cost-effective

6.3 Innovative Technologies for Assessing Hydrological Resources

Groundwater is crucial for sustainable agriculture and livelihood in India and for recharging aquifers. However, there needs to be more understanding of the complex aquifer system in the country (Tiwari, 2023). Due to changing and dynamic factors, innovative technologies are necessary to assess and utilize hydrological resources (Ibid.).

A robust information and knowledge system for replenishing groundwater and mapping aquifers is urgently needed. Airborne and satellite-based models can provide a quality output based on input data from these technologies. India has recently adopted EVRI as a novel method for 3D subsurface mapping (Tiwari, 2023). Unlike conventional electrical imaging, EVRI measures voltage and current flow, making measurements possible in areas without electrodes. The wireless nature of this technology enables observations and notes in locations where traditional electric imaging techniques are not feasible. Using these techniques, a demonstration project in Hyderabad successfully mapped the flow of groundwater, which is essential for managing agricultural water resources (Ibid).

EVRI
electrical imaging

groundwater

Additionally, mapping groundwater flow will facilitate the placement of percolation tanks to recharge groundwater and aquifers. This method can also help identify the depth of groundwater flow, creating various opportunities. Another technique for aquifer mapping is the heli-borne geophysical mapping technique, which provides a 3D subsurface image up to a depth of 500 m (Tiwari, 2023). This technique covers large areas quickly and has led to the discovery of contaminated and uncontaminated aquifers in the Ganga Basin. Numerical simulations at the sub-basin level can assist in identifying groundwater possibilities in arid regions, addressing the nation's water issues.

percolation tanks
aquifers

heli-borne

contaminated

Space-based technologies are also employed for hydrological observations and modelling, such as estimating the rate of evapo-transpiration in the Ganga Basin, which is estimated to be 23 per cent (Tiwari, 2023). This knowledge aids in preparing water budgets for the region.

Space-based
evapo-transpiration

groundwater depletion
hard rock

The challenges in assessing hydrological resources in the country include a need for more understanding of subsurface precipitation and storage due to variability in subsurface hydrology. Water contamination is also a significant issue, along with groundwater depletion and rugged terrains of hard rock and heterogeneous formations–a challenge for groundwater flow and transportation modelling (Tiwari, 2023).

water security
food security
spatial resolutions

Addressing these requires linking science with local scientific problems related to water security, food security, and environmental flow to develop sustainable solutions for the earth system. Given that over 70 per cent of India's subsurface conditions are heterogeneous, innovative technologies for mapping the subsurface, aquifers, and their depths with high spatial resolutions are necessary (Tiwari, 2023).

6.4 Innovative Technologies to Harness Oceanic Resources

Blue Economy
sustainability

India has recently released its draft policy framework on the Blue Economy, a model of economic development based on the ocean economy with a focus on sustainability (Kumar, 2023b). Understanding the scientific drivers of ocean dynamics and the interaction between climate and oceans is essential in this context.

underwater instruments
deep-sea mining
underwater imaging

To conserve and preserve oceans and implement the Blue Economy policy, India has launched the Deep Ocean Mission worth INR 4800 crores (Murthy, 2023). This Mission aims to develop innovative technologies for underwater instruments, deep-sea mining remotely operated vehicles, underwater imaging, autonomous scoring systems, manned submersible vehicles, and underwater mining systems to harness resources sustainably.

Matsya 6000
research vessel
Sagar Nidhi

One of the technologies developed under this Mission is Matsya 6000, a manned submersible capable of travelling to a depth of 6000 m in the ocean. It has positive buoyancy and features a watertight pressure hull and lights for subsea visibility. The submersible's underwater thrusters enable subsea research, surveying, sampling, and intervention (Murthy, 2023). The research vessel Sagar Nidhi also plays a significant role in the mission for geo-scientific, meteorological, and oceanographic research.

high-pressure conditions
low soil strength
power requirements

The development of Matsya 6000 challenges include spear design, system welding, high-pressure conditions, system configuration, and a life support system. Similarly, the underwater mining system faces challenges in the oceanic ecosystem, such as high-pressure conditions, low soil strength, power requirements, and drag forces (Murthy, 2023). Overcoming these obstacles is essential to harness the oceans' opportunities sustainably.

deep ocean survey
exploration

Developing such technologies will enable India to provide ocean and climate change advisory services, sustainable utilization of resources such as minerals, energy, and freshwater, exploration and conservation of deep-sea biodiversity, deep ocean survey and exploration, and establishment of advanced marine stations for ocean biology. These innovative means can also raise awareness among the public, students, academia, and other communities about the earth system.

6.5 Ocean-Based Observations

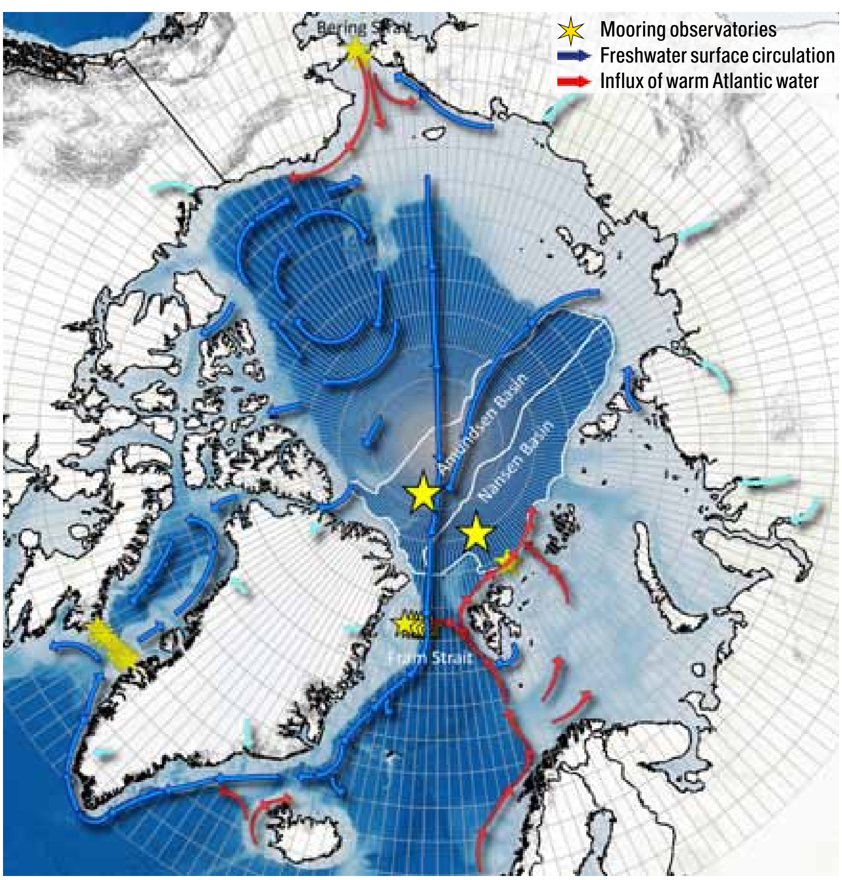
Understanding the interaction between ice-sheets, climate, and the ocean is now more important than ever. The latest IPCC Report highlights sea level rise as a significant source of uncertainty for the future. Measuring sea level rise involves determining the difference between ice flow discharges and snowfall. Regional climate models estimate snowfall, while ice flow discharge results from ice flow speed and thickness. Measuring ice thickness requires intensive topographical research, comparing ice surface and bed elevation.

topographical research

Topographical research and ocean observation are data-intensive processes. Modelling and developing prediction systems rely on diverse datasets, making data collection crucial. In addition to data availability, the accuracy of input data is vital. Therefore, fieldwork plays a significant role in accumulating accurate data and informed modelling efforts. Consequently, investing more resources in fieldwork becomes necessary.

data-intensive

Fig. 6.2: New Central Arctic Observing System



Source: Dodd, 2023

ice-sheet dynamics
sea level rise
ice flow
Drones

Furthermore, the challenge arises in determining the most effective means of collecting data to study ice-sheet dynamics and understand their role in rising sea levels. Jets flying at high altitudes make obtaining detailed information about the bed topography beneath the ice sheets nearly impossible. One alternative is to fly at lower altitudes using smaller aeroplanes, which, however, require refuelling every 1000-2000 km (Matsuoka, 2023). Moreover, technologies like satellite remote sensing are used for the regular monitoring of ice sheet surface, but measuring the bed elevation accurately from satellites is difficult. The lack of relevant and precise bed topography data hampers significant investment in satellite technology to answer sea level rise questions. Consequently, the availability of advanced computational technologies is crucial for further advancements in climatic research (Matsuoka, 2023). Additionally, apart from the need for innovation in computational technologies, technologies such as ice-penetrating radars are critical for understanding and calculating ice flow. Drones can also be deployed to study ice-sheet dynamics (Matsuoka, 2023).

vulnerable
2100

As widely known, nations and communities are vulnerable to climate change and its implications. For instance, by 2100, nearly 12 per cent of India's population will be significantly affected by sea level rise along with many economic centers located along the coast that are exposed to this threat. It is necessary to understand the contributing factors to be better prepared (Matsuoka, 2023).

Antarctic RINGS
Action Group

The vulnerability of coastal regions necessitates the development and enhancement of research capabilities. International, multi-stakeholder initiatives have been undertaken in the Antarctic and the Arctic to improve observations, modelling, and predictions. For instance, the Antarctic RINGS Action Group, under the Scientific Committee on Antarctic Research, is an international effort aimed at providing more accurate and comprehensive reference bed topography data to enable robust assessments of ice discharge from all regions of Antarctica, thereby enhancing the accuracy of ice-sheet modelling and mapping of grounding zones. The initiative also seeks to quantify ice-ocean interactions and pursue other related goals. The consortium plans to conduct geophysical surveys across the Antarctic ice sheet using aeroplanes equipped with multiple sensors, including ice-penetrating radars, magnetometers, and gravimeters, to assess surface mass balance and other factors (Matsuoka, 2023). This opportunity facilitates multidisciplinary research and the generation of robust datasets for assessments.

NPI
Amundsen
Nansen
Ice Profiling

Similarly, the Central Arctic Monitoring System has deployed moorings to observe the Arctic Ocean. The NPI has installed two moorings at the Amundsen and Nansen basins of the Central Arctic Ocean (Fig. 6.2). These moorings are equipped with various technologies, including Sonar, acoustic current profiler, Ice Profiling, SUNA, automatic water samplers, acoustic recorders, and sediment traps (Dodd, 2023). These technologies enable ocean observation beyond collecting long-term measurements at peripheral straits.

6.6 Recommendations

i. The knowledge about geothermal utilisation must be disseminated, along with capacity building through trainings, and short courses (Dolma, 2023).

ii. Geothermal tourism should be popularized as an energy source and a pilgrimage site, and site-specific demonstration projects should be planned (Dolma, 2023).

iii. The absence of a geothermal policy can act as a deterrent for foreign investors who are interested in investing money in geothermal development. Therefore, it is essential to implement a geothermal policy to attract such investors. (Dolma, 2023).

iv. As the grounding line of Antarctica measures approximately 62,000 km, which is larger than the earth's circumference of 40,000 km, there is a need for significant international collaboration to monitor it. It entails creating and merging regional initiatives to generate uninterrupted data (Matsuoka, 2023).

v. Frequent usage of drones can improve understanding of sea-ice dynamics (Matsuoka, 2023).

vi. A self-propelled track-based seabed mining system is required to address the challenges of manned submersibles due to ocean dynamics (Murthy, 2023).

vii. Innovative technologies for mapping groundwater and aquifers can enable the mapping of subsurface aquifers and their depths with spatial resolutions (Tiwari, 2023).

viii. Development of newer instruments capable of measuring subtle variations in ocean observations for effective forecasting, data assessment, and ocean and atmospheric modelling are significant requirements (Atmanand, 2023).

