

ESA Earth Observation Summer School

Earth System Monitoring & Modelling



Glaciers_cci

Remote Sensing of Glaciers and Ice Caps

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Snow



Glaciers and Ice Caps



Ice in the Sea



Frozen Ground (Permafrost)



Ice sheets



River and Lake Ice



Global sea level rise



Water resource, fresh water flux





1972 - 2007

Climate indicator / archive



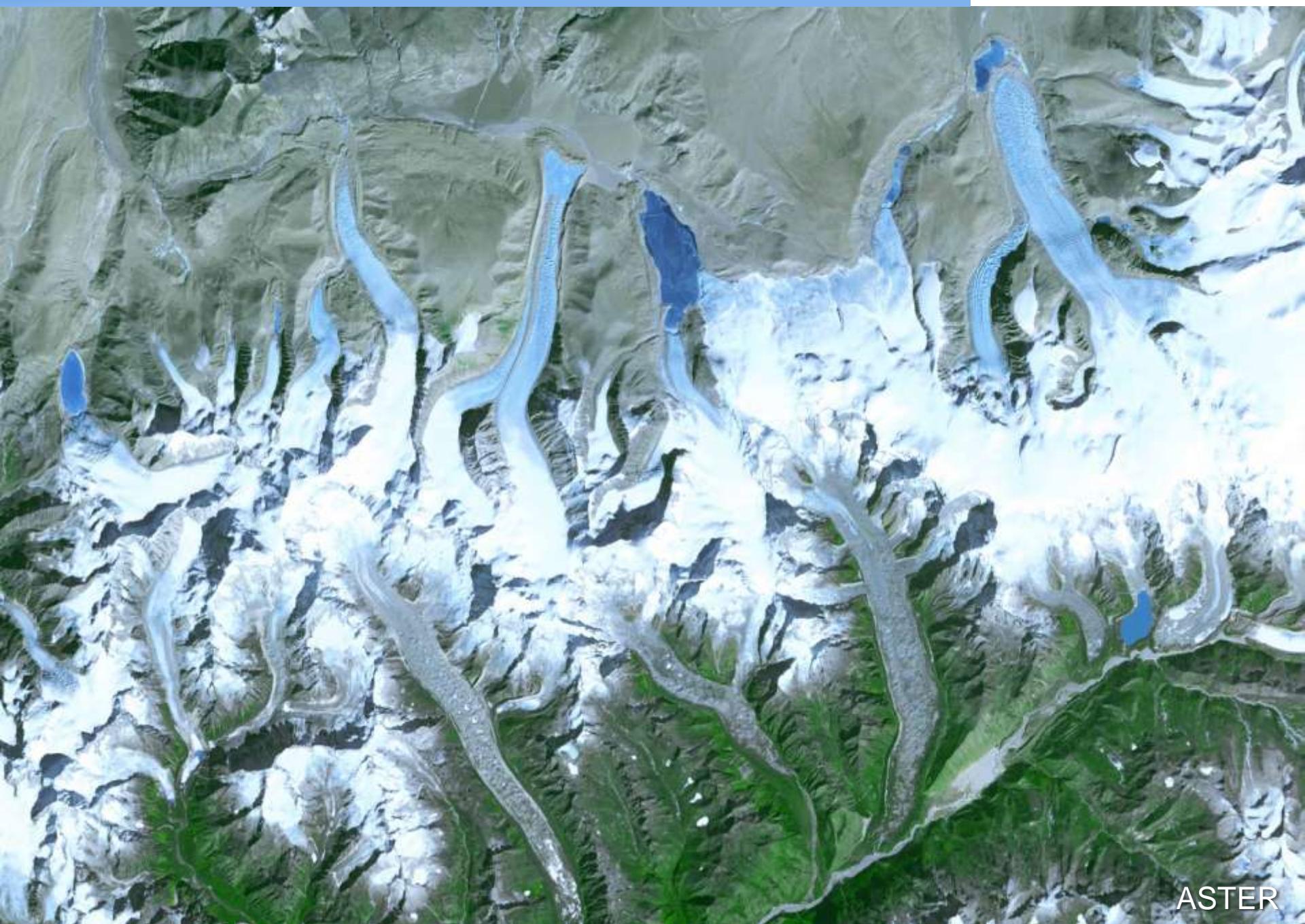
Natural hazards





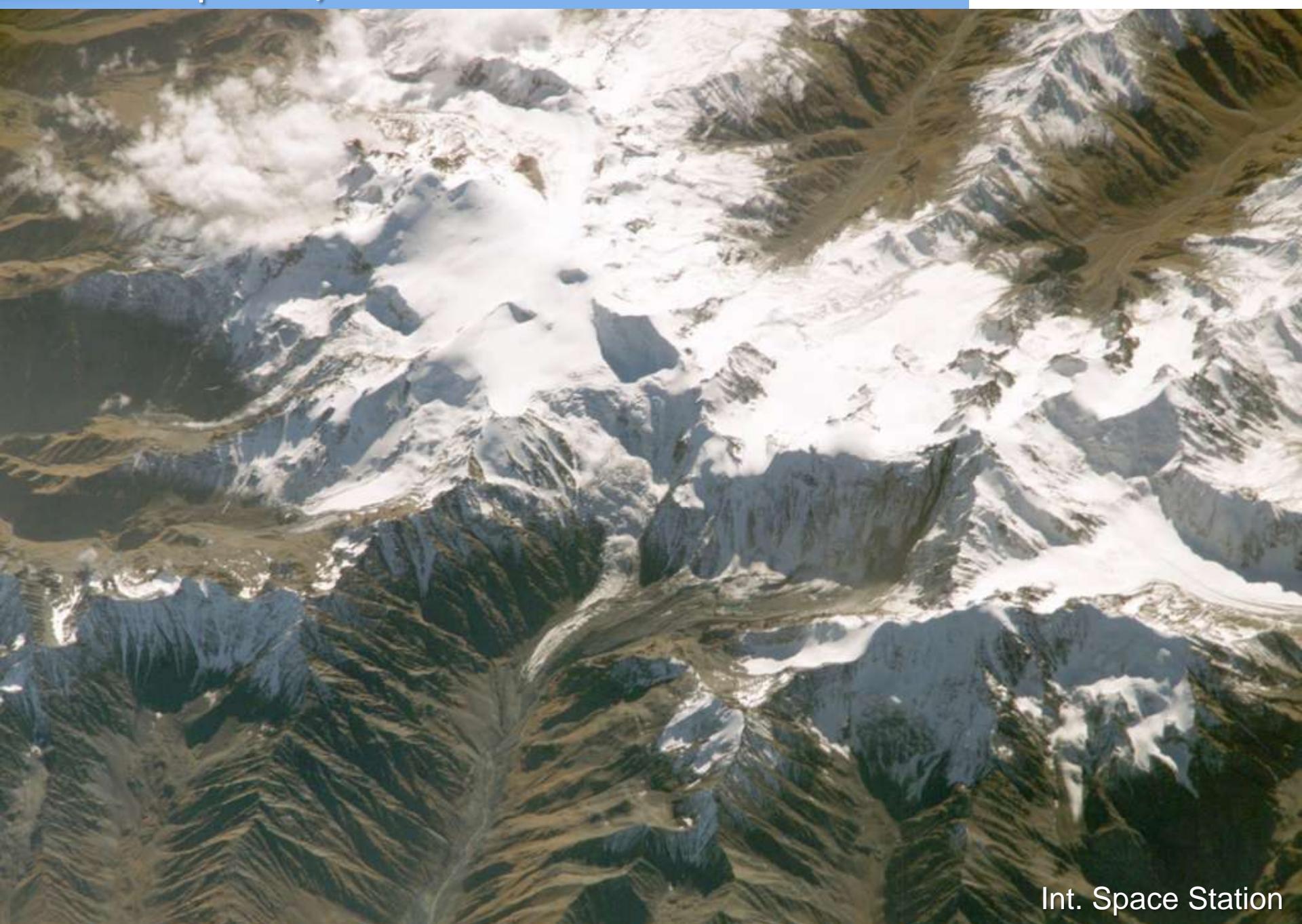


Remoteness



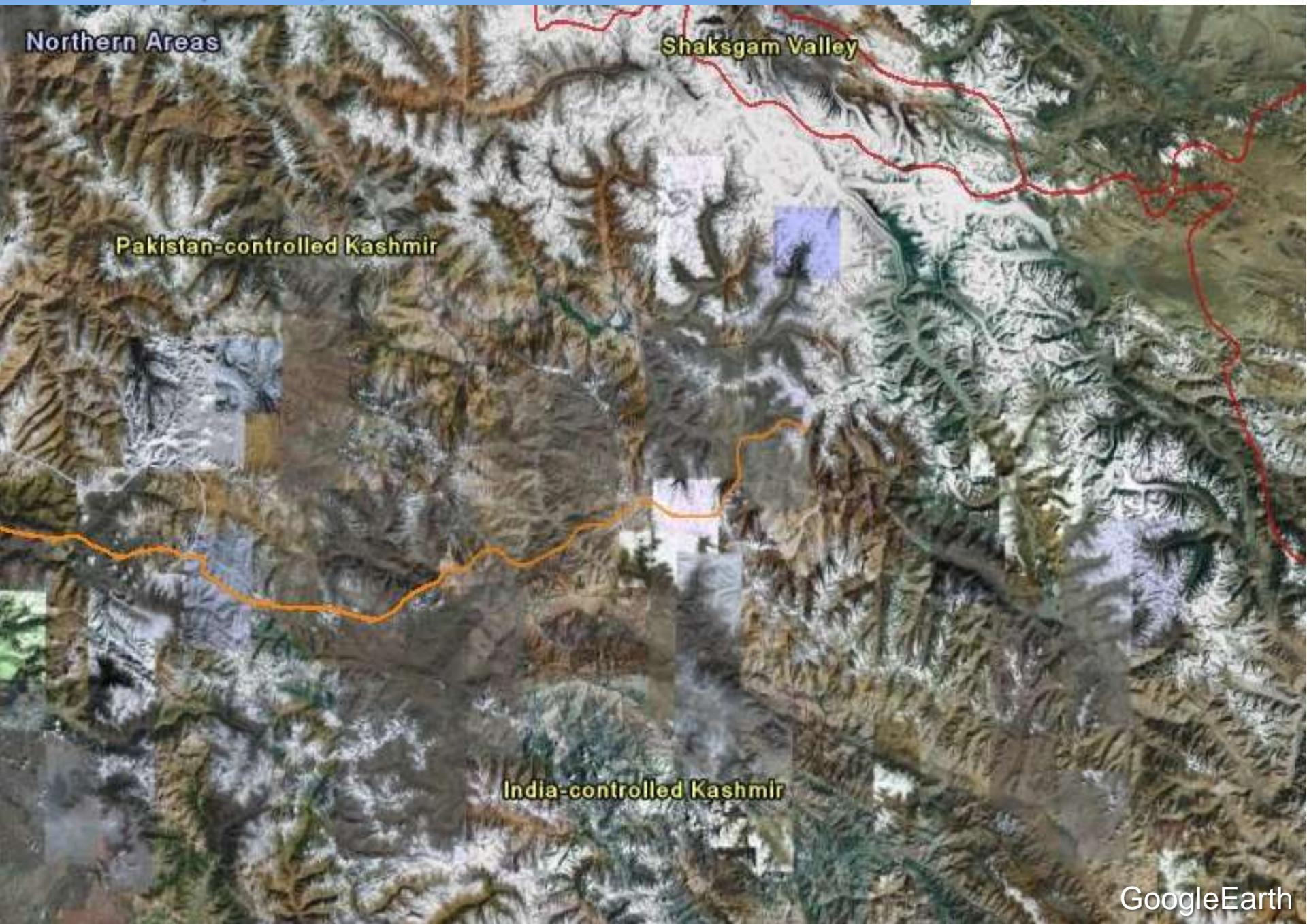
ASTER

Insecure places, access restrictions

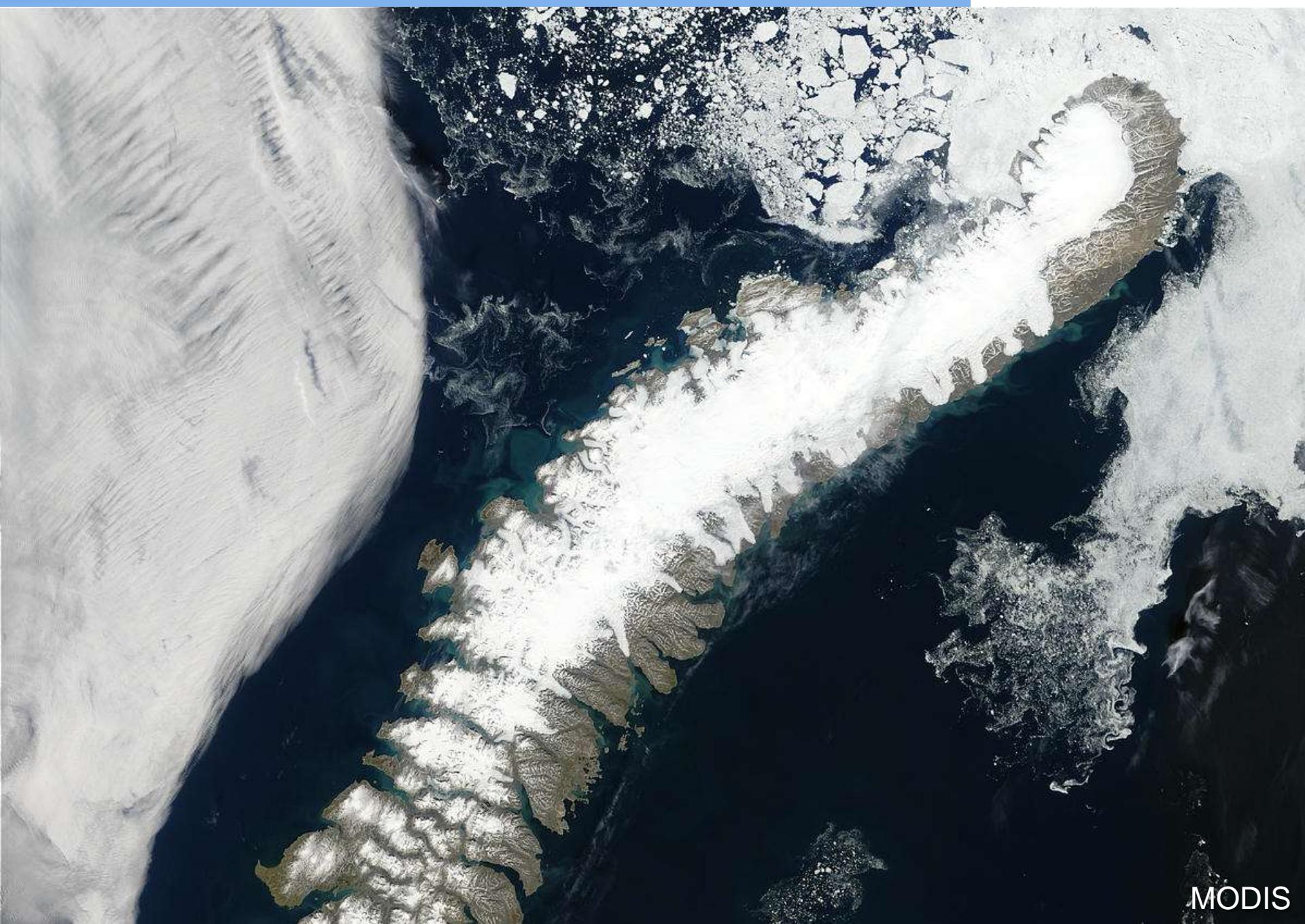


Int. Space Station

Insecure places, access restrictions

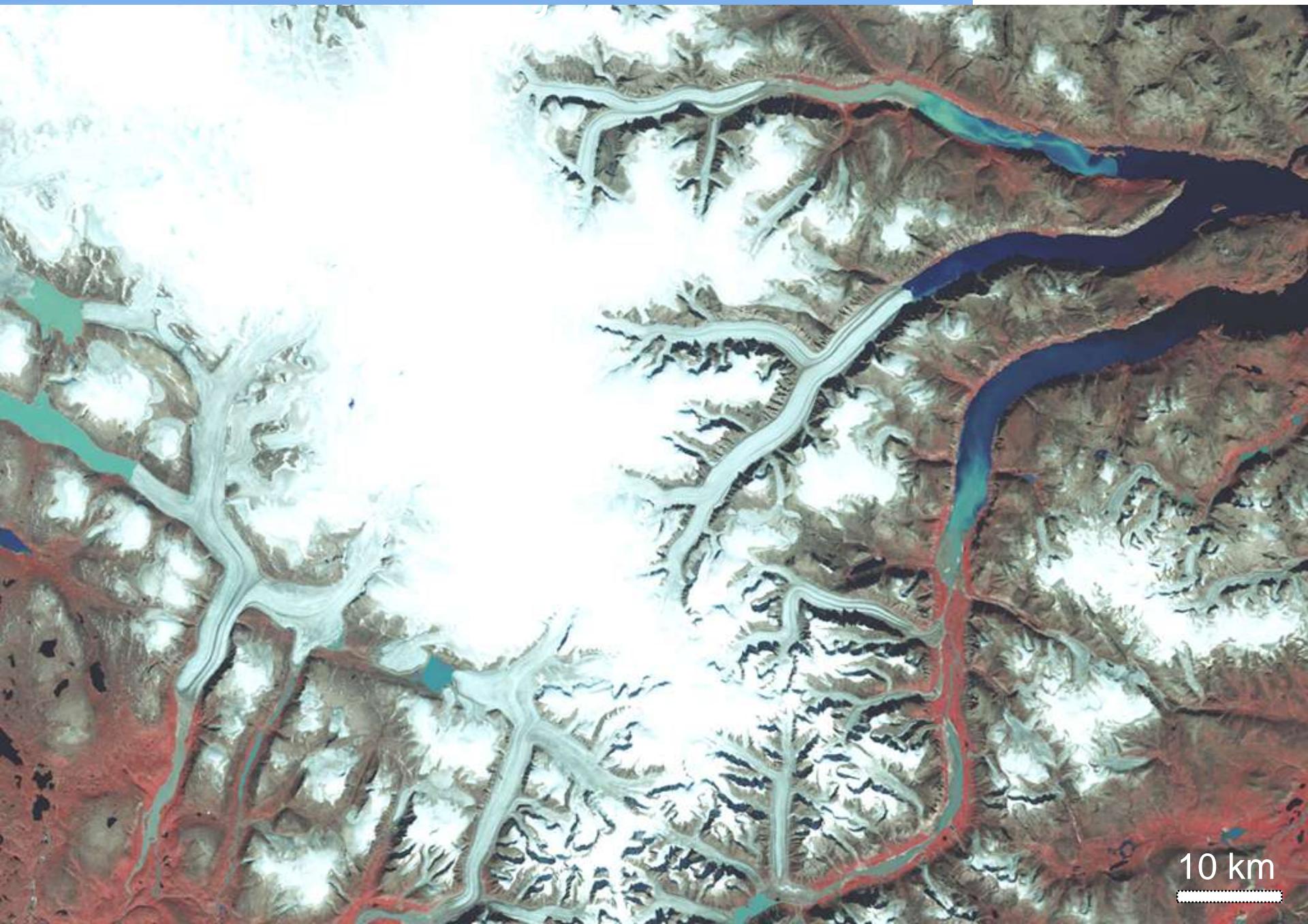


Access restrictions



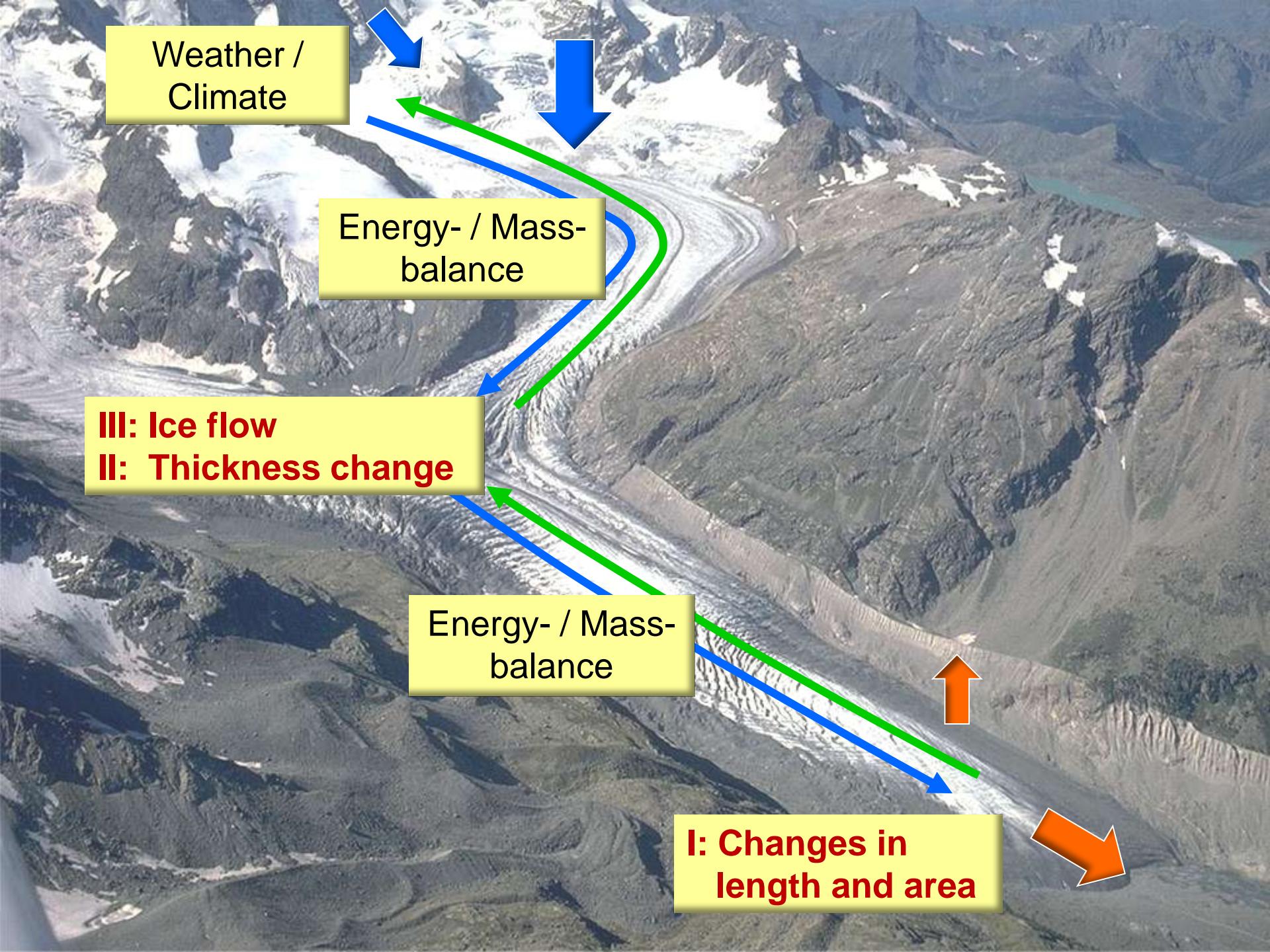
MODIS

Size and number





Apollo 17, 1972



Weather /
Climate

Energy- / Mass-
balance

III: Ice flow
II: Thickness change

Energy- / Mass-
balance

**I: Changes in
length and area**

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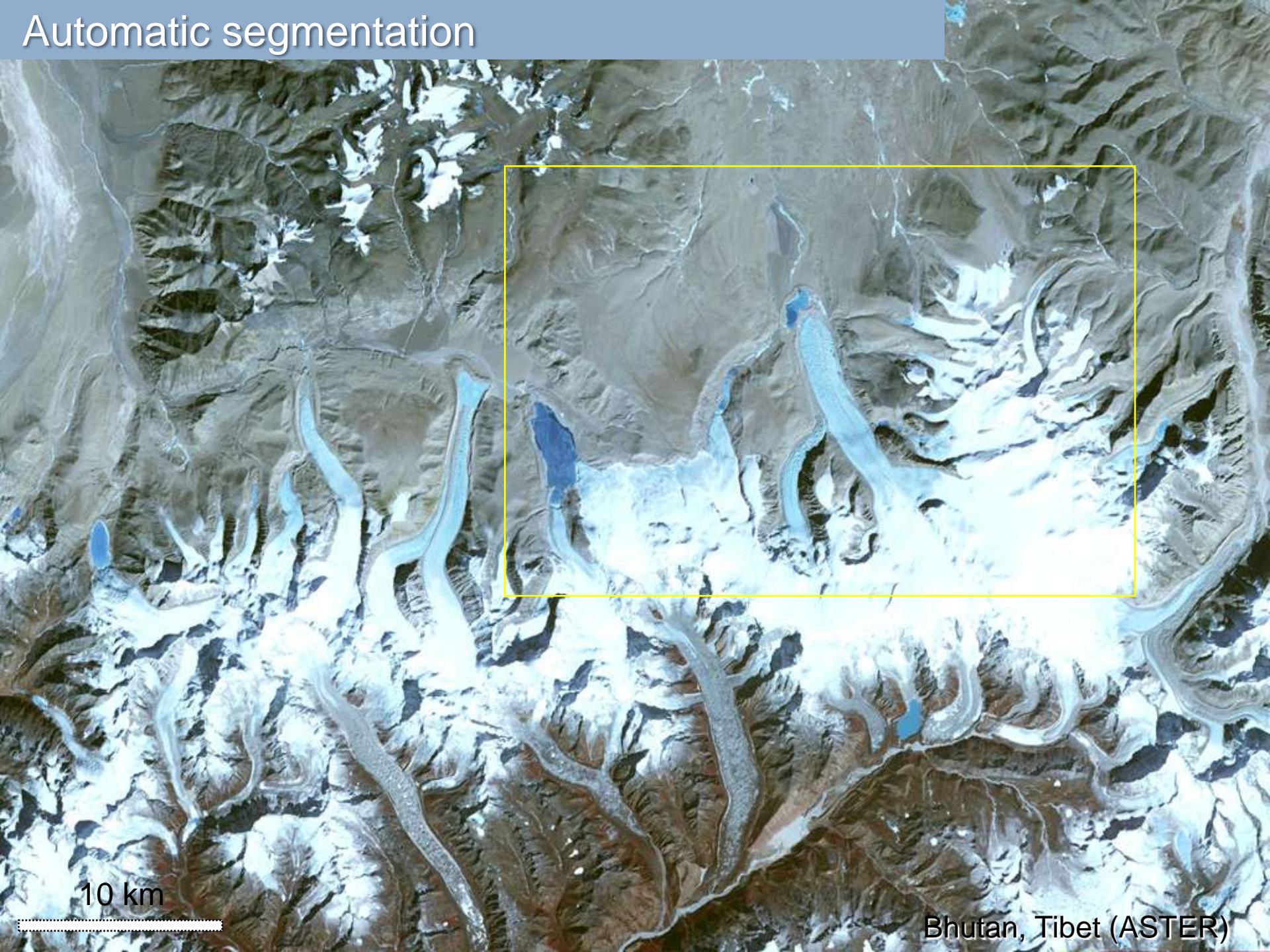
Part I: Glacier extent

