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GIS analysis to apply theoretical Minimal Model on glacier flow line and assess glacier response in climate change scenarios

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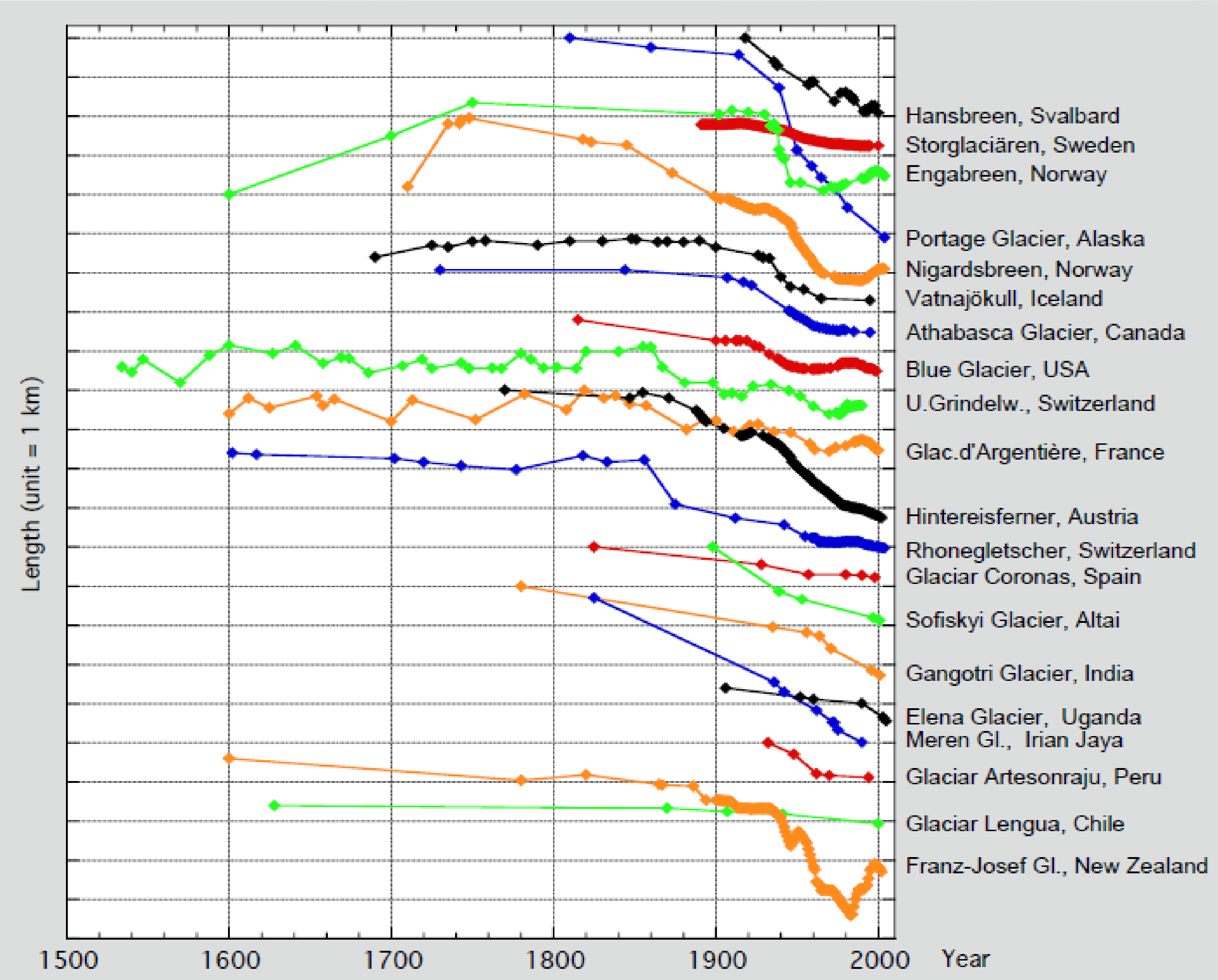
Project NextData

UN A/Res/62/196, 2008 *Glacier are sentinels of Climate Change.*

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



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Glacial dynamics are too complex to be modelled in every aspects.
Theorical Model was implemented to redux the complex situation and focus to one aspect.

