Rock Glacier Inventories and Kinematics (RGIK)

October 2021 – September 2023
Final Report

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With the support of the Federal Office of Meteorology and Climatology MeteoSwiss, in the framework of GCOS Switzerland

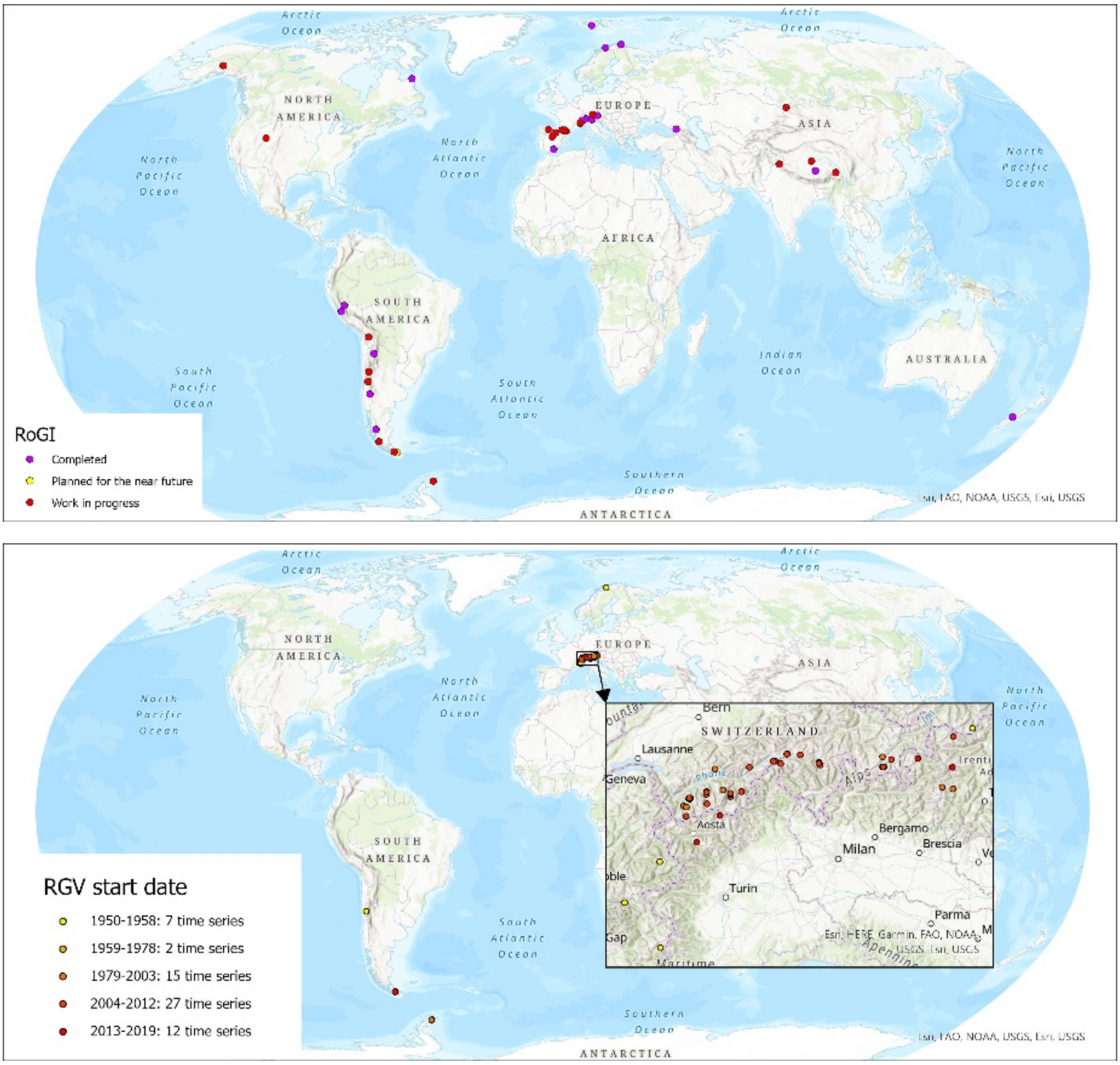

Figure 1: Worldwide inventory of available and planned RoGI and RGV data sets compiled within the RGIK project.

1 Summary

Permafrost is currently undergoing substantial warming and degradation due to climate change (Biskaborn et al. 2019, Smith et al. 2022). There are evidences of increasing ground temperatures and the occurrence of permafrost degradation in many regions of the world (e.g., Noetzli et al. 2023). Nevertheless, due to the limited availability and uneven distribution of in-situ direct monitoring data, information about the state of permafrost is often lacking especially in the vast majority of periglacial mountain areas worldwide (Boelhouwers and Hall 2002).

Globally permafrost observations primarily rely on measurements of ground temperature and active layer thickness, which provide direct, quantitative, and robust observations (Streletskiy et al. 2021). However, these observations are restricted to point-scale information and are comparatively scarce especially in mountain areas. Indirect but less costly, and logistically easier approaches such as geophysical measurements and permafrost creep velocity measurements on rock glaciers exists and have been implemented since many years in the framework of national permafrost monitoring programs (e.g., PERMOS 2023).

Rock glaciers are characteristic landforms associated with periglacial landscapes developing in most mountain ranges where permafrost currently exists or has been widespread at one point in time, making them visual indicators of mountain permafrost occurrence. Observations made in the Alps, show that the surface velocity of most rock glaciers surveyed within a given region, irrespective of size and velocity, respond sensitively and almost synchronously to inter-annual and decennial ground temperature changes (e.g., Delaloye et al. 2010; PERMOS 2023; Staub et al. 2016). Thus, rock glacier kinematics can be used as a proxy to monitor and assess the impact of climate change on mountain permafrost.

