A two parameter design storm for Mediterranean convective rainfall

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Response to Referee Comment 2016-644-RC1 – Anonymous Referee #1

The authors are truly grateful for the interest and invaluable work reviewer #1 has devoted to the manuscript and to the research embodied in it. His/her criticisms and comments have been very enriching and have helped greatly to improve it.

We would like to underline specifically the improvements related to the framework of the research, as well as the broadening of the references to other research on this topic. Also, the list of minor remarks helped to make manuscript text clearer and significantly improved.

In answer to the referee, we have discussed and argued the basic questions raised, with corresponding modifications of the manuscript text.

Regarding the 26 specific (line-to-line) observations, all of them will be included appropriately in the revised version of the manuscript, except for the one on section 2.3. There we have preferred to leave the formulae unaltered; that is, with generic Δt instead of replacing it with the value $\Delta t = 10$ minutes. We have justified this decision subsequently in the answer to the reviewer.

1. On the overlapping with Andrés-Doménech et al. (2016)

The results here exposed have been developed in the framework of a research project funded by the regional government of the Comunidad Valenciana (Spain), scheduled for two years.

Preliminary advances were presented in a communication to the 4th IAHR Europe Congress, held in Liege, Belgium (Andres-Domenech et al, 2016). That presentation described the detailed treatment of the data registered by the hydrological information automatic system corresponding to the Valencia (Spain) series with a double goal: On the one hand, the identification of statistically independent convective events from rainfall records, which our paper refers to in section 3.1. On the other hand, the study of the suitability of a theoretical gamma-type temporal pattern to represent the above mentioned events.

The present research documents most of the ulterior theoretical work undertook, with further advances within the cited research project to its completion, including:

a) A new, compact and improved formulation of i(t), function representing the temporal pattern of rain intensity, and the presentation of a series of useful and necessary analytical properties derived from the former, for its appropriate application to practical cases of hydrological design.

b) The development of an original return period assignment methodology, which takes into account both the volume and the intensity of the event.

c) The development of a practical procedure to build the design storm for a pre-established temporal aggregation level Δt and a given return period T.

d) The application to a practical case study of the new methodology and the comparison of results with a traditional method.

e) A discussion of results and general considerations about the suggested methodology in the framework of applied urban hydrology engineering.

Therefore, the contents of this research are new, original, and the necessary link with previous data-work (Andres-Domenech et al, 2016) is referred in section 3. The present work responds to the programmed continuation originally scheduled in the framework of the research project funded by the regional government (*Generalitat Valenciana*) and to its objectives. After the concern of reviewer #1, text in the introduction section (section 1 of the manuscript) has been improved, to clarify the scope of the research, and the link with previous works.

2. On the design storm

The interesting review done by reviewer#1 brings to light several arguable aspects of design storms, not only of the one proposed herein, but also of the well-known alternating blocks method and others which are usually employed in engineering practice. Indeed, all of them show several limitations, and more specifically when used in hydrological applications that require a more complete and realistic representation of the rainfall phenomenon as main input of hydrological systems.

As reviewer #1 points out rightly, the introduction of a new combined variable (X_1) allows, methodologically speaking, the convenient return period assignment to a storm described by several relevant variables. Once a return period T is established, a single value of X_1 is deducted (section 3.4). Obviously, the bigger the magnitude or importance of the storm, the bigger the value of X_1.

This first step is not enough to define the design storm, since according to equation 26, there exist infinite ratios $\alpha=P/I_{10}$ congruent with that value of X_1. In practice, only three values α_1, α_2 y α_3, are chosen, according to the empirical evidence (figure 2), which finally result in three storms associated to the previously defined T.

As reviewer #1 indicates in its comment, those storms display different durations. But it is also worth noting that, in addition, their peaks of rain intensity, total depths, and also their temporal patterns, differ from one another. This last aspect should be extended only to the known shape differences derived from different values of φ parameter.

In other words, the resulting design storms are not the result of a mere and arbitrary choice of three different durations, but are based on the characteristics of real episodes, observed and statistically synthesized in figure 2.

