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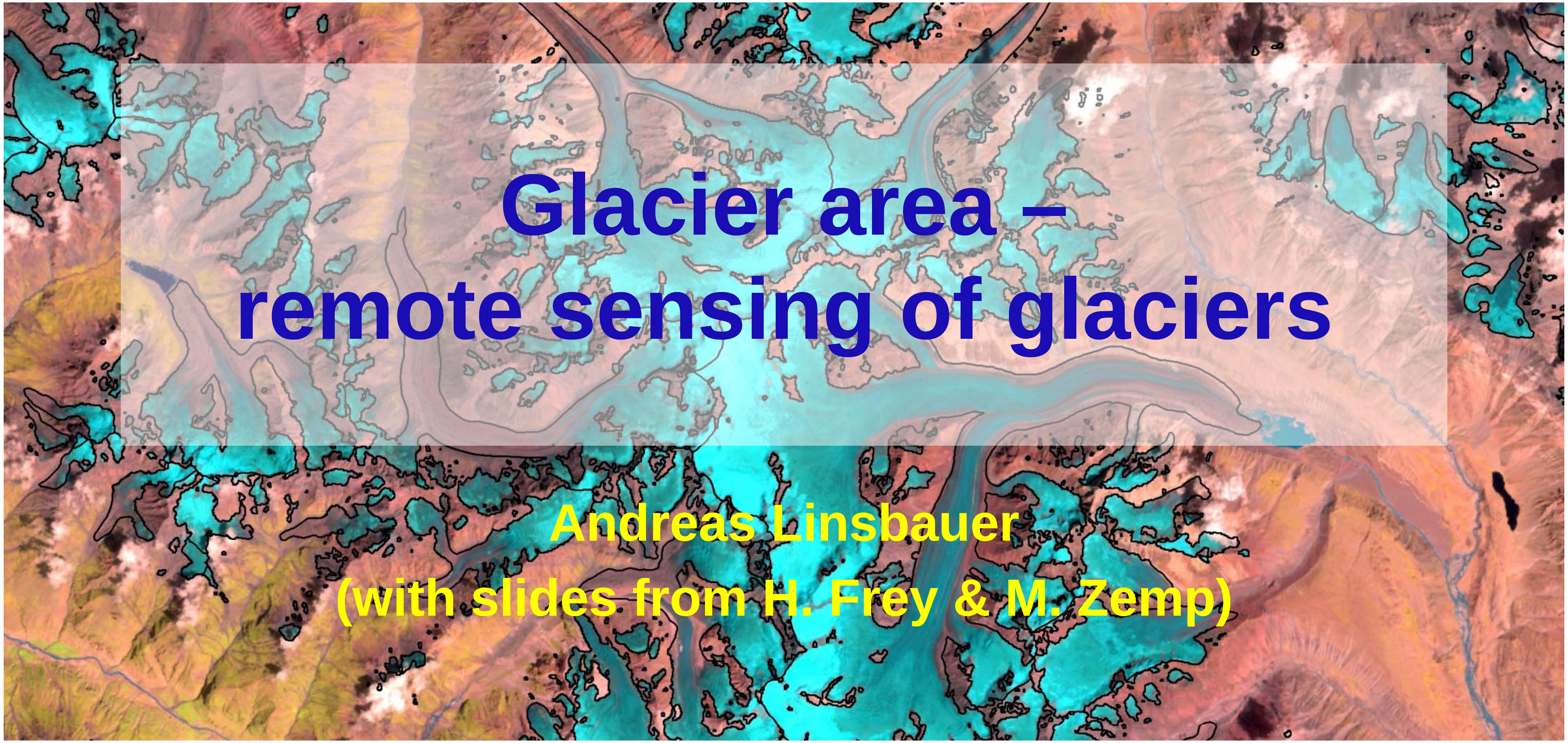


Glacier area – remote sensing of glaciers

Andreas Linsbauer
(with slides from H. Frey & M. Zemp)

IHCAP – Indian Himalayas Climate Change Adaptation Programme
Capacity building programme “Cryosphere” Level-2 (Sept 20 – Nov 22, 2013)

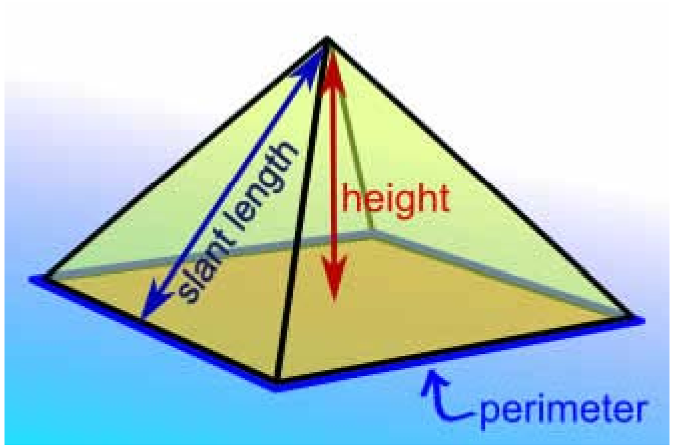
Galcier ice volume estimates

Use of glacier volumes

- Sea level rise
- Glacier evolution
- Runoff projection
- Hydrological modelling
- Future landscape
- Potential natural hazard assessment
- …

How to calculate them?

- V = A x d



1. Map glacier area (A)
2. Derive thickness (d)
3. Calculate volume (V)

GTN-G observing strategy: WGI & GLIMS

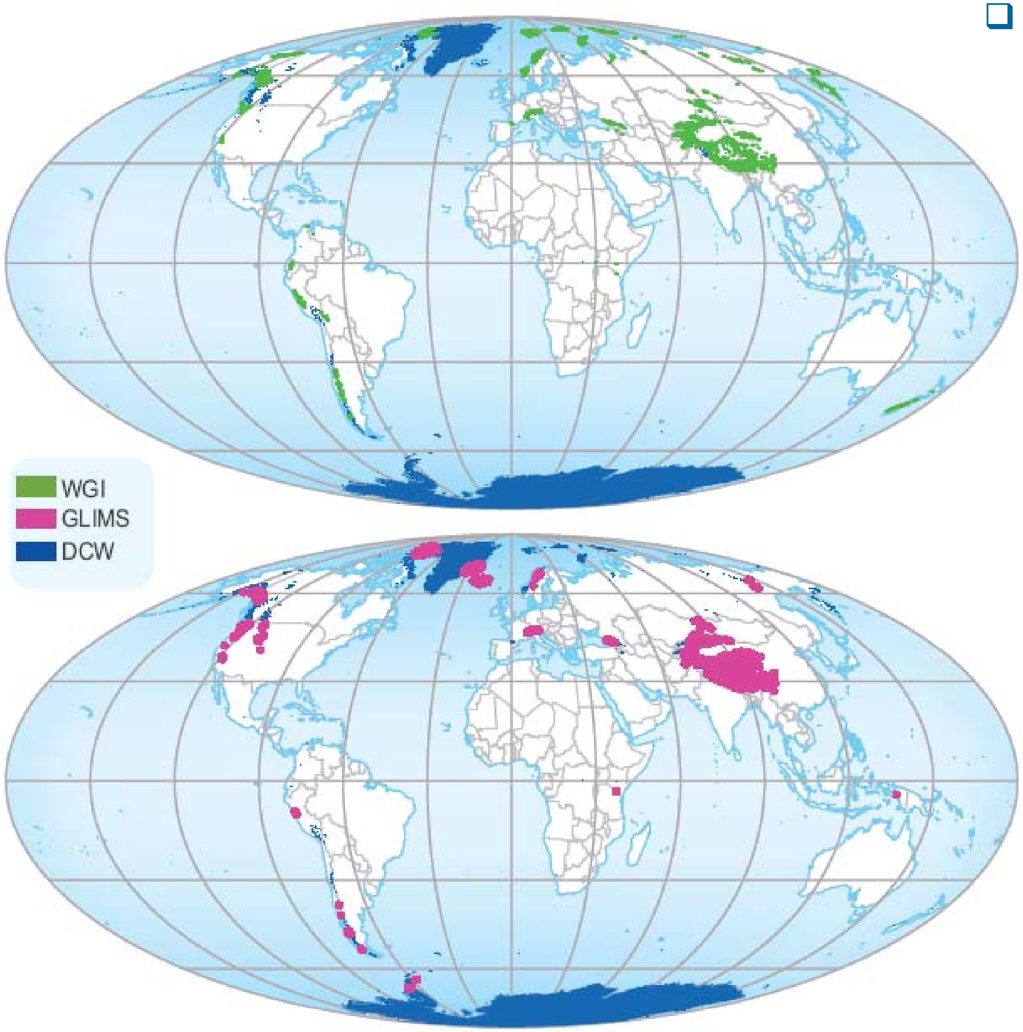
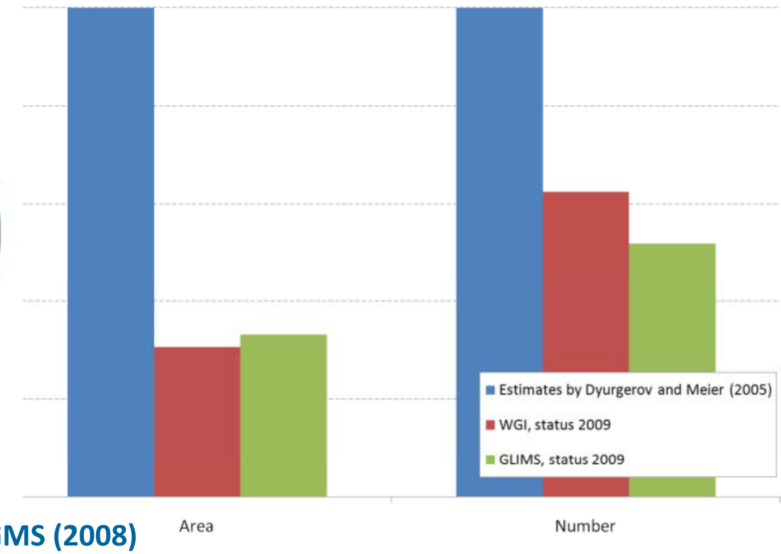


Fig. 3.6 Global glacier inventories

- Glacier inventories repeated at time intervals of a few decades by using:
  - Topographic maps and moraine dating
  - Aerial photography
  - Satellite remote sensing

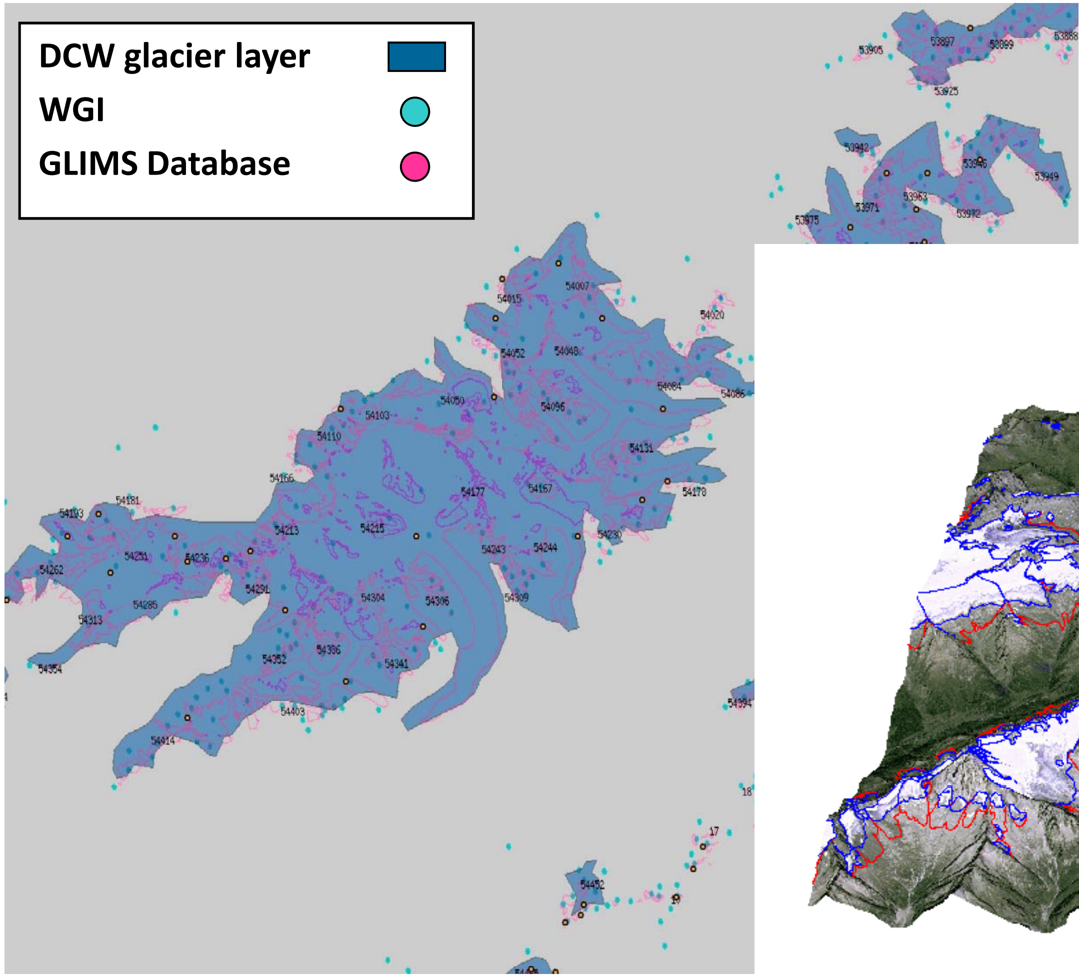
WGI: ~100,000 glaciers

GLIMS: ~80,000 glaciers



WGMS (2008)

GTN-G observing strategy: WGI & GLIMS



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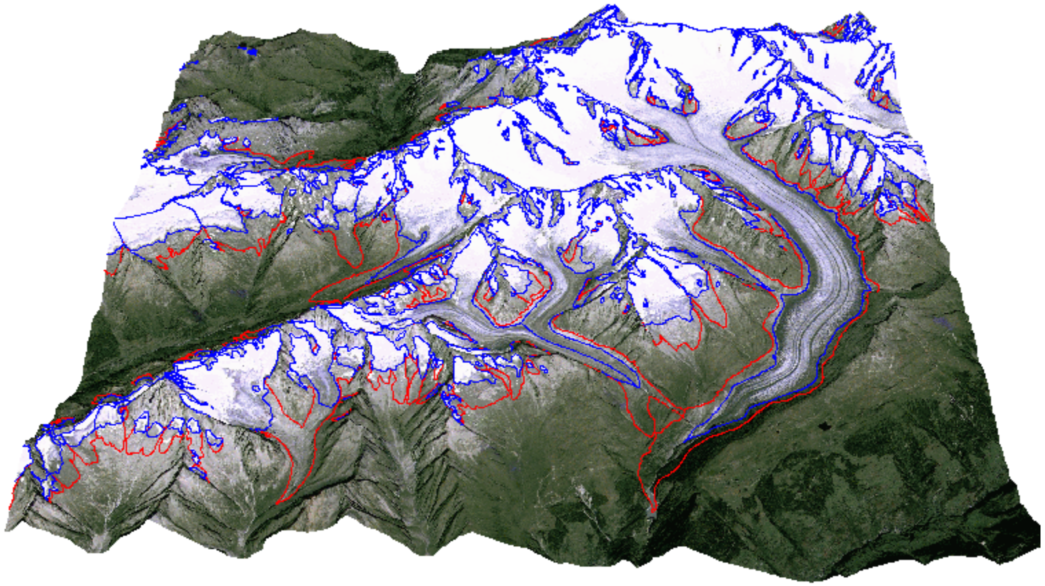
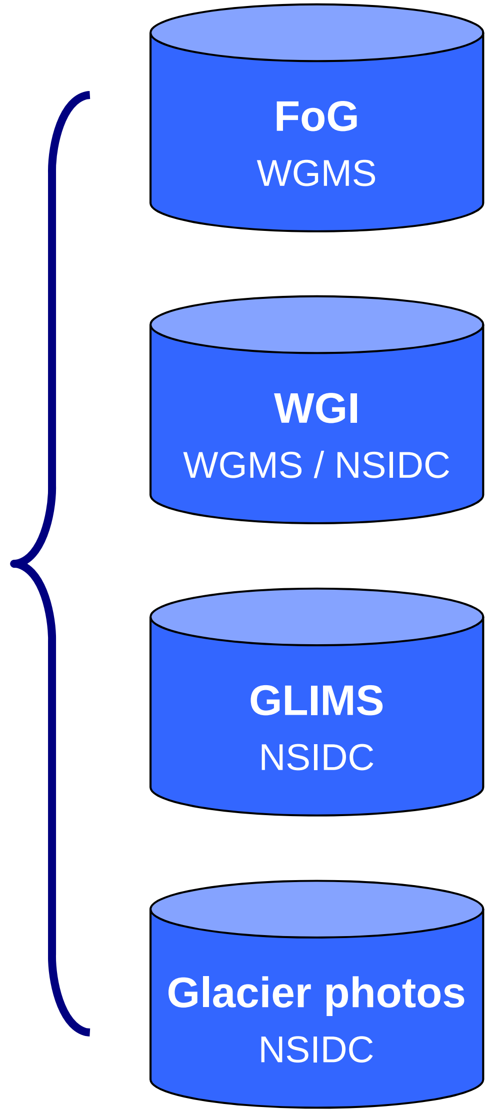
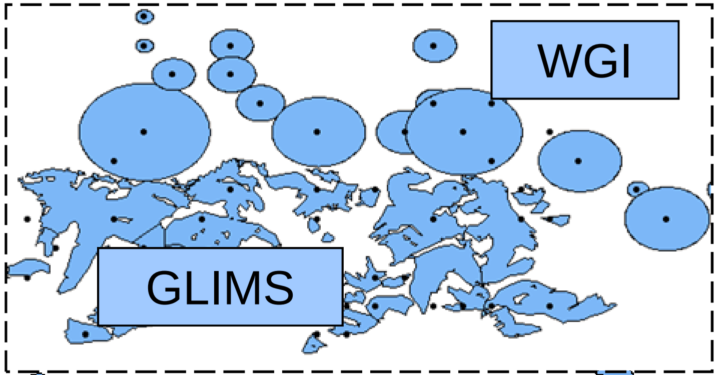


