

Research Article

Analysis of Melt and Freeze in Shyok Sub-Basin, Indus Basin of Indian Himalaya using Ku Band Scatterometer SCATSAT-1

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Abstract The spatio temporal evaluation of melting snow and ice is important, among other things for studying climatological and hydrological applications. The knowledge of melting and freezing cycles of the seasonal snow cover is essential for water resources management and flood forecasting. Microwave remote sensing is a promising tool to characterise the melt and freeze over a large spatial scale and frequent temporal basis. This study attempts to use the Ku band dual polarization satellite SCATSAT-1 launched by ISRO with a scatterometer on-board with an enhanced spatial resolution of 2.2 Km to analyse the melt and freeze conditions in the Shyok basin, which is a sub-basin of the Indus river basin. The backscatter measurements from SCATSAT are helpful in identifying melt and freeze due to its sensitivity to the water present in the illuminated region. This study aims to adopt an adaptive threshold technique to identify the melt and freeze conditions, where the winter mean and maximum standard deviation and drop in backscatter due to the water content in the snow forms the basis to identify the melt and freeze conditions of the snow covered area. Spatio-temporal variability was observed in melt onset with 18% area under melt onset in the month of June, 2018. Onset in the month of April and May was less in comparison to June. Melt incidence maps were generated for major melt months of April, May and June and were categorised into 5 categories. April observed melt for 1 – 5 days, whereas a part of the study area was in melt condition throughout the month of June. A derived snow cover map was validated with Soumi_NPP derived snow cover with correlation of 0.96, indicating that SCATSAT can be used for snow cover retrieval over Himalayas by observing melt/freeze. Availability of daily SCATSAT data makes it possible to generate daily melt incidence maps.

Keywords *Adaptive threshold; Indian Himalayas; Melt and Freeze Onset*

1. Introduction

The cryosphere represents the important part of the Earth's climate system. The presence of ice and snow on the Earth is significant over a wide range of spatial and temporal scales and seasonal snow cover occurrence is a significant water resource in mountainous regions of the globe. Many global models of climate change predict that substantial changes occur at higher altitudes, so it is important

to monitor these portions of the Earth. Among the several processes, monitoring the melting snow and ice is crucial for climatological and hydrological applications. For example, melting and refreezing cycles are responsible for increased snow grain size through constructive metamorphism, thereby affecting the albedo and the surface energy balance through the amount of solar radiation absorbed by the snow pack (Tedesco, 2015). The presence of snow and ice affects the heating and cooling disturbing the energy balance, the variation in the status of snow is the indicator of climate change (Bothale et al., 2015). The knowledge about the melt onset dates is fundamental for water resource management and helps in flood forecasting. Researchers are interested in knowing the seasonal accumulation of snow and the length of the melt period. The Himalayas, which are also considered as the 'third pole', contain the world's largest reserves of ice and snow outside the poles. Understanding the melt and freeze cycles of the Himalayas is very important as they act as the source for many important rivers. Knowing the melt and freeze conditions in the Himalayas will also help in avalanche monitoring.

In historic times the observations of weather and the physical state of the snow covered regions were possible by in situ measurements. Melting is the outcome of various connected processes, which are influenced by the surface energy balance. The ground measurements of these components are difficult to collect and are not cost effective. The remoteness of these snow covered regions from the centres of population and its hostile environment means that the investigation by means of remote sensing methods particularly satellite remote sensing is desirable (Derksen et al., 2002 and Bothale et al., 2017). Because of the long heritage of spaceborne data, especially those collected in the microwave spectrum, it is possible to study the trends in melting for longer than 30 years. This information can be used to relate the melting features with climate drivers (Tedesco et al., 2009). Furthermore, remote sensing technique has proved to be promising for analysing the melt and freeze over a large area with spatio-temporal frequency.

