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DIPARTIMENTO DI SCIENZE DELLA TERRA

Provincia Autonoma di Bolzano

Remotely Sensed Techniques for multi-temporal monitoring and mapping of glaciers: preliminary results from two case studies in Italy and Greenland.
A tribute to Roberto Filippi

R. Filippi, L. Carturan, P. Rastner, L. Bertoldi, P. Gabrielli, C. Notarnicola, R. Seppi, M. Zebisch,

University of Zurich[UZH]

museo tridentino di scienze naturali
the science museum network in Trentino - Italy

TeSAF
Dipartimento Territorio e Sistemi Agro Forestali
Università degli Studi di Padova

THE OHIO STATE UNIVERSITY

Introduction

Multi-temporal analysis on glacier extent using satellite imagery is an important and valuable tool to understand climate variability, since glaciers respond very fast to climate change.

In this context, this work will illustrate the exploitation and the preliminary results of different remotely sensed techniques (pixel based and object based) for glacier mapping and analysis of glaciers changes in two main test sites.

The first test site is the Ortles-Cevedale massif (Italy), one of the largest glacierized areas in the italian Alps, located on the border of Lombardia and Trentino-South Tyrol.

This analysis is carried out in the framework of the Ortles Project. Landsat TM and ETM+ scenes (since 1973 to 2010) were collected and analyzed in order to map the glaciers and extract snowline altitudes.

The second test site is located in Greenland where in the framework of the EU-FP7 project ice2sea the University of Zurich is currently mapping all local glaciers and ice caps (LGI) through the use of Landsat ETM+ and ASTER GDEM scenes in order to better estimate future sea-level rise from LGI.

Glaciers change with time...

Aletsch, Svizzera, 1900-2005

Glaciers change with time...

Video realized by Philipp Rastern

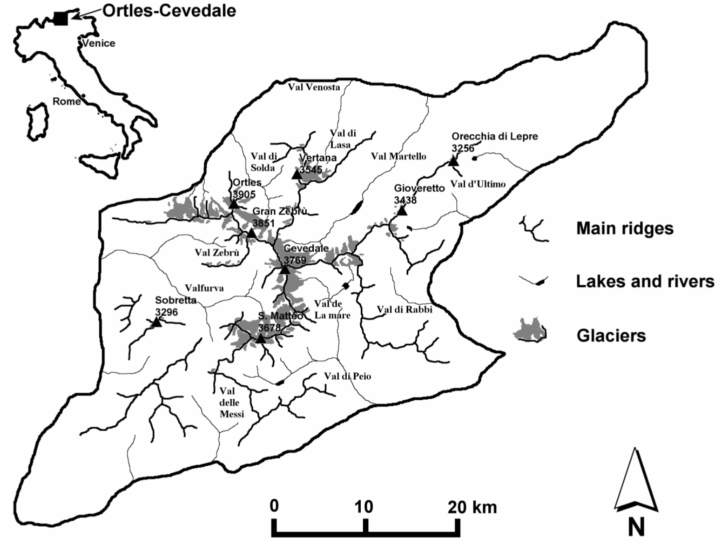
The Ortles project

Framework: international research project on the cryosphere of the Ortles-Cevedale Group

Main objectives: 1) retrieve a **glacial archive** of past climate and environmental changes in the eastern European Alps

2) set up a **strategic observatory** of the current climate and cryosphere changes at high altitude

Multidisciplinary structure:



1) Paleoclimate (The Ohio State University)

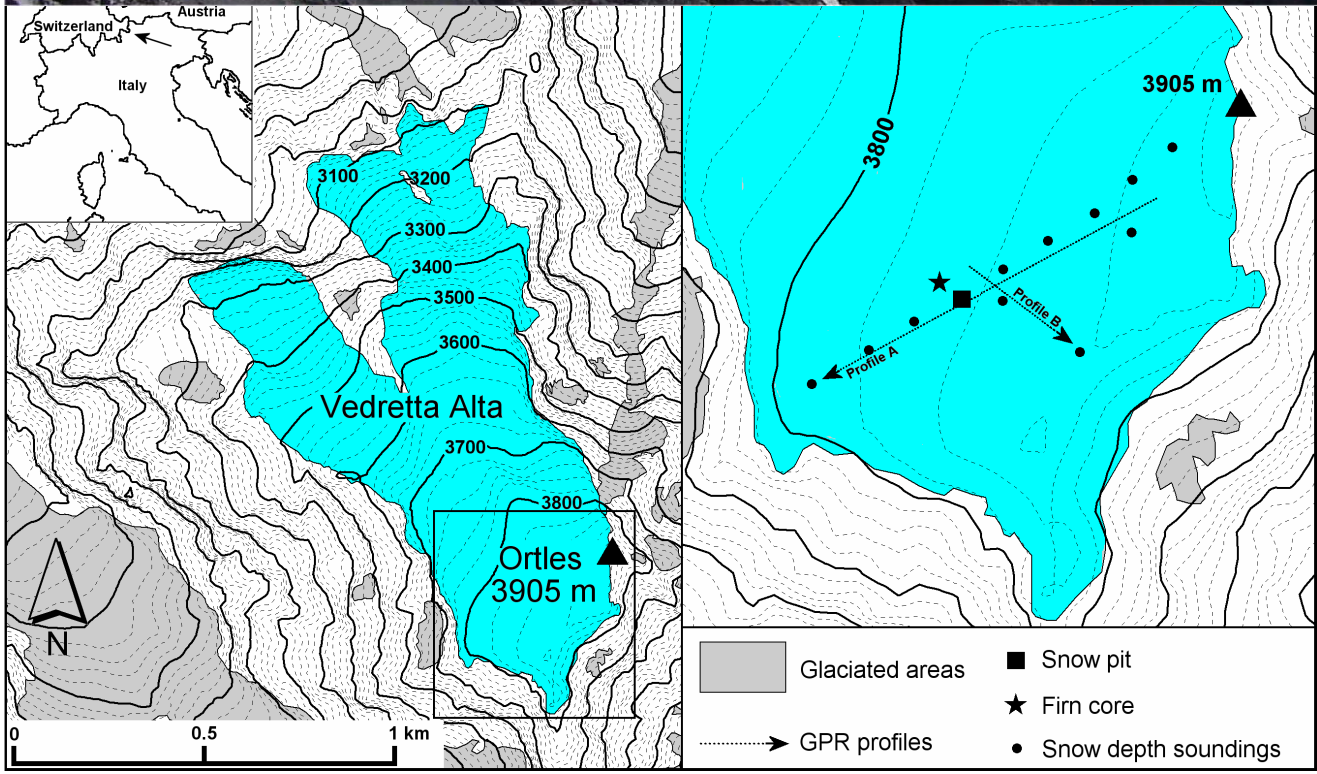
2) Environmental contamination (University of Venice)

3) Glaciology (University of Padua, Hydrological Office Province of Bolzano, University of Innsbruck, University of Wien)

4) Remote sensing (Institute for remote sensing EURAC, Bolzano)

5) Permafrost (University of Pavia and Geological office Province Bolzano)

6) Educational (Museum of Natural Science of Trento and Istituto di Cultura le Marcelline in Bolzano)



