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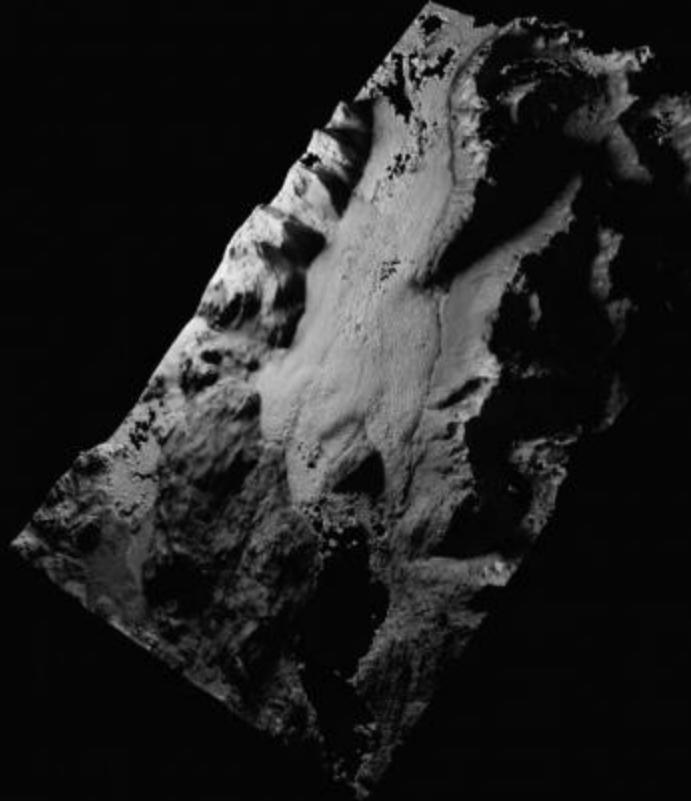
Remote Sensing of  
Environment Group

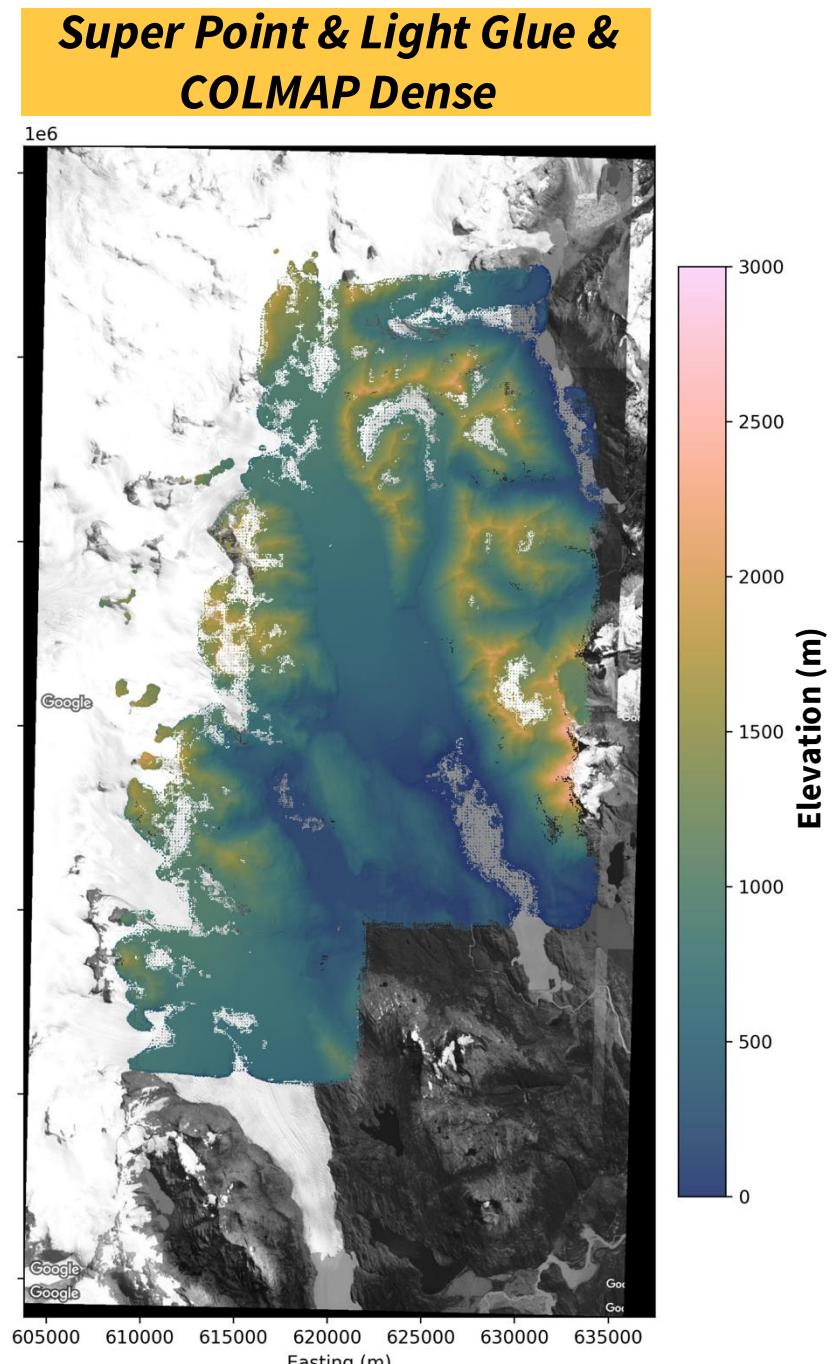
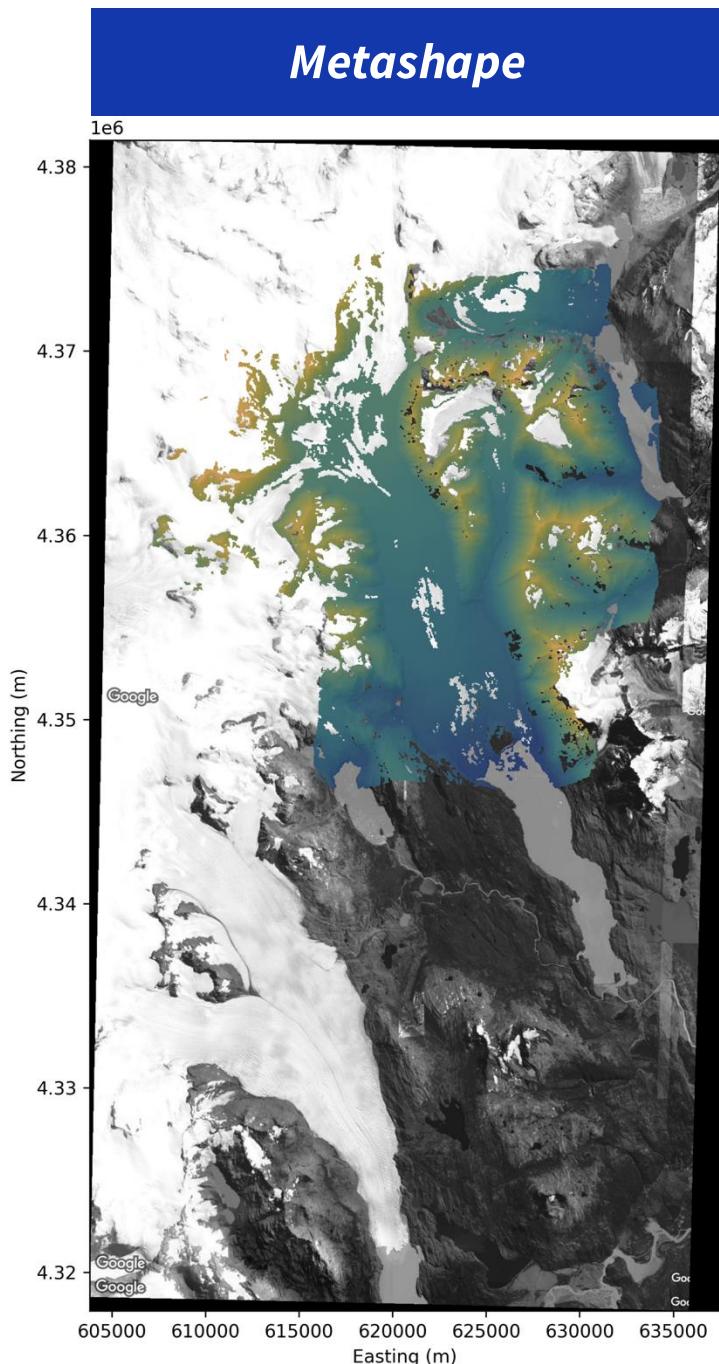
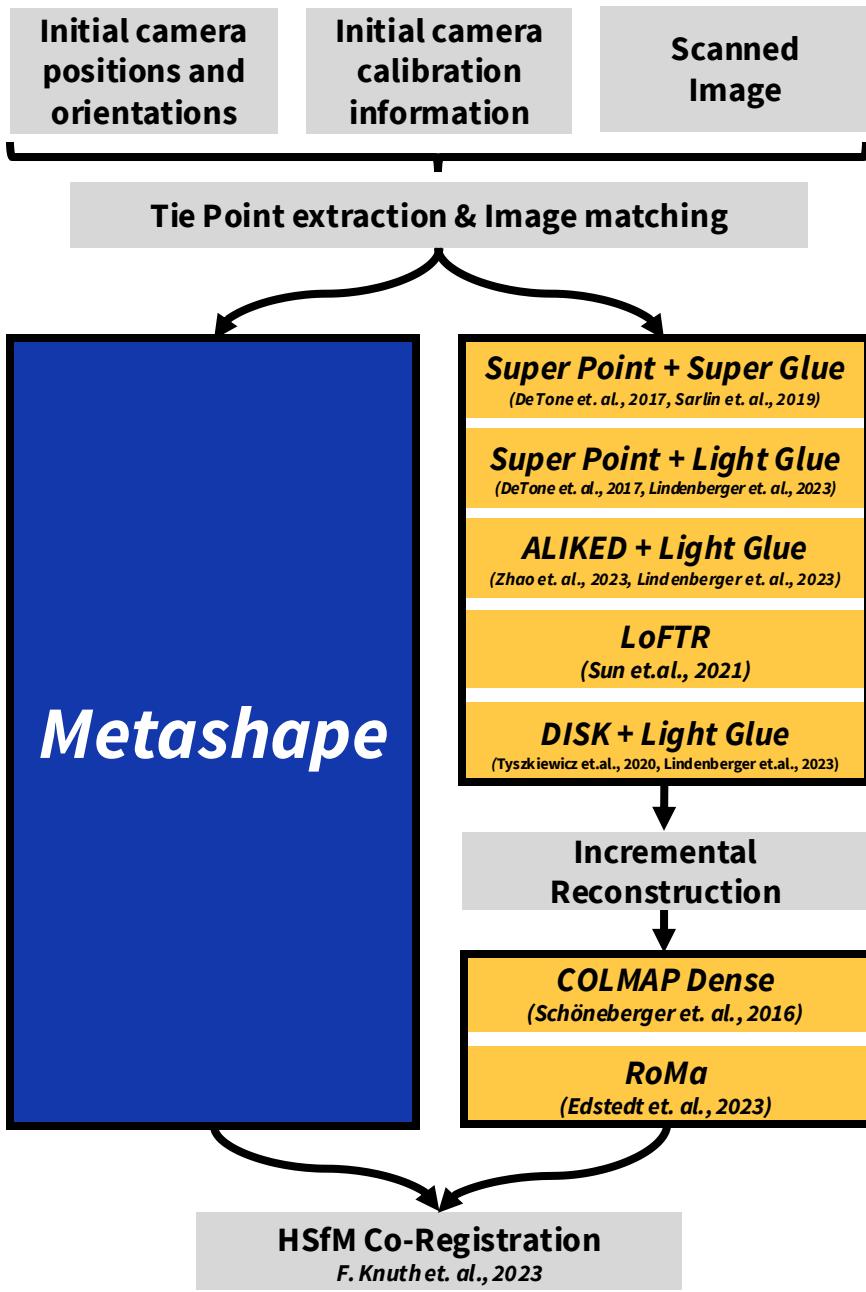
# Advances in Historical Aerial Image Analysis: *Boosting SfM Pipelines with Learned Models*

