RETRIEVING SUBSURFACE PROPERTIES OF MARS-ANALOG GLACIERS WITH DRONE-BASED GPR

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Introduction: The Shallow Radar (SHARAD, 15-25 MHz) sounder onboard the Mars Reconnaissance Orbiter has confirmed that the bulk composition of debris-covered glaciers (DCGs) at the mid-latitudes of Mars is nearly water ice [1]. However, SHARAD has only detected a few internal internal debris layers and cannot provide information about the supraglacial debris thickness. The former can help elucidate glacier evolution and paleoclimate [2]. The latter is also critical for in situ resource utilization (ISRU) of water in future landed missions to Mars [3].

Studies with ground penetrating radar (GPR) over terrestrial analogs have provided insights into the processes controlling the formation and evolution of Martian DCGs [4-6]. This geophysical method penetrates through the debris layer on the surface, allowing for the quantification of the debris thickness, total glacier thickness, ice purity, and the presence of englacial bands. Traditional surface-based GPR has a high signal-to-noise ratio (SNR), but it can be a time-consuming and hazardous manual task, since it involves walking on rough and steep surfaces, with some slopes being inaccessible.

To overcome these limitations, we integrated a drone-based GPR (DGPR) that consists of a MALA Geodrone 80 GPR system mounted on a DJI Matrice 600 Pro, with a UgCS SkyHub system for automated terrain following. This is a novel approach that hasn't been tested on DCGs but showcased effective outcomes on alpine glaciers [7]. We tested our DGPR at two DCGs: Sourdough, Alaska in July 2022, and Galena Creek, Wyoming in August 2022 and August 2023. At these two sites, we have surface-based GPR data at different center frequencies (50 MHz, 100 MHz, and 200 MHz), allowing for analyses over a range of vertical resolutions. The goal of this study is to explore the capabilities of a drone radar for retrieving the subsurface properties of Mars-analog glaciers, evaluating the potential of such platforms for future missions to Mars.

Methodology: The MALA Geodrone 80 GPR has dipole antennas with an impulse centered at 80 MHz and approximately 40 MHz bandwidth (Fig. 1). To maintain a constant speed and altitude over an uneven surface, we use a UgCS SkyHub terrain-following system consisting of an altimeter and a distance sensor for obstacle avoidance.

Figure 1: Drone GPR operations at Galena Creek, Wyoming, location marked with a red star in Fig. 3. The GPR MALA Geodrone 80 (white box) is mounted on the DJI M600 Pro drone. The length of the antennas is 1.04 m, with a separation of 0.5 m.

The GPR antennas should be as close to the ground as possible to maximize the SNR. We have conducted tests starting at 1.5 m above the ground; however, due to the roughness of the terrain, steep slopes, and the presence of large boulders, most of the surveys have been performed at altitudes between 2 and 3 m to reduce the risk of collision. These surveys were flown at a speed of 1 m/s with an along-track sampling rate of 0.25 - 0.1 s.

We have developed a methodology for direct comparison with the surface-based GPR data from Sensors & Software PulseEkko. First, we apply a background subtraction with a sliding mean fast Fourier transform function to remove the background noise caused by the drone and the GPR itself. Then, we use radar processing software to manually pick the ground surface, the debris-ice interface, the englacial layers, and the basal unit (Fig. 2). Finally, to convert the one-way travel time into depth, we use the electromagnetic wave speed obtained from existing common midpoint (CMP) surveys [4, 5].

Results: In the lower section of Sourdough, we detected with the DGPR a debris thickness of up to 2 m, and a total glacier thickness of between 15 and 22 m towards the terminus of the glacier. In the cirque of Galena Creek, we conducted drone surveys where englacial debris bands had been identified with surface-based GPR [4, 6]. The DGPR partially detected the englacial debris layers (Fig. 3), the reason can include flight orientation, destructive interference, vertical resolution, refraction effects at the surface, and/or power reflected [8].

Conclusions: We successfully employed a DGPR platform to survey terrestrial DCGs, resolving debris-ice contacts, internal glacier stratigraphy, and total glacial thickness. Moreover, this system can detect these interfaces over larger areas, with higher coverage density, and in less time than surface-based GPR. The DGPR platform and our results over Martian analog ISRU targets demonstrate the potential for drone-based planetary exploration with radar sounding.

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References: [1] Holt, J. W. et al. (2008) Science, vol. 322. [2] Butcher, F. E. G. et al. (2023) Icarus, p. 115717. [3] Baker, D. M. H. and Carter L. M., Icarus, vol. 319. [4] Petersen, E. I. et al. (2020) J. Glaciol. [5] Meng, T. M. et al. (2023) Remote Sensing 15, 4779. [6] Meng T. M. (2025) JGR Earth.[7] Rouls B. et al. (2023) J. of Glaciol. [8] Aguilar R.. J. et al. (in prep).

