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Remote Sensing Signature study and selection of Indian Antarctic calibration site for polar process modeling

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ABSTRACT

The climate of the high latitude areas is more variable than that of tropical or mid-latitude regions. Large scale changes observed over the icy surface of the polar regions demand a constant monitoring and the modelling of ice processes with greater understanding of the physical processes. This also emphasizes on the collection of in-situ observations to understand the physical processes. Studies have been carried out using in-situ data collected during 28th Indian Scientific Expedition to Antarctica and time-series of QuikSCAT scatterometer data (2000-2009). The year-to-year variation in surface melt observed over Amery ice shelf is one of the highlight of the study. Report also describes the analysis of the snow-pit samplings and surface meteorological observations collected during the expedition.

1.0 INTRODUCTION

Global climate change remains a topic of concern over last few decades. Most of the global climate models predict the increase in Earth's surface temperature with much larger increase over the polar regions. This is also supported by the evidence that the polar ice cover is thinning as well as shrinking (Hanna et al., 2013; Kwok et al., 2009). The polar regions, through their sea ice cover, ice sheets, and deep-water formation/ventilation sites (Saenko et al., 2002), have the potential to influence global atmospheric and oceanic circulations. This demands constant monitoring and modeling of polar ice dynamics and thermodynamics. The only way of the continuous monitoring of these icy regions having harsh and remote conditions is the use of remote sensing.

The polar ice regime consists of ocean, ice sheet, sea ice, ice shelf, atmosphere, and polynyas. Because of the complex feedback mechanism among these components, improved knowledge of the physical processes is required for better understanding of the potential changes in ice mass balance. Subtle changes in surface fluxes can have profound long-term impacts on environmental conditions in the polar regions (Bourassa, 2010) which in turn influence physical processes at lower latitudes. Even modest errors in estimate of fluxes can impede our ability to understand current climate and to predict likely changes. These large scale changes observed over the icy surface of the polar regions demand a constant monitoring and the modelling of ice processes with greater understanding of the physical processes. In-frequent in-situ observations available from these harshly remote area, emphasizes the utilization of space-borne observations for the scientific investigation of polar processes.

The major objective of our study is to characterise the mass, mass variability, and mass-energy-freshwater-gas exchanges between the polar ice components (sea ice, ice-sheet and ice-shelf) and the other elements of the earth system (land, atmosphere and ocean) using space-borne observations, in-situ data and models. The analysis from synergetic use of in-situ and spaceborne observations from various satellite missions of ISRO, namely Oceansat-2, RISAT, SARAL will be major thrust to monitor these changes. The necessary in-situ data, for the development of techniques and their validation, is planned to be collected by means of participation in the Antarctic expeditions.

Present report summarizes the analysis of in-situ data collected, during the 28th Indian Scientific expeditions to Antarctica (ISEA), by Space Applications Centre (SAC-ISRO).

2.0 Study Period and In-situ observations

The expedition period of 28th ISEA was from 6th January to 23rd March 2009 (Fig. 1). Scientific observations, such as surface meteorological observations, were collected during the expeditions.

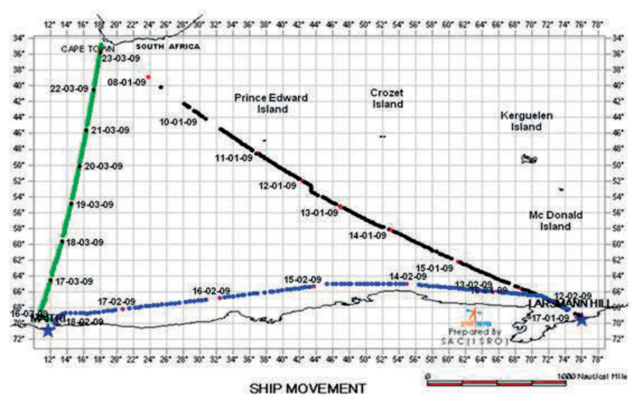

Fig. 1: Map showing dates and locations where meteorological observations were carried out during the 28th InSEA (6th January through 23rd March 2009). Such a real time map was generated for the very first time in any Indian Expedition to Antarctica during the 28th InSEA.

Important surface meteorological parameters namely, air pressure, air temperature, wind speed and direction, and cloud coverage (in oktas) including weather conditions were noted on an hourly interval. These surface meteorological observations were recorded at ~30 m ASL. Besides these parameters, a couple of parameters pertaining to sea, such as the sea surface temperature (SST) and the sea state were also noted.