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Automatic segmentation

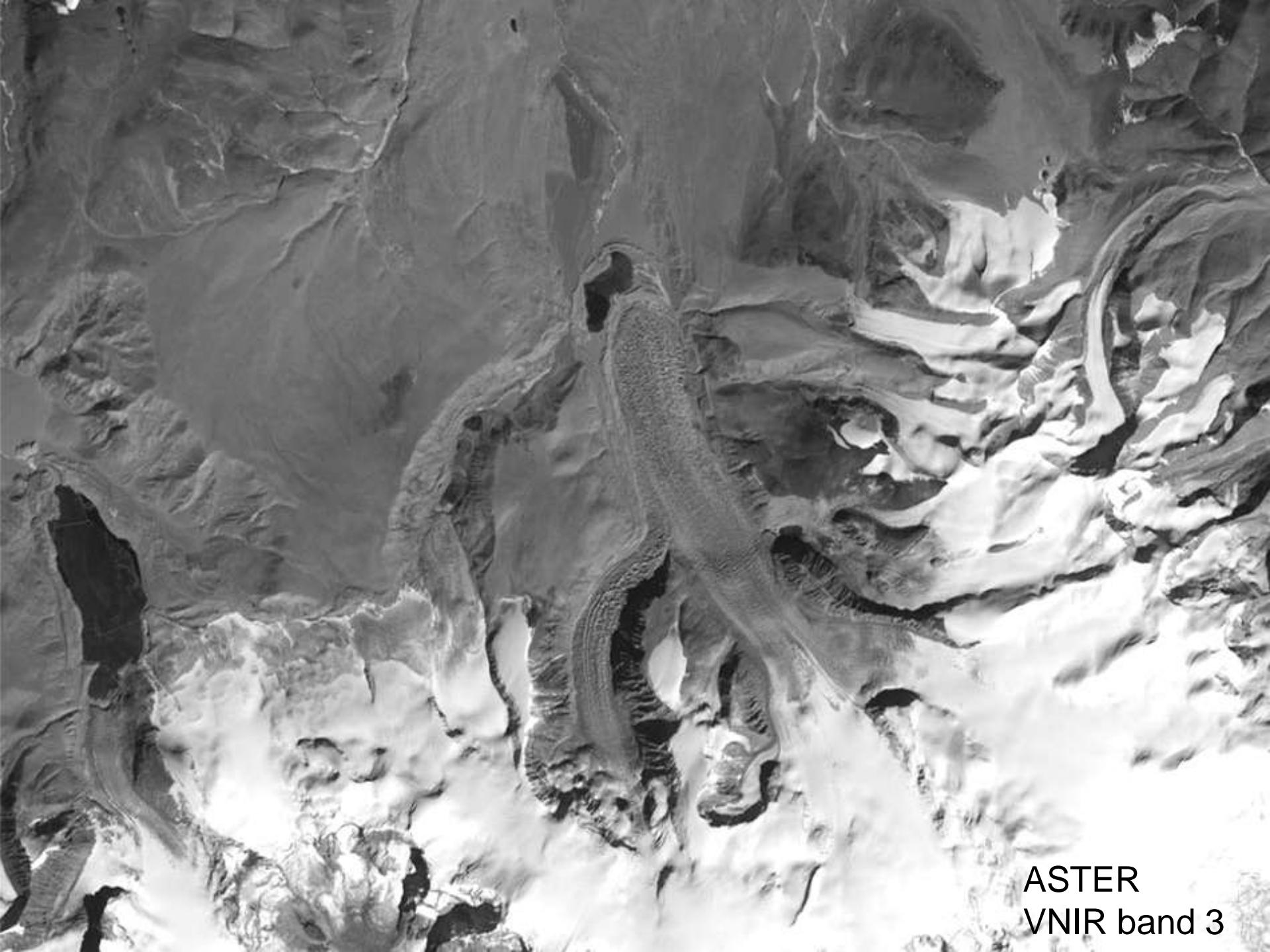


10 km

Bhutan, Tibet (ASTER)



10 km



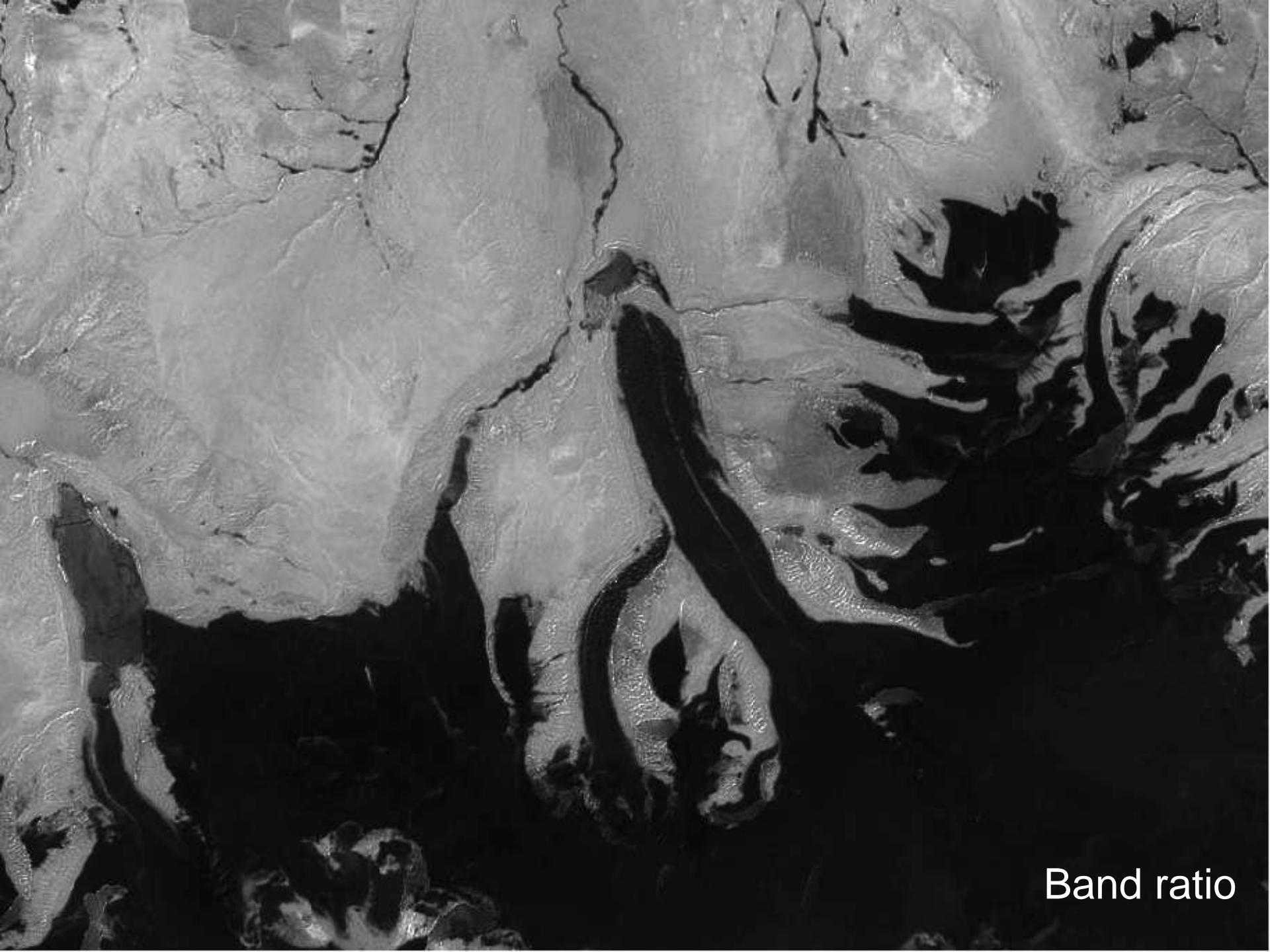
ASTER
VNIR band 3



ASTER
SWIR band 4



NDSI



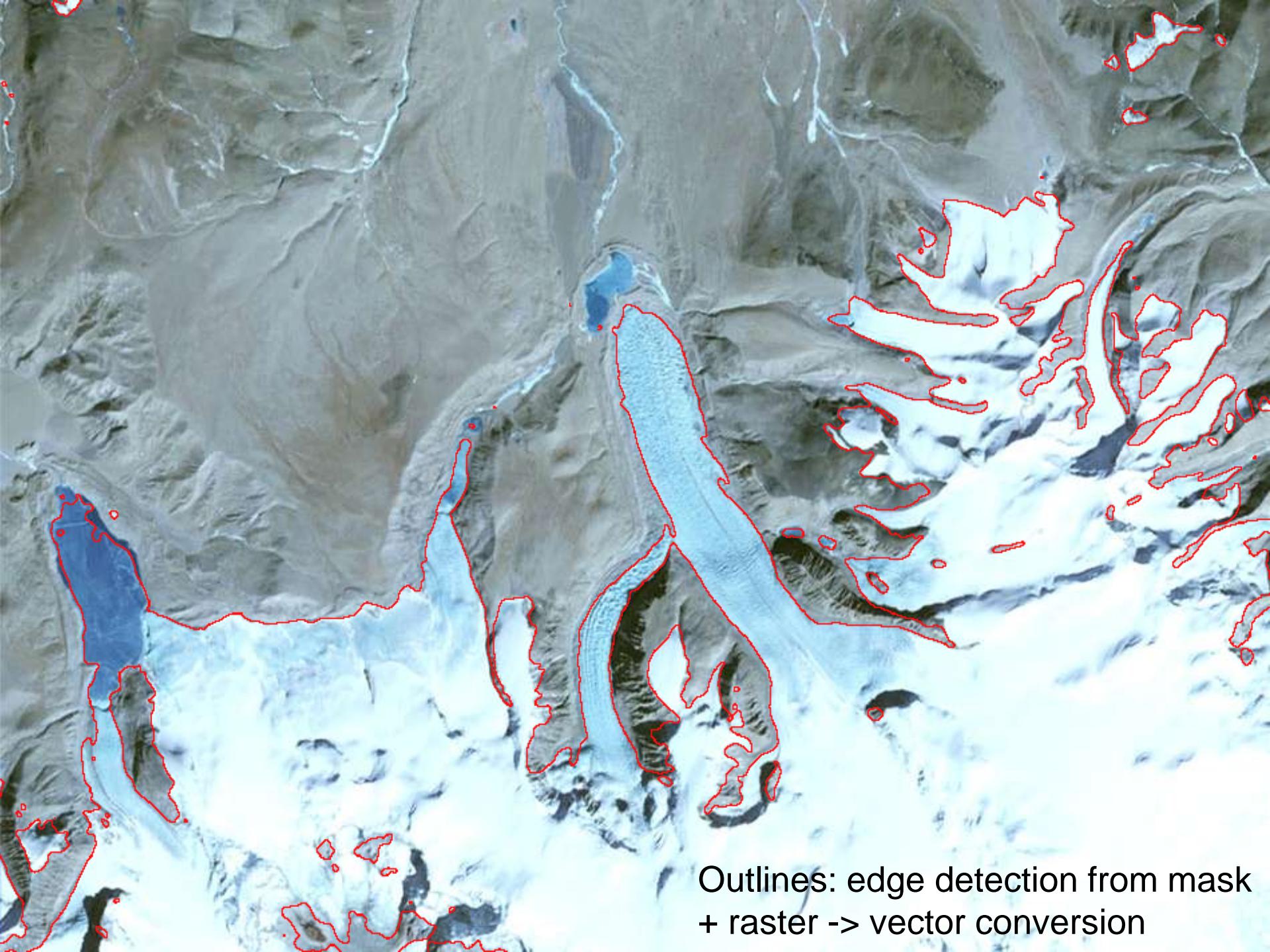
Band ratio



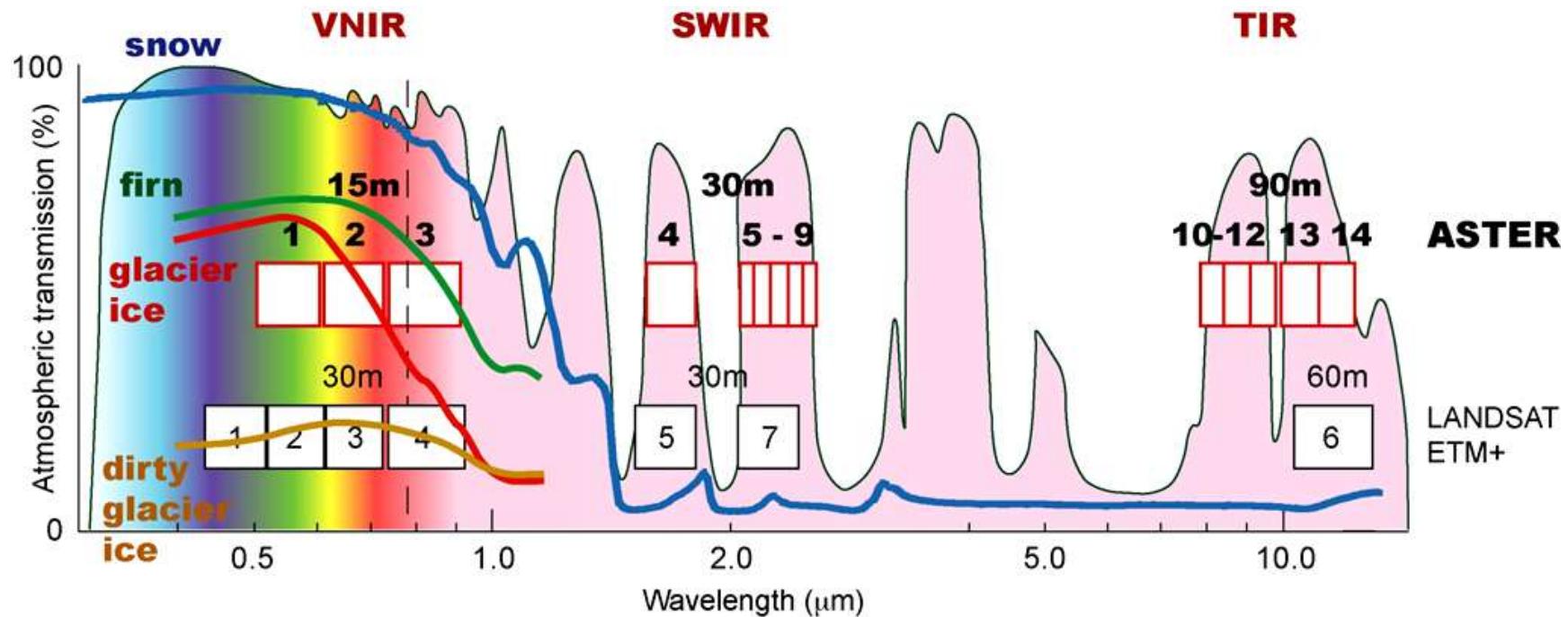
Thresholding

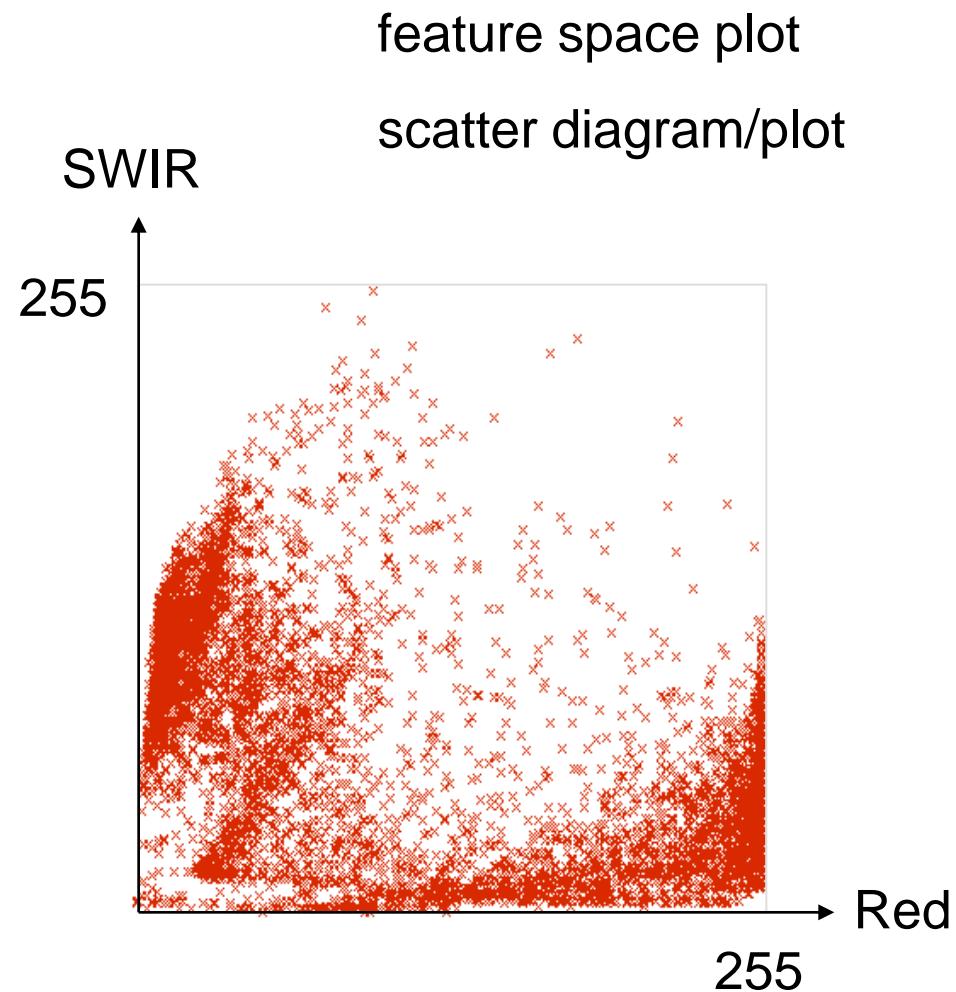
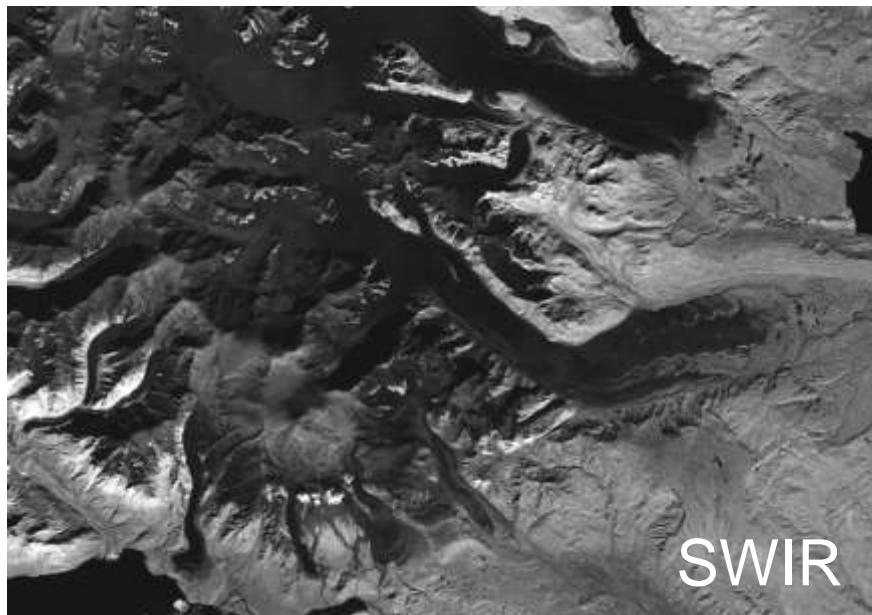
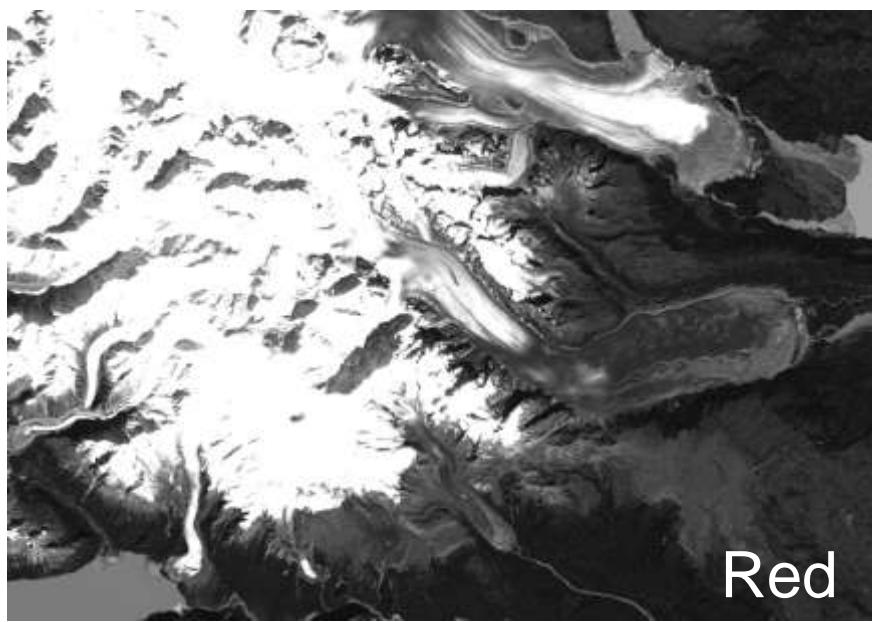


Noise-filtered mask (Median filter)



Outlines: edge detection from mask
+ raster -> vector conversion





- band ratios:

$$R_{ij} = \frac{DN_i}{DN_j}$$

Band i Band j

DN = digital number

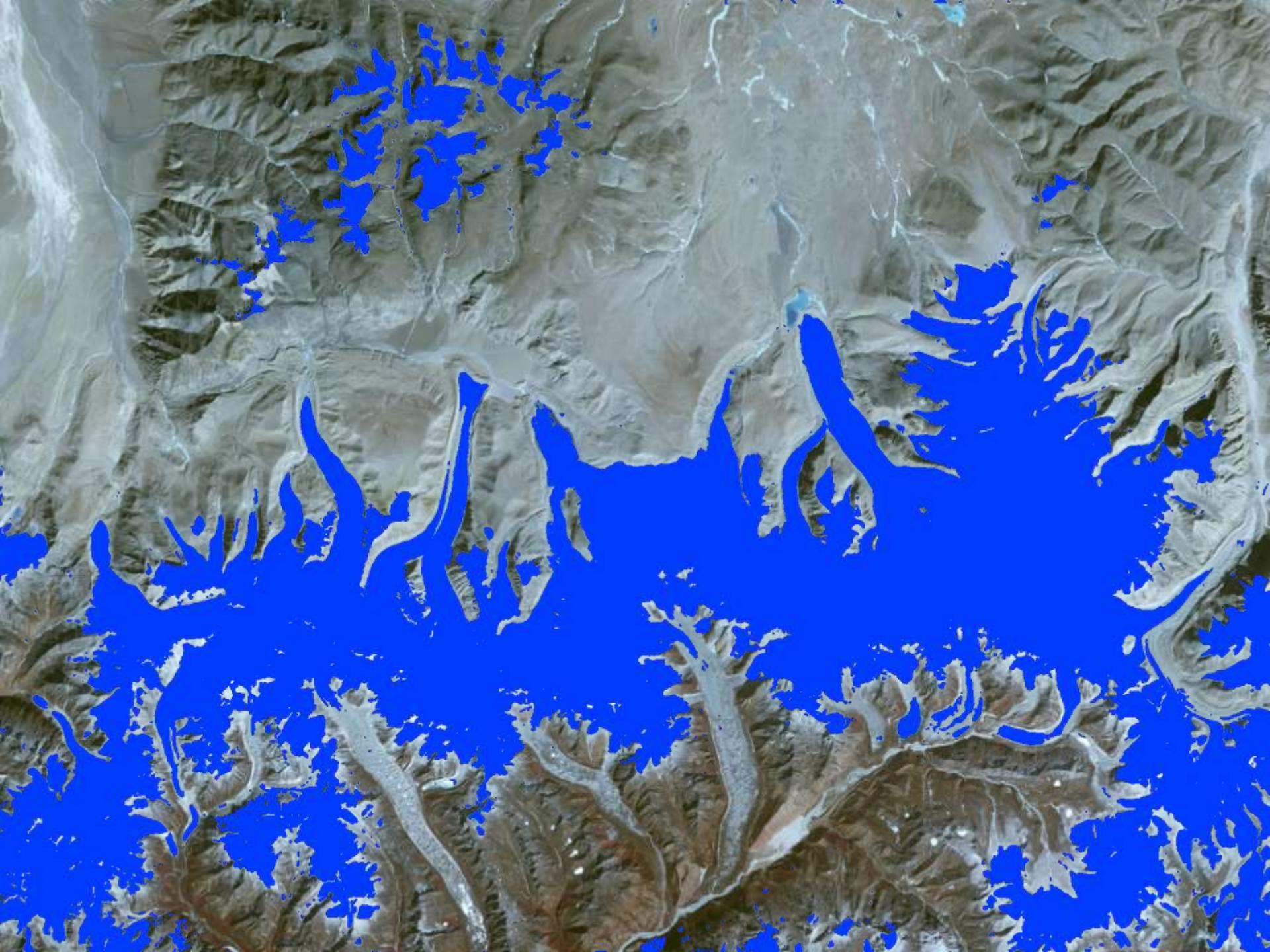
$$R_{ij} = \frac{(DN_i - DN_{\min(i)})}{(DN_j - DN_{\min(j)})}$$

“Dark object subtraction”

- normalized difference indices:

$$NDI_{ij} = \frac{(DN_i - DN_j)}{(DN_i + DN_j)}$$

for vegetation, snow, water, ...





