Tuning ICESat-2 for Mountain Snow Depth Observation: Terrain Effects on ICESat-2-derived Snow Depth in Vegetated Alpine Watersheds

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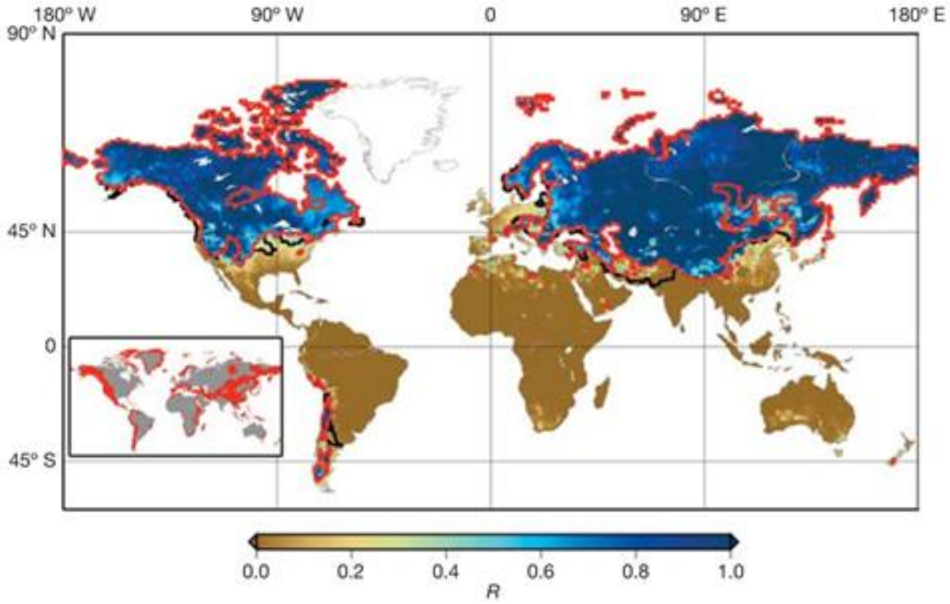
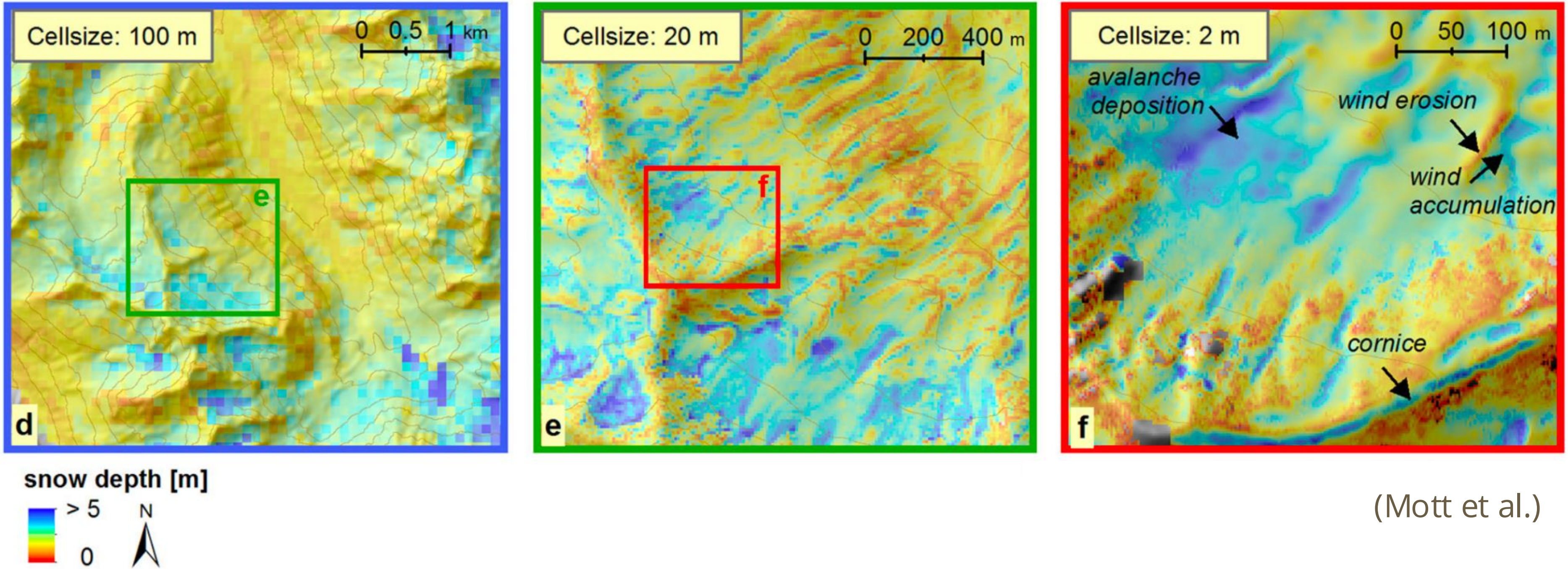
Seasonal Snow and Water resources

- Seasonal snow is a key water resource around the world and is highly sensitive to changes in climate
- In the western US over 75% of our water supply is dominated by seasonal snow run-off (Barnett)
- Watershed forecasters rely on a sparse set of observations but satellite observations can help fill data gaps



Accumulated annual snowfall divided by annual runoff over the global land regions. (Barnett)

Snow Distribution is highly variable

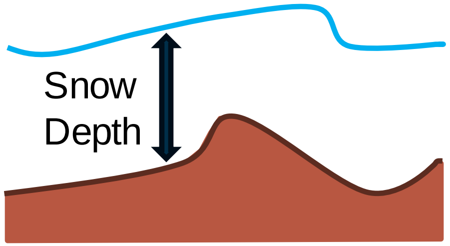


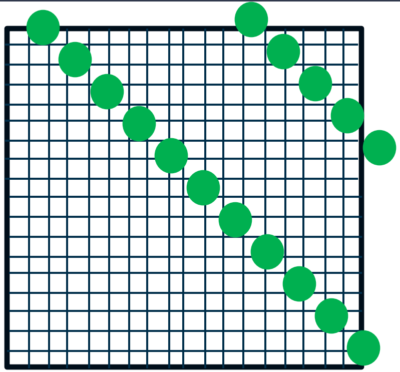
(Mott et al.)

