STUDY OF INTER-ANNUAL Ku-BAND BACKSCATTER VARIATIONS OF AMERY ICE SHELF, EAST ANTARCTICA

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ABSTRACT:

The widespread retreat of glaciers can be considered as response to the climate change. Being the largest retreating glacier-ice shelf system in East Antarctica, the Amery Ice Shelf-Lambert Glacier system plays an important role in contributing to sea level rise as well as surrounding environment and climate. The present study is focused on the investigation of this ice shelf system using mid-month Ku-band scatterometer data from January 2000 to July 2009. The corresponding monthly weather data of Davis Station was obtained from the web site of Australian Antarctic Division. Average backscatter of all the pixels, within the selected sites, was generated and Microwave Polarization Difference Index (MPDI) was computed. It was observed that backscattering coefficients of H- and V-components increase from January 2000 to June 2006. A very prominent dip in the backscatter observed in the month of January is a distinct signature taking place due to physical process of large scale melting of ice/snow surface. The increase in February is attributed to the initiation of the freezing phenomenon. The comparison with monthly air-temperature data shows significant correlation with MPDI. The correlation of the order of 0.99 of annual maximum MPDI with the annual maximum and minimum air-temperatures has been found for the site adjacent to the Lambert Glacier. The change in backscatter behavior from year 2006 is evident as decreasing trend is observed after July 2006 in the time series data. This could be due to cyclic behavior of the system with half cycle of 6-years; however, it needs further investigations

1. INTRODUCTION

The climate change issue is an important part of the larger challenge of sustainable development. The Antarctic ice sheet is also playing an important role in the climate system. However a little is known about how it changes in response to local and global forcing (Bingham and Drinkwater 2000). The widespread retreat of glaciers can be considered as a response to the climate change. The Glacier-Ice Shelf systems of Greenland and Antarctica play an important role in contributing to ice drainage system, which may make large contributions to sea level rise as well as surrounding environment and climate. A significant retreat has been observed for the ice shelves on the Western Antarctica around Antarctic Peninsula (Doake and Vaughan, 1996). Recent studies show that flow speed has increased for some Antarctic outlet glaciers, resulting in increased mass losses from the ice sheet (e.g. Payne et al., 2004; Shepherd et al., 2004).

The Amery Ice Shelf (70˚S, 70˚E) is the third largest embayed shelf in Antarctica. The Amery Ice Shelf (AIS) is the largest ice shelf within East Antarctica and is nearer to the proposed site (69.33º-69.50º S, 75.92º-76.50º E) of the third Indian Antarctic station (http://www.ncaor.gov.in). It drains the grounded ice from the interior of the Lambert Glacier drainage basin, which covers an area of 16% of the East Antarctic ice sheet and is the world's largest glacier by volume. The Lambert Glacier is up to 65km wide and 400km long, and drains about 8% of Antarctica's ice sheet. The drainage systems present in the glacier system drain the grounded ice from the interior of the glacier to the Amery Ice shelf. A significant fraction of the ice flowing from the interior of the Antarctic ice sheet is lost by melting under the deeper parts of the ice shelves (Jacobs et al., 1992). This melt cools and freshens seawater circulating in the sub-ice-shelf cavity that can lead to accretion of "marine" ice elsewhere under the cavity (Jenkins and Doake, 1991). Net melt water production (Basel melting minus freezing) is critical for both mass balance of the ice sheet, and for the freshwater flux in to the southern Ocean (Fricker et al., 2001).

The present study highlights the temporal ice surface variations that have taken place on Amery Ice shelf, during the period of 2000 to 2009 as observed using Ku-band scatterometer data. This study is also important in the context of recently launched Ku-band scatterometer on board Oceansat-II by India in September 2009.

2. MATERIALS AND METHODOLOGY

2.1 Scatterometer Data

Ku-band scatterometer data from "QuikSCAT" was utilized for the study. QuikSCAT is 13.4 GHz active microwave dual-pencil-beam conically scanning scatterometer with the outer beam vertically (V) polarized and the inner beam horizontally (H) polarized. The study months cover the period of January 2000 to July 2009. QuikSCAT daily backscatter data (at 0.2 degree resolution) for the day around middle of each month were utilized for the analysis.

