Belvedere Glacier and Monte Rosa east face (Macugnaga, NW Italy). Evolution of the from summer 2000 to present.

Andrea Tamburini (Imageo srl, Torino, Italy)

Université Européenne d'Eté sur les Risques Naturels – Gressoney, octobre 2014

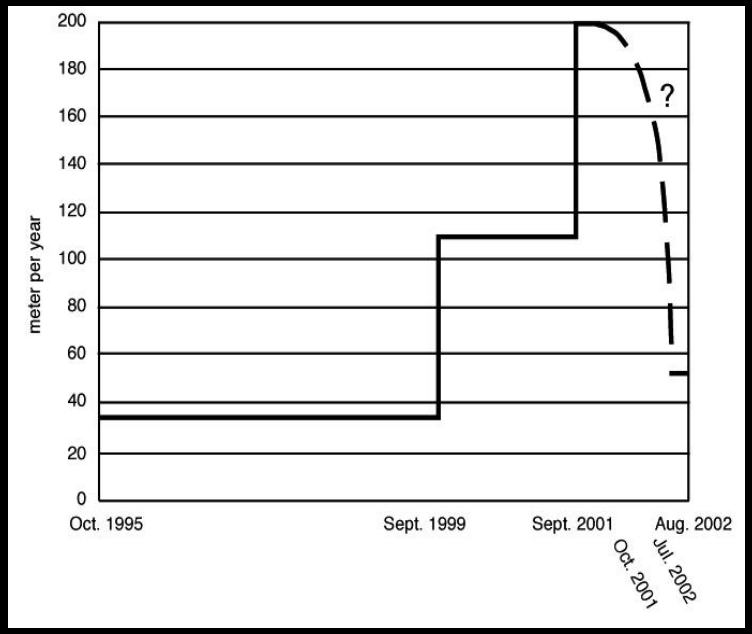
Monte Rosa East Face and Belvedere Glacier

Brief history

- ✓ Surge-type ice flow acceleration since 2000

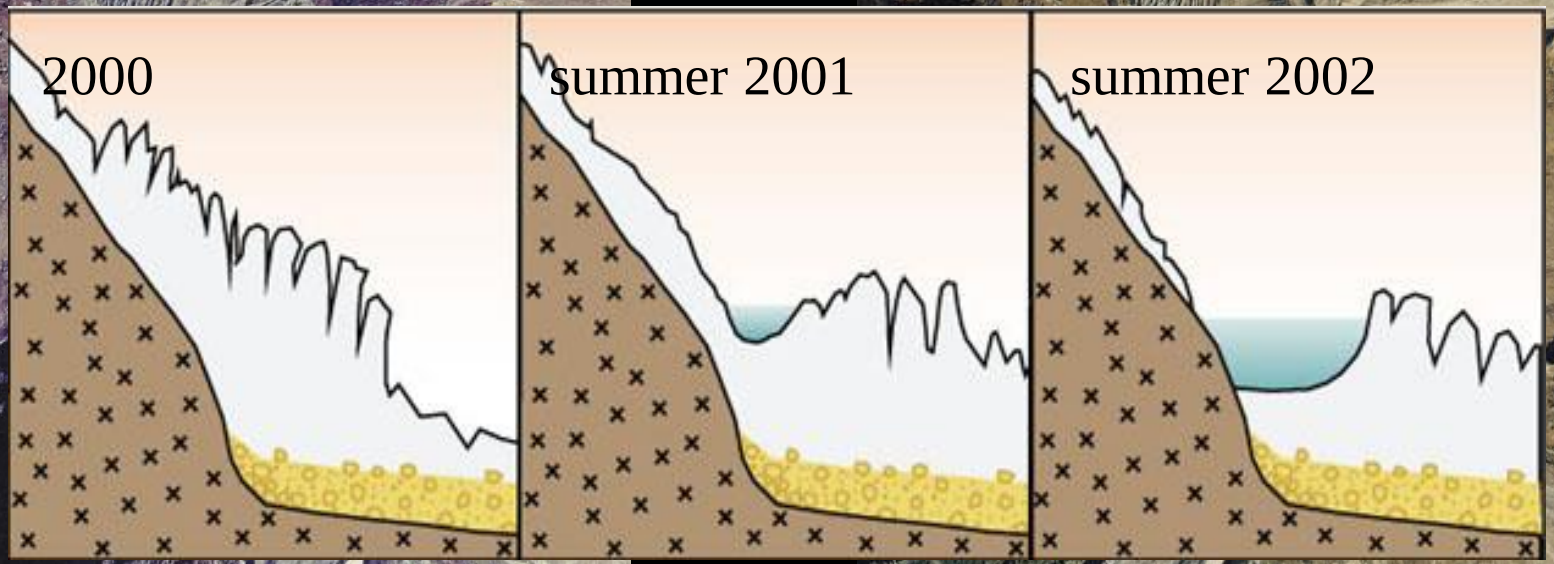
Brief history

- ✓ Surge-type ice flow acceleration



1985

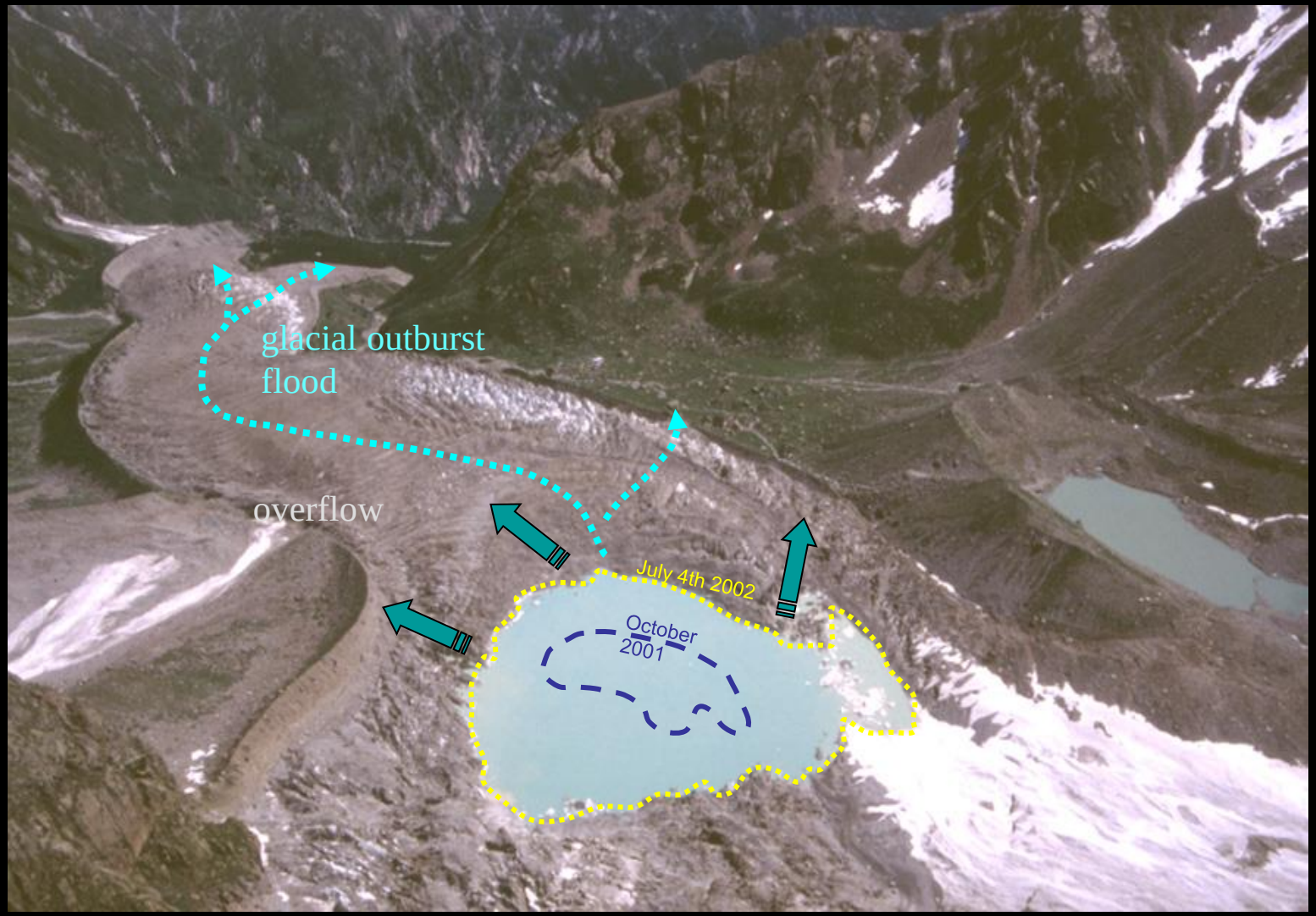
October 2001



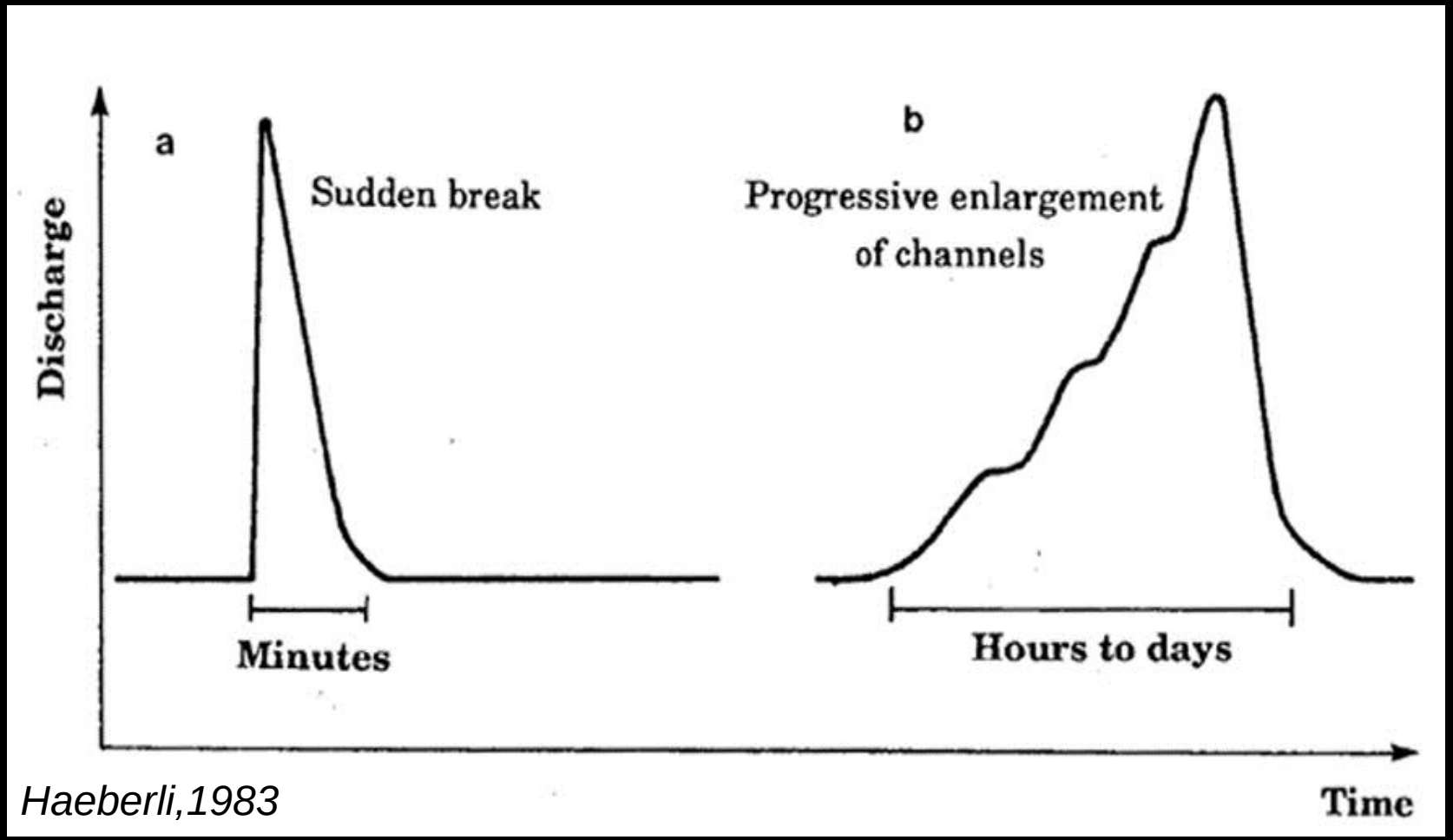
Brief history

- ✓ Surge-type ice flow acceleration since 2000
- ✓ June 2002: emergency related to supraglacial lake (Lago Effimero) formation

The surge-type movement of the Belvedere glacier: evolutive scenarios



The surge-type movement of the Belvedere glacier: evolutive scenarios



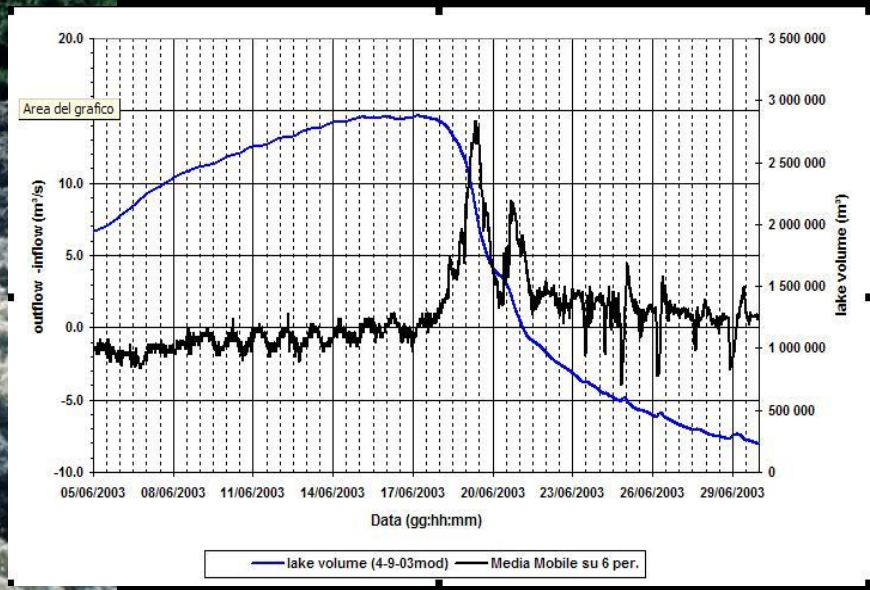
Haeberli,1983

Brief history

- ✓ Surge-type ice flow acceleration since 2000
- ✓ June 2002: emergency related to supraglacial lake (Lago Effimero) formation
- ✓ June 2003: Lago Effimero outburst flood

Brief history

- ✓ Surge-type ice flow acc
- ✓ June 2002: emergen
  Effimero) formation
- ✓ June 2003: Lago Effime

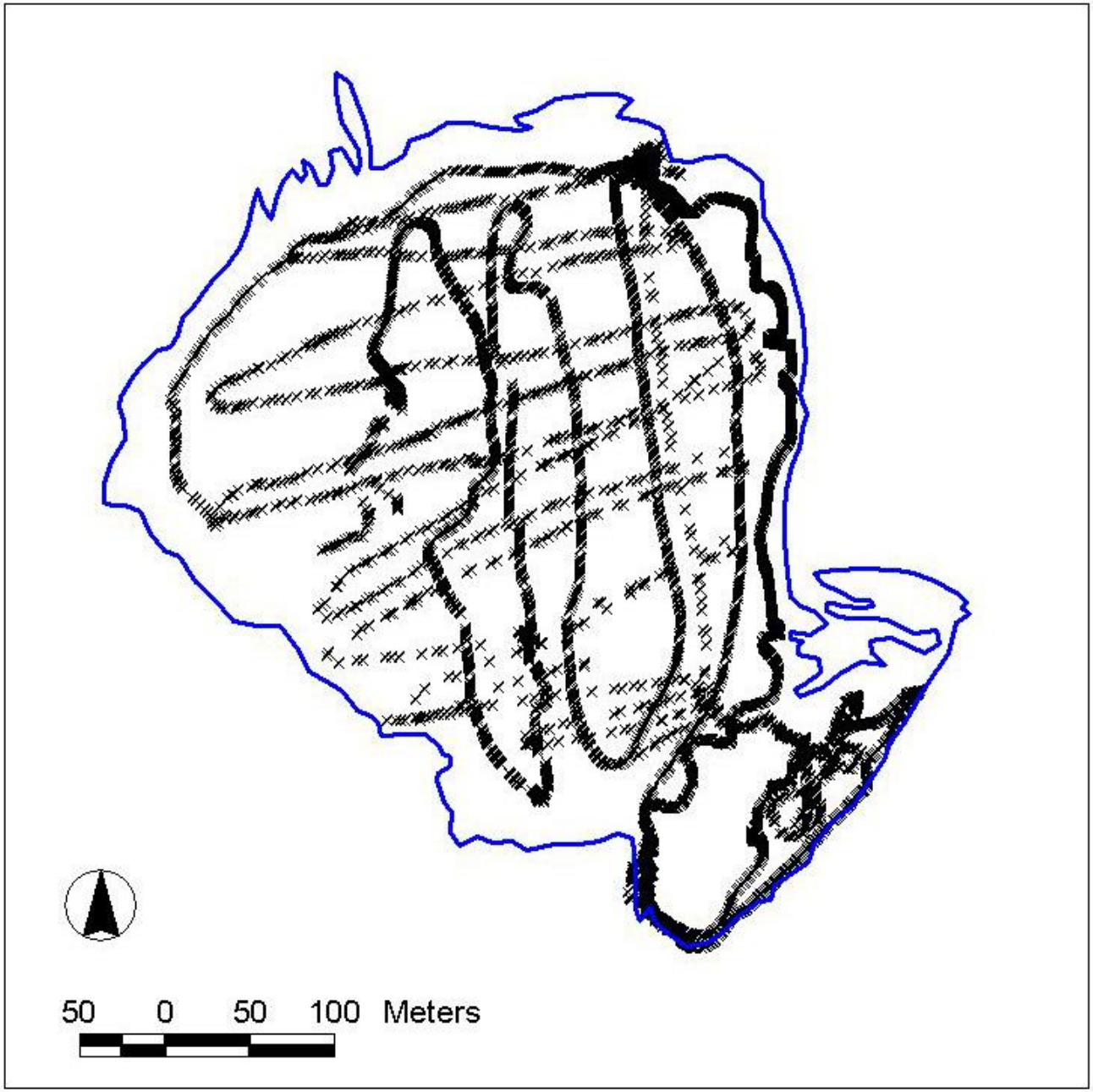


Investigations and studies during the emergency

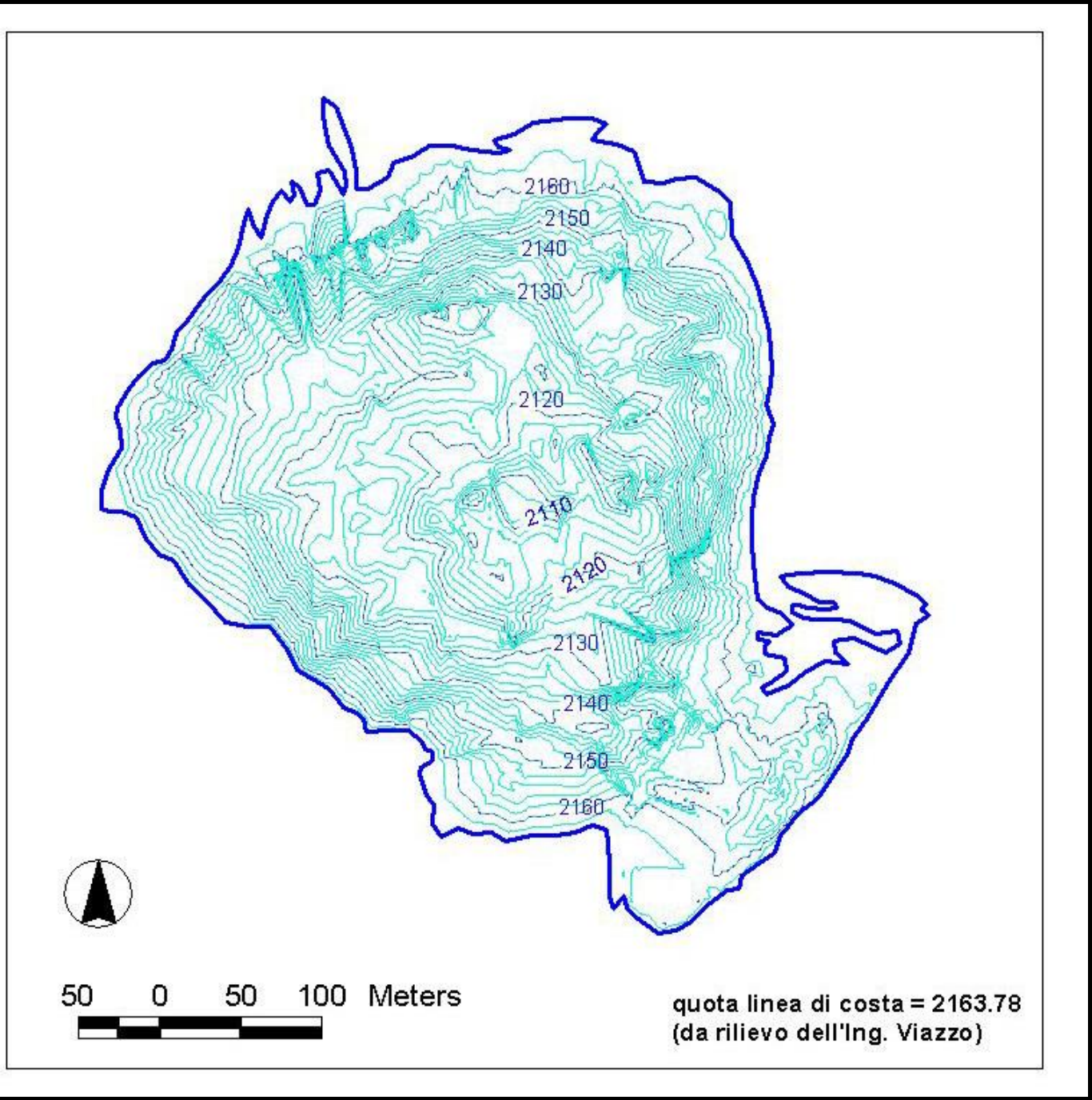
- bathymetric surveys (lake bottom morphology, lake volume and water level vs volumes curve)
- GPR surveys (ice thickness and glacial bed morphology)
- tracer tests (englacial and subglacial water drainage system)

