84 High Elevation Rock Falls and Their Climatic Control: a Case Study in the Conca di Cervinia (NW Italian Alps)

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Abstract

One of the impacts of climate warming in recent years is the evident increase of the number of rock fall occurrences at high elevations. With few exceptions, these events have small magnitudes and thus are rarely reported and documented, even less so in the past. Therefore it is difficult to use a statistical approach to analyze of the relationships between climate warming and rock slope instability. On the other hand, it is often difficult to carry out a time analysis of meteorological conditions responsible for rock fall triggering, considering that very few automatic weather stations (AWS) are located in the areas and in the altitudinal range that are affected by cryosphere degradation (i.e. above c.a. 3,000 m elevation in the Alps), and that climatic conditions in high elevation environments are spatially and temporally variable. The present study addresses the above-mentioned issues through analysis of a series of small rock falls that occurred in the last 10 years on the Matterhorn and surrounding rock slopes. A specific focus is temperature: we present a preliminary analysis of the spatial and seasonal variability of the vertical temperature gradient in the Conca di Cervinia, where the Matterhorn is located, to illustrate the uncertainty in estimates of the thermometric conditions at high elevation rock fall sites.

Keywords

High-elevation rock walls • Stability • Climate • Italian Alps

84.1 Introduction

Rock slope stability at high elevations has been affected by climate warming, and the effects have become more evident in the past ten years (Gruber et al. 2004; Tamburini et al. 2013), even though the exact role of climatic factors (precipitation and especially temperature) is not easily assessed. In fact, it commonly is difficult to carry out a punctual analysis of meteorological conditions responsible for rock fall triggering, considering that very few automatic weather stations (AWS) are located in the areas and in the altitudinal range that are affected by cryosphere degradation (i.e. above about 3,000 m elevation in the Alps). The distance of the nearest AWS from the rock fall source, as well as the specific geographic setting (e.g. slope aspect), may introduce important differences between data registered by the AWS and the actual conditions that triggered the event.

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Fig. 84.1 The Grandes Murailles ridge, on the *left*, and the Matterhorn south face, on the *right* (*Photo* Guido Nigrelli, June 26, 2013)

In addition, mountain environments are well known for their complex climatic patterns, which result in a high spatial and temporal variability of the actual values of climatic parameters (Beniston 2006).

The present contribution addresses this issue by presenting as a case study the Conca del Breuil-Cervinia in the Italian Alps.

84.2 Description of the Site

The Conca del Breuil-Cervinia is located at the head of the Valtournanche Valley (Aosta Valley, NW Italy). The most prominent peak is the Matterhorn (4,478 m), one of the highest peaks in the Alps, at the border between Switzerland and Italy. The two flanks of the Conca del Breuil-Cervinia have different morphologies due to the different geological units in which are carved. The right side (including the Matterhorn) of the Conca is formed mainly of gneisses and metagabbros, which give rise to high peaks and steep slopes (Fig. 84.1), while the left flank of the Conca is formed by the ophiolitic rocks, mainly calcshists. These slopes have been affected in recent years by several small rock falls.

In order to study the relationships between climatic parameters and rock slope stability, a monitoring system consisting of geophones and thermometers was installed in 2007 near the Carrel Hut (3,829 m) along the Italian climbing route to the Matterhorn, taking advantage of the previous experience gained in the field of the seismic monitoring of debris flows (Arattano et al. 2012; Occhiena et al. 2012; Coviello et al. 2014).

84.2.1 Documented Rock Fall Events

Rock falls are considered an important process in the geomorphological evolution of high mountains, yet they are rarely reported and documented, and they were even less reported in the past. Nevertheless, after the hot summer in the European Alps in 2003, awareness of the phenomena was raised, due to instabilities that have affected world-famous sites.

