REVIEWER 1

General comments

The paper presents a detailed analysis of the meteorological, hydrological, and social dynamics of a flash flood that occurred in Catalonia (Spain) on October 22 2019, resulting in six fatalities. This very well documented interdisciplinary study combines observation and modelling to understand the meteorological and hydrological context that led to this exceptional event. The study also provides insight into the dynamics of the warning process, the social perception of this warning and of the social response to this event.

The study relies on a comprehensive data set and the modeling study (both atmospheric and hydrological modeling) are well documented. However, some results may be analyzed in greater depth (see specific comments below) and the analysis of the social response is rather qualitative.

Furthermore, the paper lacks a "discussion" section that could allow comparison with other case studies and provide information about the elements of the study that are of interest to a wider audience, beyond the single case study presented in the article. The conclusions and abstract should be revised accordingly.

Therefore I recommend major revision of the paper to allow the authors to address all the issues pointed out in this review.

The authors would like to thank the reviewer for the highly constructive comments made. The revised manuscript addresses all the concerns pointed out by the reviewer, including a new discussion section. The new discussion section compares the results of the present work with previous outcomes and provide information about the elements of the study that are of interest for a wider audience. The conclusions and the abstract have been revised accordingly.

In addition, a more detailed description of the analysis of the social response has been included. The revised version breaks down the social response into two main components, according to Creutin et al. (2009): management activities and human responses. The former includes three different types of actions: information, organization, and protection. The latter encompasses human responses within three groups: Individual, communal and institutional. Consequently, the title of new section 5.2.1 now incorporates the more precise terms "risk management" and "human response". A more quantitative analysis has been conducted based on information gathered during the FLOOD-UP FRANCOLÍ citizen campaign in the Conca de Barberà council. New Table 7 and Figure 12 describe in detail the type of actions and timeline followed during the course of the flash flood.

N.	Action	Individual	Community	Institutional
	Warnings by the Catalan Meteorological Service (SMC)			X
	Activation of the INUNCAT plan			X
1	Searching and following information about the event			X
2	Activation of the Municipal Emergency Plans			X
3	Meeting of the INUNCAT Technical Committee at the headquarters of the Ministry of Home Affairs			X
4	Some actions: return home, move to an upper floor,... (Power cuts)	X		
5	First actions of firefighters			X
6	Civil Protection asks the population to stay at home and issues self-protection advice			X
7	The Espluga de Francolí city council ask residents not to go to the affected areas			X
8	Recovery and cleaning tasks. Damages evaluation	X		
9	Collaboration in cleaning tasks, help in recovery of wine cellar bottles, etc.		X	
10	Cleaning tasks and search for missing people. Activation of the Forest Defence Groups (ADF) until October 26			X
11	Activation by the winegrowers' association of a campaign of solidarity through the sale of recovered wine bottles. On October 25, the citizen platform "Riuada Solidària" formed		X	
12	Constitution of Municipal Emergence Command Centre at the Espluga de Francolí			X
13	First visit of the President of the Government of Catalonia to the affected areas			X

Table 7 Types of actions and classification during the course of the flash flood in the Conca de Barberà county from 21 October 2019 08 UTC to 24 October 2019 00 UTC. The colour criteria are the same as those shown in the Figure 12.