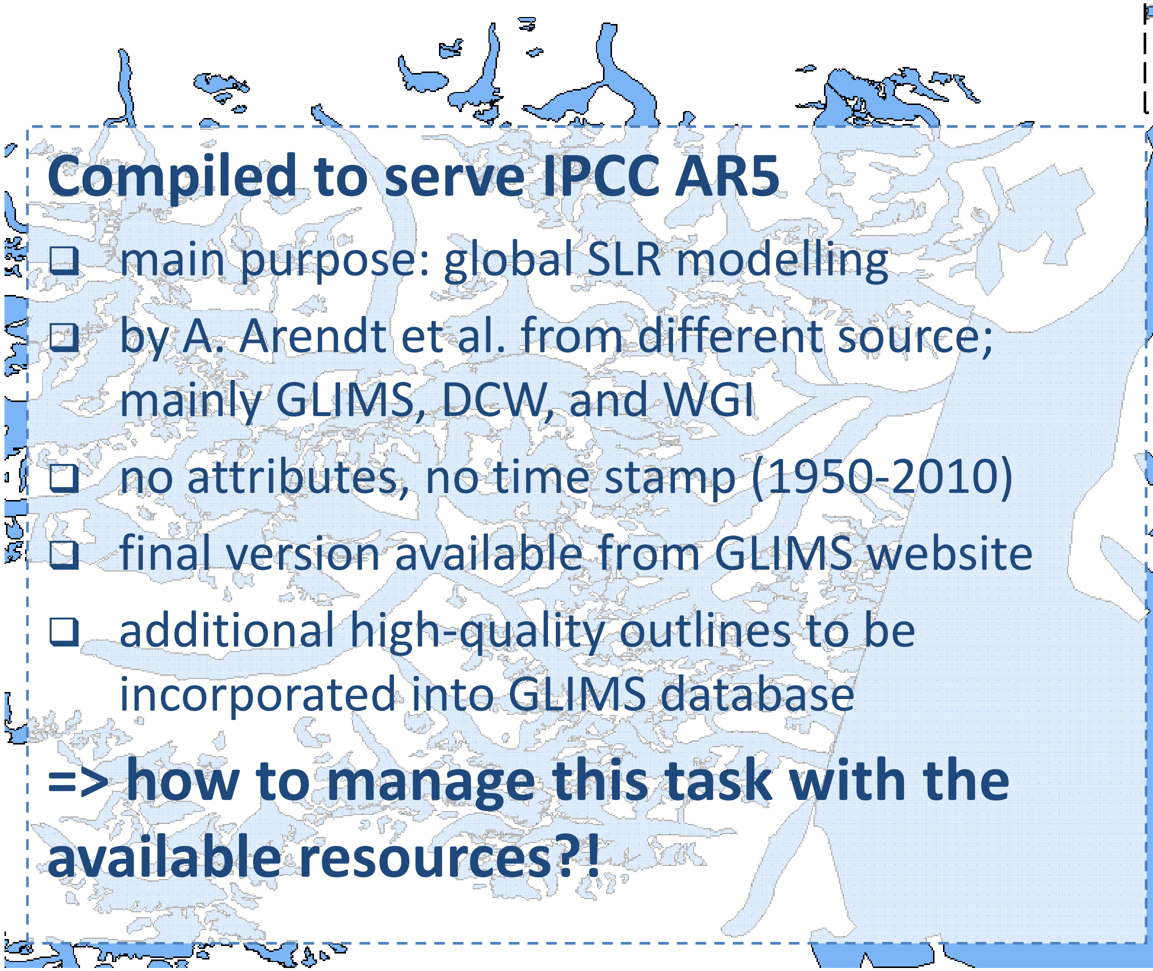
Fig. by Frank Paul

One-stop data-portal on www.gtn-g.org



Randolph (Global Glacier Map)

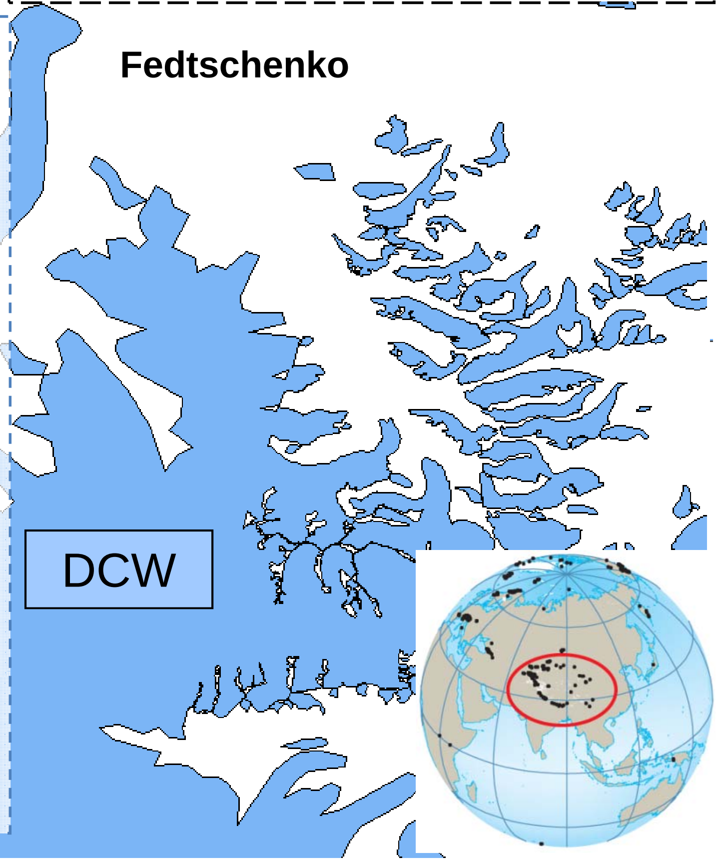




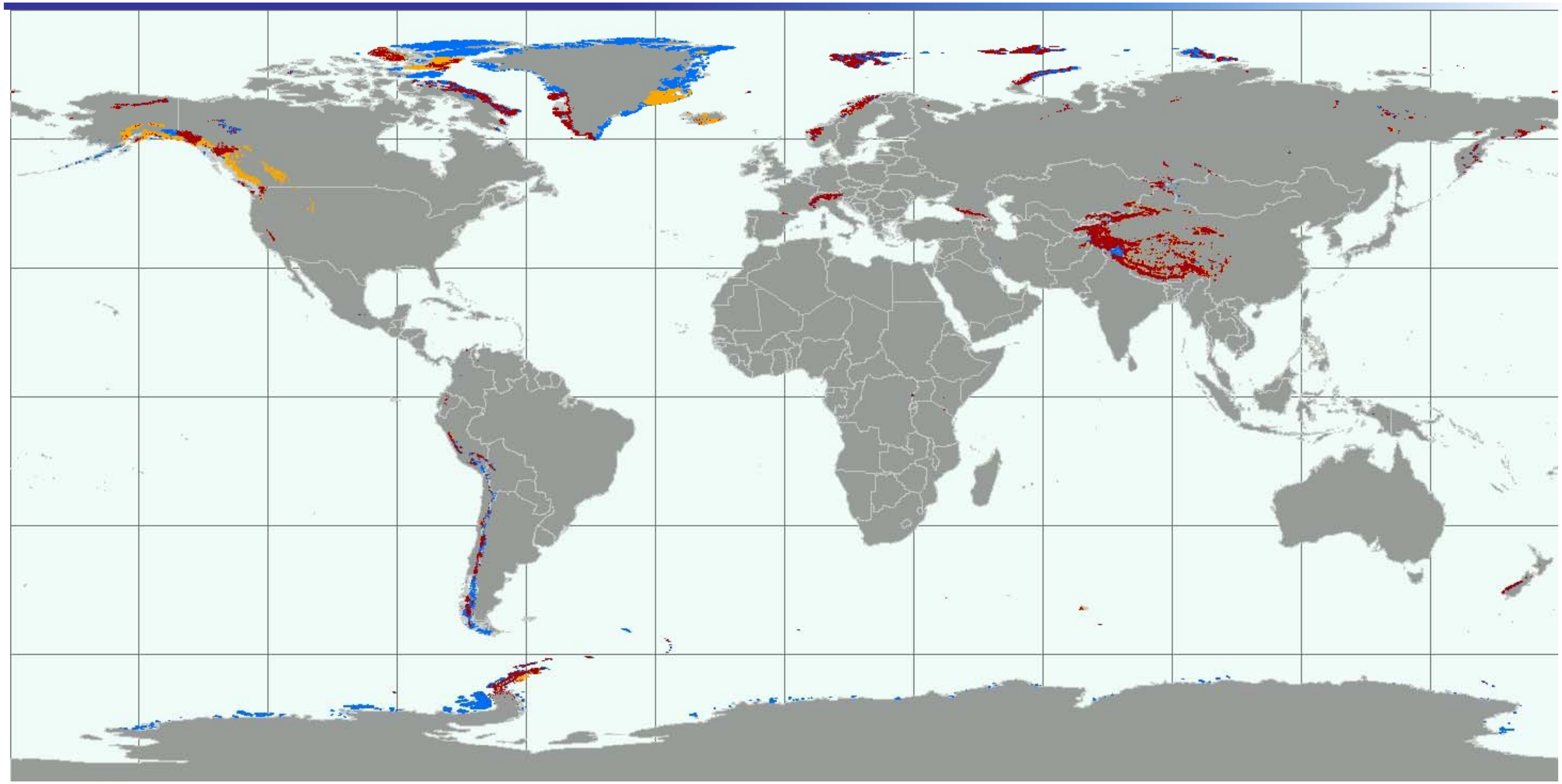
Compiled to serve IPCC AR5

- main purpose: global SLR modelling
- by A. Arendt et al. from different source; mainly GLIMS, DCW, and WGI
- no attributes, no time stamp (1950-2010)
- final version available from GLIMS website
- additional high-quality outlines to be incorporated into GLIMS database

=> how to manage this task with the available resources?!

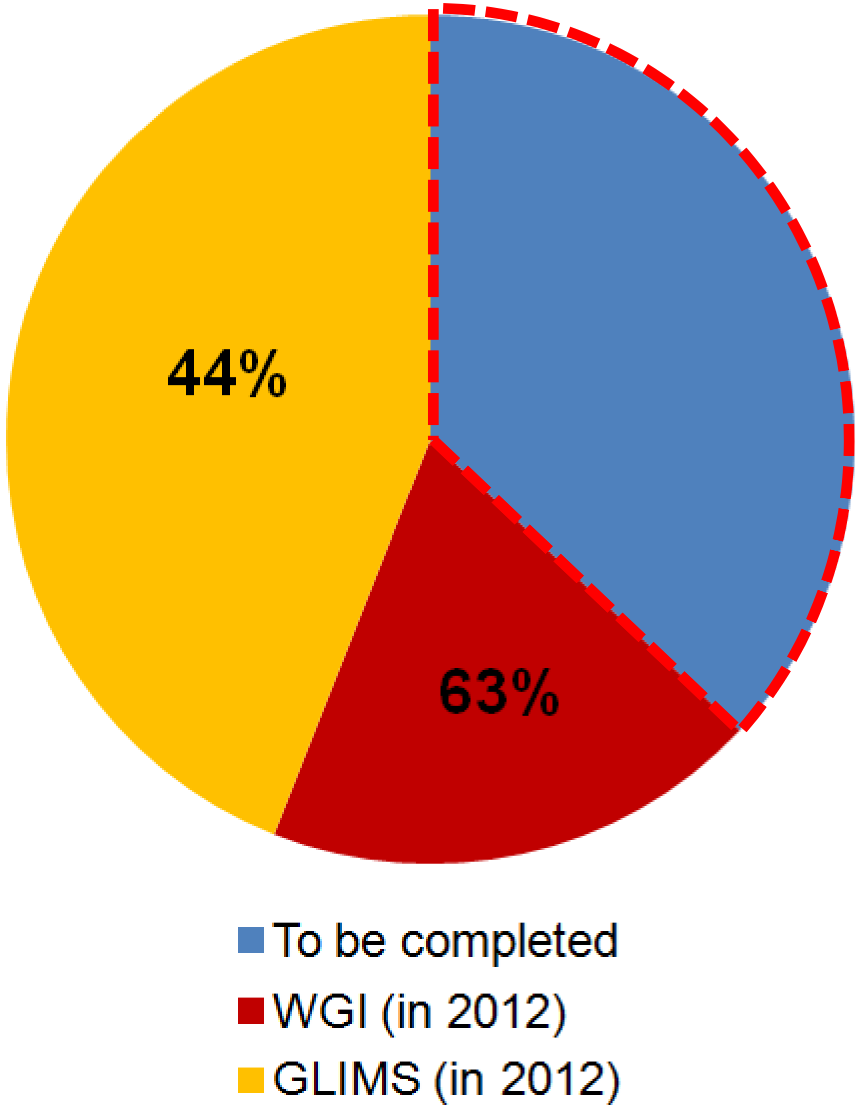


World Glacier Inventory



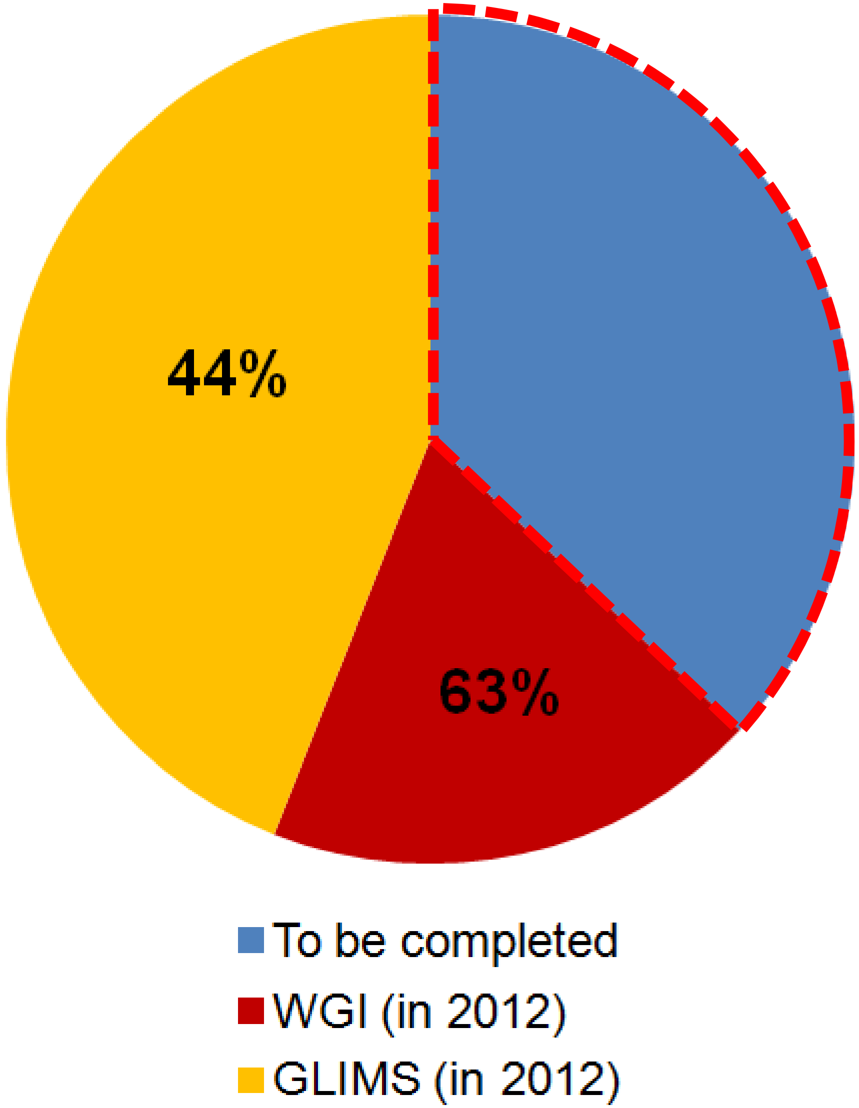
- **World Glacier Inventory:** mainly aerial photographs and maps around 1970s
- **GLIMS Inventory:** mainly satellite images after 2000
- **Randolph Glacier Map:** rough glacier outlines, rough time stamp, no attributes

After 50 years: still no complete glacier inventory!



Why?

After 50 years: still no complete glacier inventory!



Why?

Fully automated algorithms are challenged by shadow, perennial snow, and debris cover.

In some regions it is hard to get minimal snow and cloud free images at the end of ablation season.

This is a monitoring task.

