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# 20 Years of Geodetic Monitoring of Dösen Rock Glacier (Ankogel Group, Austria): A Short Review

# 20 Jahre geodätischer Beobachtung am Dösener Blockgletscher (Ankogelgruppe, Österreich): Ein kurzer Überblick

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**Abstract:** This paper gives a condensed account of the geodetic measurements carried out at Dösen rock glacier during the last 20 years (1995–2015). The measurements were taken on an annual basis in order to determine the mean annual flow velocity of the rock glacier. The long-term monitoring program was interrupted only once, i. e. in 2003. The geodetic network comprises 107 observation points located on the rock glacier (34 of which have been stabilized with brass bolts) and 17 stable reference points situated in the vicinity of the rock glacier. In 2014 traditional surveying using a total station was replaced by satellite-based surveying (real-time kinematic - global navigation satellite systems, RTK-GNSS). The flow velocities obtained reveal very well the kinematic behaviour of Dösen rock glacier over the course of time and are an excellent basis for subsequent climate change studies. The mean annual flow velocity of the 11 fastest points varied between 22.0 and 53.6 cm/a during the observation period. The highest flow velocities (up to 65.9 cm/a) were recorded for 2014–2015, confirming the ongoing speed-up of this rock glacier.

**Zusammenfassung:** Dieser Aufsatz gibt einen kurzen Überblick über die geodätischen Messungen, welche am Dösener Blockgletscher im Zeitraum 1995–2015, also über einen Zeitraum von 20 Jahren hinweg, getätigt wurden. Aus den jährlichen Messungen konnten mittlere jährliche Fließgeschwindigkeiten des Blockgletschers abgeleitet werden. Im Jahr 2003 wurde jedoch keine Wiederholungsmessung durchgeführt. Das geodätische Beobachtungsnetz umfasst 107 Beobachtungspunkte am Blockgletscher, wovon 34 Punkte mit Messingbolzen stabilisiert sind, und 17 stabile, unbewegte

Referenzpunkte im Außenbereich des Blockgletschers. Im Jahr 2014 wurde das traditionelle Messverfahren unter Verwendung einer Totalstation durch die satellitengestützte Echtzeit-Positionierung (RTK-GNSS) abgelöst. Die ermittelten Fließgeschwindigkeiten beschreiben sehr gut die Kinematik des Dösener Blockgletschers und sind eine ausgezeichnete Datengrundlage für weiterführende Studien zur Klimaänderung. Die mittlere jährliche Fließgeschwindigkeit der 11 schnellsten Blockgletscherpunkte variierte zwischen 22.0 und 53.6 cm/Jahr. Für den jüngsten Beobachtungszeitraum 2014–2015 wurden die höchsten Fließgeschwindigkeiten (bis zu 65.9 cm/Jahr) in allen Messpunkten seit Messbeginn festgestellt; dies bestätigt die in den letzten Jahren bereits festgestellte Beschleunigung des Blockgletschers.

**Key Words:** Rock glacier; Geodetic monitoring; Flow velocity; RTK-GNSS; Dösen Valley.

**Schlüsselworte:** Blockgletscher; Geodätisches Monitoring; Fließgeschwindigkeit; RTK-GNSS; Dösental.

## 1. Introduction

Dösen rock glacier (46°59'12" N, 13°17'08" E) is located in the Ankogel Group (Hohe Tauern Range, Carinthia, Austria). With an area of 28.8 ha this rock glacier is one of the largest in the Austrian Alps. It is situated at the head of Dösen Valley stretching from 2650 m to 2339 m a.s.l. (Fig. 1). The tongue-shaped rock glacier is approximately 950 m long and 300 m wide and was formed during a period of several thousand years as revealed by relative dating approaches (Kellerer-Pirklbauer 2008). Surface features, such as furrows and ridges, and a steep frontal slope are visual expressions of surface deformation and inherent creep. See computer animations prepared by Kaufmann (2015a). Creep/flow direction is from east to west. Dösen rock glacier is indexed as *mo 238* in the rock glacier inventory of the eastern European Alps (Kellerer-Pirklbauer et al. 2012).

