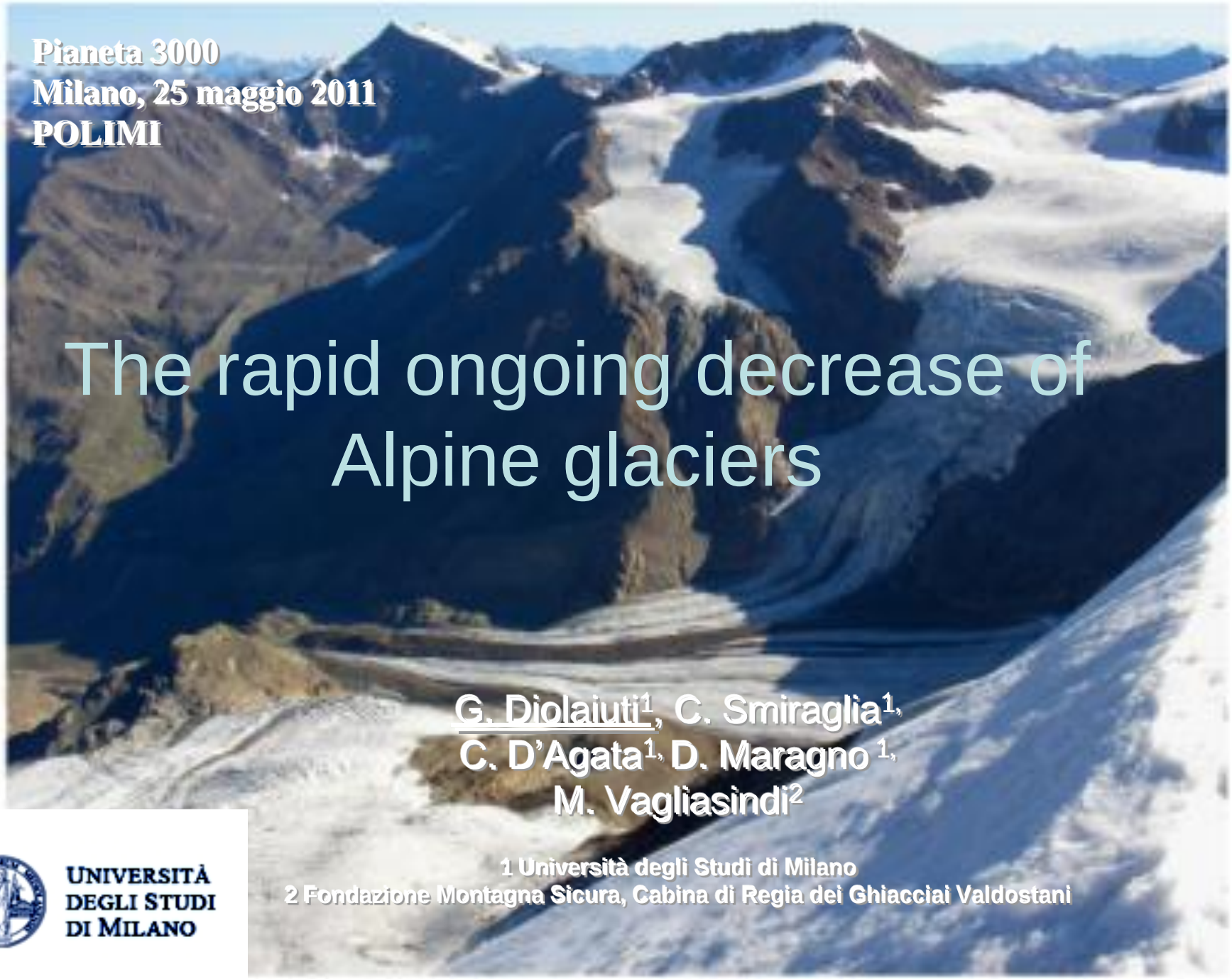

Pianeta 3000
Milano, 25 maggio 2011
POLIMI

The rapid ongoing decrease of Alpine glaciers

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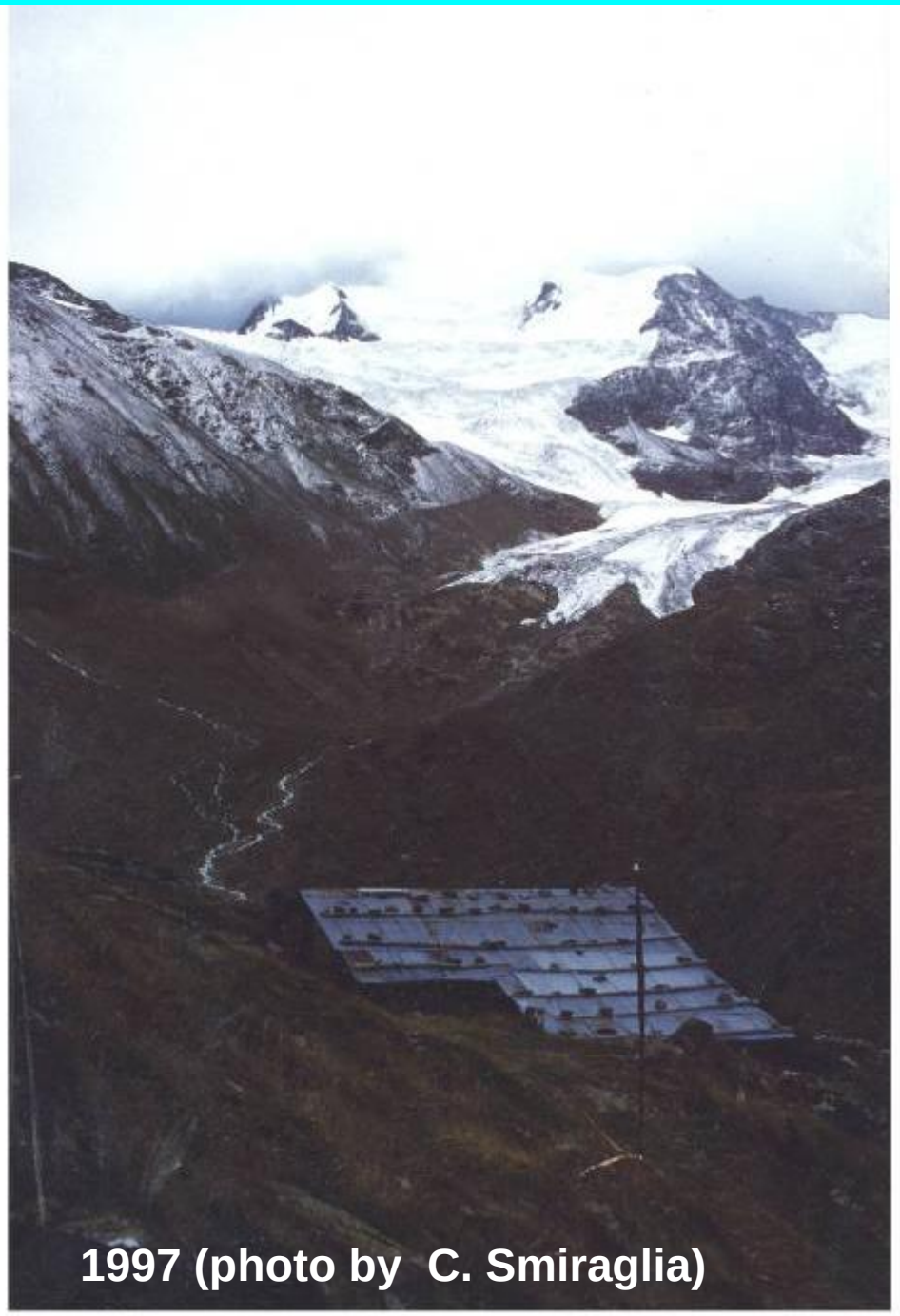
UNIVERSITÀ DEGLI STUDI DI MILANO


1997 (photo by C. Smiraglia)


2007 (photo by C. Smiraglia)

Introduction

Lex Blanche Glacier (Mont Blanc): 1908

Lex Blanche Glacier(Mont Blanc): 2002

Grande di Verra Glacier, 1903

Grande di Verra Glacier, 2003

The Italian Glaciation: a general overview

Glacier Inventory 1959-1961

838 glacier bodies (745 glaciers and 93 glacierets)

Total surface coverage : 525 km^2

Glacier Inventory 1989

807 glacier bodies (706 glaciers and 101 glacierets)

