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CLIMATIC CONDITIONS ASSOCIATED TO THE OCCURRENCE OF SLOPE INSTABILITIES IN THE ITALIAN ALPS IN YEAR 2016

Roberta PARANUNZIO[1,2], Marta CHIARLE[2], Francesco LAIO[1], Fabio LUINO[2], Guido NIGRELLI[2] and Laura TURCONI[2]

[1] Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Torino, Italy (roberta.paranunzio@polito.it)

[2] Research Institute for Geo-hydrological Protection of the National Research Council, CNR-IRPI, Torino, Italy (marta.chiarle@irpi.cnr.it)

MOTIVATION

Studies carried out in different parts of the world have shown that, in the mountain high-elevation sites, temperature can play a major role in the preparation and trigger of slope instabilities (Allen and Huggel, 2013). However, the interplay with other climatic parameters (in particular precipitation) and the nature of the climate-driven processes that lead to the development of slope instability continue to be poorly understood. This understanding is crucial in order to define reliable scenarios of the evolution of slope instability under the expected climatic and environmental changes (Gariano and Guzzetti, 2016). The present work aims to contribute to shed light on these issues by analyzing with the statistical and probabilistic method developed by Paranunzio et al. (2015; 2016) the values of the climatic parameters associated to the most significant events of slope instability occurred at high elevation in the Italian Alps in 2016. The method allows to detect the anomalies in temperature and precipitation values that are associated to the development of these slope instabilities, providing the ground for discussion of possible causes and triggering mechanisms, also in the framework of ongoing climate change.

1 - DATASETS

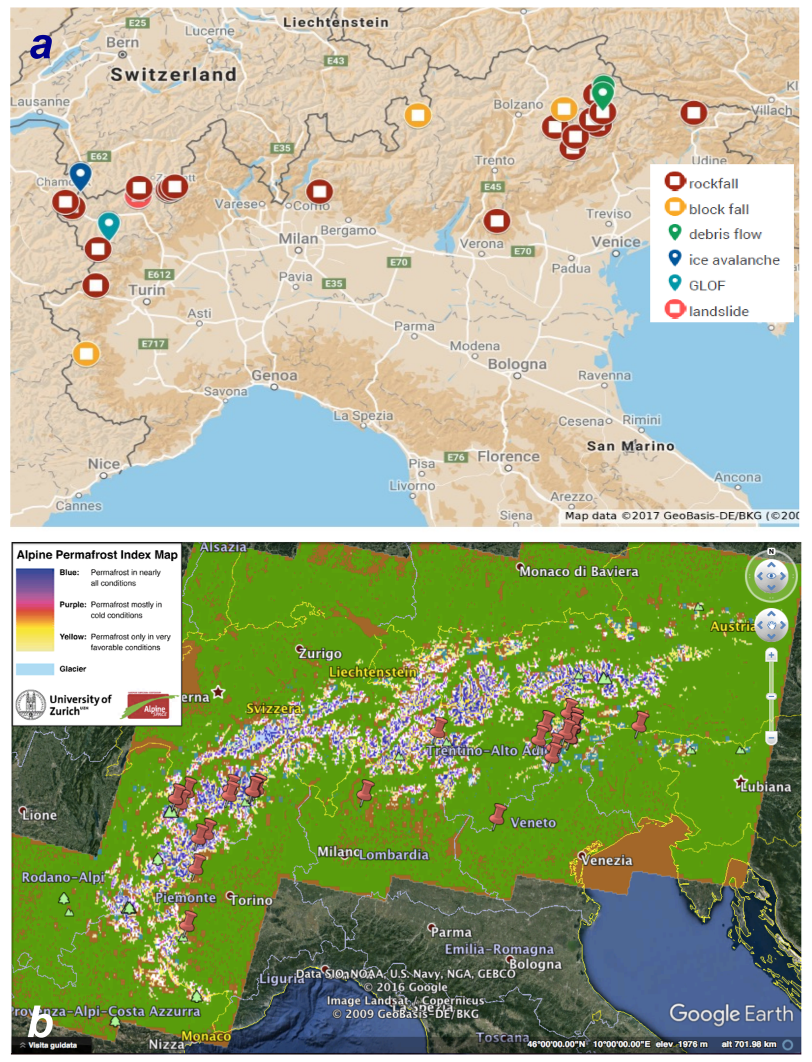

Fig. 1 a) Spatial distribution of 2016 events above 1500 m a.s.l. in the Italian Alps; b) Spatial distribution of events based on Alpine Permafrost Index Map.