CLIMATE FLUCTUATIONs → **Net Mass Balance** [*m w.e.*] / **Equilibrium Line Altitude** [*m*]

THEORETICAL MODEL: reduces a complex situation to a simple description, using laws of physics. →

$$\begin{cases} B_S = Wb(H_m + b_m - E)L \\ \dfrac{dL}{dt} = \left(\dfrac{3\alpha_m}{2(1+\upsilon s)} L^{1/2} - \dfrac{\alpha_m \upsilon}{(1+\upsilon s)^2} L^{3/2} \dfrac{\partial s_m}{\partial L} \right)^{-1} \dfrac{B_S}{W} \end{cases}$$

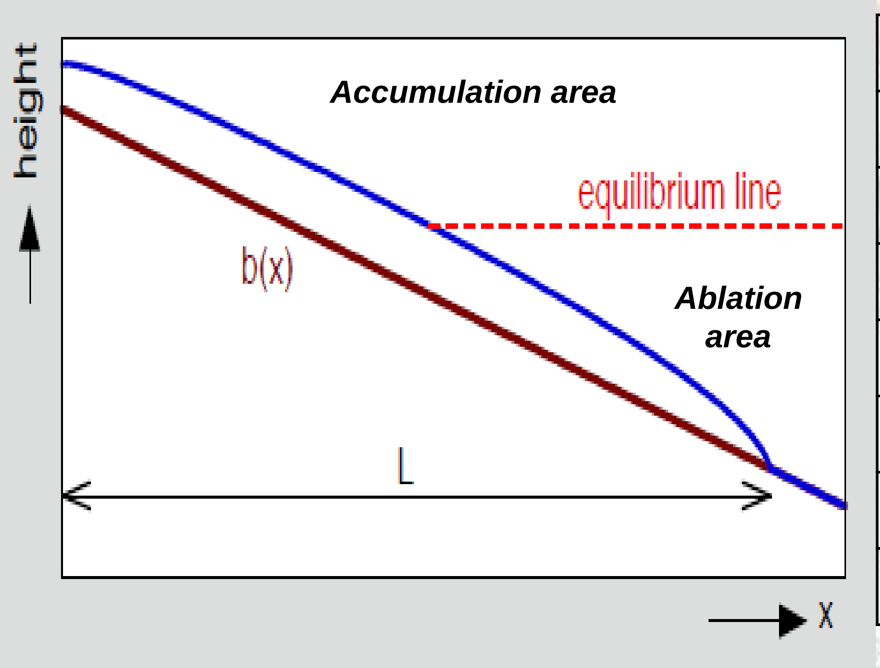
RESPONSE →

$$\boxed{\frac{dL}{dt}}$$

Minimal Glacier Models (J. Oerlemans 2008, 2011)

Minimal Model is based on continuity equation, that is integrated on entire volume of glacier, and on perfect plasticity principle, a first-order estimate of how the thickness of a glacier varies with its horizontal dimension.

The elaboration is based on reconstruction of historical time series, after have obtained ***meteoreological***, ***physical*** and ***morphological data*** to start the model it is possible compare the **flow line length variation** ,the model results, with real measured variations.



Model Input & BC
Net Mass Balance (I *annualy*)
Ela (I *annualy*)
Highest elevation [m] (BC)
Mean thickness [m] (DH) (BC)
Mean bed elevation [m] (BC)
Length of the flow line [m] (BC)
Mean slope (BC)

Algorithm →

Output

$$\frac{dL}{dt}$$

Flow line length variation

Minimal Model fundamentals and GIS interaction:

Minimal Model Input: **Mass Balance** & **ELA**

Boundary Condition:

- **B_0 = highest elevation [m] (β)**
- **H_m = mean thickness [m] (ΔH)**
- **b_m = mean bed elevation [m]**
- **L = length of the flow line [m]**
- **s = mean slope**

$$\begin{cases} B_S = W\dot{b}(H_m + b_m - E)L \\ \dfrac{dL}{dt} = \left(\dfrac{3\alpha_m}{2(1+\upsilon s)} L^{1/2} - \dfrac{\alpha_m \upsilon}{(1+\upsilon s)^2} L^{3/2} \dfrac{\partial s_m}{\partial L} \right)^{-1} \dfrac{B_S}{W} \end{cases}$$