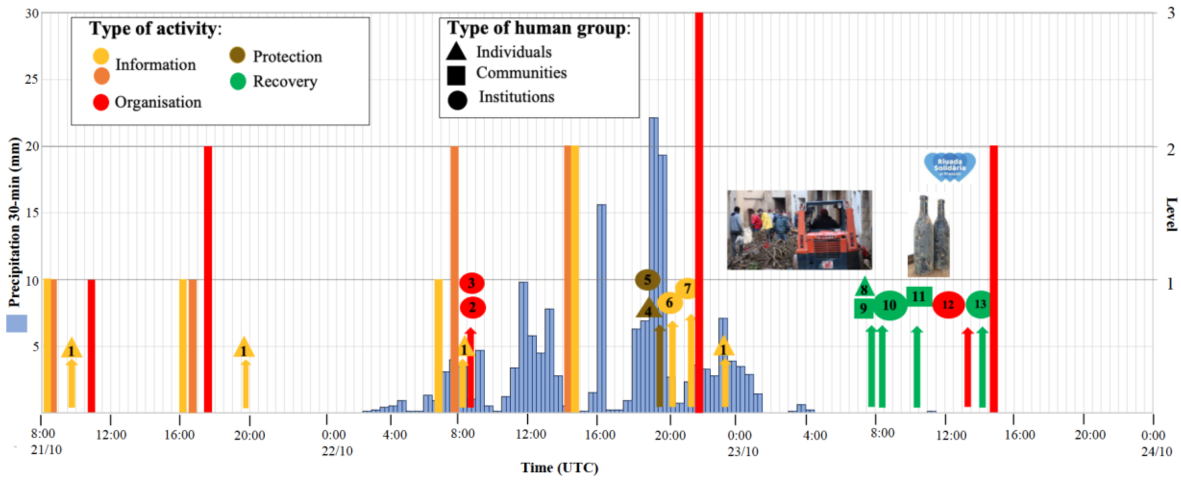

Figure 12: Timeline of warnings issued by the Catalan Meteorological Service (SMC) in the Conca de Barberà county from 21 October 08 UTC to 24 October 00 UTC. Light and dark orange bars denote accumulated precipitation and rainfall rate, respectively. On the right vertical axis, levels 1, 2, and 3 indicate moderate, high, and very high meteorological risk assessments by the SMC for these bars. The progression of activation phases in the INUNCAT plan is illustrated by the red bars. In this case, levels 1, 2 and 3 on the right vertical axis correspond to the pre-alert, alert and emergency stages, respectively. Social actions are also indicated, with colour representing management activities, and shape indicating human responses. The associated numbers align with specific actions detailed in Table 7. Additionally, the background vertical bars in blue showcase the evolution of 30-min rainfall accumulations in Espluga de Francolí.

Specific comments

0/ section 3.1. The atmospheric modeling is based on the new version of a 3D non-hydrostatic model, developed by some of the co-authors, which has been tested and shown to perform as well as more widely used model. This model is use to assess the predictability of the event and the main driving factors of the event. As the authors study the warning process in their paper, it would be interesting to also compare the numerical simulation performed in the paper, with the results of the operational model used in 2019 during the warning process, in particular in terms of positioning of the most intense rainfall. It would allow assessing the data that are crucial to properly anticipate this kind of event. If the TRAM model had been used for the forecasting of this event, would it have improved the forecast?

The TRAM model is forced using ECMWF analyses instead of forecasts, ensuring the application of the most optimal initial and lateral boundary conditions. To achieve this, the TRAM model underwent extensive evaluation against various sources of external large-scale analysis, considering diverse domain sizes, time horizons and various vertical and horizontal resolutions to optimize its performance in terms of the simulated rainfall.

Rather than focusing on the numerical predictability of the event, the model configuration is designed to accurately describe the leading physical mechanisms responsible for the onset and evolution of the convective systems. Consequently, the reference to numerical predictability in Section 3.1 has been removed. Furthermore, during the discussion and review process of this study, the study describing in detail the TRAM model was officially accepted in the QJRMS journal. In the updated reference provided, readers can find comprehensive details regarding the features and effective functioning of the model.

In a technical note (reference below), members of AEMET studied the performance of their operational models (deterministic: HRES-IFS and HARMONIE-AREMO; ensemble prediction systems: ENS-IFS ECMWF and AEMET-SREPS) for this case study. The conclusion is quite clear regarding the complexity of the situation: deterministic models faced challenges in locating the signal of extreme precipitation over Tarragona and the southern part of Lleida, due to the difficulty in representing the convergence line and convective train. Only a few members of the ensembles provided some indication of the risk of very heavy rainfall in those areas. The majority of numerical predictions (deterministic and probabilistic) indicated that the most extreme rains would occur in the northeast of the Catalan region (towards the Pyrenees and the province of Girona), performing better during the latter part of the episode.