Measuring Snow Depth with ICESat-2

Snow-on ICESat-2 elevation - Reference snow-free elevations = Snow Depth

- ICESat-2 can measure snow depths under canopy
- ICESat-2 tracks are infrequent in the mid-latitudes
  - Compare to an independent snow-free digital terrain model (DTM) to maximize available observations
- Alpine Environments introduce complications
  - Complicated terrain
  - Vegetation



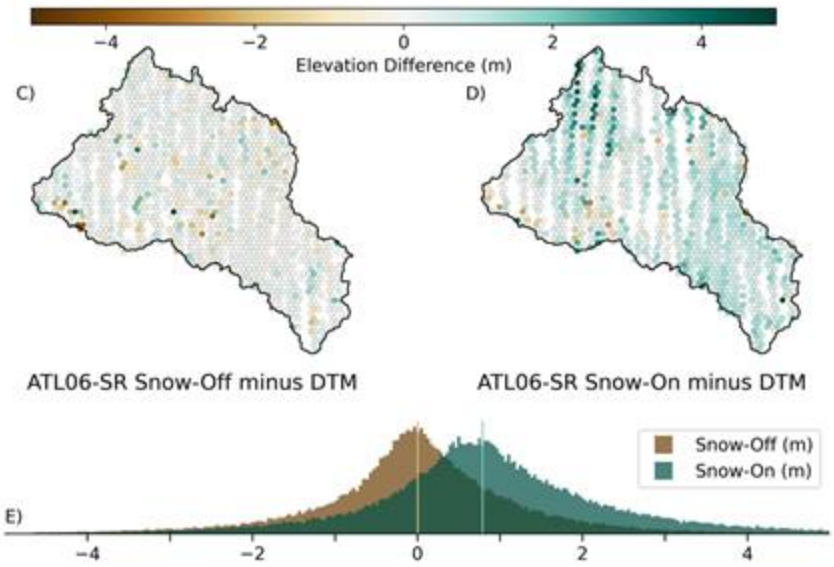


ICESat-2 Snow Depth Previous Studies

Enderlin et al. (2022)
Deschamps-Berger et al. (2023)
Besso et al. (2024)

We can identify snow signals in ICESat-2 data but:

- Uncertainties from ~0.5 m to 3 m
- As slope increases, Snow depths become increasingly negatively biased



(Besso et al.)

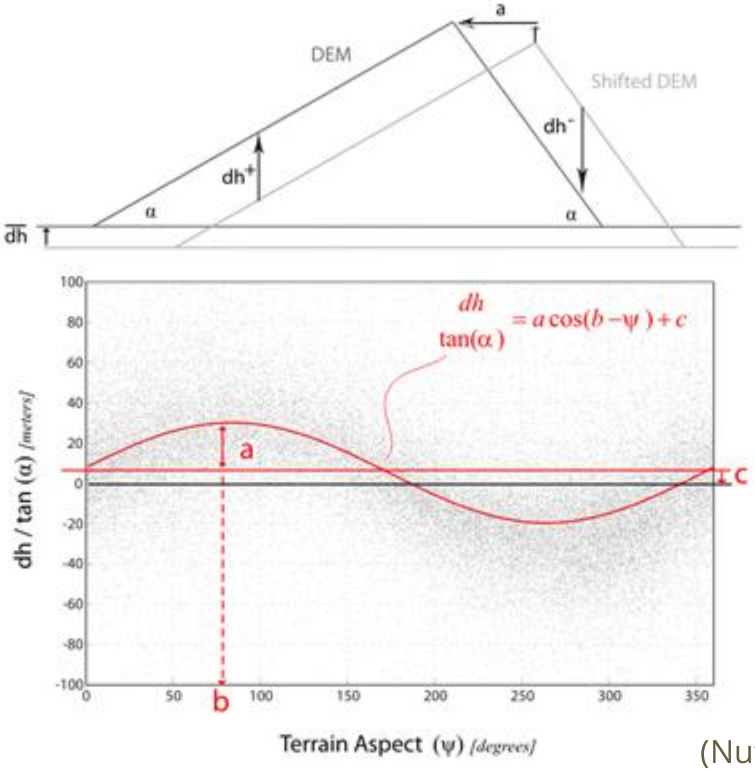
How can we increase precision in our ICESat-2 snow depth estimates?

- Coregistration ← Focus today!
- Snow cover classification ← Briefly touch on
- Reference elevation algorithm
- Length of ICESat-2 footprint
- Correcting slope bias

Another time

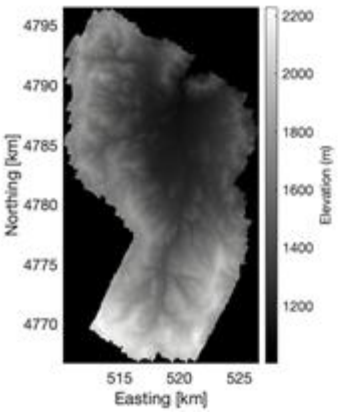
How can we increase precision in our ICESat-2 snow depth estimates?

- Coregistration
- Snow cover classification
- Reference elevation algorithm
- Length of ICESat-2 footprint
- Correcting slope bias



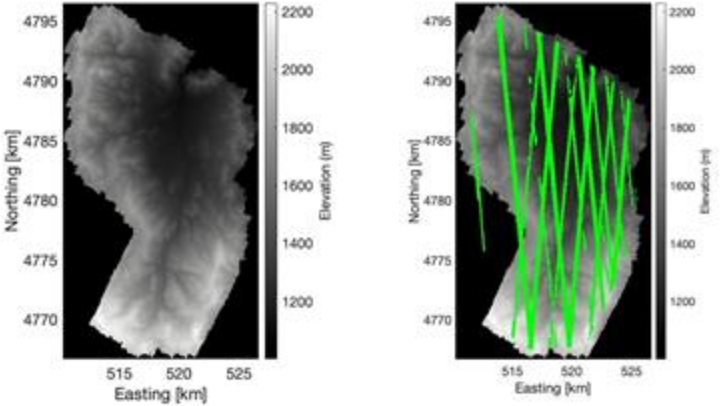
(Nuth and Kääb)