Event	z	Date	Hour	Lon	Lat	Process	Volume
Bormio Bagni Vecchi	1530	29/06/16		10.3628	46.4931	block fall	
Cignana	2300	29/06/16	5:00	7.6012	45.8819	landslide	3-20 x 10^2
Cima Lastei	2500	11/07/16	5:53	11.8907	46.2463	rockfall	8 x 10^4
Cima Pape	1900	25/07/16	about 17:00	11.9171	46.3319	rockfall	
Cima Undici	2450	07/07/16	7:30	11.7176	46.4052	rockfall	75 x 10^3
Crot	2460	03/04/16		7.6137	45.9430	rockfall	>2 x 10^2
Grand Croux	2690	14/08/16	15:00	7.3129	45.5246	GLOF	5-7 x 10^4
Mont Chetif	1820	02/05/16	4:00	6.9517	45.7955	rockfall	>2 x 10^2
Monte Zevola	1600	22/03/16	7:20	11.1424	45.6903	rockfall	
Monviso	3750	21/08/16	morning	7.0916	44.6655	block fall	
Murfreit	2300	29/08/16	morning-early afternoon	11.8058	46.5399	rockfall	
Pelmo I	2200	19/08/16	0:45	12.1508	46.4186	debris flow	
Pelmo II	3000	29/07/16	evening (about 20:00)	12.1415	46.4217	rockfall	
Piccola Croda Rossa	2800	19/08/16	about 6:00	12.1236	46.6476	rockfall	6-7 x 10^5
Pizzo Nero	1900	09/07/16	night	7.9649	45.9528	rockfall	
Punta Fourà	3411	25/06/16		7.2072	45.4757	rockfall	
Punta Tre Amici II	3400	08/01/16	12:30	7.9075	45.9296	rockfall	
Punta Tre Amici III	3400	24/08/16	9:00	7.9075	45.9296	rockfall	
Punta Tre Amici IV	3000	29/10/16		7.9240	45.9306	rockfall	
Rio Gere	2200	21/08/16		12.1944	46.5655	debris flow	
Sorapiss II	2400	20/05/16	11:30	12.1871	46.5167	rockfall	
Sorapiss III	2400	14/06/16	23:00	12.1872	46.5155	rockfall	
Sorapiss IV	2400	15/06/16	4:00	12.1872	46.5155	debris flow	
Sperone Brenva I	3647	25/09/16		6.8848	45.8366	rockfall	15-35 x 10^3
Sperone Brenva II	3647	28/09/16		6.8848	45.8366	rockfall	
Triolet	3000	25/07/16	23:00	7.0329	45.9035	ice avalanche	

Table 1 *List of 2016 events; z: elevation (m a.s.l.); volume (m^3)*

Slope instabilities occured above 1500 m a.s.l. in year 2016. The documentation is mainly based on local/national newpapers, technical reports and oral communications.
Climate data have been selected according to:
- ★ availability of records covering the failure day;
- ★ length and quality of the data set;
- ★ distance and difference of elevation between station and the failure point

2 - STATISTICAL APPROACH

The statistical approach is based on a cumulative probability function P associated to the variable *V*. We compared the meteorological conditions at failure time to the conditions typical for the area, in order to determine if the parameters involved has taken non-standard values when the slope failure occurred, this means $P(V) \le \alpha/2$ or $P(V) \ge 1-\alpha/2$ with α=0.2. We then performed a bivariate analysis to take into account additional factors that, in combination with climate anomalies, can help understanding the processes leading to slope failure (Paranunzio et al. 2015, 2016).

