Ambient seismic noise and microseismicity monitoring of the cryosphere: a case study on Gran Sometta Rock Glacier (Aosta Valley, NW Italy)

Original
Ambient seismic noise and microseismicity monitoring of the cryosphere: a case study on Gran Sometta Rock Glacier (Aosta Valley, NW Italy) / Colombero, C.; Godio, A.; Morra di Cella, U.. - ELETTRONICO. - (2023). (Intervento presentato al convegno 41° Convegno Nazionale GNGTS tenutosi a Bologna nel 7-9 Feb 2023) [10.13120/2tf2-1j75].

Publisher:
Gruppo Nazionale di Geofisica della Terra Solida

Published
DOI:10.13120/2tf2-1j75

Ambient seismic noise and microseismicity monitoring of the cryosphere: a case study on Gran Sometta Rock Glacier (Aosta Valley, NW Italy)

C. Colombero[1], A. Godio[1], U. Morra di Cella[2]

[1]*Politecnico di Torino, Dipartimento di Ingegneria dell'Ambiente, del Territorio e delle Infrastrutture (DIATI), Torino (TO), Italy*
[2]*Agenzia Regionale Protezione Ambiente (ARPA) Valle d'Aosta, Saint-Christophe (AO), Italy*

Introduction

In the last decade, several case studies of ambient seismic noise and microseismicity monitoring have been reported at different scales for landslide characterization and monitoring, hydrogeological assessments and fluvial seismology, short- and long-term monitoring of buildings and infrastructures (e.g., Larose et al., 2015; Colombero et al., 2021).

Few studies also applied ambient seismic noise methods for the monitoring of glaciers and rock glaciers (Guillemot et al., 2020). In particular, ambient seismic noise spectral analyses and cross-correlation may highlight modification in the seismic parameters within the monitored bodies that can be related to the ongoing internal processes. In the glacial and periglacial environments, the understanding and spatio-temporal tracking of these processes is becoming of uttermost importance in the light of climate change monitoring and adaptation to melting-related natural hazards. The detection, classification and location of microseismic events within these bodies may additionally indicate the most active sectors and be used to follow their evolution in space and time as a function of the external forcing related to air temperature, rainfall and snowfall modifications.

Here, we report the results of long-term ambient seismic noise and microseismicity monitoring on the Gran Sometta Rock Glacier (Valtournenche, Aosta Valley, NW Italian Alps, Fig. 1a), at an elevation ranging from 2630 m to 2770 m (Fig. 1b). The surface of the rock glacier appears as a debris mass with rock blocks of different size, in most places lacking any fine grained matrix (Fig. 1c). The frontal portion of the rock glacier is divided in two lobes, distinguishable from the debris type and color in black lobe (mainly composed by green schists and prasinites) and white lobe (marbles and dolomites). The surface of both lobes is characterized by longitudinal ridges in the extensive central part and a complex of transverse ridges and furrows in the compressive terminal part of the tongue. The rock glacier thickness, estimated from the height of the rock glacier front, is approximately 20 to 30 m.

Since 2012, the site is periodically surveyed with UAV (Unmanned Aerial Vehicle) photogrammetry by ARPA Valle d'Aosta for the evaluation of the rock glacier flow rates in the framework of climate change impacts on high-mountain environments and infrastructures, such as the ski resort of Cervinia. The front of the landform is indeed flowing on the ski run (Fig. 1c), thus requiring constant maintenance and attention. A big artificial lake for hydropower generation (Goillet Lake, Fig. 1b) is also present downward the rock glacier flow, posing additional concerns in the case of rapid movements or fluidification of the material. The highest flow rates were depicted on the black lobe, with a displacement of 3.8 m in the frontal sector between 2012 and 2015 occurring especially in the summer months (Dell'Asta et al., 2017). The site is also regularly surveyed with active geophysical measurements, including seismic refraction and electrical resistivity tomography (Bearzot et al. 2022).