Bathymetric survey

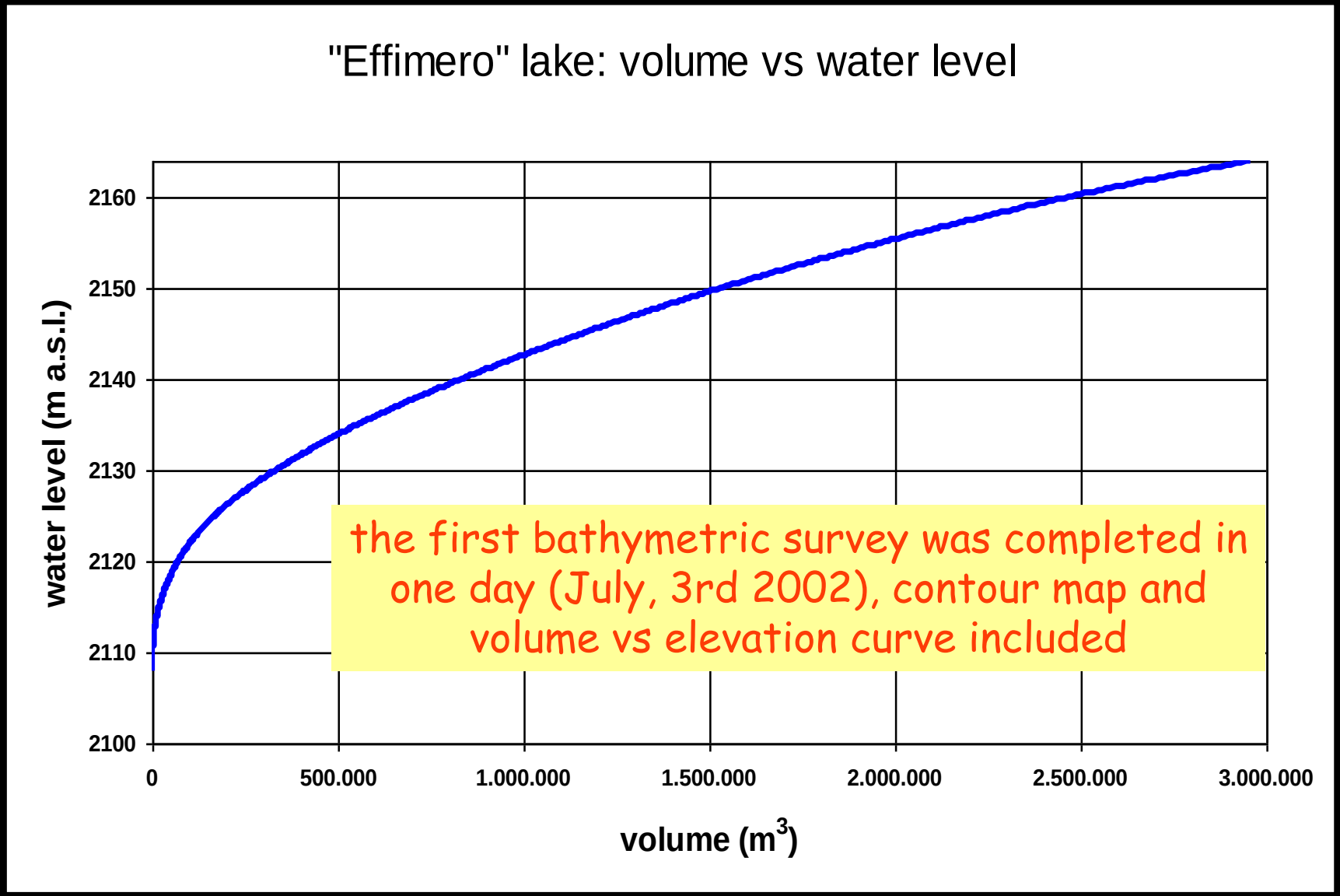
Bathymetri



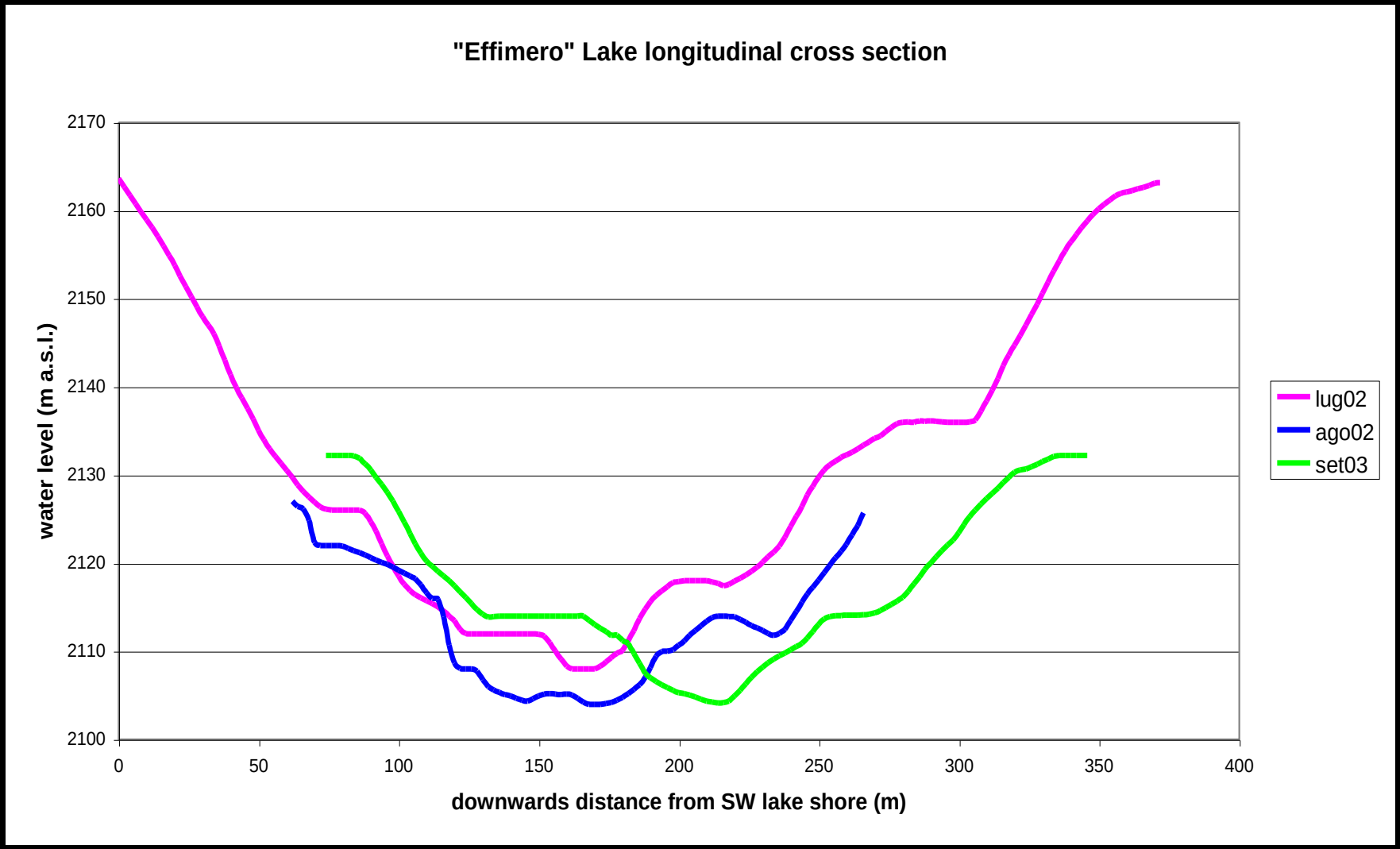
Bathymetr


2160
2150
2140
2130
2120
2110
2120
2130
2140
2150
2160
50 0 50 100 Meters
quota linea di costa = 2163.78
(da rilievo dell'Ing. Viazzo)

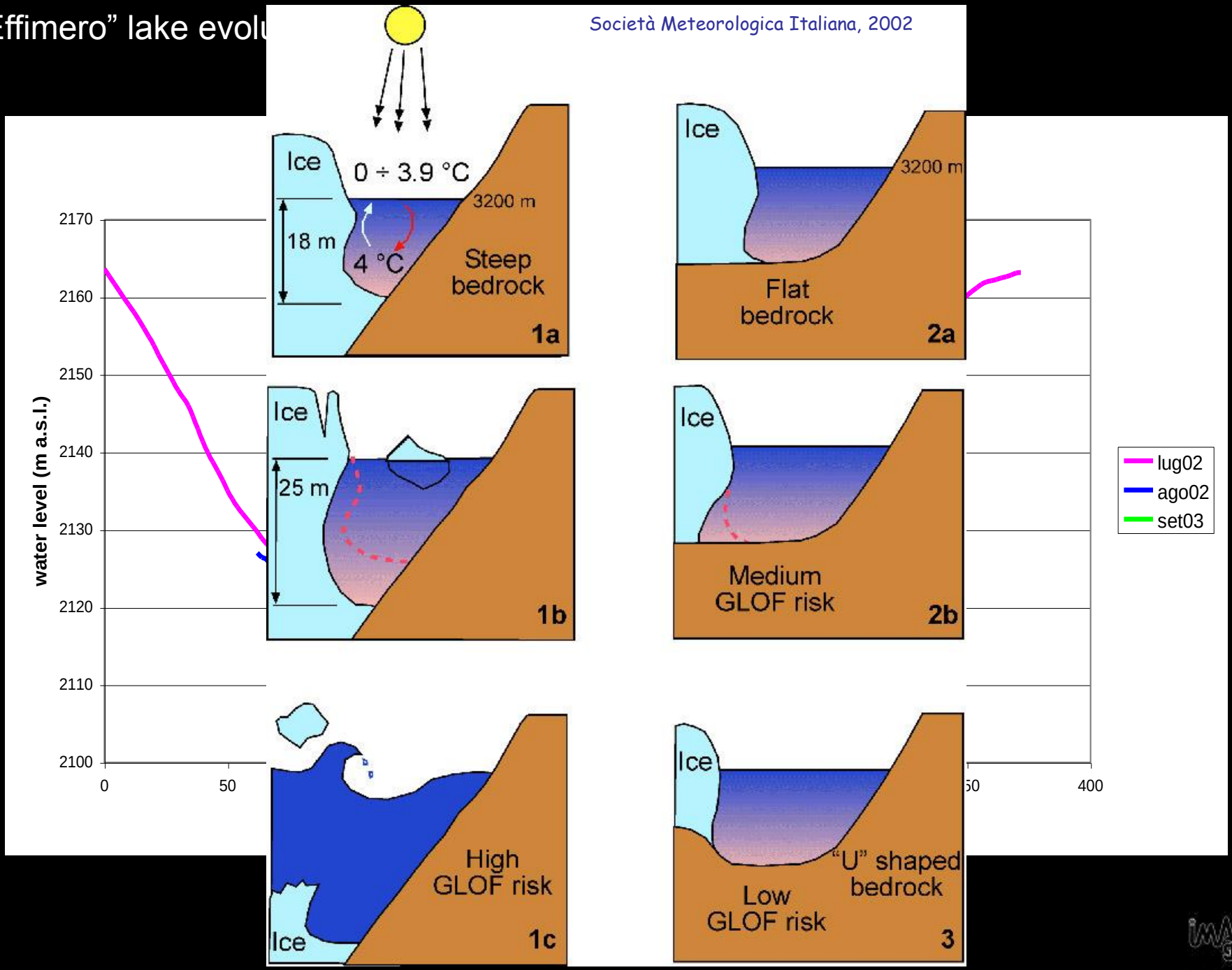
Bathymetric survey



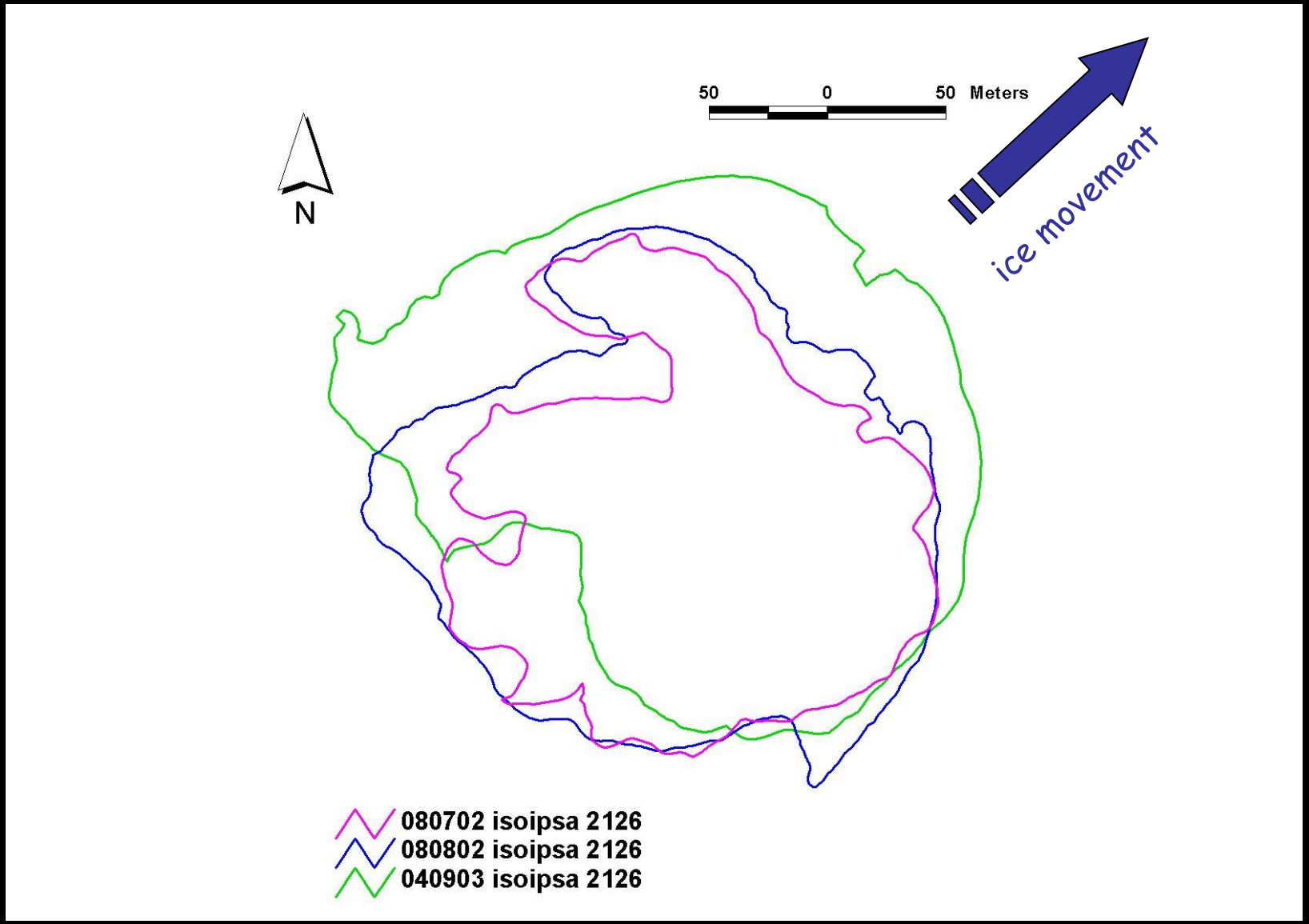
“Effimero” lake evolution from June 2002 to September 2003



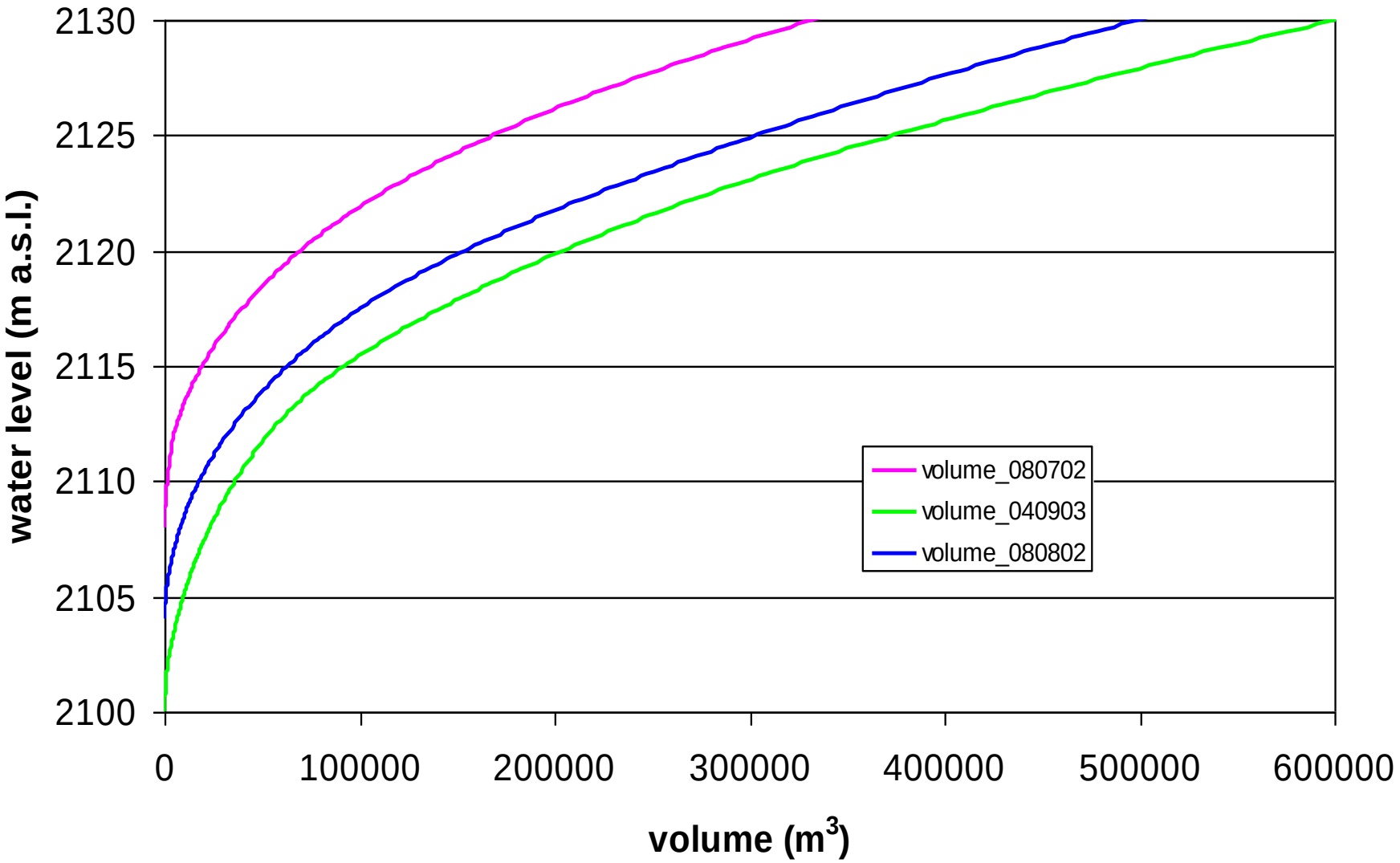
“Effimero” lake evolu



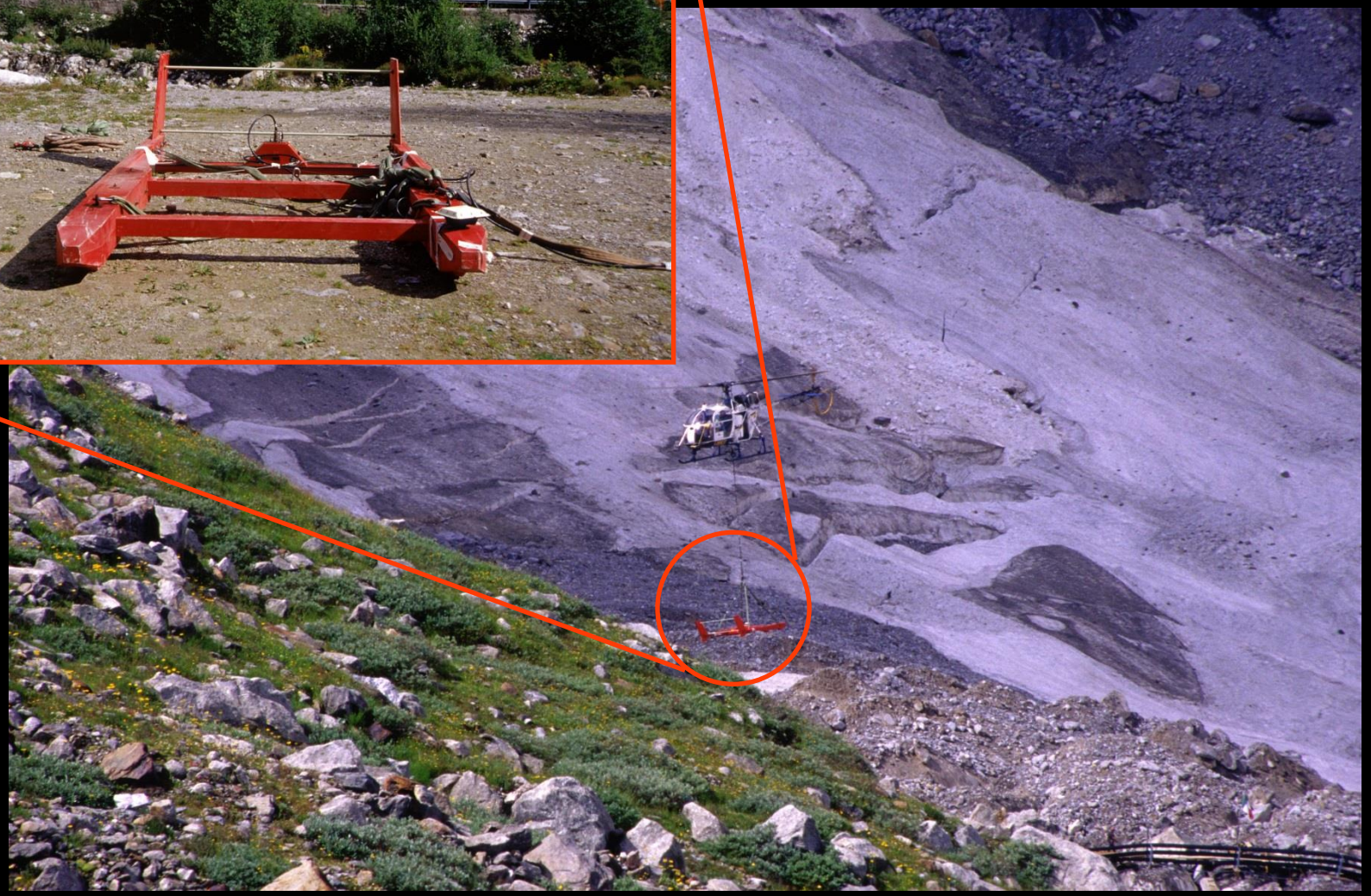
“Effimero” lake evolution from June 2002 to September 2003



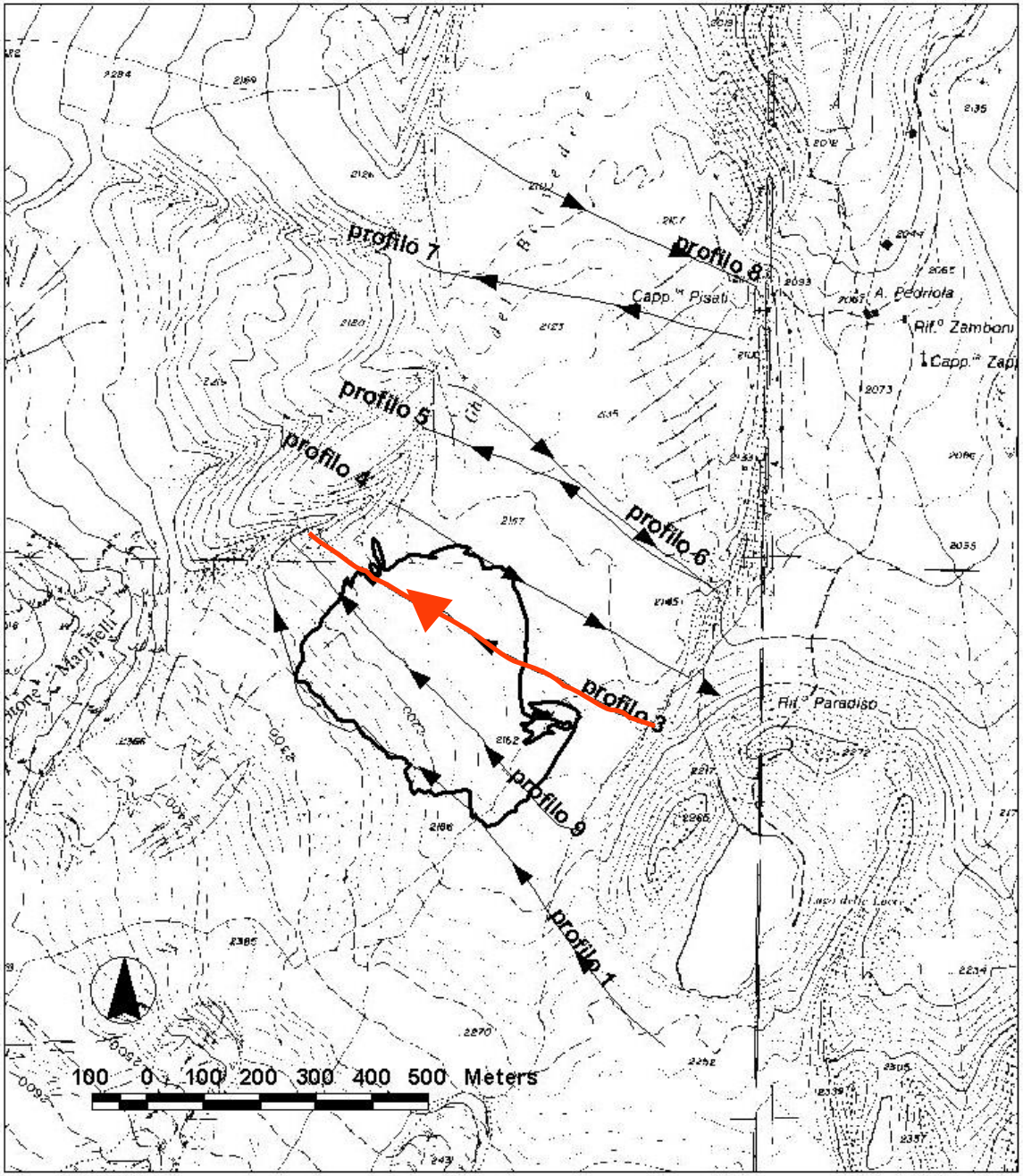
“Effimero” lake evolution from June 2002 to September 2003