The MeteoSwiss-funded project in the framework of GCOS-CH entitled "Rock glacier inventories and kinematics (RGIK)" had the objective of establishing an international service to coordinate the compilation of rock glacier inventories and to facilitate their long-term kinematic monitoring on an international level. The growing availability of open-access and high-resolution satellite products facilitates the creation of kinematic time series and regional rock glacier inventories (Bertone et al. 2022; Lambiel et al. 2023). With more datasets and research interest, globally agreed-upon guidelines are needed as well as a centralized infrastructure to collect and store these datasets. Within the RGIK project we were able to (1) compile an inventory of existing rock glacier inventory (RoGI) and rock glacier velocity (RGV) datasets and design a prototype database structure to store them; (2) compile widely accepted guidelines for generating RoGI and RGV datasets and develop a standardized RoGI tool for implementing said guidelines; (3) organize workshops and training exercises to implement the guidelines and establish an operational RGIK service; and (4) promote the international use of RoGI and RGV products as climate indicators and communicate the results from the RGIK project.

The project addresses the following elements of the GCOS Switzerland Strategy 2017-2026: ensuring the traceability and reproducibility of the data processing chain as well as the standardization of ECV observations (strategic priorities 1.5 and 1.6); enhancing the regional and global collaboration for ECV monitoring as well as further strengthen the Swiss collaboration with international initiatives (strategic priorities 2.2 and 2.3). In its first year, the project focused on compiling standard guidelines for generating RoGI and RGV datasets; during the second year, database prototypes as well as inventorying exercises were developed and tested within the RGIK community. Additionally, worldwide overviews of existing or planned RoGI and RGV time series were compiled. The RGIK project has successfully fostered collaboration between researchers and institutions through workshops and monthly seminars, allowing for the exchange of knowledge and expertise in rock glacier inventorying and monitoring. The project's efforts have also paved the way for future advancements in data collection and analysis techniques, ensuring the continued development of RGV for ECV monitoring.

2 Scientific report

2.1 Introduction

Permafrost, defined as earth material (i.e. soil, rocks, etc.) remaining at or below 0°C during at least two consecutive years, is currently undergoing substantial warming and degradation due to climate change (Biskaborn et al. 2019, Smith et al. 2022). There are evidences of increasing ground temperatures and the occurrence of permafrost degradation in many regions of the world (e.g., Gudmunsson et al., 2022, Mollaret et al. 2019, Noetzli et al. 2023, Zhao et al. 2020). Nevertheless, due to the limited availability and uneven distribution of in-situ direct monitoring data, information about the state of permafrost is often lacking especially in the vast majority of periglacial mountain areas worldwide (Boelhouwers and Hall 2002).

Warming and degrading permafrost can have significant impacts on the stores and fluxes of water, sediments, and carbon from local to global scale (Beniston et al. 2018; Vaughan et al. 2013). Especially, CO_2 and CH_4 release from thawing arctic soils can increase greenhouse gases concentration in the atmosphere (Schuur et al. 2015) and contribute to global climate warming. In mountainous terrains, permafrost evolution may impact the stability of debris-mantled slopes and rock walls (Krautblatter et al. 2013; Ravanel et al. 2017), the sediment transfer rates (e.g., Kummert et al. 2018) and thus affect infrastructures (e.g., Duvillard et al. 2019), human activities (e.g., Mourey et al. 2019) and more generally land use and land planning.

Globally permafrost observations are coordinated by the Global terrestrial network for permafrost (GTN-P) and primarily rely on measurements of ground temperature and active layer thickness (i.e., thickness of the layer of the ground above the permafrost that is subjected to annual thawing and freezing, van Everdingen, 1998). Both approaches, provide direct, quantitative, and robust observations of permafrost thermal state and evolution (Streletskiy et al. 2021). However, these observations are restricted to point-scale information and are comparatively scarce due to the high costs of borehole drilling (especially in high mountain or polar terrains) and the impossibility to perform active layer thickness measurement using the most common techniques in rocky terrains (i.e., most mountain areas). Less costly, and logistically easier methods such as geophysics or permafrost creep velocity measurements on rock glaciers exists and have been implemented since many years in the framework of permafrost monitoring programs (e.g., PERMOS 2023).

Rock glaciers are characteristic landforms associated with mountain periglacial landscapes and are defined as *debris landforms generated by a former or current gravity-driven creep of (ice-rich) frozen ground (permafrost), detectable in the landscape with the following morphology: front, lateral margins and optionally ridge-and-furrow surface topography* (RGIK 2022a). They are developing in most mountain ranges where permafrost currently exists or has been widespread at one point in time, making them visual indicators of mountain permafrost occurrence. Furthermore, observations made in the Alps, show that the surface velocity of most rock glaciers surveyed within a given region, irrespective of size and velocity, respond sensitively and almost synchronously to inter-annual and decennial ground temperature changes (e.g., Delaloye et al. 2010; PERMOS 2023; Staub et al. 2016). Thus, rock glacier kinematics can be used as a proxy to monitor and assess the impact of climate change on mountain permafrost.

The increasing emergence of open-access and high-resolution satellite imagery (e.g., optical, SAR) facilitates the set-up of regional surveys of rock glaciers and led to growing interest from the research community. Rock glaciers inventories have been set up in many regions over the world (e.g., Jones et al. 2018 for a review) and more and more studies are computing and analyzing rock glacier kinematic time-series to assess climate signal using both in-situ (e.g. Kellerer-Priklabauer et al. 2018; PERMOS 2023) and remote sensing approaches (e.g. Kääb et al. 2021; Strozzi et al. 2020; Vivero et al., 2021). With more datasets and growing research interest, globally agreed-upon guidelines are needed. Indeed, existing inventories cannot be assembled and are not directly comparable, since they have various ages and have been compiled using different methodologies, review process and source data as well as following different objectives. Similarly, assembling or comparing kinematic time-series is difficult due to the variety of methods applied (e.g. automatic and manual GNSS measurements, INSAR, satellite-/air-/UAV-borne photogrammetry) as well as to the different methodologies (velocity computed over constant areas or moving points), measurement frequencies (annual, seasonal, continuous) and data processing steps.

