Advancing ISRU Through Terrestrial Ice Resource Modeling: A Case Study from Galena Creek Rock Glacier

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Introduction

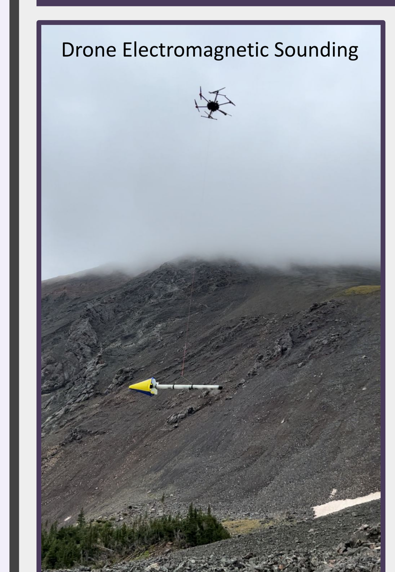
Under the NASA SSERVI Resource Exploration and Science of OUR Cosmic Environment (RESOURCE) Project, we conducted geophysical sounding experiments in the Absaroka Mountains of Wyoming to support planetary in situ resource utilization (ISRU). The Galena Creek Rock Glacier serves as an analog to buried ices on planetary bodies such as the Moon, Mars, and other airless bodies in the Solar System. Using results from the field work, we model the volume of minable ice in order to assess the feasibility of further exploration and extraction.

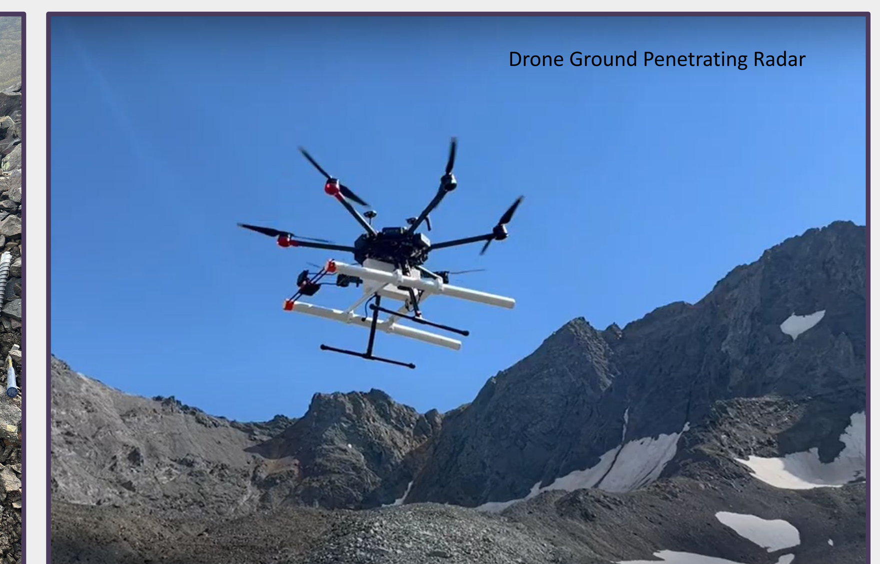
Galena Creek Rock Glacier (Right)

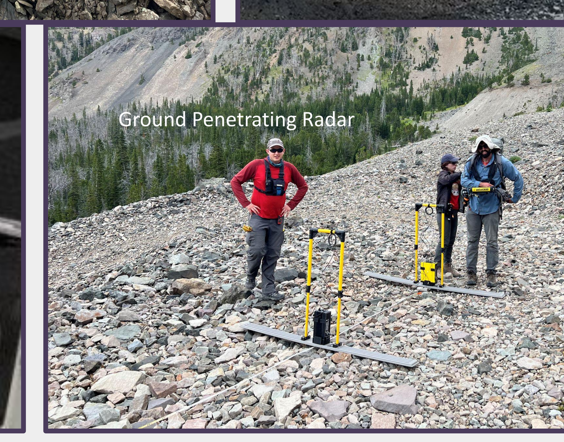
Galena Creek Rock Glacier is an ice-cored rock glacier (i.e., debris-covered glacier) located in the Absaroka Mountains, Wyoming [1] at 44.641° N, 109.791° W. About two thirds of the landform is composed of high purity glacial ice buried under 1-1.5 m of debris at the higher elevations, while the lower third is composed of lower purity interstitial ice underneath a debris layer 2-5 m thick [2-3]. We chose this site for our field efforts because (1) it is generally well characterized in terms of ice purity and depth to ice, (2) it offers a range of depth-to-ice and ice-purity scenarios to test, and (3) this work will additionally contribute to our understanding of the age, history, and health of the glacier.