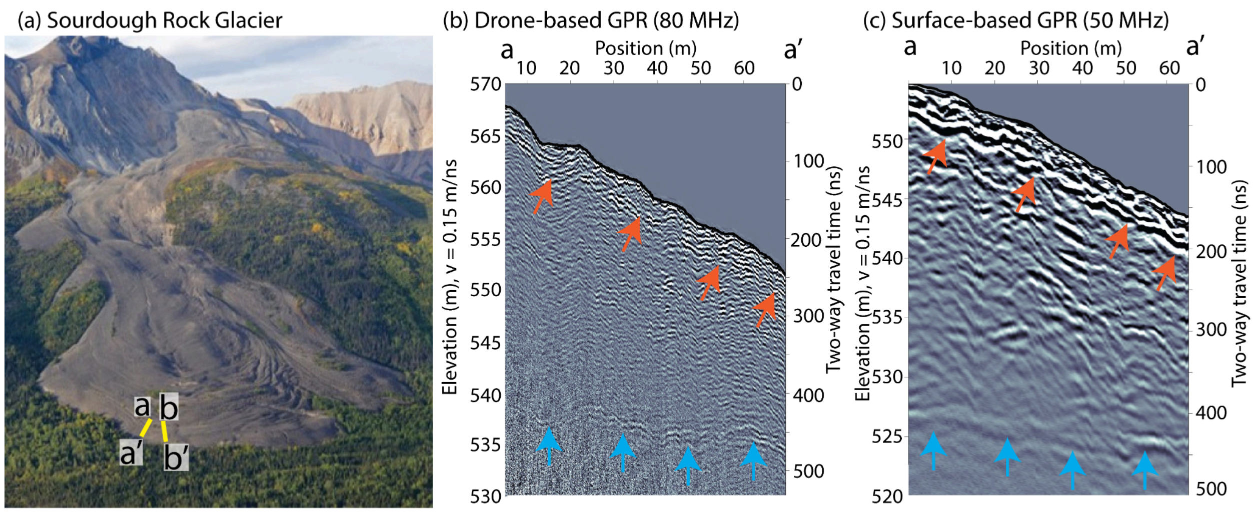

Figure 2: Sourdough Rock Glacier. Oblique photo is shown in panel **a**, the ground tracks of panels b and c are indicated with yellow lines. Radar profiles with detection of debris/ice interface (orange) and basal layer (blue) acquired with done GPR at 80 MHz and surface-based GPR at 50 MHz as shown in panels **b** and **c**, respectively.

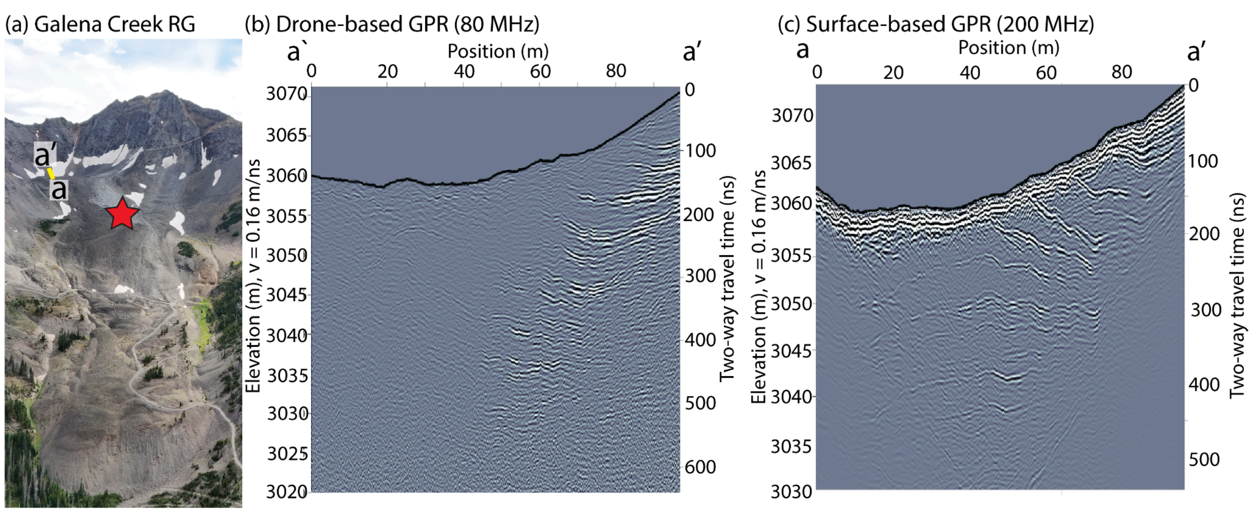

Figure 3: Galena Creek Rock Glacier. Oblique photo is shown in panel **a**, the ground tracks of panels b and c are indicated with yellow lines and the location of Fig. 1 with a red star. Radar profiles of englacial debris layers acquired with drone GPR at 80 MHz and surface-based GPR at 50 MHz as shown in panels b and c, respectively.