1.1. Background

Microwave remote sensing can be used as a reliable approach due to its capability to operate in all weather conditions. Consequently, microwave sensors can detect melt even when the surface is frozen and near-surface temperature is below freezing. A large number of studies have been conducted using passive microwave sensors to detect surface melt. The use of active microwave sensors in these types of studies is given major importance these days. The active microwave measurements obtained from the scatterometer are useful in determining the melt season for a snow covered area. Scatterometer are active microwave sensors that observe the normalised radar backscatter coefficient σ° of the Earth's surface; these scatterometer measurements are particularly sensitive to water present in the illuminated surface and it is a function of incidence angle and surface roughness and the surface's electrical properties. The backscatter signatures observed from snow covered terrain and liquid water are markedly different (Carsey, F.D., 1992). As the amount of liquid water increases the wet snow causes a decrease in backscatter (Ulaby, F.T. et al., 1981). This response of the microwave region helps the researchers in identifying the melt duration and ice layer formation (Wang et al., 2008 and Oza et al., 2011). Compared to optical data, microwave sensors have much greater ground instantaneous field of view in the order of 10's of kilometres depending on the frequency, which makes the data suitable for large spatial scale studies. Also, the large swath width of microwave sensors together with their small sensitivity to the atmosphere provides information over the Earth on a daily basis. SCATSAT-1 satellite launched by India with the scatterometer sensor on board provides the microwave measurements on a daily basis, this dual polarization Ku band scatterometer is helpful in monitoring the melt and freeze conditions over a large spatial scale. For Ku band microwave radiation the backscatter for dry snow is stronger than that of wet snow (Sites and Ulaby, 1981). There are a lot of studies, which were carried out using active microwave backscatter measurements to analyse the freeze and thaw cycles (Hillard et al., 2003 and Bothale et al., 2015).

2. Materials and Methods

2.1. Study Area

The study is carried out for Shyok river basin which is a sub-basin of Indus river basin of the Indian Himalayas (Figure 1). The Shyok which flows generally north westward is fed by melt water from numerous glaciers on its way.

