Detection of areal snow cover changes over Antarctica using SSM/I passive microwave data

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SSM/I (Special Sensor Microwave Imager) passive microwave data of two different months over the Antarctic subcontinent have been used to (i) detect the areal extent of snow cover, and (ii) to monitor the changes in the snow cover in this region. Minimum accumulation of snow over Antarctica occurs in February, and hence the detection of snow cover during January and February should indicate a depletion phase. An overall 14% decrease of snow has been observed during this period. Corresponding data for accumulation/depletion of snow indicates a matching of general trend. SSM/I data, thus, can be used as a very promising tool for monitoring of snow over the Antarctic region since it is not affected by cloud cover/darkness.

ANTARCTICA is the fifth largest continent on the earth (area approximately 14 million sq km), which surrounds the South Pole. It is almost totally covered by ice, devoid of any permanent human population. Ice-covered region over Antarctica constitutes almost 4.5% of the earth's surface area. It is also the coldest continent with ambient air temperature varying much below the freezing point of water (– 80°C to – 30°C) throughout the year. It is enriched with valuable minerals, coal and petroleum. Antarctica contains about 90 per cent of the world's ice, and if melted, it would raise the ocean by around 60 m. Antarctica is also the highest continent on the earth, because of the massive thickness of ice which overlays the land. The thickness of ice at places is beyond 4500 m (average thickness is approximately 2100 m). Snow and sea ice are dynamic geophysical features on the earth's surface. Together with land ice, they influence the local and global climate and oceanic regimes. Moreover, polar ice masses, and the ice sheets in particular, are sensitive indicators of climate change, which it is feared may result from an increase in atmospheric 'greenhouse gases' such as methane and CO_2, the latter caused by burning of fossil fuels. Study on ozone hole over Antarctica has attracted global attention due to its multifaceted impact over global warming and related hazards due to increased penetration of UV rays on the earth through the ozone hole. The seasonal sea ice covers of both polar regions may react to an increase in atmospheric temperature by reducing their areal extent[1]. Based on the study with Nimbus 7 (USA)

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SMMR (Scanning Multichannel Microwave Radiometer) passive microwave data[1,2] (with five channels, namely 6.6, 10.69, 18, 21 and 37 GHz), it has been observed that in winter, sea ice extends as far as 2200 km from the Antarctic continent, whereas in summer, the Antarctic ice pack retreats to the coast along approximately 50% of the Antarctic coastline. The seasonal cycle is characterized by a minimum in the sea ice cover during February, followed by an expansion of the ice cover until the maximum coverage during August to October, and then by a rapid decay from November through December. The satellite microwave data have the additional advantages over IR (Infrared) and TIR (Thermal Infrared) that they can penetrate through clouds and both TIR and microwave are useful at nights as well (however, TIR data are affected by atmospheric water and clouds). Passive microwave data are very useful for synoptic coverage (day and night) and through clouds and do not require specific radar systems to illuminate the foot-prints (on the earth surface) like active microwave, which also requires complicated data processing before its utilization. Hence, the passive microwave sensors have been found most useful for such type of studies with large and dynamic areal coverage. The brightness temperature of a surface feature as obtained using passive microwave radiometer depends on its emissivity (which is again dependent on incidence angle, frequency and polarization of the sensor as well as the physical characteristics of the target at microwave frequencies) and its physical temperature[3]. The ice concentration difference map is also useful for illustrating the spatially-dependent ice growth and decay over an annual cycle[2]. A close observation of the seasonal changes of the ice in the polar regions can give an indication of the excess water as a result of melting of sea ice due to global warming and the level of inundation over the coastal belts and low lying areas in the world.

