UNIVERSITÀ DEGLI STUDI DI MILANO

19th Alpine Glaciology Meeting
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A GIS – minimal glacier model on the Rutor glaciers (western Italian Alps)

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NextData
un sistema nazionale per la raccolta, conservazione, accessibilità e diffusione dei dati ambientali e climatici in aree montane e marine

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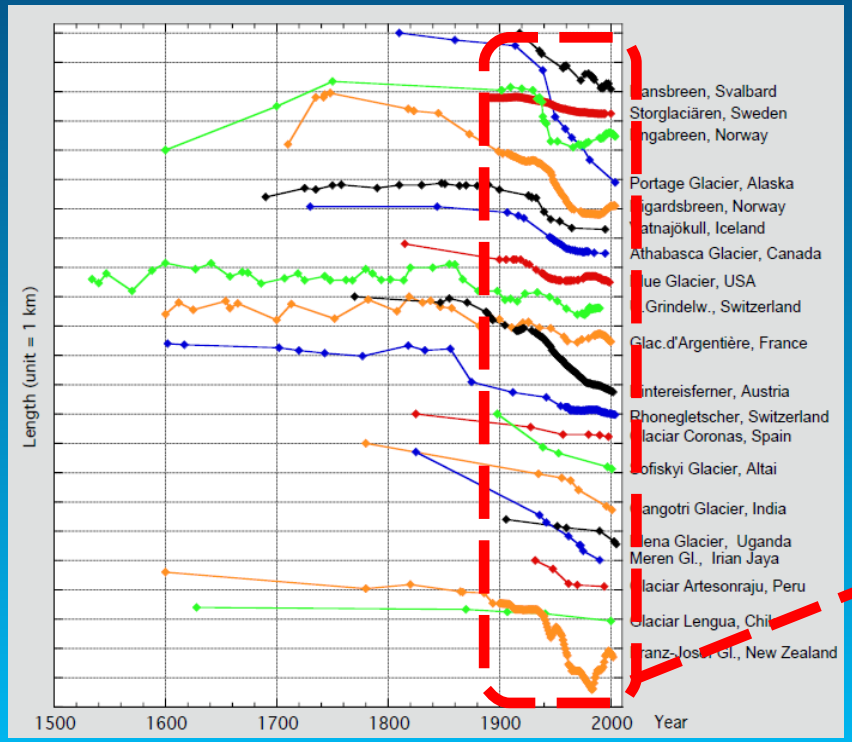
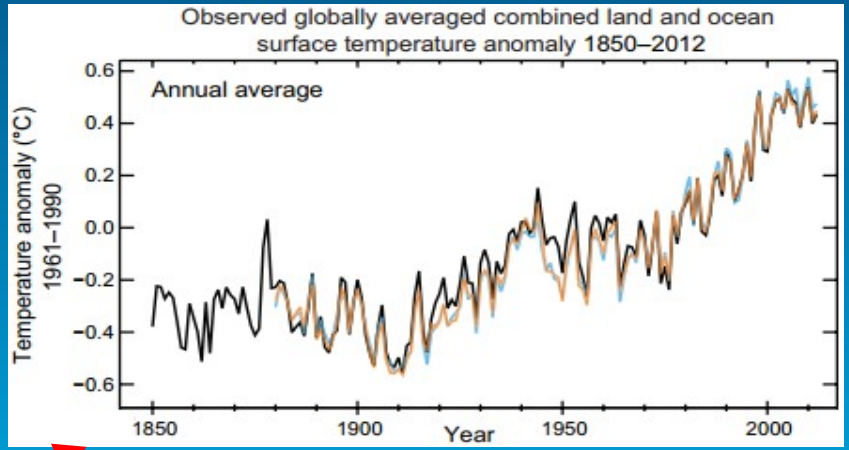
Introduction

“Recognizes that mountains provide indications of global climate change through phenomena such as […] the retreat of mountain glaciers […]”

UN A/Res/62/196, 2008





IPCC report 2013

How to study glacier response to CC?

CLIMATE FORCING

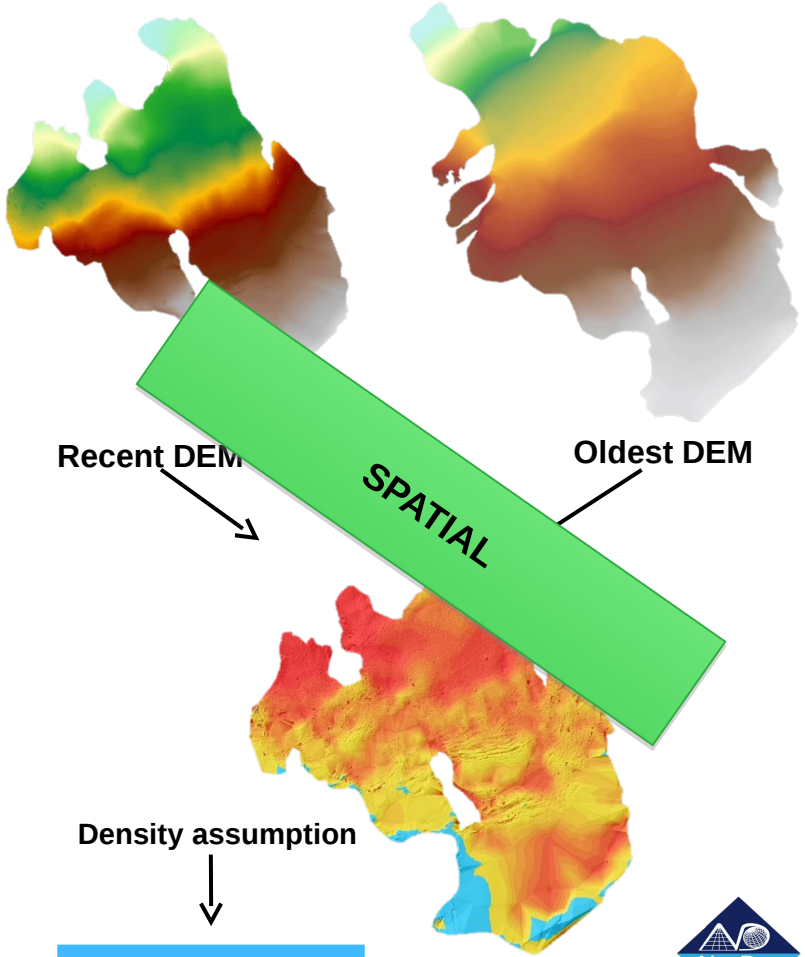
- Temperature 2m
- Precipitation
- Snow deposition
- Humidity
- Radiation balance Lw, Sw
- Wind speed & direction
- Atmospheric pressure
- ud height