Methods

Due to these considerations, the passive seismic network installed on site in late July 2020 is aimed at continuously recording ambient seismic noise for the understanding of the ongoing internal processes. Two wireless seismic stations were installed in the frontal portion of the black lobe (S2 and S3 in Fig. 1c), one station was deployed on the white lobe (S4 in Fig. 1c) and a fourth one was placed in a stable area outside the rock glacier (S1 in Fig. 1c) to be used as a reference station.

Each station comprises a 2-Hz triaxial high-sensitivity geophone and an on-purpose designed digitizer/recorder (GEA–GPS, developed by PASI s.r.l. and Iridium Italia s.a.s.), ensuring continuous seismic noise recording at 250-Hz sampling frequency, low power consumption in the absence of an external power supply (approximately 30 days of autonomy) and daily remote information about the system state of health by a GSM–GPRS module. Synchronization between the different stations is provided by GPS timing. Data from each station are stored in 1-hour files in an internal memory card.

Data processing includes ambient seismic noise spectral analyses and cross-correlation between station pairs, together with microseismicity analyses. In particular, the power spectral density of each station and/or the computation of single-station (e.g. H2/V2) and site-reference (e.g. E2/E1 or N2/N1) may highlight noise amplification in specific frequency bands related to internal glacial processes. In addition, cross-correlation of noise recorded between the same component of two stations (e.g. V1 and V2) may potentially disclose seismic velocity changes within the rock glacier due to modifications in the material properties and flow rate increase or decrease.

Microseismic events related to glacial processes (e.g. icequakes, rock glacier flow, water seepage, rock falls) were complementary extracted from continuous noise recordings through a STA/LTA detection algorithm and classified through k-means cluster analysis of selected time- and frequency-domain parameters. The temporal rate of these events can indeed supply additional information on the rock glacier stability and ongoing modifications at the daily and seasonal scales.

Results

A summary of the obtained passive seismic results after a complete year of almost continuous recording is reported in Fig. 2. Seismic parameters are shown in comparison with air temperature (Fig. 2a) and precipitation (Fig. 2b) recorded during the same period at the meteorological station of Goillet Lake (green square in Fig. 1b).

Ambient seismic noise spectral analysis of the stations located on the back and white lobes revealed amplification in different frequency bands. As an example, the H/V spectral ratio is shown in Fig. 2c for station S2. A first frequency peak, located around 8 Hz, was systematically recorded during the whole monitored period and related to the rock glacier-bedrock interface at a depth of approximately 25 m below the surface. This peak showed a value of 6 Hz on the white lobe (S4), probably indicating a deeper bedrock interface in this compartment. In both cases, no variations in the interested frequency band were depicted over time. By contrast, a second peak in the H2/V2 plot is depicted around 20 Hz at the beginning of the monitoring period (Fig. 2c). This peak shows significant fluctuations over time in both amplitude and frequency values. The trend of this peak is negatively correlated with the air temperature variations (Fig. 2a). As a consequence, it was interpreted as the fluctuation in the depth of the rock glacier active layer. Lower values of this second peak are indeed found in the summer months, likely indicating a deeper interface between the unfrozen and the frozen material within the rock glacier. At the end of the summer, with decreasing air temperature, the frequency values start to increase, mirroring the decrease in depth of the unfrozen shallow layer. During winter months, this second frequency peak is almost absent, corroborating the hypothesis of a completely frozen body.

The spectral results are supported by the outcomes of ambient seismic noise cross-correlation. The velocity changes depicted between station S2 and S1 are shown in Fig. 2d with the related correlation coefficients (Fig. 2e), computed on the vertical components and in the frequency band 10-15 Hz, with respect to the average cross-correlogram of the first days of monitoring. Minor velocity changes, negatively correlated with the precipitation amount, are found during the warm months. At the end of the summer, the inner velocity of the rock glacier significantly increases (up to +15%) as a result of the freezing processes.