2.2 Meteorological Air Temperature Data

The meteorological Automatic Weather Station (AWS) data were obtained from the Australian Antarctic Division website (http://data.aad.gov.au/aadc) for the Davis station (Figure 1) nearer to Amery Ice shelf. The geographic coordinates of the station are 68.5766° S and 77.9674° E.

2.3 Generation of Time Series Sigma-0 and MPDI Data

Two regions (Sites) were considered for the analysis (Figure 1). The Site-1 covers the outer region of the Shelf, from where ice/snow mass flows in to the ocean in the form of melted water, snow mass or ice bergs. The Site-2 is interfacing with the Glacier system, which feeds the ice shelf. The number of QuikSCAT pixels within the Site-1 are 70, where as within Site-2 are 40. The integrated response of these pixels within the site will indicate the effect of large scale ice surface phenomena. The time series of Site-specific Sigma-0 were generated using the average statistic of both the sites.

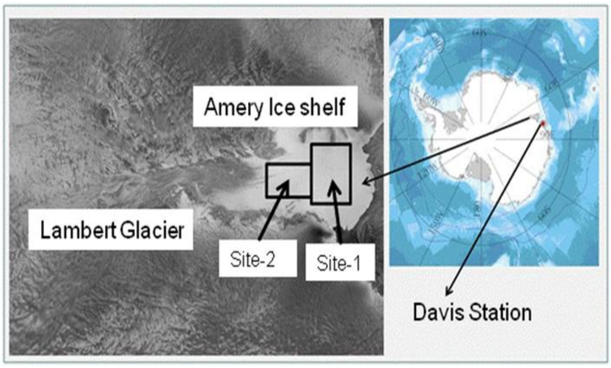


Figure 1. Study Sites of Amery Ice Shelf (Image Source: Australian Antarctic Division website **http://data.aad.gov.au**)

The time series of Microwave Polarization Difference Index (MPDI) was generated by computing MPDI as the difference of H and V components of Sigma-0 normalized by their sum i.e. MPDI= (H-V)/(H+V). These temporal variations were compared with the meteorological air temperature data of Davis AWS.

3. RESULTS AND DISCUSSION

3.1 Backscatter Time Series

The backscatter (Sigma-0) time series (H- and V-components) for both the sites are as shown in figure 2. The distinctive feature evident from the figure is the negative dip during the months of January. The January month in the Antarctic is the peak of summer period having 24 hours' daylight. The higher summer temperature affects the snow/ice surface and increases the surface melting.

The presence of liquid water in snow (wet snow) increases the permittivity of the snow layer (Ulaby et al., 1986). In addition to this, presence of liquid water in snow volume causes a dramatic increase in the dielectric loss factor of the layer which increases the absorption coefficient. This in turn, results in decrease in the backscattering coefficient.

Snow is an inhomogeneous medium consisting of ice particles, air and liquid water (if wet). The backscatter of snow pack is as low as -19 dB in 2004. This indicates that in 2004, surface water response dominates the ice/snow response in the majority of pixels. Similarly, the backscatter values higher than -12 dB, generally observed during February to November, indicates the response from the snow pack and ice in addition to melt water.

3.2 Variations in Melting/Refreezing Signatures

It is seen that Sigma-0 during peak melting phase for Site-1 is lower then that of Site-2. This indicates presence of a higher fraction of melted water layer over Site-1 as compared to Site-2. As Site-2 is towards the Glacier system, hence the melted water will flow from site-2 to site-1, due to the existence of natural slope from glacier to ice-front. Hence, over site-1, surface melting is intensive, and the wet snow zone is damp throughout the summer season (Tran et al., 2008), which could be attributed to the influence of the warm air mass coming from other regions (from ocean in the present study).

As observed in the figure 2, the yearly backscatter profile is showing increasing trend as winter progresses. The sudden increase of Sigma-0 in February month is attributed to the refrozen melt features in the form of buried ice lenses and pipes within the snow pack (Long and Drinkwater, 1994). If we exclude peak summer Sigma-0 then the average annual cyclic variation (2000-2009) is of the order of 0.4 dB, average of both the sites. The cyclic variations obtained by Bingham and Drinkwater (2000) using ERS scatterometer data for Amery Ice shelf is of the order of 0.5 dB during 1992-1997. The difference could be due to the frequency at which both the scatterometers have measured the variations viz. C-band of ERS and Ku-band of QuikSCAT.