DETERMINISTIC

MATHEMATICAL MO
They reduce a complex situation to a simple description, using laws of physics.

GLACIER RESPONSE

- Glacie terminus variation
- Area fluctuation
- Lose or gain volume
- Increase or decrease of thickness

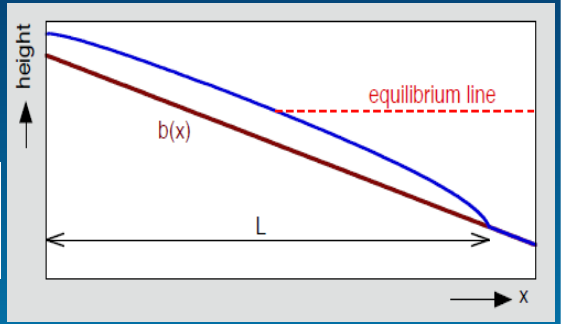


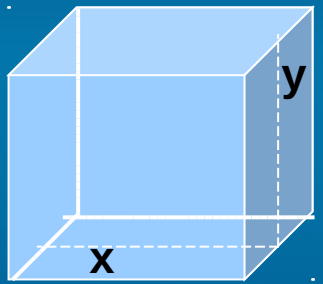
Minimal Glacier Model

CONTINUITY EQUATION:
describes the transport or variation of a conserved quantity.

$$V = H_m \cdot W_m \cdot L$$

$$\frac{dV}{dt} = H_m W_m \frac{dL}{dt} + H_m L \frac{dW_m}{dt} + W_m L \frac{dH_m}{dt} = B_S$$





PERFECT PLASTICITY PRINCIPLE:
first-order estimate of how the thickness of a glacier varies with its horizontal dimension.

The elaboration is based on **meteoreological, physical and morphological data** to reconstruct historical time series of glacier (length, mass balance, volume, area).

(Oerlemans 2008, 2011)

Input data: *climate forcing*

$$\dot{b}_i = f(Ts_i, Pw_i)$$

Minimal Glacier Model

$$\left(\frac{dL}{dt}\right) = \left(\frac{3\alpha_m}{2(1+\upsilon s)} L^{1/2}\right)^{-1} \frac{B_S}{W}$$

Hm

$$B_S = \dot{W} \cdot \dot{b} \cdot L_i$$

Initial length

Runge-Kutta method

$$L_{i+1} = RK\left(L_i, \left(dL/dt\right)_i\right)$$

Final length

Iterative process

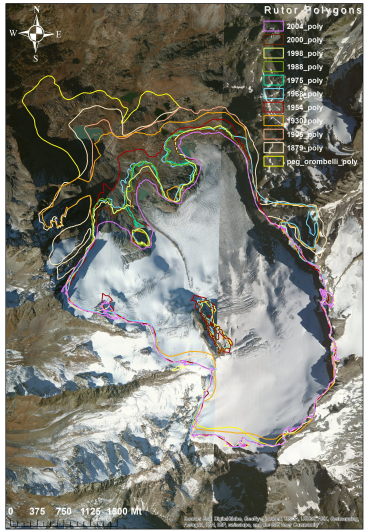
Variation of glacier terminus along the flow-line direction

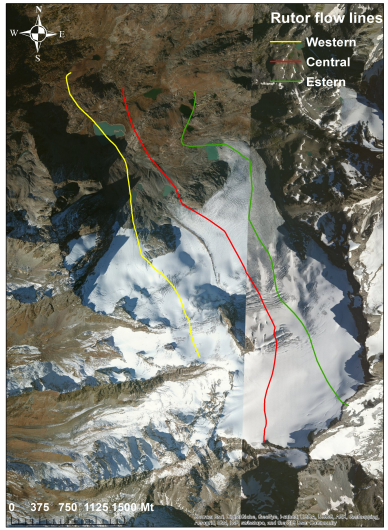
Spatial: Raster and vector analysis

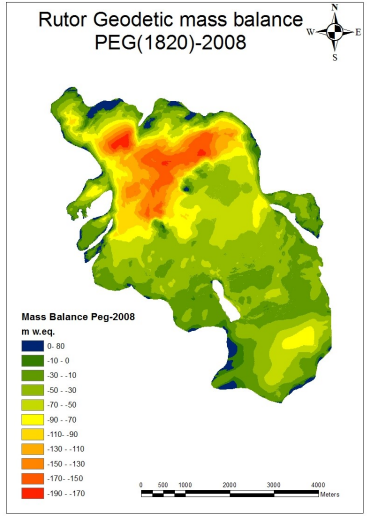
DEM:
DEM allows to calculate some parameters, as altitude, slope, thickness, flow line direction.