Snow-pit samplings were collected at several locations from Larsemann Hills area to study the stratification of seasonal layers in snowpack. Aerial visits were made to study the morphological variations observed over the icy surface around Indian Research Stations. Hyper-spectral observations were also collected from the selected sites located around "Maitri".

Daily composite QuikSCAT backscatter data of HH (σ_H) and VV (σ_V)polarization at 4.45 km resolution (Early & Long 2001) were used to study the ice surface melting. Mid-month data from January 2000 to July 2009 were obtained from the NASA sponsored Scatterometer Climate Record Pathfinder at Brigham Young University (http://scp.byu.edu).

3.0 Results and discussion

3.1 Observations on sea ice types and conditions

Early stages of the formation of sea ice during the period from late February to early March were observed. Different stages of the processes are shown in Fig. 2. The formation of sea ice starts when sea water temperature decreases to about -1.8º C. An initial stage of the formation of sea ice, the grease ice (Fig. 2a) is formed when the ice crystals (frazil ice) have coagulated to form a soupy layer of sea water which reflects less sunlight. Pancake ice is formed from grease ice due to the swelling motion. They are round in shape with raised edges due to continuous striking against each other. Pancake ice can spread rapidly to cover a huge area of open water. They are about 10cm thick. Subsequent growth of sea ice forms large sheets of sea ice, may be covered with snow deposited due to precipitation. The rise in temperature during spring/summer initiates the melting and breaking of these ice sheets in to different pieces known as sea ice floe (Fig 2e). The scatter pieces of small to medium sized floes starts moving in the resultant direction of surface wind and ocean current. The information on such kind of ice form are important to understand the remote sensing signature.

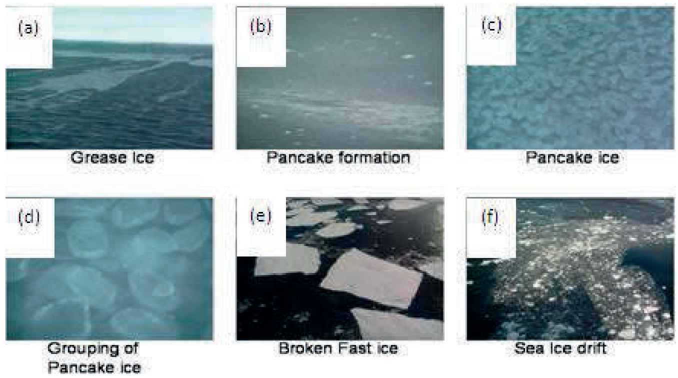

Fig. 2: Different stages of the formation of sea ice. (a) Grease ice (b) Early stage of the formation of Pancake ice (c) Pancake ice (d) Grouping of pancake ice (e) ice floe and (f) ice drift (These photographs were taken during the 28th ISEA.)

3.2 Hyper-spectral reflectance data collection of Polar ice region at Maitri

During the 28th ISEA, three visits were made to the Polar caps around Maitri to collect hyper-spectral reflectance spectra (from 0.35-1.1 micrometer) of different snow and ice features. The different snow features includes drift snow, wet snow, dry fresh snow, seasonal snow. Ice features includes Antarctic blue ice, lake ice etc. The significant difference has been observed in NIR (near-infrared) reflectance within this snow and ice features (Fig. 3).

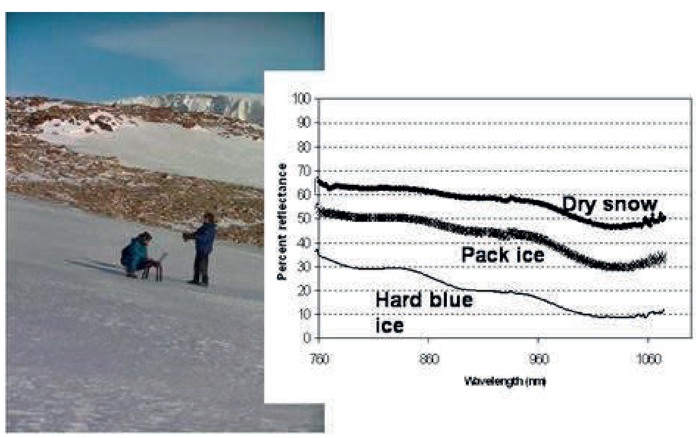

Fig. 3: Classified Hyper-spectral reflectance of different snow/ice types. At the backdrop is seen the location where the experiment was carried out.

3.3 Snow pack studies

During the expedition, several sites in the polar caps were visited for snowpack studies (Fig. 4). An example of such a visit made on 27th January 2009 is given in Fig. 5. The site had 70-80 cm snow pack depth over blue-ice. Various cross-section samples were taken and photographed to analyse the patterns that indicates the seasonal changes/weathering faced in previous years. Four different layers observed that indicates the snow pack over hard ice possibly developed in last four years.

