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Status Report

Cryosphere Research: Indian Perspective

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Indian scientists have been involved in studies of cryosphere both in the Himalayas and Polar Regions, since mid sixties. Inventories of Himalayan glaciers produced by Geological Survey of India (GSI) and Space Application Centre (SAC) have made available a platform for detailed studies on some of 9576 glaciers identified and numbered in these inventories. It has been summarized that most of Himalayan glaciers are losing mass except the Karakoram region where stability or mass gain is indicated.

In the Polar regions, studies on cryosphere have focussed on glacier dynamics, sea ice, fluctuations of the continental ice margin and snouts of glaciers. Drilling for ice cores and high-resolution data obtained from such cores has helped in establishing climatic history for the last 500 years. Studies on biogeochemistry of Antarctic snow and melt water lakes of Schirmacher Oasis have received detailed attention. In recent years, areas of investigation have been extended to Arctic Region where some of the glaciers (Broggerbreen) are being studied in detail. Microbiological studies, especially anti oxidant potential of Arctic lichens and establishing the bacterial diversity in Ny Alesund area have received attention.

Key Words: **Mass Balance; Hydrological Characters; Isotopic Variability in Ice Cores; Biogeochemistry; Aerosol; Bacterial Diversity**

Introduction

After the ocean, the Cryosphere is the second largest component of the climate system that holds ~ 75% of the Global freshwater resource. Based on the mass and heat capacity, the Cryosphere plays a significant role in the global climate. Various components of the Cryosphere (snow, lake ice, sea ice, glaciers, ice caps, ice shelves and ice sheets) contribute to short-term climate changes, whereas the ice shelves and ice sheets contribute to long-term changes including the ice age cycles. Thus, monitoring the changes in the Cryosphere regions are crucial. Indian researchers have been carrying out observations on major components of the global Cryosphere in the Himalayas, Antarctic and Arctic regions. Various departments under the Government of India (Ministry of Earth Sciences, Ministry of Mines, Defence Research and Development Organization. Department of Science and Technology, Department of Space, Ministry of Environment and others) are engaged in the Cryospheric research through different programmes. Some of the organizations involved in the Cryospheric research include: Geological Survey of India (GSI), National Centre for Antarctic and Ocean Research (NCAOR), Snow and Avalanche Study Establishment (SASE) of DRDO, Space Application Centre (SAC), Wadia Institute of Himalayan Geology (WIHG), National Institute of Hydrology (NIH), Indian Institute of Geomagnetism (IIG), Physical Research Laboratory (PRL) apart from various universities and IITs. Major cryosphere studies being conducted in India include: i) Modelling and quantification of the glaciers and ice caps *vis-a-vis* the ongoing global warming; ii) Studies on the changes and dynamics of glaciers and ice cover to understand its impact on hydrology, ecology and climate; iii) Reconstruction of the climate change during the past, using archived information on past climate and its future implications.

The Himalaya

The Himalayan mountain system hosts the world's highest peaks. About 50 peaks among these rise above 7500 m elevation. The Himalaya forms the thickest snow covered region other than the polar region and is sensitive to global warming (Sangewar and Shukla, 2009). In the Indian part of the Himalaya, 9575 glaciers exist (GSI, 2009), and some of these form the perennial source of major rivers. Changes in glacier extensions is taken as indicators of climate change, since any change in climate affects the snowfall and the ablation (melting). The rate of accumulation and ablation decides the health of a glacier. GSI has studied this aspect in a number of glaciers such as Gangotri, Bandarpunch, Jaundar Bamak, Jhajju Bamak, Tilku, Chipa, Sara Umga Gangstang, Tingal Goh Panchi nala I, Dokriani

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and Chaurabari. Raina and Srivastava (2008) have documented the origin, classification, landforms, snow cover and basinwise inventory of the Himalaya glaciers in their *Glacial Atlas of India*. Bolch *et al*. (2012) in a regional study on Himalayan glaciers have concluded that most Himalayan glaciers are loosing mass except in Karakoram region where stability or mass gain is indicated from remote sensing studies.