Polygon:
-used to evaluate the glacier retreat, the length of the flow line.

Flow line:
-Minimal model input
-Calculated from DEM elaboration and the results are interpreted based on theoretical background.





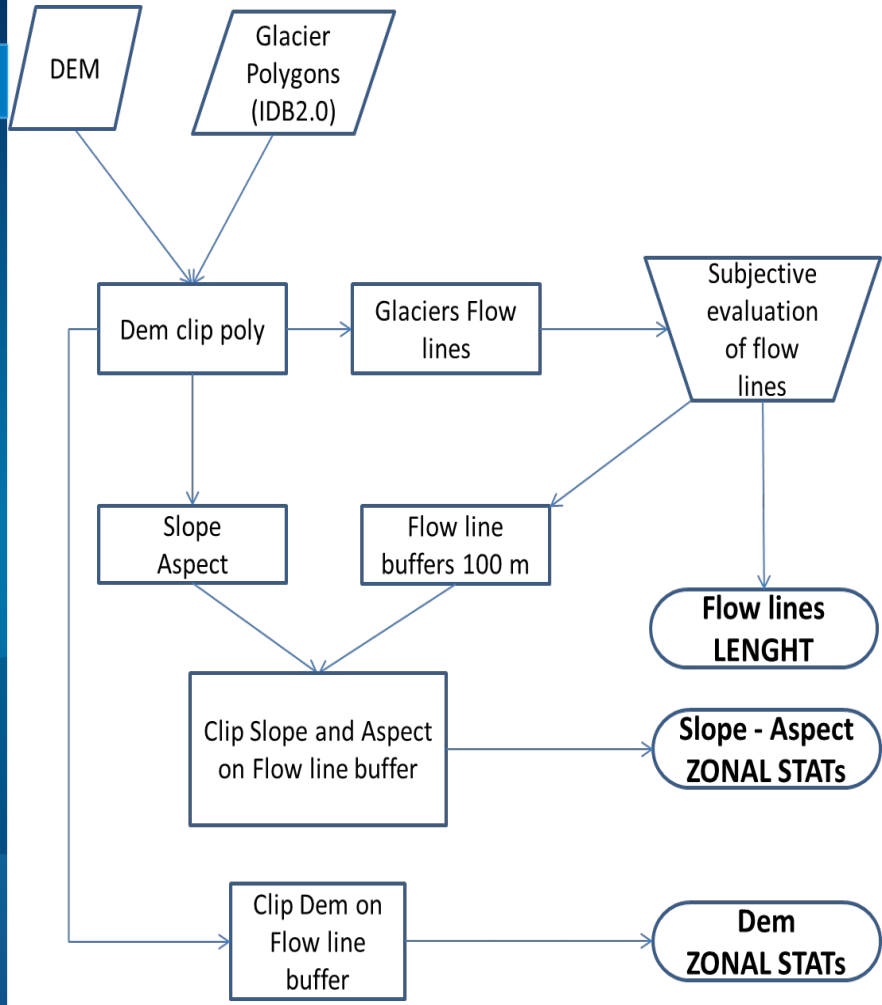


GIS module for Minimal Model

GIS algorithm allows to obtain glaciological data to set Minimum Glacier Model

DEMs are the basis for this GIS analysis, on which we can derived the flow line. Using DEMs and polygons it is possible to obtain the morphological data set to calibrate the Minimal Glacier Model.