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Francesco Ioli, Jan Dirk Wegner, Inés Dussaillant,  
Camilo Rada, Livia Piermattei



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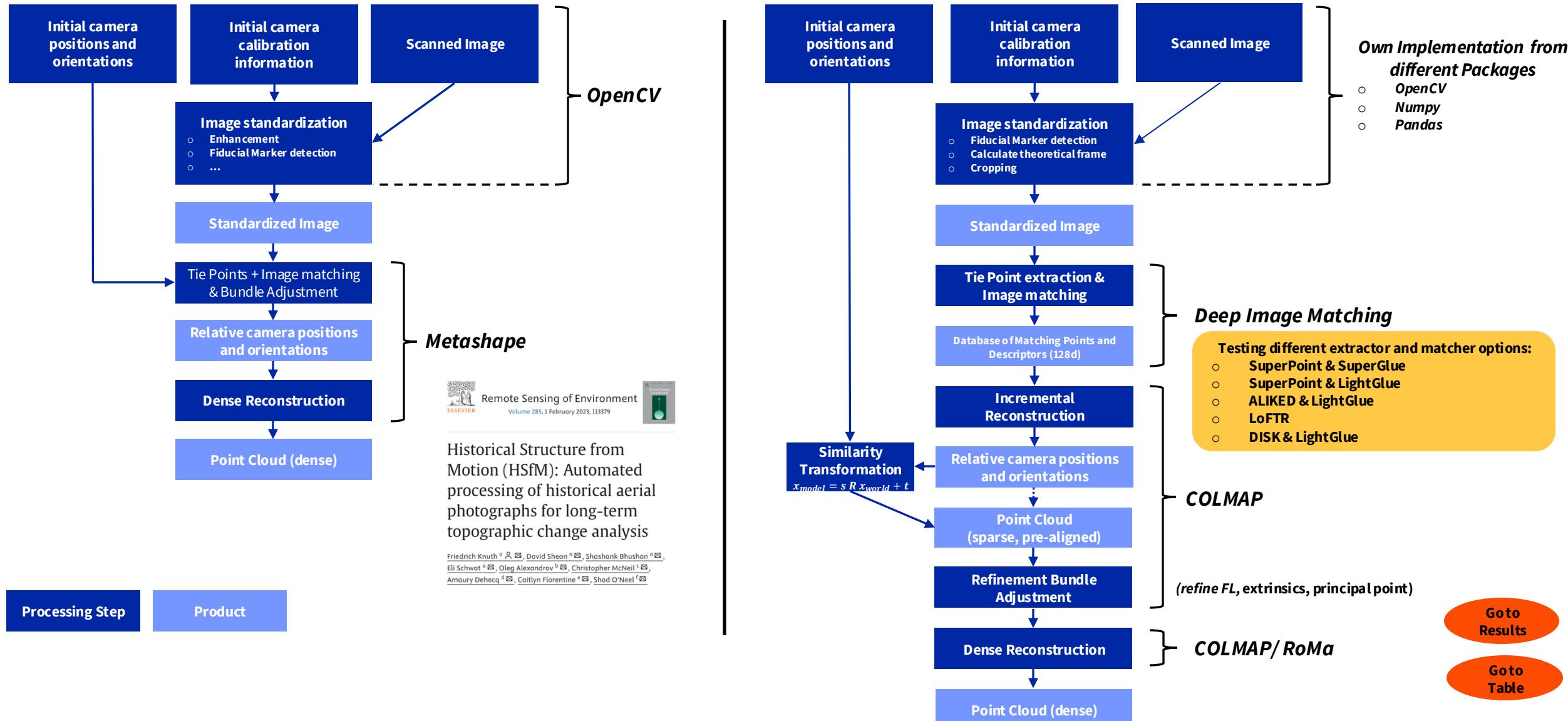


**Lucas Kugler – [lucas.kugler@geo.uzh.ch](mailto:lucas.kugler@geo.uzh.ch)**

# On-Site Presentation

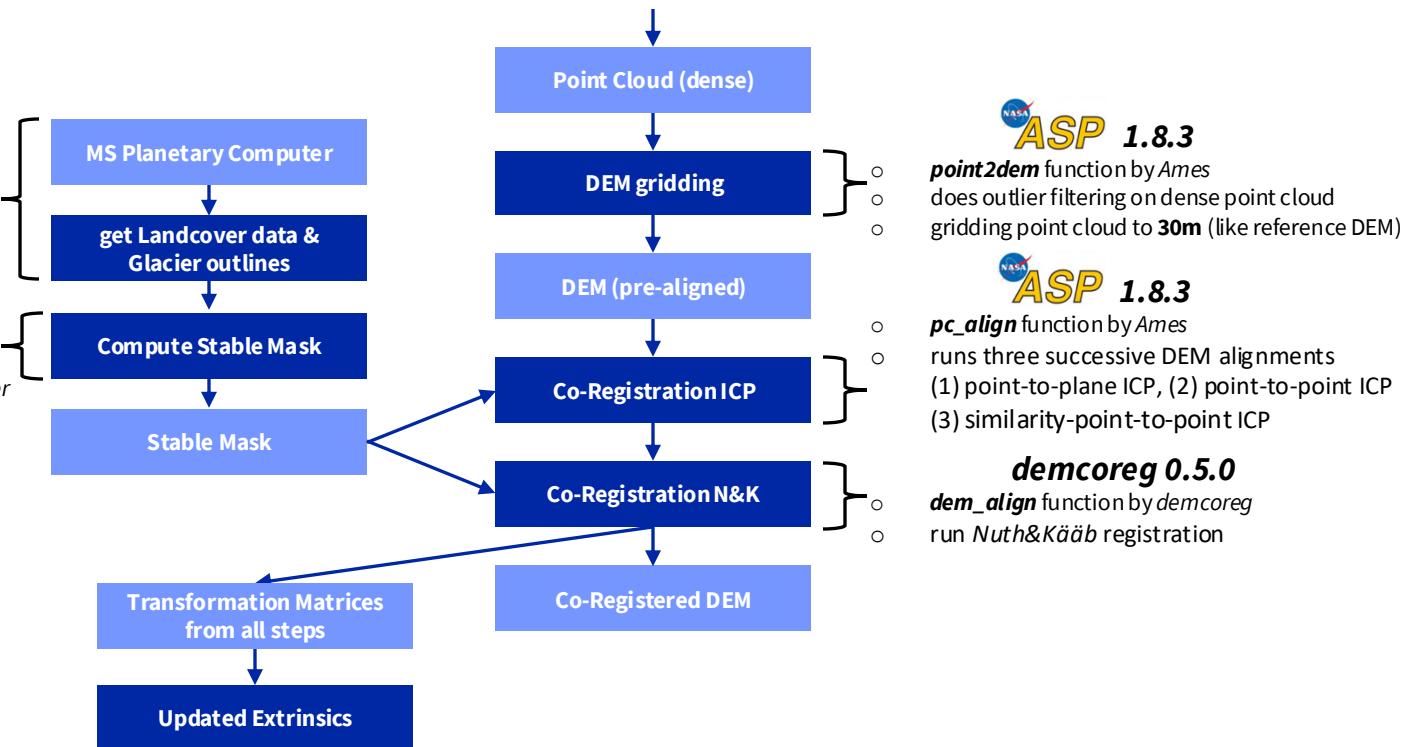
**Advances in Historical Aerial Image Analysis:  
*Boosting SfM Pipelines with Learned Models***

# Advances in Historical Aerial Image Analysis: Boosting SfM Pipelines with Learned Models



# The Co-Registration (HSfM, F. Knuth et. al., 2023)

- Land cover: *ESA world cover*
- Ref DEM: *Copernicus-Glo30*



Scheme shows the (updated) steps of the Gridding & DEM Co-registration from the HSfM pipeline.

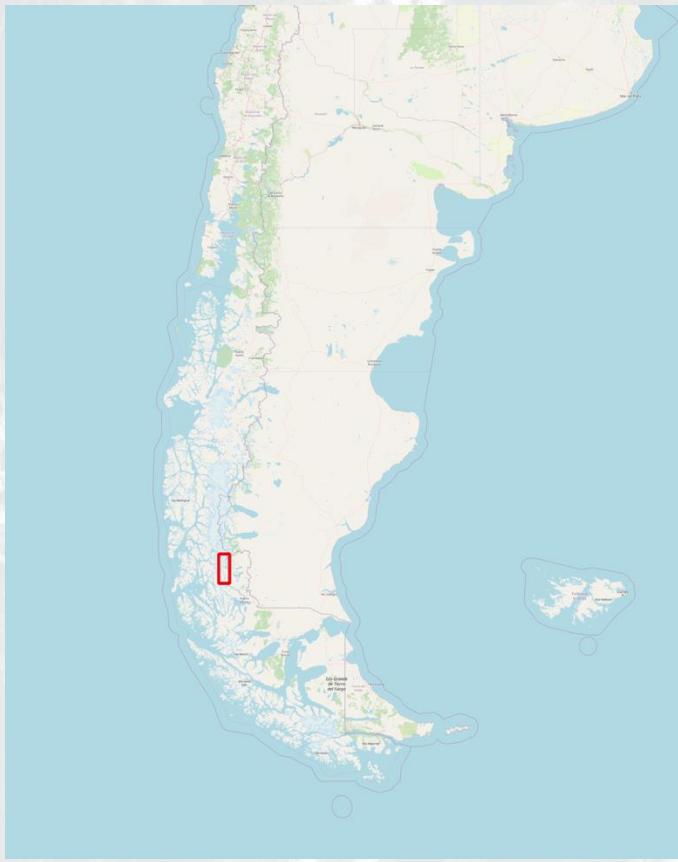
Core part is the three-fold ICP co-registration with ASP and the subpixel refinement of the co-registration using the Nuth & Käab implementation in `demcoreg`

