Using dual-band SAR imagery for characterizing and mapping of volcanic flows through their backscattering properties

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Abstract

The new dual-frequency radar satellite ASAR-ISRO provide simultaneously and for the first time a wide wavelength spectrum which is critical to discriminate surface roughness based on different backscattering characteristics. Here we use such dual L-band and S-band airborne SAR system to characterize and map various volcanic areas in the Northern Cascades through their backscattering properties. Mapping volcanic flows (lava flows, pyroclastic currents, lahars) is vastly improved by using backscattering as a metric of surface roughness. Various types of volcanic flow deposits and surface textures are distinguished by their roughness measured with radar systems. The ability of radar systems to distinguish volcanic flow textures, represented by roughness, is a key factor in understanding the processes and timescales of flow emplacement. For instance, transition from pahoehoe to aa lava flows is associated with change in flux and steepness of topographic gradient. Therefore, lava textures are essential data for calibrating and improving lava flow emplacement codes. Similarly, the textures of high velocity, and more deadly, pyroclastic currents and lahars change along their flow paths, also revealing critical data about the mechanisms of flow emplacement. As with lava flows, we use the ASAR-ISRO L+S SAR system to characterize the run-out distances of pyroclastic currents and lahars where large numbers of blocks accumulate in such deposits (places where flow momentum was lost, whether due to friction or break-in-slope and vast quantities of blocks accumulate in a relatively small area compared to the total area inundated by the flow). Mapping volcanic flow textures in a variety of volcanic terrains will provide clues about modes and rates of emplacement, and change in these through time, in a way that is simply unavailable by traditional geologic mapping. The next generation of volcanic flow maps, used for hazard assessment, will rely on radar data to delineate these textures.

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Using dual-band SAR imagery for characterizing and mapping of volcanic flows through their backscattering properties

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1. Introduction

Although, none of the spaceborne sensors to date were designed specifically just to observe and monitor volcanic eruptions, some of the sensors available today can accurately and timely record crucial data pre-, syn- and post-volcanic crises, to support operational efforts on the ground. Airborne radar, dual-band backscatter approach, presented here, has the potential of providing useful information improving identification of different volcanic deposits, such as debris avalanches and lahars, using roughness (derived from backscatter signals) as an indicator.

Volcanic mass flows, including lava flows, debris avalanches, lahars and pyroclastic currents, have been historically responsible for most fatalities during volcanic eruptions. Hazard maps depict areas that could be affected by different types of flows, by considering the high hazard areas from previous events record, coupled with an up-to-date digital topography of the target area.

The radar dual-band approach explored here may not only be useful for identification purposes and volcanic hazard assessment, but if used as time series, it can be further applied to highlight temporal structures that would allow us to distinguish between long-term processes (e.g., erosion and compaction) and abrupt changes that correlate to specific volcanic events (e.g., lahars, debris avalanches).