The most traditional use of design storms in hydraulic engineering applications contemplates the sole existence of one unique storm for each T. While maintaining a similar working framework and objectives, the present research represents a step forward, as it contemplates three storms based on observed rainfall registers, for a given T.

As mentioned before, such storms show differences among them, with regard to peak intensity, total cumulative rainfall depth, shape and also duration. The latter, as stated by reviewer #1, is a desirable quality. As a matter of fact, we totally agree with reviewer #1 regarding the interest of using a range of rainfall inputs with different durations and characteristics in hydrological engineering applications. There are several approaches to proceed this way, including direct use of historical records, rainfall stochastic models (temporal and space-time), Montecarlo simulation, and others.

Notably, the authors have had the opportunity of working intensively on some of the above mentioned methods, and more particularly on the use of space-time stochastic rainfall models as input data of water resources systems. As reviewer#1 highlights, we believe these methods (at least when working in a certain range of hydrological engineering problems), are not replaceable by simplified approaches such as the "design storm" ones. Some examples of the work of the authors on this matter can be looked at in the references here below

Garcia-Bartual, R. (2003): Synthetic Flood Scenarios for Risk Assessment in Large Dams, in "Hydrological Risk: Recent advances in peak river flow modelling, prediction and real-time forecasting". Assessment of the impacts of land-use and climate changes". EUROPEAN SCIENCE FOUNDATION. CNR-GNDCI Publ. No. 2858. Ed. BIOS. ISBN 88-7740-378-0. 369-389.

Salsón, S. and García-Bartual, R. (2003): A space-time rainfall generator for highly convective Mediterranean rainstorms. Natural Hazards and Earth System Sciences, vol. 3. 103-114. Ed. European Geophysical Union.

Frances, F., R. García-Bartual and G. Bussi (2012): High return period annual maximum reservoir water level quantiles estimation using synthetic generated flood events, in "Risk Analysis, Dam Safety, Dam Security and Critical Infrastructure Management". Taylor and Francis, ISBN 978-0-415-62078-9. 185-190.

However, the research undertaken herein is essentially framed in the context of design storm formulation. Consequently, it emerges from premises which are different from the above mentioned methods and has, therefore, its inherent limitations.

With regard to the shape of the function, another issue mentioned by reviewer #1, there is no doubt that rainfall intensity empirical records show a extremely wide range of patterns. They are difficult to reproduce by means of a single analytic function such as the one proposed herein, or a method such as the one used in the alternating blocks method. It should be pointed out, though, than in the latter, the peak is always located at the centre of the storm while duration is basically arbitrary. In the case of the gamma function, the relative position of the peak is variable (it depends on the value of φ), although it comes always before the central point as reviewer #1 states. This hypothesis clearly implies a simplification of reality, but is also statistically consistent since, according to what is described in the manuscript, it is derived from real sequences of rainfall intensities and its corresponding patterns found in selected rainfall events, unlike the temporal pattern of alternating blocks. The idea came originally after a pioneer research in this field [Brummel, 1984], referred in the manuscript. Concerning duration, it is not arbitrary, as mentioned before. It essentially depends on value of parameter φ, which originally derives from the analysis of historical rainfall events identified in the registers used.

We share the belief with reviewer #1 that gamma function is an interesting pattern and appropriate for the simplified representation of convective temporal rainfall patterns. Specifically, Mediterranean convective rainfall episodes derived from the activity of individual convective cells, show particularly short durations and high intensities, unlike typical rainfall episodes in other parts of the world. On the other hand, there exist physical and empirical foundations for such election, as the pattern represented is consistent with activity life-cycle of a convective cell, described in terms of an initial rapid development until reaching a maturity stage during which maximum intensities are attained, and then followed by a stage of dissipation in time, typified by a progressive attenuation of rainfall intensities.

We also believe, in line with the comments expressed by reviewer #1, that the use of alternating blocks storm, along with the gamma-type design storm and other simple design storms, are not the best choice for certain, larger scale hydrological applications requiring a more quantitatively detailed and extensive representation of rainfall intensity process in space and time.

