Simulated AVIRIS-3 detects species-specific patterns of vegetation succession in retrogressive thaw slumps

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Abstract: The initiation and expansion of Retrogressive Thaw Slumps (RTS) are rapidly increasing across the Arctic. These mass-wasting features are transforming permafrost landscapes, influencing localized patterns of plant species cover and abundance and associated carbon storage. Although imaging spectroscopy is capable of detecting fine-scale patterns of plant species and various plant functional types, due to its limited availability, coverage, and high cost, knowledge of the spatiotemporal patterns of plant community change following RTS disturbance remains limited. Here, we determine the viability of hyperspectral image simulation for detecting the fractional cover (FCover) of dominant plant species and plant functional types across RTS spanning the NASA-ABoVE core domain. We leveraged a data-rich RTS site, extensively sampled during the summer of 2023 in the Noatak National Preserve, which includes coincidental ground (i.e., vegetation surveys, hyperspectral, and LiDAR data), airborne (i.e., multispectral 5cm Red Edge-m and AVIRIS-3), and space-borne (i.e., Sentinel-2 MSI) datasets. We simulated AVIRIS-3 using a Sentinel-2 MSI image using a spectral reconstruction method known as the Universal Pattern Decomposition Method (UPDM), which produced a 10m spatial resolution simulated product. This method requires the Spectral Response Function (SRF) of both sensors to normalize the ground spectra of prominent endmembers. We mapped dominant shrub species and plant functional types across the RTS site using 5cm multispectral imagery and evaluated classification accuracy with ground observations. This high-resolution classification was used to compute the FCover of using AVIRIS-3 (resampled to 10m), simulated AVIRIS-3, and Sentinel-2. Preliminary results suggest FCover classification accuracies were substantially improved by hyperspectral image simulation methods, providing a pathway for scaling this analysis within RTS scars across the ABoVE core domain.

Introduction

Retrogressive thaw slumps (RTS) are a common phenomenon in permafrost region, mobilizing significant amounts of soil carbon and nutrients as temperatures rise. The rate of RTS formation has fastened in the past few decades. Due to varying patterns and rates of RTS expansion throughout the Arctic, the underlying controls on RTS morphological change and the resulting patterns of vegetation succession remain unclear. In order to answer the question a high resolution spatial and spectral information could help to understand the factors that influence patterns of vegetation succession in response to disturbances across permafrost landscapes in Alaska. Imaging spectroscopy has potential to effectively characterize and monitor such succession but it has limited availability, coverage and high cost. Therefore, in this study we simulated a hyperspectral information which possess the similar rich spectral response as that of AVIRIS-3. The spectral rich image was further integrated with fine scale spatial information obtained from a UAS derived image to study the vegetation succession and understands the RTS dynamics response across the NASA-ABoVE core domain.

