भारतीय हिमालय क्षेत्र में ओस्केट एवं क्विकसैट स्कैटरोमीटर द्वारा बर्फ गलने/जमने का अध्ययन

Snow melt / freeze in Indian Himalayas using scatterometer data (OSCAT & QuikSCAT)

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Hyderabad, INDIA

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15.	**सारांश:** ओशनसैट 2 एवं क्विकस्कैट पर सवार सूक्ष्मतरंग प्रकीर्णमापी (स्कैट्रोमीटर) आंकड़ों की मदद से हिमगलन एवं जमाव का मानीटरन एवं चिह्नांकन करने की पद्धति प्रस्तुत की गयी है। शुष्क एवं नम हिम की केयू बैंड में पश्चप्रकीर्ण (बैकस्कैटर) प्रतिक्रिया क्रमशः उच्च व निम्न पायी गयी। इस अवलोकन से गलन/जमाव की स्थित चिह्नित करने के लिए थ्रेषोल्ड आधारित पद्धति को लागू करने में मदद मिली। भारतीय हिमालय क्षेत्र में विभिन्न अवलोकनों के लिए आंकड़ों के कालिक विश्लेषण से पता चलता है कि एकल थ्रेषोल्ड (हर स्कैट्रोमीटर के लिए अलग) के उपयोग से शुष्क हिम और नम हिम को अलग किया जा सकता है। तदनुसार, संपूर्ण क्षेत्र के लिए एक थ्रेषोल्ड का उपयोग किया गया। क्विकस्कैट (2000-2009) एवं ओसकैट (2009 – 2013) के एचएच ध्रुवीकरण (पोलराइजेशन) के उपयोग से गलन/जमाव की स्थिति प्राप्त की जा सकती है। C++ एल्गोर्थिम एवं जीडीएएल लाइब्रेरी का उपयोग कर गणना की गई तता 2.25 कि.मी. विभेदन पर हिम गलन एवं जमाव का मानचित्र तैयार किया गया। **कुंजी शब्द:** क्विकस्कैट, ओसकैट, स्कैट्रोमीटर, हिमगलन/जमाव			

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15.	**Abstract:** A methodology to detect and monitor snow melt and freeze from microwave scatterometer data (OSCAT) onboard OCEANSAT2 and QuikSCAT data is presented. The backscatter response of dry and wet snow was observed to be high and low, respectively at Ku band. This observation enabled to employ a threshold based approach to identify melt/freeze status. Temporal analysis of data for different observations in Indian Himalaya shows that a single, fixed threshold satisfies determination of dry snow from wet snow. Accordingly, a constant threshold (For each scatterometer) is used for entire area. HH polarization from QuikSCAT (January 2000 – November 2009) and OSCAT (November 2009-December 2013) is used to derive melt/freeze status. C++ algorithm and GDAL library are used to compute and map snow melt and freeze at 2.25 km resolution. **Key Words: QuikSCAT,** OSCAT, Scatterometer, snow melt/freeze			

Contents

Abstract

A methodology to detect and monitor snow melt and freeze using Level-3 backscatter data from microwave scatterometer data (OSCAT) onboard Oceansat2 satellite and Seawinds scatetrometer abroad QuikSCAT satellite is presented. A threshold based approach is adopted to identify melt/freeze status in the study area. Temporal analysis of data for different observations in Indian Himalaya shows that a single, fixed threshold satisfies determination of dry snow from wet snow. Accordingly, a constant threshold (For each scatterometer) is used for entire area. HH polarization from QuikSCAT and OSCAT is used to derive melt/freeze status. The output is generated at 2.25 km grid size.

The document explains the methodology, the tools used and the efforts for validating the results. The algorithm is developed using C++ and GDAL library is used.

The melt/freeze methodology has been validated with in-situ data from Automatic Weather Stations under the Coordinated Energy and water cycle Observation Project (CEOP) and AWS data from SASE. The outputs are generated for all the available dates for QuikSCAT and OSCAT data between 2000 – 2013. The products validation would be a continuous process and validated periodically.

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QuikSCAT and OSCAT high resolution data are available at http://scp.byu.edu/data/. QuikSCAT data was used for the period 2000 - 2009 and OSCAT data was used for the period November 2009 to December 2013. We thankfully acknowledge the providers for making the data available.

Authors also wish to acknowledge the Automatic Weather Station (AWS) data of CEOP reference sites of SHARE project under Coordinated Energy and water cycle Observation Project (CEOP), obtained through EV-K2-CNR committee.

Special thanks are due to Director SASE and his team for providing data pertaining to one station in Himalayas.

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1. Introduction

The cryosphere covers a significant portion of the Earth's land and ocean surfaces. Seasonal snow cover reaches the widest extent of any cryospheric component, with a mean winter maximum extent encompassing about 31% of the total global land area, 98% of which occurs in the northern hemisphere. The cryosphere impacts global climate in a variety of ways. High albedo of snow and ice (80-90% of incident solar energy), reflects a significant amount of solar radiation back into space. Sunlight that is reflected back into space does not get absorbed by the Earth as heat and hence is an important cooling factor in the global climate system. In addition to climate factors, the cryosphere is also important to study and monitor for a variety of reasons. Snow and ice act as an insulating layer over land and ocean surfaces, holding in heat and moisture that would otherwise escape into the atmosphere. This insulation, then, also acts to cool the global climate.

