The Detection of Supra-Glacial Debris size over Himalayan Glaciers using Synthetic Aperture Radar and In-situ data

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ABSTRACT

Aim: Estimation of the glacial debris size from the Synthetic Aperture Radar (SAR) data is the primary objective of the study. The debris cover is of interest to glaciologists due to its influence on the glacier melt processes. Previous studies show a negative correlation between thicknesses of supra-glacial debris melting of glacial mass.
Study Area: This study involves collection of debris size information from the Chhota Shigri glacier of Himachal Pradesh during the year 2014. The developed model is tested to detect supra-glacial debris size over the Gangotri and Zemu glacier.
Methodology: Backscattering signals of the SAR data from the ground truth sites are correlated with debris size. A linear regression was identified and used to detect the distribution of debris size from SAR backscattering. Satellite data of RISAT-1 Medium Resolution SAR mode is the primary input. A Surface profiler is used to collect the in-situ data of debris. Predicted debris size has been cross-check by measured debris size from high resolution optical data.
Result: From the model derived outputs, the average debris size of the Gangotri glacier is around 100 – 200 mm and that of the Zemu glacier is around 300 – 400 mm.
Conclusion: Co and cross polarized SAR data are employed to derived debris size; however, cross polarized SAR backscattering has better correlation with debris size. The accuracy of the result derived from the developed method is ± 50 mm. The rugged terrain of the mountain glaciers limits collection of in-situ data. Use of satellite data can overcome this limitation to some extent and help to understand the role of debris in glacier mass balance.

Keywords: Synthetic Aperture Radar, image classification, Himalayan glaciers, glacial debris

1. INTRODUCTION

The supra-glacial debris cover has two distinct sources: englacial and extraglacial in ablation zone of the glacier. Glacier ice mass erodes the base and plucks eroded debris and carries with its flow [1, 2]. Externally sourced material is from rockfall from mountain cliffs due to physical weathering (freez and thaw actions) onto the glacier ice surface. Field studies have shown that debris cover resulting from extensive, deep (metre-scale) dominantly fine-grained rock-avalanche deposits can significantly affect mass balance of the glacier and cause it to advance on decadal to centennial timescales in the absence of climate forcing [3 - 6].
Supra-glacial debris covered ice zone is primarily found in the alpine type of glaciers, especially in Himalayan region. Himalayan glaciers, situated in low latitudinal region, receive almost perpendicular solar radiations which increase temperature of debris. Size of the debris over the glacier also controls thickness of the supra-glacial debris. Fine debris, like, sand and dust will create thin layer, while large size debris produces thick debris cover. A laboratory experiment

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showed the effect of the debris in slowing the melting rate prior to stabilization varied in direct relationship to its thickness [7]. The laboratory experiment also studied debris thickness greater than 90 m significantly delays on-set of melting. However, Melting rates under the debris were higher than those with no rainfall because percolating rain advects heat from the warm debris to the ice. To quantify the mass loss or gain due to the accumulation of debris cover over Himalayan glaciers, it is important to have size distribution of supra-glacial debris. A model has been developed using the correlation between Synthetic Aperture Radar (SAR) backscattering and changes in supra-glacial debris size.

2. MATERIAL AND METHODS

Three Himalayan glaciers, Gangotri, Chhota Shigri and Zemu glaciers are selected as study areas (Figure 1). Within these three glaciers, the Chhota Shigri has minimum area under sup-glacial debris cover. The Gangotri glacier has debris cover over half of its ablation area, while the Zemu has maximum debris accumulation among these three.

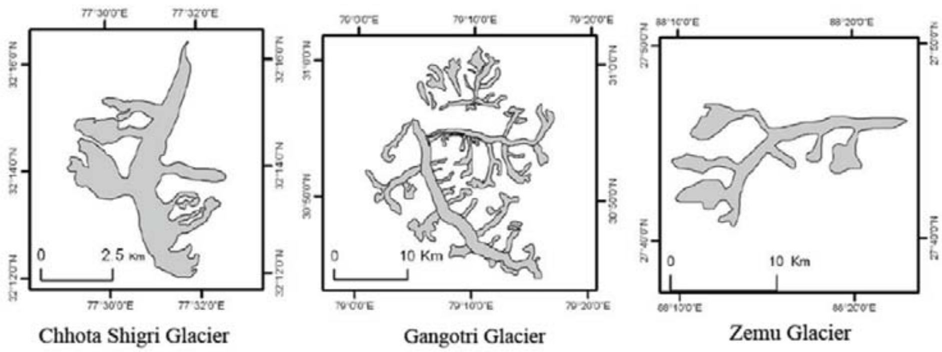

Fig. 1: Three Himalayan glaciers, namely (from left), Chhota Shigri, Gangotri and Zemu are selected as study area. The in-situ data was collected over the Chhota Shigri glacier.