In the new conclusion section, it is highlighted the need of implementing EPSs that produce disturbances at scales as small as those explicitly resolved by convection-permitting NWP models. Producing disturbances at these spatial and temporal ranges has become a paramount task to address the rapid growth of errors associated with convective and mesoscale processes. Furthermore, there is a need for a deeper investigation into ensemble generation strategies that sample uncertainties associated with the formulations of physical processes in NWP models. For instance, apart from considering multiple combinations of different physical parameterizations, exploring alternatives such as the effectiveness of HEPSs based on QPFs generated from stochastic physics parameterizations should be explored in next future. The authors have planned a future study in depth about all these issues and how these strategies can enhance numerical predictability for HPEs.

Cuevas, G., and Pascual. R., 2021: Episodio de tormentas y lluvias torrenciales en Cataluña durante los días 22 y 23 de octubre de 2019. Technical Note 36 of AEMET, 37 pp. Ministerio para la Transición Ecológica y el Reto Demográfico, Agencia Estatal de Meteorología, Delegación Territorial en Cataluña (Barcelona, Spain). https://doi.org/10.31978/666-20-027-X.

Romero, R., 2023: TRAM: A new nonhydrostatic fully compressible numerical model suited for all kinds of regional atmospheric predictions. Quart. J. R. Meteorol. Soc., DOI 10.1002/qj.4639.

1/ Line 185. The authors mention that they optimized their simulation to get a higher performance in terms of Quantitative Precipitation Estimate (QPE). Which performance criteria were used for that?

The optimization of the TRAM model settings for studying the physical factors of the episode was, indeed, primarily qualitative. No quantitative verification index of the simulated precipitation structure against observations was applied; instead, it was assessed by expert judgment that the location of the extreme precipitation core in Tarragona and the south of Lleida, as well as the quantities, were most accurate.

Specifically, the configuration of the HR domain routinely run by Meteo-UIB on a daily basis was used as a reference (see https://meteo.uib.es/tram). However, for this study, the horizontal resolution was doubled without increasing the number of grid points. The effect of nesting the model in the large-scale fields of GFS and ERA5 was especially investigated, revealing that the latter produced the best results.

2/ line 188: ERA5 reanalysis is used for the boundary conditions of the model. What is the reliability of the reanalysis for the conditions of October 22 2019? Did the authors perform a sensitivity study to uncertainties in the ERA5 reanalysis?

Yes, as mentioned in the previous point, the simulation quality (in terms of precipitation in the affected areas) was investigated based on using GFS predictions or analyses, and ERA5 reanalyses, for nesting the model. For this episode, ERA5 data provided better results in the study basin. Interestingly, other examined case studies with TRAM did not reveal significant differences between nesting the model in ERA5 and using ECMWF operational analyses. Therefore, the latter (which are less readily accessible) were not considered.

3/ Section 3.2. The authors present how they derived QPE from radar and ground station data. The method relies on radar rainfall field corrected from beam occlusion and attenuation, using a standard rainfall- reflectivity relationship. If I understood correctly, the radar fields are then corrected for possible biases using the automatic ground stations. It seems that QPE used in this study are different from those presented in Martin-Vide et al. (2023) who used co-kriging with external drift of radar and ground stations data. Have the authors compared the two estimates? Have they performed a sensitivity analysis of the hydrological response with respect to uncertainties in QPE estimates?

