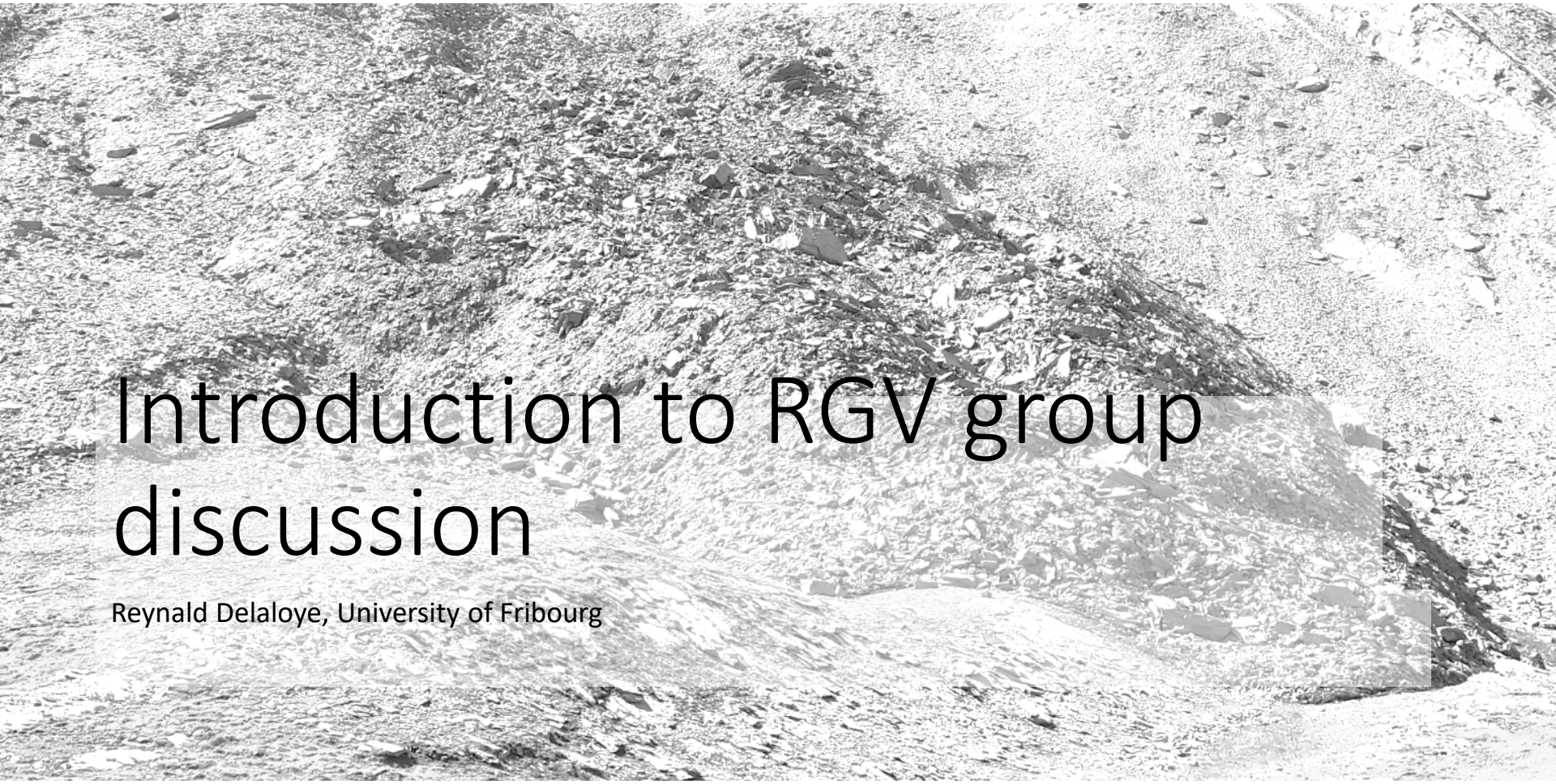


Introduction to RGV group discussion

Reynald Delaloye, University of Fribourg

Background and motivation

- Evolution of mountain permafrost is mainly observed by temperature monitoring in boreholes (direct observation method)

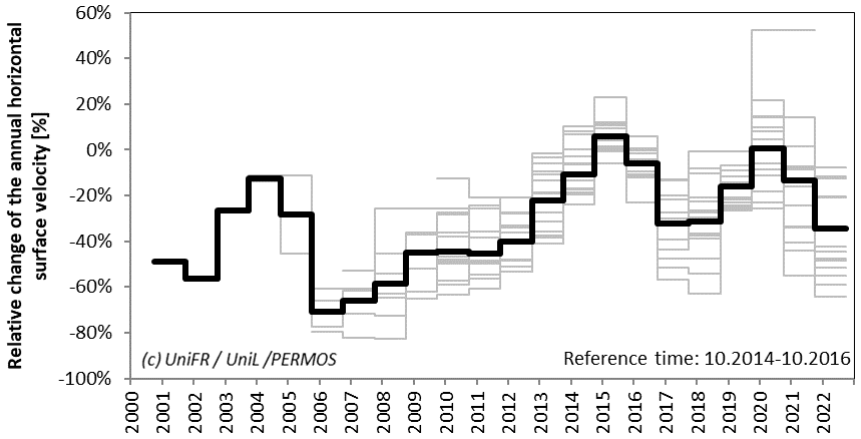
- Long-term maintenance challenging
  Observations limited to single locations scarcely distributed around the world

