Exploratory Image Processing Murtèl Rock Glacier

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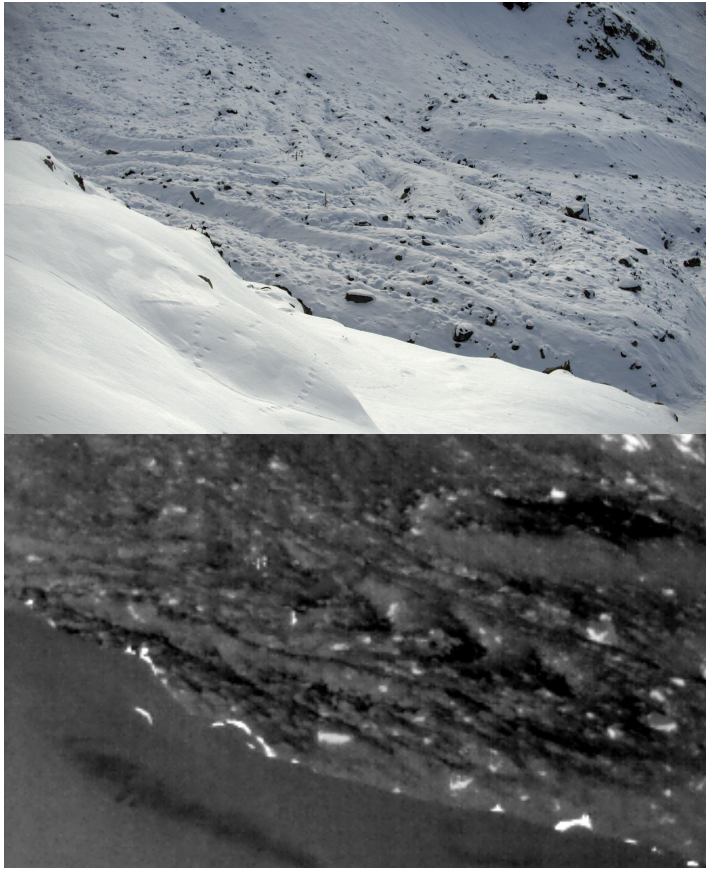
Murtèl Rock Glacier

- What is a Rock Glacier?
  - “Rock glaciers are lobate to tongue-shaped bodies of frozen debris with interstitial ice cement, ice lenses, or a core of massive ice”(K. Krainer)
- Murtel Rock Glacier
  - Located in Engadin
  - slowly moving rock glacier known for its dynamic surface
  - includes snow patches, debris surfaces, vegetation, and exposed rock
- Challenges for Image Analysis
  - changing snow conditions
  - fog, snowfall
  - varying light/shadow conditions

Murtèl Rock Glacier

Available Data

- ~30k Image Pairs
  - RGB (color)
  - Thermal Infrared (TIR)
- Metadata of Images
- Weather station data
- DEM height map



Tasks for this Project

- In order to understand how:
  - topography affects surface temperatures
  - the rock glacier moves
  - how it responds to changing weather and snow conditions
  - etc. …

- The goal of our project was to perform exploratory research on methods with which to:
  - filter / classify images based on weather
  - remove camera misalignment to create aligned timeline of pictures
  - overlay infrared image information spatially onto the color image
  - see how far we get

Proposed Workflow

- **Image filtering**
  - classify unusable images
  - RGB with SVM
  - TIR with Entropy
- **Preprocess Images**
- **Alignment / Overlay**

Problems Unusable RGB Images

Problems
- fog
- dark
- unclear
- incomplete

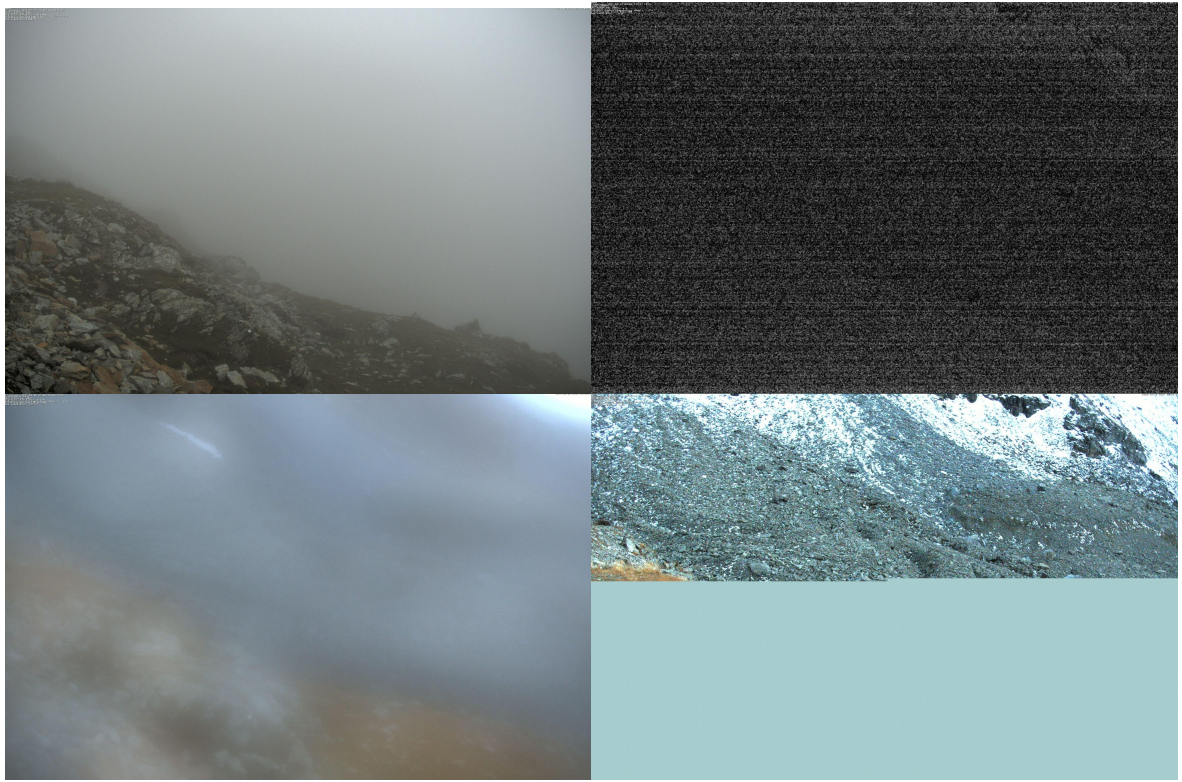


Image Filtering

Methods trialed:

- Random Forest (RF)
- Support Vector Machine (SVM)
  - Domain space separation with an optimal decision boundary.
- Information Entropy Measure
  - Shannon entropy of image histogram

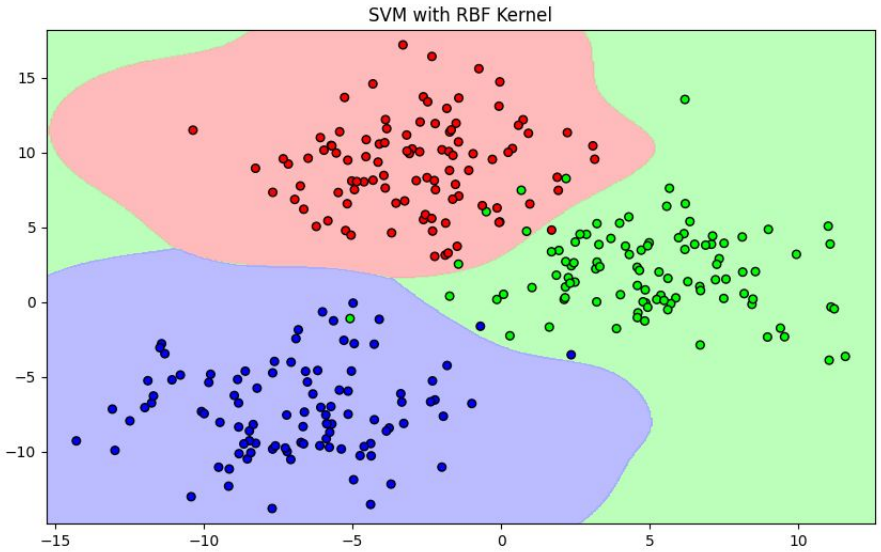


Image Filtering SVM

- 1600 train images
- 600 test images
- Idea from paper (Eden Ship et al.)
- Extracted features:
  - edge based
  - brightness
  - color distributions
  - metadata info
- best precision with radial basis function (rbf)

	Predicted Bad	Predicted Clear
Actual Bad	**35.00%**	2.50%
Actual Clear	6.17%	**56.33%**

Clear Precision: **91.50%**

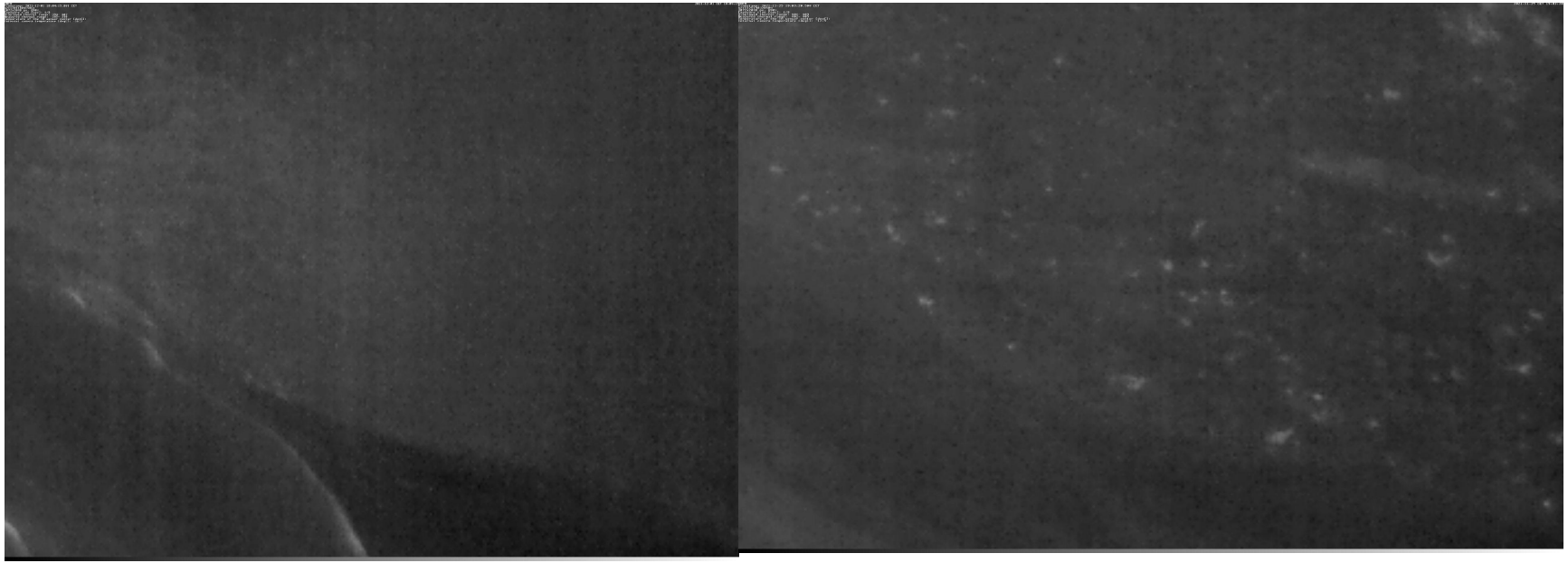
feature importance

edge_density	0,0799
g_kurtosis	0,0763
g_skewness	0,0756
b_variance	0,0673
g_variance	0,0627
r_skewness	0,0621
g_mean	0,0600
b_mean	0,0588
r_kurtosis	0,0575
b_skewness	0,0574
r_variance	0,0567
contrast	0,0536
b_kurtosis	0,0526
r_mean	0,0522
sharpness	0,0518
brightness	0,0396
noise	0,0152
time_of_day_Morning	0,0041
time_of_day_Afternoon	0,0038
season_Spring	0,0030
season_Winter	0,0030
time_of_day_Evening	0,0026
time_of_day_Night	0,0018
season_Fall	0,0015
season_Summer	0,0008