2. Method

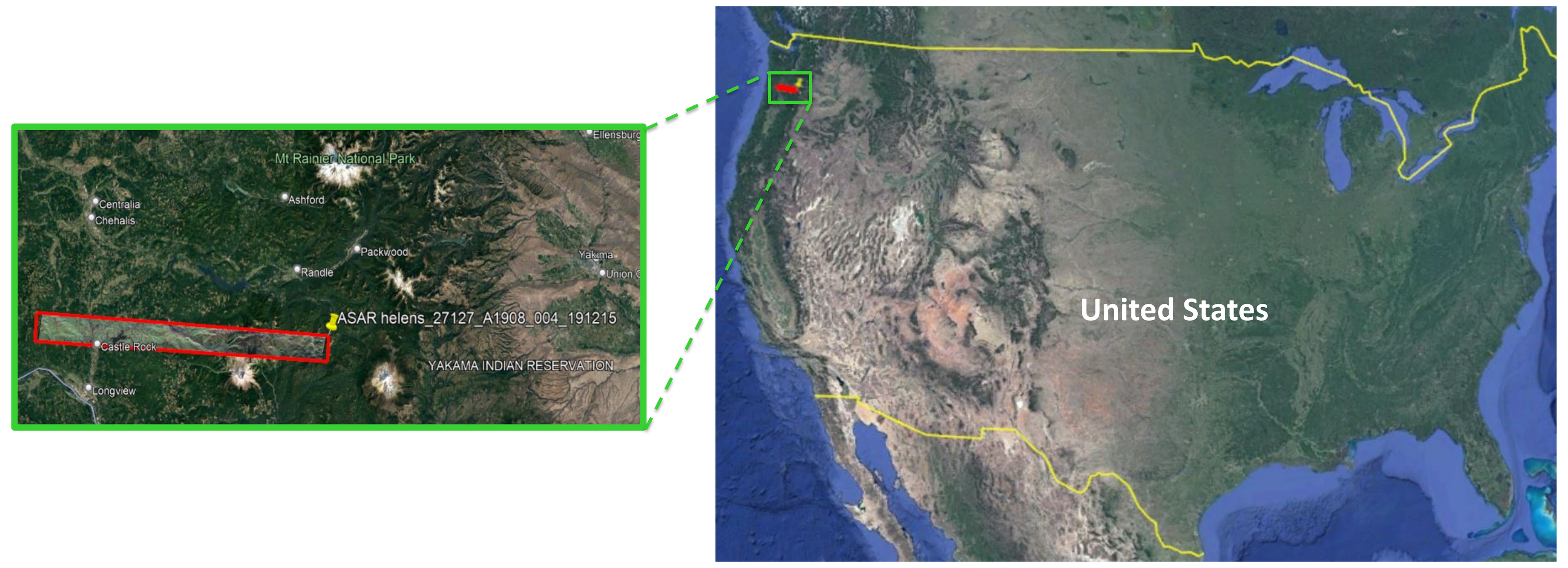

Figure 1. Approximate location of ASAR-ISRO dataset analyzed in this study (ID27127) over Mt St Helens (WA) in Northern Cascades (U.S.), shown on Google Earth. The approximate dimensions of the study area (red strip) are 110 km x 10 km. The exact coordinates of the study area are shown in Figure 2.

The motivation for this study is to assess the role of dual-band approach in the determination of backscatter obtained from spaceborne radar data and relating it to the terrain roughness. To achieve this, we use Airborne SAR (ASAR) and Indian Space Research Organization (ISRO) 2-m spatial resolution dataset ID27127 (part-of-three), acquired on 15 December 2019, released by National Aeronautics and Space Administration (NASA) in July 2020.

The new dual-frequency radar data is a part of NASA's ongoing ASAR-ISRO project, which provides simultaneously, and for the first time, a wide wavelength spectrum results at 2-m spatial resolution. Both wavelength range and high-spatial resolution are critical to discriminate surface roughness and topography based on different backscattering characteristics.

This approach exploits the ASAR-ISRO dual-band (L-band and S-band, 24 cm and 9 cm wavelength respectively) system to characterize and map various volcanic products, using their backscattering properties. The target area was a region over Mount St Helens (WA) in the Northern Cascades (Fig.1).

Mapping volcanic flows (e.g., lava flows, pyroclastic currents, lahars) can be vastly improved by using backscattering as a metric of surface roughness. Various types of volcanic flow deposits and surface textures are distinguished by their roughness measured with radar systems.

The ability of radar systems to distinguish volcanic flow textures, represented by roughness, derived from backscatter is a key factor in understanding flow emplacement processes and timescales.

