



Glacier area – remote sensing of glaciers

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

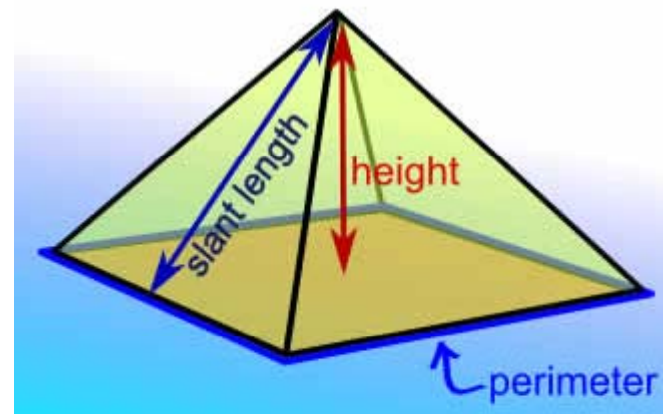
Galcier ice volume estimates

Use of glacier volumes

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

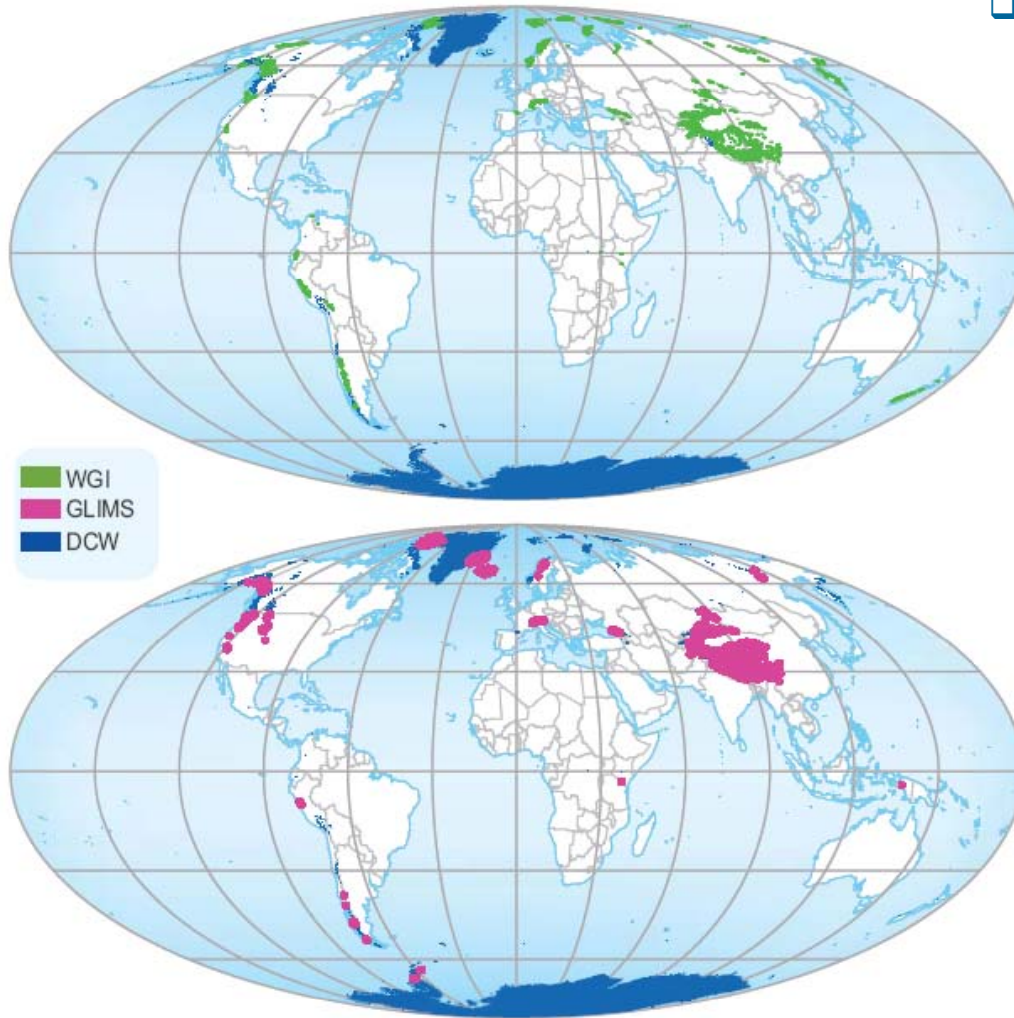
How to calculate them?

- $V = A \times d$



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

GTN-G observing strategy: WGI & GLIMS



- ❑ 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

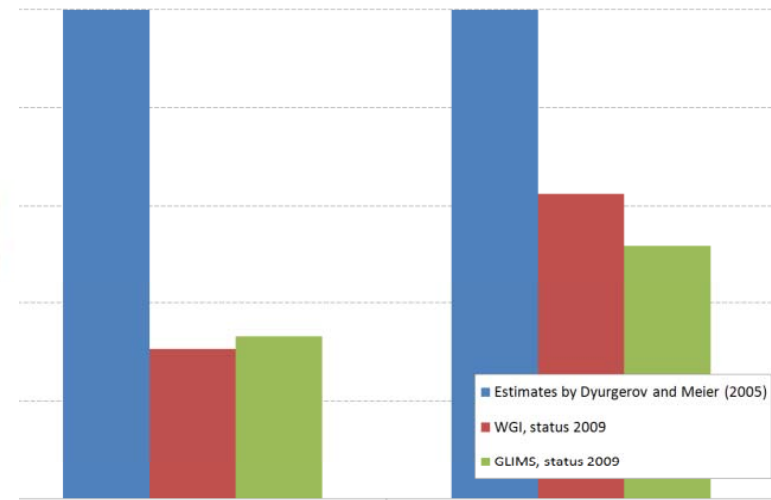


Fig. 3.6 Global glacier inventories

Glacier area – remote sensing and mapping

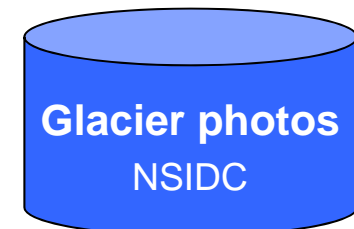
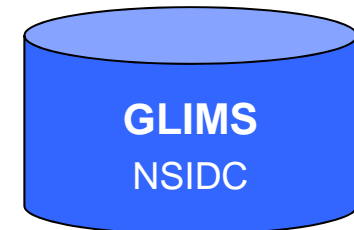
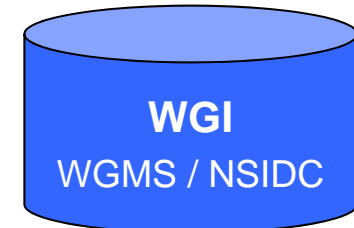
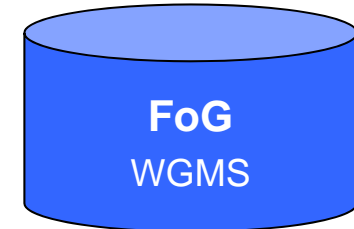
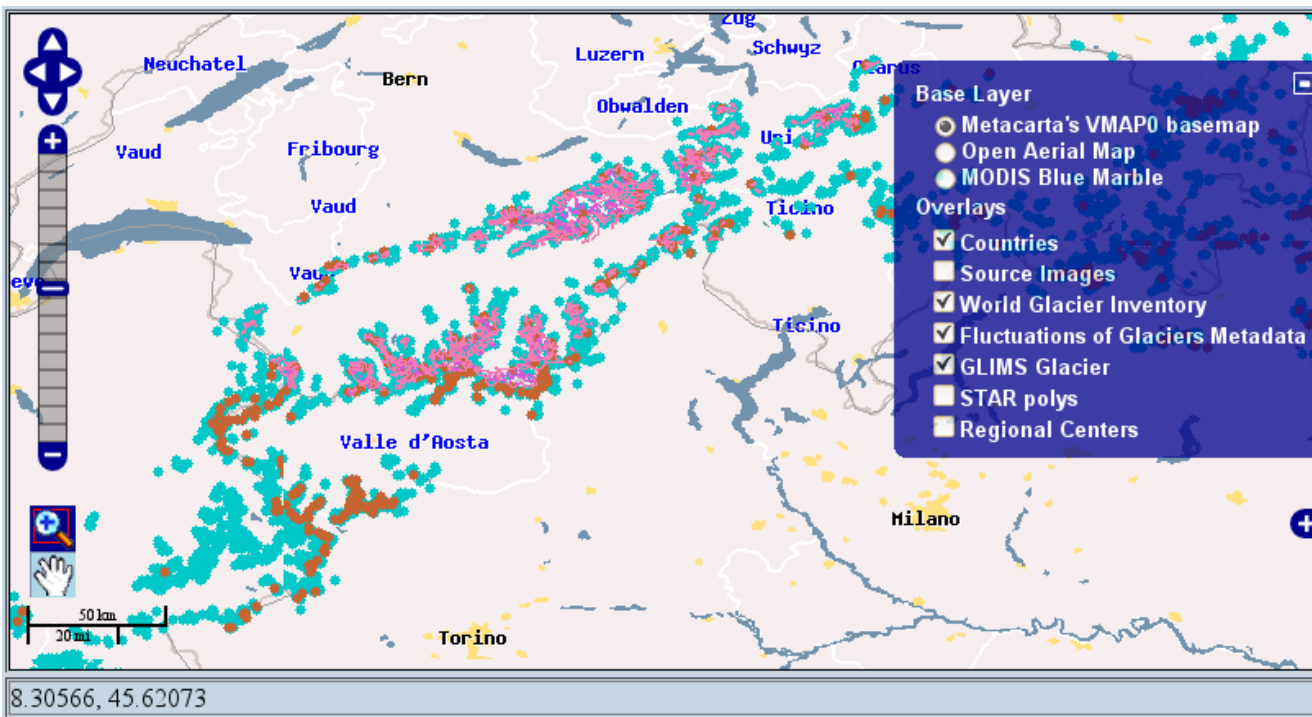
WGMS (2008)

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



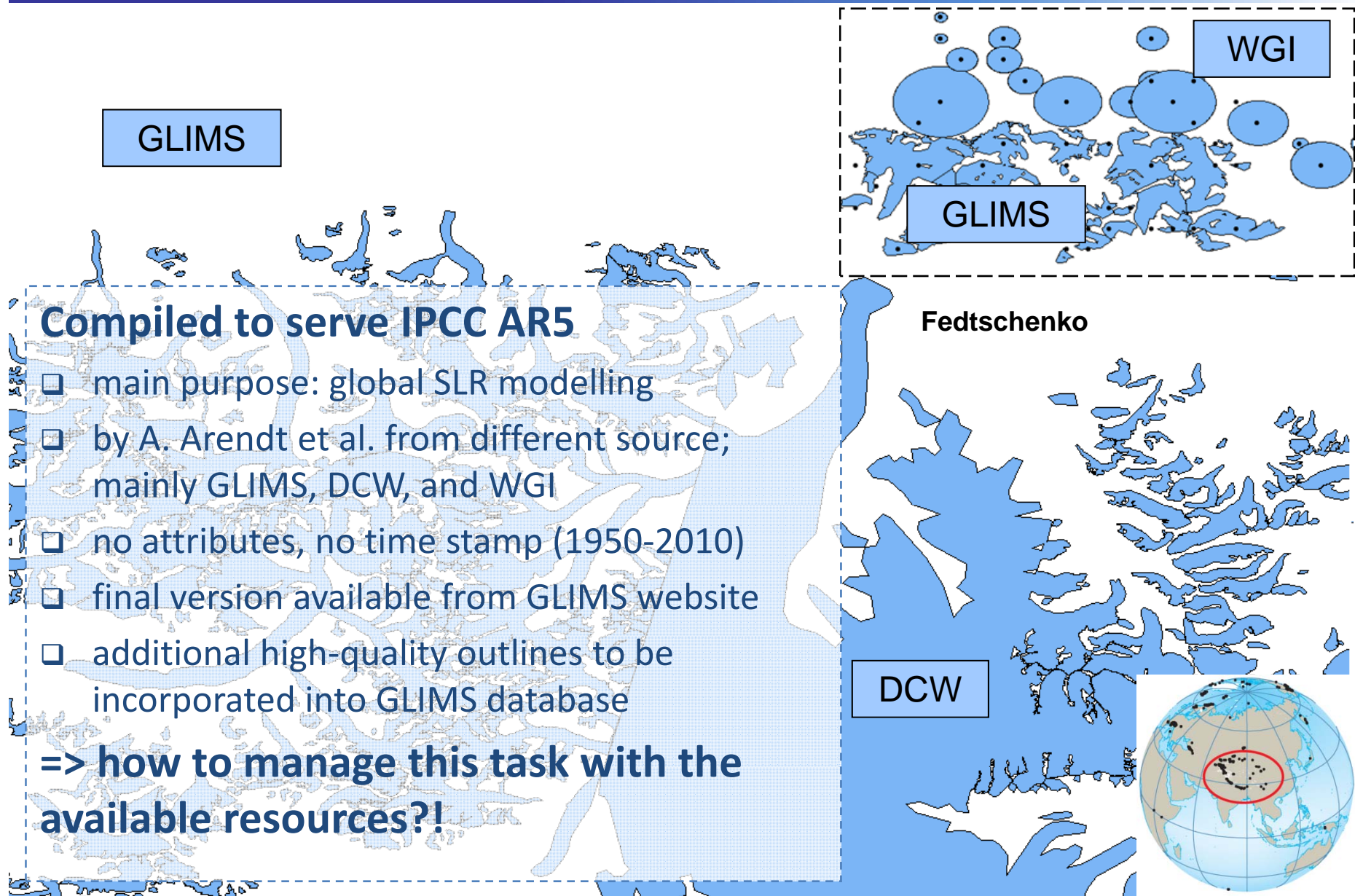
data exploration



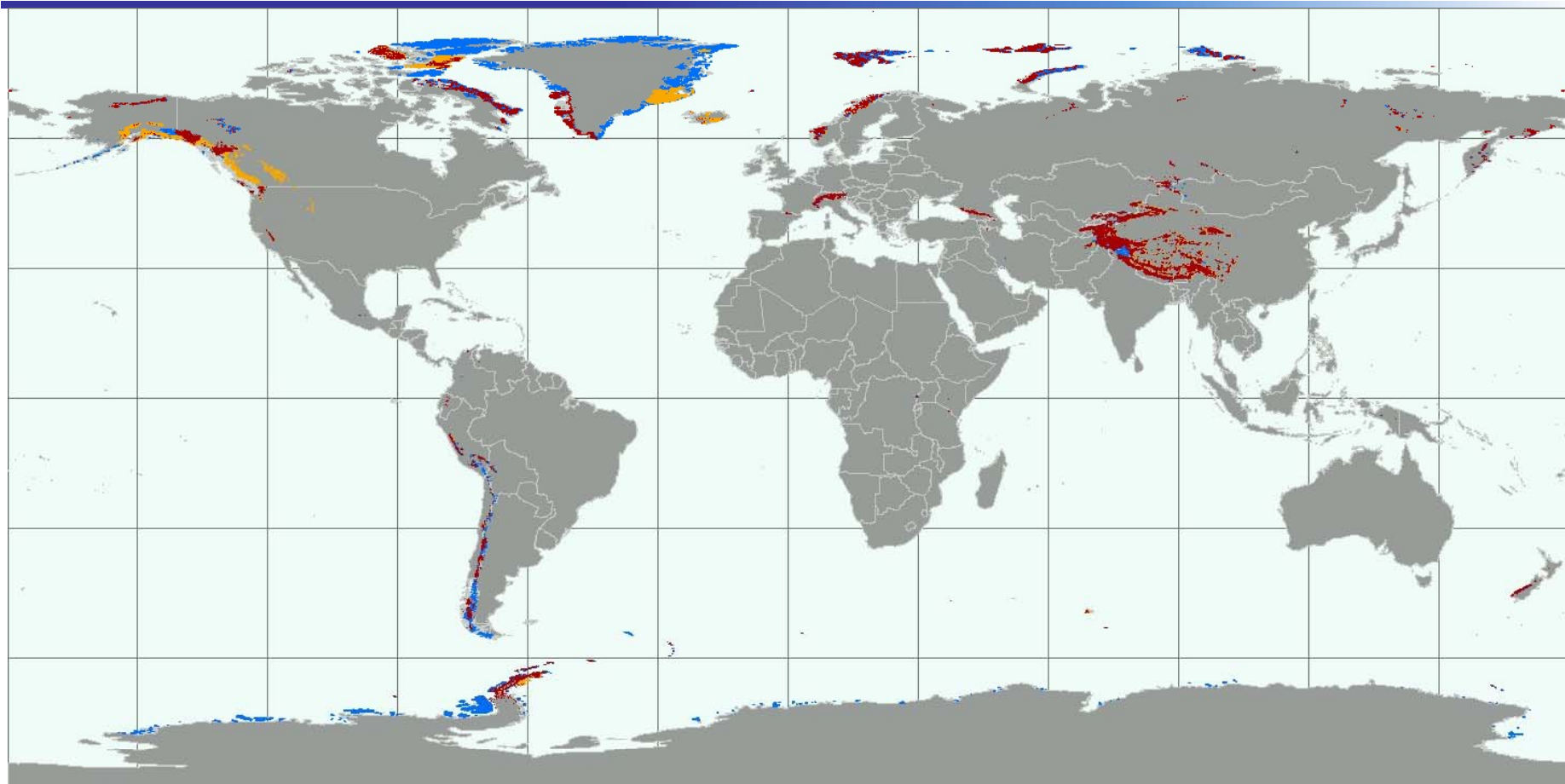
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Randolph (Global Glacier Map)