Mass Balance gradient

$$\beta = \frac{d\dot{b}}{dz} = \frac{\dot{b}}{\bar{h} - E}$$

$$\bar{h} = H_m + b_0 - \frac{L \cdot s}{2}$$

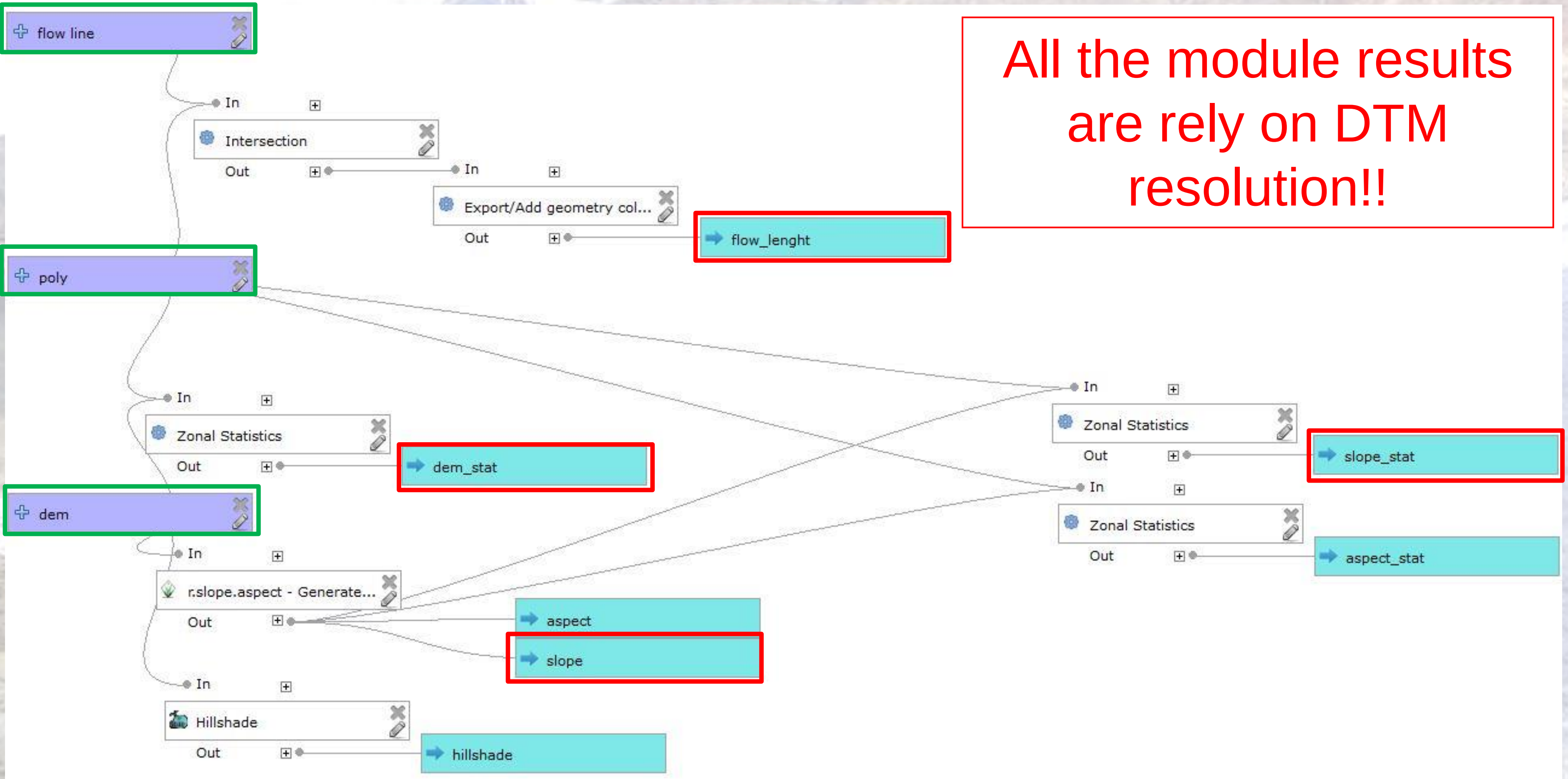
Model BC computable by GIS

Data obtainable by DTM analysis, to evaluate the accuracy it is required a multitemporal dataset → Developed of iterative GIS module.

From DETERMINISTIC to SPATIAL approach using GIS

QGIS Algorithms: MMGlacierData(*MMGD*)

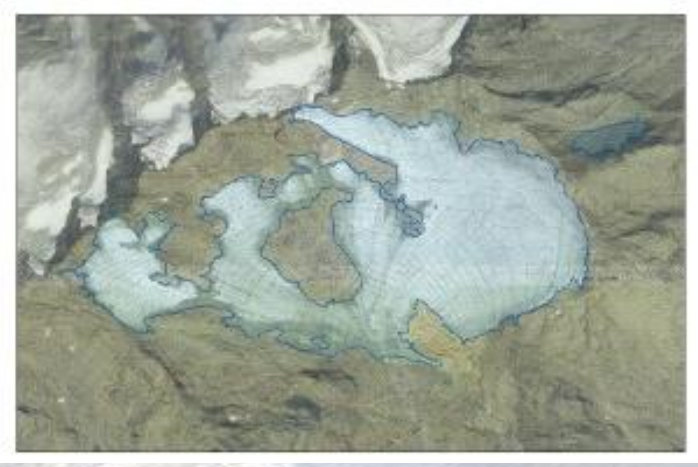
Development of an algorithm to calculate and iterate all the GIS operations to obtain the input for the minimal model. Developed in QGIS using its different available instruments: GRASS module and GDAL/OGR-libraries.



All the module results are rely on DTM resolution!!

