The Effect of Topographic Shadowing by Ice on Irradiance in Greenland's Ablation Zone

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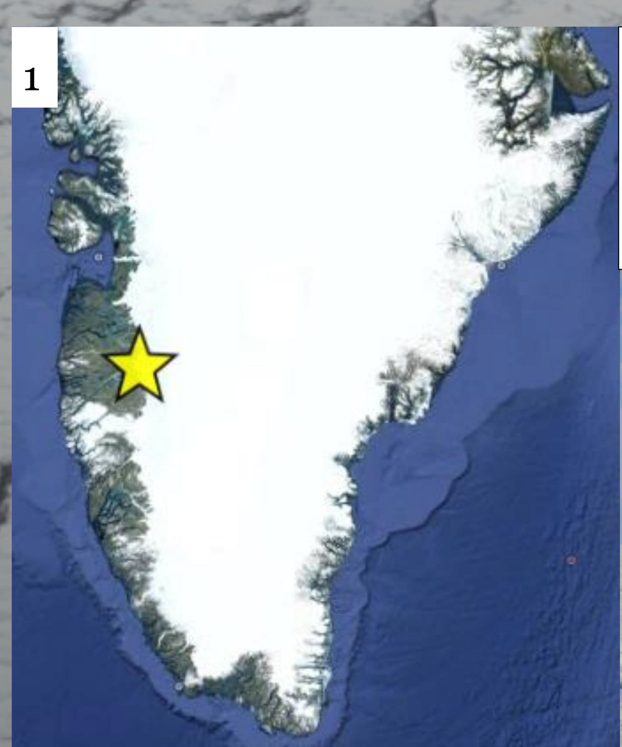
Background

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. This may explain why SMB models generally over-predict meltwater production compared to in-situ supraglacial river flow measurements (Smith, 2016). The lower ablation zone of the GrIS shows extensive surface topography caused by fracturing, supraglacial drainage features, and large-scale bed deformation. How that topography shadows out incoming radiation is not well understood.



1: Map of Greenland showing the location of the field site
2: Fixed wing UAV used for aerial imagery

Methods

1. Map field site via a camera mounted to UAV with in-situ measurements of ice density and ablation rate.
2. Use Structure from Motion software to create a 6x6 cm and 40x40cm DEM and mosaicked ortho-photo
3. Calculate incoming solar radiation using ArcGIS' solar radiation toolset and compared to a flat surface.
4. Do a cell size sensitivity analysis on the SfM DEMs
5. Calculate irradiance decrease on an ArcticDEM swath