SSM/I (Special Sensor Microwave Imager) passive microwave data are extremely useful for monitoring changes in the snow cover over the Antarctica and its surroundings. The Microwave Image has four channels, namely 19, 22, 37 and 85 GHz (H and V) with resolutions at sub-satellite point being 25 × 25 km (for 1st three channels). SSM/I data have already been found useful for meteorological and oceanographic studies[2,4] due to their penetrating capabilities through the cloud. Already a number of algorithms exist for derivation of surface brightness temperature on land/sea after correction due to atmospheric water vapour, liquid water and oxygen[4,5]. The emissivity of first year ice is almost constant as a function of wavelength, that of multi-year ice increases with wave

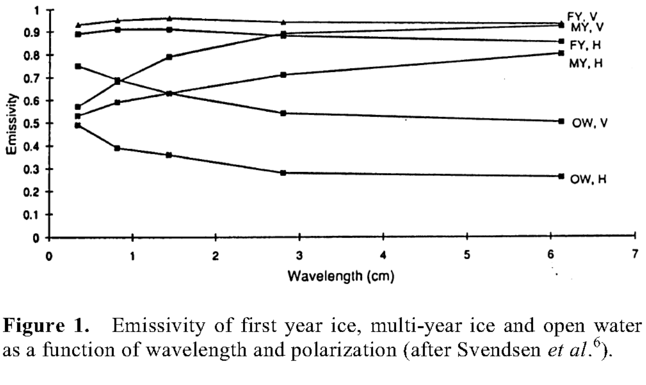

Figure 1. Emissivity of first year ice, multi-year ice and open water as a function of wavelength and polarization (after Svendsen *et al.*[6]).

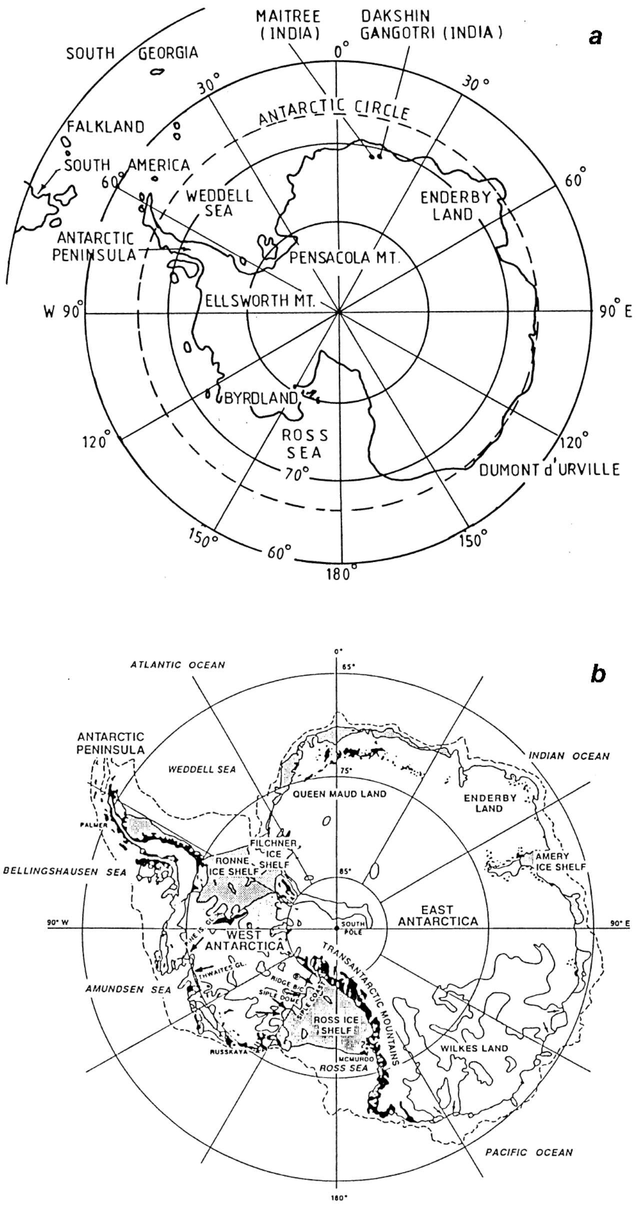

Figure 2. *a*, Location map of Antarctica (after Bhattacharya and Majumdar[7]); *b*, Physiographic map of Antarctica. Light-shaded areas represents portions of the ice sheet grounded on bed-rock more than 500 m below sea level. Arrows represent major ice streams which drains ice sheet regions. Heavily-shaded regions (e.g. Ross ice shelf, Ronne ice shelf, etc.) are ice shelves that buttress ice flow, and beneath which ocean circulation is an important process of mass exchange. Solid areas represent the approximate distribution of exposed rock. Dashed line represents the edge of the continental shelf (after Masoom[1]).