Processing Step

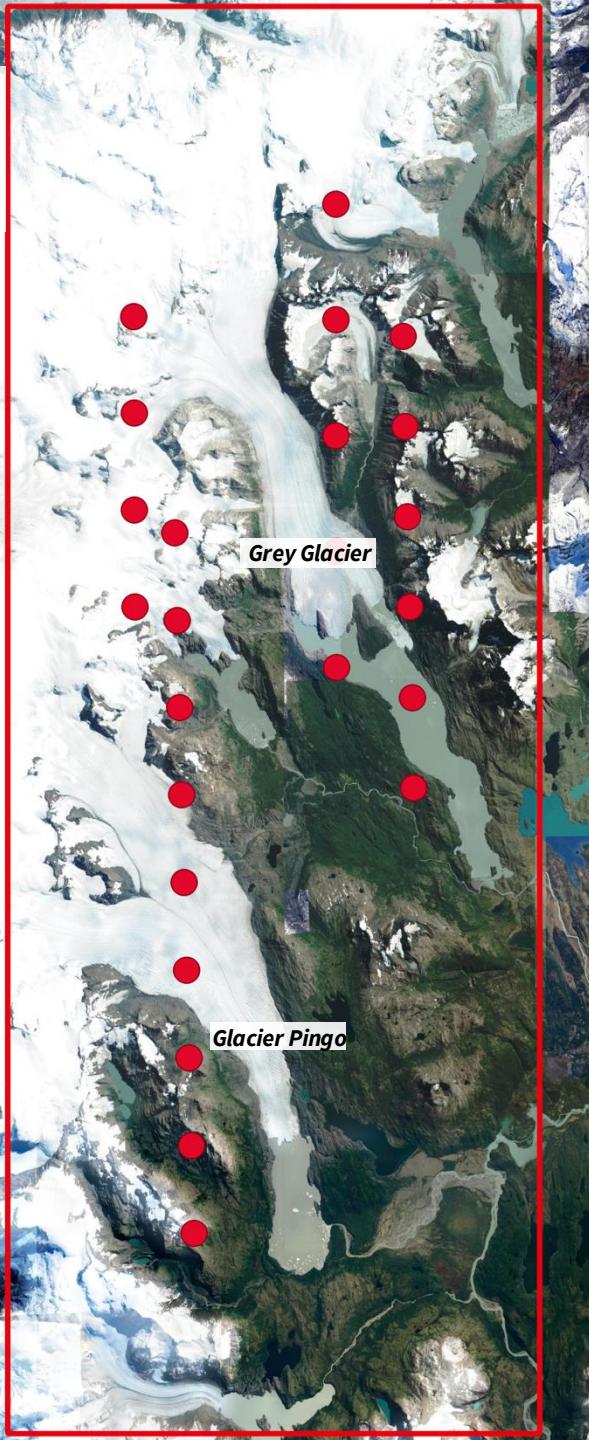
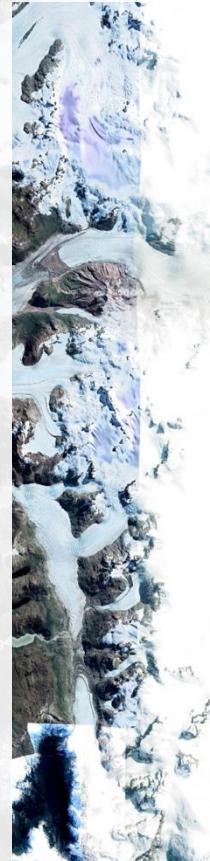
Product

[1] Randolph Glacier Inventory - A Dataset of Global Glacier Outlines  
<https://nsidc.org/data/nsidc-0770/versions/6>

# Study Site: Grey Glacier & Glacier Pingo



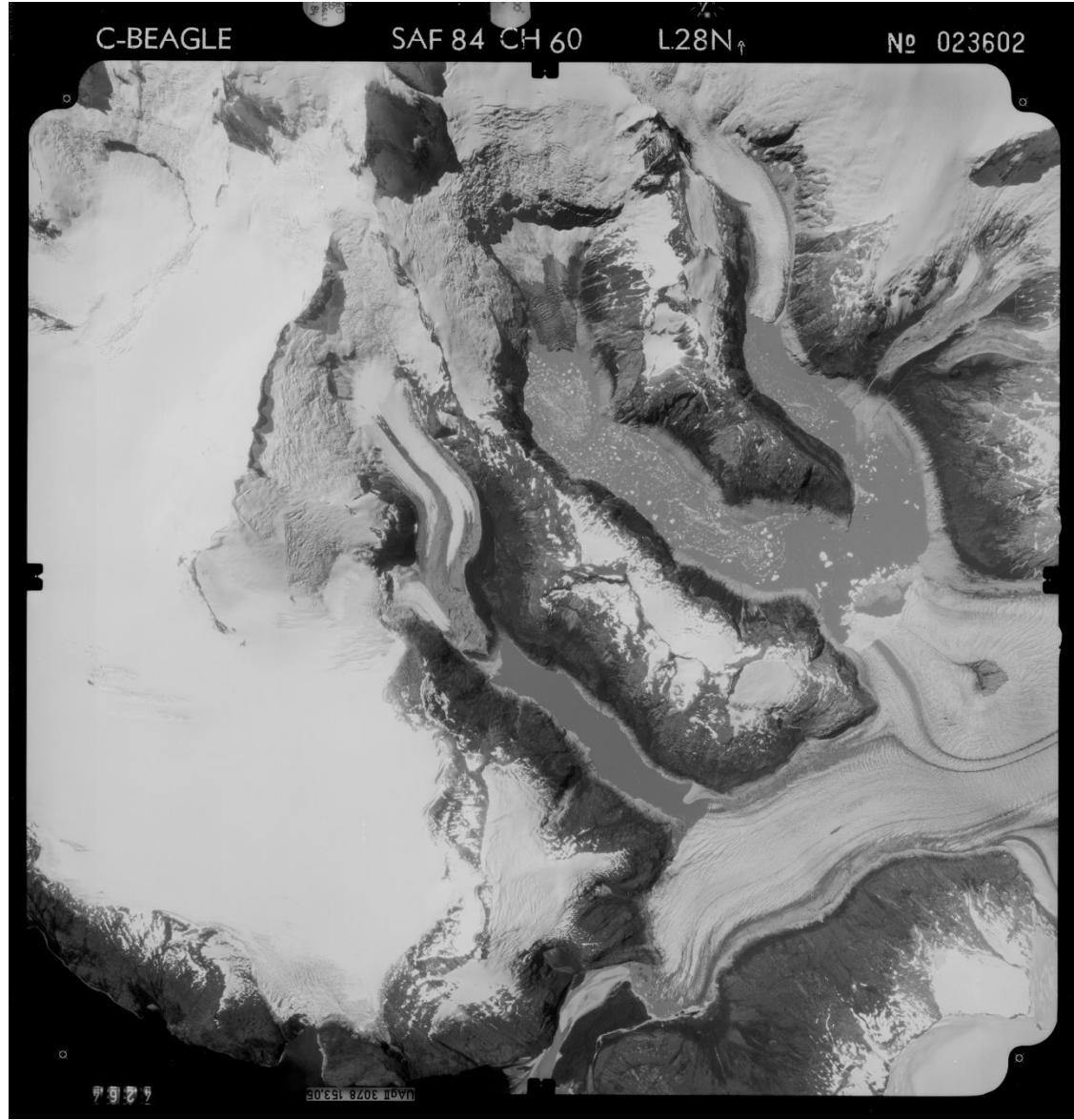
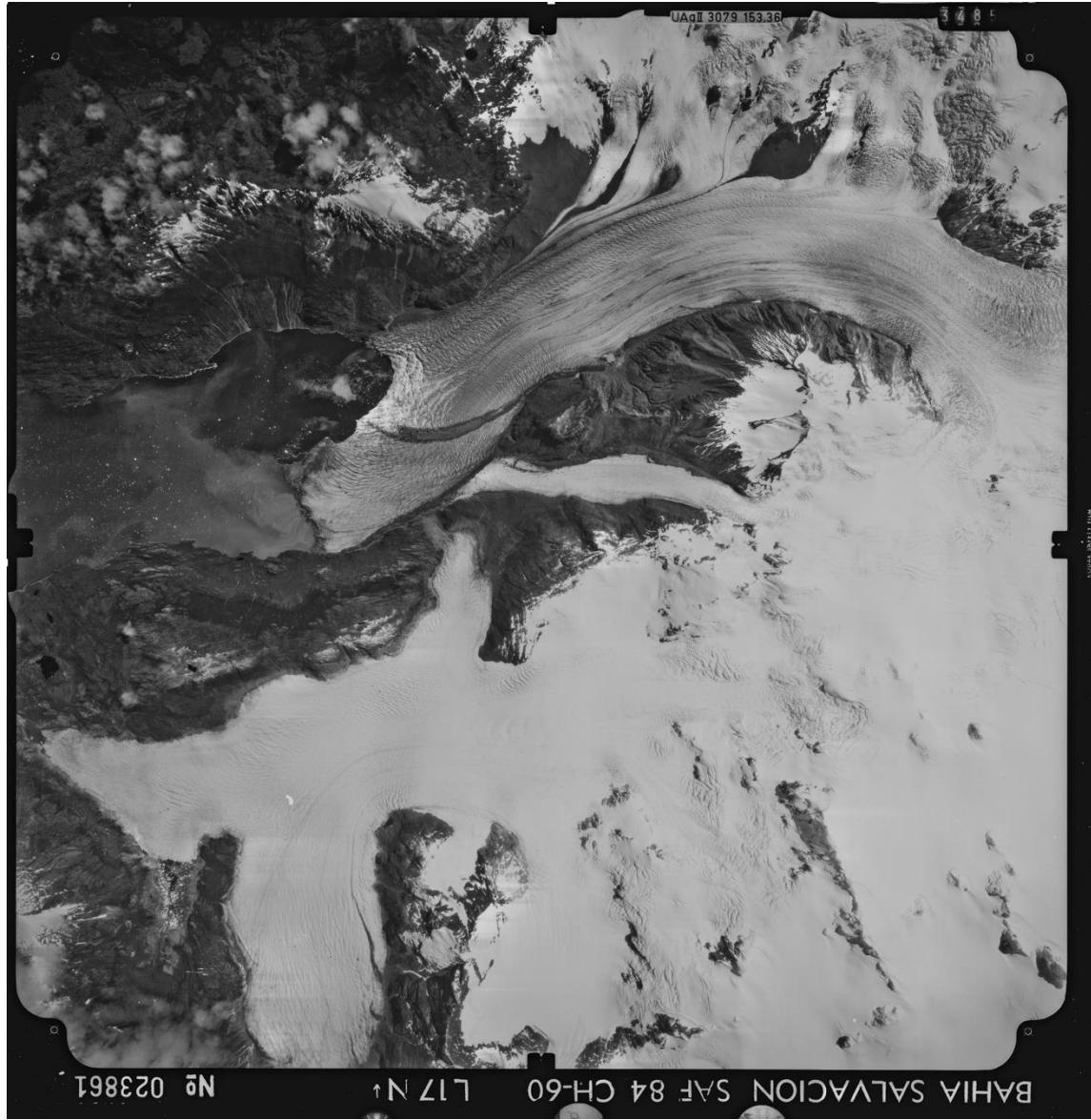
*Location of study site in Patagonia (Chile)*



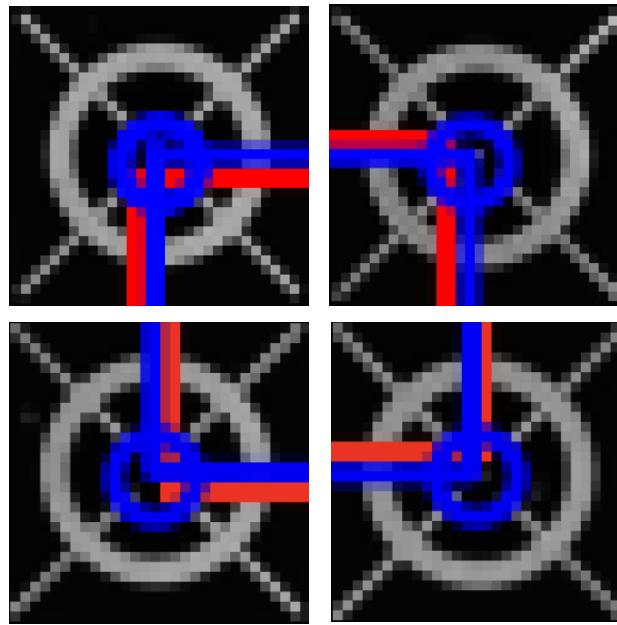
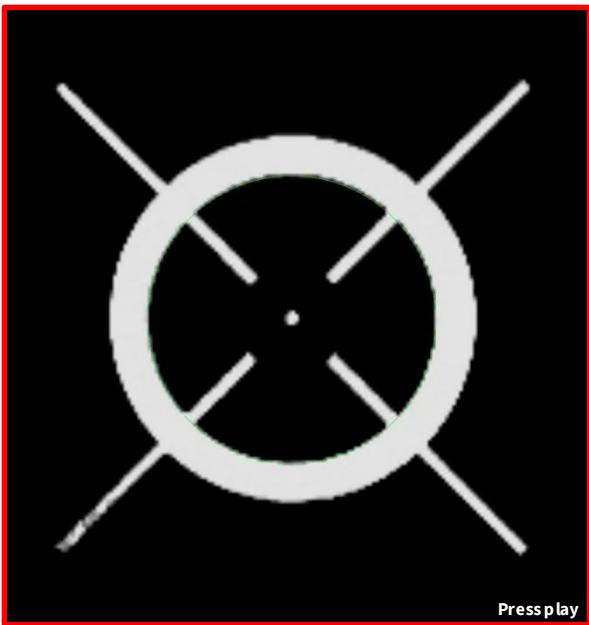
- glaciers are in *Torres del Paine National Park* in Chile (Southern Patagonian Ice Field)
- study site cover  $\approx 752\text{km}^2$
- 24 historical scanned images from two different flight campaigns
- image resolution  $\approx 1.5\text{m}$
- acquisition date 1980