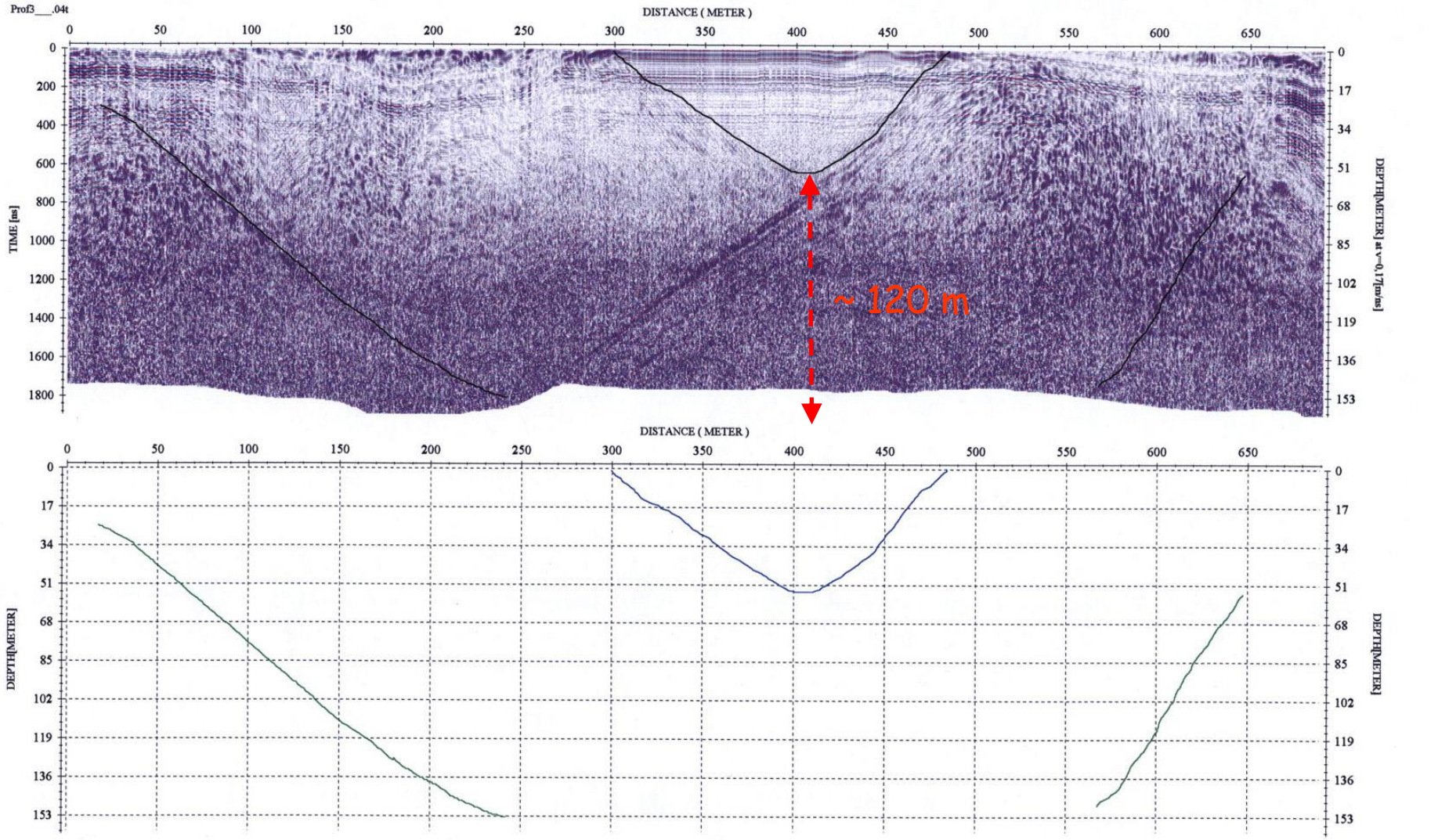
GPR surveys



GPR surveys


profilo 7
profilo 8
profilo 5
profilo 4
profilo 6
profilo 3
profilo 9
profilo 1
Capp.ª Pisati
A. Pedriola
Rif.° Zamboni
Capp.ª Zap
Rif.° Paradiso
Marinelli
100 0 100 200 300 400 500 Meters

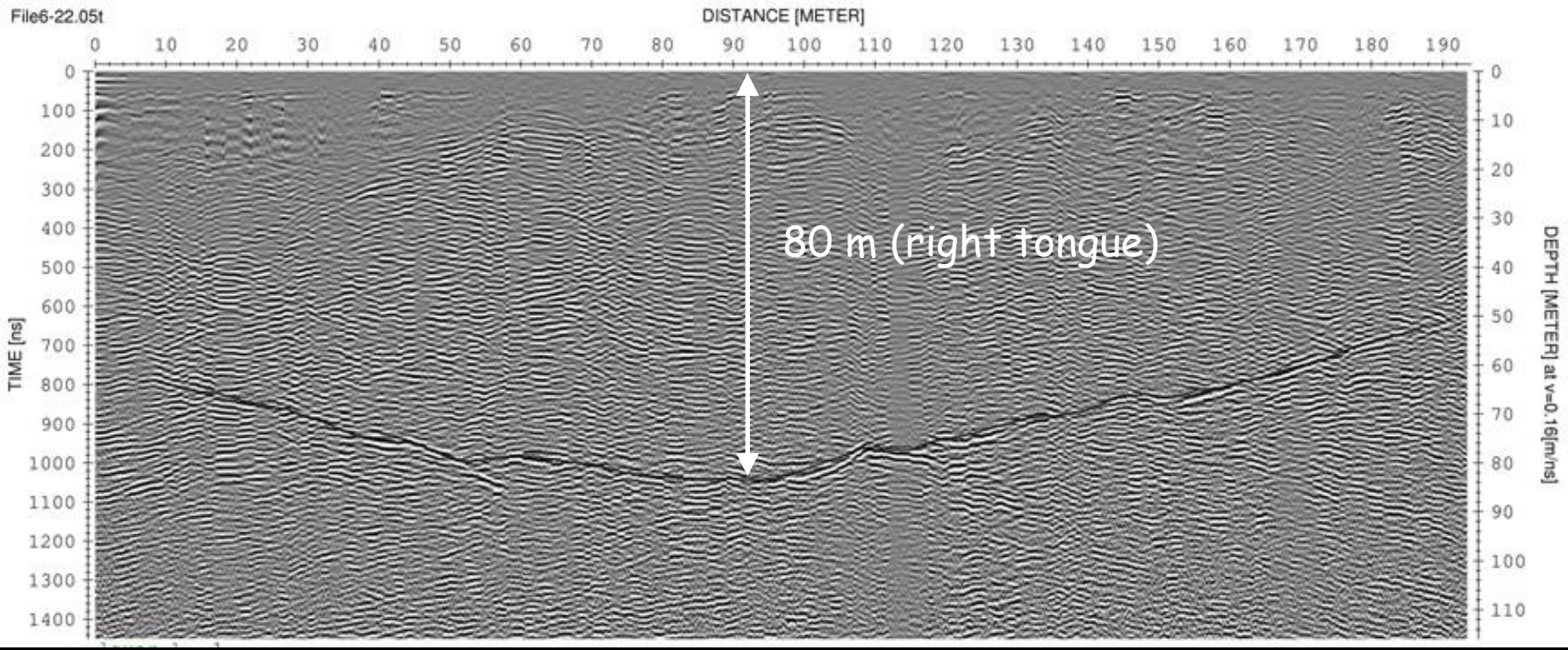
GPR surveys



The first GPR survey (from helicopter) was carried out on August 2nd-3rd 2002 and provided data about the ice thickness in the upper part of the glacier: so it was possible to estimate the ice thickness under the lake bottom (120 m)

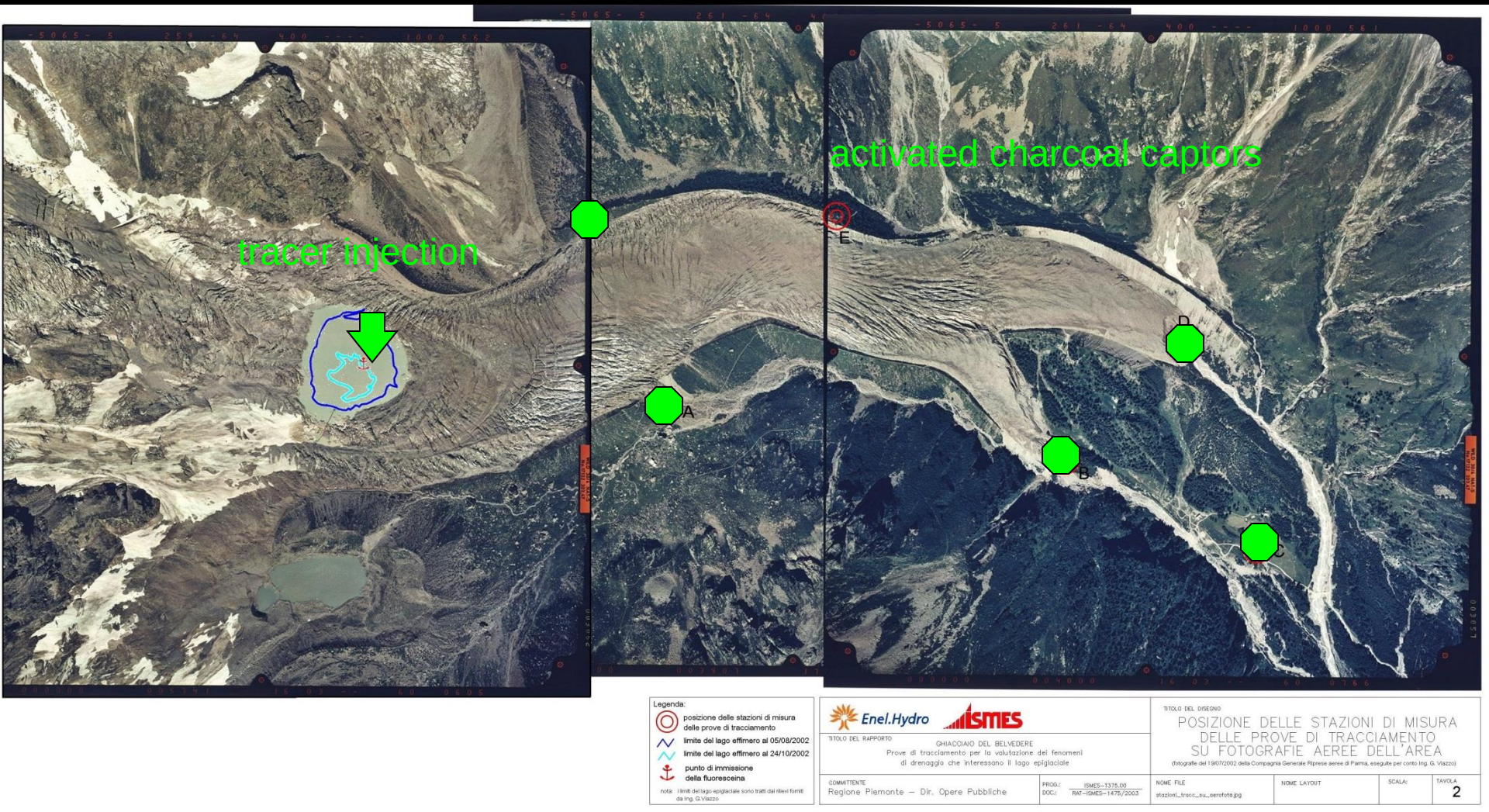
GPR surveys

GPR surveys



The second GPR survey (directly from the glacier surface) was carried out on May 22nd-23rd 2003 and provided data about the ice thickness and the glacial bed morphology in the lower part of the glacier

Dye tracer tests: site activity



Legenda:
- posizione delle stazioni di misura delle prove di tracciamento
- limite del lago effimero al 05/08/2002
- limite del lago effimero al 24/10/2002
- punto di immissione della fluoresceina

nota: i limiti del lago epiglaciale sono tratti dai rilievi forniti da Ing. G.Vlazzo

Enel.Hydro — ISMES

TITOLO DEL RAPPORTO: GHIACCIAIO DEL BELVEDERE
Prove di tracciamento per la valutazione dei fenomeni di drenaggio che interessano il lago epiglaciale

COMMITTENTE: Regione Piemonte – Dir. Opere Pubbliche

PROG.: ISMES–T375.00
DOC.: RAT–ISMES–1475/2003

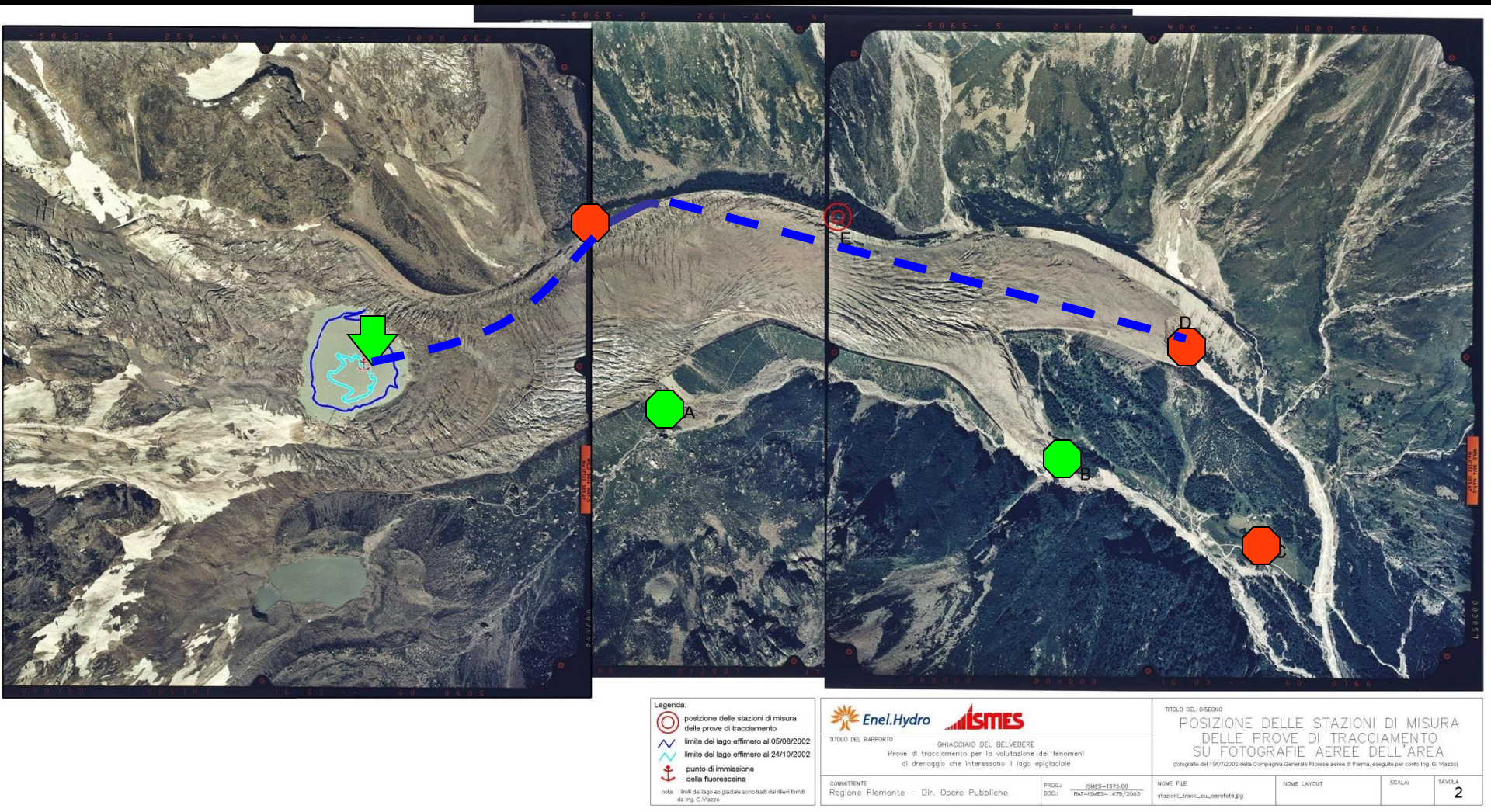
TITOLO DEL DISEGNO: POSIZIONE DELLE STAZIONI DI MISURA DELLE PROVE DI TRACCIAMENTO SU FOTOGRAFIE AEREE DELL'AREA
(fotografie del 19/07/2002 della Compagnia Generale Riprese aeree di Parma, eseguite per conto Ing. G. Vlazzo)

NOME FILE: stazioni_tracc._su_aerofoto.jpg
NOME LAYOUT:
SCALA:
TAVOLA: 2

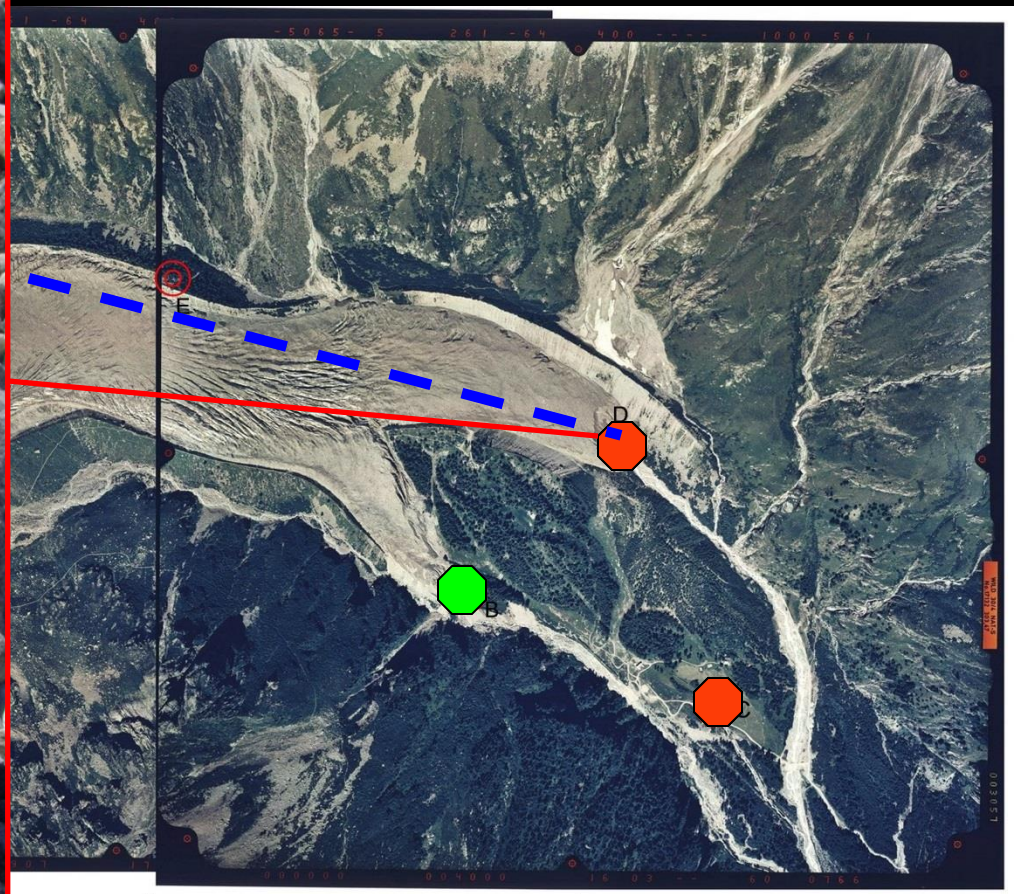
Dye tracer tests: site activity

Dye tracer tests: site activity

Dye tracer tests: results



Dye tracer tests: results (field fluorometer)



e delle stazioni di misura
ove di tracciamento
l lago effimero al 05/08/2002
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i immissione
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Enel.Hydro ISMES

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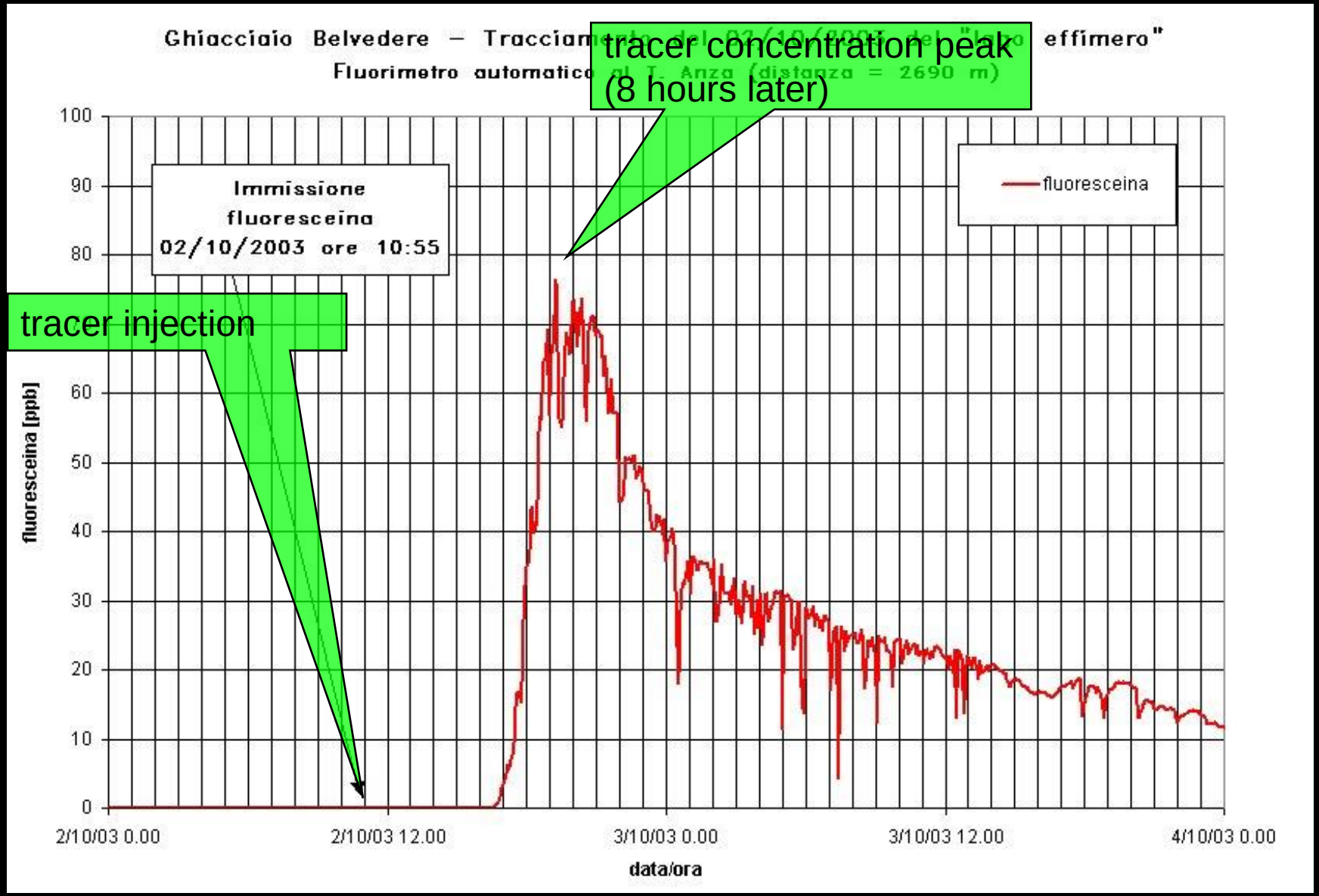
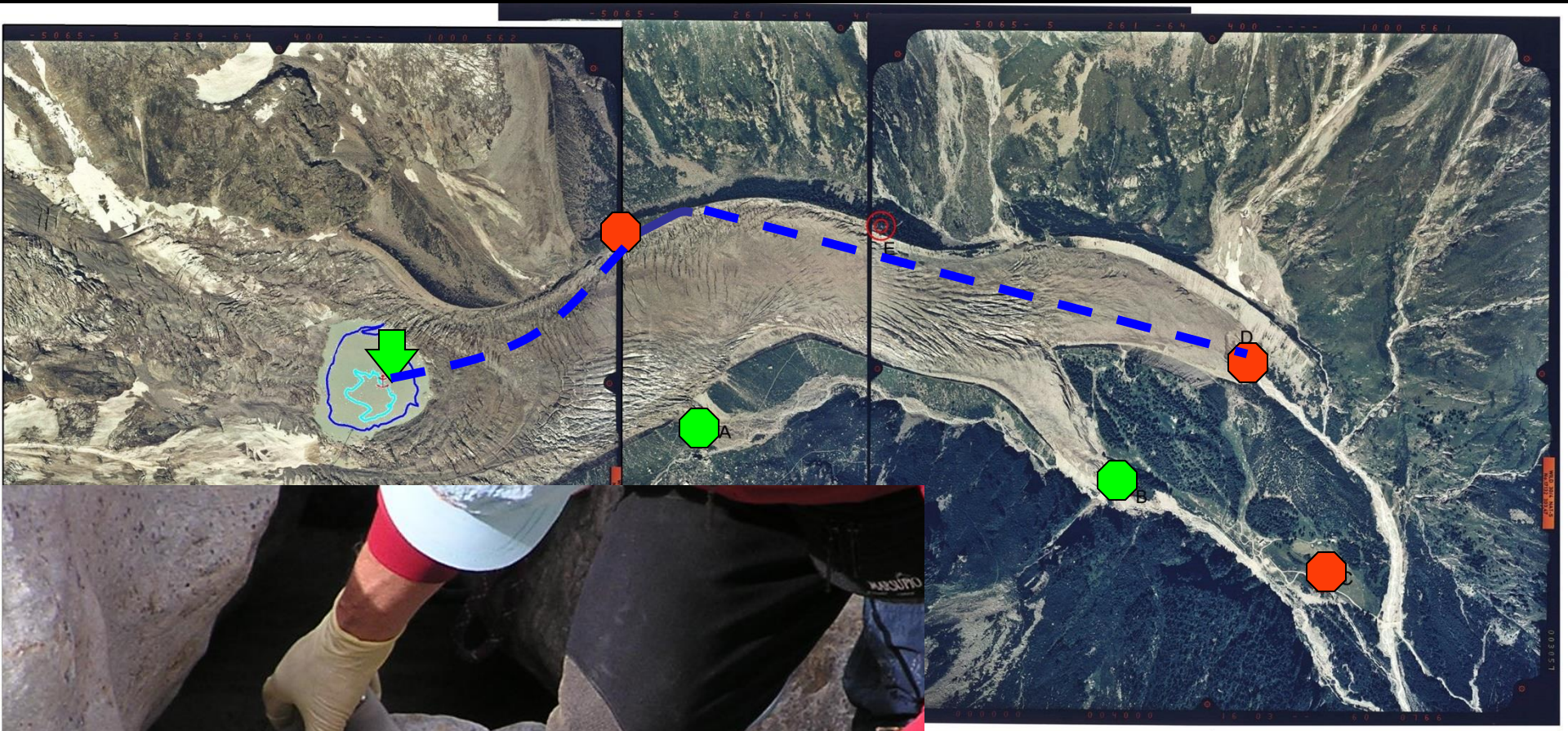
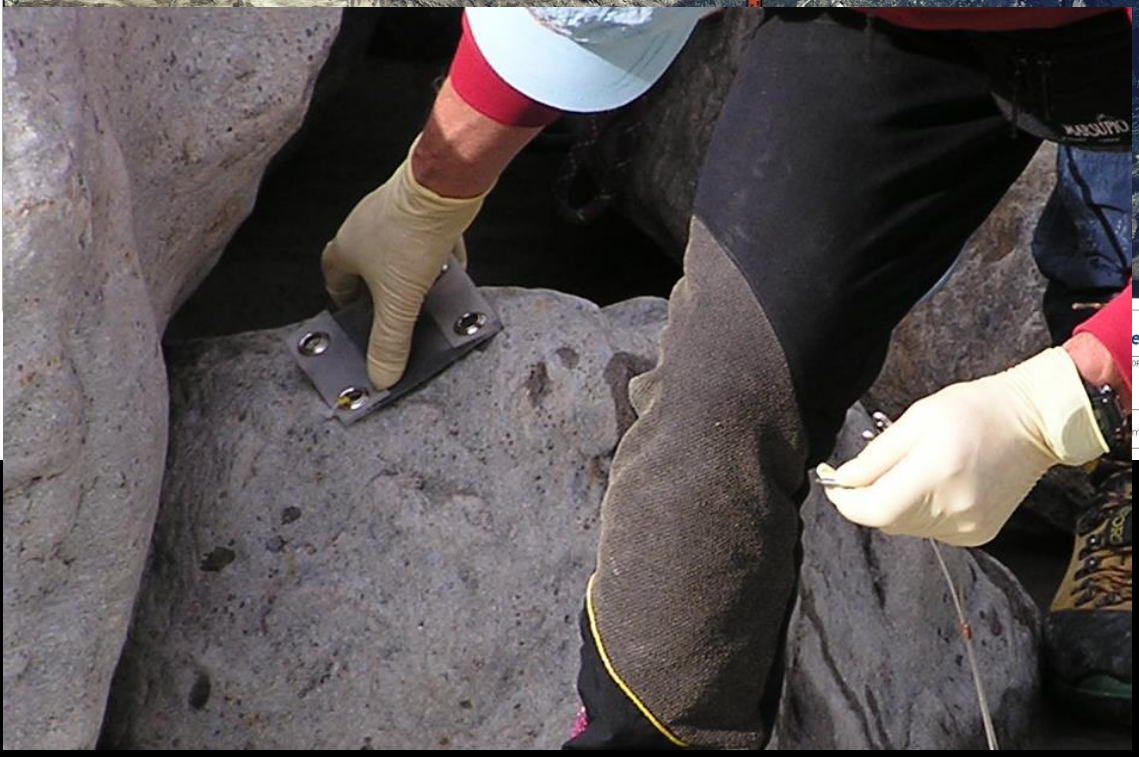
NOME FILE	NOME LAYOUT	SCALA:	TAVOLA
stazioni_tracc_su_aerofoto.jpg			2