Precipitation (in the valley, 1900 m): **750 mm y^{-1}**

Mean annual air temperature (3850 m): **-9°C**

The 2009 survey

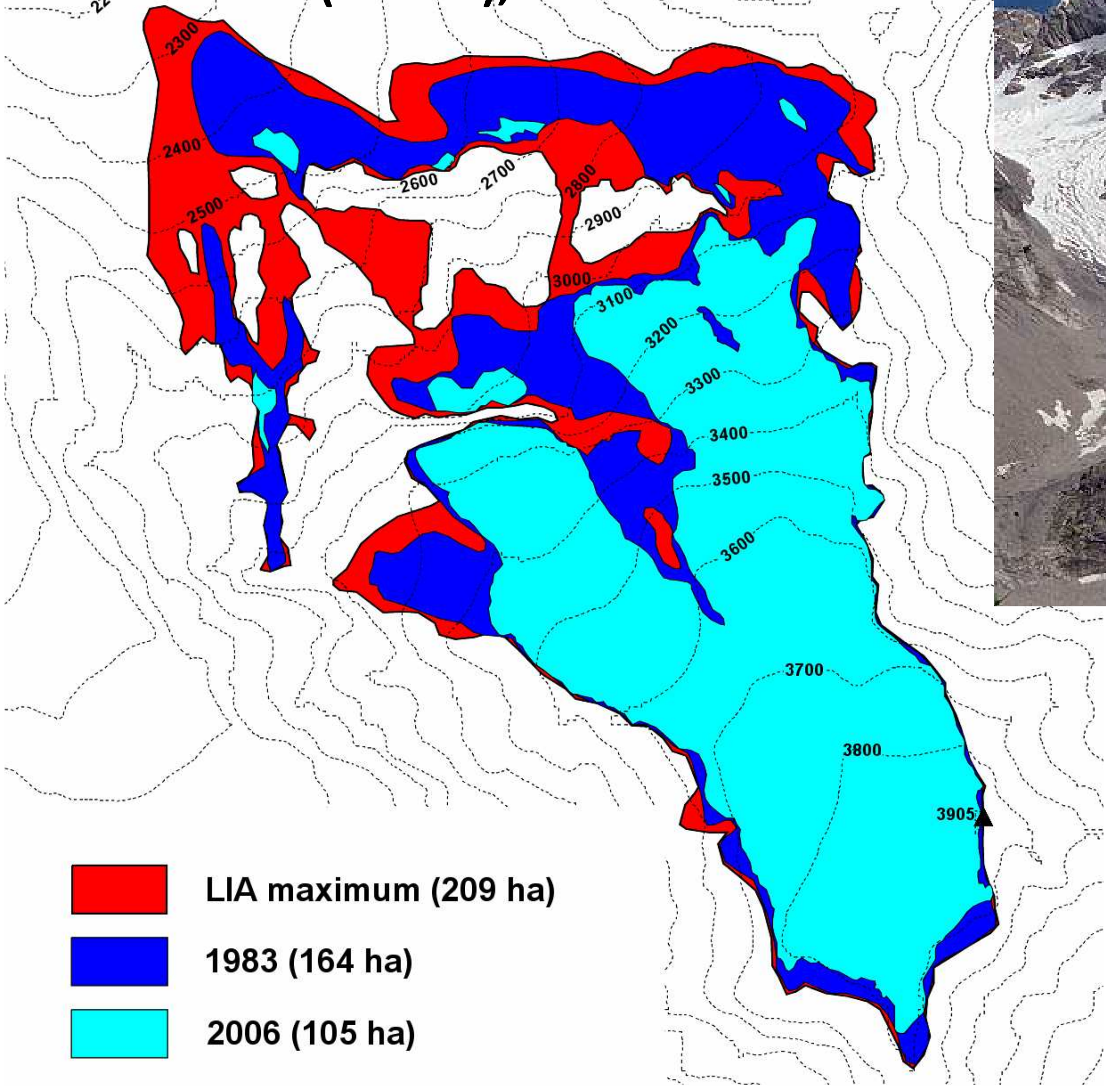
Geophysical surveys

Glacier mass balance

Glacier thermal regime

Chemistry of snow and firn

The Vedretta Alta at the Little Ice Age maximum (~ 1850), 1983 and in 2006



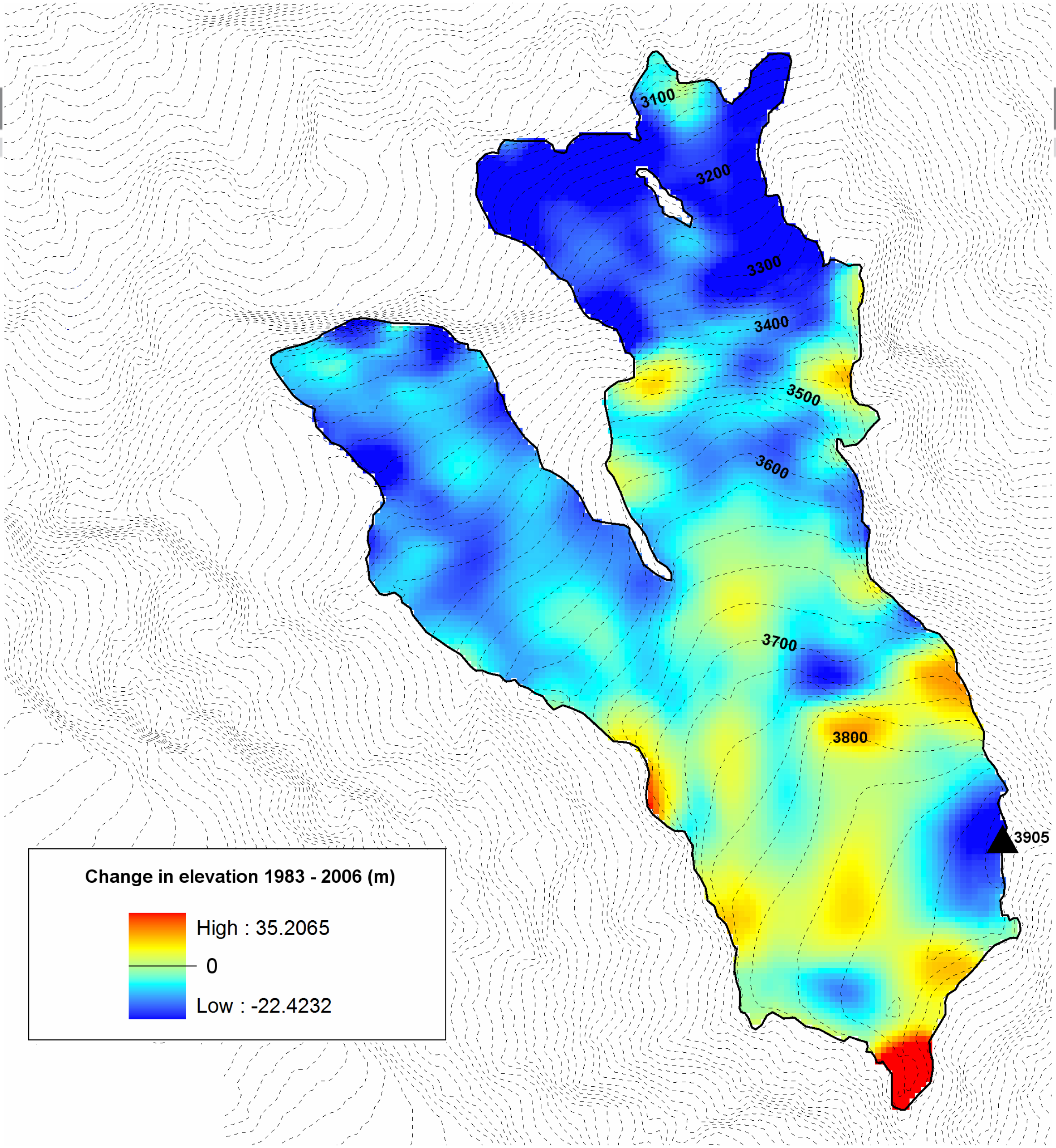
Change in surface elevation from 1983 to 2006

Elevation has significantly decreased below 3650 m.

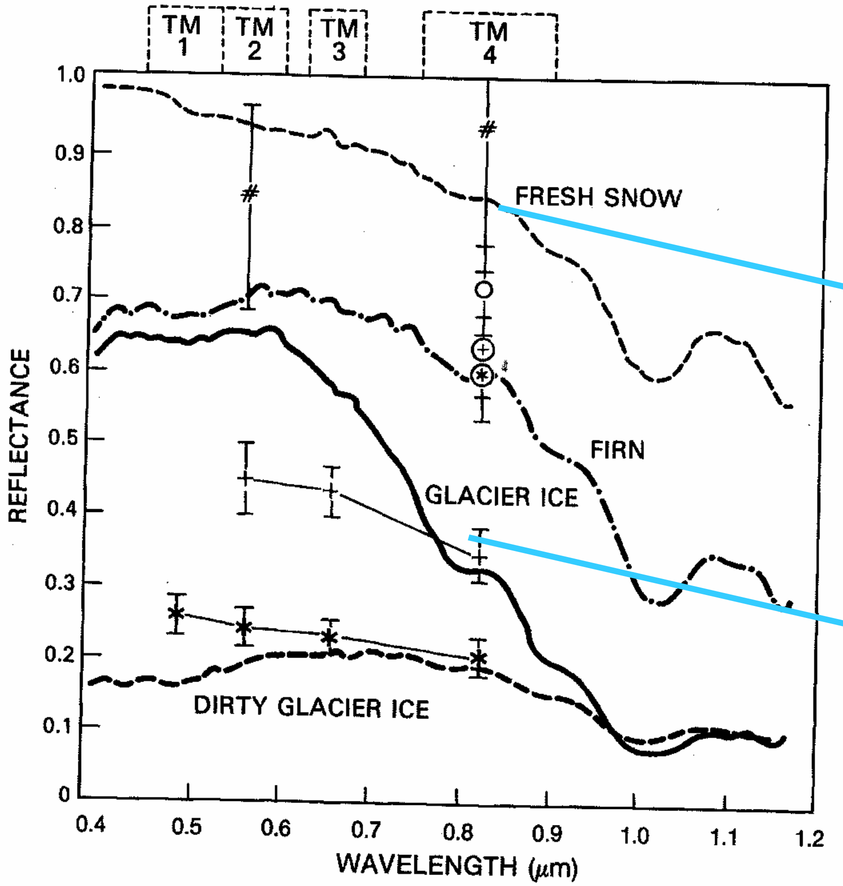
Average elevation change:
~ -4 m

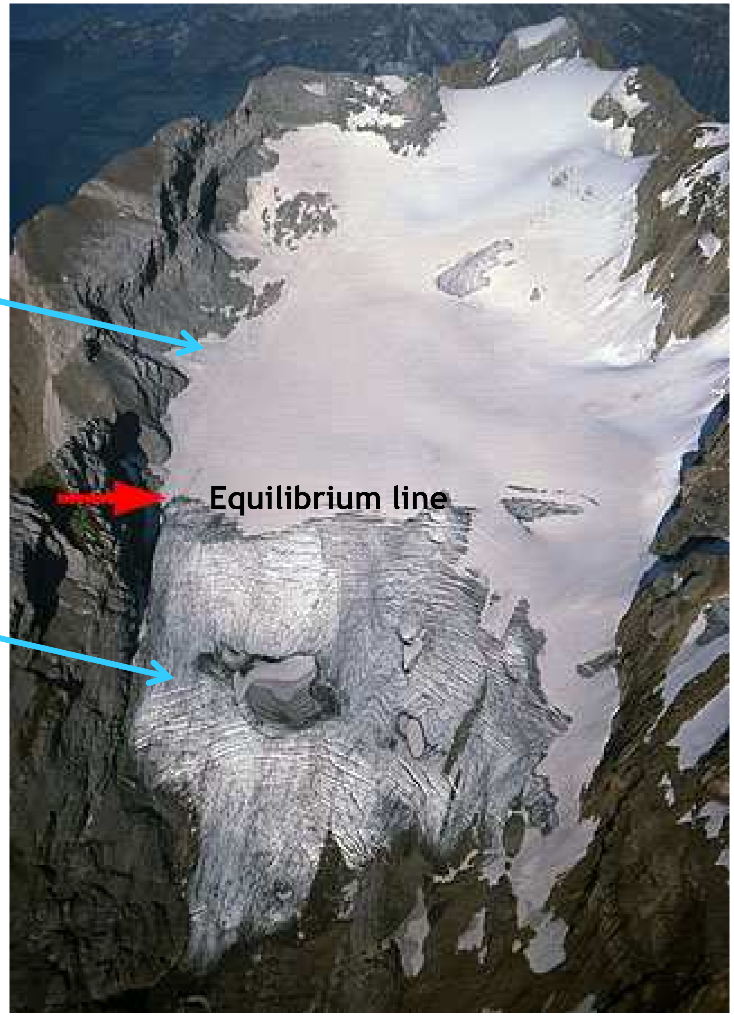
Average specific annual mass balance: **-167 mm w.e. y^{-1}**

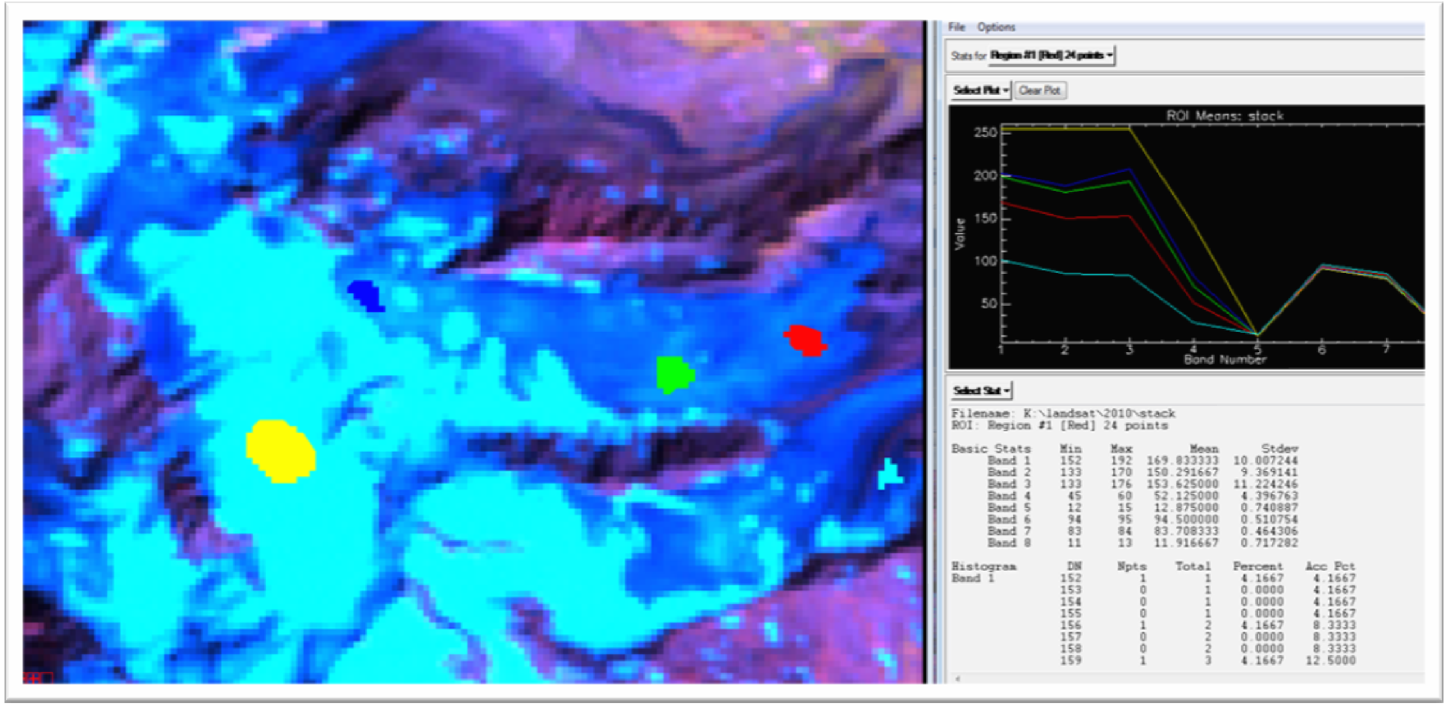
Vedretta Alta **may be slightly out of equilibrium after 1983**, in contrast with other glaciers of Ortles-Cevedale that have a strongly negative mass balance (e.g. Careser glacier, -1387 mm w.e. y^{-1})