length, and that of open water decreases with wavelength[2,6] (Figure 1). The SSM/I data used for this study are those that correspond to 19 GHz (V) and 37 GHz (V and H) with wavelengths approximately 1.65 and 0.80 cm, respectively.

The major objective of this study was to assess the potential of SSM/I data for mapping of areal extent of snow over the Antarctica. Figure 2 *a* and *b* shows the location map[7] (with Indian stations Dakshin Gangotri and Maitree) and physiographic map of Antarctica respectively[1]. Two different data sets were specially chosen for this purpose, namely those of 1 January 1999 and of 1 March 1999, to study the depletion of areal snow during January and February. In Antarctica, least snow cover has been reported in February with a maximum around September[1,2]. Figure 3 shows the seasonal recession map of Antarctic sea ice areal coverage[1]. The amount of snow cover changes (depletion phase) during January and February 1999 has been observed using SSM/I data. Suitable calibration has been used to obtain surface brightness temperature values from SSM/I data[8] collected on 1 January 1999 and 1 March 1999. Figure 4 *a* and *b* shows the SSM/I imageries over the Antarctic subcontinent.

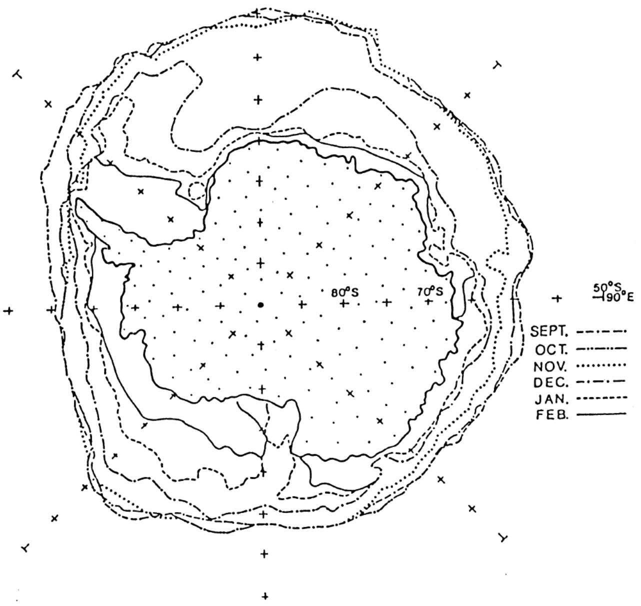

Figure 3. Seasonal recession map of Antarctic sea ice areal coverage (after Masoom[1]).

Some of the major interpretations are as follows.

(i) The changes in the areal extent of snow cover in Antarctic region in this period could be demarcated well in the FCC (False Colour Composite) generated with mainly 37 GHz (V and H) and 19 GHz (V) data (Figure 4 *a* and *b*). The change (depletion) of snow cover in percentage during January and February 1999 is around 14%. The changes were more imminent near Ross Sea/Ross Ice Shelf and Weddell Sea regions (see Figures 2 and 4). Ross ice shelf (see Figure 2 *b*) is a part of generalized Ross Sea which gets frozen during winter.

