Replies to the Interactive Discussion on **"A paradigm of extreme rainfall pluvial floods in complex urban areas: the flood event of 15 July 2020 in Palermo (Italy)."**

Antonio Francipane, Dario Pumo, Marco Sinagra, Goffredo La Loggia, Leonardo V. Noto

RC1: 'Comment on nhess-2021-61', Anonymous Referee #1, 14 Apr 2021

Dear Antonio Francipane,

We are pleased to inform you that Anonymous Referee #1 posted a new Referee comment in the interactive discussion of the following NHESS manuscript:

Title: A paradigm of extreme rainfall pluvial floods in complex urban areas: the flood event of 15 July 2020 in Palermo (Italy)
Author(s): Antonio Francipane et al.
MS No.: nhess-2021-61
MS type: Research article
Special Issue: Future risk and adaptation in coastal cities

Kind regards,

The editorial support team
Copernicus Publications
editorial@copernicus.org

Replies to the Interactive Discussion on **"A paradigm of extreme rainfall pluvial floods in complex urban areas: the flood event of 15 July 2020 in Palermo (Italy)."**

Antonio Francipane, Dario Pumo, Marco Sinagra, Goffredo La Loggia, Leonardo V. Noto

RC2: 'Comment on nhess-2021-61', Anonymous Referee #2, 26 Apr 2021

Dear Antonio Francipane,

We are pleased to inform you that Anonymous Referee #2 posted a new Referee comment in the interactive discussion of the following NHESS manuscript:

Title: A paradigm of extreme rainfall pluvial floods in complex urban areas: the flood event of 15 July 2020 in Palermo (Italy)
Author(s): Antonio Francipane et al.
MS No.: nhess-2021-61
MS type: Research article
Special Issue: Future risk and adaptation in coastal cities

Please access the discussion at: https://nhess.copernicus.org/preprints/nhess-2021-61/#discussion

To log in, please use your Copernicus Office user ID 210012.

In case any questions arise, please do not hesitate to contact me.

Kind regards,

The editorial support team
Copernicus Publications
editorial@copernicus.org

Dear Prof. Paolo Tarolli,

Thank you for your efforts in handling our manuscript. We thank the Referees, as well, for their constructive comments and observations that have contributed to improve our manuscript and clarify some specific issues.

We provide our detailed replies to the Referees' comments and changes made in the manuscript below. As you will find, the manuscript has been modified to address Referees' criticisms and clarify some of the aspects that required a better explanation.

Main changes done to the manuscript are summarized as follows:

- we modified the Introduction by adding a new paragraph about crowdsourced data and trying to stress better the aims of our work;
- we modified the Introduction, Results and Discussion sections to emphasize the link between the title of our manuscript and the topics discussed in the Introduction and Discussion sections;
- we added a new subsection in the Material and Methods section to point out the importance of crowdsourced data in the study of pluvial floods;
- we added a new paragraph in the section regarding the hydrological modelling to introduce the main outputs of the model;
- we deeply revised the English to make some polishing and improvements.

You will find responses keyed to Referees' comments with a black italic text style, while a grey oblique text style has been used for the Referees' comment.

Sincerely,
Antonio Francipane, Dario Pumo, Marco Sinagra, Goffredo La Loggia, and Leonardo V. Noto.

Responses to Referee #1:

Referee: *The authors apply a hydrological and hydraulic model for calibration and validation of an extreme pluvial event that occurred in Palermo last year. I consider the research valuable and useful in the practice of urban flood risk management. Therefore, to my view, the paper could be acceptable for publication in NHESS if some modifications are made.*

I recommend further strengthening the introduction and discussion sections and correct minor grammar issues to improve the manuscript.

We thank the Referee for the efforts in doing a so in-depth analysis of this work, which has surely improved the quality of our manuscript, and the positive feedback. Please find below our responses to the comments.

Referee: *1- Although the authors provide clear evidence of previous flooding events in the area, the manuscript does not mention the existence of local flood mapping products. Some clues for the reader to lead them to a better understanding of the background on flood risks mapping and/or metrics in the study area would be useful.*

Response: We understand the Referee's point and thank him/her for pointing this out. Actually, there is a Hydrogeological Setting Plan (*Piano stralcio per l'Assetto Idrogeologico* - PAI) for Sicily, which reports the maps for the hydraulic and geomorphological hazard and risk for the Sicilian territory. In the case of the Uditore - Passo di Rigano district, the PAI shows a hydraulic hazard only for the upper part of the domain of study. Despite this part of the domain has been affected by the event of 15 July 2020, it is undoubtedly the least interesting area in terms of pluvial flood effects and does not add any important information to the study. Moreover, the approach used for the determination of the PAI hydraulic hazard map was very simple and just based on the position of the morphological depressions within the study area without modelling any flooding dynamics. These are mainly the couple of reasons why we did not add this information in the manuscript. However, following the Referee's suggestion, in the new version of the manuscript, we have added a new paragraph to the section of Case of Study to explain what above said. The Referee can read the new part in the following:

Despite this area is often interested by flooding events, the Hydrogeological Setting Plan (Piano stralcio per l'Assetto Idrogeologico - PAI) for Sicily, which is a regional plan that reports the maps for the hydraulic and geomorphological hazard and risk for the Sicilian territory, shows the presence of a hydraulic hazard only for two little areas in the upper and central parts of the domain of study, which were scarcely affected by the flood here studied. In this case, the hazard map of the study, which dates to the early 2000s, was made by using a very simplistic approach just based on the position of the morphological depressions and without modelling any flooding dynamics in the study area.

For the Referee's convenience and information, we have reported here the map of the PAI (Figure R1), where the P1, P2, and P3 indicate increasing values of hydraulic hazard, respectively, while the red line shows the domain of study.