Workflow



Site DTM
&
Boundary
Shapefile

Workflow

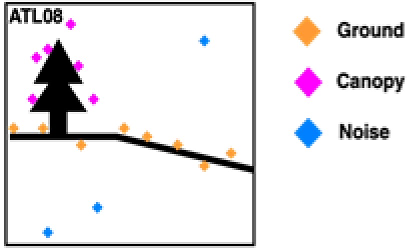


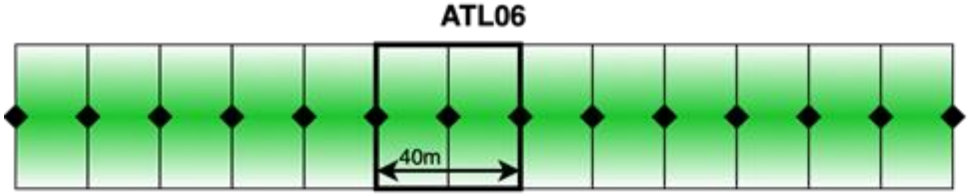
Site DTM & Boundary Shapefile → Pull ICESat-2 data

Product:

- ATL06 with ATL08 ground photon classification

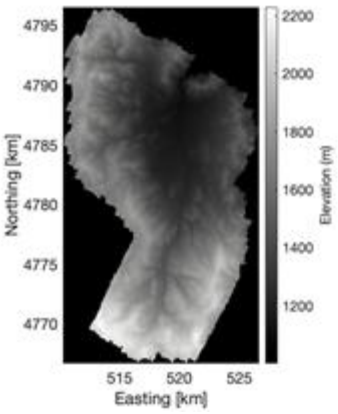
SlideRule Earth
science data processing as a service

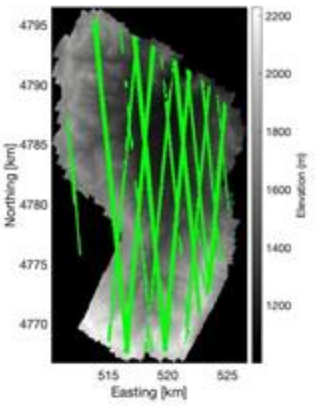


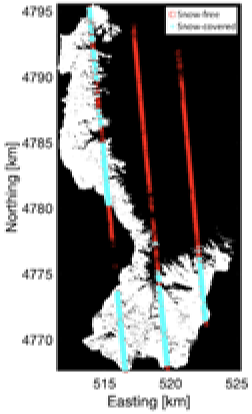


Workflow

Landsat 8/9 & Sentinel 2 Imagery







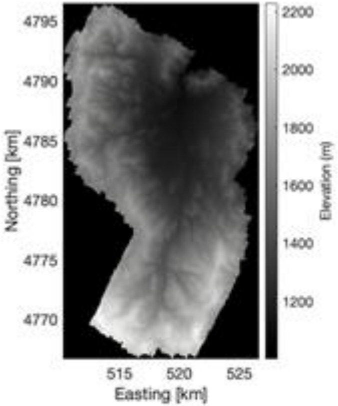
Normalized Difference Snow Index (NDSI)

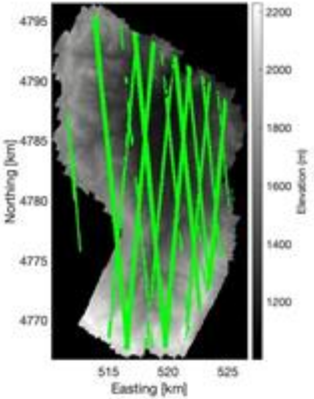
Threshold: 0.4

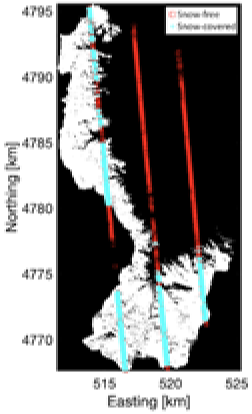
Site DTM & Boundary Shapefile → Pull ICESat-2 data → Classify snow cover

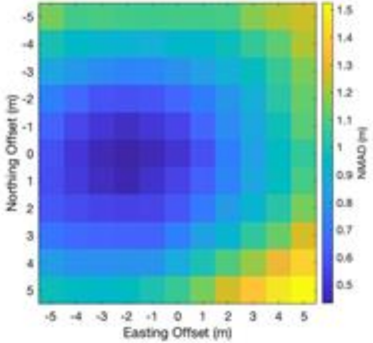
Workflow

Landsat 8/9 & Sentinel 2 Imagery





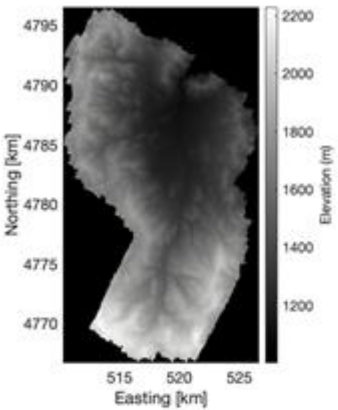


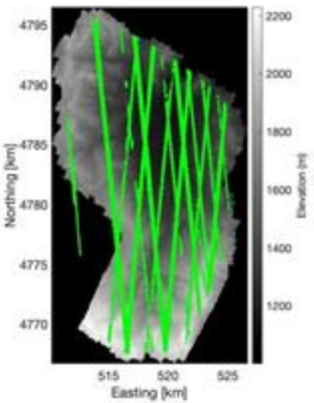


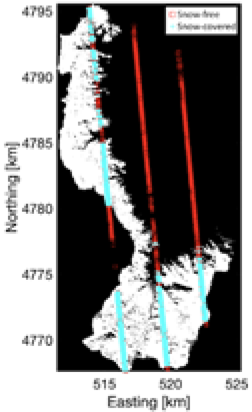
Site DTM & Boundary Shapefile → Pull ICESat-2 data → Classify snow cover → Coregister snow free ICESat-2 and DTM