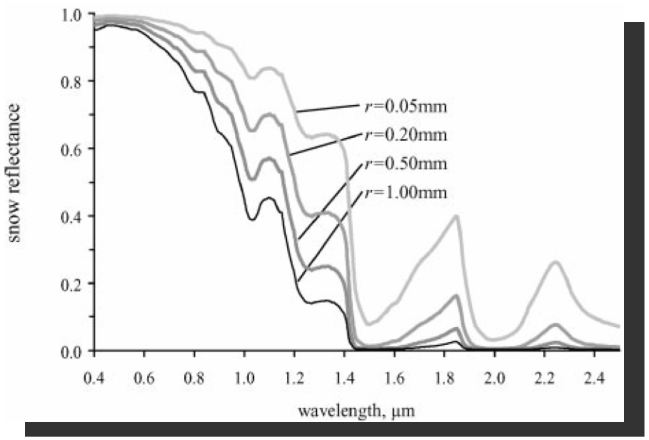


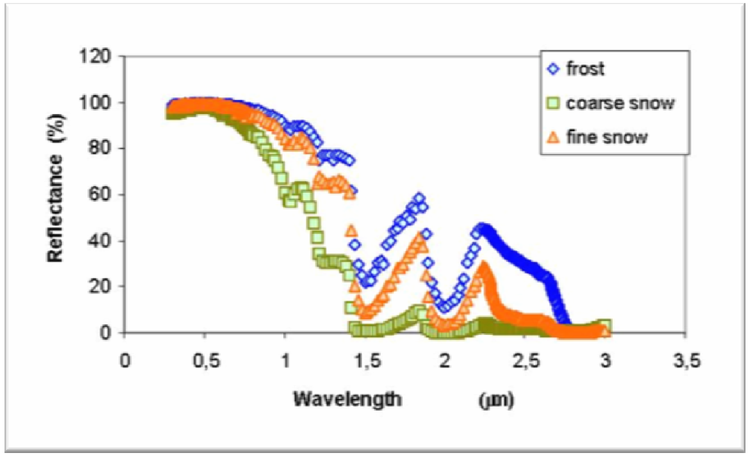
Remote Sensing: Snow reflectances





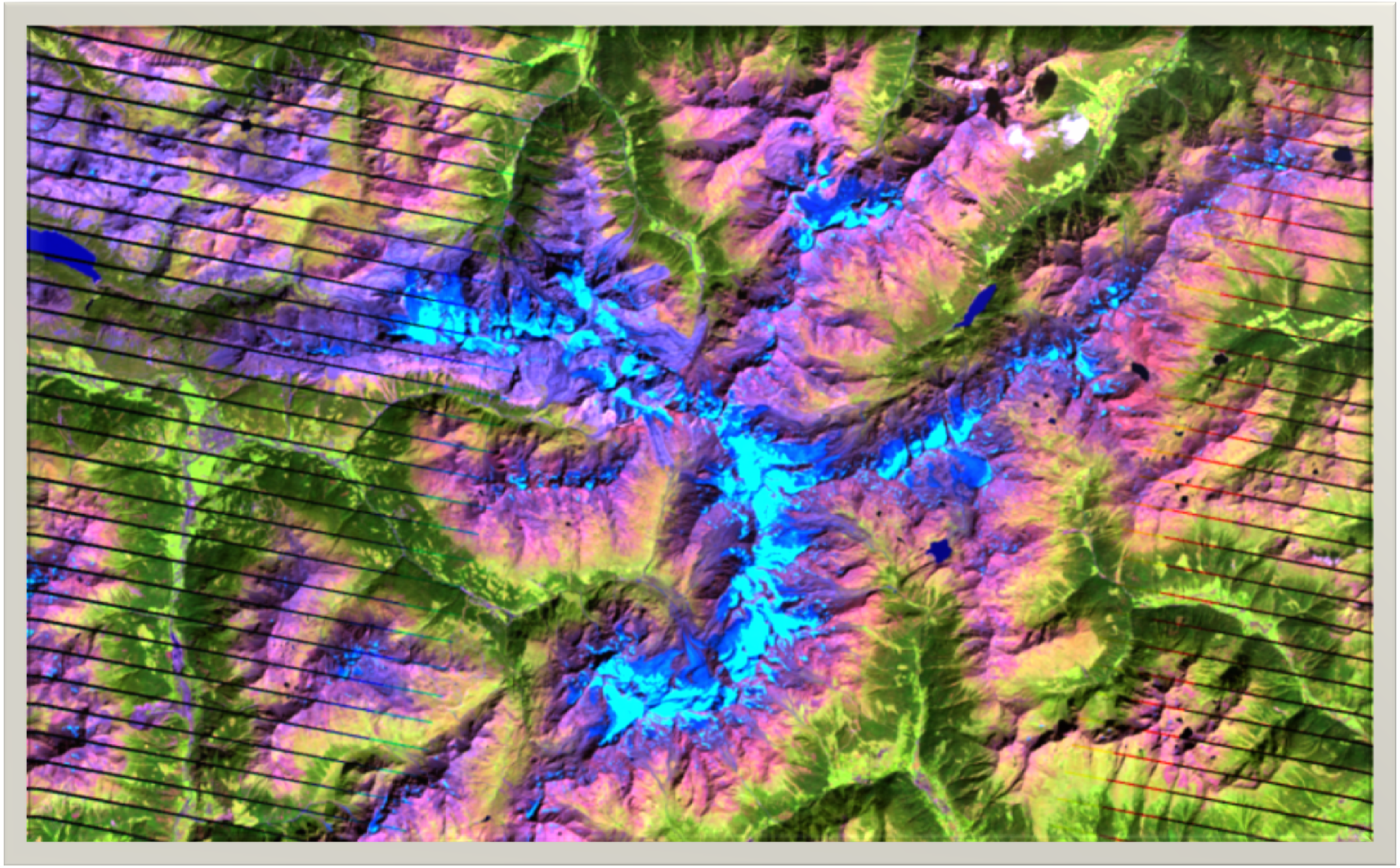

File Options
Stats for Region #1 [Red] 24 points
Select Plot
Clear Plot
ROI Means: stack
Value
Band Number
Select Stat
Filename: K:\landsat\2010\stack
ROI: Region #1 [Red] 24 points
Basic Stats Min Max Mean Stdev
Band 1 152 192 169.833333 10.007244
Band 2 133 170 150.291667 9.369141
Band 3 133 176 153.625000 11.224246
Band 4 45 60 52.125000 4.396763
Band 5 12 15 12.875000 0.740887
Band 6 94 95 94.500000 0.510754
Band 7 83 84 83.708333 0.464306
Band 8 11 13 11.916667 0.717282
Histogram DN Npts Total Percent Acc Pct
Band 1 152 1 1 4.1667 4.1667
153 0 1 0.0000 4.1667
154 0 1 0.0000 4.1667
155 0 1 0.0000 4.1667
156 1 2 4.1667 8.3333
157 0 2 0.0000 8.3333
158 0 2 0.0000 8.3333
159 1 3 4.1667 12.5000