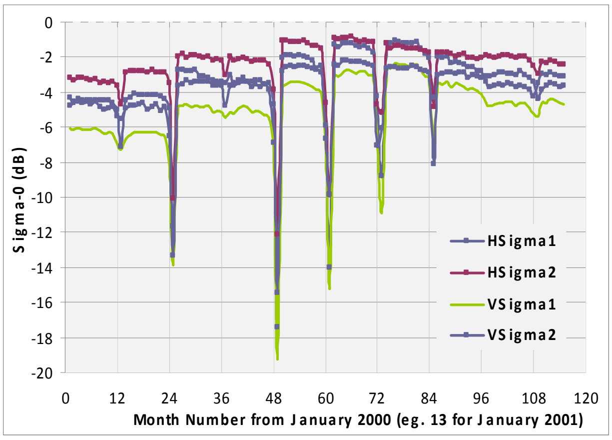


Figure 2. Time Series of Ku-band Backscattering Coefficient (Sigma-0). HSigma1 Indicates Sigma-0 value of H-Component for Site-1

3.3 Inter-Annual Trends

As observed in figure 2, backscatter time series is having an increasing trend of winter sigma-0 up to 2005 and then decreasing up to 2009. The mid-June backscatter plot shows this distinctive pattern as observed in figure 3 for site-2 (H-component). The increasing trend having R^2 value of the order of 93% and decreasing trend having R^2 values of the order of 90% is evident from the figure.

The regression summary of H- and V- components with time, for both the sites is given in Table 1. It is evident that R^2-values are higher than 85%, with better fitting statistics for Site-2 as compared to Site-1. It is also seen that trend values are higher for Site-1 for all the cases. This could be due to the lower altitude of Site-2 as compared to site-1, which is nearer to the ice-front interfacing with ocean currents.

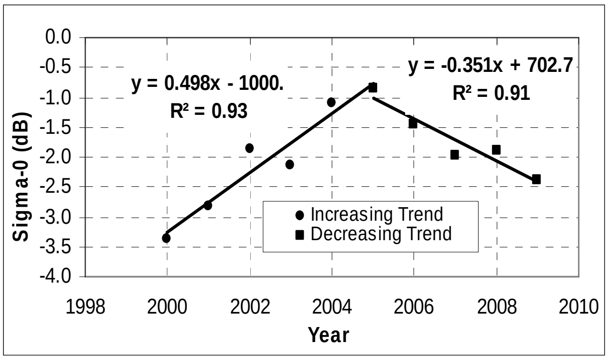


Figure 3. Inter-Annual Trend of June Month (Mid-Winter) Sigma-0 for Site-2 (H-Component)

Component	Increasing trend (2000-2005)		Decreasing trend (2005-2009)	
	Trend	R^2- Value	Trend	R^2- Value
H (Site-1)	0.72	0.88	-0.61	0.84
H (Site-2)	0.50	0.93	-0.35	0.91
V (Site-1)	0.73	0.92	-0.58	0.85
V (Site-2)	0.47	0.96	-0.33	0.90

Table 1: Site-Wise Sigma-0 (H & V) Trends

The evolution of mid-winter Sigma-0 (H-component) for entire Amery Ice shelf is shown in figure 4. The increase in backscatter value from 2001 to 2005 and decreasing trend from 2005 to 2009 in majority of the region is evident.

The microwave backscatter differs where dielectric constant (ε) changes at interfaces between air-ice and adjacent snow pack layers with different grain sizes. During the winter period, the the ice sheet is covered with the dry snow. The surface roughness of the dry snow layer has almost no contribution to the backscattering (Ulaby et al., 1986). The backscattering coefficient increases due to the greater effect of volume scattering (the magnitude depends on the size of ice particles and used frequency). Studies on Antarctic snow showed the penetration depths at Ku-band are ranging from 5 to 12 m depending on the location and snow pack properties (Arthern et al., 2001). This volume of snow pack is playing a major role in the backscatter during winter period.