2. Cryosphere

Cryosphere describes elements of the Earth system containing water in frozen state and comprises of snow, freshwater ice, sea ice, ice sheets, ice shelves, ice caps and glaciers, solid precipitation, seasonally frozen ground and permafrost. It covers a significant portion of the Earth's land and ocean surfaces. Snow is one major component of cryosphere with winter and summer extents of approximately ~47 million sq km and 26 million sq km (Barry & Gan, 2011). Sea ice is the third extensive component of cryosphere with maximum winter extent of ~14–16 million sq km in the northern hemisphere and ~17–20 million sq km in the southern hemisphere (Tedesco, 2015). Ice sheets cover areas more than 50000 sq km and hold 77% of the world's fresh water out of which Antarctica and Greenland account for 90% and 10% respectively. Winter ice is formed on lakes and rivers whose effect is mostly local.

Cryosphere plays a major role in the climate system through its impact on water cycle, energy budget, primary productivity and sea level (Barry & Gan, 2011). As it is sensitive to temperature change, cryosphere provides some of the most visible signatures of the climate change(Vaughan *et al.*, 2013). Sea ice extent has impact on ocean circulation, ocean productivity and regional climate and direct impact on shipping and exploration. Decline in snow cover and sea ice will tend to amplify regional warming through snow and ice-albedo feedback effects.

Details about the satellite missions launched for cryosphere are given in Table 1.

Table-1 Satellite missions for cryosphere

Satellite	Launch	Sensors and resolution	Objective
ICESat	2003-2009	The Geoscience Laser Altimeter System (GLAS). Spatial resolution: 170 m. Temporal resolution: 91 days.	For measuring ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics, ultimately, predict how ice sheets and sea level respond to future climate change.
ICESat-2	Scheduled launch 2017	Advanced Topographic Laser Altimeter System with improved spatial and temporal resolution.	Continuation to ICESat in 2003.
Cryosat-2	2010-present	SIRAL-2, the SAR/Interferometric Radar Altimeters, DORIS receiver, Laser retroreflector, Spatial resolution: 250m, Temporal: 369 days with 30 day sub-cycle	Aims to build a detailed picture of the trends and natural variability in Arctic sea ice and the trend in the thinning rate of the Antarctica and Greenland ice sheets.
GRACE	2002-present	hyper-sensitive microwave range finders Spatial resolution: 300km. Temporal resolution: 15 days	Observe and measure the gravitational field of the Earth, shape and composition of the planet and the distributions of water and ice.
GRACE-FO	(Scheduled launch 2017)	Laser Ranging Interferometer. With improved spatial and temporal resolution.	GRACE-FO will carry on the extremely successful work of its predecessor while testing a new technology designed to dramatically improve the already remarkable precision of its measurement system.
Sentinel	1A-03 April, 2014 1B – Scheduled for 2016	C Band SAR	S1-Monitoring sea ice zones and the arctic, global sea ice, snow cover, ice sheet/glacier monitoring S-3 – Sea ice elevation/thickness, land ice elevation, snow/ice extent

3. Microwave remote sensing and snow melt/freeze

The backscatter response σ^0 from a snow covered surface is a function of numerous interrelated factors including the dielectric properties of snow, snow temperature, density, age, and snow structure. The backscatter received from a snow covered surface includes contributions from snow pack surface component (1), underlying ground surface component (2), snow volume component (3) and ground volume interaction component (4) as shown in Figure 1.

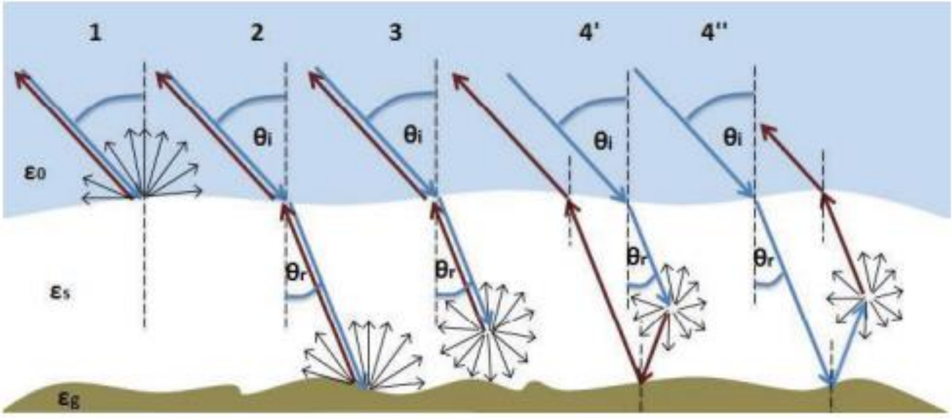


Figure 1: Snow pack backscattering mechanism

Source: Uluby *et al.*, 1981

For dry snow cover the backscattering from the snow surface may be neglected and the total backscattering is a combination of volume scattering from snow and surface scattering from the ground. In wet snow, the absorption loss is high and the scattering from the snow/ground interface may be neglected. The presence of liquid water content increases the absorption coefficient, there by reducing the backscatter response form snow (Tedesco, 2015). In passive microwave, as the liquid water content in the snow pack increases, there is rise in microwave brightness temperature. Brightness temperature recorded from dry snow is lower than that recorded from wet snow (Figure 2a left), because the presence of dry snow on soil attenuates the microwave radiation emitted by the soil. When liquid water forms in the snow, the wet snow layer absorbs the radiation from the bottom snow layer and soil and emits a signal stronger than that of the dry snow covering soil or ice (Figure 2b right). Figure 2b shows brightness temperature over two pixels over Antarctica. The continuous line refers to data measured over an area where melting occurs during summer, while the dashed line and black dots refer to an area where no melting is occurring (Tedesco, 2009).

