Shadows Over Greenland
The Effect of Topographic Shadowing by Ice on Albedo

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Background

Accurately predicting global sea level rise requires more refined surface mass balance (SMB) models of the Greenland Ice Sheet (GrIS). SMB models generally ignore how surface topography potentially causes large spatial variability of incoming solar radiation thereby shadowing out areas of low albedo. This may explain the discrepancy between modeled and observed supraglacial river discharges (Smith, 2016). The lower ablation zone of the GrIS shows extensive surface topography caused by fracturing, supraglacial drainage features, and large-scale bed deformation. The extent of this effect is not well understood and may cause a negative feedback loop as increased melting proliferates cracking and incises deeper stream channels.

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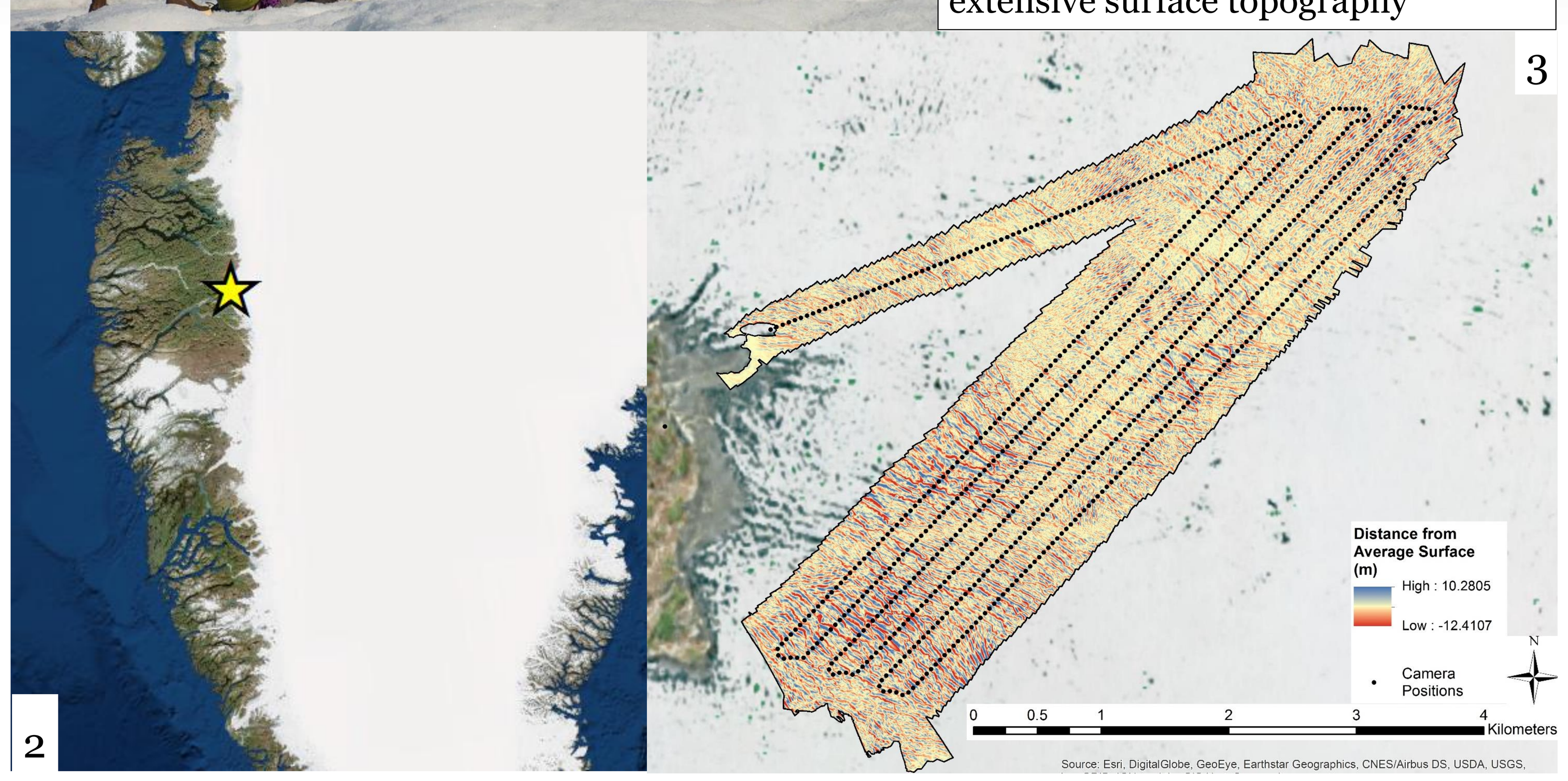
1: Fixed wing UAV used for aerial imagery
2: Map of Greenland showing the location of the field site
3: Field site map produced from stitched UAV flight photos (black dots) with coloration showing the extensive surface topography