Synthetic Aperture Radar (SAR), being sensitive to the surface roughness of the target, allows study of changes in radar backscattering due to the changes in surface roughness. Radar Imaging SATellite-1 (RISAT-1) C band Medium Resolution SAR (5.35 GHz; MRS) dual polarized (HH and HV) data of the descending pass has been studied to detect the size of the supra-glacial debris cover. Dates of acquisition of the data are 3rd August 2014 (Chhota Shigri), 4th August 2014 (Gangotri) and 3rd September 2014 (Zemu).

Field data were collected on size of supra-glacial debris from the Chhota Shigri glacier from 15 - 16 September 2014. A surface profiler is used to measure the size of the debris (Figure 2). Handheld Global Positioning System (GPS) is used to mark the location of the study sites. The photographs are taken after placing the surface profiler to get a scale of the debris. Later, these photographs are calibrated with the profiler scale to quantify the size of the debris. The size of the debris collected during the field study has been given in Table 1. Figure 3 shows photographs of different study sites.

Fig. 2: The surface profiler used to estimate size of the debris during the field study over the Chhota Shigri glacier.

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Table 1: Surface roughness measurement at different altitude over the Chhota Shigri glacier.

Photo Id	Description	Latitude (dms N)	Longitude (dms E)	Altitude in m	Debris size in mm
7857	Snout	32°16’10.8”	77°31’47.1”	4079	0-10
7863	Water channel over old snow	32°16’06.1”	77°31’43.2”	4150	0-10
7869	Moulin 2	32 16 00.16	77 31 41.87	4162	100-200
7871	Debris cover	32°15’58.5”	77°31’40.4”	4246	100-200
7872	Debris cover	32°15’47.1”	77°31’42.2”	4250	300-400
7873	Debris cover	32°15’53.5”	77°31’40.6”	4279	500-600
7875	Debris cover	32°15’43.9”	77°31’42.6”	4310	500-600
7876	Debris and Ice	32°15’36.4”	77°31’37.5”	4330	600-700
7877	Exposed ice with small debris	32°15’32.6”	77°31’38.5”	4335	100-200
7880	Exposed ice with small debris	32°15’32.3”	77°31’38.7”	4382	20-10
7881	Exposed ice with small debris and crevasses	32°15’25.5”	77°31’34.8”	4390	5 to 10

Fig. 3: Photographs of the field study over the Chhota Shigri glacier.

The backscattering signals in dB scale are plotted against the size of the debris (Figure 4).The regression equations of the correlation are used to detect debris size from SAR backscattering of other glaciers.

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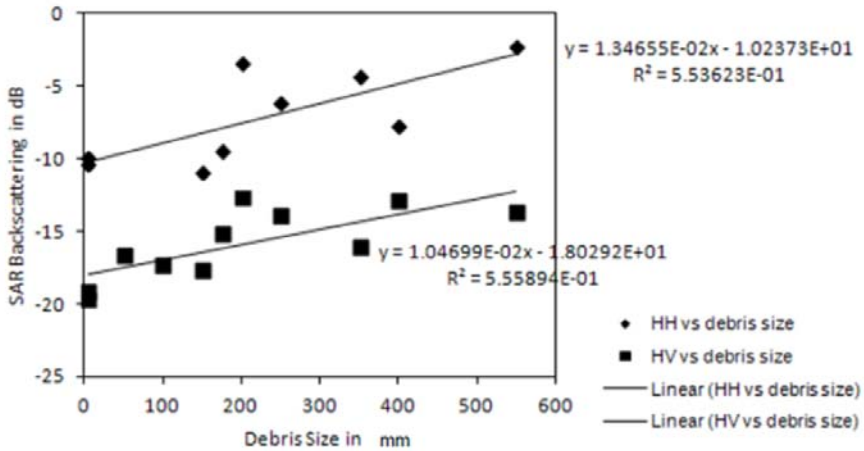

Fig. 4: Relationship between the size of the debris and SAR HH and HV backscattering.