Outlook Image Filtering

- False positive
- Remove with masking

Problem Unusable TIR images

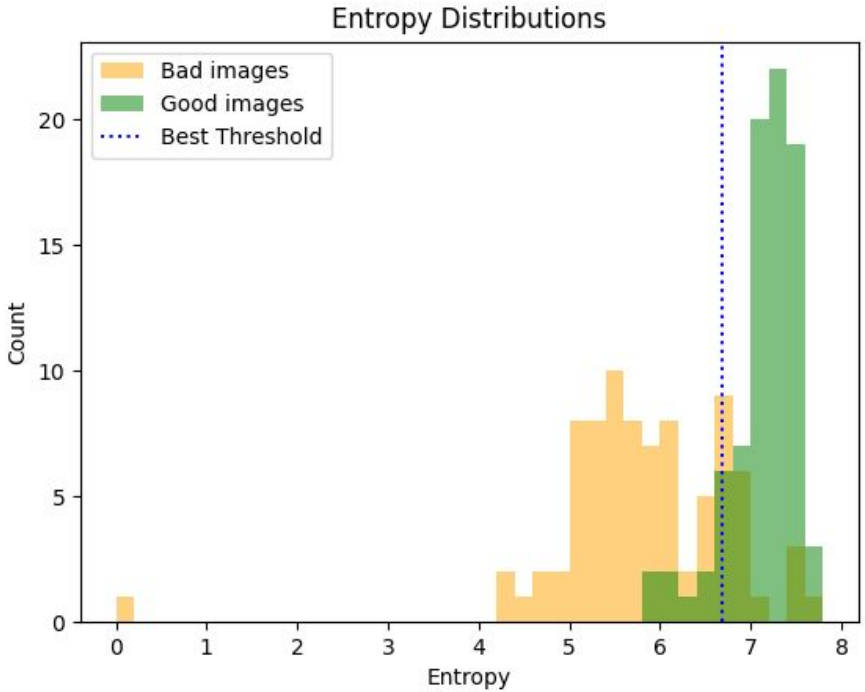


TIR Filtering

- Same feature extraction as for RGB images fails here
- Filter on Information Entropy (Tsai, DY. et al.)
- Shannon Entropy of image histogram

$$\mathrm{H}(X) := -\sum_{x \in \mathcal{X}} p(x) \log p(x)$$

- Idea from Paper (F. Ioli et al.)
- Decision Threshold (6.693)
  - in plot: Youden's index
  - Clear Precision: 92.3%
  - perhaps move for better precision



Sensitivity: 0.905 Specificity: 0.821

Proposed Workflow

- **Image filtering**
  - classify unusable images
  - RGB with SVM
  - TIR with Entropy
- **Preprocess Images**
  - pair up RGB and TIR
  - remove non-matching / filtered out
  - (kept in in further alignment displays to highlight problems)
- **Alignment / Overlay**

Proposed Workflow

- **Image filtering**
- **Preprocess Images**
- **Alignment / Overlay**
  - created 7 image sequences for testing:
    - maximum snow cover - March 21; mostly all snow covered
    - medium snow cover - October 20; snow with visible rocks; diff light, shadows
    - full mix snow-rock - June - July 21; melting snow cover over 1 month
    - summer first snow - August - October 21; full rock to first snow
    - single day - November 2, 20; almost full snow cover, diff light/colors
    - TIR date offset - 09/28-10/06 (RGB); 10/14 (TIR) 2020, 2 weeks offset
    - artificially misaligned - full mix images translated, rotated, warped
  - RGB-RGB aligning
  - TIR-RGB overlaying

Proposed Workflow

- **Image filtering**
- **Preprocess Images**
- **Alignment / Overlay**
  - created 7 image sequences for testing
  - RGB-RGB aligning
    - preprocess: crop, filter, mask
    - align with DL-Models SuperPoint & SuperGlue
  - TIR-RGB overlaying

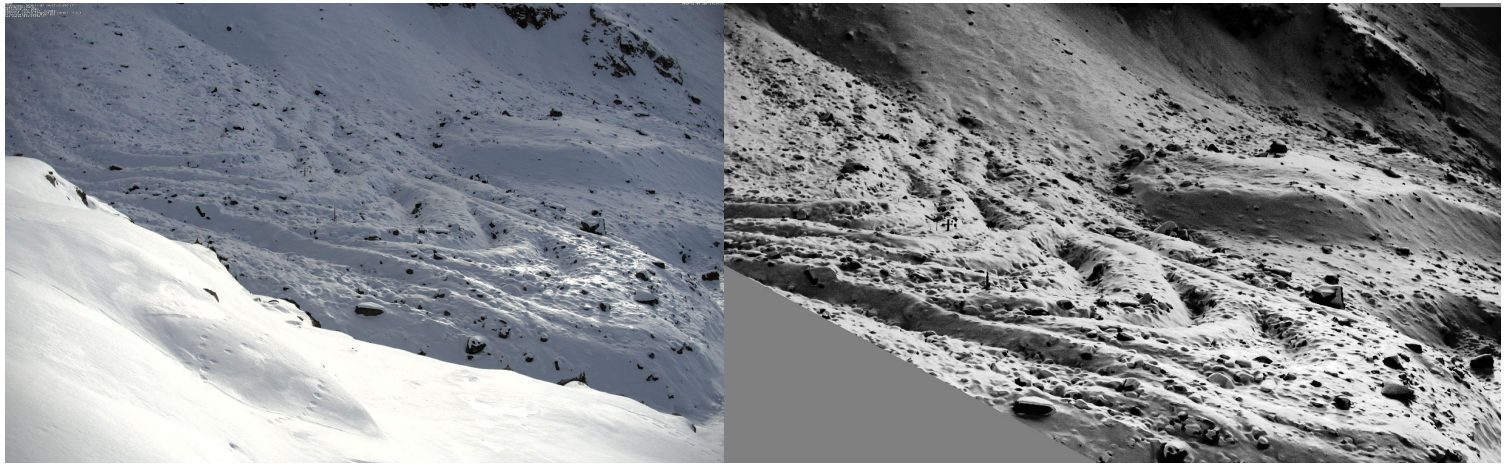
Problem Aligning RGB Images

- Camera Pylon Moves
- But:
  - no clear control points or horizon
  - changing snow & lighting conditions
  - (moving rock glacier)

- Align RGB-RGB
  - edge matching
  - cross-correlation template matching
  - **superpoint/-glue**

Pre Alignment Workflow RGB

- Remove filtered out images (not done here)
- Crop left and bottom of image
- Filter with grayscale & color histogram equalization
- Mask images to hide ledge in front and metadata text



SuperPoint (D. DeTone et al.)

- Self (semi) supervised encoder-decoder Neural Net
  - fully convolutional
  - available pretrained (P. Sarlin et al.)
  - similar to ORB, SIFT, etc
- Takes arguments
  - keypoint threshold (0.2)
  - number of keypoints (600/800)
- Outputs
  - Interest Point probability
  - n-dim Interest Point Descriptor

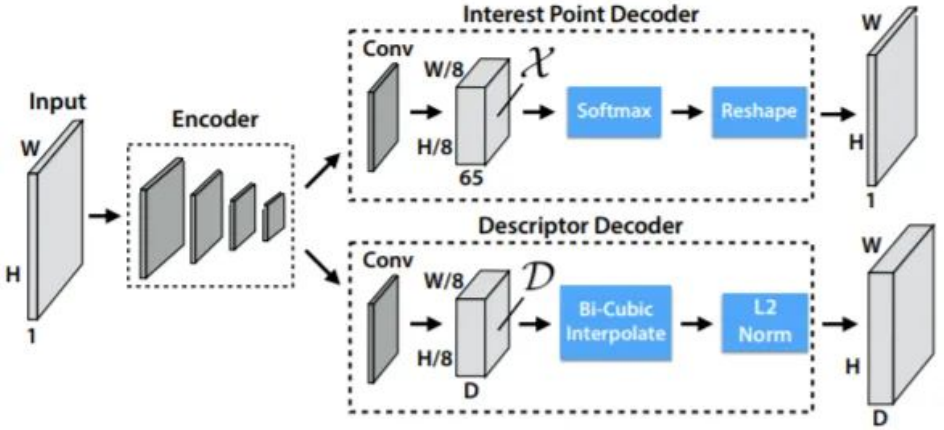


fig. 1; D. DeTone et al.

SuperGlue (P. Sarlin et al.)

- Attentional Graph Neural Network
  - creates map of matching or rejected keypoints
  - differential assignment optimization problem
  - (overpowered for our problem)
  - used for stereoscopic glacier analysis (F. Ioli et al.)

- Pretrained magicleap version (P. Sarlin et al.)
  - available with outdoor weights
- Align images
  - estimate transformation Matrix with output

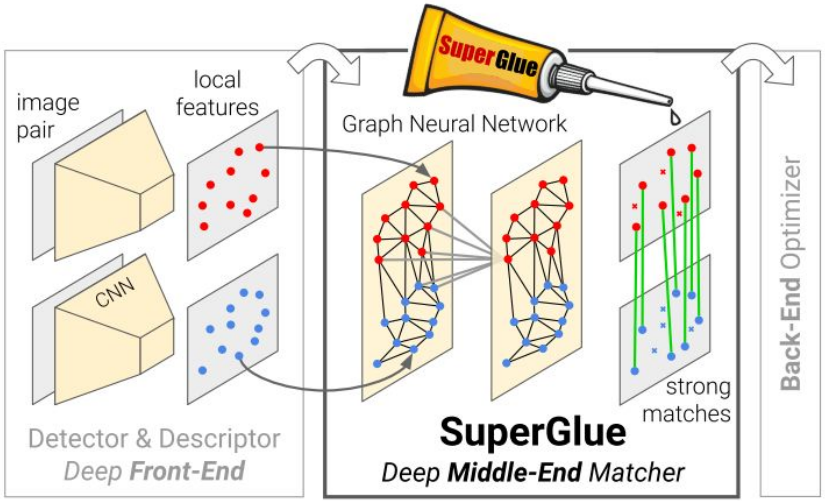
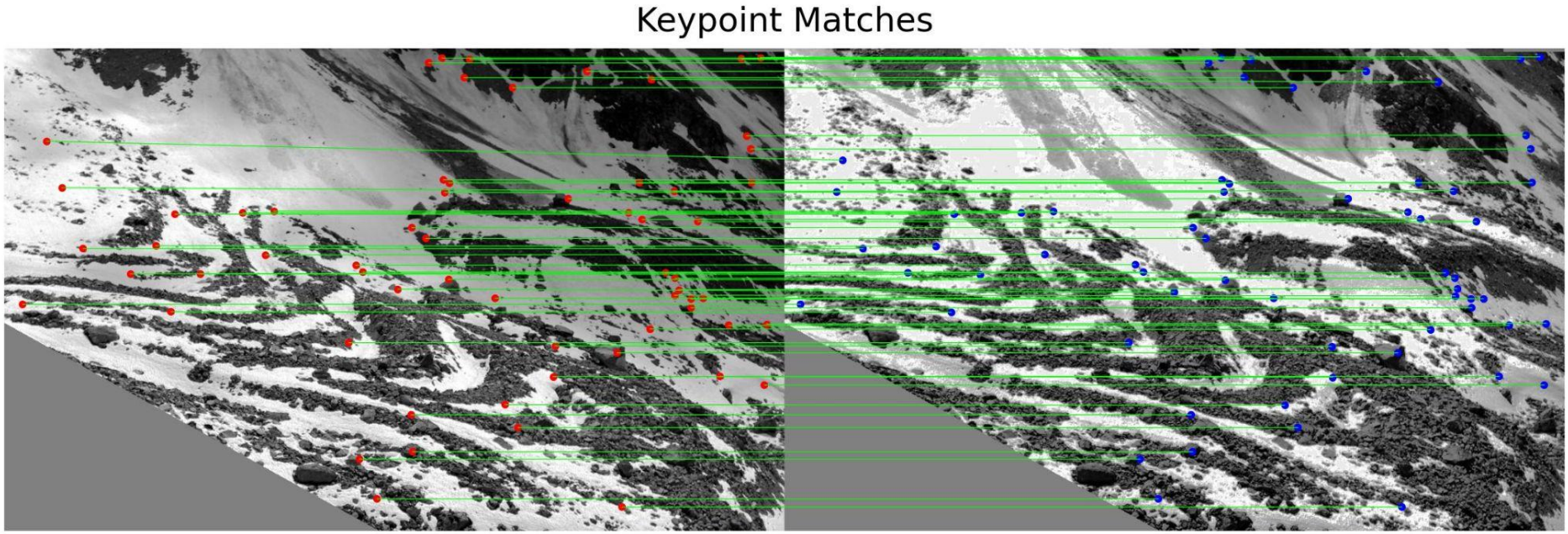