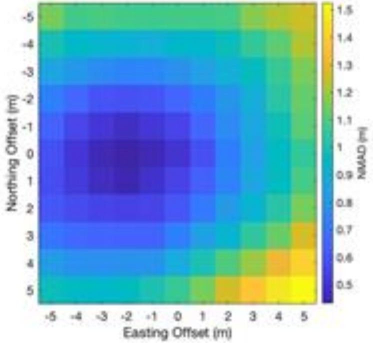
Workflow

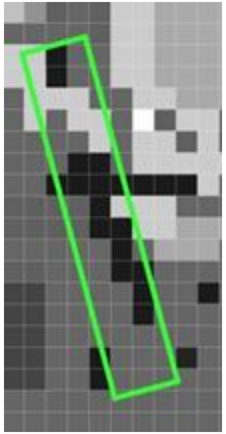
Landsat 8/9 & Sentinel 2 Imagery









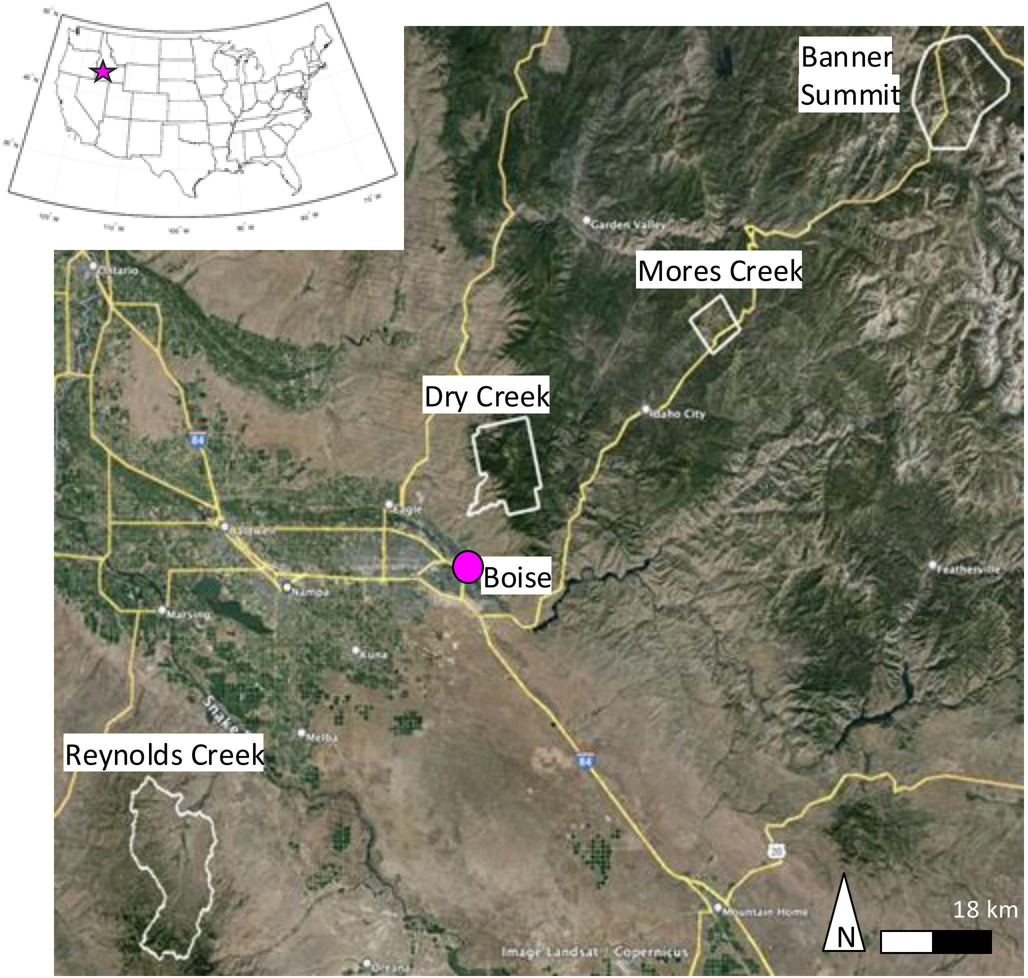


Site DTM & Boundary Shapefile → Pull ICESat-2 data → Classify snow cover → Coregister snow free ICESat-2 and DTM → Difference reference elevation and ICESat-2

Sites!


Reynolds Creek

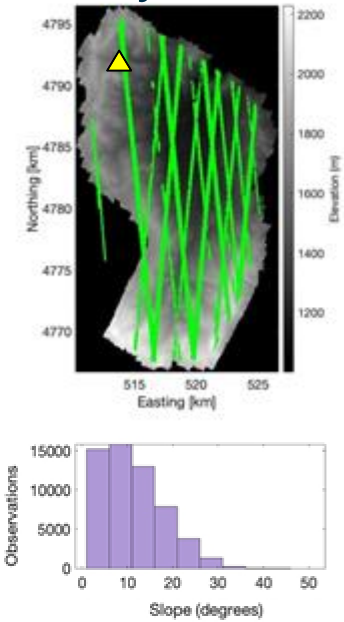

Mores Creek


Banner
Summit
Mores Creek
Dry Creek
Boise
Reynolds Creek
N
18 km
Garden Valley
Idaho City
Featherville
Eagle
Nampa
Marsing
Kuna
Melba
Mountain Home
Ontario
Snake
Image Landsat / Copernicus

