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Potential of Passive Microwave Sensor for retrieval of Snow Water Equivalent: A Review

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***ABSTRACT*-- Snow Water Equivalent (SWE) information is essential for meteorology, water cycle, hydrology and global change studies. SWE is the one of most important parameter for accurate prediction of snow melt run off. In Himalaya due to the ruggedness and inaccessibility of Himalayan terrain, it is very difficult to monitor the snow cover information. However, microwave-based sensors in various satellites have the capability to estimates the snow cover characteristic i.e. snow depth, snow density and snow water equivalent. SWE estimates can be obtained from passive microwave sensor i.e.Scanning Multichannel Microwave Radiometer (SMMR), Special Sensor Microwave/Imager (SSM/I),Advanced Microwave Scanning Radiometer-Earth Orbiting System(EOS)(AMSR-E),Advanced Microwave Scanning Radiometer (AMSR ADEOS-II) and Advanced Microwave Scanning Radiometer-2 (AMSR-2). This paper briefly reviews historical passive microwave instruments and different techniques to estimate SWE.**
Keywords: Remote sensing, Passive microwave sensor, Himalaya, Snow Water Equivalent.

I. INTRODUCTION

Seasonal snow cover plays an important role in hydrological cycles and climate processes. In northern hemisphere 46.5 million km^2 is snow covered in January, and 3.8 million km^2 even in August (D.A. Robinsonet al., 1993)[4].The monitoring of snow coverage, temperature, depth and water equivalent is important for the forecast of snowmelt runoff, water resources management and flood control.The Indian Himalaya covers an area of approximately 5 lakh sq. km and due to inaccessible terrain, harsh climatic conditions and vast region, it is very difficult to monitor the Himalayan snowcover. North West Himalaya is characterized in three different regions i.e. the lower Himalaya (Pir-Panjal range), the middle Himalaya (Great Himalayan range), the upper Himalaya (Karakoram Range) (S.S Sharma et al., 2000)[5].Different researcher have used optical and microwave satellite data for monitoring of snow cover information. Optical data is useful to estimate the snow surface properties but optical data has major problem, in winter season most of area remains under the cloud. Due to lower wavelength of optical data it will not penetrate the clouds. Microwave satellite data has the capability to provide the snow cover information in all weather conditions (D. K. Singh et al.,2012)[15].SWE the amount of water contained in snow pack is the product of snow depth and density.

II. ALGORITHMS USED FOR SWE ESTIMATION

In past 30 years, many researchers have developed various kinds of models based on different theoretical approaches which can be classified into three categories: semi-empirical models, analytical models and numerical models. Semi-empirical models are resultant based on limited measurement data, their validity range is limited, but they are simple and stable. Analytical models are derived based on Maxwell equations and some approximations. In the numerical models, the scattering properties are solved numerically based on certain snow structures; the structures may vary, and have less simplification compared to analytical models.

The electromagnetic radiation characteristics of snow vary with the changes of snow volume (snow-depth), structure and liquid water content. This is the physical fundamental of detecting snow information using passive microwave remote sensing. Both the theoretical and experimental studies show that the microwave brightness temperature decreases with the increasing snow depth (R. L. Armstrong et al., 1993)[3].

SWE static retrieval algorithms were one of the most widely used SWE retrieval algorithms. These algorithms are based on the assumption of a linear relationship between the snow depth (and snow water equivalence) and the brightness temperature difference.

CHE Tao et al., 2003[8] have used Special Sensor Microwave Imager (SSM/I) brightness temperature to retrieve the SWE using the difference of 19 and 37 GHz in vertical polarization.

SWE (cm) =0.676+0.171*(T_{19v}-T_{37v})

But in the above method some issues are still exiting like i.e. 1) decomposition of mixed–pixels of passive microwave radiation T_B data and 2) the issue of dry snow and wet snow and Criteria of the validity of snow data observed in the field.

Vijay Kumar et al., 2006[10] have used Advanced Microwave Scanning Radiometer (AMSR-E) data to estimate the SWE using empirical relation:

$$\text{SWE (mm)} = 4.8\times\frac{(T18v-T36v)}{1.0-0.2*ff}$$

Where ff is fractional forest cover and it's ranging 0 to 1.

However, researchers have also observed that except peak winter time, Passive Microwave radiometer has limitation in measuring the geophysical parameters and could not find the good correlation between satellites based SWE and in-situ data.