Dye tracer tests: results (field fluorometer)



Dye tracer tests: results (activated charcoal captors)





el.Hydro ISMES

GHIACCIAIO DEL BELVEDERE

Prove di tracciamento per la valutazione dei fenomeni di drenaggio che interessano il lago epiglaciale

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POSIZIONE DELLE STAZIONI DI MISURA DELLE PROVE DI TRACCIAMENTO SU FOTOGRAFIE AEREE DELL'AREA

(fotografie del 19/07/2002 della Compagnia Generale Riprese aeree di Parma, eseguite per conto Ing. G. Viazzo)

monte – Dir. Opere Pubbliche

PROG.: ISMES–1375.00

DOC.: RAT–ISMES–1475/2003

NOME FILE: stazioni_tracc._su_aerofoto.jpg

NOME LAYOUT

SCALA:

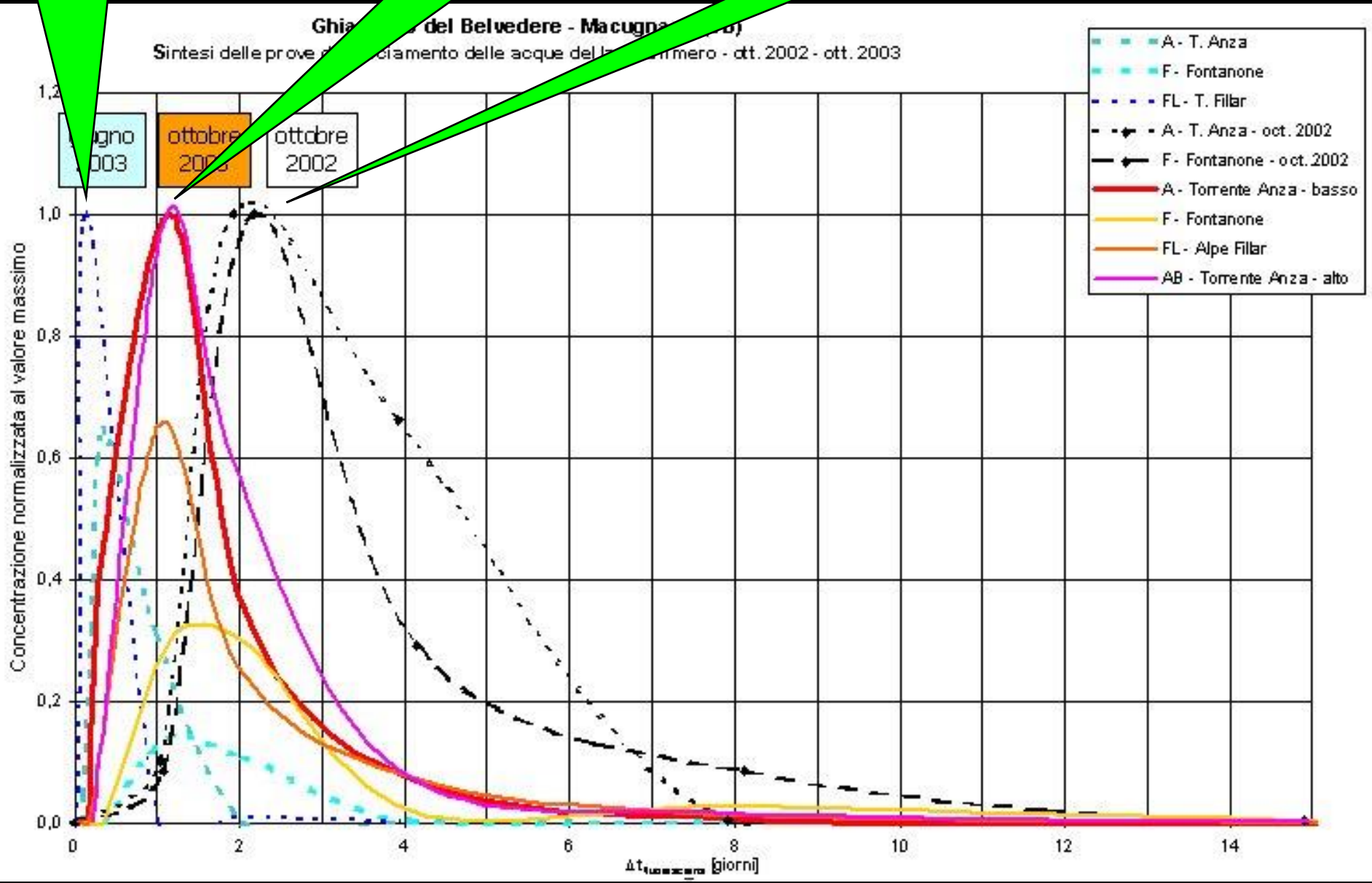
TAVOLA 2

Dye tracer tests: results (activated charcoal captors)

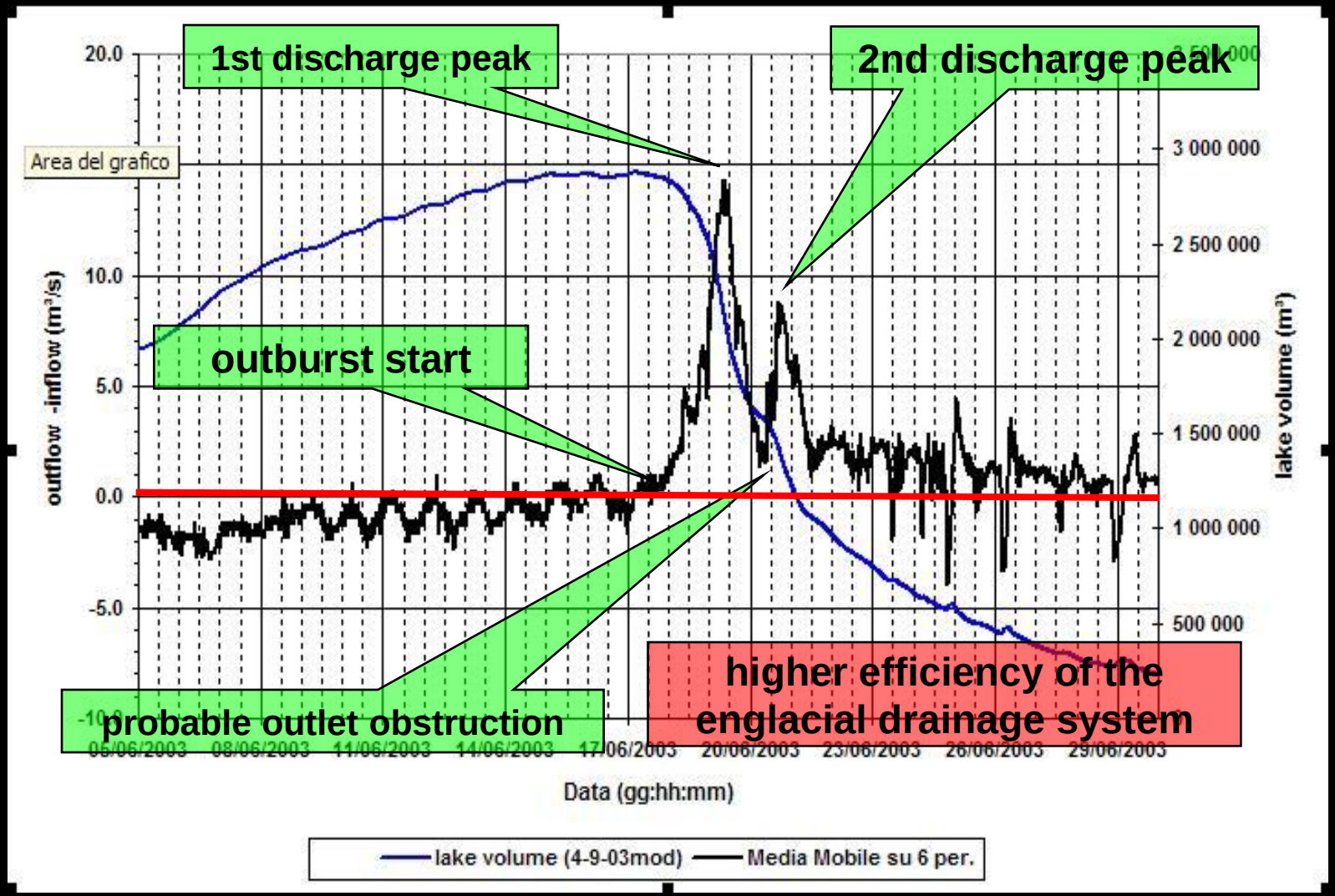
June 2003

October 2003

October 2002



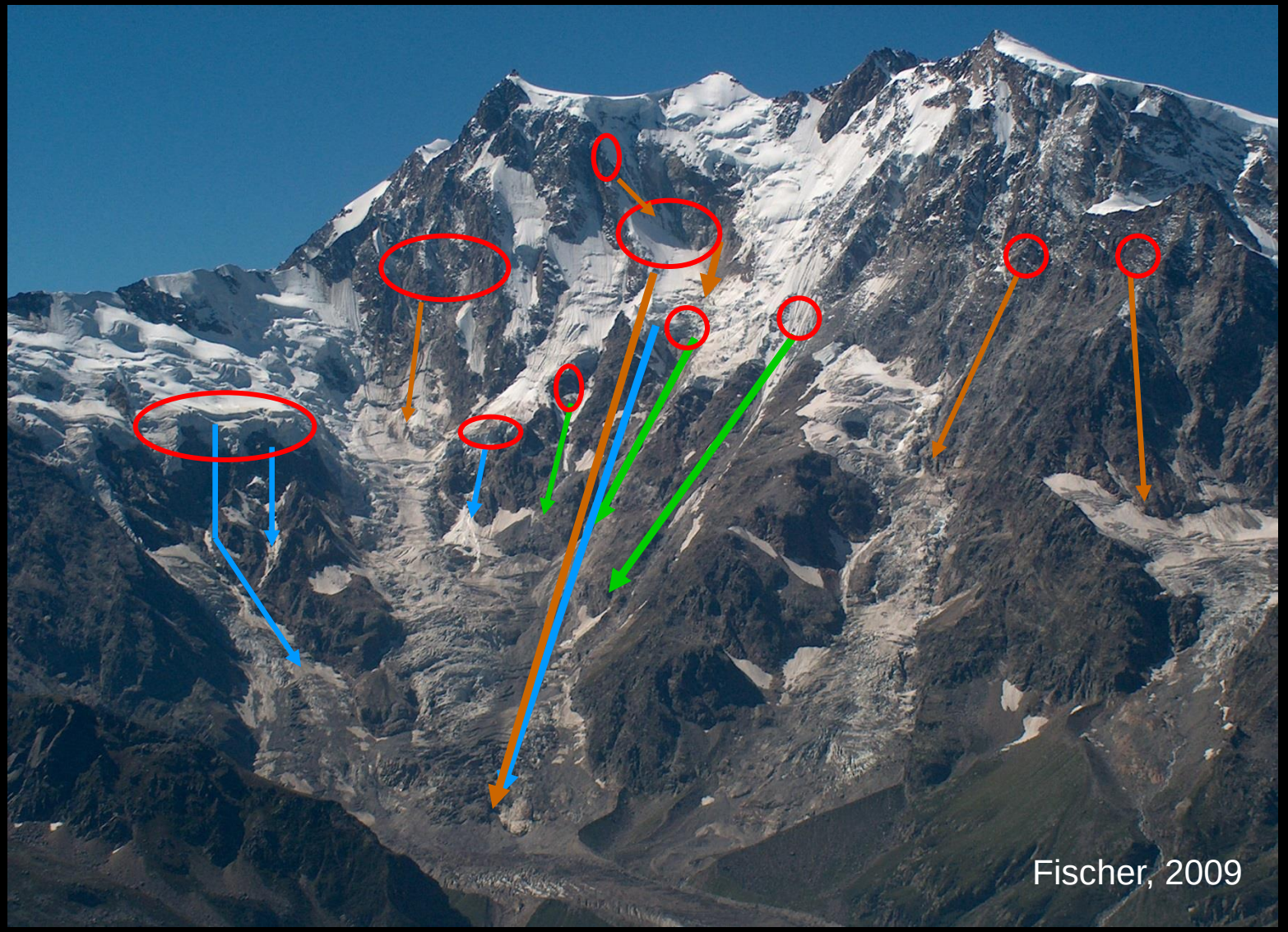
The June 2003 outburst: average discharge evaluation



Evolution of the Belvedere Glacier after 2003

- ✓ Ice and rock avalanches
- ✓ Surface displacement drop
- ✓ Surface elevation change
- ✓ Moraine instability
- ✓ Glacier snout retreat

Instabilities on the Monte Rosa East Face



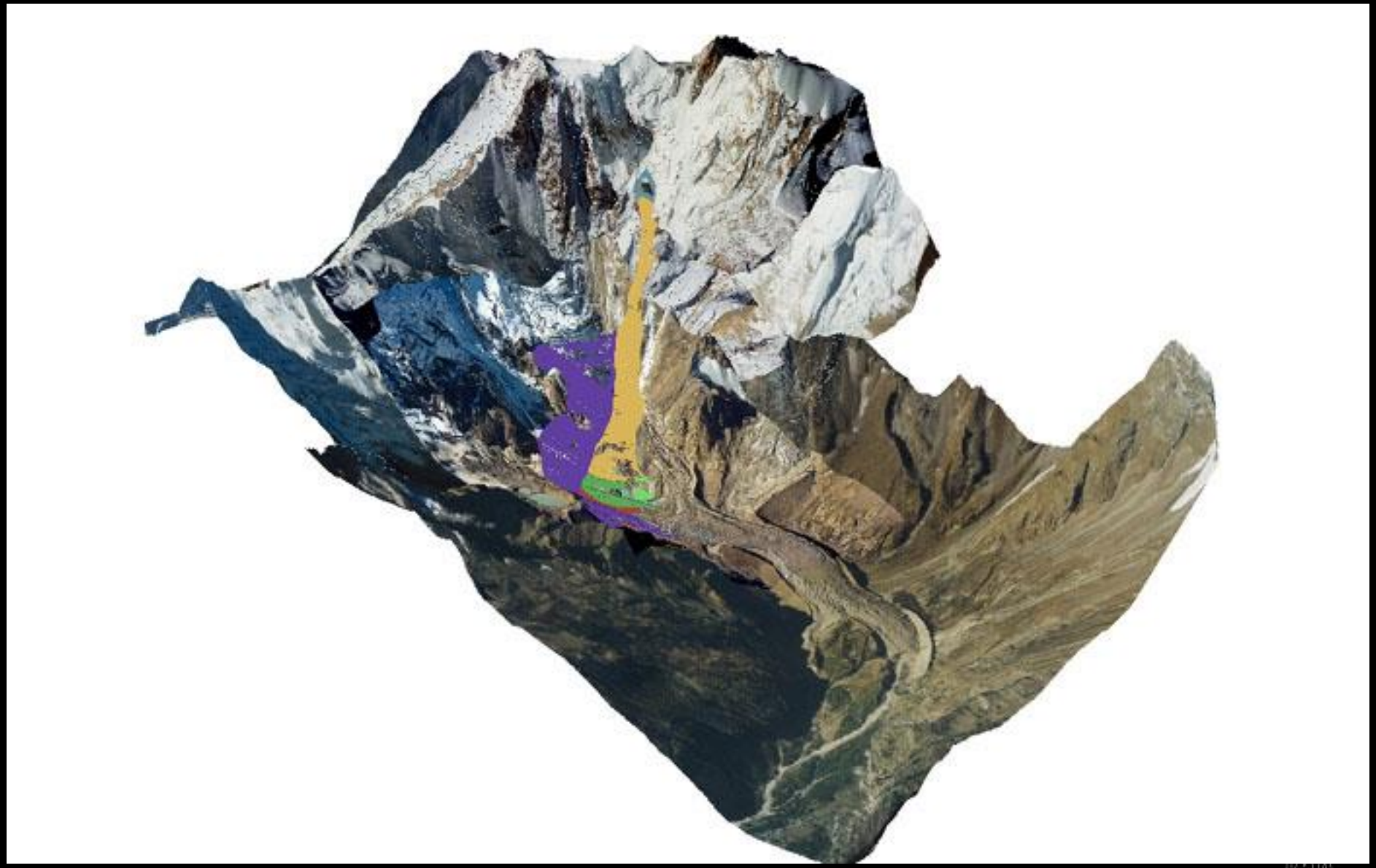
Instabilities on the Monte Rosa East Face

- ✓ Causes:
  - ✓ rapid deglaciation
  - ✓ permafrost degradation
  - ✓ geological and structural conditions
  - ✓ topography
  - ✓ intense freeze-thaw activity
- ✓ Major events:
  - ✓ August 2005: ice avalanche
  - ✓ April 2007: rock avalanche

Evolution of the Monte Rosa East Face

Evolution of the Monte Rosa East Face

The August 2005 ice avalanche (3500-3800 m a.s.l.)



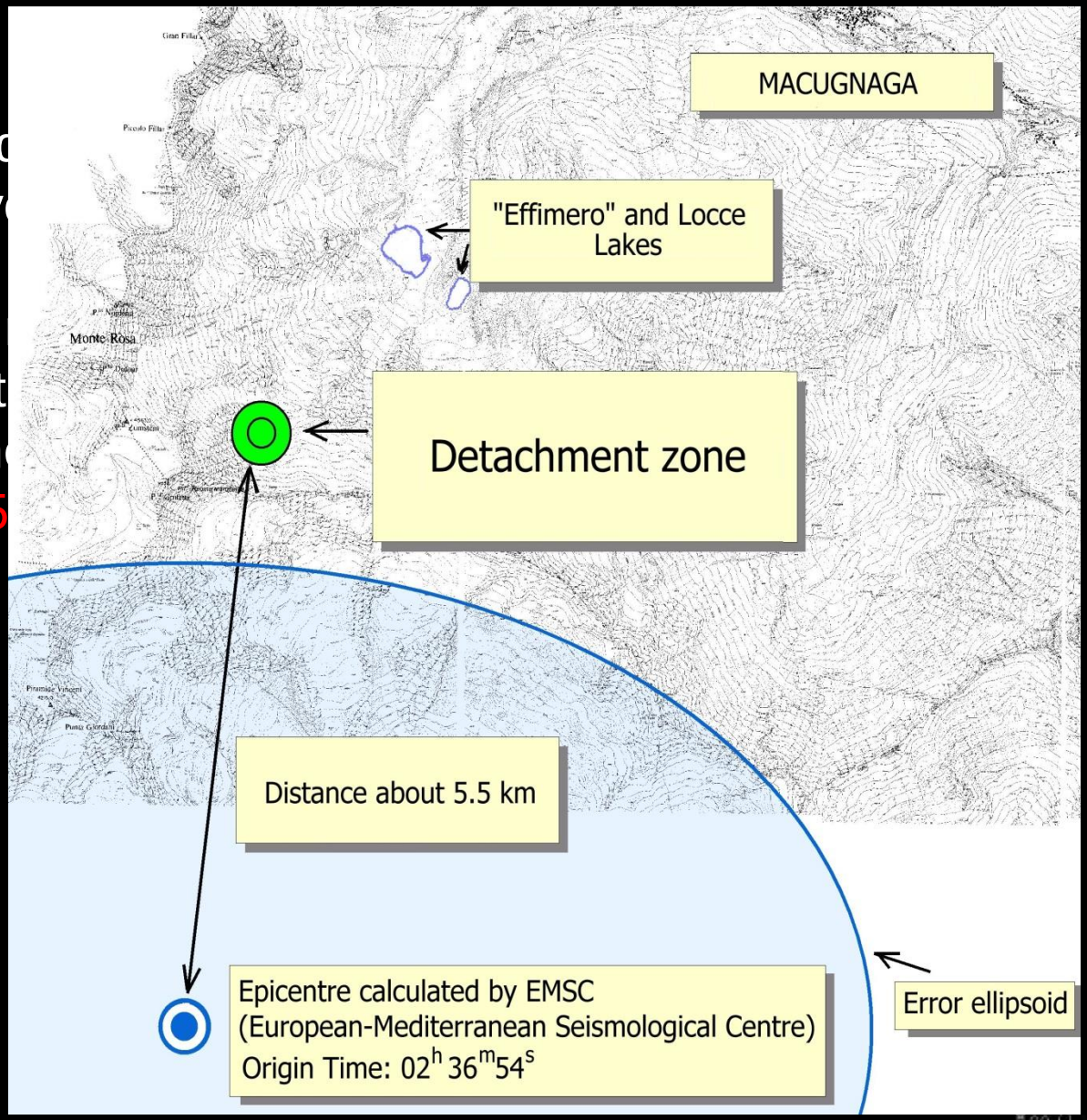
Area reached by the avalanche blow

Seismic data: EMSC

- ✓ EMSC European Mediterranean Seismological Centre and Schweizerischer Erdbebendienst (Swiss Seismological Service – SED) located the event
- ✓ The seismic phases were used for the location.
- ✓ The arrival times, not correctly recognised for the majority of seismograms, lead to a not properly accurate location
- ✓ The origin time of the event can be assumed as the starting phase of the avalanche: 25 th of August 2005 at 02h 36 m 54 s (GMT)
- ✓ Magnitude ML 2.5

Seismic data: EMSC

- ✓ EMSC European Schweizerischer Erd SED) located the ev
- ✓ The seismic phases
- ✓ The arrival times, seismograms, lead t
- ✓ The origin time of th of the avalanche: 25 .5



Seismic data: INGV

- ✓ Seismograms of MCGN (Macugnaga), ORO (Oropa) and VAI (Varese), vertical components.
- ✓ The event duration is 1 minute 30 seconds.
- ✓ The zone in the past was affected by low seismicity (70 earthquakes from magnitude 1.8 to 2.8 from 1980 to present)
- ✓ The records were analized as tectonic earthquakes by EMSC and SED and the hypothesis that an earthquake induced the avalanche was examined.
- ✓ Seismogram analysis excludes the possibility that a tectonic earthquake triggered the avalanches because of the absence in the seismograms of characteristic phases.
- ✓ Seismograms recorded show a progressive increase of intensity (P waves generated by the avalanche) and surface waves.