Challenges

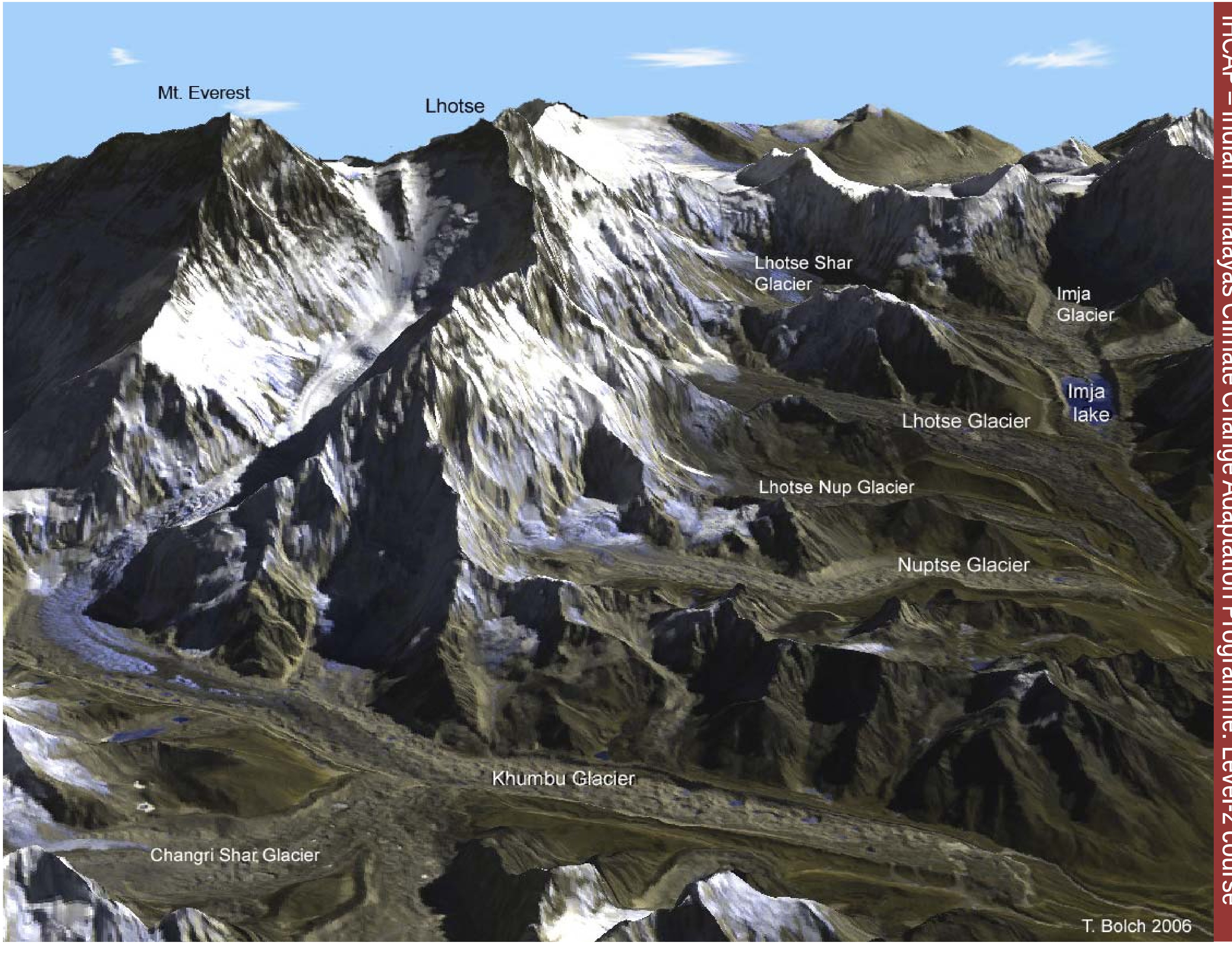
Glacier mapping challenges:

- Debris cover
- Separation of glaciers (glacier branches / tributaries, along ridges)
- Clouds
- (Problems with DEMs)

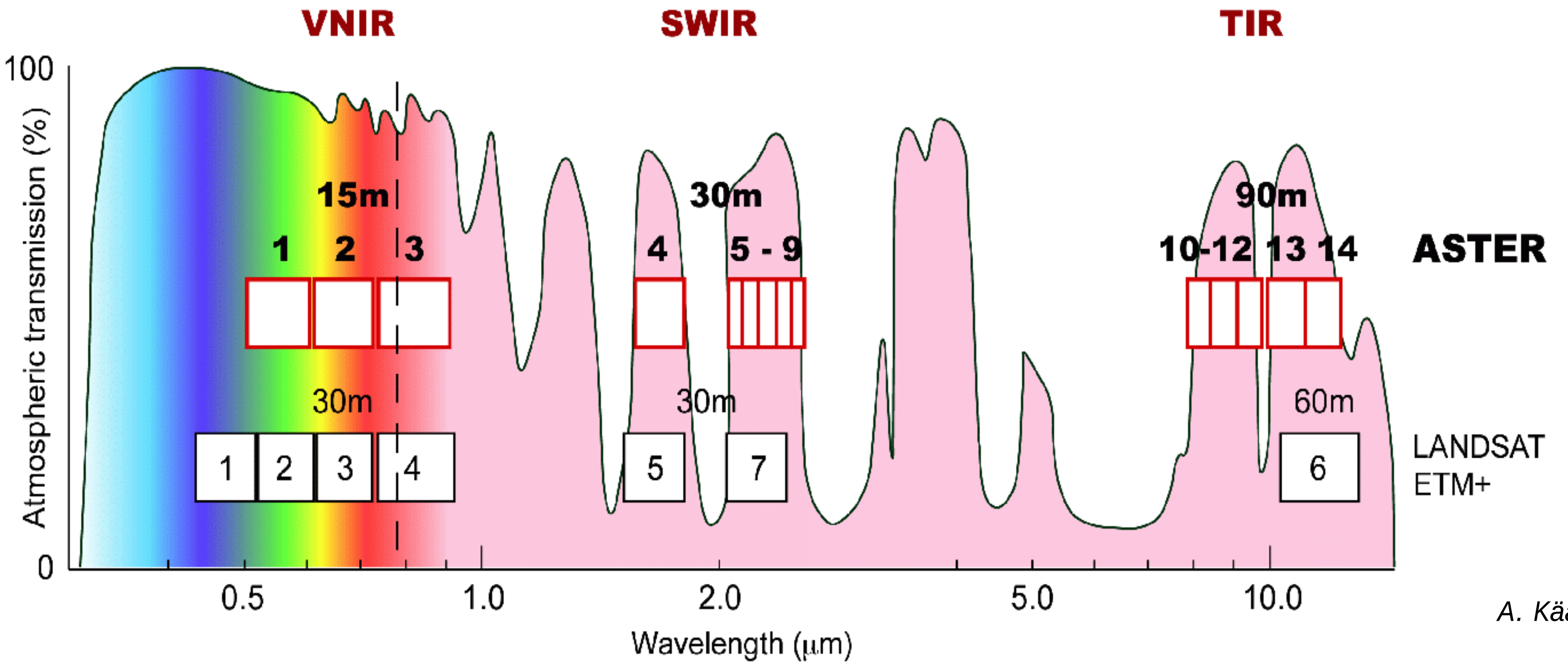
Further challenges:

- Adverse snow conditions
- Permafrost interactions
- Frozen lakes / sea ice
- Georeferencing of satellite imagery and DEMs

A typical small valley glacier in reality

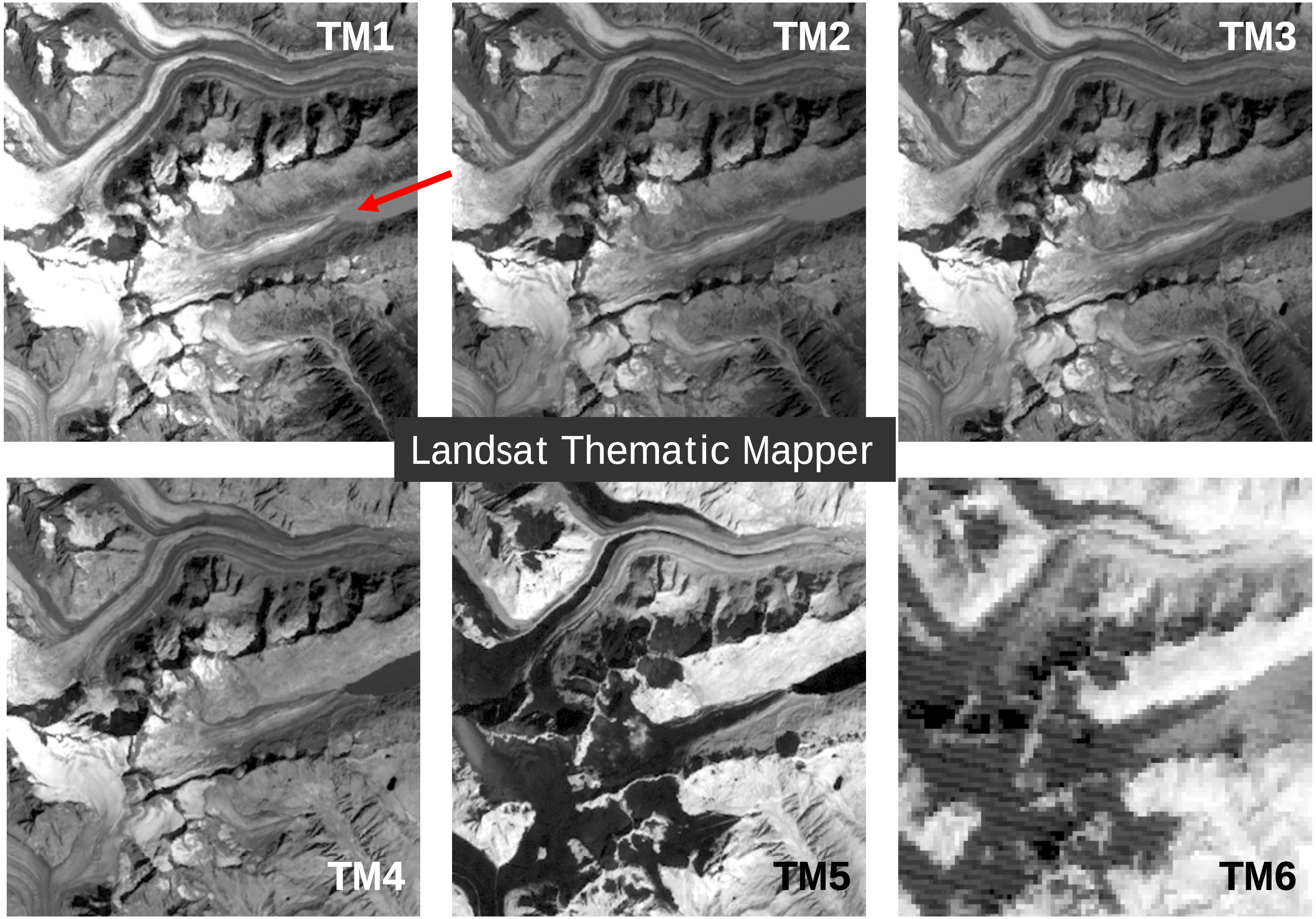

Mt. Everest
Lhotse
Lhotse Shar Glacier
Imja Glacier
Imja lake
Lhotse Glacier
Lhotse Nup Glacier
Nuptse Glacier
Khumbu Glacier
Changri Shar Glacier
T. Bolch 2006