Scientific investigations at Dösen rock glacier started under the leadership of Gerhard Karl Lieb (Department of Geography and Regional Science, University of Graz) in the early 1990s (Lieb 1996, 1998). The former Institute of Applied Geodesy and Photogrammetry, Graz University of Technology, was responsible for determining the rock glacier's kinematic state and subsequently setting up a geodetic long-term monitoring program (Kaufmann 1996, 1998, 2015b). Over the last 20 years (1995–2015) several projects have been carried out to support this ambitious program (Kienast & Kaufmann 2004). A large number of persons, i. e. colleagues, guests from abroad, students, volunteers and others, actively contributed to this program, either in the field or at the desk.

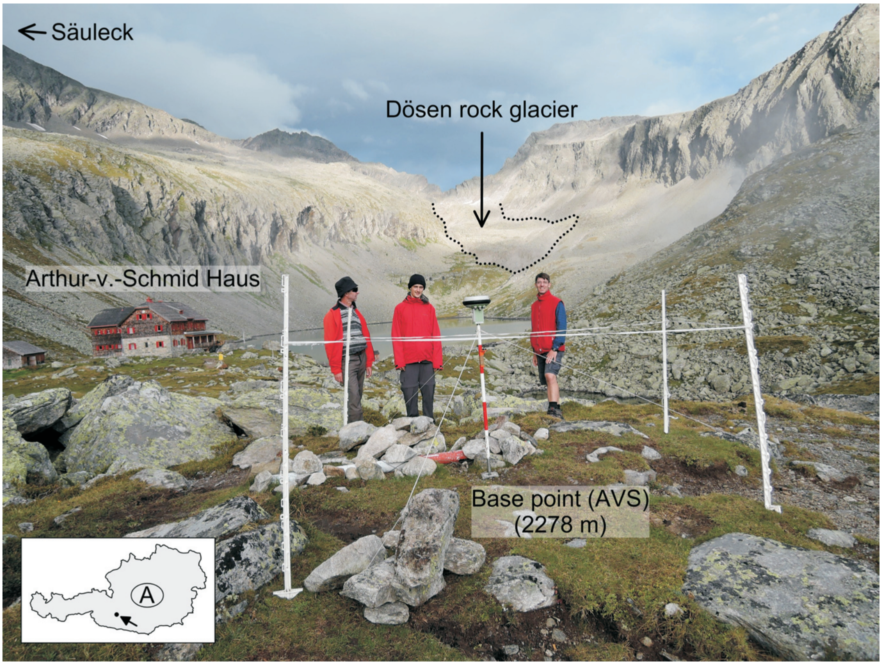


*Fig. 1:* Terrestrial view of Dösen rock glacier. The foreground shows the GNSS base station used for satellite-based surveying. The station is marked by a fence (white color). Photograph taken 18. August 2015.
*Abb. 1:* Dösener Blockgletscher im Talschluss. Im Vordergrund sieht man die mit einem provisorischen Zaun gesicherte GNSS-Basisstation für die relative Satellitenpositionierung. Photo vom 18. August 2015.

## 2. Methods

The movement of a rock glacier can be detected and quantified by different means, such as geodetic surveys using a total station or GPS/GNSS-based relative positioning, terrestrial and aerial photogrammetry, terrestrial or airborne laser scanning and satellite-based SAR interferometry (Kääb 2005).

Our measurement methods at Dösen rock glacier included not only in-situ geodetic surveys, which have been referred to previously, but also aerial photogrammetry (Kaufmann & Ladstädter 2002; Kaufmann & Kellerer-Pirklbauer 2015) and satellite-based SAR interferometry (Kenyi & Kaufmann 2003). The latter two methods are powerful remote measurement techniques for area-wide mapping of surface parameters, such as flow velocity or surface height change. In this paper, however, we focus on the geodetic surveys.

