Analysis of Aqua AMSR-E derived Snow Water Equivalent over Himalayan Snow Covered Regions

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Abstract—We have made an endeavor to investigate the snow water equivalent (SWE) variations in Himalayan mountain region which is the most difficult terrain to access during winter seasons. The area also covers the large glaciers such as Siachen and Gangotri. A time series multi scale of SWE L3 product derived from Aqua Advanced Microwave Scanning Radiometer (AMSR-E) data have been analysed for three consecutive winters during 2002-2005 for Himalayan Snow cover region. A major emphasis is on the study of SWE trend in the two glacier areas viz. Siachen and Gangotri. It has been observed through AMSR-E 5-day product that snow cover area (SCA) over whole Himalayan region is very dynamic. AMSR-E derived 5-day SWE is analysed at the two test sites viz. Patsio (Lat 32° 45', 17.89° N and Lon 77°, 15° E) and Dhundi (Lat 32°, 22', 05° N and Lon 77°, 15° E) concurrently with the available in-situ data. The result indicates that in the peak winter days only we found reasonable co-relation. At the Patsio, minimum and maximum SWE observed are 26mm and 108mm respectively using in situ data.

Keywords- Snow water equivalent, Snow cover area, Snow depth

I. INTRODUCTION

Spaceborne passive microwave remote sensing can provide useful information about snow cover characteristics for various hydrological climatological and meteorological applications[1]. The most important parameter related to snow is snow cover extent and snow water equivalent (SWE) that are very important for number of applications such as hydro power stations, resource management, irrigation requirements and flood forecasting. Many rivers in north India originate from the snow covered areas and form a major source for drinking and irrigation requirements of millions of people. It also helps in forecasting snow avalanches and mitigating land slides. Snow cover can affect dynamic Himalayan climate because snow cover over land or mountain reduces the amount of sunlight absorbed by the Earth and also restricts flow of heat from the surface beneath the snow cover.

Earlier work has been done for retrieving snow depth (SD) or SWE through the available spaceborne radiometers such as the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave Imager (SSM/I). Neither instruments were designed explicitly for snow applications but have been found to be effective for this application [2], [3]. For snow detection, passive microwave instruments tend to underestimate the SCA as compared to estimates from visible-infrared snow mapping methods [4]. The perceived need by water resource managers and land surface and climate modelers is for high accuracy, local scale estimates of snow volume on a daily basis. Unfortunately, the spatial resolution of the SMMR and SSM/I instruments tends to restrict their effective use to regional-scale studies. Furthermore, currently available SSM/I data is acquired twice daily only at high latitudes with coverage more restrictive at lower latitudes. The Advanced Microwave Scanning Radiometer—Earth Observing System (AMSR-E) aboard Aqua, which was launched in 2002, has been giving data at high spatial resolution and at more frequently to overcome some of these drawbacks. Our aim is to detect snow cover area and analyzing the SWE in the Himalayan region. The microwave brightness temperature emitted from snow cover is related to the snow mass which can be represented by the combined snow density and depth, or the SWE (a hydrological quantity that is obtained from the product of SD and density).

II. STUDY AREA

In this study entire Himalayan region falling between Lat 28°N to 46°N and Lon 66.97°E to 103.84°E is covered. Area of interest is selected keeping in mind two big glaciers like Siachen and Gangotri. The longest river of India, the Ganges originates from Gangotri glacier. In the western region of the Himalaya we have observatories for observing snow parameters. These observatories measure in Situ data of snow grain size, temperature, snow density and depth. It is well known that snow parameters are region dependent [5]. Unavailability of in-situ information will affect the study. Snow cover study in the Himalaya region is vital in the context of real time use in hydrological, climatological and agricultural applications and for long term monitoring climate variability and detection of change.

III. DATA SETS AND METHODOLOGY

The study is carried out using AMSR-E derived SWE and observatory snow parameters like SD, snow temperature, grain size and wetness. Microwaves have the capability to penetrate dry snow pack and depending on the brightness temperature and frequency used it is possible to determine the depth of the snow.
AQUA AMSR-E has operational frequencies 6.9GHz, 10.7GHz, 18.7 GHz, 23.8 GHz and 36.5 GHz. All Channels give brightness temperature in horizontal as well as vertical polarization. It is found that 18.7 GHz and 36.5 GHz channels are the most suitable for snow depth and SWE determination. Snow studies group at National Snow and Ice Data Centre (NSIDC) has used difference of these two frequencies for developing SWE algorithm. A positive difference is regarded as a scatterer and might possibly have been emitted by the snow [6]. Generally, the greater this difference, and hence, the scattering signal, the greater the snow volume assumed to be present. Unfortunately, a major problem with this assumption is that in nature, changes to snow pack physical properties can also cause changes to the microwave scattering response of the pack; a change in the observed scattering equally might be caused by an increased snow volume or a change in the physical structure of the snow resulting from snow pack metamorphism. For homogeneous snow packs, the scattered signal can be converted to SWE or snow depth using an empirical algorithm or physically based static algorithm.