Different cluster of microseismic events were recognized during the same period. The related peak frequency is shown in Fig. 2f, again for the station S2. A first cluster of low-frequency events, showing low-amplitude and low-duration was recorded through the monitored period (blue in Fig. 2f). These events were interpreted as related to the basal movements and sliding of the rock glacier. A second cluster of events (purple in Fig. 2f) exhibited peak frequencies variable with temperature and showing a trend similar to ambient seismic noise results (Fig. 2c and Fig. 2d). These events were interpreted as shallow icequakes and rockquakes related to the modifications in the rock glacier internal conditions during the warm months. By contrast, when a significant snow cover was present on site during winter months (Fig. 2b), recurrent microseismic events were depicted at higher frequencies (orange in Fig. 2f), likely related to snow and material compaction and stress modifications within the rock glacier due to increased load. A last cluster of events (yellow in Fig. 2f) showed very short duration and variable peak frequency over time. Their temporal evolution was however found to be very similar to the quakes of the purple cluster, suggesting a similar genesis.

Conclusions

Ambient seismic noise and microseismicity analyses provided useful hints to analyze the internal processes of rock glaciers at both daily and seasonal scales. The results of the different processing methods are in agreement in showing a rapid reaction of the rock glacier to temperature and precipitation modifications. The continuous passive seismic monitoring of the rock glacier can also be used as an early warning tool to identify possible melting-related natural hazards for the site.

Acknowledgments
We warmly thank Diego Franco for his support in network installation and maintenance. We are also grateful to PASI s.r.l. and Iridium Italia s.a.s. for the development of the seismic instrumentation used for this study. We are sincerely grateful to ARPA Valle d'Aosta for the help in network deployment and maintenance and site accessibility.

References

Bearzot F., Garzonio R., Di Mauro B., Colombo R., Cremonese E., Crosta G. B., Delaloye R., Hauck C., Morra Di Cella U., Pogliotti P., Frattini P. and Rossini M.; 2022: *Kinematics of an Alpine rock glacier from multi-temporal UAV surveys and GNSS data,* Geomorphology, 402, 108116, DOI 10.1016/j.geomorph.2022.108116.

Colombero C., Jongmans D., Fiolleau S., Valentin J., Baillet L. and Bièvre G.; 2021*: Seismic noise parameters as indicators of reversible modifications in slope stability: a review*, Surv. Geophys., 42, 339–375, DOI 10.1007/s10712-021-09632-w.

Dall'Asta E., Forlani G., Roncella R., Santise M., Diotri F. and Morra di Cella U.; 2017: *Unmanned aerial systems and DSM matching for rock glacier monitoring*, ISPRS J. Photogramm. Remote Sens., 127, 102–114. DOI 10.1016/j.isprsjprs.2016.10.003.

Guillemot A., Helmstetter A., Larose E., Baillet L., Garambois S., Mayoraz R. and Delaloye R.; 2020: *Seismic monitoring in the Gugla rock glacier (Switzerland): ambient noise correlation, microseismicity and modelling*, Geophys. J. Int., 221, 1719–1735, DOI 10.1093/gji/ggaa097.

Larose E., Carrière S., Voisin C., Bottelin P., Baillet L., Guéguen P., Walter F., Jongmans D., Guillier B., Garambois S., Gimbert F. and Massey C.; 2015: *Environmental seismology: What can we learn on earth surface processes with ambient noise?,* J. Appl. Geophys., 116, 62–74, DOI 10.1016/j.jappgeo.2015.02.001.