The maritime space that is of India's utmost concern is the Indo-Pacific which holds great strategic importance; Jakarta, Indonesia.

PHOTO COURTESY: WILLIAM WILLIAM

7. Values of UNCLOS in Indo-Pacific Maritime Security, Trade and Transport

Countries across the Indo-Pacific region consider UNCLOS as an important legal framework for maritime security. It is a convention to which the largest number of countries agree. It provides for resolutions to several maritime security issues and conflicts. Under the aegis of climate change, maritime security and trade are critically important because while the Arctic ice melt creates threats, it also creates opportunities for further exploration via new routes. The viability of such prospects, however, remains a matter of speculation; and in this case the availability and significance of the Northern Sea Route is also questioned.

7.1 Introduction

The legal framework on the marine activities and resources also defines maritime security. Especially, the legal framework of the UNCLOS is important for maritime security, with special reference to the Indo-Pacific region which holds global significance due to trade, transport and maritime safety. The level of national jurisdiction and control are increasing over the seas, oceans and marine resources. The possibility of better strategic outreach and the possibility of a conflict amidst cooperation is visible at the same time. UNCLOS upheld principles of equitable sharing and hence, it can promote sustainable use of maritime resources and the protection of the maritime environment (Parmar, 2023). Therefore, states continue to respect the UNCLOS provisions. The extension of the continental shelf is also an issue that draws conflict. Russia was the first Arctic nation to forward its claims for an extended continental shelf (Parmar, 2023). Ambiguities exist in the Laws of the Sea because of the perceived discordance between the scientists and technologies and because of jurisdictional problems (Rajan, 2023).

The legal framework of the UNCLOS is also important for the Strait of Malacca and the NSR, two of the most important routes that relate to the fate of the Indo-Pacific region, from the perspective of maritime security, especially bearing in mind the consequences of climate change. Various debates have emerged regarding the dynamic relationship between both the routes and its importance for the Indo-Pacific region, and by its extension, for India. A brief discussion on some of these aspects have been provided in this chapter.

7.2 Perspectives on Indo-Pacific Maritime Security

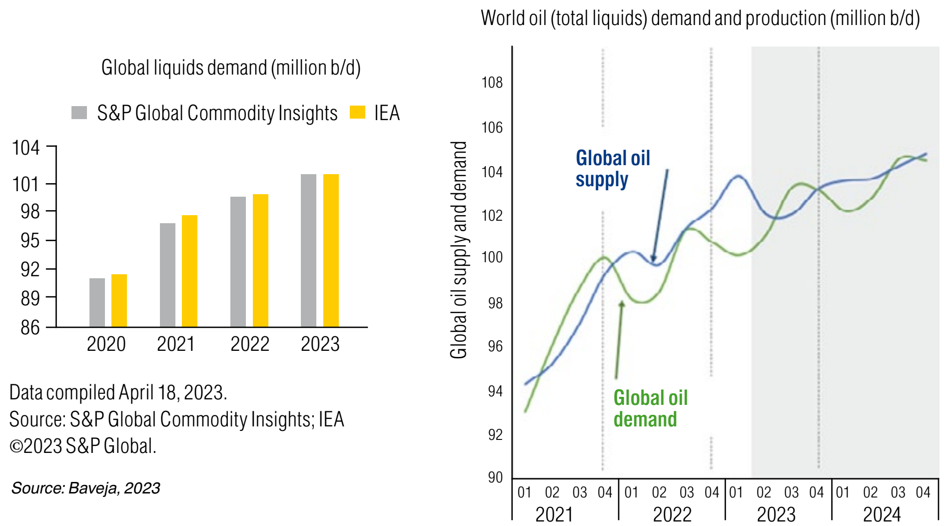
Historically speaking, sea ruled over land and this is this is true for India as well, ascribed to the large number of invasions and conquests since centuries. Transient political changes were brought by these invasions and led the foundation of new dynasties. However, India lost its Independence soon after it lost the command of the seas (Lahiri,2023). The British and Spanish colonialism spread through the seas. After Independence, India's maritime history became one of the building blocks for the construction of an oceanic perspective for an Independent India. The Indian Ocean has been relevant for about three centuries since Vasco da Gama arrived in India (Ibid.). India's great naval interest cannot be ignored, especially with China's presence in the South China Sea.

South China Sea

The maritime space that is of India's utmost concern in Indo-Pacific which holds great strategic importance for India. The shift from the Atlantic to the Pacific was a pivotal development for the Indian Ocean. However, it also laid an onus on India to awaken a maritime consciousness and to regain maritime glory (Lahiri, 2023). The Indo-Pacific

maritime consciousness

Fig. 7.1: The rising global demand for oil and natural gas



Data compiled April 18, 2023.
Source: S&P Global Commodity Insights; IEA
©2023 S&P Global.

Source: Baveja, 2023

nuclear power

ship borne energy

region is home to four most populous nations, the largest democracy and the largest autocracy in the world, four of the five largest economies, which comprise about 60 per cent of the world's GDP, and 2/3 of the present global growth, seven of the world's ten largest armies, the most sophisticated navies, and five of the world's declared nuclear powers (Ibid.). The Indo-Pacific region has nine of the ten biggest ports in the world and half of the entire world's container cargo, i.e., 50 and 70 per cent of ship-borne energy cargo flows through this area (Ibid.).

climate induced migration

maritime security

The Indo-Pacific is not an anomaly for India but rather an idea whose time has come. The activities in the region impacts the entire world (Lahiri, 2023). The major concerns with the Arctic ice melting and the rise in the sea level can be linked to climate-induced migration and refuge. Therefore, maritime security has become a serious issue in contemporary times.

7.3 The Relevance of the Strait of Malacca vs the Northern Sea Route

geopolitical tension

The impact of climate change in the Malacca Strait is visible, and the concern emerges mainly from the great significance of the Strait for the world economy (Srikanth, 2023). There has been speculation that the NSR can dilute the importance of the Strait of Malacca (Sharma, 2023a). The Strait connects all the emerging economies of the world and China's reliance on the crude oil is being fulfilled via the Malacca Strait. Meanwhile, China's control over Africa also makes the Strait crucial for the country. The number of ships sailing via Malacca and the NSR vary widely. Less than 100 vessels pass through NSR within a year, while about 80,000 vessels pass through the Strait every year (Ibid.). The global bulk carriers of oil and gas as well as coal mainly passes through the Strait. Fossil fuel is not likely to disappear from usage anytime soon and hence, the energy transition to clean energy is also distant (Fig. 7.1), which makes the Malacca even more critical to the world energy map. Moreover, there are infrastructural disadvantages of the NSR. For instance, ice-breaker vessels are necessary to navigate through the NSR, however, such vessels are expensive and limited (Ibid.). The geopolitical tension between the Russia and the West is also likely to create an obstacle for the viability of the NSR in the future. The Ukraine war has elevated tensions between Russia and the West (Ibid.). There may be efforts in the future where more vessels will try to access the NSR for cargo transportation because of its shorter route. Yet, the NSR will not be able to reduce the paramount importance of the Malacca, from both the economic and security perspective.

40 per cent

After the then Russian President M Gorbachev declared NSR open for the first time, non-Russian ships were able to access these waters, although they have to be, till date, escorted (Chattopadhyay, 2023). In theory, NSR reduces 40 per cent of the sailing distance. Yet, the route is only navigable for some parts of the year, and commercially navigable for only 1.5 months annually (Ibid.). This is one of the biggest challenges of the NSR and it also serve as a strong argument against NSR becoming an alternative of the Strait of Malacca in the near future (Ibid.). The problem of licensing to navigate via the route is also a challenge for the

NSR, along with the tonnage of commercial vessel containers and ships. Only small ships can navigate through the NSR which reduces their efficiency and increases the cost due to the prolonged time due navigating through variable sea ice extent (Ibid.).

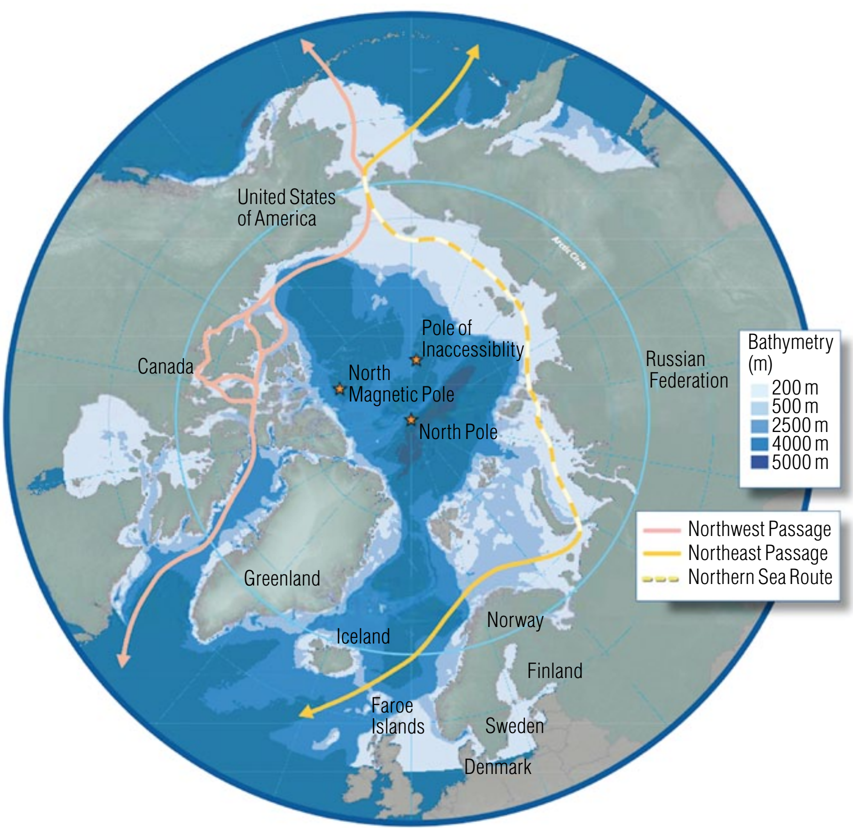
Looking from the Indian point of view, NSR is one of the primary areas for its economy and diplomacy. NSR is believed to be ice-free by 2050, and it will bring both opportunities and challenges. The INSTC is an important proposition for India if NSR becomes viable for navigation (Pradhan, 2023) (Fig. 7.2). Moreover, NSR can open opportunities for exploration of the Arctic energy resources.

INSTC

From the Saint Petersburg, to the Kara and the Barents Sea, and the Mormons are some of the important regions where energy resource exploration is possible. Russia is the biggest claimant into the area and it calls the Mormons port the NSR Western gateway (Baveja, 2023). Therefore, NSR has strategic importance, even if it is not commercially viable as of now. Other regions that the NSR can open up for energy exploration are the Beaufort Sea (North Slope, Alaska and Mackenzie Delta, Canada), Northwest part of the Russian Arctic (Barents Sea and West-Siberia), and the Canadian Arctic Archipelago (Nunavut) (Ibid.). It is estimated that the recoverable reserves in the Arctic amount to

offshore

Fig. 7.2: The NSR is believed to be ice-free by 2050



Source: Baveja, 2023

offshore

150 billion barrels of oil and natural gas liquids and 1700 trillion cubic feet of natural gas. These resources account for about 22 per cent of the undiscovered, technically recoverable resources in the world. About 84 per cent of the estimated resources are expected to occur offshore. Receding sea ice cover and permafrost thaw will influence accessibility to mineral and energy in the Arctic and opening of the NSR in the future (Ibid.). The cargo load in 2019 carried via the Yokohama, Japan to Rotterdam, Netherlands route was 26 million tonnes. Therefore, there are future prospect for energy transportation and exploration via the NSR, even if it cannot replace the Strait of Malacca in terms of strategic and economic significance (Chattopadhyay, 2023).

