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30 years (1995-2025) of measuring the velocity of the Dösen rock glacier in Austria: Overview and climatic significance

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Abstract:

Rock glaciers are composed of frozen debris and interstitial ice or ice lenses of variable sizes. They move downhill by creep and sliding (along distinct shear horizons), driven by gravity. Rock glaciers are striking visual representations of mountain permafrost and can be found in all alpine regions of the world. Permafrost is defined as any ground that remains at or below 0°C for at least two consecutive years. Thus, rock glaciers must not be confused with glaciers (Brardinoni et al. 2025). From above, rock glaciers look like lava flows (Fig. 1). In 2022, rock glacier velocity (RGV) was officially accepted by the Global Climate Observing System (GCOS) as an essential climate variable (ECV) quantity because the variability of the RGV is generally influenced by topoclimatic conditions. RGV is categorized under the ECV permafrost, complementing established parameters like permafrost temperature and active layer thickness (RGIK 2023a, 2023b). The measurement of RGV has a long tradition in Europe and especially in Austria and contributes to bringing long-term time series into the climate change debate (Kellerer-Pirklbauer et al. 2024, 2026).

The aim of the present study is to show, using the Dösen rock glaciers as an example, how changes in rock glacier surface velocity, preferably increase and decrease in speed, can be related to climate change. However, the interrelation of air and surface temperature, snow cover, and hydrology, with rock glacier movement is still a matter of debate and local site-specific conditions could alter the RGV velocity pattern of a particular rock glacier. The Dösen rock glacier (46°59’09” N, 13°17’04” E) is located at the head of Dösen valley in the Hohe Tauern Range, Austrian Alps. The talus-derived, tongue-shaped, and east-west oriented rock glaciers is approximately 900 m long and between 130 and 260 m wide and stretches between 2342 m and 2620 m asl. Bended ridges and furrows in particular at its lower part indicate surface movement and subsequent deformation.

The geodetic monitoring started in 1995 with the establishment of an observation network consisting of stable reference points and 34 presumably moving observation points, stabilized with brass bolts, on the rock glacier (Fig. 1a). Since then, the movement rate (= RGV) of the observation points has been measured annually in mid/late August by repeat measurements. In 2014, the long-term geodetic measurements using a total station were switched to the RTK-GNSS (Real-Time Kinematic - Global Navigation Satellite System) method. In support of the present study 11 points (fast-moving) out of 34 were selected to compute the RGV representing the rock glacier's kinematics for the period 1995-2025 (Fig. 1). In addition, high-resolution orthophotos from different time periods were also examined (Kaufmann 2026). Furthermore, we used continuous ground surface temperature data from one site at the rock glacier surface (DOE-UP-N; 2006-2025; 2626 m asl; snow-influenced) and air temperature data from an automatic weather station located in the rooting zone of the rock glacier (DOE-AWS; 2006-2025; 2603 m asl; Fig. 1a). The air temperature data series for the period 1995-2006 was extended using correlation analyses by using data of a neighbouring high-altitude station, Sonnblick (Kellerer-Pirklbauer et al. 2017).

Selected results are depicted in Figures 1 and 2. Figure 1a depicts photogrammetrically derived mean annual isotachs for the period 2013-2019. Maximum velocities of more than 50 cm per year are achieved in the central lower part of the rock glacier. The lowest velocity rates occur at the edges and in the rooting zone. Figure 1b depicts the mean annual displacement vectors of the 34 geodetic observation points for the period 1995-2025. In accordance with the photogrammetric data, the highest values are again located in the central lower part of the rock glacier with values of around 40 cm per year. Figure 2 shows the relationship between the annual RGV values and two air and ground temperature parameters. These parameters are the moving average of the previous 24 months – both air temperature and ground surface temperature – and the RGV of the Dösen rock glaciers. This comparison shows, on the one hand, a significant increase in RGV and air temperatures over time, and on the other hand, a clear pattern in terms of increasing velocities at higher temperatures and decreasing velocities during cooler weather periods.

Our results confirm previous findings and also demonstrate the particular value of long-term data series for climate change impact research. Considering that climate research defines a climate normal period (or "climate normal") only after 30 years, this 30-year threshold value has only been reached at the Dösen rock glacier since last year's measurement. At many other locations in the Alps and elsewhere, this time horizon is still many years away (Kellerer-Pirklbauer et al. 2024). However, this study also shows how important it is to combine kinematic monitoring with meteorological and possibly other monitoring parameters in order to better understand the effect of anthropogenic climate change.

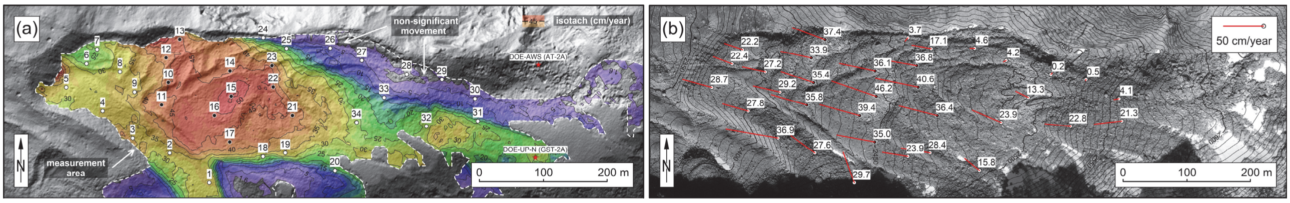

Figure 1. Surface velocity of the Dösen rock glacier: (a) Thematic map showing photogrammetrically derived isotachs (cm/year) for the period 2013-2019. The location of the 34 (11 points: 10-17, 21-23) geodetic observation points is shown on the map; (b) mean annual displacement vectors (red) of the 34 geodetic observation points for the period 1995-2025. The corresponding surface velocities are shown numerically, the maximum amounts to 46.2 cm/year at point 15.

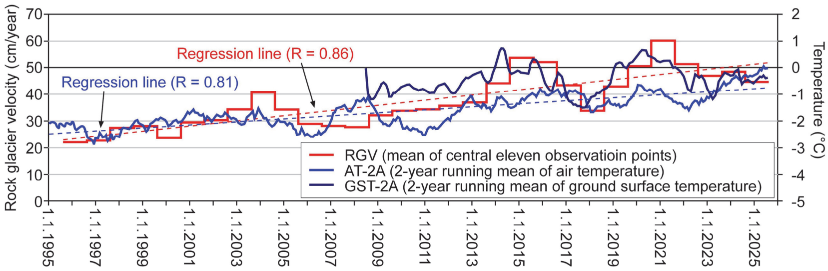

Figure 2. Long-term monitoring results: The mean annual surface velocity of the central 11 geodetic observation points for the period 1995-2025, derived from annual geodetic measurements and the running mean of the 24 previous months – of both, the air temperature at site DOE-AWS (AT-2A) and the ground surface temperature at site DOE-UP-N (GST-2A) for the period January 1995 to August 2025 from two monitoring locations at the rock glacier site. Note the statistically significant increase of the velocity and the air temperature warming.

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