World Glacier Inventory



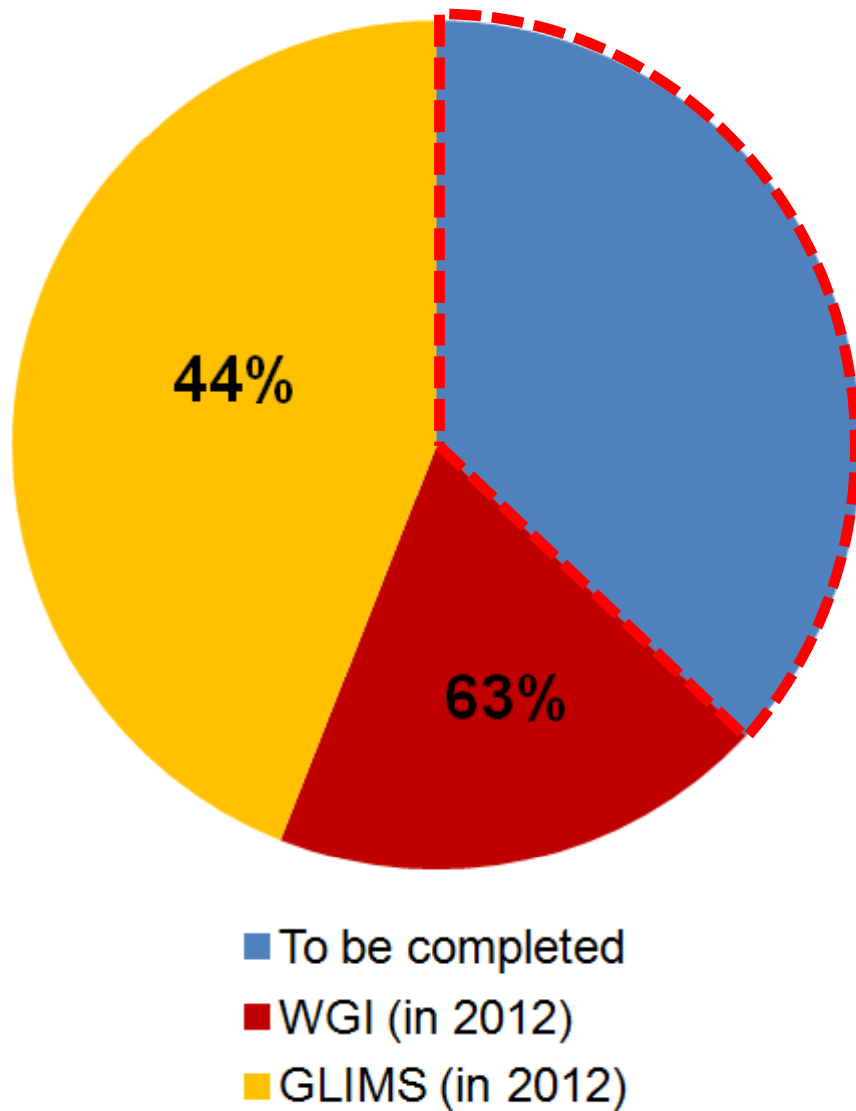
- **World Glacier Inventory:** mainly aerial photographs and maps around 1970s
- **GLIMS Inventory:** mainly satellite images after 2000
- **Randolph Glacier Map:** rough glacier outlines, rough time stamp, no attributes

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After 50 years: still no complete glacier inventory!

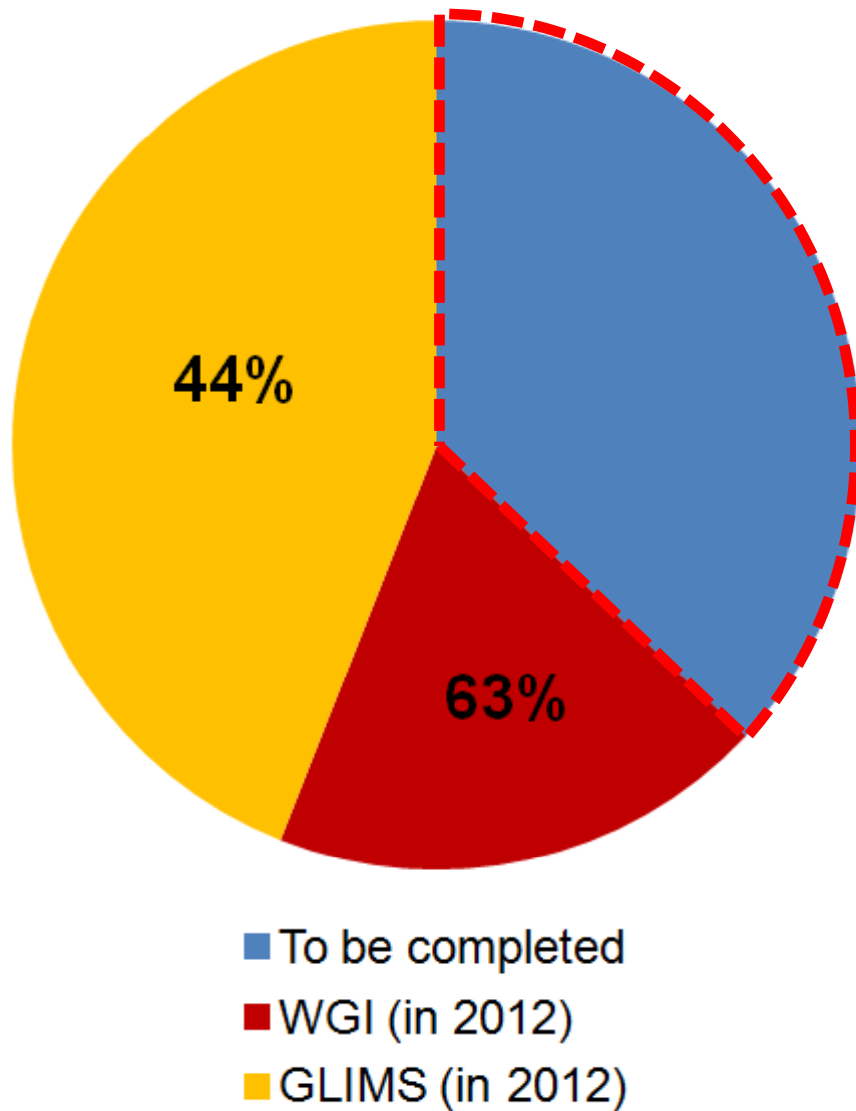


Glacier area – remote sensing and mapping

Why?

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After 50 years: still no complete glacier inventory!



Glacier area – remote sensing and mapping

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

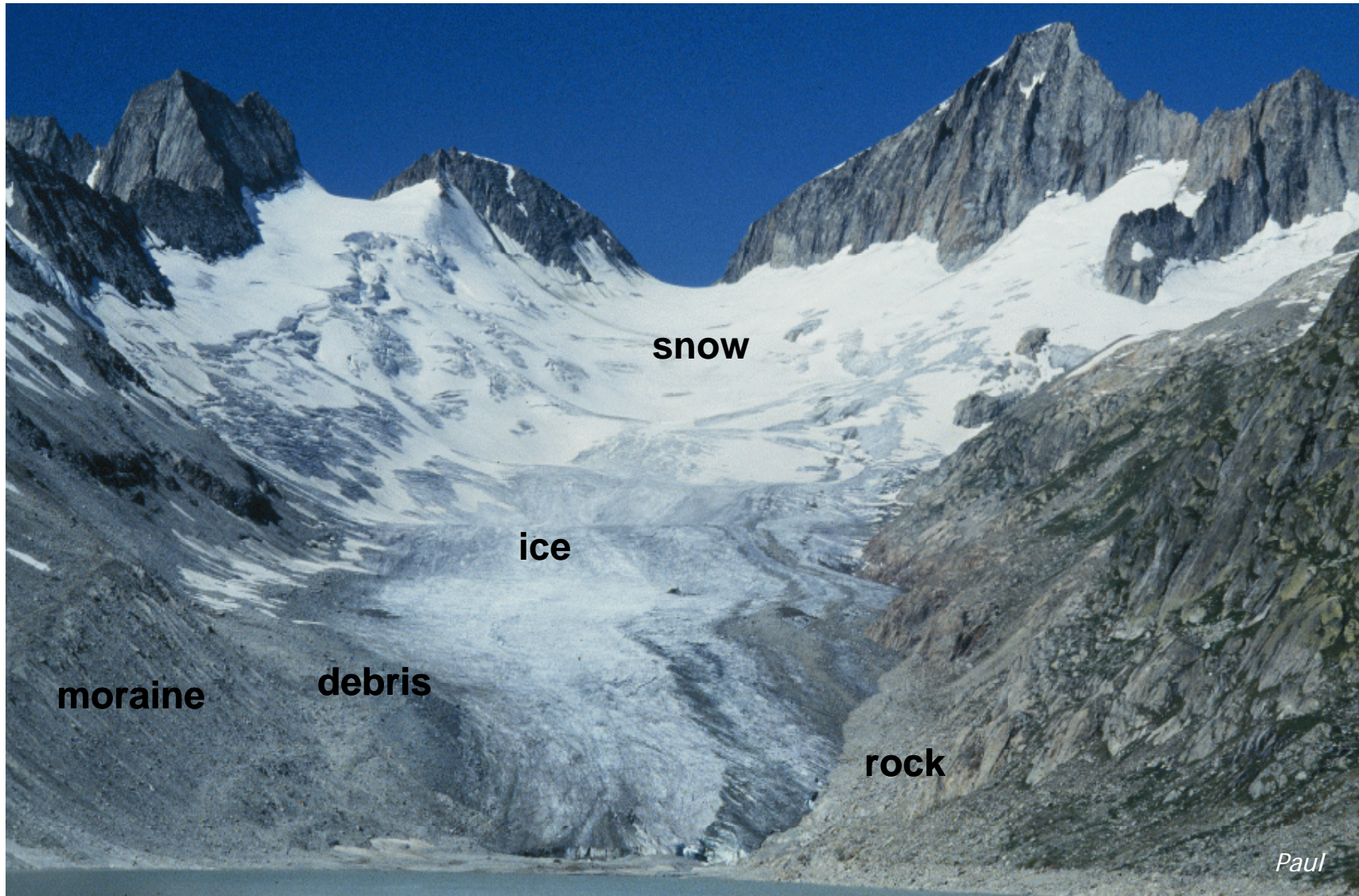
Glacier mapping challenges:

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

Further challenges:

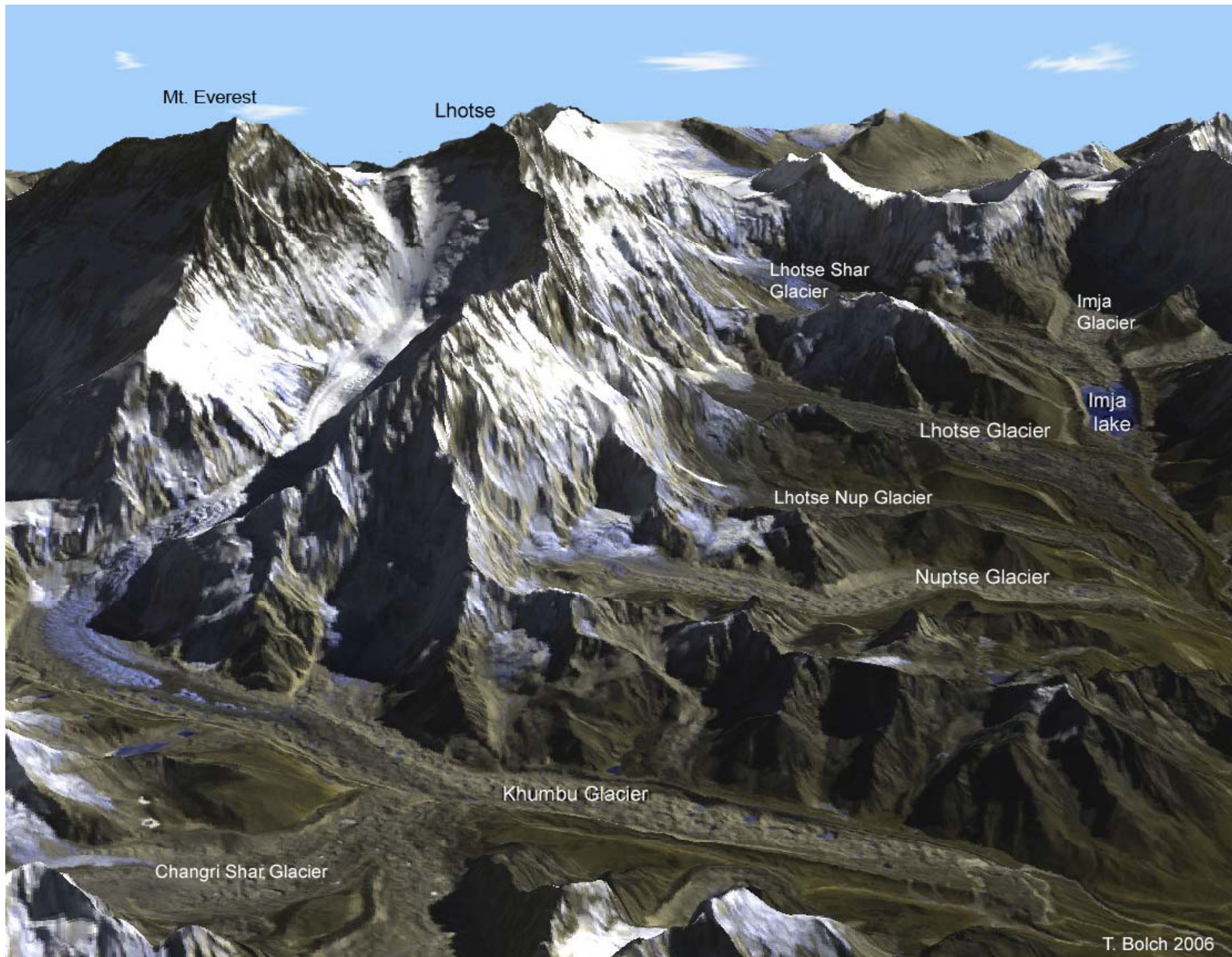
- Adverse snow conditions
- Permafrost interactions
- Frozen lakes / sea ice
- Georeferencing of satellite imagery and DEMs