Glacier Assessment and Mass Balance Studies

Indian scientists (SAC, GSI and WIHG) are adopting remote sensing techniques to compliment the ground surveys and Geographical Information Systems (GIS) to study the physiography and mass balance of glaciers viz., Gangotri, Dokraini and Chhota Sigri (Negi *et al*., 2009). Shukla *et al*. (2009) have used satellite remote sensing data to map debris cover and evaluate temporal changes in them over a glacier in the Chenab basin in Himalaya. Similar spectral responses were found between supraglacial debris (debris on the glacier) and periglacial debris (debris along glacial boundary) in the solar reflection region. Shukla *et al*. (2010a) tested the thermal infrared bands (ASTER data) to resolve the ambiguities between supraglacial and periglacial derbis in mapping of the glaciers. Based on this, a novel approach for extraction of debris-covered glaciers (Shukla *et al*., 2010b) was adopted. Kulkarni *et al*. (2011) also have studied the changes in the Himalayan Cryosphere using remote sensing techniques. The glacial mass balance and seasonal snow cover were used to estimate the retreat of 1868 glaciers over 11 basins since 1962. Observations in 28 river sub-basins over the central and western Himalayas indicated the retreat of snow even during winters. Gurung *et al*. (2011) have examined changes in snow cover over the Hindukush-Himalayan region using the MODIS data (2000 to 2010) and reported the maximum depletion to be during February. Snow-cover map in lower and middle Himalaya has been attempted by using AWiFS data of 56m resolution and it was seen that S3 with topographic correction implied improvements in accuracy as compared to Normalized Difference Snow Index (NDSI) (Sangewar, 2011).

Shukla *et al*. (2009) showed that the area of the glacier in Chenab basin reduced from 110.5 to 96.8 km^2, a recession of ~ 756 m. A change in mass balance of a glacier is the most sensitive climate indicator. Wagnon *et al*. (2007) and Berthier *et al*. (2007) used SPOT 5 images and SRTM data to study the mass balances of glaciers in Himachal Pradesh and found a rapid ice loss from the glaciers in the Spiti/Lahaul region. However, Shukla and Mishra (2007) observed that glaciers of Lahaul Himalayas are retreating at lower rates than those located south of Pir Panjal range. Keshri *et al*. (2009) have proposed new indices namely, Normalized Difference Glacier Index (NDGI) and Normalized Difference Snow Ice Index (NDSII). A combination of NDSI with NDGI and NDSII allows accurate delineation of snow, ice and ice mixed debris. In order to assess glacier mass balance (ratio between accumulation area to the total glacier area), a technique based on Accumulation Area Ratio (AAR) is used extensively. Annual mass balance, snout retreat, glacier discharge and meteorological observations for the years 2005-2009 were made by WIHG. Mass balance is an important parameter to track large-scale retreat of glaciers. Raina (2008) has compared the balance of two glaciers in Himachal Pradesh (Gara and Gorgarang). Mohd *et al*. (2011) studied the mass-balance and dynamic behaviour of Chhota Shigri Glacier and evidenced that the glacier has experienced a period of near-zero or slightly positive mass balance in the 1990s, before shifting to a strong imbalance in the 21st century. He concluded that excess winter snow precipitation leads to a positive balance or a reduced negative balance. However, on an annual basis, these glaciers continue to retreat even under intense winter accumulation.