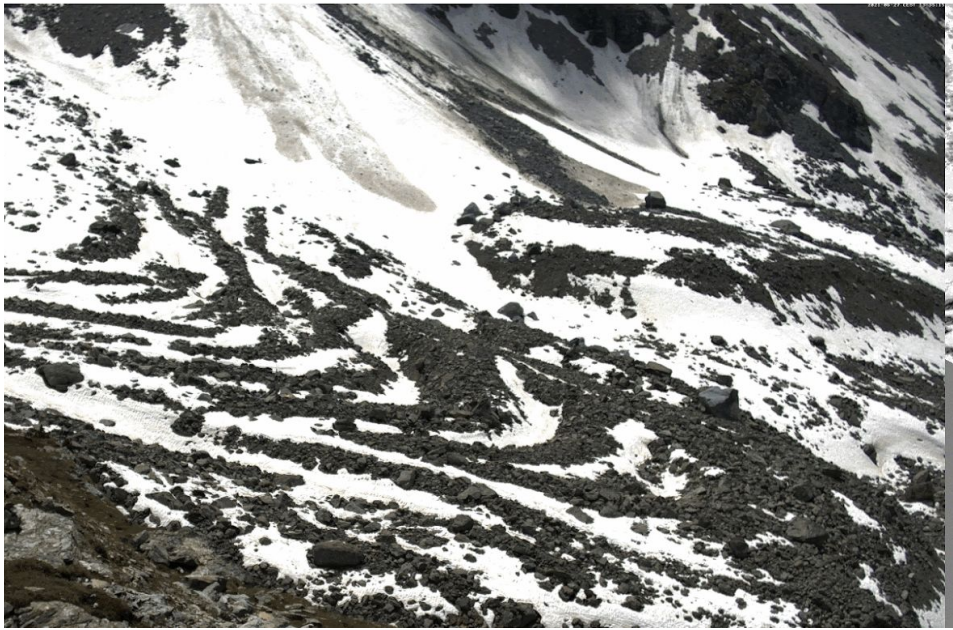
fig. 2; P. Sarlin et al.

SuperGlue Keypoint Matching

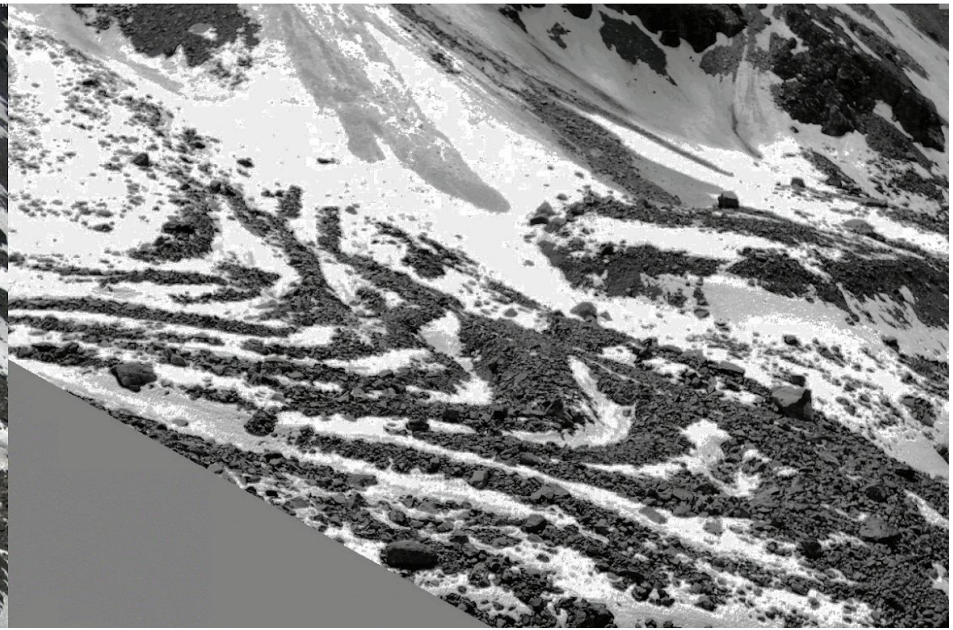


Superglue RGB-RGB Alignment - (art. misaligned)

RAW



SUPERGLUE_ALIGNED



Full Snow Cover

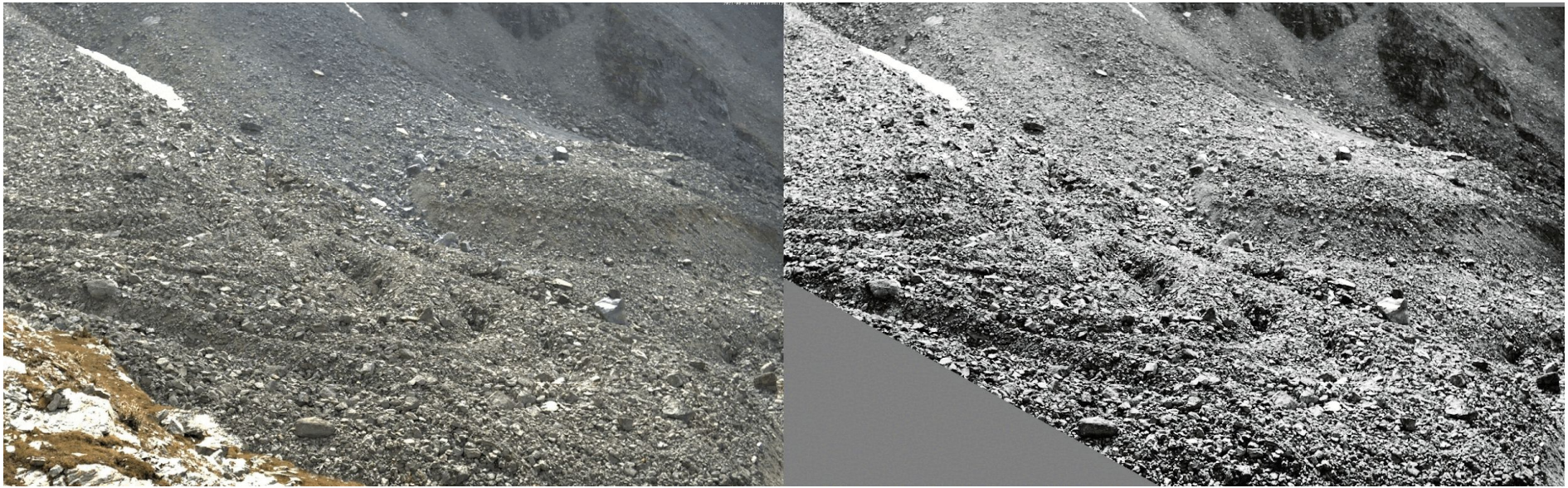
RAW

SUPERGLUE_ALIGNED

Summer and First Snow

RAW

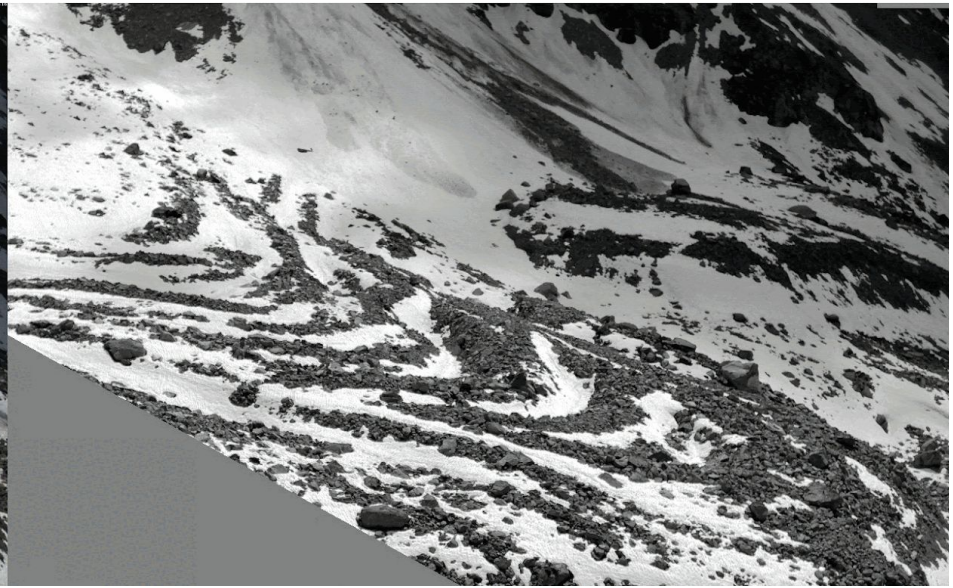
SUPERGLUE_ALIGNED



Bad Example: Full Mix

RAW

SUPERGLUE_ALIGNED



Proposed Workflow

- **Image filtering**
- **Preprocess Images**
- **Alignment / Overlay**
  - created 7 image sequences for testing
  - RGB-RGB aligning
  - TIR-RGB overlaying
    - preprocess II: scale, filter, mask
    - overlay with cross correlation based template matching