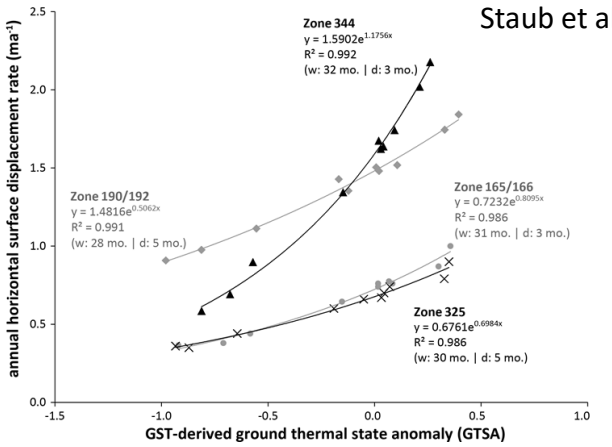
=> **Most mountain areas on Earth are lacking permafrost monitoring data**

Background and motivation

Many rock glaciers within a specific region have a similar interannual to longer term evolution of surface displacement rates, which strongly depends on ground temperature changes.

=> Changes in rock glacier velocity provide information about the impact of climate change on creeping mountain permafrost and, indirectly, on its thermal state

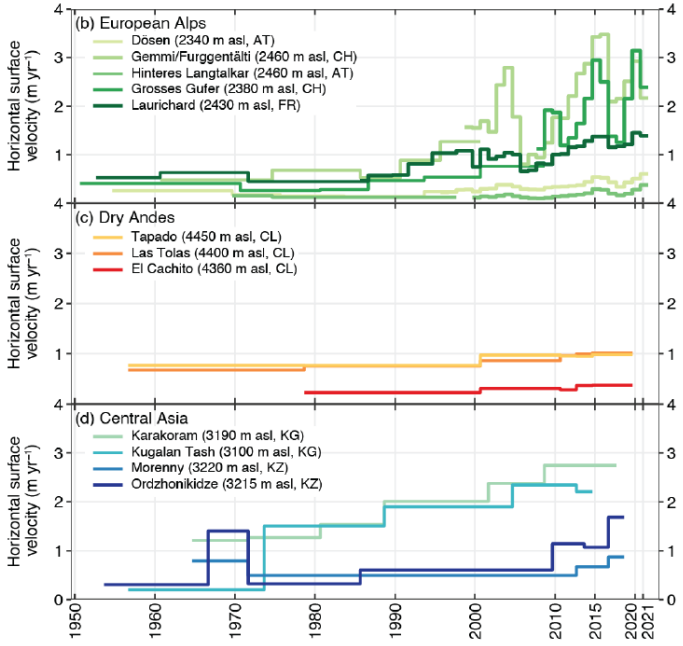




Staub et al. 2016 ICOP

Background and motivation

Remote sensing facilitates the set-up of large-scale rock glacier surveys and enable the computation of velocity time series worldwide.



RGV definition

Rock glacier velocity (RGV) is defined as a **time series of annualized surface velocity values** expressed in m/y and measured/computed on a rock glacier unit or a part of it.

The velocity data refers to :

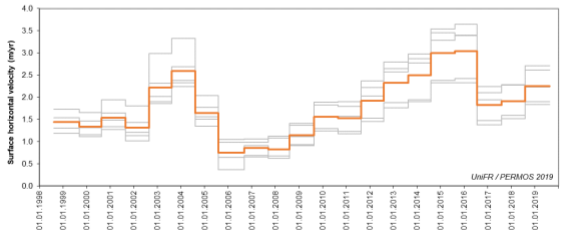
- an effective displacement rate **over a year or during a shorter period**,
  -> observation during the summer only is possible
- which is related to permafrost creep
  -> including the vertical component is not recommended

IPA Action Group Rock glacier inventories and kinematics

Rock Glacier Velocity as an associated parameter of ECV Permafrost

Baseline concepts

(Version 3.1)



https://www3.unifr.ch/geo/geomorphology/en/research/ipa-action-group-rock-glacier *(Action Group website)*

