Detection of glacier lakes buried under snow by RISAT-1 SAR in the Himalayan terrain

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Synthetic aperture radar (SAR) signals penetrate through the dry snow and cloud providing crucial data over the Himalayan temperate glaciers and complement the optical images. In the present study, RISAT-1 C band and AWiFS images of winter/ablation period over Samudra Tapu and Gepang Gath moraine dammed lakes (MDLs) in Himachal Pradesh have been analysed. Backscattering coefficient of the lake was observed to be low throughout the year. Penetration depth of SAR into dry snowpack was calculated to vary from 4 to 22 m for a range of snow density (0.1–0.5 g/cm^3), whereas it was estimated to be 1.20–2.01 m based on ground observations for 30 January and 24 February 2013. The present study provides results of RISAT-1 C-band penetration up to ~2 m through the snowpack to detect MDLs in the Himalayan terrain. The detection of MDLs using the backscattering images of winter season was validated with synchronous AWiFS sensor images.

Keywords: Backscattering coefficient, glacier lakes, snow and cloud, synthetic aperature radar.

SNOW/CLOUD blocks the land-cover features in the Himalayan region leading to availability of appropriate satellite data being considerably restricted in the optical region. Active microwave synthetic aperture radar (SAR) sensors at lower frequencies are able to penetrate through the atmosphere and thus become important during cloudy conditions[1,2]. Snow is transparent at microwave wavelengths, and depending on frequency radar penetration depth can reach up to tens of metres under dry snow conditions[3,4]. Backscatter received at SAR antenna is a sum of surface scattering at the air/snow interface, volume scattering within the snowpack, scattering at the snow/soil interface and volumetric scattering from the underlying surface[5]. SAR data have provided useful information over the complex glaciated terrain; however, not much information is available for understanding glacier signature in the Himalayan region[6,7]. ERS-1 data were studied over five lakes in Northern Montana region to understand the different processes of frozen lake and break-up date over a decade-scale time-frame[8]. TerraSAR-X and Radarsat-2 SAR data were successfully used to map and monitor glacial lake detection during snow- and ice-free seasons, emphasizing a need for integrated multi-level approach[9]. Lakes at high altitude fluctuate seasonally due to change in melt rate during accumulation and ablation period. The accessibility of these lakes is restricted in the optical spectrum due to the cloud cover in ablation period and snow cover in the accumulation period.

RISAT-1 C band SAR sensor carries multi-mode SAR system at different resolution and swath, and has enhanced the imaging capacity in the microwave region along with other existing satellite systems[10,11]. The present communication presents a case study of the use of winter-time RISAT-1 SAR MRS data to detect snow-buried glacial lakes using multi-temporal images covering Samudra Tapu and Gepang Gath Moraine dammed lakes (MDLs) in Chandra sub-basin, Lahaul and Spiti region, Himachal Pradesh, supported by synchronous AWiFS optical data.

Figure 1 shows the location of the MDLs of Samudra Tapu and Gepang Gath glaciers. Field photograph (Figure 1) shows the extension of Samudra Tapu lake and associated geomorphological features. Samudra Tapu is the second largest glacier in the Chandra sub-basin. The snout of the glacier is located at 32°30′N lat. and 77°32′E long., at an altitude of 4200 m amsl from MSL and about 10 km SW of the famous Chandra Tal Lake[12]. Gepang Gath is a debris covered glacier with an area of 13.1 sq. km, located at 32°31′N lat. and 77°14′E long. and at an altitude of 4300 m amsl from MSL.