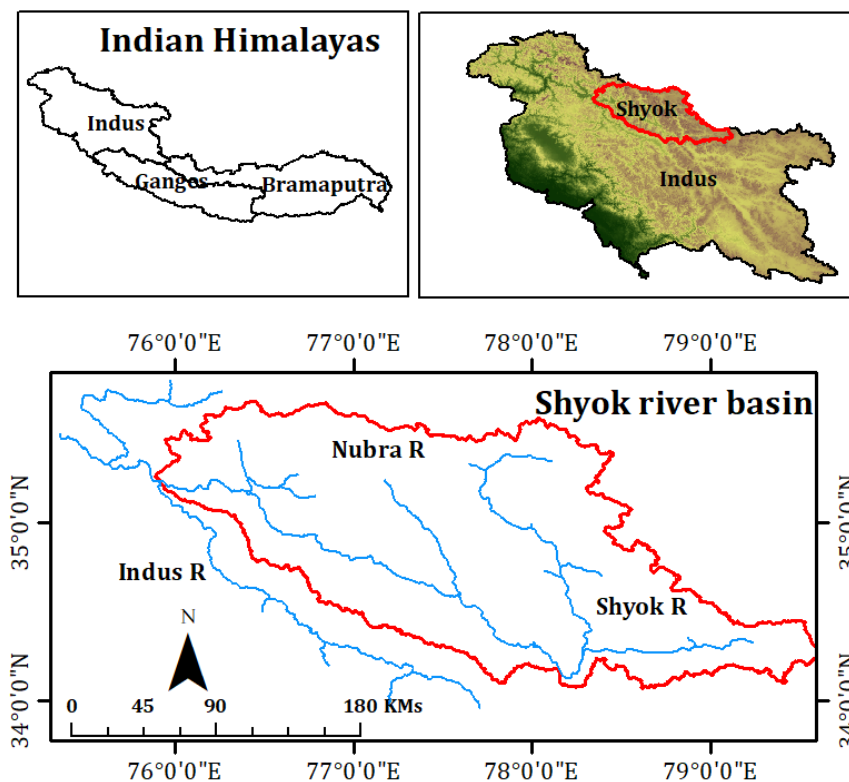


Figure 1: Study area map with location of point for backscatter response

The Shyok River originates from the Rimo glacier, which is one of the tongues of Siachen glacier. It rises in the Karakoram Range in the Himalayas. After originating from the Rimo glacier, the river flows in a south easterly direction. After merging with the Pangong range, the river takes a U turn and flows east-North westerly direction and after joining the Pangong it takes a north western turn, flowing parallel to its previous path. Shyok flows through one of the main Tectonic fault lines that separate the Himalayas from the Karakorams. The river widens at the confluence with the Nubra River. The Shyok runs in a wide valley, instantly stepping into a narrow gorge after Chalunka, continuing through Turtuk and Tyakshi before crossing into the state of Pakistan. The climate of Shyok sub-basin is semi-arid with annual precipitation less than 200 mm. The maximum temperature reaches to around 30°C in June. The velocity of the river is high, causing river erosion. Winter temperature reaches as low as -10°C.

2.2. Data used

The study uses the data from Indian satellite **SCATSAT -1** launched by Indian space Research organisation in 2016 with a scatter meter on board. It is a dual polarization pencil beam scatterometer, which operates in Ku band and gives both HH and VV images at a daily basis. The instrument has an incidence angle of 57° in VV and 49° in HH polarisation. SCATSAT –1 enhanced resolution images are available in 2.2 Km and same were downloaded from the MOSDAC website (www.mosdac.gov.in). The analysis in the present study was carried out for the year 2018.

2.3. Methodology

The methodology adopted in the study is given in the Figure 2.

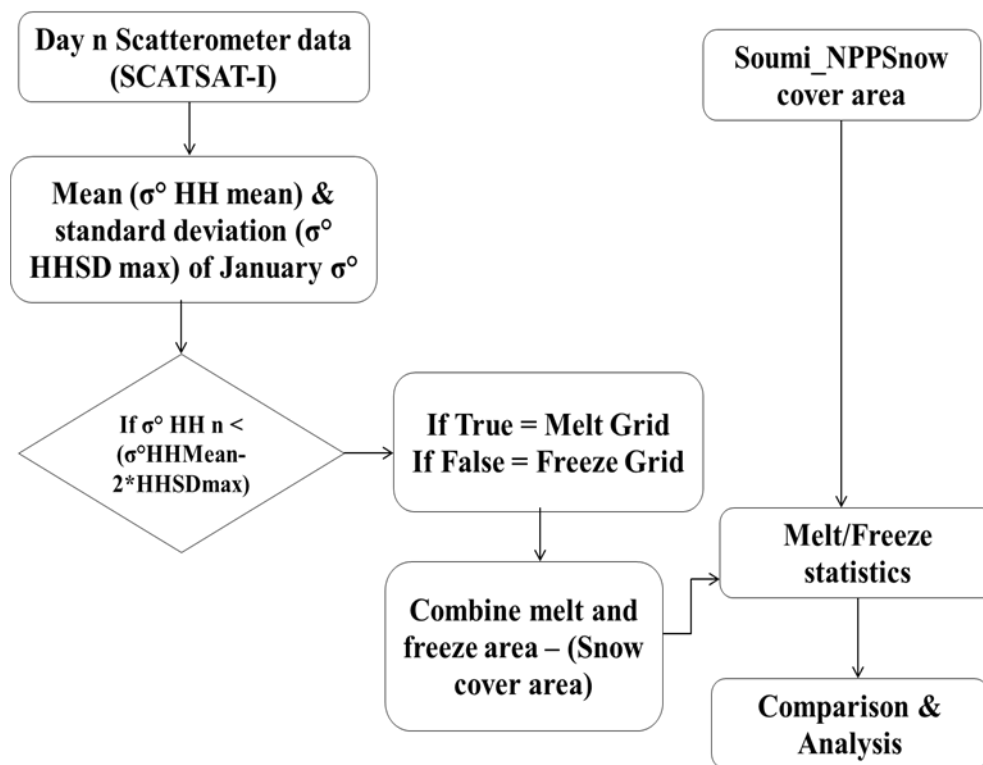


Figure 2: Methodology

Analysis of the backscatter response

As mentioned earlier, the backscatter from the scatterometer is sensitive to water content present in the illuminated region (Ulaby and Sites, 1981). The backscatter response of some points as shown in the Figure 3 from the study area was observed and it was observed that, as the water content increases, there is a sudden drop in backscatter which relates to the increase in temperature and the melt occurrence. The backscatter response of both HH and VV polarisation was analysed and it was observed that due to lower incidence angle the σ° from HH is more sensitive to the liquid water content (Wang et al., 2007) and hence it was used in the further analysis.