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SWE(mm) = 4.8 \times \left( \frac{T_{18\nu} - T_{36\nu}}{1.0 - 0.2 \times f_f} \right)
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Where \(f_f\) is representation of the fractional forest cover for that pixel obtained from the data set.

Monthly and 5-day average SWE products for 4 years were downloaded and converted into binary format using software provided by NSIDC. We developed our own program for converting the northern hemisphere SWE product to ASCII format. The ASCII data contains the information of latitude, longitude and SWE for each pixel in our region of interest. With the help of ERDAS Imagine, ASCII file is converted into raster format with a grid of 0.25 x 0.25 degree.

IV. RESULTS AND DISCUSSION

SWE has been studied from 2002 to 2005 using 5-day as well as monthly products. It has been observed through 5-day products that SCA over the whole Himalayan region is very dynamic on both time scales as shown in Fig.1 (a) (b) (c) and (d). It is revealed from 5-day products of all years that maximum SCA was observed in the month of February. From March last week onwards, it starts decreasing and becomes minimum in August. SCA in the peak of winter that is in months of December and January remains almost same. From middle of August, SCA starts increasing and becomes maximum in February. We have made a detailed study on annual SWE trend at specific locations on the two major glaciers (Gangotri and Siachen). Although SCA was maximum in February, but SWE values were observed maximum (64mm, 66mm, 55mm) in the fourth week of May 2003, second week of July 2003 respectively at Gangotri area and Sept. 2004. The location of the points studied for the work was selected at the centre of the glacier area and there is no ground truth available at those places because those areas are inaccessible.
having different climatic conditions. Patseo is located at the altitude of 3700 m and surrounded by barren mountains, whereas Dhundi was located at the altitude of 3000 m and surrounded by high peak mountains with and without vegetation cover. At the two stations, observatory data are available in terms of standing snow, fresh snow, temperature, wind speed, etc. both at morning and evening.

Seasonal trend of SWE at the two places is same in all the three winters. At Patsio maximum value (108 mm) of SWE is observed in the third week of November in 2004. From November onwards it follows increasing and decreasing trend and becomes minimum (26 mm) in the third week of April 2005. But at the same place scenario is different in 2002/03 winter. The SWE in the first week of November 2002 is observed about 60 mm and starts decreasing to 40 mm on 10th of November 2002 and then increased to maximum value 64 mm on 20th November 2002. From this onwards, it decreased to 44 mm on 20th December 2002 and finally becomes minimum (16 mm) on February 25, 2003. Similar trend of SWE is observed for Dhundi test site except 2003/04 winter season. We observed that the trend of SWE in two winters 2002/03 and 2004/05 is same at two test sites but trend of 2003/04 is entirely different. At Patsio, the maximum height of standing snow varied from 233 cm in 2002/03 to 120 cm in 2004/05 winter. But at Dhundi, maximum values were quite large and varied from 252 cm in 2003/04 winter to 319 cm in 2004/05 winter.

We analyzed 5-day average SWE and observatory record of standing snow of the day after averaging five day record. We found correlation in Jan, Feb. and March observations of 2002/03 and 2004/05 only at two test sites [Fig. 3 (a) (c)]. But for winter 2003/04 we found correlation in Feb. and March for both places [Fig. 4 (b)]. Density of snow is the governing factor in the determination of SWE and it is varying throughout the winter. Algorithm observes SWE as a bulk property of the snow pack and density is considered constant. It seems due to dynamic nature of snow density we are not finding good correlation between SWE and standing snow.

In the north-west Indian Himalayan region, there were reports of vast devastations to property and lives due to heavy snowfall in February 2005 in a short span of time. Data were analyzed of the same period day by day and weekly average. We could not find any abrupt change in snow cover and SWE in vast affected region. In order to verify the estimated SWE with ground truth measurements, it is necessary to conduct field work at different locations of the above test sites synchronous with AMSR-E passes.

V. CONCLUSION

The SWE over Himalayan regions during 2003-2005 have been studied along with ground-truth data available at some observatories. SWE results indicate that the snow cover in the Himalayan region is very dynamic on both weekly and monthly time scales. The SWE in the middle of the glaciers remained constant in August third week of 2002 and 2003. But in December (peak of winter) we found difference of SWE as large as 20 mm between the two years. These observations should be seen in the context of climatic change on the regional scale. Since passive microwave radiometers have their own limitations in measuring the geophysical parameters we could not find good correlation between satellite observed SWE and in-situ SD except peak winter months. It might be due to variability of the snow density with time.

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Fig. 3. (a) and (c) shows SWE and standing snow versus days of the winter months of 2002-03, 2003-04 and 2004-05 respectively at the Dundi test site.

REFERENCES


