General comments

As stated in the introduction, the aim of the work is to calculate the frequency variation in time and space of different climate variables in the Italian Eastern Alps, to understand the climate evolution in the area and its influence on rockfall frequency distribution. The subject is of major interest for the understanding of rockfall failure mechanism and hazard assessment, and the manuscript represent a substantial contribution. The results are discussed in an appropriate way and compared to previous works on the same topic. I think the paper is well written.

However, the methods used should be better explained. That is why I believe that some major revisions are needed to enhance the overall quality and clarity of the paper before acceptance for publication. Also, some parts of the methodology are discussed in the Results and should be moved in the Methods section.

Thanks to the reviewer. We move some parts of the manuscript from the results and/or discussion into the method section.

Minor corrections are suggested in the pdf and the more important points are developed hereafter. Some references of the text are not in the reference list. Please check that all the references are in the list.

Thank to reviewer. We correct the minor point for the annotated pdf and we checked the reference lists with the manuscript citation.

Specific comments

Conditional probability (refers to the abstract and the Methods section)

Line 16. To be clearer the expression "to study conditional probability of meteorological variables on rockfall events" should be replaced by "to study the conditional probability of meteorological variables **knowing that** a rockfall event occurs" (use the academic formulation). But is this true?

The reviewer is right. We inverted the sentence suggesting that we were investigated the conditional probability of meteorological variables given rockfall occurrences. Consistently with the following comments of the reviewer, we modify the sentence as:

"Employing a Bayesian method, we investigated the conditional probability of rockfall occurrences knowing that a meteorological variable is within a given range"

I have a doubt because: (a) The equation (10) gives the conditional probability of a rockfall event knowing a meteorological variable is in a given range

The doubt is correct. Equation (10) is used to compute $P(R|M_i)$ which represent probability of rockfall occurrences knowing that a meteorological variable is within a given range. We modify the beginning of chapter 3.4 as follows:

"The influence of a weather variable on rockfall events can be analyzed using the Bayesian method (Bayes. 1763) to determine the conditional probability of rockfall occurrence (R) under the condition that a meteorological variable is within a given range"

This is consistent with the sentence modified in the abstract.

(b) This sentence (line 235) "This study focuses on the effects of meteorological variables in triggering rockfall events" suggests that the results rather present the probability that rockfall events occur given that a meteorological variable is within a given range. This seems more useful.

Thanks to reviewer. Indeed, our target was exactly to understand how the variation in the frequencies of meteorological variable affects the rockfall events. Therefore, the new sentence (see comment above) is now more clear.

In section 4.3 (Results), the sentences like " Figure 11 shows the conditional probabilities of cumulative rainfall obtained from weather stations below 1000masl" suggest the opposite. Please precise explicitly in the introduction of the section 4.3 what probabilities are presented in this section!

The reviewer is right. It was a mistake in writing the sentence. The new sentence is:

"Figure 15 presents the conditional probabilities of rockfall events under the condition that rainfall is within a given range. Specifically, Figure 15a illustrates these probabilities for the autumn season at elevations below 1000 m a.s.l. with Sa = 90 days, while Figure 15b shows the probabilities for autumn season at elevations between 1000-2000 m a.s.l. with Sa = 30 days"

Terminology

The term "rainfall intensity" refers to the rate at which rain falls over a specific period and is expressed in mm/hour. In this paper, the variable considered is the "rainfall height" or "cumulated rainfall" or simply "rainfall". The term should be corrected unless you really want to speak about the rainfall intensity (in mm/hour).

The reviewer is right. We modify the wrong term with "total rainfall".

Methods - Bayesian method

The authors should explain why they have to use the Bayesian method (equation 10). Why don't they directly calculate P(R/Mi) by dividing the number of days with rockfalls when the meteorological variable is within the range i, by the number of days when the meteorological variable is within the range i? The way of calculating the different probabilities of equation 10 should be explained.

Thanks to the reviewer. First of all, we add in the manuscript an explanation on how the different probabilities are calculated. This is a useful suggestion. The new paragraph is:

"The conditional probability $P(R|M_i)$ that rockfall events occur, conditioned on the meteorological variable being within the range $i-th$, can be obtained as follows:

$$P(R|M_i) = P(M_i|R)\frac{P(R)}{P(M_i)} \qquad (1)$$

where $P(R)$ is the overall rockfall probability, calculated as daily probability by dividing the number of rockfall events by the number of days of observation; $P(M_i)$ is the probability of the

meteorological variable falling within the $i-th$ range, calculated as daily probability by dividing the number of days with the variable within the range by the number of observation days; and $P(M_i|R)$ is the probability of the meteorological variable being in the $i-th$ interval when a rockfall event occurs, calculated as the number of rockfall events occurred with the variable within the range divided by the total number of rockfall events."