3. Results –Backscatter Maps

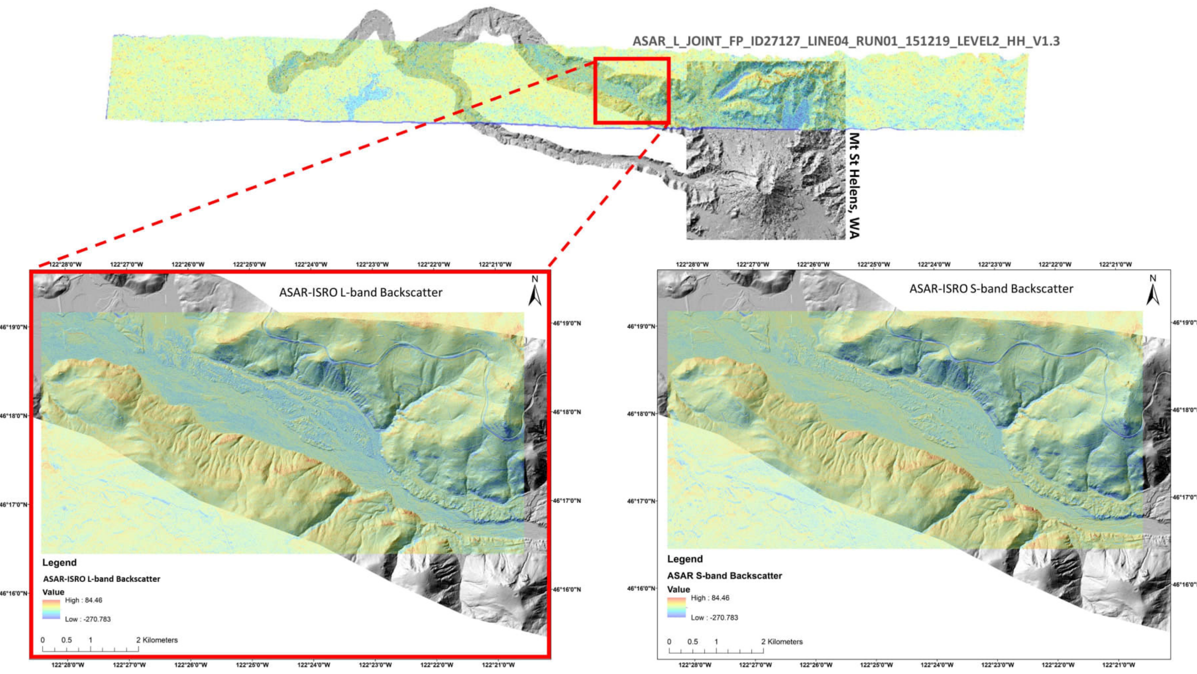

Figure 2. Displays the areal extent of the study area **(top)**, over Mt St Helens (WA), superimposed on a 3-m Lidar data DEM (USGS). **Inset** shows zoomed view of ASAR-ISRO backscatter map in L-band **(bottom left)** and S-band **(bottom right)** of the same target area, chosen for a dual-band data comparison (Figs. 3-6).

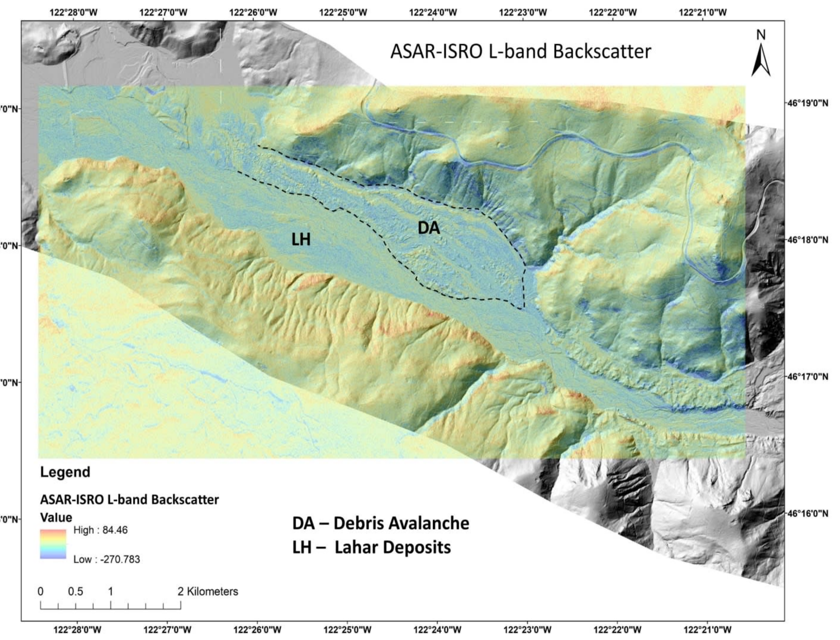

Figure 3. ASAR-ISRO L-band Backscatter map (24 cm wavelength) in HH polarization, acquired on 15 December 2019, superimposed on a 3-m Lidar DEM of Mt St Helens (USGS).