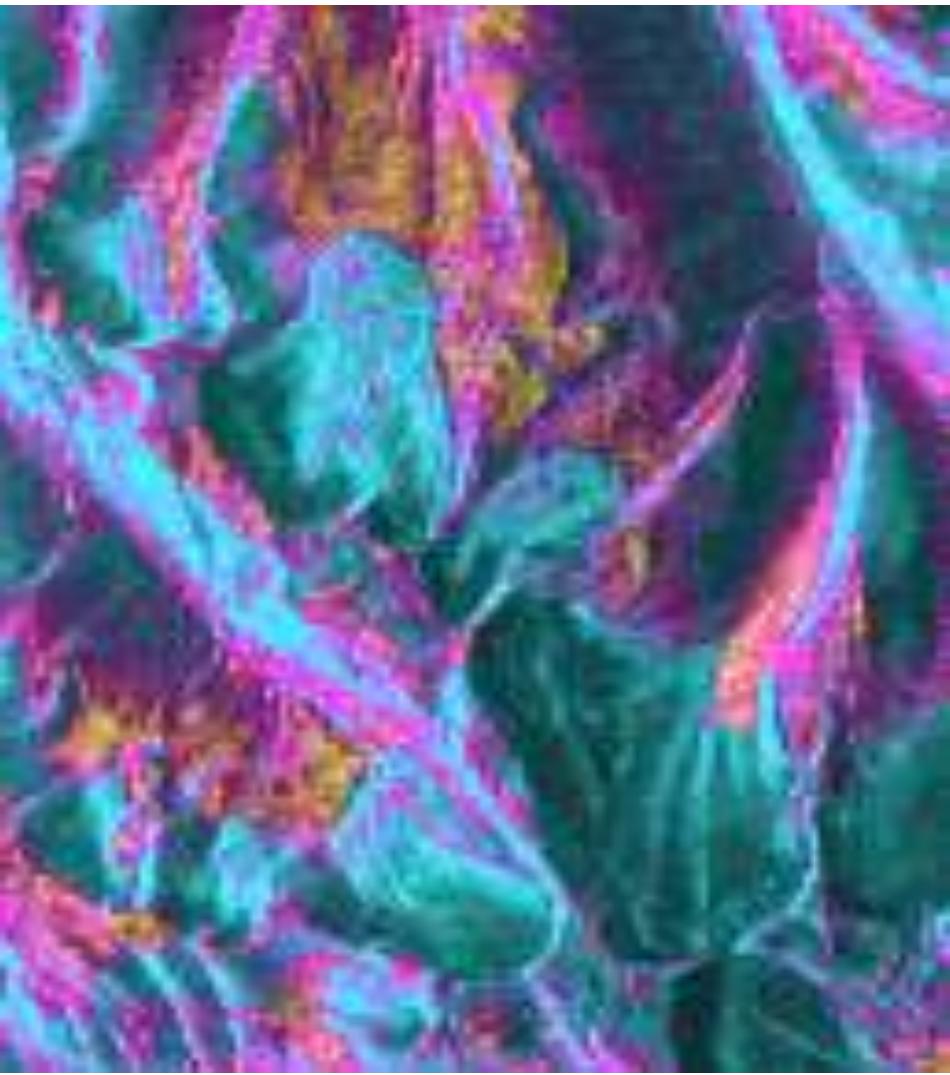
10 km

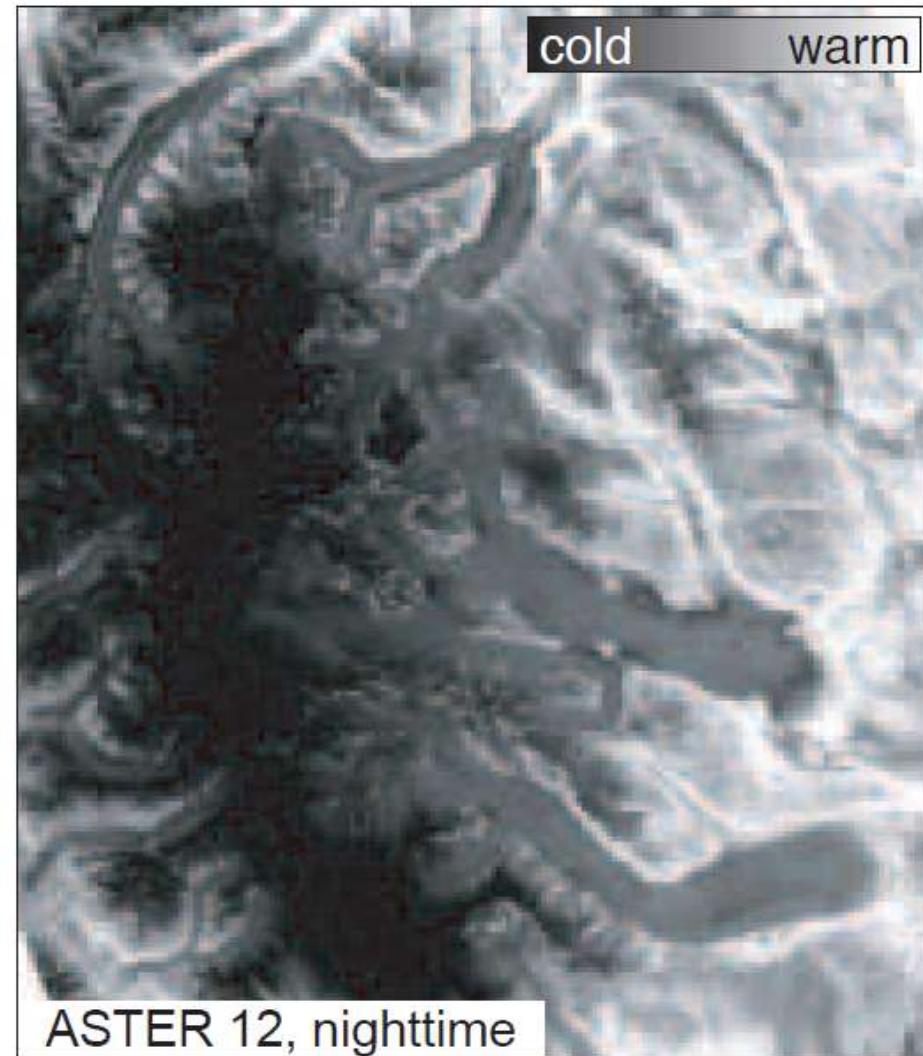
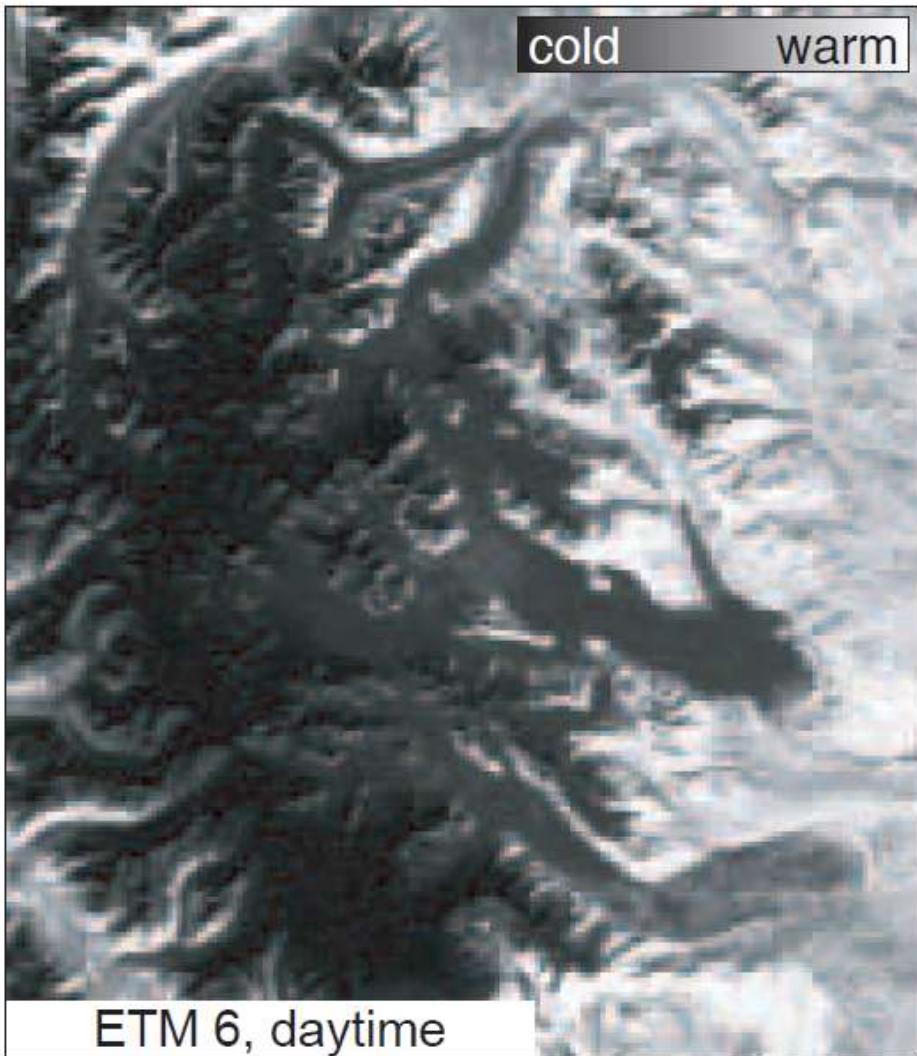
- Spectral characteristics (not unique)
- Topographic characteristics (not unique)
- Dynamic characteristics (not unique)
- Thermal characteristics (not unique)

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- Topographic characteristics (not unique)
- Dynamic characteristics
- Thermal characteristics

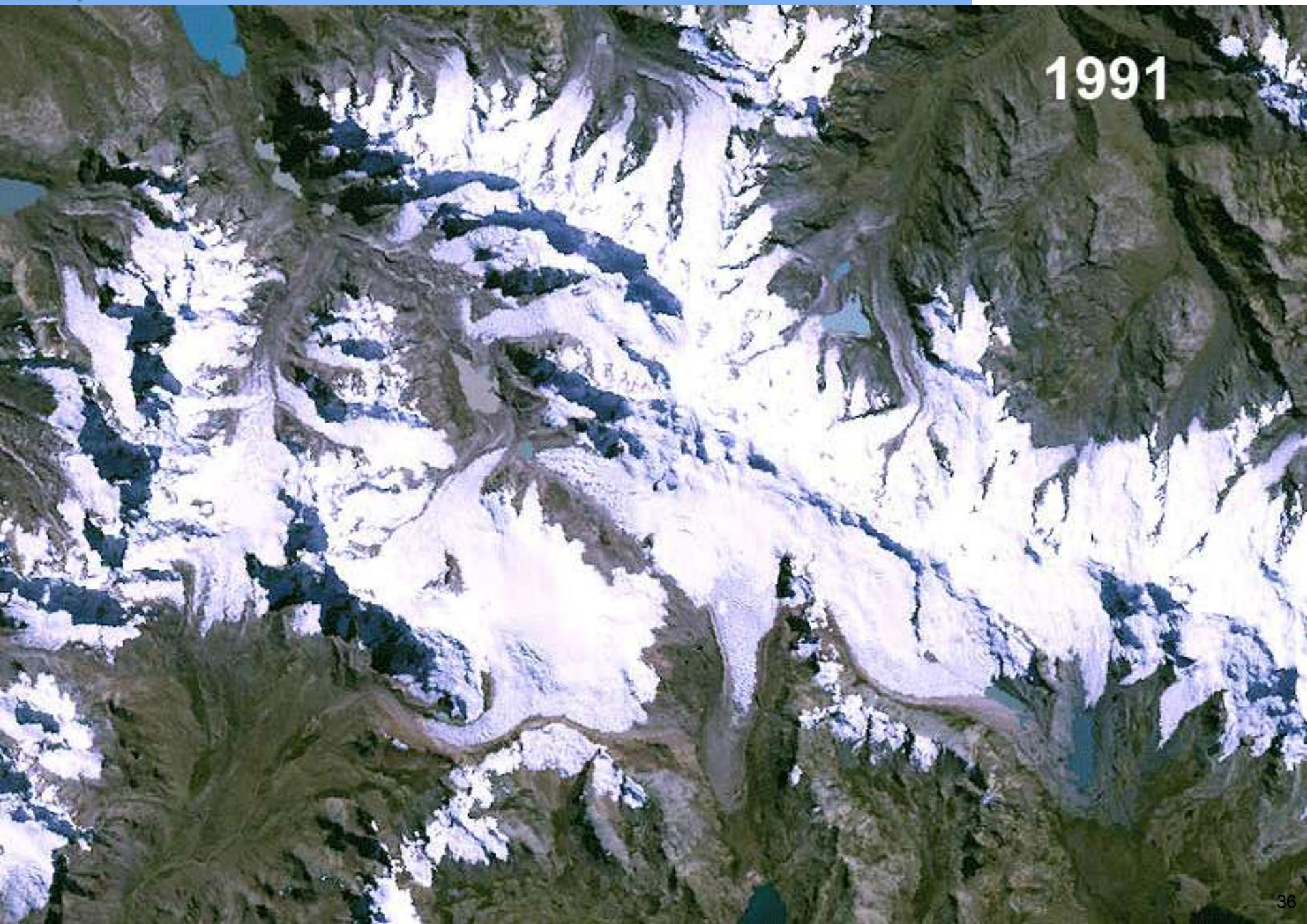


Debris cover

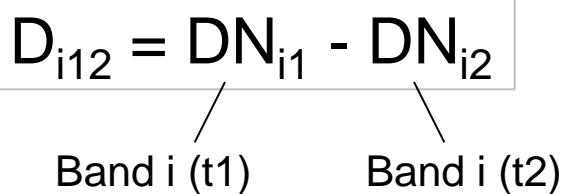




Repeat data



- differences:

$$D_{i12} = DN_{i1} - DN_{i2}$$


Band i (t1) Band i (t2)

- band ratios:

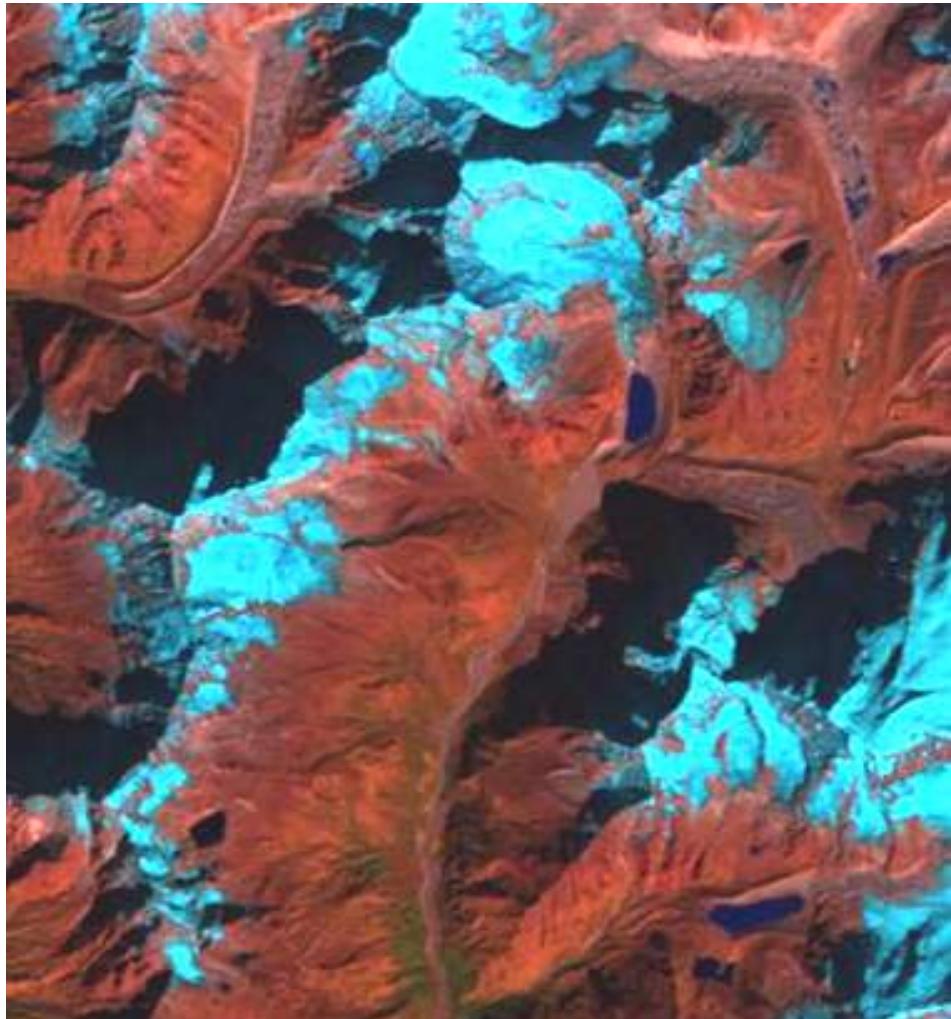
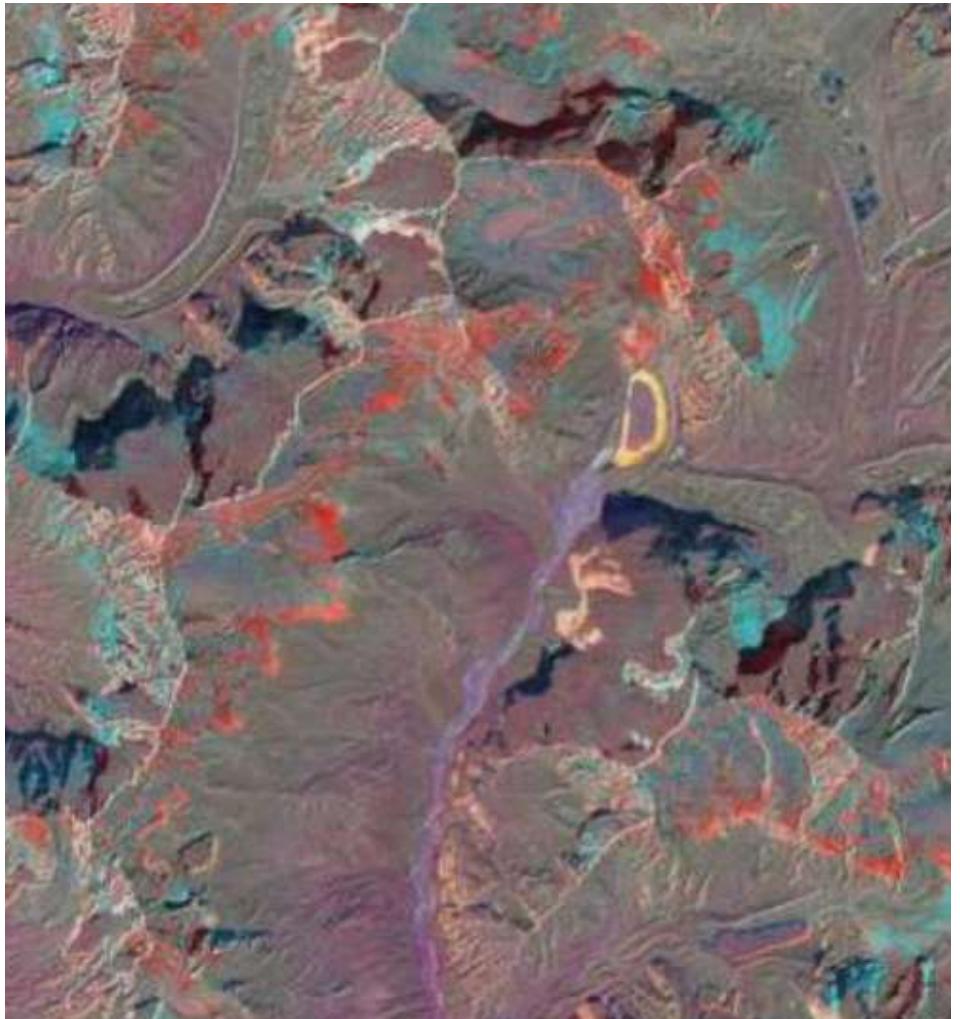
$$R_{i12} = DN_{i1} / DN_{i2}$$

- normalized difference indices:

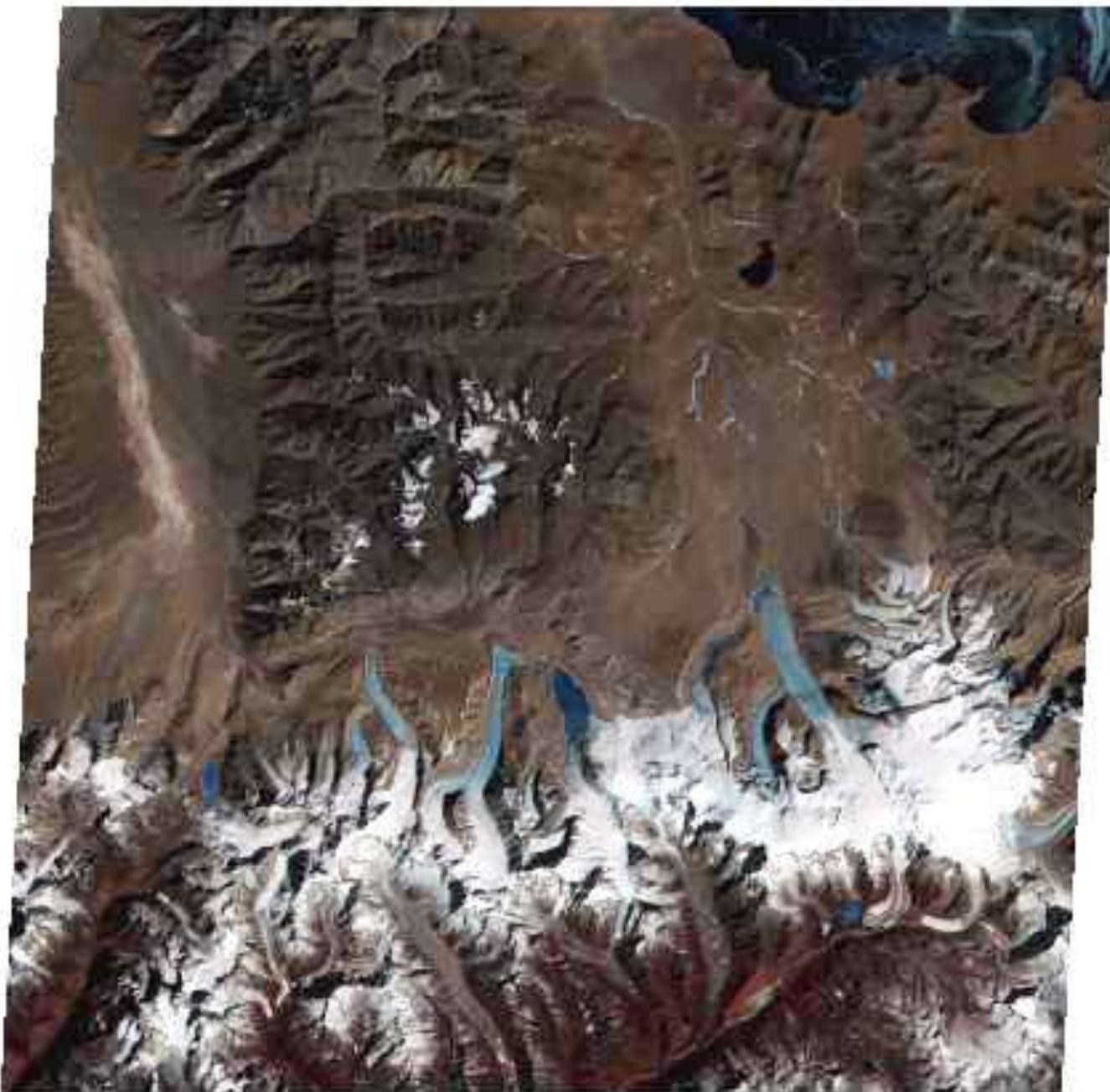
$$NDI_{i12} = (DN_{i1} - DN_{i2}) / (DN_{i1} + DN_{i2})$$

- differences, ratios, difference indices of expressions instead of DN

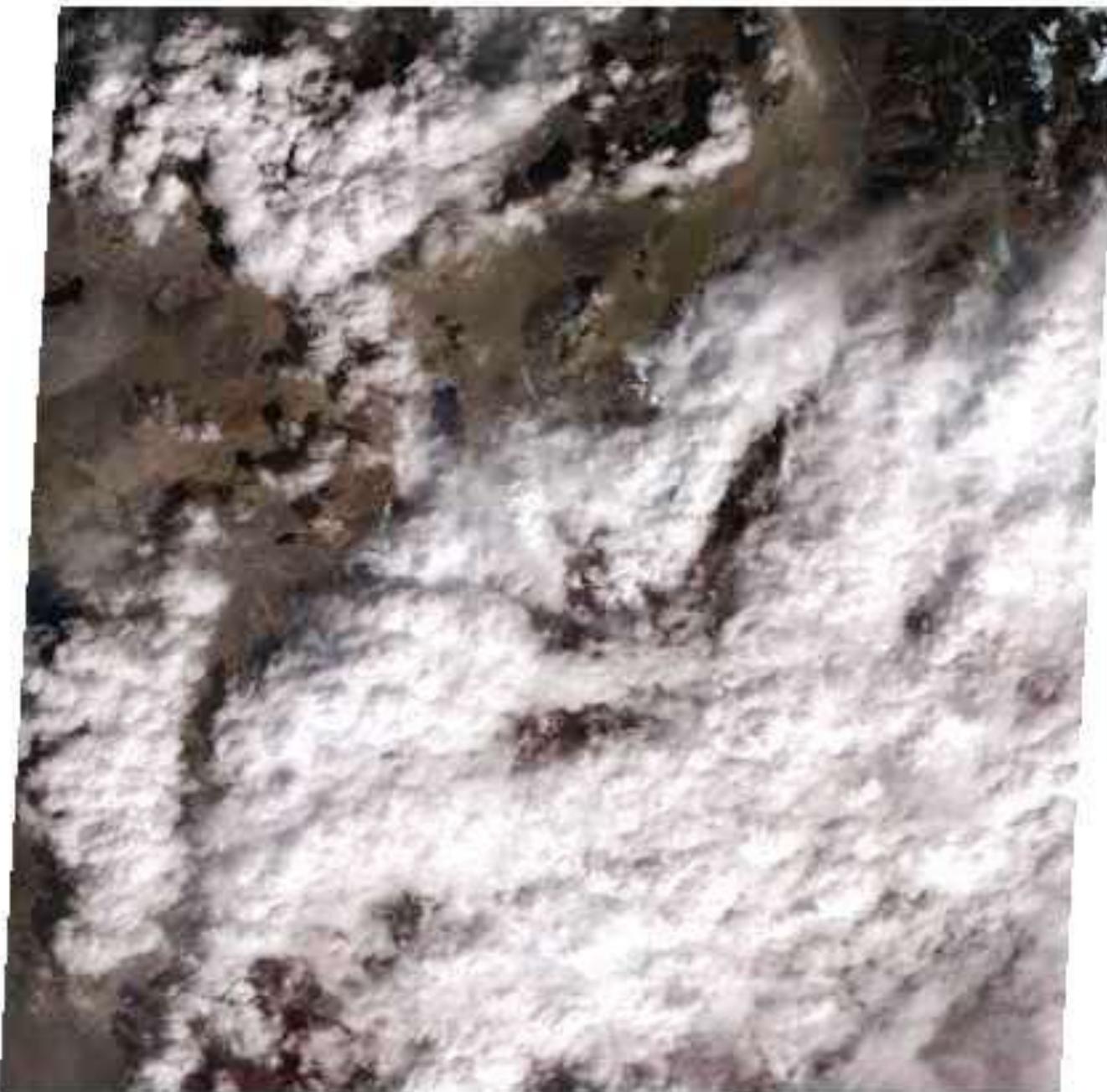
Multispectral NDI



But ...



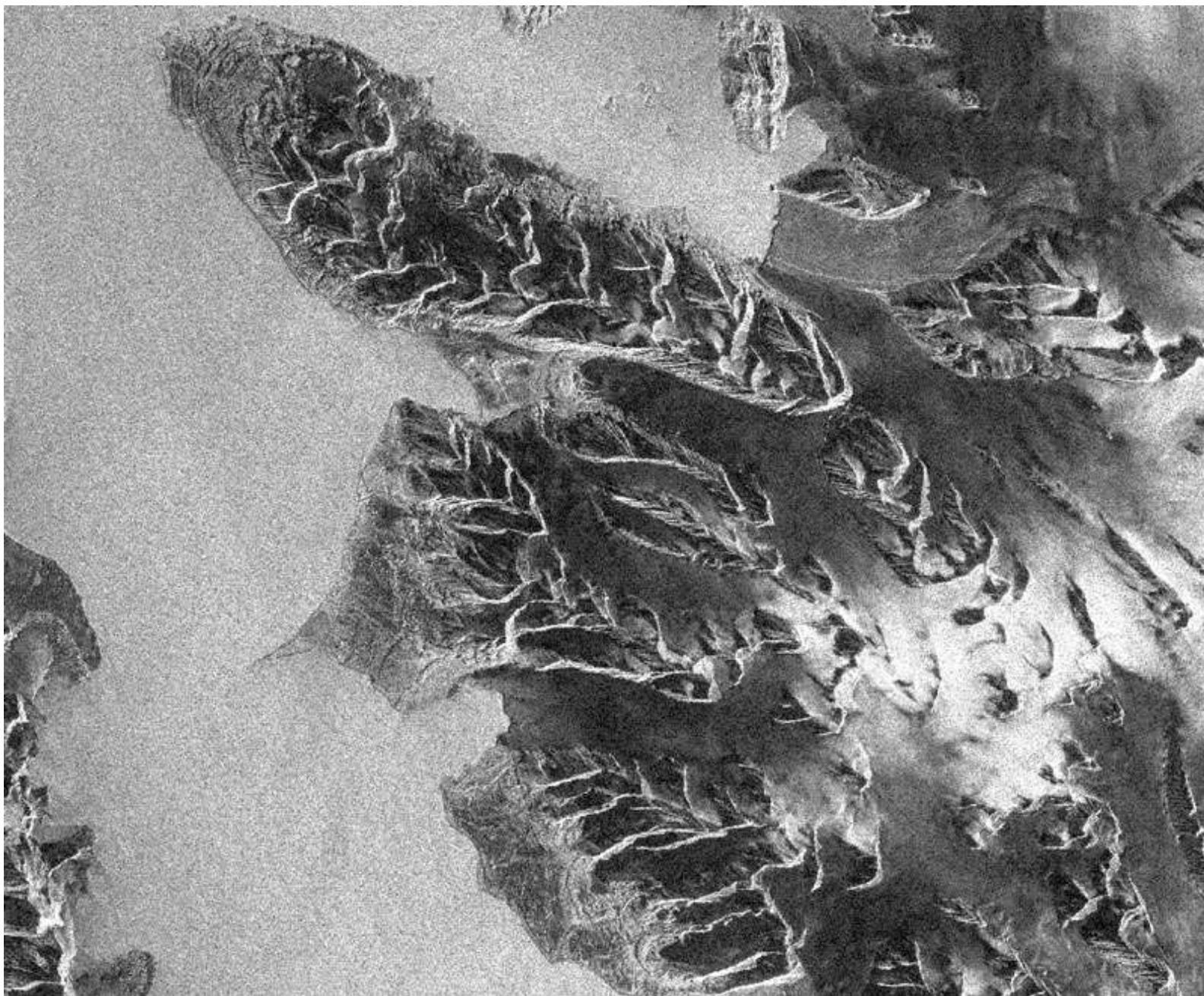
But ...