Digital seismograms are kindly provided by INGV – Italian Istituto Nazionale di Geofisica e Vulcvanologia – National Earthquake Center, Rome, Italy

Seismic data: INGV

- ✓ Seismograms of MCGN (Macugna
  (Varese), vertical components.
- ✓ The event duration is 1 minute 30 se
- ✓ The zone in the past was affe
  earthquakes from magnitude 1-3 to 2
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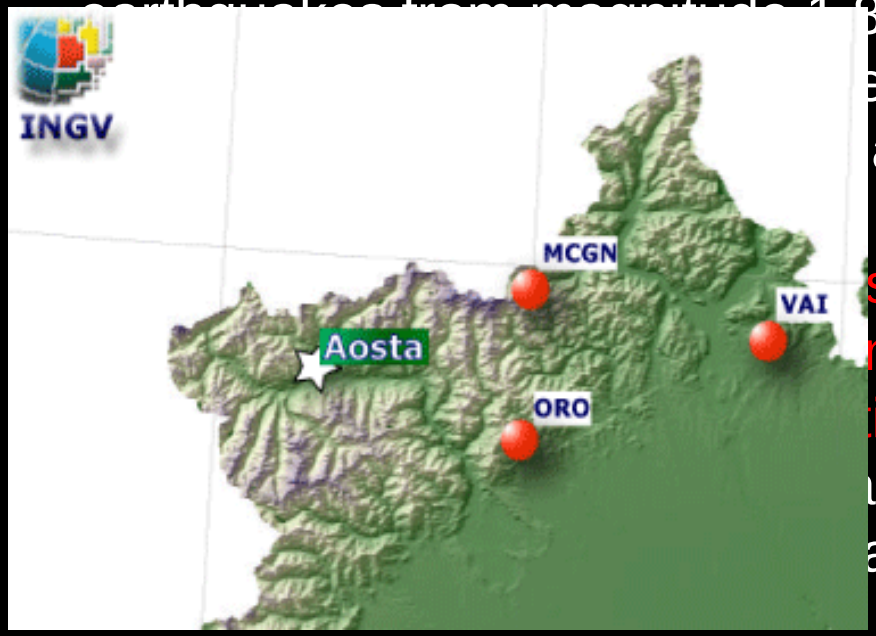

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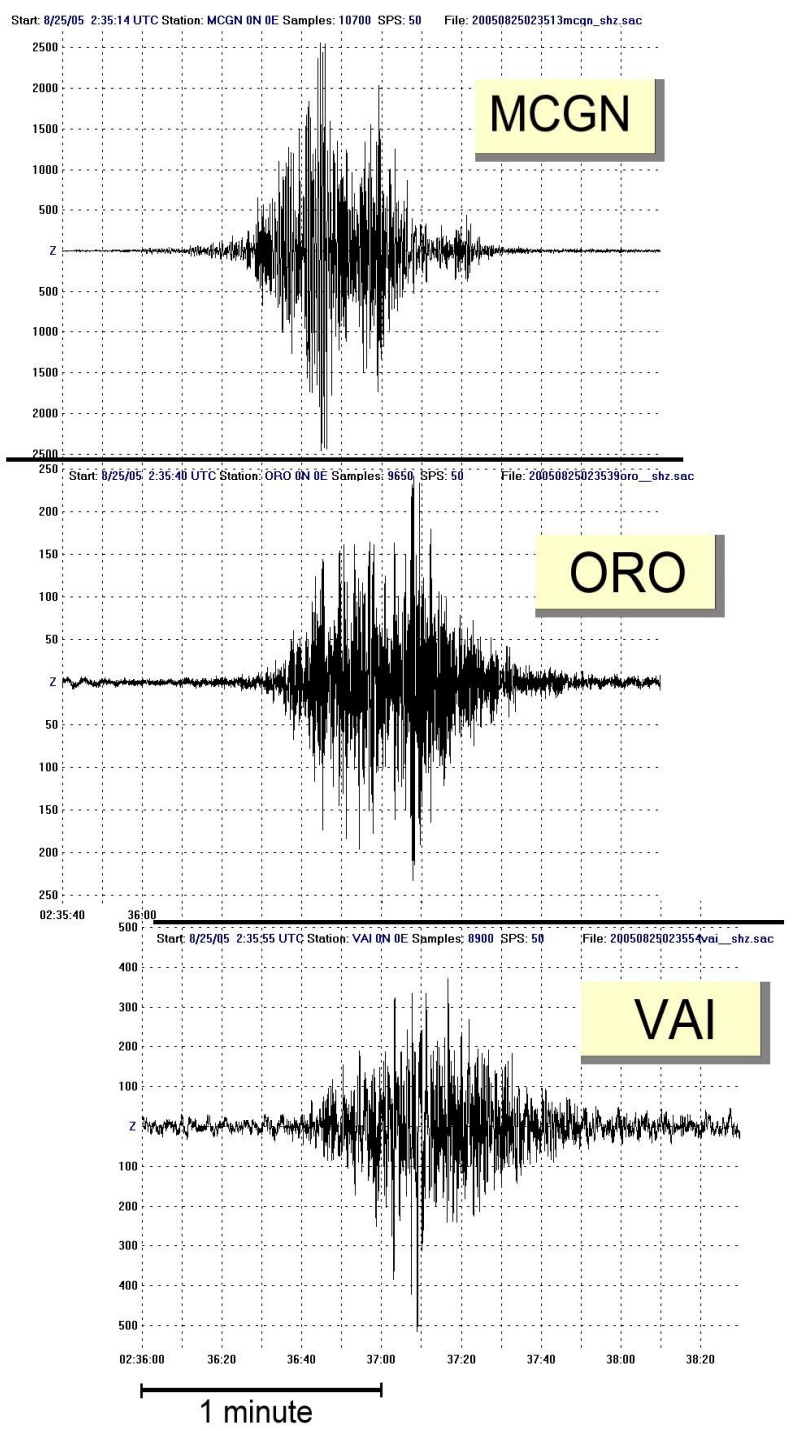
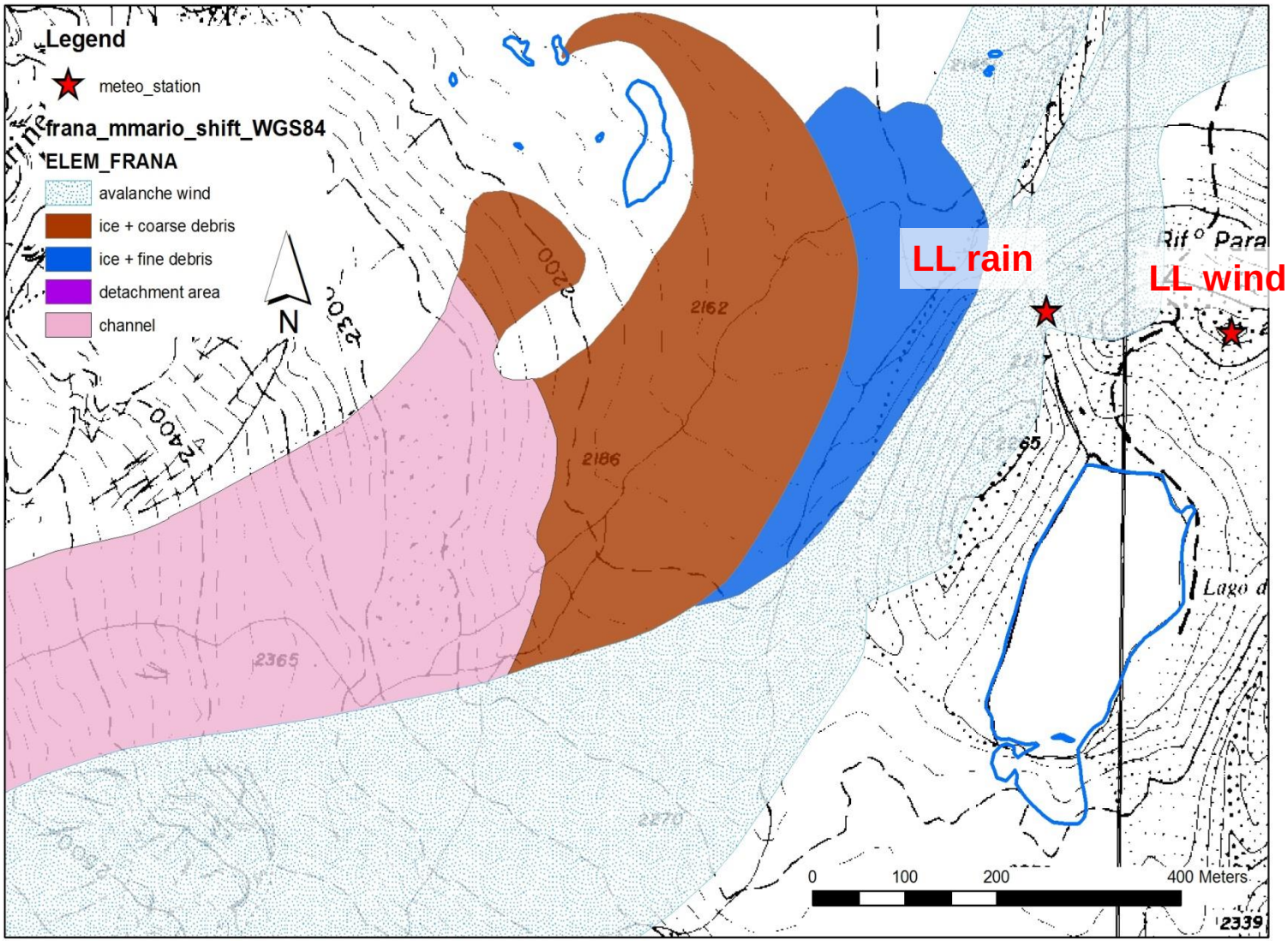


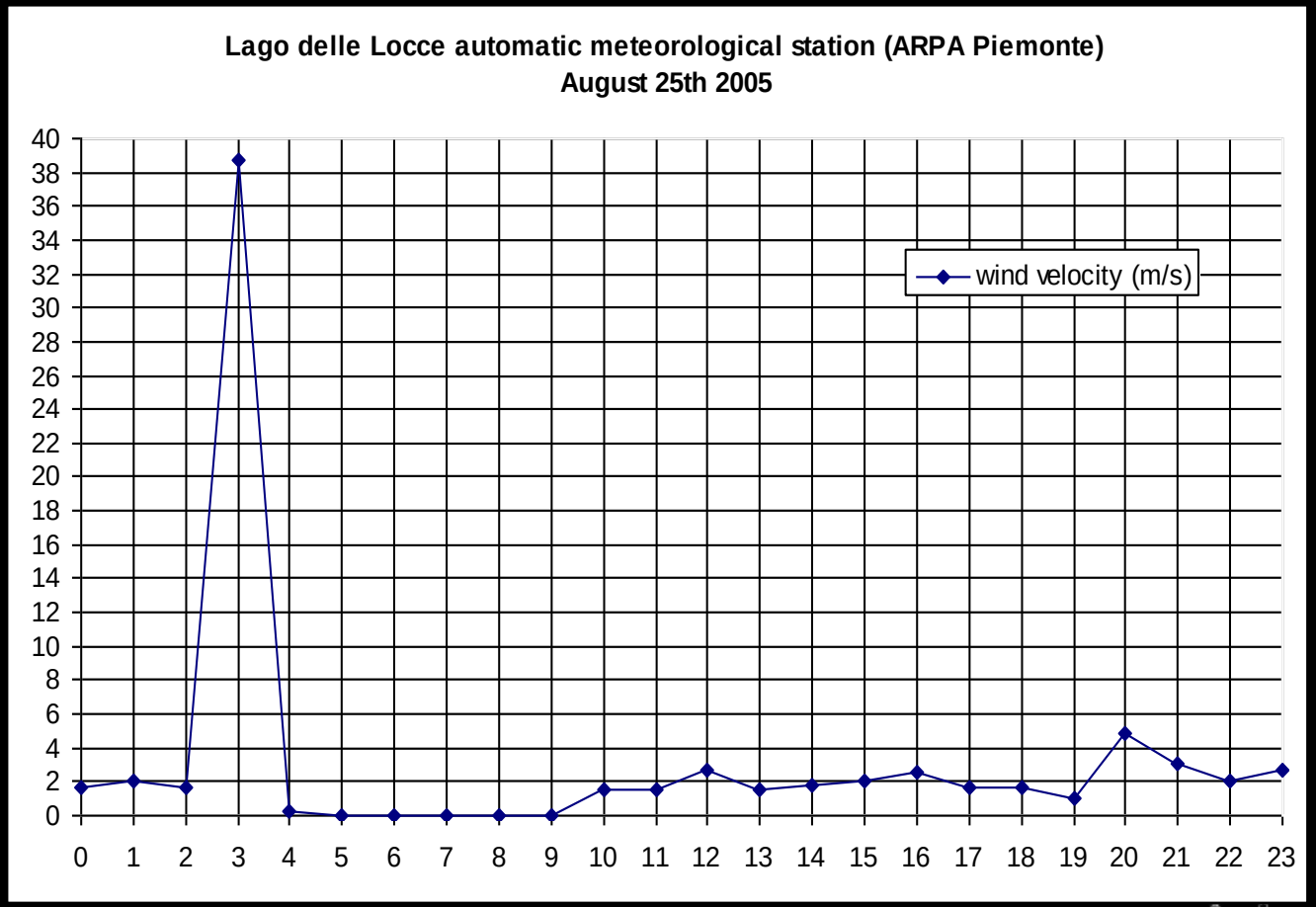
Digital seismograms are kindly provided by INGV – Italian Istituto Nazionale di Geofisica e Vulcvanologia – National Earthquake Center, Rome, Italy

Meteorological data: AWS location



Meteorological data: wind velocity

- ✓ The Lago delle Locce-wind AWS is located close to the right margin of the accumulation area
- ✓ A peak of 38.7 m/s (140 km/h) was recorded between 2 a.m. and 3 a.m. GMT

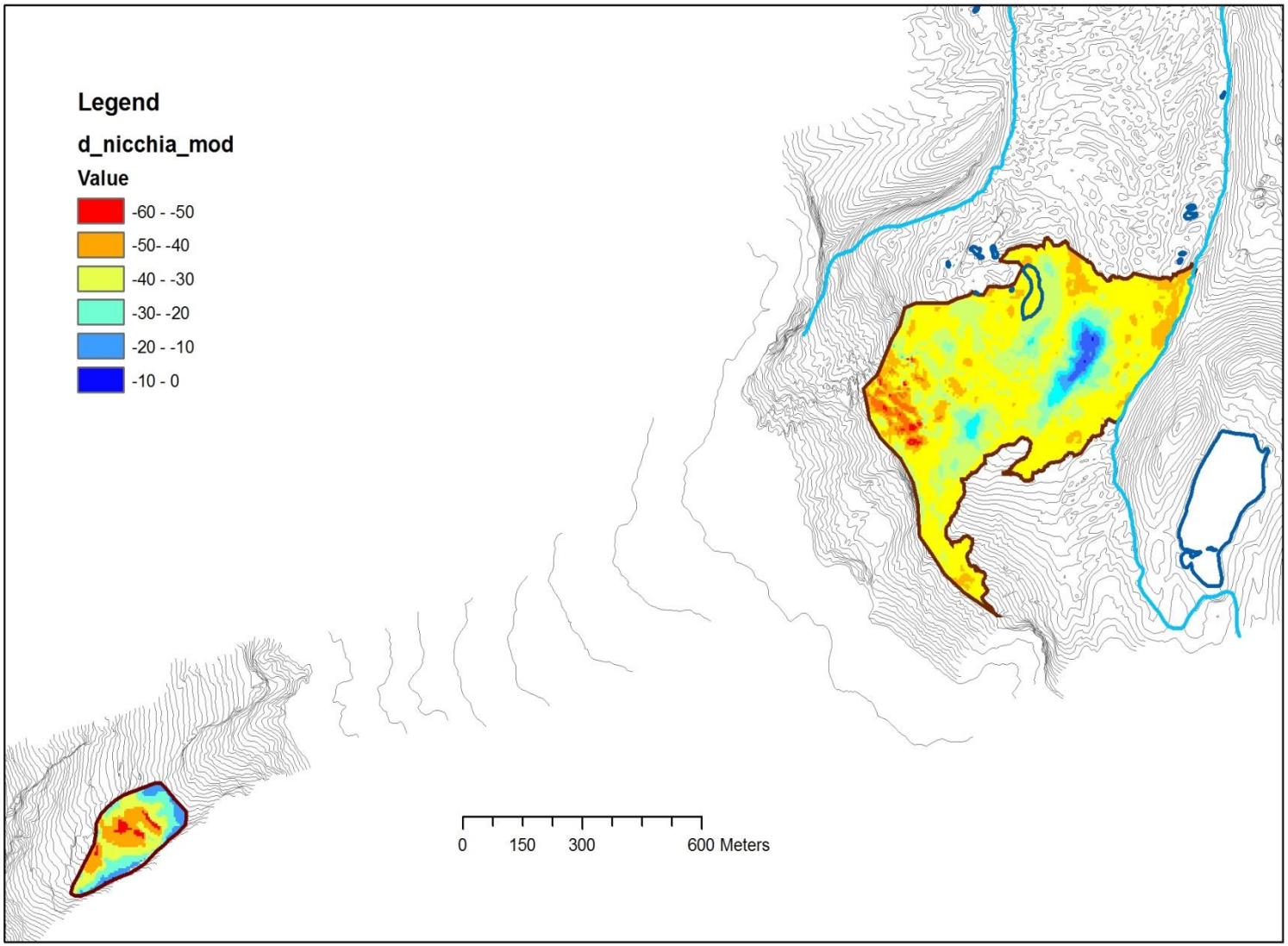


Data source: ARPA Piemonte, Italy

Volume evaluation

- ✓ The volumes of the detached mass and ice avalanche deposit were calculated by subtracting DEMs obtained by photogrammetric restitution of the following aerial surveys:
  - ✓ October 11th 2001
  - ✓ July 12th 2005 (Belvedere Glacier tongue only)
  - ✓ September 13th 2005
- ✓ Detached ice volume: 1.1 million m^3 (max thickness 56 m)
- ✓ Ice avalanche deposit: 1.4 million m^3 (max thickness 32 m)

Thickness map



The April 2007 rock avalanche (4000-4200 m a.s.l.)

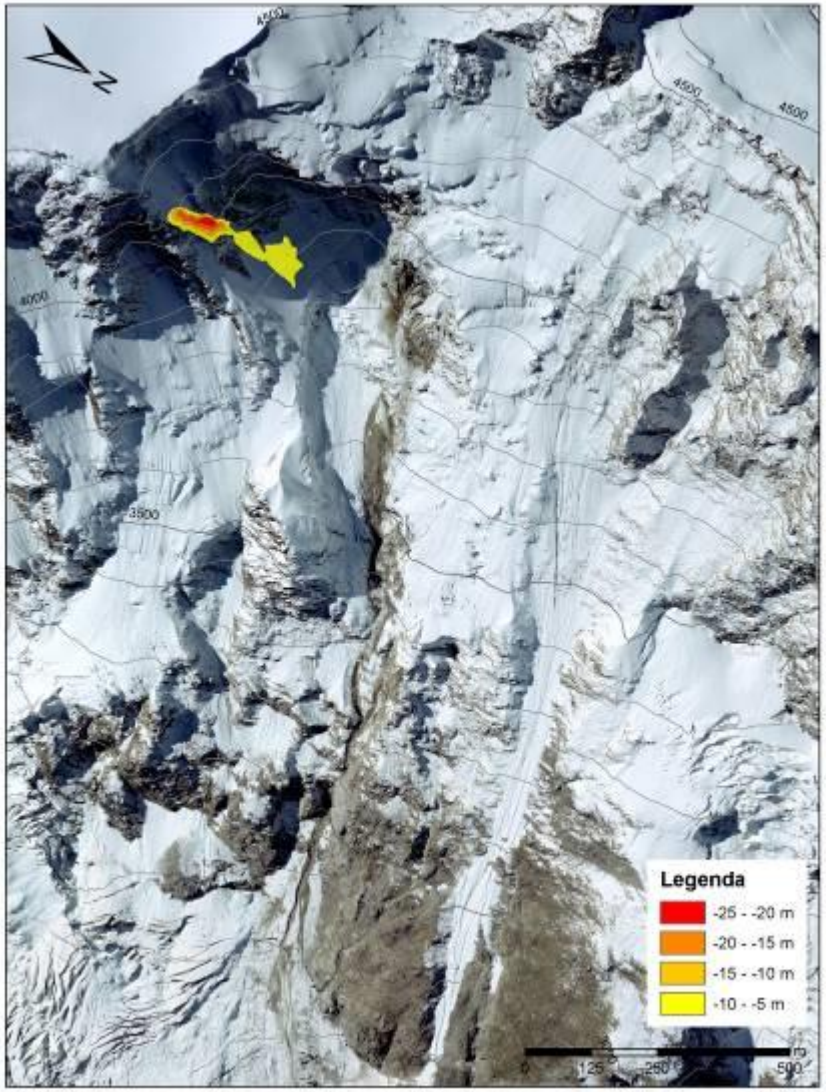
F.lli Wehrli, beginnning of XX century

CNR-IRPI, 2007

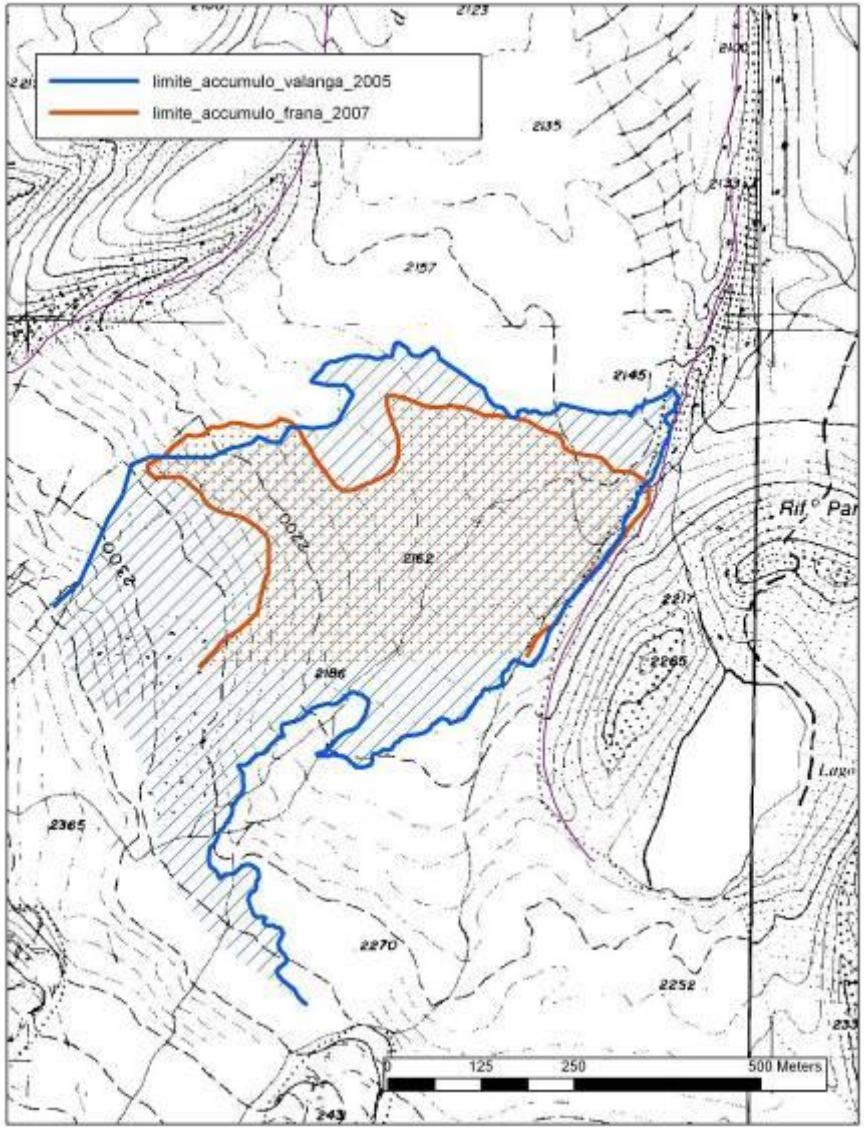
The April 2007 rock avalanche (4000-4200 m a.s.l.)