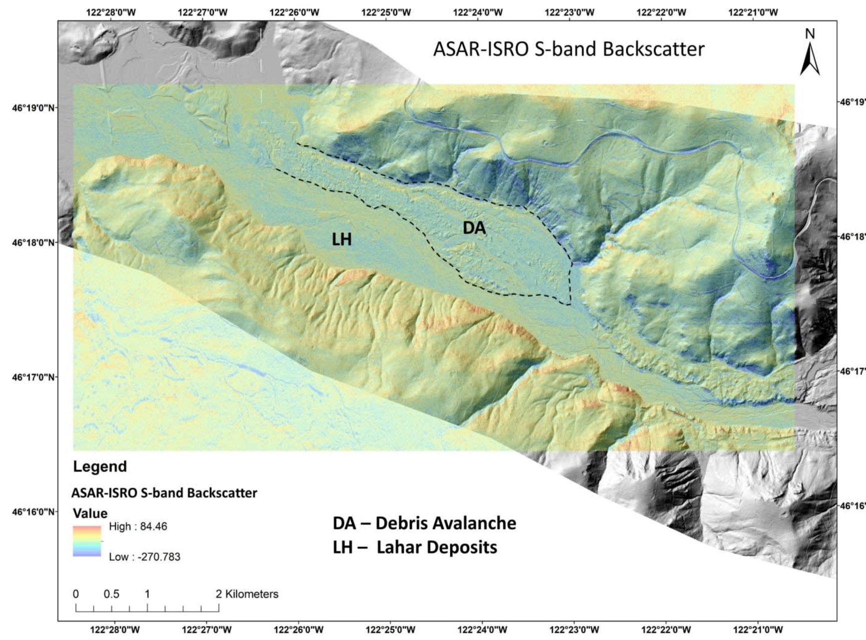

Figure 4. ASAR-ISRO S-band Backscatter map (9 cm wavelength) in HH polarization, acquired on 15 December 2019, superimposed on a 3-m Lidar DEM od Mt St Helens (USGS).

We produced full resolution (georeferenced and terrain corrected) backscatter images for both ASAR-ISRO L-band and S-band (Figs. 2-4). For radar images of non-vegetated soils, the amplitude of the radar signal depends on several factors, including (i) surface roughness, (ii) soil moisture, (iii) incidence angle, (iv) radar wavelength, and (v) polarization of the radar signal.

Here we use the ASAR-ISRO L & S-band system to characterize the extent (footprint) of Debris Avalanche (DA) and Lahar deposits (LH).

ASAR-ISRO L-band data here evidently displays substantially larger backscatter variation (Fig. 3) than the S-band (Fig. 4). This variation is prominent in the valley DA area, where hummocks (large scale, poorer sorting) show low backscatter values (dark blue) within the DA area. Conversely, LH area (fine-grained, better sorting) displays higher backscatter values in the valley (light blue to green), while vegetation displays highest backscatter values (red). This is most evident at the southern riverbank, higher ground areas, bordering LH deposits (Figs. 2-4).

Since radar Amplitude depends on radar wavelength, S-band would display higher backscatter values due to a smaller wavelength (9 cm) compared the L-band (24 cm). Additionally, presence of water and/or snow would affect backscattering results. According to NOAA databases, there was no snow presence in the region of our study area (Mt St Helens, WA) on 15 December 2019, therefore results were not affected by the snow factor (i.e., S-band not being able to penetrate through the snow as deep as L-band).

4 Results – Roughness Maps

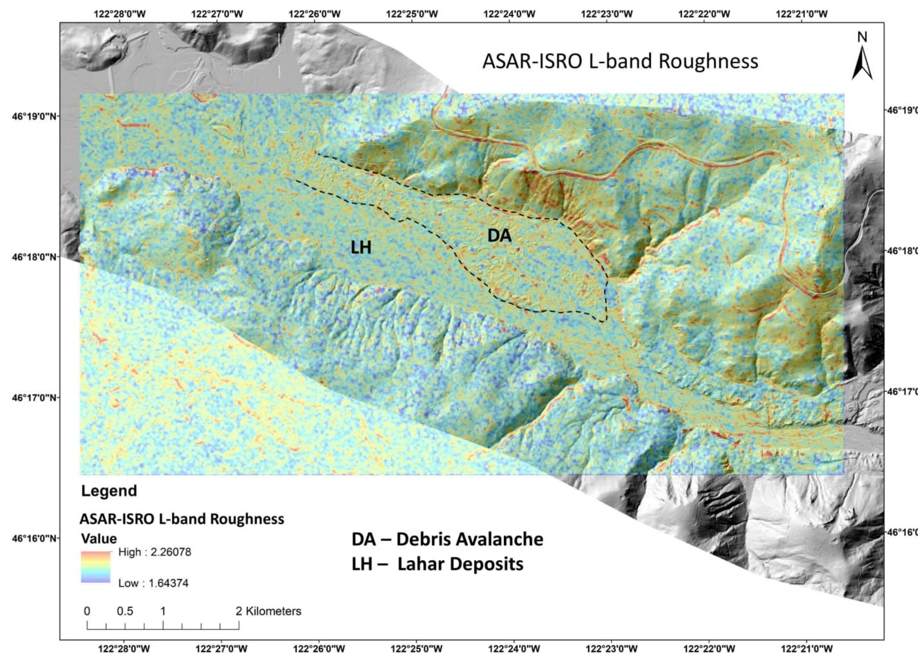

Figure 5. ASAR-ISRO L-band Roughness map (derived from backscatter), superimposed on a 3-m Lidar DEM of Mt St Helens (USGS).