Correct. In this study the QPEs are estimated by combing radar-derived precipitation with observations from the automatic rain-gauges. Before estimating precipitation, raw reflectivity volume scans are corrected from beam blockage and attenuation due to heavy rainfall. Next, the standard WSR-88D convective rainfall rate-reflectivity relationship is applied to derive rainfall rate from the radar reflectivity factor. Following this, potential biases in hourly cumulative rainfall and patterns are corrected through a dynamical fitting process involving the automatic pluviometers available across the region of interest. Finally, an independent validation is conducted by comparing the total radar-derived precipitation with observations from the AEMET independent network of daily pluviometers The cumulative precipitation from radar estimates compare well with raingauge measurements.

As highlighted by the reviewer, variations in rainfall estimates derived from radar observations are to be expected when using different methods. Martín-Vide et al. (2023) estimated the rainfall field by combining rain-gauge records and the rainfall field derived by the Catalan Meteorological Service (SMC) from its radar network, consisting of 4 single-polarization C-band radars. These authors combined rain records from rain-gauges and weather radars by implementing kriging with an external drift. This approach interpolates rain gauge observations using the radar-derived rainfall as a drift, effectively capturing the spatio-temporal variability of the rainfall field.

In this study, the authors use raw reflectivity volume scans by the Barcelona Doppler C-band radar of the Spanish Agency of Meteorology (AEMET) radar network. Firstly, it is important to note that due to differences in technical features and hardware between radar networks, they can perform differently. In this work, the direct use of the raw volume scan data by the Barcelona radar of AEMET enables the application of an integrated set of procedures. These procedures are designed to detect and correct potential sources or errors, such as, partial beam occlusion, signal attenuation, and radar hardware miscalibration.

Even though the radar-derived cumulative precipitation and raingauge measurements compare well in this study, it is important to acknowledge uncertainties in reproducing fine features of the highly variable precipitation patterns. These inaccuracies stem from the assumptions inherent in different correction procedures. While this issue is very interesting, the authors have not compared the two QPE estimates nor have performed a sensitivity analysis of the hydrological response in relation to these uncertainties. The authors agree that it represents a compelling area for future research. Consequently, statements addressing this issue have been incorporated in the revised version of the manuscript.

4/ Figure 3: this figure shows that high precipitation rainfall amounts were also recorded in the catchments located in the west of the Francoli catchment. Why did the authors focus on the Francoli catchment only?

Indeed, the HPE on October 22, 2019 HPE also impacted the basins adjacent to the Francolí catchment, leading to floods. However, these floods were less severe and did not produce catastrophic downstream impacts. Additionally, the field campaign conducted by Martín-Vide et al. (2023) focused exclusively on the

Francolí watershed. Consequently, there is a lack of detailed information regarding peak discharges and times-to-peak at small drainage scales in the adjacent catchments. Furthermore, the FLOOD-UP FRANCOLÍ citizen campaign was specifically carried out by interviewing the population in the most affected towns inside the Francolí catchment. Therefore, there is also no available information concerning human response, perceptions and specific reactions during the course of this natural hazard.

5/ section 3.3. Hydrological modeling: the hydrological model used in the study is quite simple in terms of hydraulic transfer within the river. Martin-Vide et al. (2023) show that the event led to large geomorphological changes in the riverbed. Is this process taken into account in the hydrological modeling? Does the model make hypotheses about the river bed section (width, depth)?

No, as emphasized by the reviewer, the KLEM model is simple in terms of hydraulic transfer within the river. It relies on a time-invariant velocity value along the channel network. This assumption has found application in several flood modelling studies (Marchi et al., 2010; Nicótina et al., 2008; Zanon et al., 2010, among others). The assessment of simulation results presented in these studies supports the assumption that models of the hydrologic response employing basin-constant channel celerity explain observed travel time distributions, at least for high-flows conditions as observed in Pilgrim (1976).

Furthermore, hydrological models based on the use of an infiltration equation and invariant flow velocities have been employed by several authors for simulating flash floods (Zhang et al., 2001; Giannoni et al., 2003; Javier et al., 2007; Borga et al., 2007; Sangati et al., 2009). This approach allows for the potential transposition of model results from this study to inform other investigations

Borga, M., Boscolo, P., Zanon, F., Sangati, M., 2007. Hydrometeorological analysis of the August 29, 2003 flash flood in the eastern Italian Alps. Journal of Hydrometeorology 8 (5), 1049–1067.