Regarding the Bayesian method, we observe that it is true (as the reviewer suggests) that the number of days with rockfalls when the meteorological variable is within the range i divided by the number of days when the meteorological variable is within the range i would provide the same correct probability. However, we believe that expressing this probability through the Bayes formula allows to formally show that this corresponds to the conditional probability of rockfall occurring given the meteorological variable being within the range i, starting from the observation of the number of rockfalls showing this variable range (i.e., the probability to have a certain variable range given the rockfall occurrence, P(Mi|R)), the prior rockfall probability, P(R), and the prior probability to have that variable range, P(Mi).

Example. Say we have 10 rockfall events with rainfall between 50 and 100 mm. And assume that the rockfall probability (daily probability) is 100 events in 1000 days. Finally, assume that rainfall in the range 500-100 mm occurs 20 times in 1000 days.

In this case, we have:

P(R) = 100/1000 = 0.1

P(Mi) = 20/1000 = 0.02

P(Mi|R) = 10/100 = 0.1

and:

P(R|Mi) = [P(Mi|R)*P(R)]/P(Mi)=[10/~~100~~*~~100~~/~~1000~~]/(20/~~1000~~)=10/20=0.5

This corresponds to the number of days with rockfalls when the meteorological variable is within the range i (10) divided by the number of days when the meteorological variable is within the range i (20), as suggested by the reviewer.

Concluding, the results is the same, but the formalization in terms of conditional probability with Bayes formula is more explaining, because it allows to put in evidence that this conditional probability depends on the prior probabilities and the observations.

Results

Rockfalls and climate variables (from line 355)

Line 357. Please explain (discuss) why a weather variable has a different effect according to the season or elevation. For example, has freezing different effects if it occurs in autumn or in winter? Has a high temperature different effects if it occurs in autumn or in spring?

Thanks to reviewer for the questions. We analysed the results according to season, elevation or aggregation scales in order to identify the presence of some weathered signals in different conditions. In the discussion, we highlight the most significant relationships between rockfall and meteorological variables in different season or elevation classes. This information can inform about the influence of the different meteorological variables, but in our opinion it is not sufficient to investigate the mechanisms that explains why a weather variable has a different effect according to the season or elevation. This because we are analysing a large heterogeneous inventory of rockfalls occurring on a wide range of conditions (not only meteorological, but also lithological and morphological), without constraining the analysis. In other words, the range of complexity is too large to demonstrate the mechanisms, but enough to highlight the influence of some variables in some conditions, as explained in the discussion, also comparing the results with the literature.

To recognize this limitation, we add a paragraph in the discussion:

"Due to the complexity of meteorological but also lithological and morphological conditions under which the rockfall occurred, this analysis does not allow to unravel into detail the mechanisms why a weather variable has different effects according to the season or elevation. For such detail, it should be necessary to constrain the analysis by considering only rockfalls occurring on single lithological and morphological settings through a detailed multitemporal survey that allows to focus on specific weather variables, e.g. thermal stress (Collins and Stock, 2016; Gasc-Barbier et al., 2024; Fei et al., 2025), freeze-thaw (D'Amato et al., 2016), or rainfall (Weidner et al., 2024)"

Collins, B. D., & Stock, G. M.. Rockfall triggering by cyclic thermal stressing of exfoliation fractures. Nature Geoscience, 9(5), 395-400, 2016.

Fei, L., Jaboyedoff, M., Derron, M. H., Choanji, T., & Sun, C. Multiscale observations of diurnal thermal effects on rock failure and crack dynamics in soft marl layers (La Cornalle molasse rock wall, Switzerland). Engineering Geology, 108159, 2025.

Gasc-Barbier, M., Merrien-Soukatchoff, V., Krzewinski, V., Azemard, P., & Genois, J. L.. Assessment of the influence of natural thermal cycles on dolomitic limestone rock columns: A 10-year monitoring study. Geomorphology, 464, 109353, 2024.

Weidner, L., Walton, G., & Phillips, C.. Investigating the influences of precipitation, snowmelt, and freeze-thaw on rockfall in Glenwood Canyon, Colorado using terrestrial laser scanning. Landslides, 21(9), 2073-2091, 2024

D'Amato, J., Hantz, D., Guerin, A., Jaboyedoff, M., Baillet, L., & Mariscal, A.. Influence of meteorological factors on rockfall occurrence in a middle mountain limestone cliff. Natural Hazards and earth system Sciences, 16(3), 719-735, 2016.