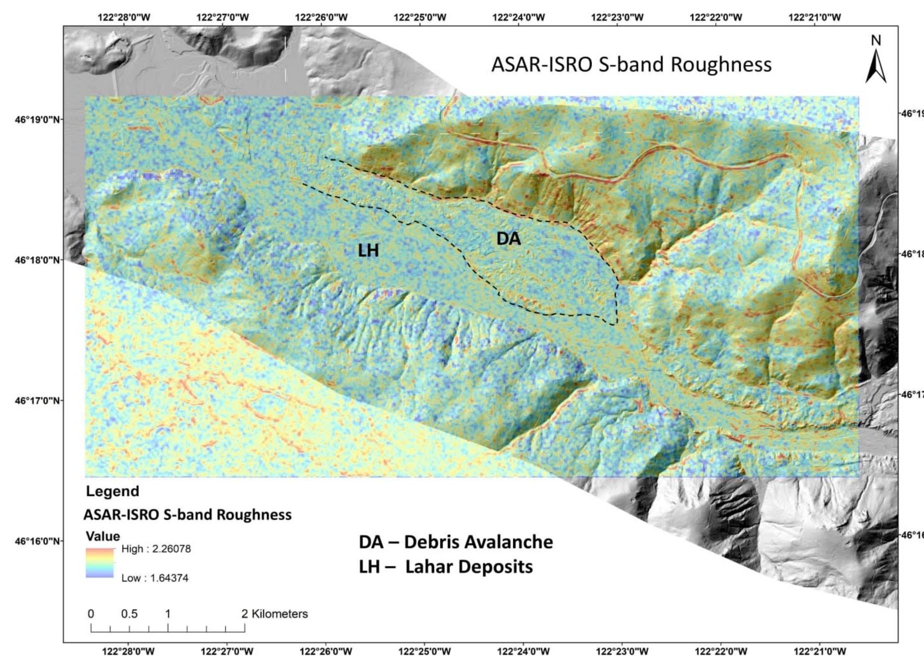

Figure 6. ASAR-ISRO S-band Roughness map (derived from backscatter), superimposed on a 3-m Lidar DEM of Mt St Helens (USGS).

The ASAR-ISRO roughness maps were created using log-scale standard deviation of the backscatter signal (20 x 20-pixel window), where the rough terrain is displayed in red and smooth terrain in blue.

On the ASAR-ISRO L-band Roughness map, the roughest terrain visible is the northern riverbank, above the DA deposits. Within the DA deposits in L-band (Fig. 5), lahar channels are visible, cutting through the debris avalanche deposits (red), in turn making the originally rough terrain smoother, with lower roughness values (blue). We would expect a fresh debris avalanche deposits to have only high roughness values (red and yellow) within DA outline (black shape line). Therefore, it can be argued that these DA deposits are not fresh, but instead, they have been reworked and affected by processes occurring after the initial DA emplacement.

Lahar deposits area shown in L-band appear to be smoother (lower roughness). The same is true for the vegetated terrain bordering the LH area at the southern riverbank. The S-band seems to be less sensitive to the change of deposits (i.e., lahar and debris avalanche) than the L-band.

The L-band roughness map clearly indicates higher roughness values for debris avalanche deposits (Fig. 5). Since hummocks in DA deposits are of large scale, they are imaged better by a longer wavelength (i.e., L-band) as opposed to the shorter wavelength (i.e., S-band), which is better at distinguishing between the vegetated and non-vegetated terrains.

5. Conclusion

ASAR-ISRO L & S-band system can characterize the extent (footprint) of Debris Avalanche (DA) and Lahar deposits (LH), through the backscattering properties and terrain roughness. The S-band seems to be less sensitive to the change of deposits (i.e., lahar to the debris avalanche), than the L-band.

The L-band can effectively differentiate larger scale structures (e.g., debris avalanche deposits) from fine-grained deposits (e.g., lahar deposits)(Figs. 3 & 5), whereas the S-band is capable of distinguishing between vegetated and non-vegetated terrains (Figs. 4 & 6). Using the dual-band roughness method (derived from backscatter) allows for better identification of the flow boundaries.

Mapping volcanic flow textures in a variety of volcanic terrains will provide clues about modes and rates of emplacement, and change through time, in a way that is unavailable by traditional geologic mapping approaches. The next generation pf volcanic flow maps will rely on radar data to delineate these textures.

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