Satellite bands and atmospheric transmission



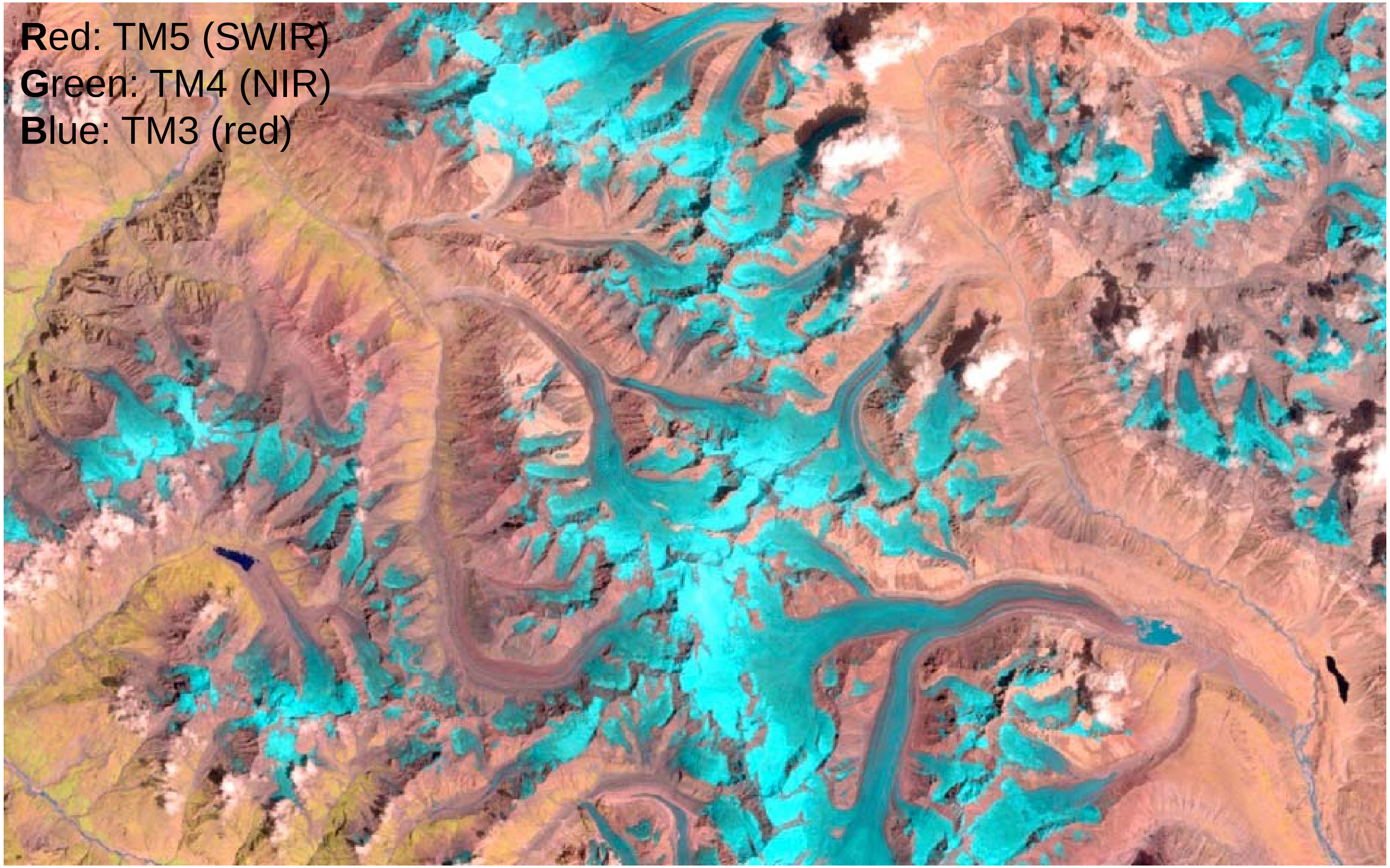
A. Kääb

Satellite bands and spectral reflectance

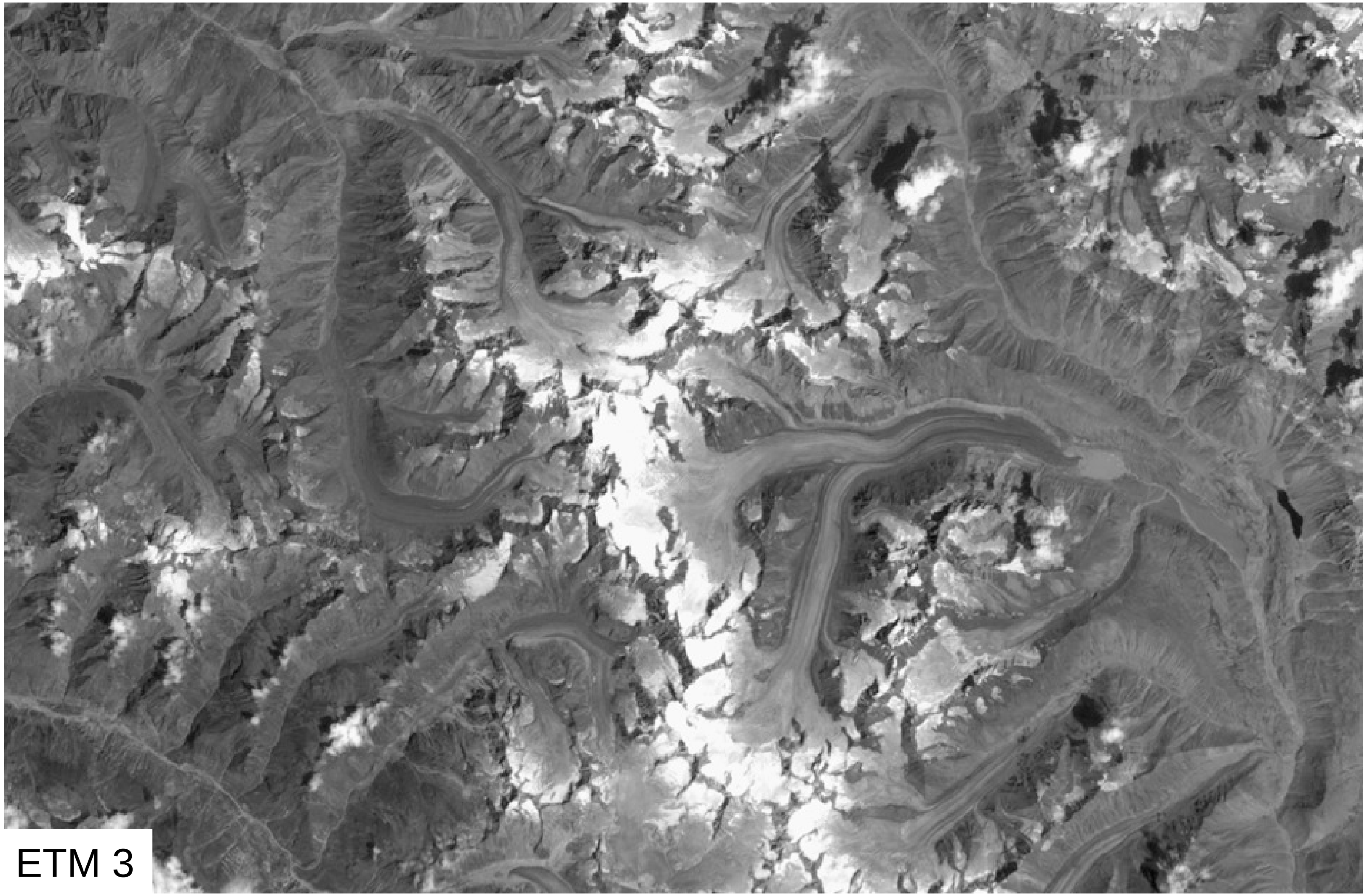


True-color composites

False-color composites

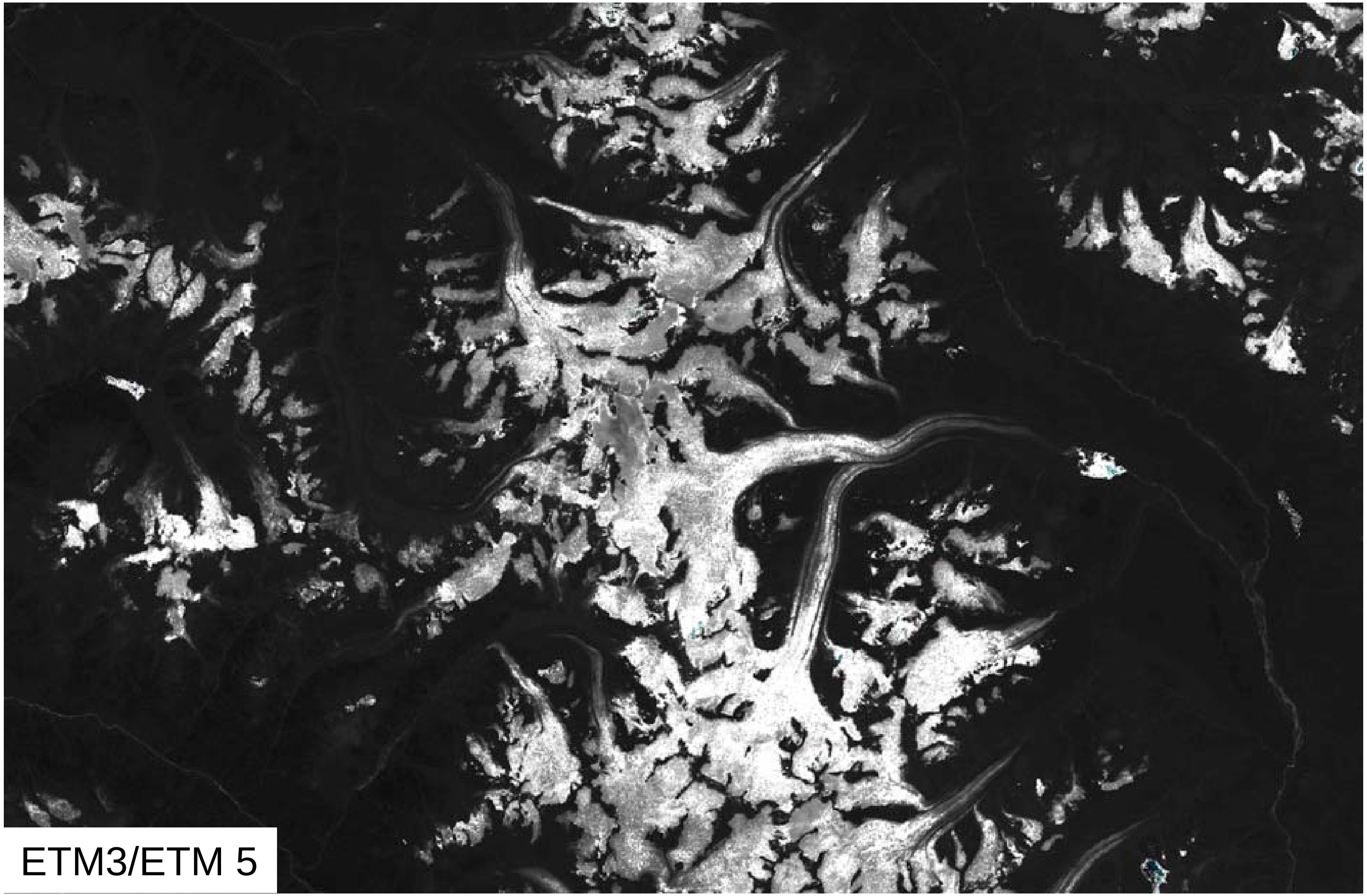


Glacier mapping with band ratio

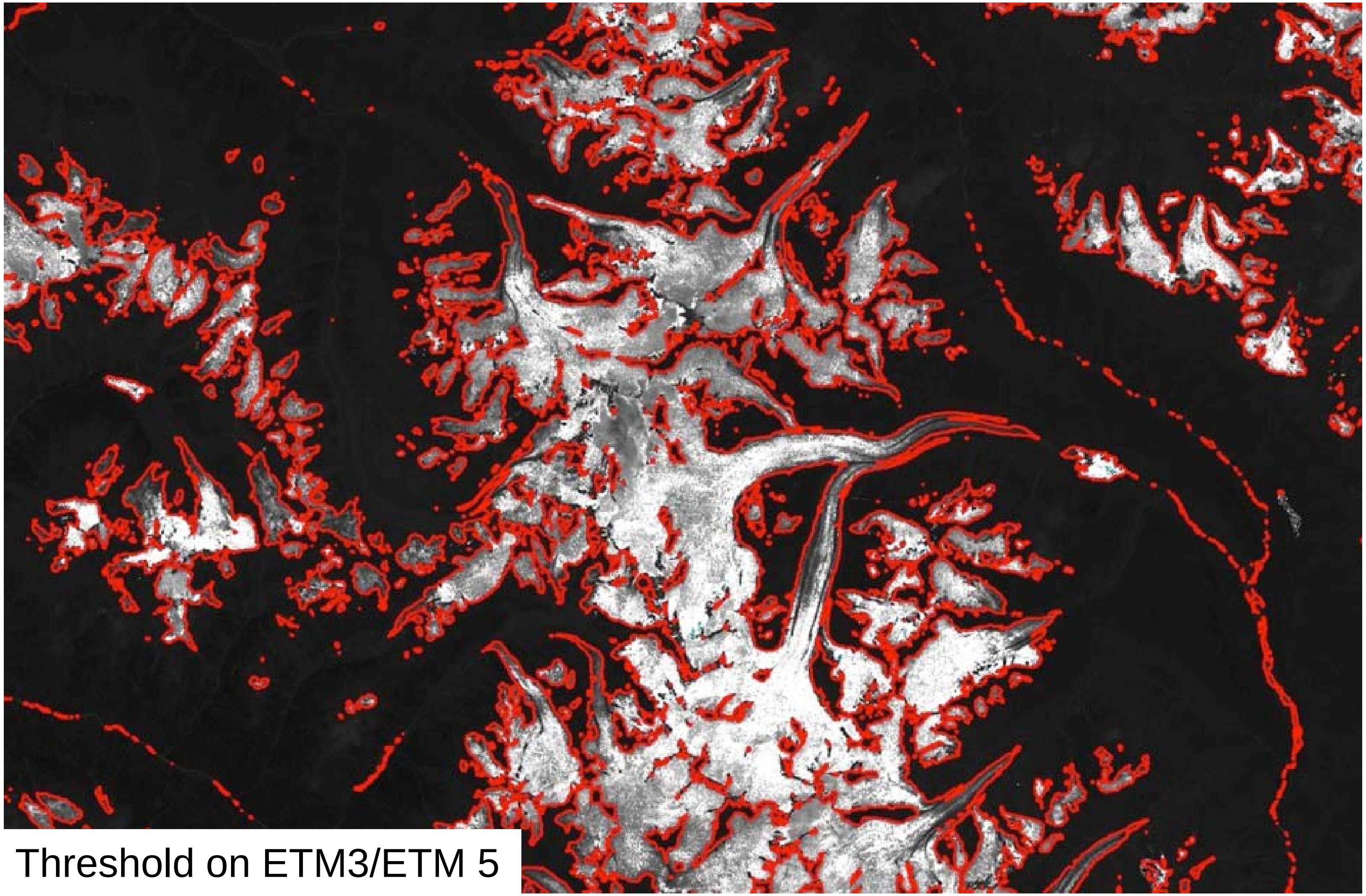