RGV baseline + practical concepts

RGV – New permafrost ECV product

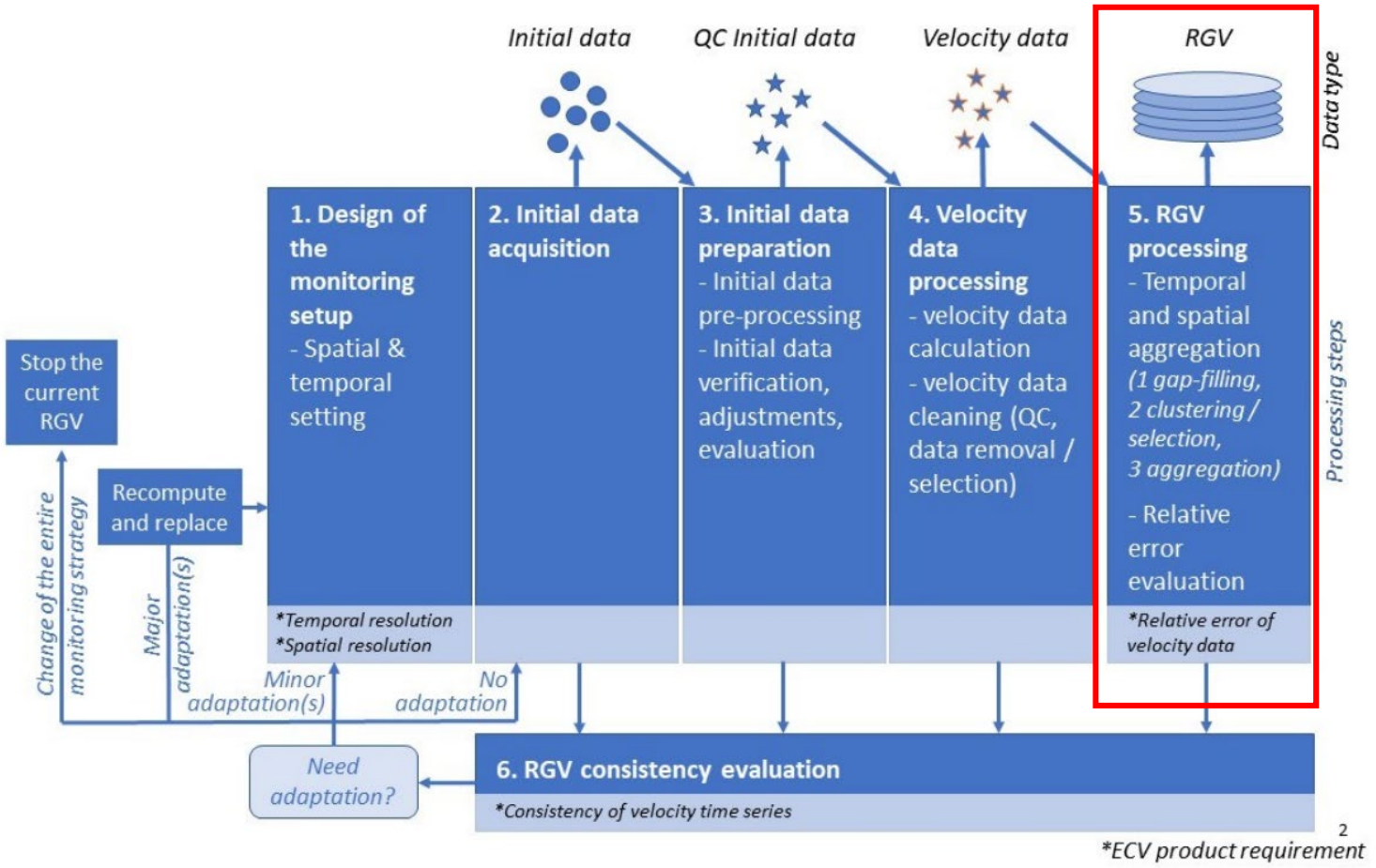
Rock Glacier Velocity (RGV) has been integrated as a new associated product to the ECV Permafrost in the implementation plans of the Global Terrestrial Network Permafrost (GTN-P) 2021-2024 and the Global Climate Observation System (GCOS) 2022

RGV – Multiple techniques

	Total station	GNSS	Terrestrial laser scanning	Terrestrial photogrammetry	Terrestrial radar interferometry	UAV-borne photogrammetry
Platform, tool, method	Terrestrial: on site	Terrestrial: on site	Terrestrial: ground base close to site	Terrestrial: ground base close to site	Terrestrial: ground base close to site	Remote: drone
Measurement footprint	Local	Local	Local	Local	Local	Local
Measurement resolution	Single point(s) based measurement	Single point(s) based measurement				
User dependent parameter	Positioning	Positioning				
Image information	Not applicable	Not applicable				
Natural radiation	Independent	Independent				
Temporal resolution (time interval measurement)	User defined	User defined				
Data value and dimension	Direct 3D point coordinates of a single point	Direct 3D point coordinates of a single point				
Geometric reference[1]	Lagrangian	Lagrangian				
Dimensionality (value provided by motion analysis)	3D coordinate differences (Displacement of an object)	3D coordinate differences (Displacement of an object)				
Accuracy (between 2 measurements)	cm	cm				

