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Signature of ice melt over the Greenland derived from MSMR (OCEANSAT-1) data

N. SHARMA, M. K. DASH*, N. K. VYAS**, S. M. BHANDARI**,
P.C. PANDEY* and N. KHARE***

National Mineral Development Corporation, Hyderabad – 500 028, India

**Indian Institute of Technology, Kharagpur (West Bengal), India*

***Space Applications Centre, Ahmedabad, India*

**** Ministry of Earth Sciences, CGO Complex, Lodhi Road, New Delhi - 110 003, India*

e mail : nilaysharma76@yahoo.co.in

सार – ध्रुवीय क्षेत्र में भूमंडलीय उष्णता परिघटना के प्रभाव का मॉनिटरन करने के लिए यह आवश्यक है कि ग्रीनलैंड और एंटार्कटिका के हिम परतों पर बर्फ/हिम पिघलन का मॉनीटरन किया जाए। एम.एस.एम.आर. आँकड़ों का उपयोग करते हुए अलग–अलग सांद्रता के स्तरों पर समुद्र के हिम का भेद कर पाना संभव है। महाद्वीपीय हिम और समुद्र के हिम के सूक्ष्मतरंग उत्सर्जकों के आधार पर हिम के बनने और पिघलने पर उपयोगी सूचना प्राप्त की जा सकती है।

इस शोध पत्र में ग्रीनलैंड में महाद्वीपीय हिम परतों के लिए एम.एस.एम.आर. प्रेक्षणों से पिघलन सिग्नल प्राप्त करने की विभिन्न नीतियों पर विचार विमर्श किया गया है। एम.एस.एम.आर. आँकड़ों से प्राप्त 21 GHz के लिए ध्रुवण अंतर (पी.डी.) का अध्ययन किया गया और हिम पिघलन के सिग्नल की विद्यमानता का पता लगाने के लिए समुचित प्रभाव सीमा का चयन किया गया है। इस अध्ययन के परिणामों से जलवायु परिवर्तनों को दिखाया गया है।

ABSTRACT. In order to monitor the impact of global warming phenomena over the Polar Regions, it is necessary to monitor snow/ice melt on the Greenland and the Antarctic ice sheets. Using MSMR data, it is possible to differentiate sea ice at different concentration levels. On the basis of microwave emissivities of continental ice and sea ice, useful information on the formation and melting of the ice can be derived.

The paper discusses different strategies to derive a melt signal from the MSMR observations for the continental ice sheets in Greenland. The Polarization Difference (PD) for 21 GHz, available from MSMR data, is studied and an appropriate threshold is selected to detect the presence of melt signal. The results of the present study have bearing on climate changes.

Key words – Global warming, Polarization difference, Climate change, Polar regions, MSMR.

1. Introduction

Studies of growth and decay of polar ice sheets have gained great importance because of the effect of melting of snow/ice on sea level. Globally two major ice-sheets of Antarctica and Greenland region hold about 91 per cent and 8 per cent of earth's ice respectively. These ice-sheets play a major role in regional as well as global climates. Small changes in the air temperature will produce large areal changes in the ice due to large size and gentle slope of the Greenland ice-sheet. Assuming an adiabatic lapse rate of 0.6° C /100 m (Orving 1970), 1° C temperature rise is expected to increase the melt area by 79×10^3 km^2 (Steffen 1995). Additionally, melting of snow and ice in the Polar Regions is very significant for the mass and the energy balance of the ice sheets as well. It is well understood that the areal extent and the duration of surface snow and ice melting, climatological changes are