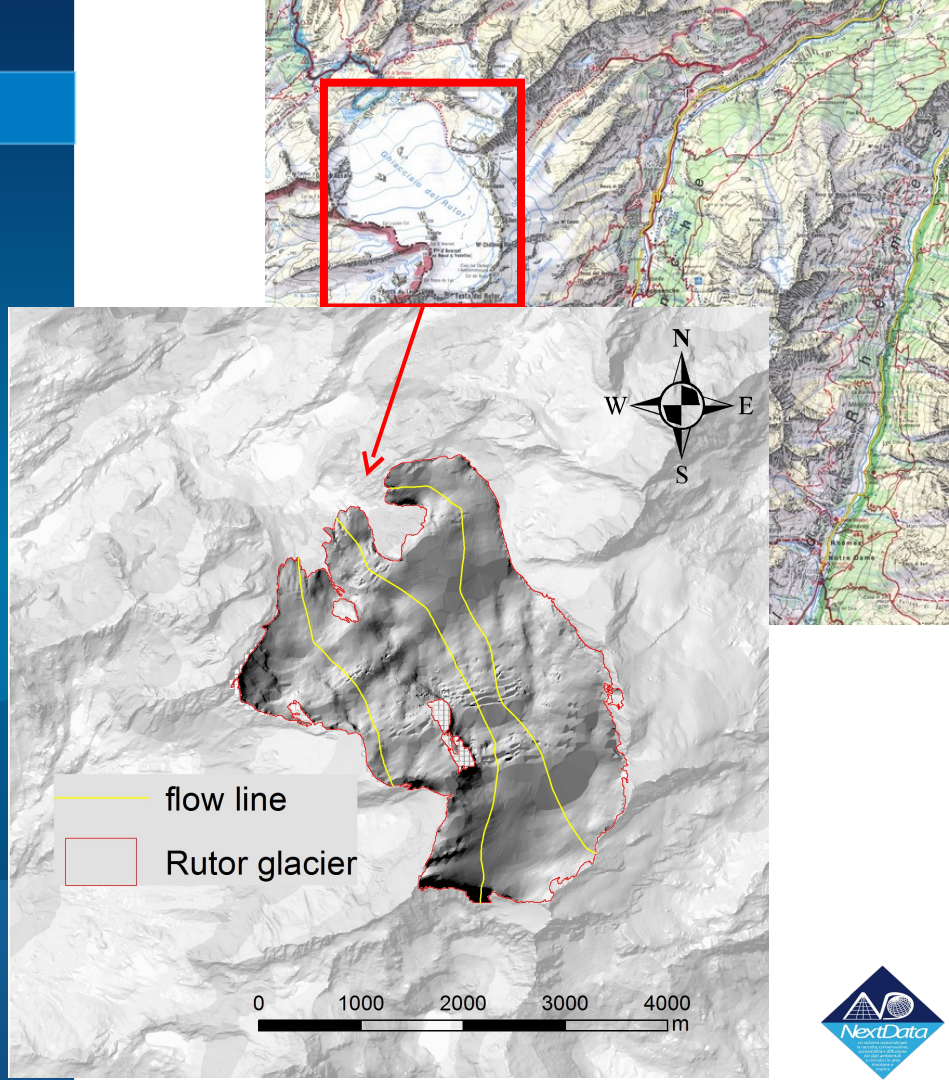
All the results are rely on DEM resolution.



Study Area

Rutor glacier *(3480–2640 m a.s.l.) – Vallone di La Thuile (AO)*

Glacier features:
- surface slope ≈ 22%;
- mainly exposed to the north;
- currently there are three main flow lines;
- L ≈ 4000m.

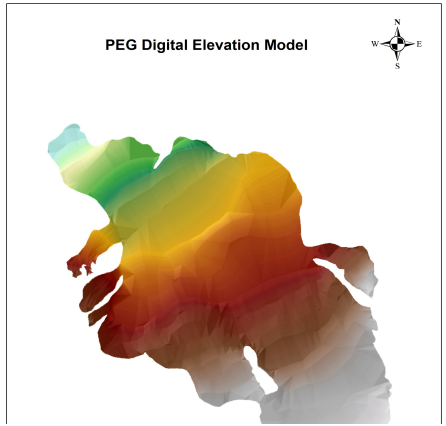


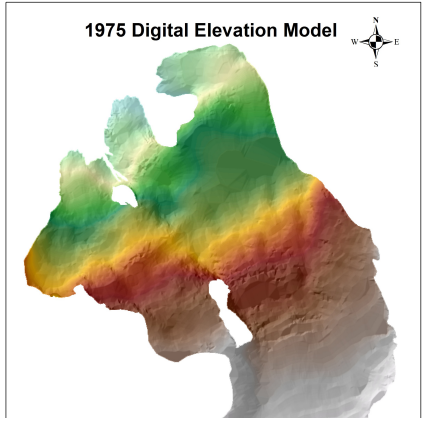
Available dataset

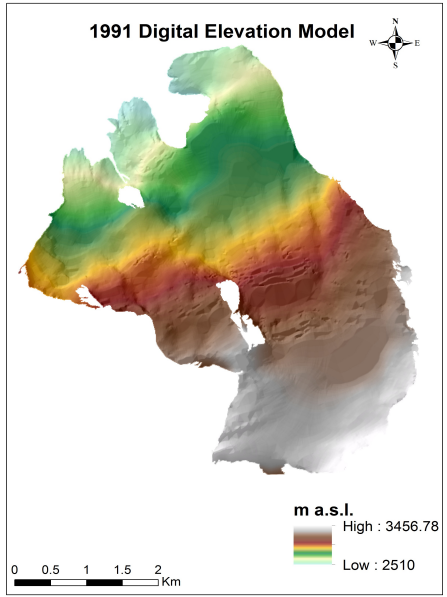
Year	Source
1820	Orombelli G., 2005

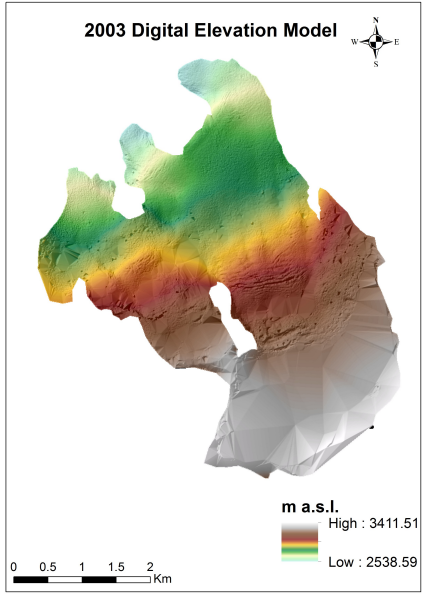
Anno di rilievo	Metodo	Risoluzione DEM	Fonte
1820 (LIA)*	Ricostruzione	25m	Orombelli G., 2005
1975	Digitalizzazione	5m	CTR raster
1991	Digitalizzazione	5m	CTR vector
2003	Modello fotogrammetrico	5m	Foto aeree
2008	LIDAR	2m	Valle D'Aosta