2.4. Melt / Freeze detection

Detecting the melt condition of snow covered areas is very crucial for monitoring and managing water resources. Previous researchers have carried out the analysis by applying a fixed threshold methodology to detect whether the pixel is in melt or freeze (Bothale et al., 2015 and Pandey et al., 2011). But the spatial variability of the Himalayan terrain makes the approach of using fixed threshold limited. This study adapts the adaptive threshold technique to detect the melt and freeze conditions. The backscatter values are higher for the month of January in winter season due to the increase in snow cover. The accumulating snow increases the backscatter values due to the strong volume scattering within the snow pack. In this study, an adaptive threshold was calculated for each pixel location based on the winter mean and the standard deviation. This technique helps in incorporating the variability in terrain and its response to backscatter. Based on the winter mean, standard deviation and drop in the backscatter due to the water content in the snow, the condition, which is used to satisfy the melt and freeze grid is as follows;

$$\text{If } \sigma_{HHn}^0 < (\sigma_{HH\text{Mean}}^0 - 2 * \sigma_{HH\text{SDmax}}^0), \text{ MG} = \text{True} \quad (1)$$

$$\text{If } \sigma_{HHn}^0 \geq (\sigma_{HH\text{Mean}}^0 - 2 * \sigma_{HH\text{SDmax}}^0), \text{ MG} = \text{False} \quad (2)$$

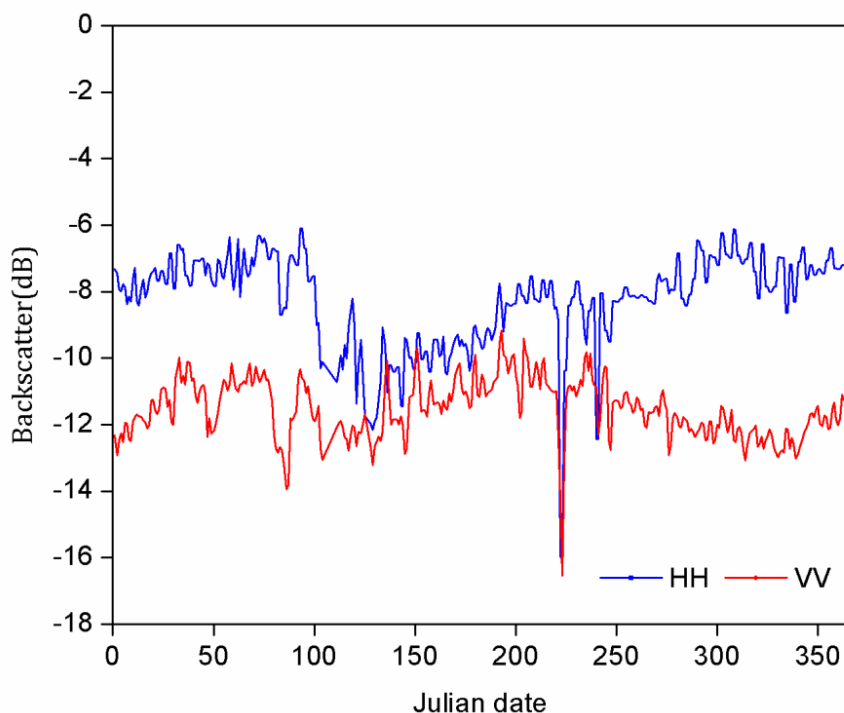


Figure 3: Scatsat-1 backscatter response for HH and VV polarisation over point shown in Figure 1

2.5. Detecting onset of melt and freeze

Based on the melt and freeze and freeze analysis, the onset of melt and freeze was identified in the study area. Whenever the backscatter of HH is lower than the adaptive threshold on the four consecutive images, the first day was considered as the onset of melt. Similarly, the onset of freeze was detected when the σ^0 of HH is higher than the threshold on 4 consecutive images. To understand the melt conditions over the entire study area, the total number of melt days was generated by counting the number of pixels under the melt throughout the year.