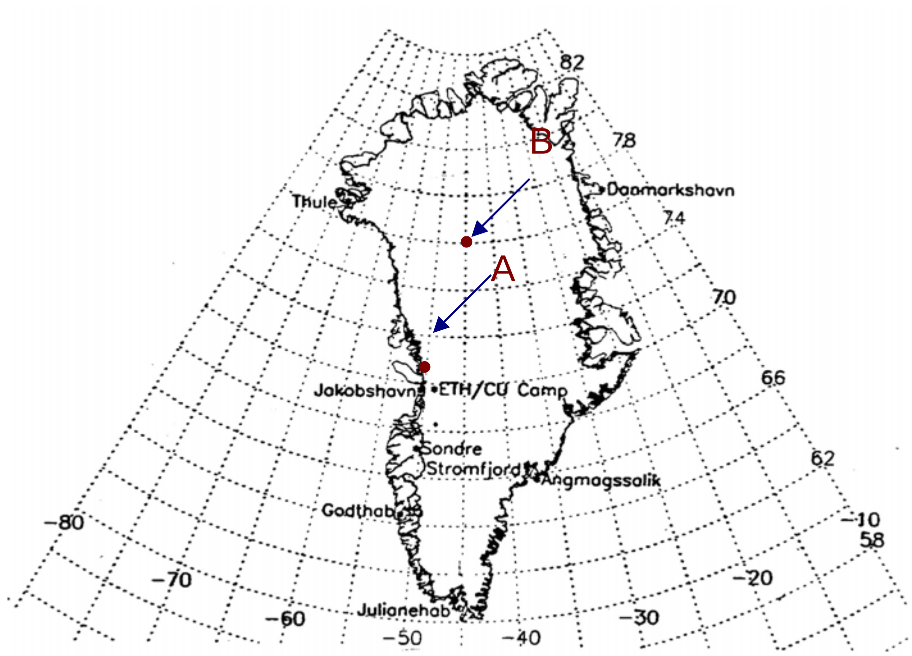


Fig. 1. Location map of Greenland showing the reference point (A) and the control point (B) [Redrawn after Abdalati and Steffen (1997)]

interlinked. The wet snow absorbs significantly more incident solar radiation than the dry snow and hence the process of melting provides an unstable positive feedback component to the climate system. In order to understand the role of melting in the evolution of climate system, monitoring of the melting process over long periods of time is necessary. Nevertheless the remoteness and unfavorable environment on the ice-sheet restricted detailed observations. However, remote sensing technique seems to be obviously the best tool to study ice-sheet dynamics. Furthermore, the passive microwaves are well suited for this purpose because of (*i*) the emissivity difference between water and snow/ice, (*ii*) the day/night capability of these sensors, (*iii*) the penetration of microwaves through clouds and (*iv*) their frequent coverage of the Polar Regions due to wide-swath.

In view of above, we present here the OCEANSAT-1 MSMR data to the study the snow and ice melting in the Greenland region.

2. Materials & methods

2.1. *Approach*

Greenland though occupies surface area of 1.75×10^6 km^2 and volume of 2.65×106 km^3 (Thomas 1993) yet, the present study is restricted to a location in Greenland, which is prone to surface melting in the summer season (Fig. 1, Point A). This point corresponds to the location of ETH/CU Camp (69° 34′ N Lat. and 49° 17′ W Long.) as considered by Abdalati and Steffen (1997). For the purpose of comparison, we selected another point at higher latitude in the central region of Greenland, which does not undergo melting throughout the year (Fig. 1, Point B).

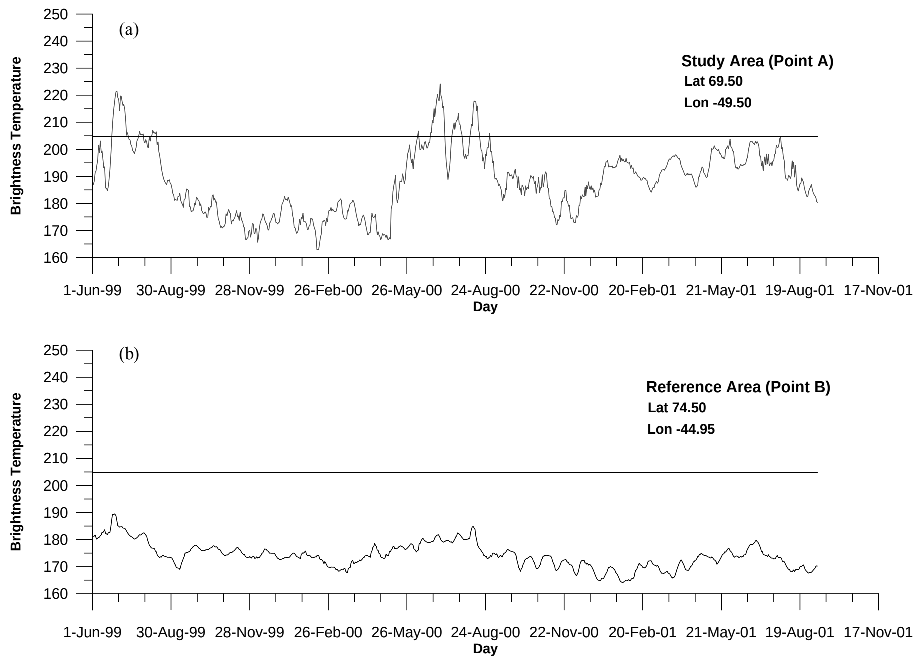
The Brightness Temperature (T_B) data over the above points are extracted and plotted for different frequencies and polarizations available for entire MSMR period. In order to further strengthen our results, we use the Polarization Difference (PD) method. The Polarization difference can be defined as the difference of brightness temperature between the vertical and the horizontal polarization at a particular frequency.