Variations of rockfall probability according to the decade are pointed out, but the variations according to the weather factor range should also be commented too.

Thanks for the suggestion. As pointed out in the previous comment, a systematic analysis of the probability as a function of single weather factors is hampered by the complexity of lithological and morphological conditions under which rockfalls have occurred. We tried to represent these variations as a function of weather factors, but the result was not clear enough.

It would be interesting to compare the conditional probability P(R/Mi) with the rockfall probability P(R).

Thanks for the suggestion. We add the rockfall probability P(R) in each figure as a reference to compare the conditional probability.

Line 410-413: Not clear. Equation 10 gives the expression of P(R/Mi) and not P(Mi/R). Please name explicitly the variables considered.

The reviewer is right. In the new paragraph (see above) we clearly describe all the probabilities. .

RAPS method

I suggest to complete the presentation of the RAPS method with this sentence: "A trend of the rainfall is suggested by a parabolic trend of the RAPS (downward parabola for an increase)". See the figure 3 in Garbrecht and Fernandez, and the comment in the same page. A trend on the RAPS plot must not be confused with a trend of the rainfall. Lines 517-519. The trends mentioned by Garbrecht and Fernandez are trends on the RAPS plot, but not trends for the annual rainfall. They highlight a shift that was the result of the relocation of the station. After correction no trend for the rainfall is mentioned. So, I suggest to suppress these lines.

Also, to avoid any confusion, I suggest to modify the lines 520-526 as follows: " In this work, RAPS analysis by altitude, was performed considering the 12 meteorological stations (Figure 20). Below 1000m, from 1974 to 2001, an upward parabola on the RAPS plot shows a downward trend of the rainfall and a from 2005 to 2019, a down ward parabola on the RAPS plot shows an upward trend of the rainfall. In 2002, a sharp increase is noted, likely corresponding to high rainfall events in May and November (Bollettino meteorologico e valanghe, Ufficio idrografico di Bolzano; Protezione Civile Provincia Autonoma di Trento). Between 1000m and 2000m, the downward parabola shows an increase of rainfall for the whole period, which accelerates from 2005. Above 2000 m, the downward parabola from 2003 to 2019 shows an increase of rainfall for this period."

Thanks to reviewer. We modify the manuscript as follows:

"For stations below 1000 m (Figure 4a) the RAPS values decrease from 1985 to 2008, followed by a sharp increase in the most recent years, indicating that rainfall tended to be higher than the mean value after 2008. A notable exception was observed in 2002, which documented a significant peak (red arrow in Figure 4a), likely corresponding to high rainfall events in May and November (as reported by Bollettino meteorologico e valanghe, Ufficio idrografico di Bolzano; Protezione Civile Provincia Autonoma di Trento). For stations between 1000m and 2000m (Figure 4b), a progressively increasing trend in rainfall is suggested by the downwards parabolic trend of the RAPS. Finally, above 2000m (Figure 4c), the RAPS plot exhibits a V-shape, reaching a minimum in 2007, followed by a sharp increase in the last decade."

Figure 20. Equation 14 implies that RAPSn = 0, as can be seen in the figures of Garbrecht and Fernandez. Yet, it is not the case in Fig. 20 of the manuscript. Is there a error in the calculation?

The review is right at the $k = n$ the RAPS has to be zero. We checked the computation and we find the error and consequently we modify the figures.

Discussion (Rockfall)

Line 564-570. This paragraph is not clear. To be significant, the number of anomalies should be reported to the number of rockfalls in each season, range of elevation or range of volume.

I suggest to highlight this point: For rainfall, it appears that positive anomalies are much more frequently positive than negative (Fig. 21a-b), showing that large cumulated rainfall favours rockfall occurrence.

Thanks to reviewer. We modified the figure according to your suggestions and we plotted the frequencies of the anomalous events according to the same meteorological variables used by Paranunzio et al. (2016) but using the strategy shown in meteorological analysis. This choice was made to make comparable the results obtained by Paranunzio's method and those proposed by us. Consequently, we modified the text content to adapt the manuscript to the new figure and the corresponding observations. According to new figure the distinction between positive and negative anomalies was aggregated into the anomalous events frequencies because the comparison with our results was meaningless with this distinction.

Figure 21. Do ST, LT, WT in the figure correspond to daily, weekly, monthly and quarterly in the text? This is not clear. Please use the same terms and give explicitly the aggregation scale in the legend. What is the difference between points and bars in Fig. 21 c and d?

The reviewer is right. After the modification of figure 21 this problem was solved since the same approach used in the previous analyses. This was mandatory in order to make the proposed results comparable with those of Paranunzio.