2000	Ortophoto and GPS campaign
2004	Ortophoto and GPS campaign
2008	Ortophoto 2008
2011	Ortophoto 2011









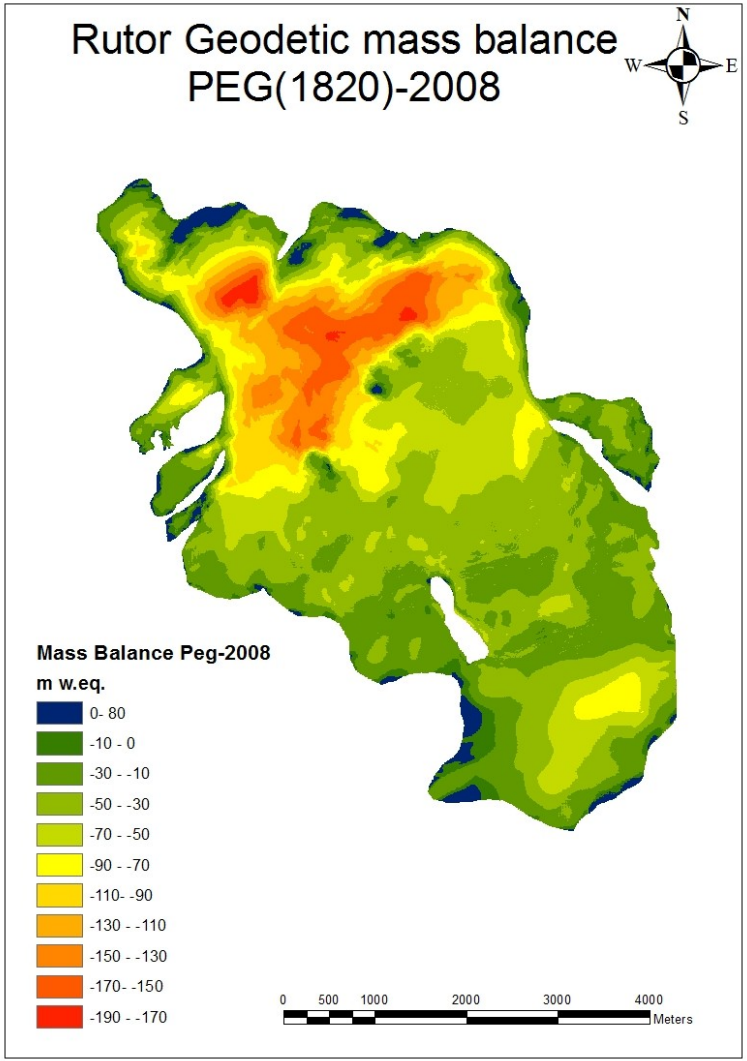
GIS Results

GIS Results

GEODETIC MASS BALANCE

- Surveying of the surface elevation of the glacier at different time (years to decade), differencing these elevations and applying assumption and adjustment about ice density and temporal factor, gives a glacier-wide cumulative balance over time.

- Averaged cumulative height change between LIA and 2008 was - 52,06 m w.eq. reaching the maximum value of -190 m w.eq. on the lowest part of Rutor (North).



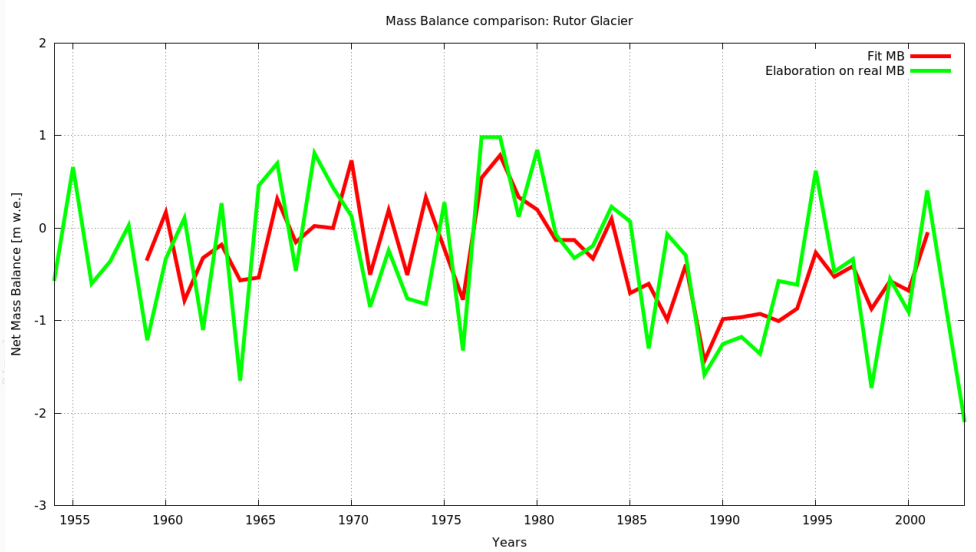
Model Data Input

In minimal glacier model, the input data set are given by Mass Balance, which is very closely related to the climate forcing and oscillations.