snow reflectance
wavelength, µm
r=0.05mm
r=0.20mm
r=0.50mm
r=1.00mm


Reflectance (%)
Wavelength (µm)
frost
coarse snow
fine snow

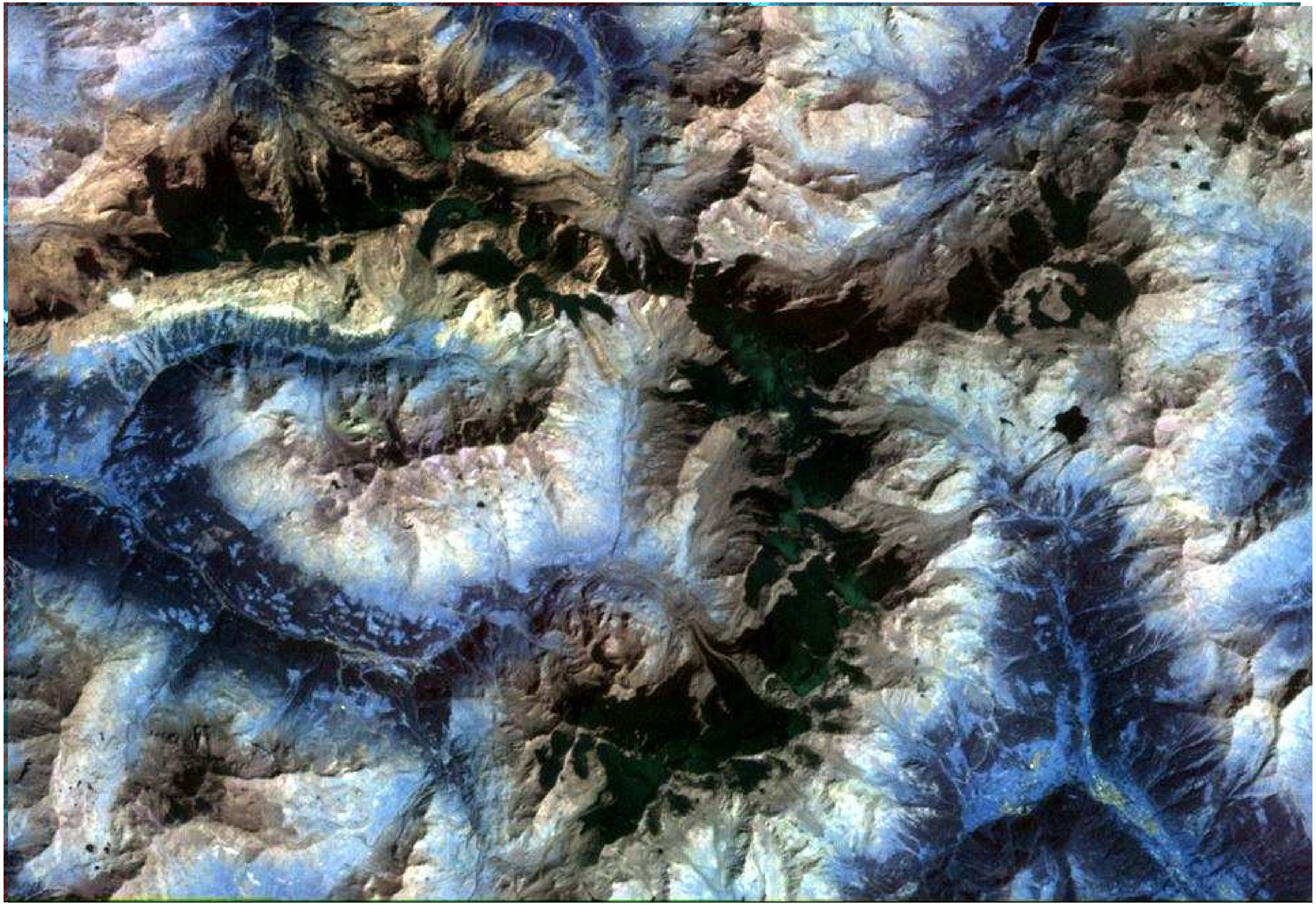
Examples of images

26 August 2010 Landsat ETM+



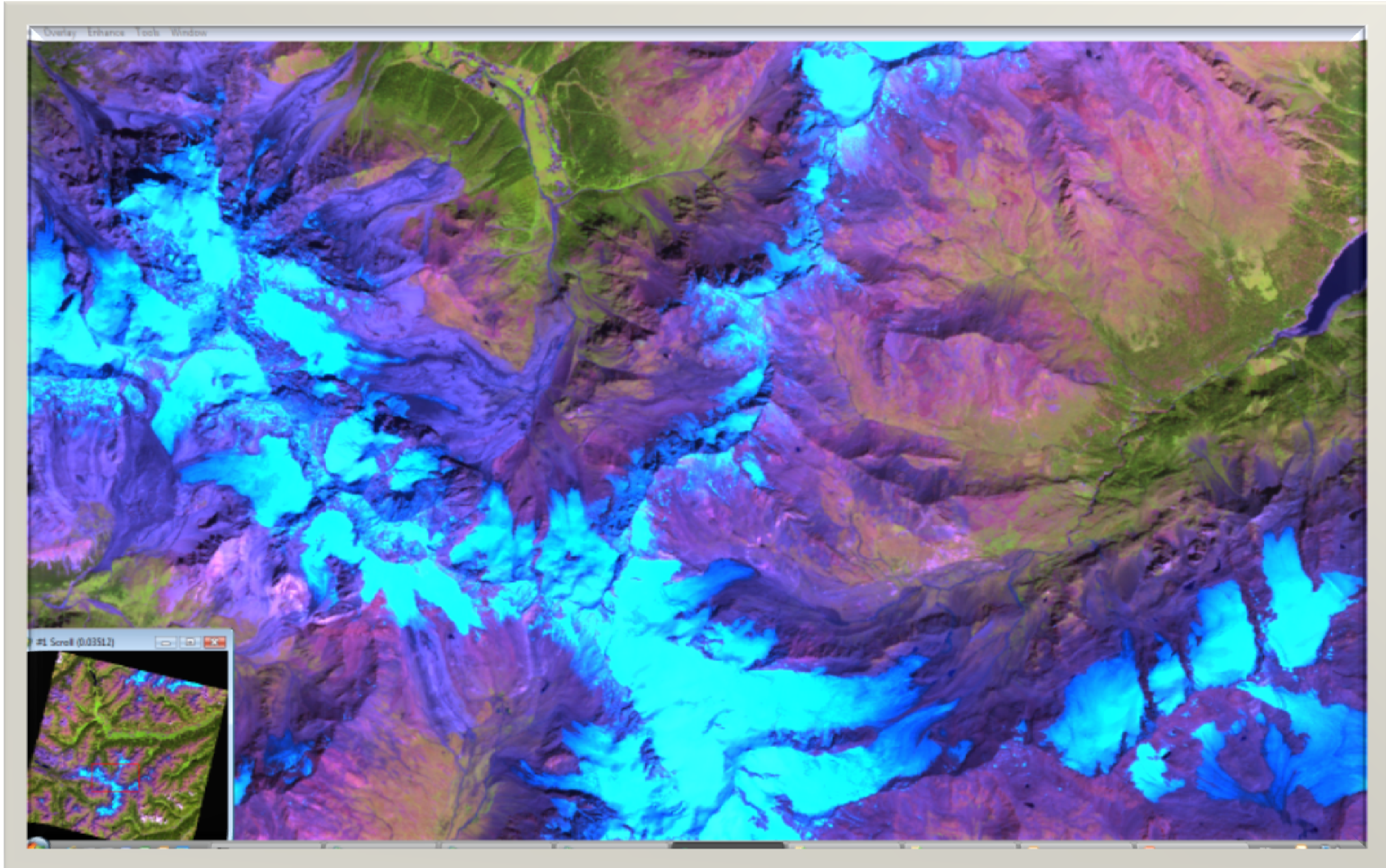
Examples of images

2007 ASTER



Examples of images

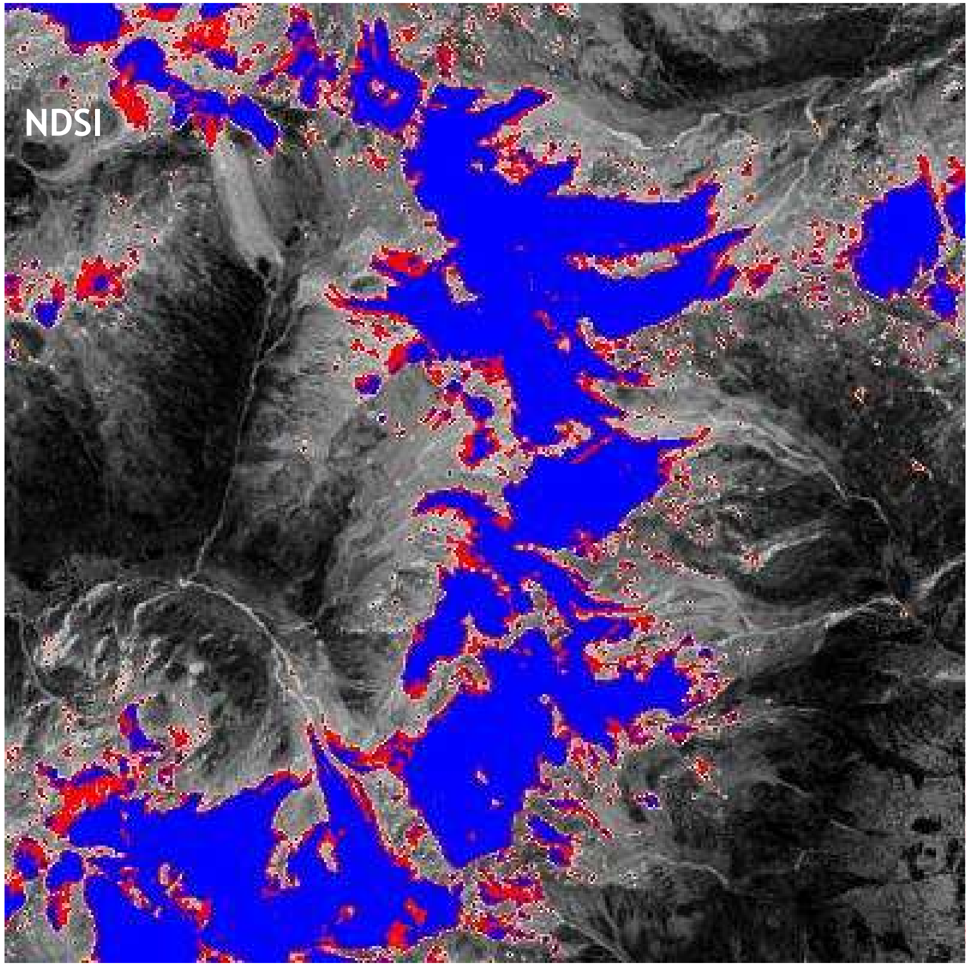
2004 SPOT5



Remote Sensing techniques: Literature review

Author	Automated methods for glacier mapping
Paul, 2000a	Best: **ratio 4/5 from raw DN** with thresholding (threshold =2) with glaciers over 0,1 km²(low reflectivity of snow and glaciers in the middle infrared, high reflectivity in the NIR. Debris-covered ice is tricky.
Paul, 2000b	Good results using **Unsupervised classification (Isodata)** and **Maximun Likelihood**
Paul, 2003	Good result with **ratio 3/5**
Kääb, 2003	ratio **3/4 ASTER**
Albert, 2002	ratio **4/5, 3/5** and **NDSI** have 90-95% accuracy
	maximum likelihood has 90% accuracy
Mc Fadden, 2010	using reflectance values (not raw DN) and **supervised classification** to detect snow and ice
Pellika, 2007	**NDWI** and **NDSI** (threshold for NDSI is 0,2)
	Debris-covered ice
Paul, 2004	Debris-covered ice detection using ratio 4/5 and DEM (slope <24°)
Bolch, 2003	debris-covered ice using temperature data (ASTER thermal band): Good result if debris size is < 0,5m². Problems: shaded areas could have the same T as ice; debris is warmer if subjected to radiation; low resolution of the thermal band.
Taschner and Ranzi, 2002	debris-covered ice using temperature data (thermal band). Good result (low T) only where are crevasses

Visual comparison of different methods



NDSI > 0.7
R45 > 2
NDSI > 0.4
R45 > 7
R45 > 1.8

Study on the Ortles- Cevedale glaciers

An assessment of changes in glacier extent from 1987 to 2010 in the Ortles-Cevedale massif (one of the largest glacierized areas in the italian Alps) by means of satellite images.

Analyses focused on semi-automatic classification of exposed ice areas, accumulation areas and debris-covered areas in different years, by using Landsat imagery. Validations were accomplished on a sample of four glaciers by comparison with surveyed outlines.

SATELLITE IMAGES :

•**Landsat** (7ETM+, 4-5 TM, 1-5 MSS)
Ikonos

→Images are selected during the end of the melt season (summer, late July -September) to enhance the probability to have the lower amount of fresh snow
BEST IMAGES: 2010,2009,1999,1987,1973

→**Problems**: fresh snow, clouds, different geometric and spectral resolution of the sensors.
→**Ikonos** : the scene doesn´t cover the entire mountain chain

ORTOPHOTOS:
1982, 1997, 1999, 2006, 2008 (+ Volo G.A.I. 1953)

DEM: LIDAR 2006

Pictures
Field data of La Mare and Careser
Maps

Methodology

Several Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper (ETM+) scenes with 30 m resolution (since 1987 to 2010) were collected and analyzed in order to investigate changes in glacier extent.

Late-summer (end of August to September) and clear-sky images were selected in order to minimize the occurrence of seasonal snow on the ground and cloud cover.

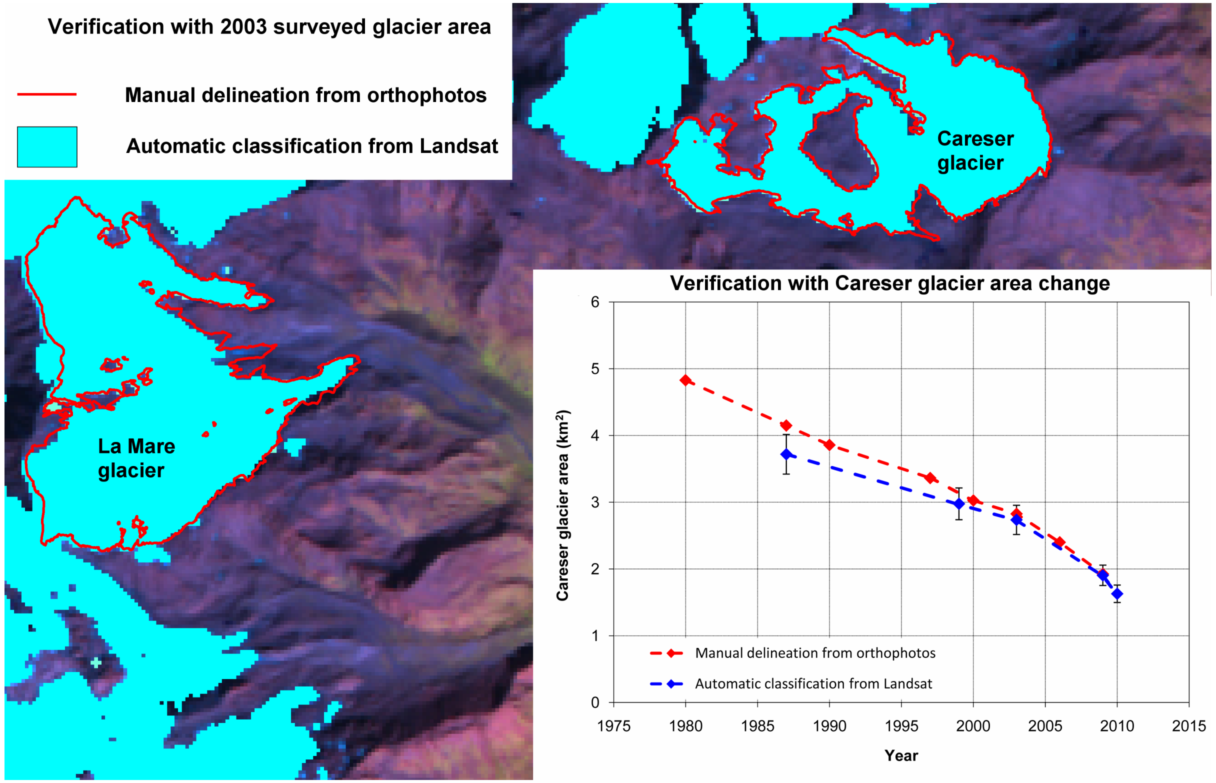
Landsat 5 TM images were used for 1987, 1999, 2003, 2009 and a Landsat 7 ETM+ was used for 2010.