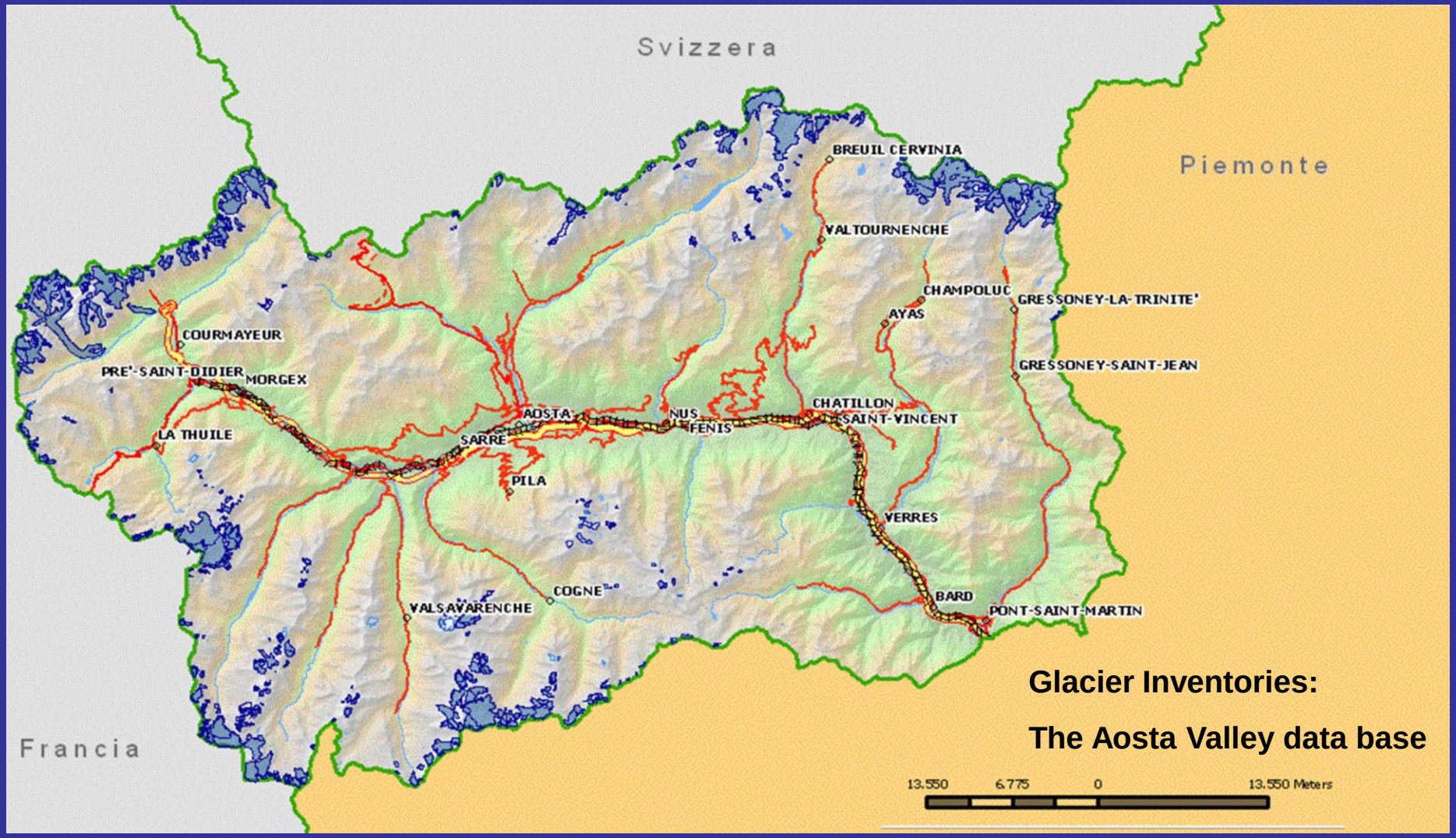
Total surface coverage : 482 km^2

-43 Kmq /28 years = -1,5 Km^2/year

-31 glaciers /28 years

from Citterio et al., 2007

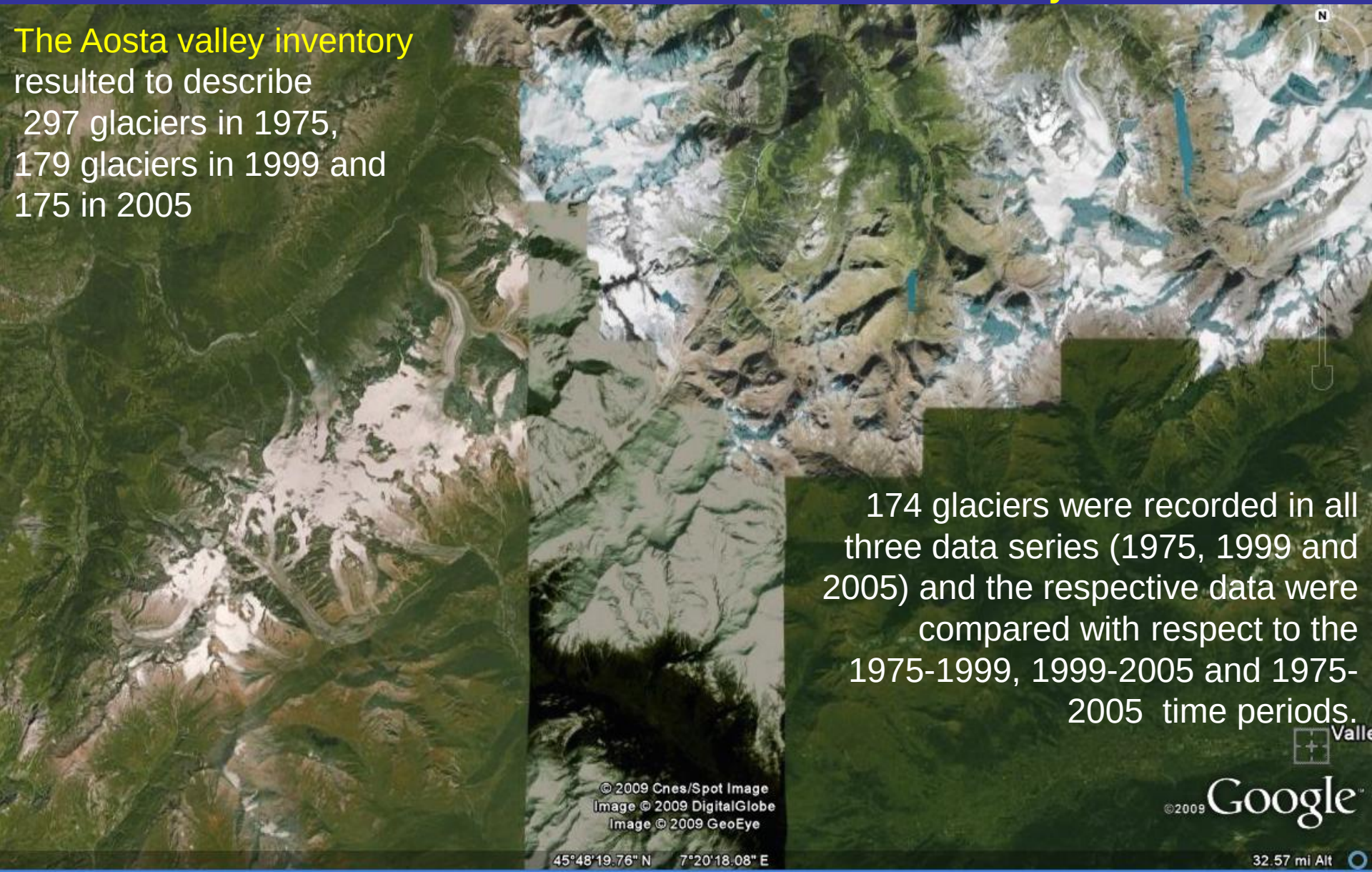
Data: The Aosta Valley glaciation



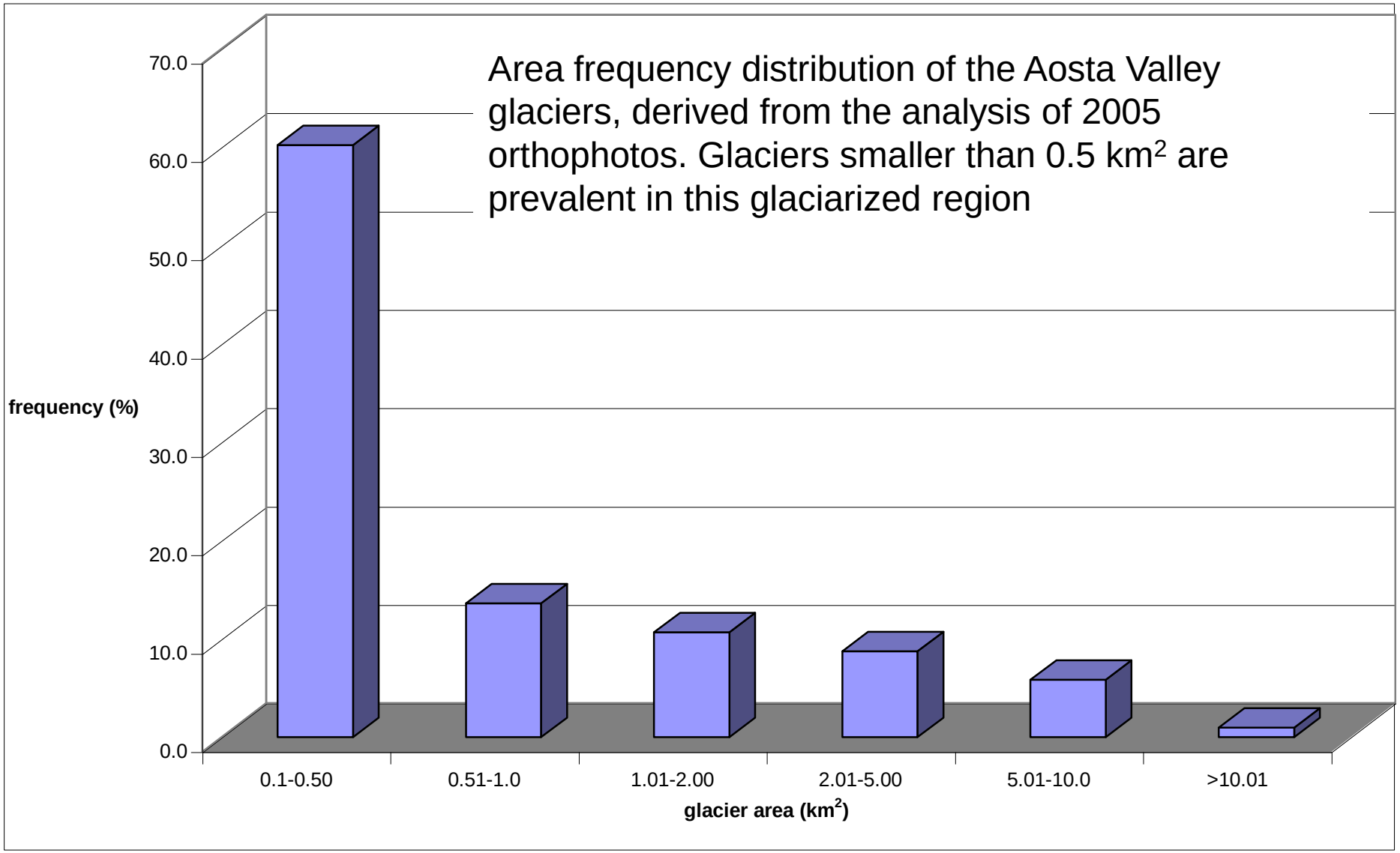
The Aosta valley inventory resulted to describe 297 glaciers in 1975 (VDAGI, 1975)

Glacier Inventories:

The Aosta Valley data base

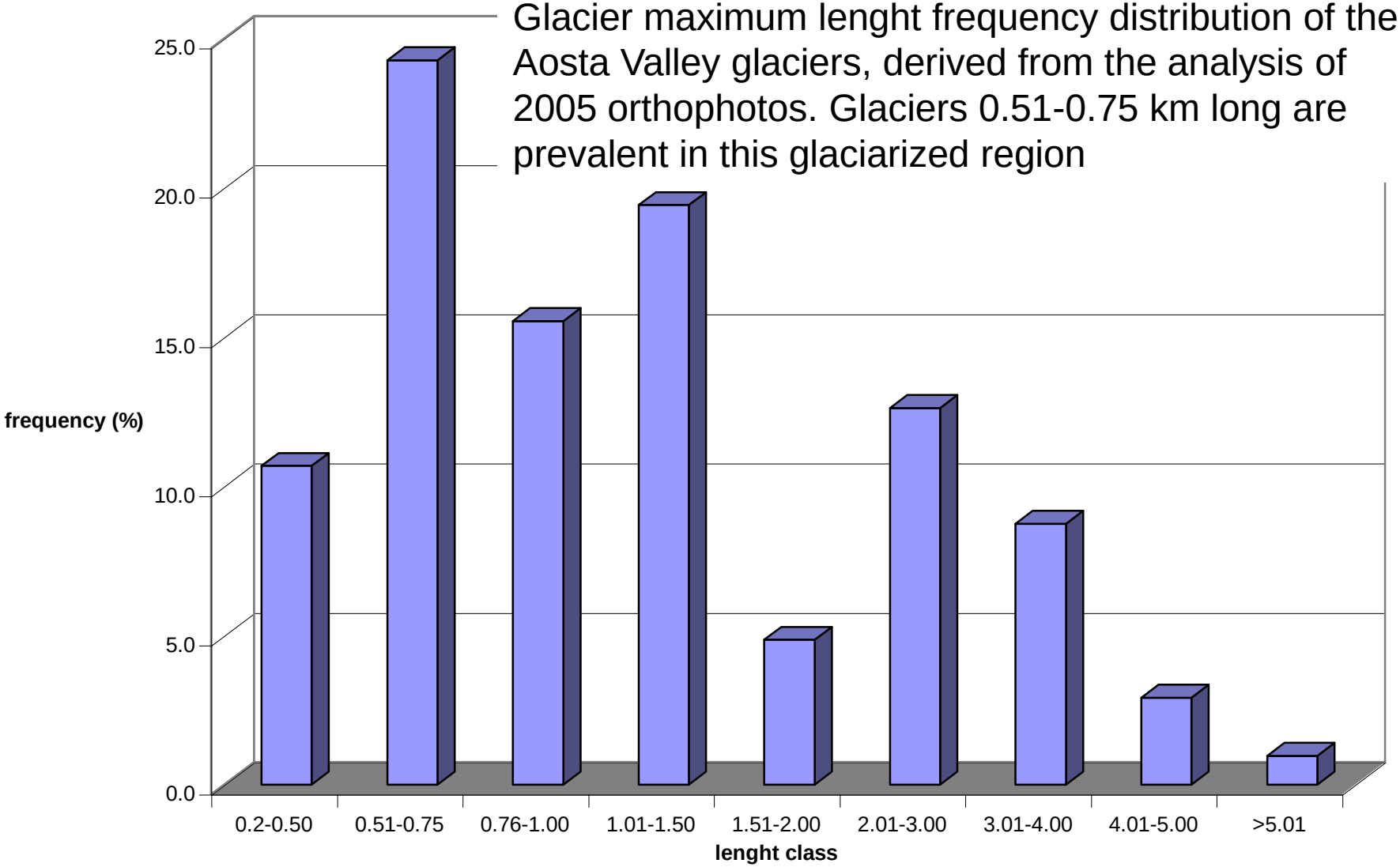


The 2005 glacier inventory



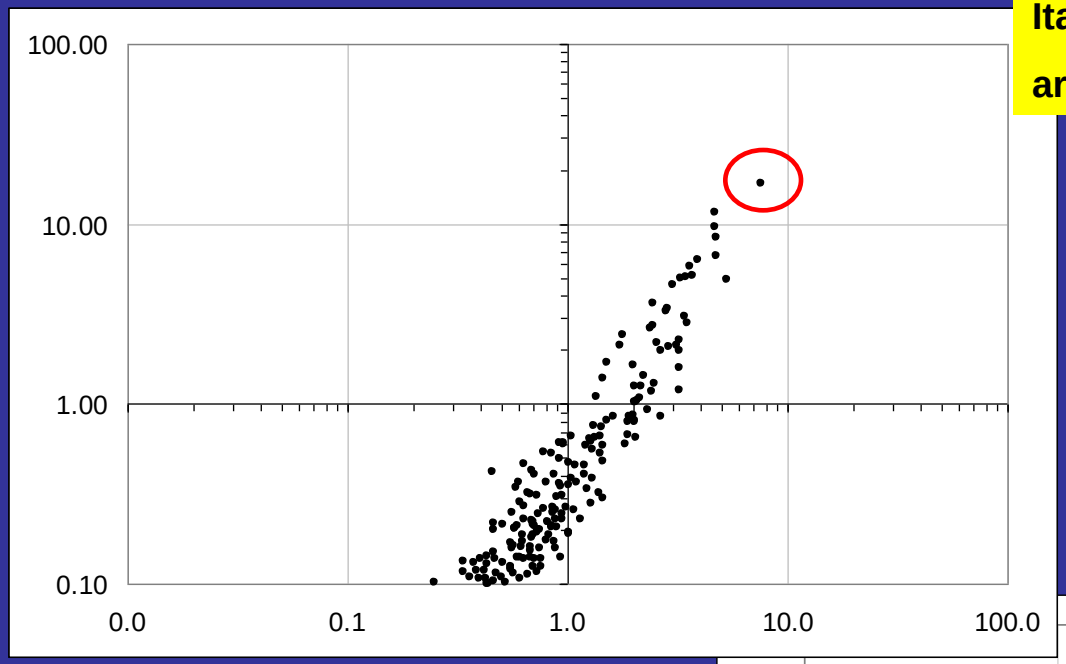
The 2005 glacier inventory

Glacier maximum lenght frequency distribution of the Aosta Valley glaciers, derived from the analysis of 2005 orthophotos. Glaciers 0.51-0.75 km long are prevalent in this glaciarized region



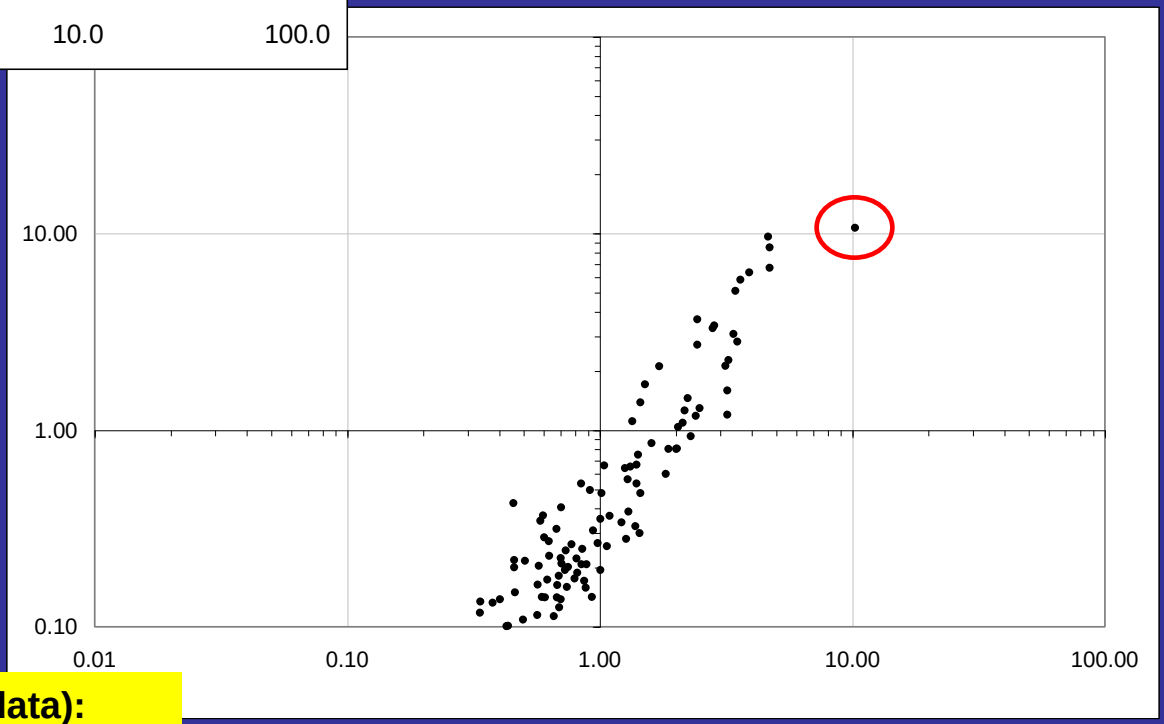
glaciers > 0.1 km^2

Results: glacier region representativeness



Italian glaciers > 0.1 km² (WGI data):

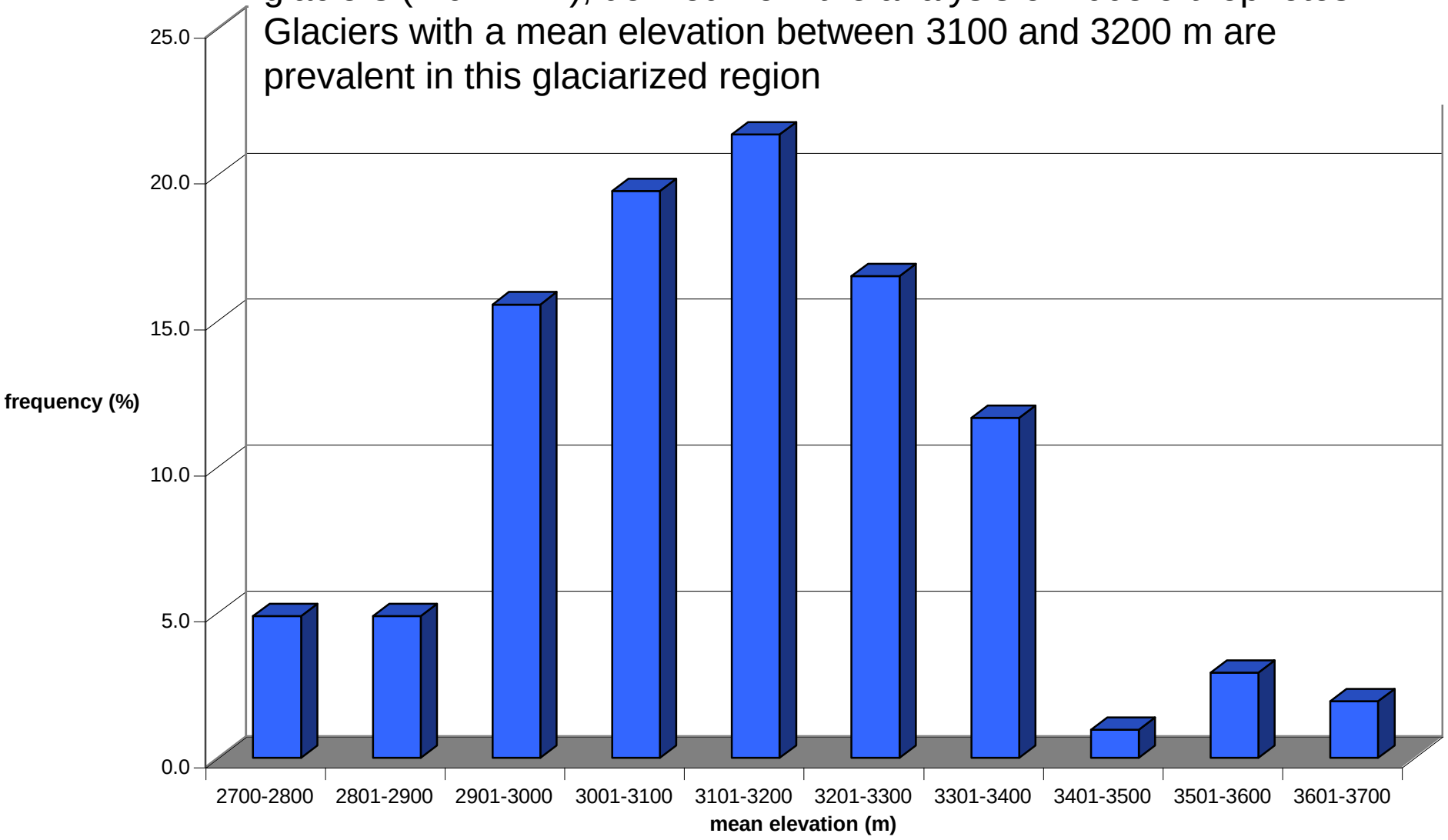
area vs max lenght (value in km² and km)