	Airborne laser scanning	Airborne photogrammetry	Spaceborne photogrammetry	Spaceborne SAR interferometry	Spaceborne SAR offset tracking
Platform, tool, method	Remote: plane/helicopter	Remote: plane	Remote: satellite	Remote: satellite	Remote: satellite
Measurement footprint	Local to regional	Local to regional	Regional to global	Regional to global	Regional to global
Measurement resolution	Area based, dm	Area based, cm	Area based, cm	Area based, m	Area based, m
User dependent parameter	no	no	no	no	no
Image information	Referenced image, point cloud coloring	Multiband image information	Multiband image information	Radar image	Radar image
Natural radiation	Independent	Dependent	Dependent	Independent	Independent
Temporal resolution (time interval measurement)	User defined (or depending on country authorities)	User defined (or depending on country authorities)	Days to years depending on sensor	Days to years depending on sensor	Days to years depending on sensor
Measurement value and dimension	Direct 3D coordinate of random surface points	Indirect 3D coordinate of random surface points	Indirect 3D coordinate of random surface points	Direct 1D change of distance in the LOS	Indirect 2D coordinate of random surface points
Geometric reference	Lagrangian or Eulerian	Lagrangian or Eulerian	Lagrangian or Eulerian	Eulerian	Lagrangian or Eulerian
Dimensionality (value provided by motion analysis)	2.5D-3D coordinate differences (horizontal shift of a surface patch & Dz at defined location in CS)	2.5D-3D coordinate differences (horizontal shift of a surface patch & Dz at defined location in CS)	2.5D-3D coordinate differences (horizontal shift of a surface patch & Dz at defined location in CS)	Direct 1D coordinate differences in line of sight, potentially 3D by combining both ascending and descending modes	2D coordinate differences (slant-range and azimuth)
Accuracy (between 2 measurements)	dm	cm-m	dm-m	mm-cm	dm-m

RGV – Processing steps



RGV extraction from dGNSS time series

With example from the Becs-de-Bosson rock glacier (2004-2022, 18 years, 200 measurement points)

1. Monitoring setup

Monitoring setup as described in Lambiel and Delaloye (2004). Set of measurement points spread on a rock glacier unit and on non-moving areas aside (control-points). The points could be aligned along a longitudinal profile but are more often drawing an irregular grid.

2. Initial data acquisition

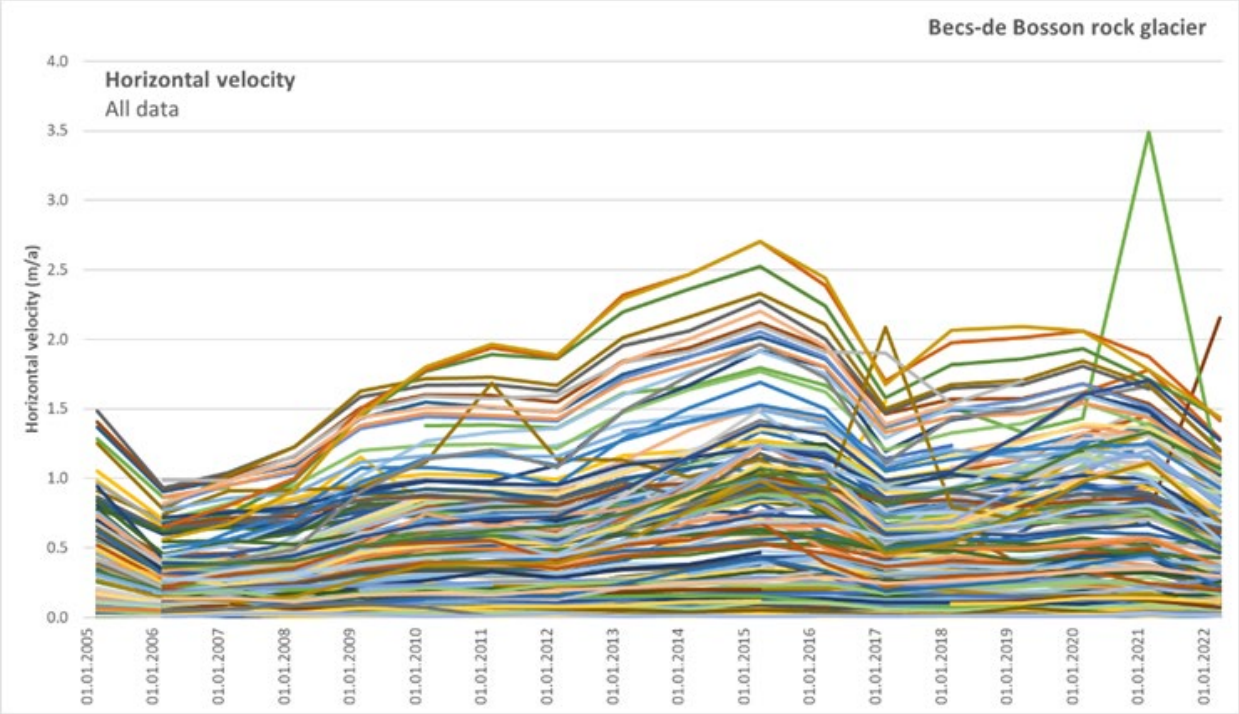
Annual positioning of all measurement points in RTK (real-time kinematic) mode. Accuracy is about +/- 2 cm in planimetry (xy) and +/- 3 cm in elevation (z) (standard error).