Glacier mapping with band ratio

Glacier mapping with band ratio

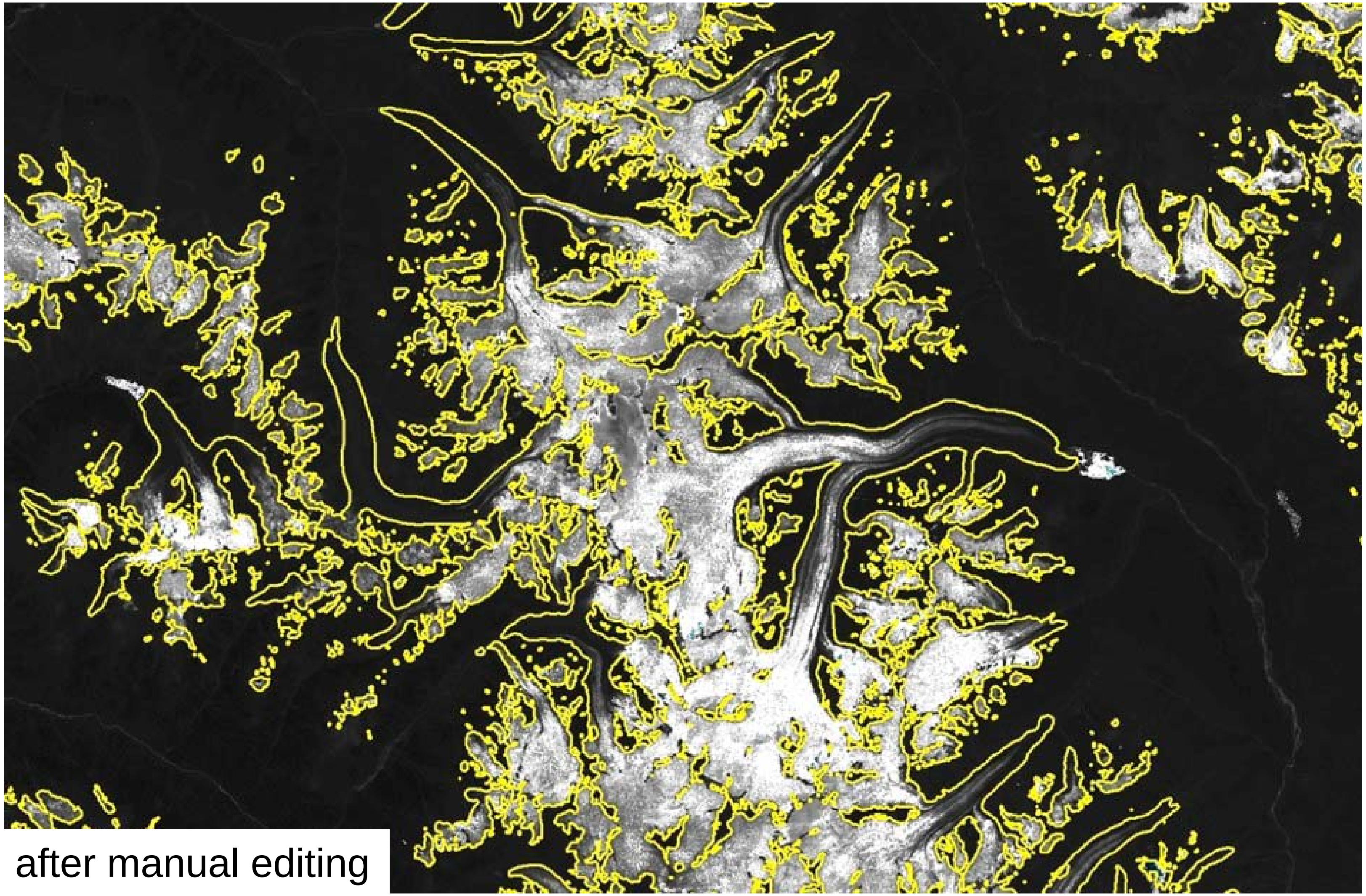


Glacier mapping with band ratio

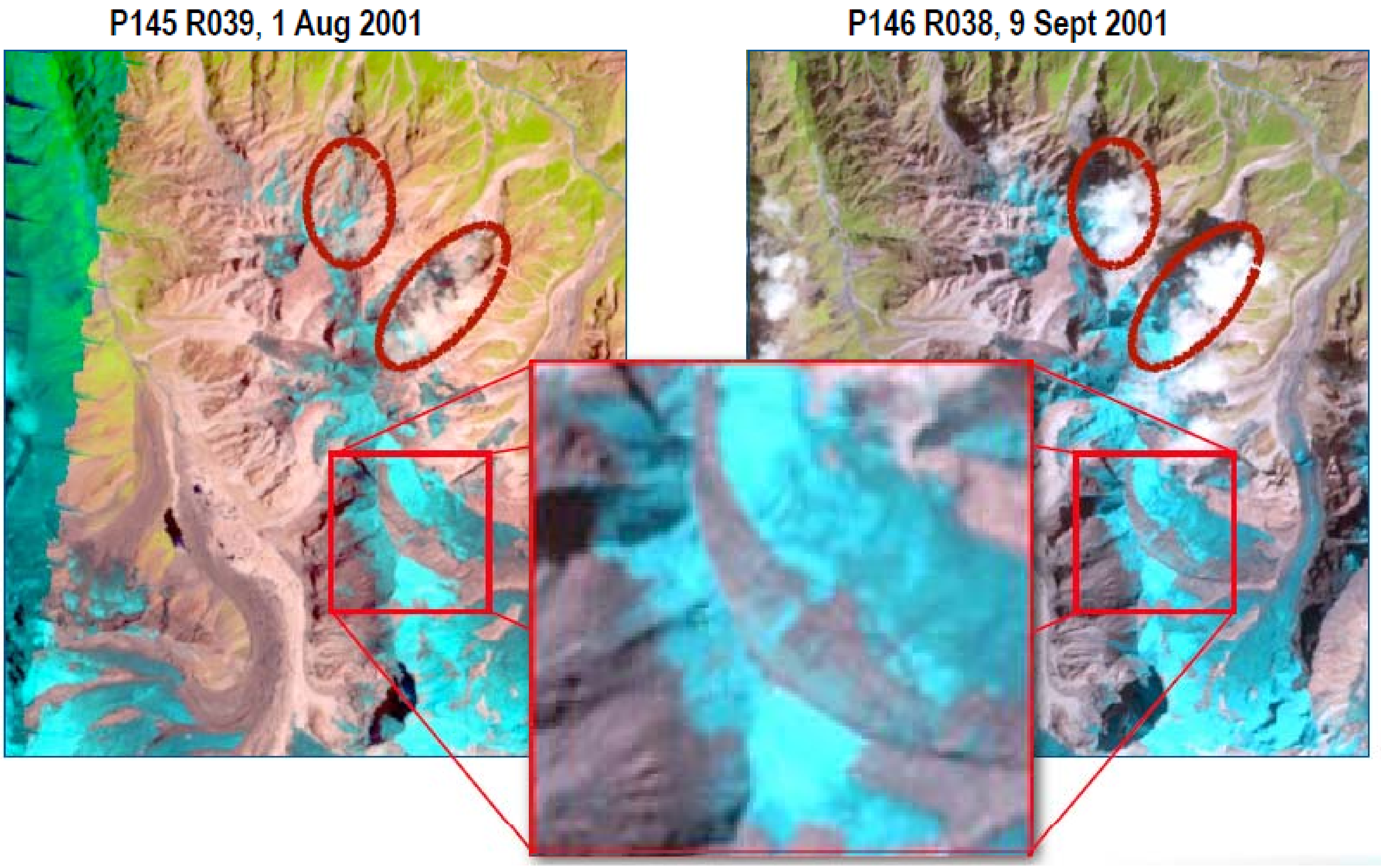


Threshold on ETM3/ETM 5

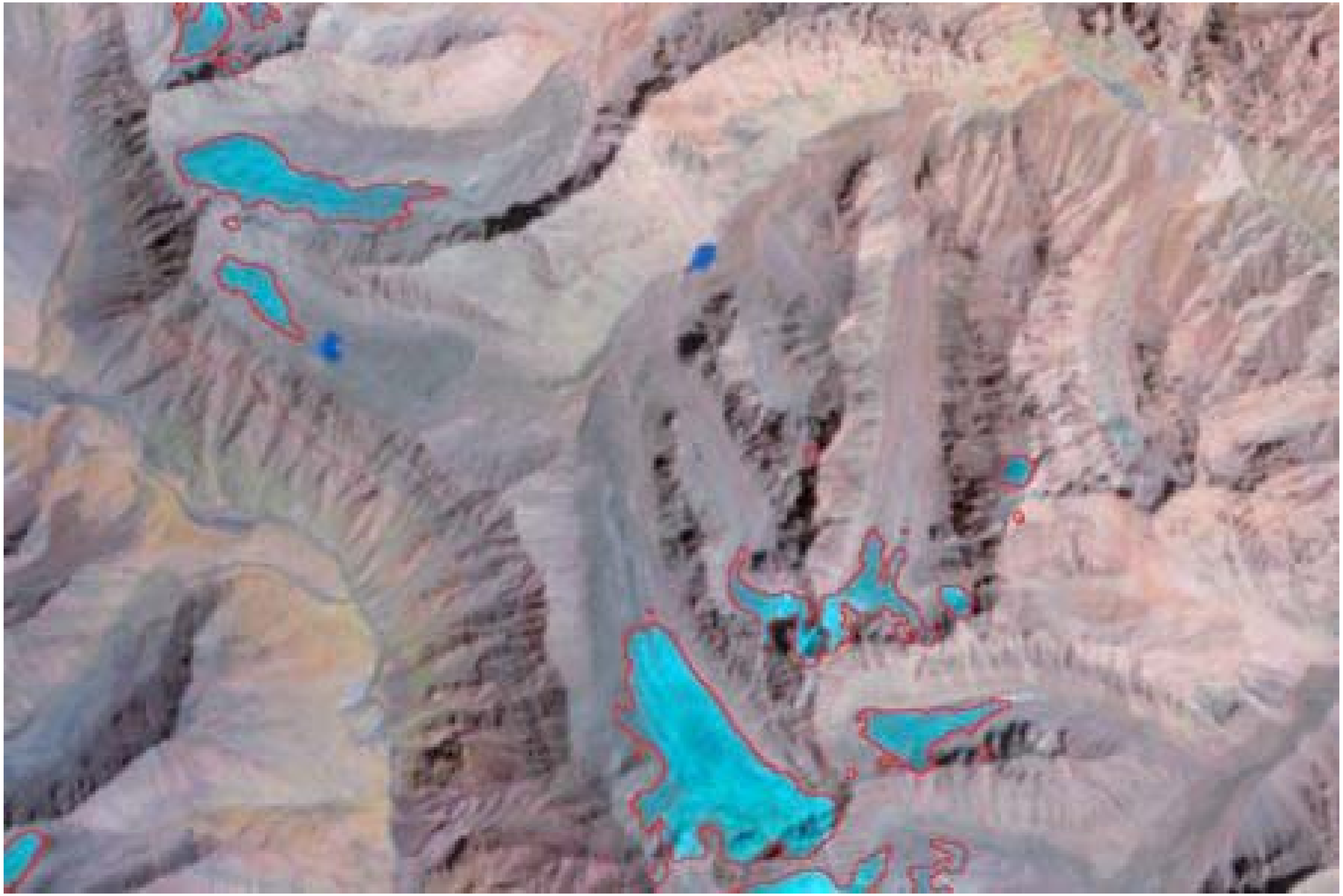
Glacier mapping with band ratio



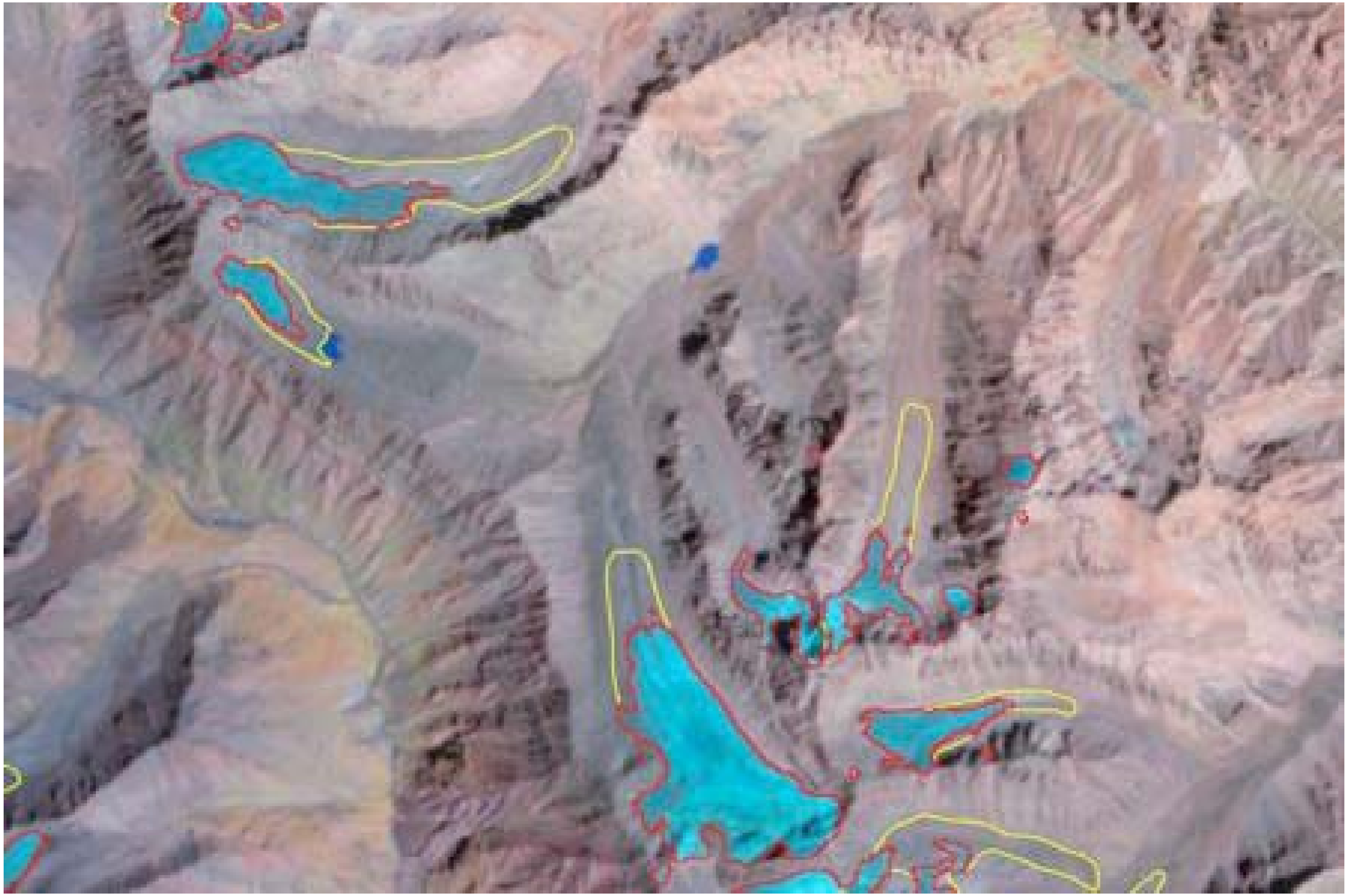
Mapping challenges: snow, cloud, shadows