Raw imagery was used, without any calibration or atmospheric correction. Images pre-processing consisted in 2 major steps: application of a mask of the study area and correction of the 2010 Landsat 7 ETM+ scene for striping (due to failure of the Scan Line Corrector).

ENVI, ERDAS and ARCMAP softwares were used for image processing, classification and calculations.

Classification of exposed ice areas

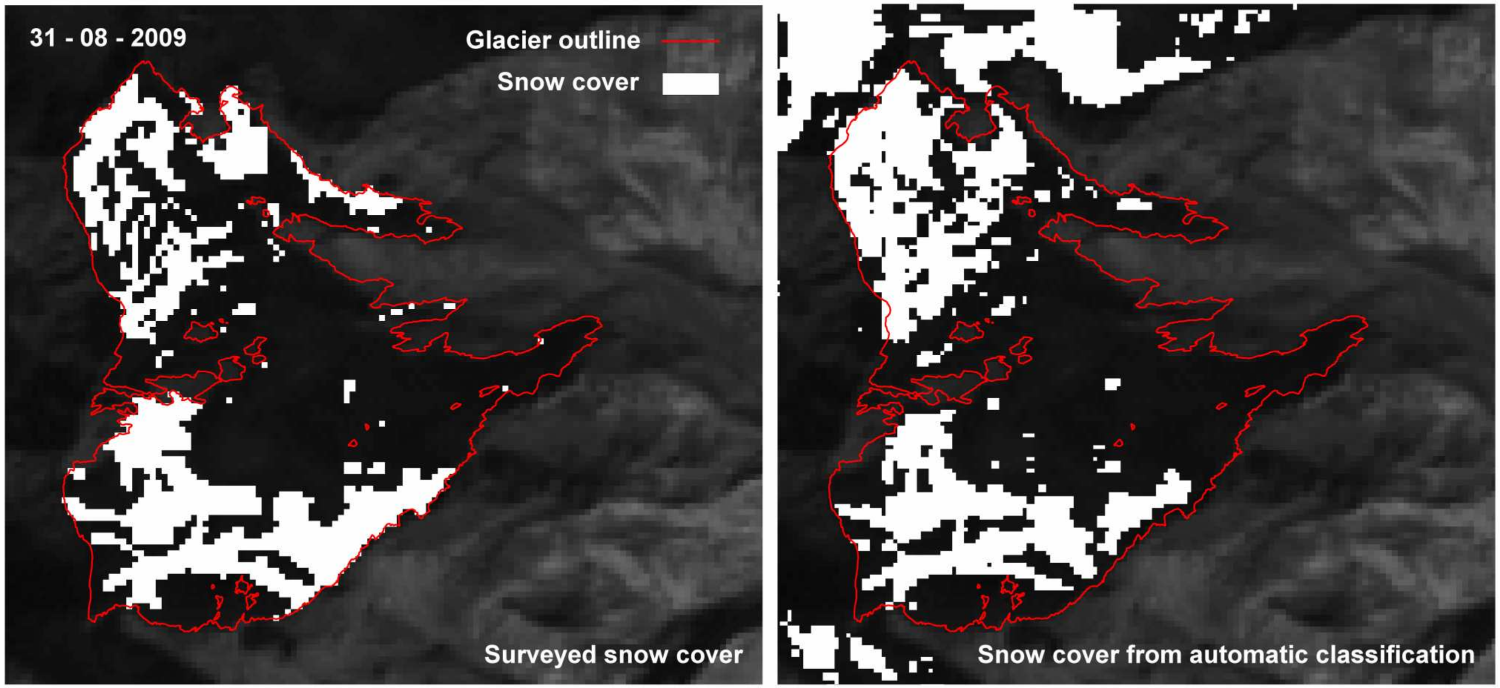
Thresholded band ratio images from TM and ETM+ channels 4 and 5 (Hall et al, 1987; Paul, 2000, Paul et al., 2002) were used.
This method was applied on raw digital numbers (DN) images. Results were additionally filtered (majority filter 3x3) in order to avoid misclassification of isolated pixel not connected to the glaciers.
Thresholding was optimized by comparisons with manual delineations of false colour composites (bands combination 5-4-3 of TM and ETM+) and with surveyed outlines of Careser and La Mare glaciers in 2003 and 2009. In addition, detailed geodetic surveys of Careser glacier were available in the last 30 years for validation.



Verification of automatic area classifications with surveyed glacier outlines. Error bars indicate an uncertainty of 8% in classifications, depending on the band ratio 4/5 threshold.

Classification of accumulation area

Ratio images of the raw digital numbers from TM and ETM+ channel 4 and 5 were also used to map snow cover. Clear-sky and late-summer images were available for 1987, 1999, 2009 and 2010 and allowed an analysis of the recent evolution of the accumulation areas.
Calibrations and validations were accompished by comparison of classifications with surveyed snow cover maps .



Comparison between Landsat derived and surveyed snow cover maps on La Mare glacier on 31-08-2009.

Change in glacier area and Accumulation Area Ratio (AAR) from 1987 to 2010

From 1987 to 2010 glaciers lost 29% of their surface. This loss rate (-1.3% y^{-1}) is consistent with similar studies carried out elsewhere in the European Alps (Paul et al., 2004b; Knoll and Kerschner, 2009).

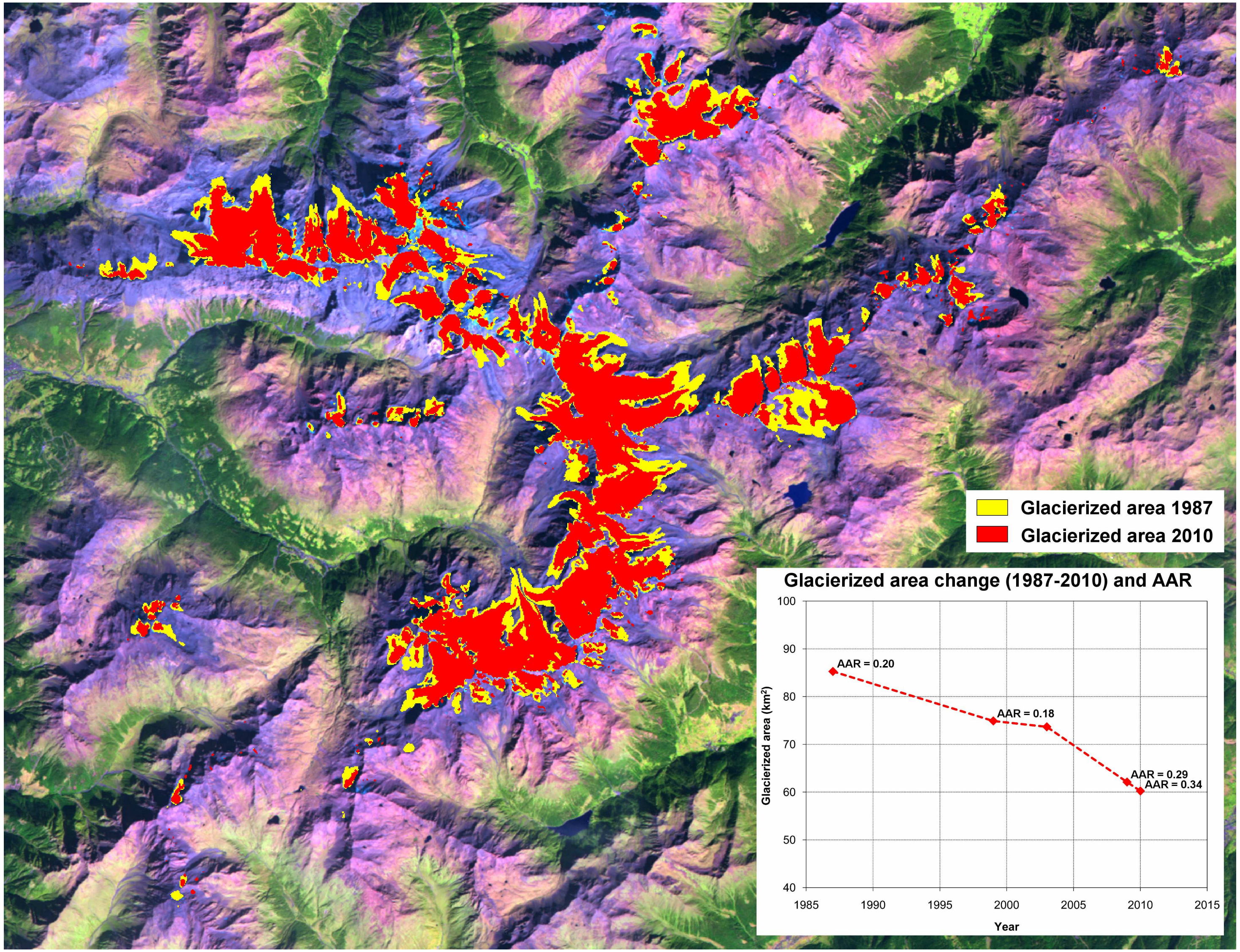
The area loss rate increased from -0.8% y^{-1} before 2003 to -1.4% y^{-1} after 2003, in accordance with the increased climatic forcing registered by mass balance measurements on Ortles-Cevedale glaciers (e.g. Carturan and Seppi, 2007).

The accumulation area, in the early 80,s it was already subjected to an important reduction (average 1987 AAR = 0.19). A small increase in accumulation area was observed in the last two years (2009 and 2010).

Year	Glacierized area (km^2)	Accumulation area (km^2)	AAR
1987	85.3	16.6	0.20
1999	74.9	13.1	0.18
2003	73.7	-	-
2009	62.1	17.6	0.29
2010	60.2	20.4	0.34

The total glacier area reduction and the recent increase of the accumulation area led to a significant increase of the average AAR. However, the current accumulation area is still far from yielding equilibrium conditions (i.e. AAR ~ 0.60, Benn and Evans, 1998).

Change in glacier area and Accumulation Area Ratio (AAR) from 1987 to 2010

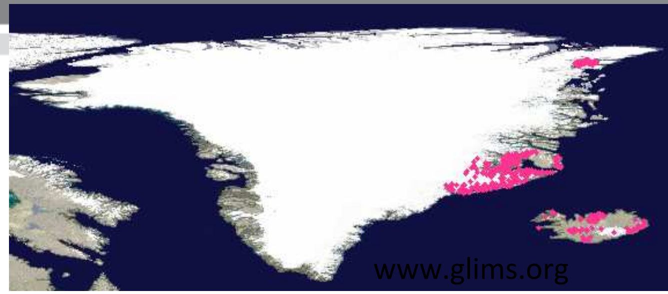


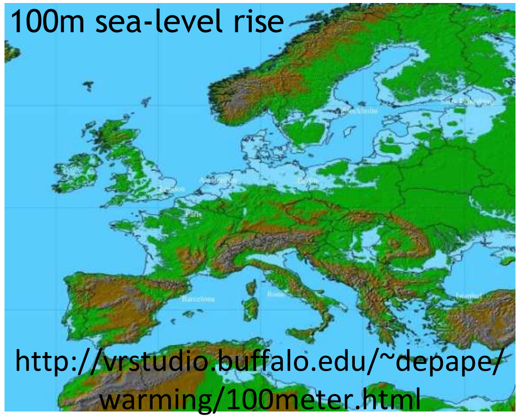
The upcoming Glacier Inventory for Greenland

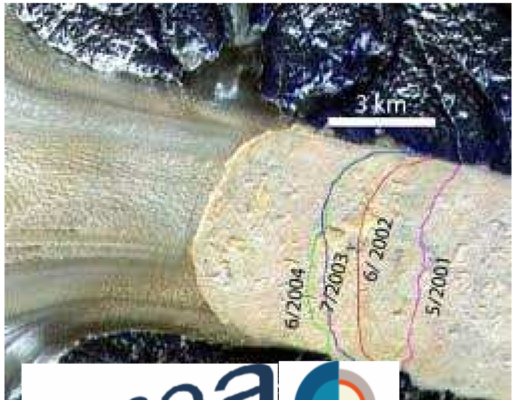
Philipp Rastner, 2010

Why Glacier Inventory?