Study Area

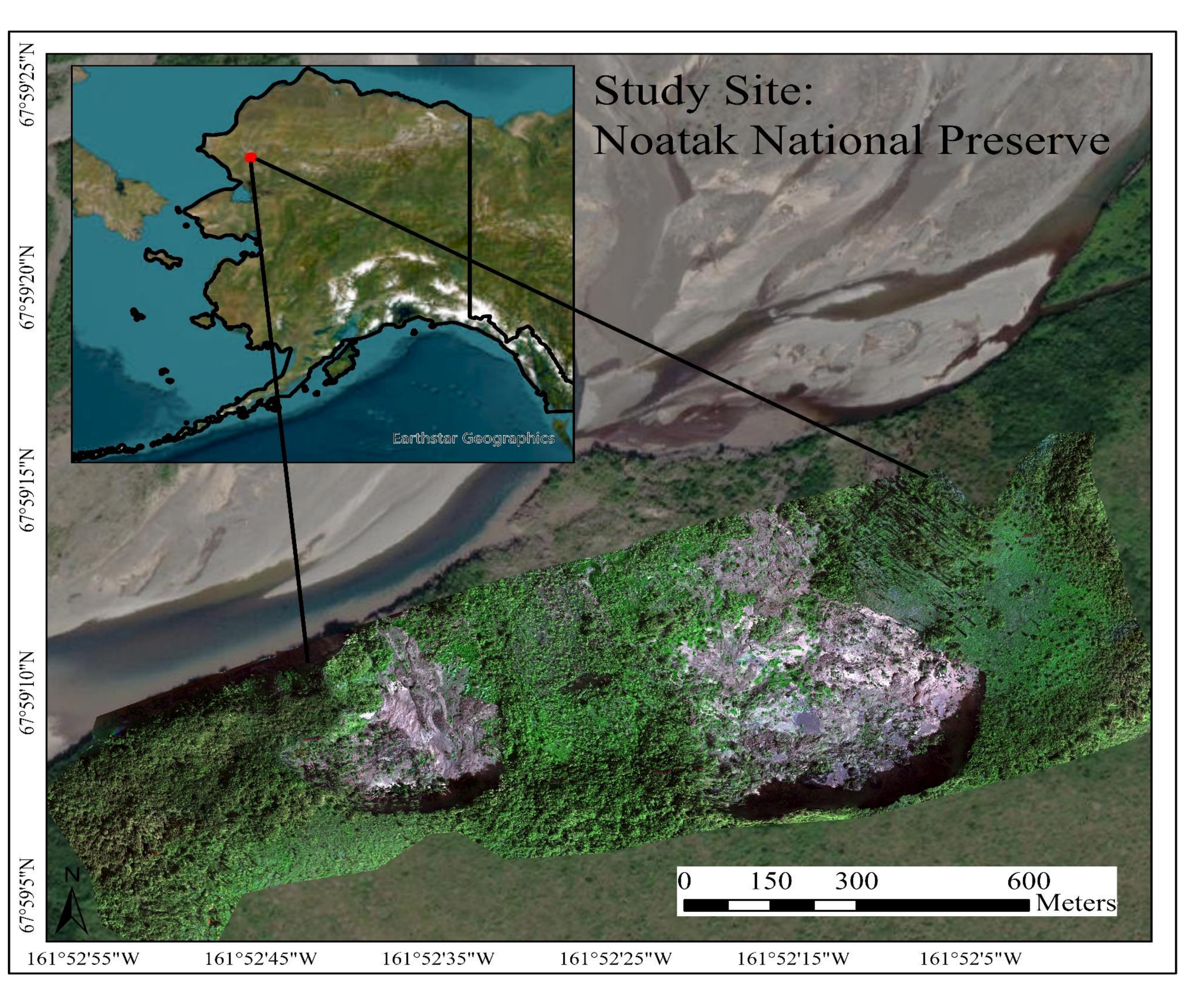

Figure 1. Study site

The study area is present in the Noatak National Preserve in northern and northwestern Alaska. This slump among others were visited during the summer of July 2023. The ground spectra for different species was recorded from a hand held spectroradiometer HR-1024i_SVC, this device records the spectra from visible to SWIR region (350-2500nm) in 1024 bands. Table 1 shows the detail for the satellite and airborne sensors used for the study

Data and Software

1. Satellite and airborne data:

Sensor	Date of Acquisition	Product type	Resolution (m)
Sentinel-2 MSI	07/17/2023	L2A	10,20,60
AVIRIS-3	07/23/2023	L2A	~2.5
RedEdge-M	07/23/2023		~0.05

2. Data Sampling: HR-1024i-SVC spectroradiometer

Table 1. Data acquisition

Software Used

SNAP, ArcMap, Python, RStudio,, Agisoft Metashape, ENVI (5.3)