Giannoni, F., Smith, J.A., Zhang, Z., Roth, G., 2003. Hydrologic modeling of extreme floods using radar rainfall observations. Advances in Water Resources 26, 195–203.

Javier, J.R.N., Smith, J.A., Meierdiercks, K.L., Baeck, M.L., Miller, A.J., 2007. Flash flood forecasting for small urban watersheds in the Baltimore metropolitan region. Weather and Forecasting 22 (6), 1331–1344.

Marchi, L., Borga, M., Preciso, E., Gaume, E., 2010. Characterisation of selected extreme flash floods in Europe and implications for flood risk management. Journal of Hydrology 394 (1–2), 118–133. doi:10.1016/j.jhydrol.2010.07.017.

Nicótina, L., Alessi Celegon, E., Rinaldo, A., Marani, M., 2008. On the impact of rainfall patterns on the hydrologic response. Water Resources Research 44, W12401. doi:10.1029/2007WR006654.

Pilgrim, D.H., 1976. Travel times and nonlinearity of flood runoff from tracer measurements on a small watershed. Water Resour. Res. 12 (3), 487–496.

Sangati, M., Borga, M., 2009. Influence of rainfall spatial resolution on flash flood modelling. Natural Hazards and Earth System Sciences 9, 575–584. <http://www.nat-hazards-earth-syst-sci.net/9/575/2009/>.

Zanon, F., Borga, M., Zoccatelli, D., Marchi, L., Gaume, E., Bonnifait, L., and Delrieu, G. (2010). Hydrological analysis of a flash flood across a climatic and geologic gradient: The September 18, 2007 event in Western Slovenia. Journal of Hydrology, 394(1-2), 182-197.

Zhang, Y., Smith, J.A., Baeck, M.L., 2001. The hydrology and hydrometeorology of extreme floods in the Great Plains of eastern Nebraska. Advances in Water Resources 24, 1037–1050.

6/ Line 238. Could you define the term helicity?

Storm Relative Helicity (SRH) is a meteorological parameter used to assess the potential for rotating updrafts within a storm environment (e.g. Markowski and Richardson, 2010). It quantifies the relative rotation of air near a storm, particularly in the lower atmosphere. SRH is calculated by considering the wind speed and direction at different altitudes within the 1000-700 hPa layer in the case of the TRAM output. A clarifying sentence has been included in the revised version of the paper.

Markowski, P. and Richardson, Y. (2010) Mesoscale meteorology in midlatitudes. Wiley-Blackwell, p. 407.

7/ Line 272. The simulation with an erased topography is particularly interesting, as it perfectly highlights the role of topography in enhancing precipitation amounts.

Indeed, these simulations, by excluding the topography in the model, shed light on the physical influence of this factor—often dominant (or at least influential to a considerable extent) in flooding episodes affecting Mediterranean coastal regions

8/ Line 297. "Cumulative precipitation of 29.8 mm to 39.5 mm ...". Does this amount refer to the third part of the rainfall event?

Yes, it does. The dynamics of the successive convective systems impacting the Francolí basin have been further clarified in the revised manuscript. To ease the understanding of the sequence, the text simply alludes to three distinct organized convective systems that sequentially affected the basins.

9/ Line 310 "the relationship between the temporal and spatial scales" and caption of Figure 8d. You should be more explicit on the variable you are plotting in Figure 8d.

The authors agree with the reviewer. The sentence has been rewritten as: "*Additionally, the drainage areas impacted by precipitation intensities surpassing 20 mmh-1 and 50 mmh-1 as well as their temporal durations are explored*". The caption has been modified accordingly.

10/Line 333. The low runoff ratio over the entire basin is not so surprising as half of the catchment was almost not affected by the rainfall.