7.4 Recommendations

i. Although the CLCS and ISA (two bodies under UNCLOS) have come up with some basic regulations for exploration of deep-sea minerals, however, commercial mining is a contentious issue that needs to be resolved (Rajan, 2023). There are many countries, several scientists and many of the industries who lobby to promote sea bed mining. The UNCLOS needs to have an authority to declare any commercial mining as illegal or disprove it, in case a country declares to go for such mining. There needs to be a moratorium on deep seabed mining.

ii UNCLOS as one of the most talked about maritime legal conventions has limitations that need to be addressed. It does not encompass some of the recent challenges that exist in the field of maritime security. There are a growing number of maritime contests and disputes in the Indo-Pacific region. There is also a gap in the enforcement and compliance of the UNCLOS. The USA is not a part of this convention, despite being an important part of the Indo-Pacific region. These divergences have to be merged (Banerjee, 2023).

Rapid changes in the Arctic and its impact on India's climatic conditions are the principal motivation behind India's engagement in the region; Research stations at Spitsbergen, Svalbard, Norway.

PHOTO COURTESY: JANIK ROHLAND

8. Strengthening India's Arctic Foray

India's Arctic foray is supported by its Arctic programme and the recently released Arctic Policy (2022). The goals and objectives of India in the Arctic are represented by not only scientific exploration, but also international co-operation, economic and human development as well as capacity-building. Leading institutions in India including MoES, MEA, DST, MoEFCC, MoPS, MoPNG and MoD are the key stakeholders in Indian efforts to engage with Arctic affairs. Meanwhile, emphasis has been given on involving India's think tanks as well as academia for capacity-building through research, consultation and awareness-building. The cumulative efforts of various government bodies including joint expeditions, research and writing, organizing events, surveys and other activities are all targeted towards promoting India's foray in the Arctic.

8.1 Introduction

India's Arctic foray combines the history of the nation's scientific involvement with the future national and global needs in its Arctic Policy titled 'India and the Arctic: Building a Partnership for Sustainable Development' released by the MoES in March 2022. The Policy lays down six pillars representing its objectives and goals. It includes strengthening India's scientific research and cooperation, climate and environmental protection, economic and human development, transportation and connectivity, governance and international cooperation, and national capacity building.

Implementing India's Arctic Policy requires multiple stakeholders, including various governmental departments, academia, the research community, think tanks working on Polar issues, business, and industry. Therefore, India's Arctic journey comprises scientific studies and exploration, economic planning and international cooperation, and socio-cultural engagement and its objectives find expression through multidimensional actions.

8.2 Rationale

India's engagement in the Arctic is primarily drawn from the science of the Arctic and its significance for India. Thus, science is the instrument for Indian policy-makers, and one of the most important driving forces is climate change. Since the mid-20th century, the shrinking cryosphere in the Arctic and the high mountain areas has led to a predominantly negative influence on livelihood, including food security, health, infrastructure, transportation, tourism, as well as the culture of human societies—most importantly for the indigenous peoples (Verma, 2023). Studies show that the Arctic is warming upto four times faster than the global average, and the Polar regions are the first to respond to climate change (Ravichandran, 2023a). A result of this heating may be seen in the increased influx of freshwater in the Arctic seas and oceans (Ibid.). As what happens in the Arctic is not local but global (Ravichandran, 2023a), melting in the Arctic could adversely affect India, notwithstanding the vast distances that separate the two—profoundly impacting the Indian Monsoon (Frydenlund, 2023). Since the monsoon accounts for 70 per cent of India's rains (Verma, 2023), understanding the Arctic's changes is an imperative bedrock of its future needs. Indian scientists indicate that a decreasing sea-ice cover and an increase in the dark ocean areas in the Arctic lower

shrinking cryosphere

tourism

Fig. 8.1: Indian Arctic programme: Svalbard (2013);Canadian Arctic (2023)

Source: Jain, 2023

albedo effect

the Sun's albedo effect. Such profound changes seem to aid extreme rainfall in India, adversely impacting the Himalayan region (Ravichandran, 2023). Understanding this connection, especially when the Indian Ocean is warming fast too, is critical for India, for it affects one-fifth of humanity (Verma, 2023).

global warming

The scientific community has been quietly working to study the Poles over the years, which helped India hone a white paper on the Arctic into a Policy document in 2022 (Saran, 2023). Earlier, the study of the Poles was narrowly limited to a small set of people. The connection between India and the Poles needed to be understood with clarity. Despite humble beginnings, a small budget, and a limited workforce, Indian researchers have engaged with the Poles for decades. Climate and global warming are the most critical aspects of the study that has facilitated an understanding in India about an Arctic connection. As the Indian government began rearranging institutional arrangements, starting with the Department of Ocean Development a few decades ago into a full-fledged Ministry of Earth Sciences with dedicated institutes working on Arctic and Antarctic, it began to realize the importance of the Arctic. Over the years, other institutions have emerged to study the Arctic and the Antarctic, especially in the Indian universities (Ibid.). Therefore, the changes in the Arctic and its impact on India's climatic conditions are the principal motivation and rationale behind India's engagement in the region.

8.3 Goals and Objectives

white paper

scientific cooperation

The objectives of India's Arctic Policy 2022 align seamlessly with the Arctic science programme as it augments the needs of India's scientific community working on the Poles. The Arctic science programme, initiated considerably before the official white paper, aims at strengthening India's scientific research and cooperation. The policy document institutionalized the goals, visions, and efforts of India's scientific communities in the Arctic. Since formulating the Arctic Policy, India's Arctic engagement not only focuses on enhanced cooperation in science but also on policy-making and economic and social cooperation (Ravichandran; Khanna, 2023). Therefore, from scientific cooperation to climate protection, and human and economic development, the focus of India's Arctic policy is manifold. One important stipulated objective of India's Arctic engagement is that the Arctic or Polar research should harmonize with the Himalaya since the fate of 1.9 billion people hinges on the mountains (Ravichandran, 2023).

Himalayan cryosphere

teleconnections

From a scientific standpoint, India's Arctic science programme encompasses the activities of the NCPOR in the Arctic and the initiatives taken by its parent body, the MoES (Jain, 2023). The NCPOR is responsible for coordinating and implementing India's Polar programmes, which include the Indian Antarctic and the Arctic programmes along with studies on Himalayan cryosphere and the Southern Ocean (Ibid.) (Fig. 8.3). There are diverse scientific themes on which Indian scientists work in the Arctic, apart from studying the teleconnections between the Indian monsoon and Arctic climatic variabilities (Ibid.). Most of India's scientific themes related to the Arctic are in line with the Arctic Council's working groups, such as biodiversity assessment, long-term monitoring, atmospheric prediction, atmospheric sciences, and aerosol studies (Ibid.). India has steadfastly built the capacity to achieve scientific objectives in the Arctic region. In 2014, NCPOR collaborated with NIOT Chennai to deploy the IndArc, the first of its kind outside Indian offshore waters (Ibid.).

aerosol studies

IndArc

The six pillars of India's Arctic policy further intensify India's Arctic involvement by facilitating enhanced international cooperation in areas beyond science—a collaboration with international partners at all levels, including responsible exploration and harnessing of renewable energy and clean technology; traditional systems of medicine such as ayurveda, unani, and yoga; promoting peace, stability, and security within the framework of international laws (Khanna, 2023) (Fig. 8.2). It further includes maintaining a strong focus on the preservation of the environment and sustainable socio-economic development; enhanced understanding of legislations and regulatory framework at the regional, national, and sub-national levels; strengthening multi-disciplinary research and collaboration with international partners at all levels; building capacity through cooperation such as the NASA-ISRO SAR mission, sharing resource and data; facilitating services such as telecommunication, search and rescue, environment and climate modelling in the Arctic (Ibid.).

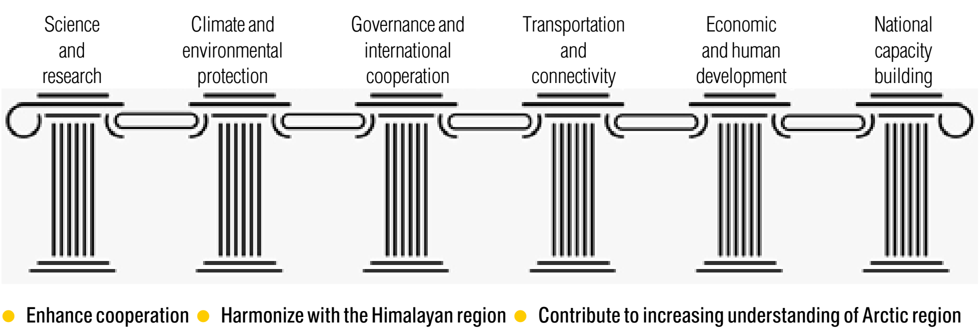
yoga

regulatory framework
multi- disciplinary

8.4 Actions

India's actions for its Arctic involvement may be explored across scientific, political, economic and socio-cultural engagement.

Fig. 8.2: Six pillars of India's Arctic policy



Source: Khanna, 2023

8.4.1 Scientific Engagement

Arctic Circle

Korean Polar Research Institute

One of the most essential objectives of India's Arctic engagement is science. It is also the first of the six pillars of India's Arctic Policy. The Arctic Council's operations were partially stalled for some time; hence engagement with international Track 2 organizations such as the Arctic Circle was enhanced. Participation of Indian scientific, policy and academic institutions in the Arctic Circle forums and events in Reykjavik and Japan was enabled (Jain, 2023). In 2019, India collaborated with the Korean Polar Research Institute to embark on an Arctic Ocean cruise (Ibid.). The focus was on microphysical and microbiological processes, specifically the teleconnection. The Korean Polar Research Institute facilitated the Indian team aboard their ship to travel to Western Arctic and engage in relevant areas of study. Himadri, India's Arctic station in Svalbard, Norway, currently functions for about 180 days roughly in a year. Efforts are being made to drive it up to 365 days, thus, making it a round-the-year station (Khanna, 2023) (Fig. 8.1).

Gruvebadet Observatory

Indian biologists from NCPOR are expanding their understanding of permafrost microbiology in the Arctic regions beyond Svalbard (Jain, 2023). Two Indian scientists are engaged in the installation of atmospheric instruments in the Gruvebadet Observatory, Svalbard, Norway, set up under the long-running Indian Arctic programme (Ibid.). India's Arctic Science programmes also links the Indian monsoon and the Arctic climatic variability using paleo-oceanographic proxies (Ibid.).

migratory birds

microplastics

Another study focuses on the role of migratory birds in the dissemination of antibiotic-resistant bacteria to the Arctic. Certain migratory birds in the Arctic travel every year to Antarctica and carry back some of the microorganisms to the Arctic and other places (Jain, 2023). This project is studying the role of this transfer on the Arctic ecosystem. NCPOR scientists are also working on microplastics in the Arctic region and their various types and sources (Ibid.). The goal is to decipher and help policy-makers decide which products to ban in the Arctic and the Poles.

POLARNET

Kongsforden

180 papers

POLARNET is an atmosphere-based system initiated to monitor various greenhouse and aerosol measurements to assist modelling (Jain, 2023). It attempts to cover all Polar regions, viz. Antarctica, the Southern Ocean, and the Arctic. Charts and instruments have been designed to get a more holistic picture of the aerosol and the atmospheric variability in the Arctic region. Other flagship scientific projects of India in the Arctic include monitoring of Kongsforden for climate change studies, Arctic precipitation, bacteria and plankton and more (Ibid.). The Indian Arctic programme has contributed around 180 papers so far, with increasing intensity in the later years, marking heightened interest in Arctic research (Ibid.). These contributions are made across biology, physics, geology, mathematics and statistics.