3. RESULTS AND DISCUSSION

The classification results of three glaciers are shown in Figure 5. Concentration of supra-glacial debris over the Chhota Shigri glacier is observed in west flank of the glacier. This is may be due to higher rate of physical weather caused by longer exposure to the solar radiation than right flank.

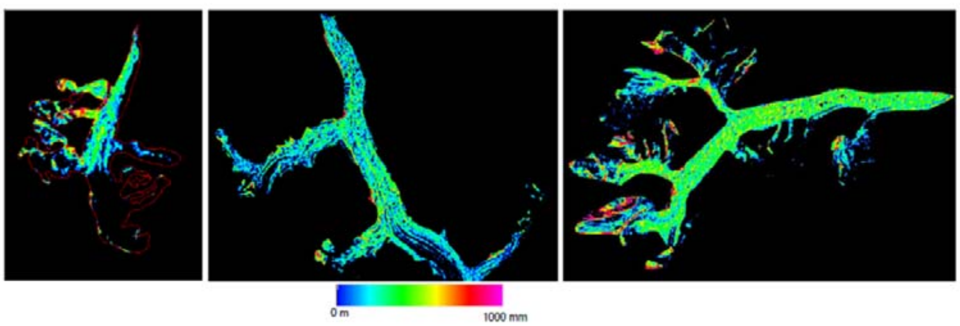

Fig. 5: Classification result of debris size by using the developed model based on the relationship between SAR backscattering and glacial debris size.

Over the Gangotri glacier average debris size is around 100 – 200 mm. The size increases near the confluence with the Ghanohim around 4600 m a.s.l. (above sea level). This may be contributed by the tributary glacier of the Gangotri. The size of the debris sharply falls near 4700 m asl with beginning of exposed ice zone.

The Zemu glacier of the Sikkim Himalaya has extensive supra-glacial cover over the glacial ice. The average debris size is also large, around 300 – 400 mm. Some clusters of the pixels over the ablation region of the Zemu glaciers are classified as zero debris size which are actually supra-glacial lakes over the glacier. The water surface acts as a specular reflector to the radar beam and minimizes backscattering.

The derived sizes of the debris of the Gangotri and Zemu glaciers are checked in high resolution Google Earth images. As the pixel size of the SAR data is 18 m × 18 m, in high resolution optical data similar area is selected to measure debris size. Figure 6 shows a debris covered part of the Gangorti glacier where average debris size is measured around 480 mm. The classification result of the same location is estimated size of the debris as 521 mm. The average deviation from the actual debris size is approximately ± 50 mm.

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Fig. 6: Google earth image of 26th September 2014. The average debris size at the highlighted location is estimated as 480 mm. From the classification output the size is detected as 521 mm.

4. CONCLUSION

Debris cover in the ablation area of most of the Himalayan glaciers acts as an insulator and renders the ablation zone less sensitive to melting [8]. This protects the termini at lower altitudes (below 4000 m) where maintenance of the glacier mass elsewhere in the world is not possible due to unfavourable temperatures [9, 10]. Co and cross polarized SAR data are employed to derived debris size. The average size of debris over ChhotaShigri glacier is 50 – 100 mm. Over the Gangotri glacier it is 100 – 200 mm, however, the Zemu glacier has 300 – 400 mm average debris size. The accuracy of the classification is ± 50 mm. The large size debris over the Zemu glacier protects the glacier ice to some extent during the on-set of melting. However, according to [7], thick debris cover accelerates melting during rainfall events by transferring heat from debris to ice through liquid percolated rain water. To estimate energy balance of the Himalayan glaciers, size of the debris is an important parameter and will help to understand differential mass loss patterns of the glaciers.

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COMPETING INTERESTS

The Authors have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration between both authors. Authors SD and MC designed the study, conducted the survey, performed the statistical analysis. Author SD managed the literature searches and wrote the first draft of the manuscript. Both of the Authors managed the analyses of the study and read to approve the final manuscript.

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