**red dots** → foot print image location

# Data examples:



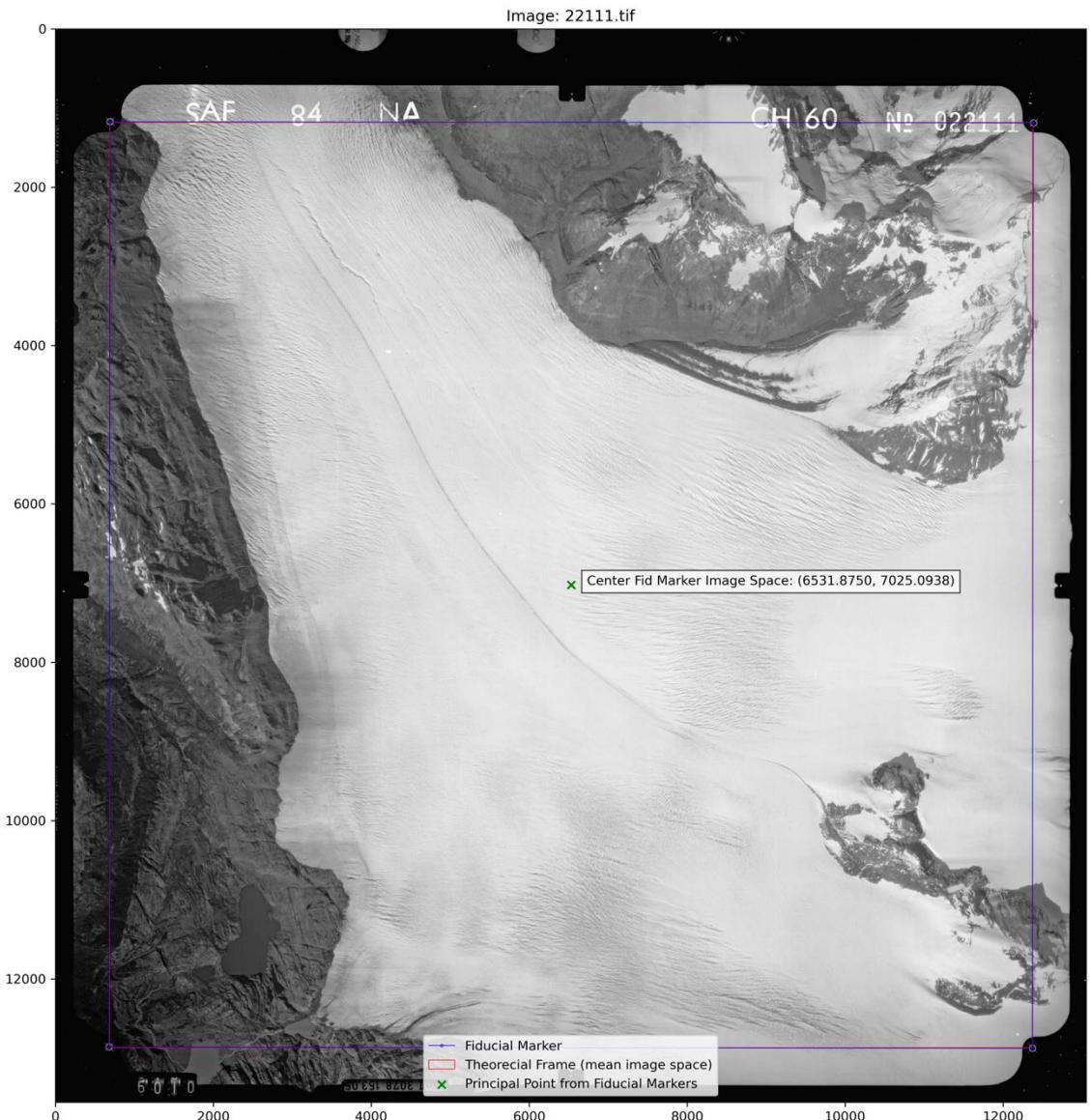
# Pre-Processing: Fiducial Marker Detection



1. find circle candidates using *Hough Transform*.
2. score pairs by pixel variance and centroid distance.
3. define regions around centroids with assumed white center points.
4. use *OPTICS* to cluster and identify anomaly hotspots.

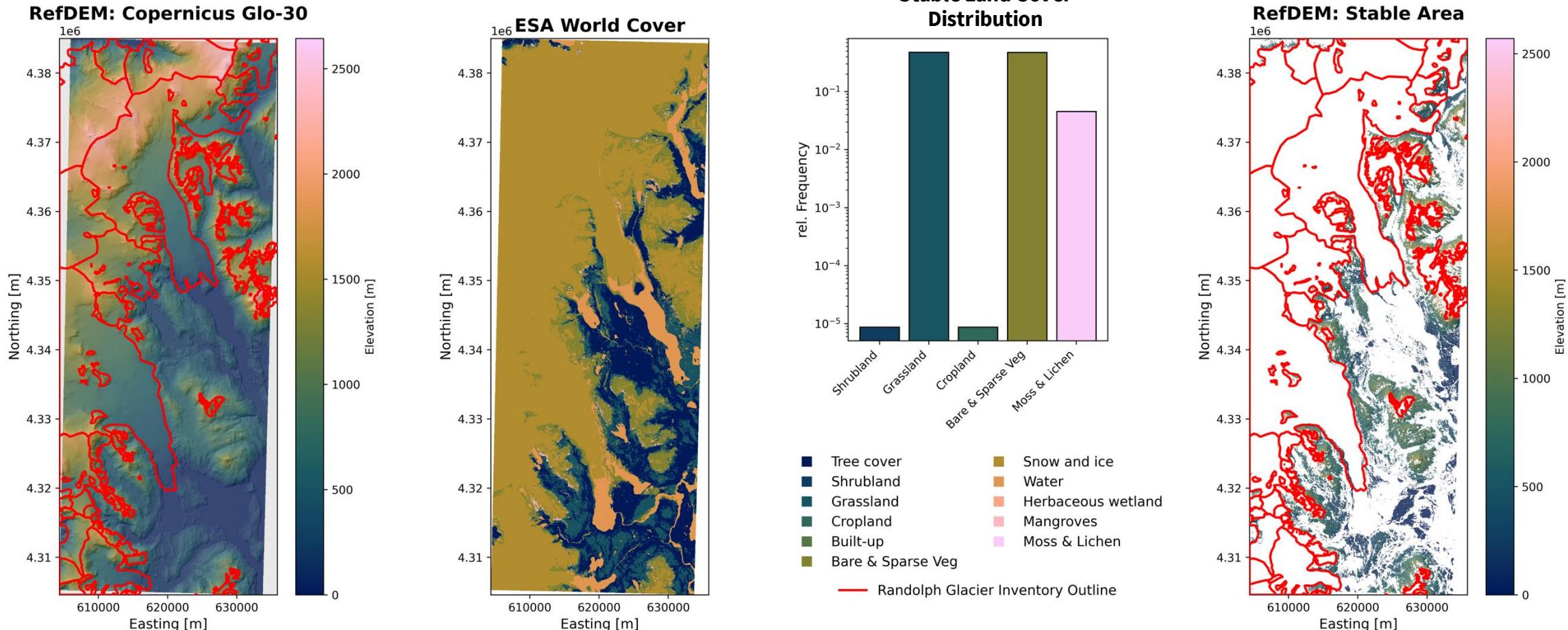
Screenshot example for detected image space (**blue**) and actual cropped frame (**red**).

The actual cropped frame is equal across all images and is currently calculated by the median size across all images



# Results: Stable Mask generation

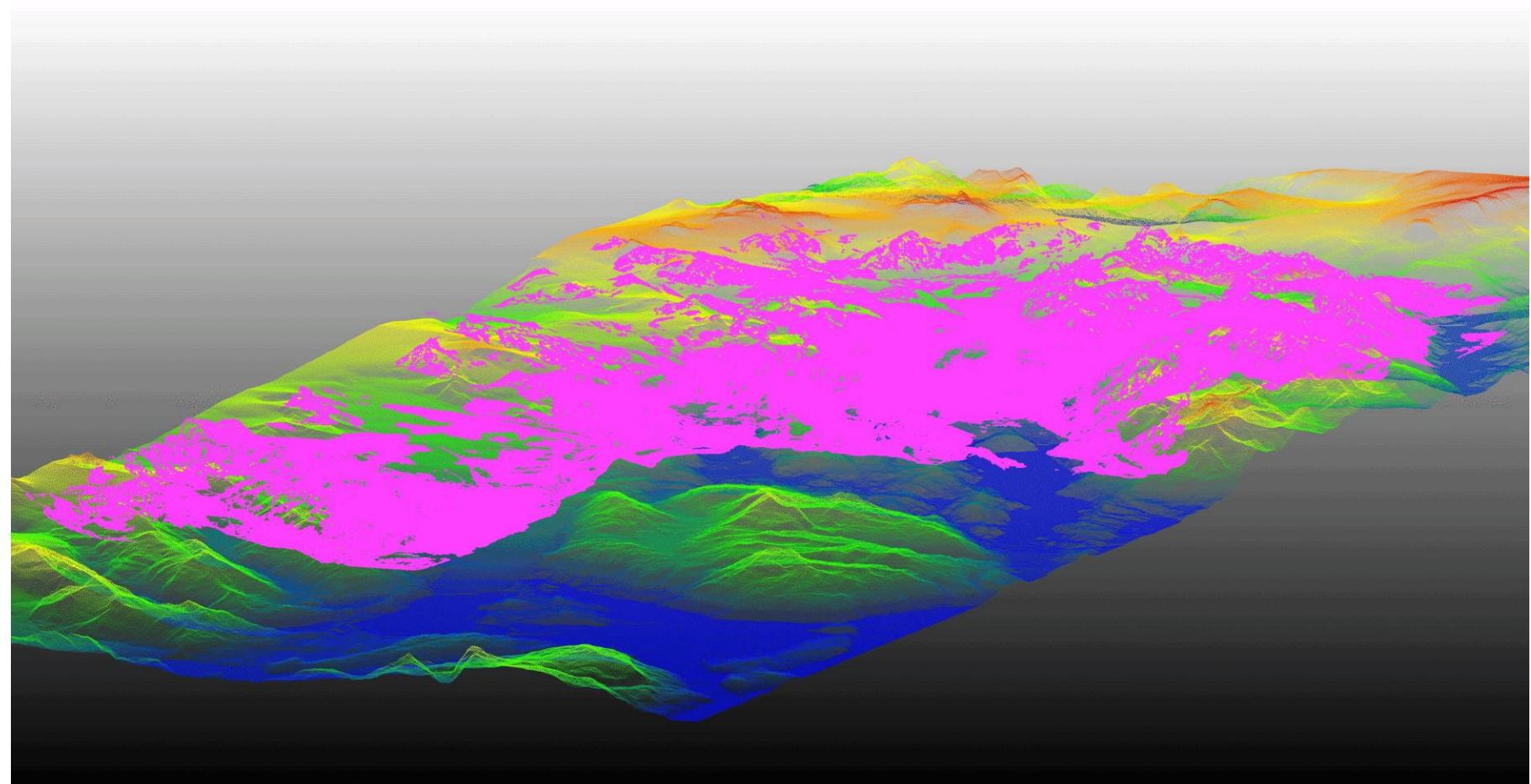
- using *ESA world cover* as land cover data for stable mask generation
- assuming that the classes **Shrubland, Grassland, Cropland, Bare & Sparse Vegetation, Moss & Lichen** are stable surfaces
- final mask processed with land cover data combined with *Randolph Glacier Inventory 6.0* outlines