Aosta Valley glaciers > 0.1 km² (2005 RI data):
area vs max lenght (value in km² and km)

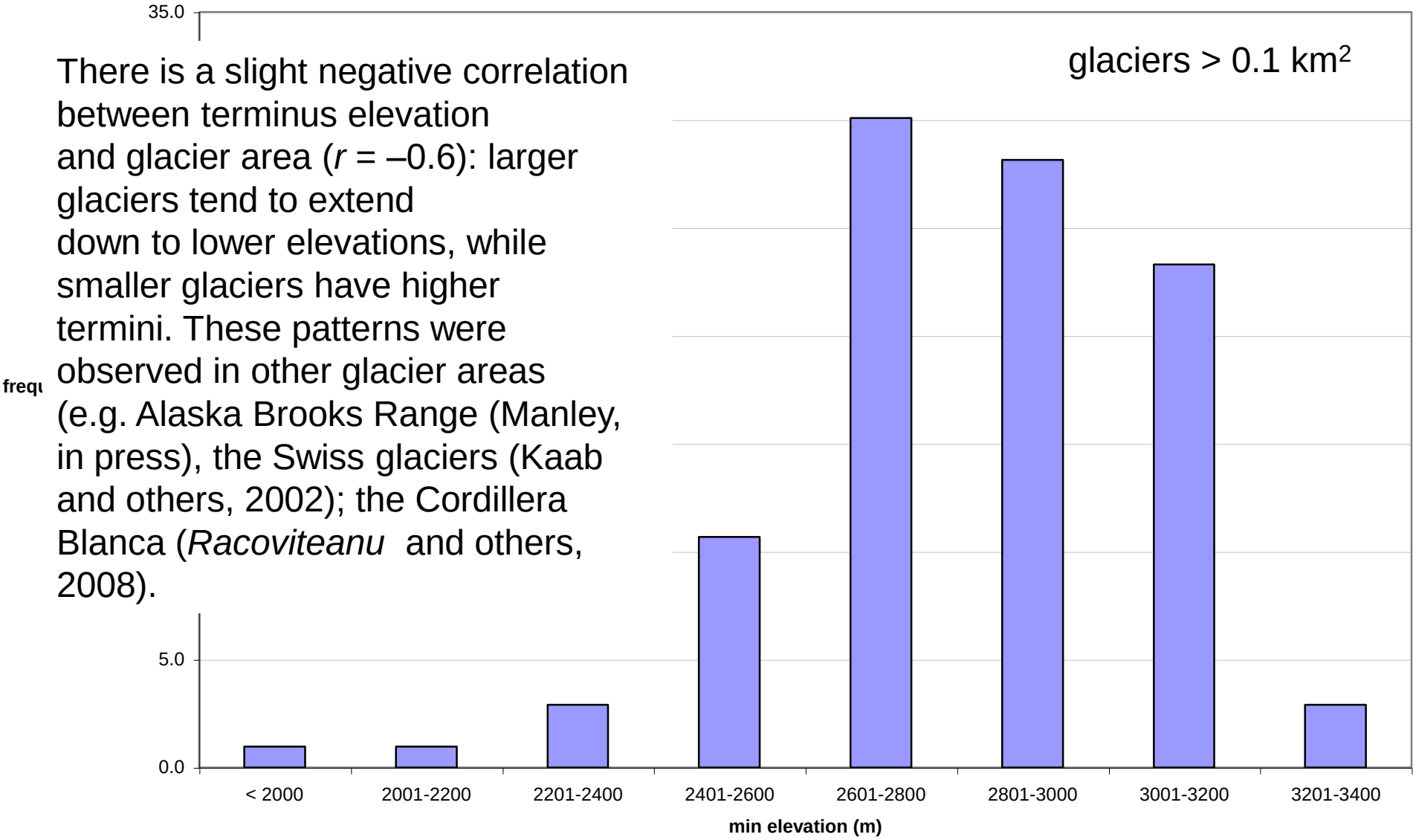
The 2005 glacier inventory

Glacier mean elevation frequency distribution of the Aosta Valley glaciers (> 0.1 km^2), derived from the analysis of 2005 orthophotos. Glaciers with a mean elevation between 3100 and 3200 m are prevalent in this glaciarized region



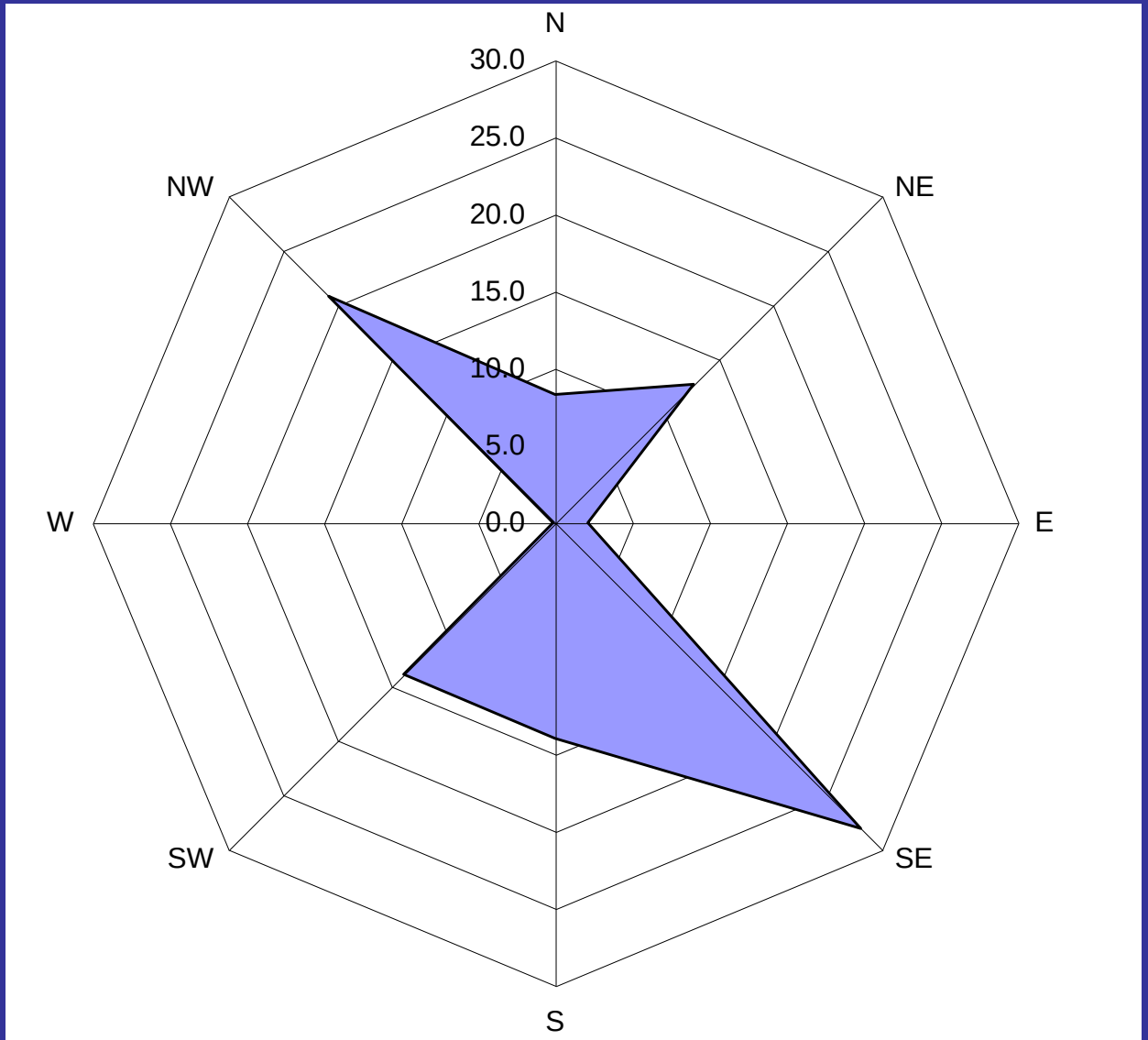
The 2005 glacier inventory

There is a slight negative correlation between terminus elevation and glacier area (r = –0.6): larger glaciers tend to extend down to lower elevations, while smaller glaciers have higher termini. These patterns were observed in other glacier areas (e.g. Alaska Brooks Range (Manley, in press), the Swiss glaciers (Kaab and others, 2002); the Cordillera Blanca (*Racoviteanu* and others, 2008).



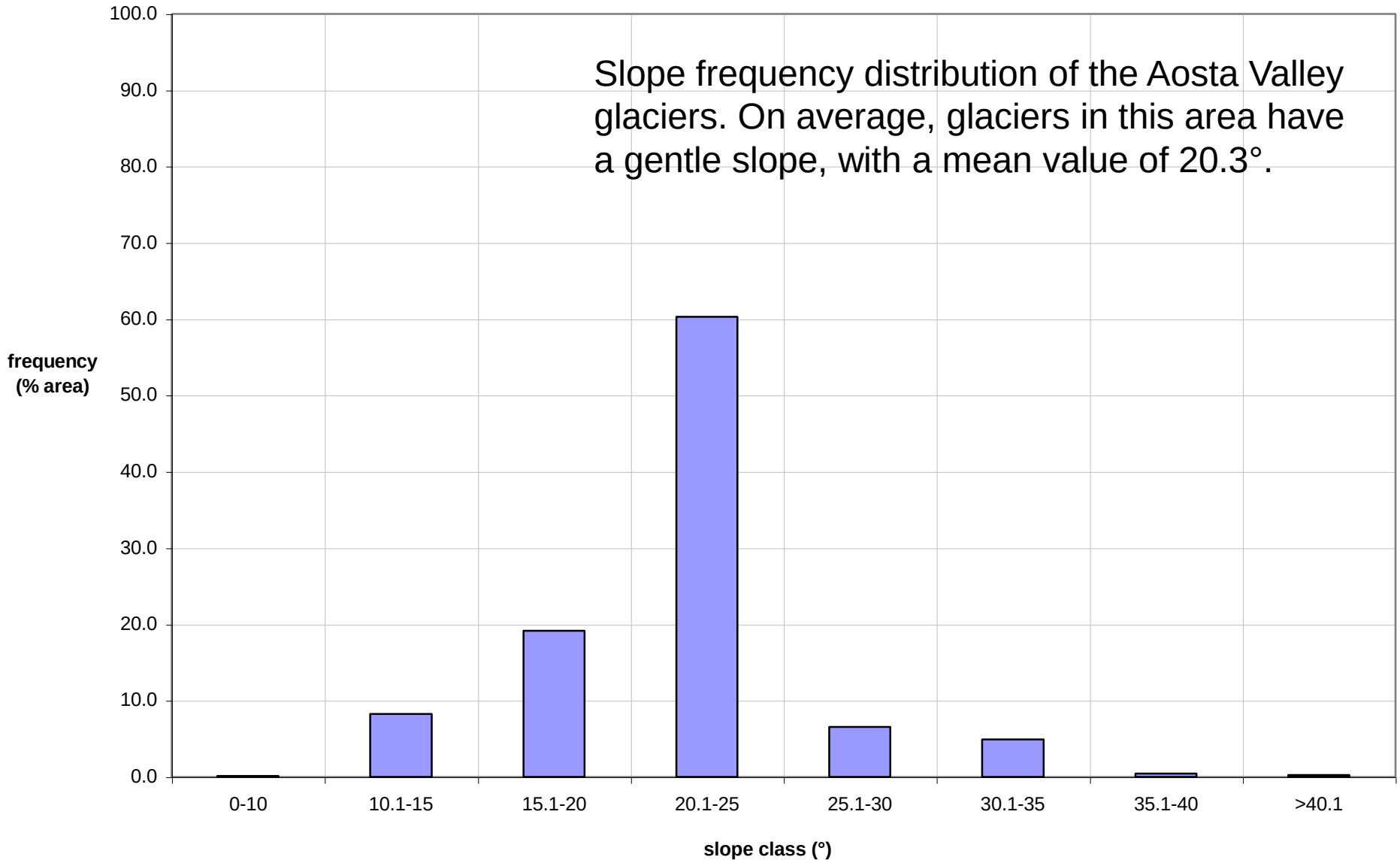
Results: glacier aspect

The 2005 glacier inventory



Aspect frequency distribution of the Aosta Valley glaciers (> 0.1 km^2). Numbers represent the percent of glacier area in 45° aspect bins. Glaciers show a southeast preferred aspect.

The 2005 glacier inventory



Magnitude and rates of Aosta Valley glaciers' changes

Size class (km^2)	1975 Glacier number	1999 Glacier number	2005 Glacier number
<0.1	18	51	70
0.1-0.5	97	77	63
0.5-1	22	14	14
1-2.0	18	16	11
2-5.0	12	9	9
5-10.0	5	5	6
>10	2	2	1
total	**174**	**174**	**174**

Tab. 1: numerical distribution of the analysed glaciers respect to the 7 size- classes

The total loss in glacierized area from 1975 to 2005 amounted to 44.3 km2 ± 1.3 % and the strongest contribution (-12.46 km2 equal to -28.1% of the total area change) to this area loss came from the second most-populated size class (0.1 - 0.5 km2), which constituted only c. 9 % of the remaining glacierized area in 2005.

size class (km^2)	1975 area coverage (km^2)	1999 area coverage (km^2)	2005 area coverage (km^2)	1975-2005 area change (km^2)	1975-1999 area change (km^2)	1999-2005 area change (km^2)
<0.1	1.22	0.80	0.46	-0.76	-0.42	-0.34
0.1-0.5	23.55	15.48	11.09	-12.46	-8.07	-4.38
0.5-1	14.93	10.85	9.11	-5.82	-4.08	-1.73
1-2.0	24.97	20.99	18.31	-6.66	-3.98	-2.68
2-5.0	35.96	31.67	28.11	-7.85	-4.29	-3.56
5-10.0	38.43	35.19	32.27	-6.16	-3.24	-2.92
>10	24.85	21.58	20.23	-4.62	-3.27	-1.35
total	**163.9**	**136.6**	**119.6**	**-44.3**	**-27.35**	**-16.97**

Tab. 2: area coverage and area changes of the 174 analysed glaciers respect to the 7 size- classes