Macro Tedesco et al., 2010[14] have proposed algorithm based on brightness temperature (T_B) spectral difference but unlike previous approaches it uses information from vertical and horizontal polarizations to obtain geophysical coefficients.SWE is assumed to be linearly dependent on the T_B spectral difference at 18.7 and 36.5 GHz.Snow depth is estimated using the following equation:

$$SD=ff(SD_f)+(1-ff)*(SD_o)$$

where SD is the snow depth and SD_f and SD_o is the snow depth from the forested and non forested areas. The snow depth for forested(SD_f) and non forested(SD_o) areas are computed as follows:

$$SD_f(cm) = 1/\log_{10}(pol_{36})*(T_B18v-T_B36v)/(1-f_d*0.6)$$

$$SD_o(cm) = [1/\log_{10}(pol_{36})*(T_B10v-T_B36v)]+[1/\log_{10}(pol_{18})*(T_{B10v}-T_{B36v})$$

Where f_d is the high spatial resolution (500 m) forest density. The pol_{18} and $pol_{36}$are the differences between vertical and horizontal polarizations at 18.7 and 36.5 GHz, respectively.

The SWE is obtained from the 25 km EASE-Grid re-sampled snow depth value and ancillary snow density data is given by:

SWE (mm) =SD (cm) * density (g cm^{-3}) *10

The retrieval of snow depth from spaceborne passive microwave observations can be improved by using low frequency channelsand using a nonlinear relationship between measured TBs and ancillary data and snow depth, rather than T_B spectral differences and their combination with ancillary information.

Macro Tedesco et al., 2016[17] have used Advanced Microwave Scanning Radiometer-Earth Orbiting System (EOS) (AMSR-E)satellite data to generate operational estimates of SWE and snow depth. The first SWE retrieval algorithm developed for space borne passive microwave data was based on a linear regression between snow depth and the difference between brightness temperatures at 19 GHz and 37GHz.The Regression coefficient (Rc) was static both in space and time and its value is 1.6 cm/K for snow depth (SD).SWE was derived assuming fixed snow density of 0.3 g/cm^3.

SD=Rc × (Tb19-Tb37)

This algorithm was modified by introducing the forest cover, by dividing Rc by (1-ff) where ff is forest cover fraction.

$$SD= Rc \times \frac{1}{1-ff} \times (Tb19-Tb37)$$

An improved algorithm estimates the SWE, but there are still issue that remains to be addressed for improving SWE estimates from space borne passive microwave data.

III. PASSIVE MICROWAVE SENSOR

Passive microwave remote sensors have the capability to provide information of global snow depth and SWE over a wide area in all weather condition (J.L Foster et al.,2005,M. Tedesco and E.J. Kim, 2006)[7,9].In previous studies different passive microwavesensors are used for snow parameters start with the launch of NIMBUS-7satellite with the Scanning Multichannel Microwave Radiometer (SMMR) in 1978that was launched by National Aeronautics and Space Administration (NASA). Further in 1987 Special Sensor Microwave/ imager (SSM/I) was launched on NASA's F8 satellite.The Advanced Microwave Scanning Radiometer Advanced Earth Observing System II (AMSR ADEOS-II)) began recording brightness temperatures in Dec 14, 2002 as part of the Japan Aerospace Exploration Agency (JAXA ADEOS-II). The Advanced Microwave Scanning Radiometer-Earth observing system (AMSR-E) began recording brightness temperatures in 2002 as part of the NASA Earth Observing System Aqua spacecraft. Unfortunately, AMSR-E stopped operation in October 2011 due to a problem with its antenna. Then,Advanced Microwave Scanning Radiometer 2 (AMSR-2) launched in May 18,2012 by Japan Aerospace Exploration Agency Global Change Observation Mission-Water SHIZUKA (JAXA GCOM-W1). Table 1 shows the details of all the passive microwave satellites.

TABLE 1
SUMMARY OF PASSIVE MICROWAVE SENSORS

Parameter	**Channel Frequency GHz**	**Polarization**	**Period**
SMMR(Nimbus-7)	6.6,10.7,18,21,37	V and H for all channels	Oct 24,1978-1995
SSM/I(DMSP)	19.3,22.3,36.5,85.5	V and H for all channels ,except 22 GHz: V only	June 1987-Present
AMSR-E(Aqua)	6.9,10.7,18.7,23.8,36.5,89.0	V and H for all channels	May4,2002-Oct 2011
AMSR(ADEOS-II)	6.9,10.65,18.7,23.8,36.5,50.3,52.8,89.0	V and H for all channels	Dec14,2002-Oct 25,2003
AMSR-2	6.9,7.3,10.65,18.7,23.5,36.5,89.0	V and H for all channels	May 18,2012-Present

IV. PREVIOUS WORKS CARRIED OUT FOR SWE ESTIMATION

A.T.C. Chang et al. (1982)[1] discussed that the SWEis an important parameter required for accurate prediction of snowmelt runoff. Microwave radiation, whichcan penetrate through a snowpack, may usedto infer the SWE.According to Chang microwave radiometer observations canbe used to deduce the SWE underdry snow conditions. In this they evaluated 37 GHz radiometer by collecting the data in ground, through aircraft and spacecraft.