1 CHOICE of the VARIABLES (V)
Temperature T_{mean} T_{max} T_{min}
Precipitation *R*
Temperature variation ΔT_{mean} ΔT_{max} ΔT_{min}

2 AGGREGATION SCALE
For *T* and *R*: daily, weekly, monthly, or quarterly scale
For *ΔT*: 1 day, 3 days and 6 days

3 CHOICE of the STATIONS
Spatial proximity
Data availability

5 REFERENCE SAMPLE
For *T*: same period of the year as when the failure occurred
For *R* and *ΔT*: 3 months surrounding the failure date

6 IDENTIFICATION of the ANOMALOUS VALUES
Evaluation of the non-exceedance probability P(*V*) associated to the variable $V \rightarrow P(V) \le \alpha/2$ or $P(V) \ge 1-\alpha/2$

6 CLIMATE ANOMALIES vs SPATIO-TEMPORAL FEATURES
Spatio-temporal features as season and elevation of occurrence, presence of permafrost, volume wherever available

3 - PRELIMINARY RESULTS and FURTHER DEVELOPMENTS

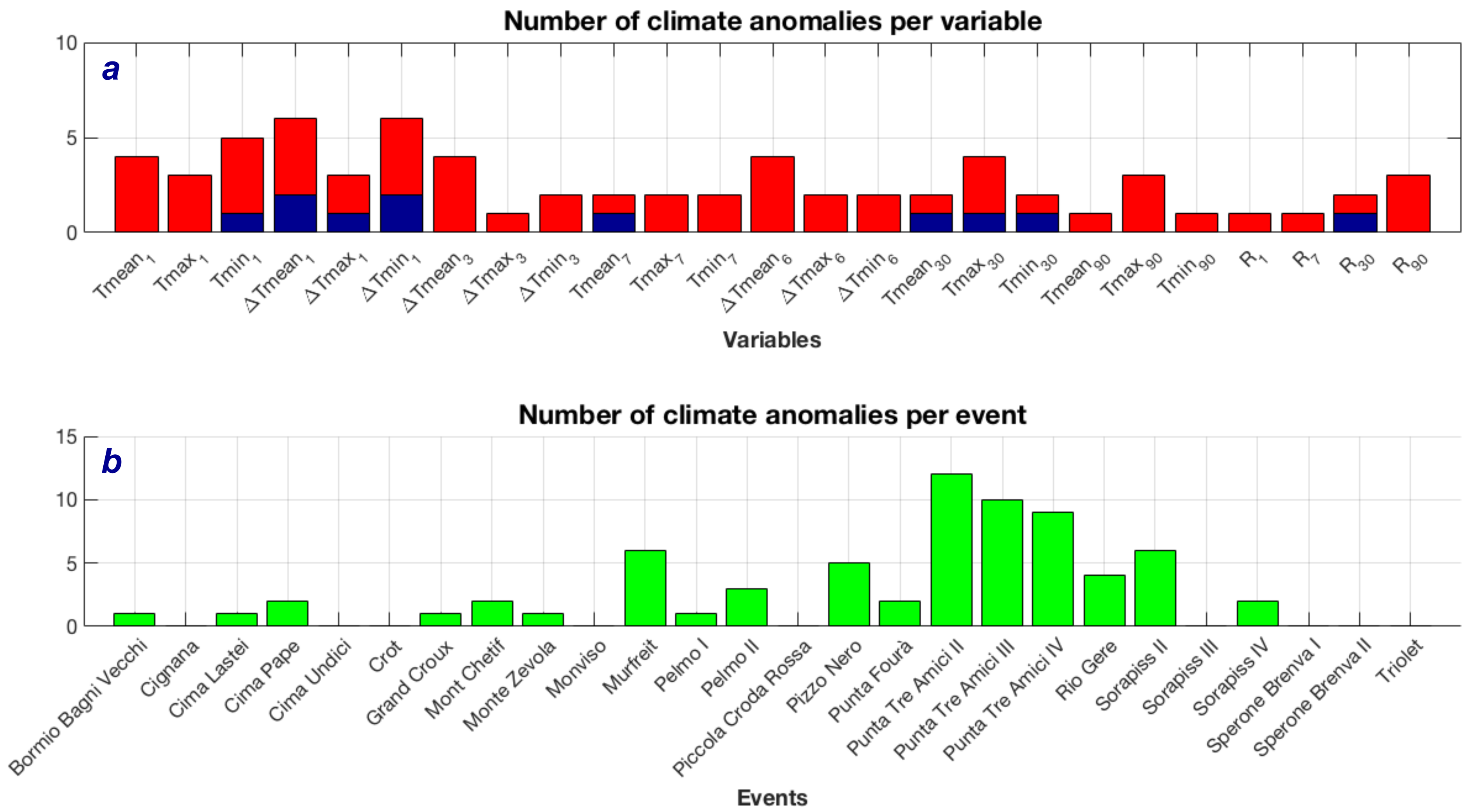

Fig. 2 a) Number of climate anomalies detected per variable; for temperature, red bar refer to warm anomalies, blue to cold ones; for precipitation: red bar refer to exceptional precipitation, wheras blue ones to low precipitation. b) Number of climate anomalies per event.