ICESat-2 Tracks

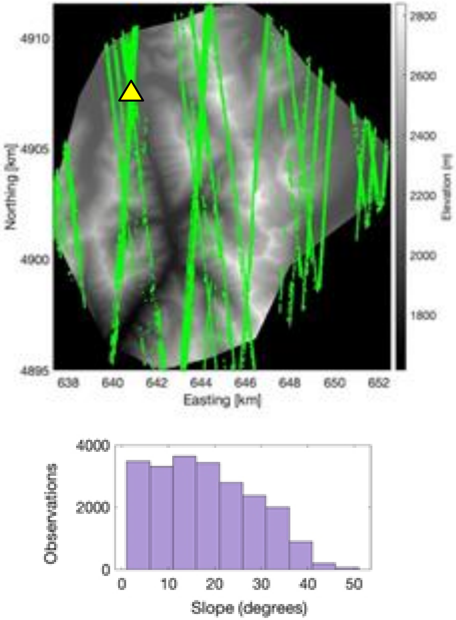
SNOTEL Station

Reynolds



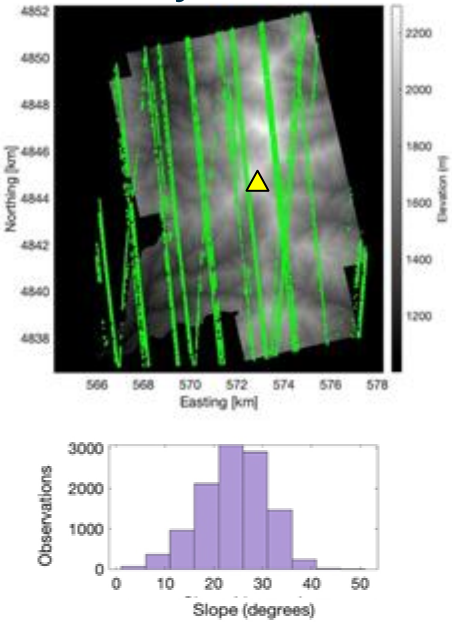
Area: 239 km^2

Banner



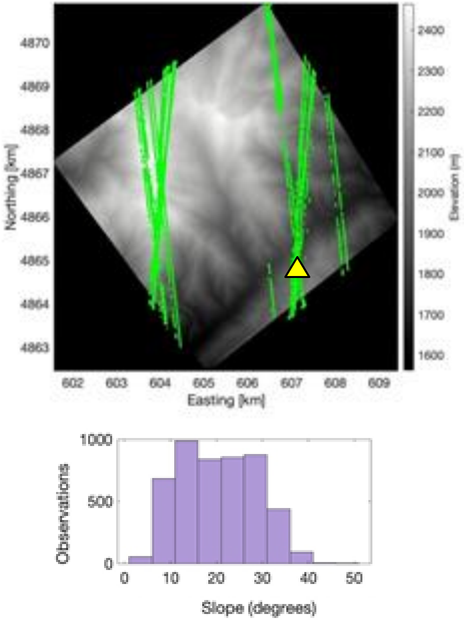
Area: 183 km^2

Dry Creek



Area: 126 km^2

Mores Creek



Area: 38 km^2

Coregistration Approach

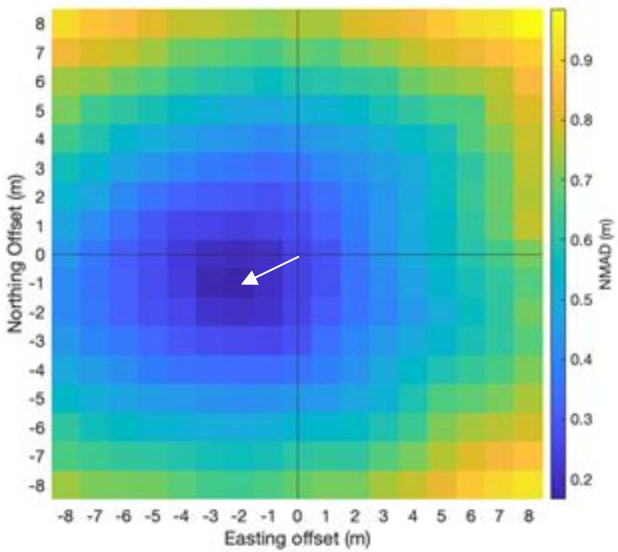
Large variation in NMAD between sites

- Minimum Grid Search
  - Time consuming and computationally demanding
  - Confident we find the global minimum
- Gradient Descent
  - Finds local minima
- Nuth and Kääb Coregistration
  - Can't run for most of our sites

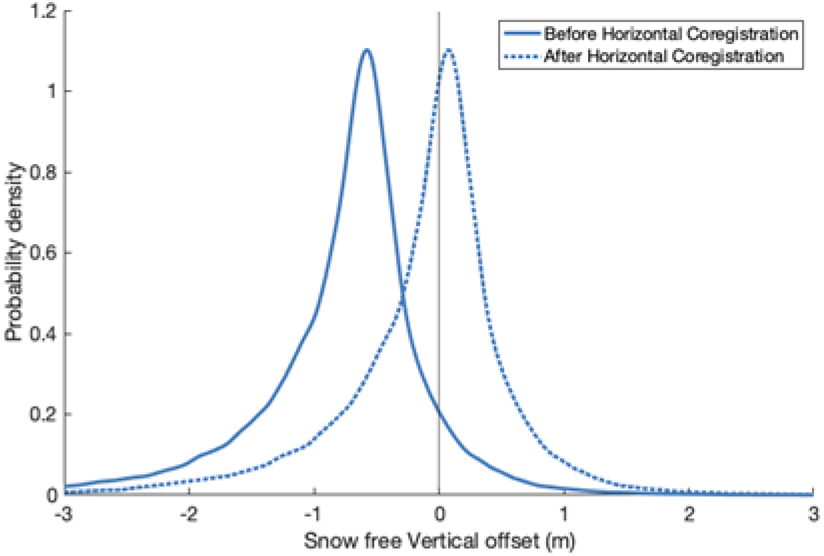
Coregistration Method	Snow Free Normalized Median Absolute Difference (NMAD)	
	Reynolds	Banner
No coregistration	0.81	1.09
Gradient Descent	0.57	1.09
Nuth and Kaab	0.54	N/A
Minimum Grid Search	0.34	1.04