In 2018, given the large amount of existing data and the need for standards, the international community of rock glacier researchers decided to combine their efforts and formed an Action Group with the support of the International Permafrost Association (IPA). The aim of this Action Group is to sustain the first steps toward the organization and the management of a network dedicated to rock glacier inventorying and monitoring and the definition of necessary standards (Delaloye et al. 2018). In collaboration and support to the Action Group the project "Rock glacier inventories and kinematics (RGIK) service" was submitted and funded by MeteoSwiss in the framework of GCOS-CH.

Project objectives

The project "Rock glacier inventories and kinematics (RGIK)" had the objective to establish an international service to coordinate, centralize and disseminate the international rock glacier monitoring efforts. More specifically, the RGIK project intended to:

1. Develop and implement a **database** and **visualization platform** for rock glacier inventories (RoGI) and rock glacier velocity time-series (RGV).
2. Develop and implement standardized **data management** procedures**, QA/QC criteria** and **data products** of R0GI and RGV.
3. Organize regular **workshops** and **training courses** to further develop and implement RoGI and RGV guidelines.
4. **Promote** the international use of RoGI and RGV as climate indicator and c**ommunicate** results to the international community.

The project addressed the following elements of the GCOS Switzerland Strategy 2017-2026: ensuring the traceability and reproducibility of the data processing chain as well as the standardization of ECV observations (strategic priorities 1.5 and 1.6); enhancing the regional and global collaboration for ECV monitoring as well as further strengthen the Swiss collaboration with international initiatives (strategic priorities 2.2 and 2.3). The first year of the project focused on compiling standard guidelines for generating RoGI and RGV datasets. During the second year, inventorying exercises and tools were developed together with a prototype database structure. Throughout the entire project duration, communication, outreach and networking events and channels have been organised to distribute the project outcomes and promote their use within the international community.

2.2 Methods and activities

2.2.1 Database and visualization platform

Collection of Metadata

A global assessment of currently available and anticipated RoGI and RGV datasets was conducted via a community survey distributed using the RGIK mailing list (see 2.2.3). The call remains open, and any interested researcher can submit their metadata at any time. This action was publicized at national and international conferences (e.g., the EGU general assembly, the European Conference on Permafrost, the Swiss Geoscience Meeting, etc.) and will be continued in the future.

The survey results have been reviewed and combined. In total, 40 RoGI datasets of various spatial extent and completeness stage have been listed as well as 64 RGV time series (see Figure 1). While RoGI datasets have a nearly global coverage, with most of the mountain ranges being covered, RGV time series are concentrated in the Alps with a few exceptions. The surveys and their corresponding results can be accessed on the official RGIK website at www.rgik.org.

Database structure development

The preliminary structure of the RGIK database was developed. This database structure was designed to centralize both inventory and velocity time series within a single structure and to link the different data types together for improved data access and analysis.

The RGV part was designed based on the datasets and database structure example provided by the Swiss Permafrost Monitoring Network (PERMOS), which has been operationally monitoring rock glacier velocity for more than 10 years. Exemplary datasets of InSAR derived time series were provided in the framework of the CCI+ Permafrost project (MSc thesis of L. Schmid at UniFR) to test the defined structure for data from a different measurement technique. The defined database structure follows the recommendations from the practical concepts document (RGIK2023c) which lists the mandatory data and metadata to be included in the database for all techniques. In addition, for each technique, one or more metadata table(s) are included to account for technique-specific requirements. Currently, only the three most used techniques (i.e., terrestrial geodetic surveys, InSAR and optical imagery) have been considered but the defined database structure was designed to accommodate many more.

The RoGI part of the database structure (see Figure 2) was designed based on the baseline and practical concepts for inventorying rock glaciers (RGIK 2022a, b). Together with the database structure, a GIS-based tool has been developed to facilitate the compilation and assembling of RoGI datasets within the defined structure. The so-called RoGI tool (see 2.2.2) was developed using the open-source program QGIS which has the advantage of allowing direct access and transfer to and from databases. The RoGI part of the database includes detailed metadata about i) the operators who performed the inventories, ii) the inventory themselves (i.e., base data, dates, updates, etc.) and iii) each point (rock glacier identifier) and polygon (rock glacier outline) included. The data included are either polygons or points and identified with a unique geographically coded id (automatically generated with the RoGI tool).