Glacial Monitoring

The Himalayas possesses one of the larger resources of snow and ice and thereby act as a large freshwater reservoir. Monitoring the glaciers is important to assess the overall reservoir health. Kulkarni *et al*. (2007) studied 466 glaciers in the Himalayan basins. The glaciers are located on the monsoon-influenced slopes where precipitation exceeds 2500 mm/yr. The mean annual temperatures over the snowline are ~ –2 to –4°C and the basal ice temperatures approach 0°C (Ganjoo, 2009). The glacial area has been reduced by 21% since the middle of the last century and, due to fragmentation, the number of glaciers has increased. Studies suggest that glaciers are retreating in response to global warming. Meticulous inventories of 1962 and 2001 have clearly demonstrated that glacier fragmentations were significantly higher than expected. The loss in surface area of large glaciers was 12% as compared to 38% for small glaciers, probably due to the depth, mass balance and rate of ice melting at the terminus. Since the response time of a glacier to climate is proportional to ice depth, small glaciers are more sensitive to global warming. The observations by Kulkarni *et al*. (2007) suggest that small glaciers and ice fields are significantly affected due to global warming from the middle of the last century. In contrast, Sangewar (2007) has stated that during 1974 to 1991, five years recorded positive balance for some glaciers.

Upadhyay (2009) has given an alarming version of the recession of Siachen glacier while Ganjoo and Koul (2009a) have argued that the glacier is stable. According to Ganjoo and Koul (2009b), the eastern Siachen glacier showed faster withdrawal due to calving and the western due to melting, while the middle part showed hardly any retreat. Their studies corroborate the fact that inter- and intra-annual variations in atmospheric temperature have more influence on the NW Himalayan glaciers. Raina and Sangewar (2007) have also reported that the Siachen glacier has not shown any appreciable retreat between 1958 and 1985. The WIHG's studies on the Uttaranchal glaciers for morphology, landform, snout fluctuation, recession/retreat and mass balance have shown that the retreat of Dokriani glacier during 2004-09 was from 14 to 21 m/yr, while that for Chorabari glacier it was from 10.2 to 5 m/yr (Dobhal and Mehta, 2010; Dobhal, 2010; Chaujar and Dobhal, 2009; Dobhal and Mehta, 2008; Dobhal *et al*., 2007). Singh *et al*. (2010) studied the depth of the site Patseo to assess glacier depth and debris cover using Ground Penetrating Radar data and site experiments.

Studies on Bhagirath Kharak and Satopanth glaciers (Nainwal *et al*., 2008) showed the retreat of Satopanth and Bhagirathi glaciers as 22.88 to 7.42 m/yr for 1962-2005 and 6.5 to 1.5 m/y for 2005-2006. Koul and Ganjoo (2009) showed the retreat of Naradu glacier between 4.3 and 2.9 m/yr during 2000-03. Similarly Bali *et al*. (2008) have observed a retreat of 6.39 m/yr for the Pindari glacier between 1966 and 2007. Anthwal *et al*. (2006) have attributed the retreat of the Himalayan glaciers to the climate change.

Cryosphere and Hydrology

Sediment load from the glaciers have been studied by National Institute of Hydrology. Akthar *et al*. (2008) estimated the water resources in three river basins over the Hindukush-Karakoram-Himalaya region using Hydrologiska Byrons Vattenbalanceavdelning-Met (HBV-Met) and Hydrologiska Byrons Vattenbalanceavdelning-Providing Regional Climate for Impact Studies (HBV-PRECIS) models. Indications of climate change on snowmelt in to the eastern Himalayan Rivers have been studied by Bhadra *et al*. (2009). Based on the solute dynamics of melting Gangotri glacier, Kumar *et al*. (2008a & b) identified the need for water resource development. Bhutiyani *et al*. (2007, 2008) observed the changes in the air temperature and stream-flow patterns in western Himalaya, while Singh *et al*. (2008) studied the hydrological characteristics of Gangotri glacier. Several workers (Sharma *et al*., 2010; Joshi, 2009; Joshi and Sharma, 2007) studied the probable hazards and disaster management related to the conservation of the Himalayan glaciers.

Cryosphere and Climate Associated Studies

The unique orientation of the Himalaya from west to east, the variations in temperature and precipitation regimes are distinct and useful in climatological studies. Borgaonkar *et al*. (2009) have prepared a 458-year chronology of Himalayan cedar from western Himalaya. This dendro-climatological study indicated a significant positive correlation for tree-ring width index with winter temperature and summer precipitation and an inverse relationship with summer temperature. Sharma (2009) has analysed the historical and palaeoclimatic data for many previous centuries and concluded that the Miyar glacier of Chenab basin is stable for last 134 years. Juyal *et al*. (2009) have reconstructed the early Holocene history from sediments of Himalayan lakes which indicated intense sedimentation between 25 to 13 ka. Snow chemistry of surface snow samples collected from different altitude across the Chhota Shigri glacier during monsoon and post-monsoon were studied by Sharma *et al.* (2009).