Coregistration

Horizontal Coregistration

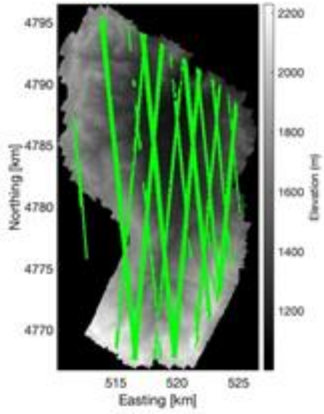


Vertical Coregistration

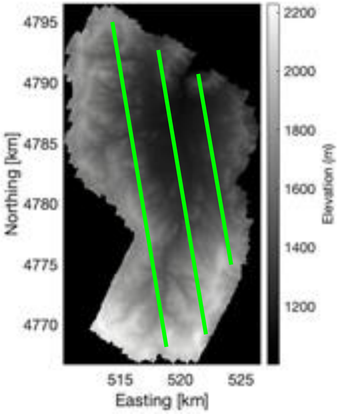


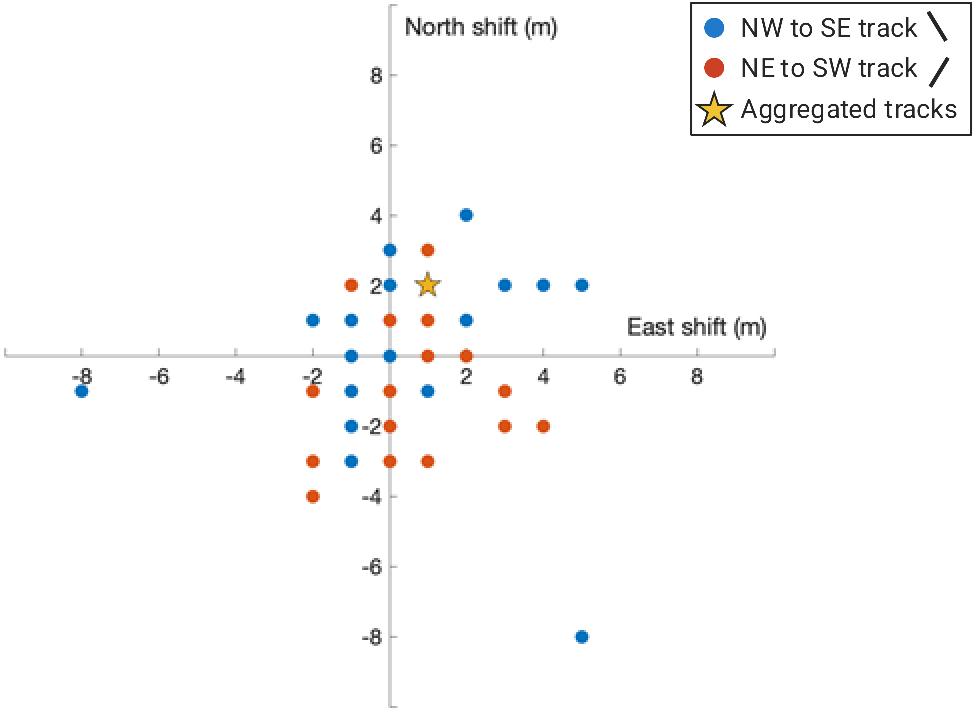
Coregistration – Aggregated vs Individual Dates