In the present study, RISAT-1 MRS data from winter period (January–February 2013) and ablation period (June–November 2013) have been used. Table 1 provides the technical specifications of RISAT-1 MRS. The synchronous optical AWiFS data were used to validate the existing conditions during SAR data acquisition dates. ERDAS Image processing software has been used to process the RISAT-1 and AWiFS data. Digital number (DN) of RISAT-1 MRS mode was converted into backscattering coefficient for each pixel using meta data. Equation (1) is used to estimate the backscattering coefficient (σ_0) as given below:

$$\sigma_0 = 20\log_{10}(\mathrm{DN}_p) - K_{\mathrm{db}} + 10\log_{10}\left(\frac{\sigma \sin I_p}{\sin I_{\mathrm{centre}}}\right), \qquad (1)$$

where I_p is the incidence angle at the pth pixel, I_{centre} the incidence angle at the centre of the scene, K_{db} is the absolute calibration constant and DN is the average pixel intensity. Area of interest (AOI) of backscattering coefficients data over MDL was extracted using the aoi tool. Average σ_0 was calculated over the lake region for temporal RISAT-1 MRS data. Snowfall takes place due to the NW disturbances and the region remains under sub-zero temperature conditions during February in Chandra basin. Snow remains dry in nature, which is a mixture of air and ice crystals causing volume scattering losses more

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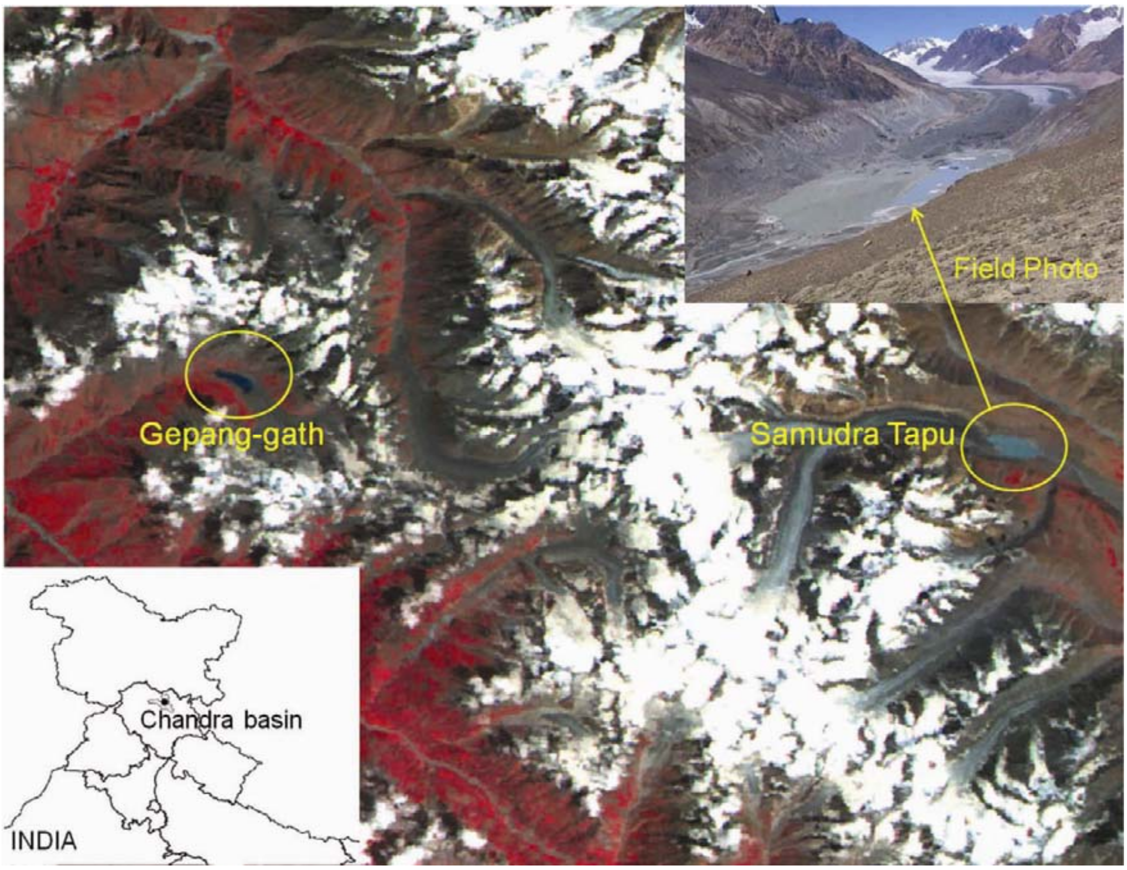

Figure 1. Location map and optical image (AWiFS FCC) during ablation period of Samudra Tapu and Gepang Gath glaciers in Chandra sub-basin, a part of the Chenab basin. Moraine dammed lakes (MDLs) are marked by yellow circle. Field photograph (September) of Samudra Tapu is also shown.