(F. Bettoli)

April 2007 rock avalanche: detachment and accumulation areas



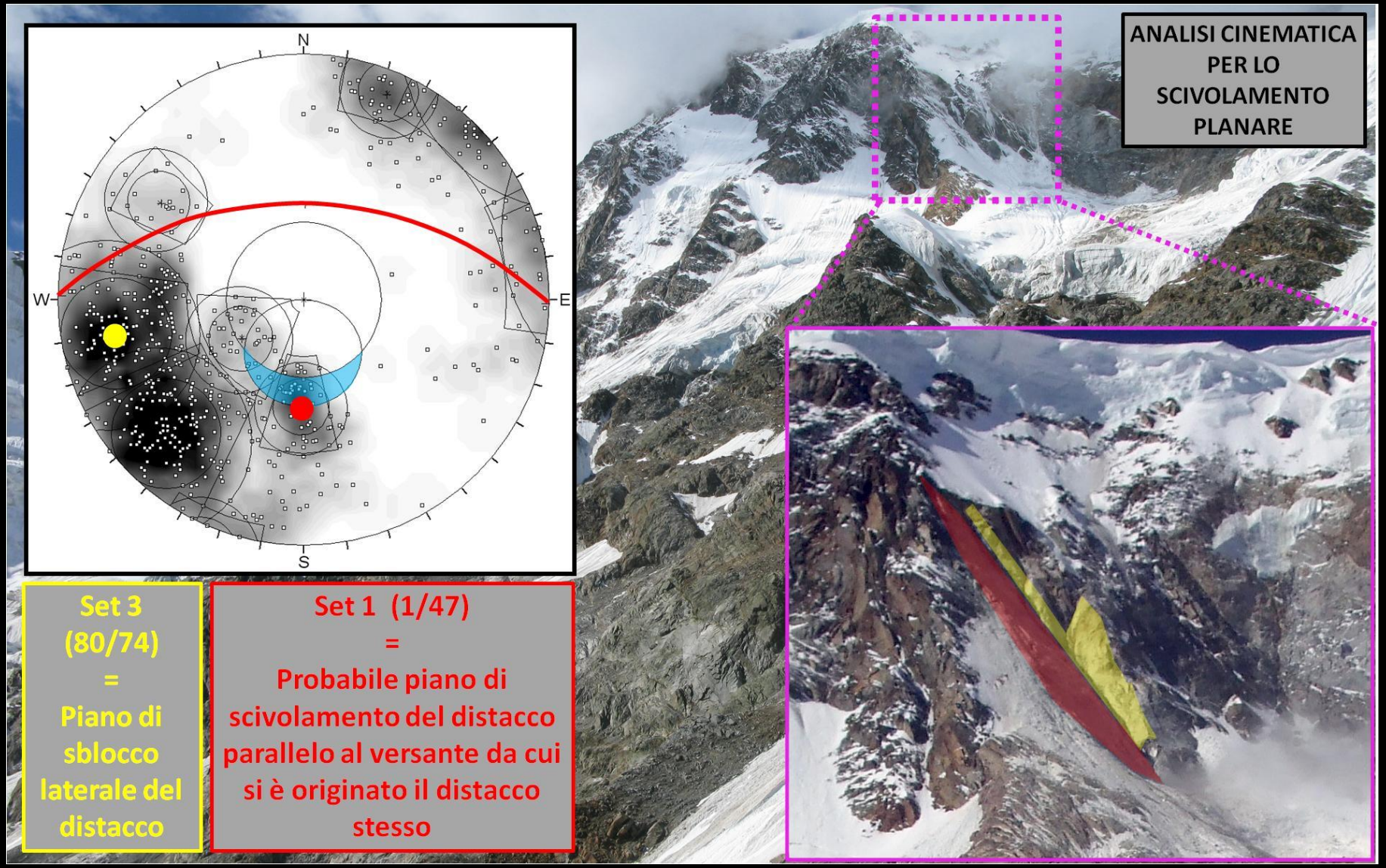
detachment area



accumulation area

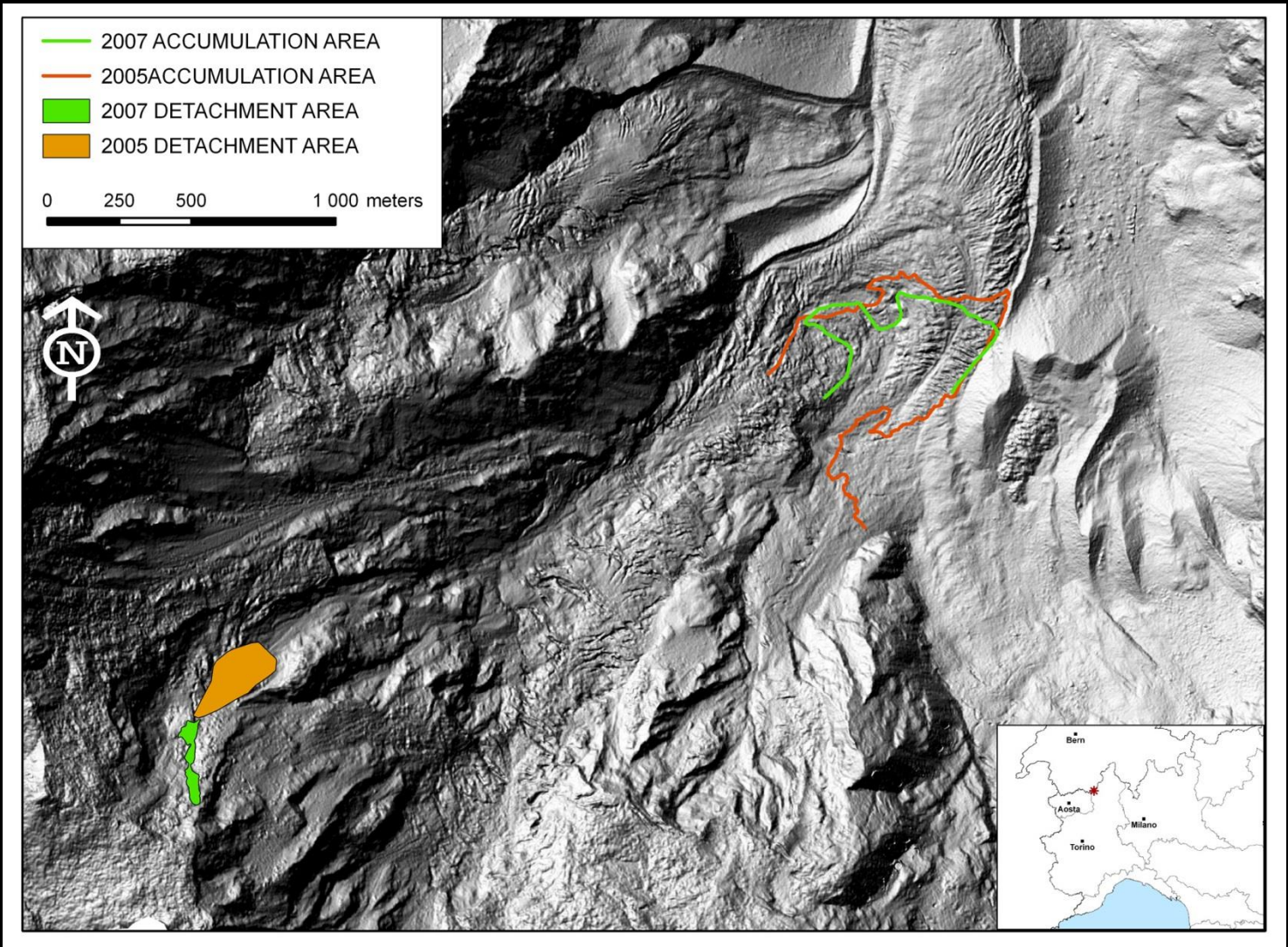
April 2007 rock avalanche accumulation area

Probable failure mechanism: planar sliding

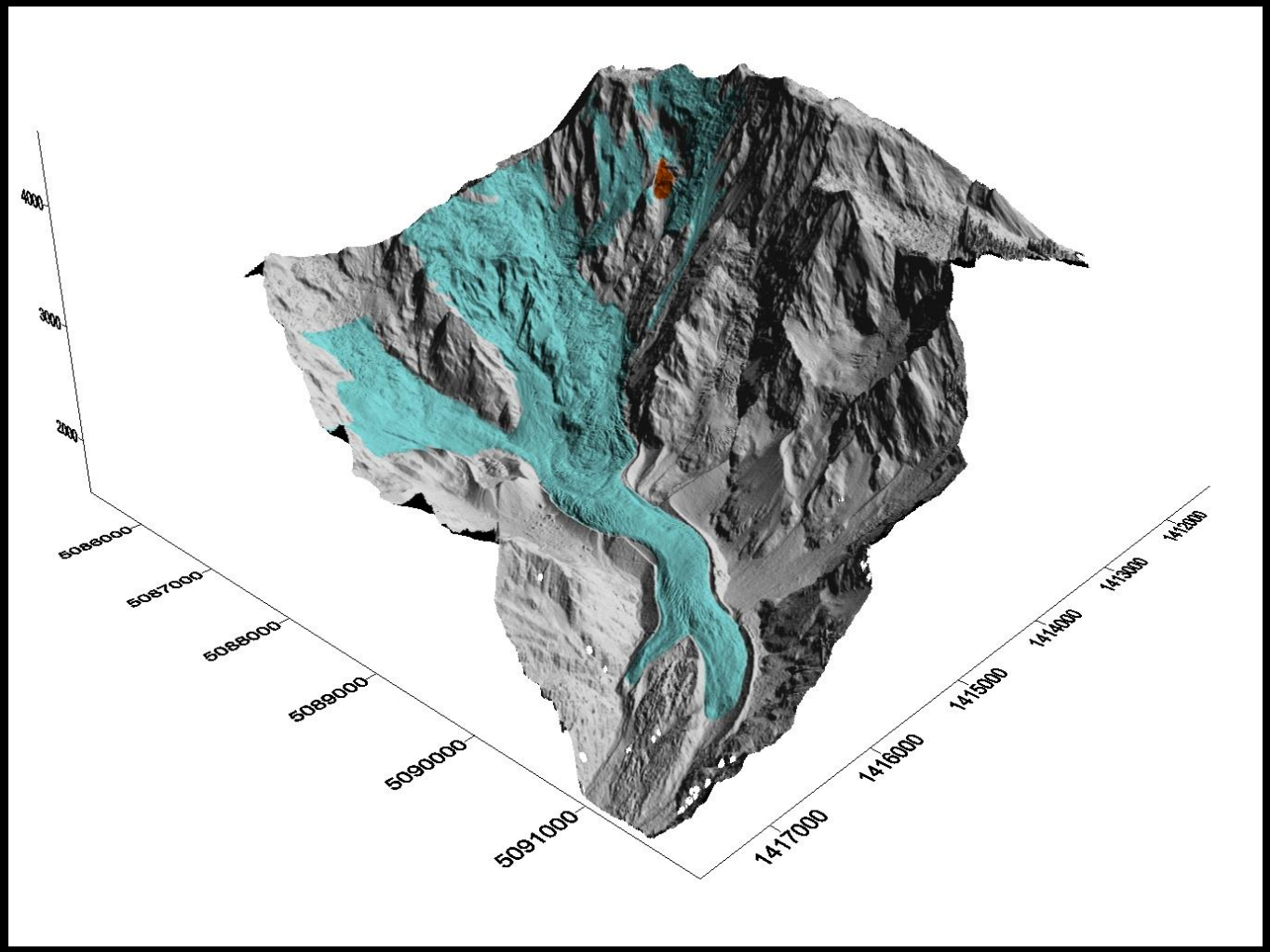


terrestrial laser scanner geomechanical characterization

Accumulation area: 2005 vs 2007

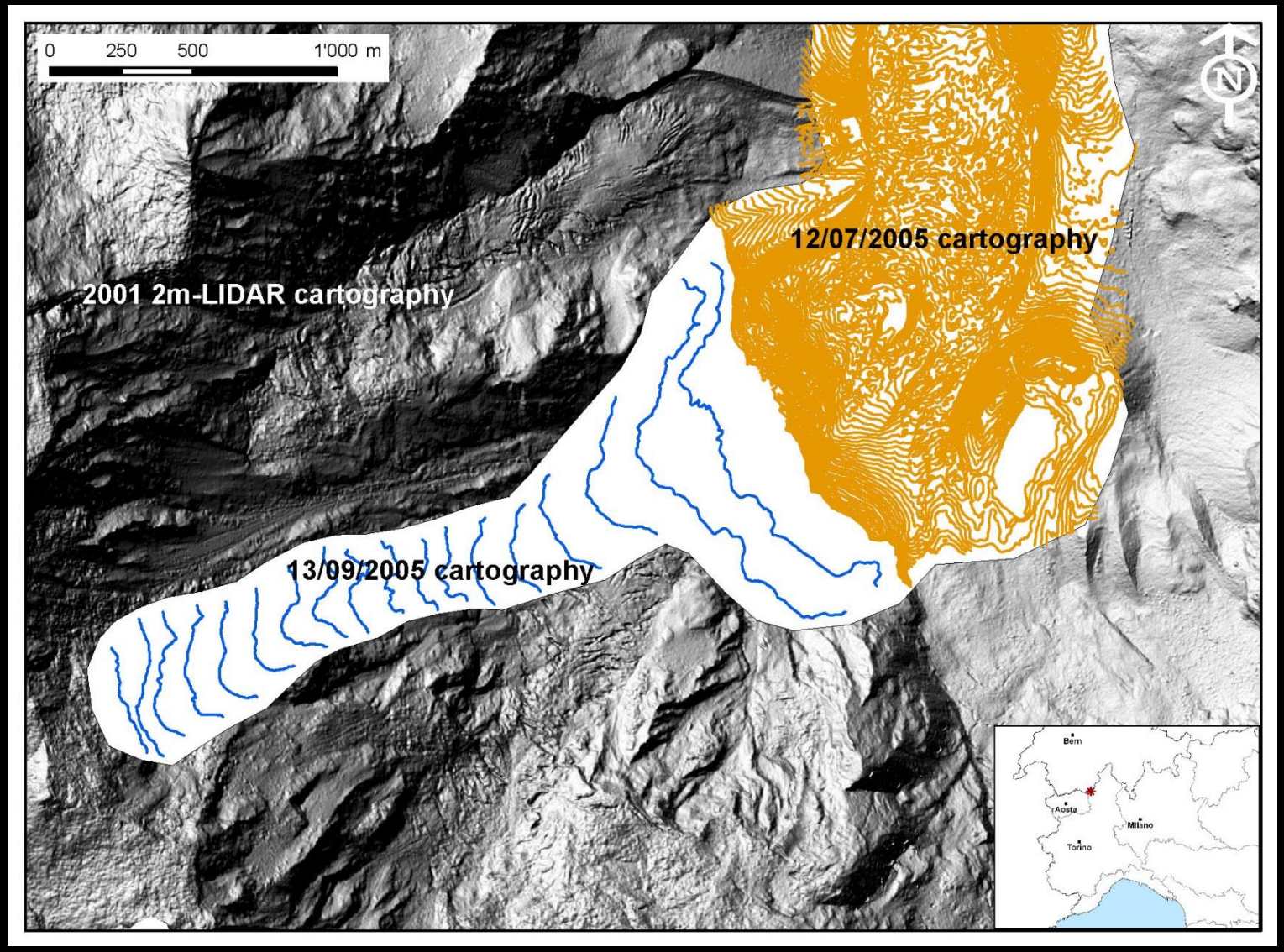


Runout modelling with DAN3D: input data

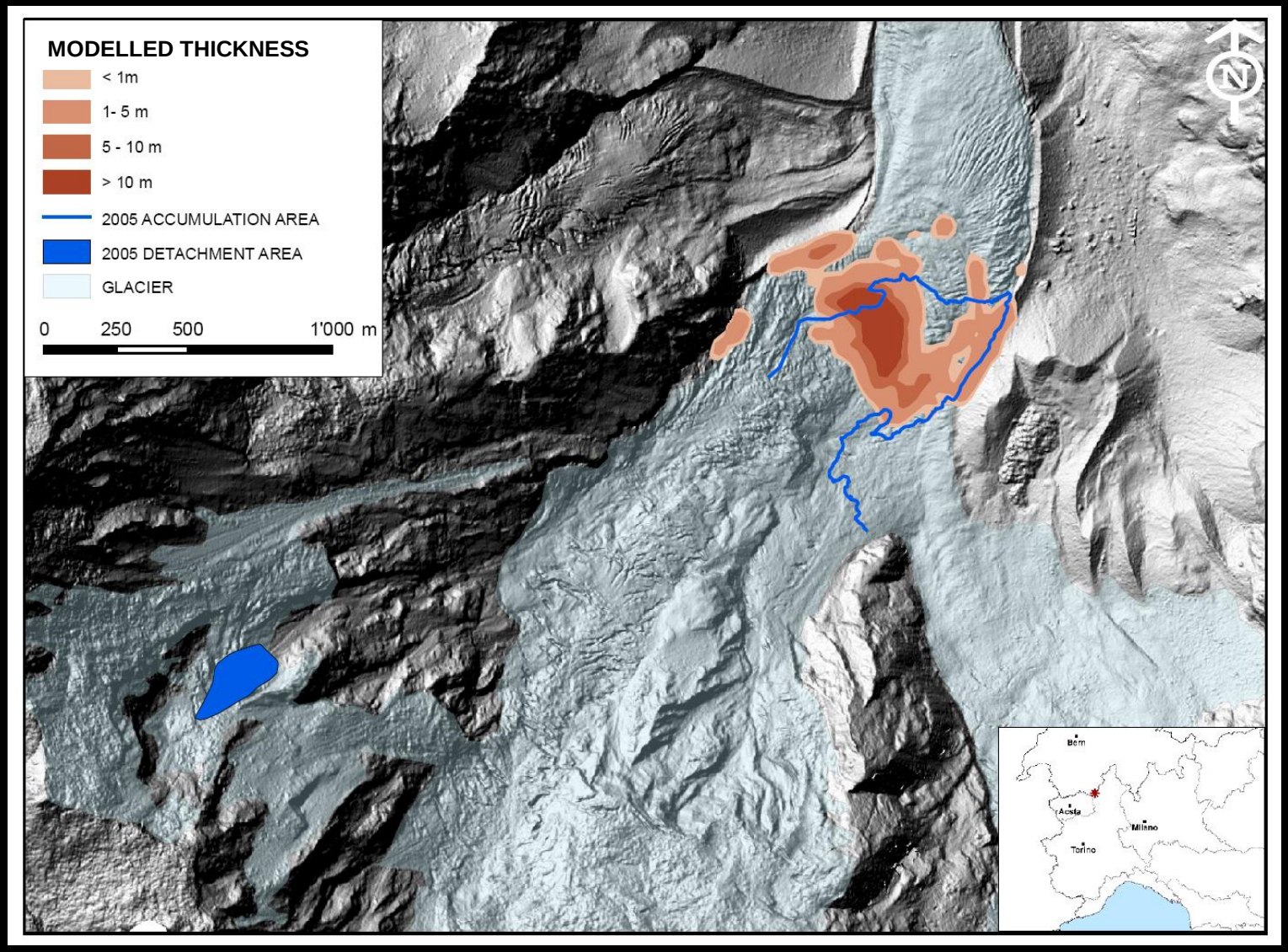


- Frictional rheology => 25° bulk friction angle
- Voellmy rheology => friction coefficient 0.05-0.1, turbulence coefficient 700-1000 m/s^2

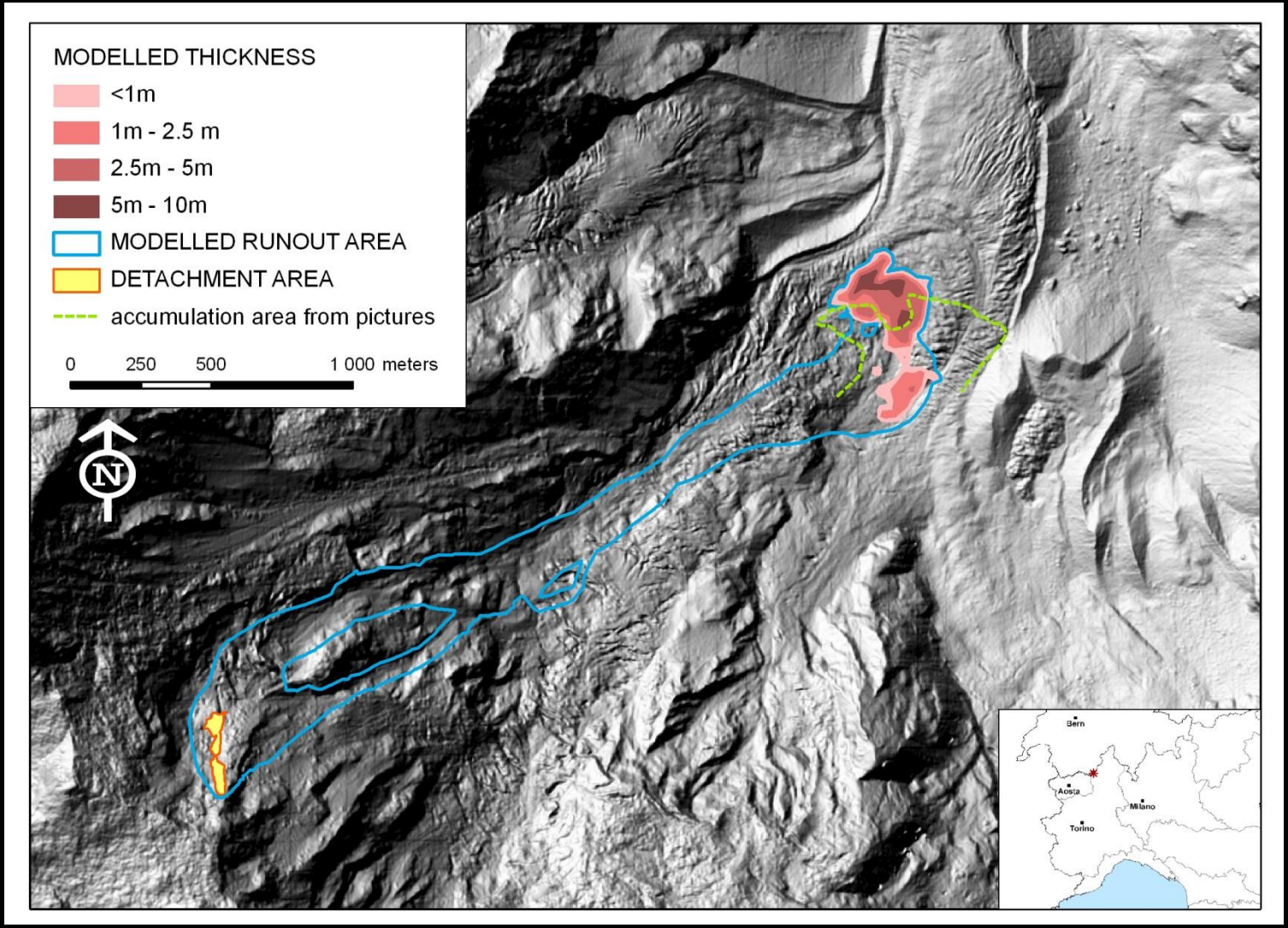
Available topographic data



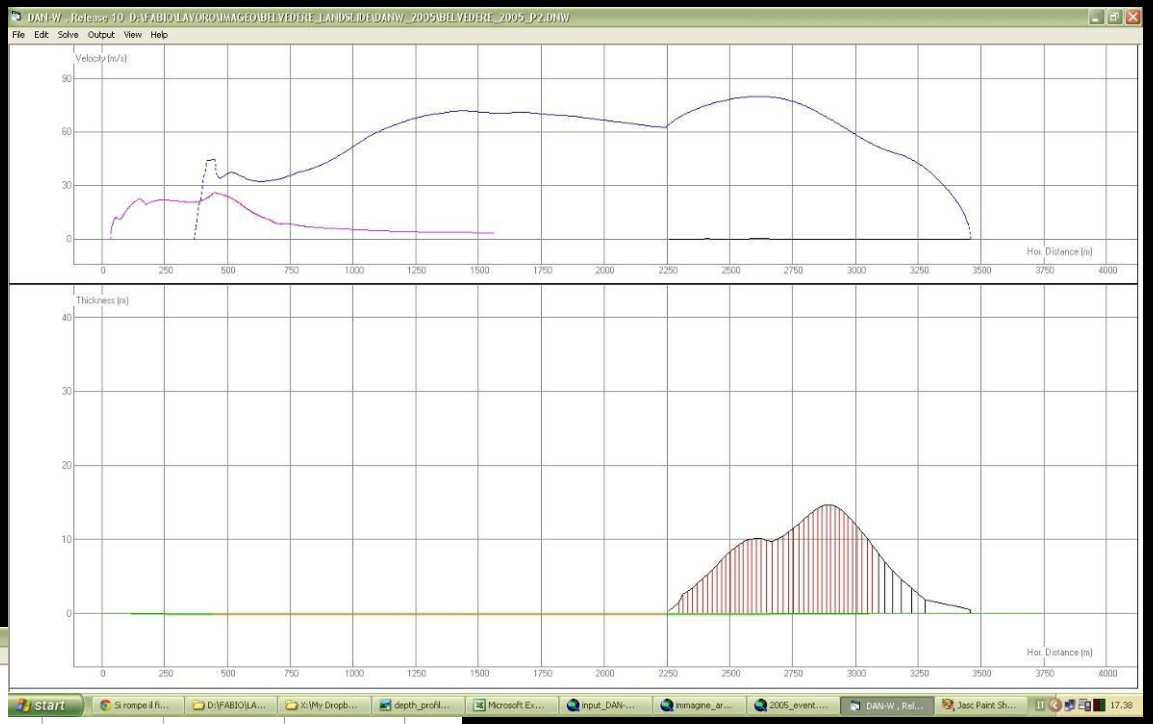
The August 2005 ice avalanche (DAN3D)