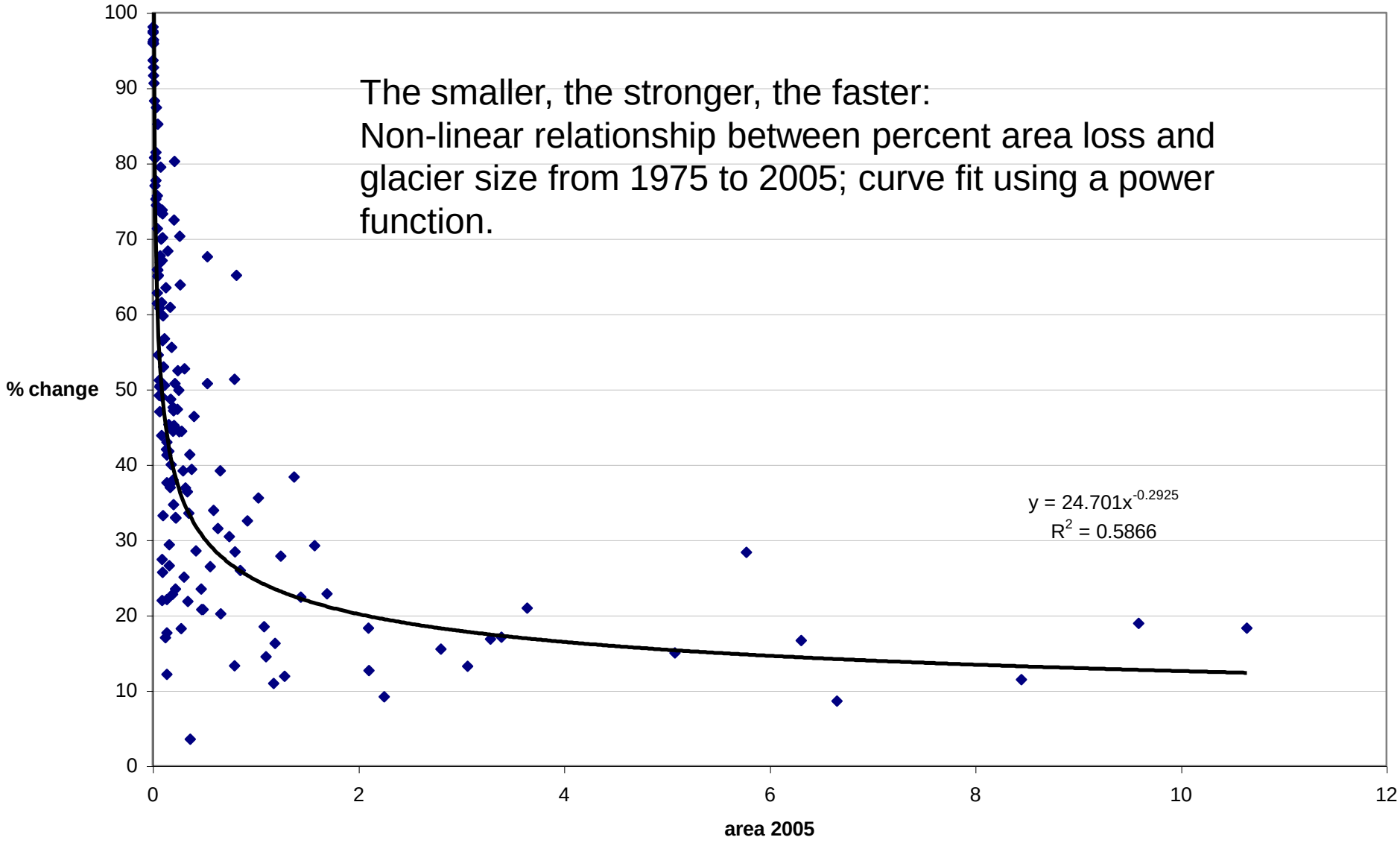
Magnitude and rates of Aosta Valley glaciers' changes

size class (values in km^2)	time frame 1975-2005	time frame 1975-1999	time frame 1999-2005
<0.1	-0.03	-0.02	-0.06
0.1-0.5	-0.42	-0.34	-0.73
0.5-1	-0.19	-0.17	-0.29
1-2.0	-0.22	-0.17	-0.45
2-5.0	-0.26	-0.18	-0.59
5-10.0	-0.21	-0.14	-0.49
>10	-0.15	-0.14	-0.23
total	-1.48	-1.14	-2.83

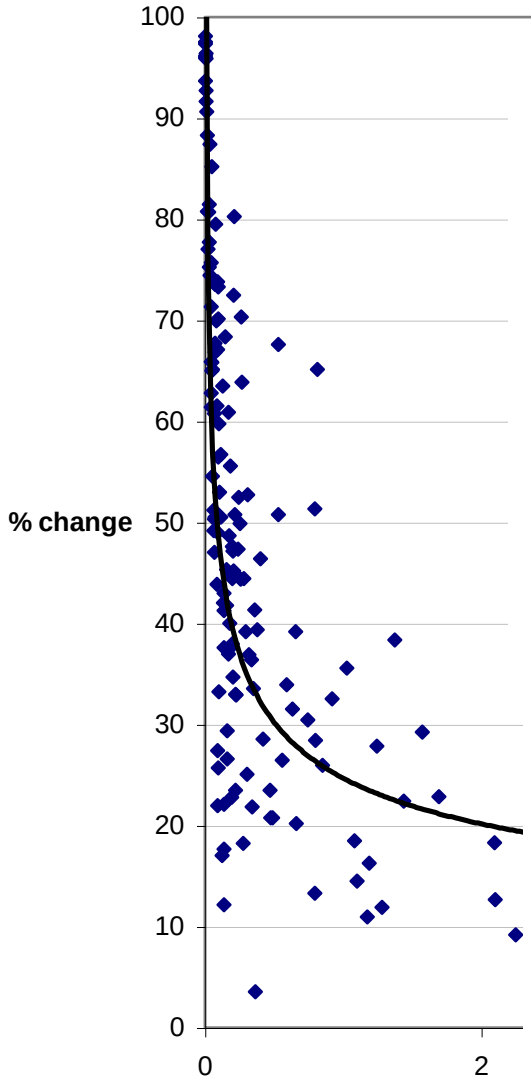
size class | class (% of total area lost)
st) | 2005 | 1999-2005
<0.1 | -2.0
0.1-0.5 | -25.8
0.5-1 | -10.2
1-2.0 | -15.8
2-5.0 | -21.0
5-10.0 | -17.2
>10 | -8.0
total | -100.0

Tab. 3: a… area cove… and as pe… reference …ntage respect to the columns 2, 4 and 6) …lacier sample in the

Magnitude and rates of Aosta Valley glaciers' changes



Magnitude and rates of Aosta Valley glaciers' changes



Correlation analysis showed that small glaciers tend to have both smaller altitudinal ranges and median elevations closer to the glacier head (r = 0.8).

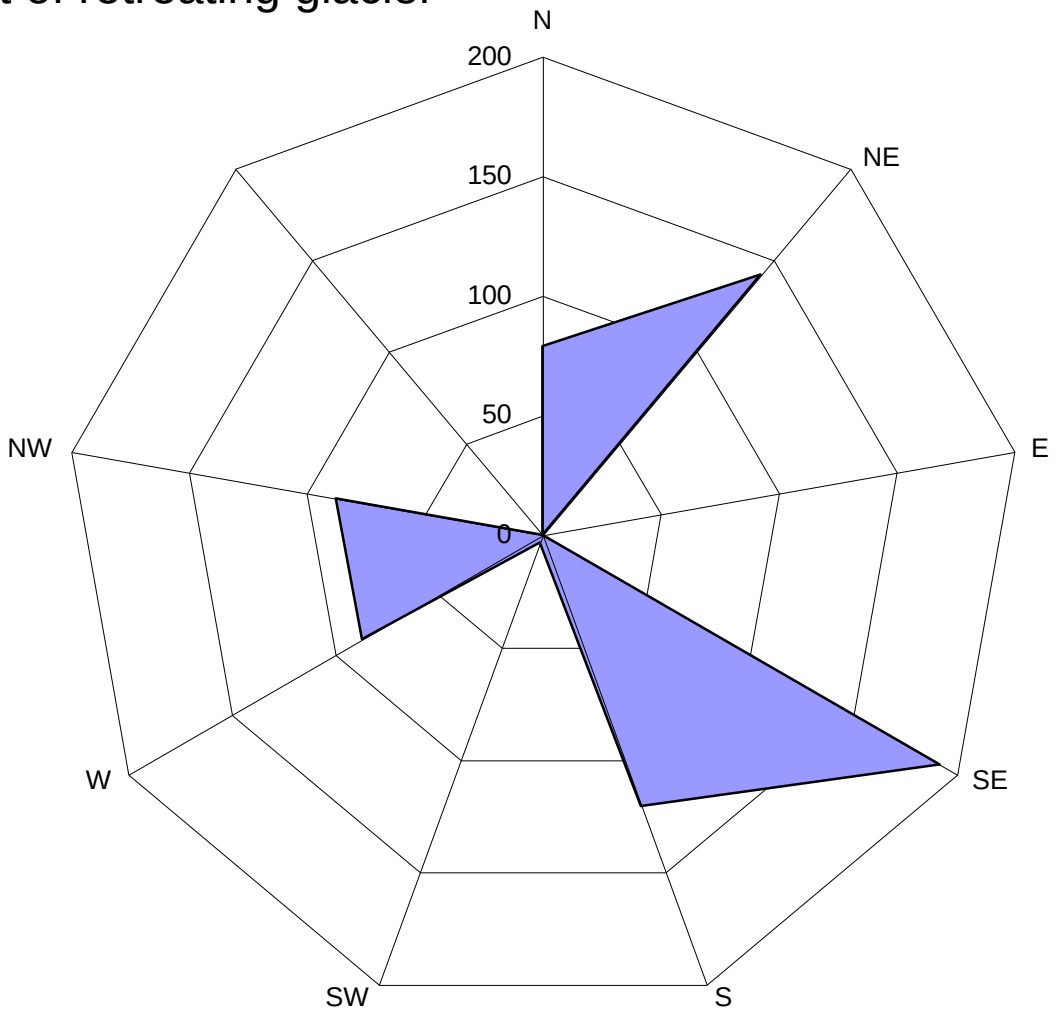
These statistical results support the idea that small glaciers with narrow altitudinal range are losing more of their area, also noted in other studies (Kaser and Osmaston, 2002; Mark and Seltzer, 2005; Racoviteanu and others, 2008).

This may be explained by the fact that a change in local climate may raise the ELA of those glaciers above their maximum elevation, putting the whole area of the glacier in the year-round ablation zone (Kaser and Osmaston, 2002). In contrast, larger glaciers have a very wide altitudinal range, with ELAs well below the maximum elevation at the glacier head.

12

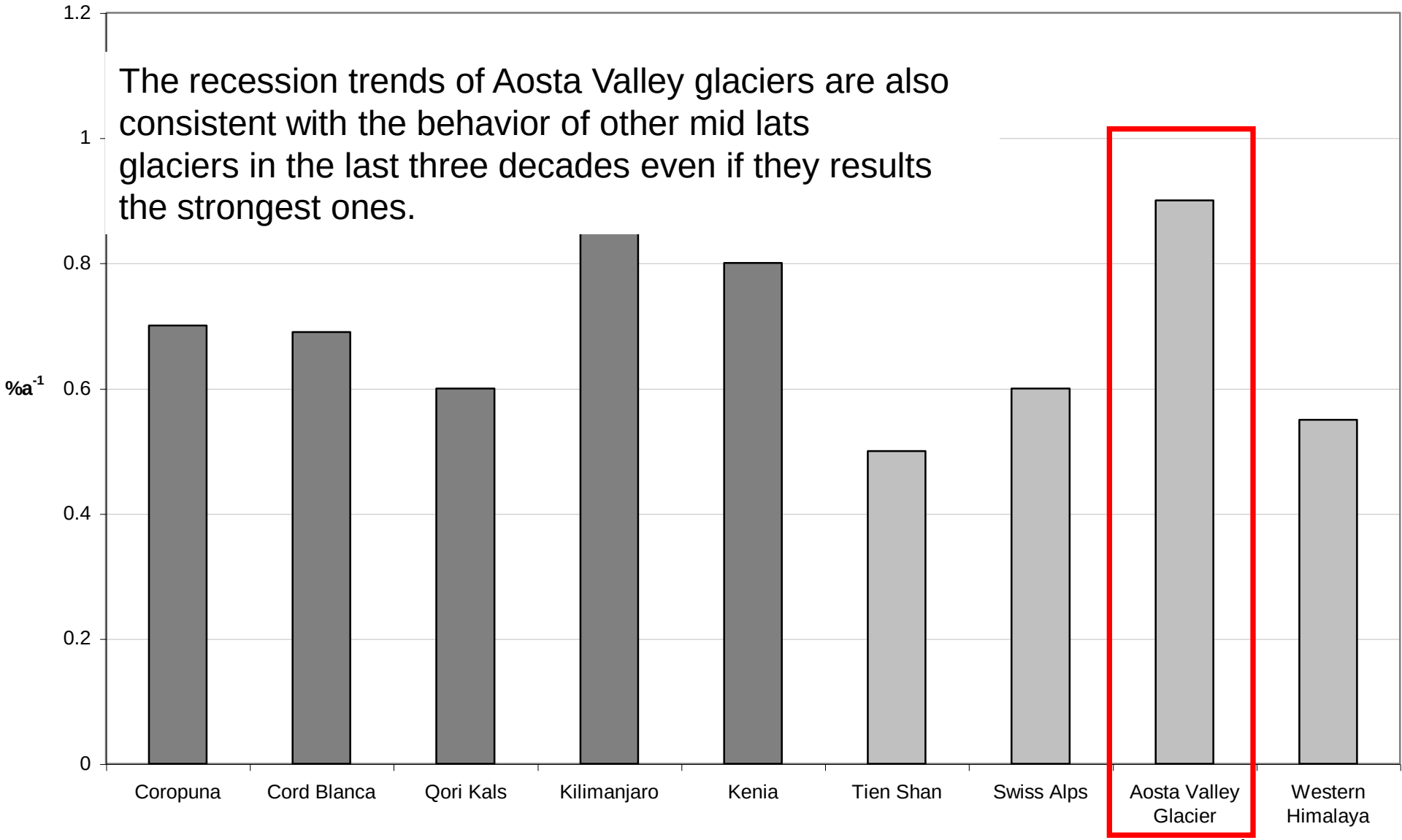
Magnitude and rates of Aosta Valley glaciers' changes

Preferential aspect of retreating glacier



Magnitude and rates of Aosta Valley glaciers' changes

The recession trends of Aosta Valley glaciers are also consistent with the behavior of other mid lats glaciers in the last three decades even if they results the strongest ones.



Rates of area change in other glacierized areas of the world, expressed as $\%a^{-1}$ based on various studies. Dark grey bars represent glaciers situated in the tropics; light grey bars represent mid-latitude glaciers.

Results:

Summarizing:

We examined changes in glacier area on the Aosta Valley Region in relation to topographic and climate variables (temperature and precipitation).