A typical small valley glacier in reality

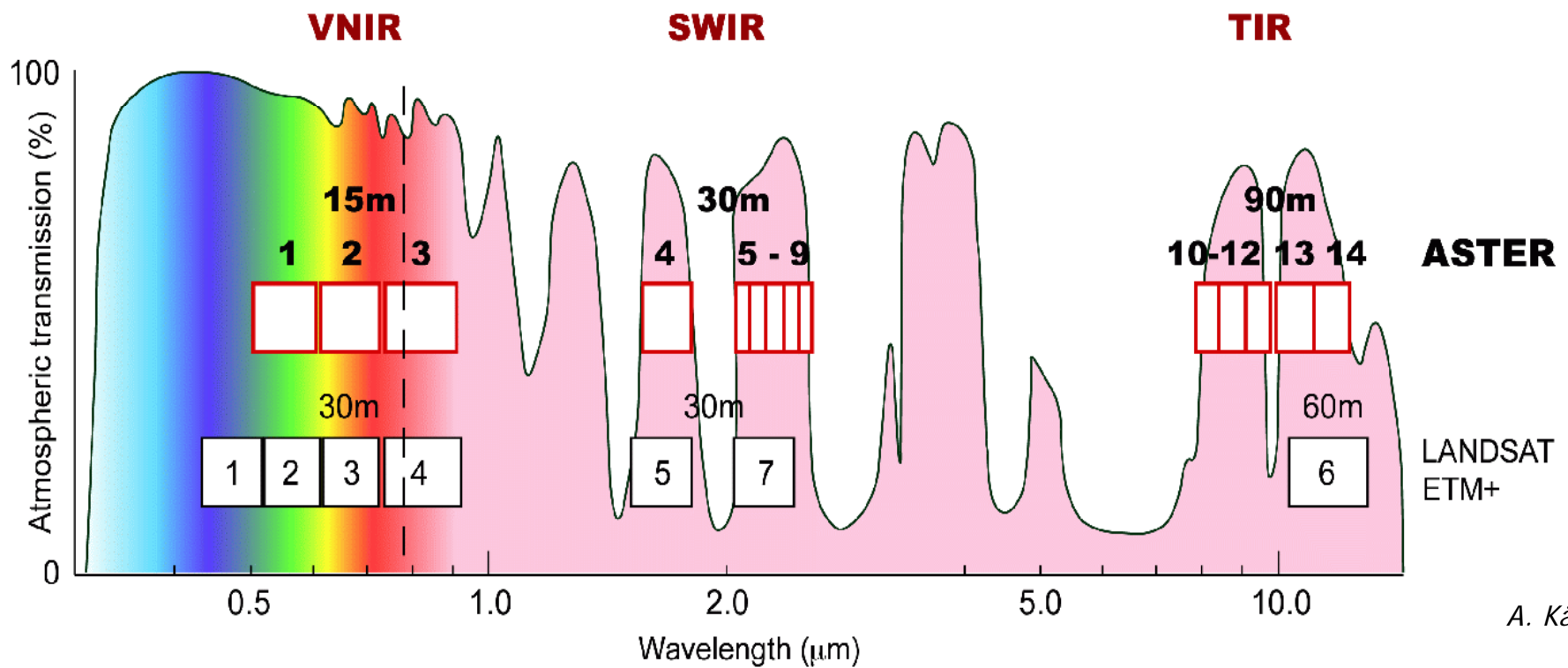


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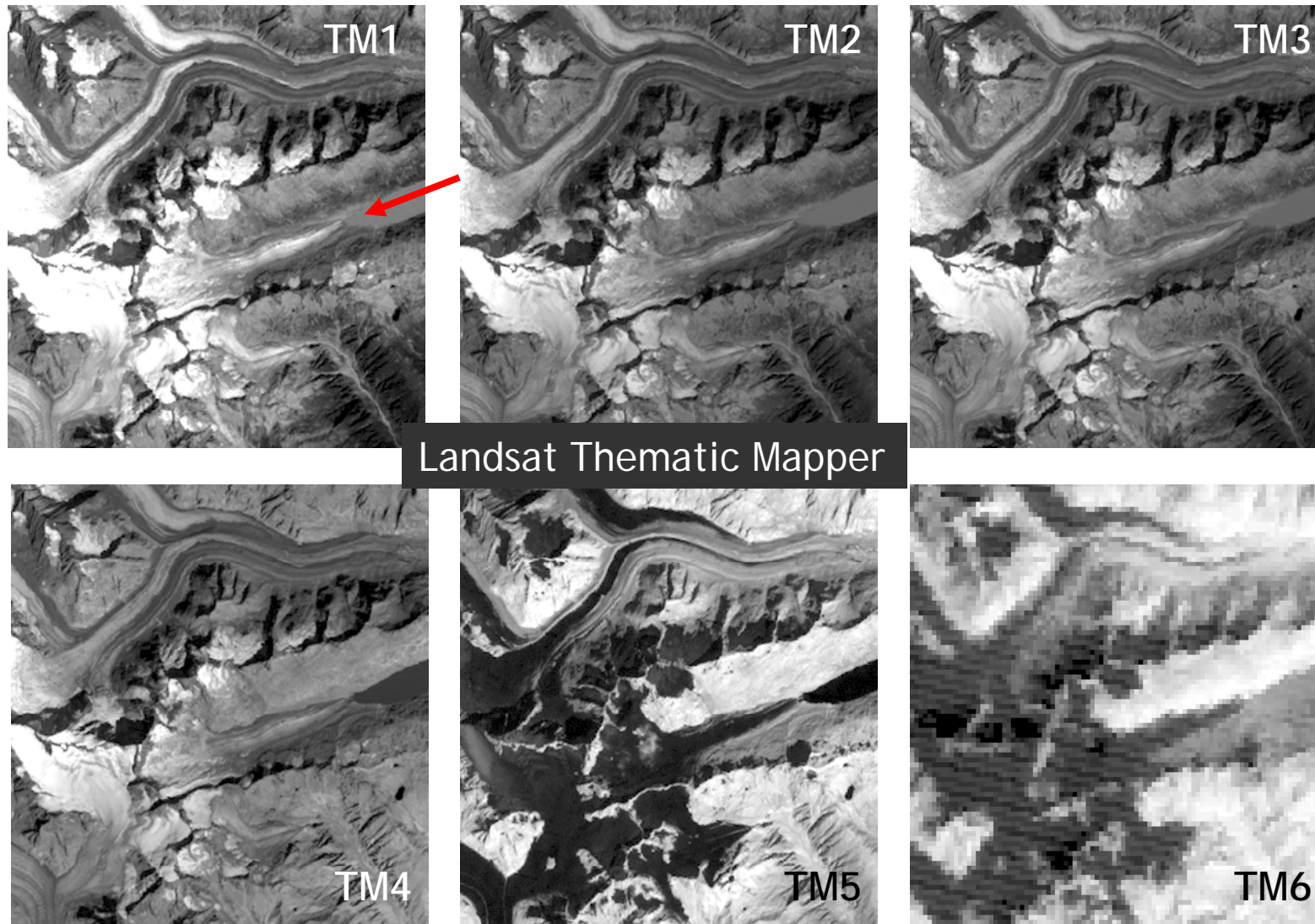


Satellite bands and atmospheric transmission



A. Käab

Satellite bands and spectral reflectance

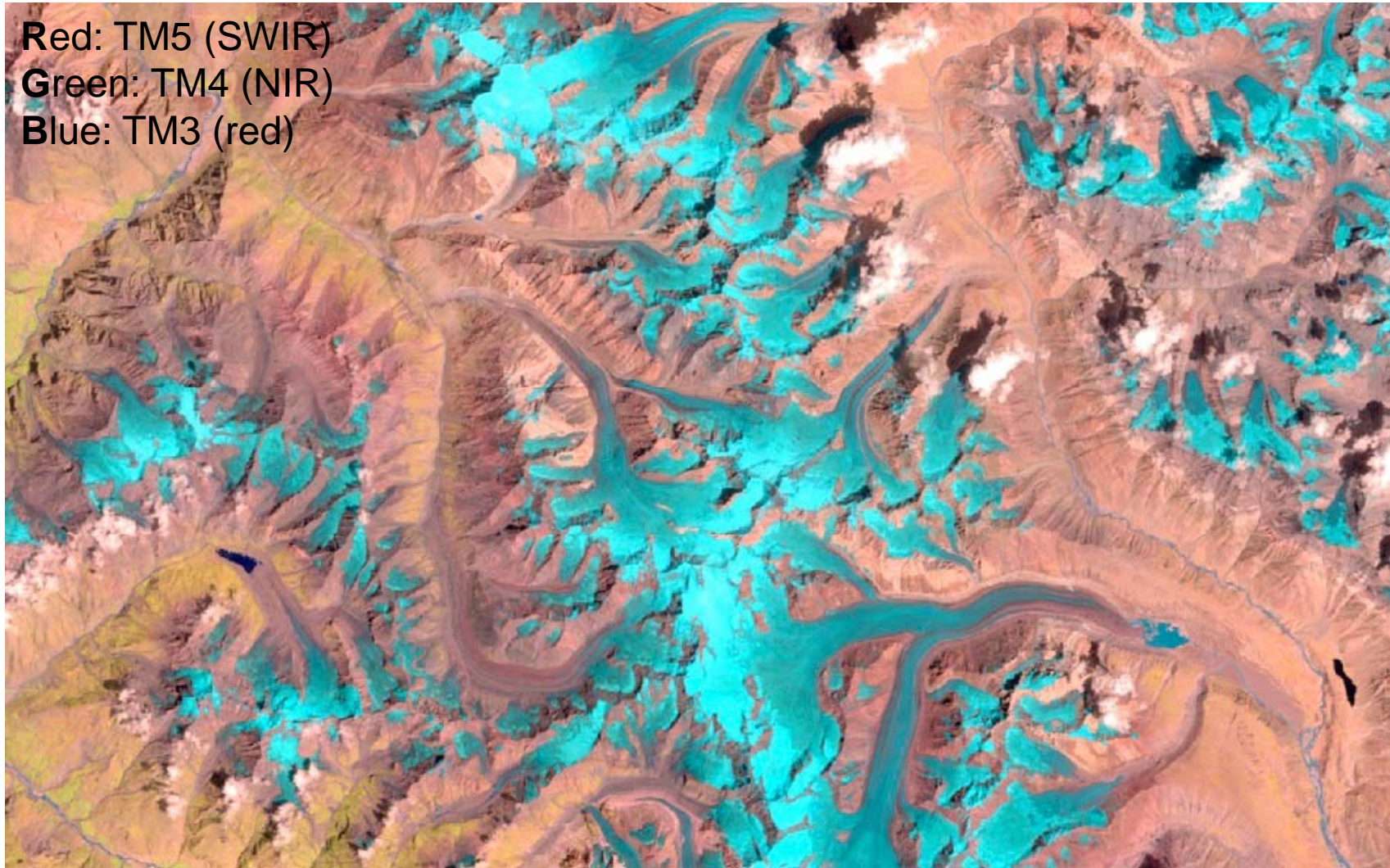


True-color composites



False-color composites

Red: TM5 (SWIR)
Green: TM4 (NIR)
Blue: TM3 (red)