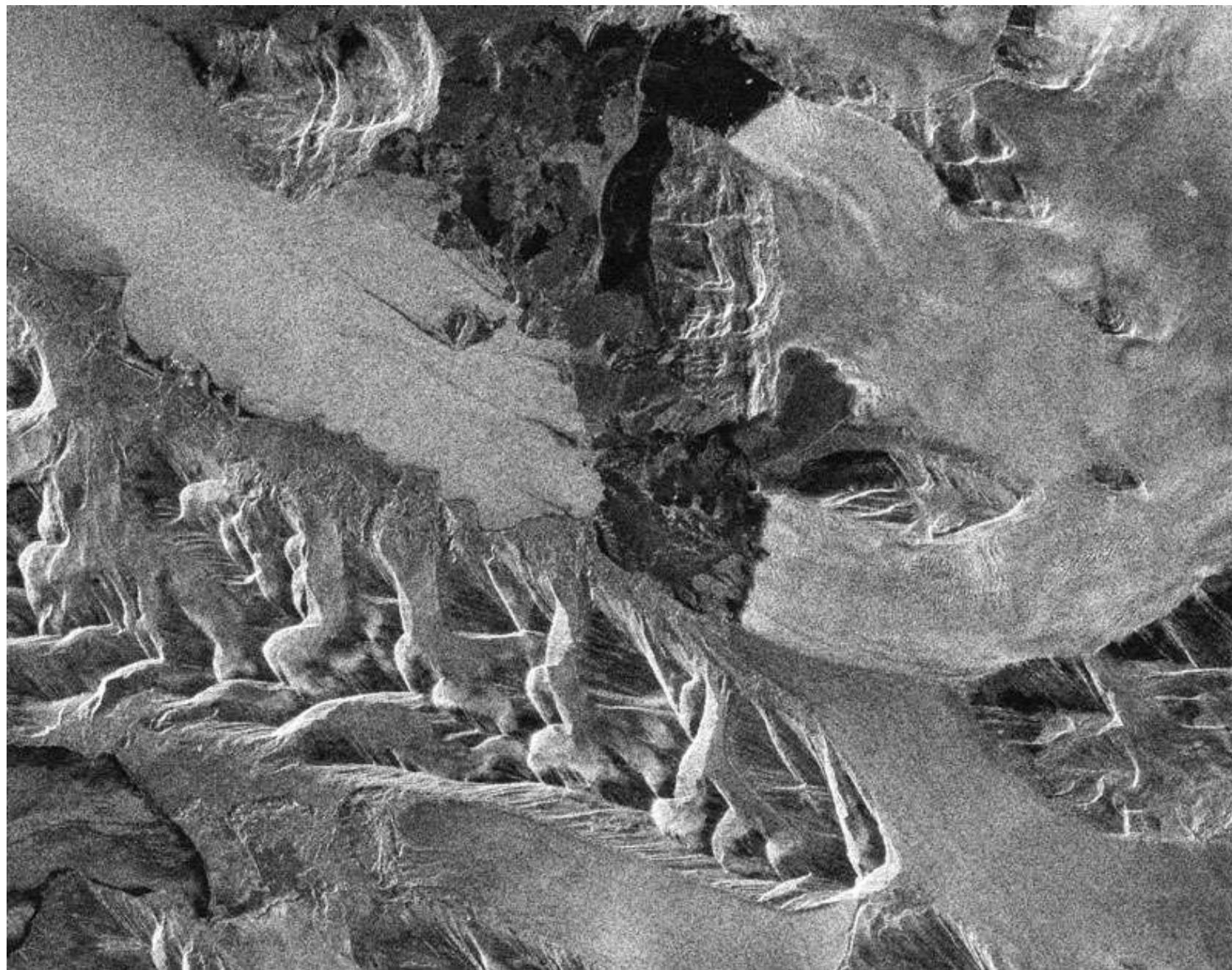
Ny Ålesund, Svalbard (ASTER)



Synthetic Aperture Radar (SAR)



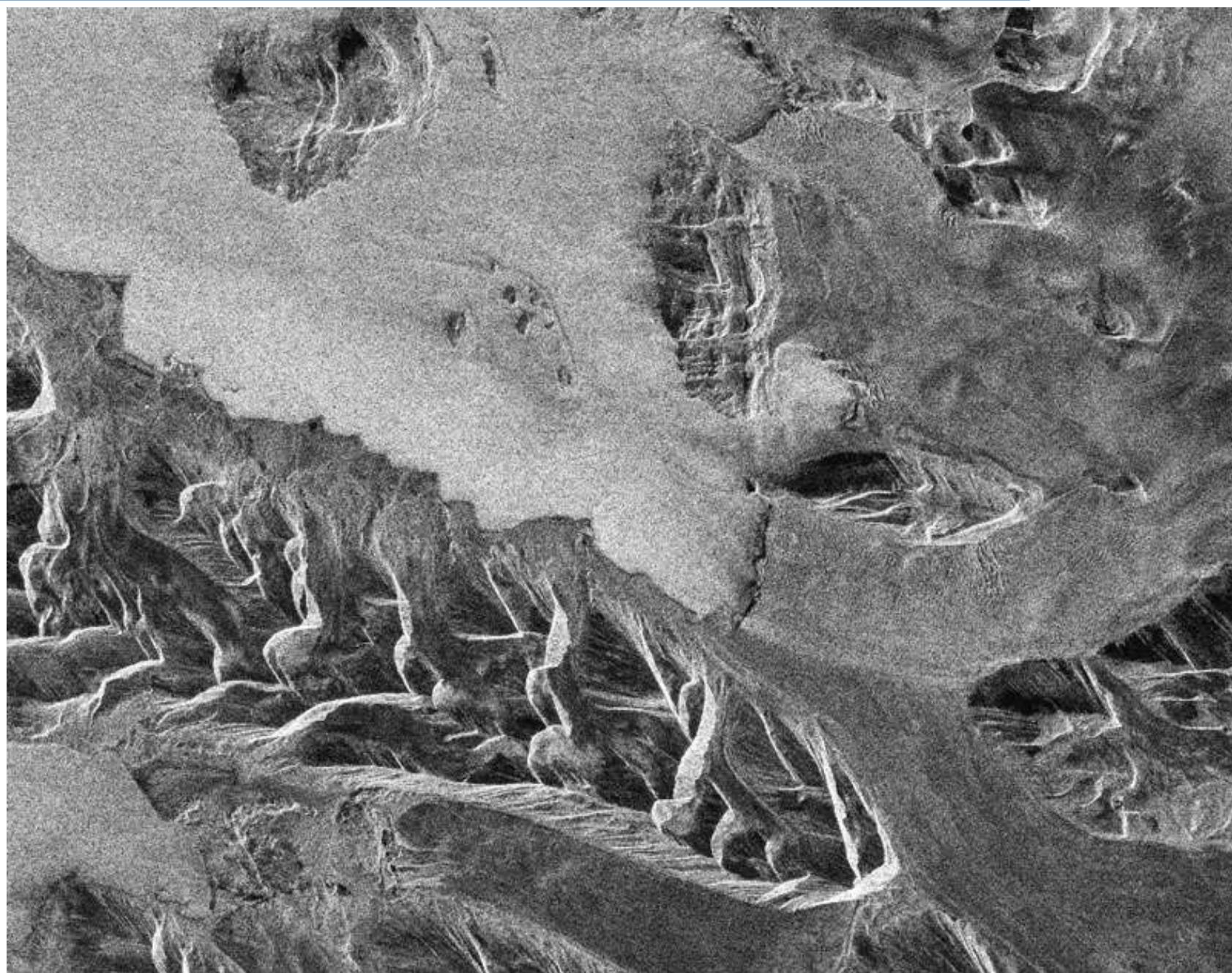
Synthetic Aperture Radar (SAR)



Synthetic Aperture Radar (SAR)

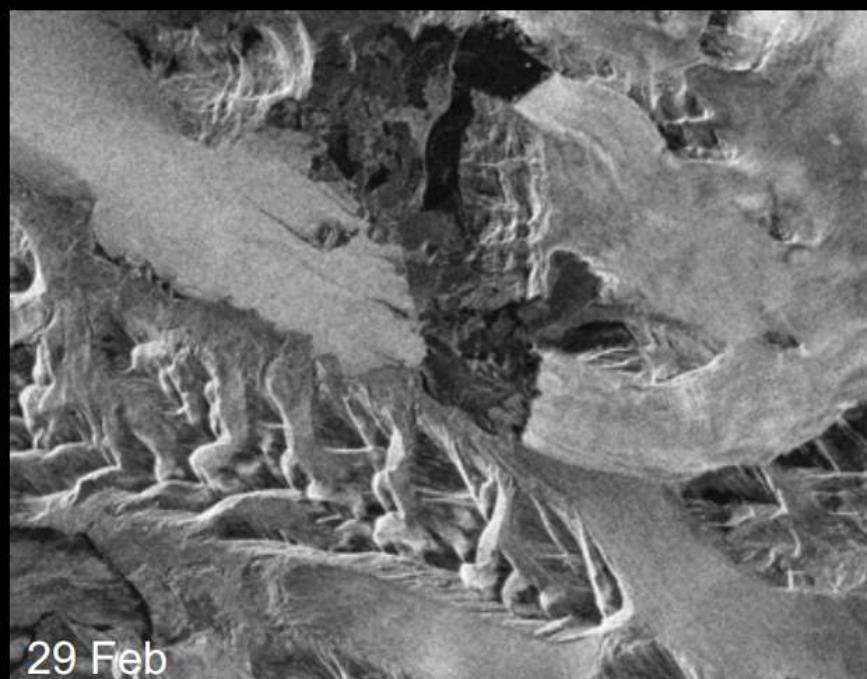
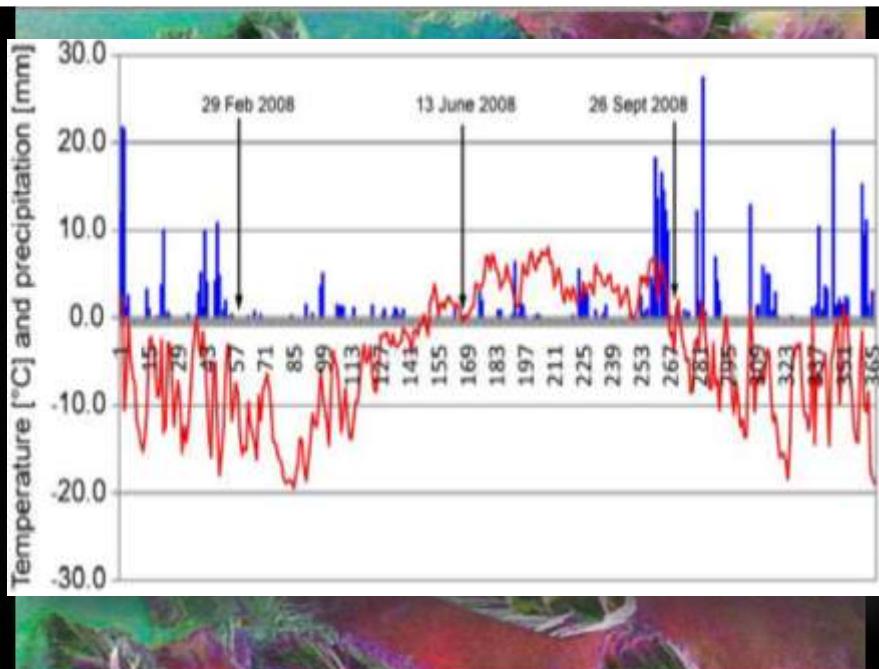


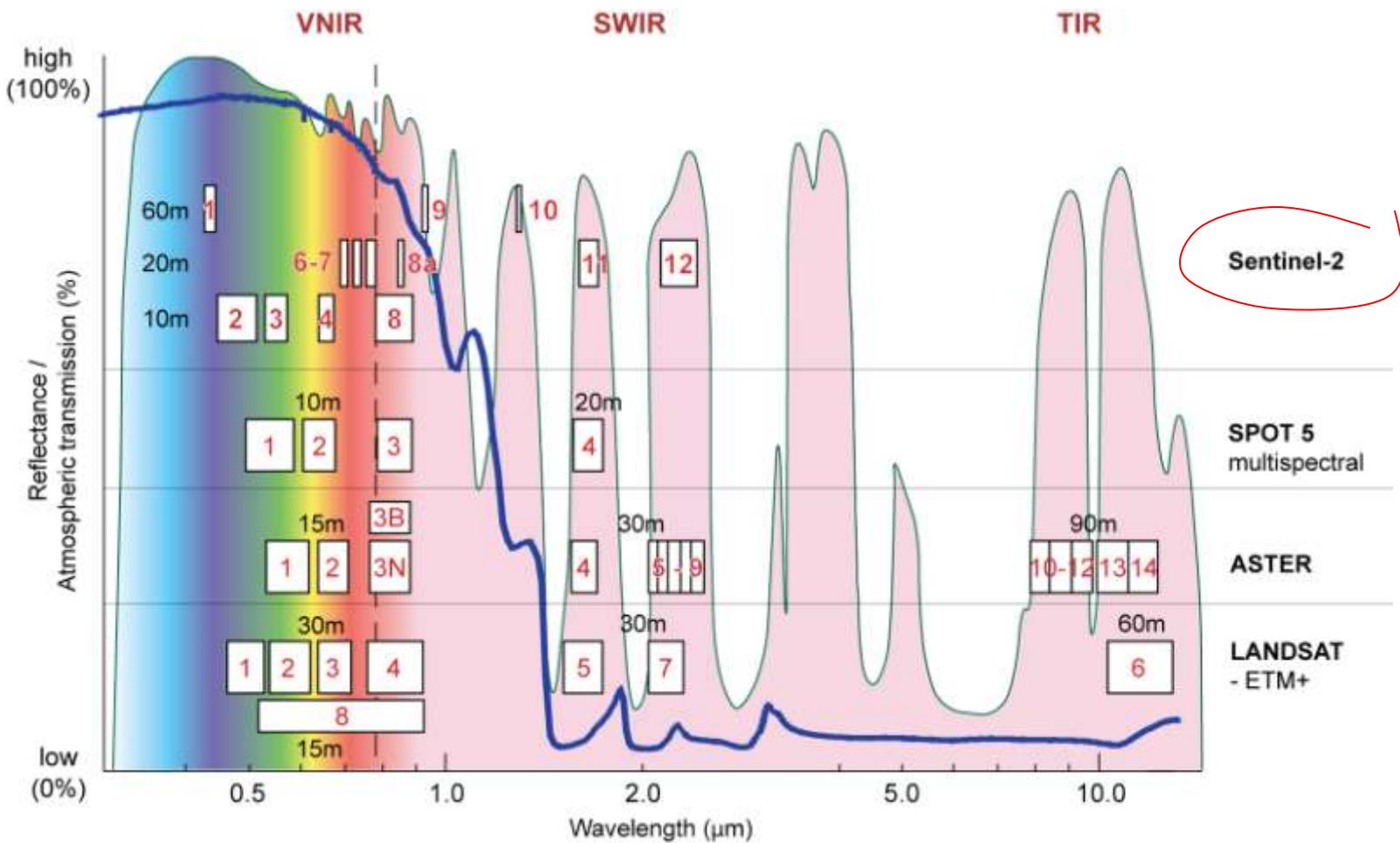
Synthetic Aperture Radar (SAR)

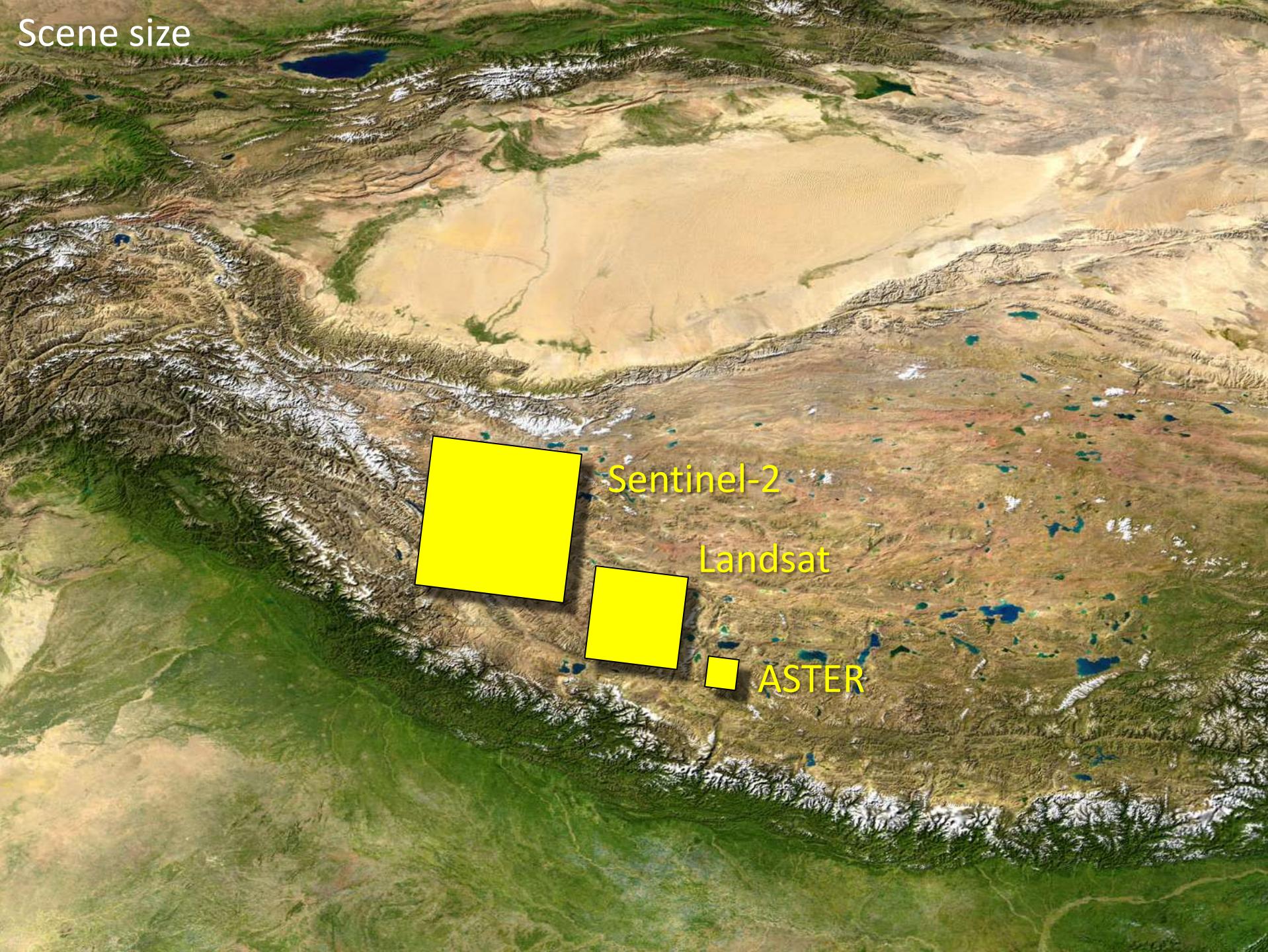


SAR multitemporal composite









Scene size

Sentinel-2 for *glacier mapping and monitoring*:

- 290 km swath width
- 10-20 m resolution, 10 m VNIR
- SWIR band
- Temporal resolution (5 days @ equator, 2-3 days @ mid-lat)
- *Area changes*: novel multitemp. approaches
- *Snow line*: atmospheric correction bands
- *Ice flow*: combination with Sentinel-1

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Glacier elevation

Andreas Kääb

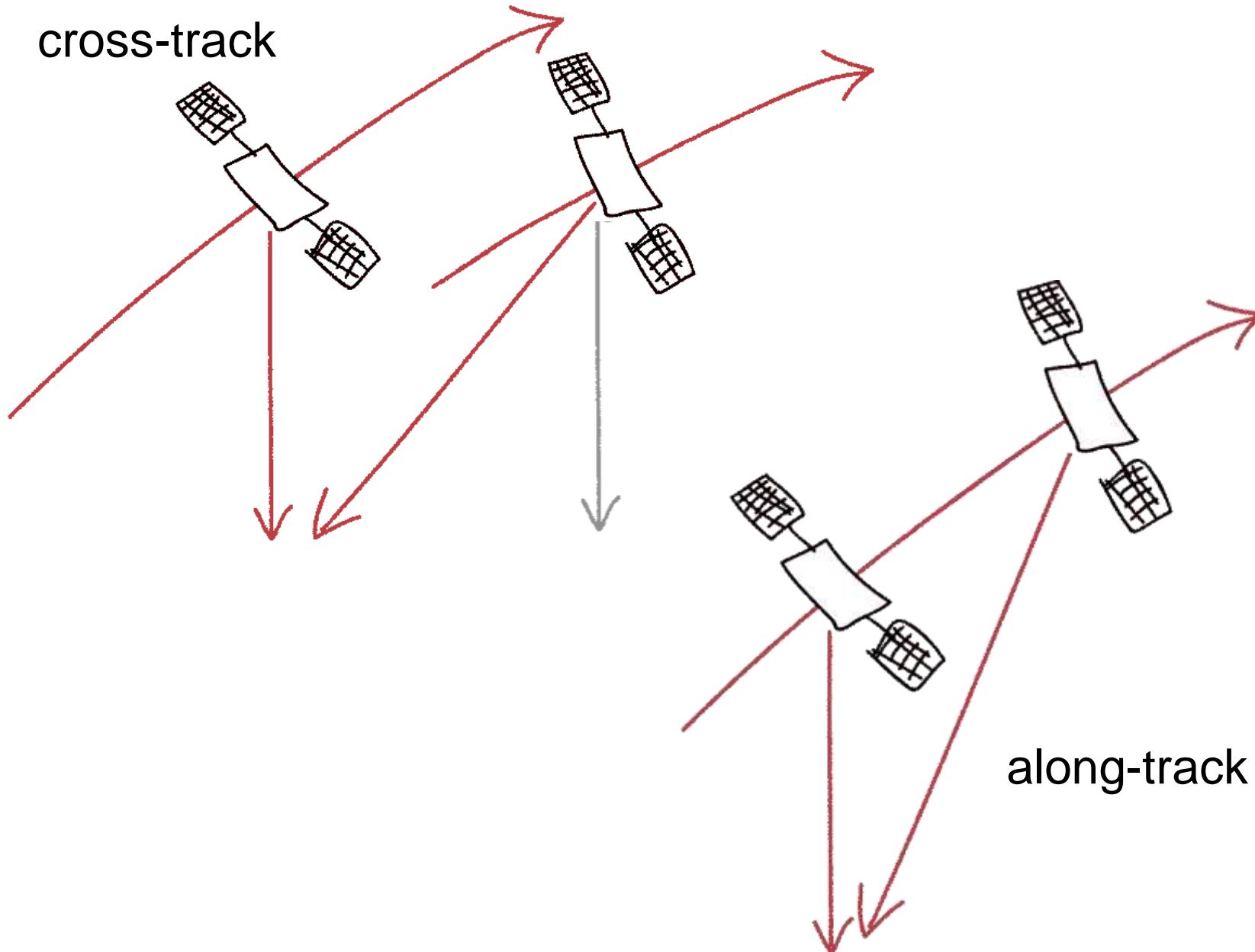
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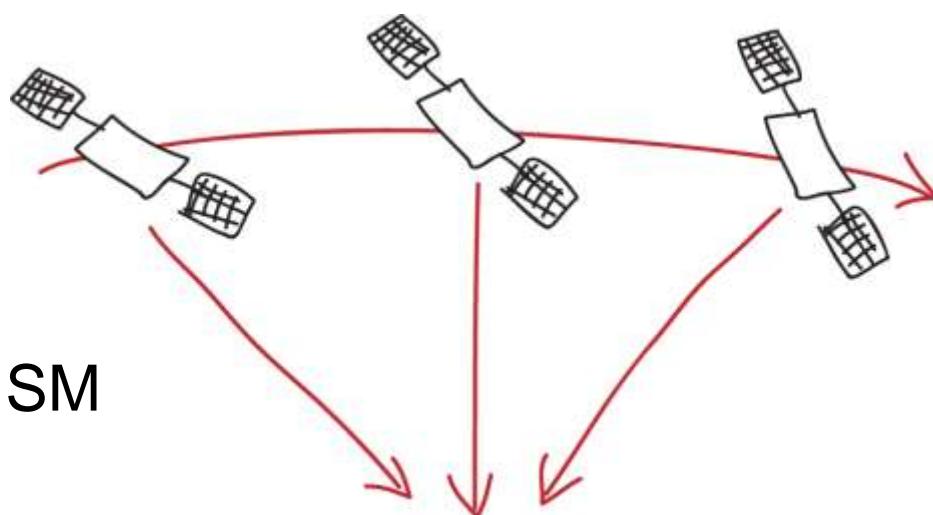
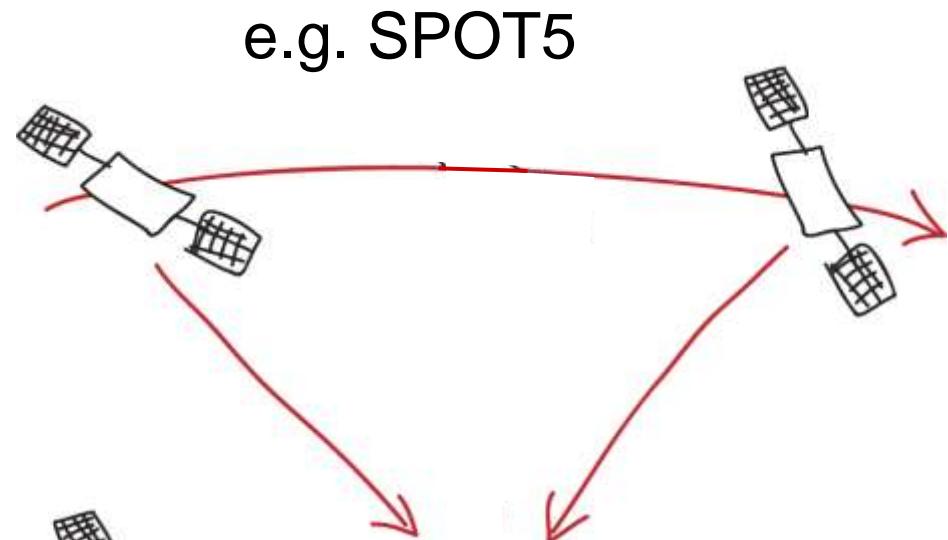
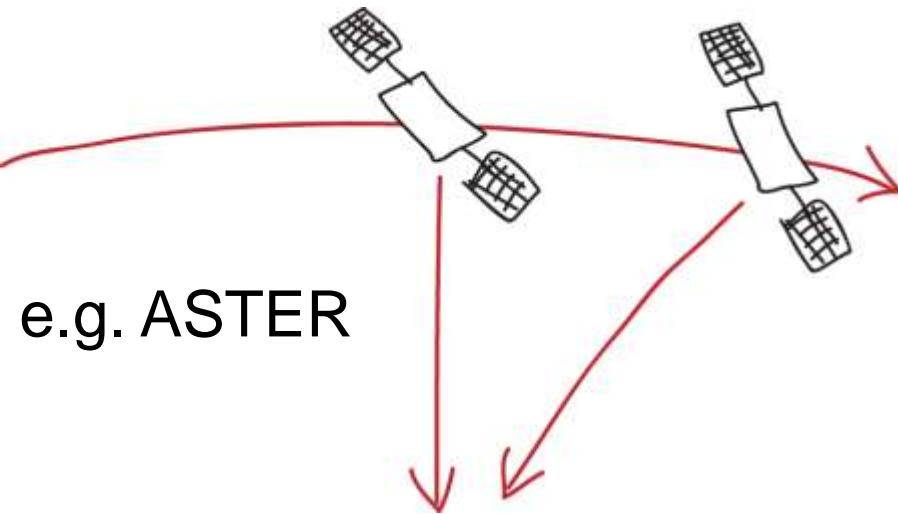
Elevation changes from space