References and Acknowledgements

Ryan, J. C., Hubbard, A., Stibal, M., Box, J. E., & Project, S. (2016). Attribution of Greenland ' s ablating ice surfaces on ice sheet albedo using unmanned aerial systems. *The Cryosphere Disc.*, (Sept), 1–23.
Smith, L. C. (2016). Surface water hydrology and the Greenland Ice Sheet. In *AGU*.
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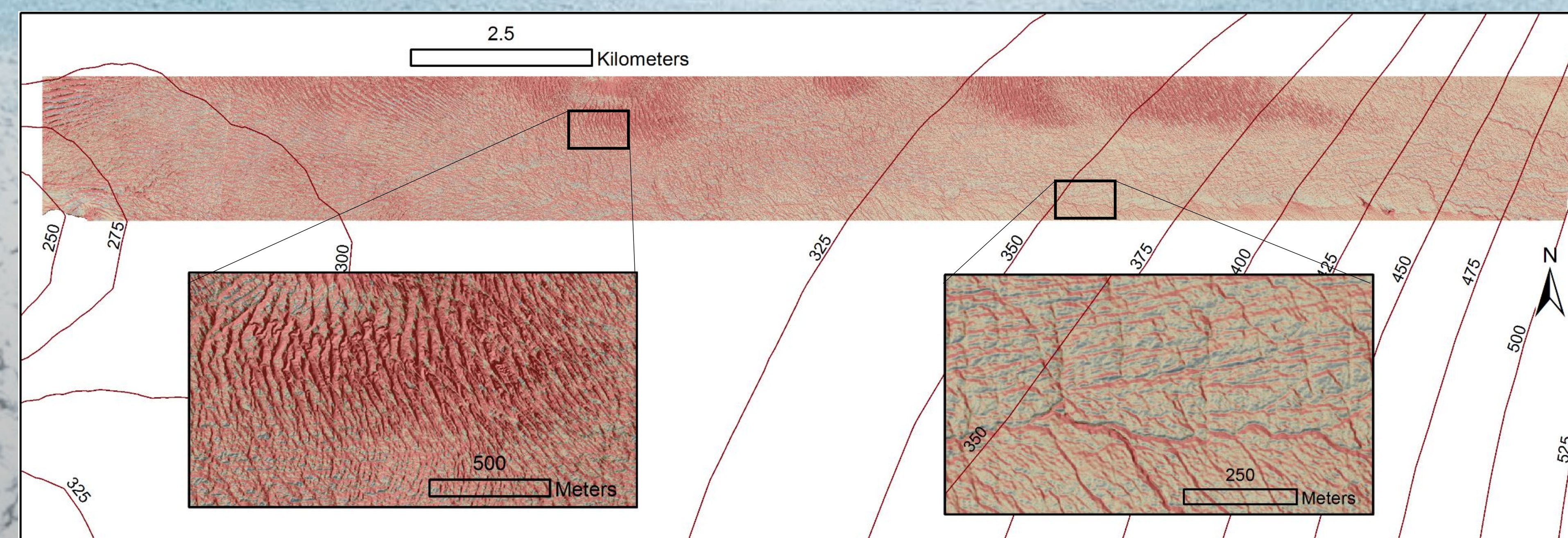
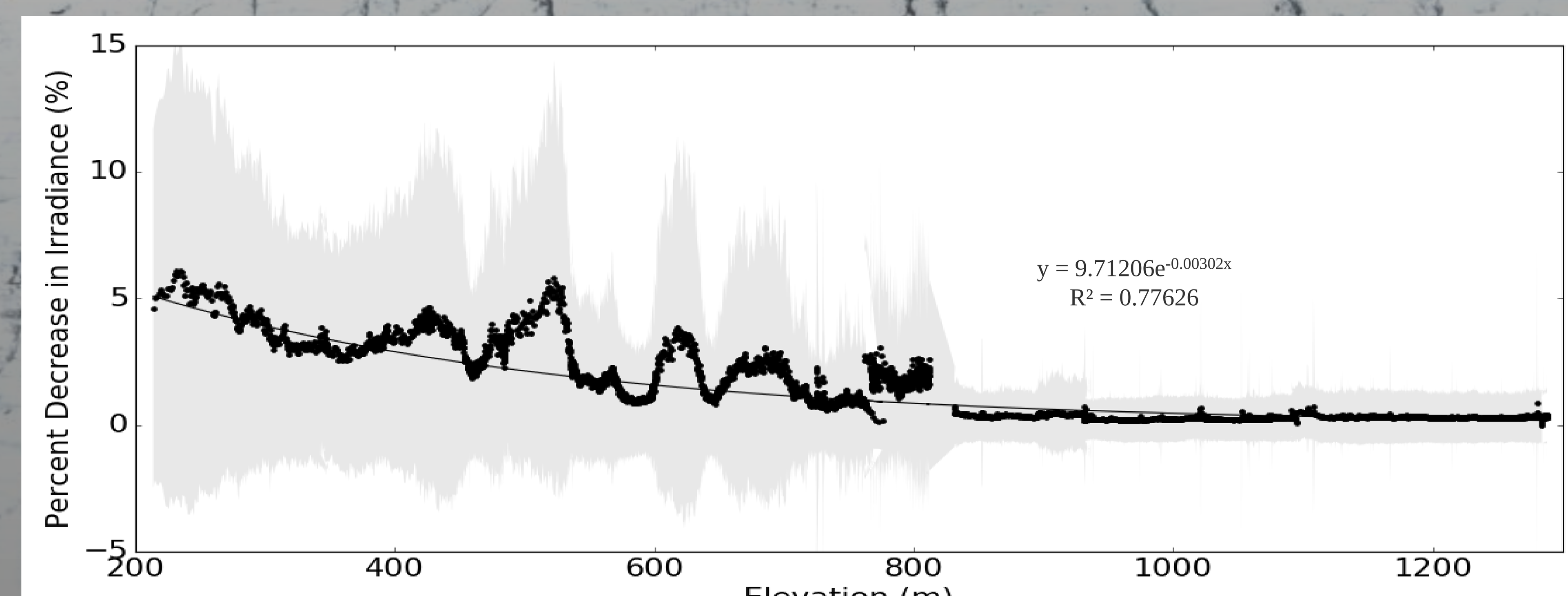
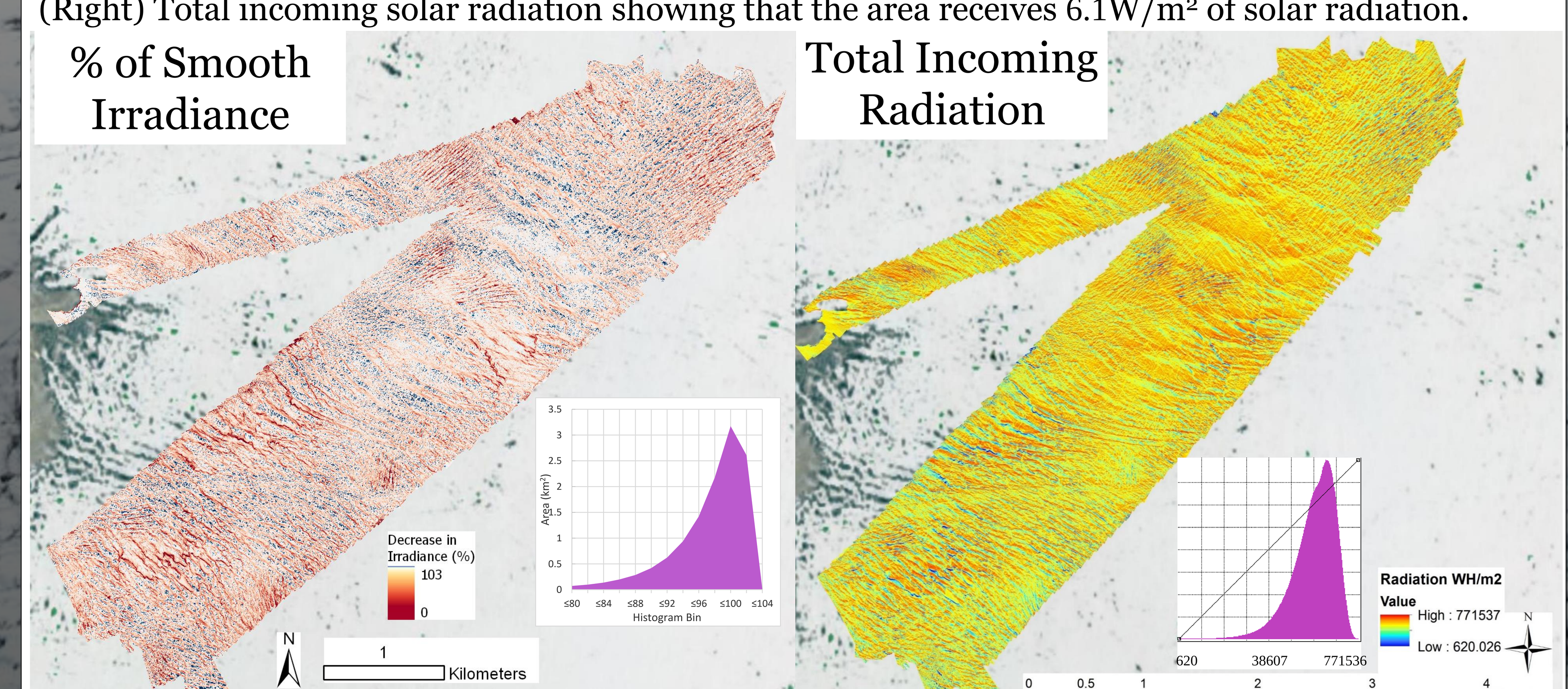