Table 1. Sensor characteristics of RISAT-1 MRS data

Sensor specifications	RISAT-1 (MRS)
Frequency	C (5.350 GHz)
Resolution (m)	25 × 25
Swath (km)	115
Sensitivity (σ^0 in dB)	–17.0
Polarization	Dual

prominent during SAR interaction. Depth of penetration of SAR signal depends on the relative permittivity of dry snow, which further depends on snow density. Snow density for dry snow generally varies from 0.1 to 0.5 g/cm[3]. Imaginary part of dielectric constant of ice (ε_i'') is taken as 0.01 to compute penetration depth at different microwave frequencies[13]. The depth of penetration (δ_p) in snow (a lossless medium) is computed using eq. (2) as given below[3]

$$\delta_p = \frac{\lambda\sqrt{\varepsilon'}}{2\pi\varepsilon''}, \quad (2)$$

where λ is the wavelength, and ε' and ε'' are the real and imaginary components of the dielectric constant of dry snow.

Figure 2 shows that how the land-cover information is completely opaque in AWiFS data due to cloud cover, which is a common phenomenon in the Himalayan terrain, and is clearly visible in RISAT-1 SAR data for the same day (12 September 2013). Red circles show the location of Samudra Tapu and Gepang Gath MDLs in the Chandra sub-basin. This region experiences heavy snowfall during winter and the whole area is buried under thick snowpack. The snow starts melting as one moves towards the ablation period and glacier features attain a state of minimum snow cover. During this period, snow deposited on the lake is completely melted and the lake is fully exposed. Figures 3 and 4 show the synchronous capture of RISAT-1 and AWiFS images over Samudra Tapu and Gepang Gath MDLs. It can be observed that the lakes are completely snow-covered on 3 and 5 January, 30 January and 24 February 2013 and not visible in AWiFS. However, they are completely visible on RISAT-1 images of same dates, which demonstrates the penetration capability of RISAT-1 C-band through thick snow cover and its ability to retrieve the buried lake signature. The lake starts melting as summer approaches, which is visible in Figure 3 on 8 and 30 June 2013. AWiFS image shows distinct signature of melted water on 7 October 2013