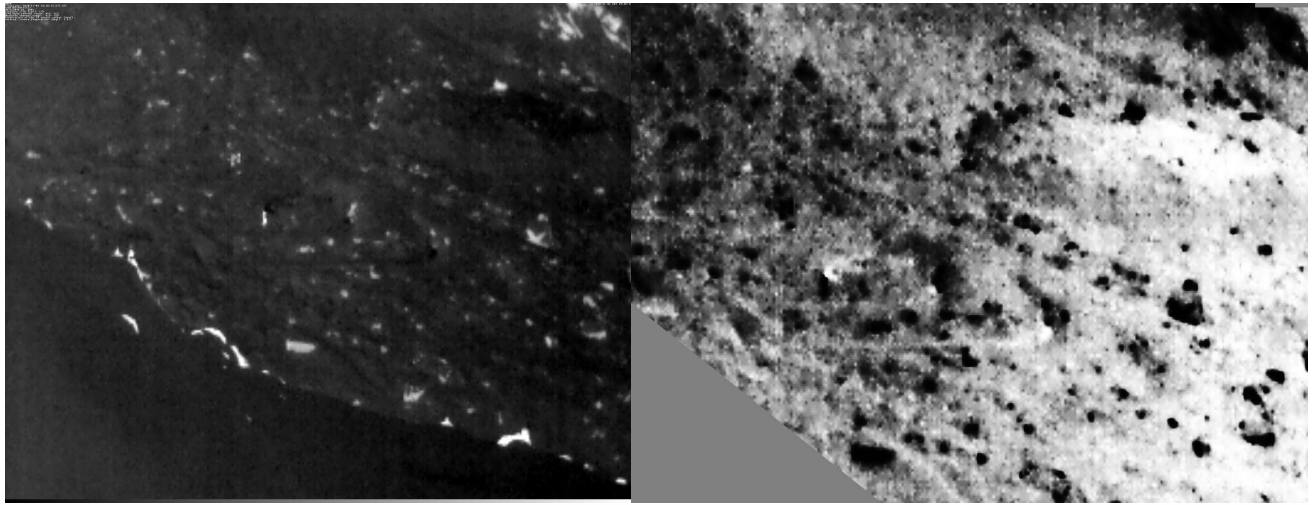
Problem Overlaying TIR Images

- Camera Pylon Moves
  - RGB and TIR images are not taken at the same time
- TIR Camera has different
  - data modality
  - different resolution, scale, perspective, …

- Align TIR on RGB
  - ssim
  - edge matching
  - **cross-correlation template matching**
  - orb
  - superpoint/-glue

Pre Alignment Workflow

- Remove filtered out images (not done here)
- Crop left and bottom of image
- Filter RGB additionally with gaussian blur
- Filter TIR with color inversion (in winter), histogram equalization
- Scale tir image to match rgb image (found static x0.82)



Alignment with cross-correlation

- Template matching
  - Sliding the template over the picture
  - Creates value for each sliding position
- Highest value can be found and template placed accordingly
- CCORR:

$$R(x,y) = \sum_{x',y'} (T(x',y') \cdot I(x+x', y+y'))$$

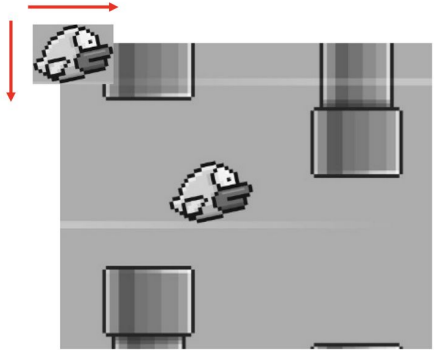
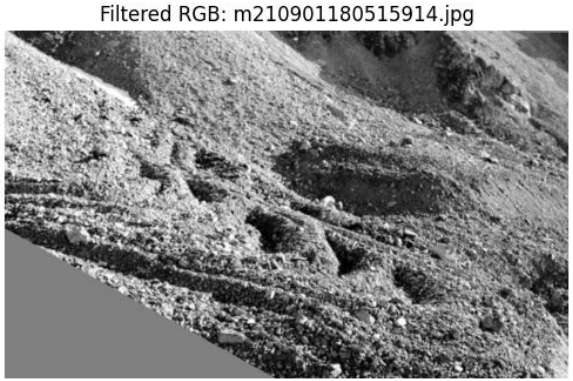
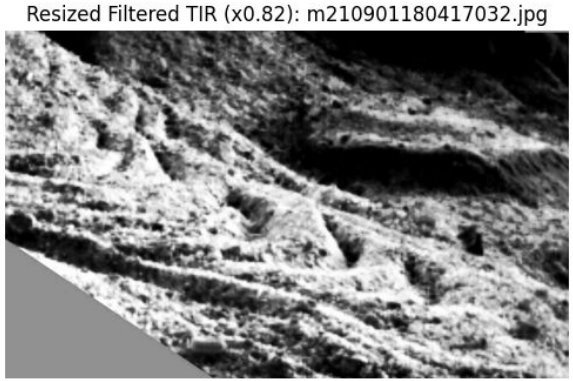


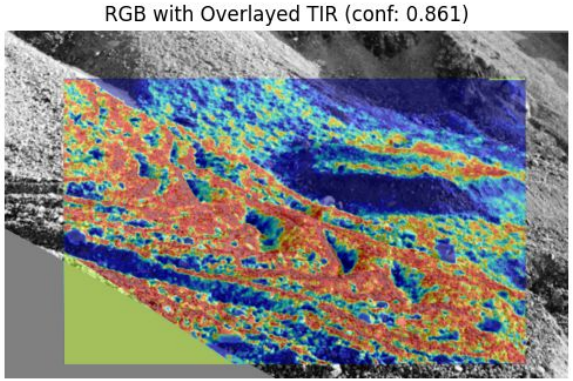
fig. 3; T. Malche

xCorr TIR - RGB Overlay

- Preprocessing for TIR images
- Find infrared image in rgb image
  - slide over rgb image
  - Rotate template to compensate camera rotation
  - Choose position with highest confidence
  - Try inverted as well as normal TIR

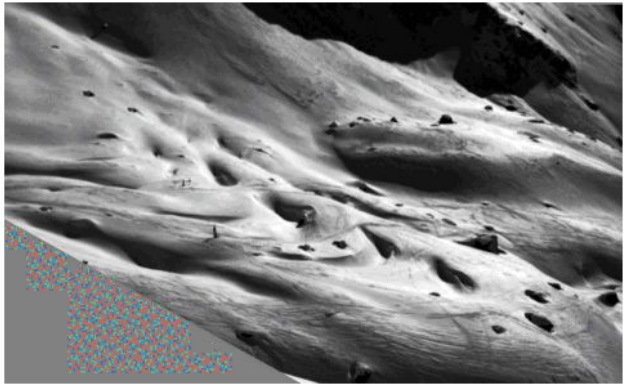




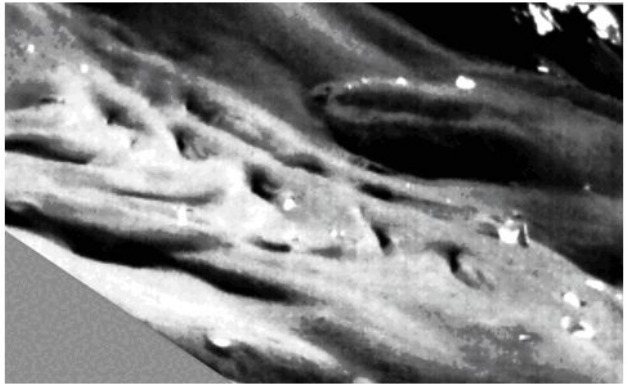


Full Snow

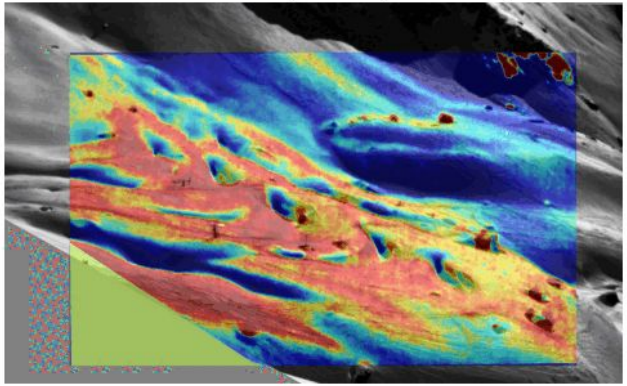
Filtered RGB: m210330160516418.jpg



Resized Filtered TIR (x0.82): m210330160516553.jpg

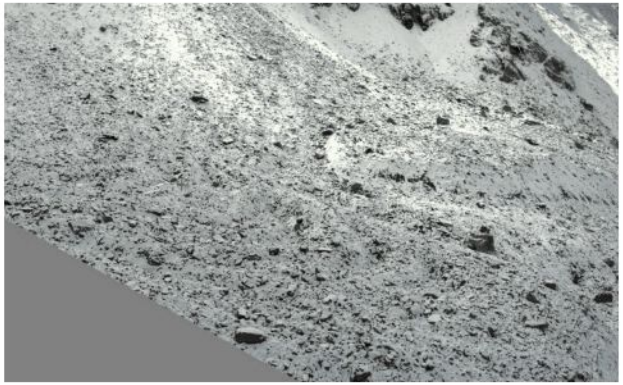


RGB with Overlayed TIR (conf: 0.899)