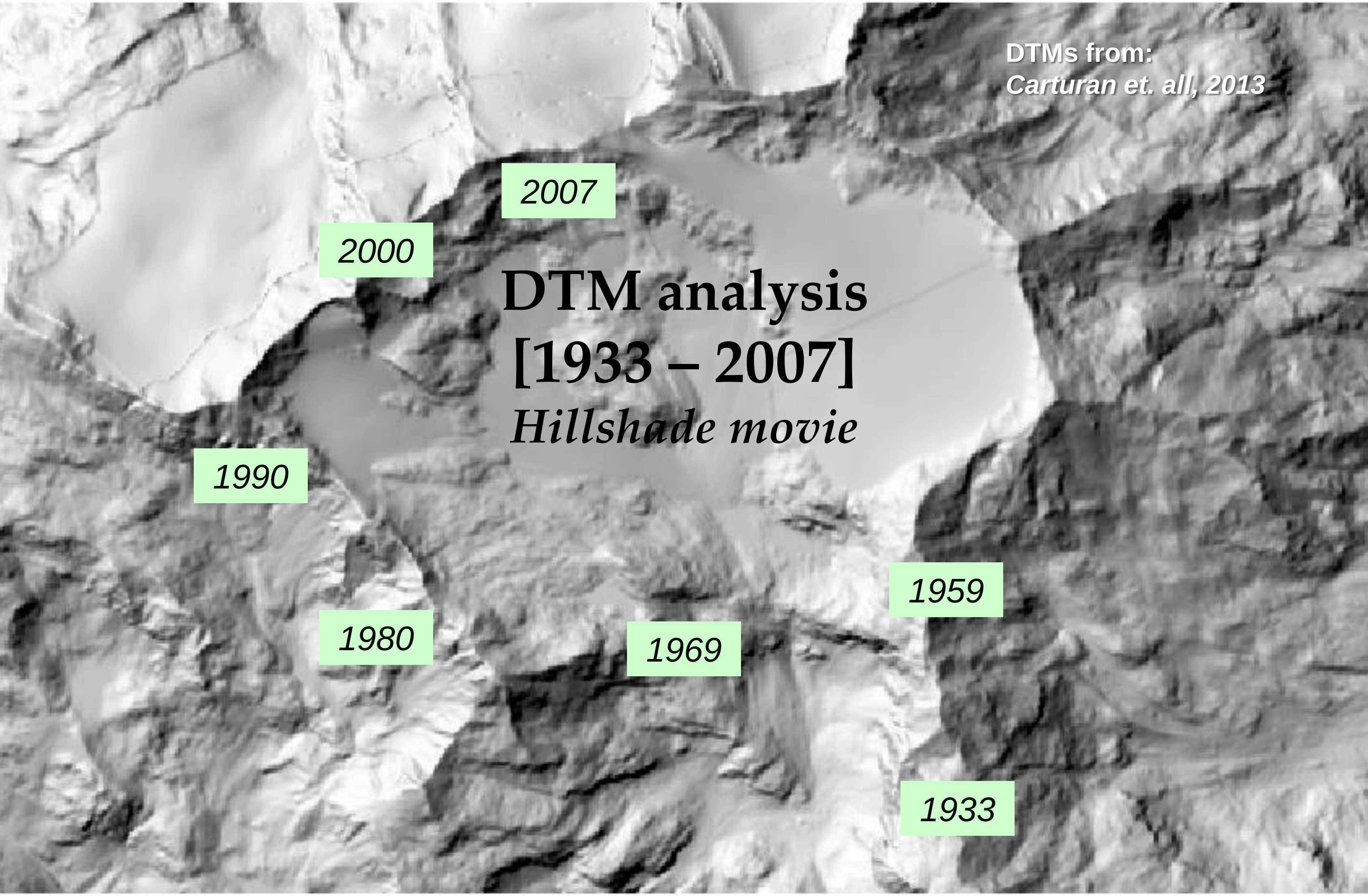
Study Area

Module MMGlacierData and Minimal Model were tested on Careser and Rutor glacier.