8.4.2 International Cooperation

India's efforts for international cooperation in the Arctic, which is the fifth pillar of the Arctic policy, can be explained through various institutional collaborations. The bilateral relations between India and Norway are well positioned on Polar research and extends to other areas of collaboration such as the blue economy, research in Antarctica, deep ocean technologies, and integrated ocean management, amongst others (Frydenlund, 2023). India is working towards strengthening the Empowered Arctic Policy Group (EAPG), prioritizing activities through the preparation of a roadmap, establishment of points of contact in key ministries such as MoES, MOEF&CC, MEA, MOPSW, MOPNG, MoD and DST through quarterly meetings for coordination and reviewing its activities. In addition, compilation and dissemination of a newsletter, interaction with think tanks, consultative mechanisms with Asian observers to the Arctic Council, establishment of points of contact for enhancing collaboration and multilateral construct amongst Asian observers for engaging in the Arctic is also being undertaken (Khanna, 2023). Towards enhancement of international cooperation, India is interacting with Greenland as India intends to assist resource sharing pathways from the region. Especially in the case of rare earth and other minerals which are unique to the region, India is therefore, closely engaging with Greenland and its leadership. India is also looking to develop ties with Asian Observers and explore collaborative work. Recently a meeting took place between India and Singapore's Special Envoy for Arctic Affairs to discuss matters of Arctic cooperation (Ibid.).

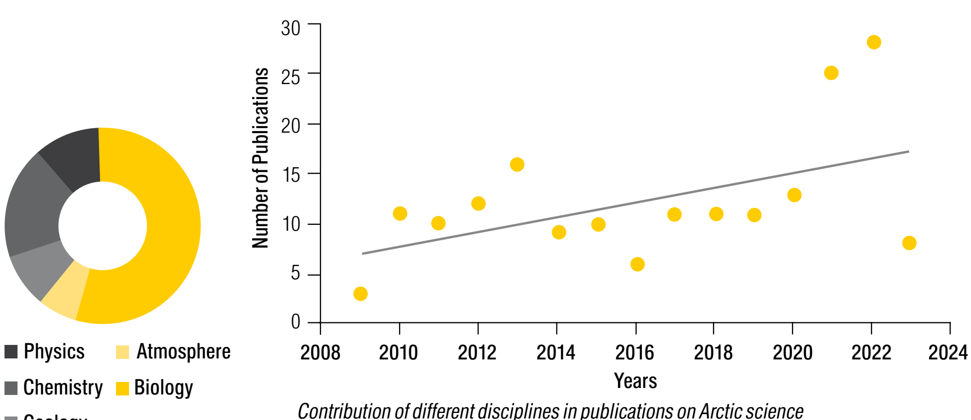
blue economy

Empowered Arctic Policy Group

8.4.3 Socio-economic and Cultural Engagement

India is engaging in the Arctic to enhance socio-economic development and cooperation, i.e., the third pillar in its Arctic policy. Interaction between policy-makers and industry

Fig. 8.3: Indian Arctic programme: Scientific contribution



Contribution of different disciplines in publications on Arctic science

Source: Jain, 2023

is being enhanced. India has organized meetings between the AEC and all of India's industrial chambers – FICCI, ASSOCHAM and ICC among others in order to explore synergies (Khanna, 2023). The synergies can help further economic cooperation in the Arctic between India and prominent international actors in the region.

soft power diplomacy

Indian embassies

Cultural instruments or soft power diplomacy have been enabled to further India's human development goals in the Arctic. One such example of this is when India celebrated International Yoga Day on June 21, 2022. Yoga being a globally widespread form of Indian meditation, holds the power to promote human development in the Arctic, boosting physical and mental health awareness. Not only did the Indian station in the Arctic (Himadri) celebrate and observe Yoga Day, but the Indian embassies in Finland, Russia and Denmark (Greenland) also organized Yoga Day celebrations, all being prominent part of the Arctic (Ibid.).

newsletter

Another goal of India's Arctic involvement is to increase awareness and understanding of the Arctic region within the nation. Prominent figures were involved in television programmes to discuss Arctic-related issues. Additionally, an EAPG has been established, and points of contact have been appointed in key ministries such as MoES, MoEFCC, MEA, MoPS, MoPNG, MoD, and DST (Khanna, 2023). A quarterly newsletter is sent to all parts of the government and missions overseas, capturing all the activities related to the Arctic.

AYUSH
AEC

Interaction with think tanks is undertaken every six months, and a think tank section is introduced in the newsletter to capture their activities. The focus is on sharing best practices, engaging in international collaboration with Asian observers, promoting AYUSH and Yoga, building capacity in shipbuilding and seafaring, offering Arctic courses, and think tanks becoming members of the AEC (Khanna, 2023). The aim is to ensure year-round engagement in the Arctic and facilitate collaboration among various stakeholders.

8.5 Achievements

India has hit several milestones in exploring the Arctic and engaging as a stakeholder. Some of its recent achievements are listed below:

i. India's key institutions, such as the NCPOR which is regarded as India's gateway to the Polar regions, have taken initiatives towards scientific capacity-building and have earned accomplishments in this area. For example, the NCPOR has invested in a laboratory for DNA sequencing with both types of sequencing facilities, first-generation sequencing and second-generation sequencing, to understand the impact of climate change on the microbial community and their response to climate change (Jain, 2023).

ii. Indian scientists, collaborating with the Norwegian Polar Institute, visited the geographical North Pole via the Norwegian research vessel Kron PrinsHaakon on

October, 2022. A team of two scientists collected samples from the North Pole (Jain, 2023).

iii. Monitoring Kongsfjorden and Krossfjorden for climate change and ecosystem modelling studies have been conducted (Jain, 2023).

iv. Monitoring of Arctic precipitation and atmospheric variabilities and characterization of aerosol and black carbon measurements are being done (Jain, 2023).

v. Indian scientists are expanding scientific activities beyond Svalbard. Two scientists from NCPOR have planned to visit the CHARS in the Arctic region to pursue research in atmospheric and marine science, environmental chemistry, cryospheric studies and more (Jain, 2023).

vi. India has planned an Arctic Ocean Paleoceanography expedition from 15th August – 10th September 2023 (Jain, 2023).

vii. Presently, India produces the third largest number of seafarers, in terms of officers and has fulfilled 10 per cent of the global demand (Khanna, 2023). Efforts have been made to build capacity in education. The UGC has conducted online courses on the SWAYAM portal and received many proposals (92). India is currently selecting four proposals and exploring ways to finance them so that Indians can access the information and learn online (Khanna, 2023).

ix. Indian universities are looking to gain membership to the UArctic, as outlined during an online interaction with the UArctic (Khanna, 2023). UGC and UArctic organized a national webinar on capacity-building in education on December 9, 2022.

x. Arctic-related questions were included in Kaun Banega Karodpati and Think You, a quiz involving 7,500 schools organized by the Navy (Khanna, 2023).

8.6 Recommendations

Despite the accomplishments, there is a need to expand India's Arctic involvement, and various actions and strategies are required to promote a deeper engagement.

i. The six pillars of Arctic policy need a focused, multi-stakeholder approach involving not just the government entities but also research institutions, think tanks, universities and the private sector (Verma, 2023).

ii. The current period is an extraordinarily difficult time in global geopolitics (Frydenlund, 2023). The Arctic should never be a region for geopolitical or geostrategic contestation between major powers. It should remain an area for cooperation for the benefit of all humanity (Saran, 2023). The stability of the Arctic Council is, therefore, crucial for the geopolitical stability of the Arctic (Hoglund, 2023).

iii. India is worried about the Himalaya and the consequences of climate change. Therefore, it needs to bolster institutional support, enhance investments, and put in place state-of-the-art monitoring networks and satellite-based observations to better cryospheric science in all three Polar regions and the oceans. India's modelling effort also needs strengthening to better future predictions (Ravichandran, 2023). India needs to enhance its scientific presence at Himadri all year round through multiple scientific projects (Khanna, 2023).

iv. The nation needs to heighten international engagement, focusing on Asian Observers to the Arctic Council. India's proactive role in Arctic Council Working Groups needs to be strengthened through increased participation (Khanna, 2023). International outreach through membership in the Arctic Economic Council may also be sought (Khanna, 2023).

v. Arctic is congruent with the ideas of Mission LiFE, an India-led global mass movement encouraging individual and community action to protect and preserve the environment. Therefore, best practices from the Arctic must be shared globally for sustainable development (Khanna, 2023).

vi. India can strengthen its Arctic involvement by providing satellite medical services in the Arctic (Khanna, 2023).

vii. India can help make the Northern Sea Route and associated waterways commercially important, contributing a workforce towards hydrography or satellite-based communications for ships on the Arctic routes (Khanna, 2023). Collaboration on shipbuilding is another area that India needs to work on to improve its engagement in the region. India is poised to procure its icebreaker and strategise on building yards to enable the building of ice-class vessels (Khanna, 2023).

viii. The UGC can introduce Arctic courses by including them in NCERT textbooks, gaining memberships for various universities in the UArctic (Khanna, 2023). Increased research on the Arctic in Indian universities will enable high-quality capacity building in the nation (Ravichandran, 2023a).

ix. There is also a need to conduct regular conferences, seminars and workshops to increase awareness among the Indian milieu (Khanna, 2023). Round-table discussions at the national and international level on Polar issues need to be enabled (Goel, 2023).

The Antarctic Treaty was conceived and thereafter, ratified for the purpose of isolating Antarctica to eliminate human impact, yet man continues to imprint the pristine land; Galindez Island, Antarctic.

PHOTO COURTESY: VOLODYMYR GOINYK

9. Fate of the Antarctic Treaty

The Antarctic Treaty of 1961 is a seminal document, isolating the continent from international conflict and human impact. The Treaty has been hailed for its uniqueness. However, as the Treaty approaches its year of review, there are speculations that the changed geopolitical scenario and the vested interests of certain signatory members may impact the sanctity of the Antarctic as a peaceful and stable region for scientific collaboration. It is in this context that discussions on the fate of the Treaty in 2048 is needed.

9.1 Introduction

The Antarctic Treaty that came into effect in 1961 has rightly been hailed as a unique Treaty of the twentieth and twenty-first century, comparable probably to Magna Carta, standing the test of the time (Mohan, 2023). The Treaty was conceived and thereafter, ratified for the purpose of isolating Antarctica to eliminate human impact (Pant, 2023a). The current idea of the Antarctic Treaty is a romantic notion as it speaks about isolating Antarctica for preservation. Some scholars express uncertainty over its effectiveness given the signs of tremendous human influence in Antarctica and calls for the reworking of the spirit of the Treaty (Ibid.). Visualising the geopolitical context of Antarctica in contemporary times requires attention on both material and emotive aspects of the Antarctic Treaty. Scholars also talk about the hollowing effect of the Antarctic Treaty System (ATS), given its complex nature. Originally, the Treaty was built on the hope of keeping Antarctica free of international discord and preserve it as a place of nature and science (Chaturvedi, 2023).

9.2 Rationale

The apprehension that the Treaty has an uncertain future, as hinted by the challenging title of the Third Discussion Panel 'Fate of the Antarctic Treaty after 2048' does not probably reflect the spirit of the Treaty (Jortikka-Laitinen, 2023). It is worth noting that despite the Treaty's requirement for a review after 30 years in 1991 under Article 12, all parties expressed their commitment to upholding and enhancing the Treaty on its 30th anniversary. A similar resolution, termed as 'Washington Declaration' was passed by all the Consultative Parties on 50 years of signing the Treaty in 2009 at Washington hailing the Treaty and expressed their continued support in furtherance of the provisions of the Treaty aimed at preserving and protecting the Antarctic environment and its dependent and associated ecosystem (Ravindra, 2023; Parmar, 2023). However, since Article 25 of Madrid Protocol permits a Review after 50 years, there is a growing feeling in some quarters that due to changed geopolitical environment and emergence of new global players, the exclusiveness of 'Antarctic Club' may be breached.