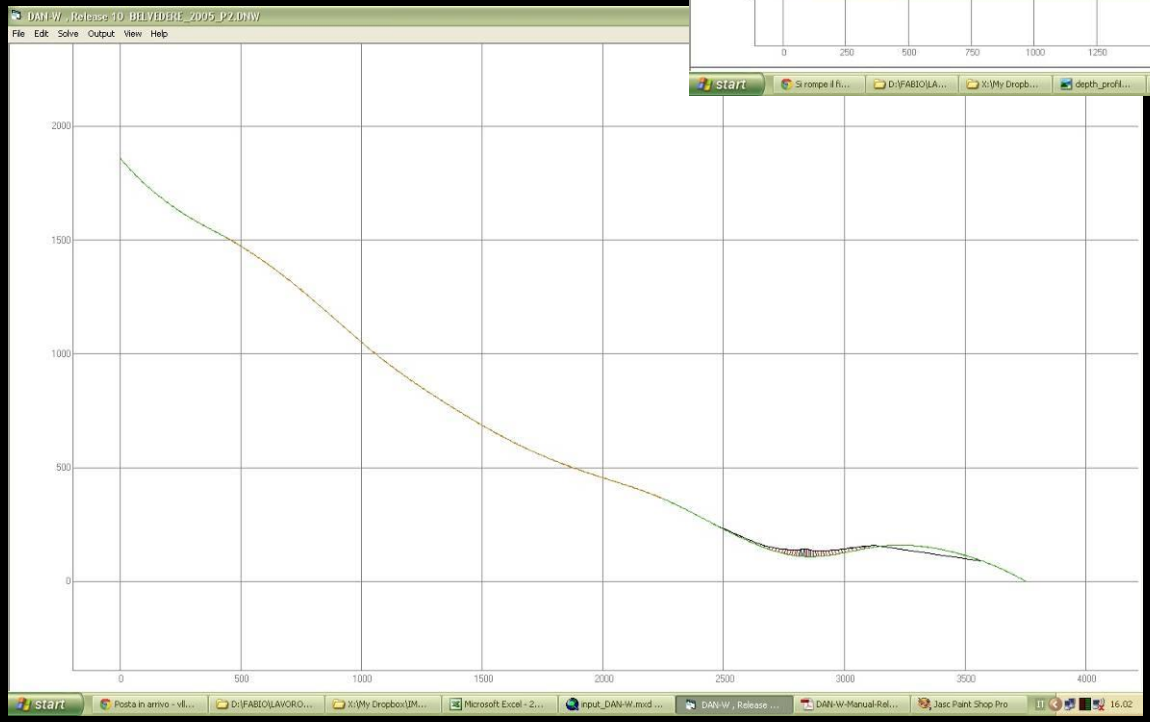


The April 2007 rock avalanche (DAN3D)

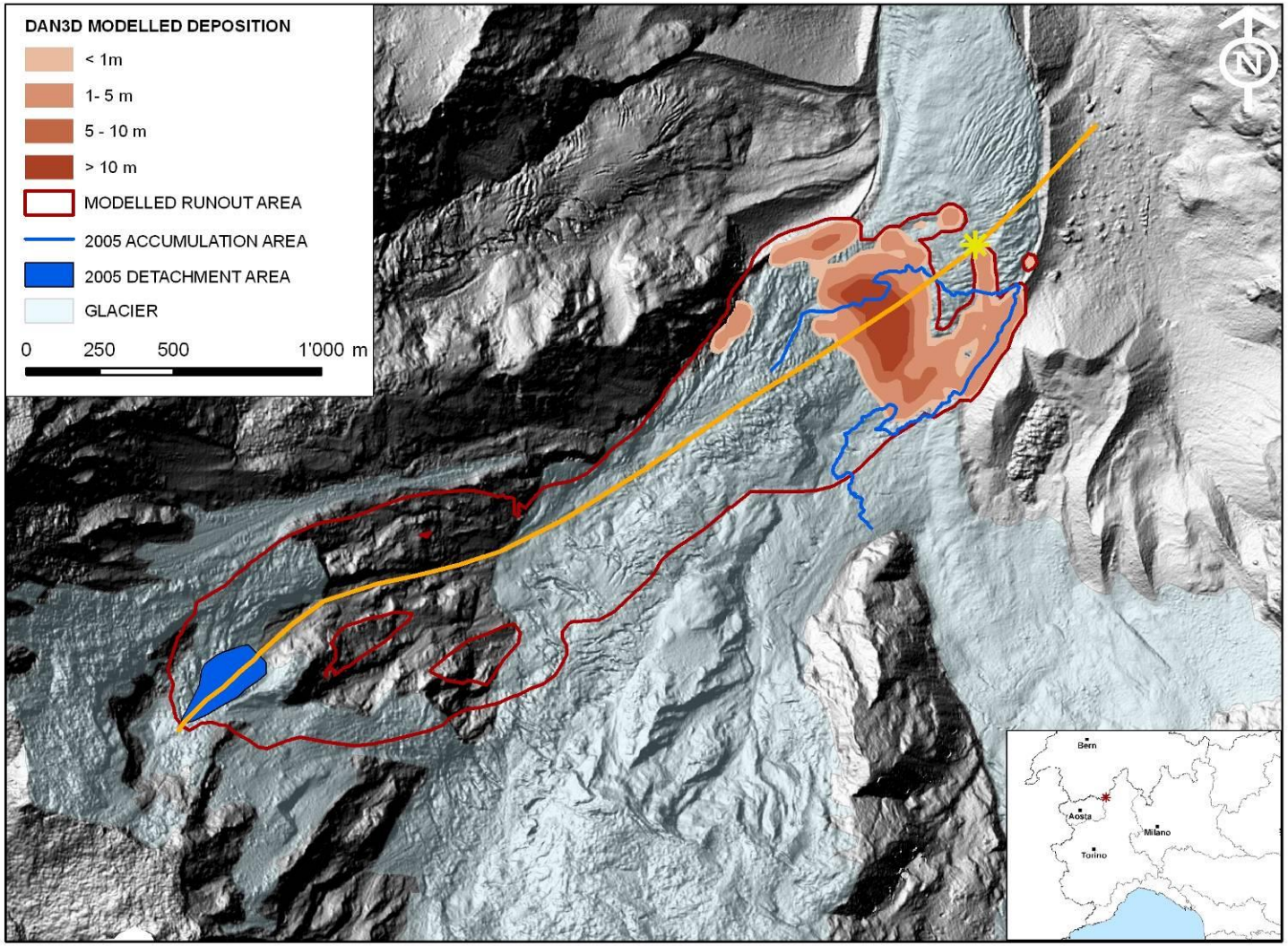


2D analysis (DAN-W)

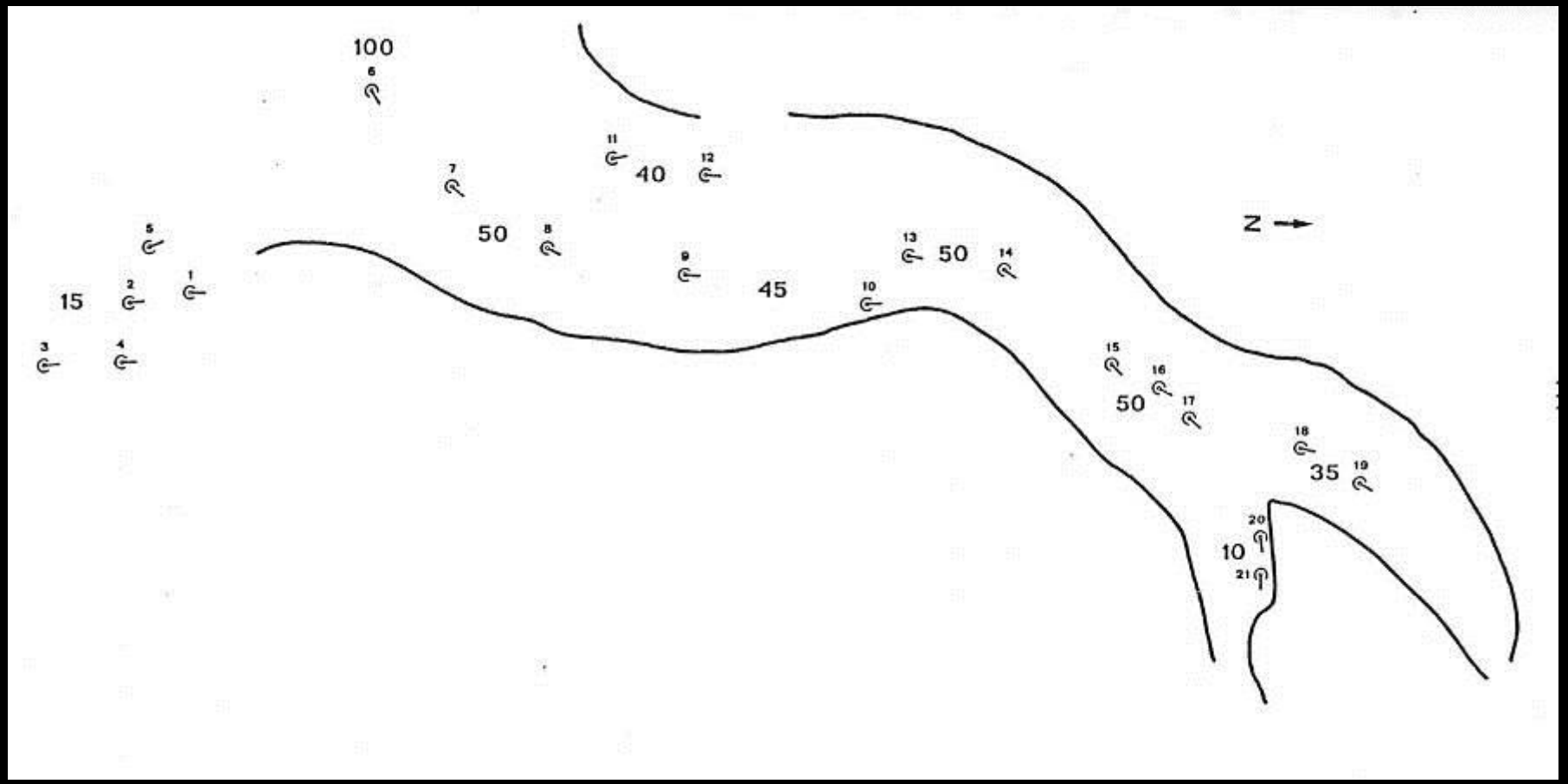




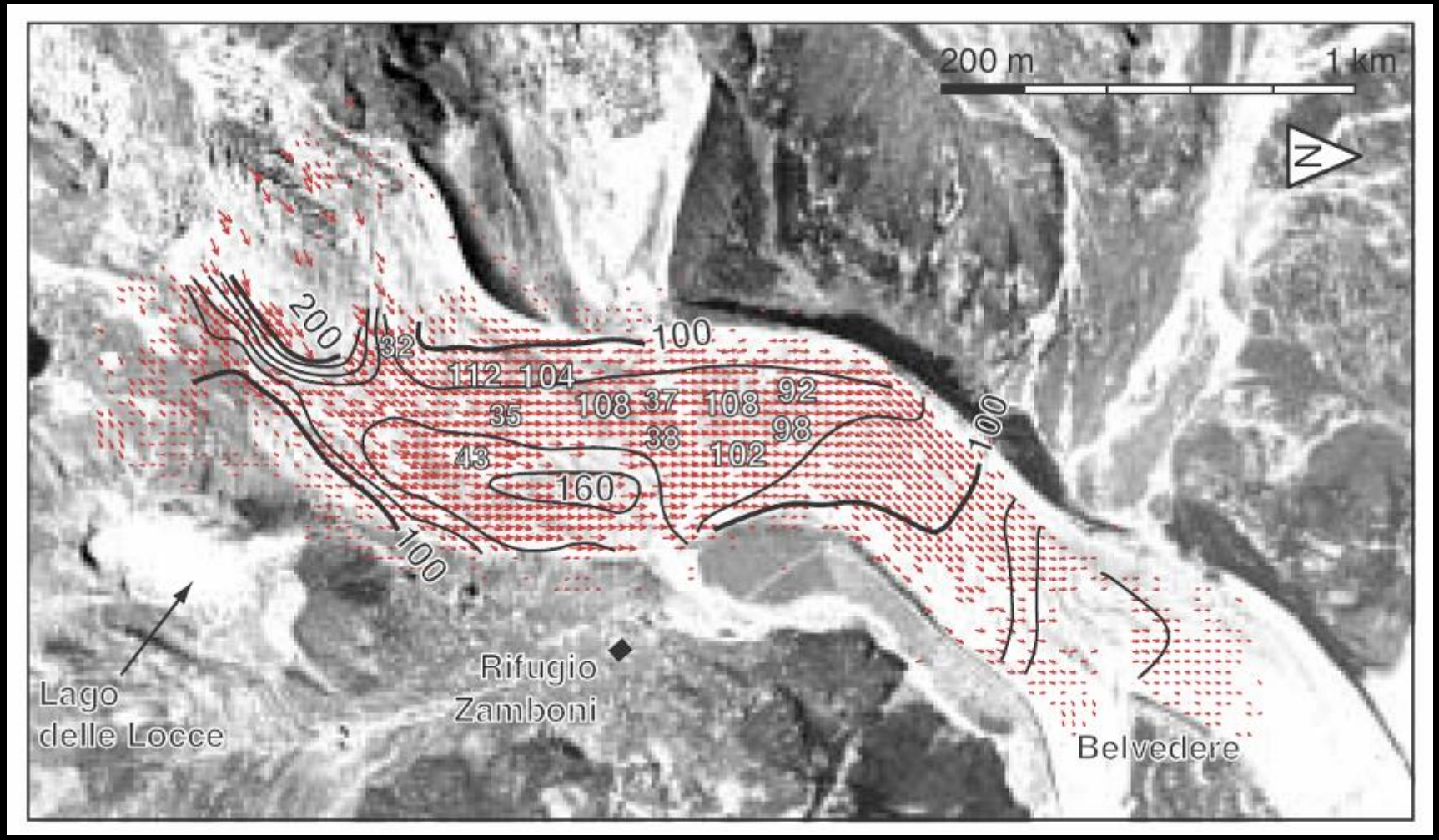
The August 2005 ice avalanche: 2D vs 3D



Surface displacements from July 1983 to October 1984 (stakes)



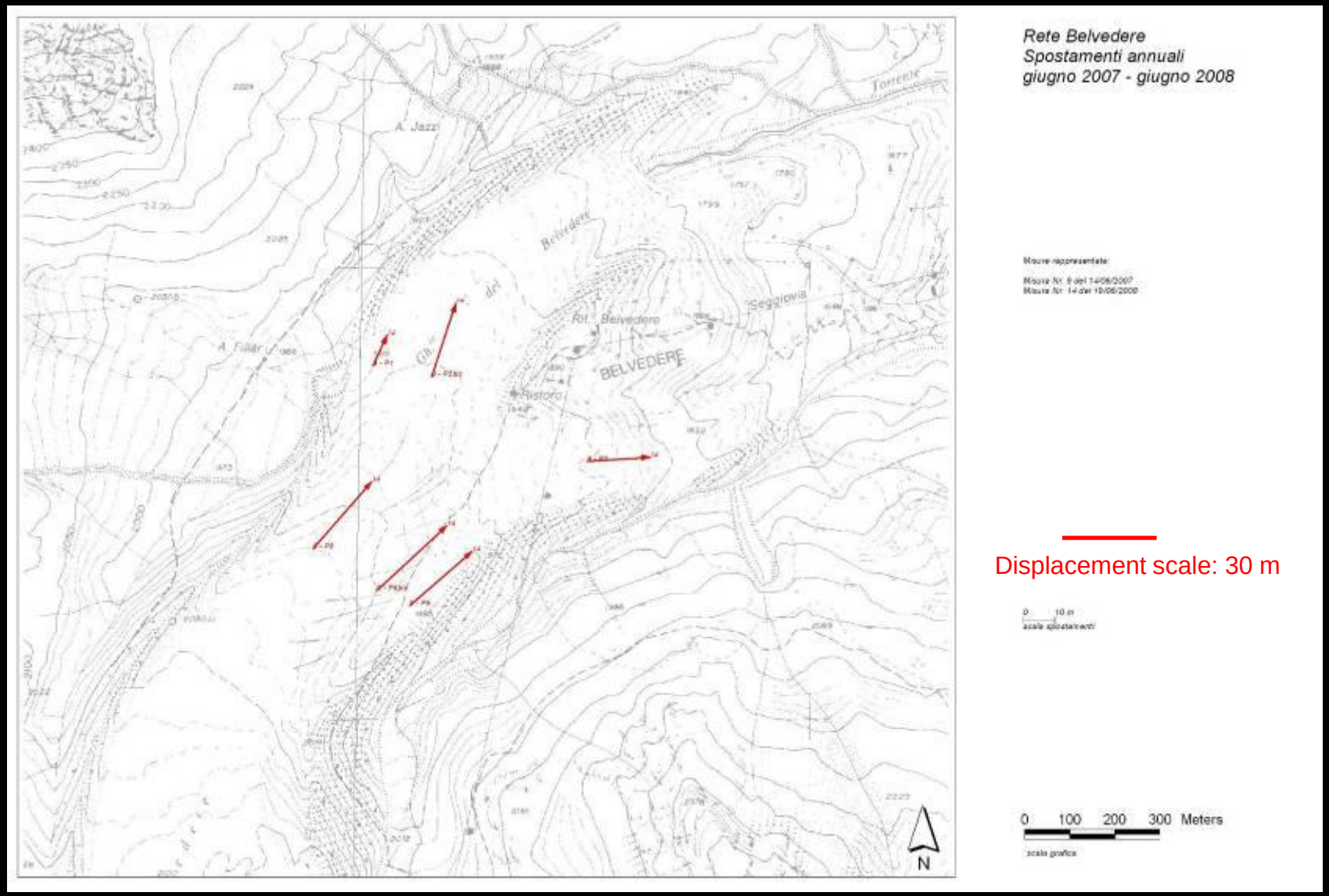
Surface displacements from 2000 to 2002 (aerial photogrammetry)



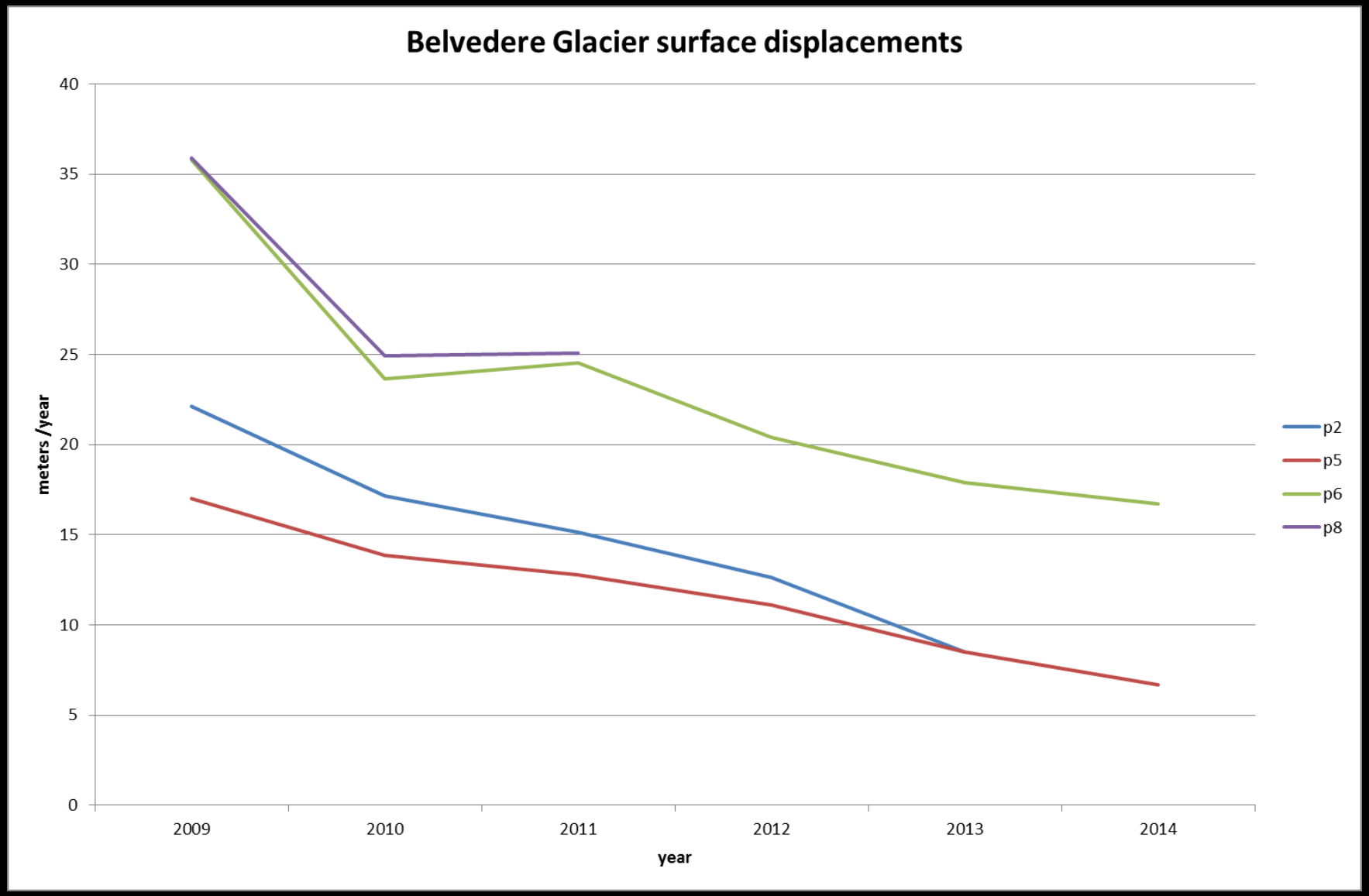
Surface velocity field on Ghiacciaio del Belvedere, Italian Alps, between 6 September 2001 and 11 October 2001. Underlying orthoimage of 11 October 2001 (original air-photo © CNR-IRPI/Glaciorisk). The black numbers and isolines indicate the glacier speeds of the autumn 2001 period. The large white numbers (92–112 m a−1) give speeds at selected points between 2 September 1999 and 6 September 2001; the smaller white numbers (32–43 m a−1) indicate speeds from 12 October 1995 to 2 September 1999. Speeds are given in metres per year. (Kääb et al, 2005)

Surface displacement rate increase up to 200 m/yr (horizontal) and 10-15 m/yr (vertical)