3. Initial data preparation

e.g. checking for point ID issues

4. Velocity data processing

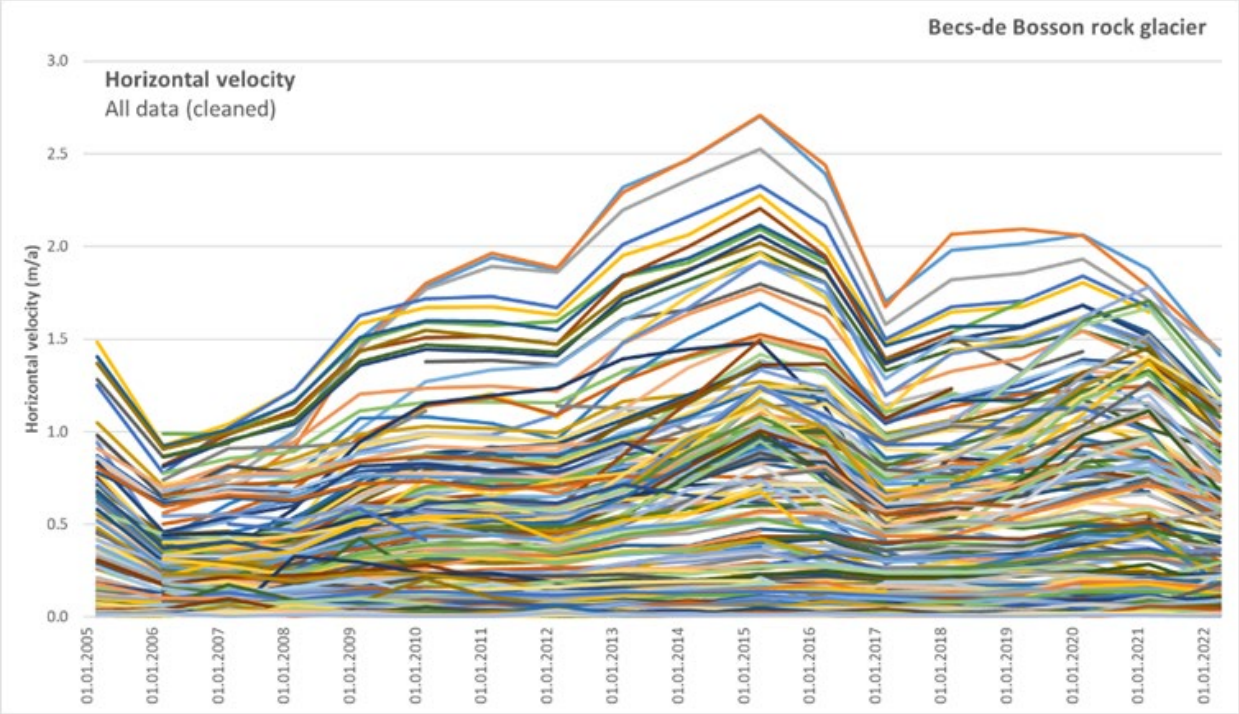
4.1. **2D (horizontal) velocity calculation**



5. Velocity data evaluation

5.1. **Velocity data cleaning**

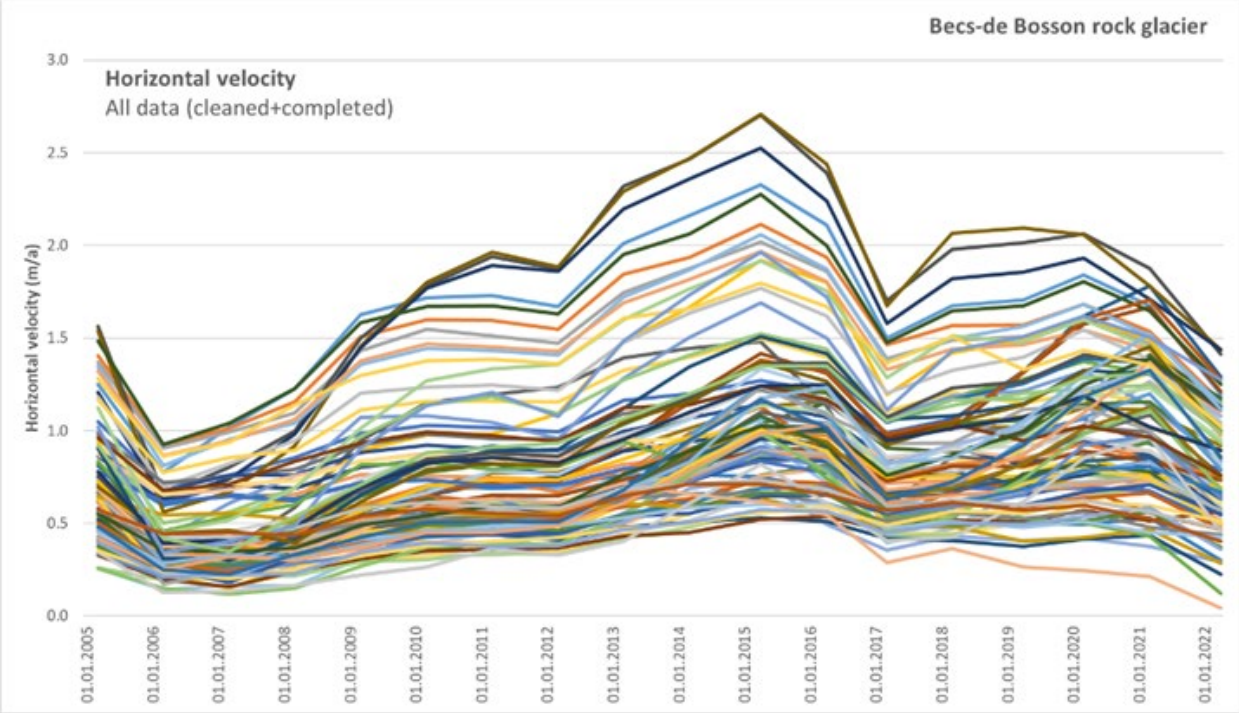
Removal of outliers (by systematic visual/comparative inspection) **and**