# Results: Visualisation of HSfM Co-Registration (Knuth et. al., 2023)

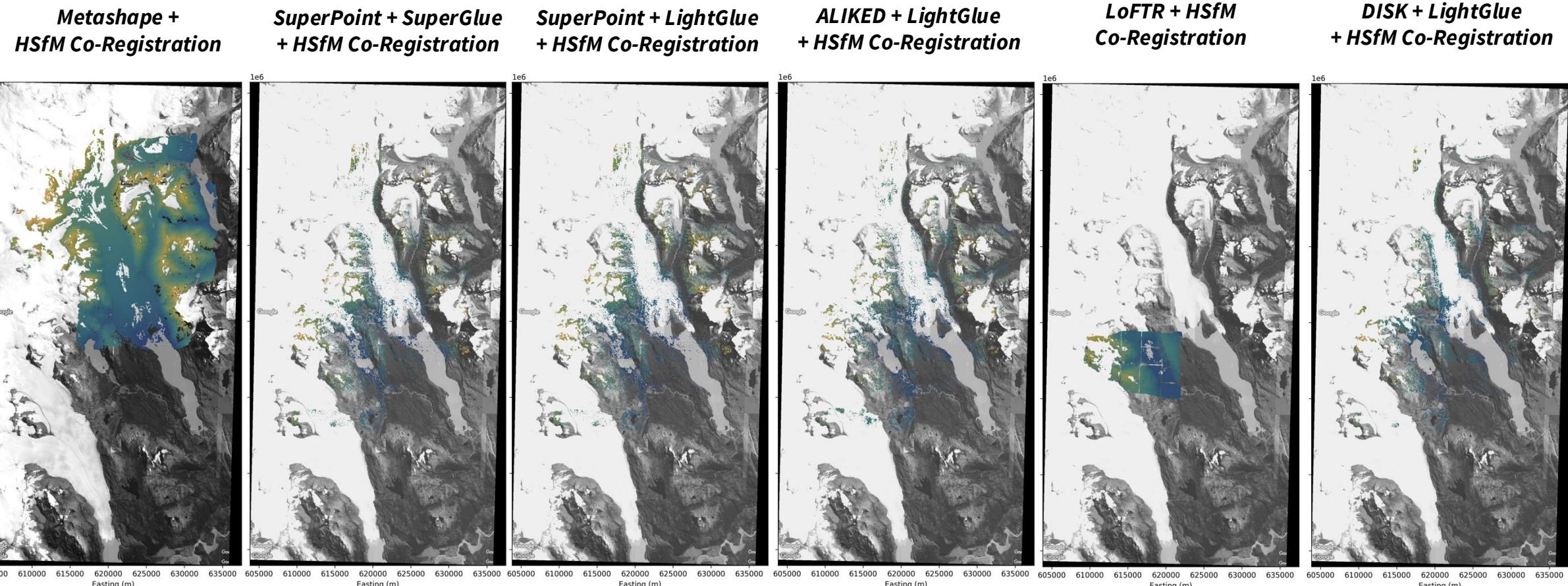
- **visualisation of the Co-Registrations steps in HSfM**

1. **Initial Alignment** (using image footprint information and flight height rumors)
2. **ICP Point-to-Plane** (ASP, pc\_align)
3. **ICP Point-to-Point** (ASP, pc\_align)
4. **ICP Point-to-Plane** (ASP, pc\_align with stable mask)
5. **Nuth & Kääb** (demcoreg, dem\_align, using stable mask)



pink represents historical point cloud,  
background point cloud shows CopernicusGlo-30

# Test Results: DEM comparison

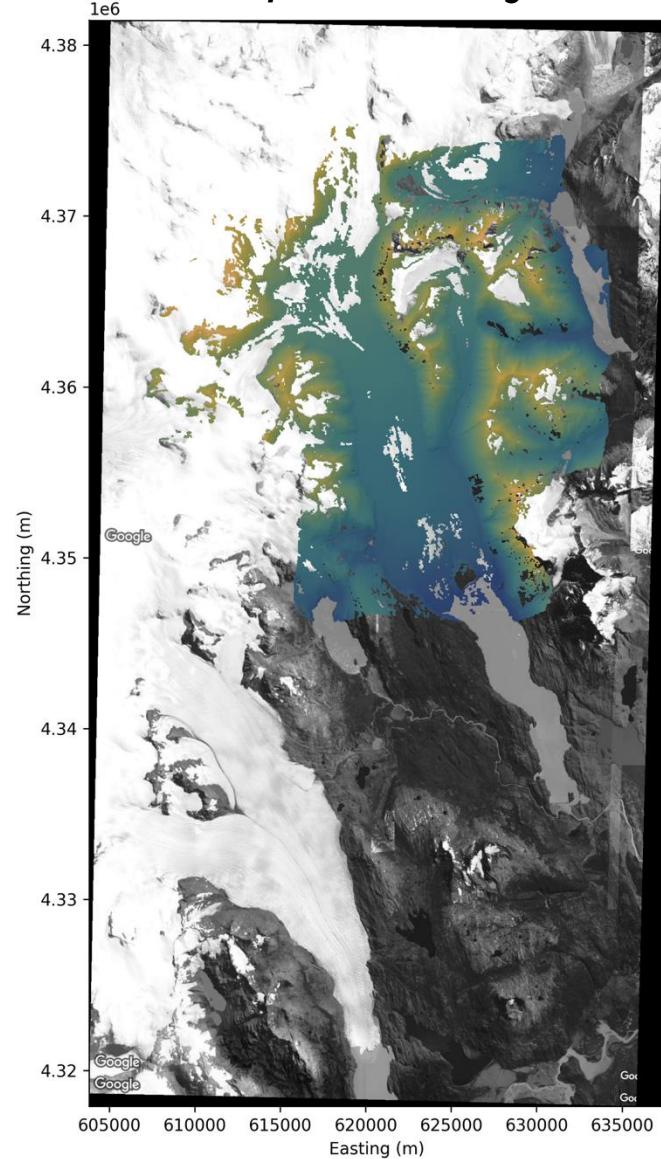


[Go to DEM maps](#)

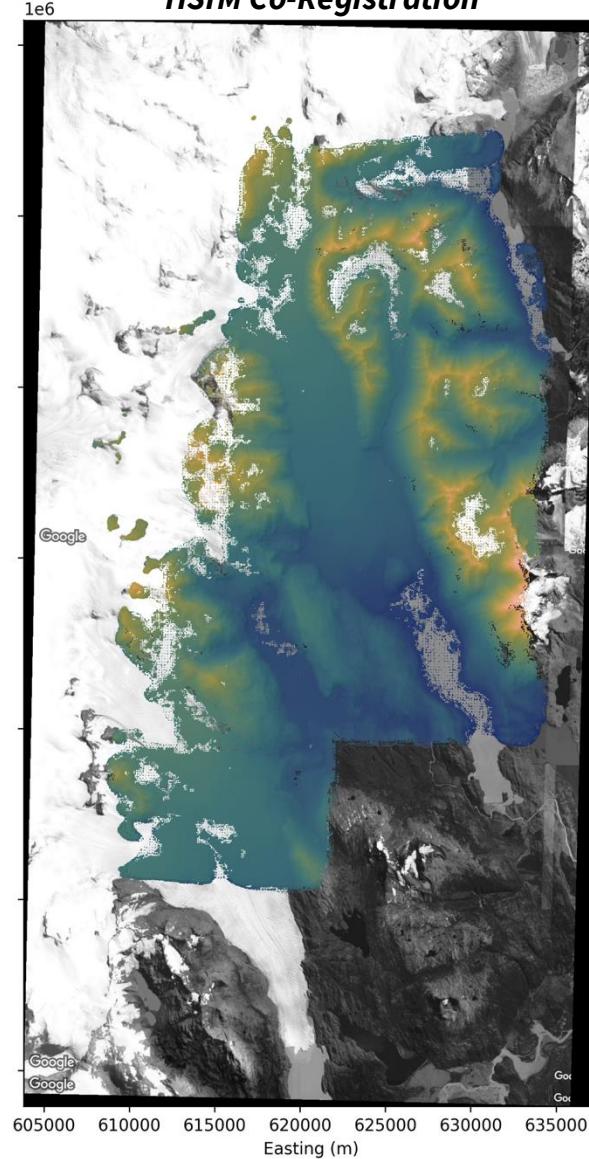
Image source: Google Earth

# Test Results: DEM comparison

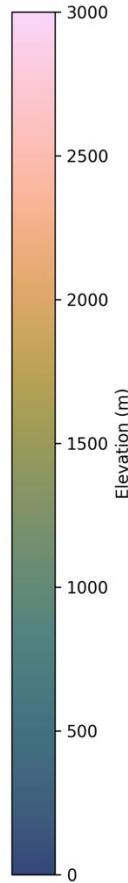
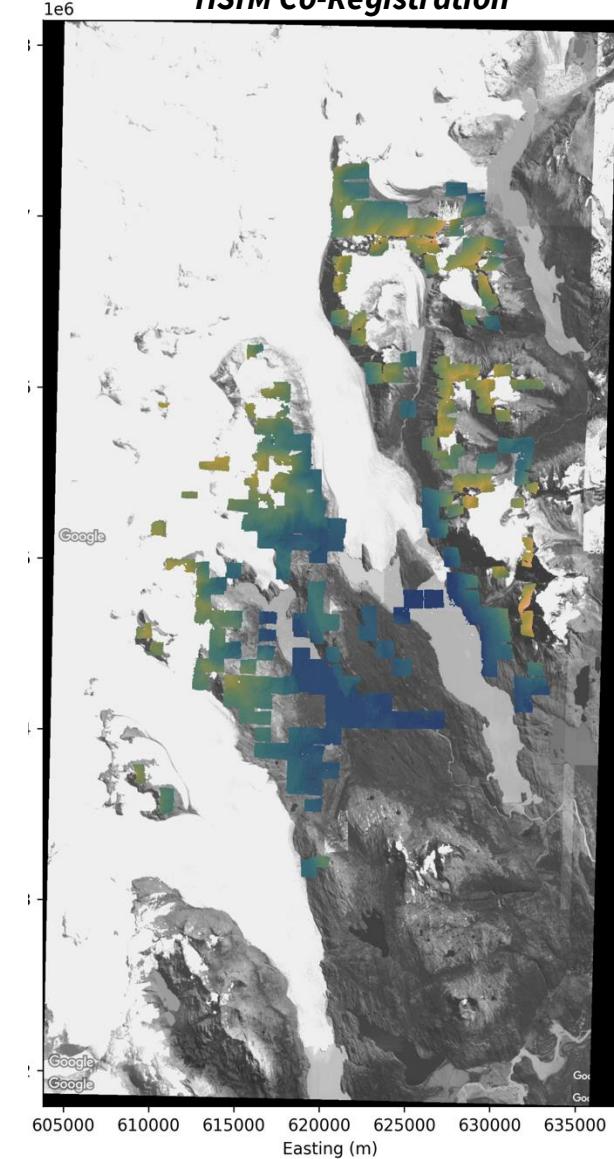
*Metashape + HSfM Co-Registration*