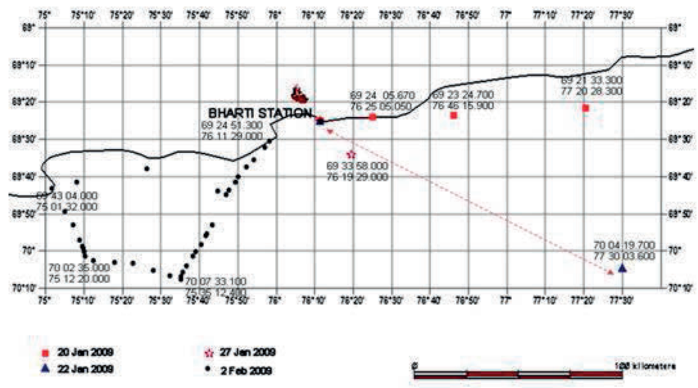

Fig. 4: Snow pit samplings at various locations at the Larsemann Hills during the 28th InSEA, 2009

Fig. 5: Vertical cross-section view of snow-pack for the ground-truth site visited on 27th January 2009 on polar caps at Larsemann Hills.

Fig. 6: Possible invariant ground-truth site visited on Polar Ice at Larsemanns Hills

The site visited on January 22 (Fig. 4) was 49 mile (~90 km) inside the polar ice edge. This distance from ice-ocean edge ensures that even in coarse resolution (satellite data) of the order of 25 to 50 km ice signature will not mix with other features like open ocean, sea-ice, rocks or lakes etc. The prevailing ambient temperature at 5:30 GMT was -14 degrees Centigrade at 1336 meter altitude. Snow pack having vertical depth of 8 inch over hard blue ice was found with uniform signature in vertical and horizontal direction (Fig. 6).The surface pattern after 20 km from ice-edge up to the site is having uniform pattern (roughness) of wind and weathering events at satellite resolution. The same pattern extends up to another 20 km beyond the site (as observed from Helicopter). This indicates the possibility of the reliable signature of surface feature observed by optical and microwave sensors onboard satellites.

3.4 Investigations of surface melting

Temporal variations of QuikSCAT observations over the visited sites were evaluated and observed that the QuikSCAT scatterometer backscattering coefficient is higher for the dry snow compared to wet snow.

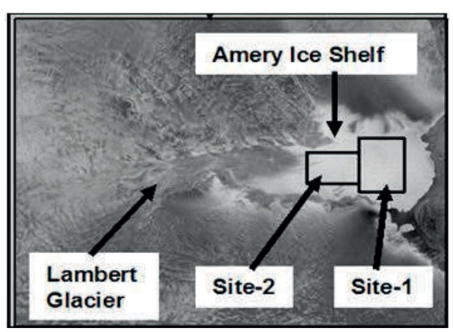

Fig. 7: Study sites located over Amery Ice shelf- Lambert Glacier System

Using this principle, a study was carried out to understand temporal ice surface variations in Amery Ice shelf for two distinct sites (Fig. 7) using QuikSCAT scatterometer data for the period of 2000 to 2009.

This study was important in the context of the scheduled launch of India's Ku-band scatterometer OSCAT on board Oceansat-2, which was launched in September 2009. The study highlighted the significant variations observed over the ice surface of Amery Ice Shelf during 2000 to 2009. The study suggests that the largest surface melting phenomenon on Amery ice shelf was observed in January 2004. The summer (December-January) months of 2000-01, 2002-03 and 2007-08 have faced minimum surface melting as compared to other years (Fig. 8a and Fig 8b). The maximum snow depth during this period is observed for the winter period (June) of the years 2004 and 2005 (Fig. 8c). The number of positive degree days, with higher than 4º C air temperature, is found to have significant effect on surface melting (Oza et al., 2011). The increasing/decreasing trend observed in the backscatter time series during the study period needs further investigation to understand its contribution to the change in Atmosphere/Ocean parameters and their possible implications for climate change.