Ts and Pw drive the glacier evolution.

We use a bi-variate fit to describe mass balance as a functions of summer temperature and winter precipitation, year by year.

$$\dot{b}_i = aT_{s,i} + bP_{w,i} + c$$



MGM Calibration

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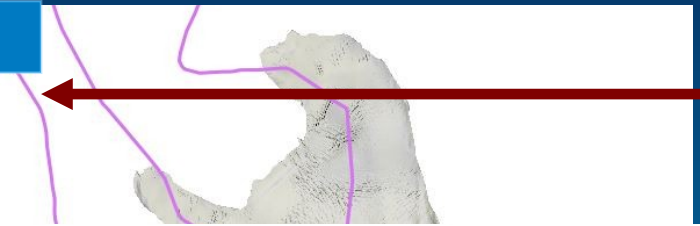
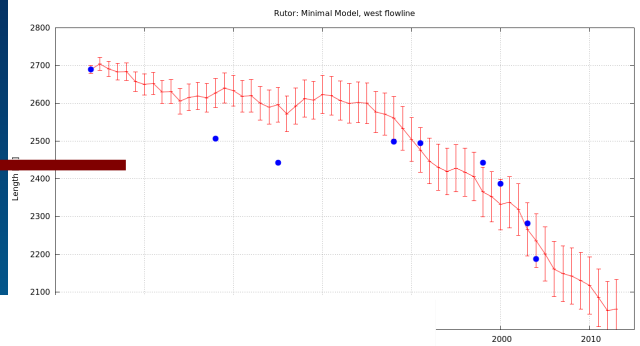
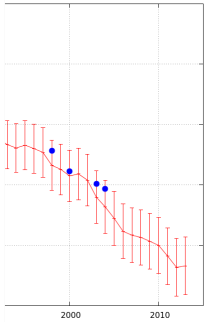
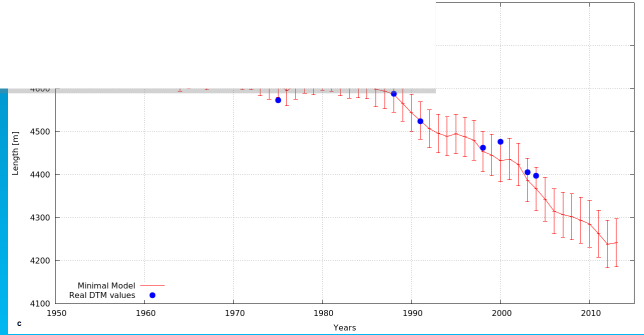




The calibration allows the application of MGM to simulate the future behavior of Rutor Glacier, following climate models that forecast future scenarios.

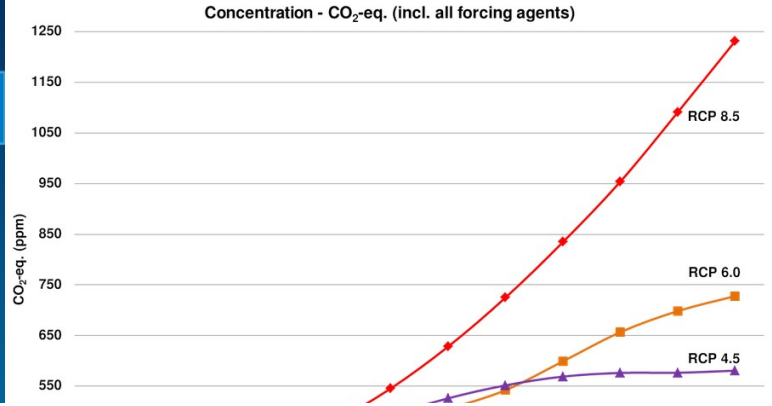




Good approximation of the simulated model with real values, obtained with DTM analysis, since 1954.

GCM: CMIP5 project

The minimal glacier model is coupling with the General Circulation Model (GCM) ensembles CMIP5 (Ts, Pw),



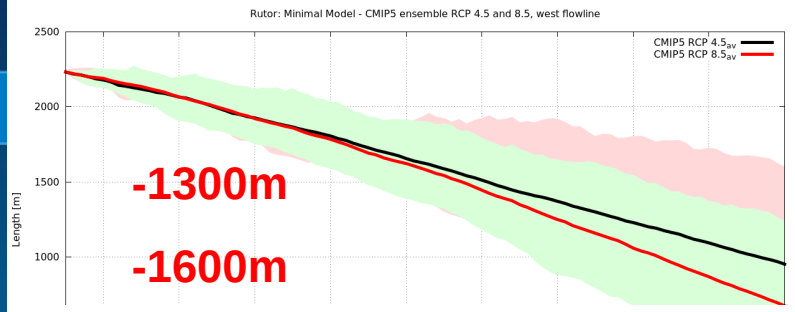
Model ID	Resolution LonxLat° Lev < 2°	Institution ID	Reference
ACCESS1-0	1.875x1.25L38	CSIRO-BOM	Bi and others, 2013
ACCESS1-3	1.875x1.25L38	CSIRO-BOM	Bi and others, 2013
bcc-csm1-1-m	1.125x1.125L26 (T106)	BCC	Wu and others, 2013
CCSM4	1.256x0.9L27 (T63)	NCAR	Meehl and others, 2012
CESM1-BGC	1.25x0.9L27	NSF-DOE-NCAR	Hurrell and others, 2013
CESM1-CAM5	1.25x0.9L27	NSF-DOE-NCAR	Hurrell and others, 2013
CNRM-CM5	1.40625x1.40625L31 (T127)	CNRM-CERFACS	Voldoire and others, 2013
CSIRO-Mk3-6-0	1.875x1.875L18 (T63)	CSIRO-QCCCE	Rotstayn and others, 2012
EC-EARTH-r8i1p1	1.125x1.121 (T159)	EC-EARTH	Hazeleger and others, 2012
HadGEM2-AO	1.875x1.25L60	MOHC	Martin and others, 2011
HadGEM2-CC	1.875x1.25L60	MOHC	Martin and others, 2011
HadGEM2-ES	1.875x1.25L38	MOHC	Bellouin and others, 2011
MIROC5	1.40625x1.40625L40 (T85)	MIROC	Watanabe and others, 2010
MPI-ESM-LR	1.875x1.875L47 (T63)	MPI-M	Giorgetta and others, 2013
MPI-ESM-MR	1.875x1.875L95 (T63)	MPI-M	Giorgetta and others, 2013
MRI-CGCM3	1.125x1.125L48 (T159)	MRI	Yukimoto and others, 2012