One of these events was the "Cheminée" rock fall, which occurred on August 18, 2003 along the Italian climbing route to the Matterhorn, just below the Carrel Hut, at an elevation of about 3,770 m. No one was injured but the route was blocked to climbers for a long period. This event was of particular scientific interest because a large ice lens was observed on the detachment surface. Other rock falls occurred on the Matterhorn Peak in the same summer: on August 4 a few tens of cubic meters fell along the same climbing route, but just above the Carrel Hut at an elevation of about 3,850 m. Earlier in the summer, on July 15 and 16, 1,000–2,000 m^3 of rock fell in two separate events on the Swiss side of the peak, at the base of the northeastern ridge known as the Hörnligrat, at an approximate elevation of 3,400 m; 84 climbers had to be evacuated (Hasler et al. 2012). Ice was observed along the failure plane shortly after the second rock fall. All these events occurred without significant precipitations. Finally, on October 8, 2003, a few hundreds m^3 of rock fell from the base of the Cresta De Amicis, on the eastern side of the Lower Tyndall Glacier (Pogliotti 2006).

The instability of these slopes continued in the following years (Coviello 2009). A rock fall occurred during heavy rain on July 18, 2005 on the Testa del Leone ridge, at an elevation of 3,715 m, impacting the Italian route to the Matterhorn. On July 25, 2006, a failure occurred on the west side of the Italian route to the Matterhorn at about 3,750 m of elevation forcing the evacuation of 24 climbers from the Carrel Hut. Finally, on August 28, 2009, several climbers were rescued because of slope instability along the Italian route to the peak, at an elevation of about 3,900 m (Fig. 84.2).

Fig. 84.2 **a** Rock fall on the Matterhorn in 1862 ("A cannonade on the Matterhorn"); **b** scar of the 2003 "Cheminée" rock fall, where ice was exposed; **c** rock fall in 2006 (*black circle*); the arrow points to the Carrel Hut (*Photos* courtesy of Lucio Trucco, Guide del Cervino)