A.T.C Chang et al. (1991)[2] have developed a physical model to explain thebrightness temperature variations due to terrain, vegetation cover and different snowconditions for a mountainous watershed. Researchers have used satellite microwave data to derive SWE in flat homogeneous areas successfully. However, in heterogeneous mountainous areas different algorithms are needed to retrieve the SWE of the snow cover.In this study a relationship was formulated between the difference in brightness temperature at two differentfrequencies (37and 18GHz horizontal polarization)and average SWE.They observed that the SWE values derived from the model were consistent with values generated by a reliable snowmelt run-off model using snow cover extent data.

CHE Tao et al (2003)[8] have used SSM/I data to retrieve the snow depth using the difference of T_B at 19 and 37 GHz in horizontal polarization.According to them all the existing algorithms overestimate the snowdepth in the Tibetan region.They further explored the possible reasons of this overestimation by analysing the water content in the snowpack, presenceof large water bodies in the study area and abnormal field snow depth data.After removing the futile data they could able to formulate an improved algorithm to retrive the snow depth using the difference of 19 and 37 GHz brightness temperature (T_B) in horizontal polarization. As for SWE estimation along with snow depth the density of snow is also required hence they used snow density as the time function of fresh snow density. For SWE estimation data they have useddifference of 19 and 37 GHz brightness temperature (T_B) in vertical polarization and obtained good results for Tibetan region.

K.K. Singh et al. (2007)[11] have developed a new algorithm using SSM/I passive microwave sensor to estimate the SWE and snow depth that suits the Indian Himalayan conditions. Again SWE is obtained by the difference of microwave brightness temperature at two different frequencies 37 GHz and 18 GHz in horizontal polarization.

Indrani Das et al. (2008)[12] estimates the snow depth over north-western Indian Himalaya using the 18.7H and 36.5H GHz channels of Advanced Microwave Scanning Radiometer-EOS (AMSR-E). The Microwave Emission Model of Layered Snowpacks (MEMLS) was used along with AMSR-E to understand the difference in the snow pack emitted and sensor received signals due to the prevailing topography. The study shows that the brightness temperature of AMSR-E and MEMLS are comparable at 18.7 GHz with some differences in their values at 36.5 GHz showing the sensitivity of this channel to the prevailing topography. Three years of AMSR-E data were used to modify the 1.59 algorithm (Chang algorithm) to suit the terrain and snow conditions of the north-western Indian Himalayas. The retrieved snow depth was compared with ground based data observations. The modified algorithm estimates the snow depth better than the old algorithm over the mountainous terrains of the north-western Himalayas.

K.K. Singh et al. (2016)[16] used Ground-penetrating radar (GPR) for snow/glacier depth estimation, snow layer identification and SWE assessment. They conducted experiments at field observatories of Snow and Avalanche Study Establishment located in different Himalayan ranges: Patseo (Greater Himalayan range), Dhundhi and Solang (Pir Panjal range).

Marco Tedesco et al. (2016)[17] discussed that SWE and snow depth can be obtained from spaceborne sensors at global scale and high temporal resolution (daily).The data recorded by the Advanced Microwave Scanning Radiometer—Earth Orbiting System (EOS) (AMSR-E) onboard the National Aeronautics and Space Administration's (NASA) AQUA spacecraft have been used to generate operational estimates of SWE and snow depth.

V. CONCLUSION

The study of SWE assessment based on microwave remote sensing has lasted for more than 30 years. In recent years, as continuous attention is paid to the climate change and global environment, the snow information plays an important role. For snowcover analysis and snow parameter extraction many passive and active microwave remote sensing models have been proposed, but in the future these models need further improvements. Current algorithms of SWE retrieval by passive microwave remote sensing adopts semi-empirical approach and are developed from the limited experimental data.In future with the more number of field collected SWE values, the empirical relation can be formulated relating SWE and T_B values and can provide the SWE values more accurately using the satellite data.

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