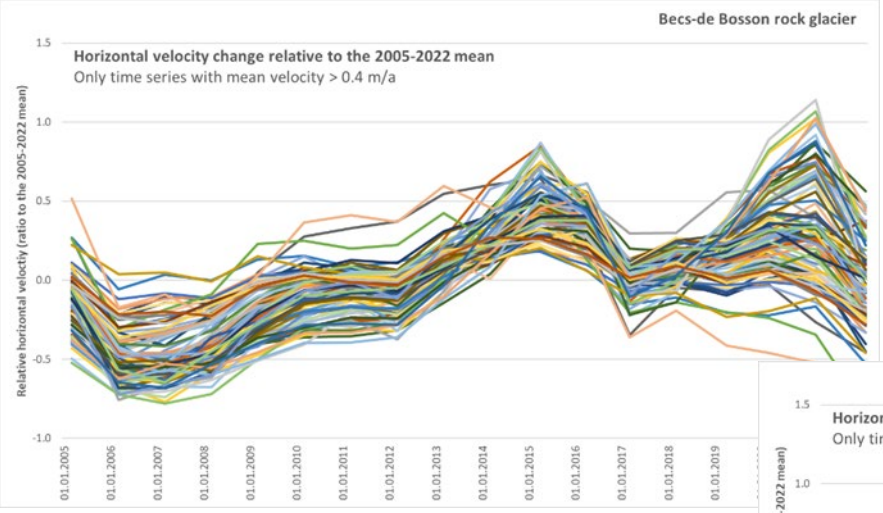
Slow moving points not considered further.

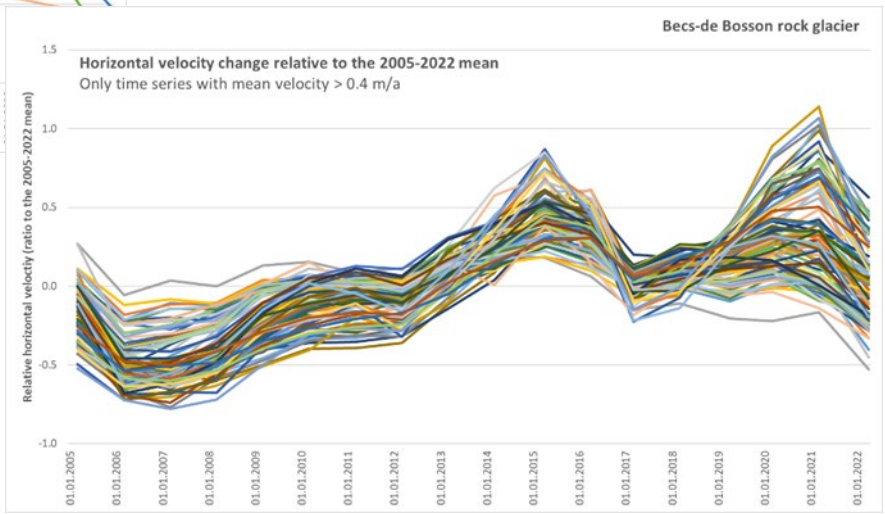
5.2. **Gap-filling**

Estimation by behavior similitude.