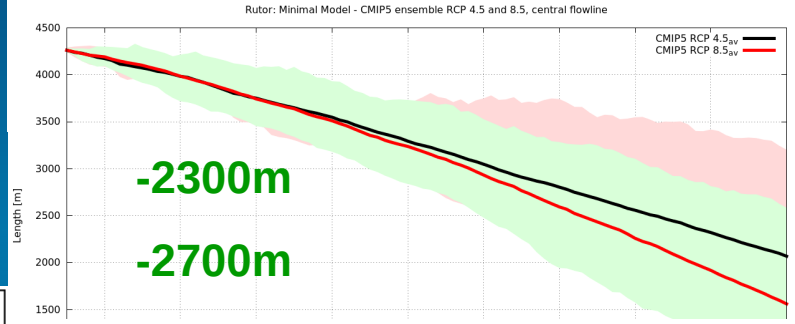
Future projections

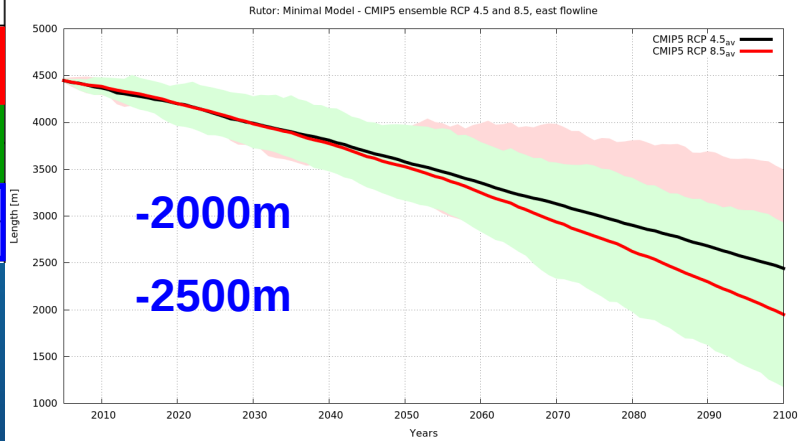
The Rutor future projections in 2100 show the lost of the 70-75% of west region.

The future dynamics will be concentrate on east area (around the middle moraine).

GCMs	Emission scenarios	Flow line	Initial length at 2004 [m]	Final length at 2100 [m]	Standard deviation (1σ)
CMIP5	RCP 4.5	West	2243,70	953,68	346,13
	RCP 8.5			676,76	347,08
	RCP 4.5	Central	4279,97	2067,35	614,53
	RCP 8.5			1560,23	639,81
	RCP 4.5	East	4463,48	2441,99	579,86
	RCP 8.5			1950,45	623,82