$$\text{PD}(f) = T_B(f, \text{V}) - T_B(f, \text{H})$$

Where f - frequency

V and H - horizontal and vertical polarization.

This method utilizes both, the frequency and the polarization dependence of snow emission on liquid water content.



Figs. 2(a&b). Graph of Brightness temperature *v/s* day number for 18 GHz (H) for points A and B

Lower microwave frequencies like 19/18 GHz, are more sensitive to melting than the higher frequencies such as 37 GHz. The polarization dependence makes small amounts of water in the snow cause horizontal brightness temperature strengthen compared to the vertical brightness temperature. The Polarization Difference (PD), should give a good signature of the presence of melt water, (if any), in snow/ice packs.

In the view of above PD values are plotted as a function of time and their behavior is studied over the melting season as well as over the whole year. The average onset date of melting and the completion of melt season are taken approximately same as those considered by Abdalati and Steffen (1997) and an approximate threshold is set accordingly. The results obtained from this method are then compared with the other method stated above and the results are critically examined.

2.2. *Data set*

Indian remote sensing satellite, IRS-P4, also called as OCEANSAT-1, launched on 26 May 1999, in polar sun-synchronous orbit is developed with the capability to monitor the polar ice with a repeat cycle of two days. The payload, Multi-frequency Scanning Microwave Radiometer (MSMR), which receives the passive microwave radiation emitted from the earth's surface, can be used for the study of polar ice. The Polar Regions are dark for several months in the year and are very frequently cloudy in the remaining months. The ability of MSMR microwave sensors to view the earth's surface, in day or in night, under all weather conditions, provides us an opportunity to obtain the required observations of both, the continental ice and the sea ice.

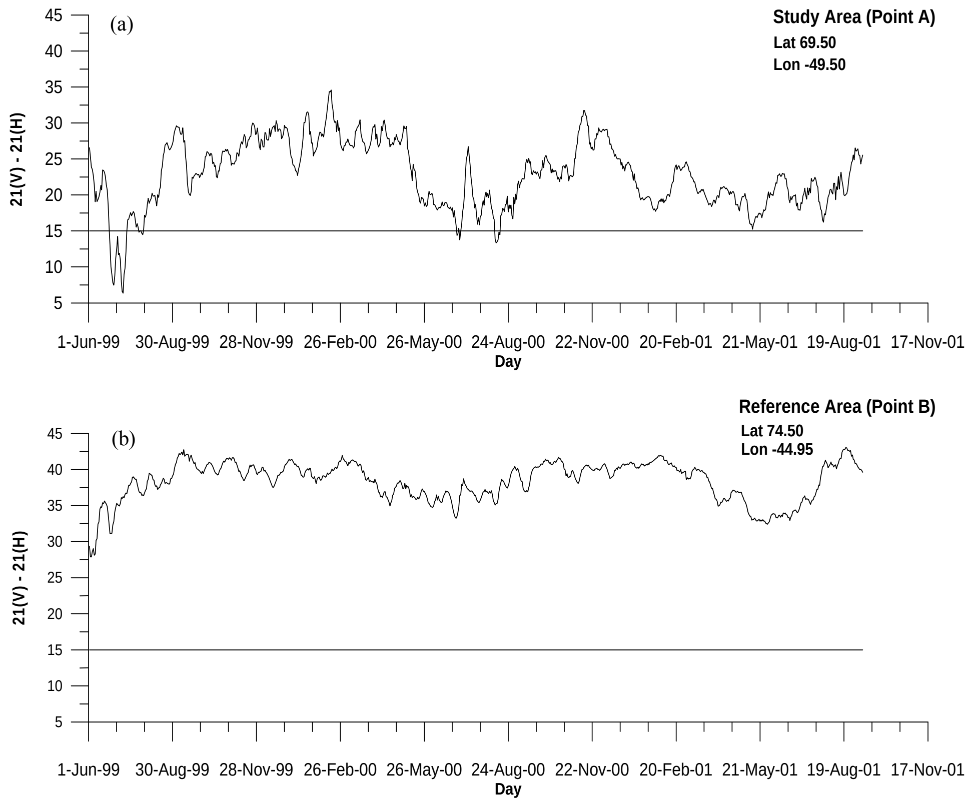
For present study, the data from MSMR during June 1999 to September 2001 has been used. The MSMR has four frequencies 6.6, 10.65, 18 and 21 GHz each having both, the horizontal (H) and the vertical (V) polarizations. The spatial resolution at 18 and 21 GHz is the finest, *i.e.*, 50 km × 50 km, and the same has been used for this study. The coordinates of the points studied are as given below:

Location

(*i*) Point A: Prone to surface melting (Fig. 1) (Corresponding to camp ETH/CU)

Latitude 69° 30′ N

Longitude 49° 30′ W



Figs. 3(a&b). Graph of polarization difference *v/s* day number for points A and B

(*ii*) Point B: Reference point for comparison (Fig. 1)

Latitude 74° 30′ N

Longitude 44° 57′ W

For setting of threshold, to detect the melt signature, we followed the two steps: briefly outlined below :

(*i*) Microwave emissivity of Greenland ice sheet at 18 GHz (H) lies in the range of 0.65 to 0.85 as obtained from aircraft survey (Gloersen *et al*., 1974). Firstly, we consider the emissivity of snow cover/ice sheet to have an average value of 0.75. Taking the physical temperature corresponding to melting of ice at 273 °K, we fix the T_B threshold for melting of ice as 204.75 K.

(*ii*) Secondly, we consider the PD range for 21 GHz channel available for MSMR period at the control point B, which is found to be from 28 K to 43 K (or 15 K from average value) (Fig. 3). This range of variability may be due to the change in physical temperature alone as no melting is likely. Any reduction above 15 K in PD, may be ascribed due to the melting of snow/ice.

The melting is considered to have occurred for those days for which both, the T_B value is greater than 204.75 K and the reduction in PD is more than 15 K.

Accordingly, a rectangular grid of 1° × 1° is chosen as study area taking the central coordinate as 69.5° N and 49.5° W, corresponding to point A. The MSMR data for the above region have been extracted from the global data set for each Julian day. The T_B data for the above grid is averaged on a daily basis (24 hours) for the entire period (June 1999 to September 2001). In the similar way, data have been extracted for a rectangular grid of 1° × 2° taking the central coordinate as 74.50° N and 44.95° W, corresponding to point B. The data extracted have been averaged as described earlier. The time series are generated for Points A and B (as shown in Fig. 2) for the four MSMR channels [18(V), 18(H), 21(V), and 21(H) in GHz]. The 18 GHz (H) channel appears to provide the best seasonal variation in T_B. The processed data have been passed through a 6-day running average to suppress the high frequency noise in the data set. The polarization differences for 21 GHz channels [PD (21GHz) = T_B (21V) – T_B (21H)] are calculated for both the locations, A and B. They seem to appear giving the maximum difference between V and H polarization during the melting signal.

3. Results and discussion

Changes in the microwave emissivities during the melting process have been used earlier to determine the extent and duration of surface melting in the polar regions, Ridley (1993), Mote *et al*., (1993), Steffen *et al.* (1993), Zwally and Fiegles, (1994), Mote and Anderson (1995) and Abdalati and Steffen (1995 & 1997). Some of the authors have used single channel data while others have used combination of channels with cross polarizations.