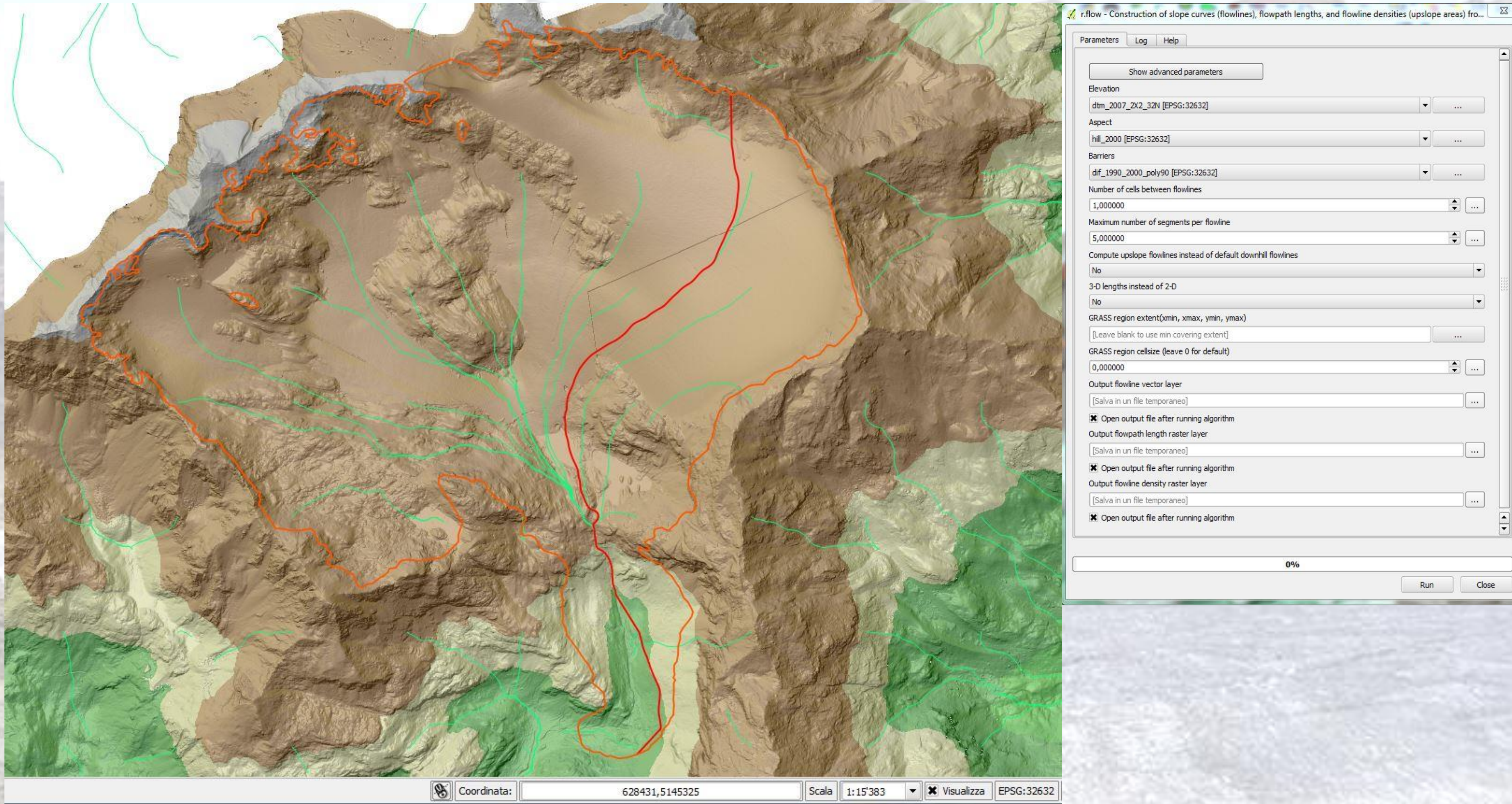
Careser is one the most studied glacier. All dataset used derived by UNIPD TESAF work (Carturan et all, 2007, 2012, 2013)

Rutor glacier is the most studied glacier by UNIMIB DISAT and there is a sufficient dataset to start.


DTMs from:
Carturan et. all, 2013
2007
2000
DTM analysis
[1933 – 2007]
Hillshade movie
1990
1959
1980
1969
1933

MMGD Input: FLOWLINE

Flowlines calculated with Grass **r.flow** used in Qgis and corrected by a geomorfological analysis to choose the most probably.