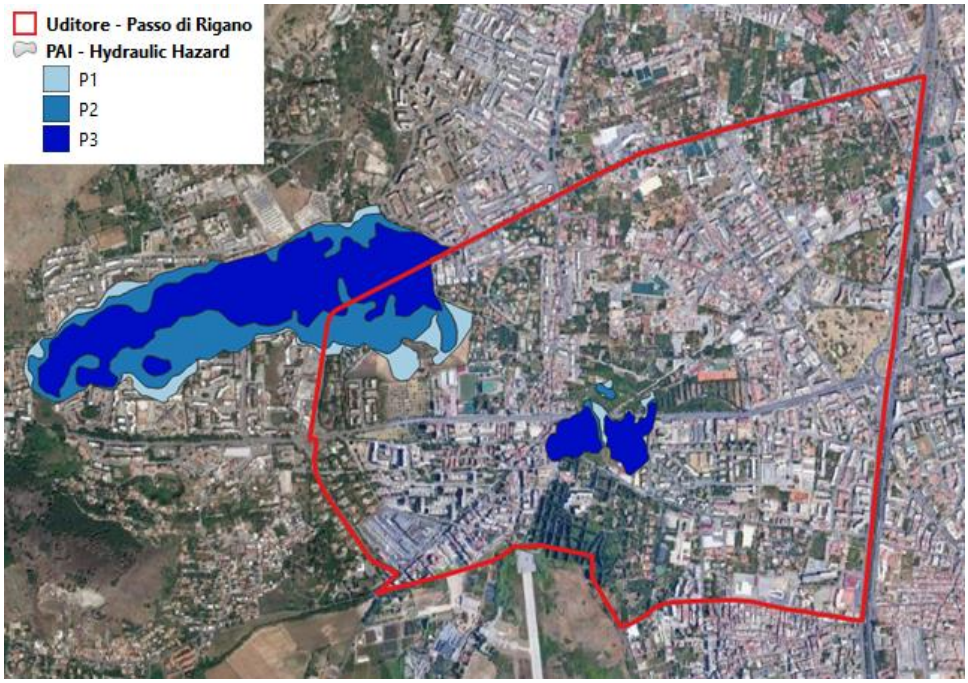

Figure R1 – Hydraulic hazard map for the domain of study (information gathered from the PAI of Sicilian Region)

In addition, following the indication of the Referee, in which he/she suggests strengthening the Introduction, and some indications by the Referee #2 as well, in the new version of the manuscript we have modified the Introduction by making some references to the use of the crowdsourcing data in hydraulic modelling of pluvial floods and stressing better the aims of our work.

Referee: *2- The discussion section is very long and should be greatly shortened. The introduction could also be shortened and should justify why it is important to use crowdsourcing data in pluvial flood risk studies. See Annis et al. 2019 and See 2019.*

Annis, Antonio & Nardi, Fernando. (2019). Integrating VGI and 2D hydraulic models into a data assimilation framework for real time flood forecasting and mapping. Geo-spatial Information Science. 22. 1-14. 10.1080/10095020.2019.1626135.

See, Linda (2019). A review of citizen science and crowdsourcing in applications of pluvial flooding. URL=https://www.frontiersin.org/article/10.3389/feart.2019.00044.

Response: Despite we believe that a detailed discussion is essential to clearly communicate to the reader the main future solutions/interventions to face the effects of pluvial floods, especially in a paper in which we propose to give to the people a "paradigm" to face similar future events, we understand the Referee's concerns. For this reason, in the new version of the manuscript, we have shortened the old Discussion joining it to the Results section thus making a unique section entitled Results and Discussion.
About the opportunity to add some justifications on the importance of the crowdsourcing data in pluvial flood risk studies, we totally agree with the Referee. For this reason, in the new version of the manuscript, we have added a new paragraph in the Introduction, as already stated in our previous response, about the use of crowdsourcing data in pluvial flood risk studies. The Referee can read the new part in the following:

Modelling such a type of floods is never easy, especially when these affect very complex urban areas. Bulti and Abebe (2020) provided a review of the main flood modelling methods adopted for the study of pluvial floods highlighting the benefits and drawbacks of each approach. Some approaches, such as the rapid flood spreading (Lhomme et al., 2008; Wallingford, 2006), are easy to apply but return only the final state of inundation. Other approaches, such as the 1D, are recommended for studies that do not require high precision in describing the surface runoff routing, while still others, such as the 2D approach, seem to be more suitable for applications in urban areas where there is no stormwater drainage or the influence of stormwater drainage is considered insignificant on the flood phenomenon under the study. Coupled models (i.e., 1D-2D) can provide accurate information but being computationally expensive both in terms of run-time and data requirements. In all cases, however, reliable modelling of the phenomenon always requires many kinds of information and level of accuracy, which are not always available or easy to obtain.
In this perspective, one of the main issues to deal with is the lack of observed data to be used as a reference for the calibration and validation of models (See, 2019). Indeed, differently than the case of fluvial (or river) floods in gauged systems, where the monitoring of the rivers makes available measures (i.e., water level, discharge, etc.) in different points of the domain, in urban areas there are no gauged sites that provide water level observations. Nowadays, one of the possibilities to deal with such a problem is represented by remote sensing data, which can provide the opportunity to overview flooded areas quickly and precisely (Di Baldassarre et al., 2009; Bates, 2012; Grimaldi et al., 2016). However, remote sensing data may not be always adequate to describe the evolution and the effects of a pluvial flood either because they are often not timely available for the satellite orbit revisit time (Annis and Nardi, 2019), especially when floods have rapid temporal evolution and limited flood area extent (Notti et al., 2018), or because the substantial areas of urban ground surface may not be visible due to the shadow caused by buildings (Lu et al., 2010; Mason et al., 2021; Mason et al., 2014; Notti et al., 2018). In addition to remote sensing data, in recent times, data gathered by citizens (i.e., crowdsourced data) are becoming increasingly important, even because of the spreading of smartphones and social media users (Hilbert, 2016). The growing availability of crowdsourced data, especially in urban areas, such as pictures and videos acquired by mobile devices (e.g., smartphones, tablets, digital cameras, etc.) and content sharing on social media platforms (e.g., YouTube, Facebook, Instagram, etc.), offers the possibility to gather precious information about the temporal and spatial evolution of flooding events to be used for the calibration of hydraulic models. Many studies have used crowdsourced data to investigate flood events in the last years (Annis and Nardi, 2019; Mazzoleni et al., 2015; Mazzoleni et al., 2018; Smith et al., 2017; Yu et al., 2016).

Moreover, as already stated in our previous response, in the new version of the manuscript we have modified the Introduction by adding new required parts by the Referees. Despite these additional parts, we tried to make the Introduction no longer than the old version.

