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 [...]”
How glaciers respond to Climate Change

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

CLIMATE FLUCTUATIONS

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

RESPONSE

Net Mass Balance [m w.e.]

Equilibrium Line Altitude [m]

\[
B_s = W \left( H_m + b_m - E \right) L
\]

\[
\frac{dL}{dt} = \left( \frac{3\alpha_m}{2(1 + \nu s)} L^{1/2} - \frac{\alpha_m \nu}{(1 + \nu s)^2} L^{3/2} \frac{\partial s_m}{\partial L} \right)^{-1} \frac{B_s}{W}
\]

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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 meteorological, 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 \textit{annually})
- Ela (I \textit{annually})
- 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
\[ \frac{dL}{dt} \]

Flow line length variation

Output
Minimal Model fundamentals and GIS interaction:

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

\[ B_S = W (H_m + b_m - E)L \]

\[ \frac{dL}{dt} = \left( \frac{3\alpha_m}{2(1 + \nu s)} \right) L^{1/2} - \left( \frac{\alpha_m \nu}{(1 + \nu s)^2} L^{3/2} \frac{\partial s_m}{\partial L} \right)^{-1} \frac{B_S}{W} \]

**Mass Balance gradient**

\[ \beta = \frac{db}{dz} = \frac{\bar{b}}{\bar{h} - E} \]

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

**Boundary Condition:**

- \( B_0 \) = highest elevation [m] (\( \beta \))
- \( H_m \) = mean thickness [m] (\( \Delta H \))
- \( b_m \) = mean bed elevation [m]
- \( L \) = length of the flow line [m]
- \( s \) = mean slope

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.
MMGD Input: DEMs

DTM analysis [1933 – 2007]

Hillshade movie

DTMs from: Carturan et. all, 2013
MMGD Input: FLOWLINE

Flowlines calculated with Grass \texttt{r.flow} used in Qgis and corrected by a geomorphological analysis to choose the most probably.
MMGD Input: Polygons

Polygons are used in MMGD as intersect surface to measure 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

Polygons from: Carturan et. al, 2013.
From MMGlacierData to Minimal Model

**Minimal Model**

\[
L_{y_{i+1}} = L_y_i + \left( \frac{dL}{dt} \right) y_i
\]

**Boundary Condition**

\[
y_i \quad \text{from GIS}
\]

- ELAy_i
- Mby_i
- Ly_i

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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

I want to be a "Panda" in China...

www.pulci.org
References