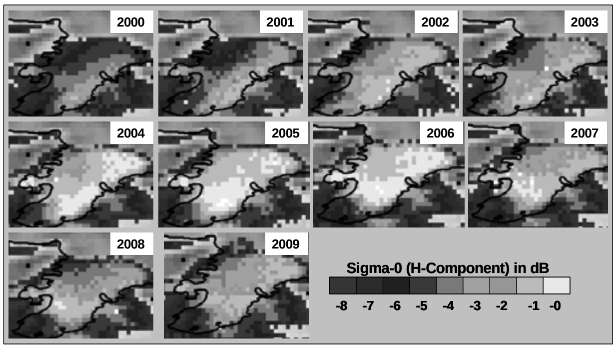


Figure 4. Evolution of Mid-Winter Sigma-0 (June) for H-Component for Amery Ice Shelf

Hence, mid-winter increasing/decreasing trend could be due to the year-to-year increase/decrease in the volume of dry snow pack contributing to the scatterometer response. Bingham and Drinkwater (2000) have found that these changes in backscatter are closely associated with the accumulated snow cover. Wen et al. (2006) have found an overall thickening trend in the Lambert-Amery Ice shelf basin from 1992 to 2003.

It is interesting to compare 2000-2009 trends with the 1992-97 trends obtained by Bingham and Drinkwater (2000). They have obtained a strong decreasing trend (r=0.96) for Amery Ice shelf region using ERS scatterometer data. The 6-yearly increasing/decreasing trend observed in figure 2 could be due to the possible climatic fluctuations or due to cyclic behavior with a half cycle of 6-years. This needs further investigations to assess the effect of surface change on the Oceanic/atmospheric parameters.

As seen in figure 5, the MPDI value for December 2003 is as low as 0.04 (minimum during study period) whereas during the same month in 2007 it is of the order of 0.3 (maximum during the study period). The December month is the summer period in the Antarctic. The change observed during the transition from winter to summer results from the greater sensitivity of H-component backscatter to liquid water present in the snow cover than V-component backscatter from the same (Kunz and Long, 2004). In such condition, the reduction in backscatter of H-component is in general, larger than that of V-component, which in turn results in the reduction of in MPDI value. This could be the reason between the MPDI difference observed between 2003 and 2007.

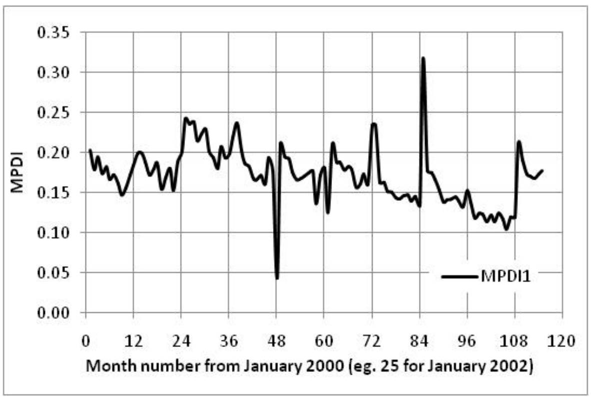


Figure 5. MPDI Time Series for site-1

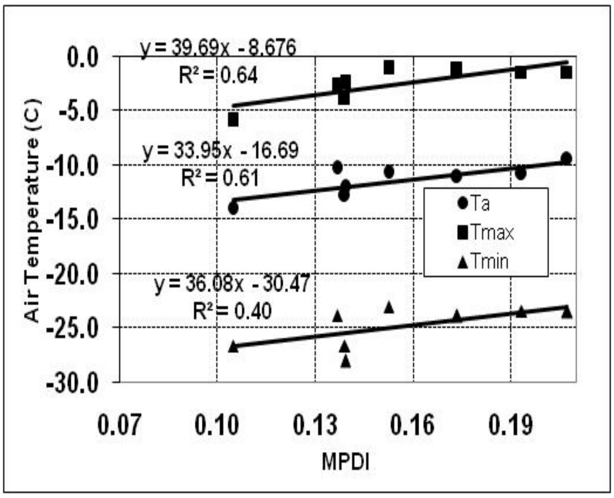
As discussed earlier, for the dry snow volume scattering dominates and the contribution from surface is negligible. However, the backscattering coefficient of wet snow is highly dependent on the snow layer wetness and roughness of the snow cover because major contribution of backscatter is caused by the air-snow interface (Fung, 1994). In case of wet snow, surface scattering dominates the volume scattering. Hence, MPDI is a function of surface roughness during the summer melting period. The minimum MPDI value is associated with the Sigma-0 value of the order of -19 dB, which suggests that January 2004 faced large-scale surface melting.