Aggregated



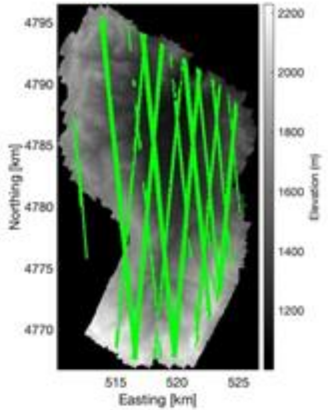
Individual Dates



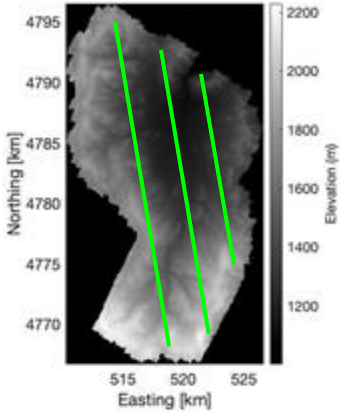


Coregistration – Aggregated vs Individual Dates

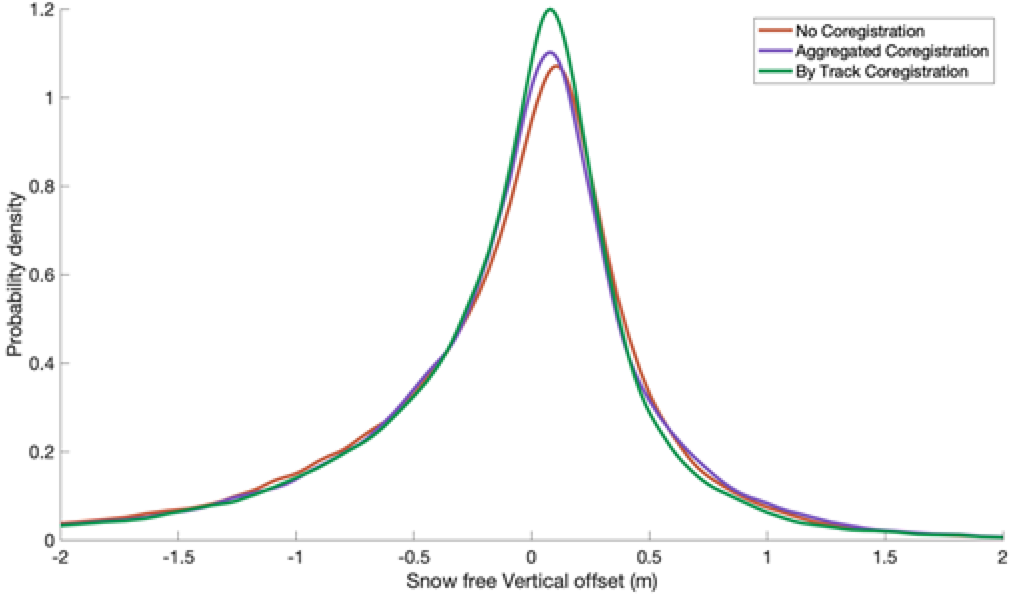
Aggregated



Individual Dates

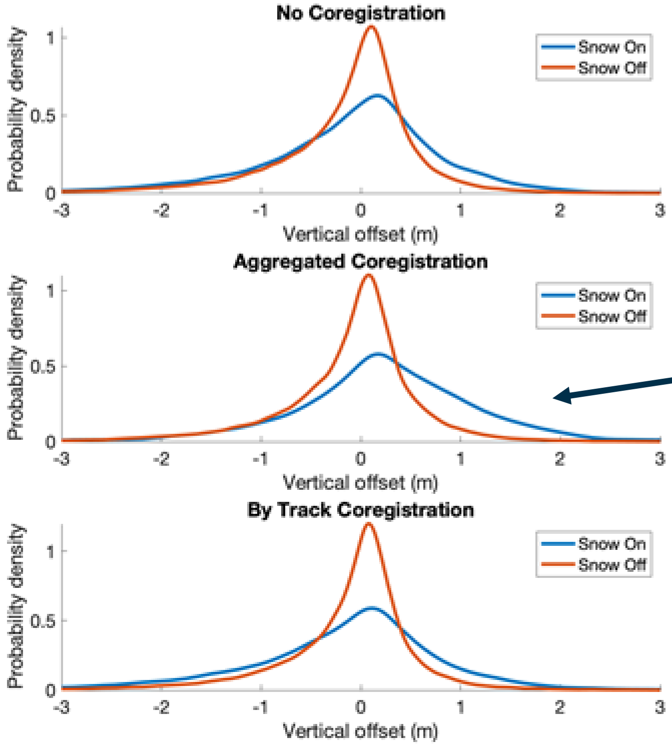


Snow Free



Coregistration - Aggregated vs Individual Dates

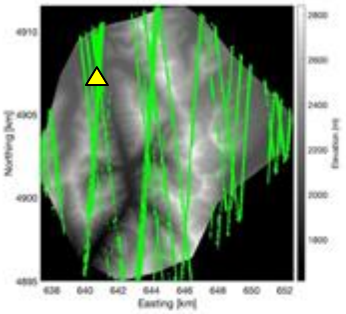
- Clearest Snow signal with aggregated coregistration
- By Track coregistration snow signal similar to no coregistration
- Possible causes of a poor individual track coregistration
    - Sparse data
    - Poor spatial coverage

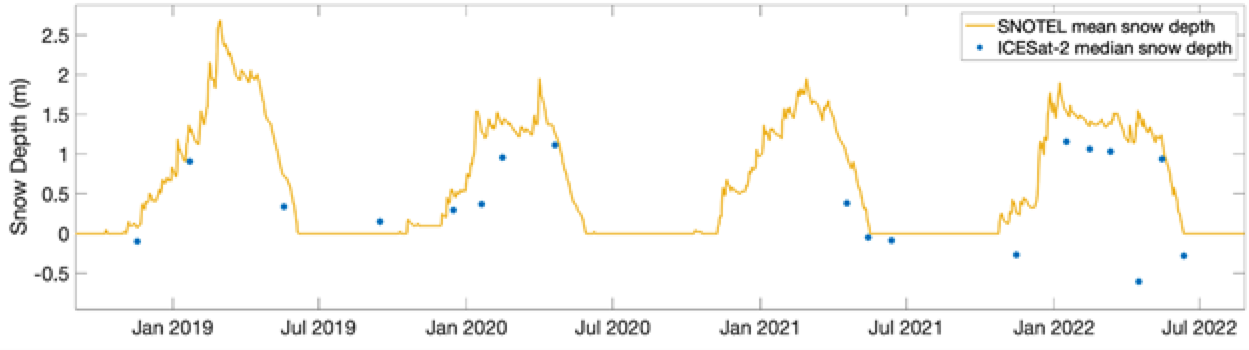


Clearest Snow Signal!

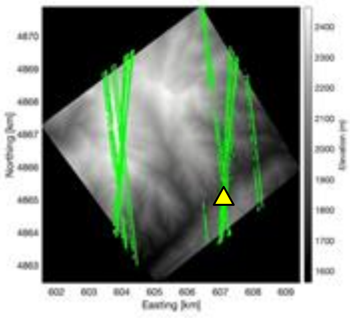
How do our snow depths compare to In-Situ?