Referee: *Please see the attached review for specific comments.*

Response: We really thank the Referee for his/her effort in such a deep analysis and for his/her useful indications that have surely improved the quality of our manuscript. The Referee can find our corrections in the following.

Referee: *line 6. have witnessed.*

Response: Done.

Referee: *lines 7-8. need some editing to make the language more precise.*

Response: We deleted this part since by "ground effects" we meant the "response to… extreme rainfall events" already stated in the first part of the sentence. By the way, following the Referee's warning we changed "ground effects" with "rainfall-runoff response" in the rest of the manuscript.

Referee: *lines 8-10. This is a pretty long sentence. Try shortening it.*

Response: We changed this sentence as follows: "*In such a context, the traditional defense of urban areas based on urban drainage systems may not be sufficient to deal with the risk deriving from the occurrence of such events*".

Referee: *lines 12-13. mostly restates the first line.*

Referee: *lines 12-13. Rewrite as "have been experiencing, especially in the Mediterranean region."*

Response: We rewrite this part as follows "*it represents a perfect example of pluvial floods due to extreme rainfalls on a complex urban area that many cities have experienced in recent years, especially in the Mediterranean region.*

Referee: *line 30. Change "has been observed also" with "has also been observed".*

Referee: *line 33. Change "increasing" with "increase".*

Referee: *line 35. Stick with one style throughout the document.*

Referee: *line 36. See previous comment.*

Referee: *line 39. Delete "more and".*

Referee: *line 39. "the ground effects" - as mentioned, need some editing to make the language more precise.*

Referee: *line 56. Change "and humid thus generating" with "and humid. In turn, generating".*

Referee: *line 91. Delete "an".*

Response: Since we have deeply modified the Introduction to address some requests of both the Referees, the sentences with the highlighted parts have been rewritten or deleted. For this reason, the Referee will not find the sentences containing the highlighted parts. However, we would like to point out that we have considered the Referee's indications so as not to repeat the same mistakes.

With reference to the line 39 Referee's observation of the above block, please have a look to our second response to the specific comments.

Referee: *lines 40-41. Change "are further exacerbated, in many areas of the region, by the ever growing urbanization" with "are further exacerbated by the ever-growing urbanization"*

Response: Done.

Referee: *lines 53-54. "one-third"*

Response: Done.

Referee: *line 54. Change "aforementioned" with "previously mentioned".*

Response: Following the Referee #2 request, the part "*As it is possible to notice from the few aforementioned examples,*" has been deleted in the new version of the manuscript.

Referee: *line 60. this part can be put in parentheses.*

Response: We put the word "hillsides" in parentheses.

Referee: *line 60. Change "floods, usually," with "floods usually".*

Response: Done.

Referee: *line 61. Change "exceed" with "exceeds".*

Response: Done.

Referee: *line 62. Change "cause immediate" with "cause an immediate".*

Response: Done.

Referee: *line 67. Do you mean flooding?.*

Response: We meant the drainage of runoff. We now changed this part as well as follows: "*Moreover, pluvial flood modelling can be useful to demonstrate how in some cases a traditional defense of urban settlements based on urban drainage systems may not be efficient.*"

Referee: *line 70. Change "are likely to become always" with "are likely to always become".*

Response: Done.

Referee: *line 71. Change "necessary a new" with "necessary for".*

Response: Done.

Referee: *line 72. The idea is good as you are trying to connect new flood strategies with the 'floodability' concept, but a more concise paragraph (lines 67-72) would be more objective.*

Response: As already said, in the new version of the manuscript we have deeply modified the Introduction. In the new version we mainly moved to the Discussion and Conclusion sections the explanation of floodability concept.

Referee: *line 79. Change "urban flood occurred" with "urban flood that occurred".*

Response: Done.

Referee: *line 72. Change "on surface" with "on the surface".*

Response: Done.

Referee: *line 143. 15. Stick with one style.*

Response: Done.

Referee: *line 144. Change "events occurred" with "events that occurred".*

Response: Done.

Referee: *line 163. Delete "certainly".*

Response: Done.

Referee: *line 164. Change "on" with "in".*

Response: Done.

Referee: *lines 168-173. I suggest to rewrite this idea.*

Referee: *line 170. Change "developing" with "development".*

Response: We have rewritten the sentence as follows: "*This generated an intense updraft that favoured the rapid cooling of the humid air coming from the sea. Moreover, the presence of hills and mountains close to the sea favoured the downdraft of cold and dry air down to the sea, where the presence of warmer and humid air created the conditions for a new updraft that fed continuously the supercell*".

Referee: *line 182. Style should be consistent throughout the document. (check line 304). This also applies to other references.*

Response: We thank the Referee for pointing this out. We have now modified the style in old line 304 to make it consistent throughout the manuscript.

Referee: *line 189-191. Editing needed.*

Response: We have rewritten the sentence as follows: "*The presence of a strong subtropical jet stream (around the 300hPa), cold and dry air (above the 600hPa), and very warm and humid air in lower layers are confirmed by the data recorded at the Radiosonde Data Station Trapani-Birgi (see Figure S2 in the supplementary material)".*

Referee: *line 208. Change "(Forestieri et al. 2018)" with "Forestieri et al. (2018)".*

Response: Done.

Referee: *lines 230-231. Change "will be used for the determination (i.e., hydrographs) of the hydraulic forcing" with "were used to determine the hydraulic forcing".*

Response: Done.

Referee: *line 236. there seems to be a missing word(s)... not clear.*

Response: We have rewritten the sentence as follows: "*The model belongs to the family of the Probability Distributed Models - PDMs (Moore, 1985), which represent the basin as a series of storages of capacity c variable within it*".

Referee: *lines 251-252. 'Due' has been used as adjective/adverb repetitively in the manuscript. Best to use synonyms or rewrite ideas.*

Response: We changed "*is due to*" with "*comes from*".

Referee: *line 254. it is not entirely clear what do you mean by "the slow response of the basin".*

Response: We mean the baseflow. To clarify this concept, we modified the sentence as follows: "*generates the slow response (i.e., baseflow) of the basin*".

Referee: *line 273. Change "runoff surface" with "surface runoff".*

Response: Done.