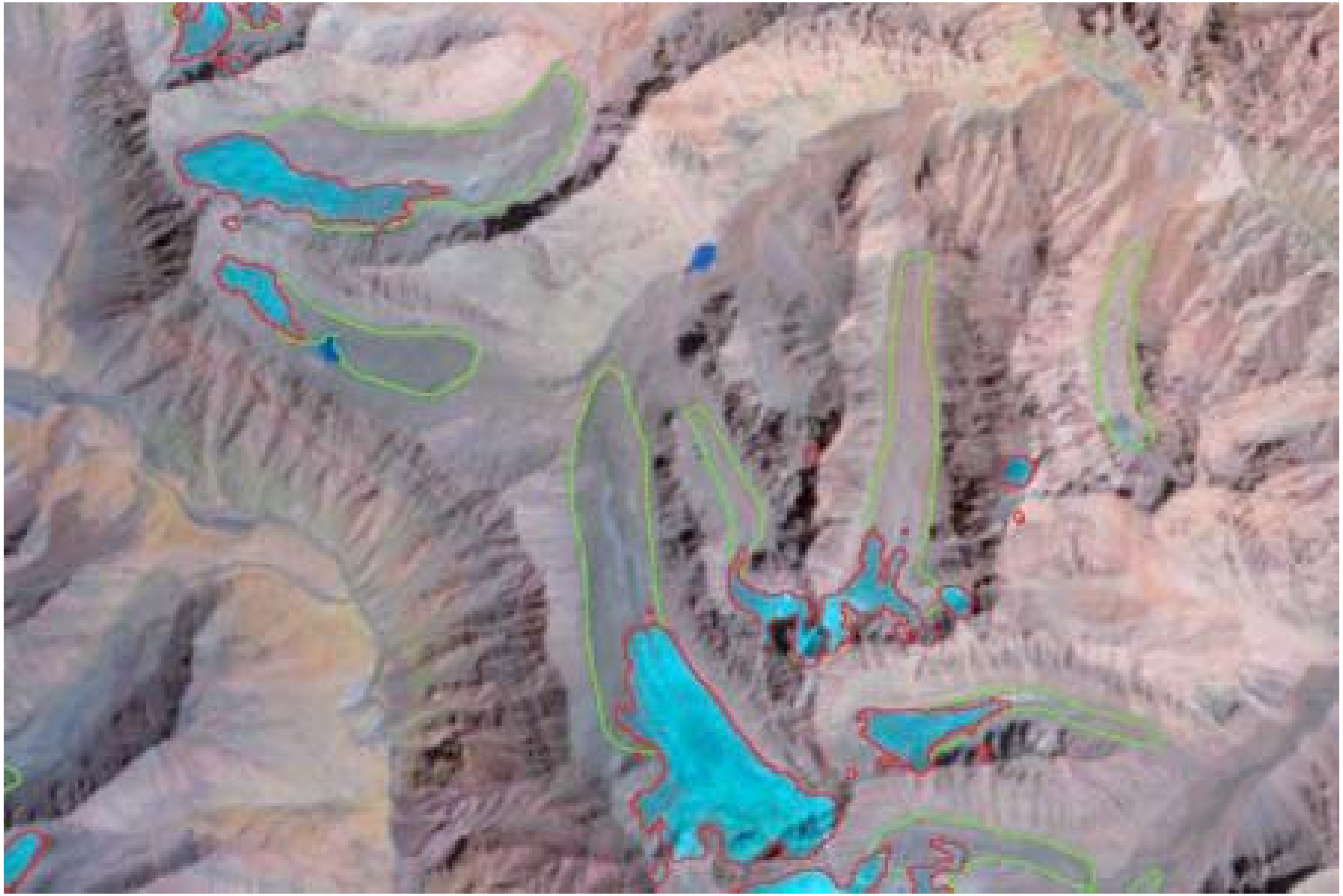
Glacier-permafrost interactions



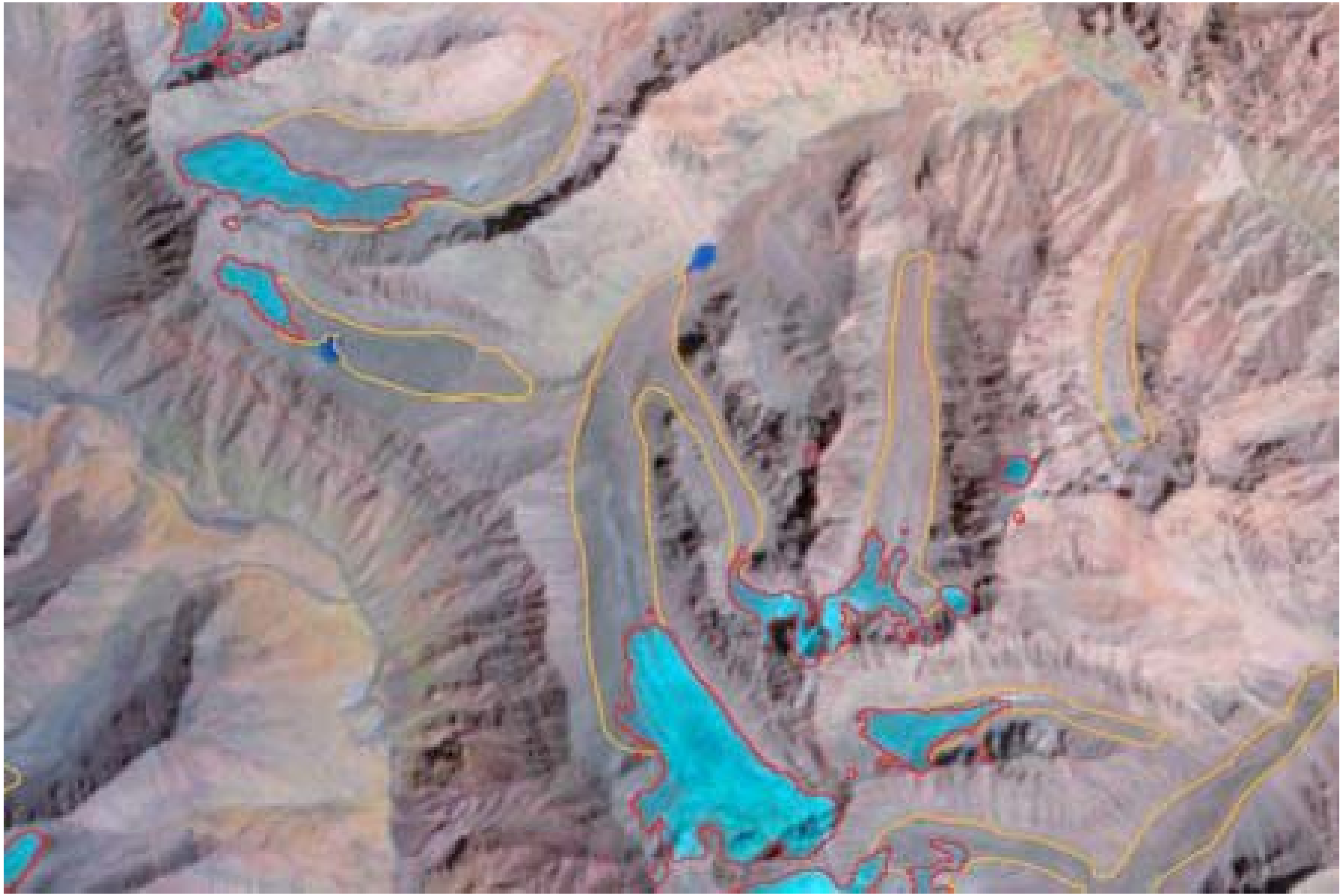
Glacier-permafrost interactions



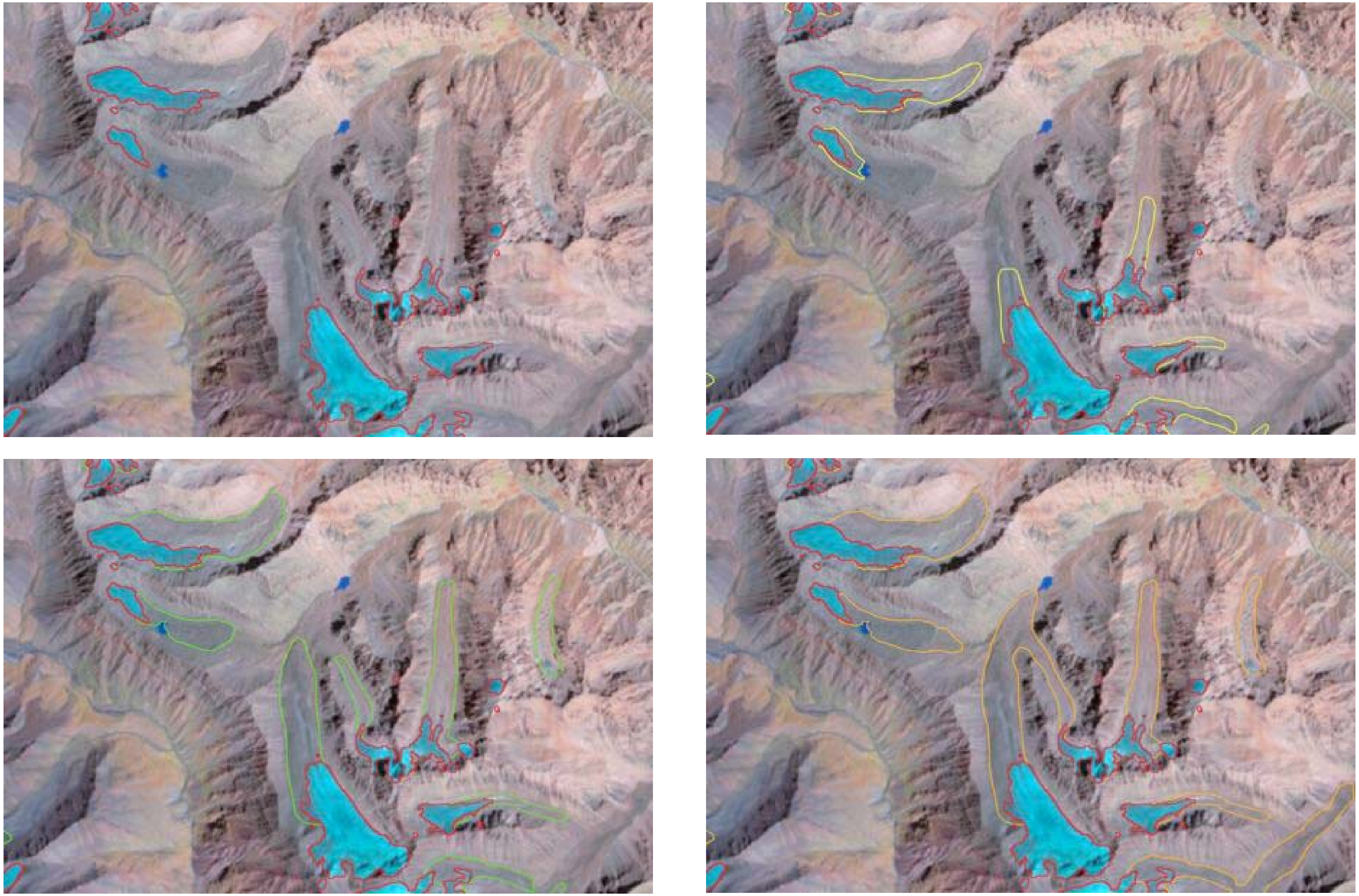
Glacier-permafrost interactions



Glacier-permafrost interactions

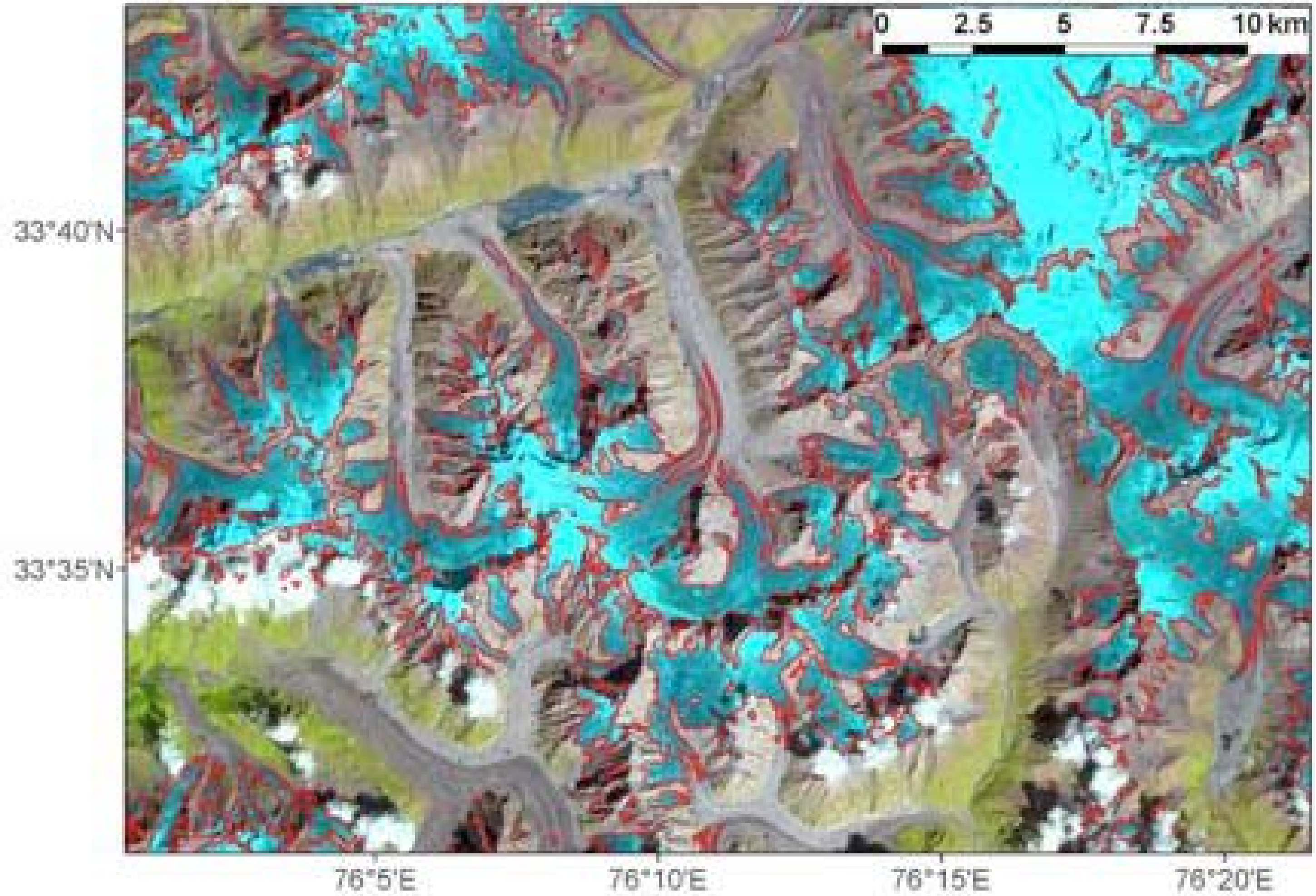


Glacier-permafrost interactions



Mapping of debris cover

coherence images from ALOS PALSAR image pairs (46 d baseline)



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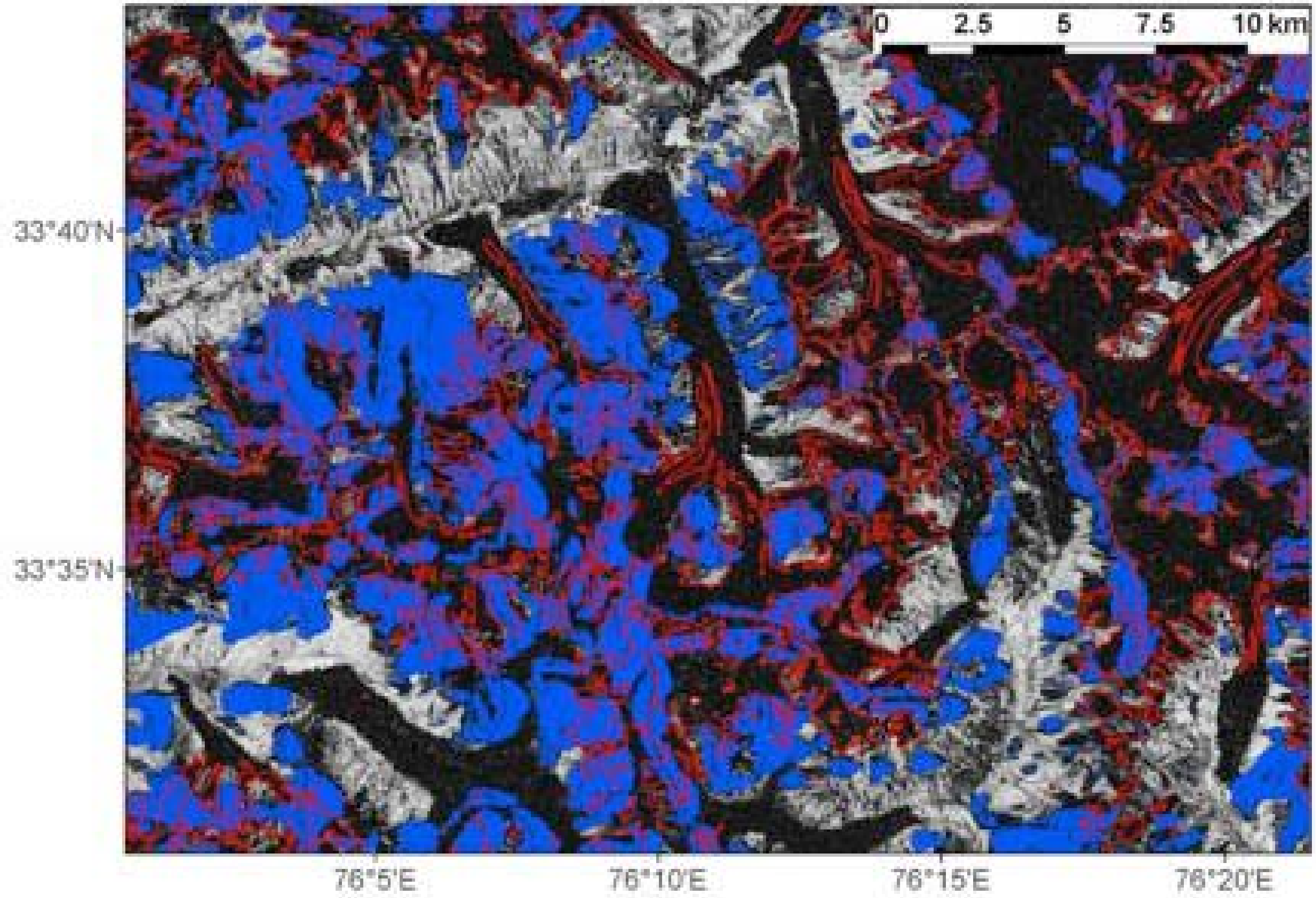

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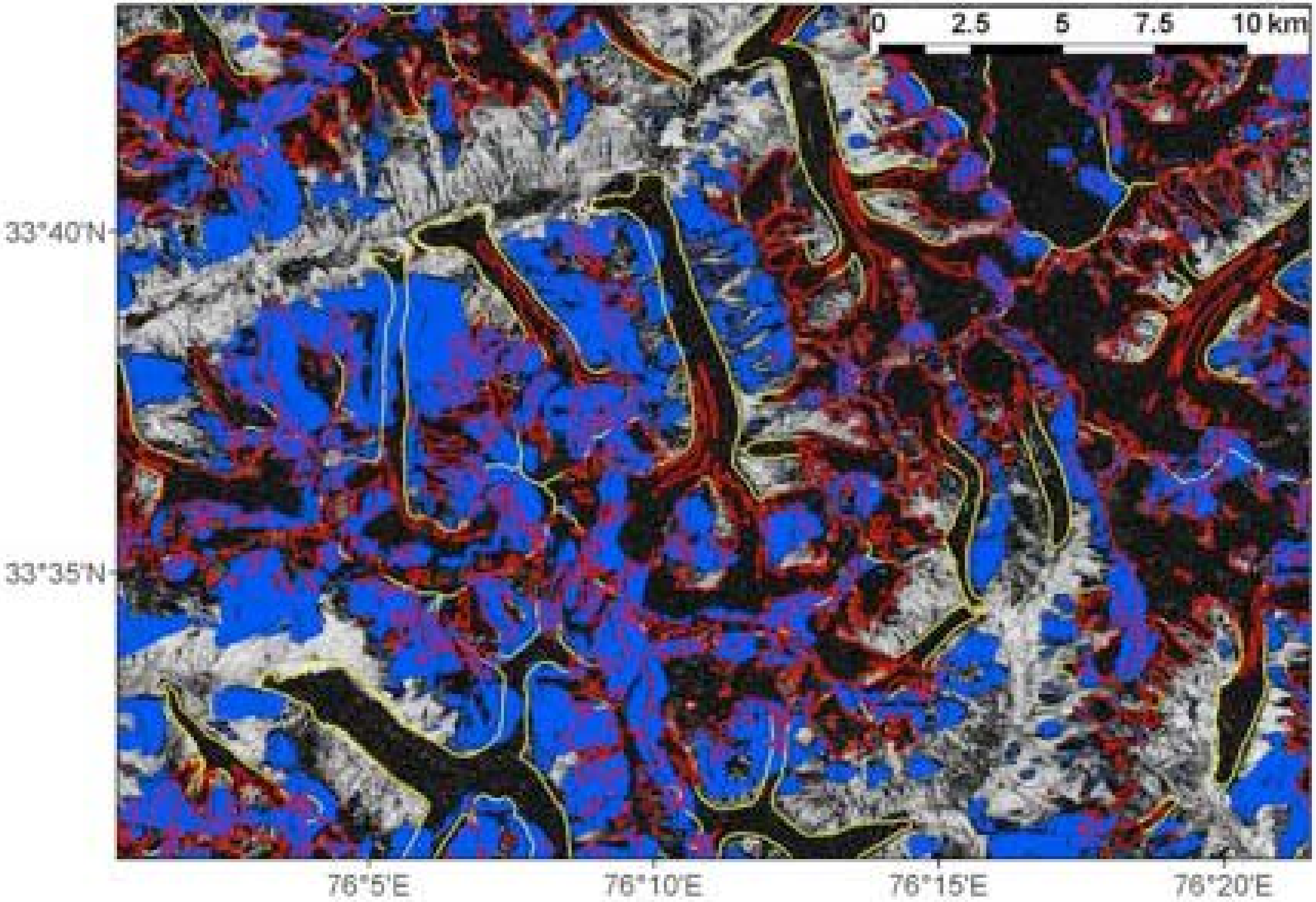

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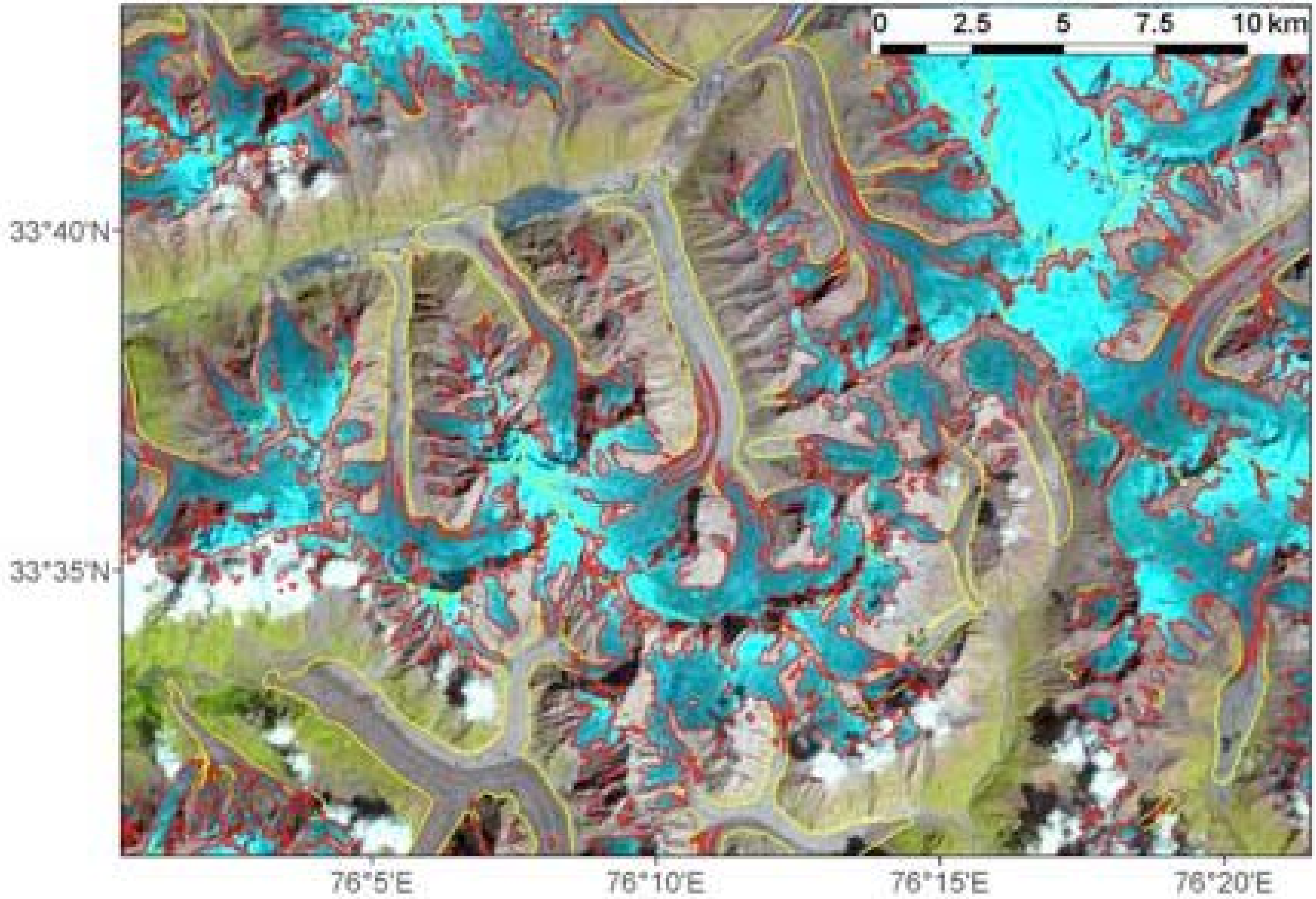
coherence images from ALOS PALSAR image pairs (46 d baseline)

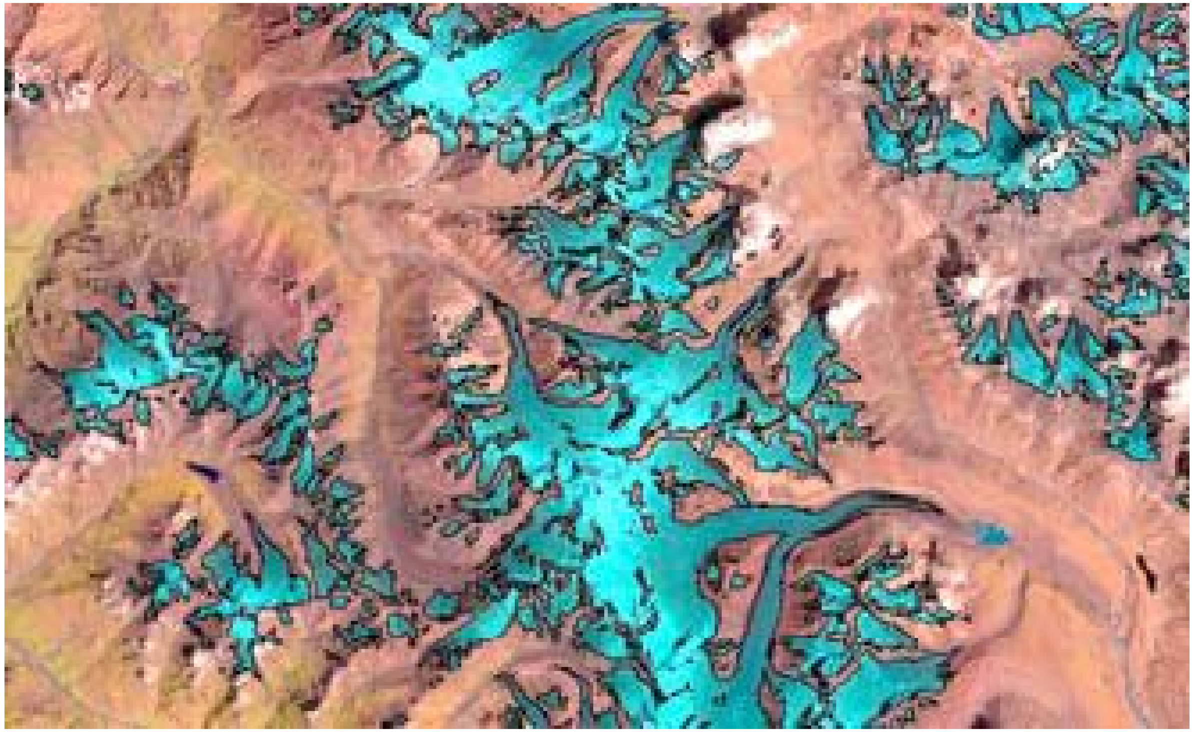


Compilation procedure for glacier inventories

Orthorectified Landsat imagery from USGS

Thresholded band ratio (TM3/TM5)