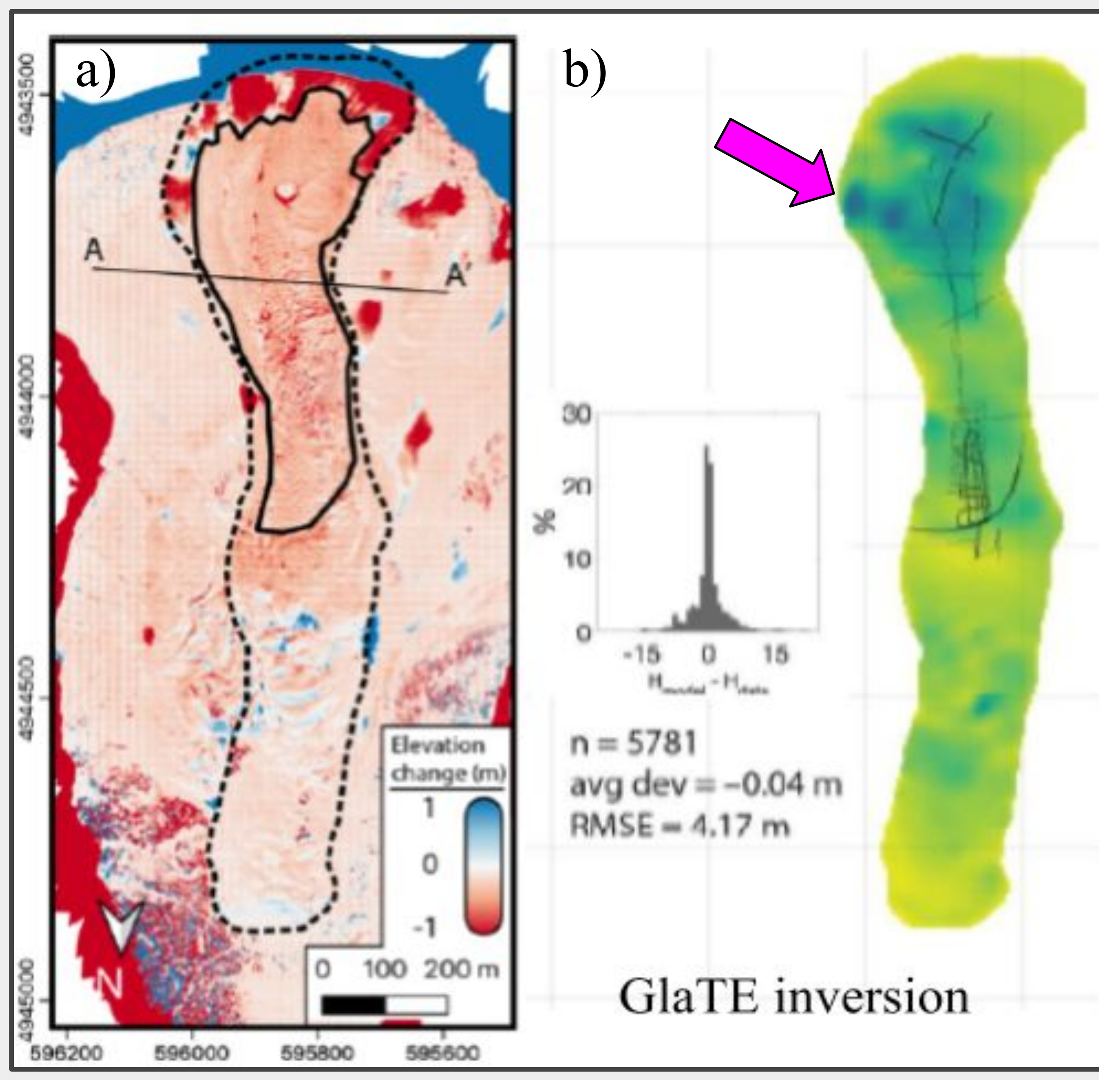
Methods

We deployed a broad suite of non-invasive geophysical techniques **(below)** at the ground surface and on drone-mounted operations, and we also tested shallow drilling technologies. Methods included both hand- and drone-operated ground penetrating radar (GPR), hand- and drone-operated electromagnetic sounding, hand- and drone-operated drilling, and passive seismic sounding. We ingested the resulting datasets into the block modeling software Leapfrog Geo to interpolate the volume of ice and overburden within a resource extraction framework. We assumed 5 m × 5 m × 5 m blocks and a uniform 5 m-thick mix of debris and glacial ice as the overburden.