Referee: *lines 275-276. this sentence could be improved to make it clearer.*

Response: We have rewritten the initial part of this section to make it clearer. The Referee can read the new version of this part in the following: "*The WEC-FLOOD (Filianoti et al., 2020; Sinagra et al., 2020) is a two-dimensional (2D) hydraulic model that solves the Saint Venant equations to study the flood propagation within a 2D domain. The model is suitable for the study in urban areas, where the high complexity in the modelling of the surface runoff prompts for the adoption of 2D models for a better simulation of the flooded areas (Abderrezzak et al., 2009; Dottori and Todini, 2013; Lamb et al., 2009; Mignot et al., 2006). The use of the diffusive form, instead of the fully dynamic one, is mainly motivated by the smaller sensitivity of the computed water depth with respect to the topographic error (Aricò et al., 2011)*".

Referee: *line 284. make problem? this sentence could be improved to make it clearer.*

Response: We have rewritten the sentence as follows: "*To make the model work properly, it is necessary to define the initial and boundary conditions for the domain (Eq. 4)*".

Referee: *line 299. typo.*

Response: We have corrected it.

Referee: *line 303. "and" seems out of place in this transition. Needs a better linking word.*

Response: We have rewritten the sentence as follows: "*In particular, the hydraulic forcing to be propagated within the study area consists of the hydrographs simulated at the outlets of the four contributing catchments (yellow circles in Figure 3) with the TOPDM*".

Referee: *lines 304-306. this sentence could be improved to make it clearer.*

Referee: *line 304. ?*

Response: We have rewritten the sentence as follows: "*The hydrographs were propagated within the study area with the WEC-FLOOD to obtain the flood map for the case study*".

Referee: *line 304. Style should be consistent throughout the document. (check line 153).*

Response: Please look at our previous response to comment on line 182.

Referee: *line 308. "Starting from the" is not needed.*

Response: We deleted this part.

Referee: *lines 311-312. "Consider breaking of ideas into two sentences.*

Response: We have rewritten the sentence as follows: "*The spatial distribution of the topographic index λ was derived from the 2 meters resolution Digital Elevation Model (DEM) data of the study area (Figure 3) with the Single-Flow Direction algorithm (SFD; O'Callaghan and Mark (1984)). The DEM is available at the SITR (Sistema Informativo Territoriale Regionale della Sicilia – Geographical Information System of Sicily). λ was used to derive the specific contributing area and the slope of each catchment with the W-M method (Wolock and McCabe Jr., 1995)".*

Referee: *line 318. this sentence could be improved to make it clearer (lines 317-319).*

Response: We have rewritten the sentence as follows: "*Rainfall data collected at the rain gauges Uditore, Zootecnico, UIR, Bellolampo, and OTT (see Figure 3) were interpolated with the Inverse Distance Weighted (IDW) interpolation to provide the spatial rainfall field over the study area; the distributed rainfall was then used to obtain the rainfall forcing, at the catchments scale, of the hydrological model*".

Referee: *lines 320-322. This sentence could be improved (e.g. The information provided by the MoP was used to.....)*

Response: Following the suggestion of the Referee, we have rewritten the sentence as follows: "*The information provided by the Municipality of Palermo was used to set the maximum discharge (i.e., channel capacity) for the Borsellino, Celona, Luparello, and Mortillaro channels equal to 40, 14, 25, and 11 m^3/s, respectively*".

Referee: *line 332. Change "area" with "environment".*

Response: "Done".

Referee: *line 341. Delete "previously obtained".*

Response: Done.

Referee: *lines 342-343. not clear if this values were adopted in the model. Recommend to be more specific.*

Response: To make it clearer, we have rewritten the sentence as follows: "*Particular attention has been paid to the choice of the roughness coefficient to be used for the simulations; two different Manning coefficient values have been adopted for urbanized and natural areas (Chow, 1959), with values equal to 0.03 $s/m^{1/3}$ and 0.05 $s/m^{1/3}$, respectively*".

Referee: *line 344. The organization and description of results needs some more work.*

Response: We thank the Referee for pointing this out. To address this criticism and some requests of the second Referee as well, we have rearranged the final part of our manuscript (i.e., results, discussion, and conclusions sections). In the new version of the manuscript, we have shortened the old Discussion and joined it to the Result section.

Referee: *line 345. Change "these regard urban floods" with "it comes to flooding in urban areas".*

Referee: *line 346. Change "values of water depth to" with "water depth values to".*

Referee: *line 347. Delete "common".*

Referee: *line 348. Change "shared in social media" with "and content sharing in social media platforms".*

Referee: *lines 350-352. sentence can be improved.*

Referee: *lines 354-355. be more specific...something like goodness-of-fit criteria for assessing the accuracy of simulations.*

Referee: *line 405. Delete "also".*

Referee: *line 405. Change "non-extraordinary storms" with "storms as well".*

Referee: *line 435. ?*

Referee: *lines 435-436. rephrase.*

Referee: *line 441. Change "to force" with "forcing".*

Referee: *line 445. Change "It is therefore" with "Therefore".*

Response: As above said the results and discussion section of the new manuscript version have been modified. In the new version of the manuscript the parts highlighted by the Referee have been changed or moved. However, we would like to point out that we have considered the Referee's indications so as not to repeat the same mistakes.

Referee: *lines 356-357. Sentence can be improve. rewrite sentence.*

Response: We tried to make the sentence clearer as follows: "*Figure 11 shows the map of the flooded areas returned by the simulations in WEC-FLOOD*". In the new version of the manuscript, the old Figure 12 has become the Figure 11 since we have moved the old Figure 6 to the Supplementary material.

Referee: *lines 365-372. grammar.*

Response: We have rewritten this part as follows: "*Figures 12 and 13 show the results of simulations in WEC-FLOOD for the underpasses Da Vinci and Michelangelo, respectively. In that occasion, the two underpasses worked as two big reservoirs where the water depth reached values higher than 4 m. Also in this case, it is possible to notice a good qualitative match with the historical pictures taken from the people in the underpasses Da Vinci (Figure 12) and Michelangelo (Figure 13). The*

simulation returned a value of about 3.2 and 5.0 m of water depth in points 1 and 2 of Figure12, respectively, which are totally compatible with values reported by the Fire Department (i.e., between 4.5 and 5.0 m in the deeper point of the underpass Da Vinci). With reference to the underpass Michelangelo, instead, the model returned a water depth of about 1.5 m in points 1 and 2 and about 2.3 m in point 3 of Figure 13, which are compatible with the water levels showed by the pictures.". In the new version of the manuscript, the old Figures 13 and 14 have become the Figures 12 and 13, respectively, since we have moved the old Figure 6 to the Supplementary material.