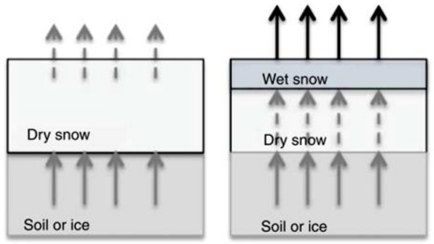


Figure 2a. Brightness temperature response over dry snow and wet snow
Source: Tedesco, 2009

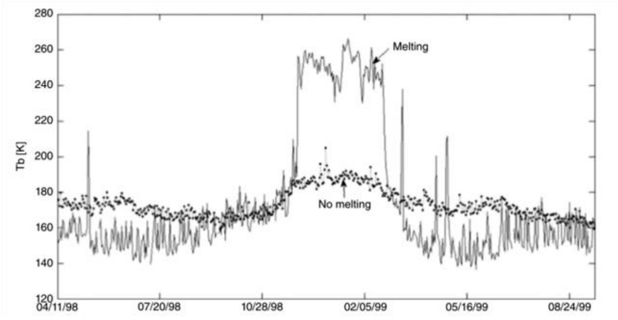


Figure 2b. Annual time series of 19.35 GHz, horizontal polarization, SSM/I brightness temperature for two pixels over Antarctica.

All regions of the electromagnetic spectrum provide useful information about the snowpack and its conditions. Table 2 gives the sensor band response relative to various snowpack properties (Rango, 1993).

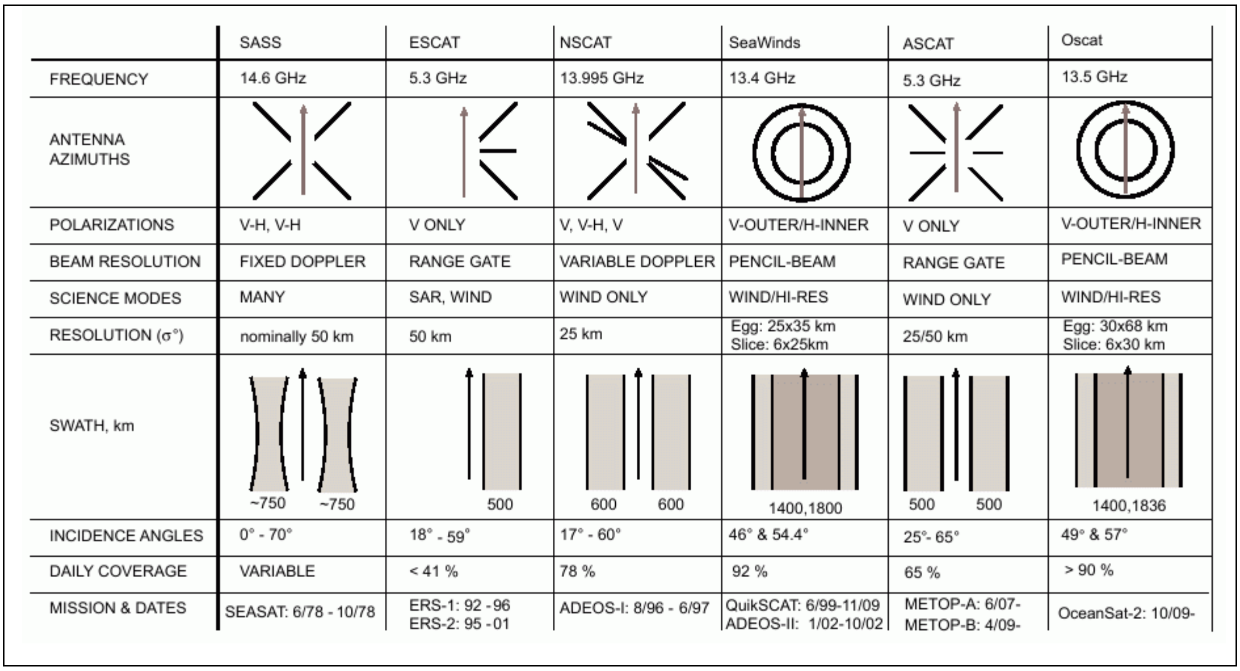
Table-2 Sensor band response relative to various snowpack properties

Snow property	**Visible/NIR**	**Thermal IR**	**Microwave**
Snow covered area	High	Medium	High
Depth	Shallow only	Low	Medium
Water equivalent	Shallow only	Low	High
Stratiography	No	No	High
Albedo	High	No	No
Liquid water content	Low	Low	High
Temperature	No	Medium	Low
Snowmelt	Low	Low	Medium
Snow-soil interface	No	No	High
All weather capability	No	No	Yes

(Source: Rango, 1993)

4. Scatterometry

Scatterometry is useful for identifying and locating the snow melt due to its extreme sensitivity to the presence of liquid water, broad areal coverage, high temporal resolution and all weather, day/night capability of mapping. The key parameter of microwave remote sensing is σ^0, the normalized radar cross-section. It is a function of incidence angle and is sensitive to the surface roughness and the surface's electrical properties. The scatterometer missions and their comparison is shown in Figure 3.