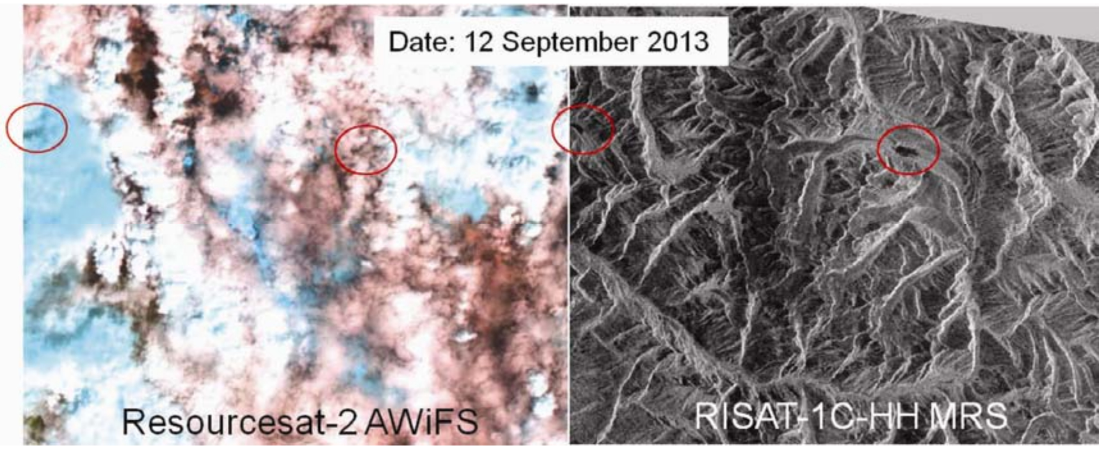

Figure 2. Satellite data of 12 September 2013 shows that the land cover features on the ground are not visible in AWiFS optical data due to presence of cloud, whereas RISAT-1 C band is able to provide unaffected observation of the glaciated terrain. Red circle shows the location of Samudra Tapu and Gepang Gath MDLs.

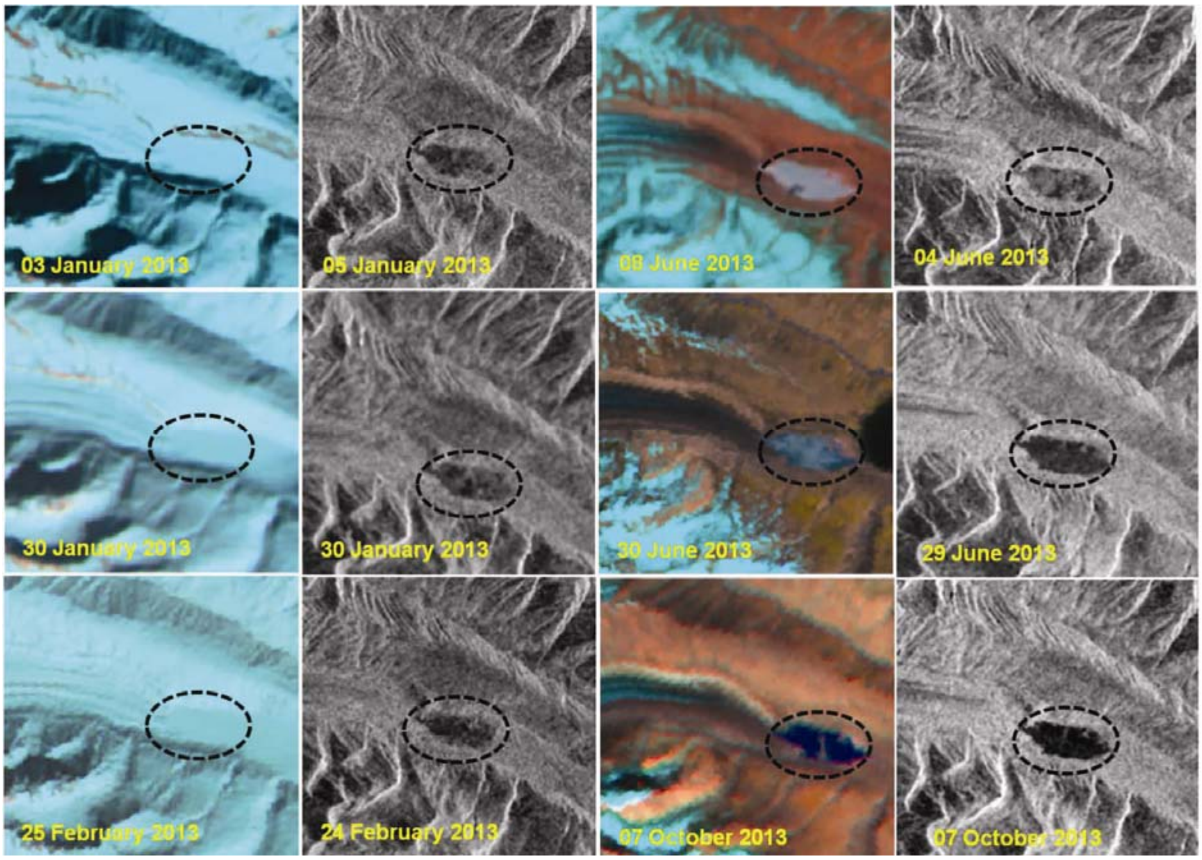

Figure 3. Synchronous RISAT-1 and AWiFS data over Samudra Tapu MDL. AWiFS shows that MDL is completely covered with snow during winter, whereas RISAT-1 is able to penetrate and detect the presence of MDL buried under snow. MDL is shown in both the datasets as black dotted circles.