Referee: *line 378. it would be great to improve the quality of Figure S2.*

Response: We completely understand the Referee's point. Unfortunately, the resolution of the image is the best available from the website containing the products of Copernicus Sentinel-2 mission.

Referee: *line 381. The discussion session is really long and should be greatly shortened.*

Response: As already said, to address to this criticism and some requests of the second Referee as well, we have rearranged the final part of our manuscript (i.e., results, discussion, and conclusions sections). In the new version of the manuscript, we have shortened the old Discussion and joined it to the Result section.

Referee: *line 382. Change "An effective" with "Effective".*

Response: Done.

Referee: *line 412. Delete "the".*

Response: Done.

Referee: *line 416. Change "real time" with "real-time".*

Response: Done.

Referee: *line 426. Change "cope the combined" with "cope with the combined".*

Response: Done.

Referee: *line 426. Change "With this regard" with "In this regard".*

Response: Done.

Referee: *line 429. Change "green roofs and" with "green roofs, and".*

Response: Done.

Referee: *line 433. Delete “the”.*

Response: Done.

Referee: *line 449. Change “of” with “for”.*

Response: Done.

Referee: *line 451. Change “for” with “to”.*

Response: Done.

Referee: *lines 454-455. Rephrase: "For extraordinary rainfall events, such as the one that has originated the event of Palermo investigated here, the only solution that could contribute to reducing damages and risks are probably those oriented to the concept of floodability.".*

Response: Done. We really thank the Referee for the suggestion.

Referee: *line 451. Change “fulfil” with “fulfill”.*

Response: Done.

Referee: *line 459. Delete “an”.*

Response: Done.

Referee: *line 459. Change “architectural” with “architecture”.*

Response: Done.

Referee: *line 467. Change “less and less rare” with “a new normal”.*

Response: Done.

Referee: *line 468. Change “increasing” with “increased occurrence”.*

Response: Done.

Referee: *line 479. Change “in urban” with “in an urban”.*

Response: Done.

Referee: *linse 480-481. again.*

Response: Done.

Referee: *line 482. Delete "the".*

Response: Done.

Referee: *line 625. Whats the resolution?*

Response: To specify the resolution of the DEM we slightly changed the caption of the Figure 1 as follows: "*Figure 1. **20 meters resolution Digital Elevation Model** of Palermo (Sicily, Italy) with location of the Uditore - Passo di Rigano district (red line) and the Uditore rain gauge station (red point) of the SIAS rain gauges' network. The yellow star in the inset indicates the location of Palermo. Source aerial: © Google Maps Satellite basemap available within the QuickMapServices plugin of Quantum GIS*".

Referee: *line 636. Main contributing catchments for the study area: Borsellino.....*

Response: Done. We thank the Referee for the suggestion.

Referee: *line 671. This figure would be clearer with more explanations.*

Response: The Referee is completely right. In the new version of our manuscript, we modified the caption of the Figure 8 (Figure 9 in the old version of the manuscript) as follows: "*Figure 8. Computational mesh of WEC-FLOOD model. The vertices of each cell (black dots) are the computational centers of the cells (i.e., the point where the water surface is computed for the cell) and are obtained as the circumcenters of the generalized Delaunay triangulation*".

Referee: *Figure 10. lines in legend are blurry.*

Response: We thank the Referee for pointing this out. We have corrected the legend of the Figure 9 (Figure 10 in the old version of the manuscript). For the Referee's convenience and information, we have reported here the new Figure 9.

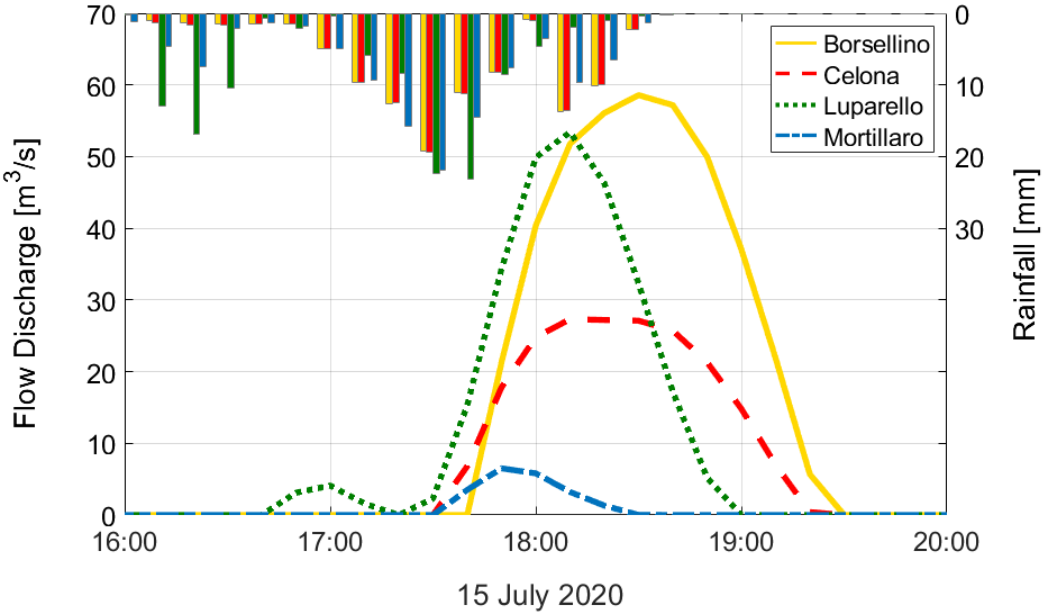

Figure 9. Rainfall Discharge obtained from the hydrological simulations in TOPDM. The bars in the upper part of the figure indicate the IDW interpolated precipitation over the four basins.