*SuperPoint + LightGlue + COLMAP Dense + HSfM Co-Registration*

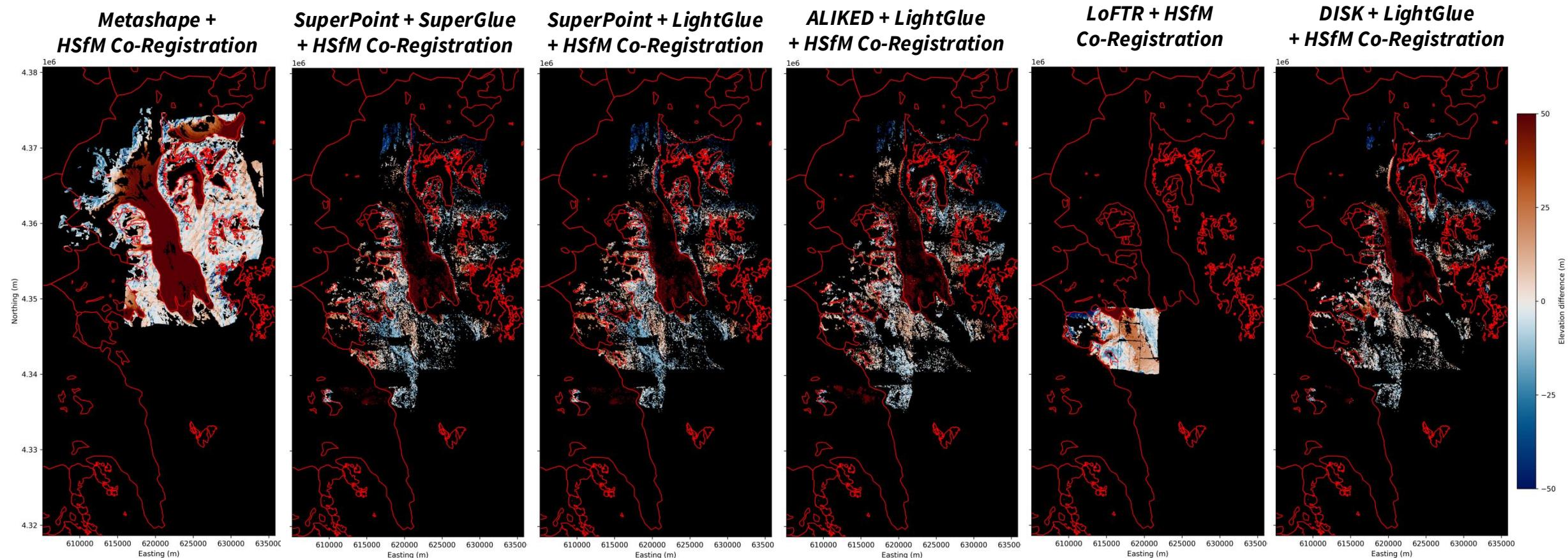


*SuperPoint + LightGlue + RoMa Dense + HSfM Co-Registration*



**Image source: Google Earth**

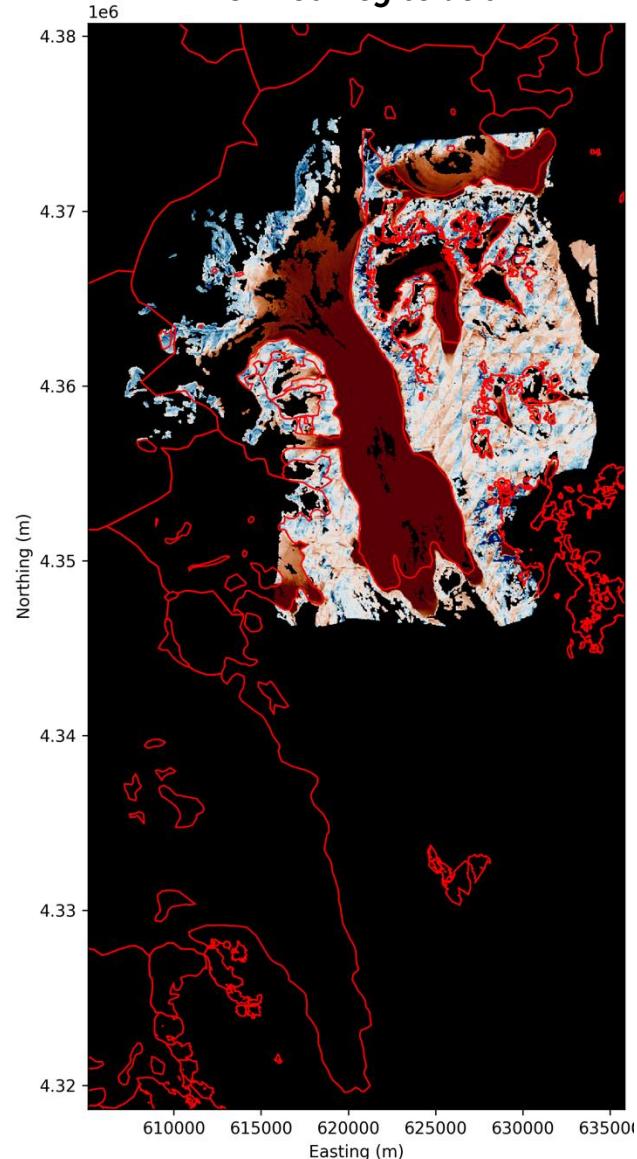
# Test Results: DEM difference comparison



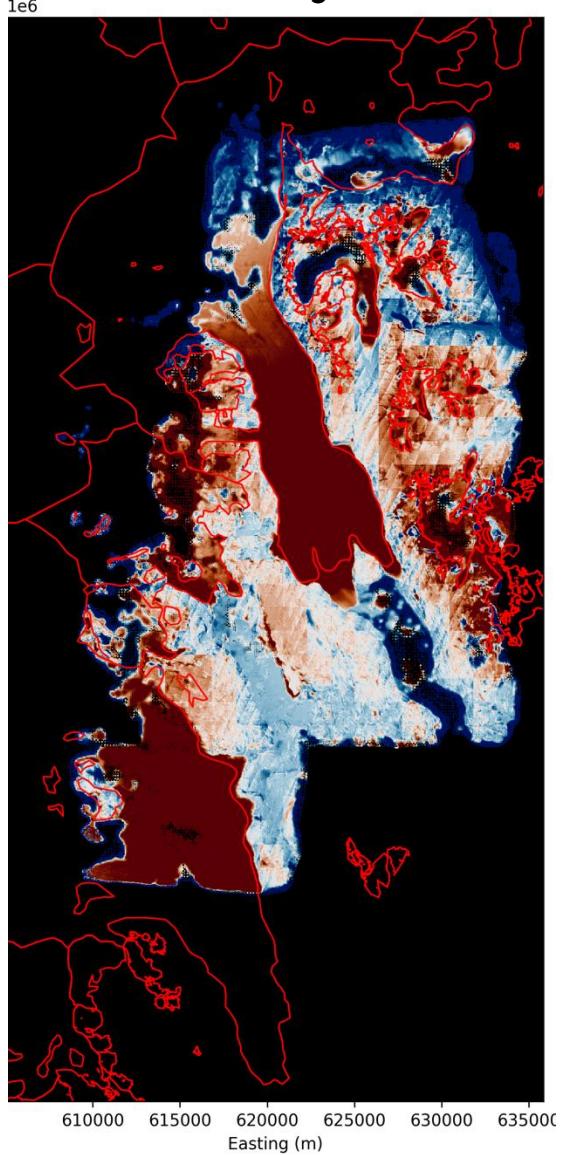
[Go to DEM maps](#)