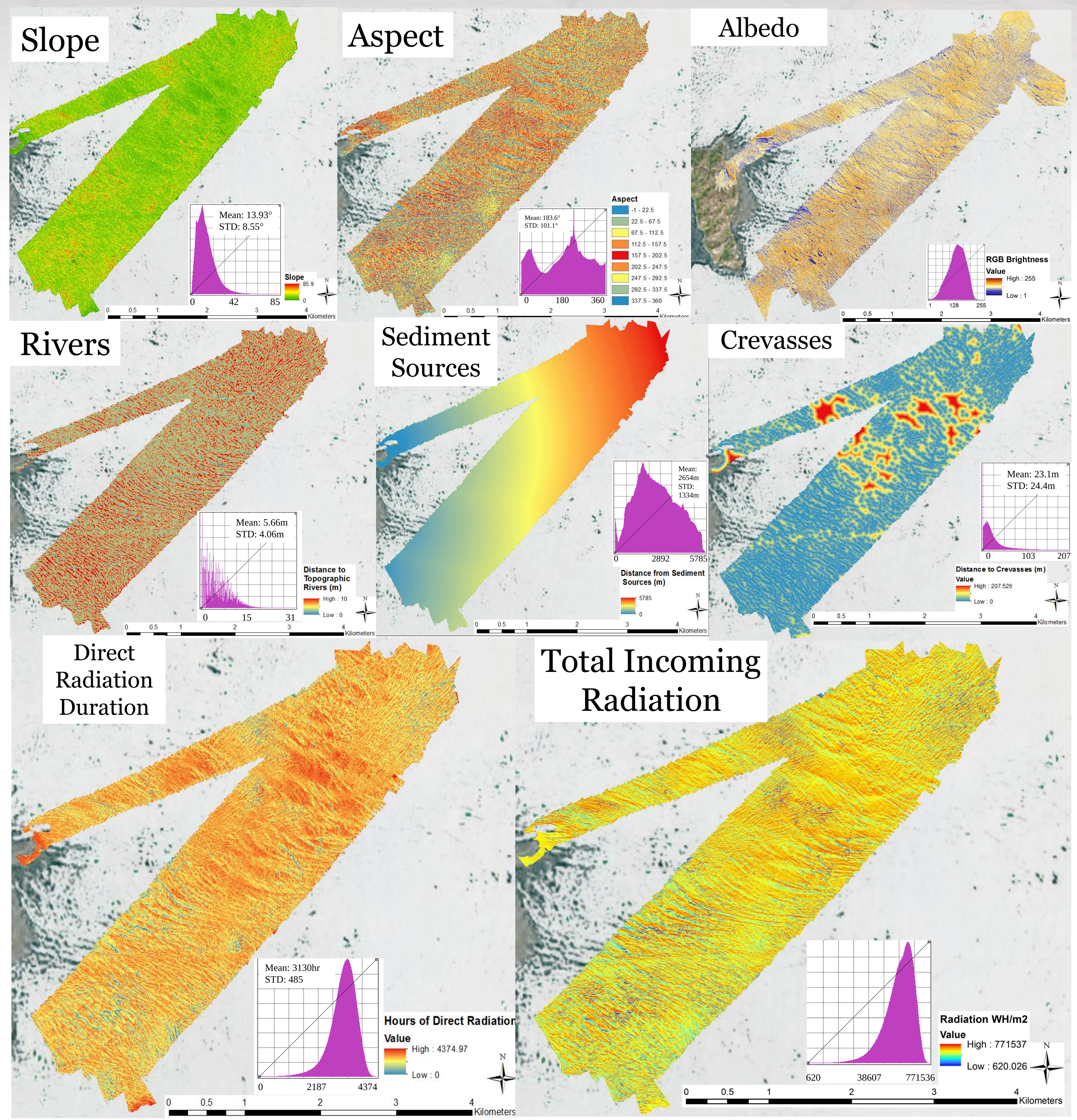


Methods

1. Map field site via a camera mounted to fixed wing UAV.
2. In-situ measurements of ice density and ablation rate.
3. Analyze the imagery using Structure from Motion (SFM) software to create a 40x40cm DEM and ortho-mosaic.
4. Develop a shadowing model using a python script incorporating the Pysolar module and the ArcGIS solar radiation toolset to calculate incoming solar radiation.
5. Create a raster suite of slope, aspect, and distance from best-fit flow-accumulation rivers, crevasses, and moraines
6. Do a principle component analysis to compare correlation and eigenvalues for RGB reflectance and the raster suite.

Results

- Surface types that impact albedo are highly spatially heterogeneous with available solar radiation ranging by four orders of magnitude.
- Annual solar radiation values average $2.1 \times 10^9 \pm 3.2 \times 10^8$ J/m² or 8.39m of melting based on density measurements of the weathering crust.
- Ablation stake measurements of 1.77m/month during peak melt season suggest that **solar radiation accounts for 54% of the total melt** rate.
- The average **percentage of time exposed to direct radiation** for the study area is only **35.7%** due to shadowing.
- The observed average **radiation is 24.5% less than if there was no shadowing occurring.**



Predicting Albedo Variability

- Total incoming solar radiation is very well correlated with RGB brightness (Correlation=0.448) and 99.97% of albedo variability is explained by solar radiation.