Several researchers have studied the influence of aerosol on the recession of glaciers (Ramanathan *et al*., 2007; Hedge *et al*., 2007; Pandithurai *et al*., 2008; Das *et al*., 2008). The relationship between AOD (Aerosol Optical Depth) and recession of Dokriani glacier in Bhagirathi valley (Das *et al*., 2010) was significant (r^2= 0.86) and led to the conclusion that increased AOD over the Himalayan region has enhanced the aerosol heating leading to recession of glaciers.

Antarctica

The Antarctic continent makes up about 10% area of the Earth, while the ice sheets and ice shelves covers about 14 x 10^6 km^2 area. About 98% of Antarctica is covered by thick ice sheets that contain about 90% of the world's 'permanent' ice and 70% of its fresh water. The cryosphere, hydrosphere and atmosphere in and around Antarctica are the closely interactive components of a complex climate system, with global, regional, as well as local influences. Ravindra and Chaturvedi (2011), Ravindra (2008, 2011), Ravindra *et al.* (2008), and Ravindra and Tiwari (2011) have reviewed the geology and glaciology in the Polar region within Antarctica.

Glacier Dynamics

Global Positioning System (GPS) campaigns in the Schirmacher Oasis of the central Dronning Maud Land, Eastern Antarctica (Sunil *et al*., 2007, 2009; Reddy *et al*., 2009) have provided the horizontal velocity to be in the range 1.89-10.88 m/yr (average 6.21m/yr) along NNE direction. The study also suggested that the velocity is influenced by topography, subsurface undulations, fractures/crevasses and blockage. The extensional strained area coincided with the surface gradient and crevasses, while the region of compressional strain was due to the blockage caused by Schirmacher Oasis and nunataks. In general, the low velocities are primarily attributed to the ice cap located in exposed nunataks extending along the ice-shelf. The motion of Nivlisen ice shelf measured using the DGPS in the base station Maitri and nearby International GNNS service (IGS) stations, suggest the influence of oceanic tides, wind stress and surface currents (Sunil and Reddy, 2010). Further studies using Synthetic Aperture Radar (SAR) suggest the importance of continuous monitoring to understand the influence of atmospheric conditions on velocity fields (Reddy *et al*., 2009). The GSI has also studied the accumulation/ablation of the ice shelf since 1985. The winds support snow accumulation of 0.45 to 0.55 m/yr (Dharwadkar *et al*., 2010).

Studies on Sea Ice

The ice surrounding the Antarctic continent has a maximum coverage of 20 million km^2 during winter, which leads to a severe climatic perturbations and biological productivity. The Indian scientists have been successful in the reconstruction of past climatic changes using remote sensing data as well as modelling. Using passive microwave observations on the variability in the ice edge during 1982-2004 in Antarctica it was inferred that the sea-ice concentration peaked during the summer seasons of 1982-1998 (Bhandari and Khare, 2009). The Ross and Weddle Sea also showed a positive trend, whereas Bellinghausen/ Amundsen Sea showed a negative trend. Simulations of sea ice using Semtner's and Winton's models (Mitra and Das, 2007) were able to capture the seasonality of Antarctic sea ice. Artificial neural network (ANN) could simulate the sea ice anomalies with dominant annual and half-yearly cycles (Tripathi and Das, 2008). However, the accuracy of prediction for intra-seasonal variability was compromised when the trends were removed. A comparison of Antarctica sea-ice variability with Indian Ocean SST yielded a significant positive correlation in the SE Indian Ocean (Rai *et al*., 2008). Studies of Nuncio *et al*. (2011a) on the sea-ice anomalies revealed the presence of southerly Antarctic Circumpolar Current. The eastward propagating anomalies additionally advected southwards, deviating from its original east-west path. Furthermore, a reduction in the amplitude of positive sea-ice concentration followed their interaction with the warmer waters of the east. Similar to oceanic Antarctic Circumpolar Wave (ACW) anomalies, the atmospheric anomalies are also distinct to the west of equator (Nuncio *et al*., 2011a). The satellite-derived ice covers in the Indian Ocean Sector (IOS) during the period 1978-2006 (Nuncio *et al*., 2011b) revealed that sea-ice cover was maximum when the ocean remained stable. A low ice cover was observed during 1985 to 1993, when the zonal winds and latent heat flux were relatively weak to deepen the mixed layer to ~250 m (Nuncio *et al*., 2011b) such that lower air temperature and higher stratification support increase in sea-ice extent.