# Test Results: DEM difference comparison

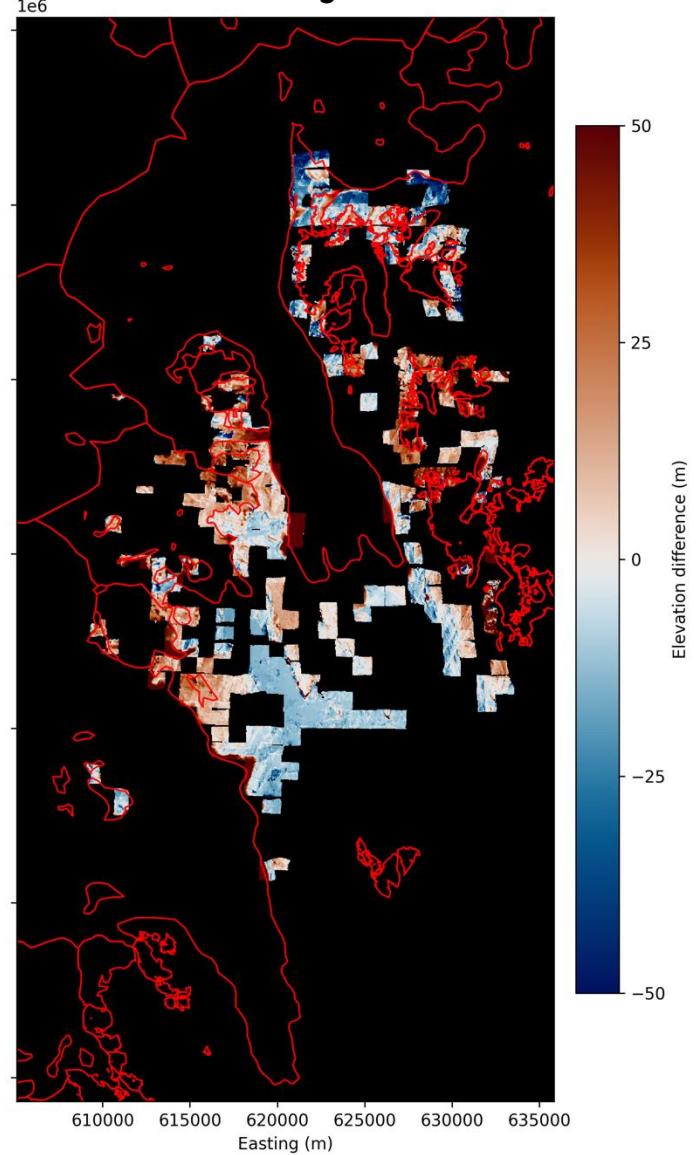
*Metashape +  
HSfM Co-Registration*



*SuperPoint + LightGlue + COLMAP Dense +  
HSfM Co-Registration*



*SuperPoint + LightGlue + RoMa Dense +  
HSfM Co-Registration*



# Test Results: Comparison

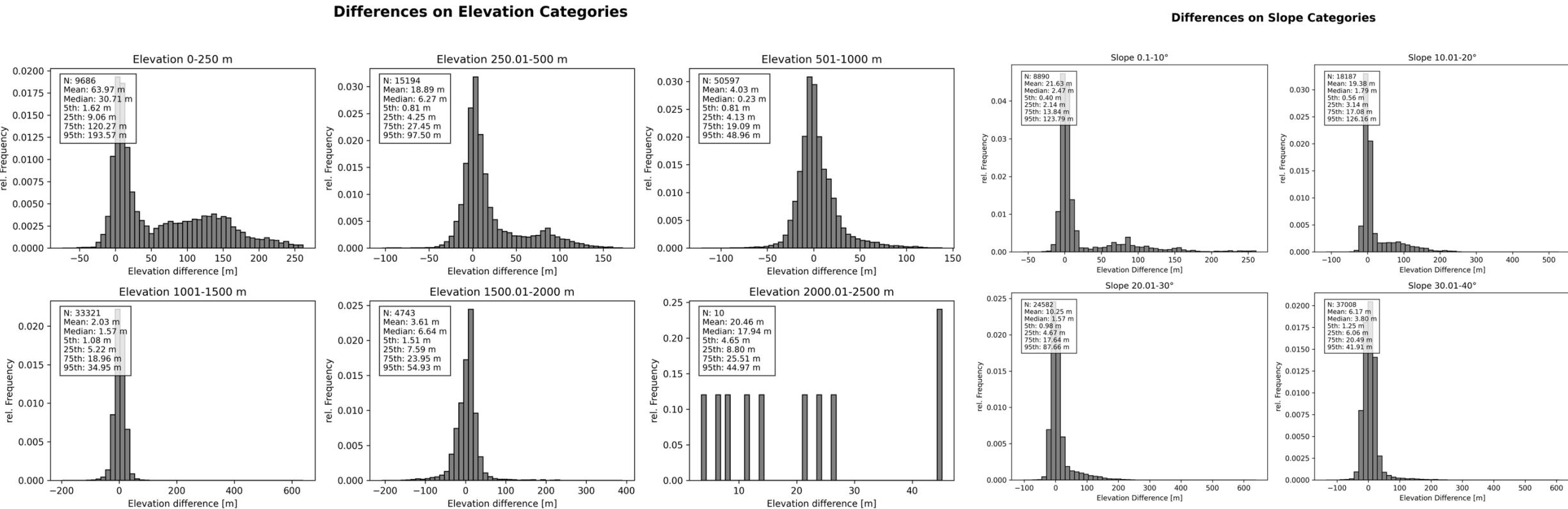
	Metashape + HSfM Co-Registration	SuperPoint + SuperGlue + HSfM Co-Registration	SuperPoint + LightGlue + HSfM Co-Registration	ALIKED + LightGlue + HSfM Co-Registration	LoFTR + HSfM Co-Registration	DISK + LightGlue + HSfM Co-Registration	SuperPoint + LightGlue + COLMAP Dense + HSfM Co-Registration	SuperPoint + LightGlue + RoMa Dense + HSfM Co-Registration
Reconstruction	<b>Aligned Images</b>	11/24	20/24	20/24	20/24	2/24	20/24	20/24
	<b>unique stereo matches</b>	-	74	85	74	-	73	?
	<b>reprojection error (Bundle Adjustment)</b>	1.58 px	1.97 px	1.96 px	1.79 px	1.69 px	1.78 px	1.96 px
	<b>Sparse Point Cloud (points)</b>	27,425 pts	46,617 pts	46,215	46,196 pts	171,238 pts	38,401 pts	-
	<b>Points Dense Point Cloud</b>	66,572,302 pts	-	-	-	-	603,028 pts	4,440,182 pts
	<b>Stable Area DEM Pixels</b>	?	?	?	?	?	?	?
	<b>Median (abs.) DEM Difference (Stable Landcover Locations)</b>	3.06 m	0.69 m	0.43 m	2.00 m	3.01 m	1.35 m	1.62 m
Co-Registration	<b>Mean (abs.) DEM Difference (Stable Landcover Locations)</b>	10.53 m	7.01 m	5.97 m	7.88 m	9.22 m	9.64 m	3.37 m
	<b>Quantile Error 5%</b>	0.94 m	1.22 m	1.38 m	1.15 m	1.05 m	0.94 m	1.37 m
	<b>Quantile Error 25%</b>	4.78 m	6.18 m	6.70 m	5.54 m	5.57 m	4.83 m	7.00 m
	<b>Quantile Error 75%</b>	21.31 m	24.96 m	26.62 m	25.90 m	21.11 m	24.69 m	31.27 m
	<b>Quantile Error 95%</b>	84.02 m	86.15 m	85.67 m	93.77 m	65.98 m	99.41 m	67.75 m