- Satellite stereo
- Laser altimetry (ICESat)
- Radar interferometry
- Radar altimetry
- *Shape-from-shade*

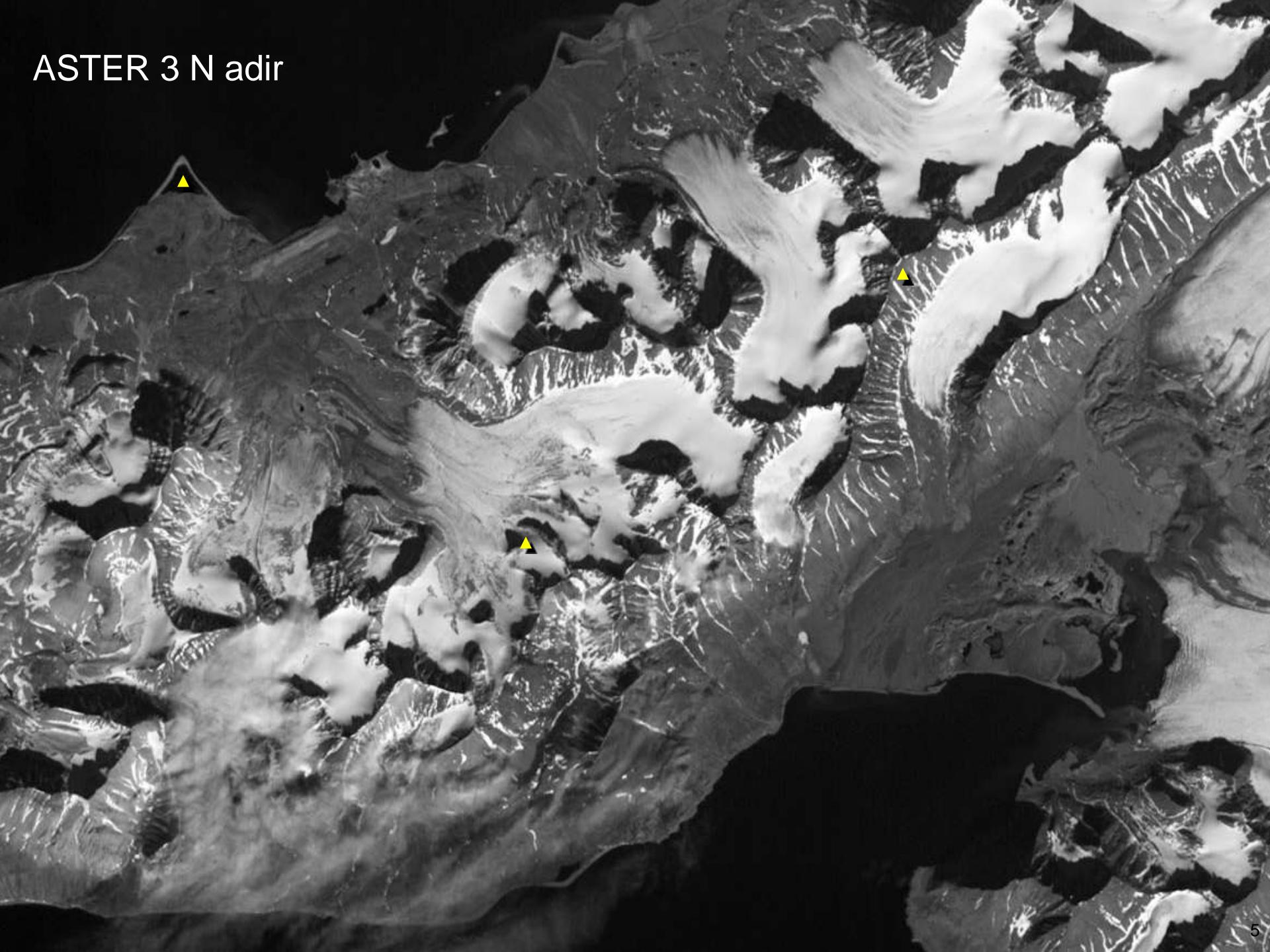
cross-track



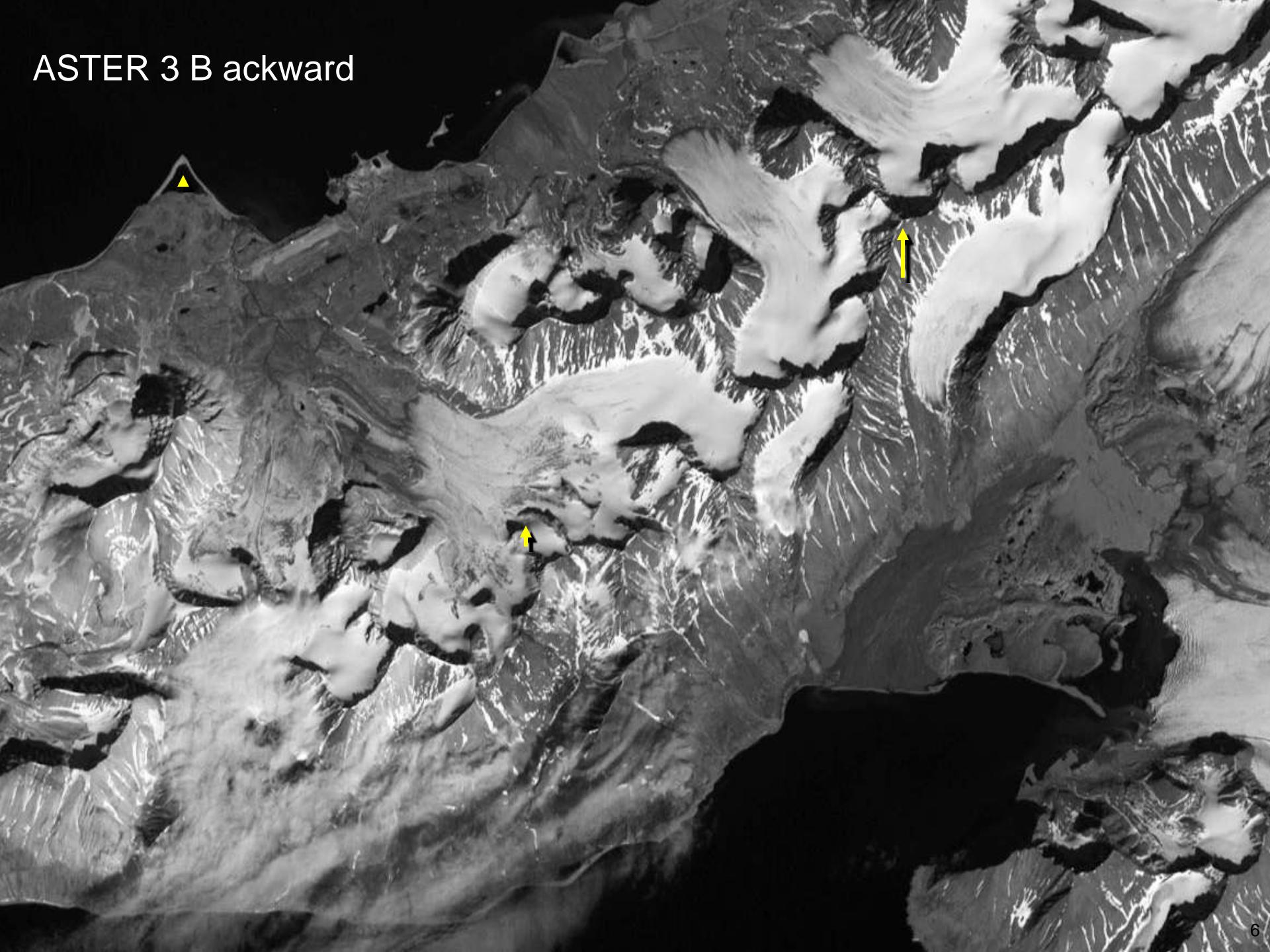
along-track

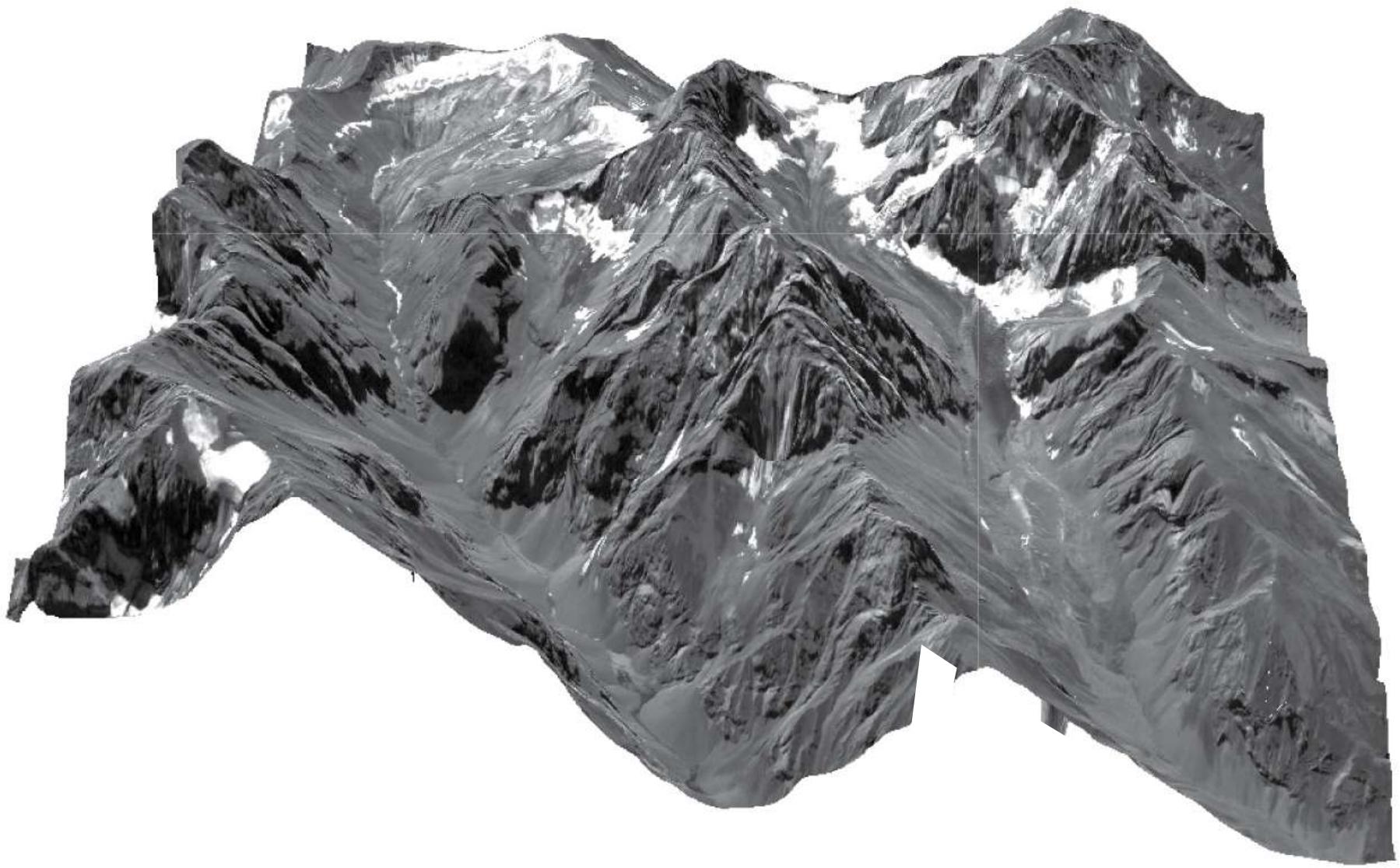


ASTER 3 N adir



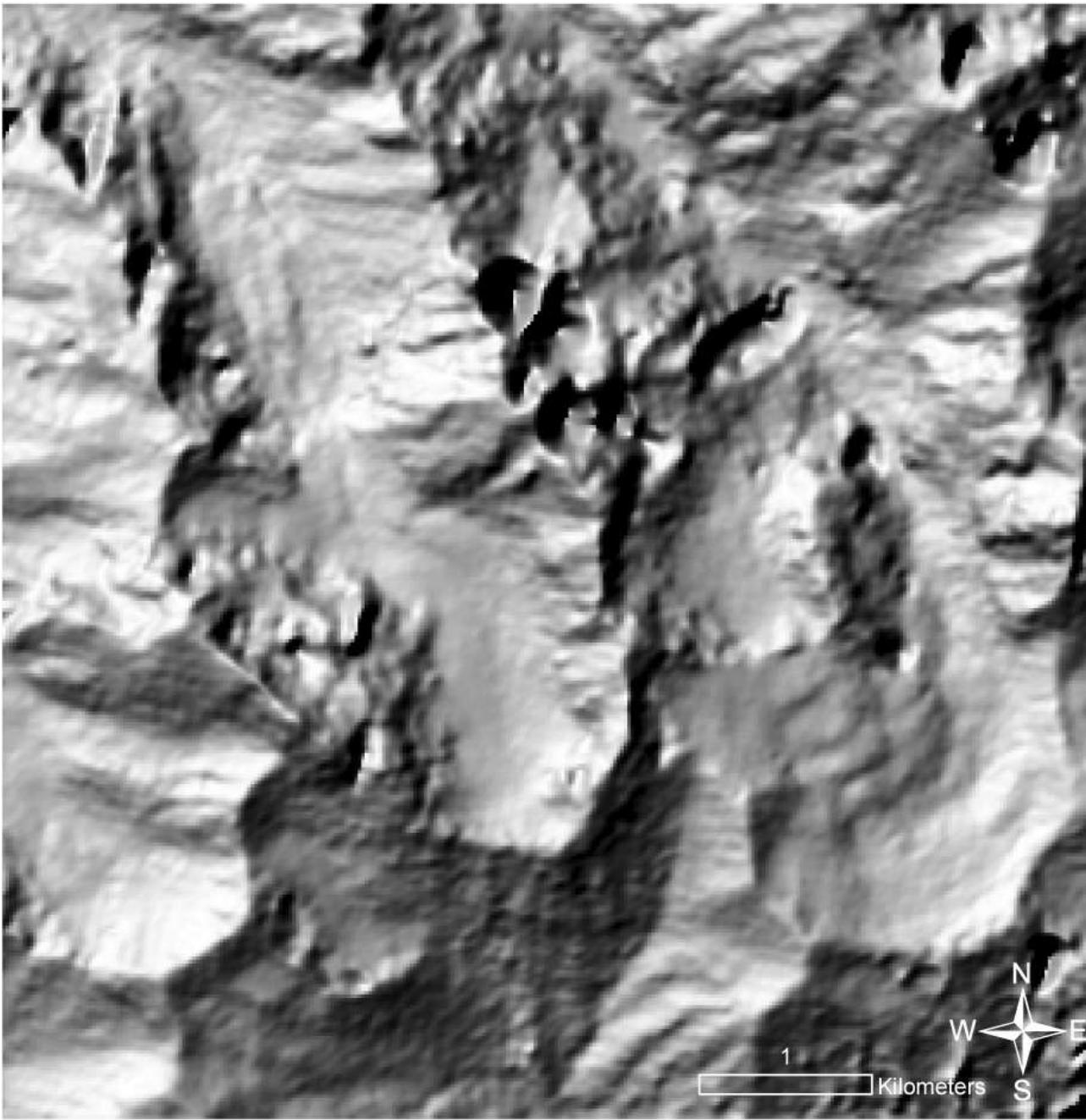
ASTER 3 B backward

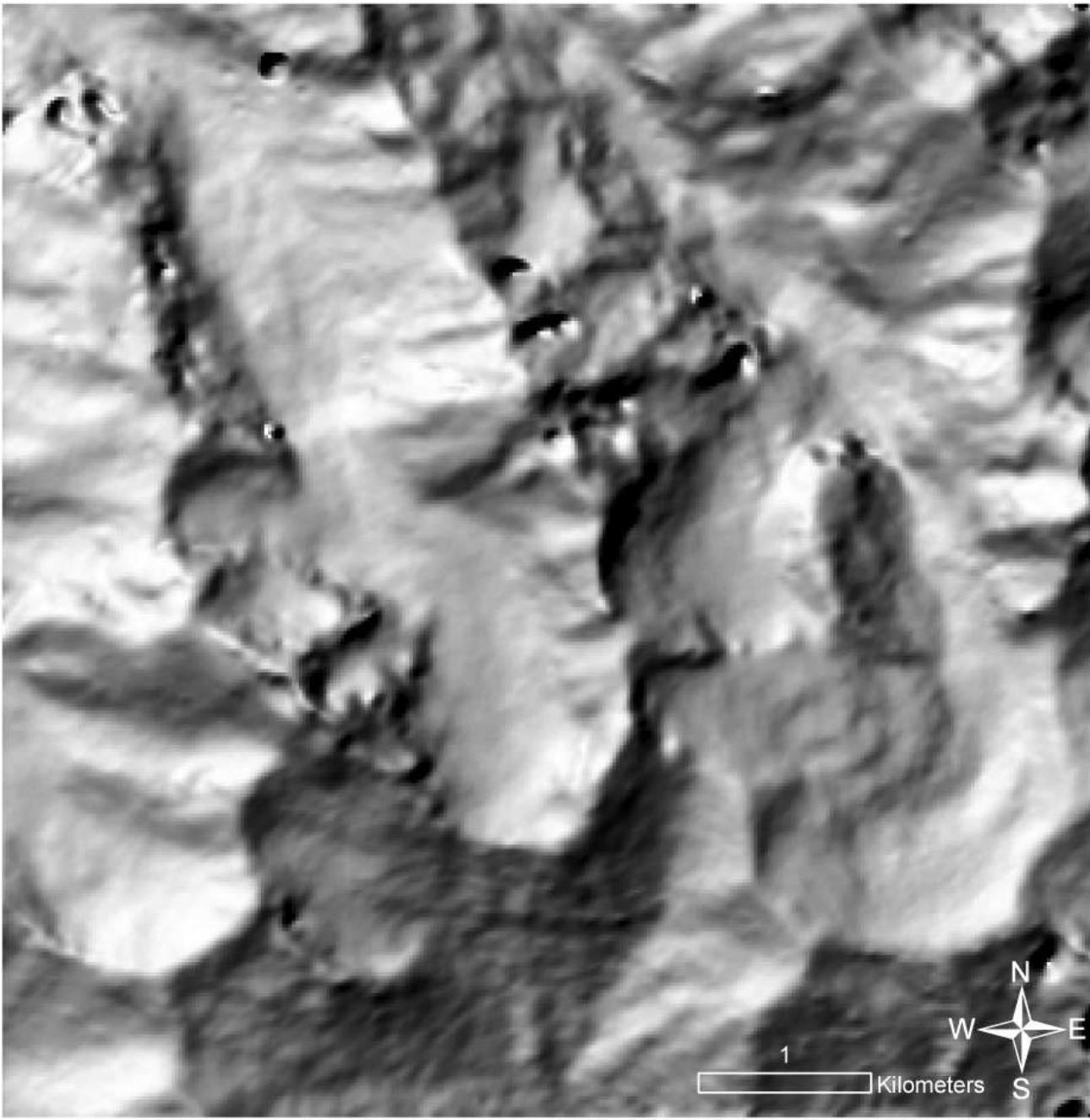




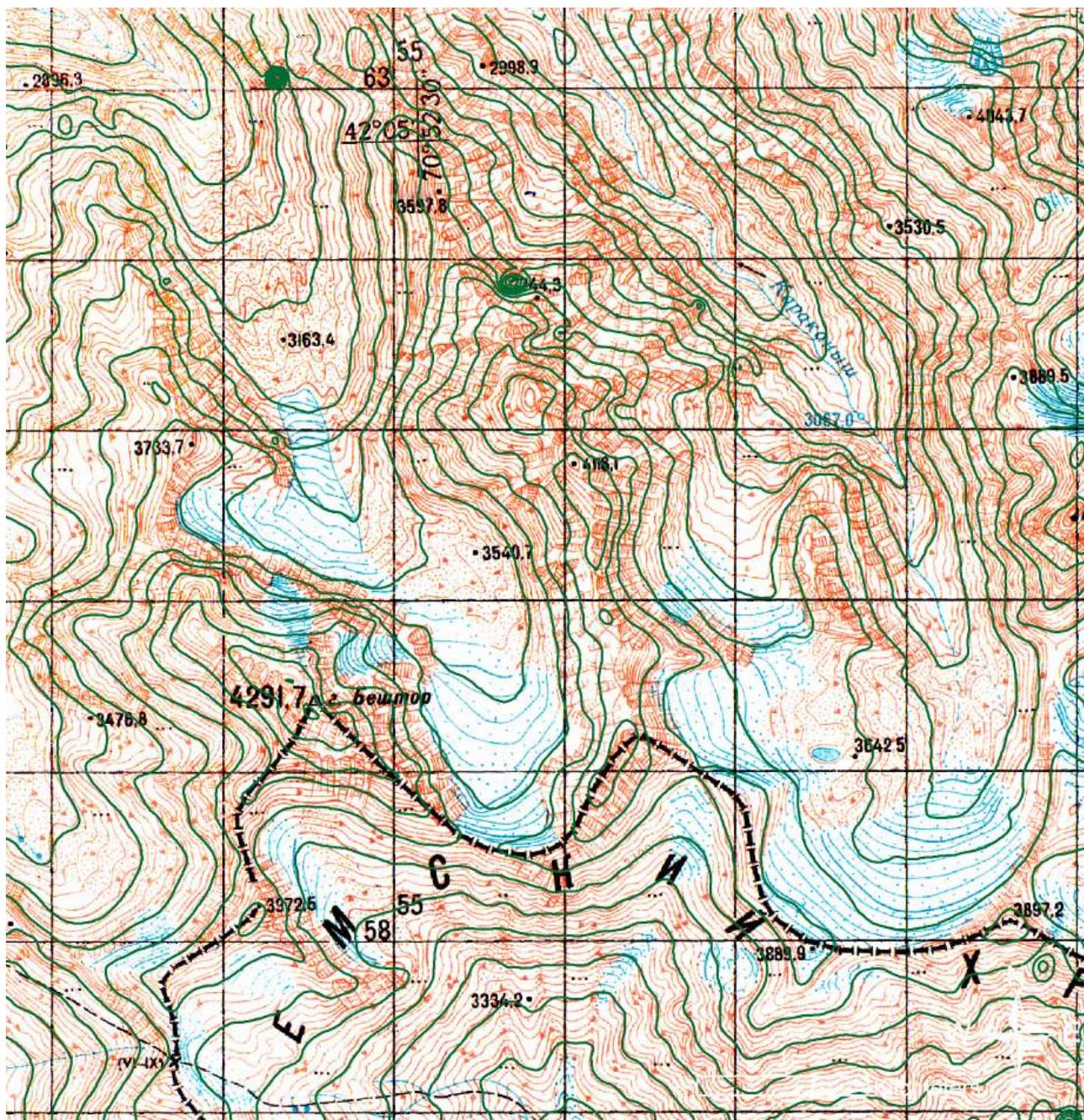
6.5 km

A. Kaab





Map (1970s) – PRISM (2007)

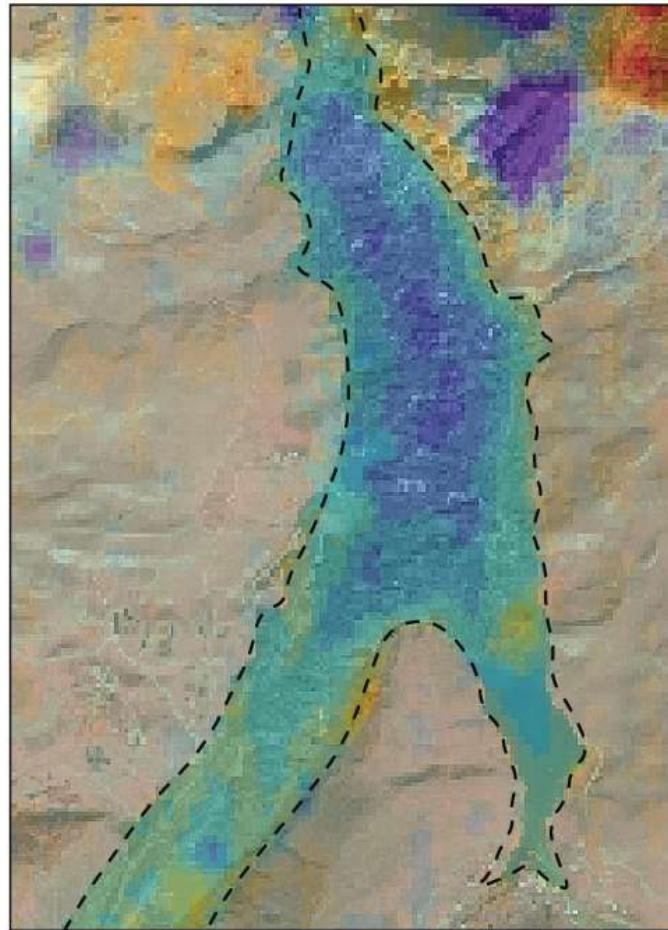
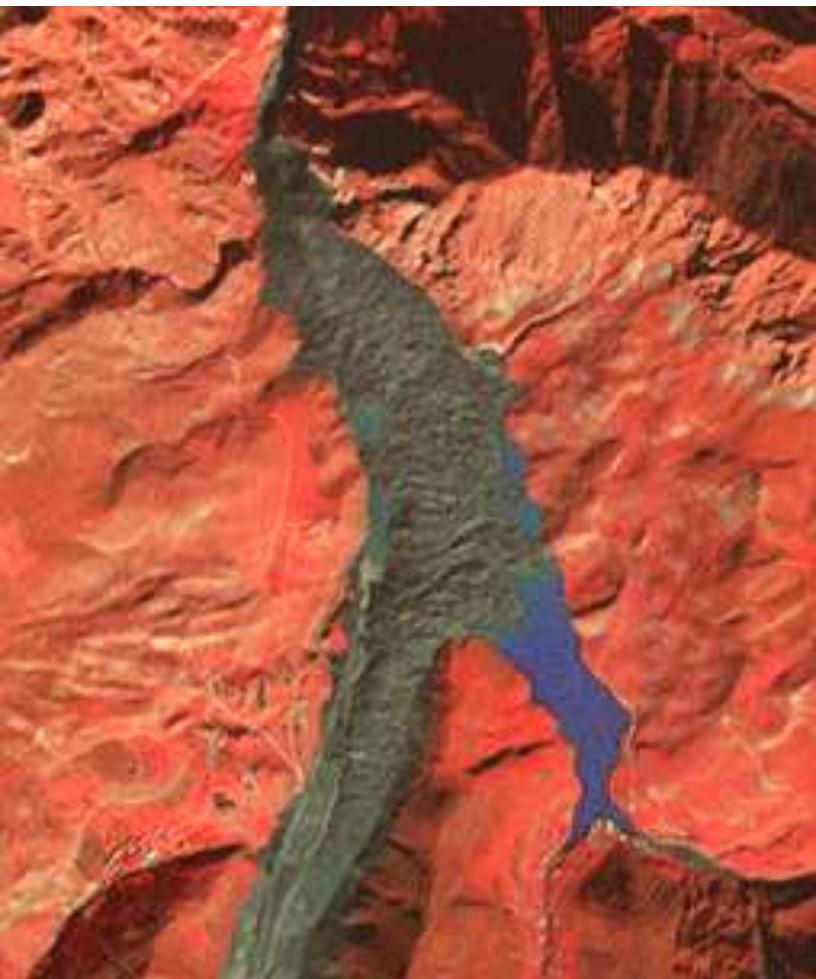