Results include

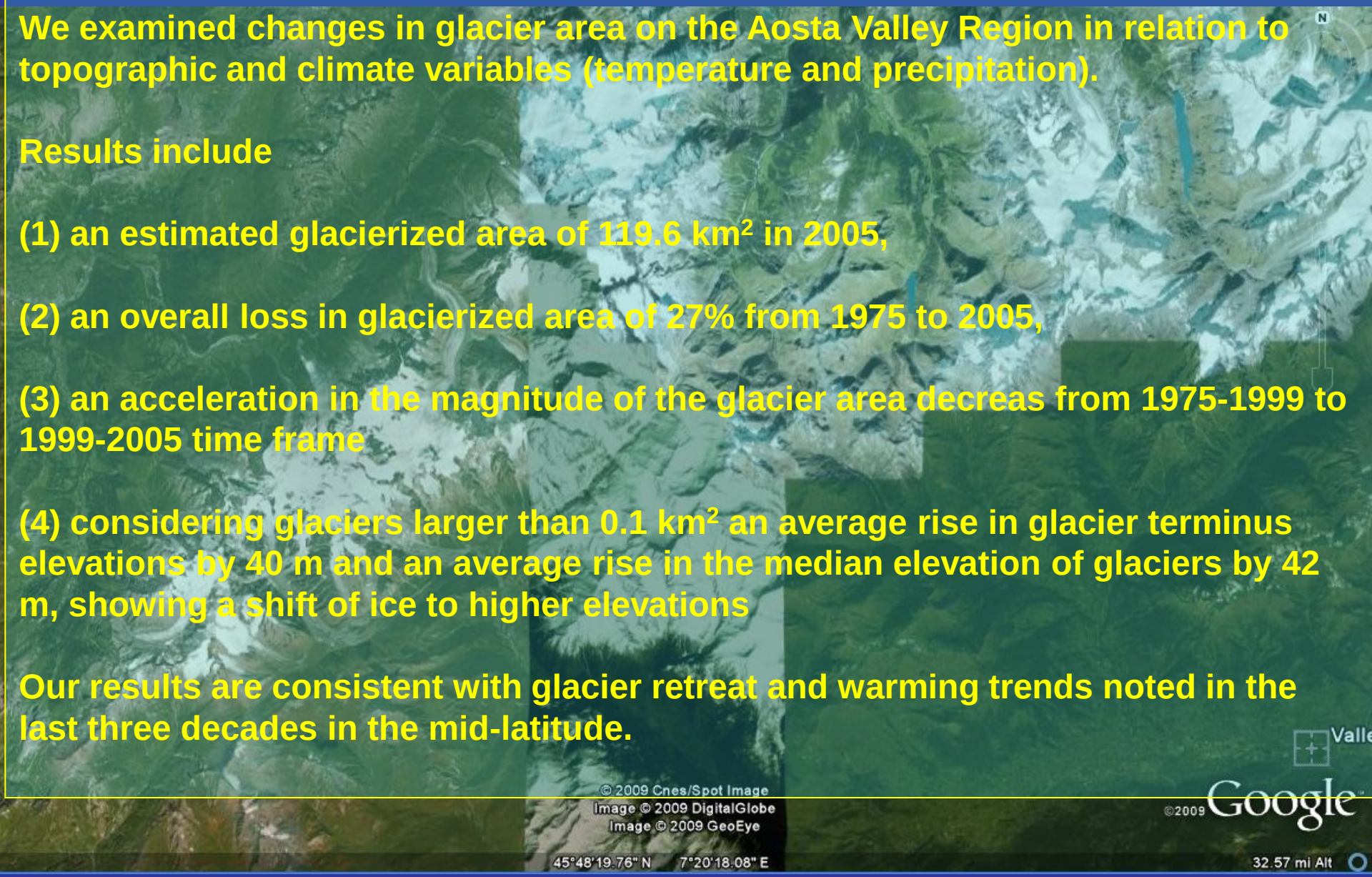
(1) an estimated glacierized area of 119.6 km^2 in 2005,

(2) an overall loss in glacierized area of 27% from 1975 to 2005,

(3) an acceleration in the magnitude of the glacier area decreas from 1975-1999 to 1999-2005 time frame

(4) considering glaciers larger than 0.1 km^2 an average rise in glacier terminus elevations by 40 m and an average rise in the median elevation of glaciers by 42 m, showing a shift of ice to higher elevations

Our results are consistent with glacier retreat and warming trends noted in the last three decades in the mid-latitude.



Results:

Glacier Inventories:

The Lombardy Region data base

Magnitude and rates of Lombardy glaciers' changes

	time frame	time frame	time frame
size class (values in km^2)	1991-1999	1999-2003	1991-2003
<0.1	-0.18	-0.2	-0.18
0.1-0.5	-0.53	-0.7	-0.64
0.5-1	-0.18	-0.5	-0.28
1-2	-0.18	-0.3	-0.18
2-5	-0. 26	-0.6	-0.37
5-10	-0.09	-0.3	-0.18
>10	-0.18	-0.4	-0.18
total	-1.58	-3.1	-2.11

Table 2: Yearly reduction rates (values in km^2/year) calculated for Lombardy glaciers by averaging the surface area changes occurring in each size class with respect to the different time frames (1991-1999, 1999-2003 and 1991-2003).

Data from Smiraglia and Diolaiuti, 2009

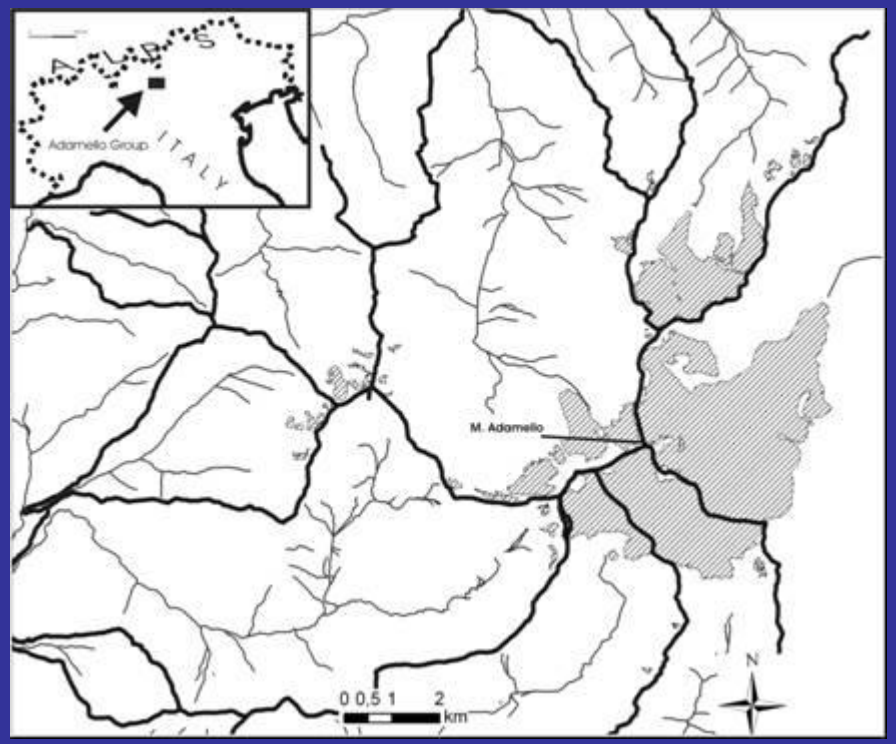
An accelerating retreat phase?

Evidences of such acceleration from Adamello glaciers

Average area change 1983-1991
c. -0.21 km²/y

Average area change 1991-1999
c. -0.23 km²/y

Average area change 1999-2003
c. -0.34 km²/y



Data from Maragno et al., 2009

An accelerating retreat phase?

Evidences of such acceleration

from Ortles-Cevedale glaciers

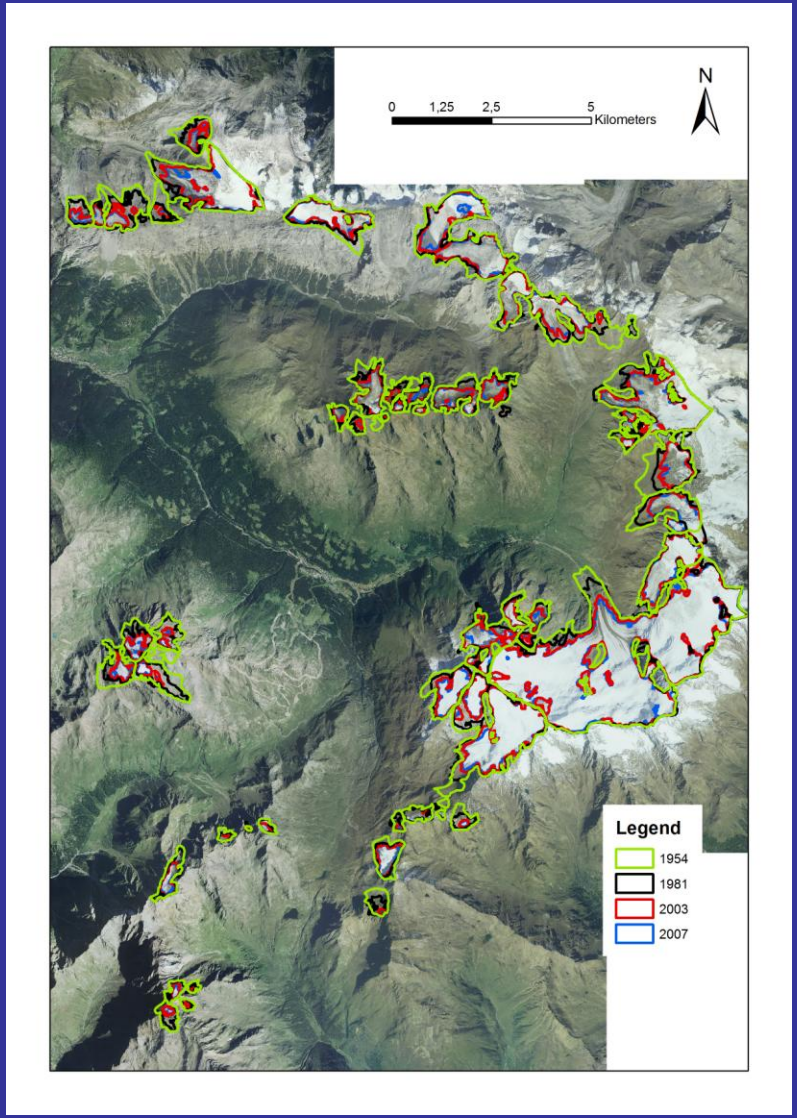
Area change 1954-2007
-19.43 km² ~ 39.9% of 1954 glacier coverage

Area change 1954-1981
-6.54 km² ~ 13.44%, -0.242 km²/y

Area change 1981-1990
- 3.93 km² ~ 9.31%, -0.436 km²/y

Area change 1990-2003
-6.18 km² ~ 16.2%, -0.476 km²/y

Area change 2003-2007
-2.77 km² ~ 8.7%, -0.693 km²/y



Data from D'Agata et al., in preparation

An accelerating retreat phase?

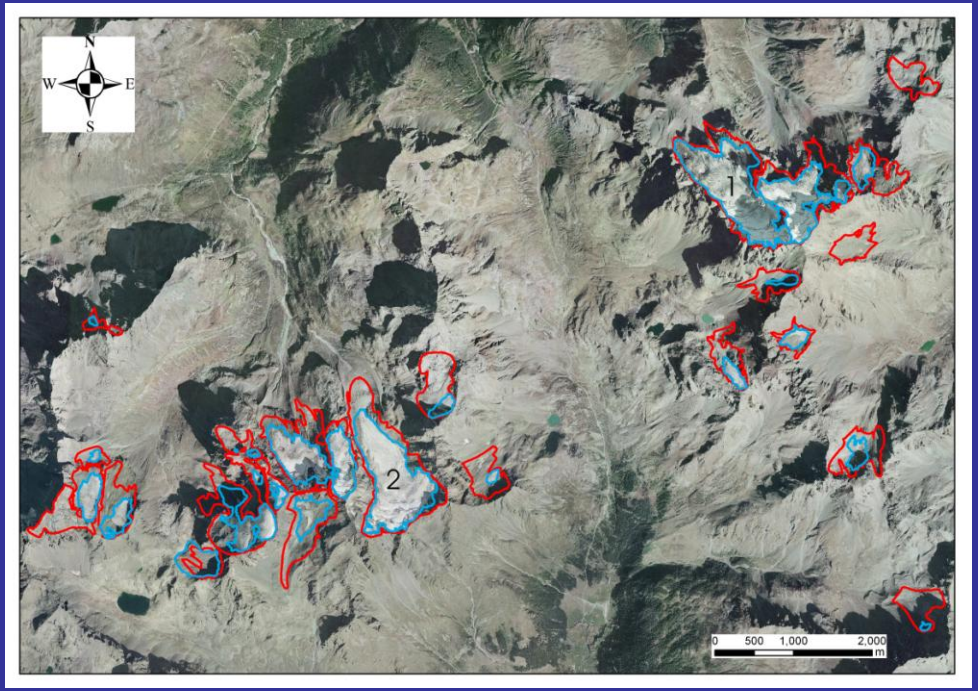
Evidences of such acceleration from Piazzi-Dosdè Glaciers

Area change 1954-2003
-3.974 km^2 ~ 51% of 1954 glacier coverage

Area change 1954-1981
-1.566 km^2 ~ 20.2%, -0.058 km^2/y

Area change 1981-1991
- 0.672 km^2 ~ 10.8%, -0.067 km^2/y

Area change 1991-2003
-1.736 km^2 ~ 31.5 %, -0.145 km^2/y

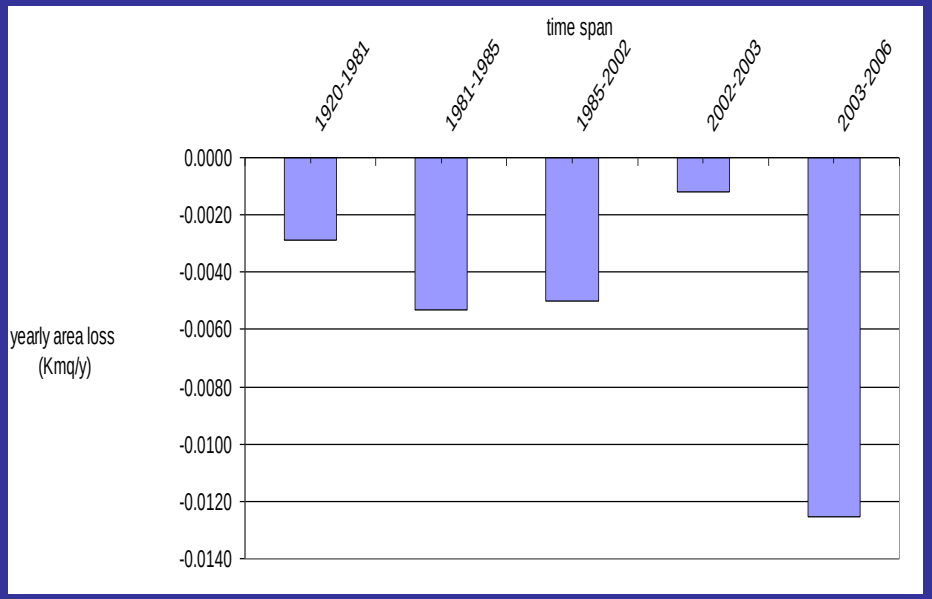


(from Diolaiuti et al., 2011- PPG)

An accelerating retreat phase?