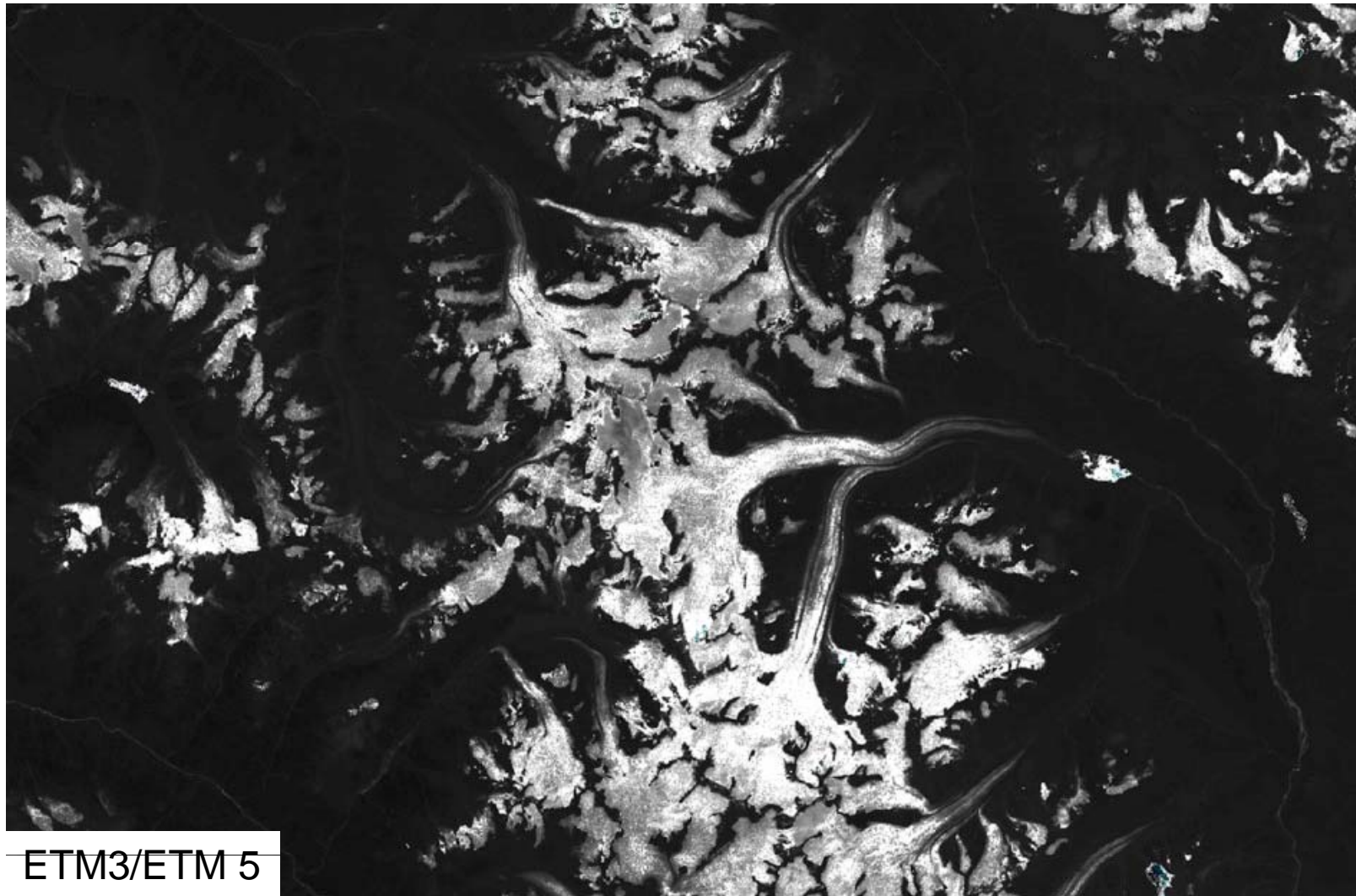
Glacier mapping with band ratio



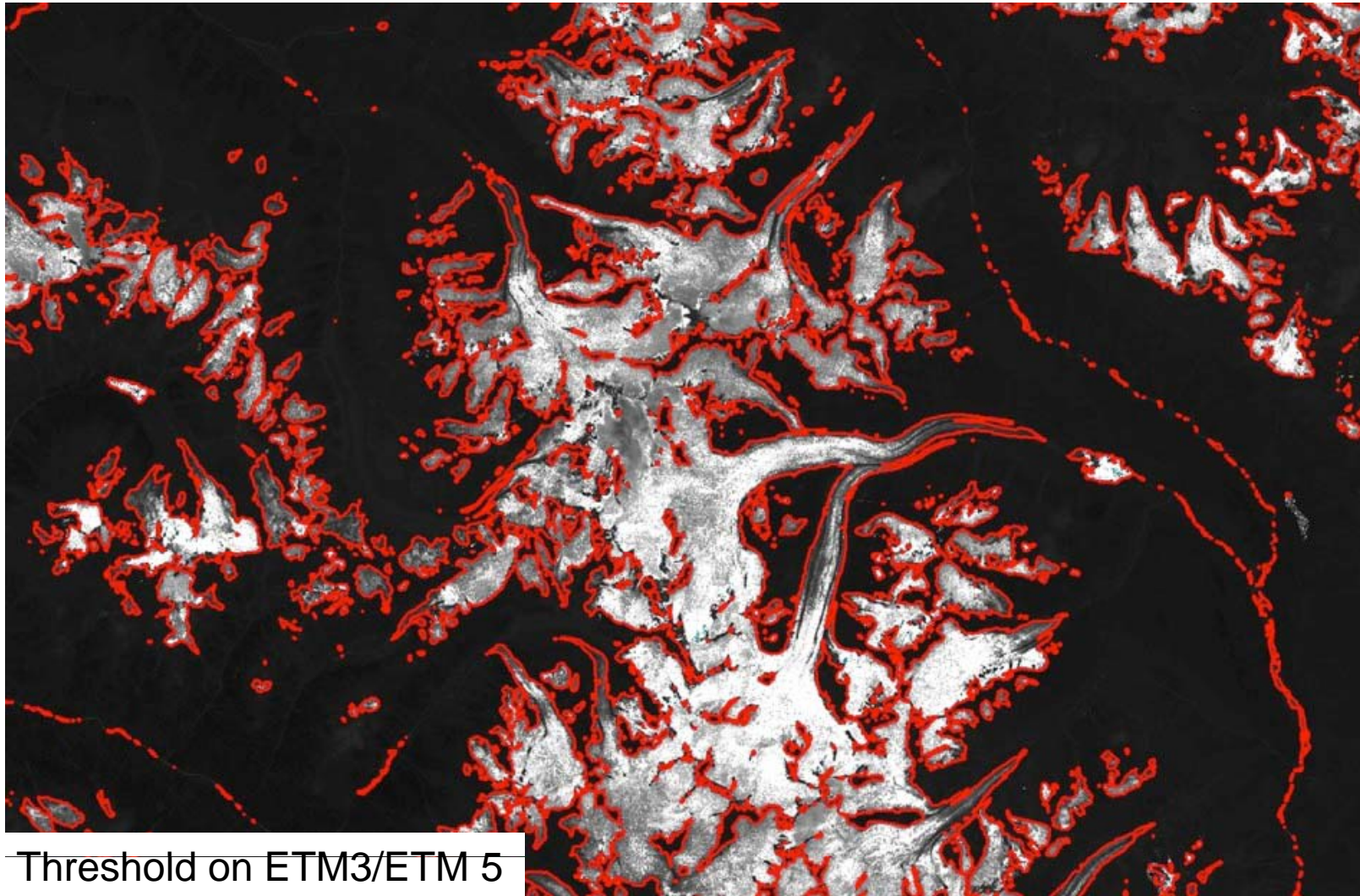
Glacier mapping with band ratio



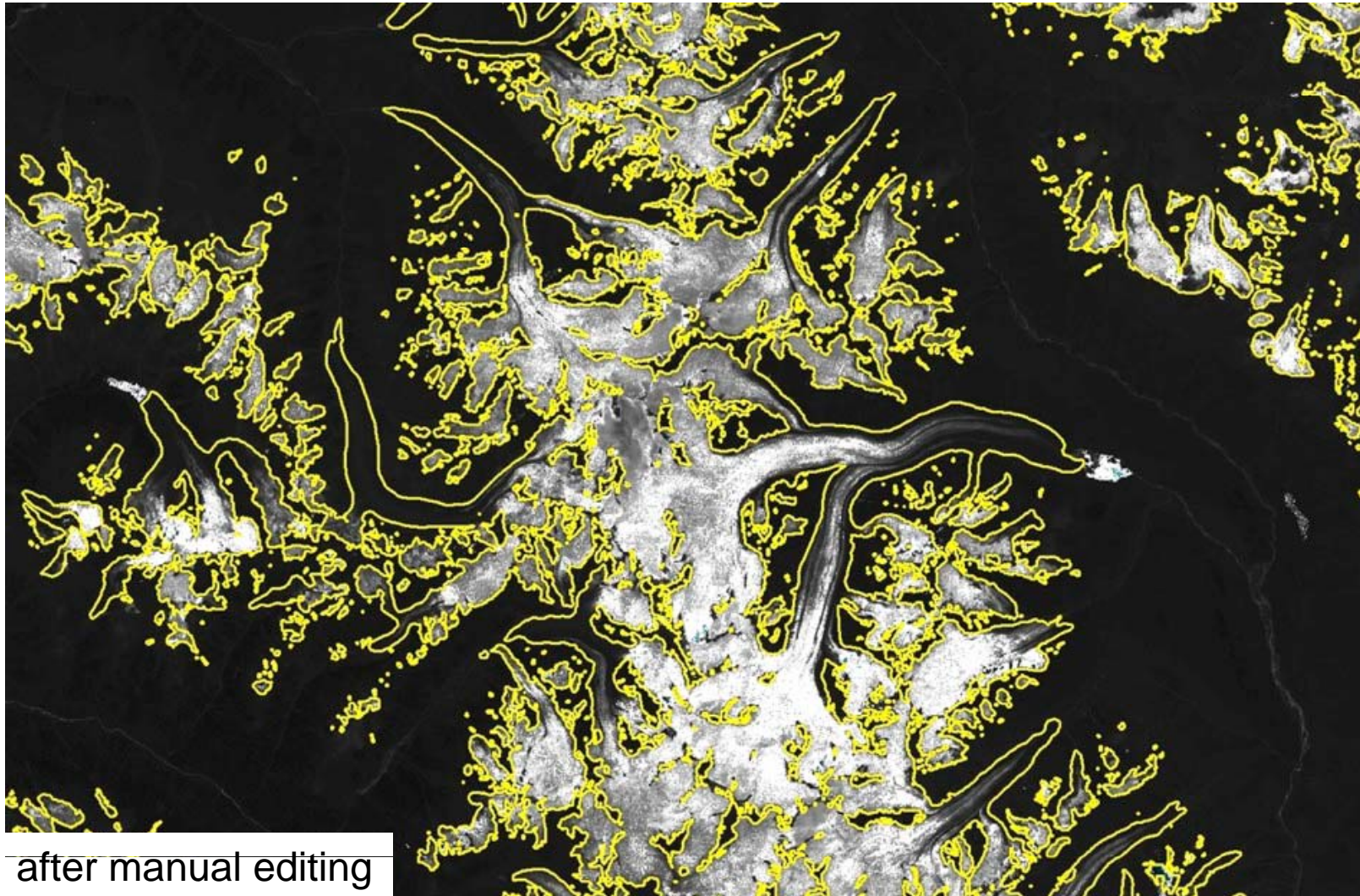
Glacier mapping with band ratio



Glacier mapping with band ratio



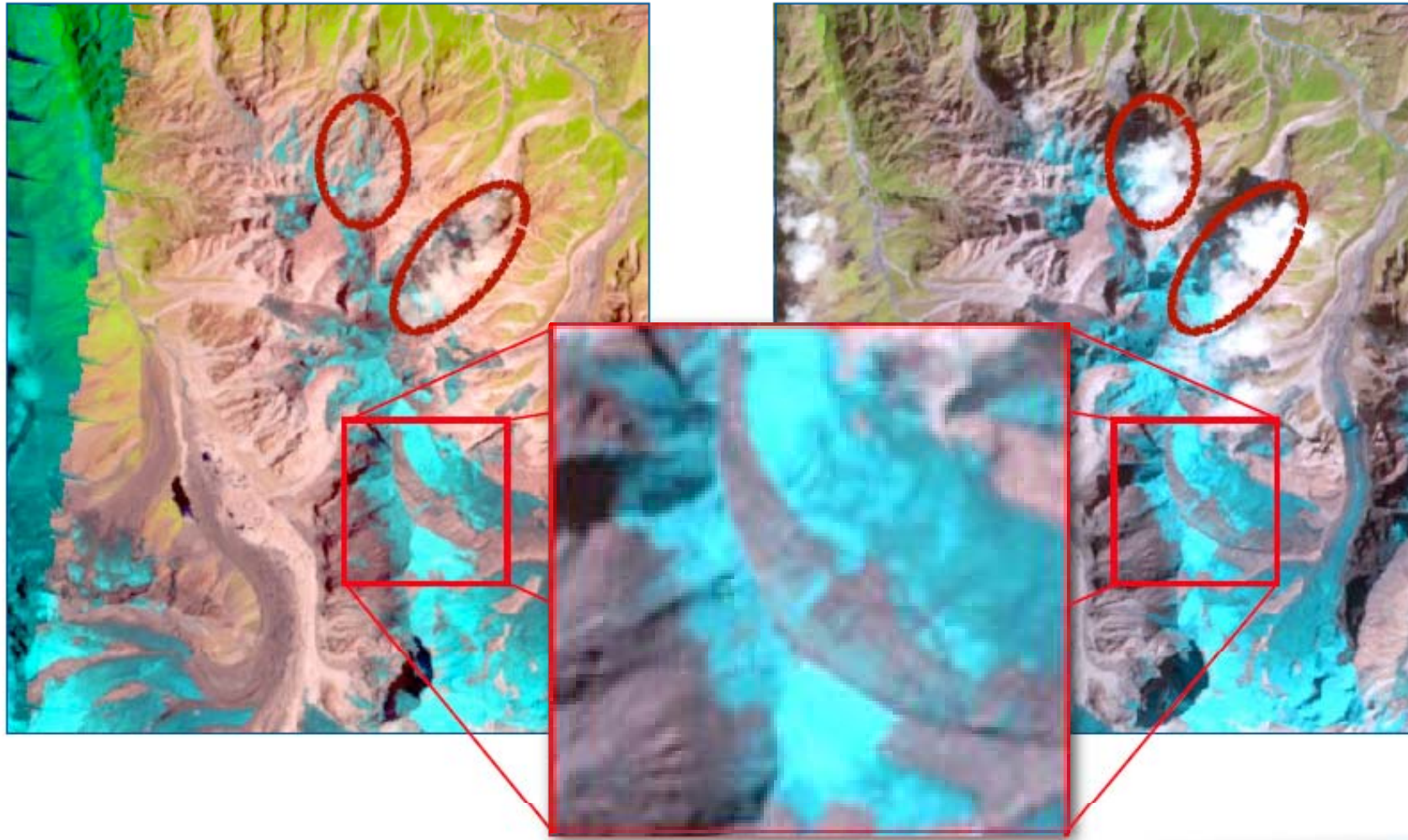
Glacier mapping with band ratio



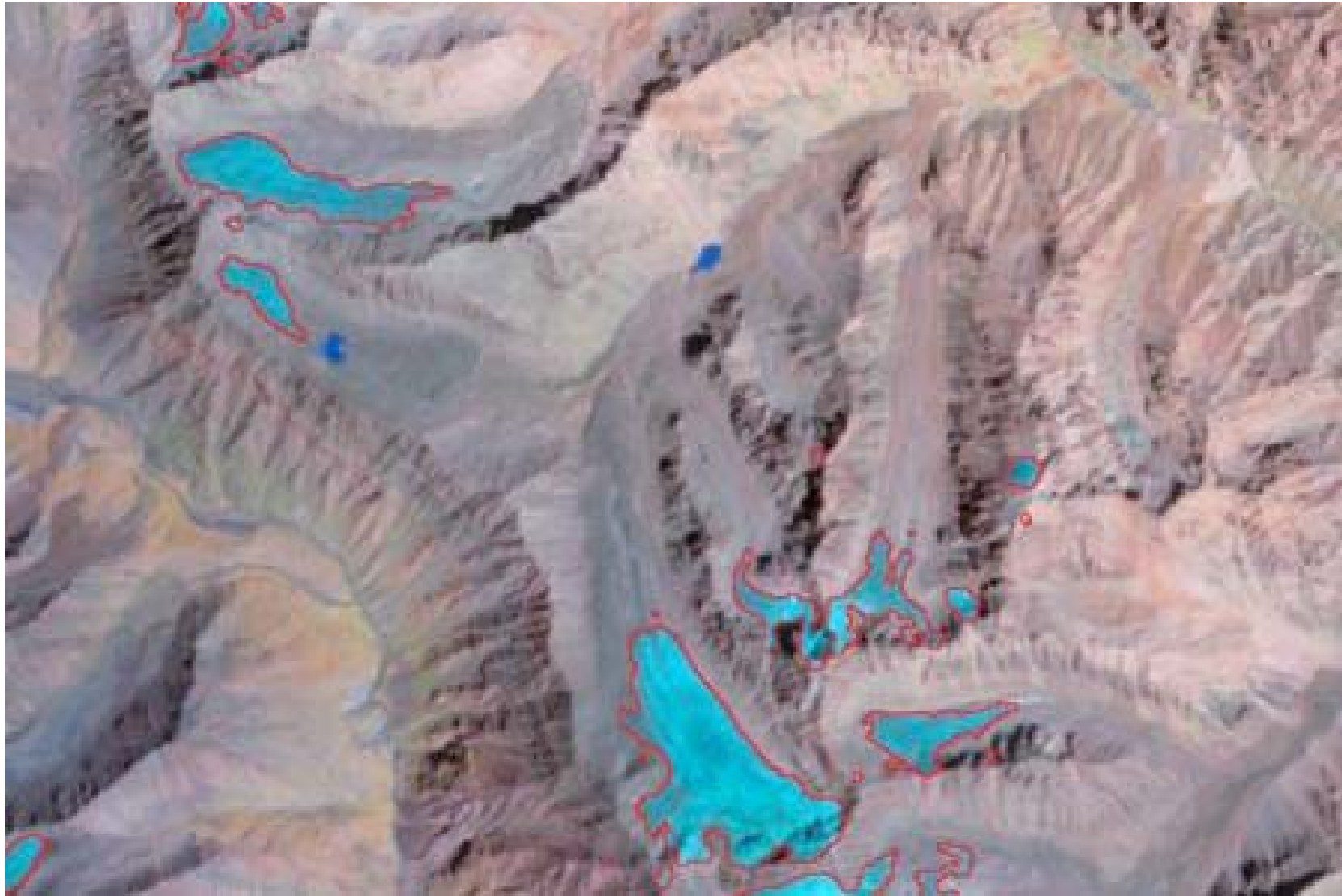
Mapping challenges: snow, cloud, shadows