3. Results and Discussions

3.1. Melt and Freeze onset

The melt and freeze onset for the Shyok basin is shown in the Figure 4. The year 2018 observed 18% area under melt onset in the month of June, followed by 14% in the month of April. Lower areas observed melt in the month of March itself with 13% area under melt onset. Some areas observed melt and freeze in the same month, indicating they are predominantly in freeze condition with one or two days of melt. In places of higher elevation, where the snow is present throughout the year, the melt and freeze onset variations are more. 15% of the area received freeze onset in the month of April and 8% in the month of March itself. Majority of non-snow areas depicted by white colour, follow the river valley of Shyok and Nubra. The North-Eastern region of the basin area is devoid of snow cover. The melt/freeze status maps were generated daily as the SCATSAT data is available on daily basis. Figure 4 shows day-wise number of pixels under melt for the study area. Majority of the area is under melt onset in June as shown in the Figure 5.

3.2. Melt Incidence

The total melt incidence output generated for Shyok basin is shown in the Figure 6. Melt incidence map was generated by counting the number of pixels, which are in melt status, in the respective month. The melt incidence was classified in 5 melt categories, viz.; melt for 1-5 days, 6-15 days, 16-20 days, 21-25 days and 26-30 days. During the months of April & May, pixels were not in melt condition throughout the month. Part of the study area was in 1-5 days melt and remaining area was in 6-15 days melt. Major melt was observed in the North-North-West of the basin where the pixels were in melt state throughout the month as shown in the Figure 6c. In the month of June, the same area falls in the category of 26-30 days. The total number of melt days also vary depending upon the elevation range in the study area. This type of output helps in understanding the spatio-temporal variability of the melt conditions in the study area.