## 2.1. Geodetic surveys using a total station

In 1995 a geodetic network consisting of observation points (in total 107) on rocks of the glacier surface presumed to be moving and stable reference points (in total 11) positioned in the surroundings of the rock glacier was set up (Kaufmann 1996). Since that time, geodetic measurements have been carried out on an annual basis, with the exception of 2003, when measurements were interrupted due to a shortage of funds. In 2006 and 2013 the network of stable reference points was expanded with an additional 6 points in lower-lying areas for easier access. The set of observation points on the rock glacier consists of 34 points stabilized with brass bolts and 73 supplemental points marked with red colour forming two longitudinal and two transversal profiles. In 2014 this traditional surveying method was replaced by satellite-based surveying. Geodetic surveys using a total station are highly accurate and productive in terms of measured points per hour. Such surveys however, require experienced operators (at the instrument) and several helpers for carrying the equipment and for in-situ positioning of the geodetic reflectors. In 2013 a comparative study was carried out on Dösen rock glacier to confirm that state-of-the-art satellite-based surveying, i. e. real-time kinematic (RTK) technique, can deliver positions with an accuracy in the centimetre range (±1 to 3 cm), which allows to compute annual flow velocities with an accuracy of a few centimetres. Since the flow velocity of Dösen rock glacier (up to 0.5 m/a on average) is in the intermediate range in relation to other monitored rock glaciers in Austria, the relative accuracy of the annual flow velocities obtained is in the range of several percent, which is sufficient to support, for instance, climate change studies.

## 2.2. Geodetic surveys using RTK-GNSS

Since 2014 geodetic surveys have been carried out using RTK-GNSS only. In order to support the ease of measurement we use a triangulation point (named AVS, see Figure 1) located in the vicinity of the Arthur-v.-Schmid Haus refuge as a local reference point for setup of the GNSS base station and 3 dedicated stable points (M1 to M3; M1 and M2 are located next to Arthur-v.-Schmid Haus, and M3 is close to the rock glacier next to the walking trail) for quality control of the RTK-GNSS setup. Because of potential shadowing of the satellite signals and multipath effects, both GPS and GLONASS must be available simultaneously to assure accurate point positioning within a short period of time. If the weather is fine and the surface of the rock glacier is dry, all 34 observation points can be measured within one work day. The measurement of the additional four profiles would require another full day of work in the field. As a result of these time factors and also financial constraints we were obliged to abandon the annual measurement of the four profiles.

## 3. Results

Based on the annual geodetic measurements, three-dimensional displacement vectors can be computed. These vectors serve as a basis for further analysis and visualization. For example, the mean annual horizontal flow/creep velocity can be computed for each observation point. Observed acceleration or deceleration of the movement is highly indicative of environmental changes, e. g. atmospheric warming or cooling. In figure 2 the multi-annual horizontal movement (1995–2015) of the 34 observation points of Dösen rock glacier is depicted. A good approach is to spatially average concordant velocities in order to derive mean values. Their temporal change (revealing acceleration/deceleration) can be best visualized in a graph (Fig. 3). Furthermore, strain parameters can get computed by means of stringent deformation analysis or estimates for permafrost degradation (ice melt) were deduced (Kaufmann 1998). Such an estimate is quite ambitious and needs additional information, e. g. a rheological model.

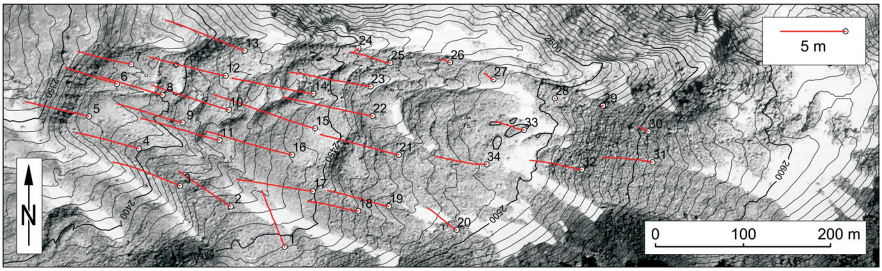


*Fig. 2:* Multi-annual movement (1995–2015) of the 34 observation points at Dösen rock glacier. The horizontal movement (tracks shown in red colour) is exaggerated by a factor of 15. Highest flow velocities were always measured at point 15.
*Abb. 2:* Bewegungsspur der 34 am Dösener Blockgletscher gemessen Beobachtungspunkte für den Zeitraum 1995–2015 (rote Linien). Die Bewegungen sind mit einem Skalierungsfaktor von 15 gestreckt. Die größten Fließgeschwindigkeiten wurden jeweils im Punkt 15 in allen Epochen gemessen.