Manual correction of debris cover, water, snow, shadows



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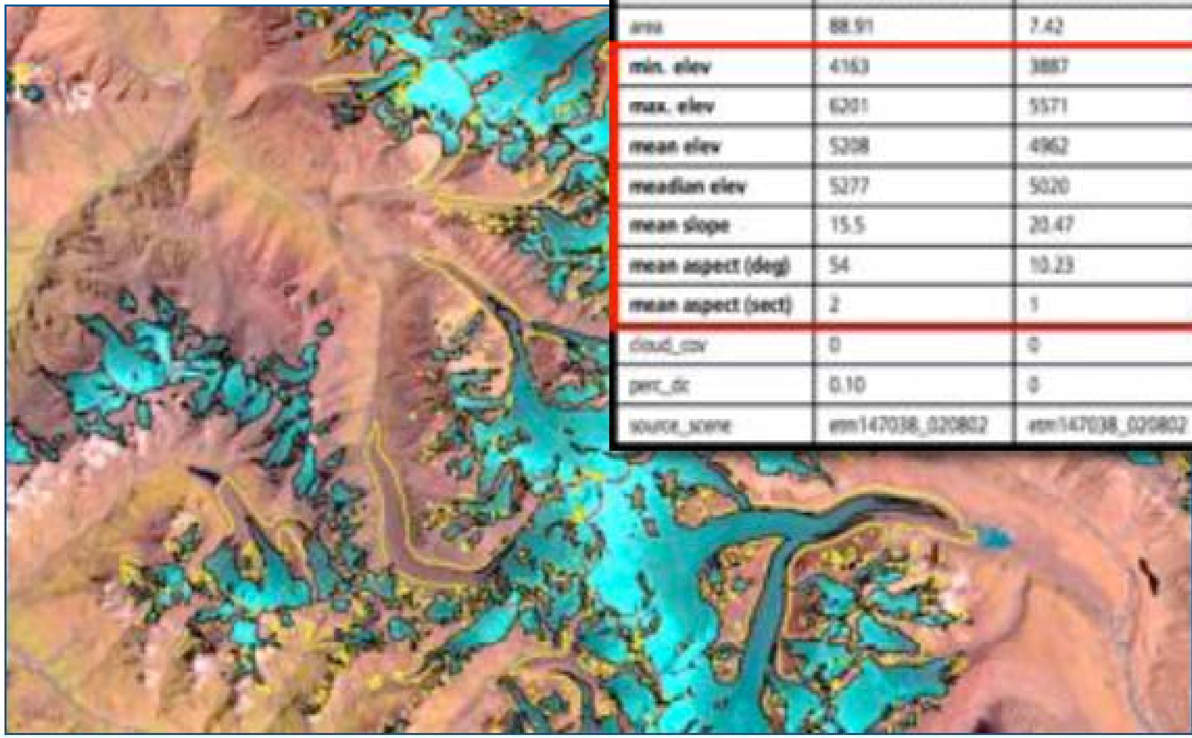

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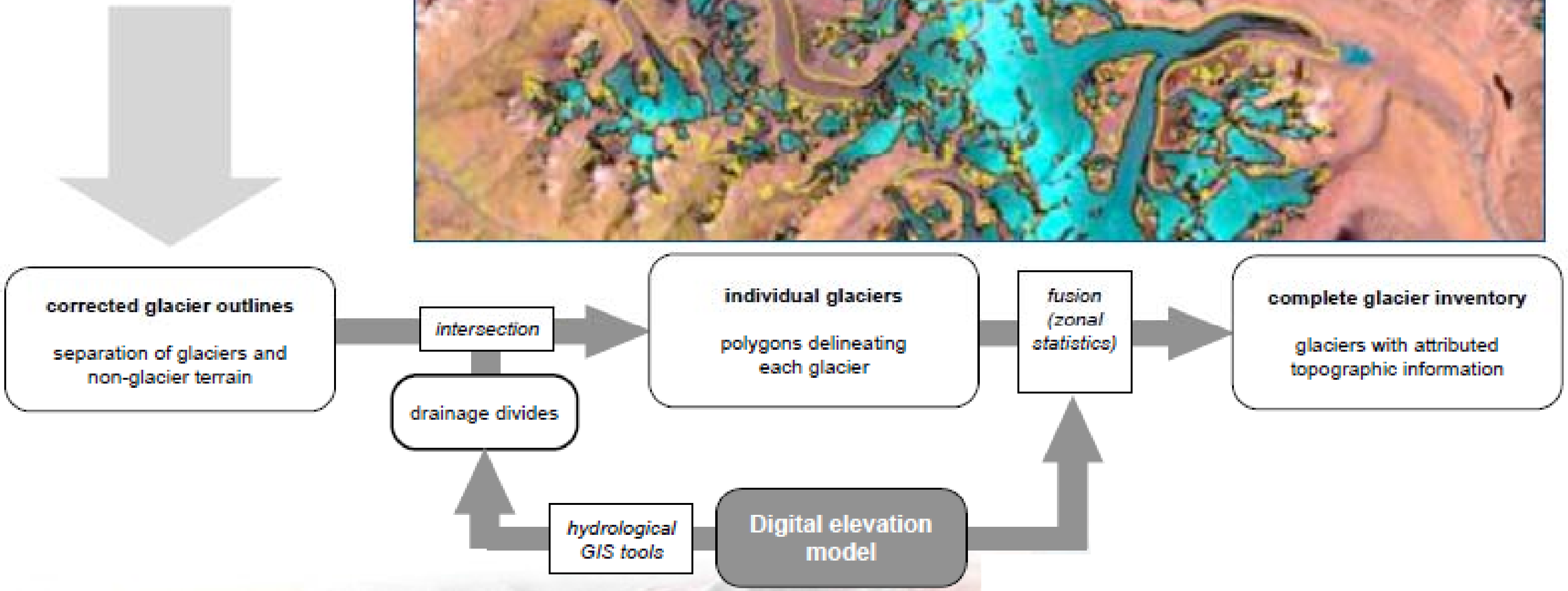
area	88.91	7.42
min. elev	4163	3887
max. elev	6201	5571
mean elev	5208	4962
median elev	5277	5020
mean slope	15.5	20.47
mean aspect (deg)	54	10.23
mean aspect (sect)	2	1
cloud_cov	0	0
perc_dc	0.10	0
source_scene	etm147038_020802	etm147038_020802



Choosing a digital elevation model (DEM)

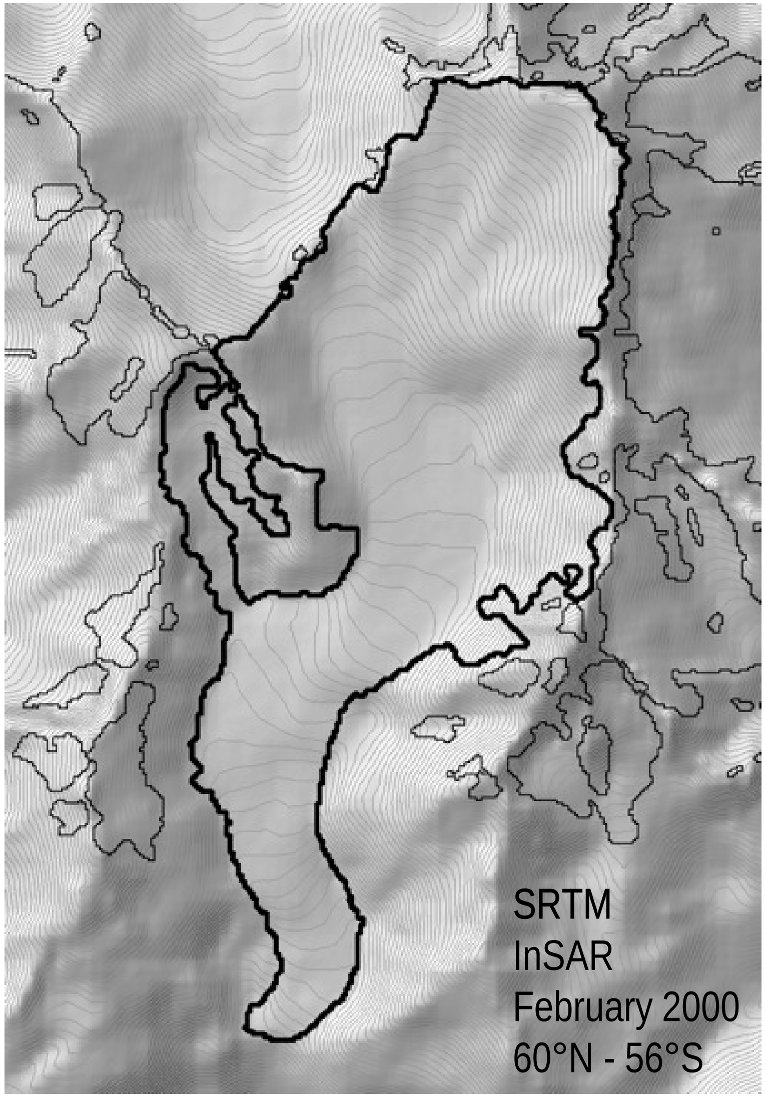
Purposes:

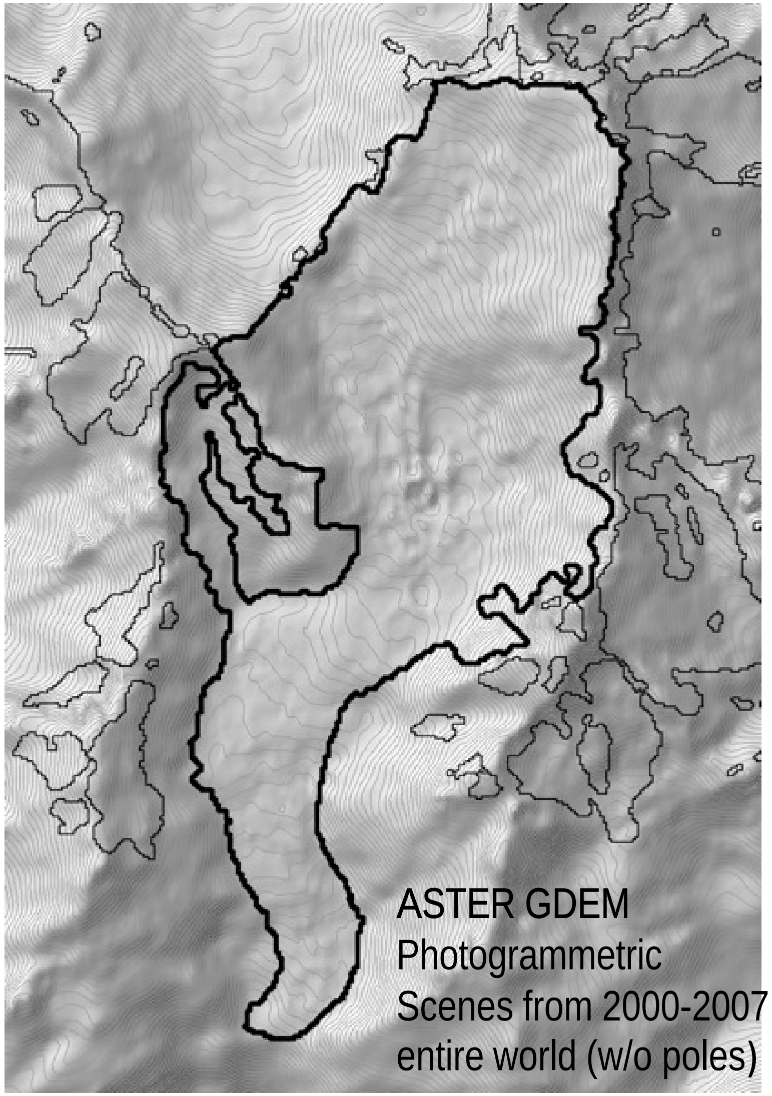
- Calculation of topographic glacier parameters
- Derivation of hydrological drainage divides (separation of individual glaciers)

In India

- No national DEM publicly available
- SRTM DEM and ASTER GDEM (near-global coverage) provide a valuable alternative

Choosing a digital elevation model (DEM)

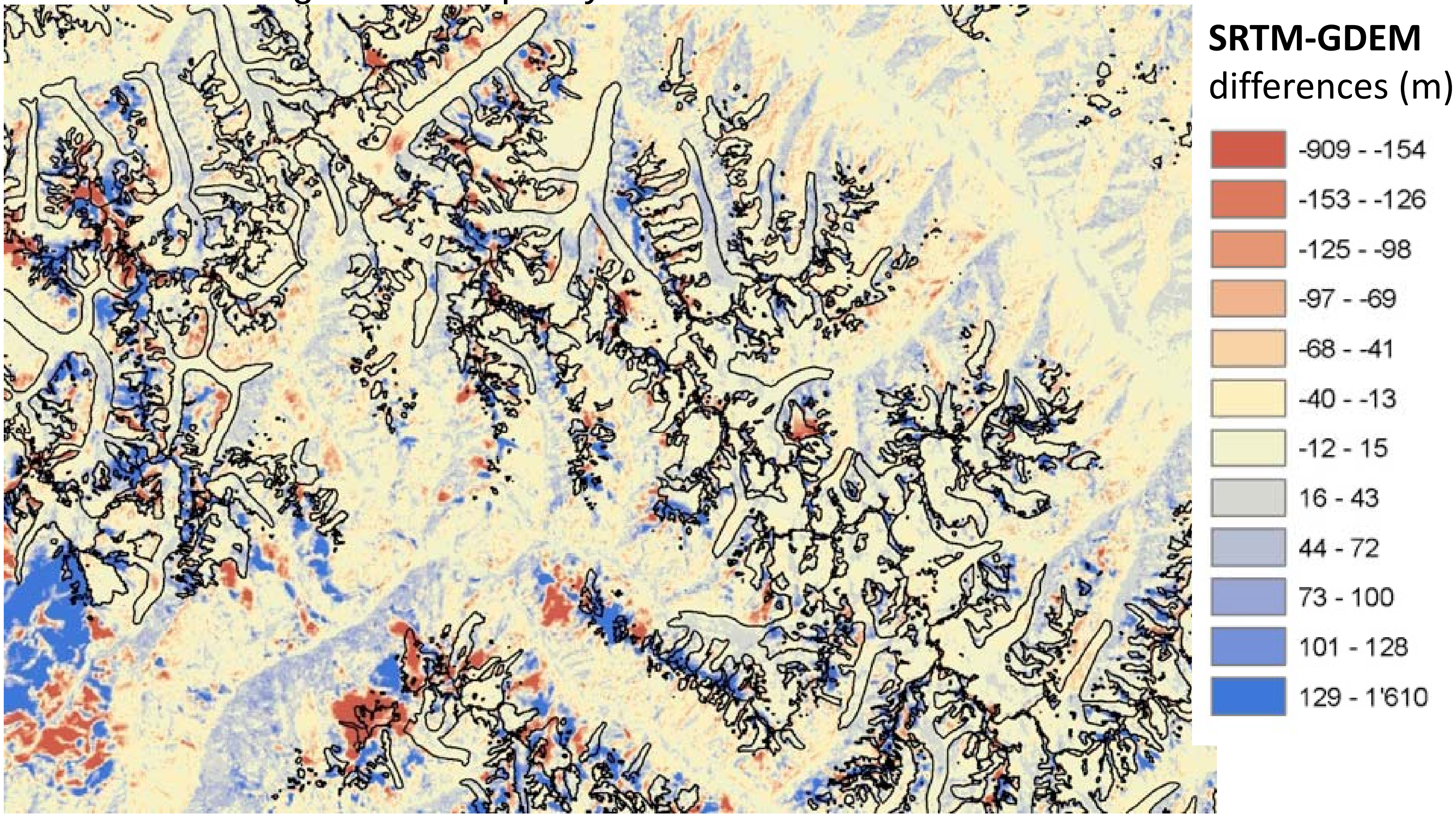




Choosing a digital elevation model (DEM)

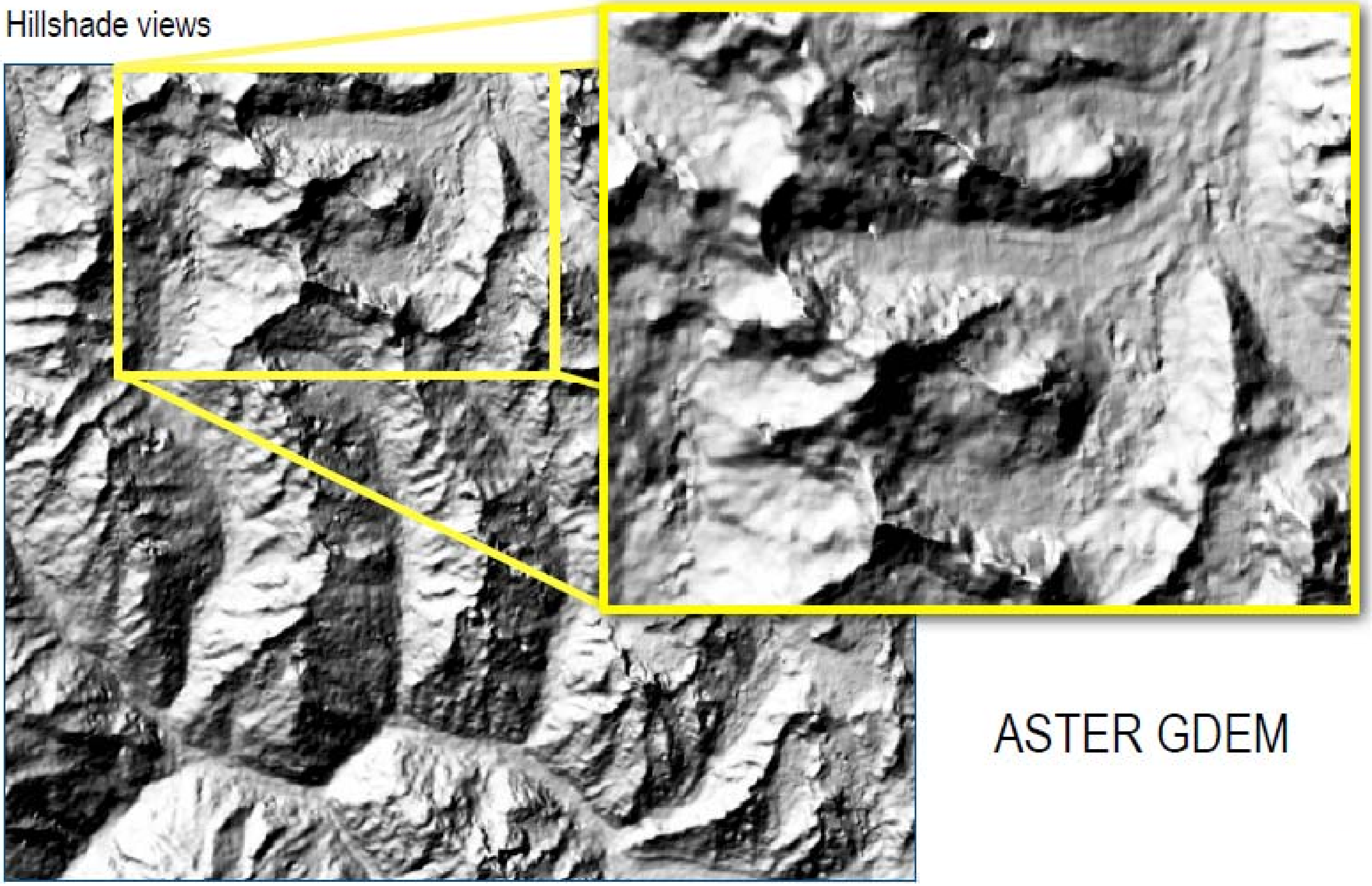
Required to obtain topographic parameters and to delineate drainage divides