	SASS	ESCAT	NSCAT	SeaWinds	ASCAT	Oscat
FREQUENCY	14.6 GHz	5.3 GHz	13.995 GHz	13.4 GHz	5.3 GHz	13.5 GHz
ANTENNA AZIMUTHS						
POLARIZATIONS	V-H, V-H	V ONLY	V, V-H, V	V-OUTER/H-INNER	V ONLY	V-OUTER/H-INNER
BEAM RESOLUTION	FIXED DOPPLER	RANGE GATE	VARIABLE DOPPLER	PENCIL-BEAM	RANGE GATE	PENCIL-BEAM
SCIENCE MODES	MANY	SAR, WIND	WIND ONLY	WIND/HI-RES	WIND ONLY	WIND/HI-RES
RESOLUTION (σ°)	nominally 50 km	50 km	25 km	Egg: 25x35 km Slice: 6x25km	25/50 km	Egg: 30x68 km Slice: 6x30 km
SWATH, km	~750 ~750	500	600 600	1400,1800	500 500	1400,1836
INCIDENCE ANGLES	0° - 70°	18° - 59°	17° - 60°	46° & 54.4°	25°- 65°	49° & 57°
DAILY COVERAGE	VARIABLE	< 41 %	78 %	92 %	65 %	> 90 %
MISSION & DATES	SEASAT: 6/78 - 10/78	ERS-1: 92 -96 ERS-2: 95 -01	ADEOS-I: 8/96 - 6/97	QuikSCAT: 6/99-11/09 ADEOS-II: 1/02-10/02	METOP-A: 6/07- METOP-B: 4/09-	OceanSat-2: 10/09-

Figure 3: Comparison of scatterometer missions

Source: http://www.scp.byu.edu/

OSCAT scatterometer is similar in characteristics to SeaWinds from QuikSCAT (Figure 3). OSCAT scatterometer is launched onboard Oceansat-2 on 23rd September, 2009. With orbit altitude of 720 km and inclination 98.28^0, it has orbit ascending node time of 11:30 PM. The orbit revisit cycle is 2 days with approximately 14.5 orbits / day. It operates in Ku band with frequency of 13.6 GHz or wavelength of 2.21 cm. Incidence angle of HH polarisation is 49^0 and for VV polarisation is 57^0.

5. Datasets

The analysis uses QuikSCAT and OSCAT Enhance Resolution Image available at http://www.scp.byu.edu/ in slice mode at 2.225 km resolution which are generated by Scatterometer Image Reconstruction (SIR) algorithm with filtering (SIRF). All passes HH resolution data has been used in the study. Analysis has been done for data from January 2000 to November 2009 using QuikSCAT data and then from November 2009 to December 2013 using OSCAT data.

Automatic Weather Stations (AWS) data of 9 stations obtained from the Coordinated Energy and water cycle Observation Project (CEOP) were also used in the study (http://www.ceop-he.org/cms/the_ev-k2-cnr_committee.html).

AWS data pertaining to one station in Himalaya obtained from Snow and Avalanche Study Establishment (SASE) has also been used for validating the methodology.

6. Study area

The present analysis is carried out in Himalayas which is part of Hindu Kush Himalayas (HKH). Its boundary is obtained by joining the catchments of rivers providing water to India. It stretches from Jammu & Kashmir in the West to Arunachal Pradesh in the East ($21^{0}57'$ – $37^{0}5'$ & $72^{0}40'$ – $97^{0}25'$) and occupies 0.9 M sq. km. in Nepal, Bhutan, Tibet and India. Figure 4 shows the location map of study area along with AWS stations used in the study.

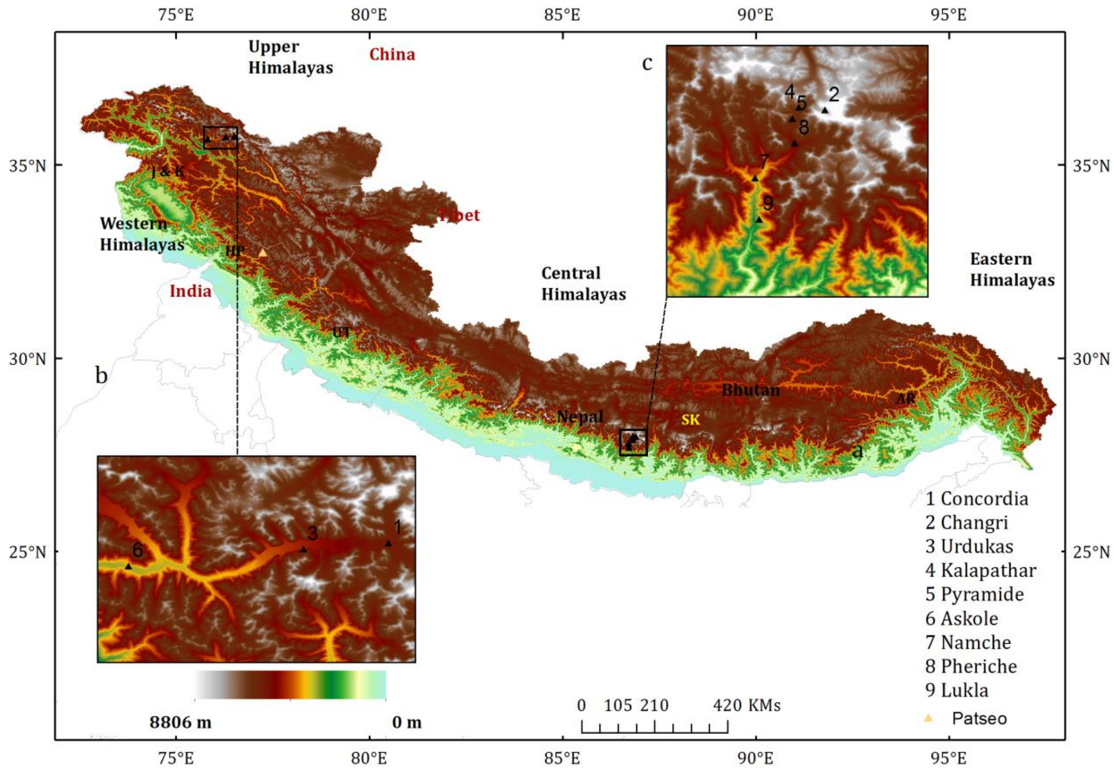


Figure 4. Map of Indian Himalayas with location of AWS stations and SASE station (yellow triangle)