During the winter, the melted surface will re-freeze and snow will be accumulated over the surface due to either precipitation or drift from higher altitude regions of the Antarctic Glaciers. Similar observations were made by Wismann (2000) over Greenland using C-band ERS scatterometer data. He observed that the normalized radar cross section of snow decreases with increasing snow wetness when the snow starts melting.

The variations in the backscatter values are also subject to the attenuation from the atmosphere. In the Antarctic precipitation mainly comes in the form of snow fall that is very low at annual scale. Thus due to the presence of low precipitation/humidity the attenuation of the Ku-band backscatter, in the data used in the present study, is expected to be low. However, weekly composite data will further reduce the atmospheric effect by selecting/computing the backscatter value having minimum attenuation. This can be attempted in future.

3.4 MPDI-Temperature Relationship

As winter progresses, the dry snow pack will becomes compact due to pressure from the surface. It is interesting to compare the October month's MPDI with the AWS measured air temperatures from the near by Davis station (Figure 5).



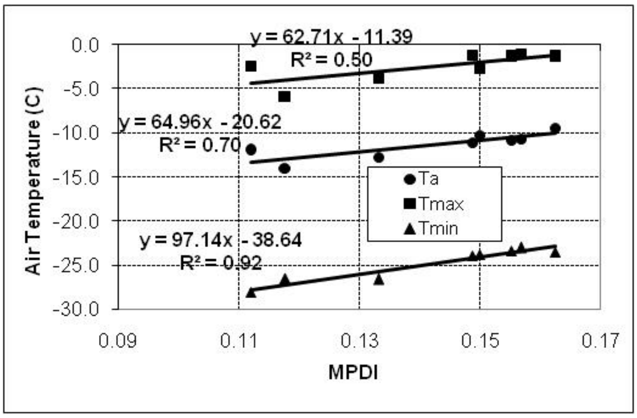


Figure 6. MPDI-Air Temperature Relationships for (a) site-1 and (b) site-2. Ta is Monthly Averaged Air Temperature. Tmax and Tmin Represents Respectively, Monthly Maximum and Minimum Air Temperatures

The October month is the beginning of the southern summer. The correlation is found to be better with Tmax for Site-1 (Figure 6a), where as it is better with Tmin in the case of Site-2 (Figure 6b). The MPDI-Tmax relation is also strong for Site-2 whereas it is not the case for MPDI-Tmin case for Site-1. These results indicate that for the ice shelf area located closer to inner glacier system, both, the minimum and maximum temperatures, are associated with the backscatter from the ice surface. However, for the area located nearer to the ice front (edge interfacing with water) maximum temperature is playing a greater role as compared to minimum temperature.

CONCLUSION

The study highlighted the significant variations observed over ice surface of Amery Ice shelf during recent past from 2000 to 2009. The study suggests that the largest surface melting phenomenon on Amery ice shelf was observed in January 2004. The maximum snow depth during the period is observed during the winter period from 2006 to 2007, as observed by the maximum backscattering of Ku-band scatterometer signals. However, summer months of 2000-01, 2002-03, 2007-08 have faced minimum surface melting as compared to other years.

The mid-winter Microwave Polarization Difference Index (MPDI) from 2000 to 2005 show increasing trend and there after decreasing trend is evident, which reflects the variation in the effective snow depth over ice shelf surface. The MPDI of the October month is found to be strongly related with the maximum and minimum air temperatures.

The 6-yearly increasing/decreasing trend observed in the backscatter time series needs further investigations to understand its contribution to the change in Atmosphere/Ocean parameters.

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