Well, the authors partially agree with the reviewer's statement. Indeed, the runoff ratio decreased with an increasing drainage basin due to the limited area affected by exceptionally high rainfall. However, the drainage areas less impacted by the HPE within the Francolí basin still accumulated rainfall amounts exceeding 50 mm, as indicated by radar-derived precipitation. It would have been highly insightful to estimate runoff ratios at the different hydrometric sections (Fig. 1) using the hydrological control simulation. However, the moderate error in the simulated flow volume at the catchment outlet has hindered the execution of this task, as a result of the large uncertainties at these river sections.

11/ Section 4.3.2 The hydrological model is only evaluated by comparing with the outlet discharge, which is not well representative of the area with high specific discharge. The model evaluation would be more convincing if the model results were also compared with the maximum peak discharge and time to peak estimated by Martin-Vide et al. (2023). I would have expected this comparison in the paper. A discussion about the impact of the strong geomorphological changes and large wood transport mentioned by Martin-Vide et al. (2023) and induced by the flood on the hydrological model would also be welcome.

The authors appreciate this comment by the reviewer. We agree that evaluating the hydrological model's performance only at the basin outlet may not adequately represent the drainage areas most severely impacted by the flash flood.

Originally, the intent was to assess whether the hydrological model could effectively capture the overall hydrological response based on the measured flood hydrograph at the catchment outlet. In the revised manuscript, the authors have addressed the reviewer's concerns by comparing flood peak estimates and times-to-peak at the hydrometric sections where estimates are available. The first two paragraphs in Section 4.3.2 have been revised accordingly. The hydrological simulation now provides information for all the hydrometric sections surveyed by Martín-Vide et al. (2023).

In addition, a new table 4 has been included to explicitly compare model results with estimates. These modelling outcomes confirms the reliability of the control simulation not only in reproducing the overall basin response, but also in capturing the hydrological response at smaller drainage areas. Figure 11 has been updated to incorporate simulated times for all the aforementioned river sections, facilitating a graphical comparison between model outputs, estimates, and observations. To enhance clarity, the names of the hydrometric sections with available estimates/observations have been included.

River section	Area (km^2)	Peak discharge (m^3s^{-1})	Simulated peak discharge (m^3s^{-1})	Time of peak discharge (UTC)	Simulated time of peak discharge (UTC)
1-Viern (headwaters)	7.1	40–110*	95.4	–	–
2-Viern	9.5	60–120*	133.7	–	–
3-Milans	26.6	115–360*	286.2	19:30*	19:30
4-Sec	38.8	90-110*	181.4	–	–
5-Espluga	97.3	500–775*	550.1	19:50–20:15*	20:00
6-Montblanc	339.9	610–790*	630.1	20:20–20:45*	20:30
7-Riba	449.0	740–870*	758.6	21:00–21:30*	21:00
8-Tarragona	809.1	*871.0*	798.8	*22:30*	22:40

Table 4 Comparison among data obtained from the hydrological control simulation and estimates based on field observations and hydraulic modelling conducted by Martín-Vide et al. (2023). Estimates are marked with an asterisk (*). Observations have been included for completeness (in italics). Refer to Fig. 1 for locations.