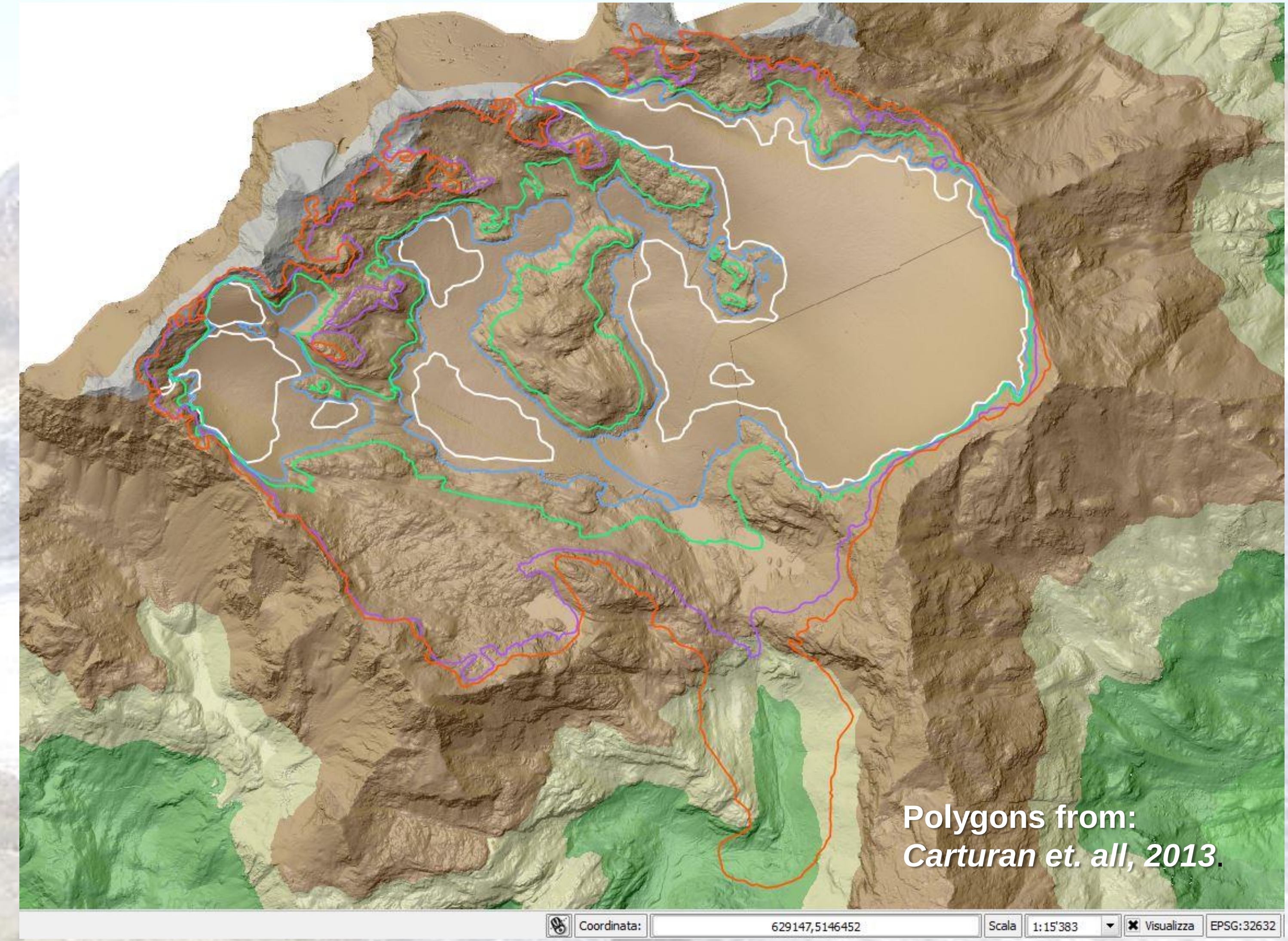


MMGD Input: Polygons

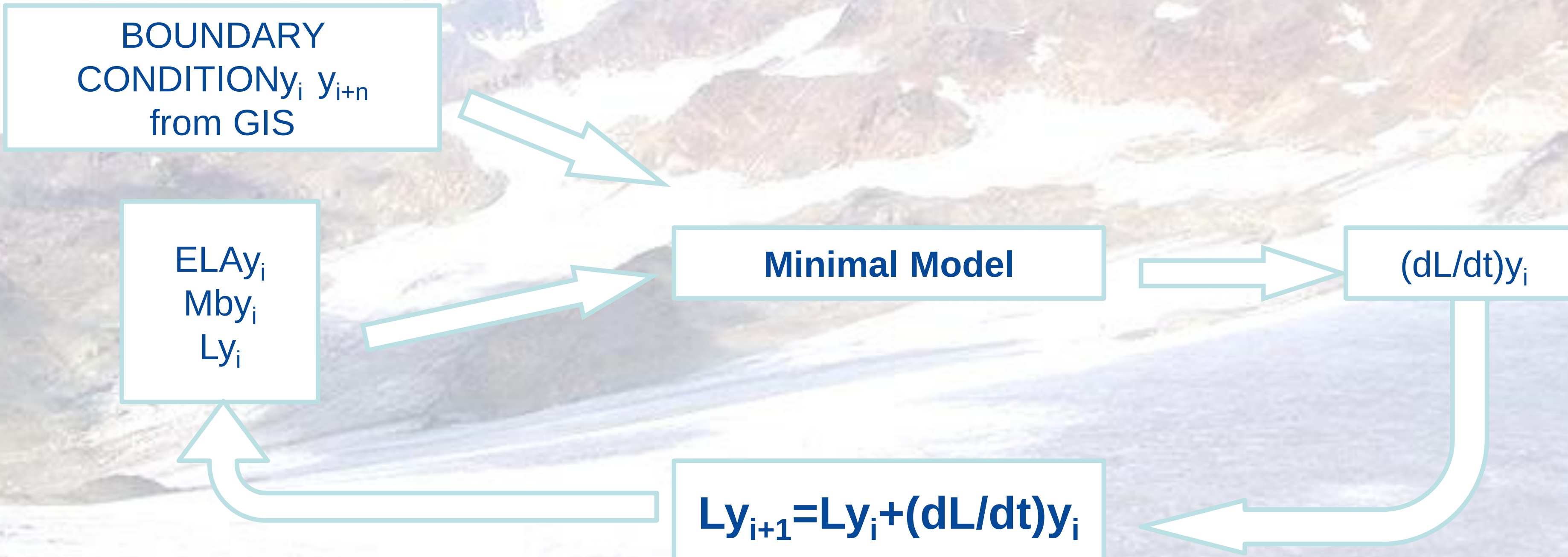
Polygons are used in MMGD as intersect surface to misure the length of the flowline and to obtain the DTM statistics for a single year.