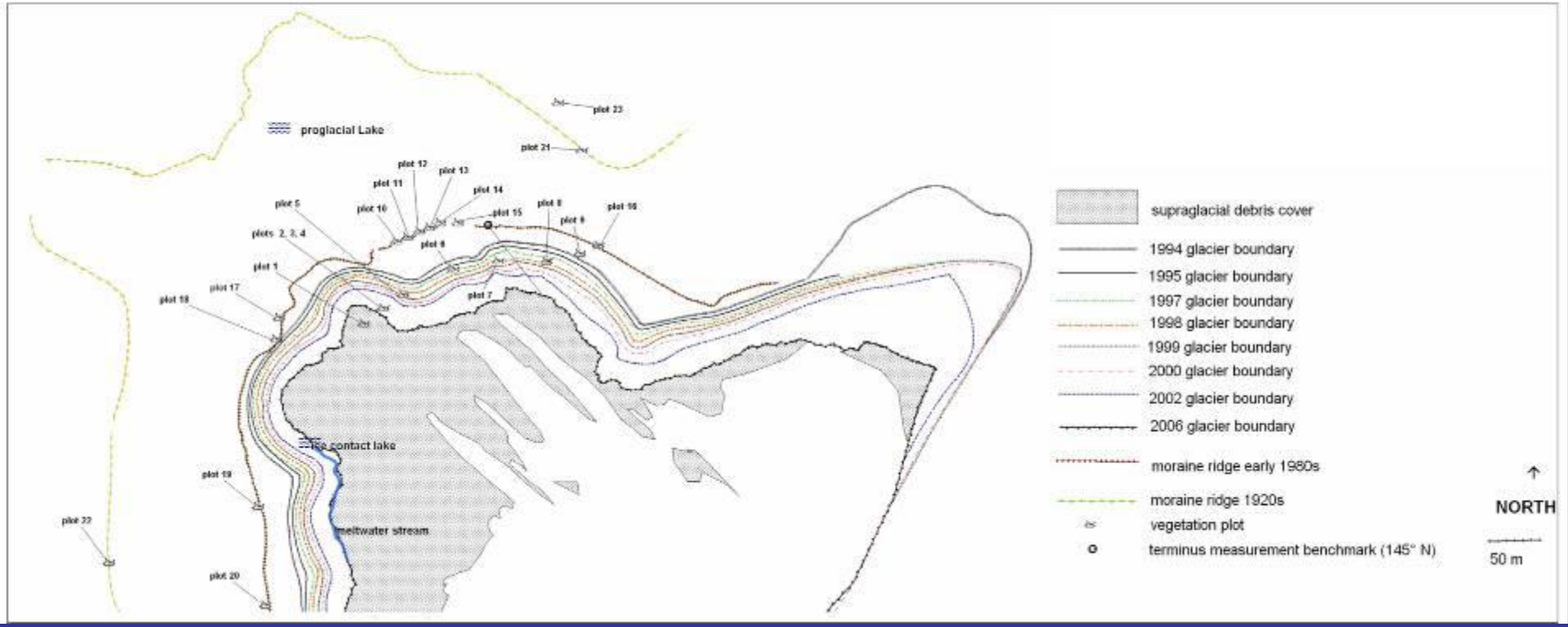
Evidences of such acceleration from Sforzellina Glacier

Ghiacciaio Sforzellina, photo by C. Smiraglia, summer 1987



Results:

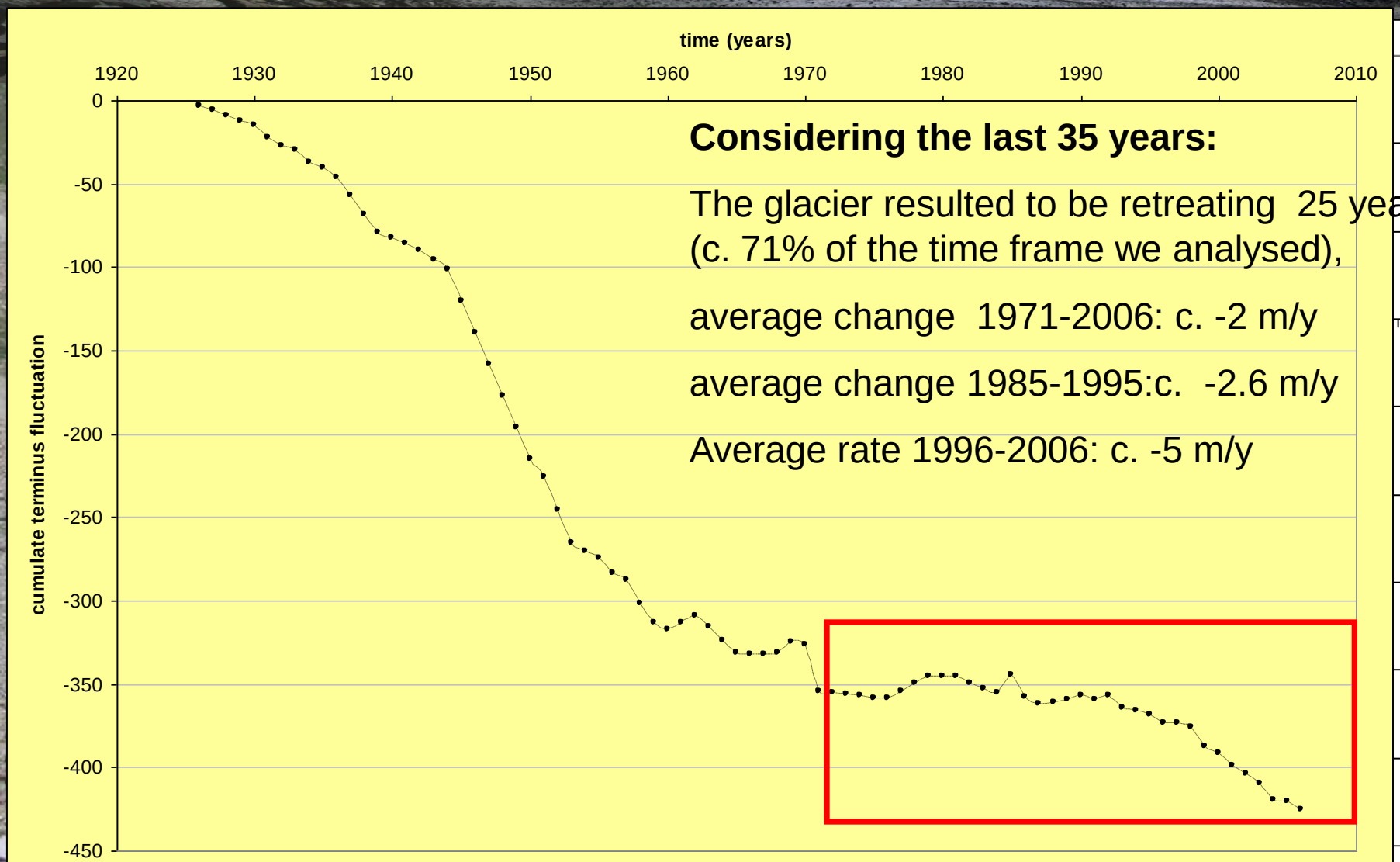
Sforzellina Glacier recent changes



From Cannone et al., 2008

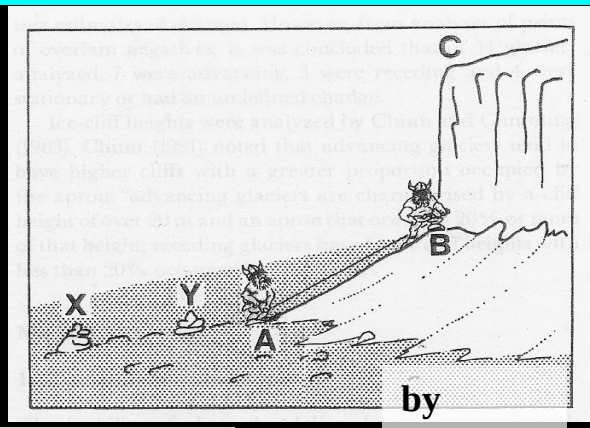
Results:

Sforzellina Glacier recent changes

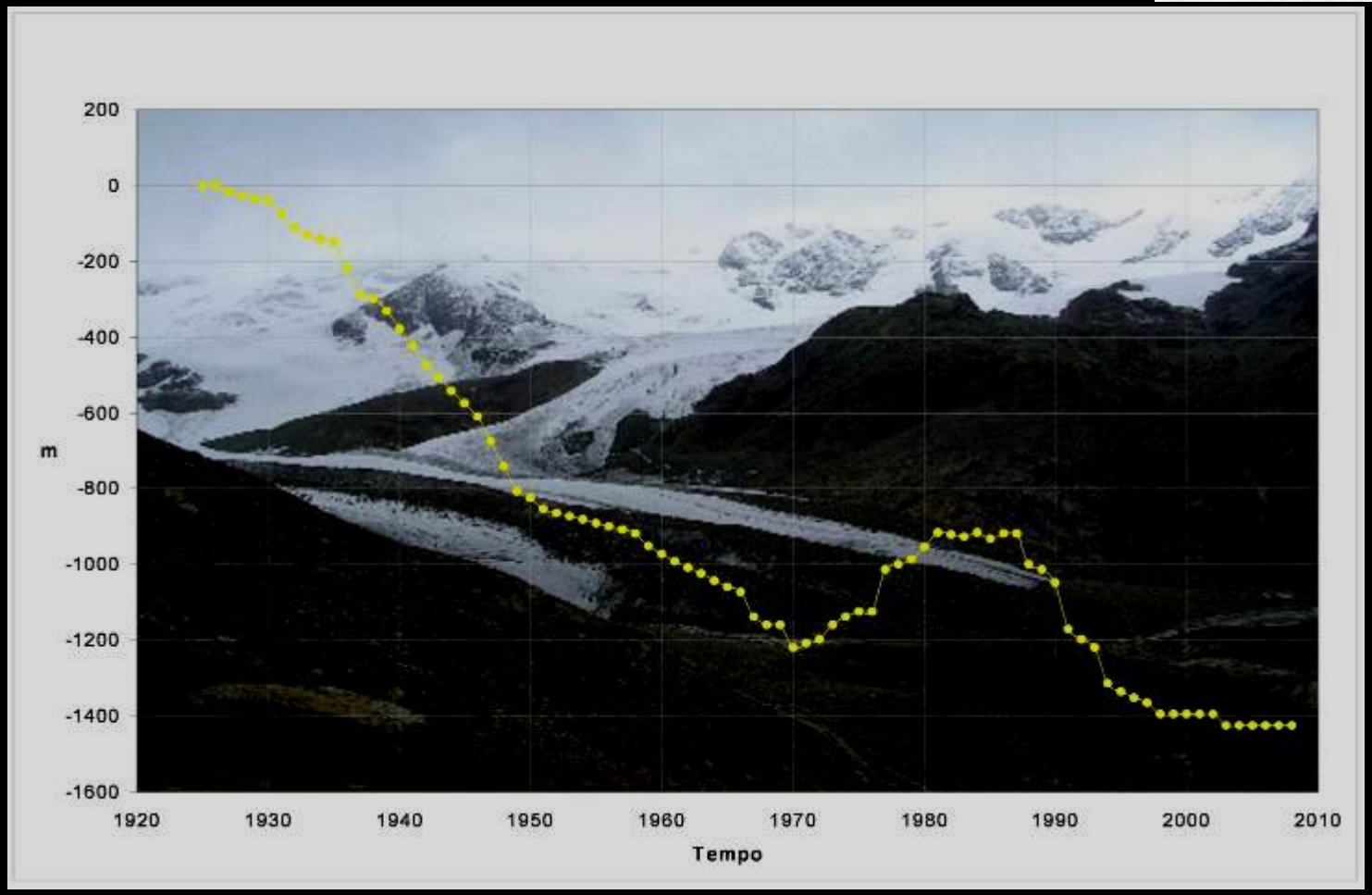


THE RECORDS OF TERMINUS FLUCTUATIONS

- The longest records : Forni …



by Chinn, 1985



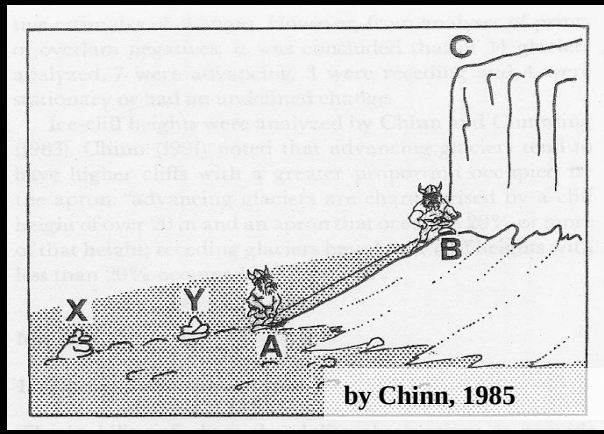
THE RECORDS OF TERMINUS FLUCTUATIONS

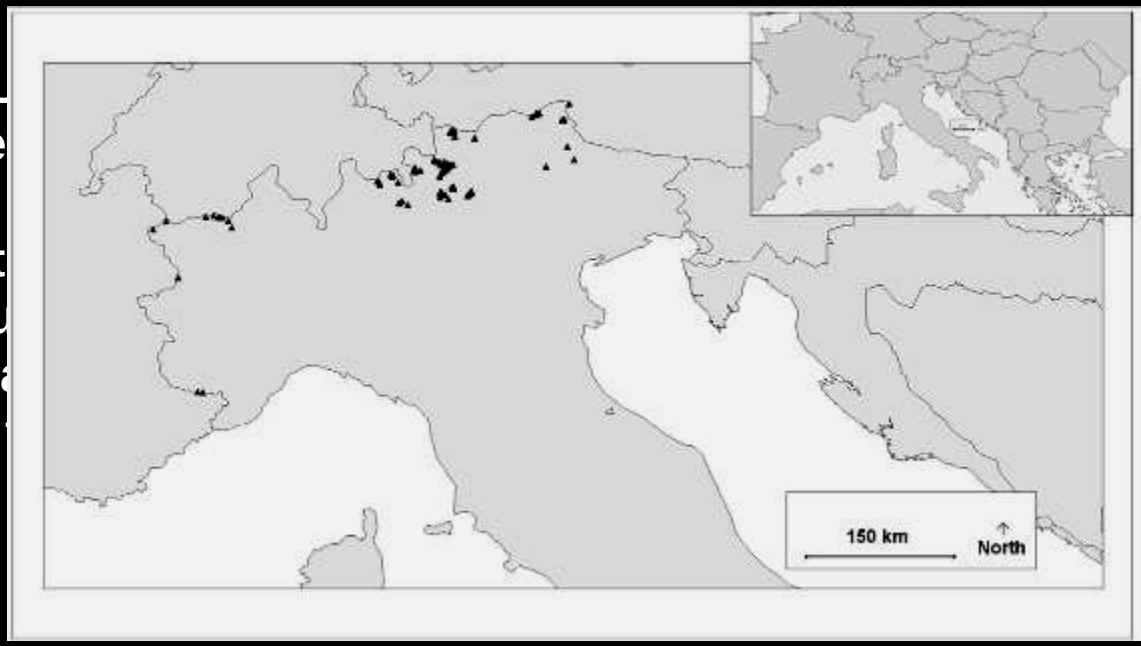
- **GLAD, the GLAcier Database**

GLAD Database contains all the available terminus fluctuation data on Italian Glaciers (883 glacier records) collected by extracting field measurements from all the past issues of the official journals published by the Italian Glaciological Committee (CGI, 1914-2003).

The 883 glaciers entered in GL
with variable continuity betwe

Since the time series for most
are short or very discontinuou
representative subset of 95 gl
longer and more reliable data