Rock-falls are the dominant instability process at high altitude in the Italian Alps (Table 1), and temperature seems to plays a major role for the initiation of slope instability (Fig. 2).

Based on the results of Fig. 2, many events are related to short-term temperature climate anomalies i.e., *T* and *ΔT* anomalies at daily and weekly scale. Negative anomalies have been detected, but warm ones prevail.

Events occurred mainly in summer and at whatever elevations (Fig. 3).

As in Fig.1, in the Western Alps, 64% out of the total number of 2016 events occurred in areas where permafrost is present in all conditions, whereas in the Eastern sector most part of events occurred in areas where permafrost is absent (77% out of the total). Peak elevation in Eastern Alps is much lower than the Western ones and permafrost is expected mainly in cold or favorable conditions (Fig. 4). Summer and autumn events occurred mainly in permafrost areas, in agreement with previous studies (Paranunzio et al., 2016).

A considerable number of 2016 events seems not to be linked to climate anomalies. Additional analysis, taking into account predisposing factors, as lithology/geology of the impacted areas, could be of help in the detection of the triggering factors. Also the use of a fixed temporal aggregation could somehow limit our knowledge on the mechanisms of failure. The use of moving windows could be of help in this catching, for example, a possible succession of warm and cold periods in the period before the event.

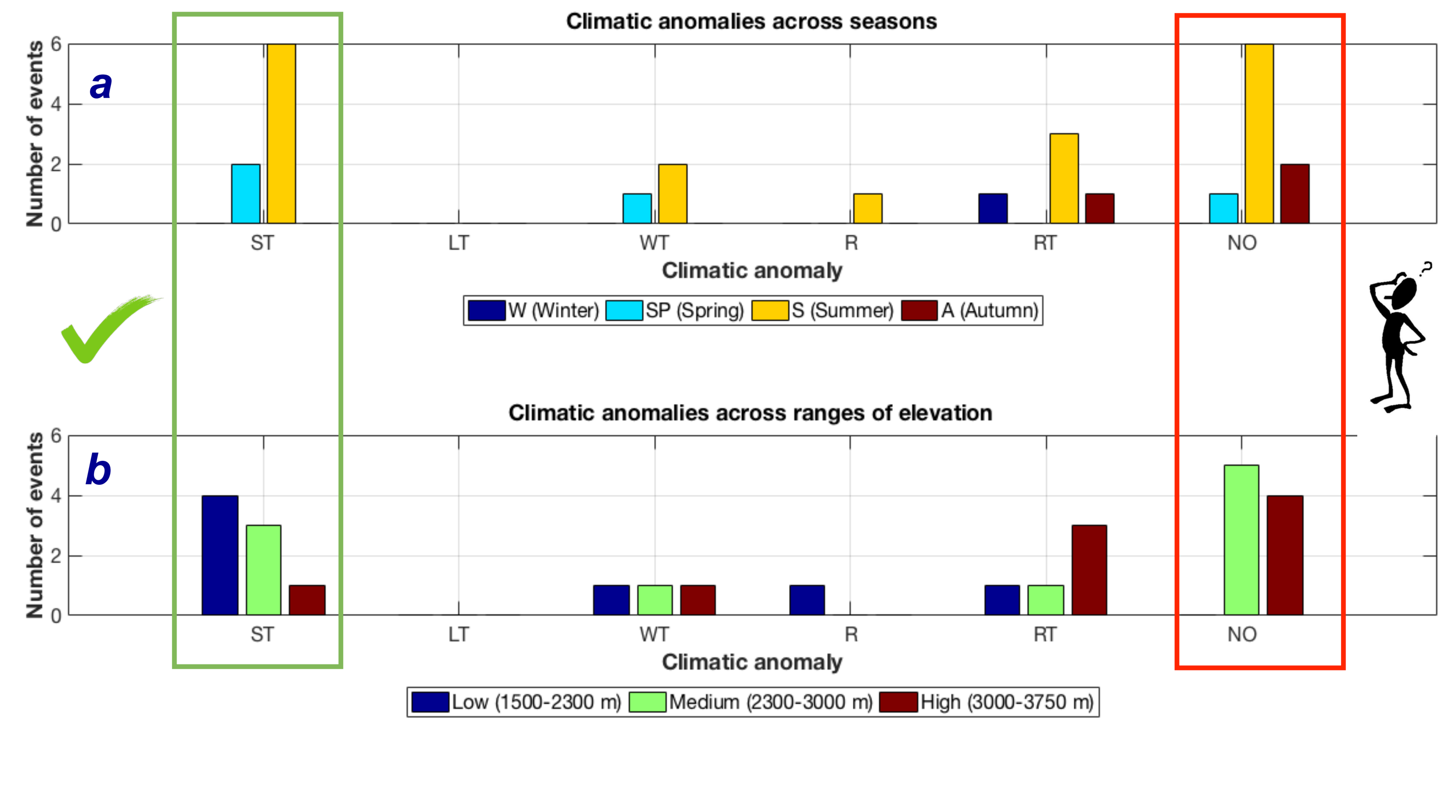