Caucasus rock-ice avalanche, Sept 2002

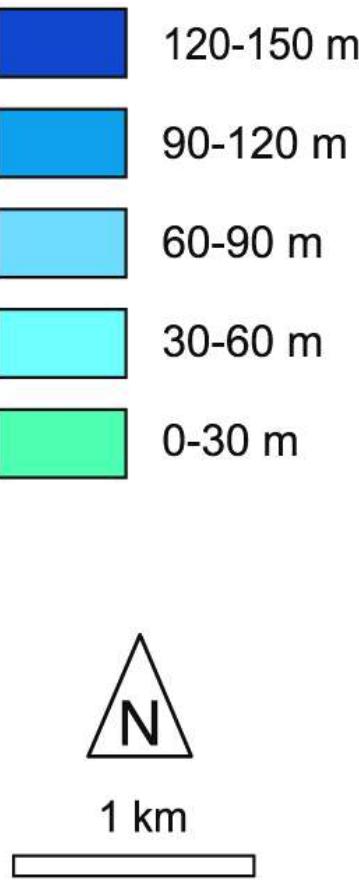


I. Galushkin

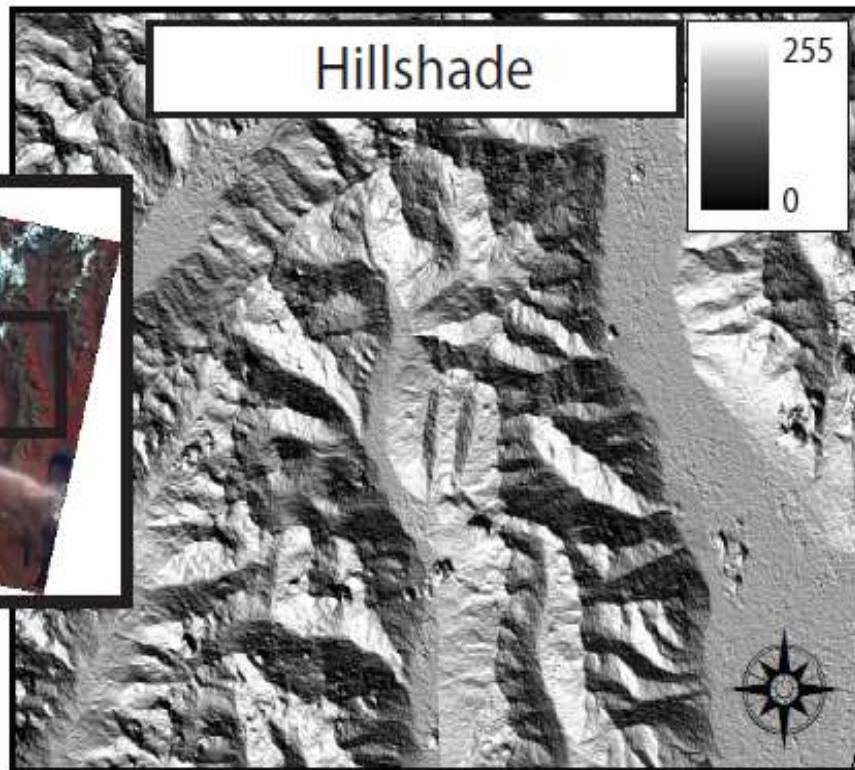
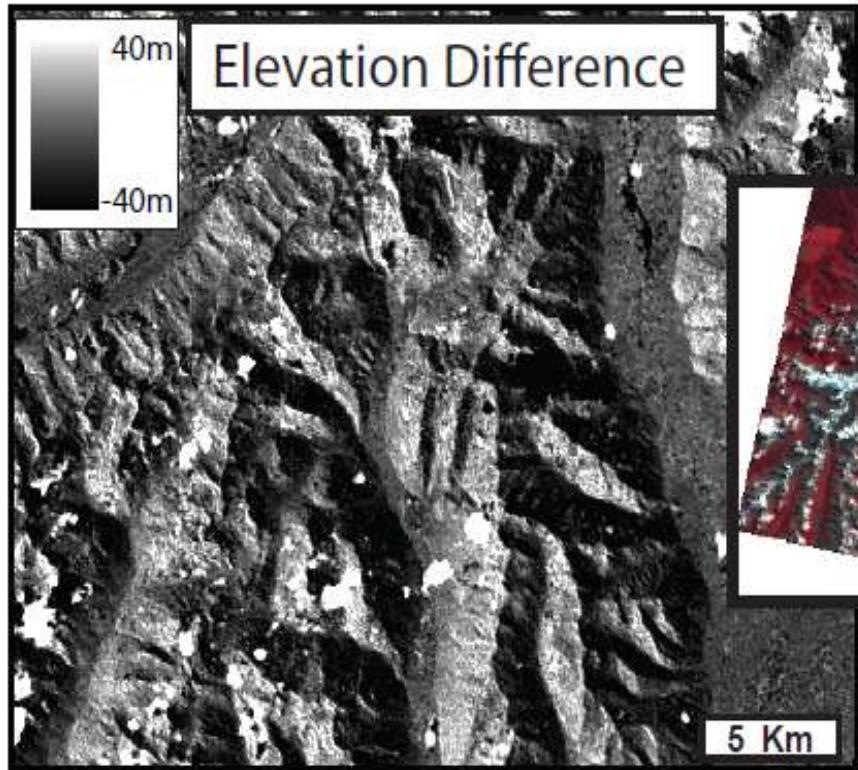
Caucasus rock-ice avalanche, Sept 2002



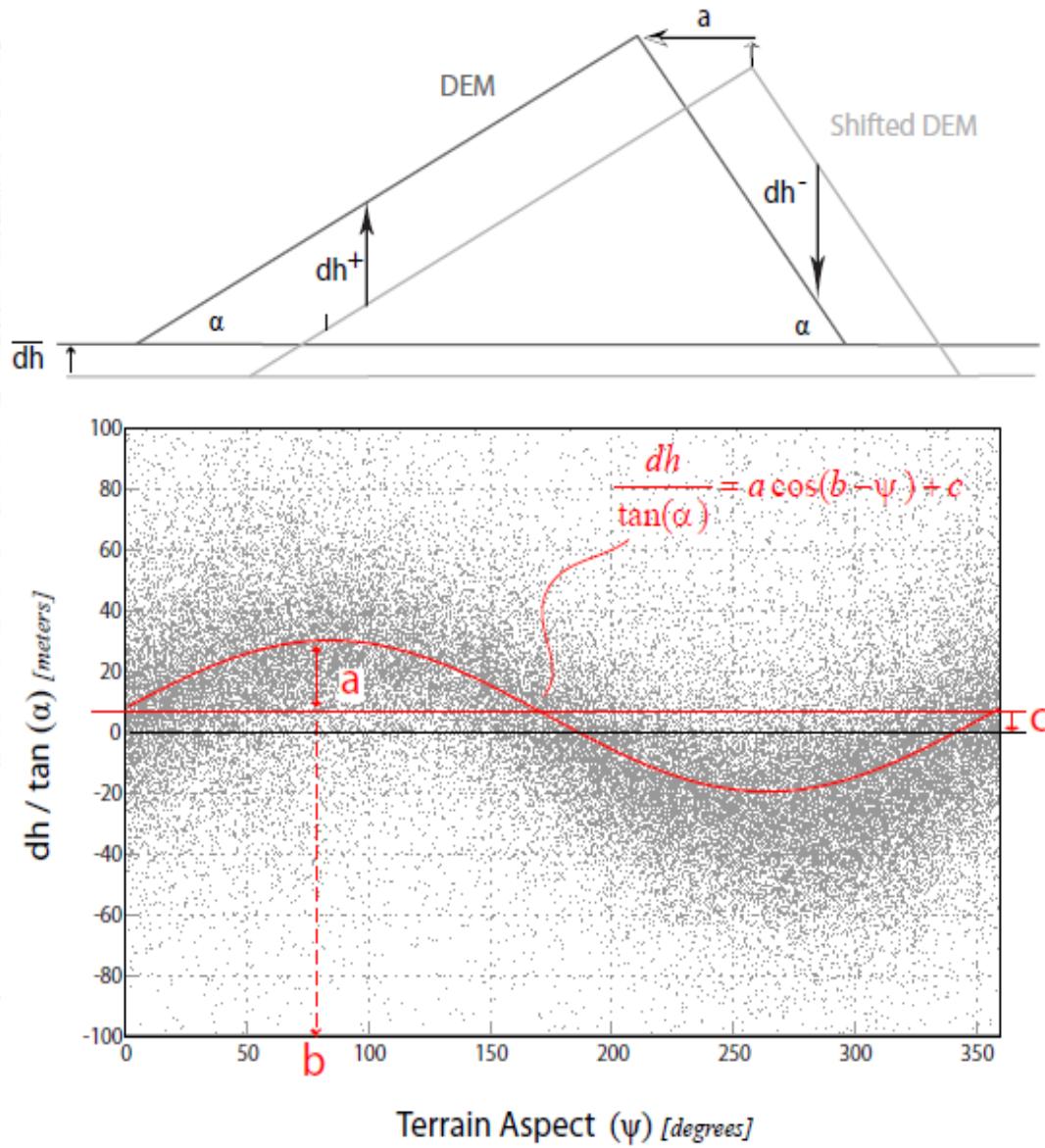
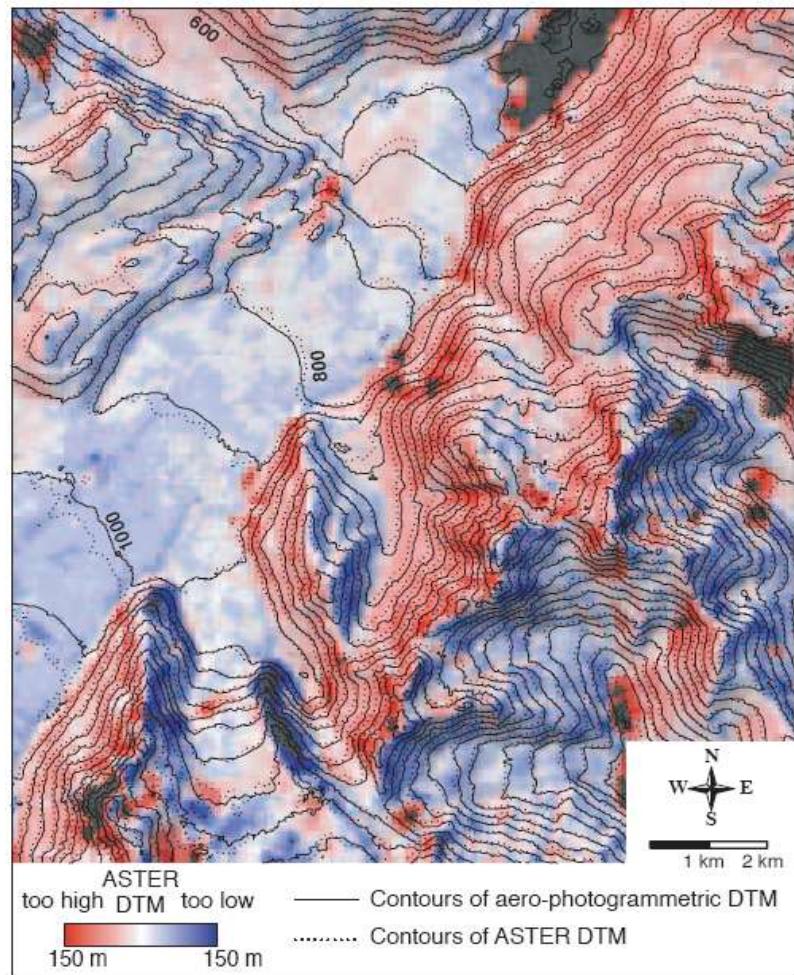
ASTER 2002 - SRTM 2000



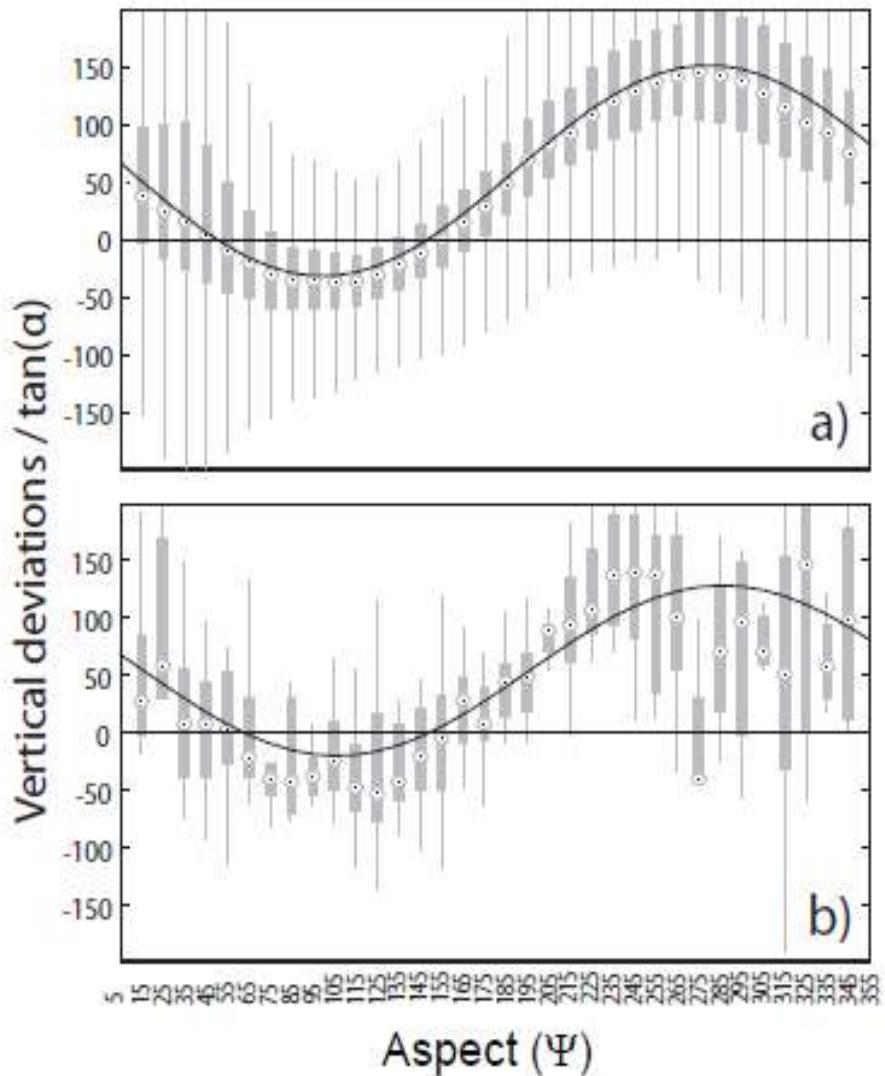
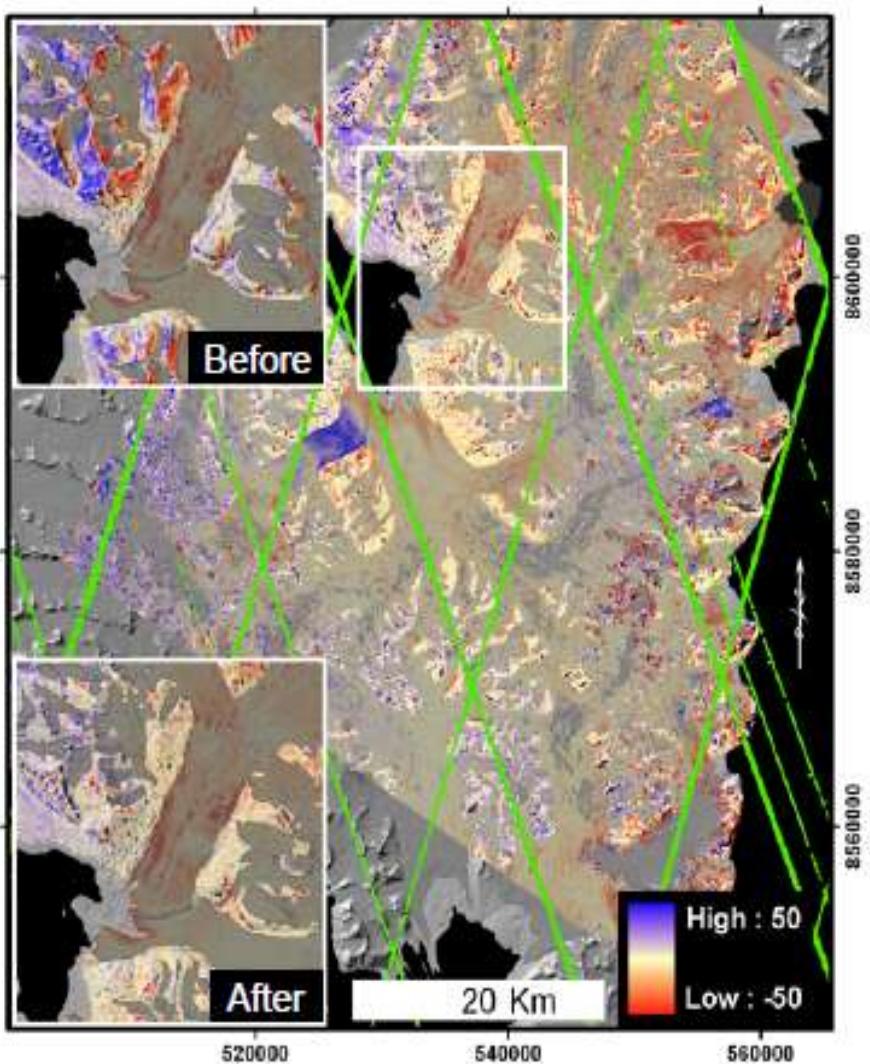
Co-registration of DEMs



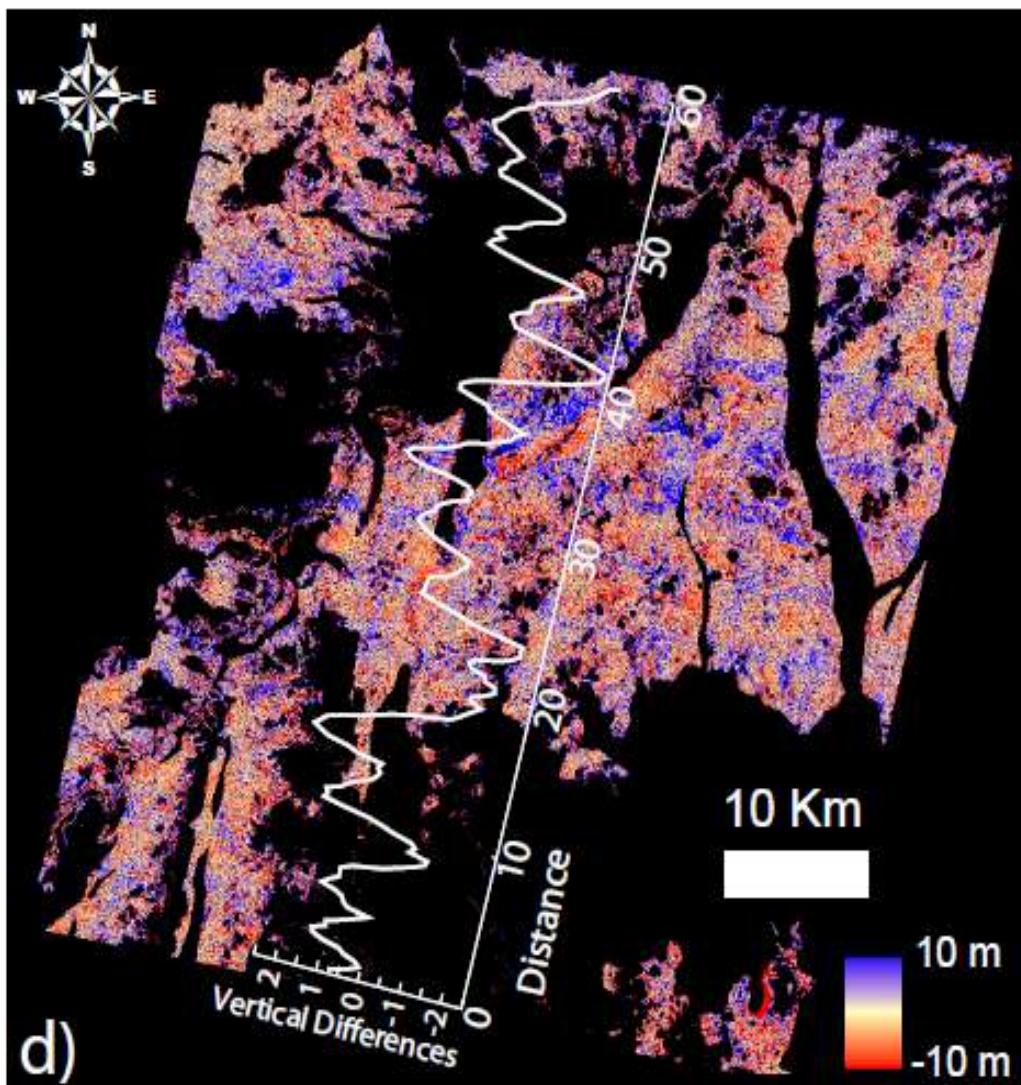
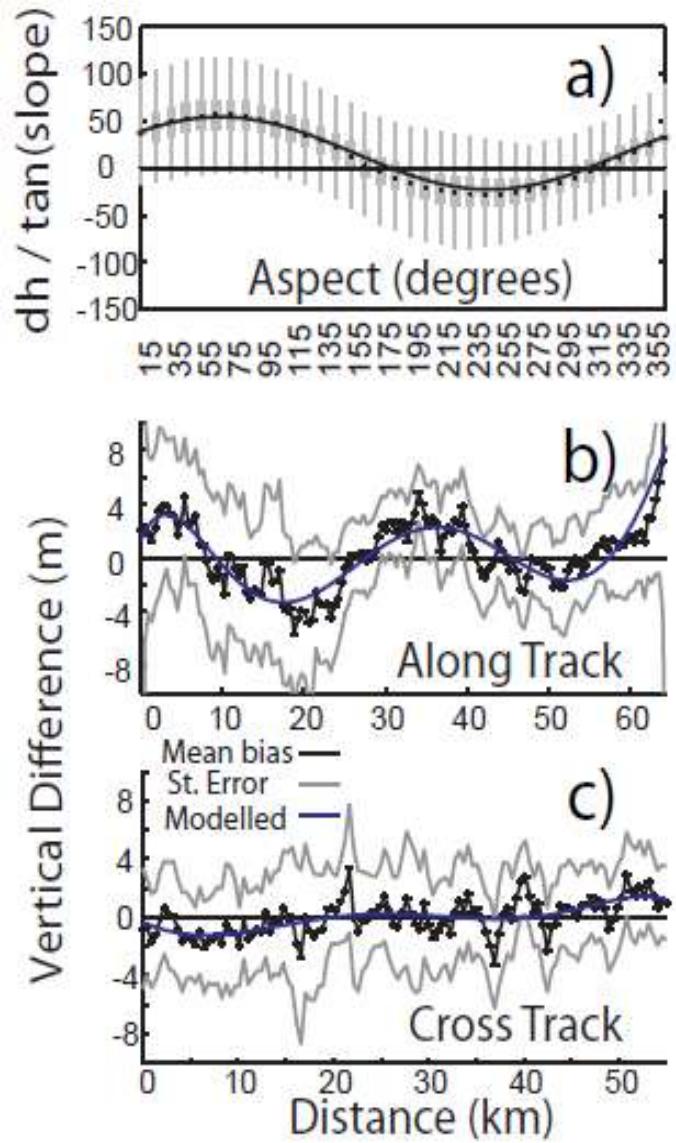
Co-registration of DEMs