Above: Maps of percent change in irradiance compared to a smoothed surface with areas of decreased irradiance in red and increased irradiance in blue. Left: Blow up of crevasse zone showing extensive decreases in irradiance. Right: Blow up of supraglacial stream network showing high aspect sensitivity. Contours are in 25m intervals.
Below: Percent change in irradiance for each elevation bin with elevation showing that lower areas have more shadowing and more variability than upper elevations.



(Left) Percent decrease in irradiance from a 500m smoothed surface derived from drone imagery showing that topography mostly decreases irradiance and that decrease is greatest in crevassed areas. (Right) Total incoming solar radiation showing that the area receives 6.1W/m² of solar radiation.

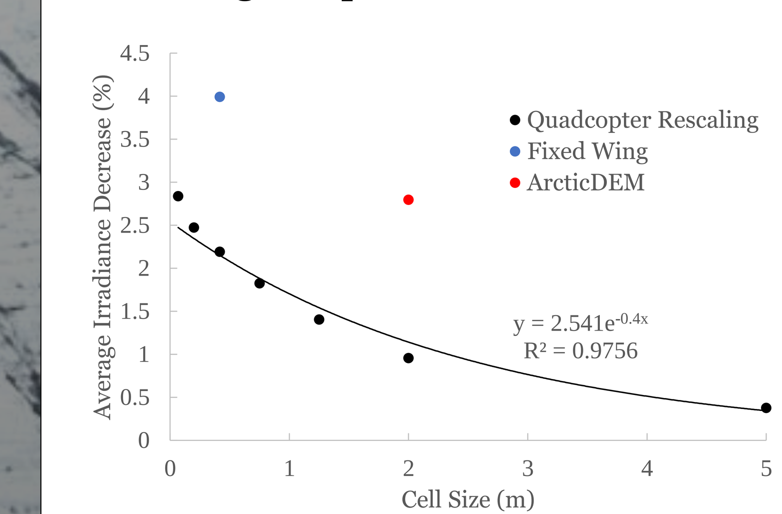


Results

- Shadowing decreases irradiance by 3% on average compared to smoothed surfaces.
- The effect of shadowing is highly elevation dependent with a negligible effect by 900m in the study area.
- The effect of shadowing decreases with DEM cell size with only 14% of the effect observed at 5m resolution.
- Irradiance is highly spatially heterogeneous 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
- The average percentage of time exposed to direct radiation for the study area is only 35.7% due to shadowing.

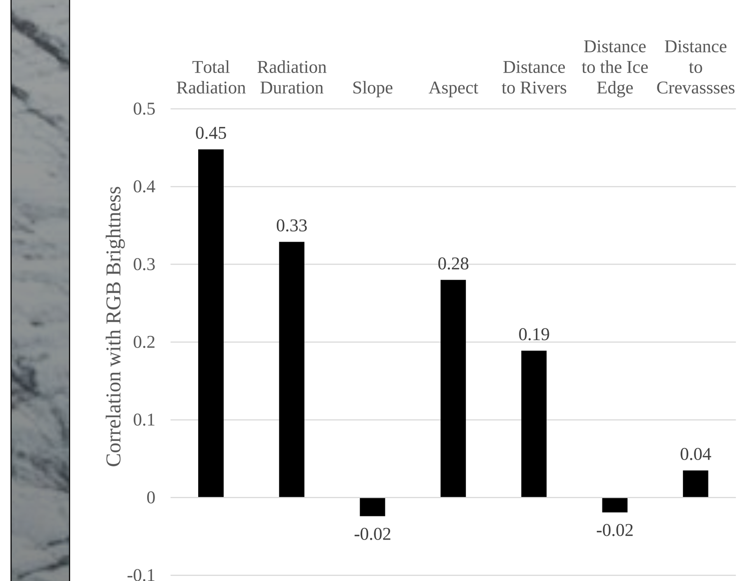
Spatial Scale Sensitivity Analysis

- The effect of shadowing increases exponentially with decreasing cell size.
- The total effect is a 2.5% decrease in irradiance or 700kg/m²yr of decreased melting compared to a flat surface.



Correlation with Albedo Variability

Shadowing is a far better predictor of albedo variability than all other variables.



Conclusions

Shadowing causes...

↓	Irradiance on the ice sheet, especially at lower, more crevassed regions
↑	Predictability of albedo variability compared to other parameters
↑	Discrepancies between SMB models and in-situ supraglacial discharge measurement
↓	Effects on irradiance with decreasing spatial resolution of analysis
↑	Negative feedback loop for melting as crevassing and stream incision increases