DEM differencing as a first quality assessment



Choosing a DEM for the Himalaya inventory

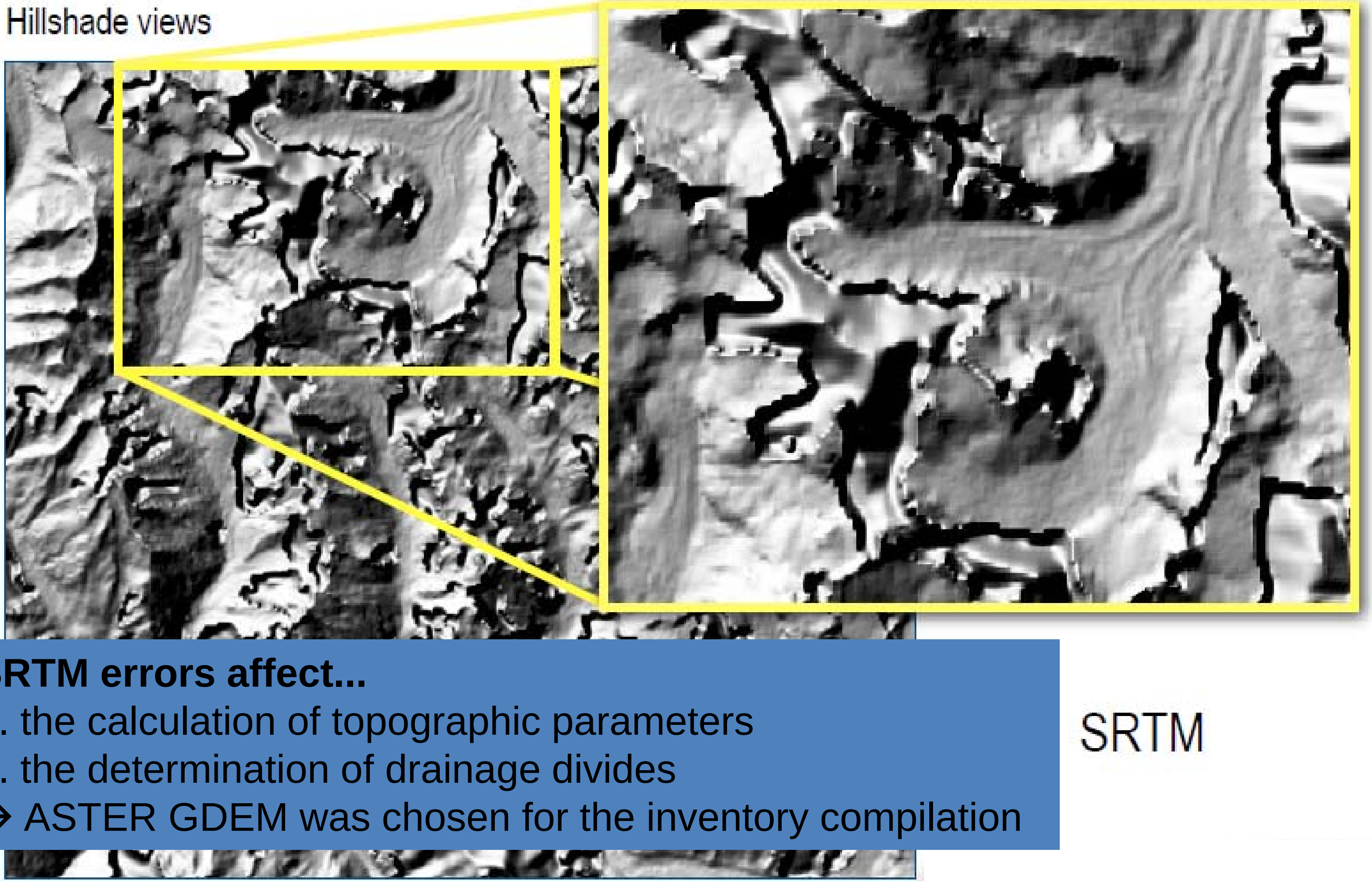
Hillshade views



ASTER GDEM

Choosing a DEM for the Himalaya inventory

Hillshade views

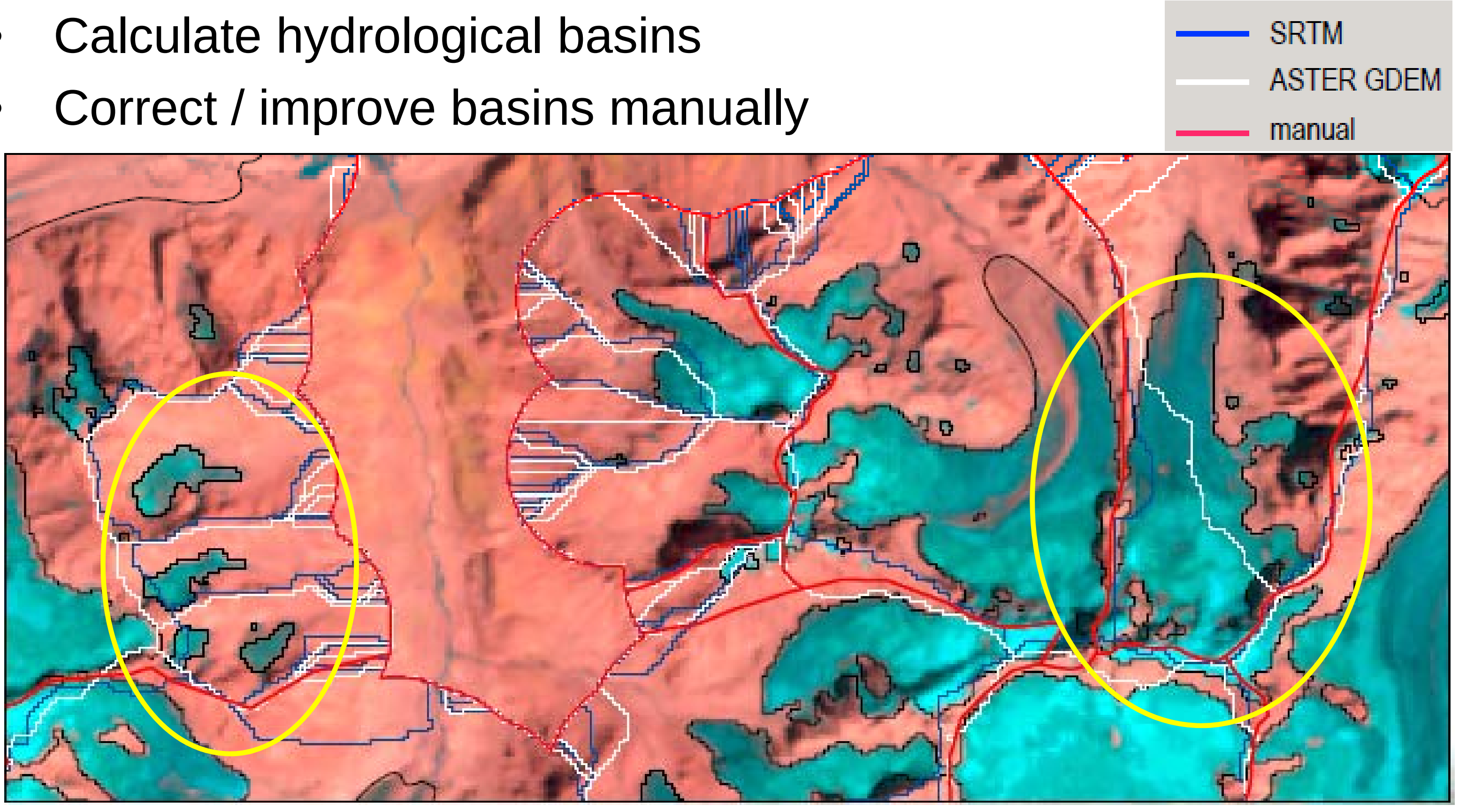


SRTM errors affect...
... the calculation of topographic parameters
... the determination of drainage divides
→ ASTER GDEM was chosen for the inventory compilation

SRTM

Drainage divides

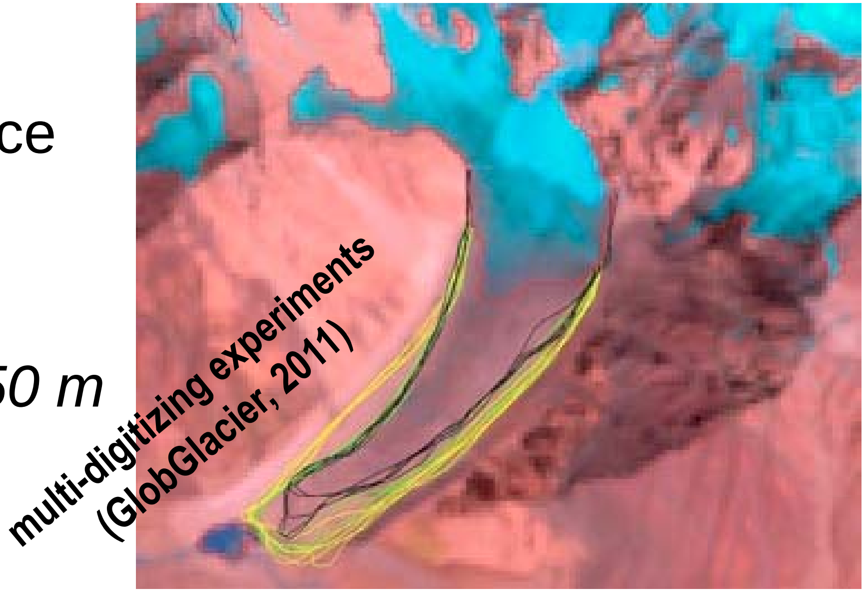
- Method from Bolch et al. (2010)
- Buffer around glacier outlines
- Clip DEM with this buffer
- Calculate hydrological basins
- Correct / improve basins manually



Sources of uncertainties

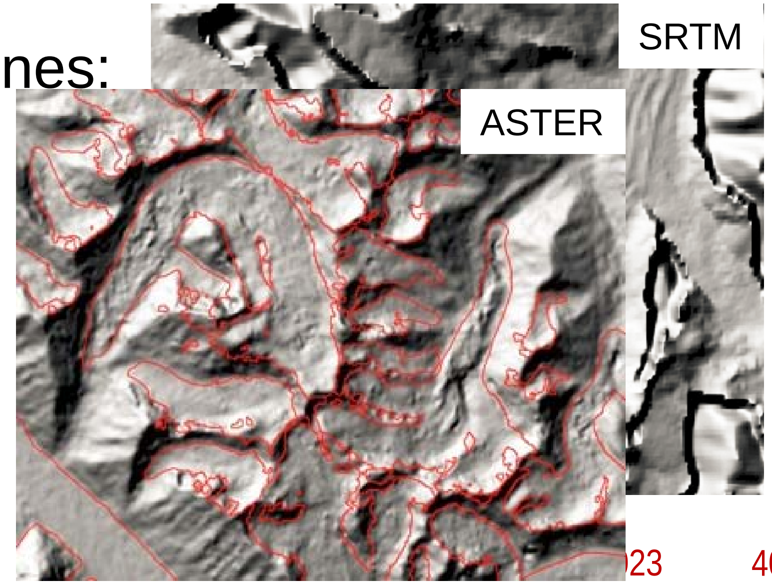
Glacier mapping

- Automated mapping of clean-ice parts: ±*5%*
- Manual corrections of glacier outlines:
- *margins: ±60 m, terminus: ±150 m*



DEM inaccuracies

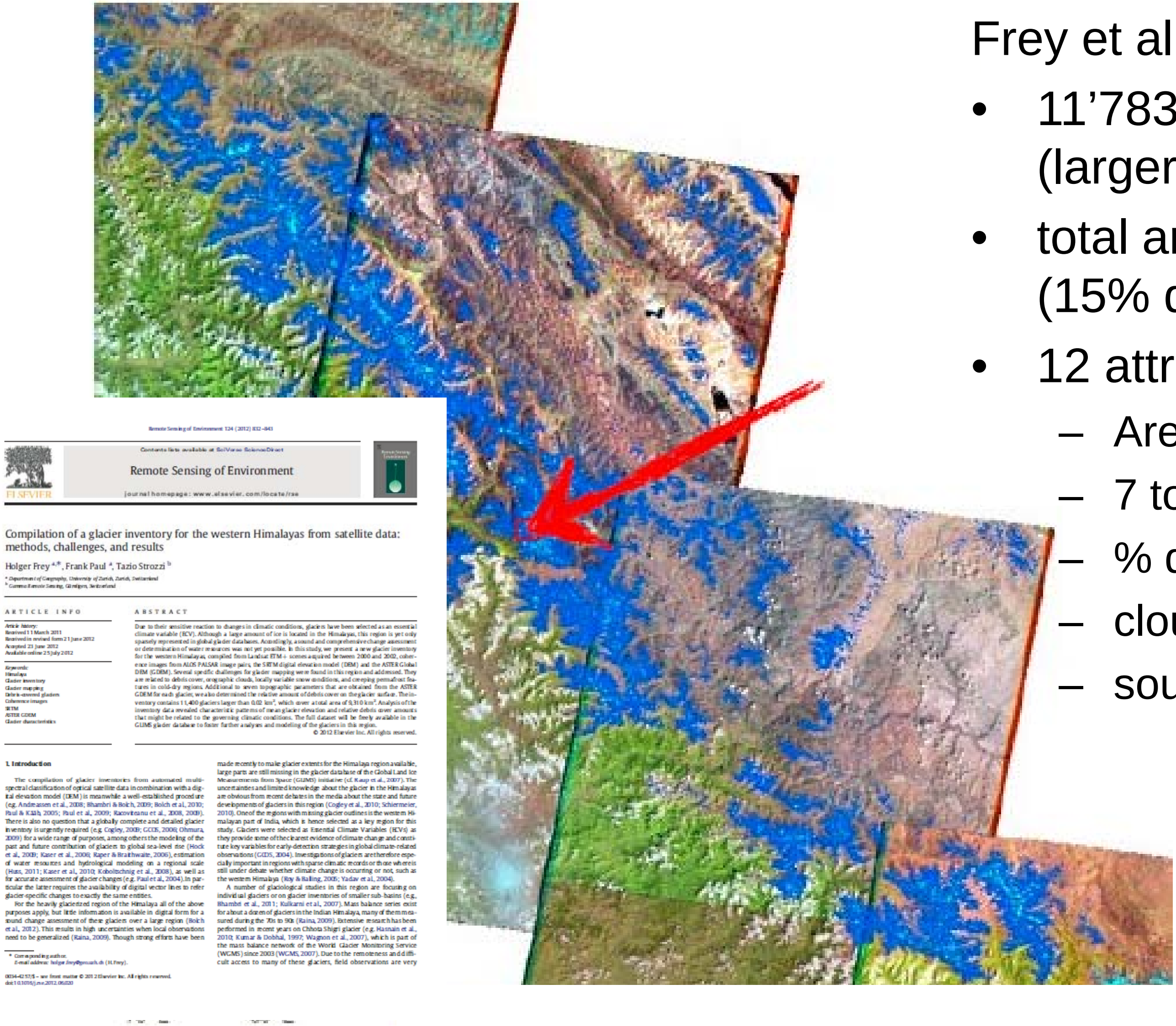
- Orthorectification of satellite scenes:
- Calculation of topographic parameters:
  - *min-/max elevation: ±45 m*
  - *mean elevation: ±30 m*
  - *mean slope: ±5°*



Important points of this lecture

- Multispectral optical imagery allow semi-automated glacier mapping
- Major mapping challenges are related to debris-cover, clouds, snow, shadows, permafrost features, ...
- A DEM of sufficient quality is required to separate individual glaciers and to derive topographic glacier parameters
- Analyzing topographic parameters allows assessing glacier characteristics

The glacier inventory for the W Himalayas



Frey et al. 2012:

- 11’783 glaciers (larger than 0.02 km^2)
- total area of 9’372 km^2 (15% debris-covered)
- 12 attributes for each glacier
  - Area
  - 7 topographic parameters
  - % debris cover
  - cloud-cover flag
  - source scene ID

Exercise: glacier mapping

- Map the outlines and central flowlines of 4 glaciers
- Derive topographic parameter for the mapped glacier
- Answer questions about glacier mapping

→ http://www.geo.uzh.ch/~alinsbau/ihacp/level2/ex1_glacier_mapping