Similarly, the analyses from T_B graphs shows a possible signature of melting around point A during the fourth week of June [Fig. 2 (b)], whereas the T_B threshold set for melting is quite above the actual brightness temperature at the control point [point B, Fig. 2(a)]. This shows that there is no melting occurring at Point B (because the point has been so chosen), whereas a possible melting period of about seven weeks (with intermittent refreezing) is observed during the year 1999. The year 2000 shows possible melting signature at the study site (Point A) during the fourth week of June, this continues for about eight weeks. No melting signature is observed for the year 2001, although the signature reaches close to the threshold value. The physical temperature thus reaches 0° C but melting may or may not take place.

The analyses of polarization difference for 21 GHz channel shows a possible melting signature during the fourth week of June for the year 1999. Also, in the year 2000, the onset of melting possibly seems to start in the fourth week of June, whereas no melting possibility is found for the year 2001. The length of melting season is found to be for four to five weeks (with intermittent refreezing) for the above melting years [Fig. 3(b)]. There is absolutely no melting signature found for the reference area point B) [Fig 3(a)] in terms of polarization difference as expected.

The process of refreezing is found to be occurring during the melt season, which is reflected in both, the T_B (lowering of brightness temperature) and the PD (increasing in polarization difference) graphs [Fig. 2(b) and Fig. 3(b)], our inference of melting and refreezing are in agreement with the finding of earlier studies, which suggest that the melting takes place at point A on June, July and August of each year from 1979-2001 and after these month refreeze begin to occur on the ice-sheet. (Abdalati and Steffen, 1997).

4. Conclusions

It may be summarized that the melting starts during the fourth week of June at point A. The melting appears to exist for five to seven weeks with intermittent refreezing. The melt season lasts upto approximately second week of August for the above two years, 1999 and 2000. However to arrive at much conclusions, the validation with ground truth data is imperative.

In future, more detailed studies need to be carried out to understand the onset of melting and the length of melting season using both, the ground station data and a long record of satellite observations. Once the method is established, it can be used to map the potential melting zones and to derive the inter-annual trend of melting zone area to detect the climate change signal (if any). Such studies are significant in the light of earlier projected increase of about 7m sea levels, if all the ice on Greenland gets melted (Warrick and Oerlemans 1990), which may have devastating impact on the coastal region & inhabitants.

References

Abdalati, W. and Steffen, K., 1997, "Snowmelt on the Greenland ice sheet as derived from passive microwave satellite data", *J. of Climate*, **10**, 165-175.

Abdalati, W. and Steffen, K., 1995, "Passive microwave-derived snow melt regions on the Greenland ice sheet", *Geophysical Research Letter*, **22**, 787-790.

Gloersen, P., Schmugge, T. J. and Chang, T. C., 1974, "Microwave signatures of snow, ice and soil at several wavelengths", Proceedings of the Commission II, Specialist meeting on microwave scattering and emission from earth, Berne (Switzerland), 23rd to 26th September 1974, 101-111.

Mote, T. L., Anderson, M. R., Kuivinen, K. C. and Rowe, C. M., 1993, "Passive microwave-derived spatial and temporal variations of summer melt on the Greenland ice sheet", *Ann. Glaciology*, **17**, 233-238.

Mote, T. L. and Anderson, M. R., 1995, "Variations in snowpack melt on the Greenland ice sheet based on passive microwave-measurements", *J. Glaciology*, **41**, 51-60.

Orving, S., 1970, "Climates of the Polar Region", World Survey of Climatology, **14**, p370.

Ridley, J., 1993, "Surface melting on Antarctic Peninsula ice sheet detected by passive microwave sensors", *Geophysical Research Letter*, **20**, 2639-2642.

Steffen, K., Abdalati, W. and Stroeve, J., 1993, "Climate sensitivity studies of the Greenland ice sheet using satellite AVHRR, SMMR, SSM/I, and in situ data", *Meteorology and Atmospheric Physics*, **51**, 239-258.

Steffen, K., 1995, "Surface energy exchange at the equilibrium line on of melt", *Ann. Glaciology*, **21**, 13-18.

Warrick, R. and Oerlemans, J., 1990, "Sea level rise. Climate changes: The IPCC Scientific Assessment", J. T. Houghton, G. J. Jenkins, and J. J. Ephrams, Eds., Cambridge University Press: 257-282.

Zwally, H. J. and Fiegles, S., 1994, "Extent and duration of Antarctic surface melting", *J. Glaciology*, **40**, 463-476.