DEM results based on sparse point clouds

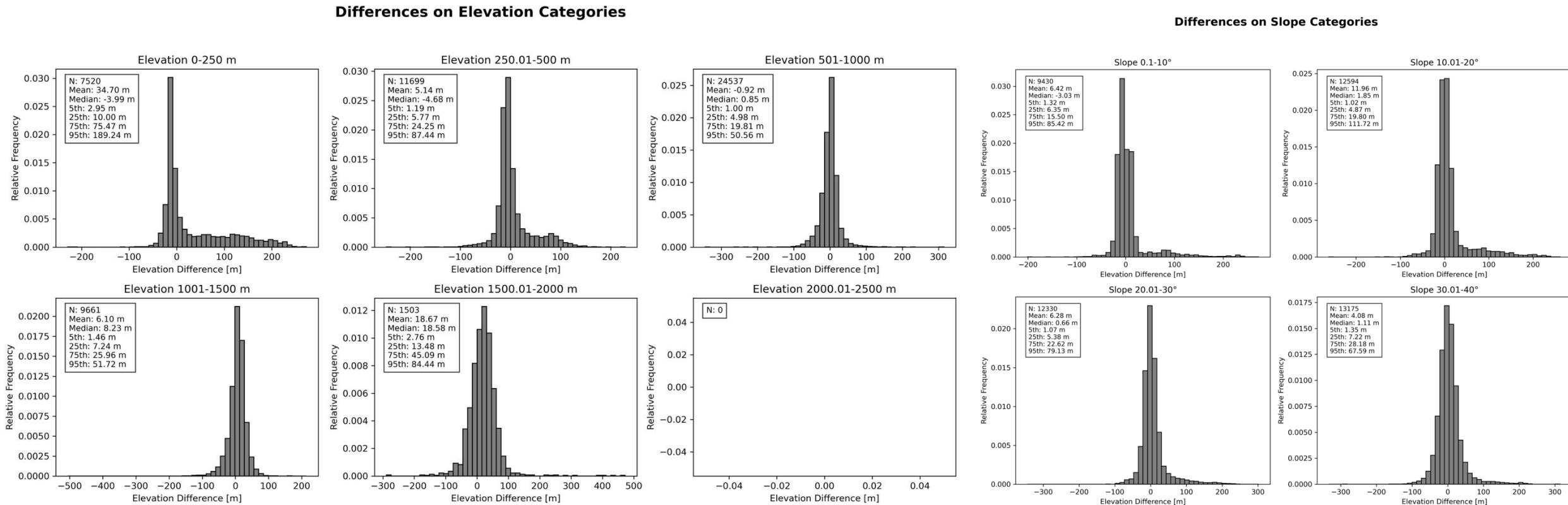
DEM results based on dense point clouds

# **Appendix**

# Test Result: Metashape + HSfM Co-Registration Final DEM comparison

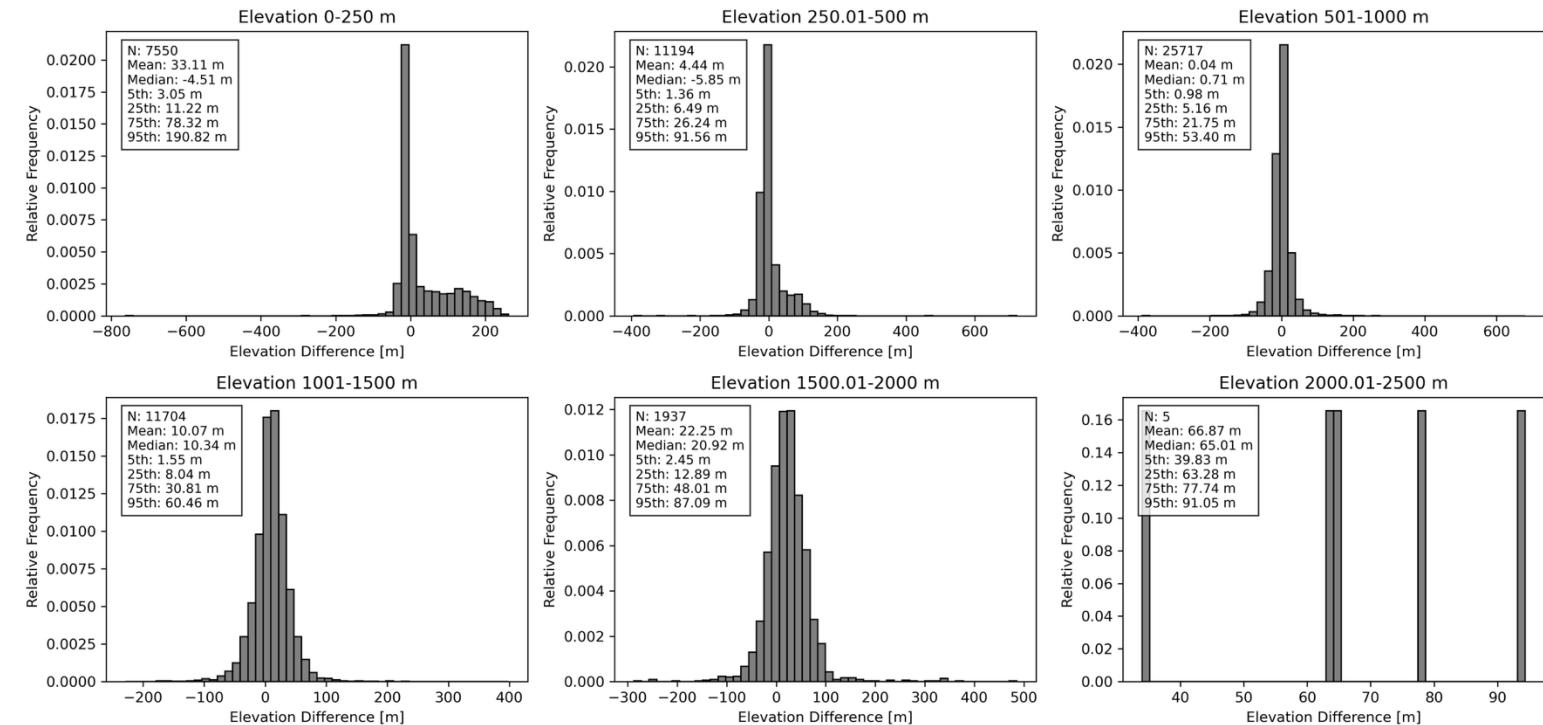


# Test Result: *SuperPoint* + *SuperGlue* + Final DEM comparison (no dense matching) (using HSfM Co-Registration)

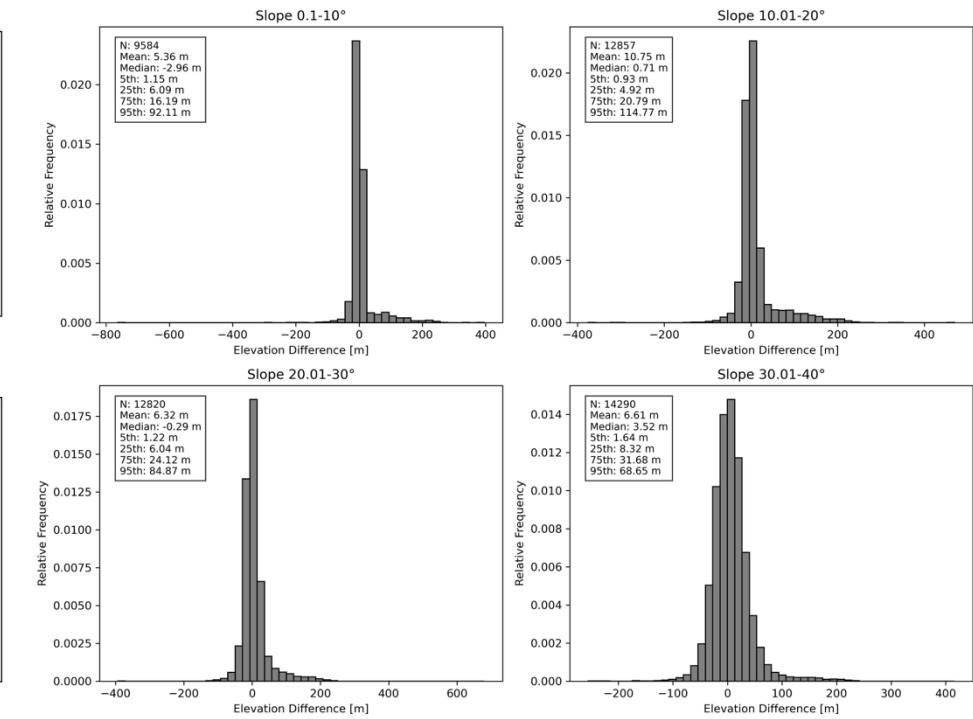


# Test Result: *SuperPoint + LightGlue + Final DEM* comparison (no dense matching) (using HSfM Co-Registration)

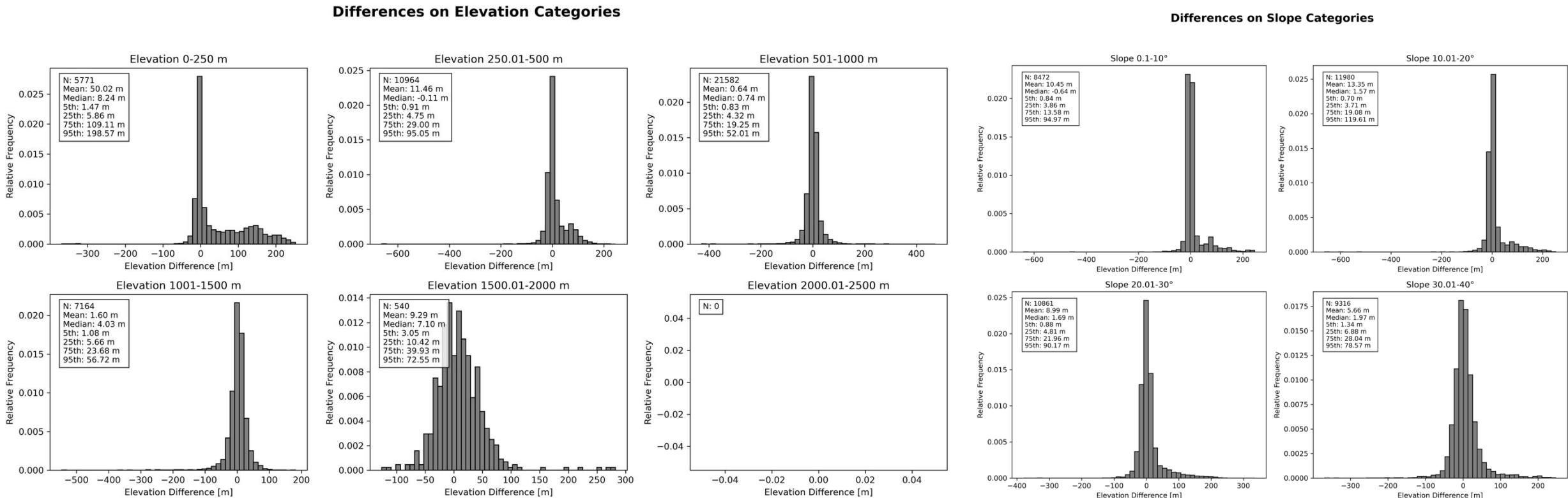
Differences on Elevation Categories



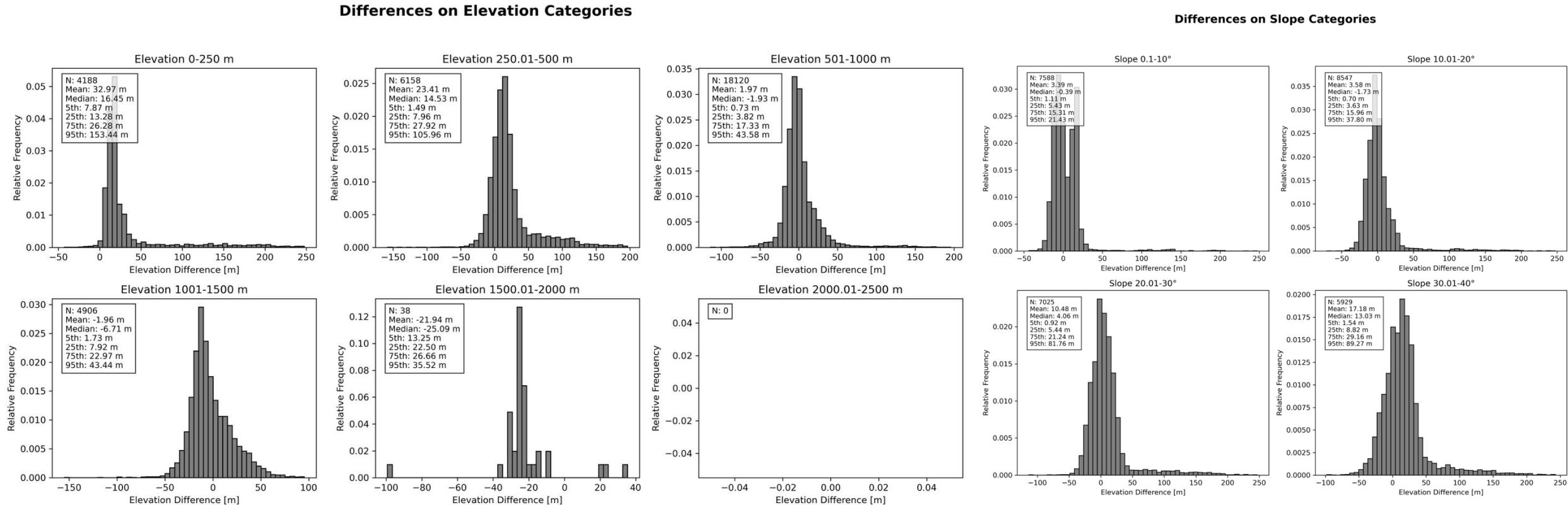
Differences on Slope Categories



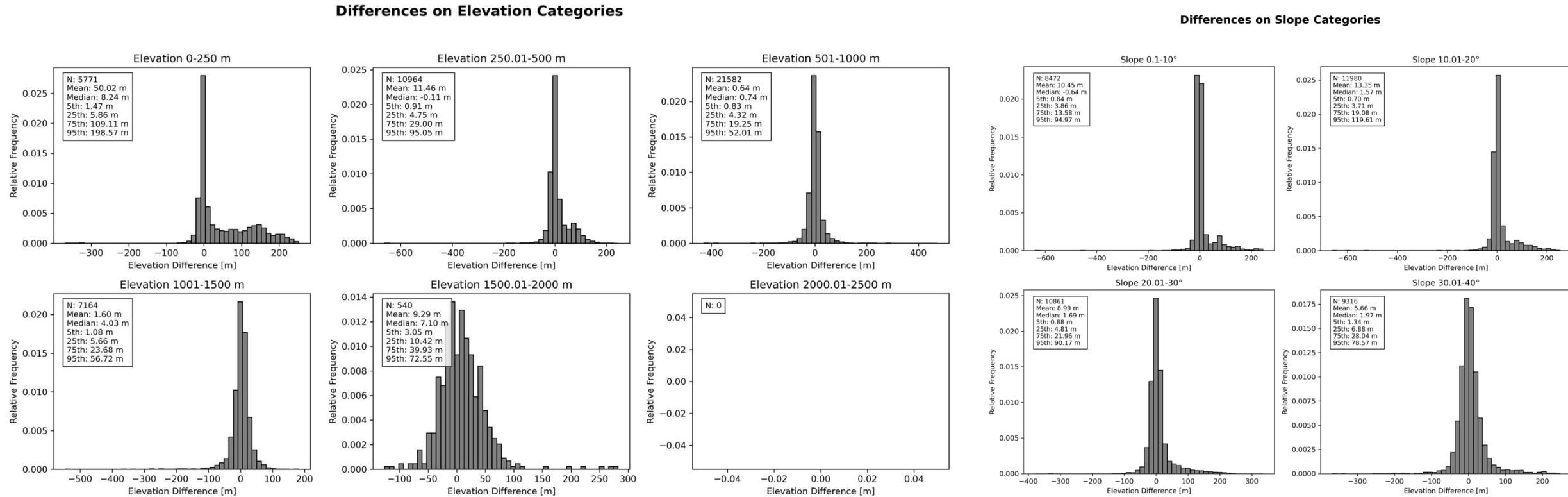
# Test Result: ALIKED + LightGlue + Final DEM comparison (no dense matching) (using HSfM Co-Registration)



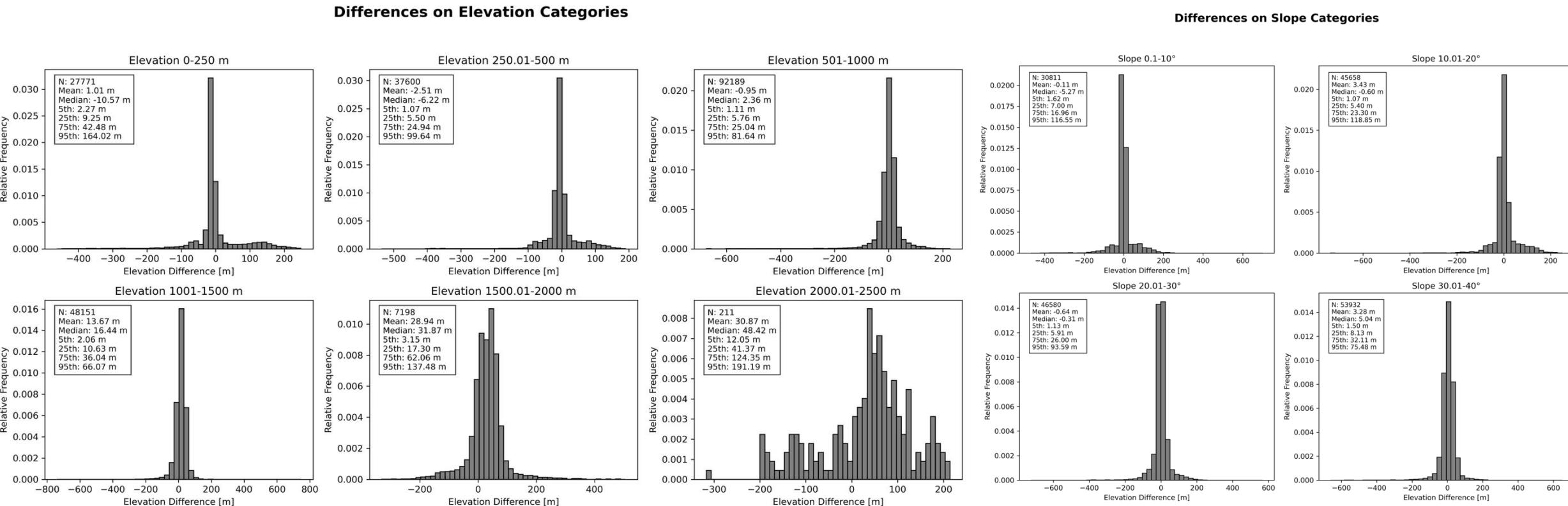
# Test Result: LoFTR + Final DEM comparison (no dense matching) (using HSfM Co-Registration)



# Test Result: *DISK* + *LightGlue* + Final DEM comparison (no dense matching) (using *HSfM* Co-Registration)



# Test Result: *SuperPoint + LightGlue + COLMAP Dense* (using HSfM Co-Registration)



# Test Result: SuperPoint + LightGlue + RoMa (using HSfM Co-Registration)

Differences on Elevation Categories