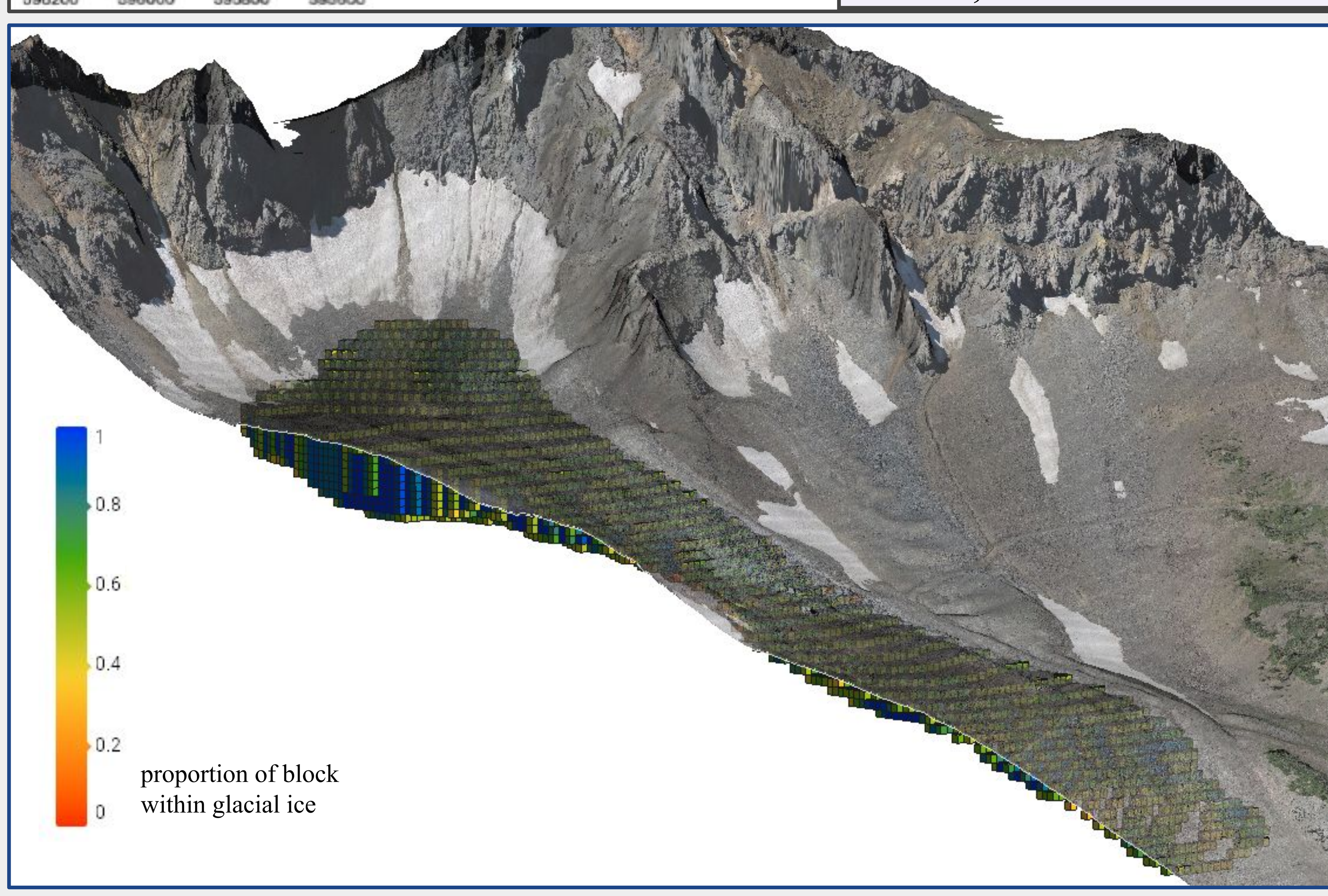






Results

Surface elevation change data [4] from August 2020/August 2022 UAS DEM pairs **(left a)** was also ingested into our block modeling software. The dashed line is the extended rock glacier. The solid line indicates areas of high ablation, increased GPR data density, and our selected extent of the block model. The glacier thickness estimate (GlaTE) method **(left b)**, adapted from [5], tended to overestimate ice thickness in regions characterized by low surface velocity, likely corresponding to stagnant or non-glacial surfaces, and where supporting GPR data were sparse or absent. A snow field **(arrow)**, was the cause of the largest overestimation, accounting for ~ 15% of the total estimated volume of the extended rock glacier. These overestimations could be corrected through targeted ground-truthing on Earth, but such validation would be infeasible on the Moon or Mars. Glacial ice volume estimates for the extended rock glacier extent, and our selected extent are ~ 4×10^6 and 2×10^6 tons, respectively.



Discussion

Each geophysical method employed during the campaign had distinct limitations in terms of resolution, signal reliability, and operational constraints.Ground-based GPR performed reliably in mid- and upper-glacier zones, especially where debris thickness was minimal. However, near-surface scattering in highly heterogeneous debris limited its effectiveness in lower glacier zones. UAV-borne GPR offered rapid coverage over challenging terrain but exhibited reduced vertical resolution and was more sensitive to variations in altitude and surface roughness. Both ground- and UAV-based electromagnetic (EM) methods were constrained by the high resistivity of the debris layer, which led to weak signal returns. Additionally, UAV-EM data were heavily influenced by variations in altitude above ground, making it difficult to isolate changes in subsurface properties. Despite these challenges, we demonstrated that a UAV-EM platform with tethered power can be operated successfully in rugged, high-relief environments—an encouraging result for planetary analog testing. Passive seismic methods are still under evaluation; preliminary data suggest they may provide three-dimensional imaging capabilities, but signal strength and sensor coupling remain technical challenges to address in future deployments. We will continue to refine our block modeling **(left)** accounting for more accurate estimates of overburden thickness and content, any internal layering, additional data that becomes available. We will also be comparing these block modeling results with results we obtain by block modeling a martian debris covered glacier [6].

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