Studies on the Mass Balance

The mass balance study of the ice sheet is of great importance due to role of Antarctic continent on the global warming and sea-level rise. Geological Survey of India has been carrying out stake measurements on snow accumulation in the Schirmacher and Nivlisen glaciers. Core data from other sources like snow/ice have provided valuable information on the spatial and temporal variability of snow accumulation in this region. Near the Indian station *Dakshin Gangotri* (70º 5.62'S, 12º E), a net accumulation of 62.7cm was recorded during 1999-2001. A recent study on the surface energy of the Schirmacher close to the non-glaciated region revealed that there is intense ablation (0.0172 m water equivalent per day) during summer (Gusain *et al*., 2009). During November 2007 to February 2008, the mass balance was –1.53 m.w.e, proportional to the observed hourly ablation of the glacier. Sublimation and melting contributed 16 and 83% respectively to the net summer ablation (Gusain *et al*., 2009).

Long-Term Changes on the DG Glaciers

Monitoring of glacier snout along the continental ice margin was initiated as a long-term project by the GSI in 1983. The annual fluctuations in continental ice margin over the last two decades are being monitored along Dakshin Gangotri Glaciers in the Schirmacher Oasis (Latitude: 70º45' S; Longitude: 11º33' E). The snout showed a significant recession of 6.5 to 7 m per decade (Dharwadkar, 2010; Gaur and Prasad, 2007). This is possibly indicative of the effects of global warming in Antarctica. From the average annual temperature of Schirmacher Oasis, it has been suggested that the rate of recession of DG glacier has been affected by a warm year previous to the year of glacier observations (Chaturvedi *et al*., 2009).

Climatic Reconstruction Using Ice Cores

The ice core proxies provide one of the most direct and accurate method to study the Antarctic climate change. India has initiated similar studies in the coastal regions of East Antarctica in the 1990s. With the use of sophisticated techniques in storage, archival, processing and analysis of ice cores at NCAOR, the program has received enhanced attention. Several shallow (<100 m) ice cores were collected from the coastal Dronning Maud Land, with an expected coverage in the climate variability for the past few centuries and their implications. These were the part of International Trans-Antarctic Scientific Expedition (ITASE), IPICS (International participation in Ice Core science) and the Frontline Scientific Activity of Scientific Committee on Antarctic Research (SCAR).

High-resolution data such as non-sea salt sulphate, oxygen isotope and major ions were used to reconstruct the natural environmental processes such as volcanic eruptions, microbial life in frozen environments and the polar and extra-tropical climatic tele-connections during previous centuries. The IND 22/B4 ice core profiles spanning ~470 years indicated sulphate anomalies associated with volcanic eruptions causing short-term changes in climatic conditions. The tephra analysis of this core revealed presence of a plethora of microbial cells adhered to the surfaces (Laluraj *et al*., 2009). These tiny living entities adhered on to particles in accreted ice appear to provide a hitherto unknown micro-niche. The nitrate record of the above ice core revealed synchronous changes with solar activity, with enhanced nitrate concentration during periods of reduced solar activity like the Dalton Minimum (~1790-1830 AD) and Maunder Minimum (~1640-1710 AD). This study suggests that the nitrate concentrations in Antarctic ice cores is influenced by its production, meteorological conditions and the temperature at the site of precipitation (Thamban *et al*., 2009; Laluraj *et al*., 2011). The $\delta^{18}O$ records of the core revealed a warming of 2.7°C for the past 470 years, especially during the last several decades (Thamban *et al*., 2010).