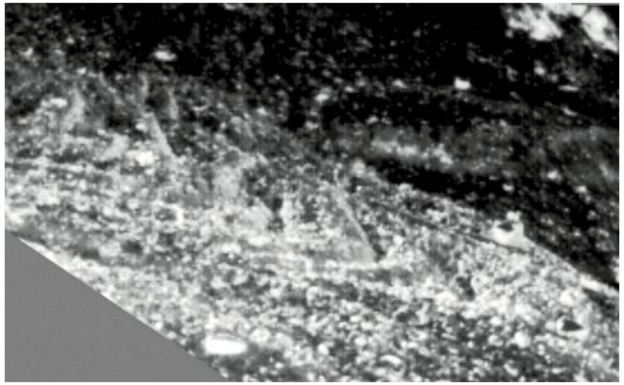


TIR 15 days after RGB

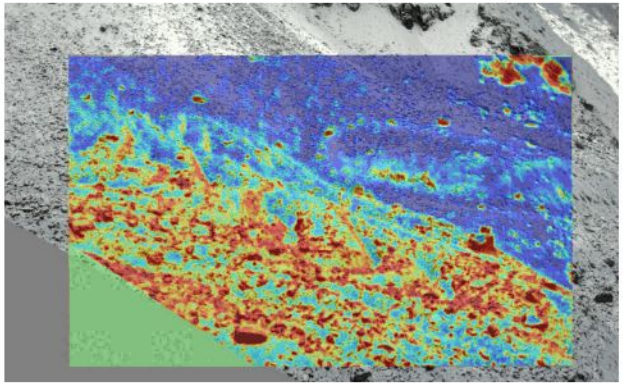
Filtered RGB: m200928113648438.jpg



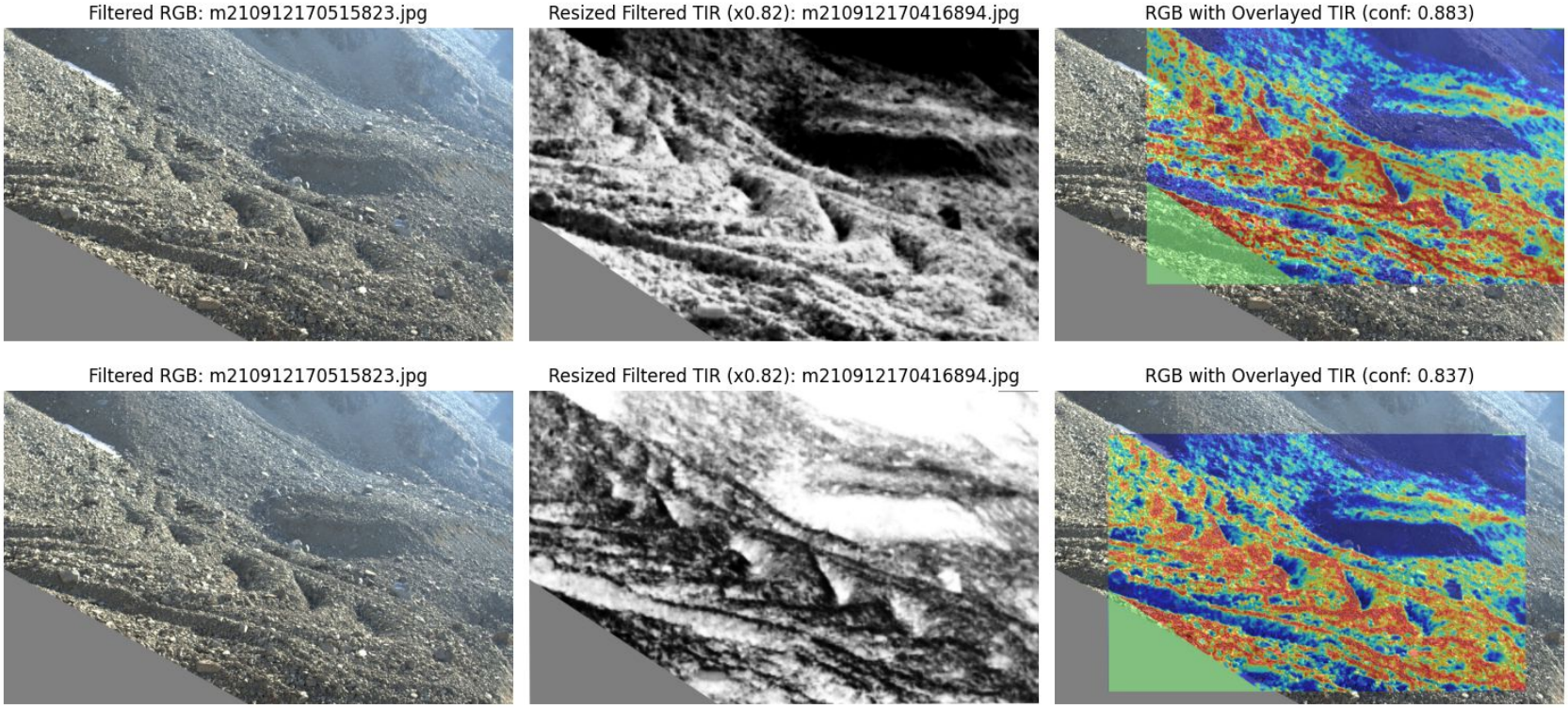
Resized Filtered TIR (x0.82): m201014153119130.jpg



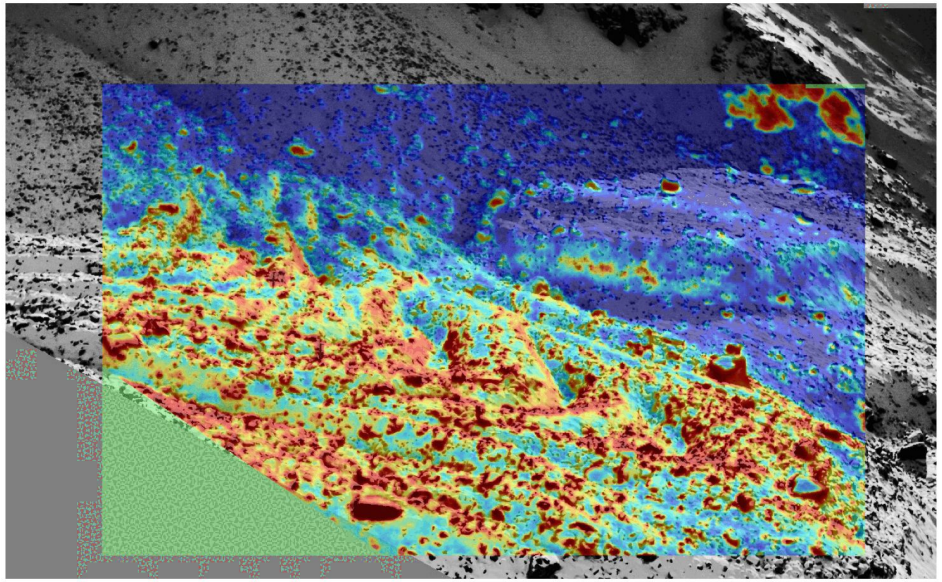
RGB with Overlayed TIR (conf: 0.922)



Inversion Problem Example



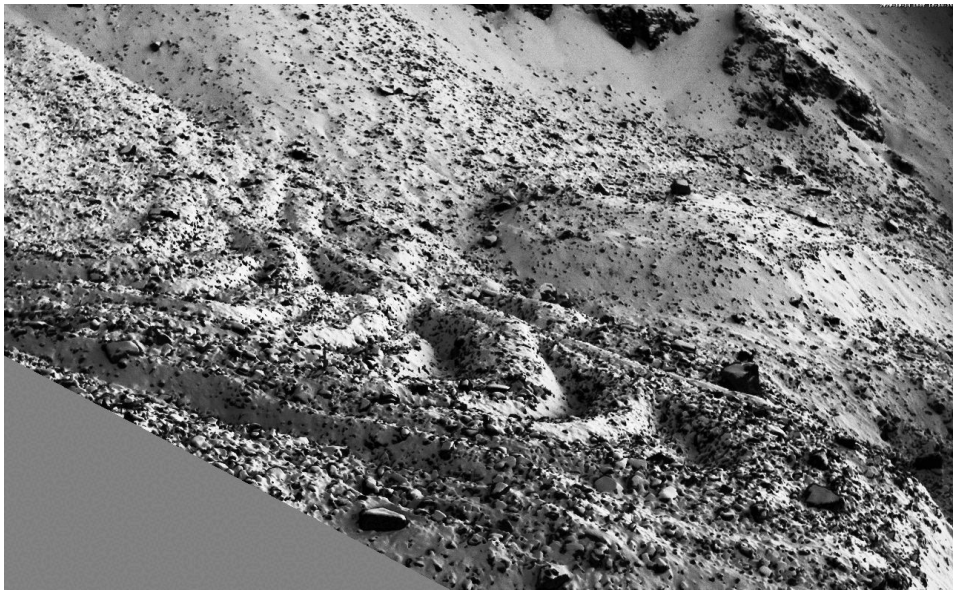
Outlook



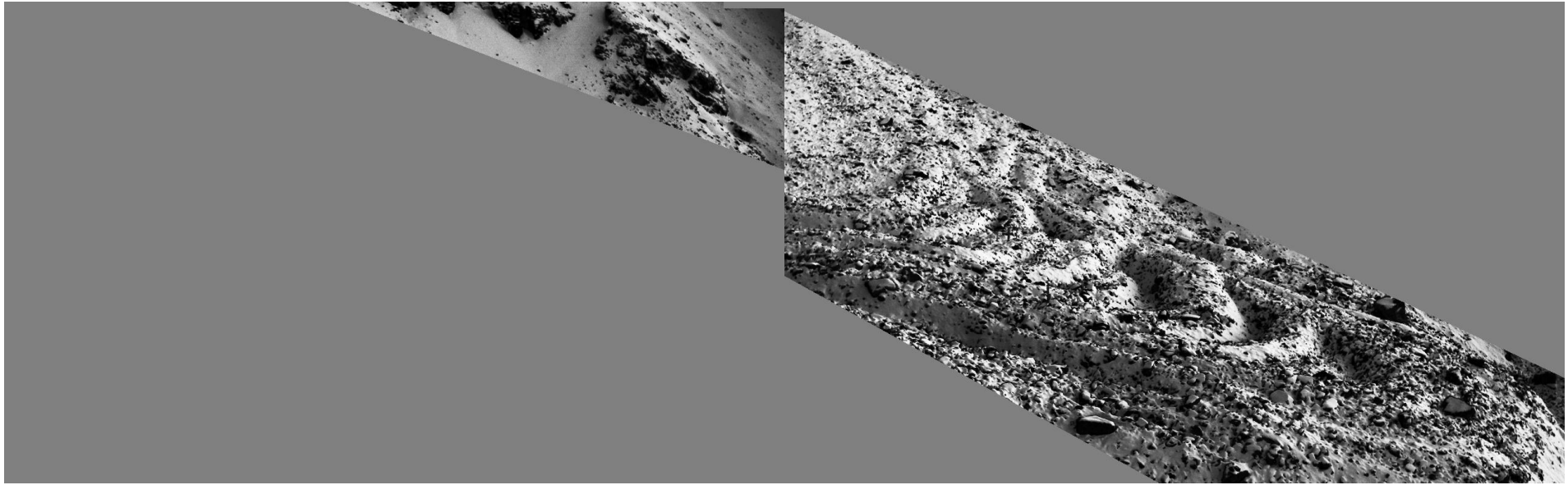
- What can now be achieved?
  - Analyze weather patterns
  - study surface features: snow patches melt / avalanche
  - Spatial Mapping: images to spatial coordinates deformation analysis
  - Change Detection: rockfalls, new boulders, and surface deformations over time

Identify Surface Deformations Over Time

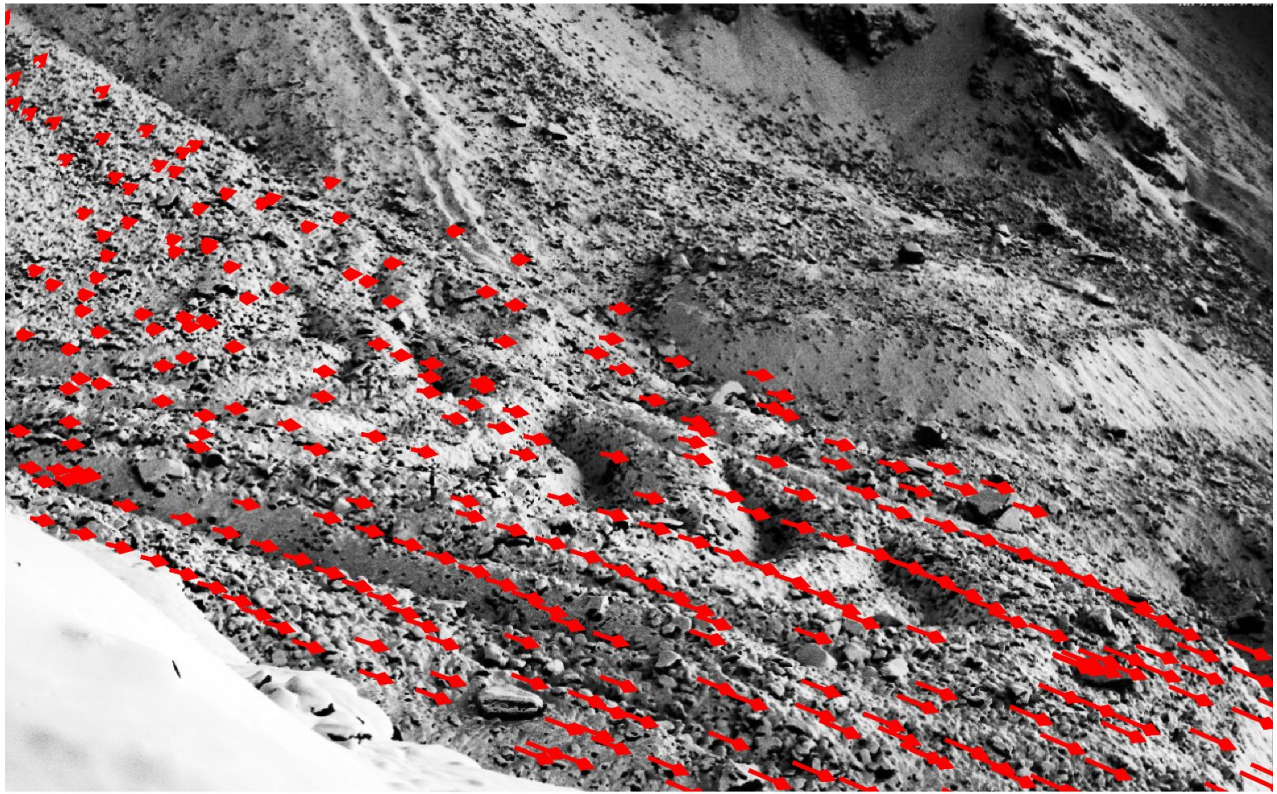
- track rock glacier movement
  - 2 years apart