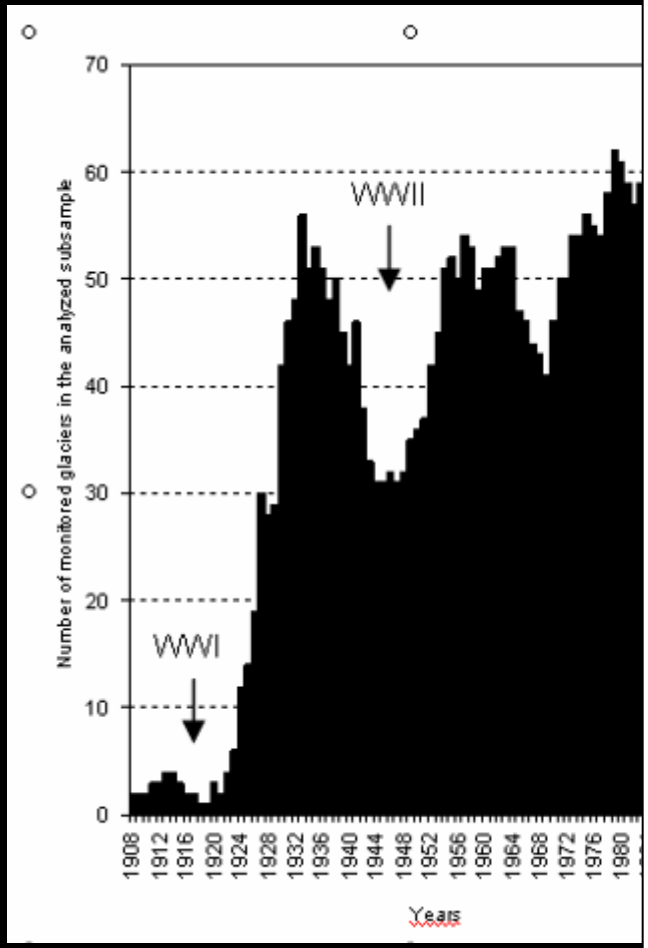


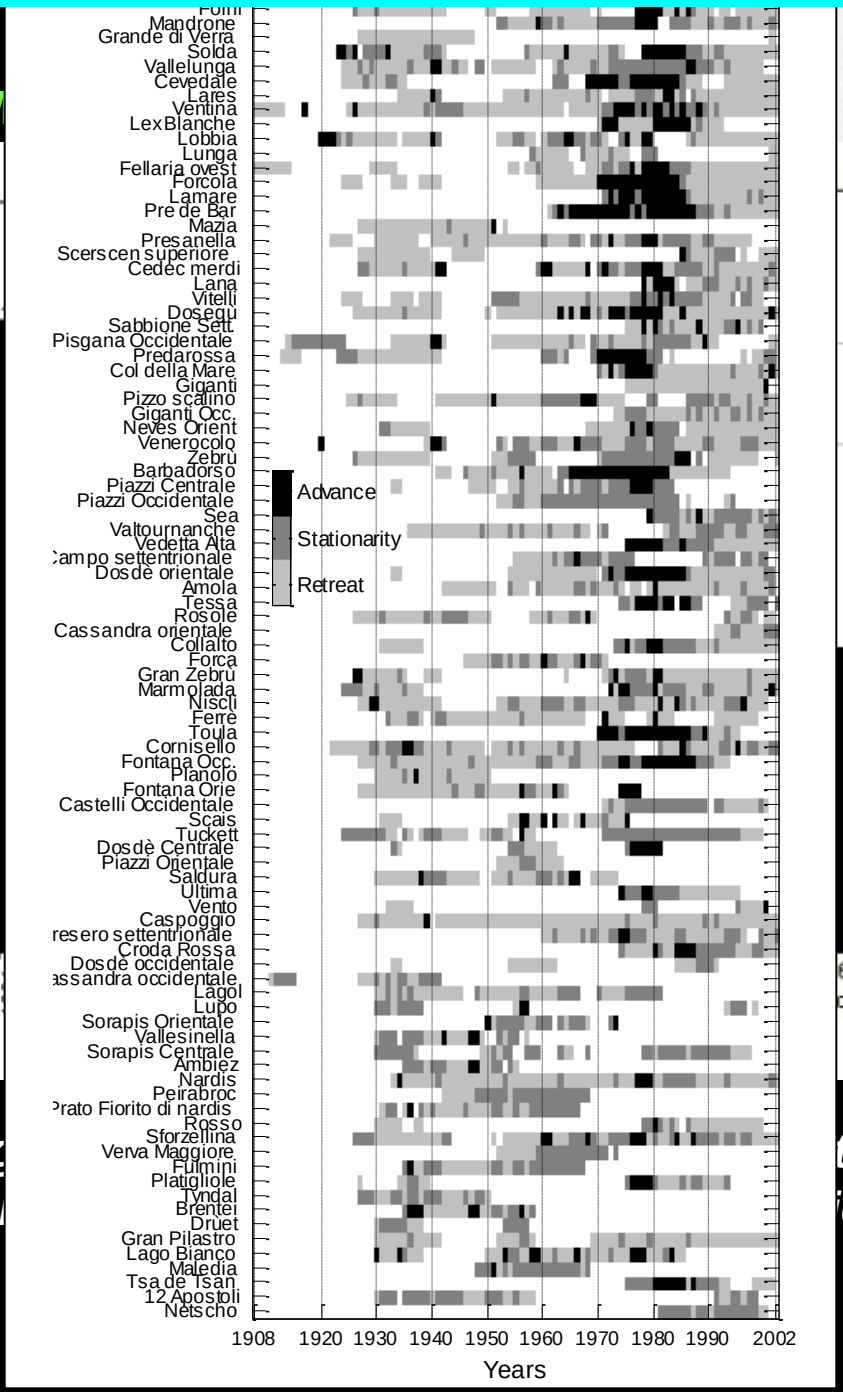


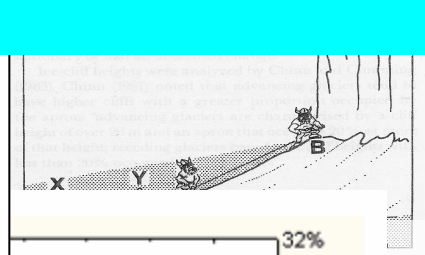
Map showing the location of the analyzed 95 glaciers subset

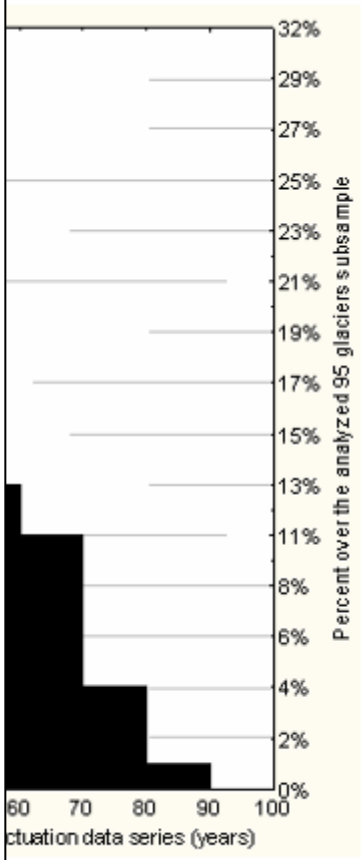
Results:

THE RECORDS OF TERM









Bar plot of the number of g… time from 1908 to 2002 (left panel); histogr… ion of record lengths (right panel)

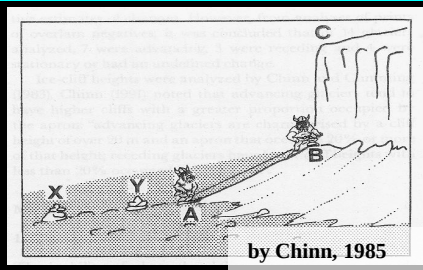
Res

length >4 km	pre-1913	1913-1922	1923-1932	1933-1942	1943-1952	1953-1962	1963-1972	1973-1982	1983-1992	1993-2002
number of glaciers	0	0	4	4	3	4	4	4	4	5
complete series	0	0	0	4	1	2	3	1	3	4
number of retreating glaciers	-	-	3	4	3	4	4	1	4	5
% of retreating glaciers	-	-	75	100	100	100	100	25	100	100
Standard deviation of glacier fluctuations			±11.5	±13.2	± 19.3	±14.4	±17.6	±26.2	± 15.8	±19.6
average rate (my^{-1})	-	-	-7.1	-17.0	-24.7	-14.9	-11.6	8.8	-5.1	-17.3

length: 2-4 km	pre-1913	1913-1922	1923-1932	1933-1942	1943-1952	1953-1962	1963-1972	1973-1982	1983-1992	1993-2002
number of glaciers	2	8	18	22	16	23	26	30	30	30
complete series	2	0	2	7	4	10	11	22	18	18
number of retreating glaciers	2	5	18	22	16	22	20	13	26	30
% of retreating glaciers	100	63	100	100	100	96	77	43	87	100
Standard deviation of glacier fluctuations	±2.4	± 5.7	±12.1	±17.1	±20.3	± 11.0	± 22.1	±17.2	±11.7	±13.6
average rate (my^{-1})	-7.5	-0.5	-12.5	-15.3	-16.7	-11.8	-7.7	2.8	-5.3	-12.9

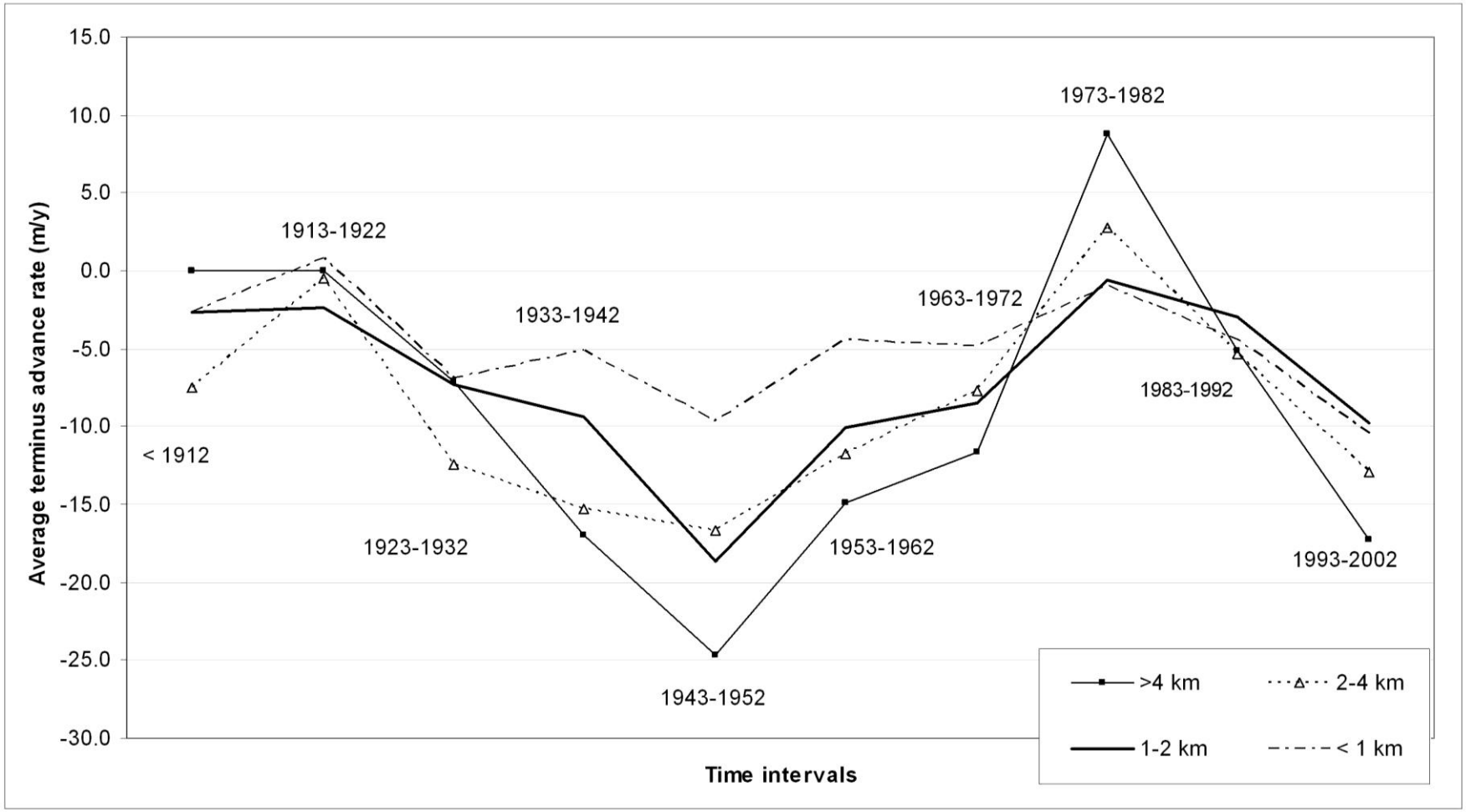
length: 1-2 km	pre-1913	1913-1922	1923-1932	1933-1942	1943-1952	1953-1962	1963-1972	1973-1982	1983-1992	1993-2002
number of glaciers	0	0	11	15	9	14	15	18	17	17
complete series	0	0	0	4	2	5	6	11	12	5
number of retreating glaciers	-	-	11	15	9	14	11	8	12	17
% of retreating glaciers	-	-	100	100	100	100	73	44	71	100
Standard deviation of glacier fluctuations			± 7.9	± 15.0	± 32.3	± 13.4	± 10.0	± 12.6	±9.6	±16.0
average rate (my^{-1})	-	-	-6.7	-12.3	-18.2	-10.3	-7.0	-0.4	-3.0	-10.2

length <1 km	pre-1913	1913-1922	1923-1932	1933-1942	1943-1952	1953-1962	1963-1972	1973-1982	1983-1992	1993-2002
number of glaciers	1	2	16	21	21	22	16	14	10	10
complete series	0	0	1	7	7	12	4	4	8	4
number of retreating glaciers	1	1	16	21	19	20	14	7	9	10
% of retreating glaciers	100	50	100	100	90	91	88	50	90	100
Standard deviation of glacier fluctuations	± 4.8	± 6.3	±8.9	±8.8	±23.2	± 7.8	±15.5	± 12.4	±10.2	± 22.7
average rate (my^{-1})	-2.6	-2.4	-7.3	-5.3	-10.1	-4.4	-6.9	-1.2	-4.1	-10.0

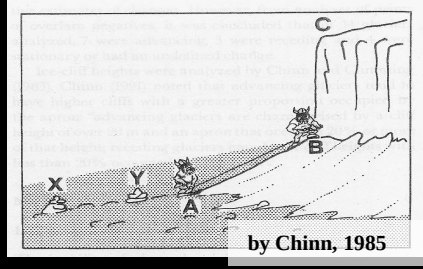


by Chinn, 1985

Citterio et al., 2007



Average terminus fluctuation rates (my-1) vs. time intervals. The data have been sorted by the size classes as reported in Table 1



by Chinn, 1985

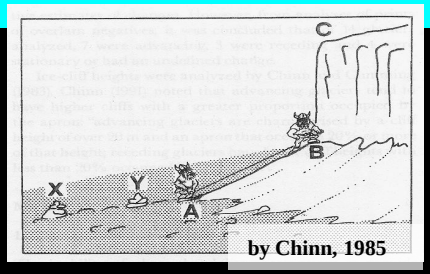
THE RECORDS OF TERMINUS FLUCTUATIONS

- **GLAD, the GLAcier Database**

With only minor exceptions, larger glaciers underwent greater terminus fluctuations than smaller glaciers, and the strong retreat rate in 1943-1952 was the highest ever observed in our dataset for all size classes except for the smallest one.

During the 1943-1952 interval, glaciers shorter than 1 km (as of the 1989 inventory) were retreating at the rate of -10.1 my^{-1}, more or less the same of the 1993-2002 interval. (-10 my^{-1}).

Conversely, comparison of the 1993-2002 data for the other three size classes revealed slower retreat rates (by 23% to 30%) than the 1943-1952 data.



THE RECORDS OF TERMINUS FLUCTUATIONS

•GLAD, the GLAcier Database

We have thus compared glaciers of similar sizes, noting that the size classes selected for the Italian Alps (<1 km, 1 – 2 km, 2 – 4 km and > 4 km) roughly fit the short to intermediate size classes of Haeberli (1990) or Hoelzle *et al*. (2003).

The advance phase of the 1970s and 1980s described in our results is clearly visible in the data summarized by Hoelzle *et al*. (2003) for the European Alps, as is the strong retreat centred around the early 1940s for most glaciers.

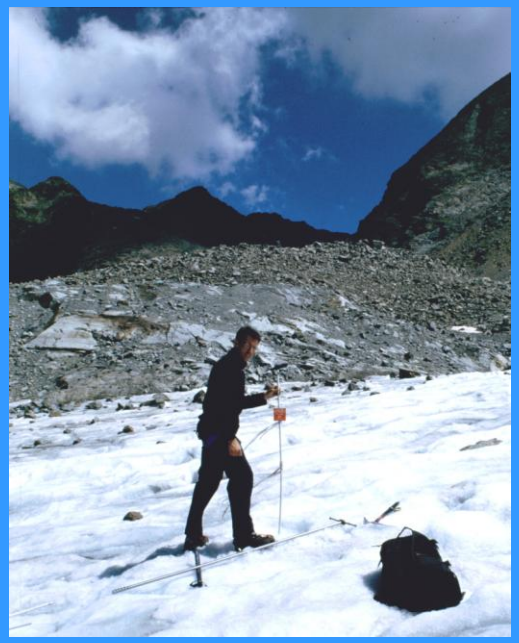
As regards the magnitude of the cumulated length change, the scatter between individual glaciers proved to be large, but comparable to the curves reported by Haeberli (1990), which for the period from 1900 to 1983 show average cumulated length changes of about -480 m for glaciers shorter than 2 km and -671 m for glaciers between 2 and 5 km long.

Integrating decadal averages of the 95 glaciers analysed up to 1982, we obtained a cumulated retreat until 1982 of -338 m, -595 m and -692 m, respectively for the glaciers of lengths <1 km, 1 – 2 km and 2 – 4 km.