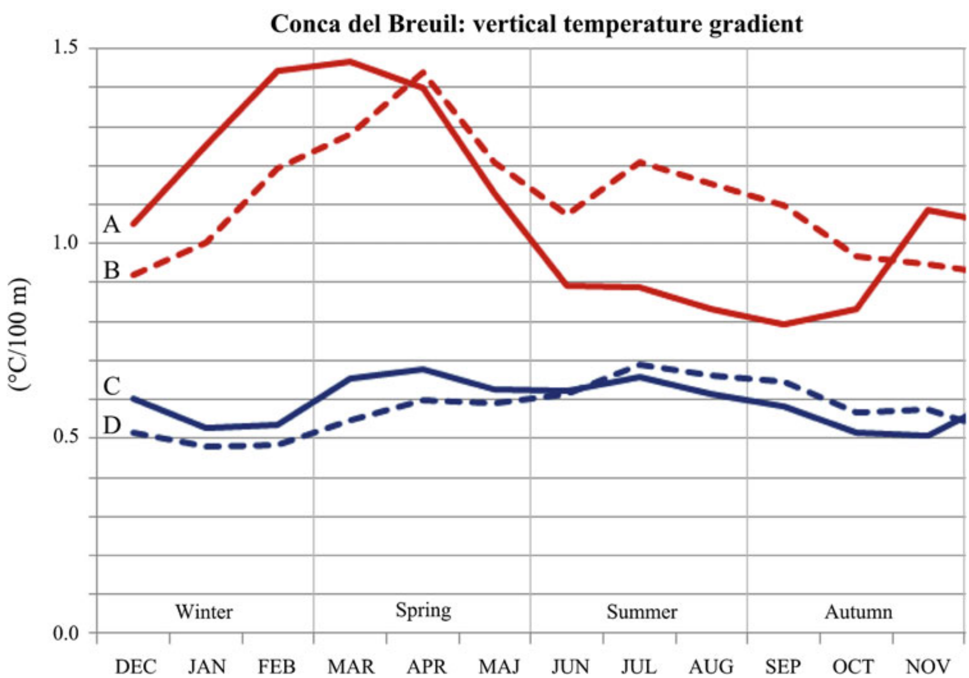

Fig. 84.3 Mean monthly vertical temperature gradient (*VTG*) in the Conca del Breuil, calculated using four pairwise comparisons. **A** daily maximum temperature VG (AWS 3,100 m a.s.l. vs. AWS 2,566 m); **B** daily maximum temperature VG (AWS 3,100 m vs. AWS 2,541 m); **C** daily minimum temperature VG (AWS 3,100 m vs. AWS 2,566 m); **D** daily minimum temperature VG (AWS 3,100 m vs. AWS 2,541 m). *Red* and *blue lines* identify, respectively, daily maximum and minimum temperature VG. *Continuous* and *dotted lines* indicate, respectively, the comparisons AWS 3,100 m vs. AWS 2,566 m and the comparisons AWS 3,100 m vs. AWS 2,541 m

84.3 Variability of the Vertical Temperature Gradient

In the case of most of the above-mentioned events, precipitation did not play a significant role in triggering the instability. Rather, the main trigger was warm temperatures. In order to assess the role of temperature in landslide initiation, series of data of rock temperature would be needed. Unfortunately, very few rock slopes are instrumented with temperature sensors. As a consequence, in most cases thermal conditions at the times of rock falls must be inferred from air temperature measures registered at meteorological stations. Usually, a standard vertical temperature gradient (VTG) is used to extrapolate temperatures

Table 84.1 Main characteristics of the automatic weather stations (AWS) at high elevation sites in the Conca del Breuil

	A	B	C	D
Temperature	Maximum	Maximum	Minimum	Minimum
Aggregation	daily	daily	daily	daily
Obs. period	2007–2012	2003–2012	2007–2012	2003–2012
Highest AWS	3,100 m a.s.l.	3,100 m a.s.l.	3,100 m a.s.l.	3,100 m a.s.l.
Lowest AWS	2,566 m a.s.l.	2,541 m a.s.l.	2,566 m a.s.l.	2,541 m a.s.l.
Distance	6.9 km	2.7 km	6.9 km	2.7 km

Data from these AWS were used to calculate the four mean monthly vertical temperature gradients (A, B, C and D; results are shown in Fig. 84.3)

at meteorological stations to rock fall sites. We quantified the errors that can be made by using a standard VTG instead of the actual temperature gradient by carrying out a detailed analysis of the VTG and of its variability in the Conca del Breuil over a short period. We calculated VTG values by comparing daily maximum and minimum temperatures at three weather stations located at elevations between 2,541 and 3,100 m (Table 84.1). Each comparison was based on data from two stations (Fig. 84.3). In addition, daily and monthly mean VTG values and seasonal means were calculated. Three main trends with increasing elevation are evident: (1) an increase in the mean VTG value, (2) an increase in the irregularity of seasonal cycles, and (3) a decrease in variability. The mean VTG is 0,51 ± 0,24 °C/hm, averaged between two elevation levels; the seasonal fluctuations are greatest in April, July and December.

84.4 Concluding Remarks

Although the relation between climate warming and increased high-altitude rock slope instability is now widely recognized, as is apparent from the series of rock falls documented at the Matterhorn in the past ten years, in many cases this relationship is difficult to prove. In fact, in most cases, thermal conditions at times of slope failures must be inferred from air temperatures measured at meteorological stations that are located at elevations and in topographical contexts that are different from those of the failure zone. The analysis presented here shows that the use of a standard vertical temperature gradient may be misleading; while minimum temperatures show a gradient very close to standard VTG and are stable during the year, maximum temperatures follow much higher VTG values that are highly dependent on the season and on the range of altitude that has been considered.

The study is still in progress. Future developments include the use of resulting VTG to extrapolate temperature conditions at failures sites, and the comparison of extrapolated values with rock temperatures that have been monitored in the vicinity of the Carrel Hut since 2005 (Pogliotti et al. 2008).

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