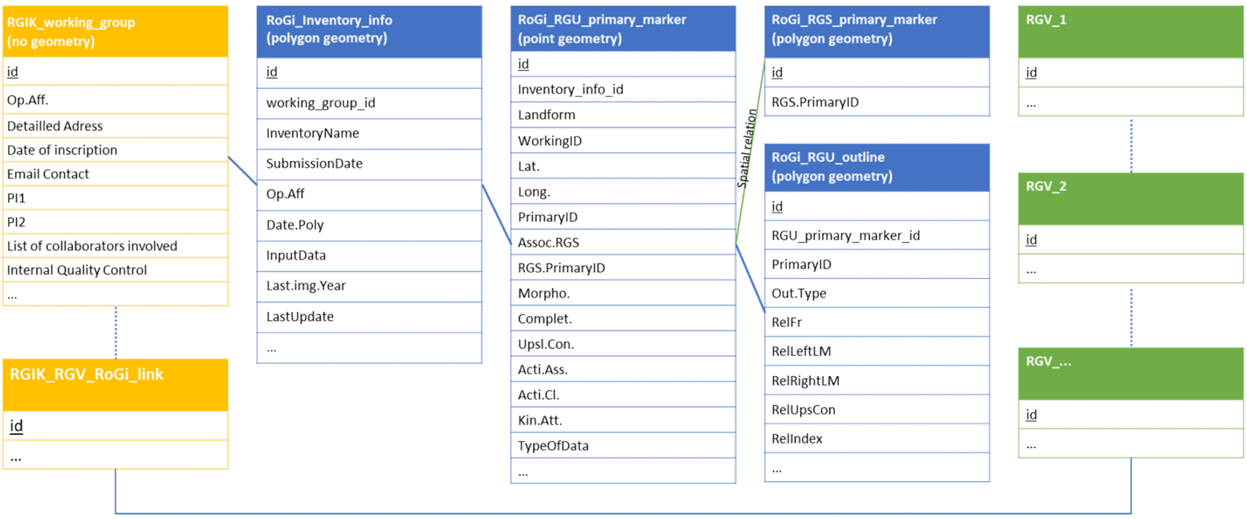

Figure 2. Prototype database structure for RoGI and RGV datasets. The structure includes general information about the inventory operator (yellow) as well as RoGI metadata (blue) and RGV data (green).

2.2.2 Data management and exploitation

RoGI and RGV guidelines compilation

The main activity of this project was the compilation and finalization of widely accepted guidelines to inventory rock glaciers (RGIK 2022a; b), assess their kinematics (RGIK 2022c; 2023a) and monitor their velocity in a climate-oriented perspective (RGIK 2023b; c). For each of the three areas, a similar procedure was followed: first the baseline concepts were defined (i.e., general concepts and considerations were defined), then practical concepts were compiled and finally for the inventory and kinematic assessment exercises and implementation tools were developed (see below).

The compilation of these guidelines started in 2019 in preparation of the first workshop of the IPA-Action Group and continued until the finalization of the documents in 2023. The documents were prepared by the core RGIK team, which since 2021 is made of the applicants and employees of this project (in alphabetical order, Barboux, C., Delaloye, R., Echelard, T., Pellet C. and Vivero S.). Once written, the documents were submitted to the scientific committees (RoGI and RGV) for a first review, adapted accordingly and submitted to the entire community for at least one (and up to three) review round. Open issues and major discussion points were finally solved during in person workshops and/or virtual meetings. Although the consultation process is relatively slow and time-consuming, the involvement of the entire RGIK community in this process, ensures the acceptance of the guidelines and guarantees their large-scale implementation around the world.

Throughout the duration of the MeteoSwiss funded project in the framework of GCOS-CH, the baseline and practical concepts for inventorying rock glaciers and assess their kinematics were refined and finalized. Similarly, the baseline concepts for monitoring Rock Glacier Velocity (RGV) as an associated parameter of ECV Permafrost were refined and finalized. Finally, the practical concepts for RGV monitoring were initiated and finalized within this project.

RoGI Tool development

To ensure the standard and easy implementation of the rock glacier inventorying and kinematic assessment guidelines a GIS-based tool was developed using the open-source program QGIS. This so-called RoGI tool consists of formatted QGIS layers for inventorying rock glacier units and systems as well as delineating rock glacier outlines and moving areas. This tool includes i) an automatic generator of unique rock glacier (unit and system) identification number (following the RGIK recommendations), ii) a predefined and formatted attribute table including all required metadata and rock glacier characteristics and uncertainty assessments and iii) a comprehensive user manual with the reference to the relevant part of the guidelines. This tool was tested in two areas in Switzerland by 6 operators (see 2.3 for the results). Data and results have been published as training exercise for implementing RoGI guidelines and using the tool. Additionally, in collaboration with the CCI+ Permafrost, the RoGI tool is currently being tested by multiple operators in 12 regions worldwide (e.g., Andes, Central Asia, Greenland, Svalbard, etc.). Results will be made available to the RGIK community for training.

2.2.3 Training workshop and service

RGIK service consolidation

The RGIK community started as a loose structure of interested researchers working together with a core group leading the activities. Thanks to the support of MeteoSwiss, an operational RGIK office was created with three people (S. Vivero, T. Echelard and C. Barboux) working part time to coordinate and lead the activities, answer inquiries from the community and communicate new outcomes.

The RGIK office oversaw maintaining and moderating the RGIK mailing list, which currently counts 215 subscribers from 28 countries. It answered numerous questions, provided information on the ongoing activities, and put interested researchers in contacts. In 2021, the RGIK office created a slack channel (online forum platform) to encourage and foster informal discussion and exchanges about rock glaciers in general and about ongoing research activities amongst the RGIK members.

To consolidate the RGIK structure several in person and online meetings of the RoGI and RGV committees have been organized. These two committees are tasked with supporting the RGIK office, providing strategic advice regarding next steps and next activities as well as solving open scientific questions and issues regarding the guidelines. Meetings have been organized separately or together depending on the topics and needs.

The final activity of the project was the organization of a one-day workshop for the entire community in June 2023 at the European Conference on Permafrost. This workshop counted 56 participants and was dedicated to finalizing all guideline documents as well as defining the road map for the future of the RGIK community. This workshop led to the decision to form a permanent RGIK structure and to the compilation of the so-called Puigcerdà commitment, defining the objectives and organization of this future structure. This commitment, signed by 60 researchers, was presented to the International Permafrost Association (IPA), which extended its support and agreed to host the future permanent structure in the form of a Standing committee.

2.2.4 International promotion and communication

RGIK promotion

Promotion of the RGIK activities and outcomes was mainly achieved by presenting talks and posters at international conference (see 2.5.4 for a complete list). In addition, the RGIK office and members of the RoGI and RGV committees organized sessions dedicated to rock glaciers at the regional conference on permafrost in 2021 and the European conference on permafrost in 2023, thus putting forward recent advances in the field of rock glacier studies. Rock glacier sessions will also be organized at the EGU general assembly in spring 2024 as well as at the international permafrost conference in summer 2024.