Masking Rock Glacier / non-Rock Glacier



Masking Rock Glacier / non-Rock Glacier



References

- Tsai, DY., Lee, Y. & Matsuyama, E. Information Entropy Measure for Evaluation of Image Quality. J Digit Imaging 21, 338–347 (2008). https://doi.org/10.1007/s10278-007-9044-5
- Eden Ship, Eitan Spivak, Shubham Agarwal, Raz Birman, Ofer Hadar, Real-Time Weather Image Classification with SVM: A Feature-Based Approach. https://arxiv.org/html/2409.00821v1
- Matching with Graph Neural Networks," in CVPR, 2020.
- Paper using SuperGlue: F. Ioli, N. Dematteis, D. Giordan et al. Deep Learning Low-cost Photogrammetry for 4D Short-term Glacier Dynamics Monitoring. PFG 92, 657–678 (2024). https://doi.org/10.1007/s41064-023-00272-w
- Krainer, K. and Mostler, W., Rock Glaciers - An introduction with examples from the Austrian Alps, Rockglacier Intro. Available at: https://www.uibk.ac.at/projects/rockglacier/rockglacier_intro.html (Accessed: 22 January 2025)

- figure 1 : D. DeTone, T. Malisiewicz and A. Rabinovich, "SuperPoint: Self-Supervised Interest Point Detection and Description," 2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW), Salt Lake City, UT, USA, 2018, pp. 337-33712, doi: 10.1109/CVPRW.2018.00060.
- figure 2 and Pretrained SuperGlue: P. Sarlin, D. DeTone, T. Malisiewicz and A. Rabinovich, "SuperGlue: Learning Feature
- figure 3. Malche, T. (2024, October 31). What is template matching? an introduction. Roboflow Blog. https://blog.roboflow.com/template-matching/

Questions

Appendix

Image filtering RF

- 1600 train images
- 600 test images

	Predicted Bad	Predicted Clear
Actual Bad	**33.83%**	3.67%
Actual Clear	4.83%	**57.67%**
	Clear Precision	**88.04%**

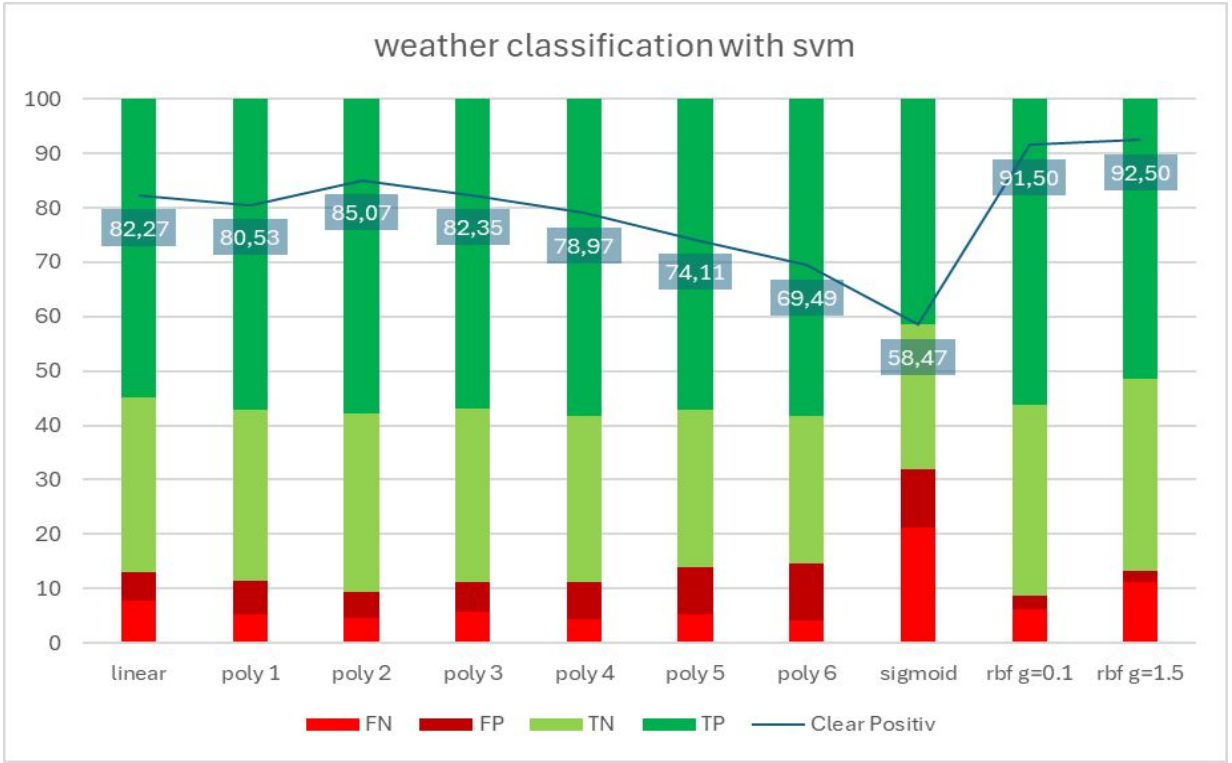
extracted features

brightness	0,144844
edge_density	0,139226
noise	0,083384
contrast	0,07753
sharpness	0,07471
b_variance	0,055578
b_mean	0,050221
time_of_day_Night	0,041498
r_variance	0,040674
b_kurtosis	0,037018
r_mean	0,029826
r_kurtosis	0,029373
g_mean	0,0281
r_skewness	0,027923
g_variance	0,027778
b_skewness	0,027654
g_kurtosis	0,0255
g_skewness	0,022537
time_of_day_Afternoon	0,008969
time_of_day_Evening	0,00735
season_Summer	0,004791
time_of_day_Morning	0,004608
season_Fall	0,003979
season_Spring	0,003626
season_Winter	0,003302

Image filtering SVM

- 1600 train images
- 600 test images

- best working with radial basis function (rbf)