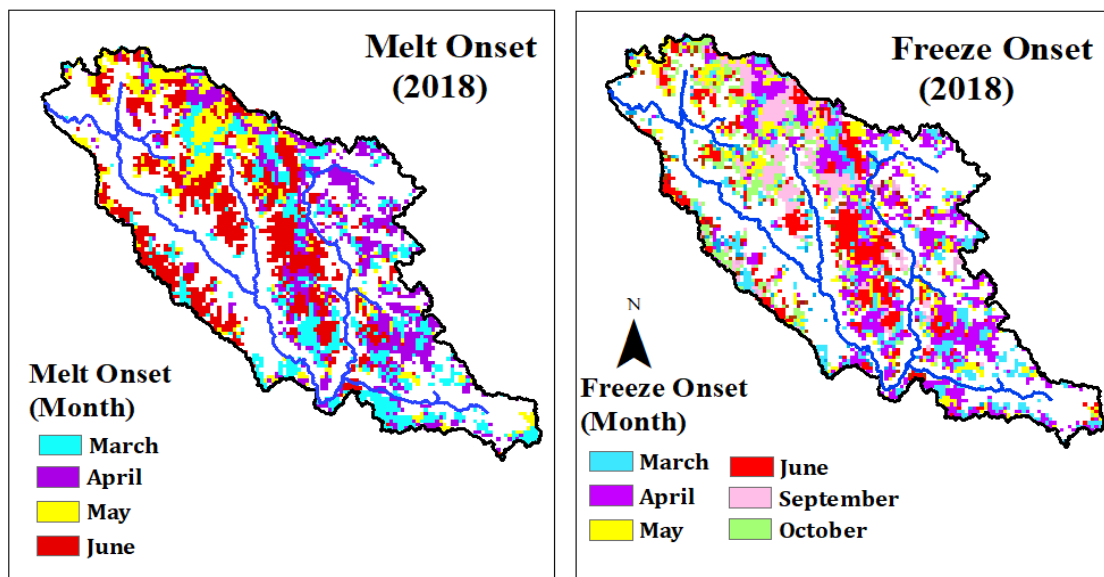


Figure 4: Melt Onset and Freeze onset in Shyok basin for the year 2018

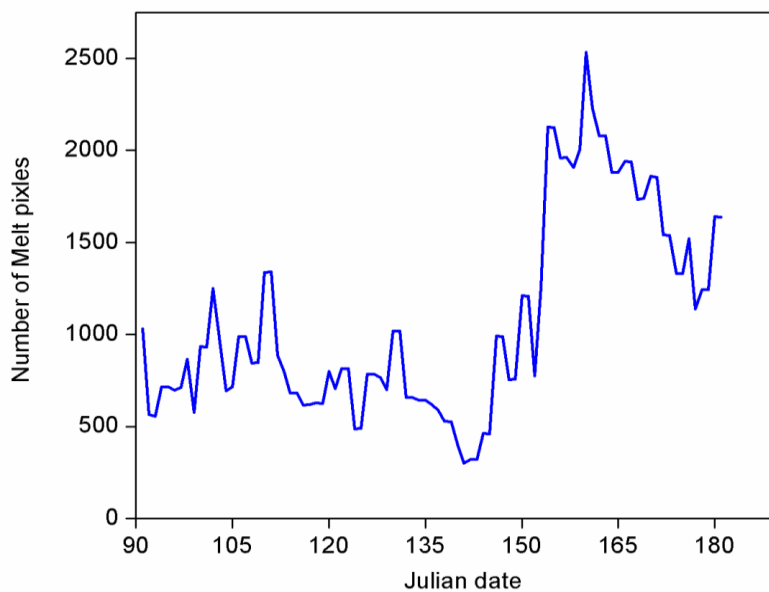


Figure 5: Day wise melt pixels over Shyok Basin

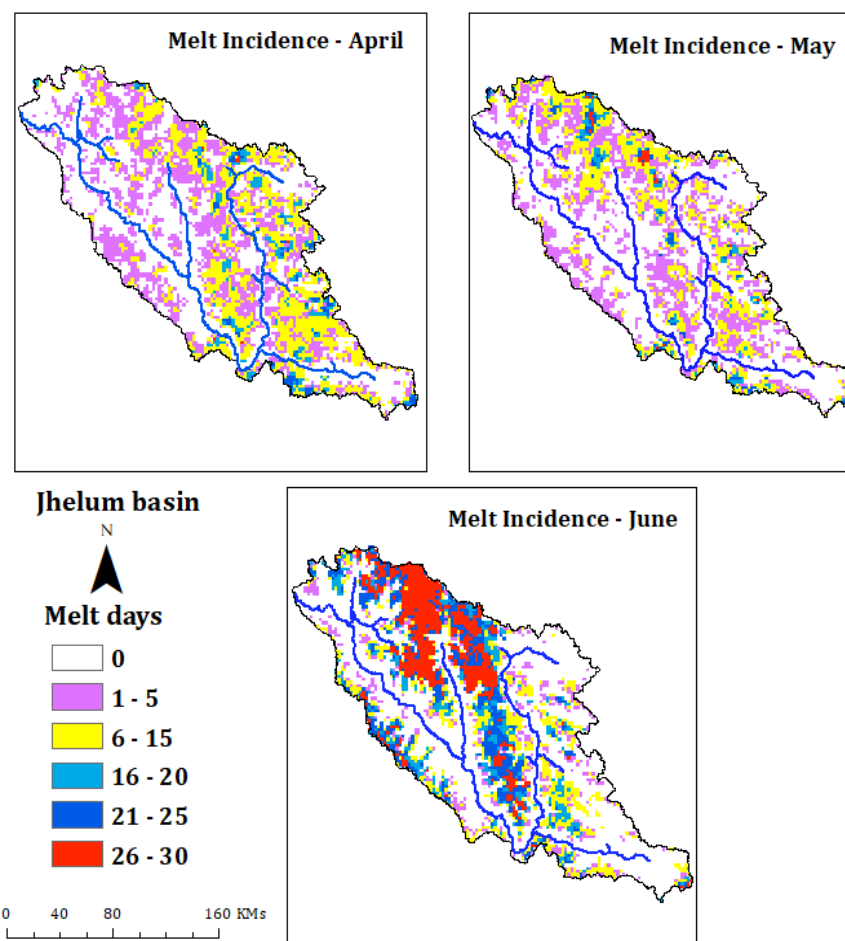


Figure 6: Melt Incidence in Shyok basin a) for April, b) May and c) June

3.3 Validation

From the generated daily melt and freeze outputs, the snow cover area was calculated by adding up the pixels in melt and freeze conditions. The generated snow cover area map was compared with the snow cover area map generated using Suomi_NPP data, which is already available. The comparison was made for the major melt months of April, May and June. Figure 7 shows the comparison of the snow cover areas generated using two different datasets of SCATSAT and Suomi-NPP. A correlation of 0.96 was obtained between both, which indicates that by observing melt/freeze status of snow area through active microwave scatterometer data, snow cover retrieval is also possible. Munoz et al (2013) in