7. Methodology

The methodology for detection of snow melt/freeze is based on the response of scatterometer to the presence of liquid water in the snow. Owing to lower incidence angle, backscatter response from snow is stronger at horizontal polarization than vertical polarization (Wang *et al.*, 2007) and hence analysis has been done using all-pass horizontal polarisation data. Time series of average daily temperature data was generated from available hourly observations at AWS stations. The Time series of temperature and σ^{0}_{HH} is shown for Changri, Kalapathar and Pyramid stations in Figure 5 which clearly shows a seasonal pattern in the temperature and backscatter response. These stations are well above permanent snow line and show similar pattern of temperature and σ^{0}_{HH}. A drop in σ^{0}_{HH} is visible, which coincides with a positive temperature window indicating above freeze (or melt) conditions. Presence of liquid water in the snow reduces the backscatter from snow. There is again increase in backscatter when snow refreezes. This cyclic behaviour of snow is utilised in identifying melt / freeze status.

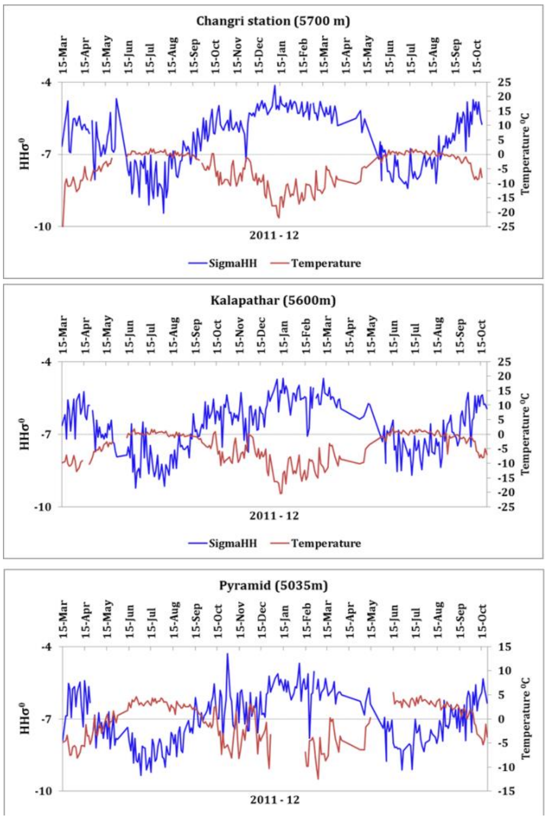


Figure 5a. Time series of OSCAT HH backscatter and temperature over Changri, Kalapathar and Pyramid stations

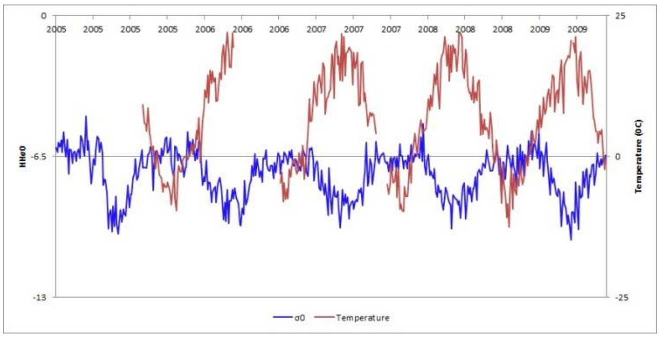


Figure 5b. Time series of QSCAT HH backscatter and temperature over Askole station

It was observed that higher σ^0_{HH} occurs during January to March (winter season) in the study area. This is caused by an increasing snow cover, which leads to increase in backscatter coefficient. The falling and accumulating snow increases the backscatter values due to strong volume scattering of microwave energy within the snow pack. Average backscatter coefficient for these months was found to be -7.03dB. Average backscatter coefficient from the graph was also noted whenever temperature changed from negative to positive or vice versa (-7.0dB). Based on all these, an empirical value of -7.00dB was used as a threshold to identify melt and freeze for OSCAT data. Based on the similar analysis, a threshold of -6.5dB was used for QuikSCAT data (Figure 5b). The methodology flow chart for the automatic generation of snow melt/freeze images from scatterometer data is shown in Figure 6.