(Figure 3). In November, fresh snowfall again took place covering lake with snowpack. Figure 4 shows another example of the presence of the Gepang Gath MDL buried under snow. These observations show the results of RISAT-1 SAR data penetration to detect the signature of buried lakes and validated using optical datasets. Samudra Tapu MDL shows low backscattering coefficient throughout the year (-15.16 ± 3.5 on average). Penetration depth was computed for dry snowpack for varying densities (0.1–0.50 g/cm^3) at various microwave

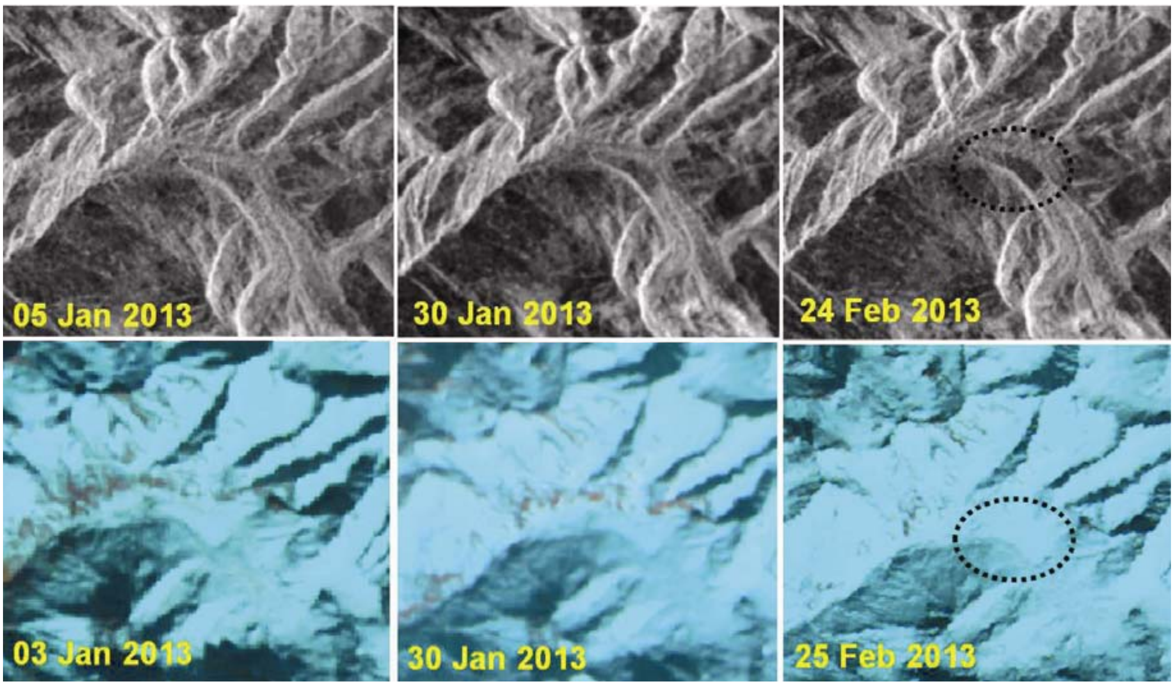

Figure 4. Another example of lake penetration using synchronous RISAT-1 and AWiFS data over Gepang Gath MDL. It can be seen that MDL is completely covered with snow during winter. RISAT-1 is able to penetrate and detect the presence of MDL shown in both the datasets as black dotted circles.