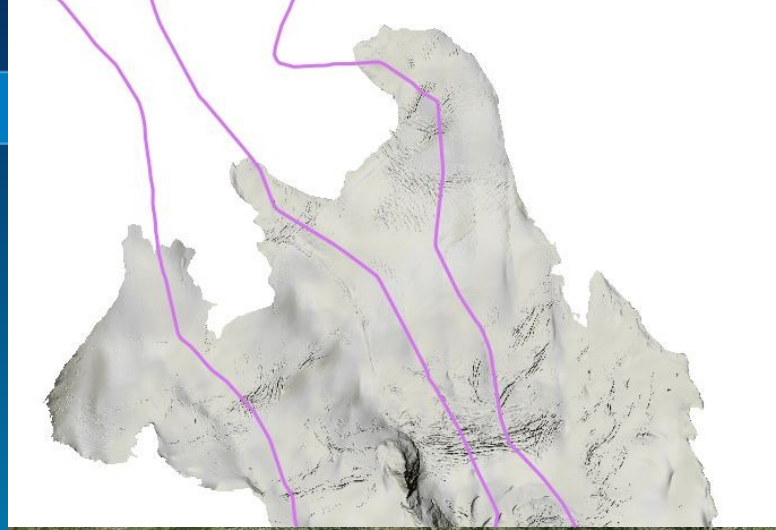


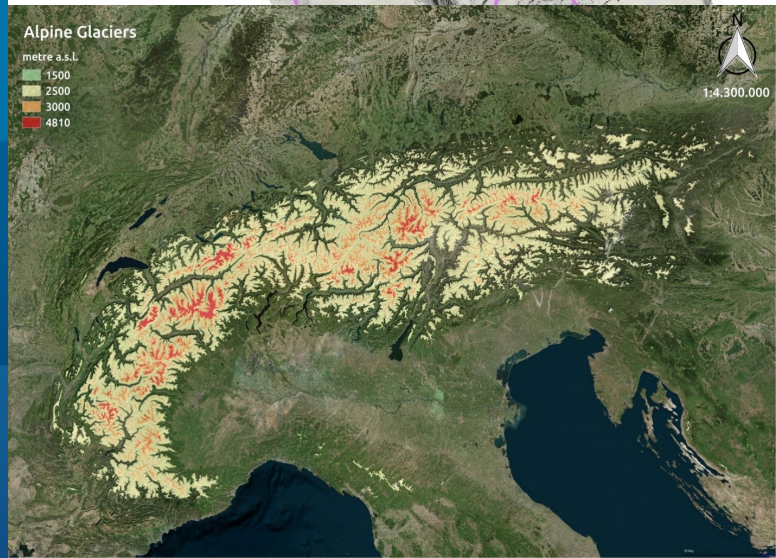


Coming developments

- Visualize the results of glacier retreats by DEM, following drawn flow lines.

- Apply MGM coupled with GIS on entire G.A.R.





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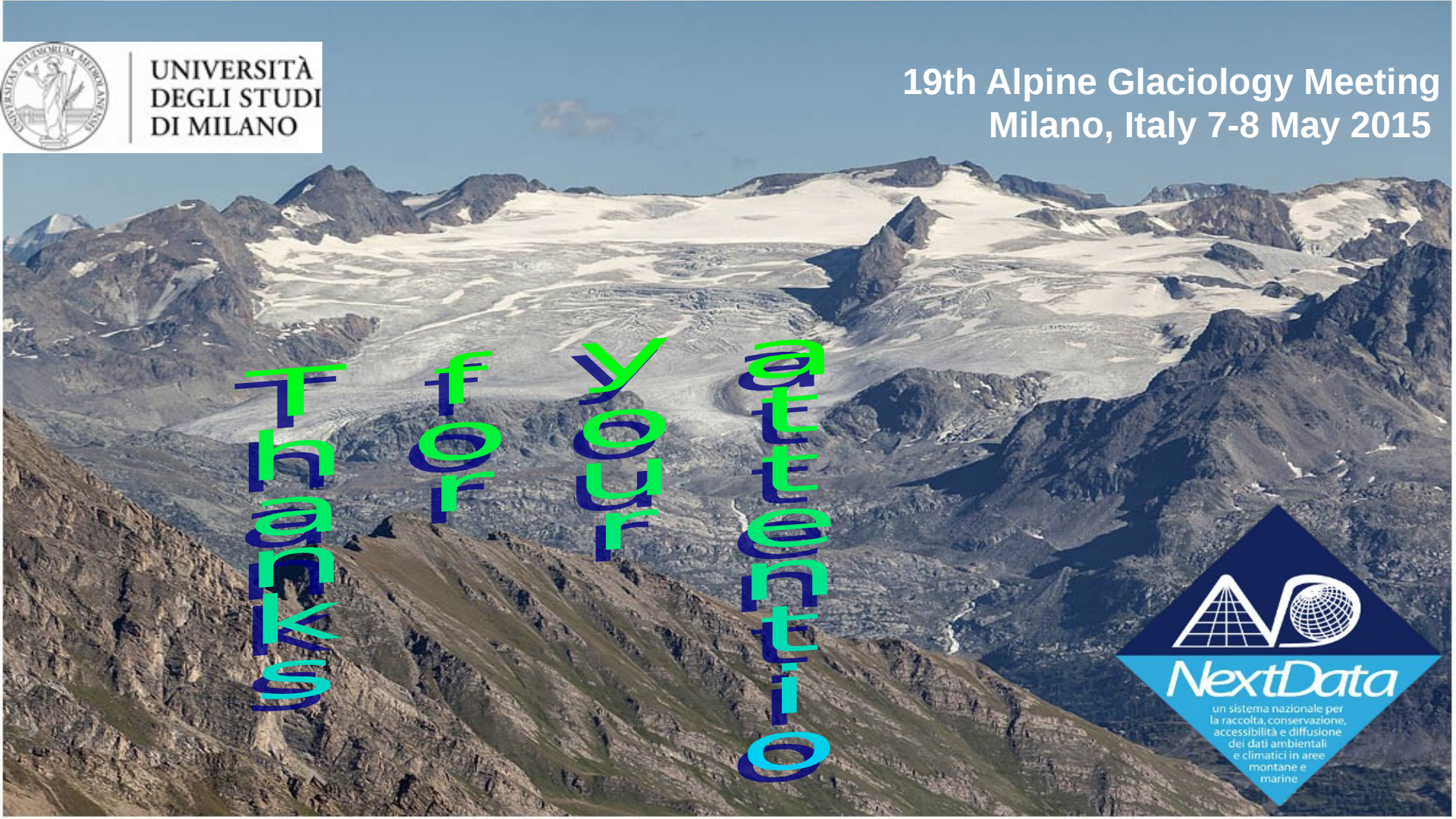

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