P145 R039, 1 Aug 2001

P146 R038, 9 Sept 2001



Glacier-permafrost interactions

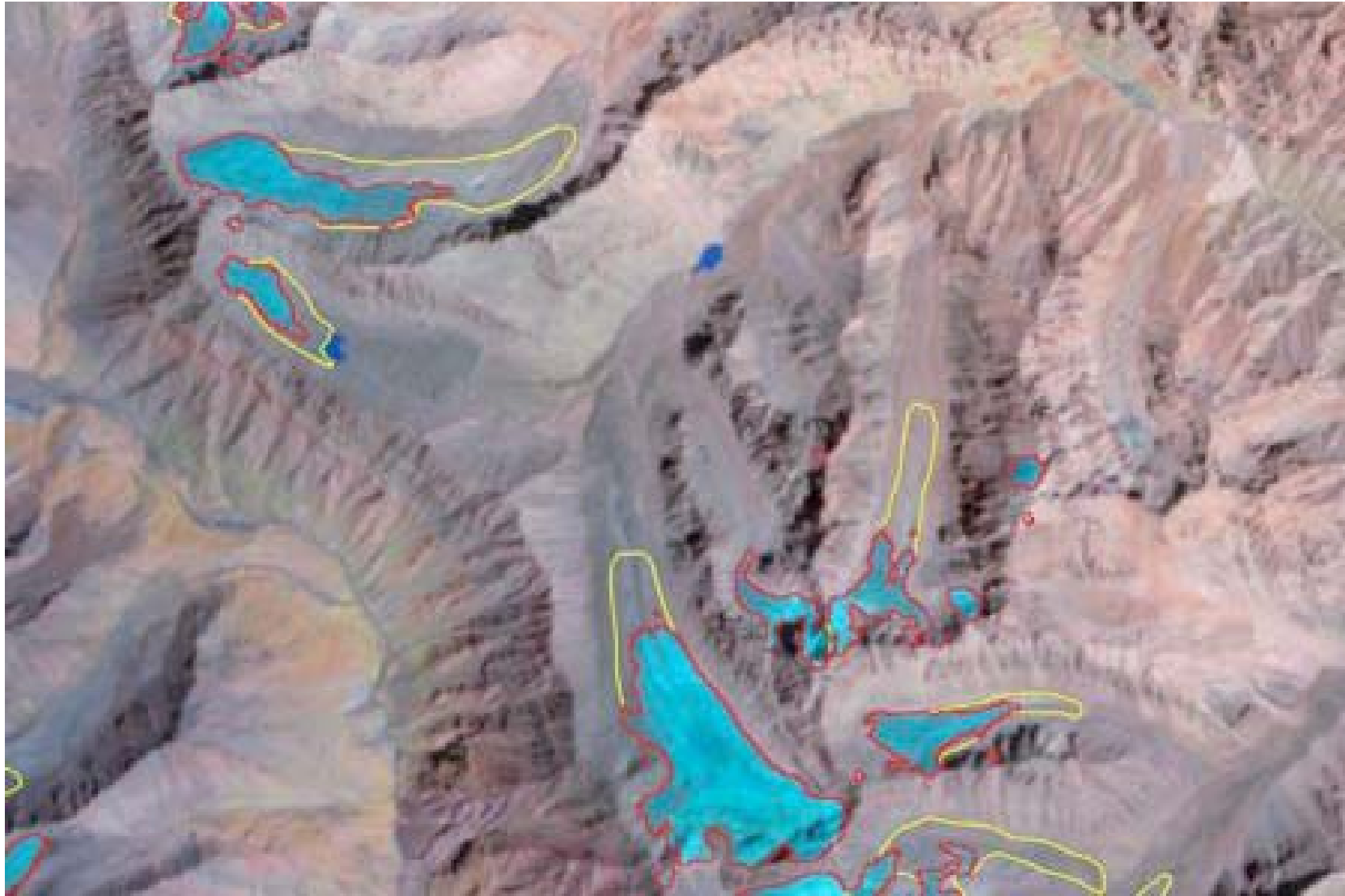


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Glacier-permafrost interactions



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Glacier-permafrost interactions



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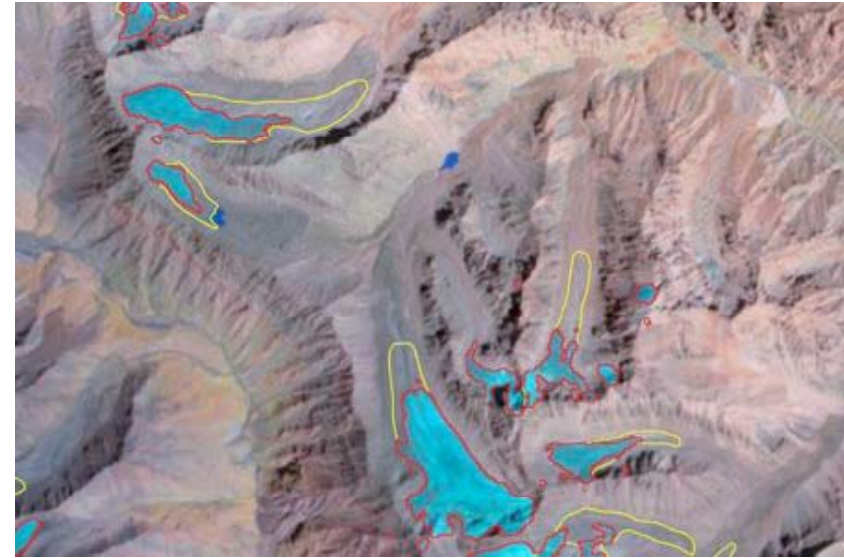
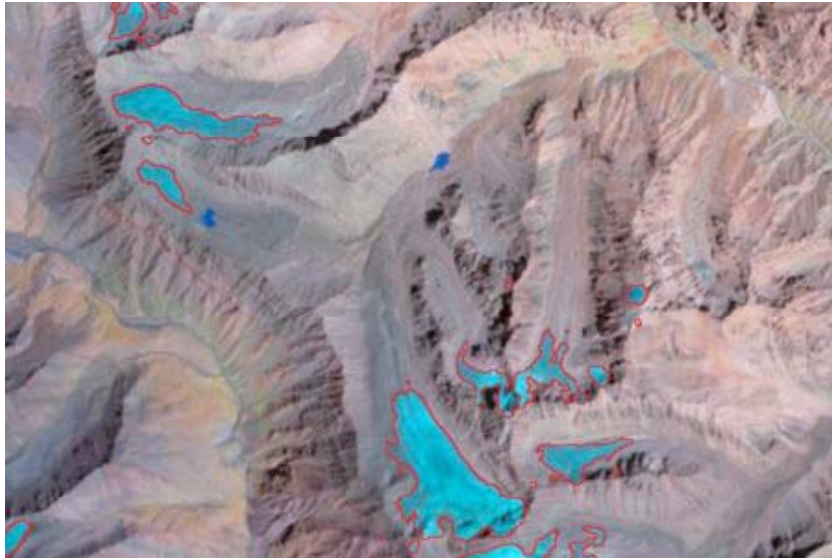
Glacier-permafrost interactions



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Glacier-permafrost interactions

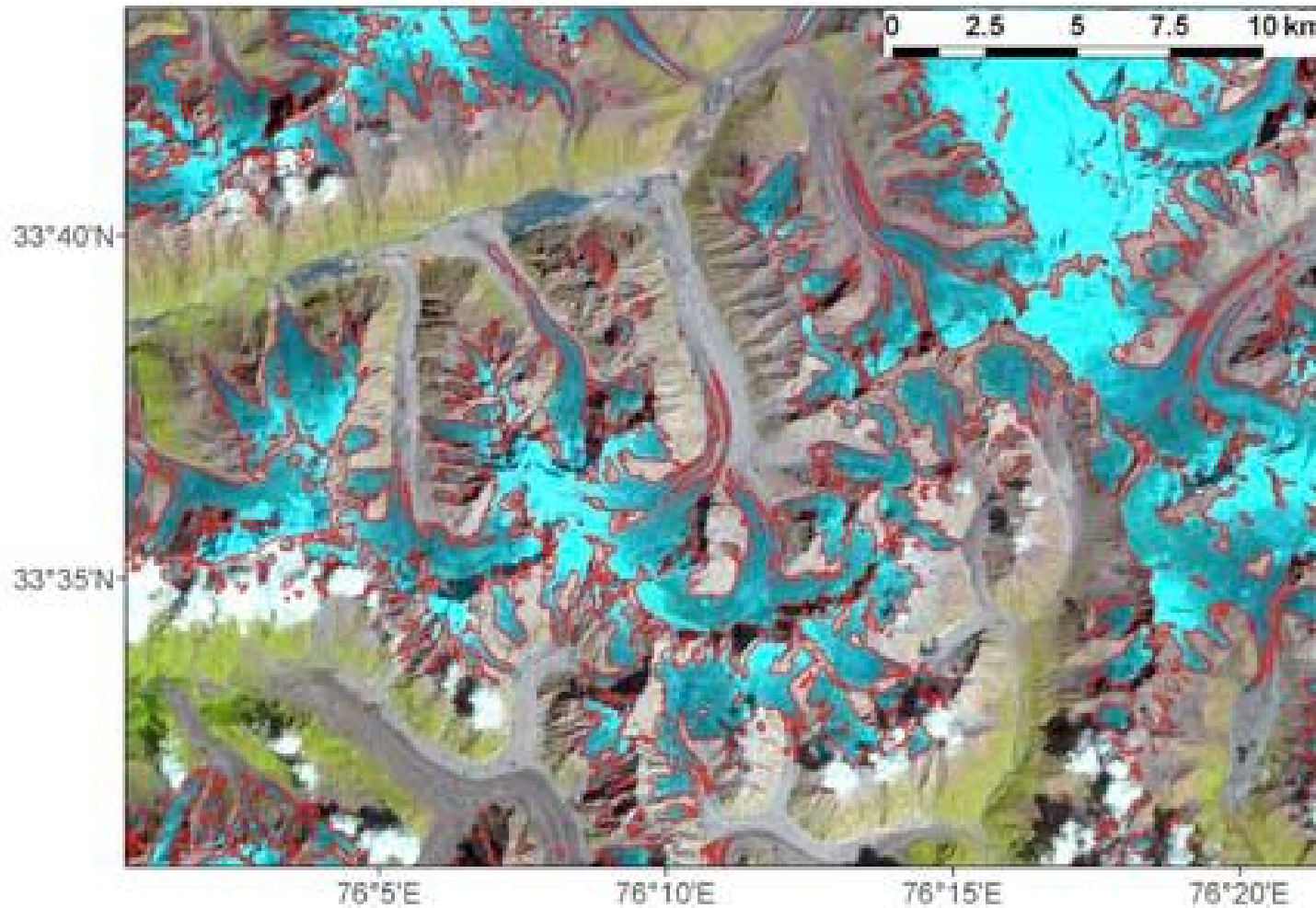


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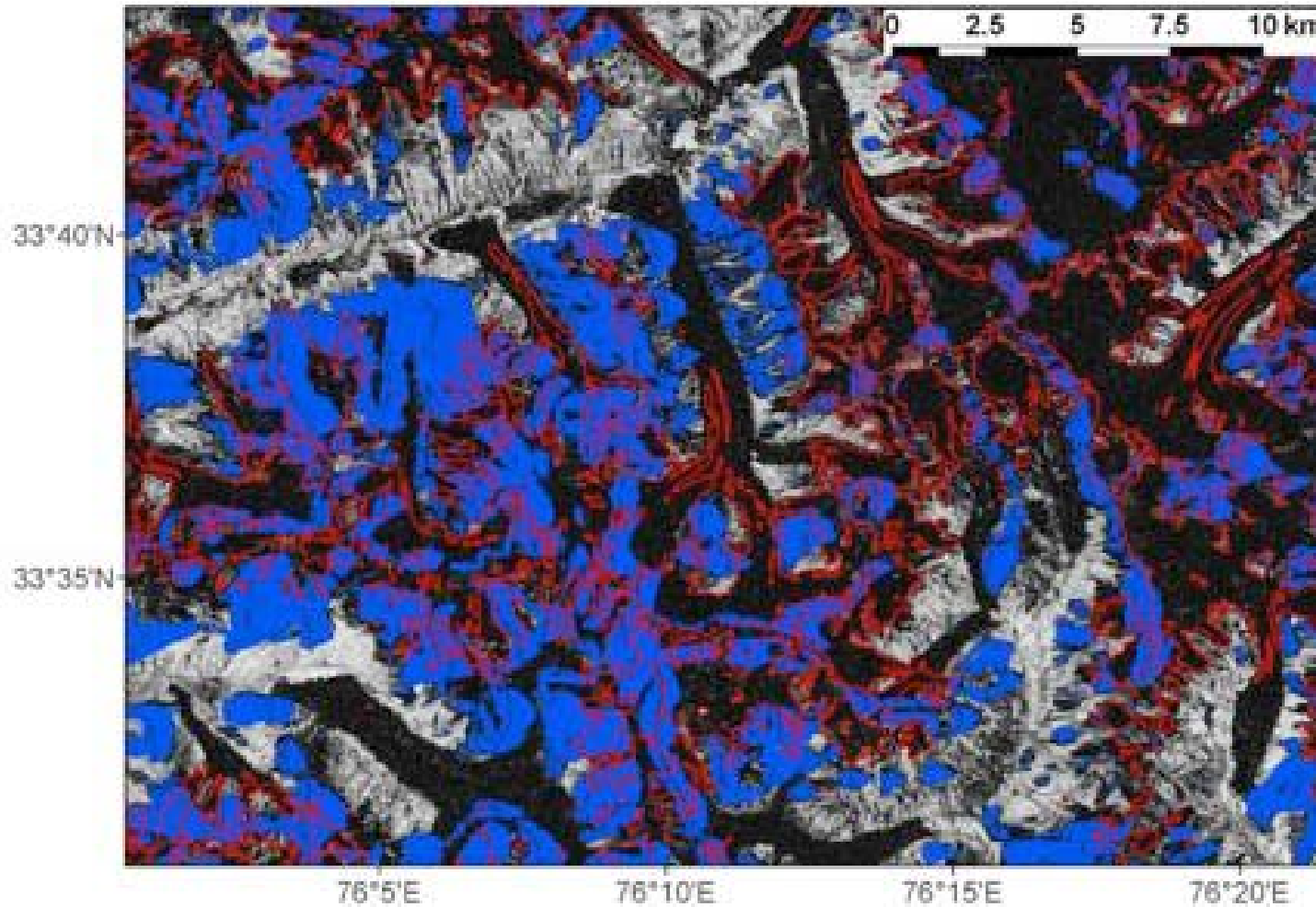
Mapping of debris cover