Washington Declaration

Antarctic environment

Madrid Protocol

9.3 Major Concerns

Some of the major concerns regarding the future of the Antarctic Treaty are that certain member nations and recent geopolitical shifts may attempt to alter the provisions of the Treaty. A growing human involvement may harm Antarctica and cause turbulence in the region's governance, is another area of concern. There are only 54 signatories to the Treaty including the 29 Consultative Parties with scores of nations being left out of the Antarctic Treaty System. Inclusiveness rather than exclusiveness is the order of the day (Chaturvedi, 2023).

geopolitical shifts

There is an apprehension that the ATS is collapsing under the ever increasing heavy agenda of the ATCMs, which is set by minority Parties but has to be followed by the majority. The generational shift in diplomacy, gradual loss of institutional memory and rising aspirations of some nations who have come up to stand side by side with main players or advanced nations as a result of newly gained financial and technological strength (Chaturvedi, 2023) may be a game changer. This economical or technological supremacy is bound to clash with traditional Antarctic nations in the terms of Antarctic governance. Besides, the success of the ATS cannot be taken for granted. There are challenges in the governance which can pose a major risk to the functionality of the Antarctic governance model (Chaturvedi, 2023).

ATS collapse

institutional memory

functionality

9.4 Addressing the Concerns

Notwithstanding the provision of Article 25 of Madrid Protocol, the Review is not an automatic process and the Treaty does not have an end date. One or more parties from among the Consultative Parties has to ask for a discussion on the subject of an intended review. There are no indications so far that any Party will ask for such a review, as status quo in the Treaty is best suited to both claimant and non- claimant Parties (Ravindra, 2023). The issue has to be viewed with the perspective that the global geopolitics has changed considerably since the Treaty was conceived in 1959 and a new world order has taken over an era of colonisation. The assumption that need for the exploitation of depleting mineral resources from the inhabited continents and the probability of availability of such resources in Antarctica, may speed up a race for mining, appears to be more speculative rather than supported by logic; firstly, because no detailed mineral exploration has been conducted over Antarctica and secondly, the huge thickness of ice, as overburden, will act as a major deterrent to economic exploitation of mineral resources. Moreover, the prohibition on mineral resource activities cannot be removed unless a binding legal regime on Antarctic mineral resource activities is in force (Art. 25.5). The latter is a near

Consultative Parties

colonisation

economic exploitation

impossible exercise as there is a growing international pressure to reduce the ill effect of climate change and no nation would like to endanger safety by disturbing the delicate balance between the cryosphere and the environment. The breaking of the Antarctic ice sheet and the damage it would cause to the global ecology is unthinkable.

resolution

monitoring

Madrid Protocol

Further, the adoption of a resolution by UN General Assembly on the 'Question of Antarctica' on December 9, 1992 urging Antarctic Treaty Consultative Parties to establish monitoring and implementation mechanisms to ensure compliance with the provisions of the Madrid Protocol (1991) on Environmental Protection and reiterating its call for 'the ban to be made permanent', comes as a ray of hope (Ravindra, 2023).

Quaternary

ice cores

Science, as usual, is exceedingly taking over the pivotal role in deciding the environmental issues in Antarctica. The very fact that one full day is earmarked for discussions on climate change at 45th ATCM in Helsinki, Finland, speaks for itself about the growing recognition of scientific analysis being forced by anthropogenic activities on the earth's environment. Antarctica attains growing importance in the climate change discussions owing to its ice sheets being one of the best archives for the signatures of human induced changes in the environment, such as imprints of beta radioactivity, methane, carbon dioxide, industrial sulphur, nitrates, etc. It is from such evidence that Anthropocene–the youngest epoch of Quaternary period after Holocene has been differentiated based on the activities of homo sapiens that have overtaken the control of geological processes (Pant, 2023a). The high resolution of ice cores present an accurate account of recent past climate of the earth and hence the Anthropocene is the subject of intense research (Ibid.).

Measures will be taken to discuss significant issues pertaining Antarctica and its various aspects to secure and sustain the region. Both the 45th and 46th ATCM will devote considerable time on environmental protection, climate change, responsible tourism and other relevant issues (Mohan, 2023; Jortikka-Laitinen, 2023). On an optimistic note, none of the major powers is heard or seen making any serious attempt to disturb the peaceful regime on Antarctica nor is there any possibility of doing away with the existing consensus on Antarctica (Rao, 2023).

9.5 Recommendations

i. Antarctic governance requires more democratisation and a deep look into the resilience of the Antarctic Treaty System.

ii. It is necessary to ensure that the existing Antarctic Treaty that has been assiduously built and strengthened over a period of sixty years continues to inspire the international legal regime and keeps Antarctica safe and pristine for future generations.

iii. As the Treaty was built on emotions of hope and trust, the ATCMs have a great role to play in channelling the opinions of member States and hold up the preamble of the Treaty which says that Antarctica will never become a site of discord (Mohan, 2023; Jortikka-Laitinen, 2023).

Communities living in the Himalaya can share with the world a host of lessons on simple and sustainable living: Maharka valley, Ladakh.

PHOTO COURTESY: HEYHIMALAYAS.COM

10. Developing People centric Climate Change Science

Climate change science needs to be made people-centric by including various groups and communities as stakeholders in the process of creating sustainable solutions. From Himalayan communities to women, students, academics and researchers and institutions, development of advanced intervention is necessary. Inclusion of sustainable lifestyle, customs, tourism, institutional development to address the emerging challenges of climate change can contribute towards the fight against it.

10.1 Introduction

Society shares an intricate relationship with climate change, not only because climate change is affecting communities, their livelihoods, habitation, customs and lifestyle in many ways but also because societal aspects influence the understanding and practices in addressing the issue of climate change. Whether it is communities, gender perspectives, involvement of institutions, research communities and academics, climate change science is influenced by people-led developments. When climate change science is people-centric; it focuses on the challenges faced by communities living in different areas, to provide a platform for better or advanced intervention. This is why it is necessary to understand the dynamics between climate change science and human society, especially in the context of India. In doing this, various aspects of livelihood including food, habitation, economy, community involvement and institutional developments around climate change should be discussed to promote an inclusive understanding of the problem.

10.2 Community Knowledge as Intervention in Climate Change Science

The Himalayas have a fragile ecosystem in which lives and livelihoods heavily depend on the surrounding environment. For instance, glaciers are a major life support as it provides fresh drinking water to the local communities (Wangchuk, 2023). The glaciers are melting rapidly due to climate change and 'modernity causing destruction'. People in the Himalayas are not against modernity or science, but they rather believe in the 'science of healing' and this is why the local communities living in the difficult Himalayan terrains can contribute towards solving the problems of climate change (Ibid.). These communities can share with the world a host of lessons on simple and sustainable living. Ladakh is located in the high Himalayas, in a low precipitation, rain shadow region. In the winters, whatever snow and ice accumulates in the glaciers higher up, sustain the communities through the dry summer (Ibid.). There are five glaciers in Ladakh along with those located in the Hindukush Himalayan region, on which roughly two billion people in the Indian subcontinent and the Tibetan Chinese depend (Wangchuk, 2023).

climate change

Ladakh

Hindukush
Tibetan Chinese

People who lived in the region thousands of years ago, survived and thrived as a result of which a colourful civilisation with its own language, literature, music, dance, spirituality and a life in harmony with nature came into being. Such knowledge of life and sustainability that lies in the roots of local communities of the Himalayas and should serve as a lesson for humanity to fight climate change (Wangchuk, 2023). Glacier melts, cloud bursts, flooding and summer heat are some of the impacts of global warming in the Himalaya. In 2006, a flash flood in Pyang saw loss of several lives and the disruption of livelihoods. In the 2010 floods, more than 1,000 people lost their lives and another 1,000 people went missing (Ibid.). Melting of the glaciers and other conditions are causing devastation in human abodes in the Himalayas. Looking at this devastation, the local people of the Himalayas have attempted to adopt mitigation and adaptation in their own way. SECMOL, an alternative school, built sustainably with natural materials, was set-up in the mid 90s (Ibid.). Heated and powered by solar power, passive solar heating and possibly world's first carbon neutral off grid energy, the campus is one of the examples of how sustainable infrastructure can deal with climate change. Greenhouse farming and natural inventory are some of the other sustainable means that have been adopted by the local communities. The textbooks in the 9th and 10th grade are also designed to

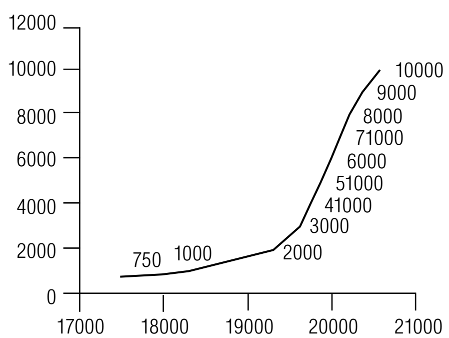
local communities

Pyang

SECMOL

Greenhouse farming

Fig. 10.1: Rising population has rising resource-based demands



Source: Das, 2023

energy for livelihood
alternative university
biodiversity loss
IARC
SCAR

teach about sustainable ways of using energy for livelihood. The clean and green energy technology is being extended to the Indian army campuses too. The Ladakh Indian Army is perhaps one of the most advanced armies in the world going green and adopting carbon neutral, solar heated shelters for their soldiers. Furthermore, an alternative university for mountain development is being set-up in Ladakh where young students learn through field experiences (Wangchuk, 2023). The artificial 'stupa' glacier was developed in the region corroboratively, with the help of local scholars and students. To incorporate socially relevant research in areas of critical biodiversity loss and climate change the IARC along with other international science communities such as SCAR and annual Arctic conferences such as the Arctic Frontiers need to discuss new ideas with the international community (Koc, 2023).

10.3 A Socio-cultural Inclusive and Sensitive Climate Change Science

gender equality
geothermal energy
Iceland's foreign policy

Emphasis has been given on sensitising climate change science by making it more inclusive. In the talk titled 'Gender equality in the Arctic', it is argued that the agenda for Sustainable Development Goals highlights gender equality as a necessary foundation for a peaceful and prosperous world (Agustsson, 2023). In fact, gender equality is a crucial contribution to progress across all the goals. In the sphere of Arctic studies and policy making, several steps have been taken. One of them is the inclusion of gender equality in the Arctic as part of the Arctic Council Sustainable Development Working Groups Project in 2013. In the Indian climate change science, gender representation is yet to be developed, although efforts are being made to ensure inclusion (Mendiratta, 2023). In Iceland, the geothermal energy sector is ensuring gender representation to a certain extent; there are about 25 per cent of women working in the boating industry in Iceland which is run with the help of geothermal energy (Dolma, 2023). Gender equality in Polar research and policy is an important concern where India and Iceland can cooperate since promoting gender equality is an essential component of Iceland's foreign policy; and, India shares similar values of human rights, gender equality, and women empowerment (Bragason, 2023).