- No complete inventory available (GLIMS)
- Potential large contribution to sea-level rise
- Required for:
  - Investigation of glacier fluctuations (length, area…)
  - Determination of ice volume
  - Distributed mass balance models
  - Calculation of future glacier development

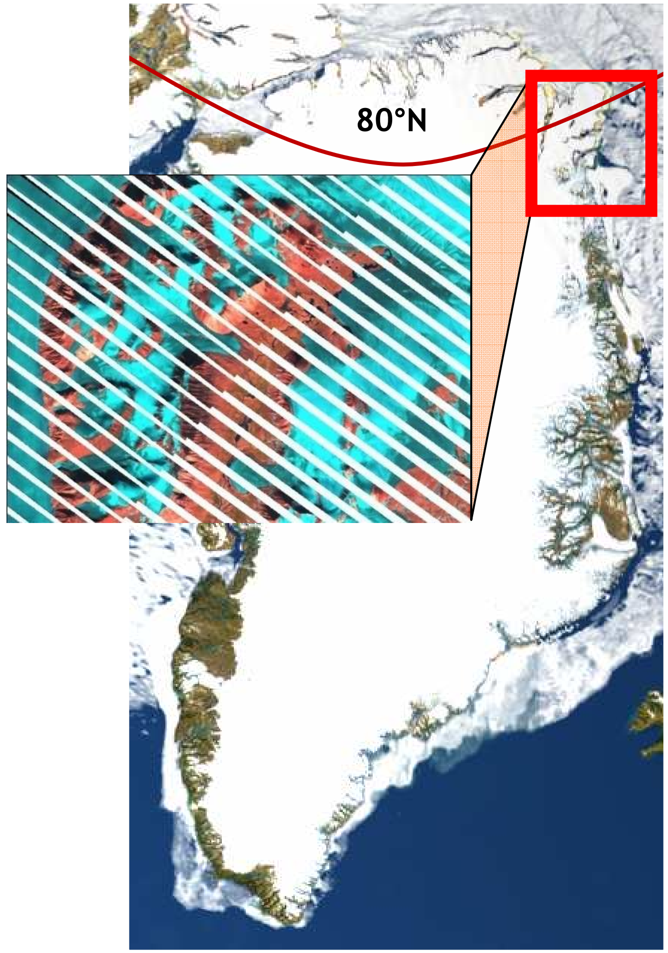




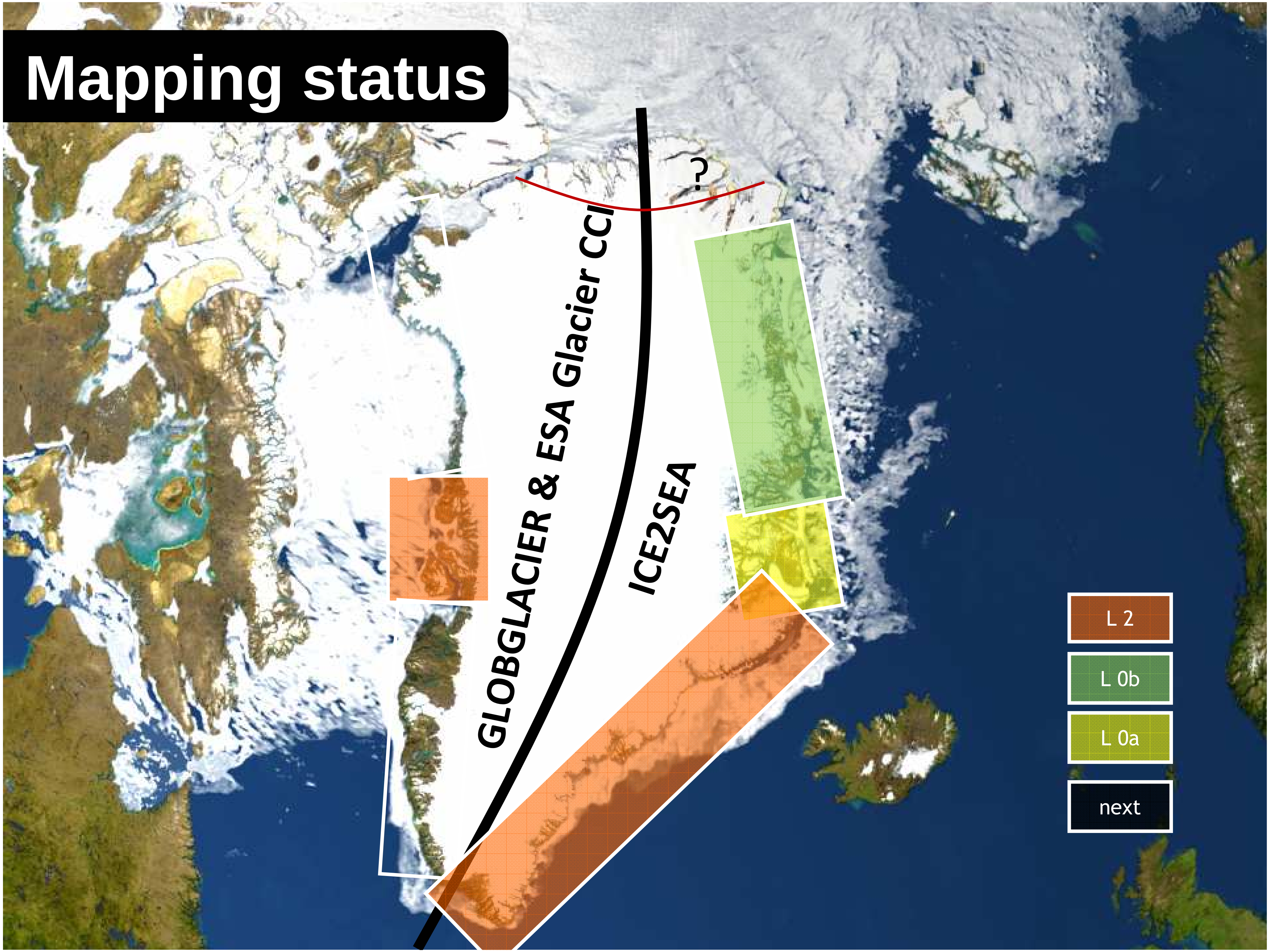


The Greenland Glacier Inventory

- **Data (~2000):**
  - Landsat ETM+, 30m resolution
  - ASTER GDEM, 30m resolution
- **MMU:** 0.1km²
- **Challenges:**
  - No Landsat coverage > 80°N
  - SLCoff scenes

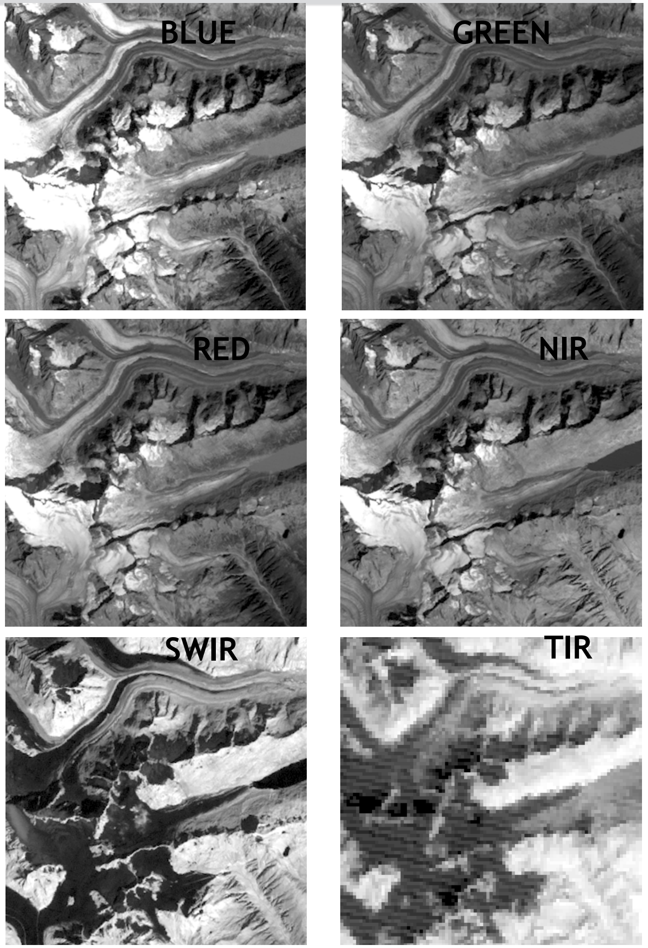


Mapping status

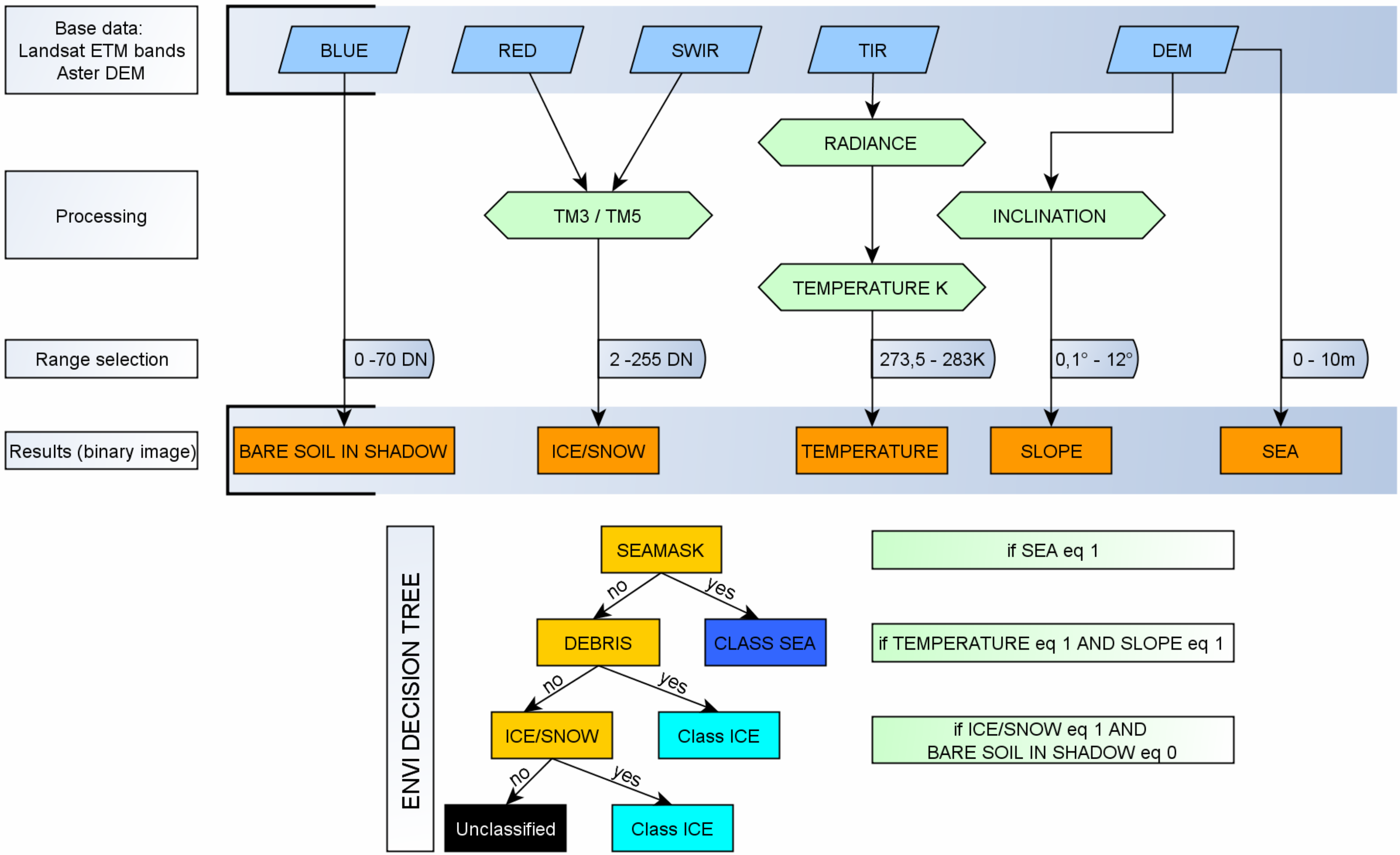


Glacier Mapping methods

- Ratio Images:
  - Red/Swir -> good results in shadow zones
  - Nir/Swir -> good results in areas facing sun
- Helpful bands:
  - Blue -> good for mapping snow/ice in shadow areas
  - Tir -> good for mapping debris cover
- Additional dataset:
  - Digital elevation models