6.1. **Transformation to relative values**



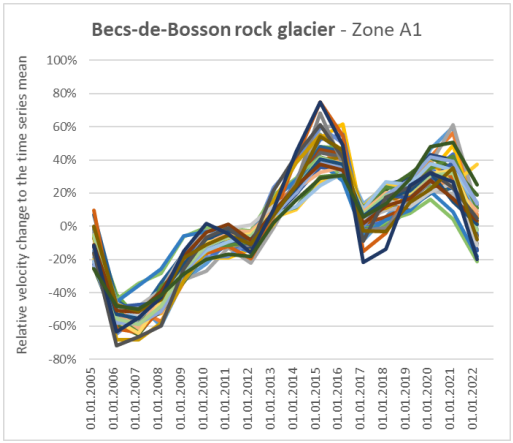


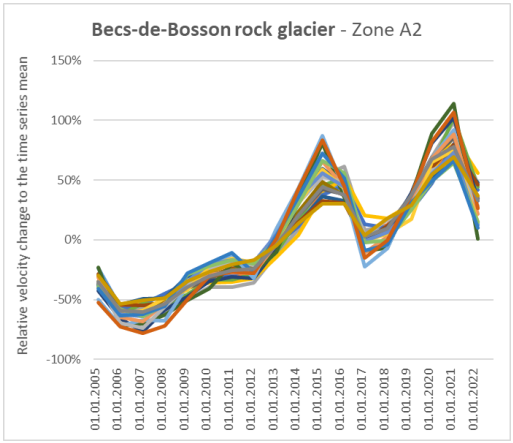
+ removal of outlying times series

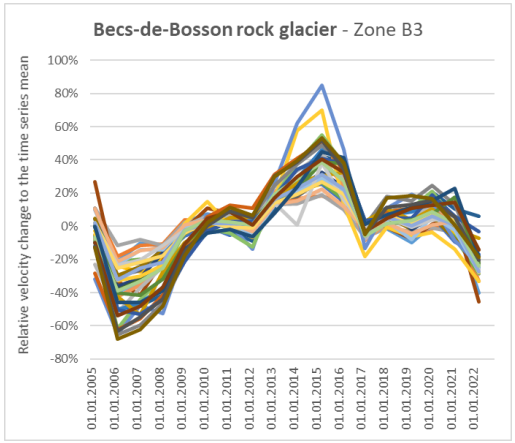
Clustering

Hierarchical clustering analysis

- Ward's minimum variance method
- Based on the squared Euclidian distance between observations
- Not depending specifically on time, but on the similarity of the observations (annual values).







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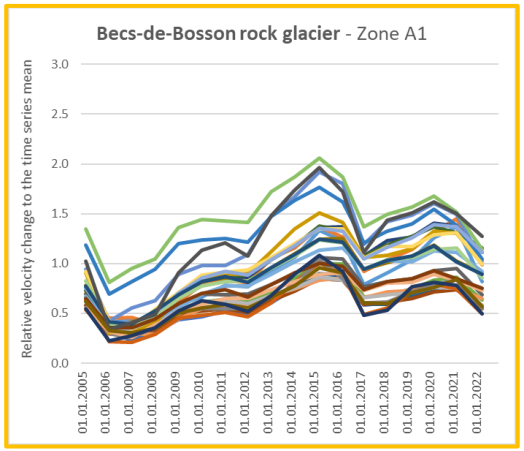
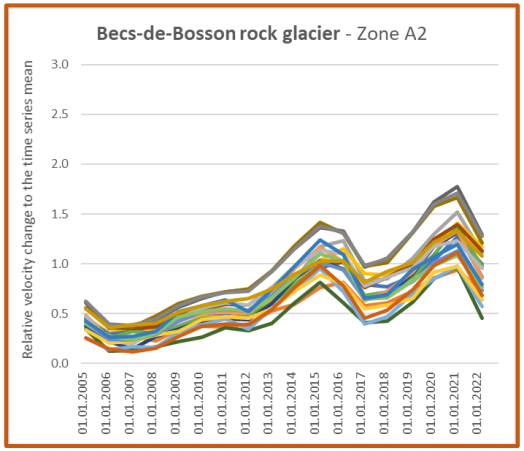
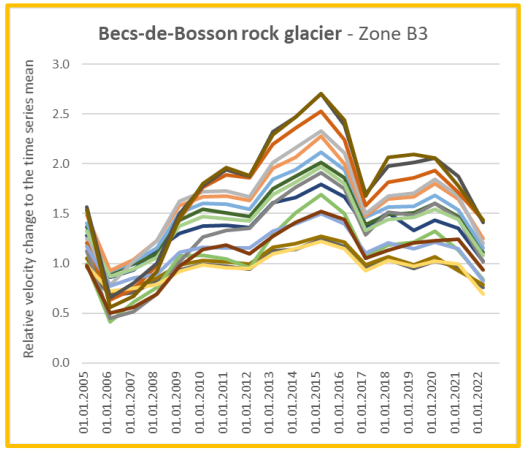
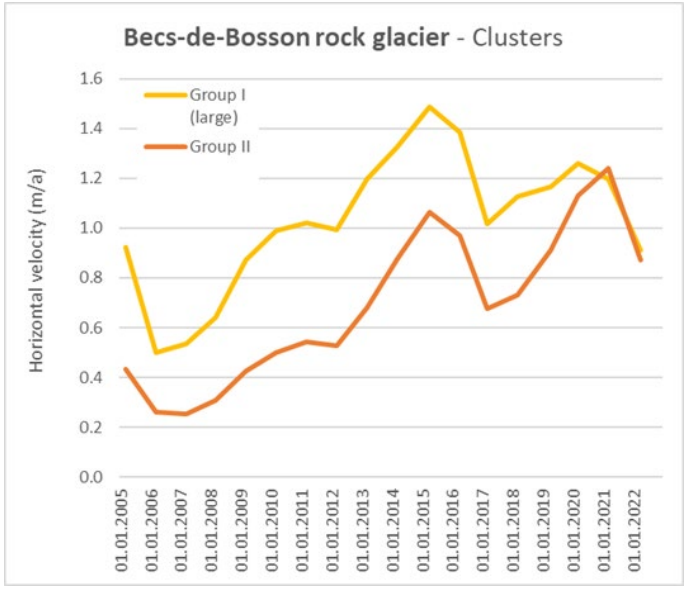
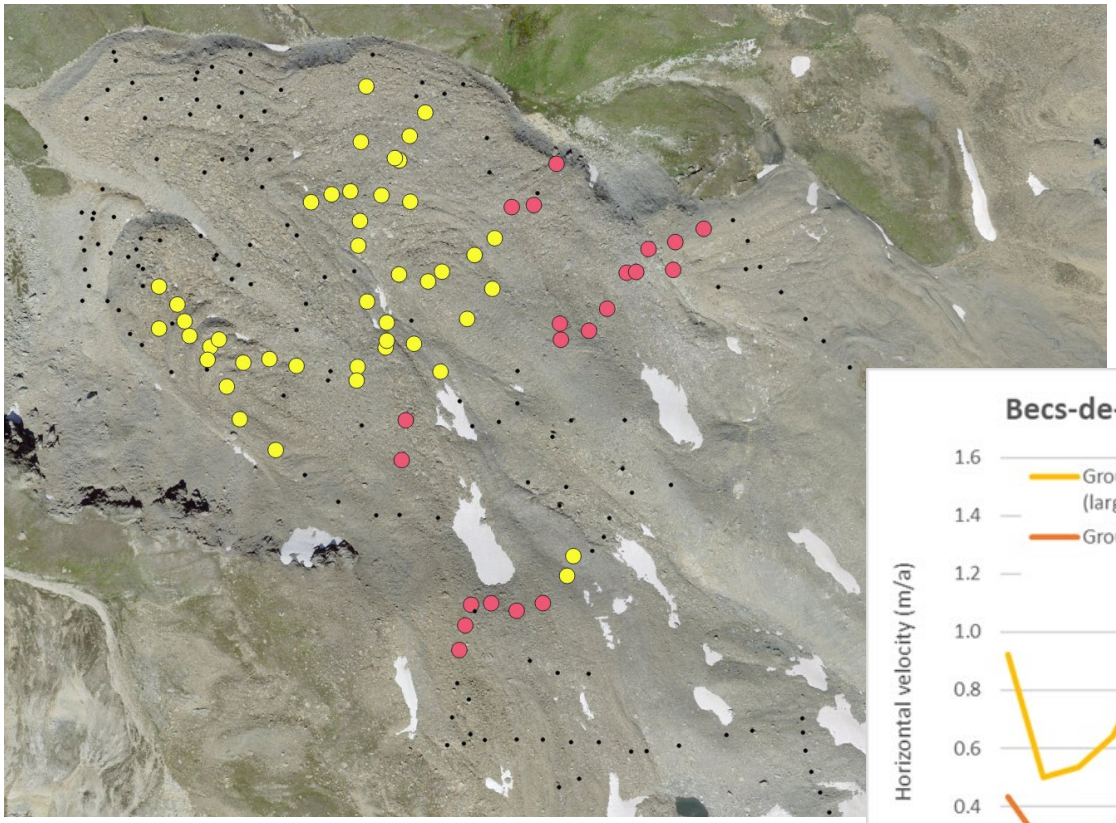