## 4. Discussion and Outlook

Figure 3 reveals that the flow velocity of Dösen rock glacier has changed significantly over time. There are periods of acceleration and deceleration leading to higher or lower flow velocities. A possible explanation for this behaviour is given in Kellerer-Pirklbauer & Kaufmann (2012) revealing synchronous velocity changes for several rock glaciers in the Hohe Tauern Range attributed to climatic conditions. The most recent observation period (2014-2015) showed the highest flow velocities (up to 65.9 cm/a at point 15) ever measured at this rock glacier. The fastest point (15) has moved some 8.1 m in horizontal direction during the last 20 years.

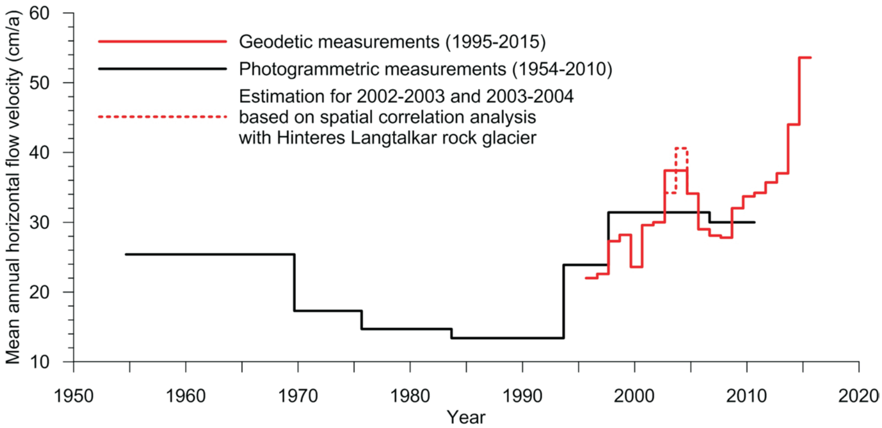


*Fig. 3:* Mean annual horizontal flow velocity of Dösen rock glacier for the time period 1995–2015 (red line). For reasons of comparison, photogrammetrically derived flow velocities are added for the time period 1954–2010 (black line). The velocities shown are mean values derived from 11 representative observation points (10–17, 21–23).
*Abb. 3:* Mittlere jährliche horizontale Fließgeschwindigkeit am Dösener Blockgletscher für den Zeitraum 1995–2015 (rote Linie). Für Vergleichszwecke sind auch die photogrammetrisch ermittelten Geschwindigkeiten für den Zeitraum 1954–2010 eingetragen (schwarze Linie). Alle Geschwindigkeiten sind Mittelwerte aus 11 repräsentativen Beobachtungspunkten (10–17, 21–23).

The observation period covered by the geodetic measurements was extended by photogrammetric analysis of aerial photographs dating back to the early 1950s (Figure 3), which showed the lowest flow velocities (down to 13.4 cm/a) for the time period from 1983 to 1993. Furthermore, it is worthwhile to note that rock glaciers not only in Austria but also in other European countries, e. g. Switzerland, France and Italy, seem to behave in a similar way from a kinematic point of view (Delaloye et al. 2008). This phenomenon is still a hotly debated research question and good answers have not yet been given, although natural hazards might emerge from rock glacier movement changes (Schoeneich et al. 2015). From this point of view, continuation of the work is of great importance, at least by maintaining the existing annual observation plan. A future scenario for Dösen rock glacier would be to monitor its movement on a daily basis using freely deployable Web-based sensor nodes hosting, e. g. GNSS receivers, temperature loggers, and other sensors.

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