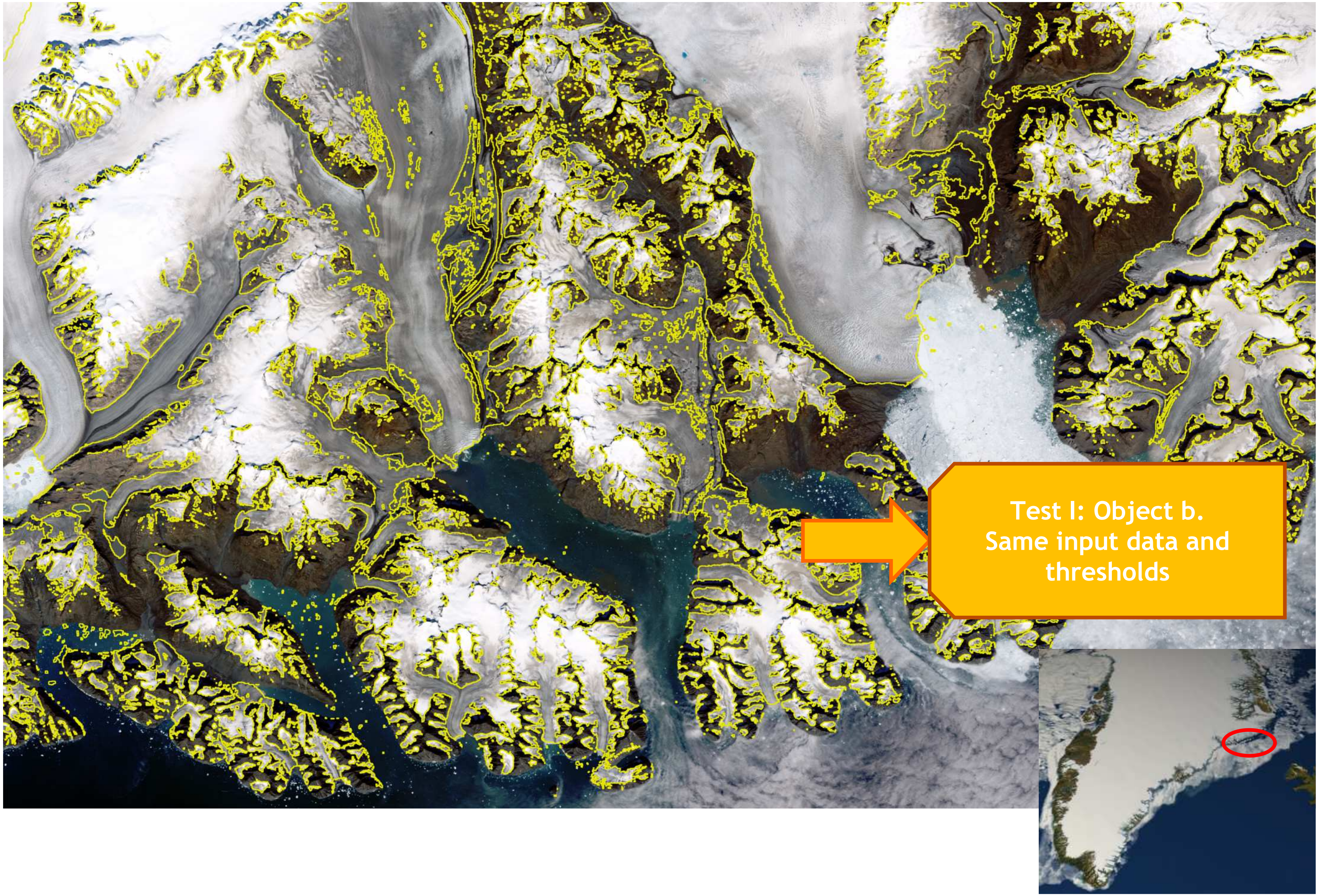


Pixel-based Glacier Mapping



Philipp Rastner, 2010

Results (pixel based)



Object based classification

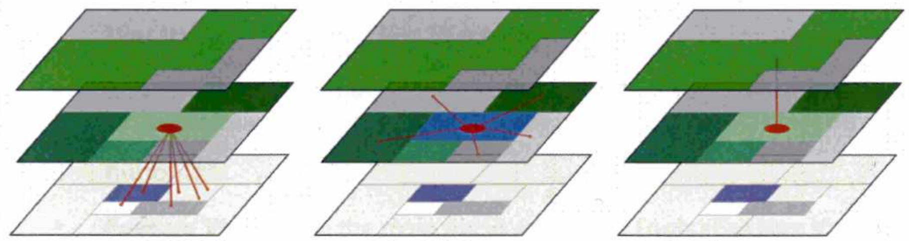
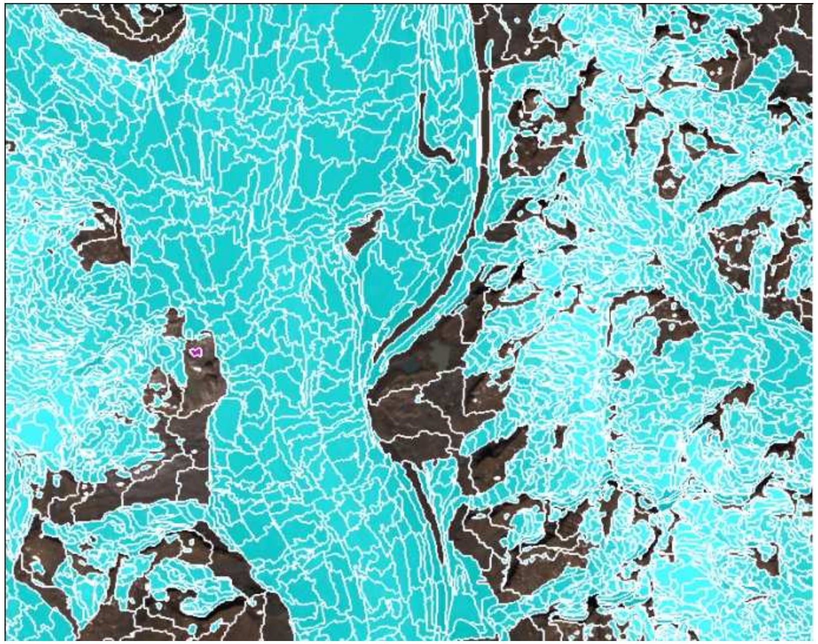
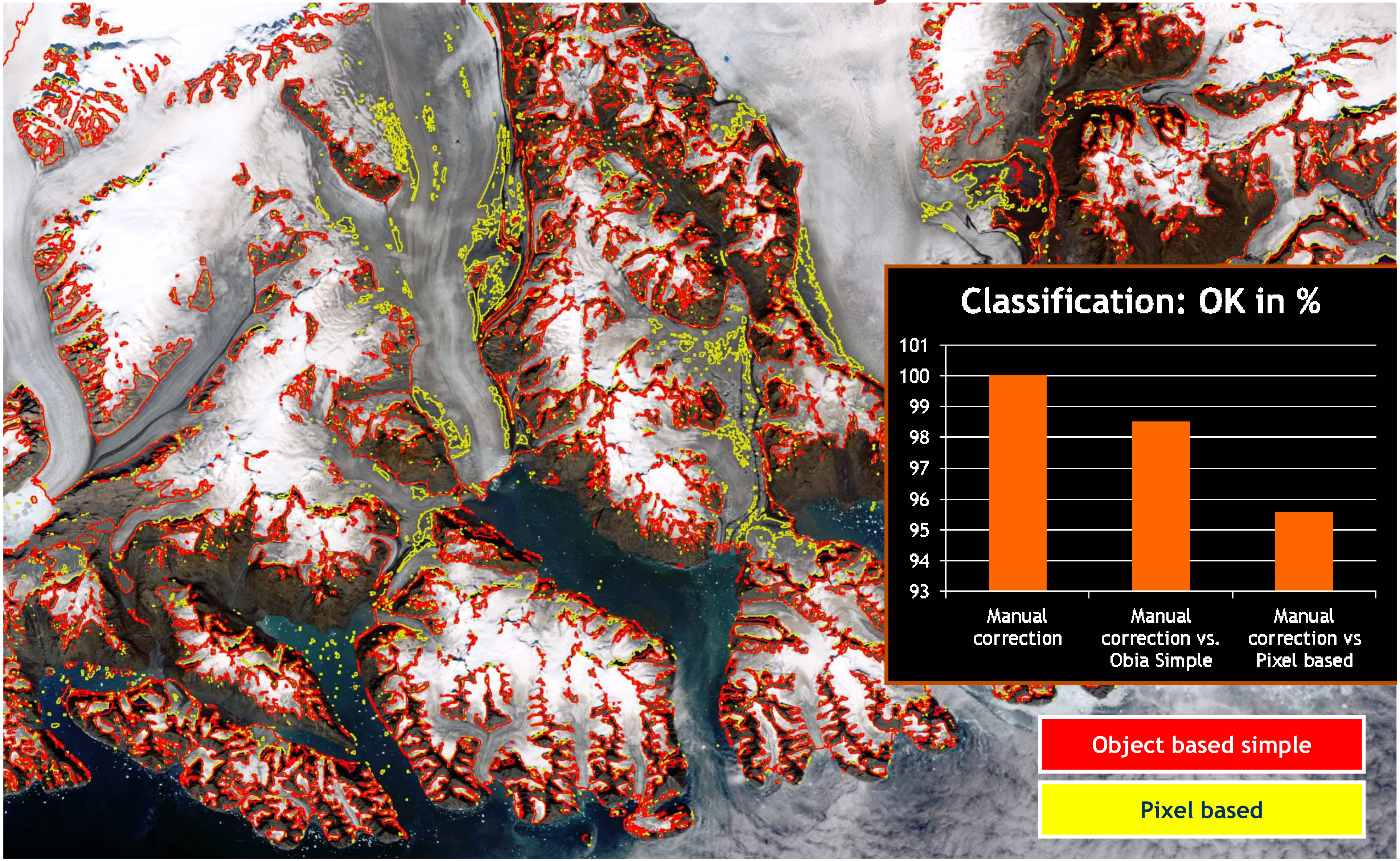


Figure 33: 2 schemes of hierarchical network of image objects in abstract illustration.