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



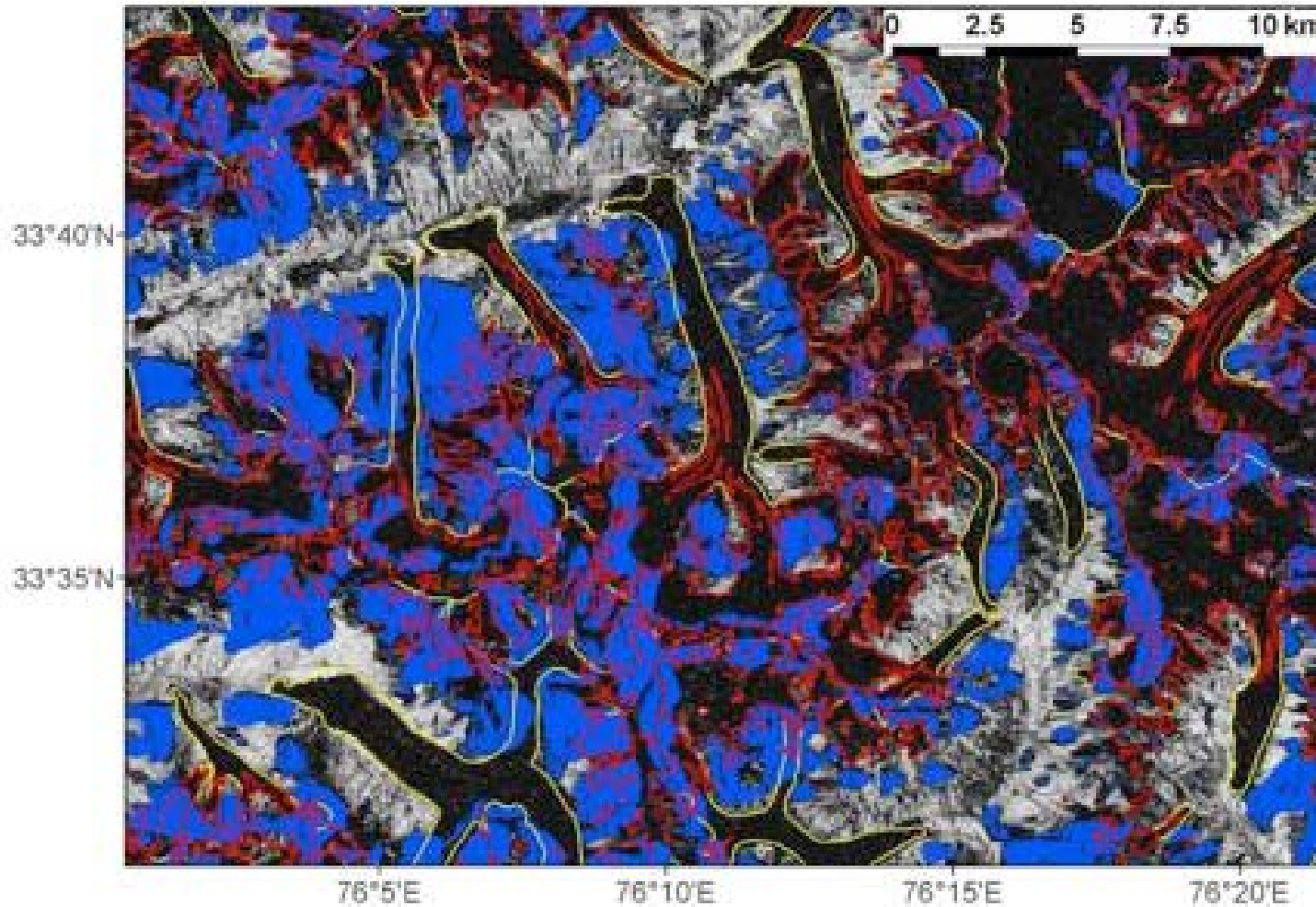
Mapping of debris cover

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



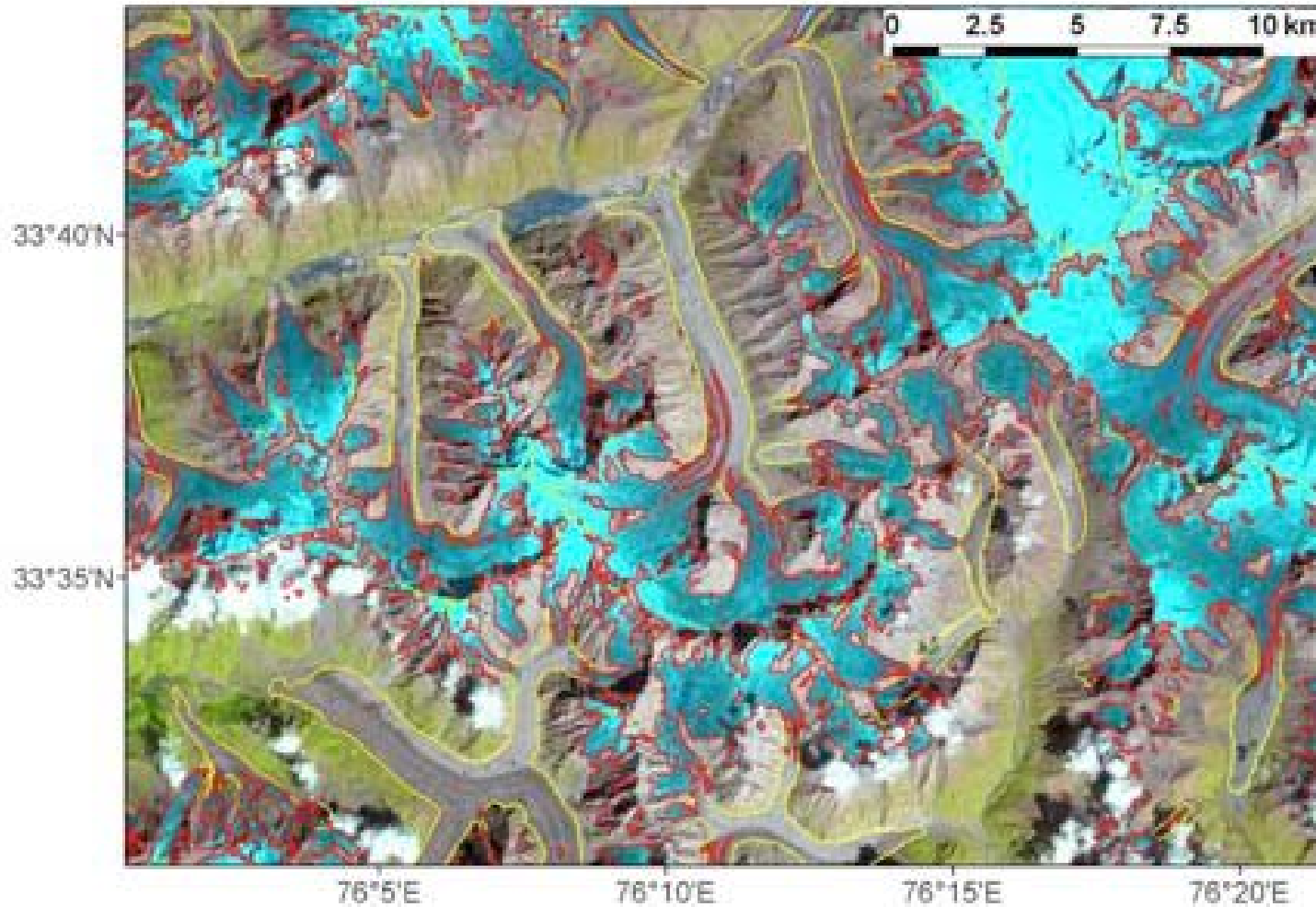
Mapping of debris cover

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



Mapping of debris cover

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

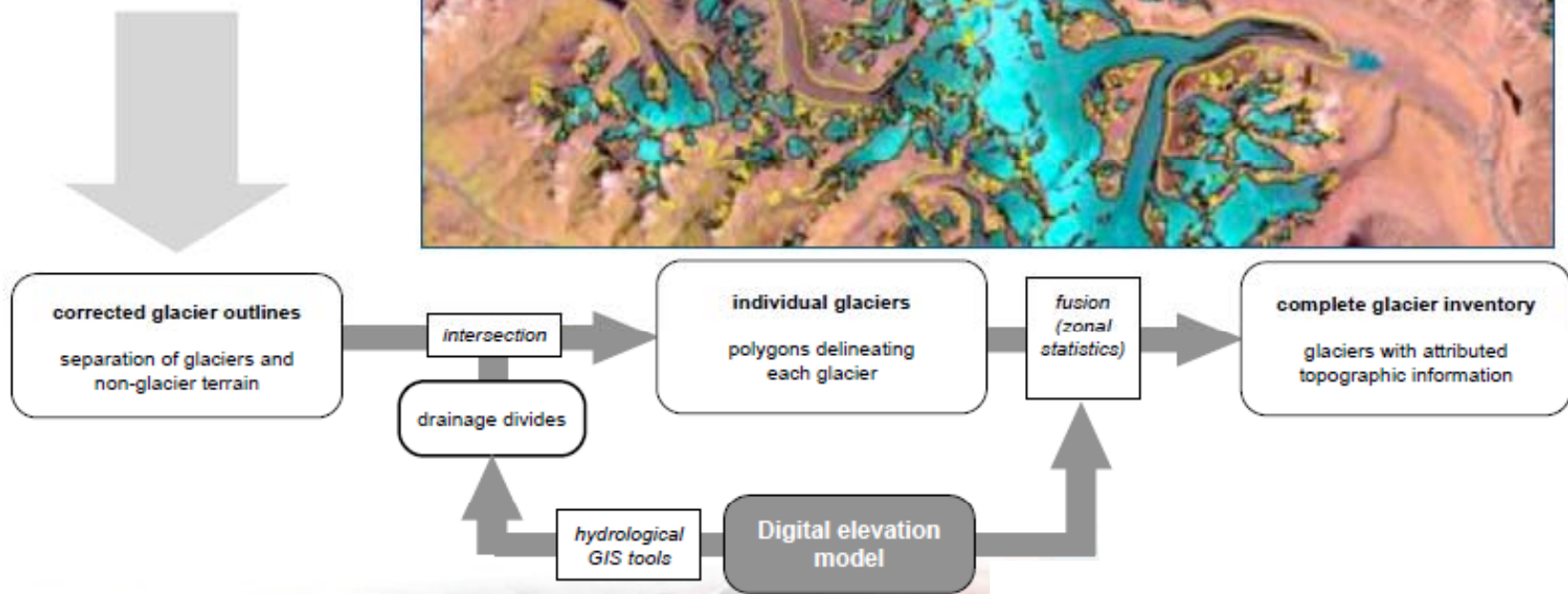
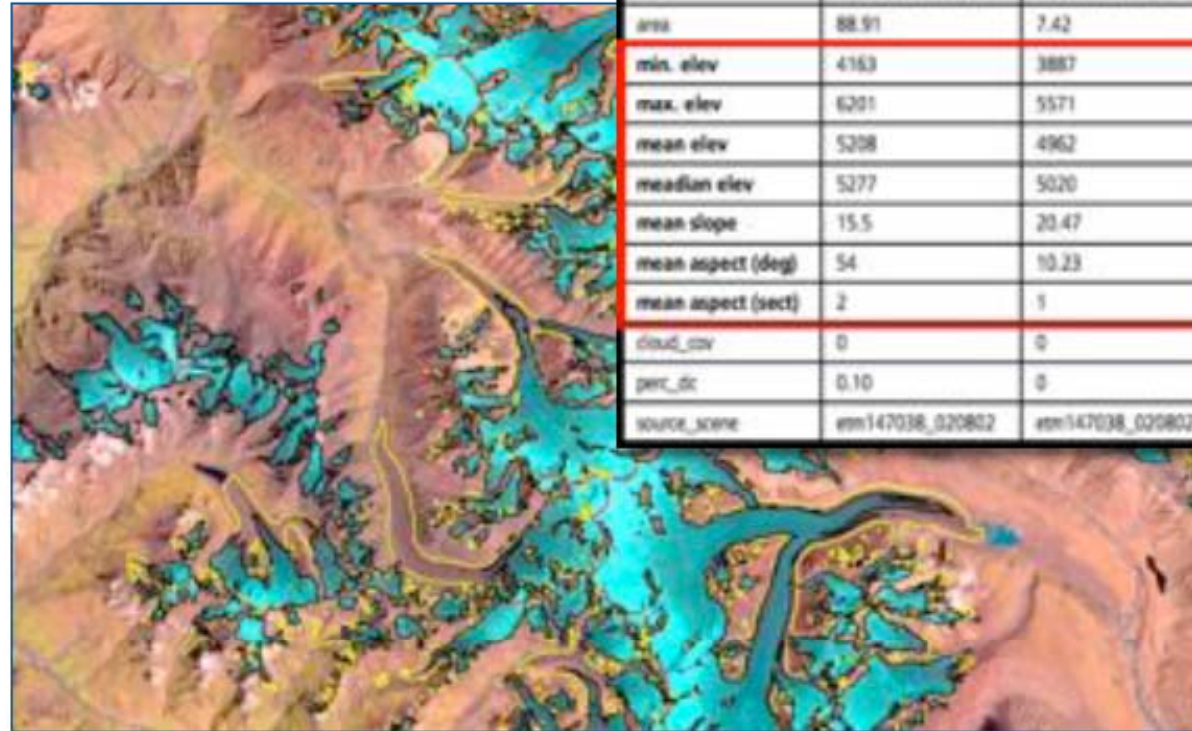


Compilation procedure for glacier inventories

Orthorectified Landsat imagery from USGS

Thresholded band ratio (TM3/TM5)

Manual correction of debris cover, water, snow, shadows



Choosing a digital elevation model (DEM)

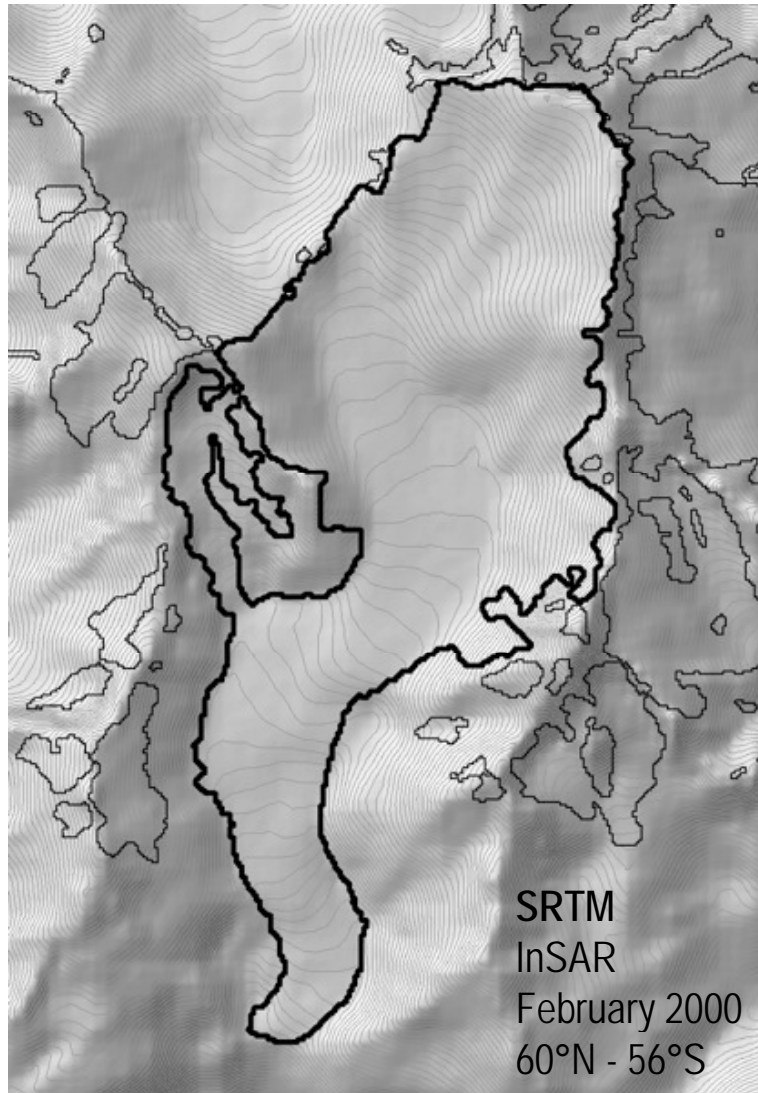
Purposes:

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

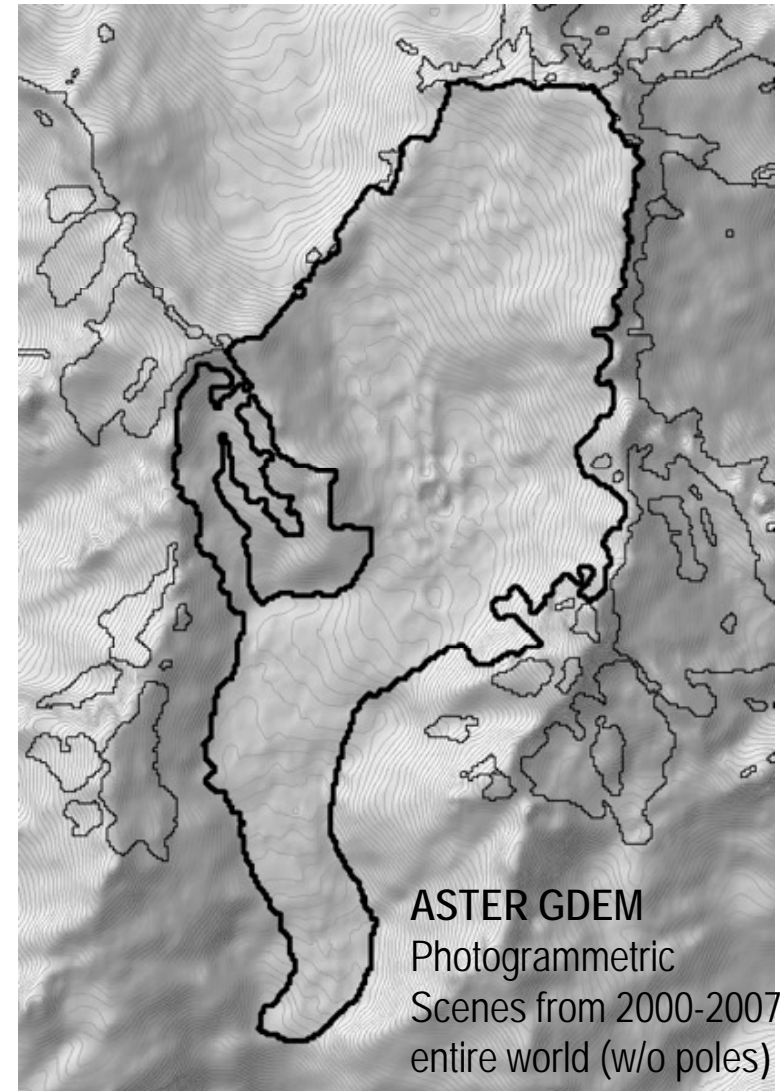
In India

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

Choosing a digital elevation model (DEM)