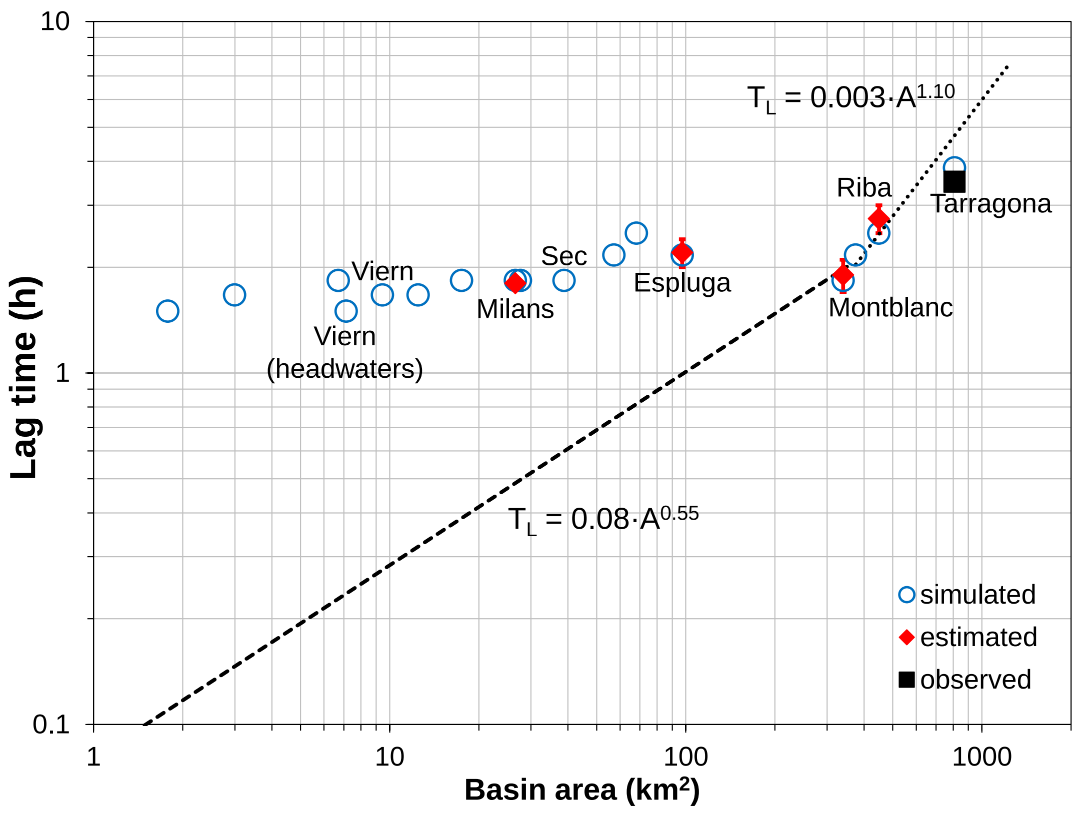

Figure 11. Lag time versus drainage area for the 22 October 2019 flash flood event in the Francolí basin. Uncertainties in the estimated lag times (i.e. derived from the post-event field campaign) are shown as vertical

bars. The "observed" lag-time label refers that it has been derived from the stream-gauge measurements at the Tarragona hydrometric section. Also shown the power-law relationships after Marchi et al. (2010). Refer to Table 1 and Fig. 1 for the names and locations of the surveyed river sections.

Well, KLEM model does not account for geomorphological changes in river channels or for the interaction of woody debris with bridges. These factors primarily influence peak discharges and timing at various river sections in the hydrological model simulations. Transmission losses through the channels are not explicitly considered as well. Infiltration through river beds is indirectly accounted for via the infiltration scheme through the initial abstraction rate, which is considered a calibration parameter. Curve numbers are an input to this work as they are derived from field measurements.

Uncertainties in times-to-peak are minimized using field estimates from Martín-Vide et al. (2023). The hydrological model accurately simulates all times-to-peak within the estimated ranges at the different hydrometric sections (Table 4), providing robust outputs for further analysis of catchment dynamics in Section 5. However, the model is unable to consider the interaction of woody debris with various bridges along the river and its consequential impact on peak discharges at surveyed river sections. All concerns raised by the reviewer have been properly addressed in the rewritten section 3.2 of the revised manuscript, which is dedicated to hydrological modelling.

12/ Line 444. Was the rainfall hyetograph computed for each sub-catchment where peak discharge was estimated?

Yes, it was. A comment to this respect has been included in the new version of the manuscript.

13/ Figure 11: why only 3 estimates appear in this figure whereas Table 1 provides 7 estimates of peak discharge from the post-event survey? Could the location of the estimates be plotted in Figure 1?