End of 2021, Rock Glacier Velocity (RGV) has been formally accepted as a new associated parameter to the ECV Permafrost under the framework of GTN-P and GCOS. Members of the RGIK office and committees coordinated with representatives of both organisations to include RGV and the relevant RGIK recommendations within their implementation plans as well as in the GCOS ECV requirement document. This was successfully achieved in 2022 (see Streletskiy et al. 2021, GCOS 2022a, b).

A task team from the Global Cryosphere Watch and representatives from GTN-P is currently compiling permafrost measurement best practices for the WMO guide no 8 to be released in 2024. Since 2022, RGV was added to the content of this chapter and C. Pellet has been invited to lead the RGV section and coordinate with the RGIK community.

RGIK communication

RGIK guideline documents as well as tools and training data sets have been published online on the project website (www.rgik.org) which is maintained by the RGIK office. In addition, a number of peer-review papers have been and will be published presenting and implementing the RGIK guidelines (see 2.5.3 for an overview). Especially of note are the two publications in preparation from the RoGI committee (Vivero et al., publication of the RoGI guidelines and implementation examples) and the RGV committee (Hu et al., review of current knowledge about rock glacier velocity as an ECV parameter).

To foster scientific exchanges and collaboration within the RGIK community, a monthly seminar series is organized and coordinated by the RGIK office since March 2022. With these seminars RGIK members are invited to present their recent work for 20 minutes, with 10 to 15 minutes of questions and discussion among the attendees. Overall, 13 speakers presented their research to the community on topics related to inventories and kinematics (see 2.5.6). The seminars reached in average an attendance of 30 people.

2.3 Results

2.3.1 Rock glacier inventory

The first systematic implementation and test of the RGIK guidelines for inventorying rock glaciers was performed on two small regions in the Swiss Alps. The RoGI guidelines and developed RoGI tool were provided to six operators with diverse backgrounds and inventorying experiences in order to evaluate the documents and tool. In a first step, operators were asked identify and locate all rock glacier within a given area. Following the consensus-based strategy proposed by Way et al. (2021) and adopted within the RGIK guidelines, the identified rock glaciers were discussed and agreed upon by all operators. In a second step, all operators were asked to characterize and outline the identified rock glaciers. Figure 2 shows exemplary results from the second phase of the test.

Results show that the combination of the RGIK guidelines and the consensus-based approach significantly increases the confidence that all detectable landforms have been identified. Regarding outlining, the guidelines combined with a prior agreement of which landforms should be considered, enabled a significant improvement of the inter-operator agreement level compared to previous studies (see Figure 3a and e.g. Brardinoni et al. 2019). Operators were asked to assess the reliability of their outlines in the front, lateral margins, and rooting zone areas. Again, results from the different operators matched well (i.e. uncertain outlines were uncertain for most of the operators and vice versa).

Regarding the characterization of inventoried landforms, results vary strongly depending on the parameter. Easily observable and assessable parameters such as the upslope connection (Figure 3c), landform complexity or completeness, showed only little inter-operator disagreement. However, results show that the activity parameter remains extremely difficult to assess. Even with the guidelines and similar baseline data (in this case optical images and InSAR interferograms) operators often do not agree. This is partly explained by the different experience in using InSAR for the various operators but also to the inherent difficulty to differentiate transitional (i.e., rock glacier with slow movement only detectable by measurements or movement restricted to areas of non-dominant extent) from active or relict landforms.

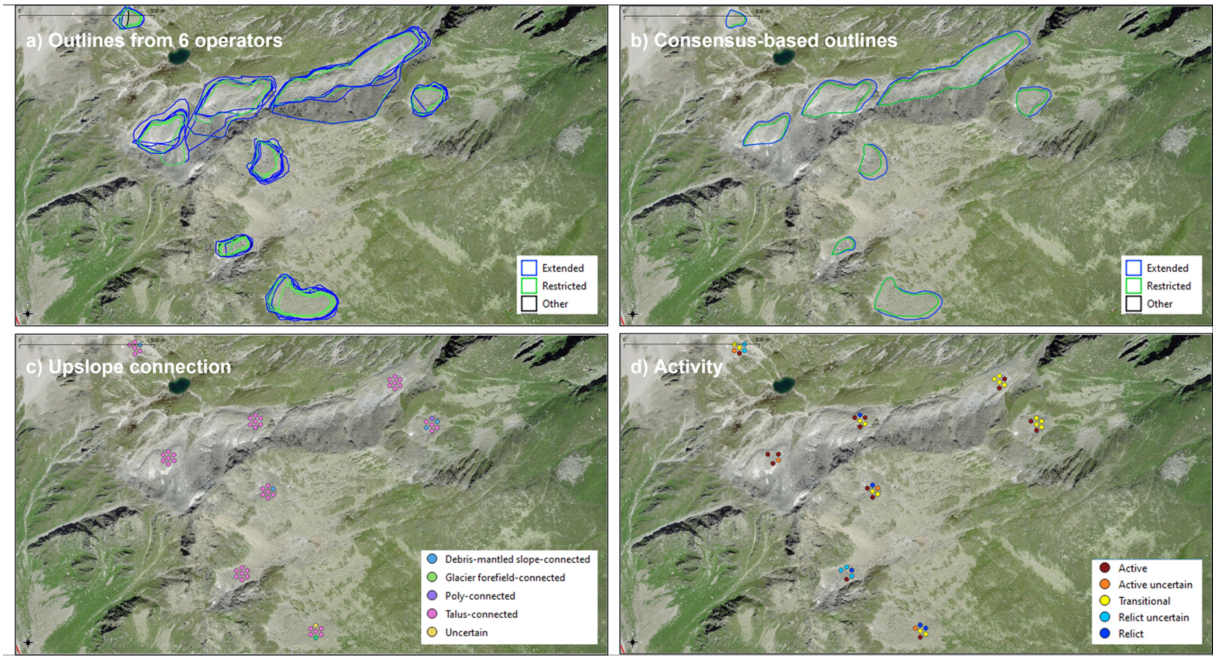

Figure 3: Test of the RGIK guidelines for inventorying rock glacier performed by 6 operators on the same area. Panel a shows individual rock glacier outlines and panel b the results of the consensus discussion. Panel c shows the variability of upslope connection characterisation and panel d the variability of the activity characterisation.