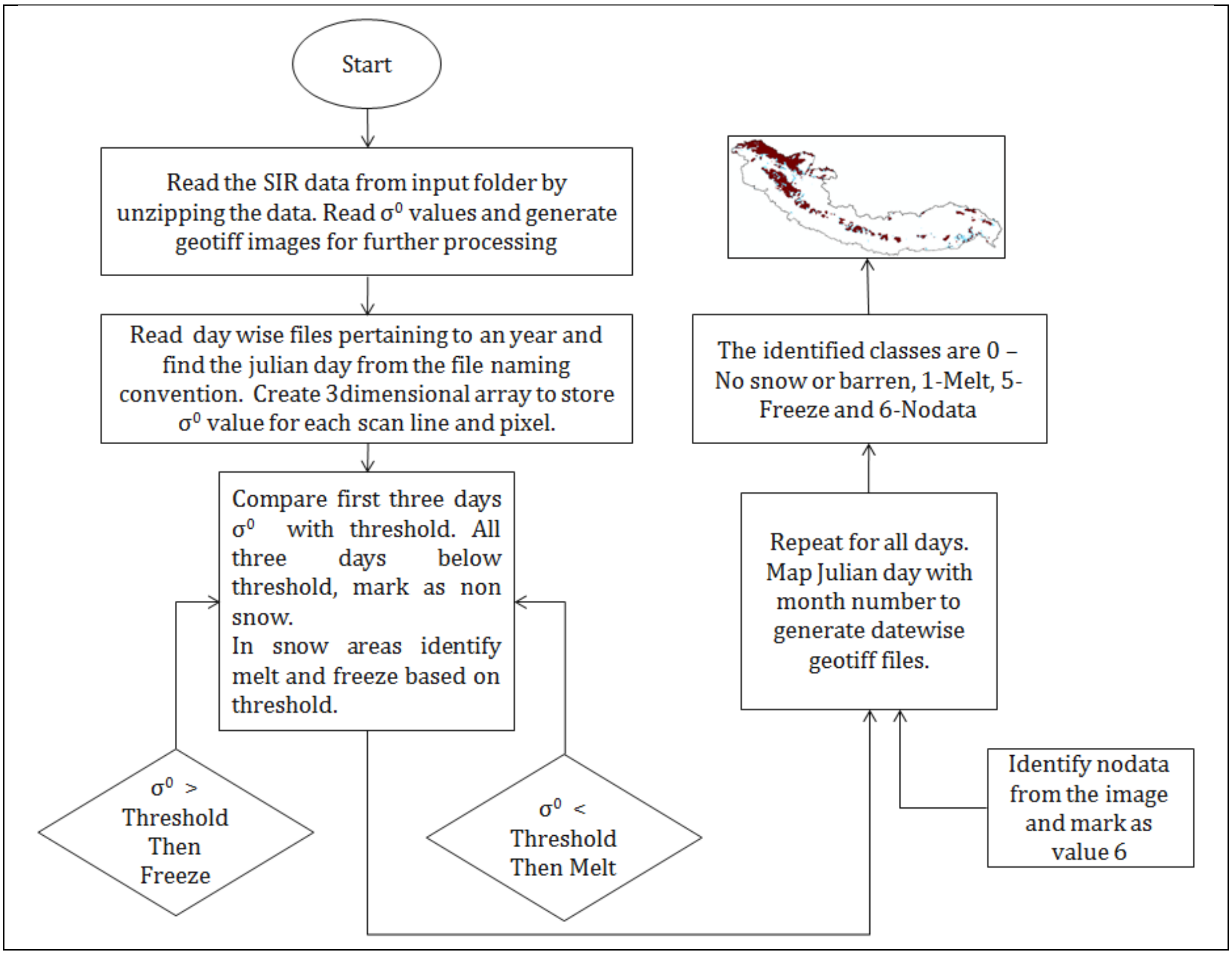


Figure 6. Flowchart for the methodology

8. Validation

Validation of the methodology has been carried out using AWS observations at 6 stations of SHARE project and AWS data obtained from SASE. Time series of σ^0_{HH} and the temperature plot is shown in Figure 7. The trend of σ^0_{HH} followed at these stations is similar to other stations data, which was used for methodology finalisation. The time series of backscatter showed similar trend of reduction with onset of melt associated with above freezing temperature.