Methodology

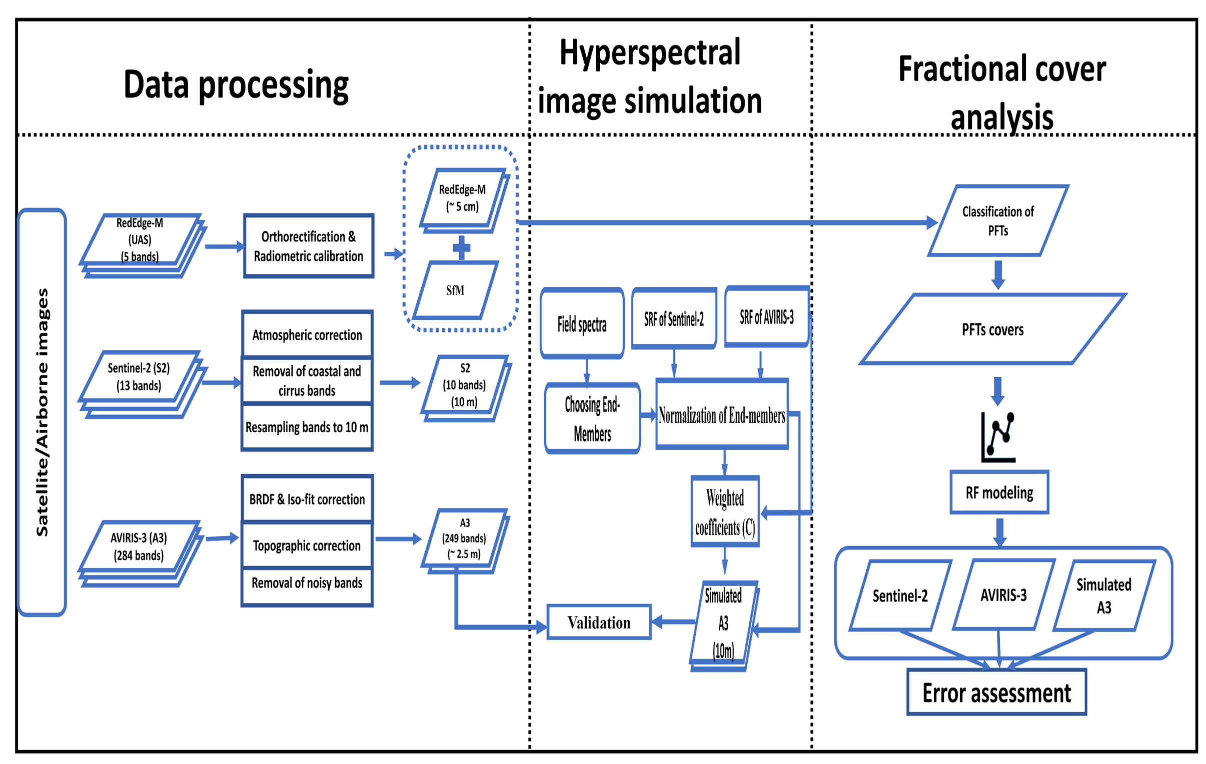

Figure 2. Flowchart of the work

Results

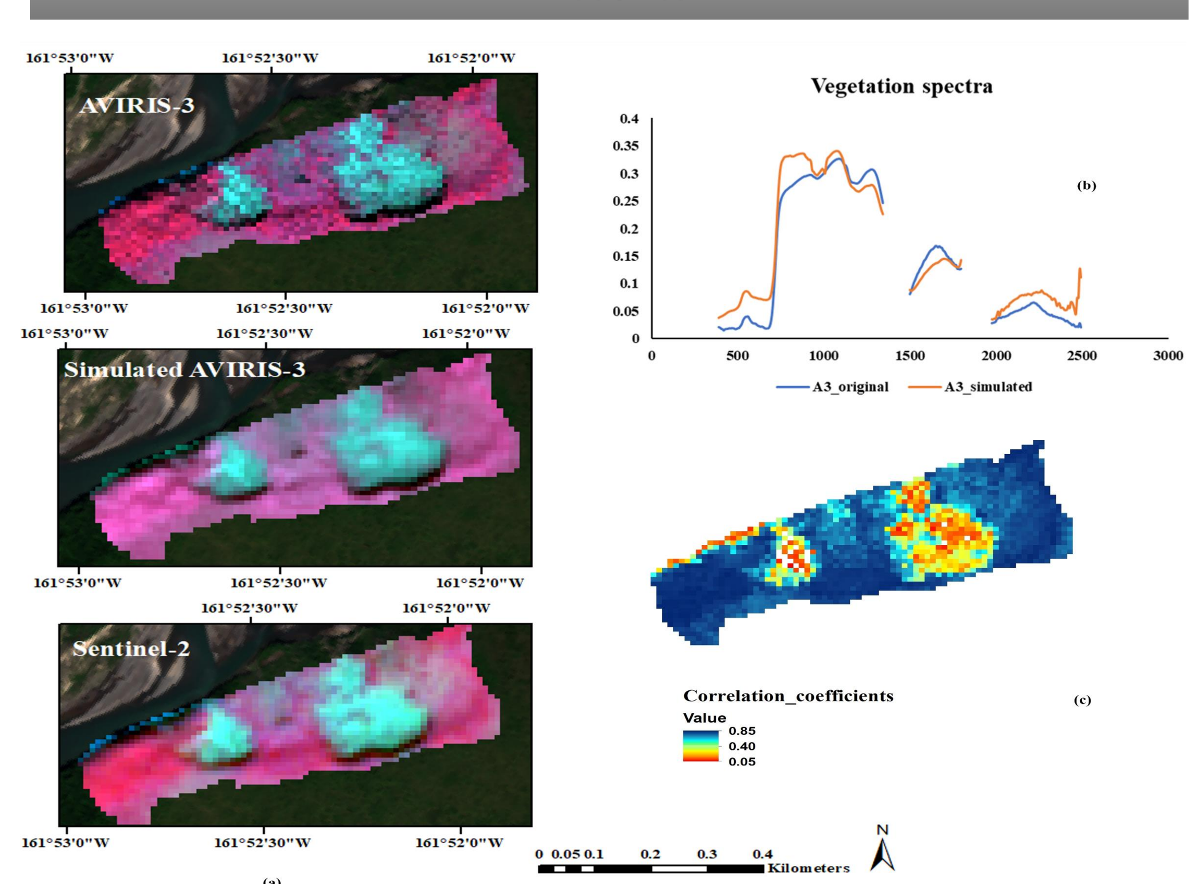

Figure 3. (a) River slump coverage from S2 B(8, 4, 3), Simulated A3 B(62, 35, 22), and A3 B(62, 35, 22); (b) Spectra comparison between a vegetation pixel; and (c) pixel by pixel correlation map between A3 and simulated A3