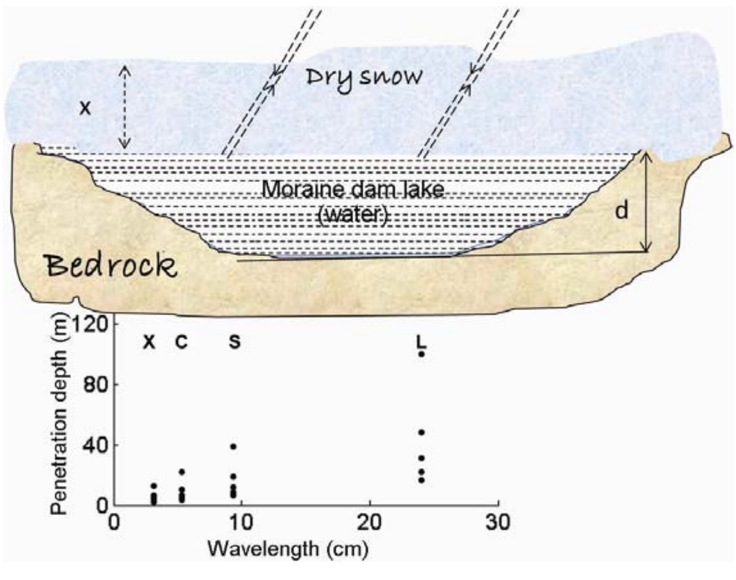

Figure 5. Penetration depth in dry snow for varying values of dielectric constant (for density range 0.1–0.5 g/cm^3) at typical spaceborne SAR sensors frequencies. Schematic diagram shows the thick snowpack over MDL during accumulation month.

frequencies such as X, C, S and L. Figure 5 is a schematic diagram of snow deposited on the lake and modelled penetration depth for dry snow. It shows that the penetration depth over snow increases as we move towards lower microwave frequencies. This penetration will allow the SAR signal to interact with MDL at the base of snow-covered surface. Penetration depth is observed to vary from 4 to 22 m for 0.1–0.5 g/cm^3 snow density at the C band. These observations were further linked with field snow thickness obtained using airborne GPR survey data made available by SASE, Chandigarh in that region. Airborne GPR survey conducted during March 2009 and 2010 over Samudra Tapu glacier region has shown snow accumulation of 1.47 and 1.68 m respectively. The standing snow was further correlated using nearest Patseo observatory data for 30 January and 25

February 2013 with an estimated snow thickness of 1.20 and 2.01 m respectively (A. Ganju, pers. commun), which matches with the modelled thickness.

The present analysis shows that RISAT-1 C-band has the capacity to penetrate the thick accumulated snowpack and is able to detect the buried lake signature in the Himalayan region. This study emphasizes the advantage of RISAT-1 SAR data over optical data, which have limited window period due to the presence of snow and cloud for monitoring the expansion of high-altitude lakes in the Himalayan region.

This study provides the results of detecting the signature of MDLs buried under snowpack using RISAT-1 C band SAR data in the Himalayan region, validated using AWiFS optical images. RISAT-1 SAR was able to detect MDLs throughout the year irrespective of snow and cloudy conditions, with Samudra Tapu MDL showing low backscattering coefficient throughout the year (–15.16 ± 3.5 on average). Snowpack thickness over Samudra Tapu MDL was reported around 1.20–2.01 m on ground, which was modelled to vary from 4 to 22 m for dry snow at RISAT-1 C-band. This analysis shows the potential of RISAT-1 data to detect buried lakes under snow, and opens up avenues for other related applications in the Himalayan region such as disasters, fluctuations in lake area during freeze/melt conditions, melt onset of snow cover and enhanced topography due to slant viewing geometry of SAR.

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ACKNOWLEDGEMENTS. We thank A. S. Kiran Kumar, Director, SAC, Ahmedabad for his guidance and encouragement during the present study. We also thank A. Ganju, Director, SASE, Chandigarh for providing information on snow thickness of the region.

Received 16 December 2014; revised accepted 16 July 2015

doi: 10.18520/v109/i9/1735-1739