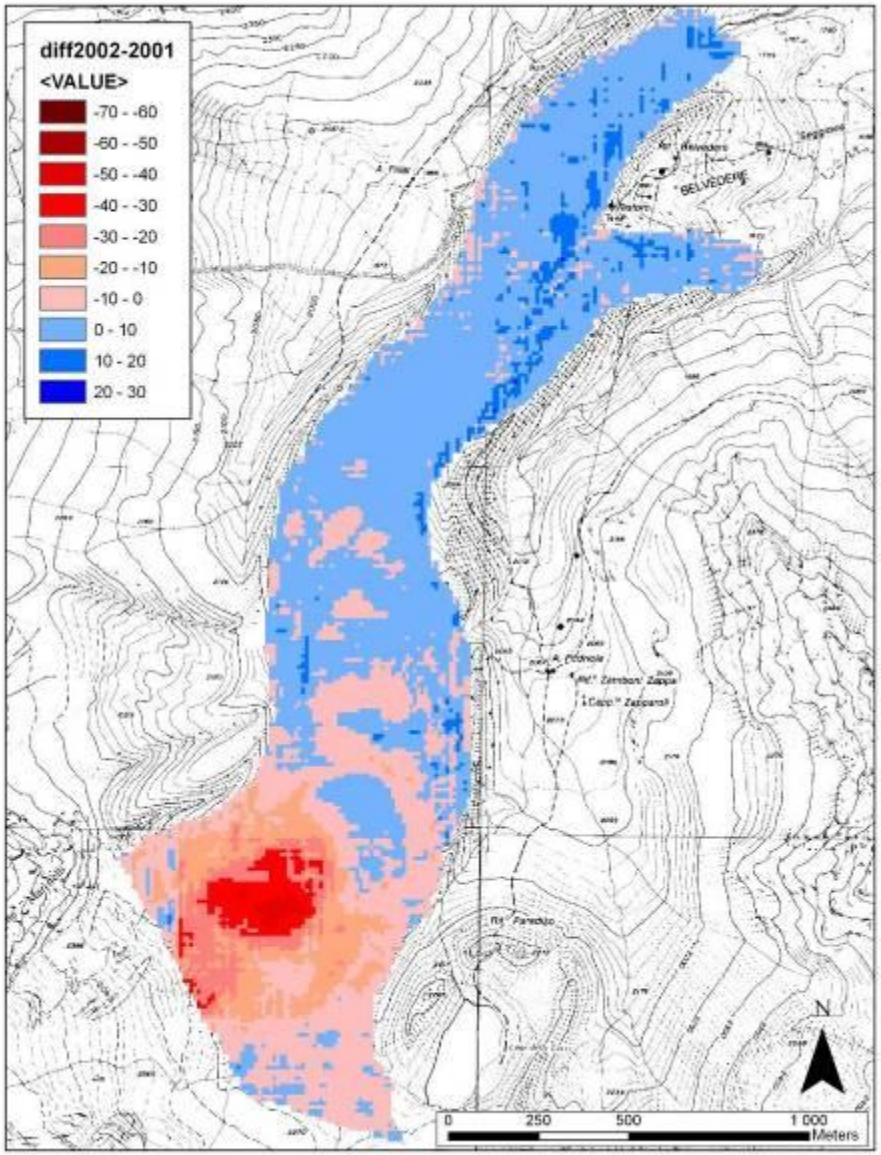
Surface displacements from June 2007 to June 2008 (stakes)

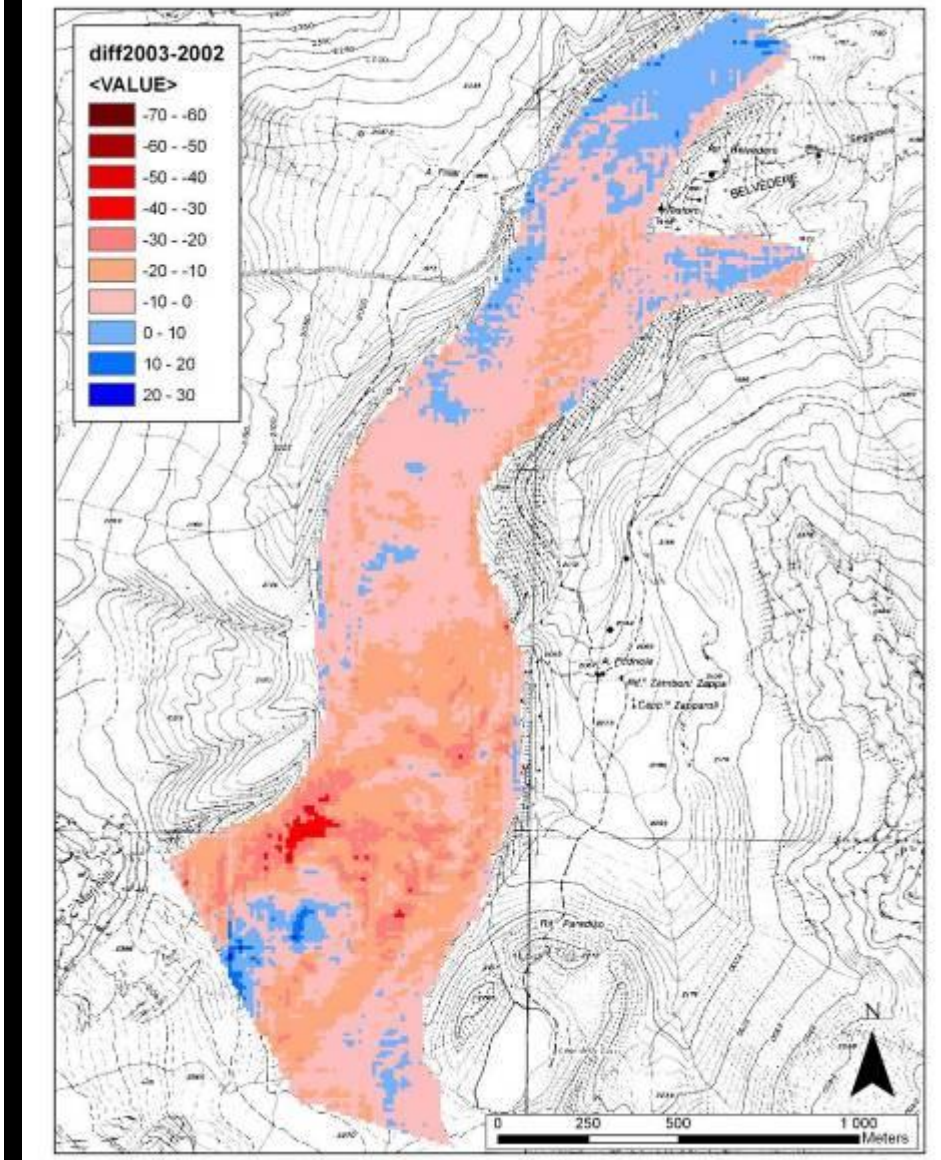


Surface displacement rate drop from 2009 to 2014 (stakes)

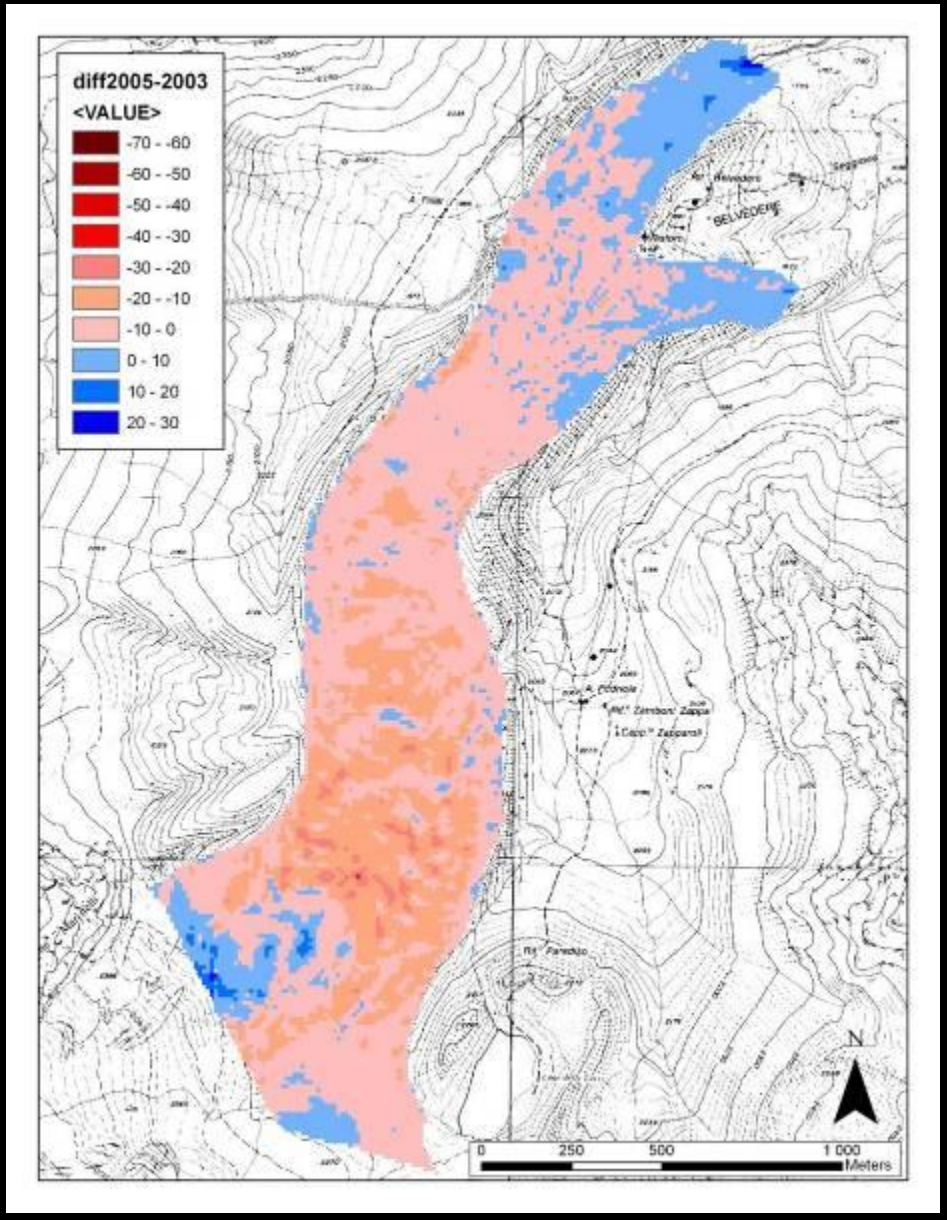


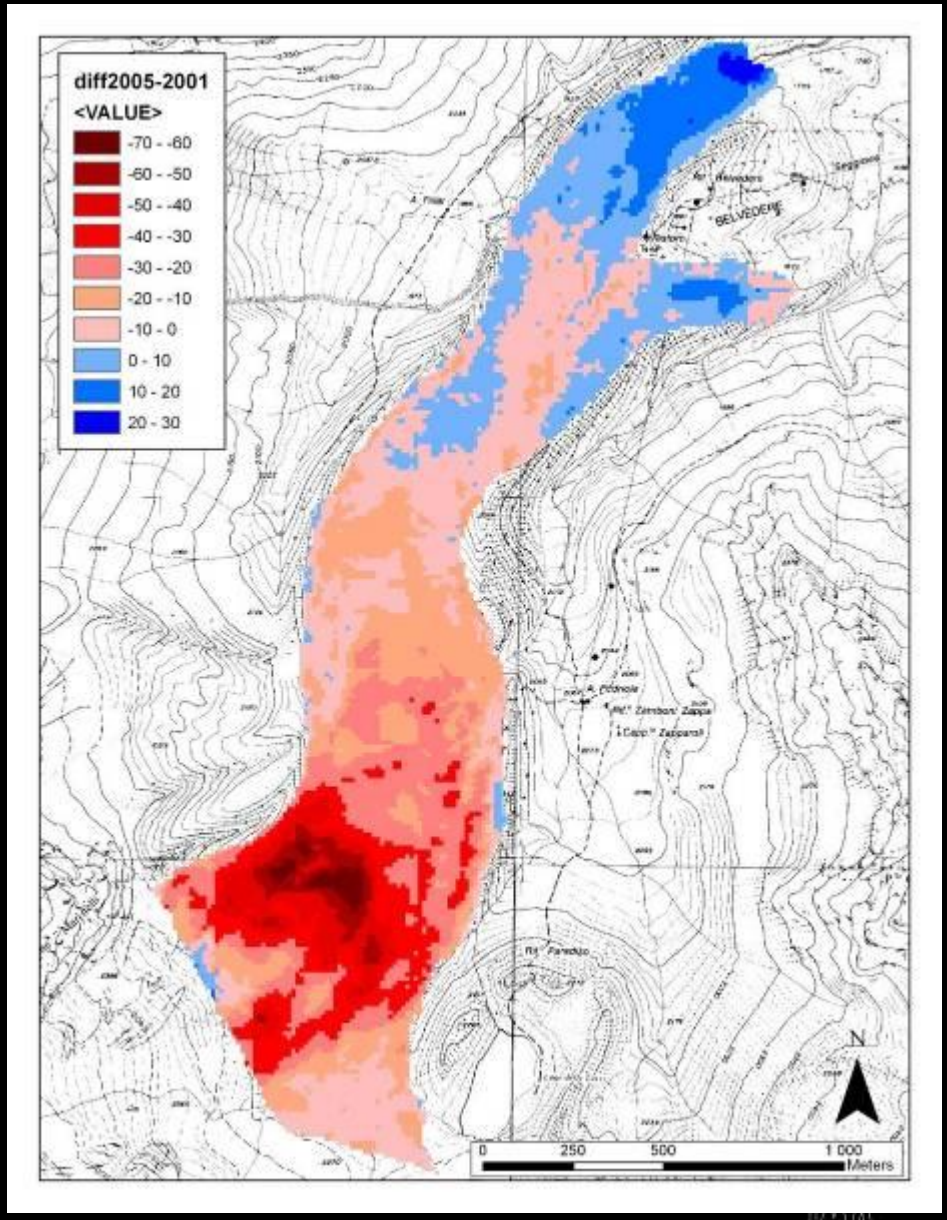
Surface elevation change 2001 - 2003





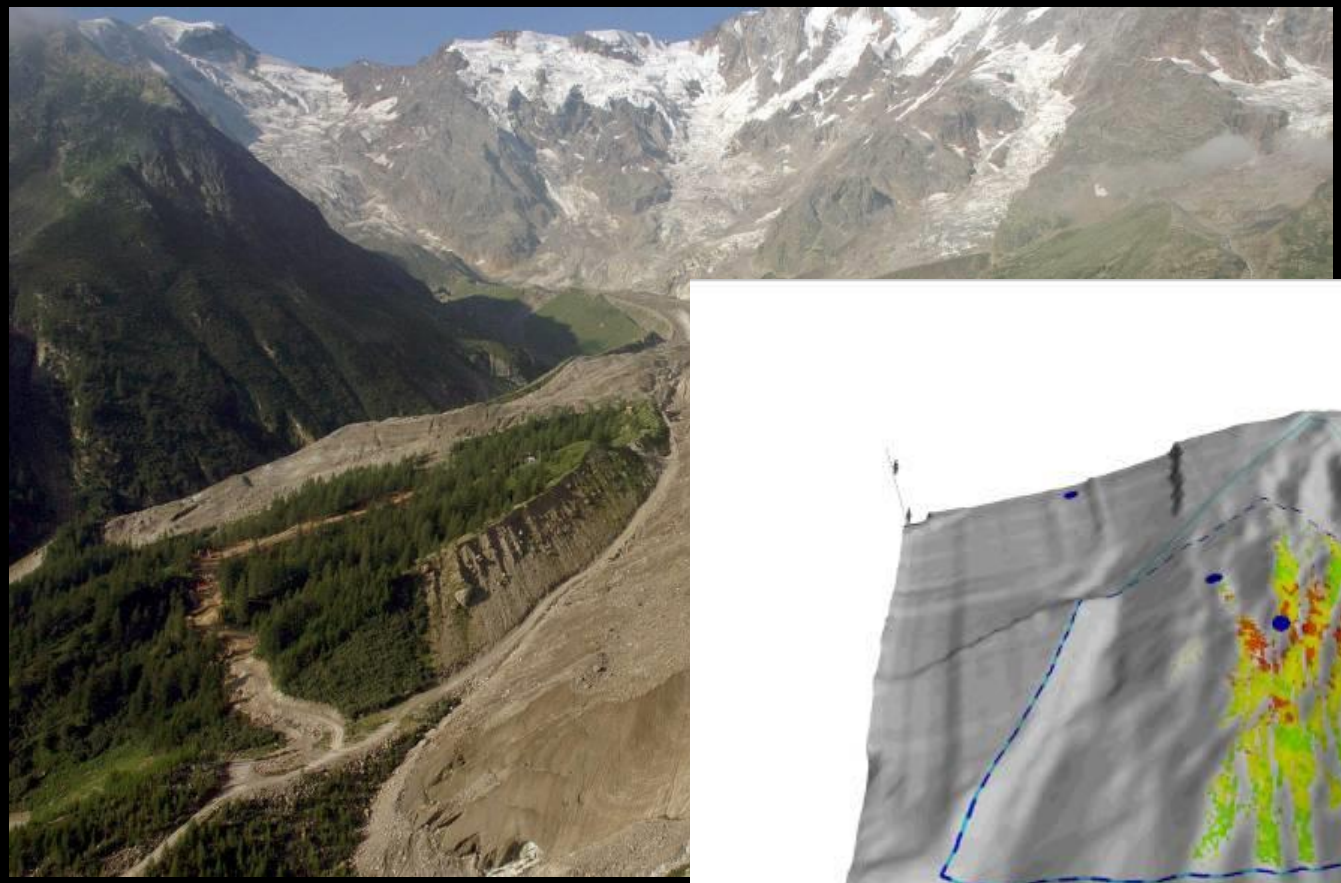
Surface elevation change 2003 - 2005

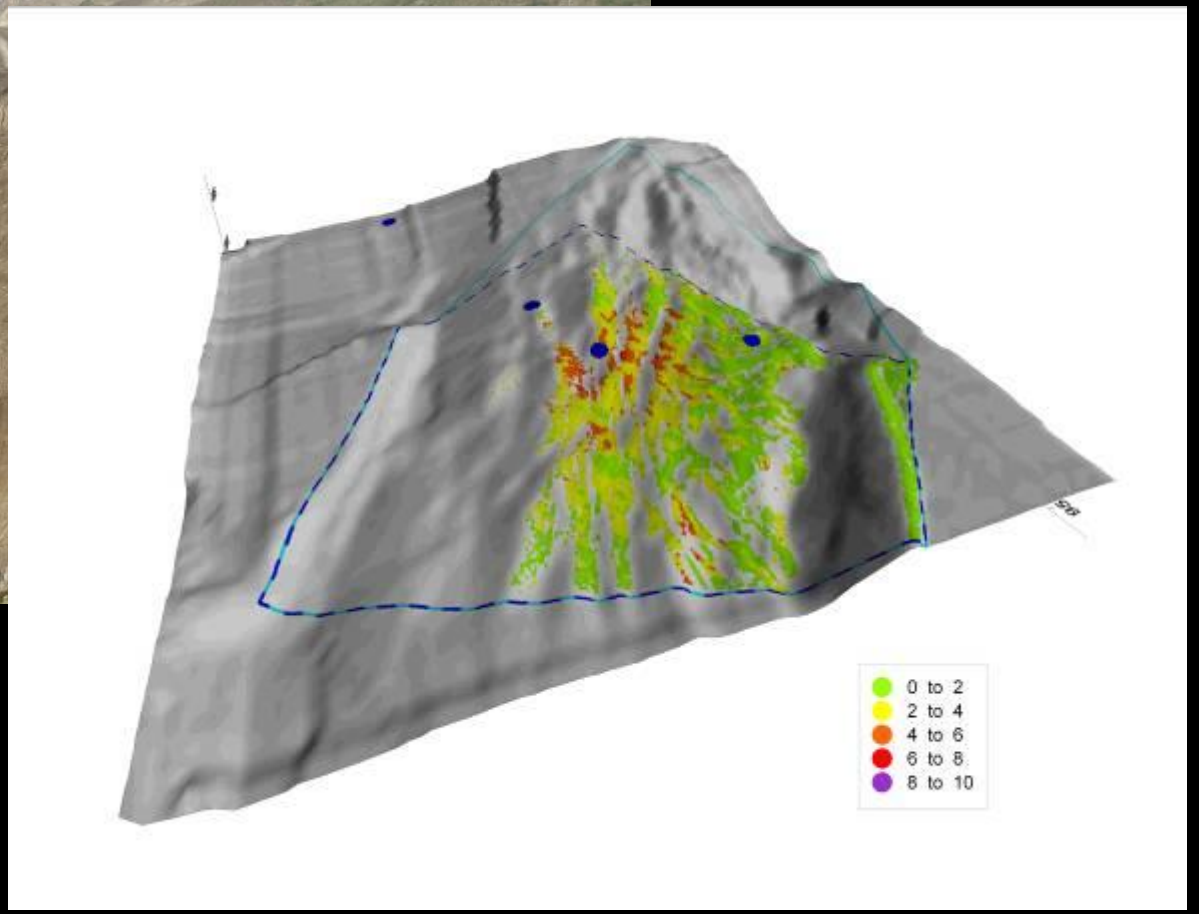


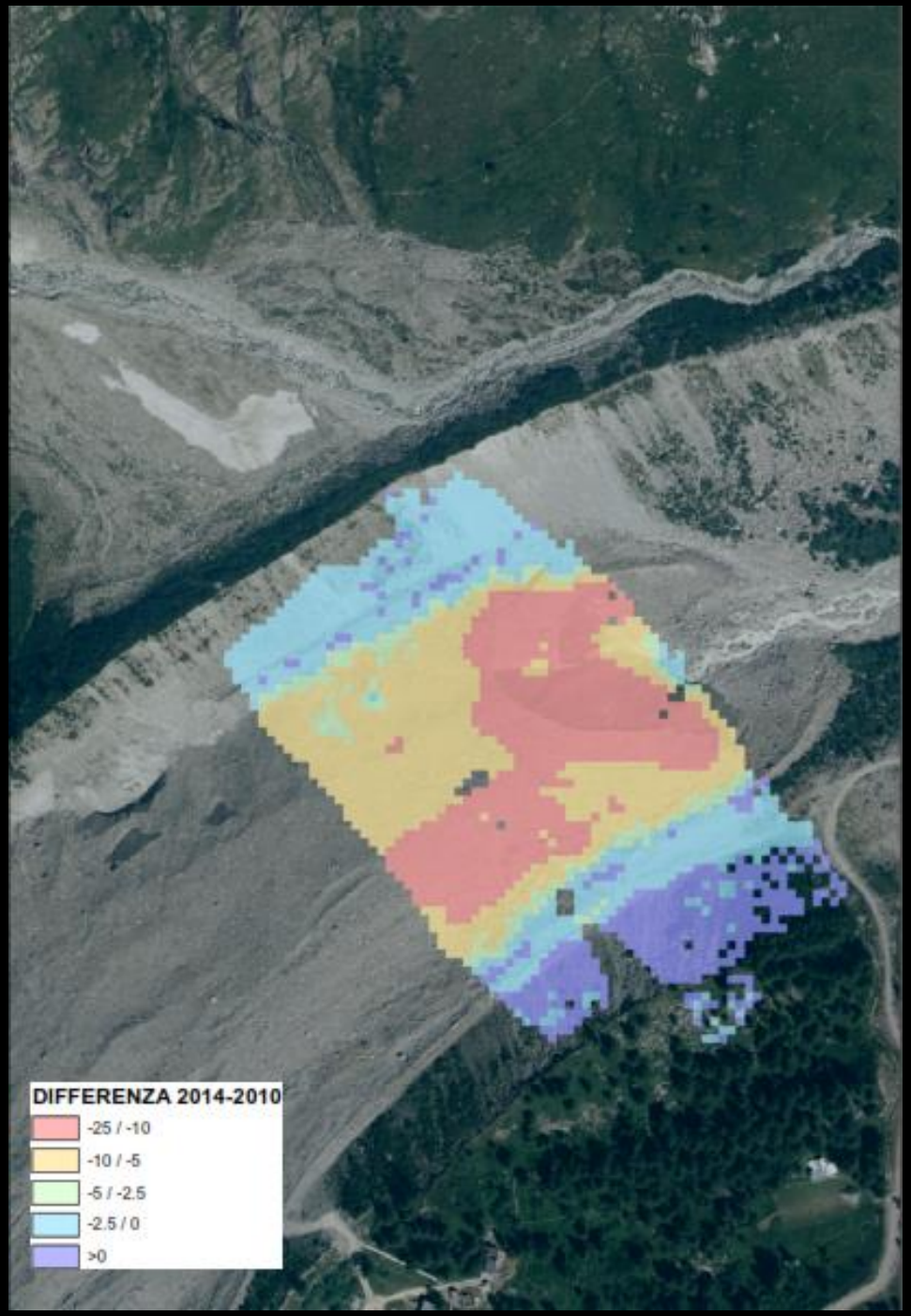


Surface elevation change: ablation season 2008

Surface elevation change: ablation season 2008







Surface elevation difference 2010-2014

2010: Lidar DEM
2014: UAV DEM

Right PEG moraine evolution: 2005 - 2007

Belvedere snout evolution: 2009 vs 2013

From 2012 to 2014:
more than 40 m retreat

Summary

- ✓ Surge-type ice flow acceleration since 2000
- ✓ “Effimero” supraglacial lake formation in summer 2002
  - ✓ Multi-temporal bathymetric surveys
  - ✓ Ice thickness measurements with GPR surveys
  - ✓ Multi-temporal dye tracer tests
- ✓ “Effimero” supraglacial lake outburst in June 2003
- ✓ Frequent ice- and rockfalls from the Monte Rosa East Face are related to rapid deglaciation and permafrost degradation: major events 2005 ice avalanche and 2007 rock avalanche
  - ✓ Repeated photogrammetric surveys
  - ✓ Repeated Lidar surveys of the Monte Rosa East face (topography and geomecanics)
  - ✓ Runout 2D and 3D back analysis
- ✓ Dramatic surface displacement rate and surface elevation drop after 2005
  - ✓ Stake measurements (ablation and displacement rate)
  - ✓ Ground based and airborne Lidar
  - ✓ UAV survey of the snout (summer 2014)

Thank you!

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