In order to assess the isotopic variability of ice cores, as high-resolution (>12 samples per year) ice core record was compared with the instrumental records (Naik *et al*., 2010). The results showed its utility in reconstructing the past climate changes like the El Niño Southern Oscillation (ENSO) and Southern Annular Mode (SAM). A detailed study was conducted on the regional atmospheric circulation associated with a reversal in the SAM and near-surface temperature in coastal parts of East Antarctica based on the data from Halley station and coastal Dronning Maud Land (Marshall *et al*., 2009). The study revealed that the regional SAM-temperature is influenced by the relative dominance of the low pressure centres in the west and east of the area, which also initiates the advection of air into the region. The $\delta^{18}O$ record of an ice core from the central Dronning Maud Land region during 1905-2005 revealed significant correlation with SAM. A warming by 1°C during 1905-2005 was reflected in the surface air temperature, confirming that the coastal Dronning Maud Land region, East Antarctica is sensitive to a warming of 0.1°C per decade (Naik *et al*., 2010).

Biogeochemical Studies on the Antarctic Snow

In the Polar Regions, the sources of reactive halogens were found to be the sea-salt in snow, aerosols, frost flowers and the photodegradable halogenated carbons of biological or anthropogenic origin. Recent studies have shown that Antarctica is not pristine due to the presence of toxic species like the dimethylsulfide (DMS), NO*x*, nitrate ions, HCHO, O_3, H_2O_2 and other halogenated compounds. Therefore the snow–ice interfaces are important media for exploring new and unexpected pollutants in the atmosphere. With this backdrop, NCAOR has initiated studies on snow that could provide new information on the influence of bacteria and other microbes in the biogeochemical cycling of Antaractic snow.

Analysis of 55 surface snow samples from the Ingrid Christensen Coast revealed that the sea spray was responsible for the supply of Na^+, Cl^-, K^+ and Mg^{2+}, whereas the crustal input was the primary source for Ca^{2+} (Thamban *et al*., 2010). The distribution pattern was proportional to the distance from the sea as well as the altitude. Secondary sulphur species ($nssSO_4^{2-}$ and MSA) within the snow samples varied possibly due to biological activities. The $nssSO_4^{2-}$ data revealed that several snow deposits are significantly fractionated, especially during the summer (Thamban *et al*., 2010). Biogeochemical analysis of the above snow samples showed elevated nutrient levels that favoured the growth of microalgae, while the subsequent biogeochemical reactions might have released bromide. Activated bromine is oxidised by ozone to BrO, while the oxidation of DMS produces sulphur aerosols. This has led to a crucial finding that since BrO based oxidation of DMS is faster than OH/NO_3 pathway, increase in the bromide concentration in Antarctica can trigger the formation of cloud nuclei condensation (CCN) at the expense of ozone (Antony *et al*., 2010). This suggests that biogenic sources of halocarbons are important factor for the ozone depletion. Studies on the fresh snow deposits revealed the crucial role of bacteria (e.g. *Cellulosimicrobium cellulans*) in the biogeochemical cycling of coastal Antarctica (Antony *et al*., 2009). The *C. cellulans* strain demonstrated physiological traits in contrast to the mesophilic *C. cellulans* type strains, indicating that these physiological properties help their survival in extreme environments (Antony *et al*., 2009).