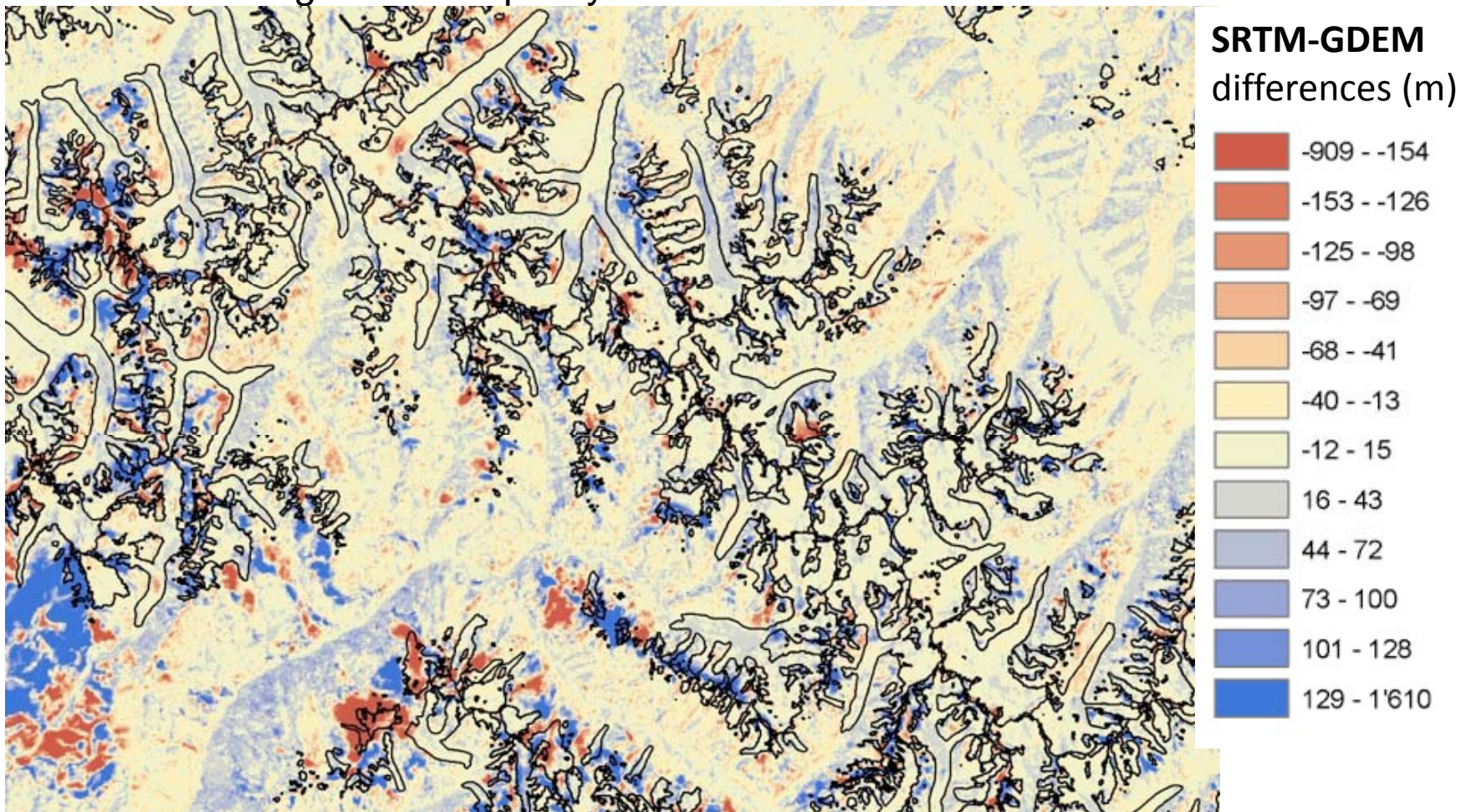
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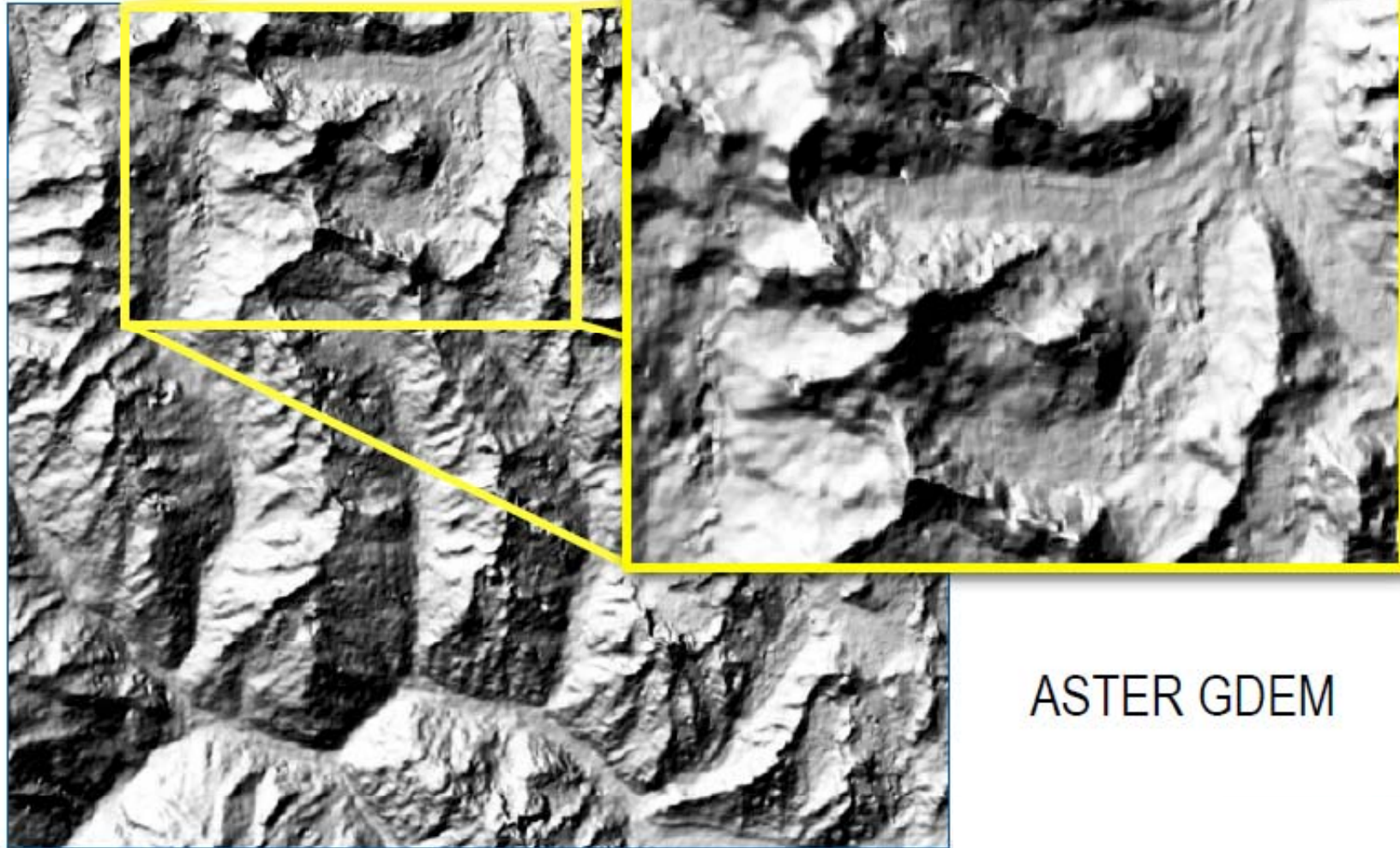
Choosing a digital elevation model (DEM)

Required to obtain topographic parameters and to delineate drainage divides
DEM differencing as a first quality assessment



Choosing a DEM for the Himalaya inventory

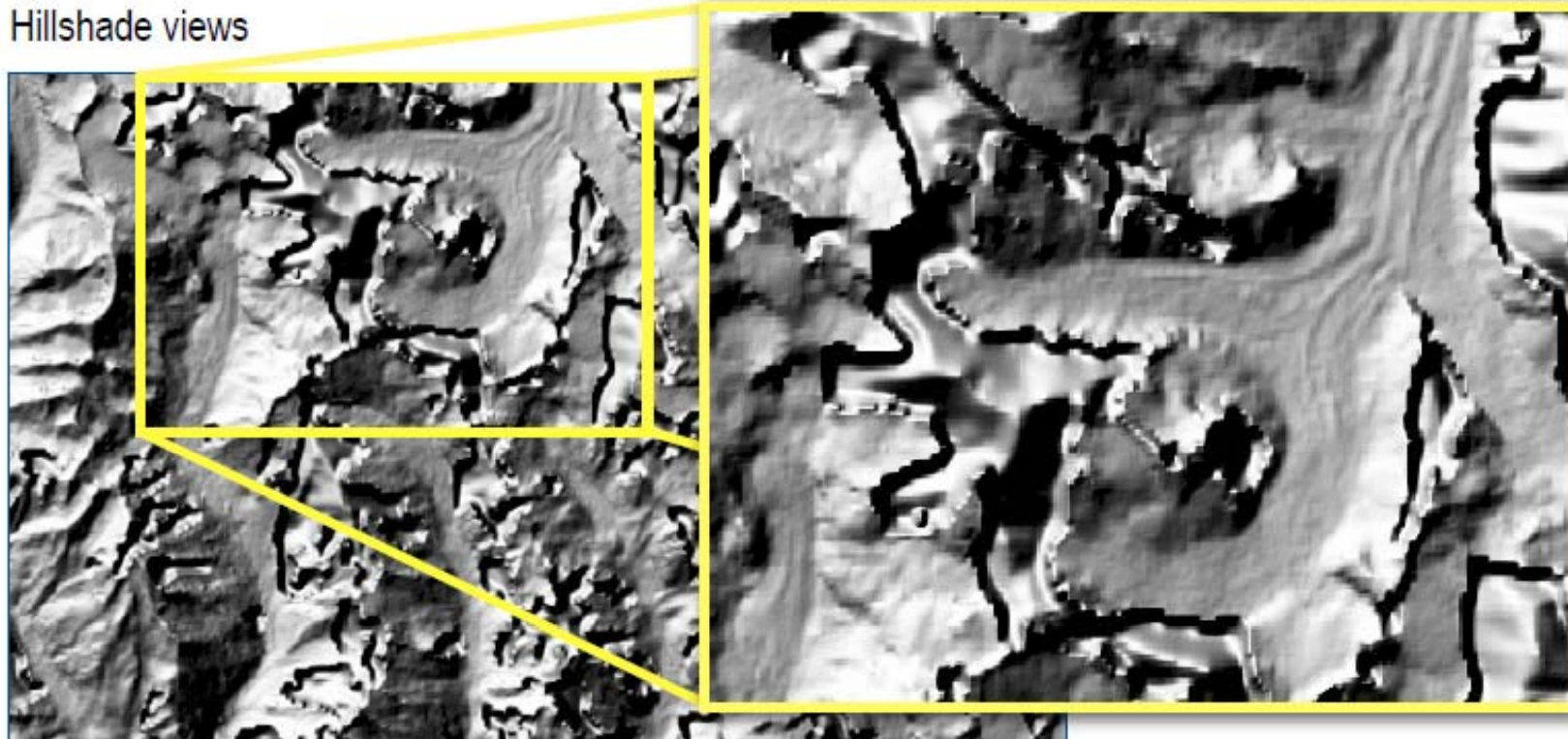
Hillshade views



ASTER GDEM

Choosing a DEM for the Himalaya inventory

Hillshade views



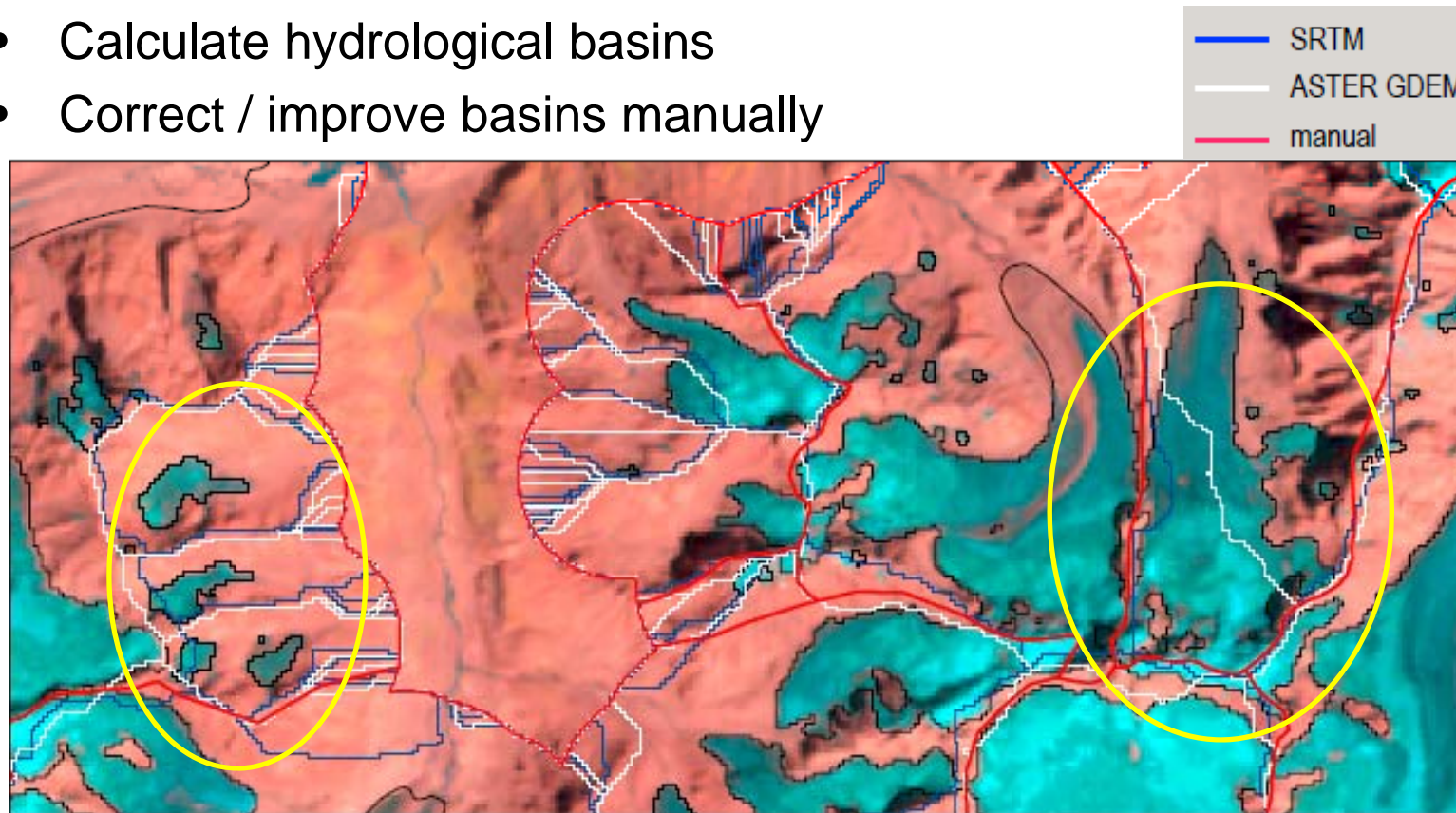
SRTM errors affect...