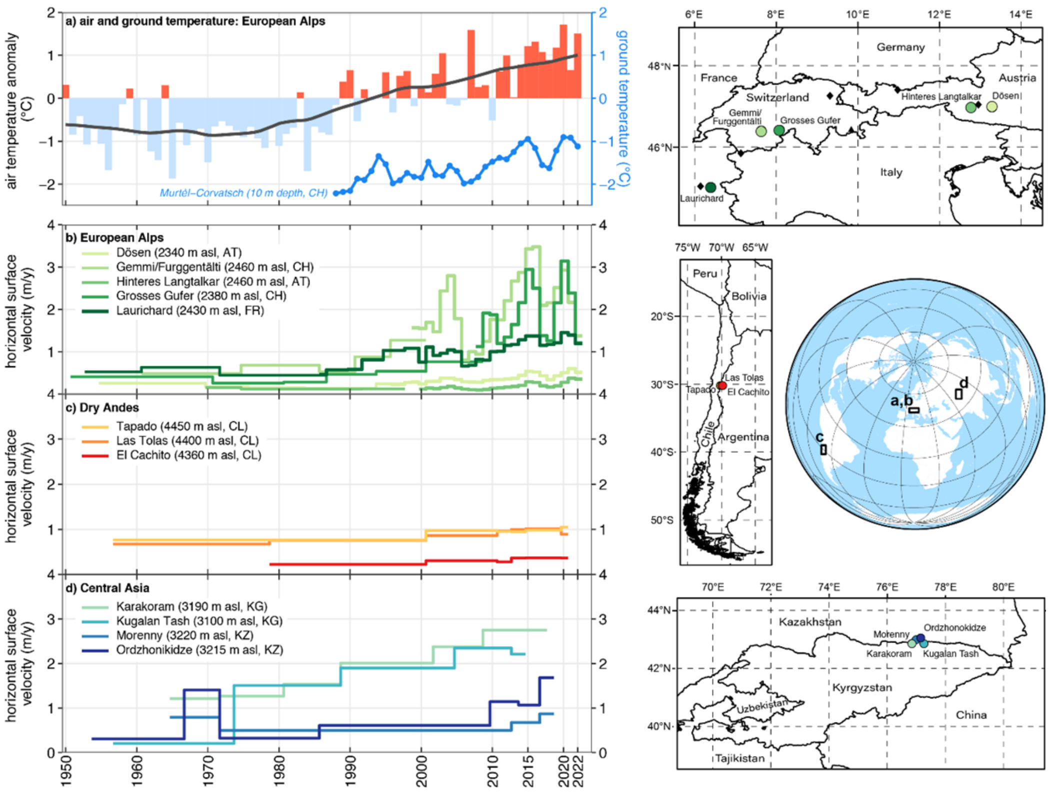

Figure 4: Rock glacier velocities based on in-situ geodetic surveys or photogrammetry in the context of long-term air and ground temperature observations: air and ground temperature in the European Alps (a), rock glacier velocities at selected sites in the European Alps (b), the Dry Andes (c, adapted from Vivero et al. 2021) and Central Asia (d, adapted from Kääb et al. 2021).In-situ hydrological mean annual permafrost temperature measured at 10m depth (blue line) at Murtèl Corvatsch (black triangle on Europe map) and air temperature: composite anomaly to the 1981–2010 norm (bars) and composite 20-year running mean (solid line) at Besse (FR), Grand Saint-Bernard (CH), Saentis (CH), Sonnblick (AT) and Zugspitze (D, black diamonds on Europe map). (Figure from Pellet et al. 2023)

2.3.1 Rock glacier velocity

The established RGIK network enabled the comparison of rock glacier velocity data product worldwide and the assessment of their evolution in the context of climate change. Figure 4 shows exemplary rock glacier velocity time series from three mountain regions around the world and their evolution in relation with warming atmospheric conditions and warming permafrost temperatures (see also Pellet et al. 2023). Overall rock glacier velocities have been increasing in all regions since the 1950s with large regional and inter-annual variability. In Europe, these changes are consistent with the observed evolution of permafrost temperatures, to which rock glacier surface velocities have been shown to respond synchronously (e.g., Kääb et al. 2007; Staub et al. 2016).

2.4 Conclusion and limitations

In conclusion, we were able throughout past two years to strengthen and consolidate the RGIK service as well as further the development of standard guidelines, tools and training exercises thus satisfactorily fulfilling the main objectives of the project.

The MeteoSwiss funded RGIK project in the framework of GCOS-CH was instrumental in pursuing the activities initiated within the IPA supported Action Group of the same name. It successfully organized in person and virtual networking activities for the entire community (over 200 researchers from 28 countries) as well as lead the redaction of widely accepted guidelines for inventorying rock glaciers and monitoring their surface velocity. This project laid the foundation for standardized observations in the field of rock glacier studies. However, the operationalization and implementation of these standards was limited to few case studies and exemplary datasets. Priority was given in this project on the finalization of the guidelines and the development of training exercises, which are needed for large-scale implementation.

A first inventory of existing rock glacier inventory and rock glacier velocity datasets was performed, and relevant metadata were collected. Based on these obtained metadata as well as the guideline recommendations and exemplary datasets a prototype database structure was established within the RGIK project. Yet an operational database and visualization platform are still lacking though it was one objective of this project. The coordination and compilation of guidelines and tools took more efforts than anticipated and thus the operationalization of rock glacier observations was put on hold. The prototype data base structure defined in this project is a step forward and efforts in this direction will be continued in the future since the RGIK initiative intends to continue its work beyond this project.