Microcosm studies on the carbon utilization by bacteria in snow under substrates of low molecular weight [LMW (glucose < 1KDa)] and high molecular weight [HMW (starch > 1KDa)] were also conducted. Results showed their diverse utilization of substrates (carbohydrates, amino acids, amines, amides, complex polymers) indicating that bacteria are capable of consuming diverse sources of snow and control the snow chemistry (Antony *et al*., 2011 a). The total organic carbon (TOC) contents of the snow associated with sea-salt Na+, dust, and bacteria of the two locations in East Antarctica (88-928 $\mu g l^{-1}$ in Princess Elizabeth Land, PEL and 13-345 $\mu g\ l^{-1}$ in Dronning Maud Land, DML) were quite different. It is found that the distance from the sea and elevation determines the TOC concentrations. In addition to the marine contribution, *in situ* bacterial activity could contribute 365 and 320 ng Cl^{-1} in PEL and DML respectively. Correlation with dust suggests that crustal contribution of organic carbon was marginal. Though TOC was predominantly influenced by sea-spray of aerosols, microbial activity was also significant in locations where the sea-spray input was minimal (Antony *et al*., 2011 b).

Other Cryosphere Related Studies

Indian researchers have also contributed to other related areas of Cryosphere research such as the influence of snow and the impact of snow melts on the hydrology of lakes in Antarctica. Observations on different ionic concentrations (small, intermediate, large) along with the air-earth current density and aerosol particles (4.4-163 nm and 0.5-20 μm) to determine the shift in the snow fall period after the occurrence of a blizzard at Maitri, Antarctica (Kamra *et al*., 2009), were made. It was found that the ionic concentrations and density simultaneously decreased by an order of magnitude as the wind speed increased by 2 fold (5 to 10 ms^{-1}). Thus, scavenging of ions and aerosols by the drifting snow influenced the size distribution of particles in the region. The loss is greater for large ions and smaller for small ions. The concentration of aerosol with size 4.4-163 nm decreased and there was an increase in the 0.5-20 μm size range with wind speed. The distribution of nano particles (~ 30 nm) was also high, which decreased with wind speed. However, larger particles with a maximum of ~ 0.7 μm increased with wind speed.

Understanding the melting of lakes in Antarctica is intimately related to the accumulation and melt water processes. Ravindra *et al*. (2008) have described the genetic aspects of more than 100 such lakes that exist in the Schirmacher Oasis. These lakes originated during the late Pleistocene retreat of glaciers and their morphological and genetic behaviour enabled their classification as proglacial, landlocked and epiglacial lakes. Palaeoclimate studies using sediment cores as proxies, have been undertaken by Phartiyal *et al*. (2011); Shrivastava *et al*. (2012); Asthana *et al*. (2009) and Govil *et al*. (2012) in Schirmacher and Larsemann area of East Antarctica giving chronology of events in post-LGM period.

Arctic

India initiated Cryospheric studies in 2007 by launching its first expedition to the Ny-Alesund in Arctic. This region is located within the Svalbard archipelago and has several glaciers including Kongsvegen, Midre Lovenbreen, Austre Broggerbreen and Vestre Broggerbreen. In continuation of the extensive work carried out by the Norwegian researchers on the former three glaciers, Indian studies focussed on the Vestre Broggerbreen glacier. The organizations concentrating on the glaciological studies are GSI and NCAOR. Lucknow University has conducted some preliminary glaciological studies in the Ny Alesund (Singh *et al*., 2010; Singh and Ravindra, 2009 a & b; Singh and Ravindra 2010; Singh and Vimlesh, 2009). The project *Parameterisation of Glaciers of Northern Hemisphere to inter and intra-annual variations in the climate* envisages mapping the bed rock and assess the mass balance of this glacier in comparison with data from other glaciers. NCAOR has undertaken a project *Study of snow biogeochemistry in the Svalbard region* with a major objective of mapping the distribution of soluble ions, trace metals and volatile halogenated organic carbons in the snow pack and associated microbial diversity to evaluate the biogeochemical processes influencing atmospheric composition and climate over the Svalbard region. Recent research in the field of Cryobiology in India has gained momentum with workers such as Srinivas *et al*. (2009), Reddy *et al*. (2009), Shivaji *et al*. (2009) on bacterial diversity of the cold active enzymes in the Ny Alesund glaciers. Studies in Arctic region by Singh *et al*. (2011) have also indicated significant antioxidant potential of Arctic lichens.

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