(ii) The areas where snow melt has occurred during this period (1 January 1999 to 1 March 1999) could be seen with a different signature (refer to Figure 4 *a* and *b*) com-

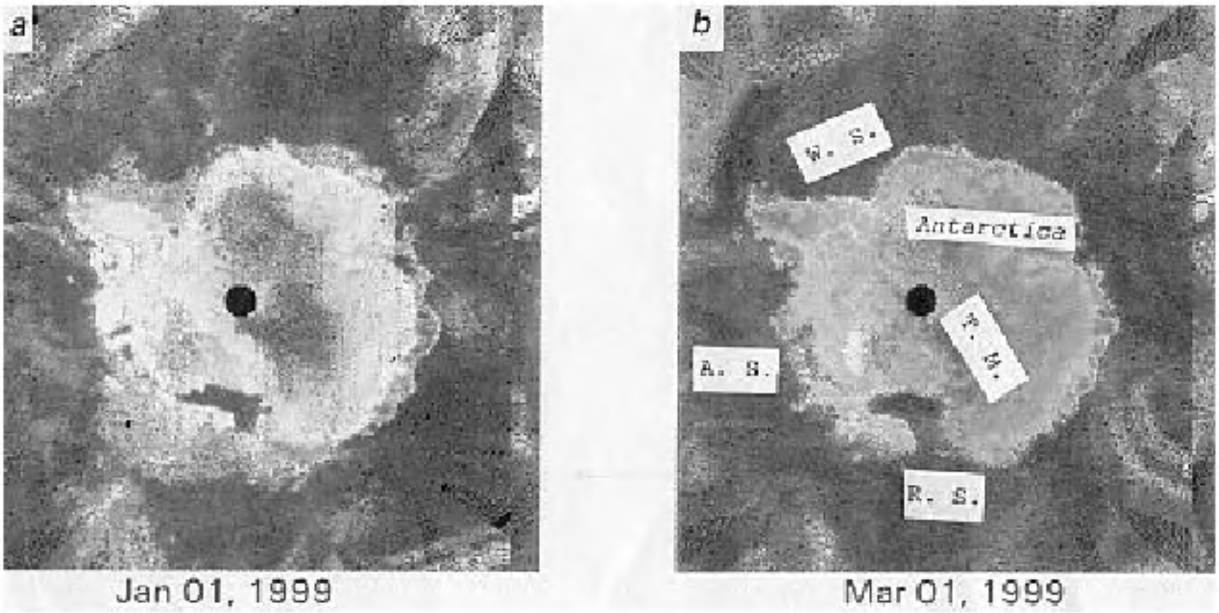

Figure 4. ***a***, FCC (False Colour Composite) of SSM/I images with 19 GHz (V) and 37 GHz (H and V) data over the Antarctic sub-continent on 1 January 1999. Noticeable snow accumulation could be observed near Weddell sea coast and near Ross Sea. ***b***, FCC (False Colour Composite) of SSM/I images with 19 GHz (V) and 37 GHz (H and V) data over the Antarctic subcontinent on 1 March 1999. Transantarctic Mountains (see also Figure 2 *b*) and ocean circulation (and associated production of Antarctic bottom water) are quite clear in this figure. W.S., Weddell Sea; R.S., Ross Sea; T.M., Transantarctic Mountains; A.S., Amundsen Sea.

pared to those areas where snow/ice is prevailing in these two months. For example, a marked change in ice accumulation could be demarcated near Ross ice shelf and Weddell Sea regions (Figures 2 *a*, 4 *a* and *b*).

(iii) The Antarctic region could be depicted along with the subtle distinction of regional relief and tectonic features (Figures 2 *b*, 4 *a* and *b*). Transantarctic mountains are clearly depicted in Figure 4 *b*. Similar features have been reported elsewhere[1,2] (also, see Figure 2 *b*).

(iv) In addition to snow/ice cover changes over Antarctica, marked changes in the sea surface processes could be observed (Figure 4 *a* and *b*) around the Antarctic subcontinent in the surrounding oceans, which need further study. Vertical circulation of the ocean and the associated production of Antarctic bottom water is an important oceanographic phenomenon[2]. However, there are some noise patterns occurring over this region in the processed imagery. Unfortunately, noises are bound to occur in any product obtained by image processing techniques[9]. Hence, during interpretation, the pseudo-features which are really not existing on the ground may be discarded. Most of these interpretations match well with ground-based observations.

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