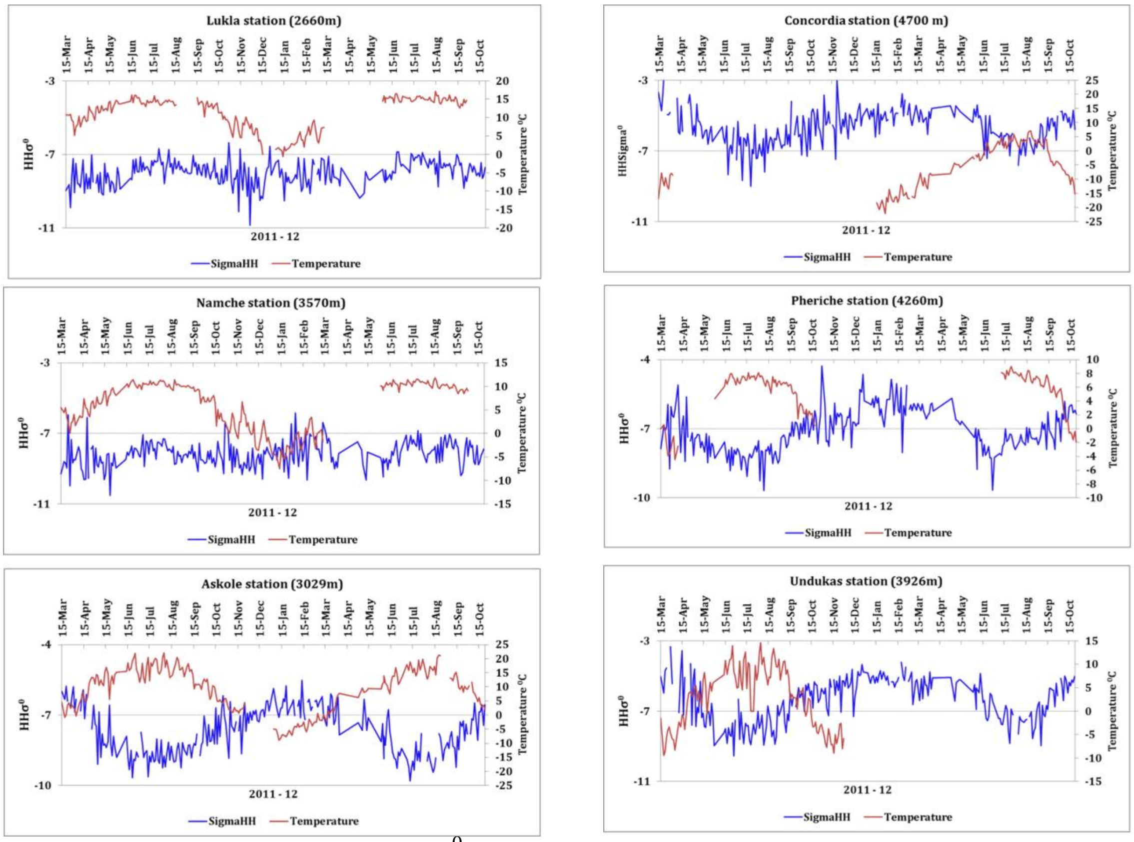


Figure 7. Time series of OSCAT σ^0_{HH} and temperature for 6 AWS stations

The results were checked with data obtained from SASE and with limited observations available, a good correlation was found between melt/ freeze and standing snow. Table 2 shows the comparison between both the observations.

Table 3: Comparison between SASE observations and OSCAT derived observations

• Total number of snow days – 75 (Observed in-situ)	• Days common with satellite data - 25	Snow identified correctly - 100%
• Total number of days with snow temperature < 0^0C - 124^0C	• Days common with satellite data - 49	All common days show presence of snow
• 03rd January to 14th May - common data for 54 days	• Number of days with Temperature above -1^0C (SASE) - 10	Number of melt days from OSCAT data - 15

9. Outputs

Figure 8 shows the sample output for January 17 pertaining to the years 2000 to 2013. Cyan colour shows snow in melt and maroon colour shows snow in freeze condition. The output data is named as QSCAT/OSCAT-SNOW-D1toD2-MMMYY-V01.tiff. where D pertains to date, MMM pertains to month and YY pertains to years.

A paper on ‘Detection of snow melt and freezing in Himalaya using OSCAT data’ by Bothale, Rajashree V., Rao, P.V.N., Dutt, C.B.S. and Dadhwal, V.K. has been published in *J. Earth Syst. Sci.* 124, No. 1, February 2015, pp. 1–13.

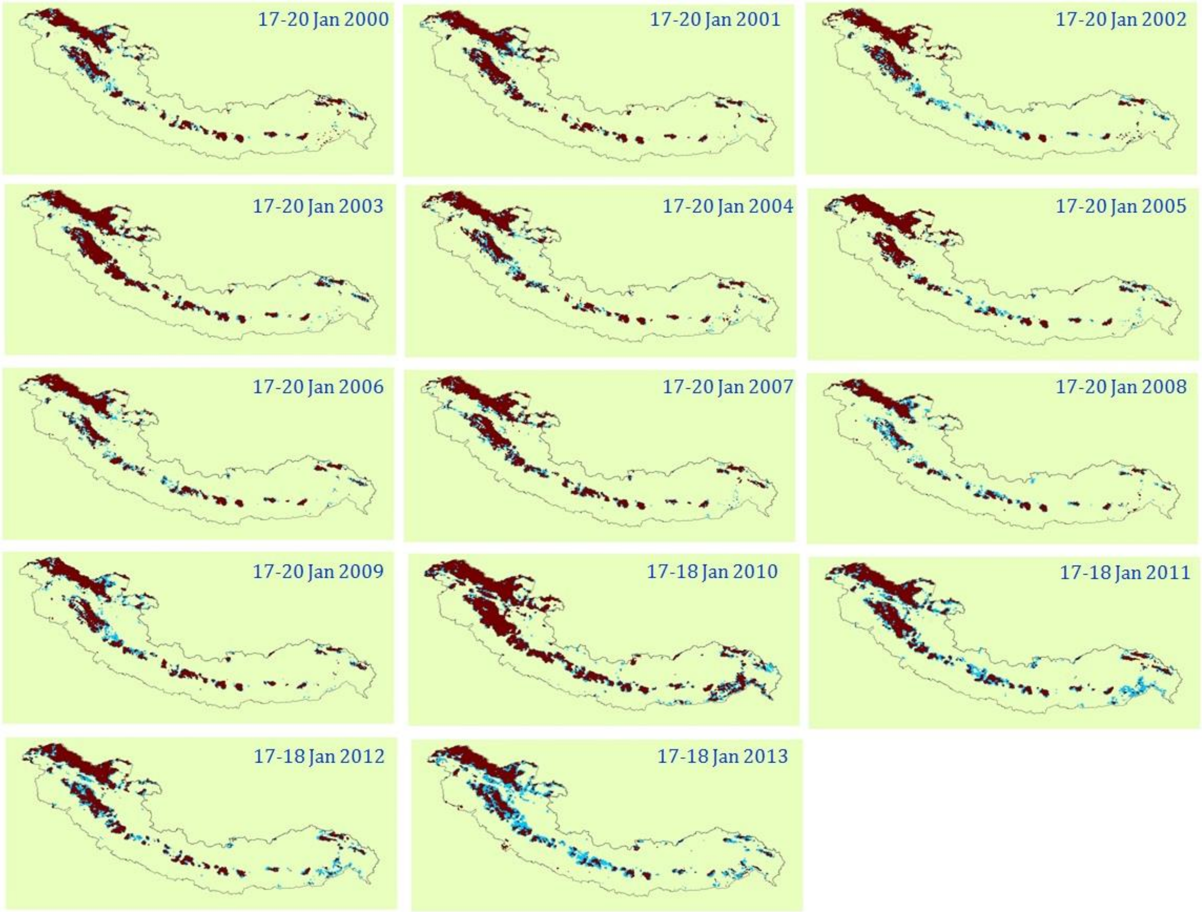


Figure 8. Snow melt and freeze status (For 17 Jan 2000 - 2013)

10. Summary and Conclusions

Melting and freezing of snow affects the exchange of heat between the land and atmosphere and this in turn affects a wide range of human activities including water resources planning and management. Snow melt status is also important for wet avalanche studies where knowledge of melt status combined with aspect, slope angle and altitude can help predict avalanche. The highly dynamic nature of snow melt/freeze needs regular information on melt/freeze dynamics.