Fig. 3 Distribution of rockfalls according to the type of climate anomaly, and considering: (a) the season of occurrence: W (winter), SP (spring), S (summer), A (autumn); (b) the elevation: Low (1500-2300 m); Medium (300-3000 m); High (3000-3750 m). Climate anomaly groups: ST: short-term temperature anomaly; LT: long-term temperature anomaly; WT: widespread temperature anomaly; R: precipitation anomaly; RT: precipitation associated with temperature anomaly; NO: no anomaly

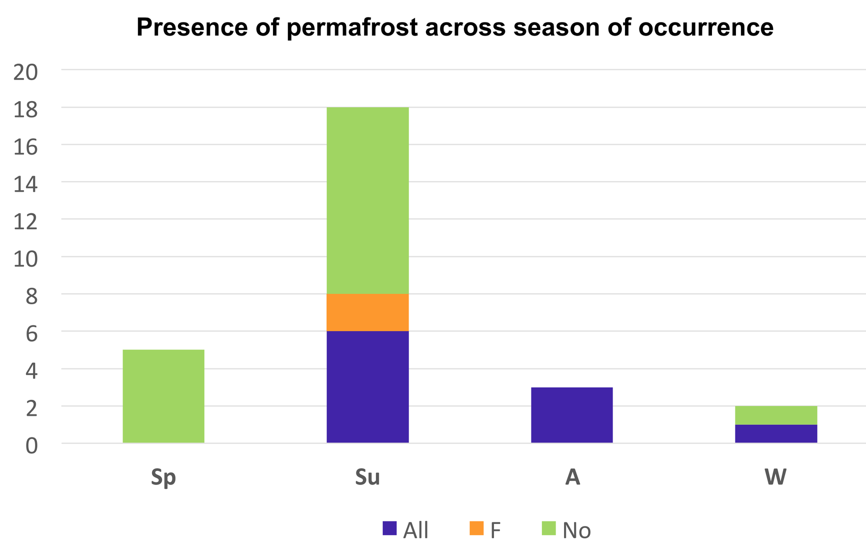

Fig. 4 Seasonal distribution of rockfalls according to permafrost distribution (based on APIM - PermaNet Project); All: all conditions; F: only favourable conditions, No: no permafrost. Graphics: M. Chiarle

The work presented here is part of a wider ongoing study focusing on instability processes at high altitude in the Italian Alps in the recent decades. Further details at http://geoclimalp.irpi.cnr.it/index.php/en

The lack of weather stations at high elevation sites and the fragmentation into regional datasets of data at national scale is a limiting factor for this analysis. For improving knowledge on the role of climate parameters on the initiation of slope instabilities in high-mountain areas, new technologies and approaches are needed, in order to guarantee good quality data. In this context, new projects and partnerships (as http://www.irpi.cnr.it/en/project/rist-project/) aim to deepen the knowledge on the relationship between natural hazards at high-elevation sites and climate change in open air laboratories by means of innovative, low-cost solutions (Fig. 5).

Fig. 5 Livecam 360° PANOMAX of the Bessanese Glacier basin

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