Alps
tribal population
North-eastern region

Meanwhile, sensitising climate change science towards vulnerable groups is also crucial. India considers its largest population as an economic asset; however, providing a minimum standard of living to each person is demanding and it is often left out from the mainstream discourse. Every Indian requires about 150 to 300 l of water daily. Hence, it is important to ask if India has the resources while talking about climate change and the anthropogenic factors (Das, 2023). Climate change is occurring even in the Alps but it is not a matter of discussion because population density in that area is low. India's population density, on the other hand, is high which can increase the suffering of a multitude of people (Fig. 10.1). In India's case, local communities are living in the margins and of the 90 districts that have more than 50 per cent tribal population, majority of them are based in the Himalayan region, mostly in the North-eastern region (Ibid.). The North-eastern region is an extremely vulnerable ecological zone. IPCC has also pointed out the role of climate change in temperature and rainfall variations

(Ramesh, 2023). The economic characteristics of this section of population was traditional as they instilled common property norms in their resource-based economy. However, now mainstreaming has caused them to adopt land rights, causing the majority of the tribal/indigenous population to lose their land (Das, 2023).

common property

Climate change science needs to deal with inequality in land holding. The emerging social characteristics of marginalisation is making the tribes less educated, suffering from poor health and eroding traditional knowledge, habitation and living conditions (Das, 2023). Tribes have their own political system of managing common property resources through which they survive by using the natural resources harmoniously. They treat every element of nature as their deity, practising totemism and their traditional houses are built from locally sourced materials. The current climate debate is missing a major link with population, their lifestyle and the challenges. For instance, the ecosystem of the Himalaya is becoming increasingly fragile due to modernisation and tourism (Ibid.). The infrastructure built across the Himalayan region is massive and in terms of planning and a majoritarian view is reflected. It does not take into account the plight of the local Himalayan tribes (Ibid.). In the high altitudes of Ladakh, Himachal Pradesh and Sikkim, agriculture, animal husbandry and lifestyle is deeply affected. The local communities do not have information, training and adaptation methods to cope with these changes (Ibid.). This is leading them to shift from their occupation and acquire new livelihoods that are environmentally unsustainable. Homogenization in planning

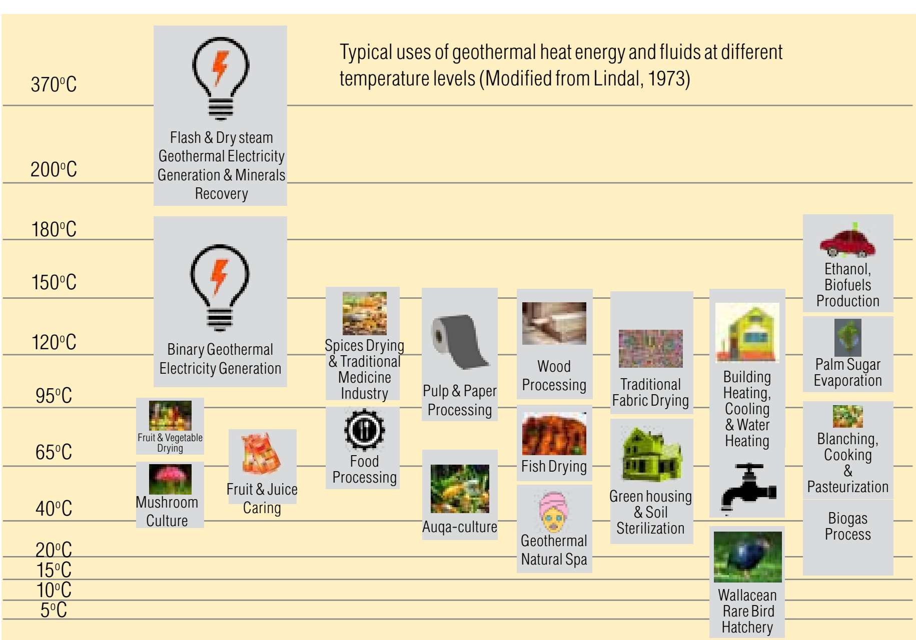
climate change science

political system

totemism

tourism

Fig. 10.2: Geothermal energy can be used across various sectors



Source: Dolma, 2023

is causing loss of valuable traditional knowledge which can help in the adaptation process with climate change (Ibid.). Exploring traditional knowledge bases is difficult as little funds are available for climate change and agricultural practices in high altitude Himalaya.

10.4 Institutional Support for Climate Change Science

NMSHE

Himalayan ecosystem

Various initiatives for Himalayan region have been taken up under the National Mission on Sustaining Himalayan Ecosystem (NMSHE), which is one of the eight missions launched by the Prime Minister Council on Climate Change in the year 2008 and 2009 (Mendiratta, 2023). To enhance the capacity in climate change, NMSHE is the only mission which is location specific. The broad theme or the aim of this Mission is to understand the vast Himalayan ecosystem and bring out certain strategies by mapping and formulating a comprehensive information system. Having data from all possible aspects which are affecting the growth and development of Himalayan ecosystem is also a goal of this Mission. Broadly, various programmes which have been launched so far under the Mission are catering to the different sectors such as glaciology. There are six areas—agriculture, biodiversity, water, snow, traditional knowledge systems and wildlife, where decision makers require information. About six thematic task forces centered around national agencies of the department have been developed.

Swiss ADC

bilateral programme

Another important area of NMSHE is to have dedicated centres of climate change. Centres have been established in all the 12 states and UTs (Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, Assam, West Bengal, Jammu and Kashmir and Ladakh) of Himalaya and broadly given the task of mapping their states, working out the vulnerability (Mendiratta, 2023). A centre of excellence has also been developed in the areas of glaciology, social aspect and water hydrology in Sikkim University and Kashmir University (Ibid). Six states (Himachal Pradesh, Meghalaya, Manipur, Sikkim, Mizoram, Tripura and Jammu and Kashmir) have been already covered as various research institutions have been established and brought together in a coordinated manner. With regard to international experience, a programme with Swiss ADC has been started. This Mission is for 12 years and has three phases, two of which have been completed and the third phase is in progress. Through this bilateral programme, during the first phase a specialised programme on glaciology has been developed in which 55 young researchers were trained. In phase two, students and researchers were identified and taken to the glacier site for two months. Thus, institutional collaboration and inclusion of scientists, students and researchers has been intertwined to develop the framework for climate change science in India.

10.5 Policy-intervention in Climate Change Science

In India, the studies for geothermal resources started way back in the late 1840s, when the British undertook surveys to locate different geothermal sources (Dolma, 2023). In the 1970s, the GSI started taking geothermal sites seriously and put up a demonstration projects in Puga, Ladakh. The current utilization of geothermal energy in India is not much because most of them are marked as sacred, religious sites. Near these sites, religious ceremonies are performed, food and water are also distributed as part of such rituals. Several restaurants have been established that use the spring water for cooking, cleaning and other purposes. Due to this, the geothermal energy sites in India have become hubs of various economic activities. Examples include Sohna in Haryana, Tapovan in Uttarakhand, Demchok in Ladakh, Rajgir in Bihar, and Manikaran in Himachal Pradesh (Ibid.). Developing geothermal energy in these sacred places is a challenge for various reasons.

GSI
Puga

Iceland started utilizing its geothermal energy recently, when the oil crisis hit in 1973. Coal and oil prices increased by more than 70 per cent during the time and the Ministry of Industry in Iceland considered it necessary to combine both fossil fuel and geothermal energy (Dolma, 2023) (Fig. 10.2). New policies were developed that enabled a small country like Iceland to develop an impressive geothermal sector. Soon, this industry became global in terms of knowledge sharing. Switching to geothermal energy also helped Iceland in terms of a clean environment. Before the 1970s, Iceland was heavily polluted due to coal. However, after embracing geothermal energy, air pollution decreased in the country (Ibid.). Vegetables are also cultivated in Iceland with the help of geothermal energy, along with bread-making, fish farming, skin care industry, spas and other recreational places (Ibid.). Geothermal energy helps in running institutions, offices, schools and colleges even when there is no sunlight in the dark winter months. India is collaborating with Iceland on the utilization of its geothermal capabilities following a formal cooperation prompted by the Prime Ministers of both countries at the meeting in Copenhagen in 2022 whence a task force was established (Bragason, 2023).

clean environment

10.6 Recommendations

i. The vacuum in knowledge and technologies for the mountain region should be attempted to be filled with the help of native knowledge and skills of the Himalayan communities (Wangchuk, 2023).

ii. There is a need to recognize and appreciate the diversity and balanced participation in leadership and decision making towards gender inclusion (Augustsson, 2023).

iii. Geothermal energy utilization can reduce energy import and thus, the cost of energy. A more sensitive approach in India is necessary to develop geothermal energy in India because many sites with spring water are religious places (Dolma, 2023). Therefore, drilling and exploration has to be conducted, keeping in mind the religious sentiments of the people.

iv. Countries such as the USA and Australia and even China are focusing on developing sustainability and climate related courses, such as sustainable accounting (Singhania, 2023). Environment economic database compilation is another new area that needs to be developed in India as well to make climate change science more people-centric and robust.

There is a need to shift from conventional approach to careers and consider more variations in academic fields that are focused on climate change; Young explorers in the Arctic.

PHOTO COURTESY: CONSTANCE GARCIA-BARRIO

11. Promoting Youth Engagement and Capacity-Building in Polar Knowledge Goals

The consequences of climate change in Polar regions are anticipated to disproportionately affect the younger generation, making it crucial to encourage them to engage in climate and environmental science more than ever. There is a gap between the interest and awareness of the youth towards Polar studies and its opportunities, especially in India. The goal is to shift away from the conventional approach of pursuing careers and instead consider more variations in academic fields that are focused on climate change and the science and policy of it. It is also essential to promote inter, trans and multidisciplinary expertise in the study and research of Poles. Therefore, the need of the hour is to broaden the horizons of Polar understanding for the youth by introducing and developing curriculum, organizing events and programmes, promoting knowledge about career opportunities in Polar studies, embracing technologies and innovations for sustainable and transformative ecosystems and thus, ensuring overall capacity-building in Polar knowledge goals.

11.1 Introduction

Polar regions are facing a myriad of challenges such as climate change, sea-level rise, plastic pollution, ocean acidification. Every biotic and abiotic entity on earth is facing the consequences of climate change directly or indirectly and youth is no different. Engaging the youth in Polar knowledge goals is essential for addressing the global challenges of climate change and promoting a broader understanding of environmental issues. By presenting Polar studies as an attractive educational and career option, a new generation of dedicated Polar professionals can be developed so that they can contribute towards the preservation and sustainable development of the Polar regions.

11.2 Rationale

India is becoming increasingly vulnerable to the effects of climate change, especially those occurring in the Polar regions. These impacts can be seen on agriculture, lifestyle, sustainable growth and livelihood of various communities. The rise in sea level is posing a threat to coastal communities of India, while alterations to monsoon patterns are affecting agriculture. These changes are consistent with the climatic changes, especially in the Arctic as studies have pointed out a relationship between Arctic ice melt and the monsoon precipitation (Verma, 2023). Furthermore, the loss of water resources and habitat, as well as disruptions in allied sectors such as fisheries and tourism are also being felt (Dayal, 2023). Additionally, the costs of disaster management and infrastructure adaptation are increasing (Ibid.).

disaster management

The youth is most likely to bear most of the consequences of climate change. Unfortunately, there is a significant lack of data in many areas of research (Dayal, 2023). However, the youth should be encouraged to recognise the abundance of job opportunities available in fields of climate and environmental science (Ibid.). To achieve this, there is a need to shift from the conventional careers such as doctors or engineers and instead consider new academic interests (Ibid.). Due to the widespread nature of climate change, it is also crucial for the students to have inter, trans and multidisciplinary expertise from different countries. Given the fact that the events in Polar regions, the Indian Oceans and the Himalayan glaciers are interlinked, it is shortsightedness to not open people's minds and study these existing links, even though the Poles may appear to be far away from India in terms of geography (Saran, 2023). Besides, COP 26 critically argued that climate change has to be tackled at three levels; at the country, company/organisation, and at the citizen level (Singhania, 2023). This articulation by the COP 26 calls for youth participation in the Polar affairs to promote people's engagement with critical issues at the individual level.

job opportunities

COP 26
youth participation

Furthermore, the youth can consider both science and policy and geopolitical aspects of Polar studies. Historically, Polar discourse has been predominantly centred around science but with the escalated melting of sea ice, the Polar regions are being transformed resulting in increased strategic competition; thus, exposing a geopolitical hue. This is creating new opportunities for youth in various disciplines other than science to engage and explore in Polar research.

11.3 Capacity Building in Youth

A number of steps have been taken in India to achieve its Polar knowledge goals for the youth. These efforts can be categorised into four areas: recent initiatives at the elementary level of education, developments in Polar research at the academic level, advancements in professional research, and initiatives to generate interest to develop sustainable businesses.