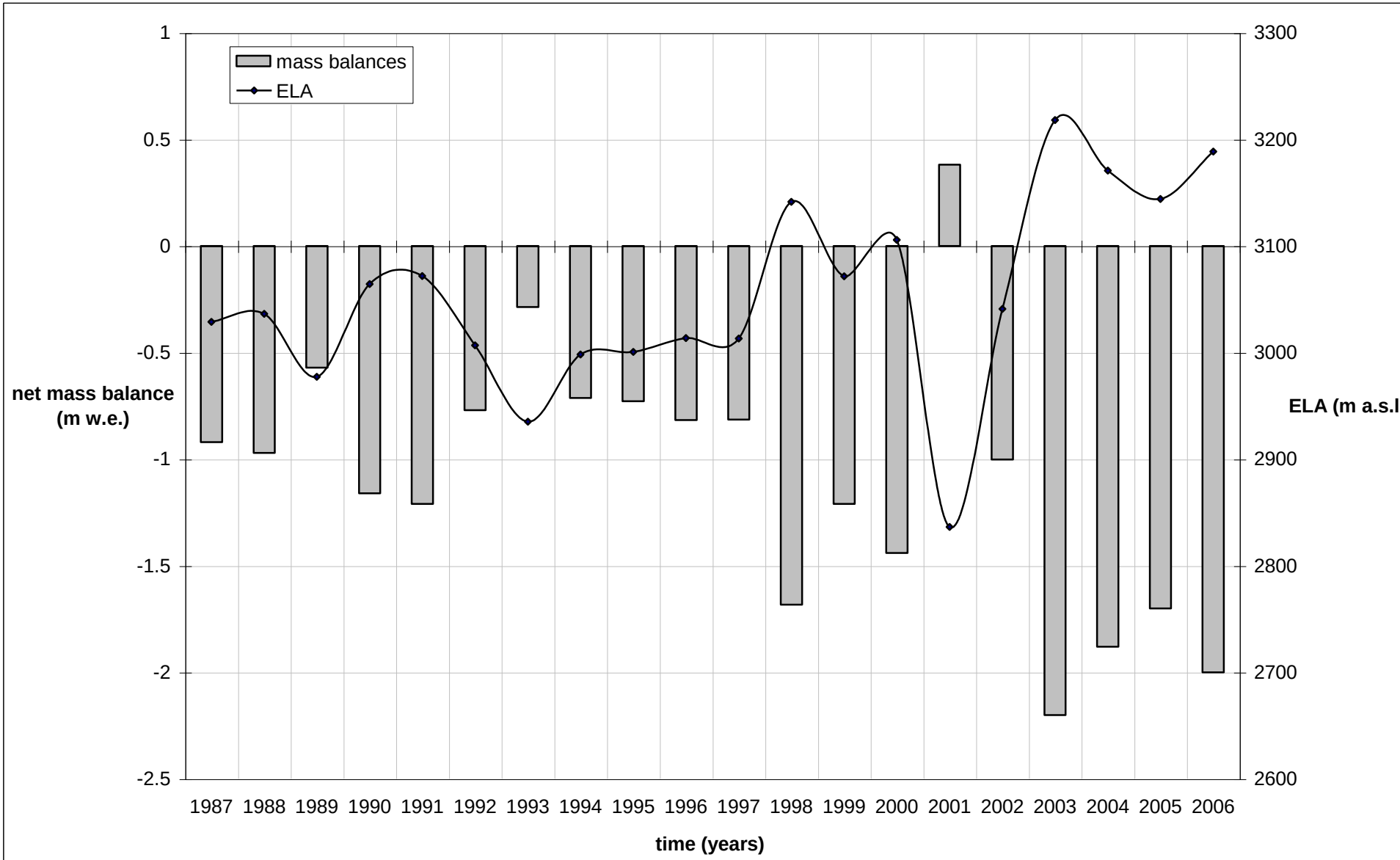
Given the simplifications involved in such comparisons, the two datasets show very good agreement, even considering that the exact starting year for the Italian glaciers surveys was not 1900

Results:

Glacier mass balances



Sforzellina Glacier: mass balances and ELA

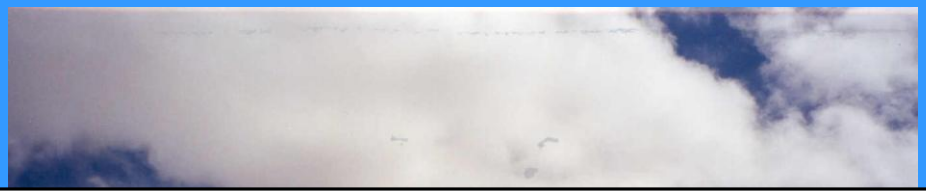


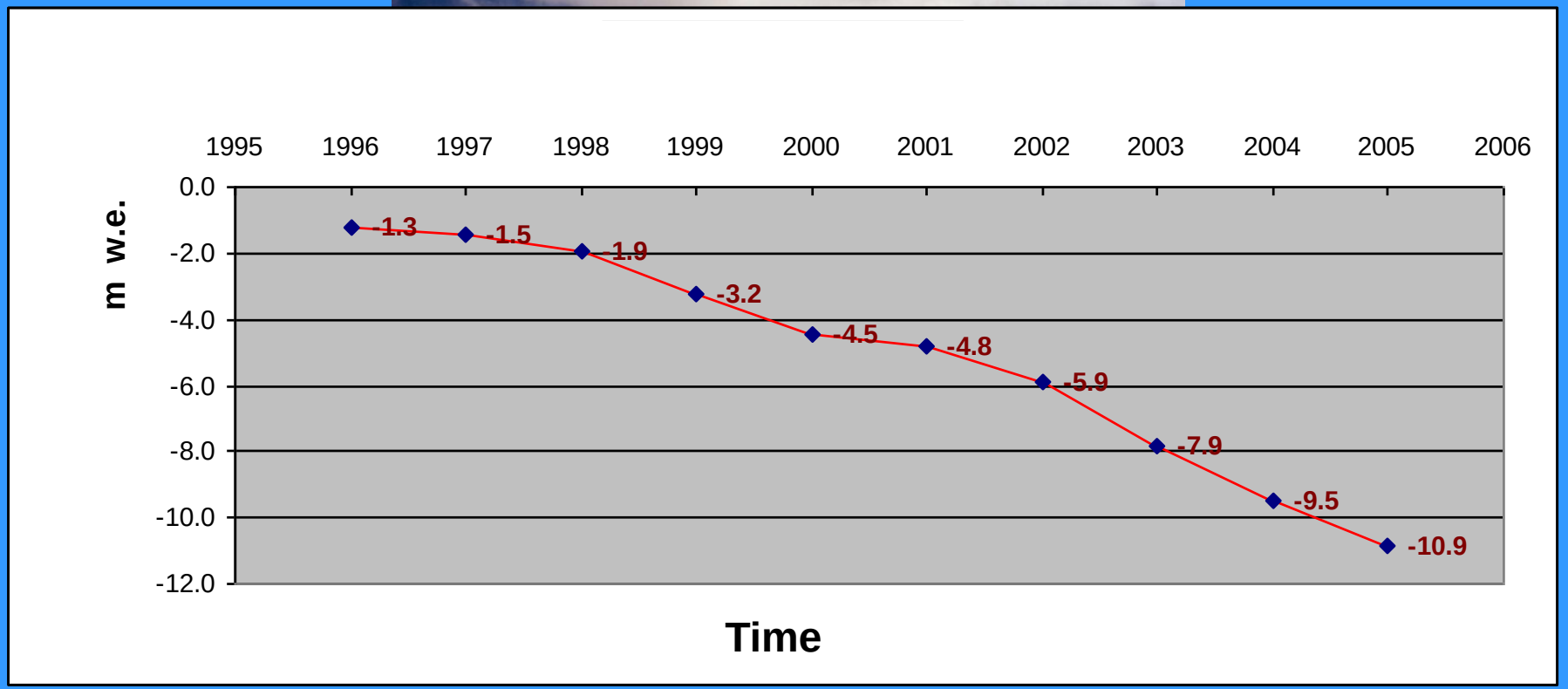
Results:

Glacier mass balances

Dosdè Est Glacier:

Cumulate values





The environmental effects of the glacier shrinkage

July 2004

October 2006


2003


2004


2005

October 2006

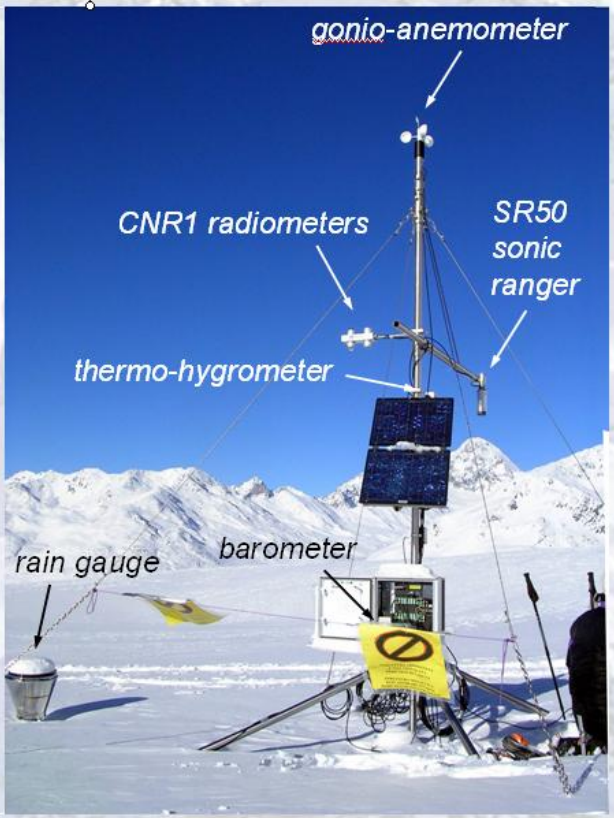

2005

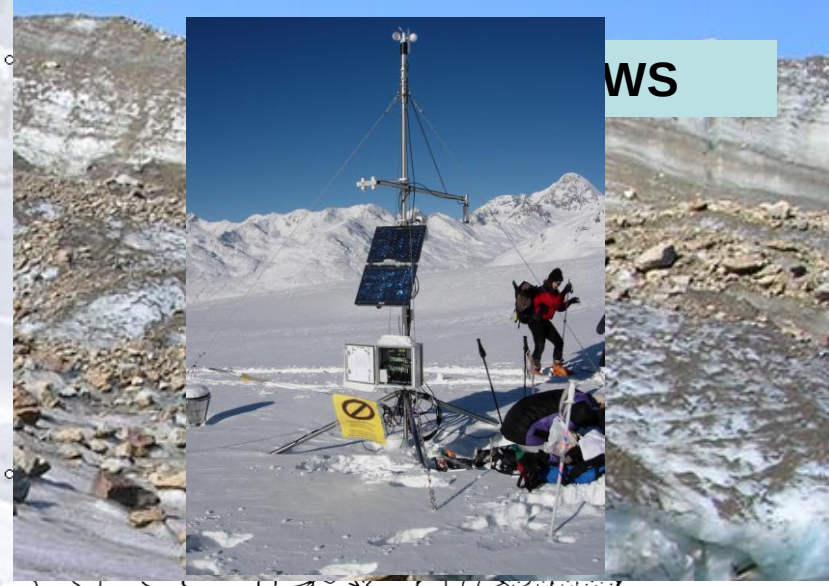

2006

Instruments

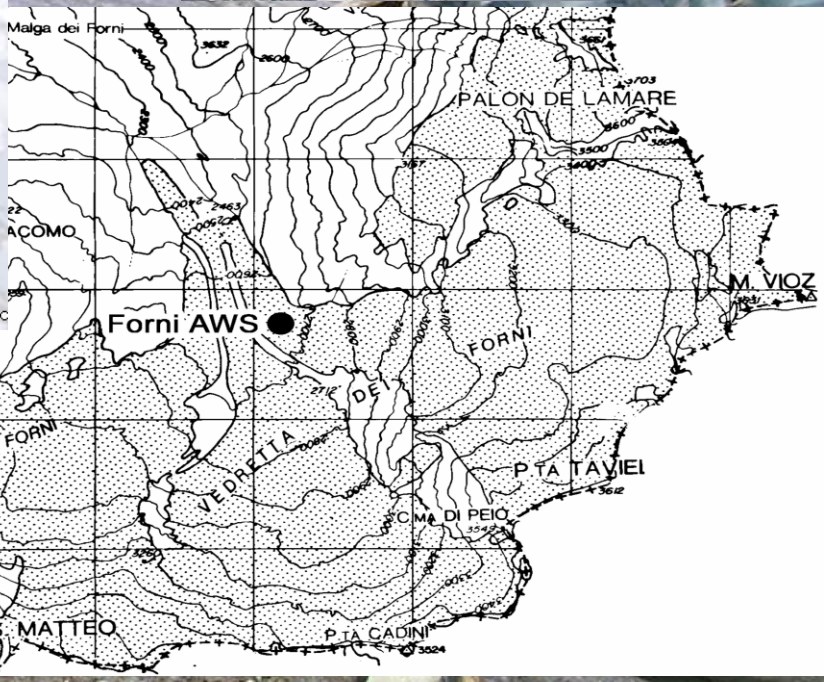
To-date, the AWS is equipped with the following sensors:

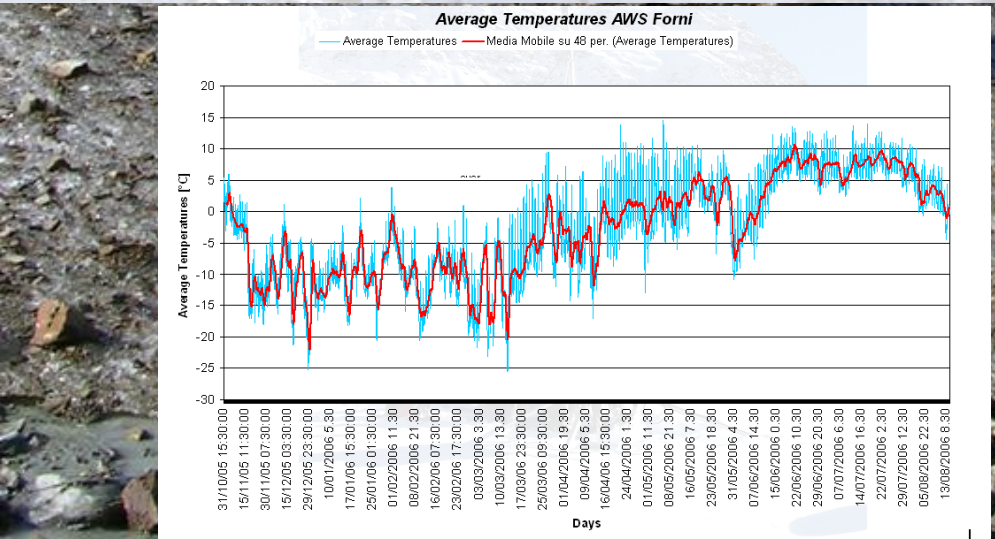
T air	LSI Lastem DMA570
rel. hum.	LSI Lastem DMA570
Patm	LSI Lastem DQA223
wind dir.	LSI Lastem DNA022
wind speed	LSI Lastem DNA022
rain	LSI Lastem DQA035
↓ SW Rad	Kipp & Zonen CNR1
↓ LW Rad	Kipp & Zonen CNR1
↑ SW Rad	Kipp & Zonen CNR1
↑ LW Rad	Kipp & Zonen CNR1
T CNR1	Kipp & Zonen CNR1
snow h.	Campbell SR50





WS





Conclusions on the health of Italian glaciers…

-A strong glacier area decrease which is becoming stronger

-Several small glaciers: the smaller the faster

-Retreating glacier termini with rates comparable with the other alpine ones

-Negative glacier mass balances

-Large impacts on Alpine mountain environment and landscape

-Fundamental role played by studies field-based which analyse data collected at the glacier surface (from AWSs) to ebvaluate glacier melt water discharge under a changing climate


Thank you for the interest