The main achievement of this project in addition to the guideline documents is the international promotion of rock glacier inventories and velocity as climate indicators. Rock glacier velocity has been added as product associated to the ECV permafrost and is now included in the GTN-P and GCOS implementation plans. Additionally, the RGIK guidelines will be added to the permafrost measurement best practice chapter within the WMO guide no 8 to be released in 2024. With the success of this project and the continued interest and support of the research community, the RGIK initiative is in the process of transitioning into a permanent structure as a Standing committee of the International Permafrost Association (IPA). The work performed within this project will thus continue in the future and we will make up for the limitations of this project.

2.5 Outreach work, publication of data and results

The RGIK project as well as the associate RGIK IPA Action Group are presented on the official website hosted by the Department of Geosciences, University of Fribourg:

www.rgik.org

The main outcomes of the project (i.e., guidelines documents, inventorying exercises, standard inventorying tool and data overview) can be found on this website together with summary and material from the RGIK workshops and seminars.

2.5.1 RGIK guidelines

RGIK (2022a). Towards standard guidelines for inventorying rock glaciers: baseline concepts (version 4.2.2). IPA Action Group Rock glacier inventories and kinematics, 13 pp. (pdf)

RGIK (2022b). Towards standard guidelines for inventorying rock glaciers: practical concepts (version 2.0). IPA Action Group Rock glacier inventories and kinematics, 10 pp. (pdf)

RGIK (2022c). Optional kinematic attribute in standardized rock glacier inventories (version 3.0.1). IPA Action Group Rock glacier inventories and kinematics, 8pp. (pdf)

RGIK (2023a). InSAR-based kinematic attribute in rock glacier inventories. Practical InSAR guidelines (version 4.0). IPA Action Group Rock glacier inventories and kinematics, 31pp. (pdf)

RGIK (2023b). Rock Glacier Velocity as an associated parameter of ECV Permafrost: baseline concepts (Version 3.2). IPA Action Group Rock glacier inventories and kinematics, 12pp. (pdf)

RGIK (2023c). Rock Glacier Velocity as associated product of ECV Permafrost: practical concepts (version 1.2). IPA Action Group Rock glacier inventories and kinematics, 17 pp. (pdf)

2.5.2 RGIK training exercises

RGIK (2023a). Rock glacier inventory (RoGI) exercise in the Dirru-Steintälli area (Swiss Alps). IPA Action Group Rock glacier inventories and kinematics (data set)

RGIK (2023b). Rock glacier inventory (RoGI) exercise in the Goms area (Swiss Alps). IPA Action Group Rock glacier inventories and kinematics (data set)

2.5.3 Peer-reviewed articles

Bertone, A., Barboux, C., Bodin, X., Bolch, T., Brardinoni, F., Caduff, R., Christiansen, H. H., Darrow, M. M., Delaloye, R., Etzelmüller, B., Humlum, O., Lambiel, C., Lilleøren, K. S., Mair, V., Pellegrinon, G., Rouyet, L., Ruiz, L., and Strozzi, T. (2022). Incorporating InSAR kinematics into rock glacier inventories: insights from 11 regions worldwide, The Cryosphere, 16, 2769–2792, https://doi.org/10.5194/tc-16-2769-2022.

Hu, Y., Arenson, A., Barboux, C., Bodin, X., Cicoira, A., Delaloye, R., Gärtner-Roer, I., Kääb, A., Kellerer-Pirklbauer, A., Lambiel, C., Liu, L., Pellet, C., Rouyet, L., Schoeneich, P., Seier, G., Strozzi, T. Rock Glacier Velocity as a new product of Essential Climate Variable for Permafrost. **In preparation**

Lambiel, C., Strozzi, T., Paillex, N., Vivero, S., and Jones, N. (2023). Inventory and kinematics of active and transitional rock glaciers in the Southern Alps of New Zealand from Sentinel-1 InSAR. Arctic, Antarctic, and Alpine Research, 55(1).

Pellet, C., Bodin, X., Cusicanqui, D., Delaloye, R., Kääb, A., Kaufmann, V., Noetzli, J., Thibert, E., Vivero, S. and Kellerer-Pirklbauer, A. (2022). Rock Glacier Velocity. In State of Climate 2021. Bulletin of the American Meteorology Society.

Pellet, C., Bodin, X., Cusicanqui, D., Delaloye, R., Kääb, A., Kaufmann, V., Noetzli, J., Thibert, E., Vivero, S., and Kellerer-Pirklbauer, A. (2023). Rock Glacier Velocity. In State of Climate 2022. Bulletin of the American Meteorology Society.

Vivero, S., Barboux, C., Bodin, X., Cicoira, A., Delaloye, R., Echelard, T., Hu, Y., Lambiel, C., MacDonell, S., Pellet, C., Ruiz, L., Rouyet, L., Schaffer, N., Wehbe, M. and Brardinoni, F. The RGIK initiative: recommendations for inventorying and mapping rock glaciers worldwide. **In preparation.**

2.5.4 Presentation at conferences

Echelard, T., Vivero, S., Pellet, C., Barboux, C., Rouyet, L., and Delaloye, R. (2023). Towards practical guidelines for Rock Glaciers inventories (RoGI): a new 'user-friendly' GIS tool for training the community. 6th European Conference on Permafrost (EUCOP 2023), Puigcerdà, Spain.

Echelard, T., Delaloye, R., Vivero, S., Pellet, C., and Barboux, C. (2022). IPA Action Group – Towards standard guidelines for Rock Glaciers inventories (RoGI): overview of the outcome documents, ongoing work and next steps. Swiss Geoscience Meeting 2022, Lausanne, Switzerland.

Pellet, C., Barboux, C., Echelard, T., Vivero, S., and Delaloye, R. (2022). Rock Glacier Velocity as a new associated product to the ECV permafrost: basic concepts and exemplary results. Swiss Geoscience Meeting 2022, Lausanne, Switzerland.