- Object-based image classification:
  - Combination of spectral and spatial information
  - Basic processing units are segments, not single pixels
  - Based on fuzzy theory ->membership values

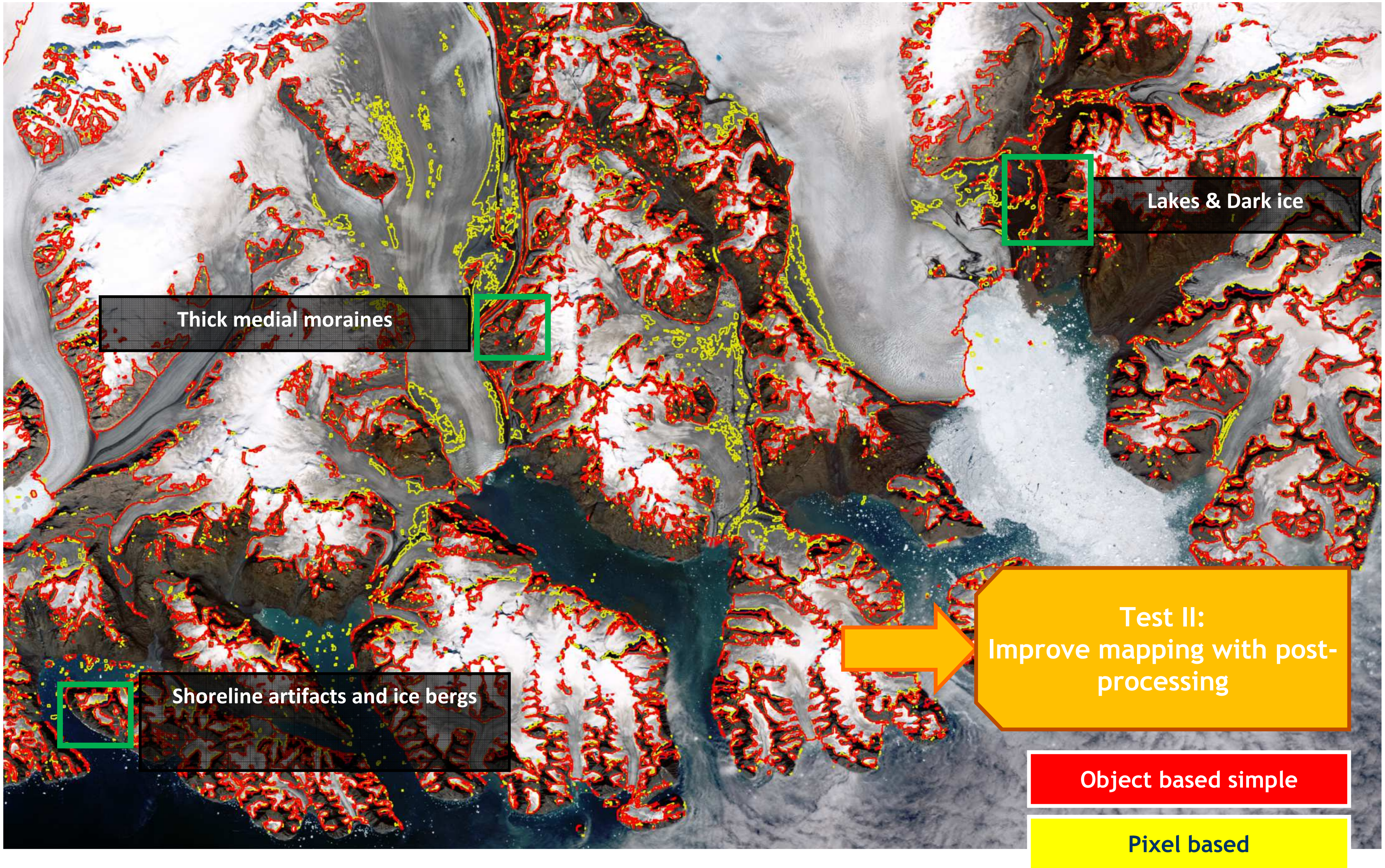


Comparison: Pixel-Object-based



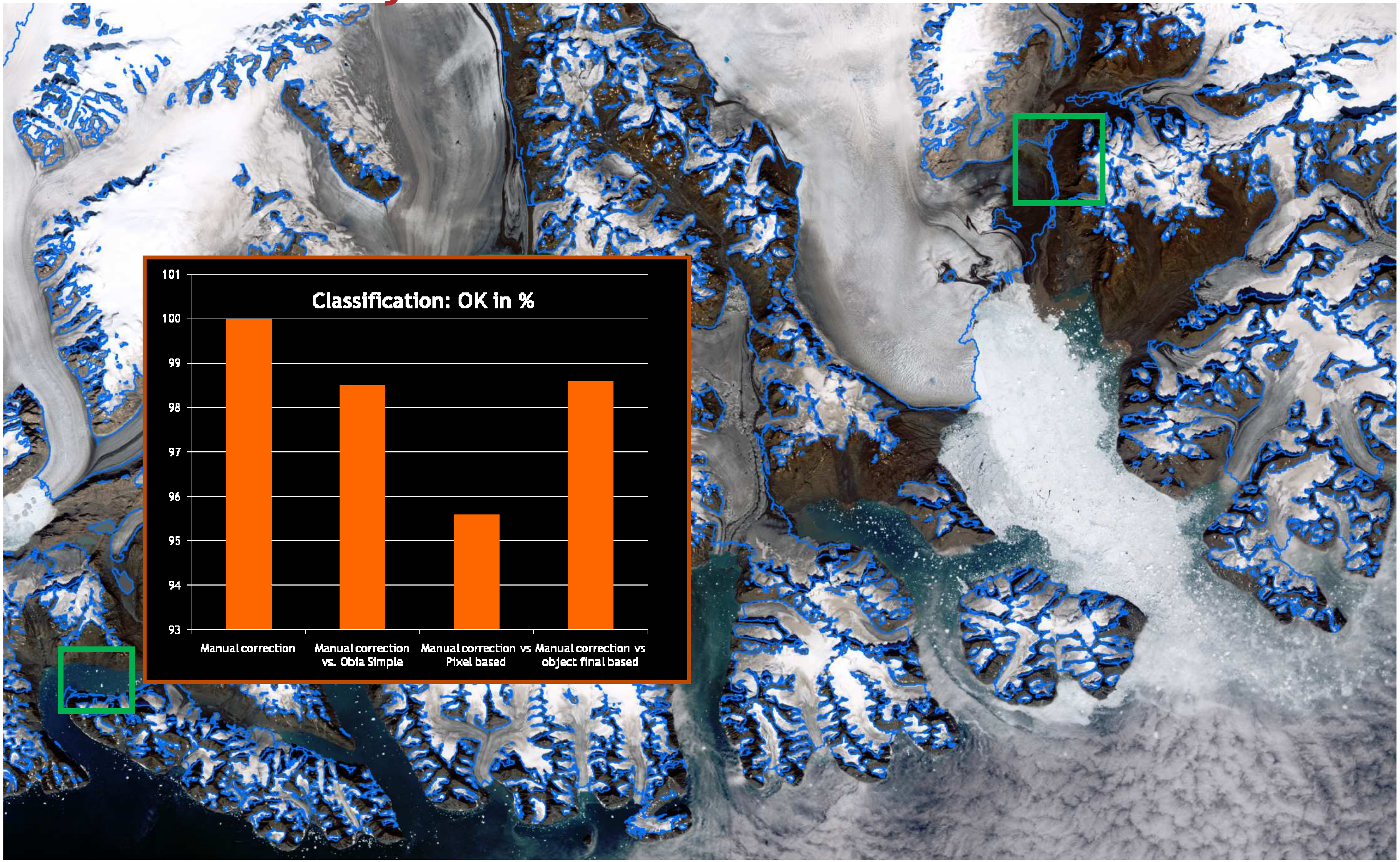
Philipp Rastner, 2010

Identified mapping inaccuracies



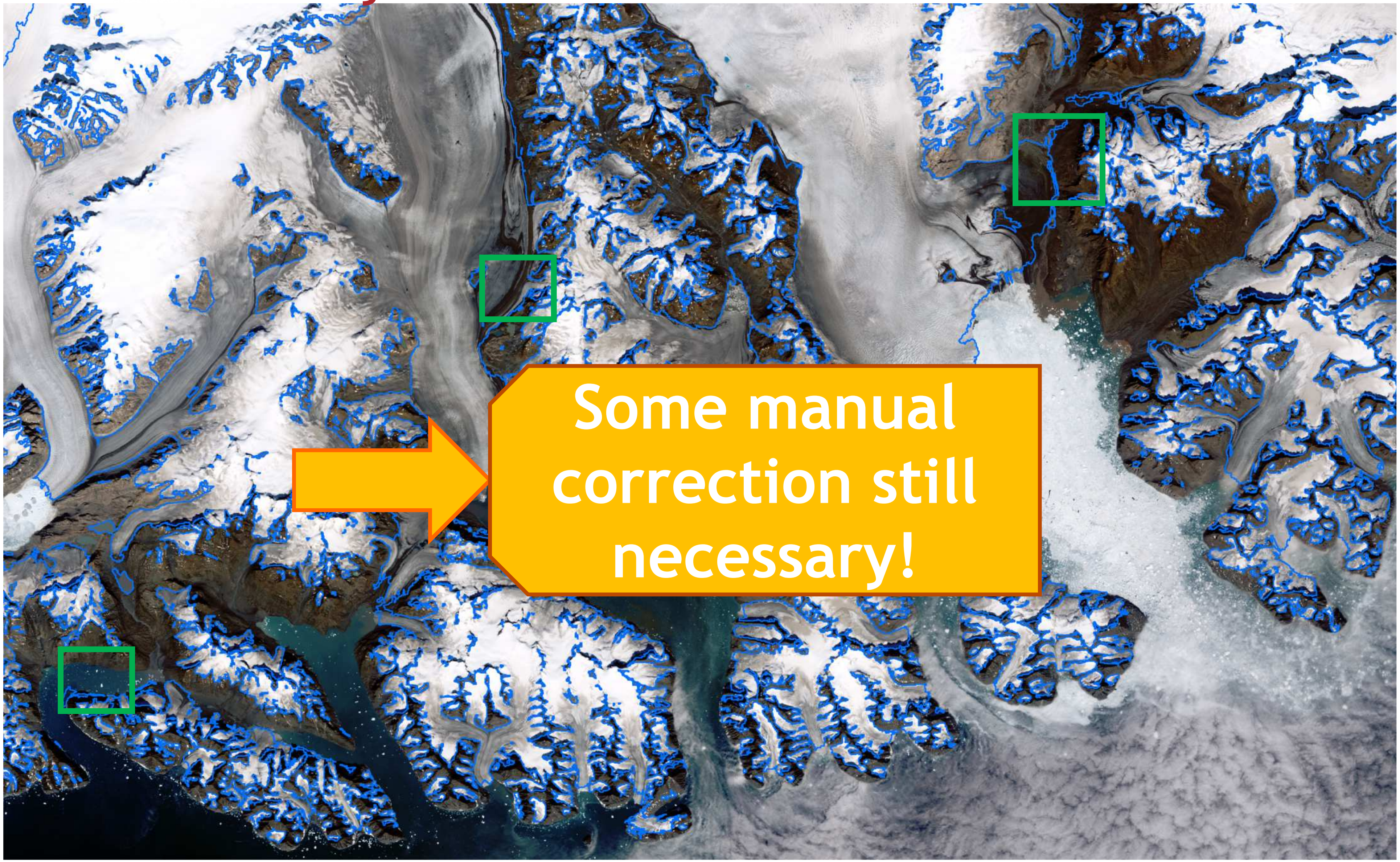
Philipp Rastner, 2010

Object-based classification result



Philipp Rastner, 2010

Object-based classification results



Philipp Rastner, 2010

Conclusive remarks

1. Semi-automatic classification based on thresholds of optical images (LANDSAT, ASTER or equivalent) is a valuable tool for multitemporal analyses of glacier and snow-cover changes.
2. Debris-covered ice is difficult to map by means of semi-automatic classification without manual supervision, since it could be misclassified with recently deglaciated terrain at high altitude. Slope and TIR are suitable for mapping debris-covered ice. The BLUE band is helpful for mapping ice in shadow
3. In the comparison between pixel based and object based methods, both classification methods face the same mapping problems
4. Clearly less wrong classified pixels in the GEOBIA approach
5. GEOBIA mapping approach is clearly stronger then the pixel-based one, however manual correction remains as well

Thank you very much
for the attention!

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