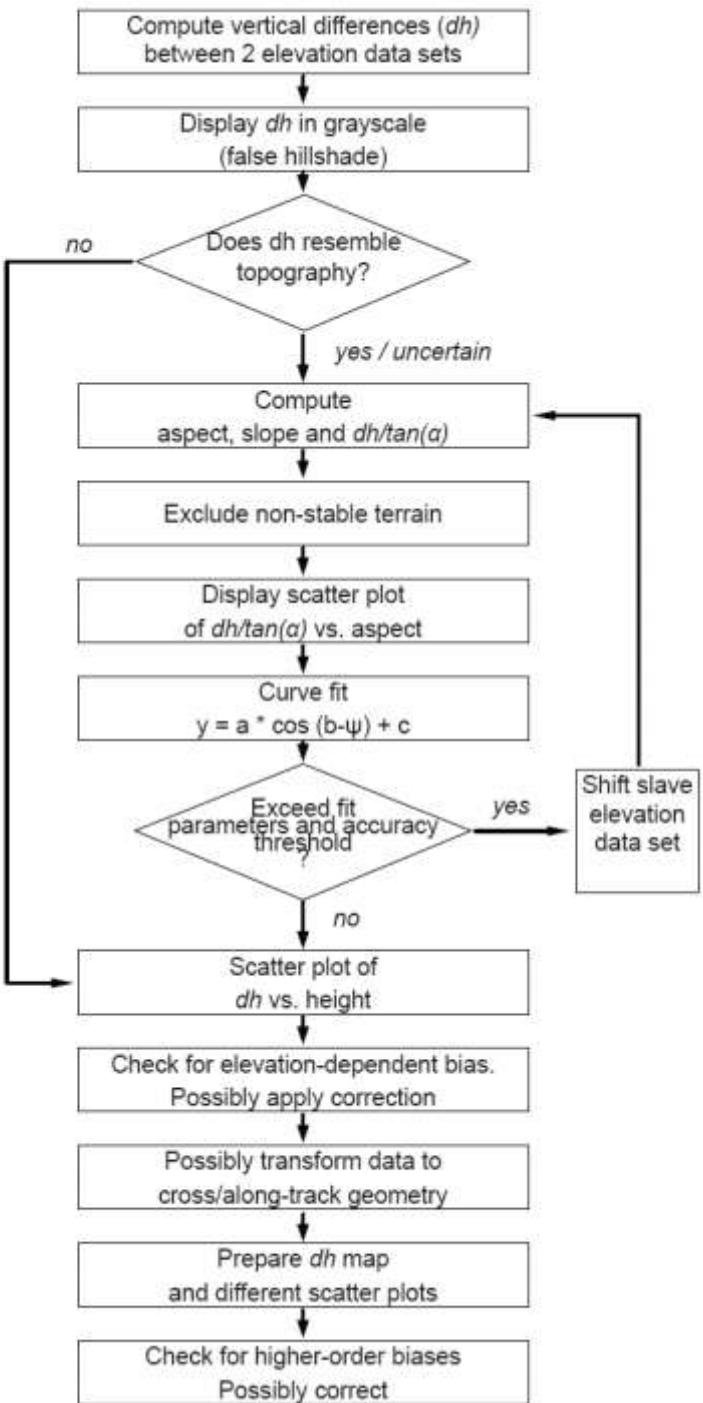


Co-registration of DEMs

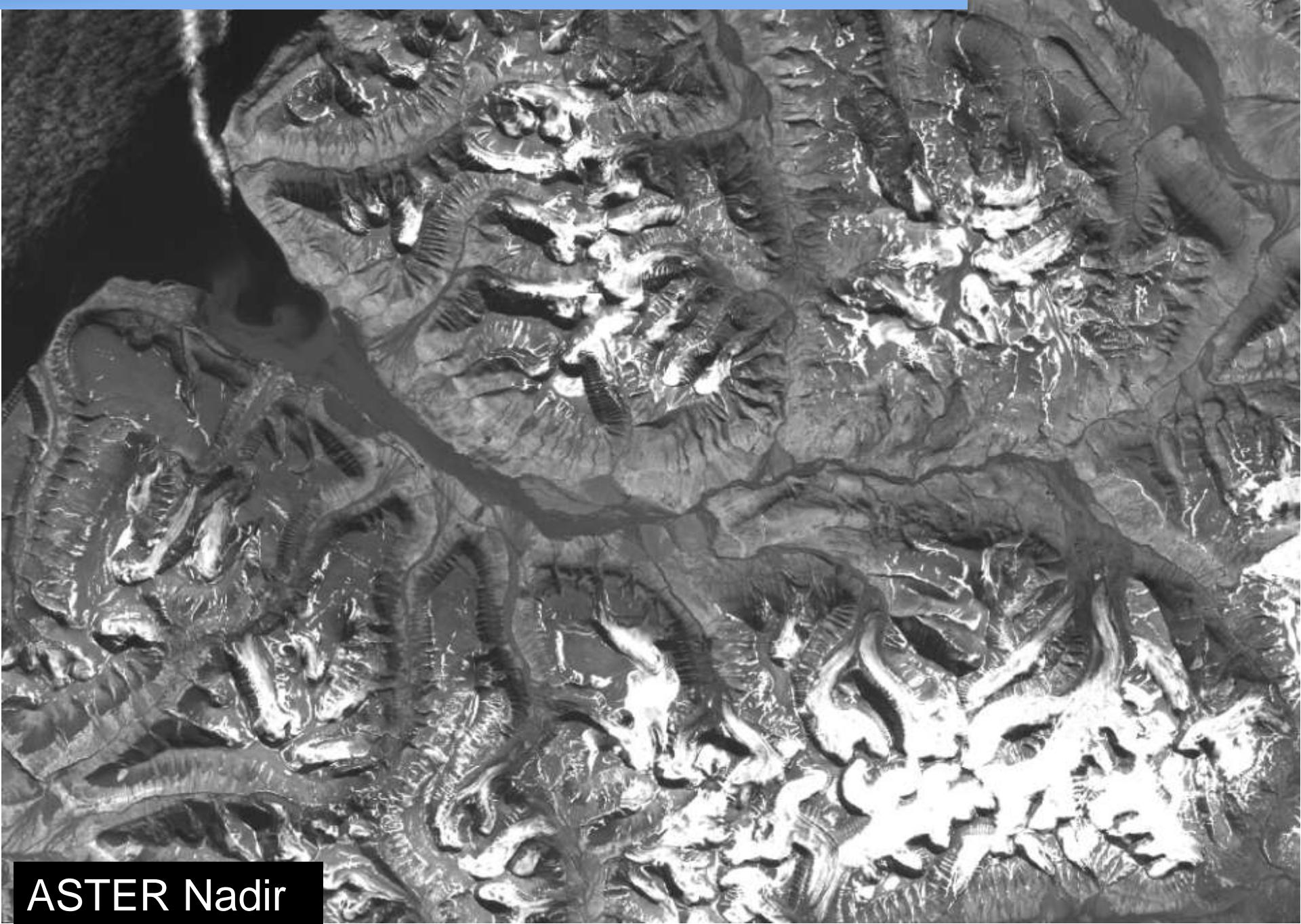


Co-registration of DEMs



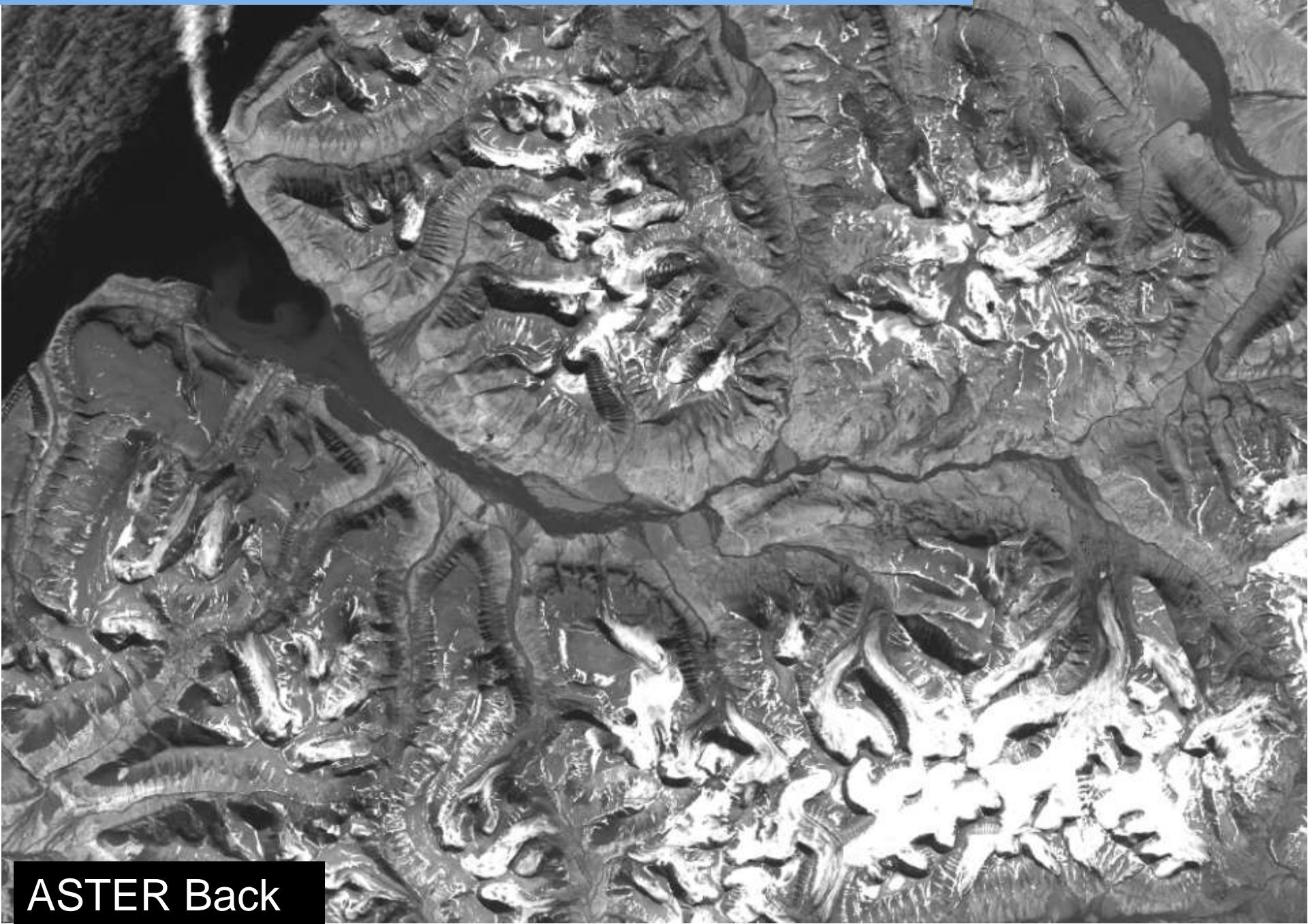


BRDF



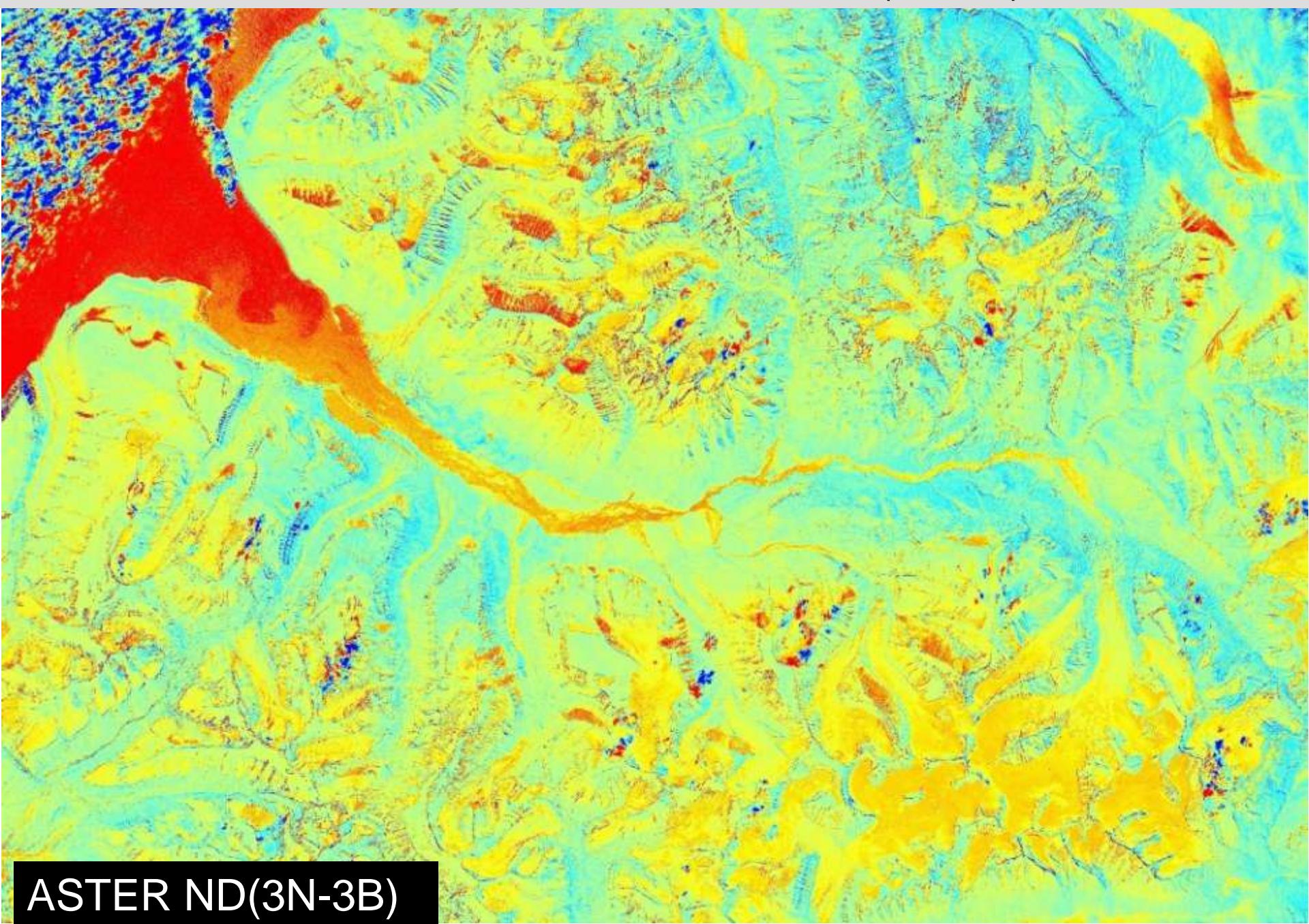
ASTER Nadir

BRDF

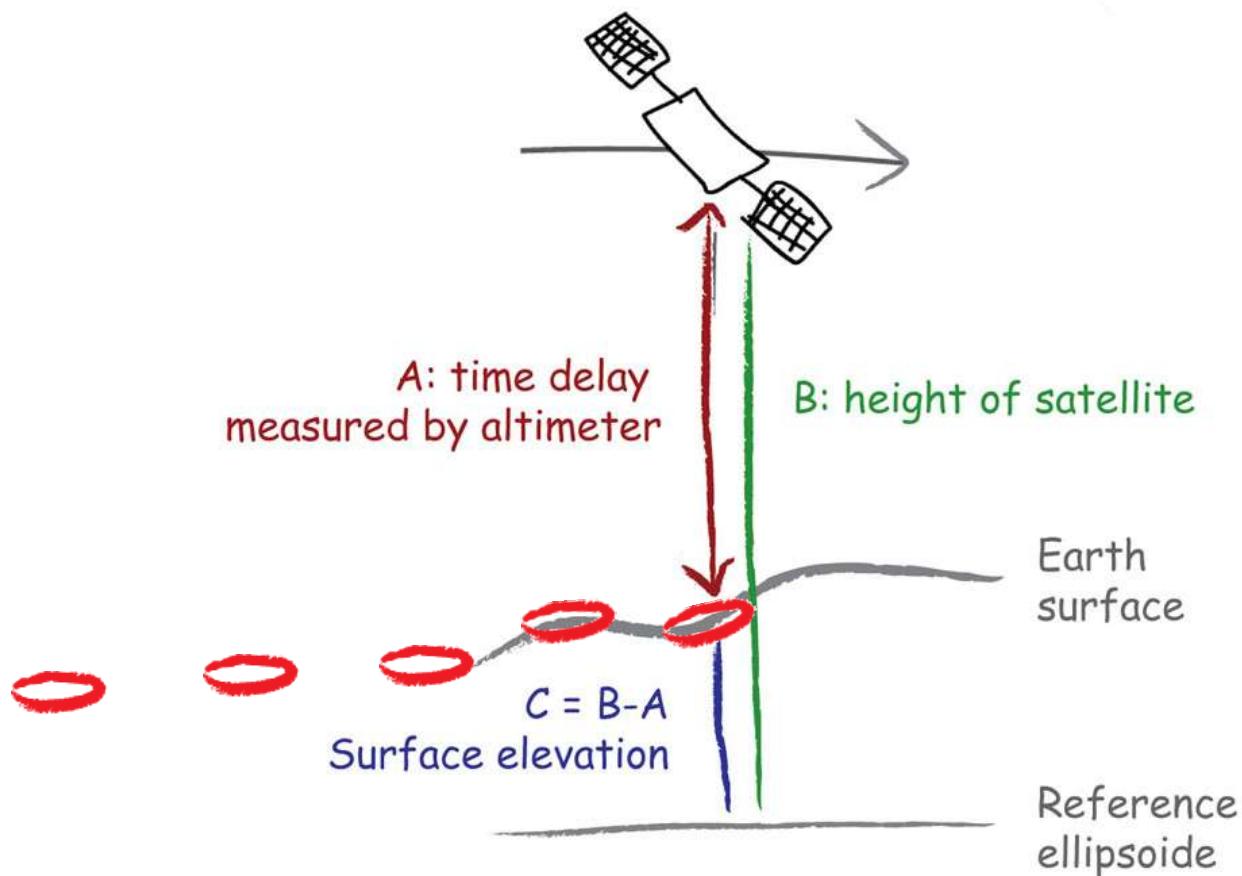


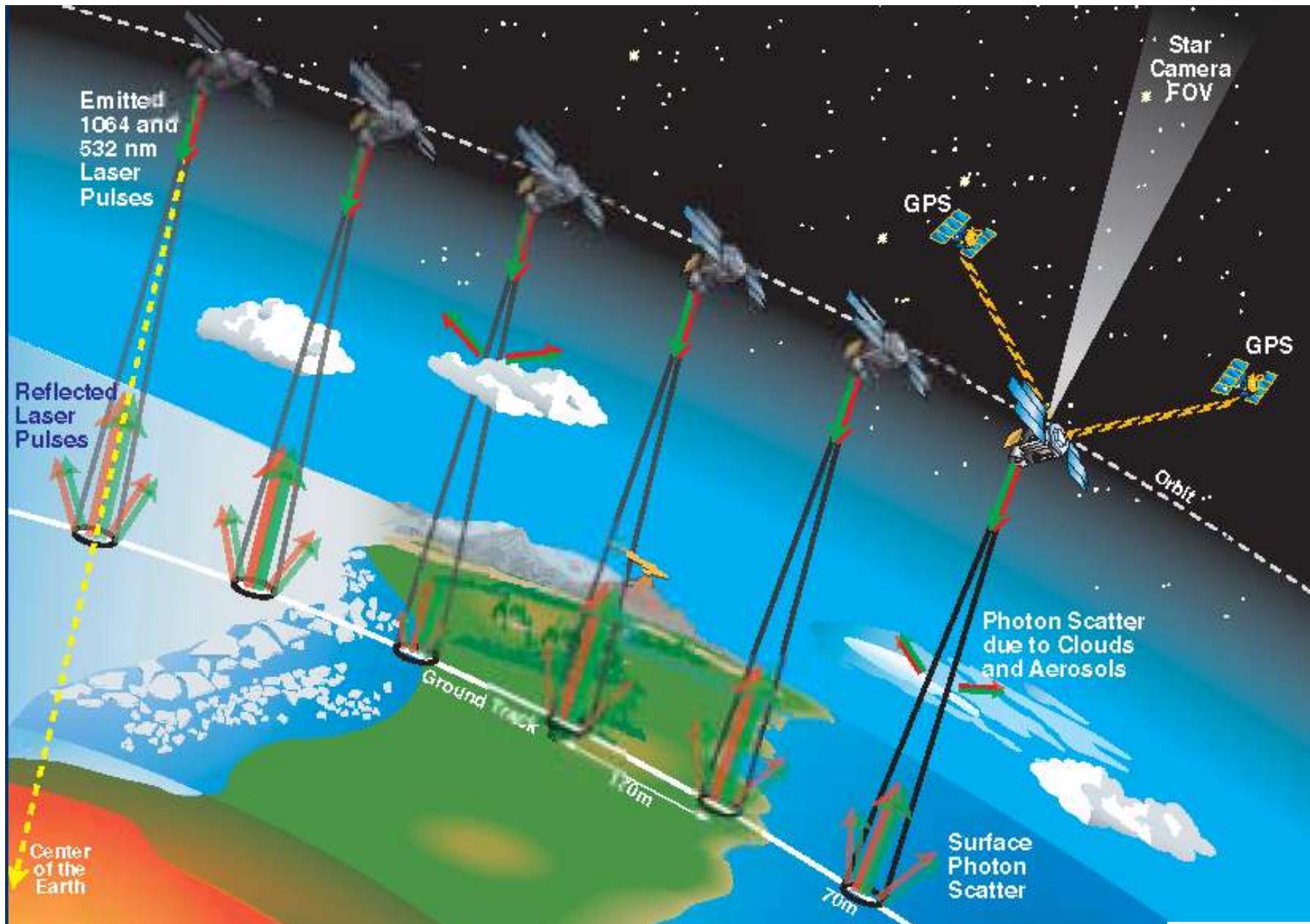
ASTER Back

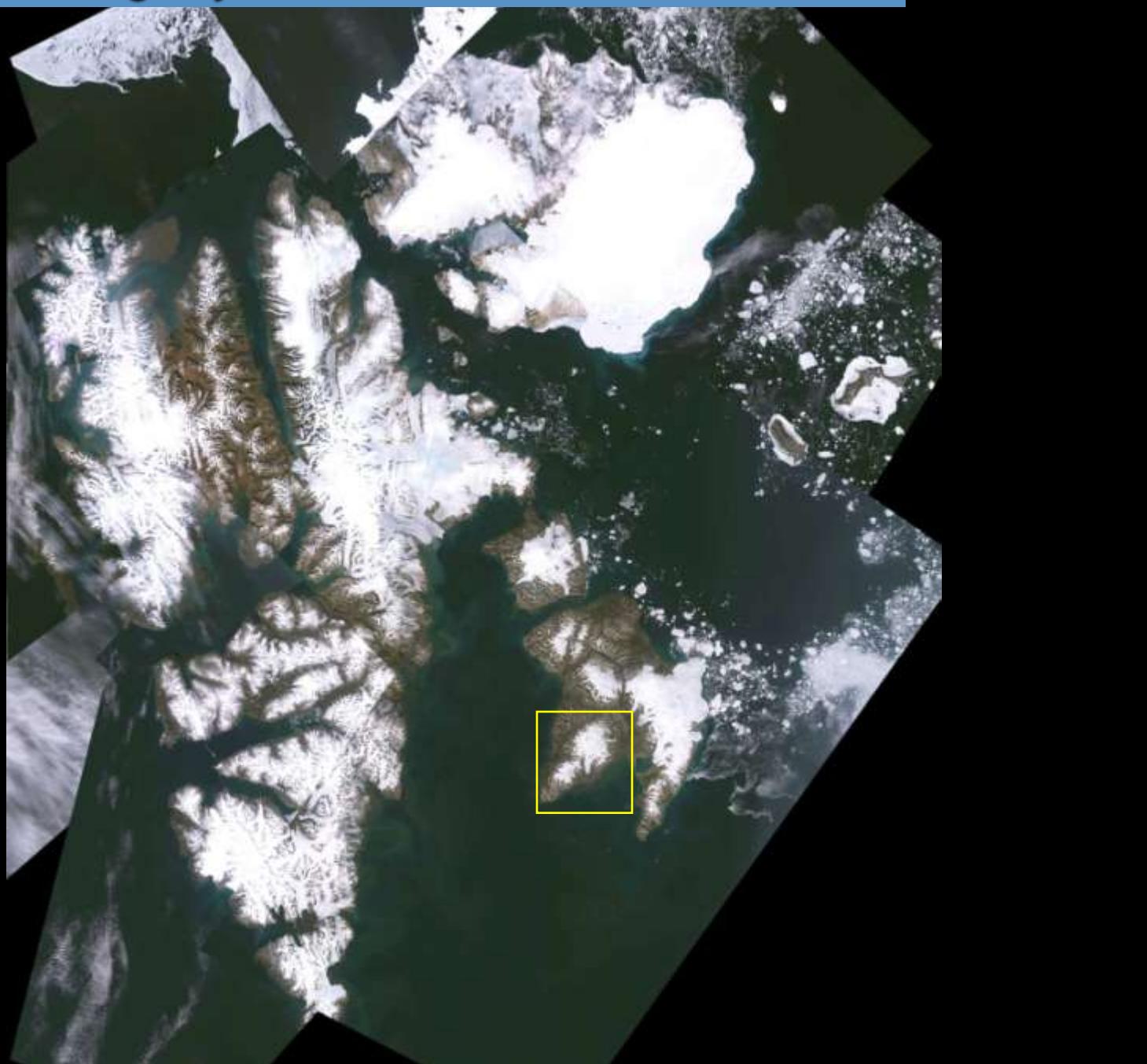
Bidirectional reflectance distribution function (BRDF)



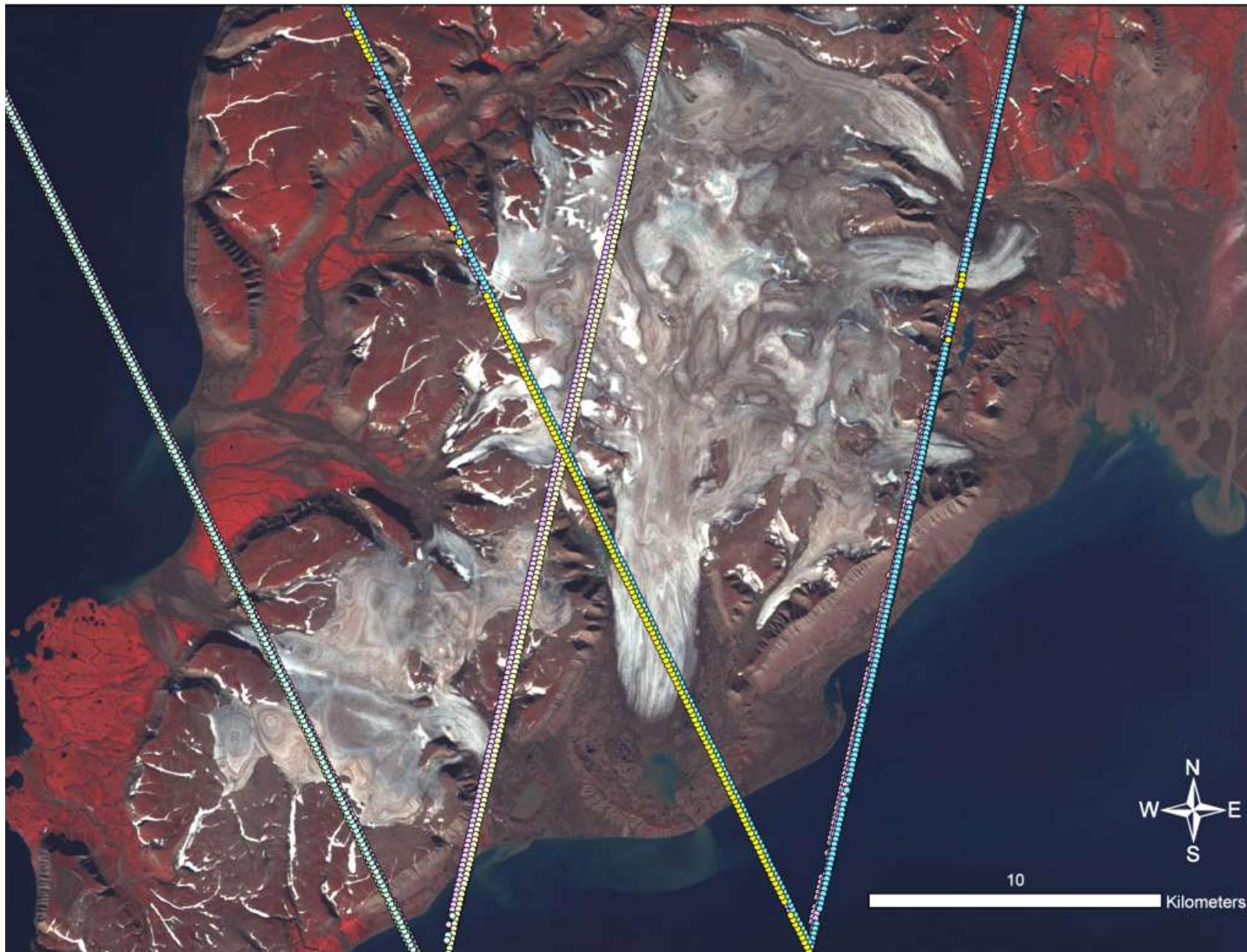
ASTER ND(3N-3B)