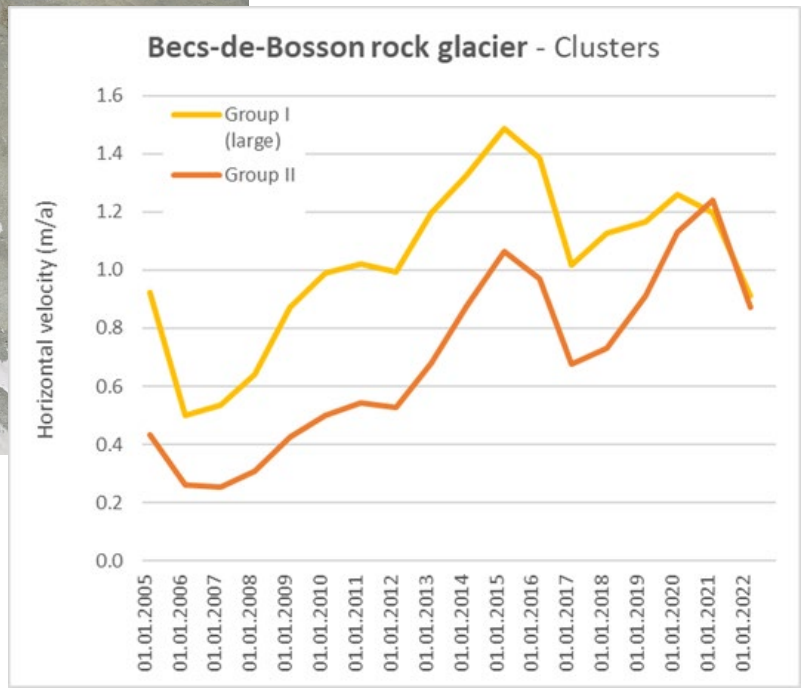






IPA Action Group RGIK – RGV





RGV – Group discussion

Topic 1:
Standard methodology to compute RGV from raw velocity (kinematic) data

Topic 2:
RGV as climate change indicator and current knowledge gaps