A methodology for the snow melt/freeze using 13.6 GHz QuikSCAT and OSCAT is presented here. A constant threshold method is used to identify melt and freeze status.

Validation of the methodology is done by correlating with occurrence of positive temperature and the observations by SASE at one field location.

The version 1.0 product of snow melt / freeze has been generated for the period of January 2000 to December 2013 using QuikSCAT and OSCAT data. The accuracy of the output can be increased by using snow cover map at similar resolution. The said methodology will work better on permanent snow areas above snow line.

Further improvement in next version will see use of variable threshold approach to cater to variability in the study area.

References

- http://nsidc.org/data/docs/daac/scatterometer_instrument.gd.html
- Bothale, Rajashree V., Rao, P.V.N., Dutt, C.B.S. and Dadhwal, V.K. 2015. Detection of snow melt and freezing in Himalaya using OSCAT data. *J. Earth Syst. Sci*. 124, No. 1, February 2015, pp. 1–13.
- Long, D. G. & Drinkwater M. R. 1999. Cryosphere Applications of NSCAT Data. *IEEE transactions on geoscience and remote sensing*, Vol. 37, No. 3, May 1999.
- Munoz, J., Infante, J. Lakhankar, T., Khanbilvardi, R. , Romanov, P., Krakauer, N., Powell, A. 2013. Synergistic Use of Remote Sensing for Snow Cover and Snow Water Equivalent Estimation. *British Journal of Environment and Climate Change*., 3(4): 612-627. DOI : 10.9734/BJECC/2013/7699.
- Rango, A. 1993. Snow hydrology processes and remote sensing. *Hydrological Processes*. 7(2), pp. 121-138.
- Wang, L., Sharp, M., Rivard, B. and Steffen, K. 2007. Melt season duration and ice layer formation on the Greenland ice sheet, 2000–2004. Journal of geophysical research, Volume 112, F04013. doi:10.1029/2007JF000760, 2007.
- Wismann, V. R. 2000, Monitoring of seasonal snowmelt in Greenland with ERS scatterometer data, *IEEE Trans. Geosci. Remote Sens*., 38,1821–1826.
- Wismann, V. R. and Boehnke, K. 1997. Monitoring snow properties on Greenland with ERS scatterometer and SAR. Eur. Space Agency Spec. Publ. ESA SP-414: 857-862.

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Detection of snow melt and freezing in Himalaya using OSCAT data

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A study of the snow cover melt and freeze using Ku band Oceansat scatterometer (OSCAT) HH polarised backscatter coefficient (σ^0_{HH}) for 2011 and 2012 is reported for the Himalayas, which contain the world's largest reserve of ice and snow outside polar regions. The analysis shows spatial and temporal inter-annual variations in the onset of melt/freeze across four regions (Upper Himalaya, Western Himalaya, Central Himalaya, and Eastern Himalaya), nine elevation bands and four aspect zones. A threshold based on temperature–σ^0_{HH} relation and average σ^0_{HH} for the months January–March was used for melt/freeze detection. When the three consecutive images (6 days) satisfied the threshold, the day of first image was selected as melt onset/freeze day. The average melt onset dates were found to be March 11 ± 11 days for Eastern Himalaya, April 3 ± 18 days for Central Himalaya, April 16 ± 27 days for Western Himalaya, and May 12 ± 18 days for Upper Himalaya. Similarly average freeze onset dates were found to be August 23 ± 27 days for Eastern Himalaya, September 08 ± 24 days for Central Himalaya, August 27 ± 11 days for Western Himalaya, and September 13 ± 11 days for Upper Himalaya. All the zones experienced the melt onset earlier by around 20 days in 2011 at elevation above 5000 m. All the zones experienced freeze earlier in 2012, with onset being 18, 19, 11, and 21 days earlier in Eastern, Central, Western, and Upper Himalaya, respectively.

1. Introduction

The cryosphere covers a significant portion of the Earth's land and ocean surfaces. It is the key factor in the Earth's energy balance, a major source of fresh water, and affects climate and environment. It is extremely sensitive to changes in temperature. Melting snow decreases the albedo, increases the absorbed radiation and in turn leads to further decrease in the albedo. However, the variations in atmospheric temperature and humidity result in melting or freezing of snow covered areas. The cryosphere also has an impact on hydroelectric energy production and freshwater supply from seasonal snowmelt. Hydrologists are interested in seasonal accumulation of snow and their lengthy melt period of months. As long as freezing temperature and high humidity levels persist in the atmosphere, snow cover remains. The Himalayas also known as the 'Third pole' contain the world's largest reserve of ice and snow outside poles. Understanding the snow cover melt and freezing is an important hydrological variable as the Himalayas are the source of 10 large Asian river systems out of which, Indus, Ganges, and Brahmaputra affect India and provide water due to melting snow.

The presence of snow/ice affects the heating/cooling thereby disturbing the energy balance. The variation in the status of snow is indicative of the changing climate. The snow melt is sensitive to climate change (warming) and also an influencing factor to the climate change. For different studies

Keywords. OSCAT; Himalaya; snow melt; snow freeze; scatterometer.