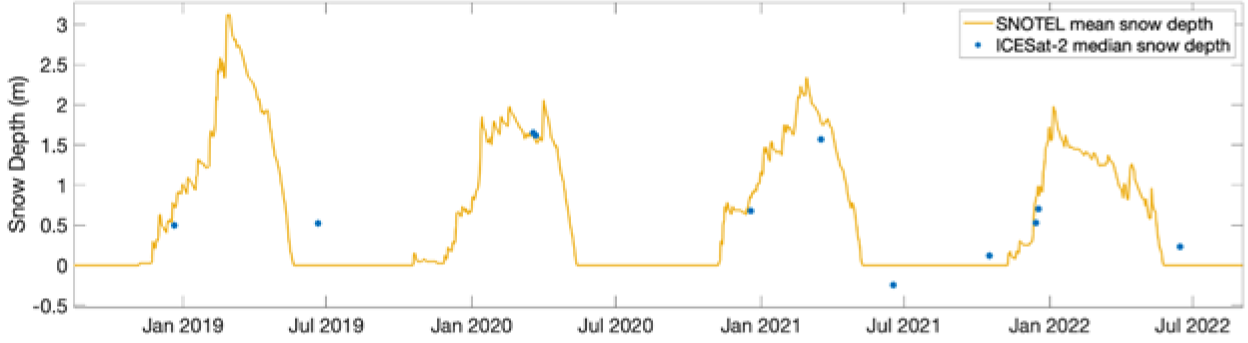
Banner





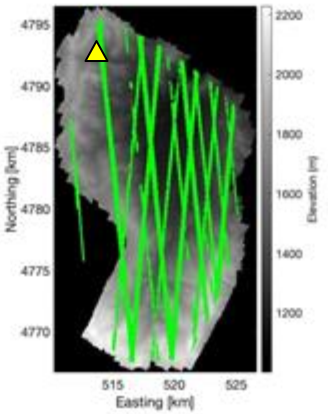
Mores

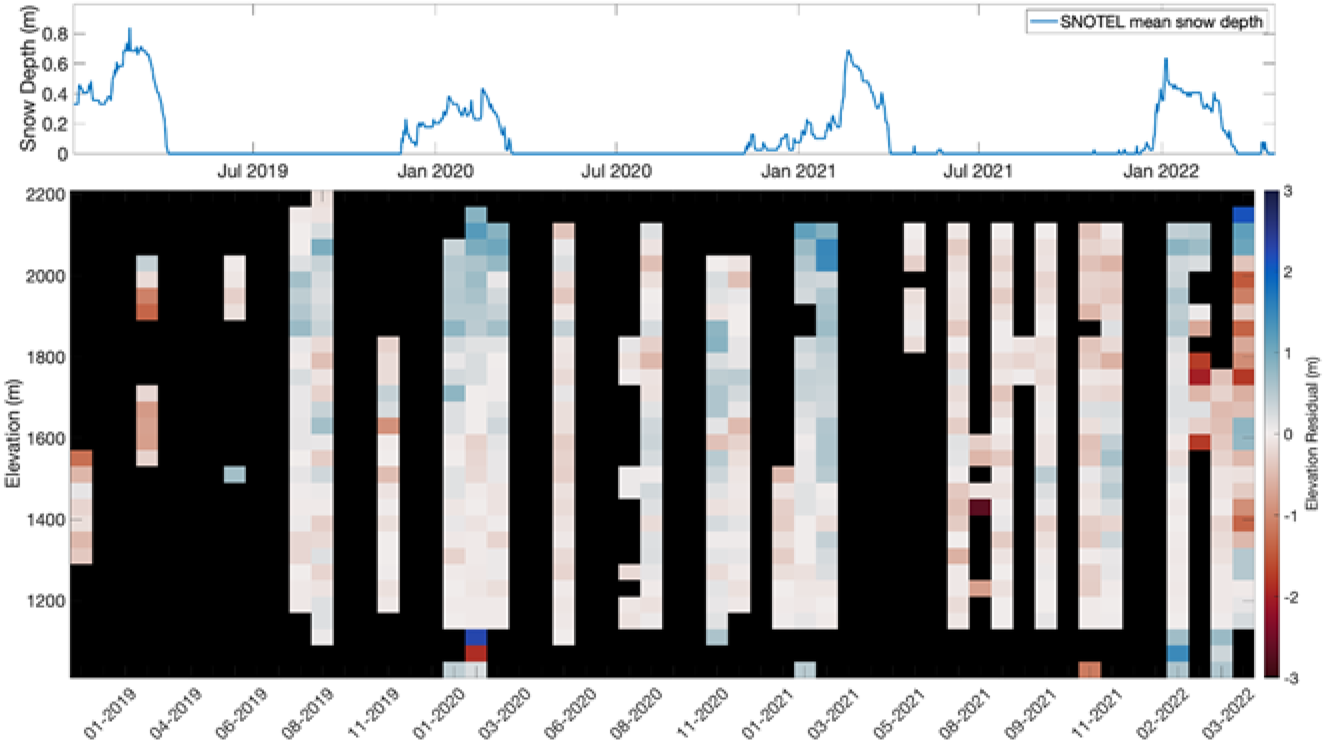




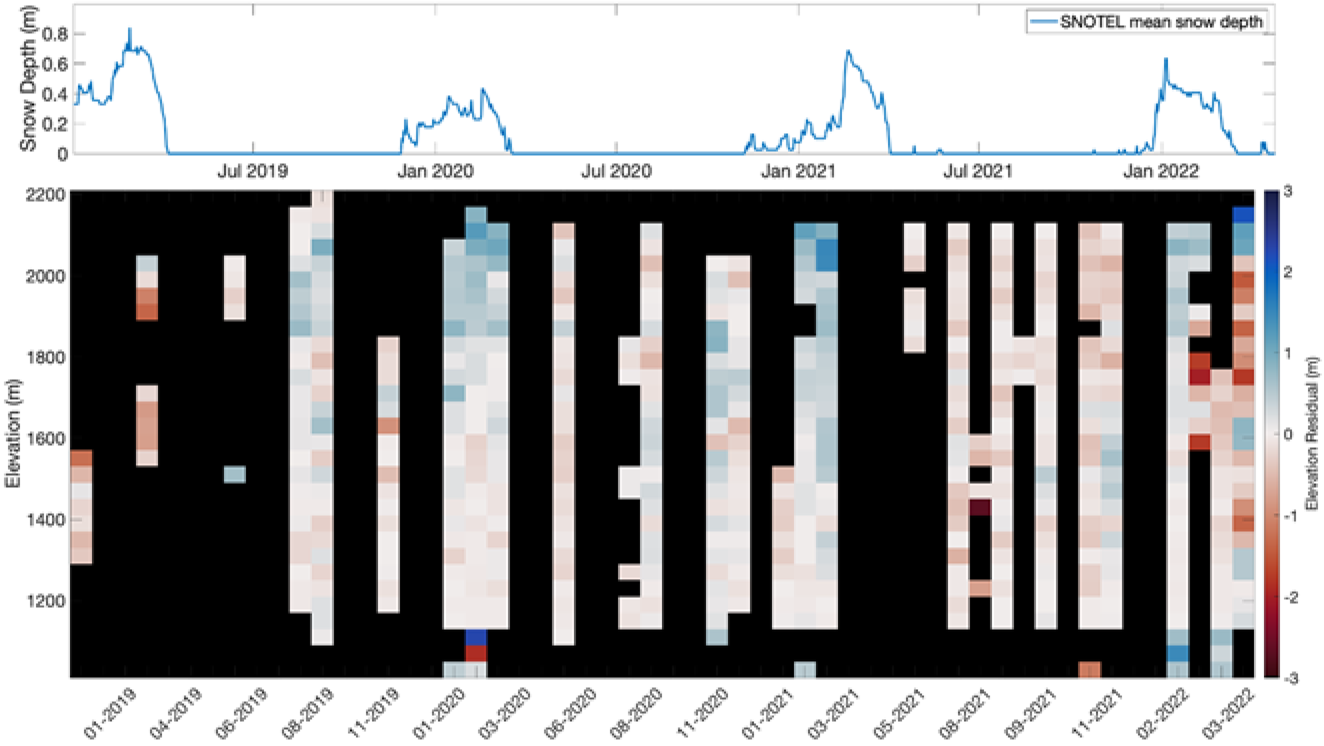
Orographic patterns in ICESat-2 snow signal!

Reynolds





ICESat-2 Snow Depth tracks - Reynolds



Thank You!

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