Polar research

11.3.1 Education and outreach

Indian Navy
UGC
SWAYAM

Efforts have been made at the elementary or school level, to familiarise the students with the Poles and create the awareness that Polar studies could be a viable career option. For instance, the Indian Navy conducted a quiz related to Polar areas that involved 7,500 schools. The UGC has been reached out to conduct online courses on the SWAYAM portal to survey proposals for new educational courses. Among the 92 proposals, efforts are underway to consider four options to promote knowledge and awareness of the Poles. It is yet to be figured out as to how these can be financed so that the youth can get information online (Khanna, 2023).

In addition to conventional approaches, it is necessary to explore out-of-the-box solutions. SECMOL is an alternative school that aims to find solutions to prevent human involvement in emissions and pollution. The school teaches students innovative solutions such as ice stupas and refreezing of glacial lakes using thermal pumps and heat engines from an early age. Furthermore, the building itself serves as an inspiration for students to pursue a greener and more sustainable future. Built in the mid-1990s, the school was constructed using soil as the primary building material, which is readily available to everyone, regardless of their financial status. The building is also heated and powered by the sun, which is accessible to all. When these resources are combined with human ingenuity, remarkable accomplishments can be achieved, leading to a happier and healthier life for all (Wangchuk, 2023).

carbon-neutral
energy-positive school

Ladakh

The school building is powered entirely by solar electricity, with other major needs such as heating being met through passive solar heating. This innovative approach could potentially make it the world's first carbon-neutral, off-grid, energy-positive school. The use of solar energy is integrated into nearly all aspects of life at the school, from cooking with concentrated dishes to providing natural lighting, pumping electricity, and heating water. Even the cows on the campus live in solar-heated cow sheds. The concepts covered in 9th and 10th-grade textbooks, such as heat conduction, convection, and radiation, are put into practice to improve life at the school. Students collaborate on building designs that use only solar energy for heating, resulting in modern living conditions in even the coldest climates, such as Ladakh, that are comparable to those in New York or London without any negative impact on the atmosphere. Furthermore, by incorporating geography, it is possible to determine the orientation of the sun in each season, which can inform building design that maximizes natural cooling in the summer and warmth in the winter. The school strives to reduce its carbon footprint and mitigate air pollution through the implementation of sustainable practices, while also instilling these values in its students for lifelong adoption (Wangchuk, 2023).

Mission LiFE

Another effort to promote Polar knowledge and interest among the youth is being done through public schemes such as Mission LiFE, launched by the Prime Minister of India on June 5, 2022. This Mission does not rely solely on engineering-based solutions to address environmental issues. Rather, it emphasises on the importance of minimizing our impact on the environment by practising conservation in every aspect of people's daily lives (Khanna, 2023). Apart from this, the Indian government is conducting television programmes where various government officials participate to convey Arctic related issues to the youth of India. UGC held a seminar along with the UArctic and Rashtriya Raksha University is the first university to gain a membership of the UArctic (Ibid.).

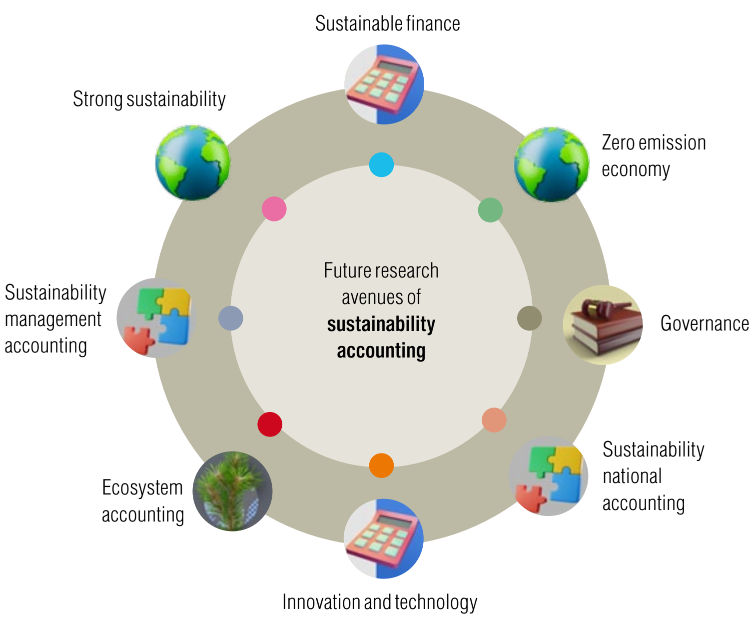
UArctic
Rashtriya Raksha University

11.3.2 Multidisciplinary Polar Studies

Academic research in multidisciplinary Polar studies is an area where youth participation has been lacking. A major reason for this has been the common misapprehension that one needs to be exclusively trained in physics, mathematics and natural sciences to work in the Polar regions (Dayal, 2023). However, the challenges faced by the Polar regions are not only climate change, but also security-related. This calls for the growth of transdisciplinary and multidisciplinary academic expertise in the field of Polar studies. For instance, there is research on areas related to accounting on climate change, climate finance, blue economy and more such issues that directly and indirectly facilitate the understanding of the Polar regions. Students pursuing undergraduate and post-graduate studies in the academic disciplines of biology can also pursue doctoral studies or higher education in climate sciences or climate studies (Ibid.). However, such opportunities are limited in India since there is a dearth of multidisciplinary academic programmes in the educational institutes (Ibid.). This is one of the biggest concerns

multidisciplinary academic programmes

Fig. 11.1: A holistic figure displaying future research avenues for youth in sustainability accounting



Source: Singhania, 2023

TERI
NCPOR
opportunities

for the Indian academia striving to involve the youth in Polar research. Despite this, institutes such as TERI and NCPOR provide opportunities for students to pursue postgraduate courses in sustainable development, environmental studies, and public policy and for minor internship projects in Polar studies, respectively (Ibid.). Students from different academic backgrounds including biological sciences, social sciences, environmental studies and more can pursue academic research in issues pertaining to Polar understanding. There are also various student participation schemes in India where students can submit independent research projects and even get opportunities to travel to the Polar regions of the Arctic and Antarctic (Ibid.). Thus, there are both field and lab-based academic opportunities for the youth wanting to pursue Polar research. An interested candidate can choose to be involved in lab-based studies of the Polar regions, or with several funding opportunities they can venture into the field, collecting samples and bringing them to the lab for extensive studies. Either way, today's youth can access limited but plausible opportunities in Polar academic research.

11.3.3 Sustainability Accounting

ESG

There are many new disciplines coming up in the field of climate change and Polar research. One of them is sustainability accounting or ESG (environmental, social and governance) accounting (Fig. 11.1). Sustainability accounting is an emerging trans-disciplinary field which culminates the actions, techniques and frameworks for recording, measuring and reporting the financial impact of social and environmental factors, impact of financial and economic activities on social and ecological systems and their interaction to attain socio-efficiency, eco-efficiency and eco-justice (Singhania, 2023). Sustainability accounting is interwoven with the complex challenge of climate change which mandates it to aggressively expand and entwine with other disciplines.

socio-efficiency
eco-efficiency
eco-justice

The new areas of study is lucrative for the youth since climate change is now a topic that businesses are also engaging in. Sustainability accounting is one aspect of it, which refers to non-financial reporting from a business perspective. The goal is to achieve a universal standard for sustainability reporting, similar to the standardised, number-driven approach of financial accounting (Singhania, 2023). As a result, numerous research opportunities are emerging in this field around the world. Australia is placing significant emphasis on sustainability accounting, while countries such as the United States and China are also increasing their attention to this area (Ibid.). Therefore, the youth can explore climate change related sustainable businesses as both educational, research and career options.

sustainability
reporting
Australia

The adage 'what gets measured gets done' highlights the significance of corporate sustainability reporting. There are four levels of sustainability from an accounting and finance perspective: sustainable finance, zero emissions economy, governance, and national accounting (Singhania, 2023). The Scandinavian countries are leading the way in terms of emissions control, followed by the US and other countries at the second level, and China, India, and the rest of Asia at the third (Ibid.). In India, the Securities and

sustainable finance
zero emissions
economy governance
national accounting

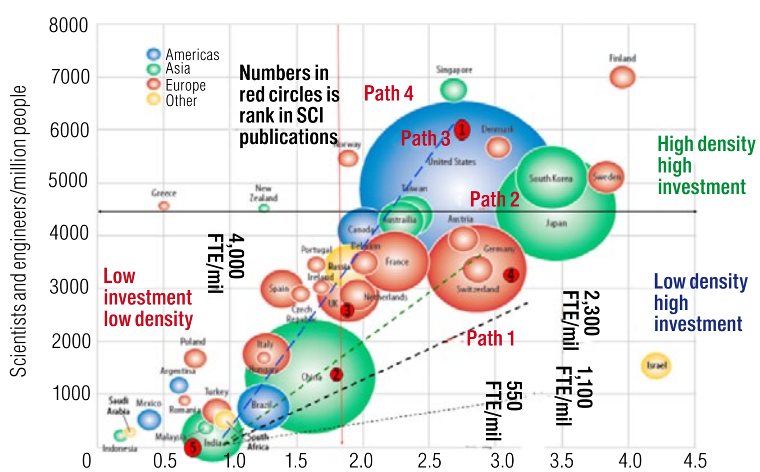
Exchange Board of India has mandated that the top 1000 listed companies need to report on sustainability beginning on April 1, 2023 (Ibid.). This regulation has generated interest in sustainability reporting in India. Therefore, sustainability reporting is a suitable career option for students pursuing finance and accounting and looking forward to engaging with sustainable development, climate change control and other similar fields.

Securities and Exchange Board

Another such area, ecosystem accounting, also known as biodiversity accounting, is gaining traction in research, as shown by the development of various frameworks and mechanisms. Accounting for climate change provides an excellent opportunity for academic research, including the examination of pressure from stakeholders such as employees, investors, media, and regulators (Singhania, 2023). At the national level, mapping of biodiversity footprints and carbon emissions accounting are important considerations. This interdisciplinary field appeals to the youth with a background in accounting and finance who are interested in making a concrete contribution towards addressing climate change.

Sustainability management accounting is another critical area that many companies are exploring, particularly in terms of their in-house products. India is a textile-driven economy with a significant focus on textile exports. Leading textile exporters from India are now incorporating sustainable value tags that demonstrate their commitment to environment-friendly production processes across the entire value chain. These initiatives are becoming the subject of case studies, which business schools are documenting as examples of successful transformation. For the youth working in companies, it is recommended that they utilize sustainability accounting to its fullest potential to reduce unnecessary costs and enhance the firm's performance. Research

Fig. 11.2: Number of researchers (per million people) vs annual R&D spending in the world, 2011



Number of resear chers (per million people) vs annual R&D spending in the world, 2011.

Source: Mehajan, 2023

indicates that companies that are aware of their ESG footprints and conduct their operations responsibly are valued differently. Greater attention to sustainability practices may also attract foreign investment.

carbon neutrality

Environmental considerations are crucial, particularly for environmentally sensitive industries in developing countries, which require a heightened focus on strategic risk planning. Additionally, technological advancements are enabling faster progress toward achieving carbon neutrality. These developments offer opportunities for young researchers to create case studies, drive theoretical innovations, and make meaningful contributions to the field.

11.3.4 Scientific Research in the Arctic

technical workforce

In the past 15 years, India has made significant progress in Polar research, especially when compared to the previous two decades. This is mainly because India has established itself as a scientific community, with the distinction of having the world's third-largest scientific and technical workforce (Mehajan, 2023). These efforts were further boosted by India unveiling its Arctic Policy in 2022, but its scientific community has been conducting research on the Poles for several years prior to its announcement. Earlier, the Poles were very narrowly limited to a small set of people and the connection between India and the Poles were not understood. Starting with humble beginnings, small budget, limited manpower, Indian researchers have engaged with the Poles for decades (Saran, 2023). Climate change and global warming are perhaps the most important aspect of the study that has facilitated an understanding in India about that connection. Gradually, the Indian government started making institutional arrangements, starting with the Department of Ocean Development a few decades ago to a full-fledged MoES. Over the years, other institutions have emerged to study the Arctic and the Antarctic, especially in the Indian Universities.