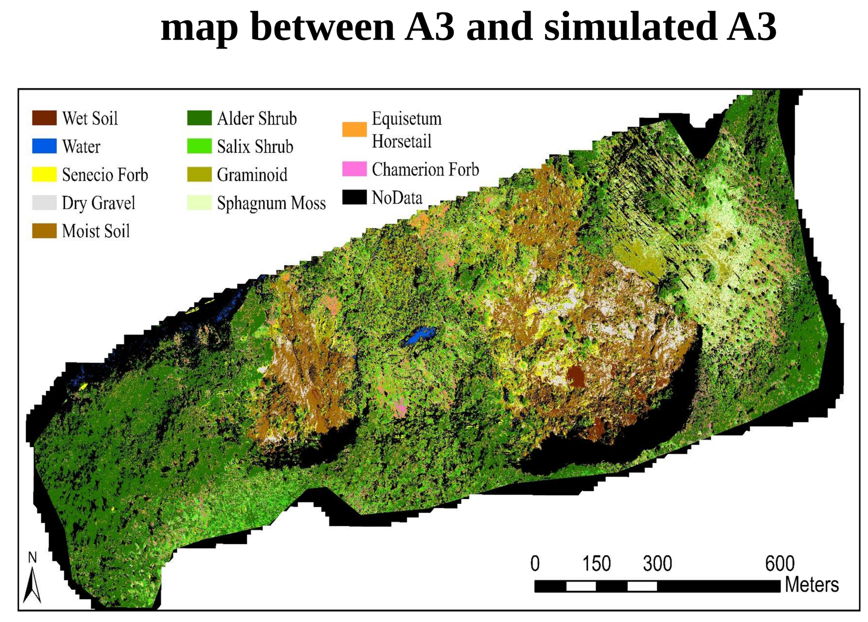

Figure 4. Classification of the slump with Maximum Likelihood classifier

Species names	Sentinel-2 (R^2/RMSE) Max coverage	AVIRIS-3 (R^2/RMSE) Max coverage	Simulated AVIRIS-3 (R^2/RMSE) Max coverage
Wet soil (W)	(0.17/0.031) 0.09	(0.51/0.016) 0.06	(0.014/0.023) 0.25
Water (P)	(0.04/0.029) 0.005	(0.15/0.003) 0.01	(0.23/0.004) 0.31
Senecio forb (SF)	(0.58/0.019) 0.13	(0.35/0.038) 0.17	(0.46/0.031) 0.23
Dry gravel (D)	(0.62/0.042) 0.33	(0.39/0.082) 0.33	(0.41/0.018) 0.34
Moist soil (M)	(0.79/0.086) 0.52	(0.69/0.105) 0.56	(0.67/0.102) 0.49
Alder shrub (A)	(0.47/0.211) 0.76	(0.24/0.200) 0.68	(0.31/0.181) 0.73
Salix shrub (S)	(0.13/0.092) 0.29	(0.10/0.087) 0.27	(0.27/0.090) 0.24
Graminoid (G)	(0.54/0.079) 0.35	(0.14/0.101) 0.31	(0.61/0.048) 0.53
Sphagnum moss (SM)	(0.37/0.055) 0.34	(0.30/0.073) 0.12	(0.22/0.091) 0.36
Equisetum horsetail (H)	(0.22/0.075) 0.22	(0.12/0.063) 0.30	(0.13/0.067) 0.29
Chamerion forb (C)	(0.11/0.016) 0.06	(0.14/0.023) 0.07	(0.11/0.024) 0.10

Table 2. FCover performance of the model for different images

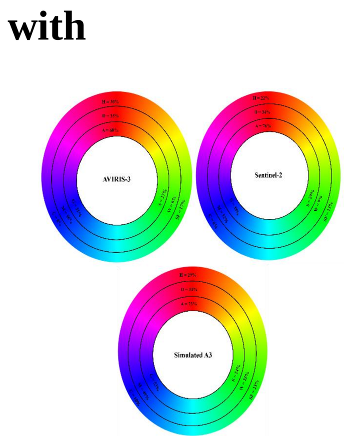

Figure 5. RGB wheel for the stacks of FCover classes for AVIRIS-3, Sentinel-2, and Simulated A3