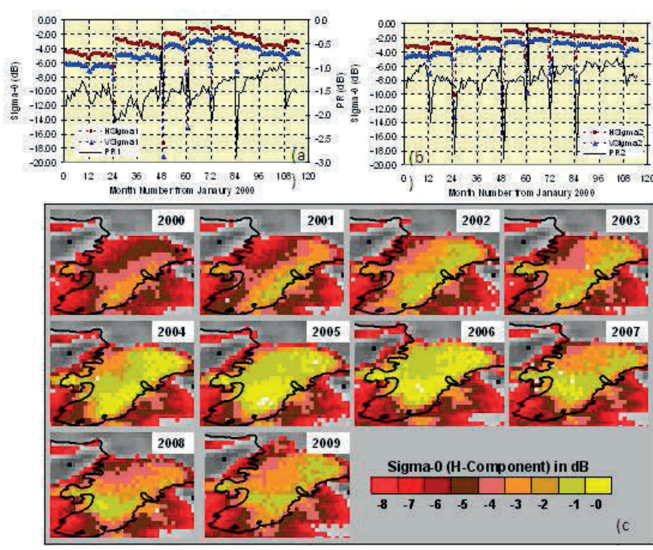

Fig. 8: (a) Time series of Ku-band backscattering coefficient (σ) for Site-1 and (b) Site-2. HSigma1 and HSigma2 represent σH values for Site-1 and Site-2, respectively. Polarisation Ratio PR = (σV - σH). (c) Evolution of mid-winter σH (June) for Amery Ice shelf. The variations in the σ values from year to year may be noticed. The possible cause is the difference in volume scattering from the dry snow having different thickness from year to year.

3.5 Investigation of surface observations

The three hourly surface meteorological observations (subset of hourly data) were studied in five different sectors, namely, (1) during the voyage from Cape Town (henceforth abbreviated as CT) to Larsemann Hills (henceforth abbreviated as LH) from 10th-17th January 2009, (2) during the stay at LH (18th Jan - 11th Feb 2009), (3) during the journey from LH to India Bay (11th Feb - 17th Feb 2009), (4) during the stay at India Bay (IB)/ Leningradskiy Bay (18th Feb - 15th Mar 2009), and (5) during the return journey from IB/ to CT (16th Mar - 23th Mar 2009).

3.5.1 Analysis of air temperature data

The air temperature data recorded are shown in Fig. 9, viz. (a) from CT to LH ; (b) from LH to IB and (c) from IB to CT. Data collected during CT to LH (Fig. 9a) and IB to CT (Fig. 9c) are plotted against varying latitudes, where as that for LH to IB is plotted against varying longitudes (Fig 9c). In the latitude range between 45° S and 65° S (Fig. 9a) the air temperature decreases rapidly from a maximum of around 7°C to a minimum of about -0.5° C. Decrease in air temperature, from ~1° C to ~(-5)° C, while approaching the Bay is clearly visible (Fig. 9b). The Bay is situated on the ice shelves and so the temperature, as expected, is very low. During the return journey from IB to CT (Fig 9c), the air temperature slowly increases from negative values to zero at around 65 °S and from around 55 °S, it increases rapidly as seen in Fig. 9c.

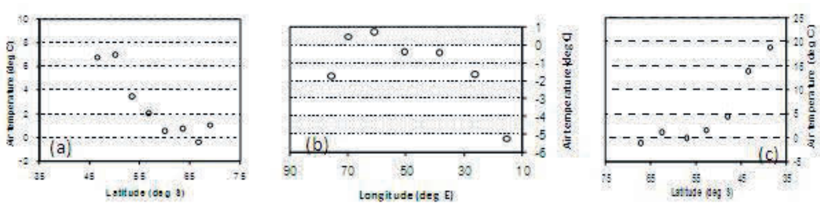

Fig. 9: Variations in daily average air temperature (in C) with latitude during the journey from (a) Cape Town to Larsemann Hills (~ 6923'S, 7611'E), East Antarctica (10th Jan - 17th Jan 2009); (b) from LH to India Bay in 28th InSEA (11th Feb - 17th Feb 2009); and (c) from India Bay to Cape Town.

3.5.2 Analysis of Wind observations

The summary of the wind speed and direction observations are shown in Fig. 10. The wind fields were converted into their true values using the heading information of the Ship. During the expedition, numerous occasions of storms were taking place owing to which the wind speeds are found to be quite high. A look in to Fig. 10a reveals that as high as 29% of the wind speed observations are in excess of 30 m/s. Of all the wind direction data collected, about 80% are concentrated in the S-NW sector. The specific pattern in wind direction can be thought of to be due to the cyclonic systems prevailing at that time which drifted the wind in a specific direction. The wind speeds observed during the 28th ISEA, are found to be relatively higher than the climatological data for this period of the year.