Responses to Referee #2:

Referee: *This research investigates on flood risk management of complex coastal urban areas. The case study of the city of Palermo is presented. Severe flooding events impacted the city in recent years. The meteo-climatic forcing and the dense urbanization are the major causes of flood risk for the city where natural channels were substituted by artificial sewer/drainage systems, urban growth increased the nuisance effects of flash floods linked to climate change with related increase of the frequency and severity of rainfall events.*
The flood monitoring systems of the city seems also to be inadequate, and not being able to provide accurate, timely and distributed information of inundation events especially in the pre-event and during the event phases. The rainfall-induced fast flooding phenomena were the subject of citizen-driven observations that may present an important source of information to understand and mitigate the adverse impacts of floods.
As a result, this paper explores methods for developing useful and validated flood models in support of flood risk management and mitigation. Authors demonstrate to have solid knowledge, and scientific hydro-modelling tools (integrating geospatial, hydrologic and hydraulic modelling) and to provide interesting insights for how to develop accurate flood models and validate findings by means of available information. This is a relevant topic for this journal, matching NHESS topics of interest. Nevertheless, I see there are some major issues with this work that I do hope authors will address to improve this submission that – to my view and knowledge – is of interest for a potential publication on the NHESS journal. The general remarks and specific comments are provided here below.

We thank the Referee for the efforts in doing a so in-depth analysis of this work, which has surely improved the quality of our manuscript, and the positive feedback. Please find below our responses to the comments.

Referee: *1 - **The introduction is missing to specify the scientific question or specific science advancement(s) proposed in this work**. In the introduction you extensively introduced the issues of coastal Mediterranean areas affected by intense rainfall storms and flooding, with focus on the Palermo case study. Then, while mentioning uncertainties associated to urban growth and climate change, you referenced the flood adaptation and mitigation measures and more specifically the floodability concept. The use of integrated hydro-modelling is also cited (but not properly references with citations of authors' works or related works to the methods used). As a result, it is not clear – reading the introduction – where this work is specifically pointing to. The manuscript of course include these information afterwards (methods, results later inserted), but I'd suggest authors to insert a paragraph in the introduction to properly guide the reader, citing relevant works and share with the reader the general and specific scientific aims of this work. See also next comment in this regard.*

Referee: *2- **The use of crowdsourcing is spread out from the methods to the results, but not cited in the introduction**. I see this part as relevant for this work. You are validating your flood model using crowdsourced data. While waiting the revised work to understand the major focus (see general comment n.1) and you show how satellite images (supplementary) as well as standard flood observations from the regional agencies are not supporting with actionable information for post-event reconstruction. So, as also shared in specific comments, I see the material section as the one needing to be expanded to include the crowdsourcing and also other EO material citing pros and cons, inaccuracies and opportunities. As also suggested in the specific comments, this work needs some restructuring (some material information inserted in the results etc., see specific comments).*

Referee: *3 - **The manuscript title and the discussion**. I am missing to see the link of the title and introduction to the discussion points. To what I read I think the "paradigm" in the title is not motivated and adequately linked to the final outcomes and critical discussion point of this work. To date, I'd think that post-event reconstruction would be a keyword and focus of this work. But, I see also a lot of potential in the information on meteo-climatic forcings and the way authors design the hydro-modelling of the complex system where natural channels and related hydrologic forcings are linked to the modelling within the city. The complex hydrologic domain is also a key factor of the challenges of similar cases.*

Response: We really thank the Referee for the constructive comments and for pointing out some aspects to be clarified. Since the first three comments are somehow connected to each other, we decided to provide a unique answer to those.

Reading the paper in the light of the Referee's comment, we admit that the Referee is completely right in saying that "*it is not clear – reading the introduction – where this work is specifically pointing to*" and he/she is "*missing to see the link of the title and introduction to the discussion points*". For this reason, following the precious indications of both the Referees, in the new version of our manuscript we have modified the Introduction to stress in a better way the aims of our work. We essentially tried to stress three main aspects that are: 1) the importance to develop a modelling framework to simulate and analyze pluvial flooding events in a complex urban area that can be used as a paradigm for many other cities that may experience similar phenomena as the city of Palermo; 2) the importance of crowdsourced data in the urban environment that is characterized by the lack of observed data (i.e., water levels) to be used as a reference for the calibration and validation of the models; 3) the importance to develop a new way to deal with the flood risk in urban settlements in all those cases in which the economic, social, and cultural conditions do not allow either to renew the old urban drainage systems, no longer suitable to drain the rain coming from some extreme events that are likely to always become more frequent and heavier, or to build new ones. In this perspective, the modelling framework developed on the occasion of the flooding event that affected the city of Palermo on 15 July 2020 can be assumed as a "paradigm" for other cities. We also inserted a paragraph to guide the reader through the aims of this work. In this regard, the Referee can read an extract of the new Introduction in the following:

In this perspective, the study aims at capitalizing on this experience to create a modelling framework that can be assumed as a "paradigm" for those cases in which i) complex hydrologic domains are linked to complex systems of natural channels integrated within an urban settlement, ii) the domain is forced with extreme precipitation, iii) there is a lack of observed data but a plenty of crowdsourced data that can be used qualitatively to verify the reliability of results returned by the modelling chain. In addition, the study attempts to address questions regarding the way to deal with the flood risk in urban settlements where the economic, social, and cultural conditions do not allow either to renew the old urban drainage systems, no longer suitable to drain the rain coming from some extreme events that are likely to always become more frequent and heavier, or to build new ones.