Figure 11 has been improved to clarify the concerns raised by the reviewer. While estimates of peak discharge are available for all river sections specified in Table 1, their timing could be confidently determined for only 4 of them through interviews with witnesses. The updated Figure 11 now include labels indicating the names of the hydrometric sections where the lag times have been simulated, estimated or derived from observations.

14/ Lines 465-470: the explanation about points of larger areas lying on the Marchi et al. (2010) curve is not very clear.

The explanation of the sharp transition in lag time with increasing drainage size for this flash flood event has been clarified in the revised section 5.1. Now it reads:

"*The response times of the 22 October 2019 event for drainage sizes larger than 350 km² were strongly influenced by the collapse of a wood debris jam in a bridge between the Espluga and Montblanc towns. According to Martín-Vide et al. (2023), the sudden release resulted in a surge that travelled downstream –while attenuating– at a velocity of 10.2 ms^{-1}. This exceptional high channel velocity in this river reach led to a sharp transition in lag time with increasing drainage size. As a result, the lag times for drainage areas larger than 350 km^2 lie on the lower limit of the envelope curve (Table 1; Fig. 11)*"

15/line 517: which part of the 44 millions euros was related to the Francoli catchment?

The total compensation disbursed to the municipalities within the Francolí basin amounted to 7.4 million euros (not adjusted for inflation), representing 16.6% of the overall sum. This clarification has been incorporated into the text.

16: Lines 518-526. It seems that the fatalities in the Francoli catchment are more related to the obstruction of the bridges that led to particular conditions in terms of water height than to the hydrological conditions themselves. Does the model simulation point out to the same locations for critical hydrological conditions?

The authors refer to the answers of specific comments 5 and 11.

17/ Conclusions: the paper lacks a discussion section, before the conclusions section. The latter is quite long and should be shortened.

As mentioned earlier, a new discussion section has been added to compare the results of the current study with previous findings and provide insights into elements that may be of interest to a broader audience. The conclusions and abstract have been accordingly revised.

18/ Line 566 "belatedly"??

The authors apologize for the incorrect use of this word as they are not English native speakers. The word has been changed to delayed.

19/ Data availability. And what about the availability of post-event data, of the modeling results?

The authors have added a statement of the availability of post-event data and modelling results. These can be obtained under request to the authors.

20/ Figure 4: The caption should provide indication on which variable is shown in colors and which variable is shown with lines

The caption of the figure has been improved to this form: "*Figure 4. Results of the control simulation at 15:00 UTC on 22 October 2019, showing: (a) surface wind field (vectors and speed in m/s according to colour scale); (b) 850 hPa wind vectors and precipitable water in the tropospheric column (mm, according to colour scale); (c) storm relative helicity (m^2/s^2, contour lines) and CAPE (J/kg, according to colour scale); and (d) sea level pressure (hPa, contour lines) and accumulated precipitation in previous 3 hours (mm, according to colour scale)*."

21/Figure 12. The caption of this figure must be expanded to be understandable. For instance, what do the colored lines at the top of the figure refer to? Explain what are the rainfall centroids.

The caption of new Figure 13 now reads: *"Figure 13. Catchment and warning spatial and temporal scales during the catastrophic flash flood of the Francolí River on October 22, 2019. The number of casualties, timing and extent of the most devastating period of destruction according to witnesses (grey shaded area in the rectangle surrounded by thick black lines) are also indicated. Triangles in varying shades of grey represent observed, estimated and simulated times of the peak discharges (Tp). Uncertainties in the estimated times-to-peak based on the post-event field campaign are shown as horizontal bars. Rainfall centroid refers to the time of the centre of mass of the rainfall hyetograph. The coloured lines above the horizontal lines of the municipalities crossed by the Francolí river correspond to the total spatial extension of the risk assessment. The dashed grey line denotes the whole spatial extension of Catalonia. Risk assessment and associated colour codes can be found in Table 6."*