- Solar radiation is significantly better at predicting RGB albedo values compared to the other tested geometric and darkening rasters. Slope and elevation are particularly poor indicators of albedo variability.

Correlation Matrix

		Percent of Eigenvalues	Total Radiation	Direct Radiation Duration	Slope	Aspect	Distance to Rivers	Distance to Sediment	Distance to Crevasses
Radiation	Total Radiation	99.97	Total Radiation						
	Direct Radiation Duration	0.02	.502	Direct Radiation Duration					
Geometry	Slope	.002	-0.266	-0.546	Slope				
	Aspect	.0001	.145	.067	-.035	Aspect			
Secondary Darkening Features	Distance to Rivers	0	0.048	0.331	-0.029	-.076	Distance to Rivers		
	Distance to Sediment	0	0.074	.068	0.078	-.255	-0.004	Distance to Sediment	
	Distance to Crevasses	0	.118	.378	-.271	.068	0.008	0.095	Distance to Crevasses
Albedo	RGB Brightness	0	**.448**	.329	-.024	.280	0.189	-0.019	.035

Conclusions

- Shadowing is highly spatially heterogeneous
- Shadowing is significantly better at predicting albedo variability than other parameters
- Shadowing can decrease absorbed radiation by up to a forth suggesting that it is a significant contributor to the melt rate discrepancies of SMB models and in-situ measurements
- Shadowing is scale dependent and courser scale DEMs might not be able to predict actual radiation or albedo variability as effectively
- Shadowing may act as a negative feedback loop for melting as crevassing and stream incision increase.

References and Acknowledgements

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Smith, L. C. (2016). Surface water hydrology and the Greenland Ice Sheet. In *AGU*.
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