We also understand the Referee's concern about the need to add some material about the use of crowdsourcing and satellite data, citing pros and cons, in pluvial flood risk studies to the Introduction and Material and Methods sections. With this regard, the Referee can read the new part added in the Introduction in the following:

Modelling such a type of floods is never easy, especially when these affect very complex urban areas. Bulti and Abebe (2020) provided a review of the main flood modelling methods adopted for the study of pluvial floods highlighting the benefits and drawbacks of each approach. Some approaches, such

as the rapid flood spreading (Lhomme et al., 2008; Wallingford, 2006), are easy to apply but return only the final state of inundation. Other approaches, such as the 1D, are recommended for studies that do not require high precision in describing the surface runoff routing, while still others, such as the 2D approach, seem to be more suitable for applications in urban areas where there is no stormwater drainage or the influence of stormwater drainage is considered insignificant on the flood phenomenon under the study. Coupled models (i.e., 1D-2D) can provide accurate information but being computationally expensive both in terms of run-time and data requirements. In all cases, however, reliable modelling of the phenomenon always requires many kinds of information and level of accuracy, which are not always available or easy to obtain.
In this perspective, one of the main issues to deal with is the lack of observed data to be used as a reference for the calibration and validation of models (See, 2019). Indeed, differently than the case of fluvial (or river) floods in gauged systems, where the monitoring of the rivers makes available measures (i.e., water level, discharge, etc.) in different points of the domain, in urban areas there are no gauged sites that provide water level observations. Nowadays, one of the possibilities to deal with such a problem is represented by remote sensing data, which can provide the opportunity to overview flooded areas quickly and precisely (Di Baldassarre et al., 2009; Bates, 2012; Grimaldi et al., 2016). However, remote sensing data may not be always adequate to describe the evolution and the effects of a pluvial flood either because they are often not timely available for the satellite orbit revisit time (Annis and Nardi, 2019), especially when floods have rapid temporal evolution and limited flood area extent (Notti et al., 2018), or because the substantial areas of urban ground surface may not be visible due to the shadow caused by buildings (Lu et al., 2010; Mason et al., 2021; Mason et al., 2014; Notti et al., 2018). In addition to remote sensing data, in recent times, data gathered by citizens (i.e., crowdsourced data) are becoming increasingly important, even because of the spreading of smartphones and social media users (Hilbert, 2016). The growing availability of crowdsourced data, especially in urban areas, such as pictures and videos acquired by mobile devices (e.g., smartphones, tablets, digital cameras, etc.) and content sharing on social media platforms (e.g., YouTube, Facebook, Instagram, etc.), offers the possibility to gather precious information about the temporal and spatial evolution of flooding events to be used for the calibration of hydraulic models. Many studies have used crowdsourced data to investigate flood events in the last years (Annis and Nardi, 2019; Mazzoleni et al., 2015; Mazzoleni et al., 2018; Smith et al., 2017; Yu et al., 2016).

In addition, following the specific comments of the Referee, we have added a new subsection in the Material and Methods section in which we have moved some parts of the original manuscript and added a brief description of the type of crowdsourced data used in the study. The new subsection is entitled ***3.3 Crowdsourced data***. The Referee is referred to the new version of the manuscript to read this new subsection.

Referee: *4 - **Writing and structure**. I think the language needs some polishing and improvements. See specific comments. The structure editing may help in making the flux of information easier to read (as already requested in previous general comment n.3).*

Response: We deeply checked and revised the text by trying to improve the grammar and the sentences structures throughout the entire manuscript.

Referee: ***Specific comments.*** *See attached commented PDF.*

Response: We really thank the Referee for his/her effort in such a deep analysis and for his/her useful indications that have surely improved the quality of our manuscript. The Referee can find our corrections in the following.

Referee: *line 1. not clear which paradigm you are referring to.*

Response: The Referee is referred to our first general answer.

Referee: *line 6. "In the last years … are witnessing". Check correct tense.*

Response: We have changed "are witnessing" with "*have witnessed*"

Referee: *line 22. "Gone up to unprecedented levels". Check language.*

Response: We have changed "gone up to" with "*reached*".

Referee: *line 42. "The increasing severity of flooding events is demonstrated by the analysis of extreme events". Check language and content.*

Response: After the significant changes in the Introduction, this sentence has been modified as changed as follows: "*As a result of the above said, in recent times, many areas of the island have experienced some very intense rainfall events, that caused urban floods and flash floods with consequent economic damages and, sometimes, human lives losses.".*

Referee: *line 49. "a series of some heavy". Check language.*

Response: We have changed "a series of some heavy rainfalls" with "*some heavy rainfall events*".

Referee: *lines 54-55. Delete "As it is possible to notice from the few aforementioned examples,".*

Response: Done.

Referee: *line 58. Delete "the so called".*

Response: Done.

Referee: *line 71. "and heaviest". Check language.*

Response: We have changed "more frequent and heaviest" with "*more frequent and heavier*".

Referee: *line 72. "based on the new concepts of "design with nature" and "resilience paradigm"". Avoid redundancy, this was just introduced.*

Response: After the significant changes in the Introduction, this sentence has been removed.

Referee: *lines 88-92. "Even though the city of Palermo has suffered many flooding events in the past, the event occurred on 15 July 2020 is particularly significant, since it represents a perfect example of extreme rainfall pluvial floods in complex urban areas that many cities, especially in the Mediterranean region, have been experiencing in recent years and that, most probably, will have to face even more frequently in the near future due to the combined effects of an intensification in extreme rainfalls and an always more rapid urban growth.". This was already said earlier.*

Response: We have removed this redundancy in the new version of the manuscript.

Referee: *line 97. "the modeling framework here reported". See general comment n.1 about the scientific question and novelty of this work.*

Response: The Referee is referred to our first general answer.

Referee: *line 127. Change "hydraulic sections of channels" with "channel cross sections".*

Response: Done.

Referee: *line 129. "channels above mentioned". Check english.*

Response: We have changed "*channels above mentioned*" with "*above mentioned channels*".

Referee: *line 130. "covered parts of channels". I advise authors to be consistent either using culverts, sewer systems or any terms they prefer, but I'd use one term, provide a definition and stick to it for the entire manuscript.*

Response: We thank the Referee for this advice. We have slightly changed the sentence to define the covered parts of channels as "culverts" and then used this last term in the entire manuscript.

"*The outlets of the four contributing catchments (yellow circles in Figure 3) match with the start points of the covered parts of channels (**i.e., culverts**) Mortillaro, Celona, Borsellino, and Luparello.*".

Referee: *line 152. Delete "that caused the above-mentioned flooding events".*

Response: Done.

Referee: *lines 157-158. Delete "Despite all the events reported in Figure 5 have caused considerable events within the district Uditore – Passo di Rigano".*

Response: Done.