- ... 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

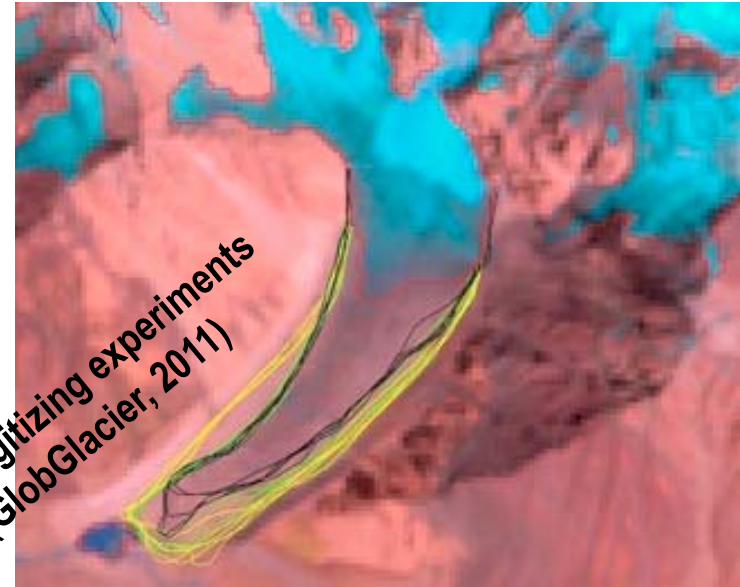


Sources of uncertainties

Glacier mapping

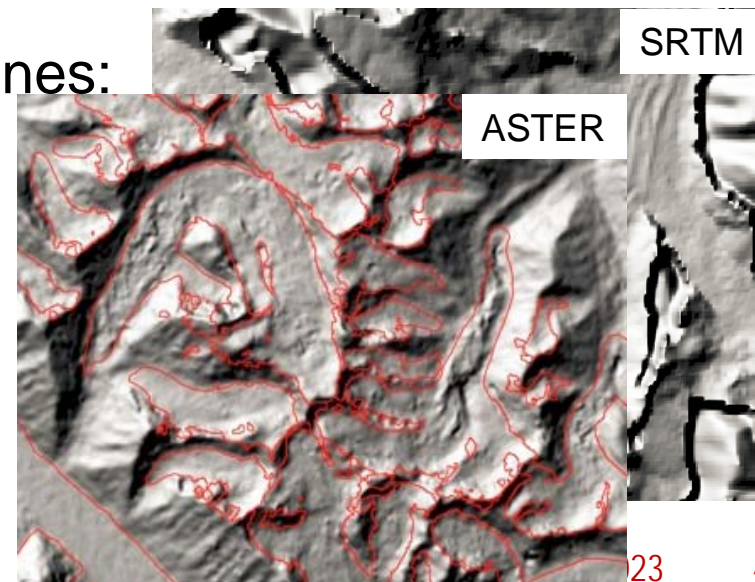
- Automated mapping of clean-ice parts: $\pm 5\%$
- Manual corrections of glacier outlines:
- *margins: ± 60 m, terminus: ± 150 m*

multi-digitizing experiments
(GlobGlacier, 2011)



DEM inaccuracies

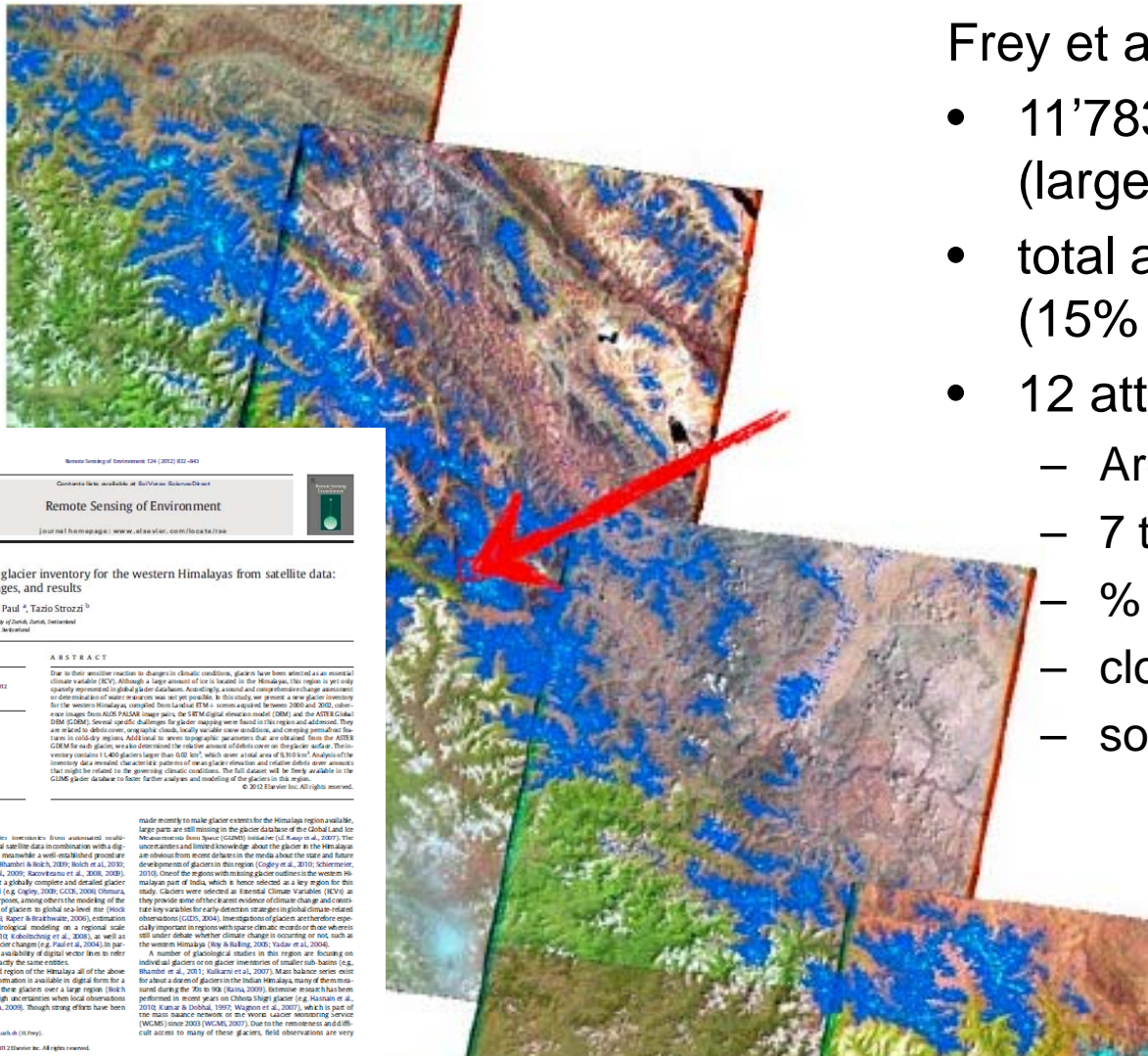
- Orthorectification of satellite scenes:
- Calculation of topographic parameters:
 - *min-/max elevation: ± 45 m*
 - *mean elevation: ± 30 m*
 - *mean slope: $\pm 5^\circ$*



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 km²)
- total area of 9'372 km² (15% debris-covered)
- 12 attributes for each glacier
 - Area
 - 7 topographic parameters
 - % debris cover
 - cloud-cover flag
 - source scene ID



Compilation of a glacier inventory for the western Himalayas from satellite data: methods, challenges, and results

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ABSTRACT

Due to their sensitive position in changing climate conditions, glaciers have been selected as an essential climate variable (ECV). Although a large amount of ice is located in the Himalayas, this region is yet only sparsely represented in global glacier databases. As a first step, an initial and comprehensive glacier inventory is derived from satellite data. In this study, we present a new glacier inventory for the western Himalayas, compiled from Landsat TM/ETM+ scenes acquired between 2000 and 2010, together with topographic data from the Shuttle Radar Topography Mission (SRTM) and the ASTER Global Digital Elevation Model (DEM). Several specific challenges for glacier mapping were found in this region and addressed. They are related to debris-cover, cryogenic clouds, heavily forested snow conditions, and complex periglacial features in cold-dry regions. Additional to seven topographic parameters that are obtained from the ASTER DEM, the new glacier inventory also determined the relative amount of debris cover on the glacier surface. The inventory contains 11,783 glaciers larger than 0.02 km², which cover a total area of 9,372 km². Analysis of the inventory data revealed characteristic patterns of mean glacier elevation and relative debris cover amounts that might be related to the prevailing climatic conditions. The full dataset will be freely available in the GDM glacier database to foster further analysis and modeling of the glaciers in the region.
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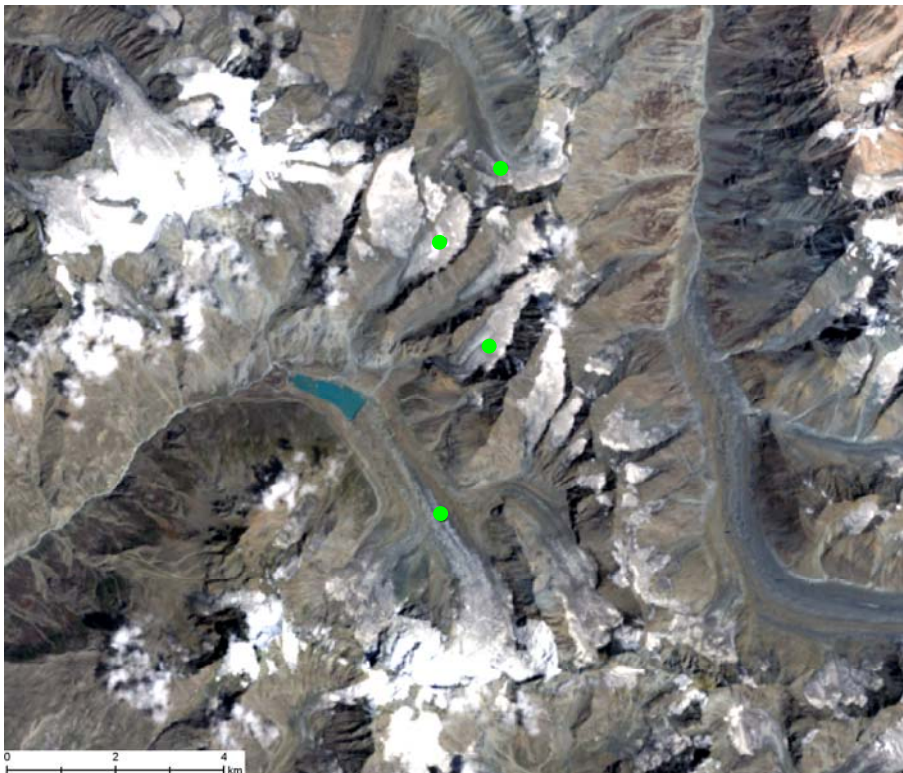
1. Introduction

The compilation of glacier inventories from automated multi-spectral classification of optical satellite data in combination with digital elevation model (DEM) is nowadays a well-established procedure (e.g. Anderson et al., 2008; Bhambri & Koch, 2009; Bolch et al., 2010; Paul & Kääb, 2009; Paul et al., 2009; Ramanamirtham et al., 2008, 2009). There is also no question that a global complete and detailed glacier inventory urgently required (e.g. Copley, 2009; Cogle, 2009; Chinnai, 2009) for a wide range of purposes, among others the modeling of the past and future contribution of glaciers in global sea-level rise (Koch et al., 2009; Kaser et al., 2009; Kaser & Braaten, 2009). Estimation of water resources and hydrological modeling on a regional scale (Fleck, 2011; Kaser et al., 2010; Kretschmer et al., 2008), as well as for accurate assessment of glacier changes (e.g. Paul et al., 2004). In particular, the latter requires the availability of digital vector files to enter glacier specific changes to existing vector files.

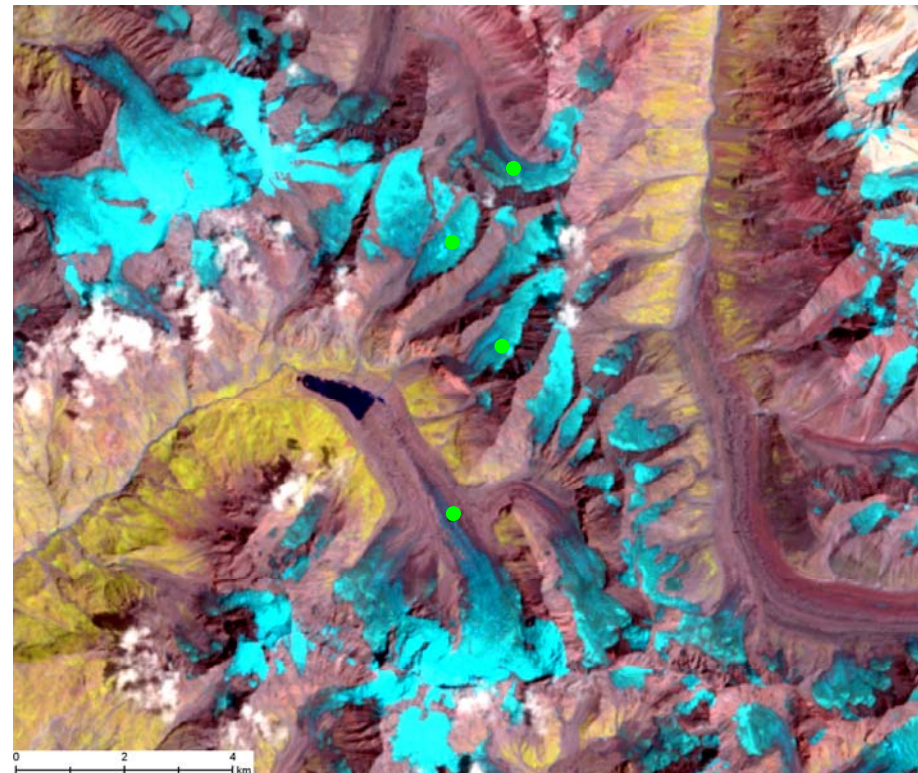
For the heavily glaciated region of the Himalaya all of the above purposes apply, but little information is available in digital form for a sound change assessment of these glaciers over a large region (Koch et al., 2012). This results in high uncertainty when local observations need to be generalized (Kainu, 2009). Though strong efforts have been made recently to make glacier extents for the Himalayas region available, large parts are still missing in the glacier database of the Global Land Ice Measurements from Space (GLIMS) (Kaser et al., 2007). The uncertainties and limited knowledge about the glacier in the Himalaya are obvious from recent debates in the media about the state and future development of glaciers in this region (Cogley et al., 2010; Schirmer, 2010). One of the regions with strong glacier retreat in the western Himalayan part of India, which is hence selected as a key region for this study. Glaciers were selected as Essential Climate Variables (ECV) as they provide some of the clearest evidence of climate change and constitute key variables for early detection strategies in global climate-related observations (GCTD, 2004). Investigations of glaciers are therefore especially important in regions with sparse climatic records or those where it is still under debate whether climate change is occurring or not, such as the western Himalaya (Jay & Hogg, 2005; Yadav et al., 2006). A number of glaciological studies in this region are focusing on individual glaciers or on glacier inventories of smaller sub-basins (e.g. Bhambri et al., 2011; Kulkarni et al., 2007). Mass balance series exist for about a dozen of glaciers in the Indian Himalaya, many of them measured during the 70s to 90s (Kainu, 2009). Remote sensing has been performed in recent years on Chinese High Glaciers (e.g. Huo et al., 2010; Kumar & Doberl, 1997; Wagnon et al., 2007), which is part of the most recent network of the world glacier monitoring system (WGMS) since 2003 (WGMS, 2007). Due to the remoteness and difficult access to many of these glaciers, field observations are very

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



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