their study mentioned the sensitivity of scatterometer to melt/freeze and Naglar, T. & Rott, H. (2000) used Synthetic Aperture Radar (SAR) data to map wet snow in mountainous terrain, which showed very good correlation with existing snow cover retrievals.

4. Conclusion

This study shows the efficiency of the SCATSAT-1 scatterometer operating in Ku band in knowing about the melt and freeze conditions of the snow covered regions in India on a daily basis. This analysis also shows the variability in the melt and freeze onset in the Shyok basin. It also shows the efficacy of SCATSAT data in snow cover retrieval. Monitoring the melt and freeze conditions is crucial for monitoring and managing water resources. Thus the data from the scatterometer is proved to be a powerful tool for monitoring melting at multiple spatial and temporal resolutions.

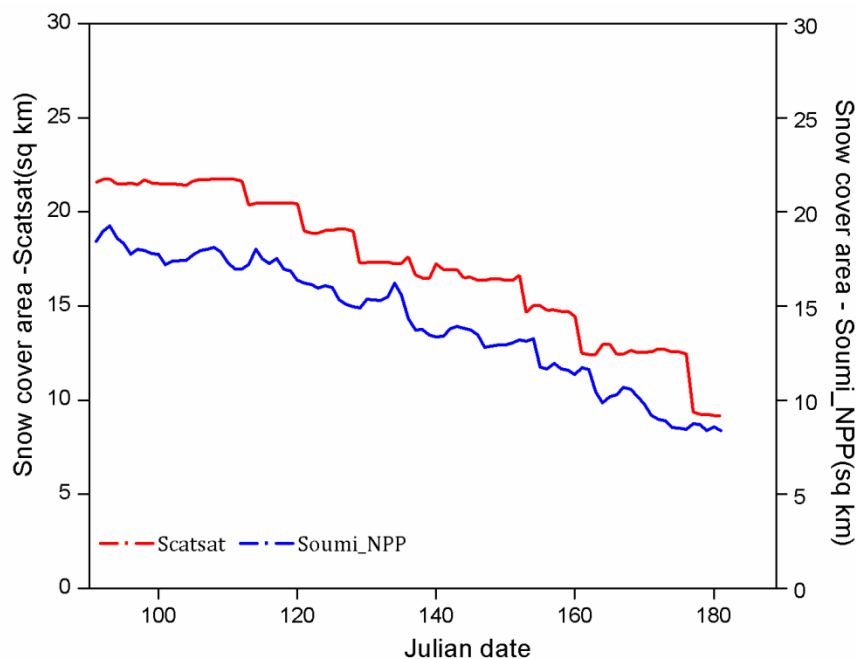


Figure 7: Comparisons between snow cover area from SCATSAT and Soumi-NPP

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