Polygons years:

- 1933 -------
- 1959 -------
- 1969
- 1980
- 1990
- 2000 -------
- 2006 -------
- 2012 -------

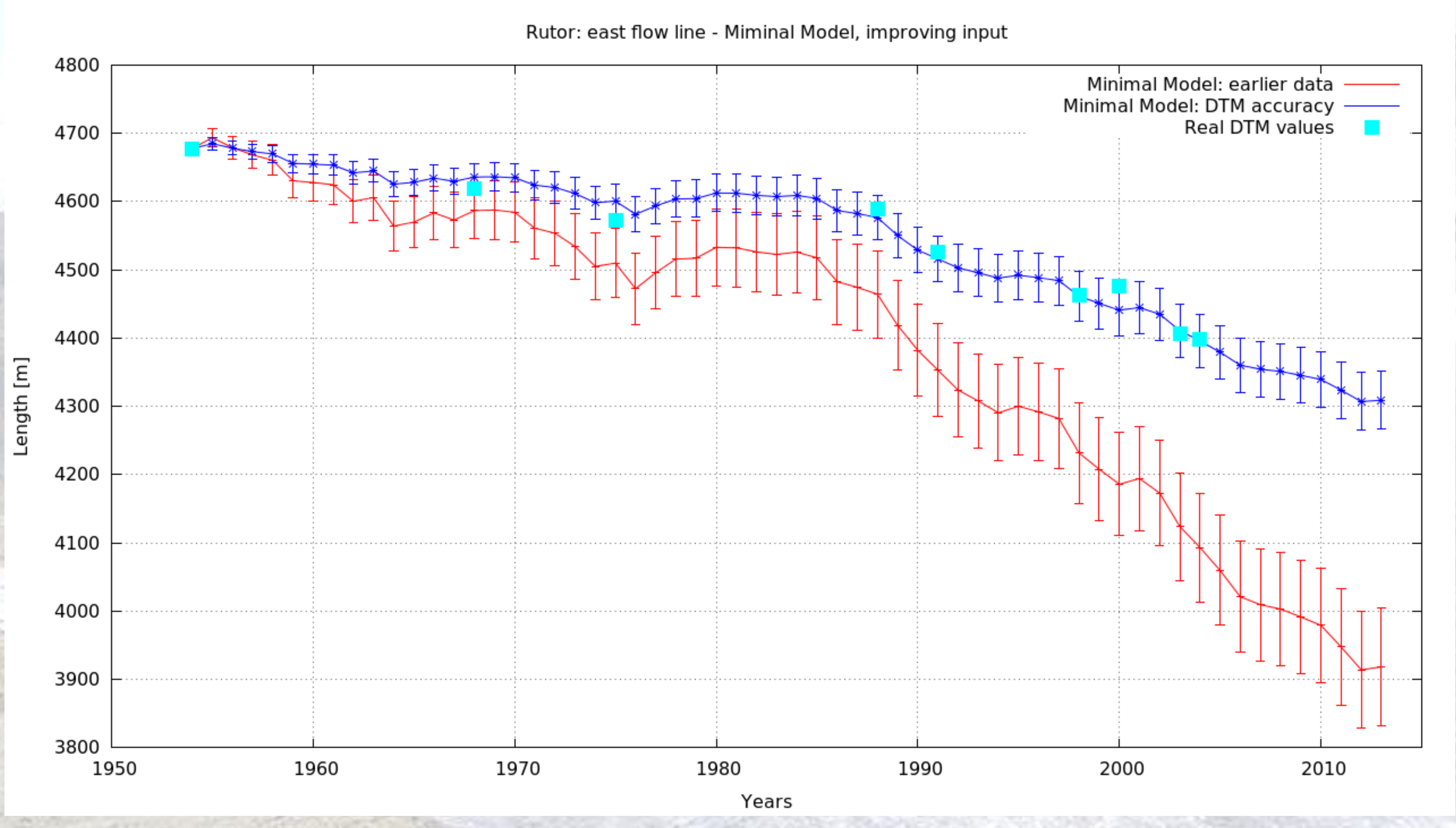


From MMGlacierData to Minimal Model

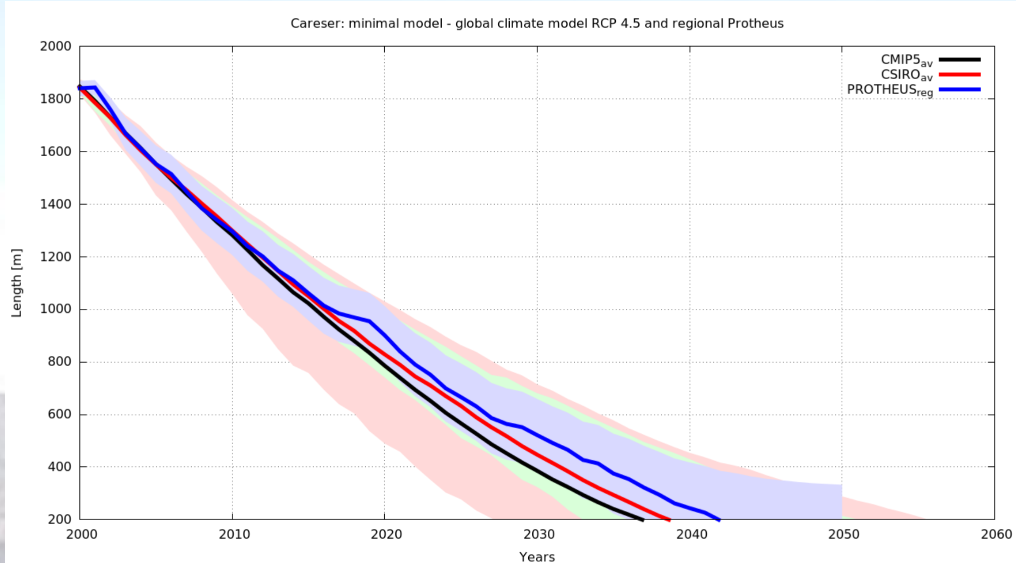


Minimal Model Results:

Minimal model accuracy using input data from MMGD(b) or input data from literature and averages.

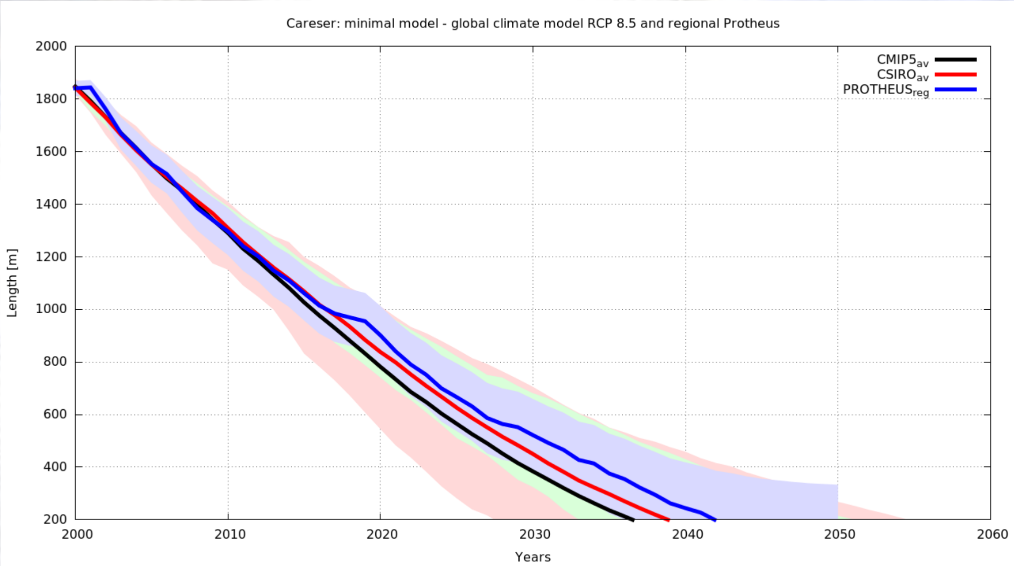


Minimal Model Results:



Future projection using RCP 4,5 scenario for CMIP5 and CSIRO global model. Comparison with regional climate model PROTHEUS based on SRES.

Future projection using RCP 8,5 scenario for CMIP5 and CSIRO global model. Comparison with regional climate model PROTHEUS based on SRES.



Glacier retreat

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