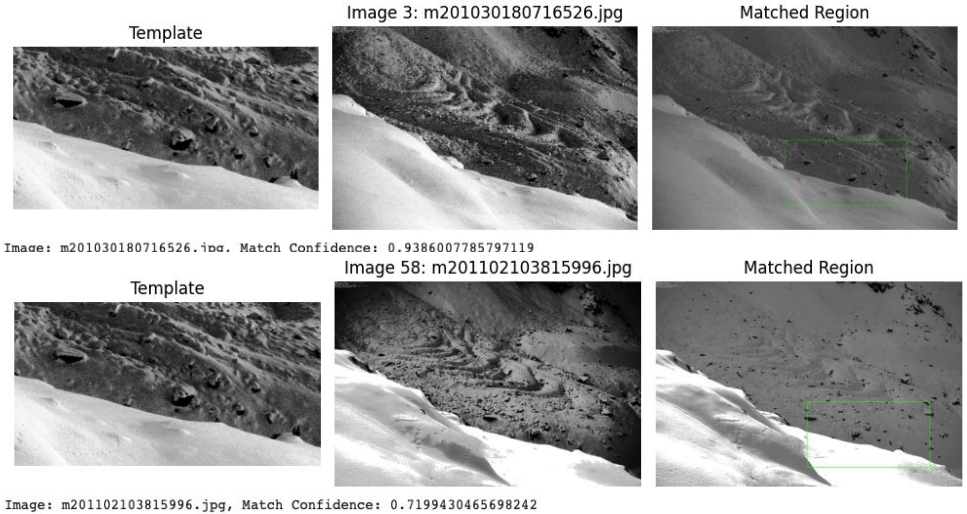


Outlook TIR Filtering

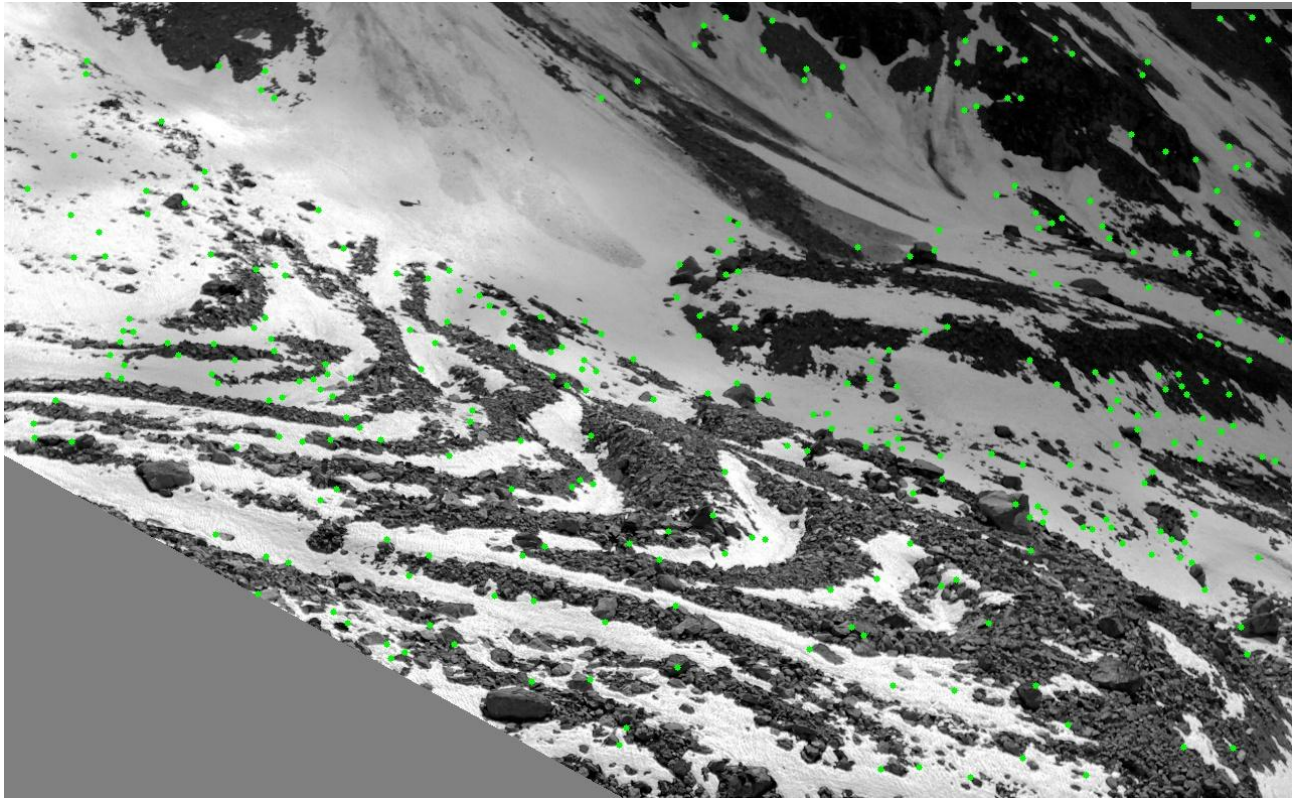
- False positive
- Remove with masking

RGB alignment with cross-correlation

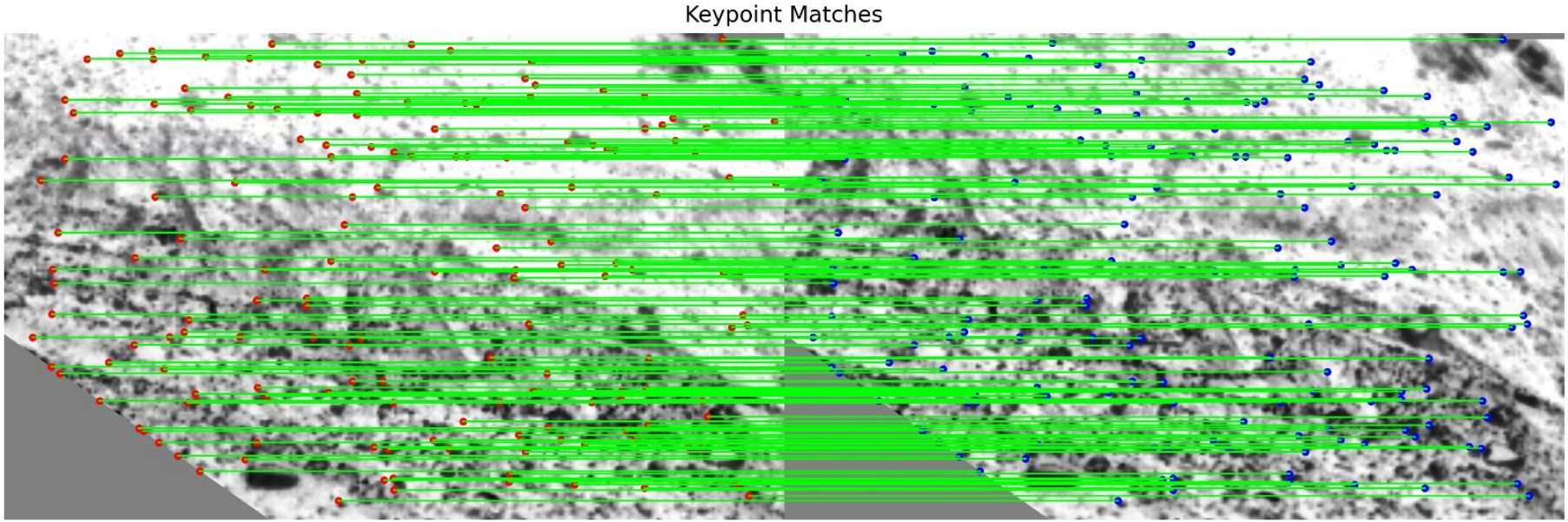
- Worked quite well with the template, but:
  - Used front ledge as important feature
  - When weather conditions change the contrast of the image, xCorr is unreliable



SuperPoint Keypoint Extraction

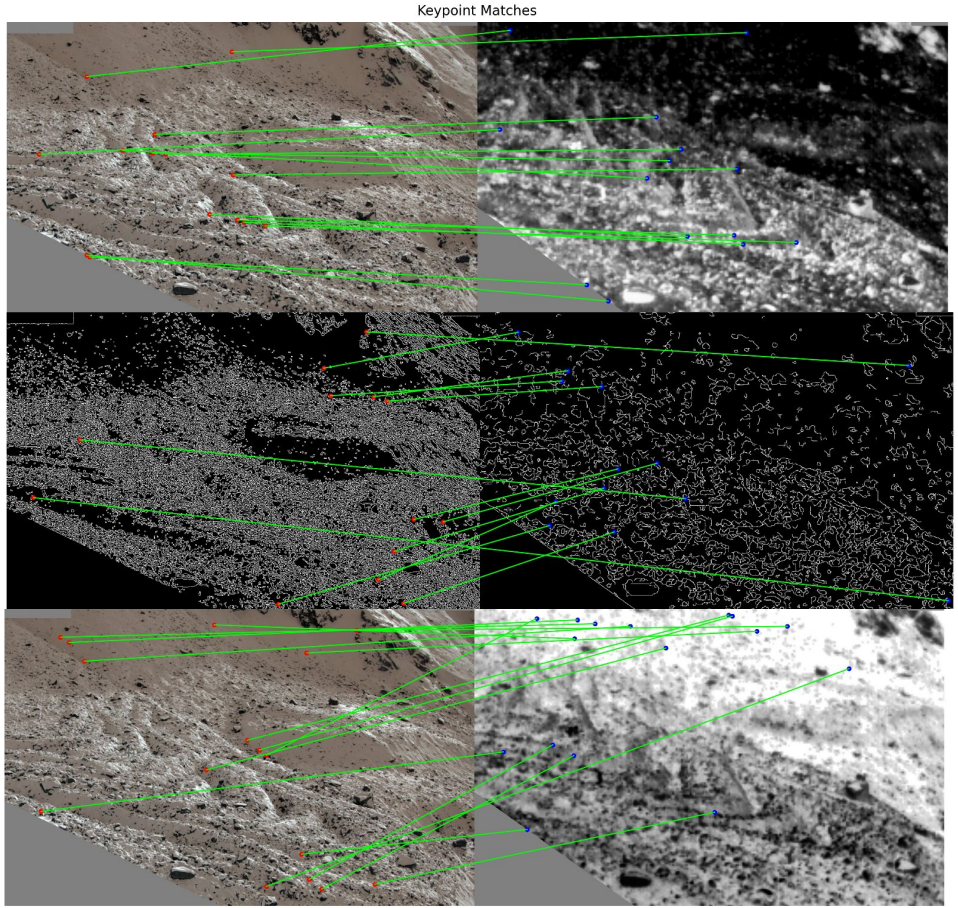


SuperPoint & SuperGlue trials filtered TIR-TIR

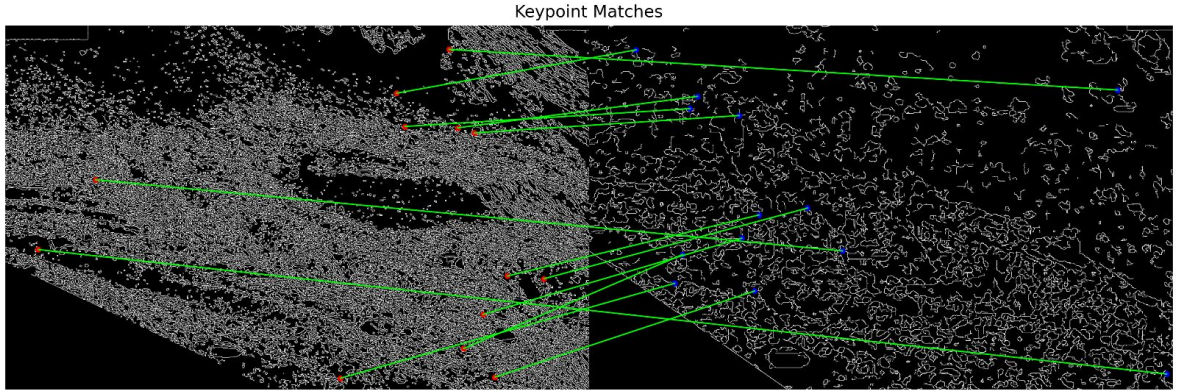


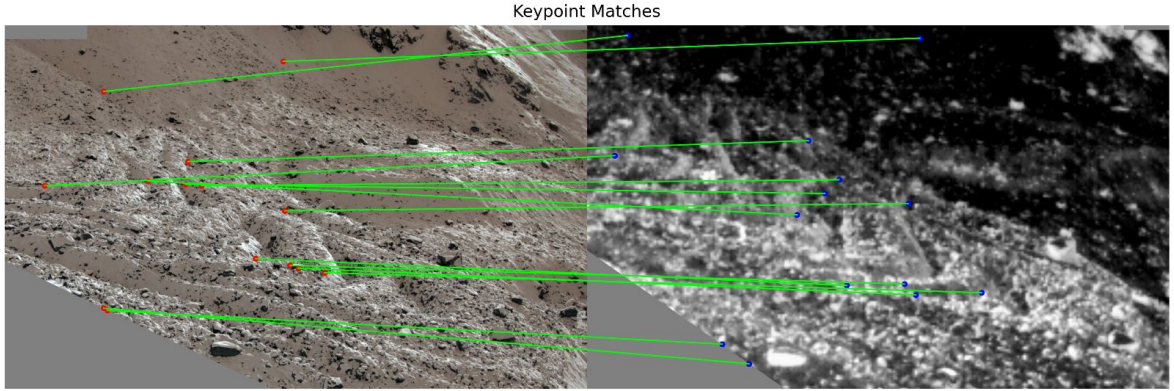
TIR-RGB SuperGlue

- Initial Test don’t necessarily show robust behaviour
- Experiments with filters underwhelming



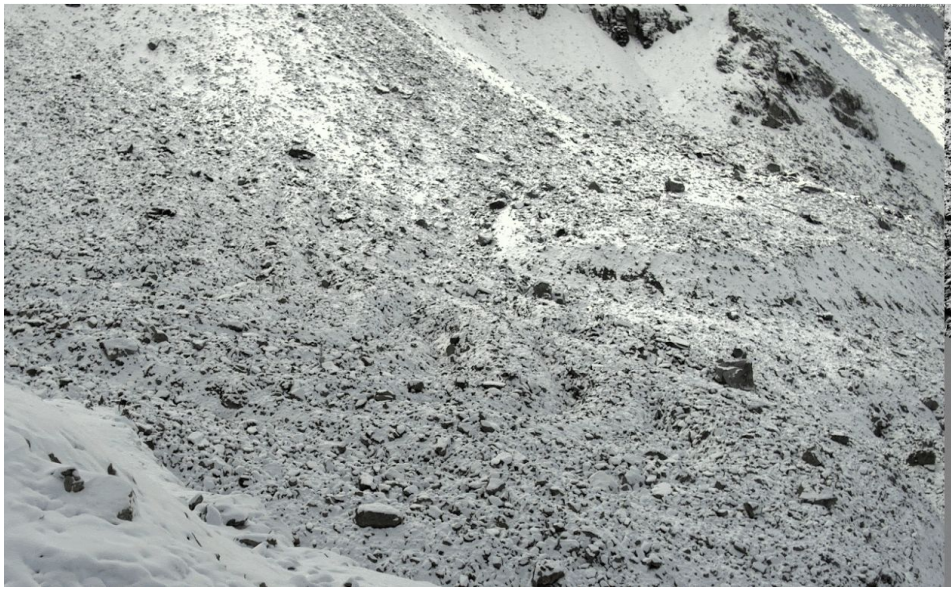
TIR-RGB SuperGlue



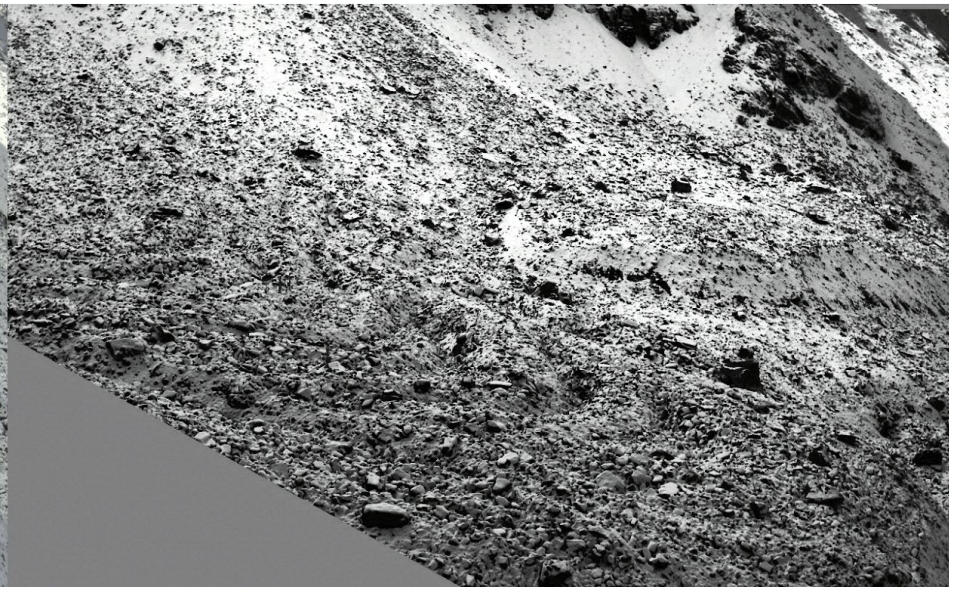


Mix (TIR Misaligned Set)