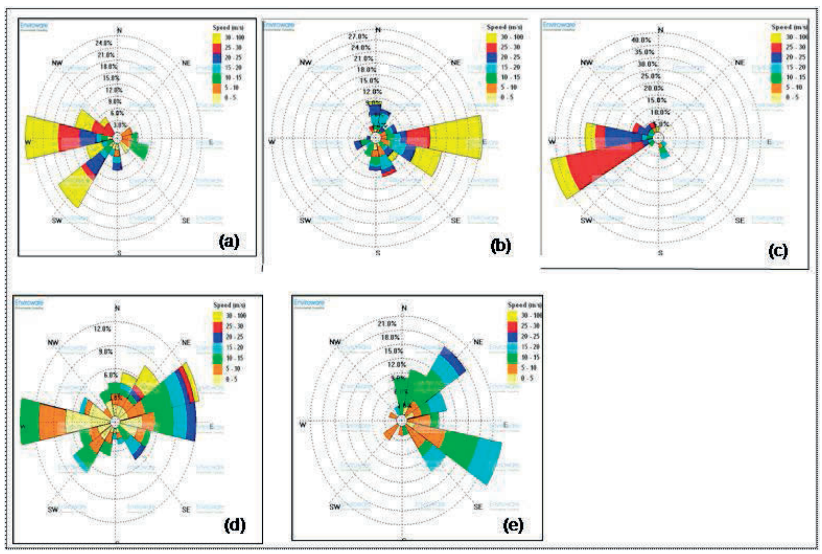

Fig. 10 Windrose chart depicting the wind distributions (speed and direction) during (a) journey from Cape Town to Larsmann Hills; (b) Larsmann Hills to India Bay; (c) India Bay to Cape Town; (d) stay at Larsmann Hills and (e) stay at India Bay.

Strong winds were prevailing in the area during the stay at LH (Fig. 10d). Strong easterly as well as westerly winds were prominent. 14% of all the wind observations were easterly, 12% westerly and the remaining are distributed throughout the different sectors. The stronger winds with a speed in excess of 30m/s were coming from the North-North East sector. 31% of the wind was within the speed range of 0-5 m/s. A high percentage of about 22% of wind had speed in excess of 10 m/s.

During the voyage from LH to IB (Fig. 10b), most of the wind (24%) was coming from the south-east/east direction while 18% were coming from the NE direction. Thirty nine percent of wind was recorded to be within the speed range of 10-15 m/s. Wind rose plot given in Fig. 10d shows that during the stay at IB, more than 27% of wind with a maximum speed in excess of 25 m/s was coming from the east direction. During voyage from IB to CT, most of the time (>40%) wind was blowing from the SWW direction (Fig. 10c). Approximately, 40% of the wind was distributed within the speed range of 25-30 m/s. Thus, we see that the direction from where the wind was coming is confined to the SWW direction most of the time.

3.5.3 Investigation of Air pressure observations

Low pressure system is visible beyond 55°S during CT to IB voyage (Fig. 11a). Similarly low pressure systems observed during LH to IB voyage (Fig. 11b) and IB to CT voyage (Fig. 11c) indicates the prevalence of stormy weather during the majority of period (beyond 60 °S).

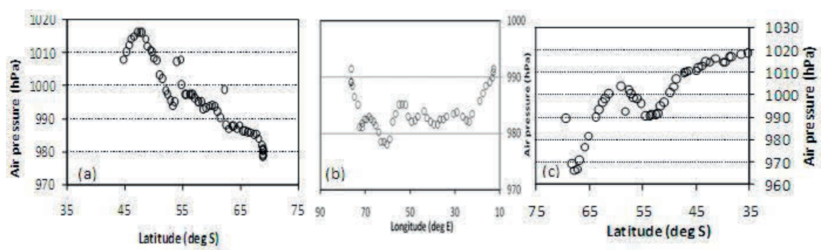

Fig. 11: Variations in air pressure (hPa) (a) with latitude during the journey from CT to LH; (b) with longitude from LH to IB; and (c) with latitude from IB to CT. Low pressure system prevailing beyond 60 degree latitude during the journey from CT to LH and during majority of period from LH to IB is visible.

4.0 Conclusions

The experience gained during the expedition has given an insight into the scientific areas where remote sensing can play a significant role. Sites visited during the expeditions were selected from polar ice region that were having different microwave backscattering properties in Ku-band scatterometer data. This is useful in Cal/Val activities for Indian satellite program carrying microwave sensors. The results obtained from the surface melt analysis carried out over the Amery ice shelf using scatterometer data can be considered as a highlight of the study. Valuable sea-truth data on extreme sea-state conditions and surface meteorological data were collected during different stages of the voyage. These observations are really useful from the viewpoint that such observations are scarce at high latitudes.

Acknowledgements

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