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).

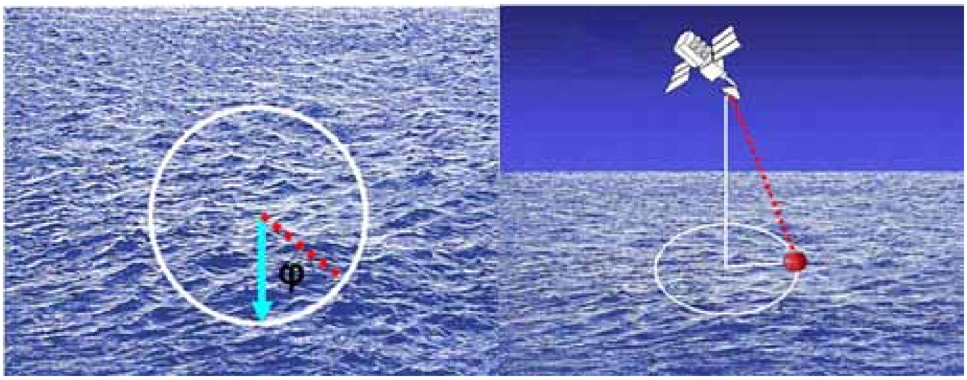
airborne monitoring

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

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.

radar systems

3.3 Advancement in Monitoring the Antarctic Ice Sheet

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.

global sea-level rise
ice sheet
surface height

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.

Indian earth
observation missions
TRISHNA

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

surface melting pattern
Antarctic

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).