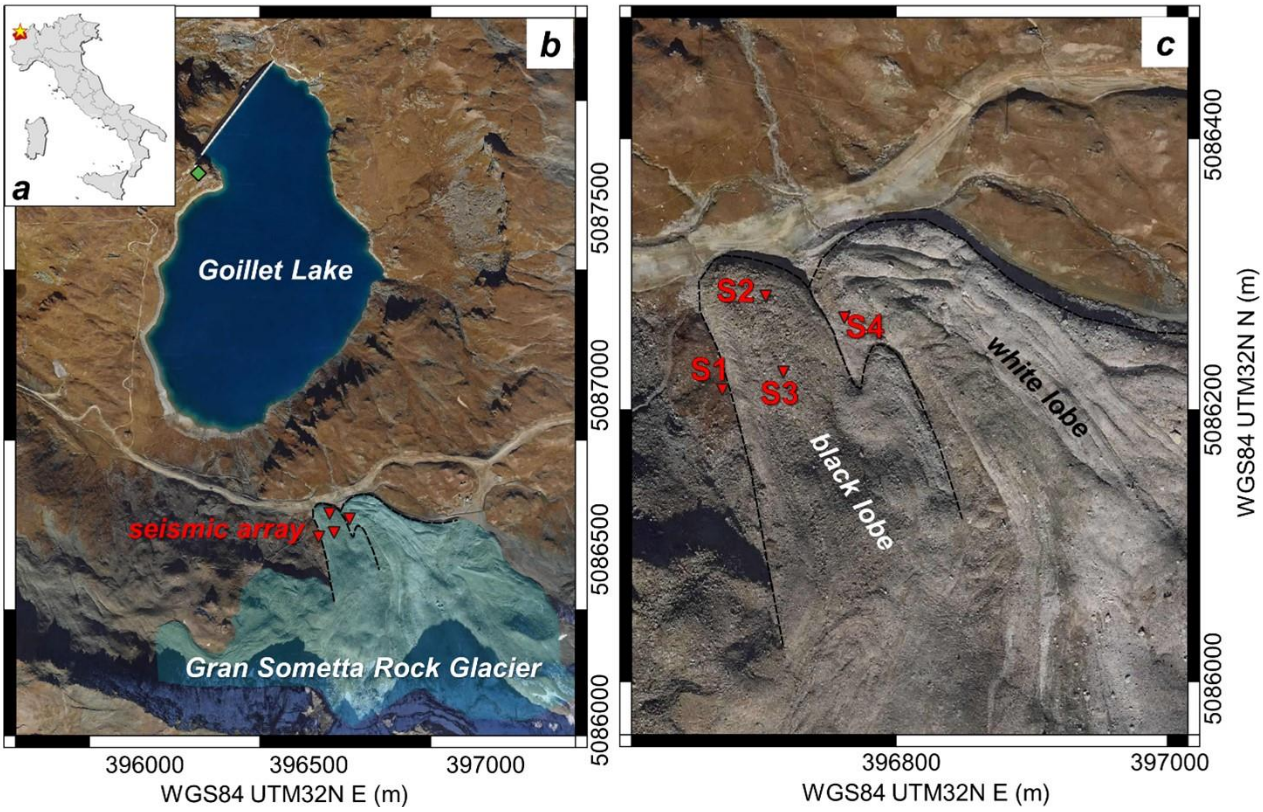

Fig. 1. (a) Geographic location of the study site. (b) Aerial picture of the site. The perimeter of Gran Sometta Rock Glacier is highlighted in blue. The red triangles display the location of the passive seismic network, the green square, close to Goillet Lake, indicates the location of the closest meteorological station. (c) Zoom on (b) with location of the four passive seismic stations.