Referee: *lines 173-176. "Figure 6 shows the self-healing thunderstorm cell observed around the 17:00 on the city of Palermo from the visible channel of Meteosat-11 project satellites and provided by the EUropean organisation for the exploitation of METeorological SATellites (EUMETSAT) of the UK Met Office.". Not sure this figure is helpful for the manuscript. It may be moved to the supplementary material.*

Response: Following the Referee's suggestion, we have moved the Figure 6 to the supplementary material. The Figure is now numbered and referred to as S1.

Referee: *line 222. "Depth of about 5 m". How this measure was obtained? Observations?*

Response: The depth and the volume were measured and estimated, respectively, by the Fire Department. We have added this information in the sentence as follows: "*In the underpass Da Vinci, **as measured by the Fire Department**, the water level reached a depth of about 5 m, with an estimated water volume of 28,000 m^3 entrapping many drivers within their cars*".

Referee: *line 235. "main". I would not say MAIN, but the ones of interest for this sort of flooding?*

Response: We have changed the sentence as follows: "*The TOPography-based Probability Distributed Model - TOPDM (Liuzzo et al., 2015;Noto, 2014) is a lumped conceptual model that allows the simulation, at the basin scale, **of all the hydrological processes of interest for the sort of flooding here studied***."

Referee: *lines 255-256. "Distributed Unit Hydrograph". Why capital letters? Is this an acronym?*

Response: Yes, it is the acronym of D-UH from Noto & La Loggia (2007). We have now added the reference to Noto & La Loggia (2007) in the manuscript.

Noto, Leonardo & la Loggia, Goffredo. (2007). *Derivation of a Distributed Unit Hydrograph Integrating GIS and Remote Sensing*. Journal of Hydrologic Engineering - J HYDROL ENG. 12. 10.1061/(ASCE)1084-0699(2007)12:6(639).

Referee: *line 271. I'd add a sentence or two to describe the hydrologic modelling output of the TOPDM model.*

Response: As suggested by the Referee, we have added the following part before the final sentence of the section: "*The model returns in output, in addition to the hydrograph at the outlet of the basin, different hydrological state variables, such as the mean level of soil moisture within the watershed, the percentage of saturated area, the groundwater storage, and the potential and actual evapotranspiration.*".

Referee: *line 274. "reconstruction". Simulation?*

Response: We have changed the word "*reconstruction*" with "*simulation*".

Referee: *lines 297-298. "Generalized Delaunay". Why capital?*

Response: We have eliminated capital letter for the word "generalized".

Referee: *lines 304-305. "so simulated". Check English.*

Response: We have deleted this part.

Referee: *line 307. "Hydrological Simulation". Be consistent with the title of 3.1 "hydrological modelling".*

Response: We have changed the title of this section as suggested by the Referee.

Referee: *lines 308. "digital elevation model". Here capital are needed.*

Response: Done.

Referee: *line 310. "single-flow direction". Capital letters for the acronym.*

Response: Done.

Referee:

lines 320-321. "the simulated hydrographs were reduced of a value equal to their discharge capacity". Please explain better this step.

lines 324-325. "The subtracted volumes were supposed to be delivered downstream the study area by the underground channels". What is subtracted volumes?

Response: We have changed the whole sentence as in the following: "*The Passo di Rigano drainage system was supposed to be in perfect condition of maintenance, even though its actual state is not known because of its complexity. The information provided by the Municipality of Palermo was used to set the maximum discharge (i.e., channel capacity) for the Borsellino, Celona, Luparello, and Mortillaro channels equal to 40, 14, 25, and 11 m3/s, respectively.* ***These channel capacities were then subtracted from the simulated hydrographs and supposed to be conveyed downstream the study area by the culverts***.".

Referee: *line 339. "to force the hydraulic model". Not sure this is the proper way to say it.*

Response: We have changed the whole sentence as follows: "*The discharge hydrographs of the basins named Borsellino, Celona, Luparello, and Mortillaro simulated with the TOPDM (Figure 9) were assigned as inlet boundary conditions and then propagated within the domain of study with the hydraulic model*".

Referee: *line 345. "the goodness of hydraulic simulations, especially when these regard urban floods". Check english.*

Response: Also following a comment from the Referee #1, we have changed this sentence as follows: "*…one of the main difficulties to evaluate the reliability of hydraulic simulations in urban areas is the* ...". Also, as suggested by the Referee in the next comment, we moved this part in the Material and Methods section.

Referee: *lines 346-355. This part on the crowdsourced data should be moved to the Materials section*

Response: As suggested by the Referee and following what said in his/her 2nd general comment, we have added a new subsection in Material and Methods section entitled "Crowdsourced data".

Referee: *line 356. "maximum flood depths". Those depths are estimated at peak time (max of hydrograph) or the maximum simulated at different time steps?".*

Response: The maximum flood depths are those simulated at different time steps.

Referee: *line 365. With regard to the numerical simulation results".*

Response: A specific comment on this part is missing in the Referee's file (it is just highlighted). By the way, we have decided to delete this part, since it seems to be redundant.

Referee: *lines 371-372. Delete "once again".*

Response: Done. Moreover, we have modified the sentence as follows. "*With reference to the underpass Michelangelo, instead, the model returned a water depth of about 1.5 m in points 1 and 2 and about 2.3 m in point 3 of Figure 13,* ***which are compatible with the water levels showed by the pictures***".

Referee: *lines 411-420. I'd stress the importance of using crowdsourcing to post-event analyses, considering satellite data (see supplementary) are not adequate as well as difficult to obtain observations during such critical events. See general comment n.2.*

Response: We have added the following point to the bulleted list.

"*use crowdsourcing data also considering that satellite data are not always adequate to obtain observations during (or after) such critical events (see, for instance, the Figure S3 in the supplementary material) and that are often not timely available because of the satellite orbit revisit time;*".

Referee: *line 625 (Figure 1). The raster DEM should have ranges in the legend, not single values.*

Response: Done.

Referee: *line 636 (Figure 3). "covered part of channels". Culverts or the sewer system.*

Response: As reported in a previous answer, we have used the term "culverts".

Referee: *line 660 (Figure 9). "Computational mesh". Of what?*

Response: We have modified the whole caption as follows: "*Computational mesh of WEC-FLOOD model. The vertices of each cell (black dots) are the computational centers of the cells (i.e., the point where the water surface is computed for the cell) and are obtained as the circumcenters of the generalized Delaunay triangulation*".