Arctic Council working groups

IndArc

Currently, India has many national Polar Programmes, which includes the Indian Antarctic programme, Indian Arctic programme, Himalayan studies, and Southern Ocean research programme (Jain, 2023). The Indian Arctic Programme started in 2007 when a team of five scientists went to the Arctic. Thereafter in 2008, Himadri Station was inaugurated in the Arctic to continue scientific observations. And in 2013, India was awarded the Arctic Council 'Observer' status. The Indian Arctic programme is conceived to cater to the Indian scientific community and we have scientific themes other than the teleconnection between Indian monsoon and the Arctic climatic variabilities. Majority of our scientific themes are in line with the Arctic Council working groups and few of them are like biodiversity assessment, long term monitoring, atmospheric prediction, atmospheric sciences, aerosol and so forth. To cater to this kind of scientific objectives, India has been constantly investing in the capacity-building in the Arctic. In 2014, India deployed IndArc mooring in collaboration with IIT, Chennai and it was the first mooring in the offshore waters or outside the Indian waters. Subsequently, an atmospheric laboratory was established in Svalbard to cater to the atmospheric study and several instruments were installed that continuously measure different atmospheric parameters. Scientists at NCPOR utilize this data to understand atmospheric variability in the Arctic to cater to a broader perspective and to gain a pan-Arctic understanding of the atmospheric processes. India embarked on an Arctic Ocean cruise in 2019. A team of two scientists from NCPOR collected samples from the region (Jain, 2023).

The Indian Antarctic Programme is one of the finest examples of a long-term research effort of key national research institutions. It is also an important component of the international scientific community's effort to understand Antarctica. Indian contributions to the knowledge of Polar science, over the last two and a half decades, have been significant, well recognized internationally and published in scientific journals. The scientific programmes being pursued in Antarctica broadly fall in eight major domains—atmospheric science, geoscience, biology, environmental sciences, human physiology, medical science, cold regions engineering and communication (Nayak, 2023).

Antarctica
Polar science

The regular participating institutions in annual Antarctic expeditions are GSI, IMD, SoI, ZSI, BSI, DRDO laboratories, CSIR laboratories (NGRI, CCMB, NBRI, NEERI, NPL, SERC, CFTRI, NIO, RRL, NAL, etc.), DST laboratories (BSIP, IIG, WIHG, etc.), academic institutions like NITs and universities and other government departments (Nayak, 2023). Such institutions bring about opportunities for Indian youth to pursue professional research careers in Polar studies (Fig. 11.2).

In addition to the aforementioned initiatives, the EAPG, led by the Secretary of MoES, has been established. This group meets twice a year, and based on their discussions, road maps are developed, incorporating feedbacks received. Points of contact have been established in key ministries including the MoES, MoEFCC, MEA, MoPS, MoPNG, MoD, and DST. Quarterly meetings are held to analyse the activities conducted, and a newsletter is circulated to the missions overseas to ensure alignment of all stakeholders. Think tanks have also been engaged, and their activities are captured in the think tank segment (Khanna, 2023).

EAPG

ministries

Besides, the existing limited organisations focussing solely on the science of Polar regions, it is crucial to involve other disciplines such as finance, politics, humanities, etc. to comprehensively examine and comprehend Polar systems and tackle the challenges they present.

11.4 Challenges

India has made progress in Polar scientific research; however, they are far from being sufficient when compared to other nations such as China. Approximately 1,500 Indians are among the top 2 per cent scientists in the world (Mehajan, 2023). There are several statistics to celebrate the progress of the country's youth, including India's 41st rank in

Global Innovation Index

policy framework

the Global Innovation Index (Ibid.). In terms of India's role in the Arctic, India has made significant scientific contributions, particularly in the last few years through seismic monitoring observations that began in 2016 and 2017, building on our decades-long history in the region. India's progress as a science powerhouse is supported by a well-crafted policy framework that promotes rising incomes and evolving lifestyles of youth. The STIP 2020 and the NRF, with a budget of approximately INR 2,000 crore provided by the DST, are instrumental in strengthening institutional and human capacity for basic research. In addition, private and philanthropic investments along with the ever-growing IT sector are providing the necessary seed funding for this research revolution.

Accelerate Vigyan Scheme

TARE

Unfortunately, India's scientific workforce is relatively small with only 200 scientists per million people, compared to China's 1,000. Nevertheless, in the last five years, the government has launched several schemes to strengthen and expand this research base—including internships and workshops and a higher number of MSc and PhD students. The TARE programme, which allows young faculties to take a three-year break from their parent institute to gain knowledge and skills from premier institutions, are also in place. Additionally, the recently launched SERB-SURE scheme targets state universities, some central universities, and private university setups. Although limited to the SERB, the results of these schemes have been promising in expanding the research base.

transformative ecosystem

India needs to establish a pioneering research and development ecosystem that not only focuses on service-centric growth but also generates cutting-edge technology applications for the betterment of society. Although India has a robust funding mechanism, it has not been able to capture the outcomes. Moreover, most of the country's programmes are organised with a focus on industrial benefits. The need of the hour is to broaden our horizons and embrace the latest technologies and innovations to create a sustainable and transformative ecosystem that can cater to the needs of the society (Mehajan, 2023).

Global Research Council

Another challenge is the absence of interdisciplinary research in Polar studies which presents a significant loophole in the research system as mankind's problems may not be fully understood by being centric to one's own field. At the Global Research Council meeting, two themes were discussed, namely women's participation and interdisciplinary research. However, many R&D funding agencies worldwide do not have specific policies supporting interdisciplinary research.

11.5 Recommendations

There are many ways for young people to participate in Polar studies beyond the traditional role of a scientist. The involvement of individuals from diverse backgrounds, such as finance, business and humanities is valuable because a multidisciplinary approach is crucial. Following are the various ways in which youth can engage in Polar studies:

i. The primary focus in realigning and revamping the innovative research ecosystem for youth in the country is to ensure that strategic road maps are synchronized with the ambitious aspirations of the 21st century. Prior to any transformation, it is essential to understand both its strengths and limitations (Mehajan, 2023).

ii. It is essential to promote Polar studies through educational governance, both at the primary and higher educational level. India is a country with the youngest demographic dividend in the world. Yet, the participation from youth in Polar studies is limited. There is an urgent need to address the gaps in Polar studies by taking appropriate steps that encourage the youth to embrace new career goals (Dayal, 2023).

iii. It is essential to modify existing review processes and give sufficient time to the principal investigators to produce tangible results. This requires a change in the mindset of researchers and reviewers alike, to make them free of risk-aversion. Moreover, mentoring research at the early stages and incentivizing it with recognition can drive significant improvements at the government sector, and the institutional levels. Nevertheless, it is crucial to balance the act on the part of the institution itself while implementing these measures (Mehajan, 2023).

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AEC	Arctic Economic Council
ASOC	Antarctic and Southern Ocean Coalition
ASSOCHAM	The Associated Chambers of Commerce and Industry of India
ATCM	Antarctic Treaty Consultative Meeting
ATS	Antarctic Treaty System
AWiFS	Advanced Wide Field Sensor
AYUSH	Ayurveda, Yoga and Naturopathy, Unani, Siddha and Homeopathy
BCE	Before Common Era
BBNJ	Biodiversity Beyond National Jurisdiction
CAV	Cumulative Absolute Velocity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CE	Common Era
CEP	Committee for Environmental Protection
CFCs	Chlorofluorocarbons
CHARS	Canadian High Arctic Research Station
CMIP6	Coupled Model Intercomparison Project 6
COP	Conference of Parties
CRAMRA	Convention on the Regulation of Antarctic Mineral Resource Activities
CSIR	Council of Scientific and Industrial Research
DNA	Deoxyribonucleic Acid
DRDO	Defence Research and Development Organisation
DST	Department of Science and Technology
EAPG	Empowered Arctic Policy Group
EEZ	Exclusive Economic Zone
ELB	Explicit Load Balancing
EVRI	Electric-field vector resistivity imaging
FICCI	Federation of India Chambers of Commerce and Industry
GDP	Gross Domestic Product
GLOF	Glacial Lake Outburst Flood
HCFCs	Hydrochlorofluorocarbons
HFCs	Hydrofluorocarbons
IACR	International Arctic Research Center
ICC	Indian Chamber of Commerce
IHR	Indian Himalayan Region
IIT	Indian Institute of Technology
IITM	Indian Institute of Tropical Meteorology
IMD	India Meteorological Department
IndArc	Indian Arctic mooring
INR	Indian Rupees
ICIMOD	International Centre for Integrated Mountain Development
IONS	Indian Ocean Naval Symposium
IORA	Indian Ocean Rim Association
IPCC	Intergovernmental Panel on Climate Change

IPCCAR6	Intergovernmental Panel on Climate Change Annual Report 6
ISA	International Seabed Authority
ISRO	Indian Space Research Organisation
KHertz	kilohertz
LIDAR	Light Detection and Ranging
LiFE	Lifestyle for Environment
LIGHTS	Learnings in Geography, History, Technology and Science
LISS	Linear Imaging Self-Scanner
MEA	Ministry of External Affairs
MoD	Ministry of Defence
MoEFCC	Ministry of Environment, Forest and Climate Change
MoES	Ministry of Earth Sciences
MoPNG	Ministry of Petroleum and Natural Gas
MoPSW	Ministry of Ports, Shipping and Waterways
NASA	National Aeronautics and Space Administration
NCERT	National Council of Educational Research and Training
NCPOR	National Centre for Polar and Ocean Research
NCS	National Center for Seismology
NIOT	National Institute of Ocean Technology
NISAR	NASA-ISRO Synthetic Aperture Radar
NIT	National Institute of Technology
NMSHE	National Mission for Sustaining the Himalayan Ecosystem
NSIDC	National Snow and Ice Data Center
NSR	Northern Sea Route
OCM	Ocean Color Monitor
ODS	Ozone Depleting Substances
OMZs	Oxygen Minimum Zones
OTEC	Ocean Thermal Energy Conservation
PDGL	Potentially Dangerous Geological Locations
PFCs	Perfluorocarbons
PPA	Post P-Wave Arrival
S2S	Subseasonal-to-seasonal
SAR	Synthetic Aperture Radar
SaGAA	Science and Geopolitics of Arctic and Antarctic
SCAR	Scientific Committee on Antarctic Research
SCAT	Scatterometer
SECMOL	The Student's Educational and Cultural Movement of Ladakh
SERB-SURE	SERB-State University Research Excellence Fellowship
SERB	Science and Engineering Research Board
SF6	Sulphur Hexafluoride
SSP	Shared Socioeconomic Pathways
SST	Sea Surface Temperatures
SUNA	Submersible Ultraviolet Nitrate Analyzer

SWAYAM	Study Webs of Active-Learning for Young Aspiring Minds
Swiss ADC	The Swiss Agency for Development and Cooperation
TARE	Teachers Associateship for Research Excellence
TERI	The Energy and Resources Institute
TRISHNA	Thermal InfraRed Imaging Satellite for High-resolution Natural Resource Assessment
UArctic	University of the Arctic
UGC	University Grants Commission
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
V-SAT	Very Small Aperture Terminal
WTO	World Trade Organisation

About the Report

Science is making it abundantly clear, confirming that global warming leads to more frequent and intense extreme weather events, droughts, and tropical cyclones, not to mention continued warming of the ocean and the atmosphere at the current rates of human-led greenhouse emissions and a continued loss of ice in all forms, whether in Arctic, Antarctic or the Himalaya. However, not all regions of the world are warming at the same rate. With the Polar regions experiencing accelerated warming compared to the oceans and equatorial regions, urgent action is required to reduce greenhouse gas emissions and mitigate the effects of climate change. Raising awareness and engaging in multiple platforms is essential to encourage faster climate action.