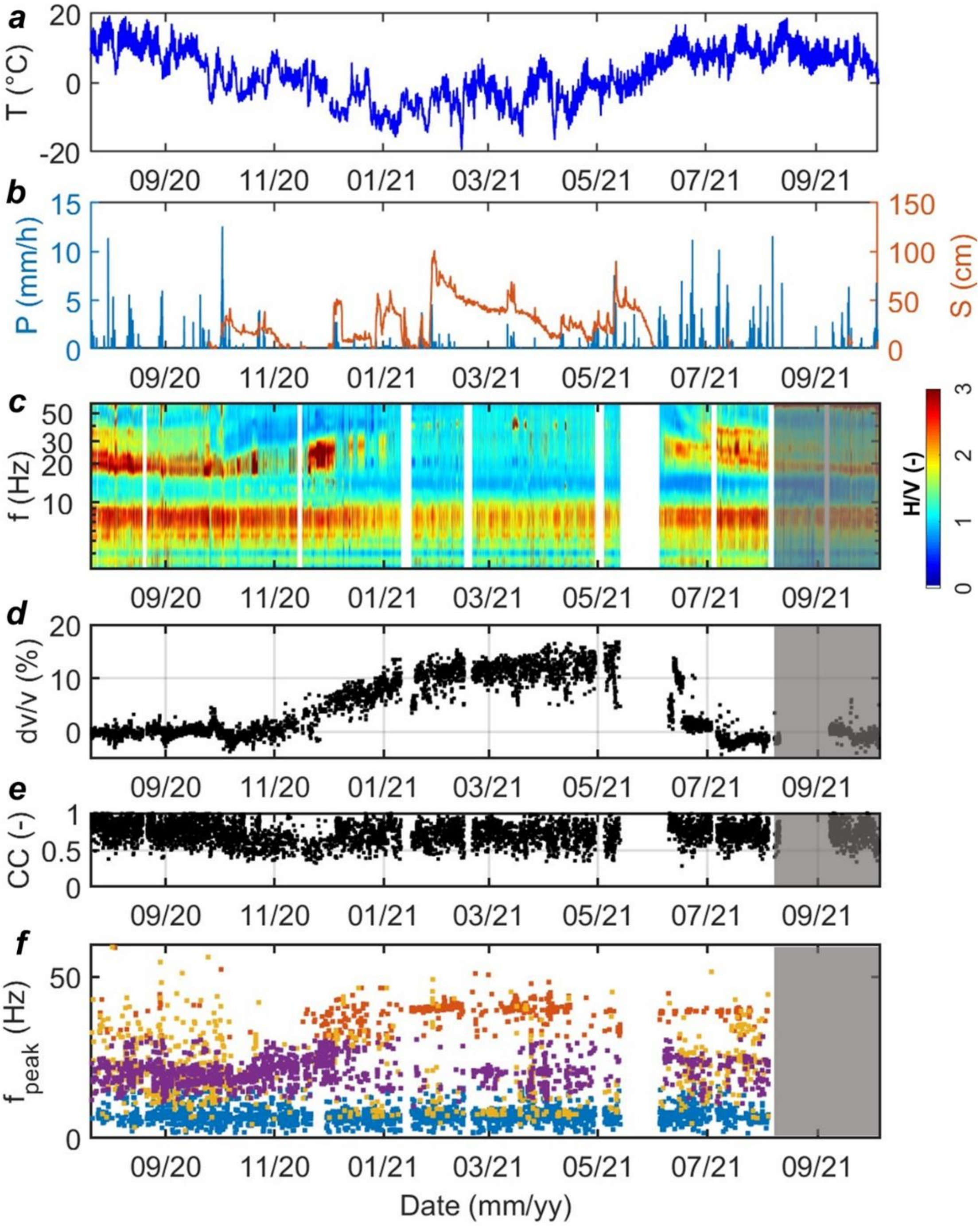

Fig. 2. (a) Air temperature and (b) hourly precipitation (blue) and snow height (orange) recorded at the meteorological station of Goillet Lake. (c) H2/V2 spectral ratios. (d) Velocity changes between the vertical components of S2 and S1 depicted from ambient seismic noise cross-correlation in the frequency band 10-15 Hz. (e) Related correlation coefficients. (f) Peak frequency of the microseismic events detected during the monitored period at station S2.

Corresponding author: Chiara Colombero, chiara.colombero@polito.it