RAW



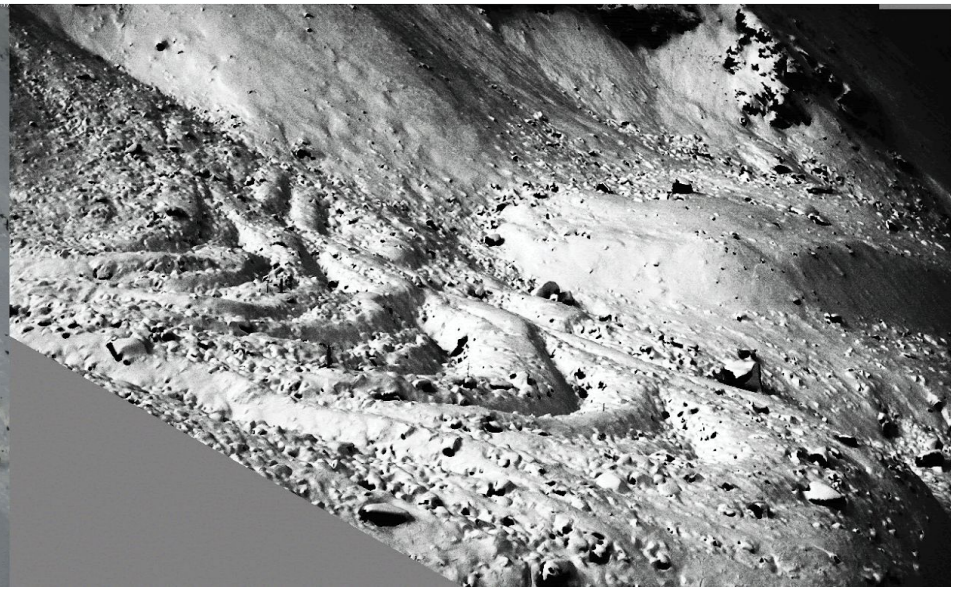
SUPERGLUE_ALIGNED



Single day Superglue

RAW

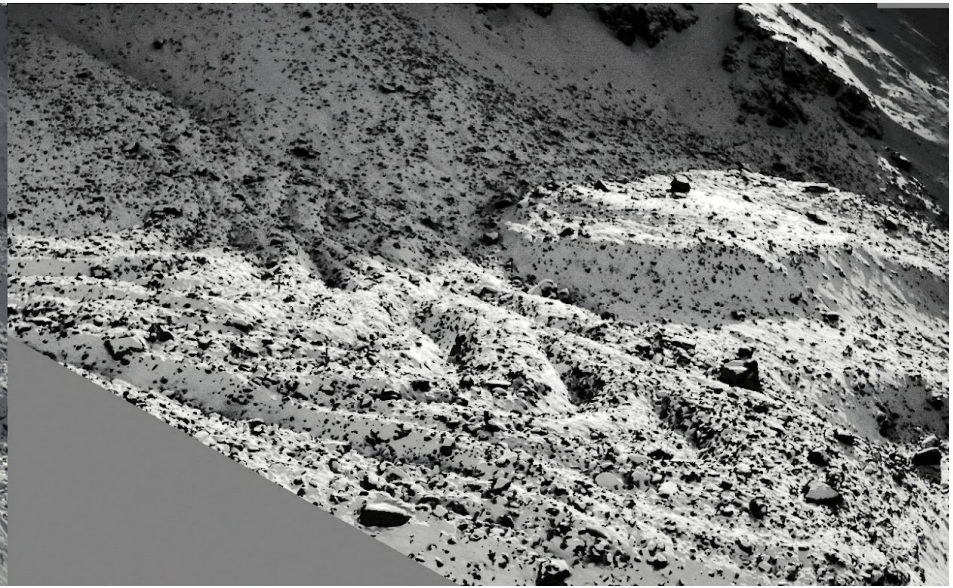
SUPERGLUE_ALIGNED



Med snowcover Superglue

RAW

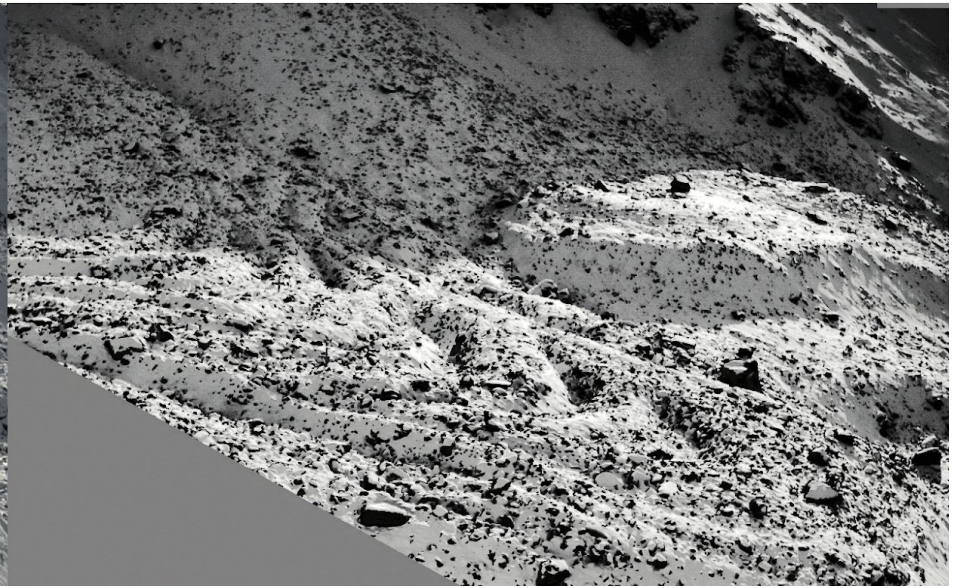
SUPERGLUE_ALIGNED



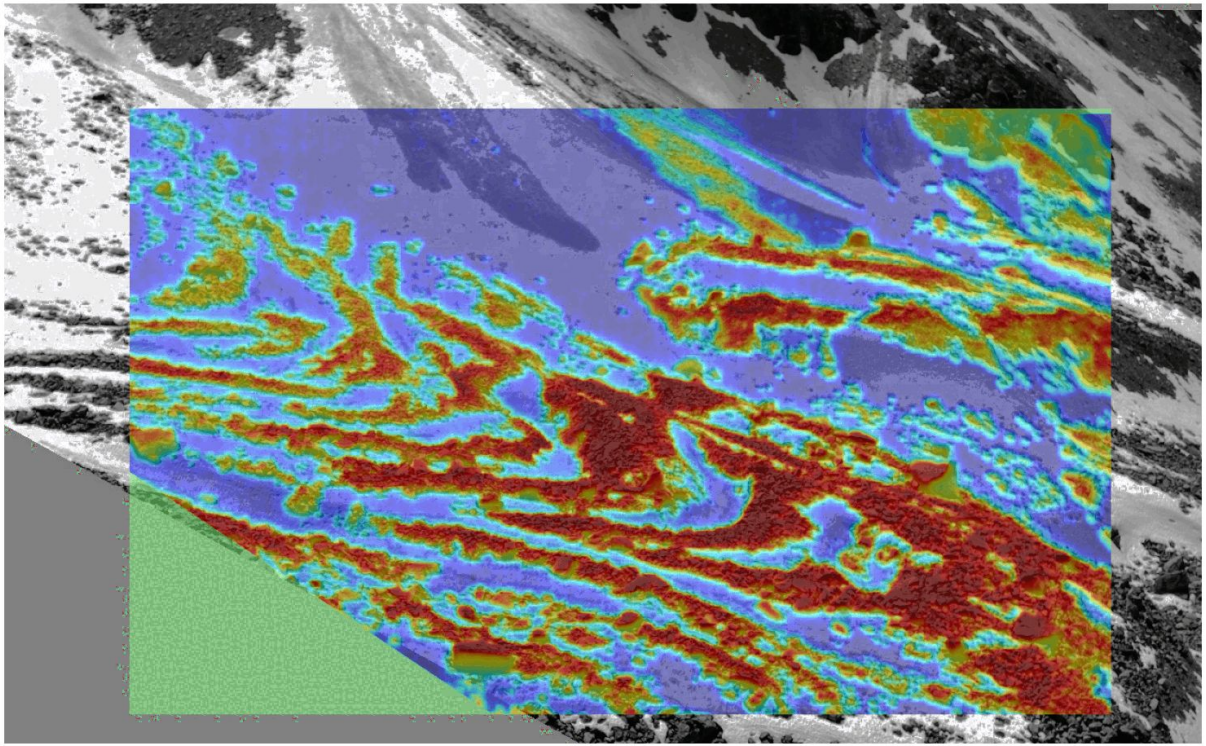
Med snowcover Superglue

RAW

SUPERGLUE_ALIGNED



Misaligned full workflow



Proposed Workflow

- **Image filtering**
  - classify unusable images
  - RGB with SVM
  - TIR with Entropy
- **Preprocess Images**
  - pair up RGB and TIR
  - remove non-matching / filtered out
  - (kept in in further alignment displays to highlight problems)
- **Alignment / Overlay**
  - created 7 image sequences for testing:
    - maximum snow cover - March 2021; mostly all snow covered
    - medium snow cover - October 2020; snow with visible rocks; diff lighting, shadows
    - full mix snow-rock - June - July 2021; melting snow cover over 1 month
    - summer and first snow - August - October 2021; full rock to first mostly snow covered rocks
    - single day - November 2, 2020; almost full snow cover: diff lighting & colors
    - TIR date offset 2 weeks - 09/28-10/06 (RGB); 10/14 (TIR) 2020
    - artificially misaligned - full mix images translated, rotated, warped
  - RGB-RGB aligning
    - preprocess: crop, filter, mask
    - align with DL-Models SuperPoint & SuperGlue
  - TIR-RGB overlaying
    - preprocess II: scale, filter, mask
    - overlay with cross correlation based template matching