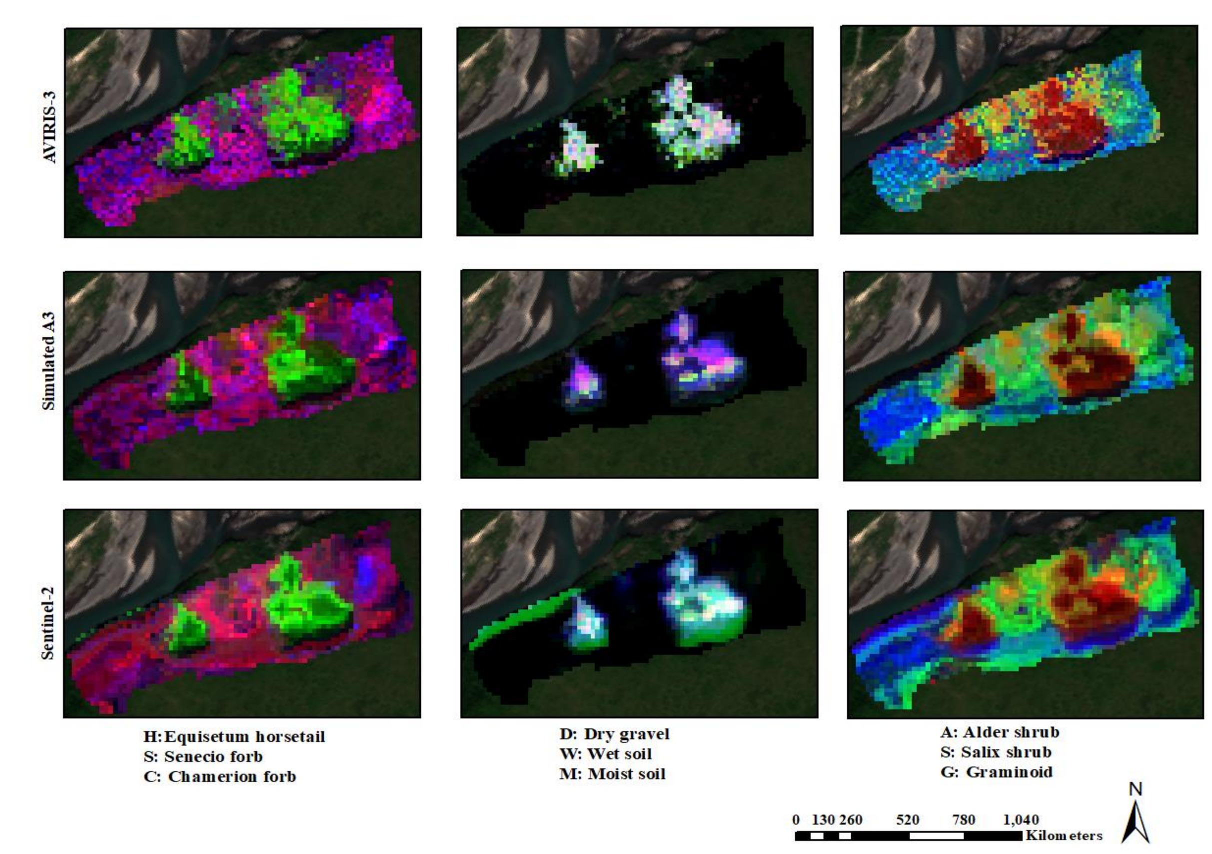

Figure 6. Stacks of FCover for 3 classes (Shrubs, soil, and grass)

a. Hyperspectral image simulation:

A synthetic hyperspectral imagery equivalent to the AVIRIS-3 was generated using UPDM algorithm, that uses the reflectance from a multispectral image which has global coverage. In total, 284 bands were generated with 10 input bands from Sentinel-2. Figure 3 (a) shows FCC images of the slump from AVIRIS-3, Simulated A3, and Sentinel 2. Simulated A3 has the spatial resolution similar to the Sentinel-2, and the spectral resolution similar to the AVIRIS-3, (b) is spectra comparison for a vegetation pixel from the AVIRIS-3 and simulated AVIRIS, the absorption characteristics and reflectance patterns of the simulated spectra is quite similar to the original spectra and (c) is the pixel by pixel correlation coefficient between those two images, for vegetation part there is higher correlation going up to 0.85 while for the wet or moist bare ground or mixed reflectance pixel has lower correlation. Additionally, the simulated image is more detailed compared to the S@ image.

b. Image classification:

Figure 4 shows the species level Maximum-Likelihood classification. The classification was done on a UAS derived 5 bands image and an additional layer of Canopy Height Model (CHM) to differentiate between the species who are spectrally very similar but has some canopy height difference.

c. Fractional cover (FCover) analysis:

The classified image was used as a reference data to generate fractional cover of 12 classes for AVIRIS-3, S2 and simulated A3 using Random Forest model. Table 2 shows the R^2/RMSE and maximum coverage of each classes for each of the sensors Figure 5 & 6 shows the RGB stacks for all three sensors for 3 broad classes. For moist soil, Alder, and Salix the coverage percentage is similar. For wet soil, and water simulated A3 is showing overestimation compared to AVIRIS-3 and S2, which shows our model generated for the simulated A3 is performing poor, but for vegetation the simulation and its RF model is working fair as expected from pixel by pixel correlation figure (figure3(c)).

Conclusion

- A free of cost hyperspectral image was generated with global coverage compared to a satellite. This image captured the essence of AVIRIS-3 to detect the fine scale spatial and spectral pattern of plant species change due to RTS expansion.
- The usability of that image was subjected by computing and comparing the fractional cover percentage of PFTs using a 5cm classification image generated by UAS + CHM images.
- In future, we will examine the scalability of the proposed method to study the succession of plant species for the region where we don't have the coverage of hi-res images.