Vivero, S., and Pellet, P. (2023). Grupo de Acción de Inventarios y Cinemática de los Glaciares Rocosos (RGIK): Estatus y Directrices Futuras (Rock Glacier Inventories and Kinematics (RGIK) Action Group: Status and Future Directions). Chilean Society of the Cryosphere (SOCHICRI) Congress, online.

Vivero, S., and Pellet, P. (2022). The Rock Glacier Inventories and Kinematics (RGIK) Action Group: status and future directions. 10th International Conference on Geomorphology, Coimbra, Portugal.

Vivero, S., Pellet, C., Echelard, T., Barboux, C., and Delaloye, R. (2022). The Rock Glacier Inventories and Kinematics (RGIK) Action Group: Recent Progress and Overview. Swiss Geoscience Meeting 2022, Lausanne, Switzerland.

Vivero, S. (2021). Challenges and recommendations for rock glacier inventories and kinematics (RGIK). Regional Conference on Permafrost RCOP, 2021, Online.

2.5.5 Session organization at conferences

R. Delaloye, together with members of the RGIK committees, organized the “Rock Glacier Inventories and Kinematics” session at the regional conference on Permafrost held online in October 2021.

C. Pellet, together with members of the RGIK committees organized the “Open session on rock glaciers” at the 6th European Conference on Permafrost (EUCOP) in June 2023 in Puigcerdà, Spain

2.5.6 RGIK seminar series

2022-03-30: Rouyet, L.: “The contribution of Radar Interferometry to Norwegian rock glacier inventories"

2022-04-27: Fleischer, F.: “Multi-decadal rock glacier kinematics analysed by high-resolution topographic data in two catchments of the Central Eastern Alps”

2022-06-01: Hu, Y.: “Inventorying rock glaciers in the arid West Kunlun of China by the combined use of SAR interferometry and deep learning”

2022-06-30: Cusicanqui, D.: ” Interpretation of Volume and Flux Changes of the Laurichard Rock Glacier Between 1952 and 2019, French Alps”

2022-09-28: Wehbe, M.: ”Inventorying rock glaciers and features of interest in Western Canada”

2022-10-26: Cicoira, A.: ”Rock Glacier Kinematics on Disko Island: preliminary results from Remote Sensing and fieldwork in the Arctic”

2022-11-30: Blöthe, J.: ”Deriving surface kinematics of Andean rock glaciers from feature tracking in optical imagery”

2022-12-07: Vivero, S.: “RGIK: Status and future directions”

2023-02-22: Robson, B.: “Glacier and rock glacier changes in the La Laguna catchment”

2023-03-29: Lehmann, B.: “Rock glaciers and long-term geomorphological evolution”

2023-04-26: Hartl, L. and Zahs, V.: “Multi-method monitoring of cyclical destabilization of Äußeres Hochebenkar Rock Glacier”

2023-05-31: Echelard, T.: “A new ‘user-friendly’ GIS tool for training the RoGI community: overview and example of results”

2023-08-30: Pellet, C. “Operational monitoring of rock glacier velocity: insights from the PERMOS network”

2.6 Outlook

The RGIK initiative continues after the completion of this project. The international permafrost association (IPA), the foremost global association dedicated to permafrost research, played a pivotal role in supporting the RGIK initiative since its inception. This support expressed in the form of an action group status for the period 2018-2023 will continue as the RGIK transitions into a permanent structure as Standing Committee of the IPA. This transition approved in June 2023 will be completed in June 2024 at the International conference on permafrost with the presentation of the new governing structure, committee members and committee status. Becoming a permanent standing committee will enable the continuation and further development of the RGIK activities. In June 2023, the main field of action for the new structure were defined as: i) network consolidation, ii) guidelines implementation, iii) product compilation, iv) data management and v) communication and educational outreach.

To sustain its activities, the RGIK standing committee is currently seeking support from various sources. The RGIK office at the University of Fribourg recently obtained funding from the SwissUniversities for the “Open Rock Glacier Data Production Tools (ORoDaPT)” project (2024). Submitted to the Swiss Open Research Data Grants, the ORoDaPT project aims to support the implementation of Open Research Data (ORD) practices in the compilation, storage, and analysis of RoGI and RGV datasets. Its main goal is in line with objectives 2-4 defined by the RGIK community and will focus on data management and establishing standard practices. An international collaborative project has also been submitted in the framework of the European Cooperation in Science and Technology (COST) actions funded by the European Union. The "Coordinated and standardized monitoring of permafrost response to climate change (PermaCOST)" project has been submitted by a consortium of 16 European countries and 4 non-European ones. The aim of this project is to bring together permafrost researchers and stakeholders working with various techniques (temperature, kinematics, geophysics, moisture, modeling, remote sensing, etc.) and in different settings (mountains, marginal zones, poles) to develop standard practices and innovative techniques as well as establish local to regional networks and collaboration in the permafrost monitoring domain. Through networking activities, this COST Action will seek to develop and implement novel permafrost monitoring practices amongst which rock glacier velocity is a prime example. It will also foster collaboration with practitioners and stakeholder to strengthen the impacts of the RGIK activities.

2.7 Acknowledgements

We would like to thank MeteoSwiss in the framework of GCOS-CH for their kind financial support of the project. We would like to thank our colleagues from the European Space Agency (ESA) CCI+ Permafrost project for their valuable support and collaboration, which enabled the successful completion of many tasks. We would like to thank Dr Line Rouyet (UNIFR and NORCE) for her valuable contribution to the research by providing her expertise in the field of Interferometric Synthetic Aperture Radar (INSAR) approaches. We would like to thank all the members of the RGIK Action Group for their active participation in online and face-to-face meetings, workshops and discussions related to the RoGI and RGV standards. Their input and insights have greatly enriched the development of these standards and ensured their relevance and applicability in different contexts. In addition, we would like to acknowledge the formal endorsement of the IPA, which has been instrumental in carrying out this research and enabling its successful completion.

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