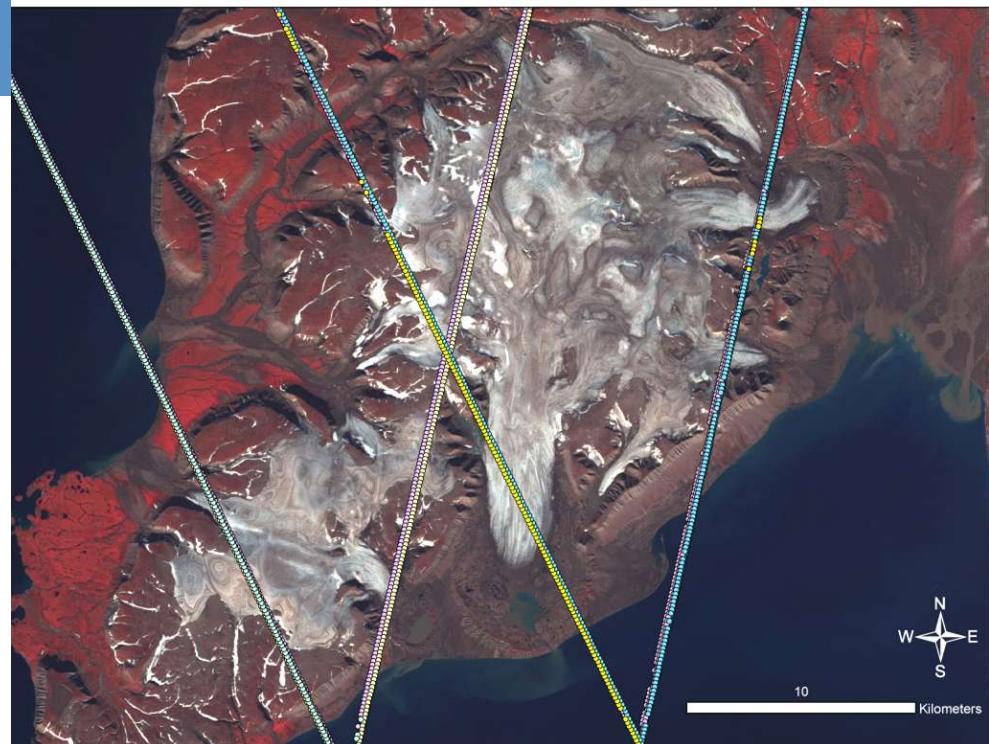
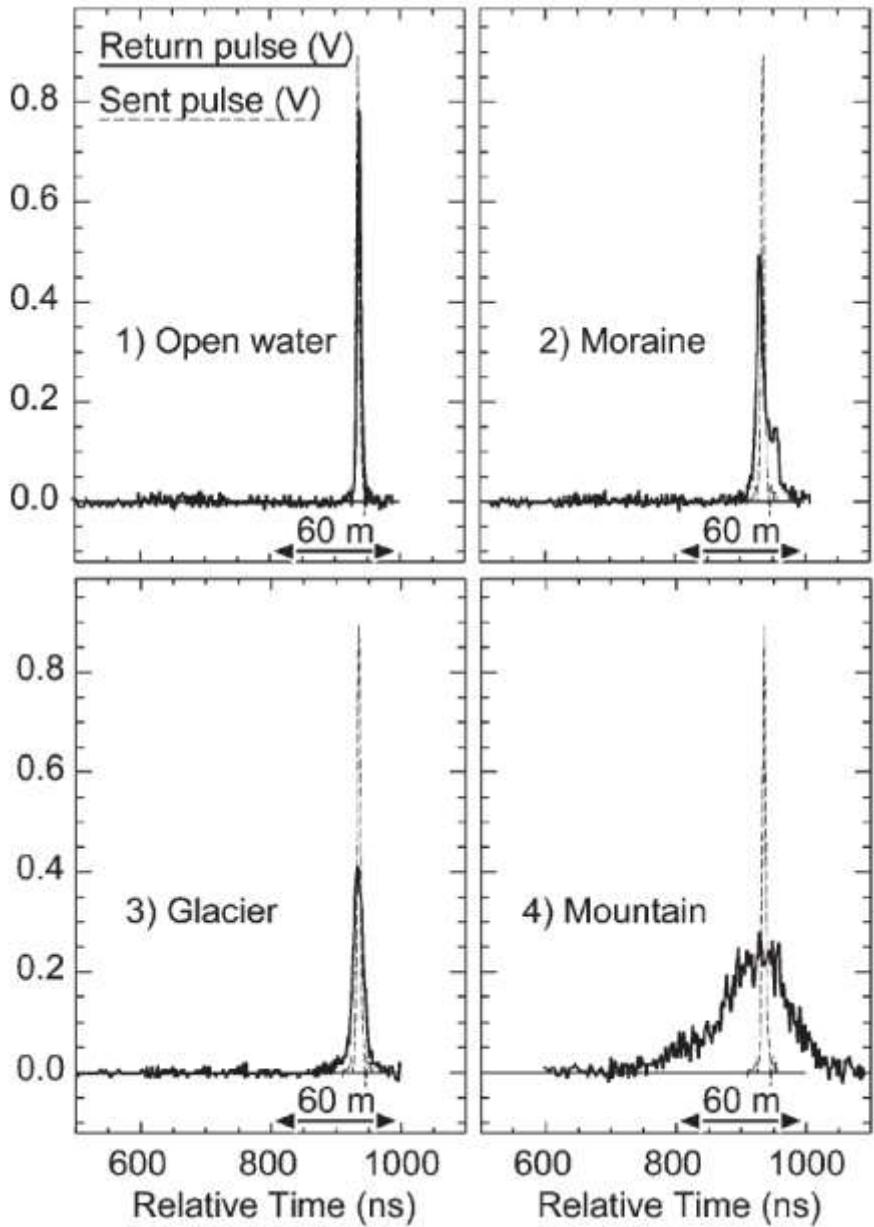






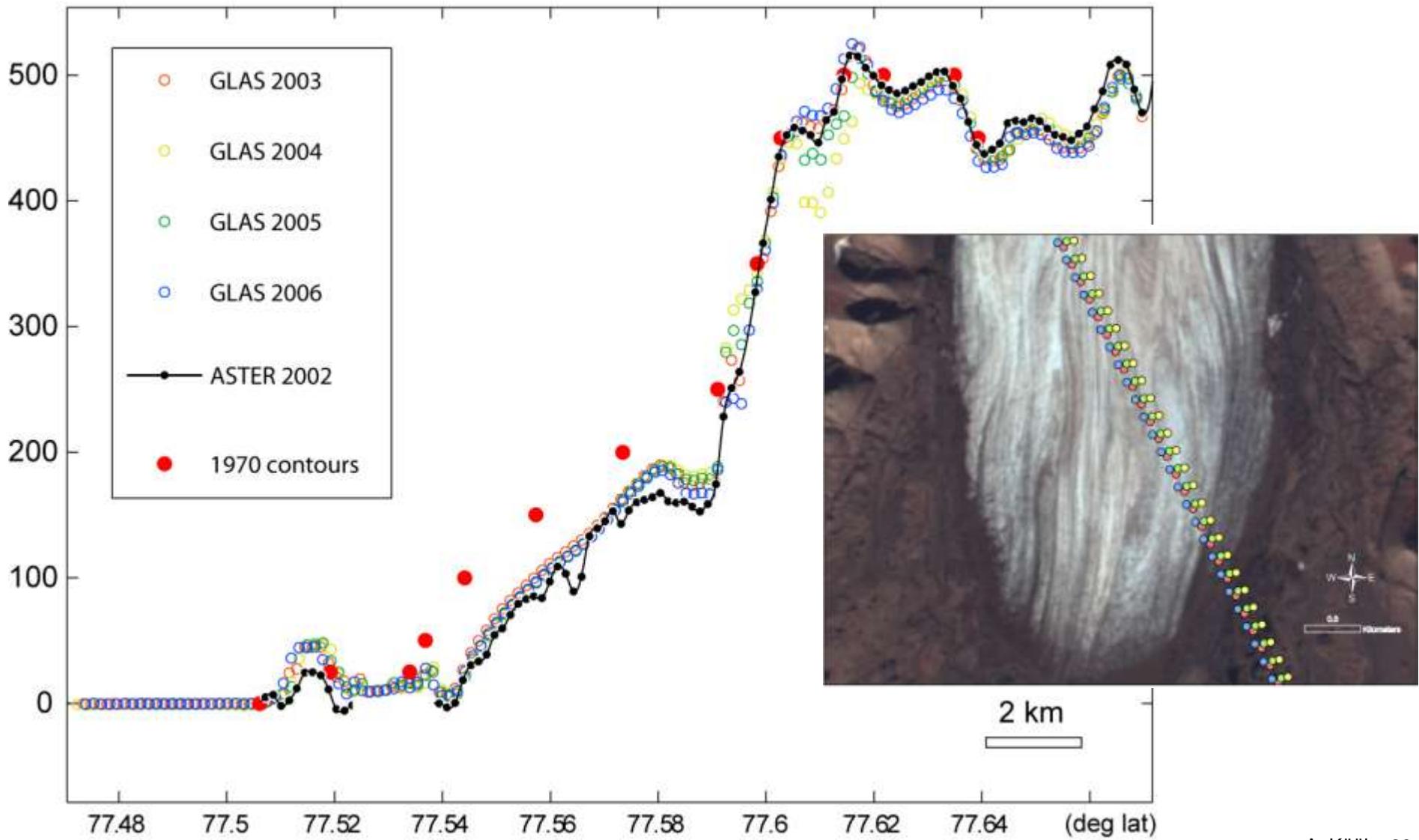


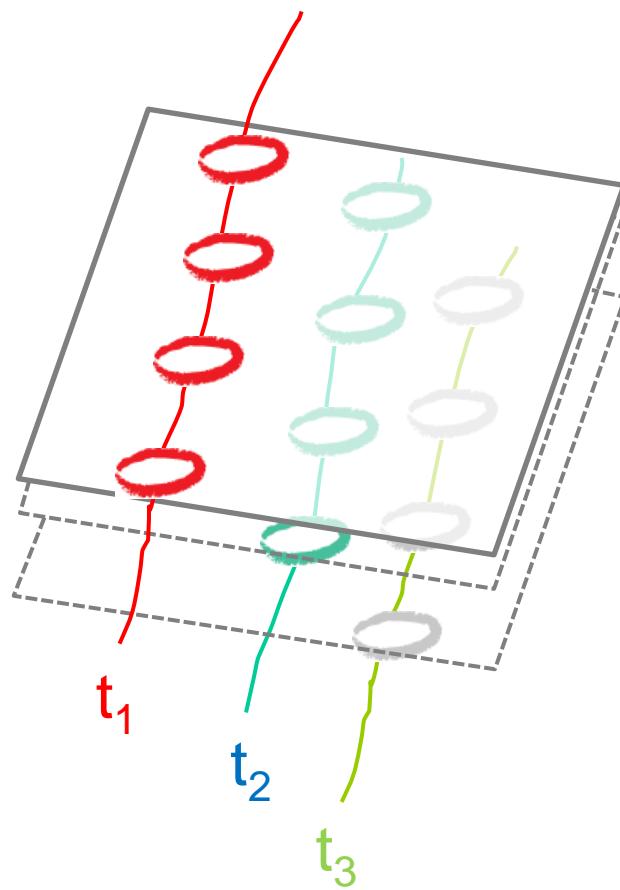
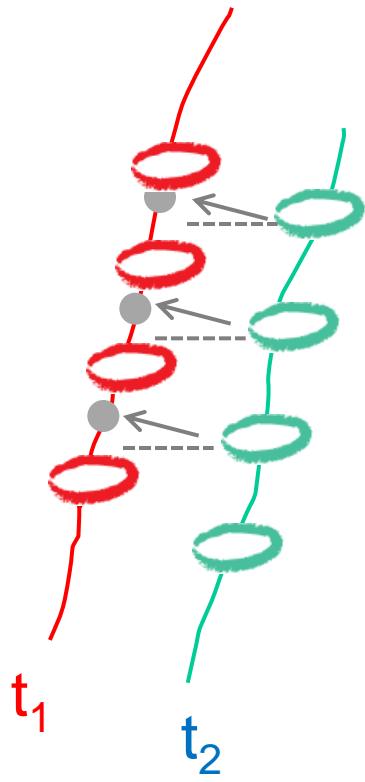
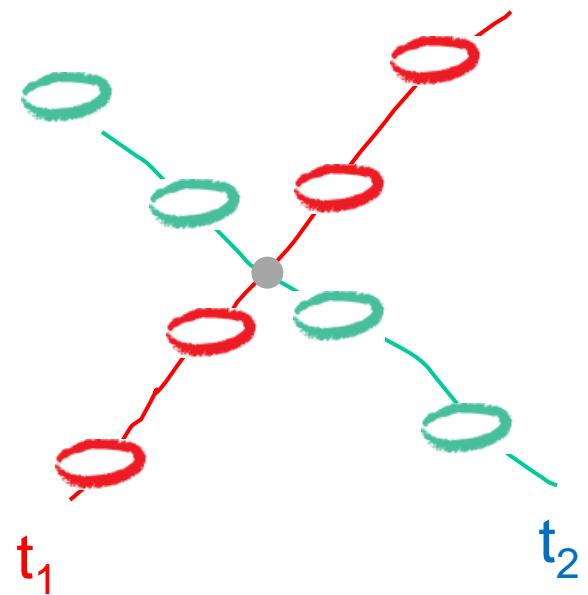
ICSat GLAS

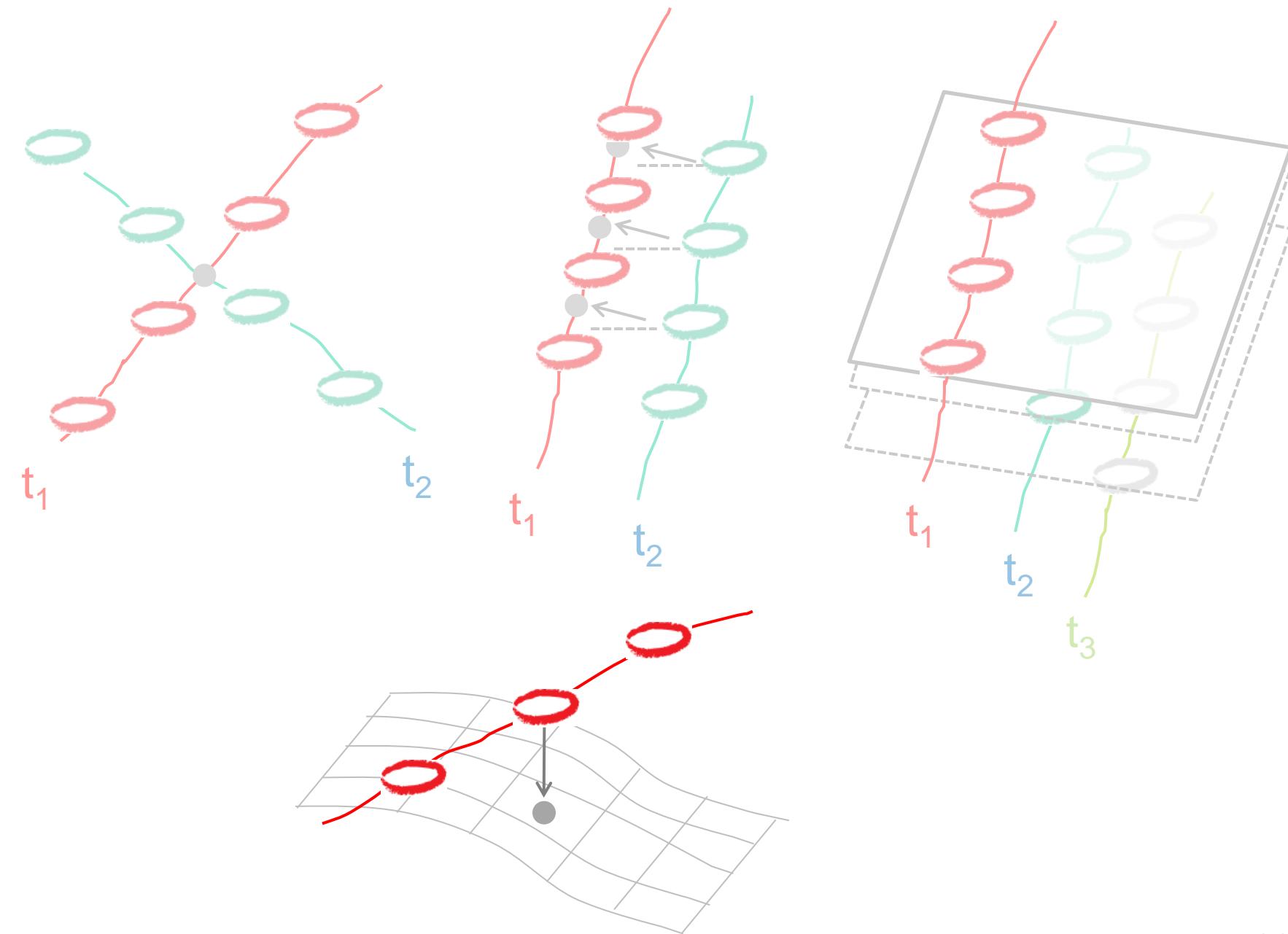


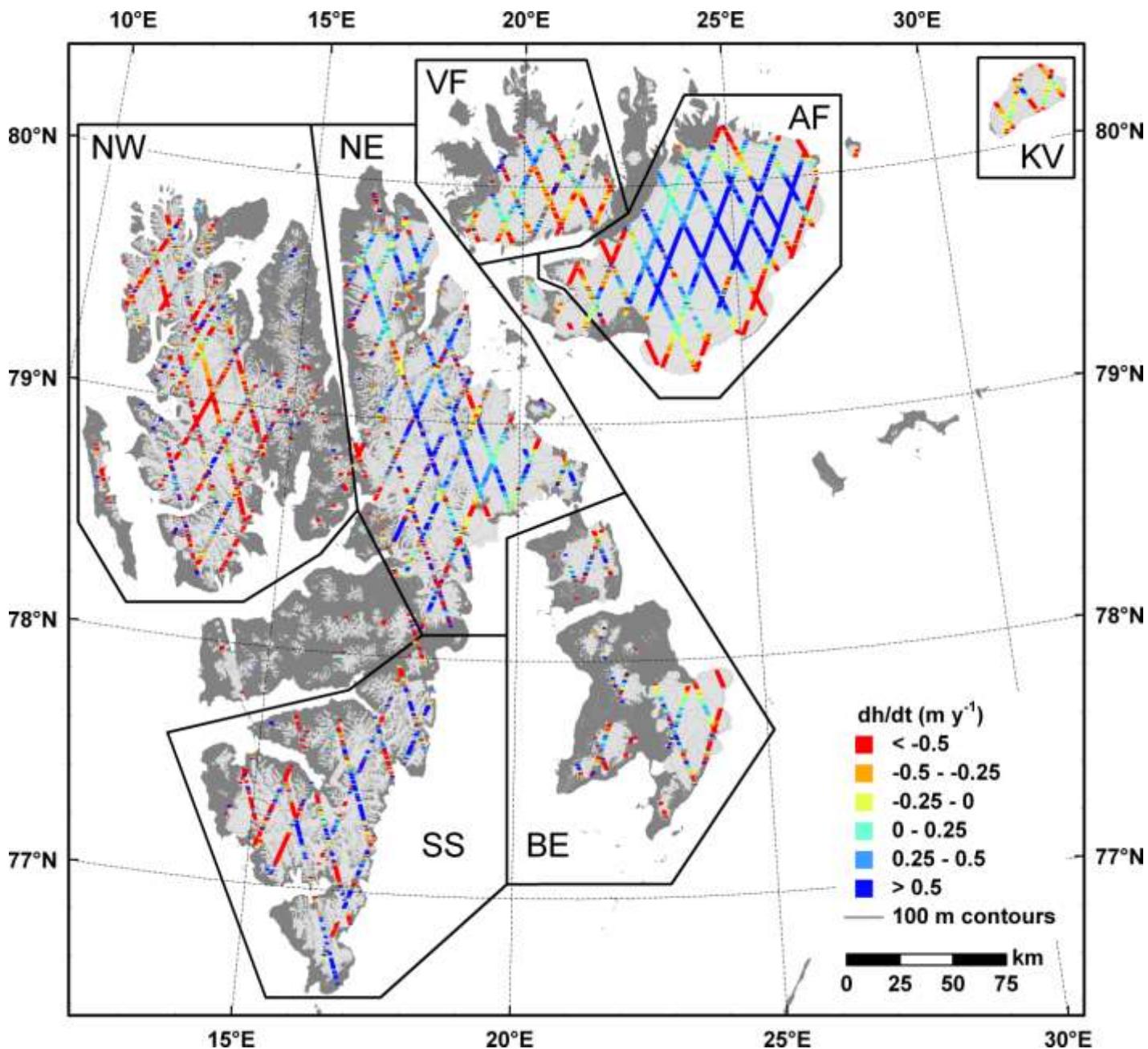


(m a.s.l.)

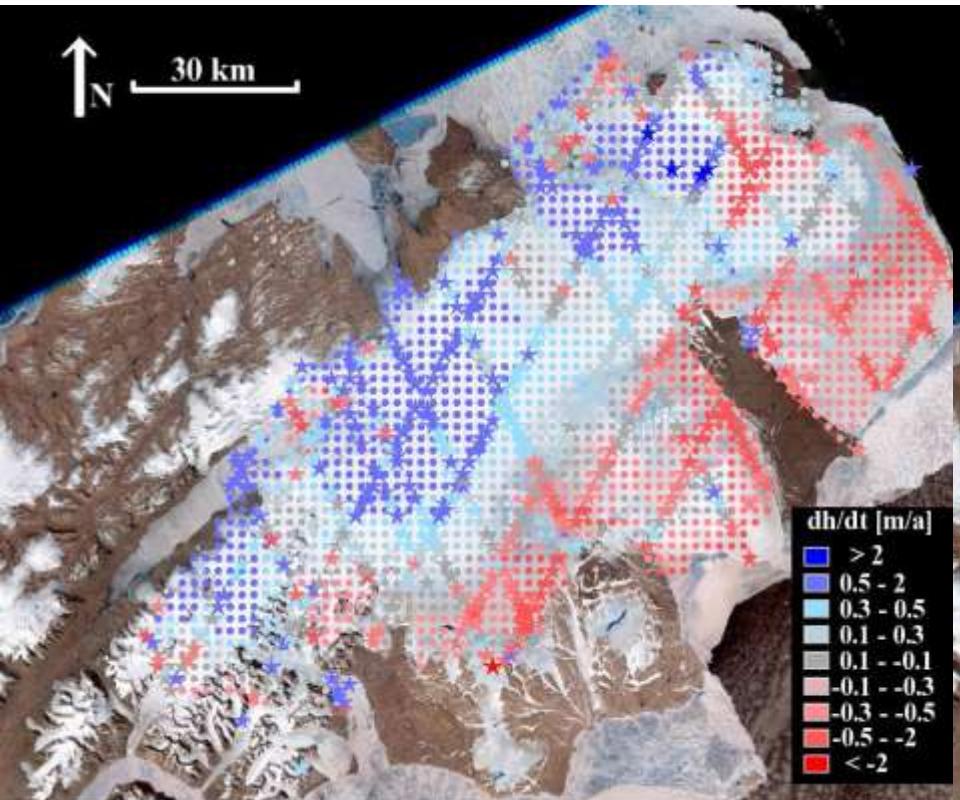




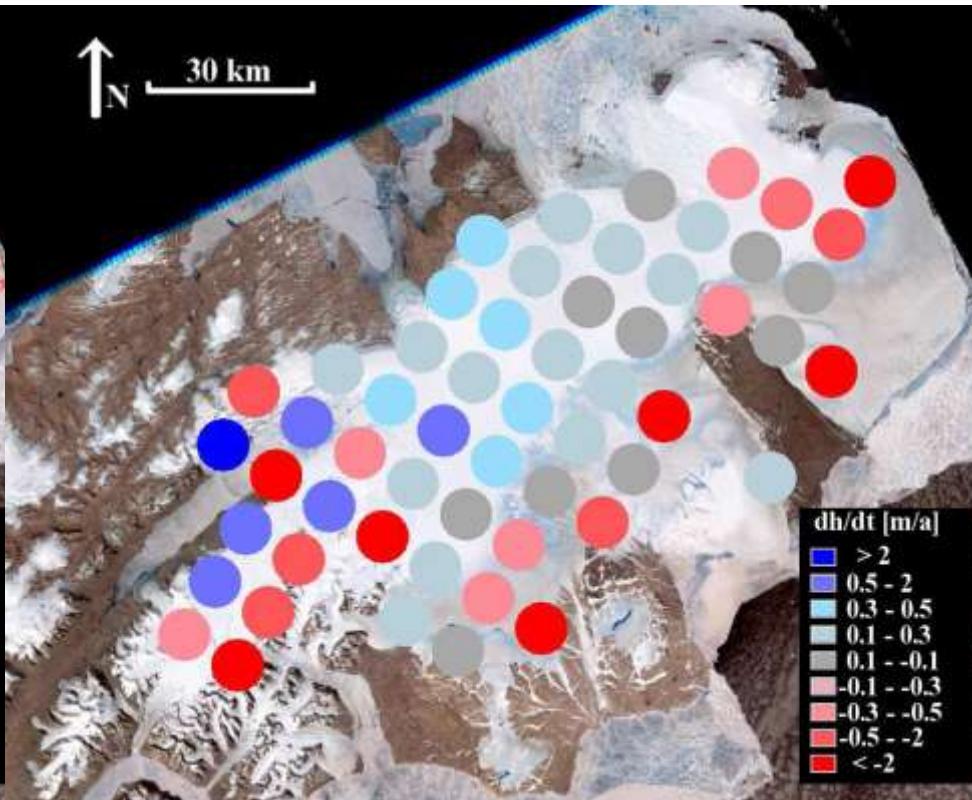




ICESat



RA-2



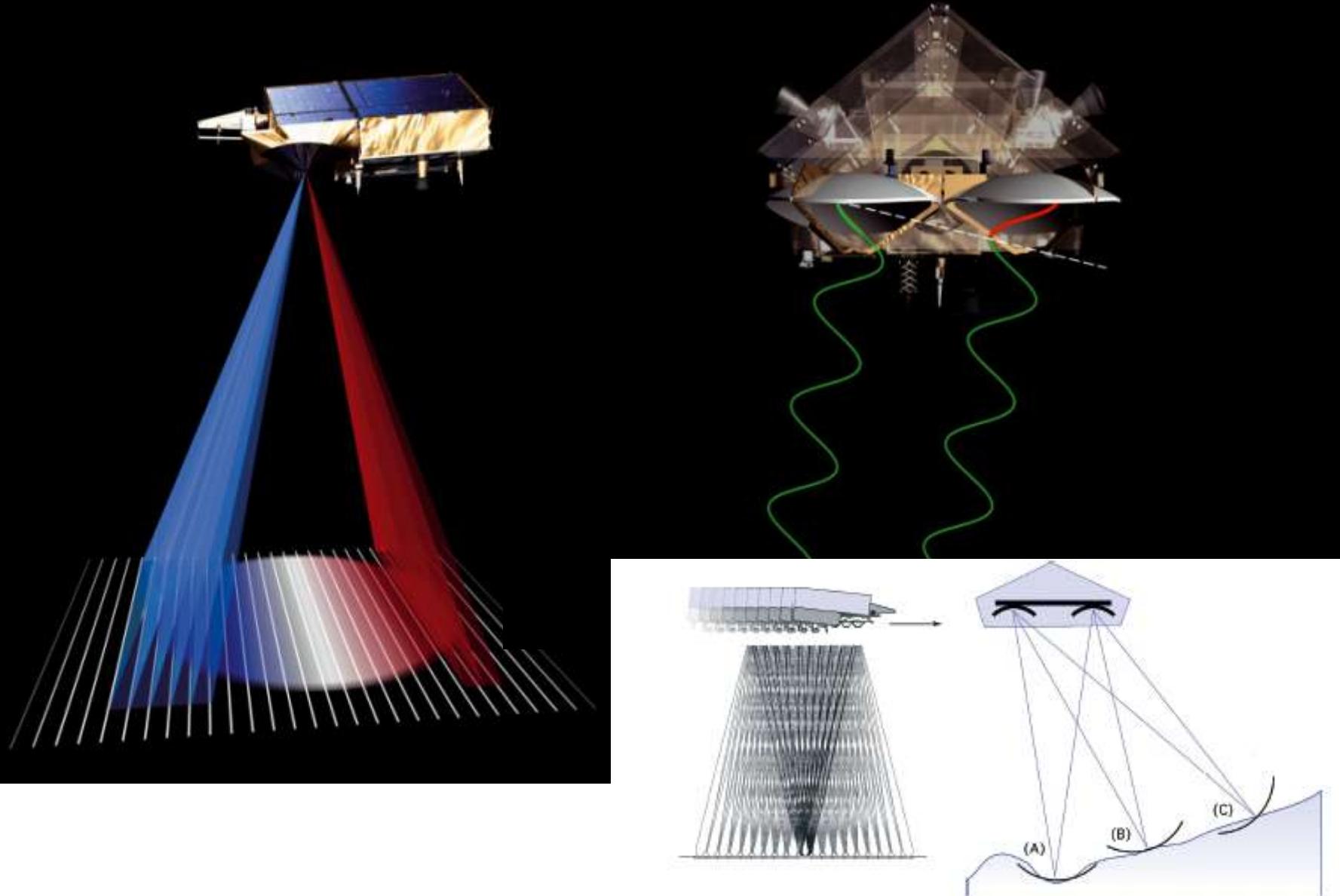


Figure 9. Principal operating modes of the SIRAL altimeter. Left: SAR-mode over sea ice. Right: SARIn-mode over steep ice sheet terrain