3. On the comparison with the alternating block method

Certainly, as reviewer #1 pointed out, the comparisons made with current methods used in hydraulic design are interesting, for example the Average Variability Method (AVM). In the draft we include a comparison with a method that is extensively used in Europe and especially in the Mediterranean countries. Section 5 of the manuscript, not being the most important one of the work, was included for illustrative purposes and for contrast with the best known method in the latter regions. Perhaps a further exhaustive comparison, not only with the AVM method, which is in itself very interesting, but with methods implemented in other parts of the world might be of interest for future research.

Line by line comments

Page 1, Line 8: Can probably remove the second "of"

We agree, it will be removed in the revised manuscript.

Page 1, Line 11: Remove "On the former work basis"

We agree, it will be removed in the revised manuscript.

Page 1, Line 13: "High" not "Highly"

We agree, "high" is the correct word.

Page 1, Line 23: "They experienced their major development . . . still unresolved" This sentence is overly vague. What was the development? What was left unresolved?

The sentence will be rewritten as follows in the revised manuscript:

"They experienced an important development during the 1970s and 1980s with more realistic approaches (Pilgrim and Cordery 1975; Walesh et al. 1979; Hogg 1980, 1982; Pilgrim 1987)."

Page 2, Line 6: "Widespread" – should this be "widely used"? "Widely known"?

Yes, the correct wording is "widely used".

Page 2, Line 33: Again, this is a very vague sentence. What are the conceptual mistakes and unrealistic assumptions? Are you addressing these here in this paper?

The sentence will be rewritten as follows in the revised manuscript:

“Some authors point out that the design storm concept itself is fraught with conceptual error when used to simplify engineer analysis by unrealistic assumptions (Adams and Howard, 1986).”

Page 3, Line 5: I think you can argue that the temporal pattern has just as much of an influence (see the aforementioned http://arr.ga.gov.au/arr-guideline for a discussion on this as well references on this topic). For example, Ball (1994) (doi: 10.1016/0022-1694(94)90058-2).

Sentence in line 5 will be rewritten as follows:

“… the influence of storm duration and temporal pattern becomes critical (Ball, 1994).”

Page 3, Line 7: Stronger consequences than what?

The text has been improved, accordingly to this comment by reviewer #1.

In fact, “stronger” is not the correct word. It will be replaced by “strong” in the revised manuscript. In addition, the following sentence will be added at the end of this paragraph:

“The above mentioned uncertainties in IDF curves estimation can affect significantly the reliability of derived design storms, especially in the definition of its peak rainfall intensities, with undesirable consequences when used for hydrologic design purposes”.

Page 3, Line 15 and 16: You have one thing being the most uncertain step and another thing being the most challenging task. This seems to be a contradiction and needs rewording.

Page 3, Line 17-23: This could be rewritten as one sentence: “As a design storm is composed of many variables (e.g. depth, duration, temporal pattern, and antecedent conditions) assigning a single return period may not be appropriate.”

The sentence “Finally … challenging tasks” will be removed. Paragraph in lines 15-23 will be rewritten as follows in the revised manuscript:

"A storm event presents many characteristics so it cannot be fully described by the statistics of only one of them. For a return period definition, a common practice is to assign a given frequency to a specific event feature (i.e., its maximum intensity). But, given that a design storm is composed of many variables (depth, duration, temporal pattern, antecedent conditions), assigning a single return period may not be appropriate.

Page 3, Lines 23-30: These lines just state what was performed in this manuscript. This should be rewritten to state exactly the problems this paper is addressing and how it is building on previous work.

Lines 23-30 in page 3 have been replaced by the following text, which helps the reader to focus better on the problems studied herein, according to reviewer's comment:

The objective herein is formulating an analytical approach in order to describe rainfall intensities in time, as an alternative for practical design storm definition in Mediterranean areas. Also, developing all required analytical properties to ensure its applicability under usual criteria and requirements of design storm approaches for hydrological design. These include a methodology for return period assignment based on both, total depth and peak intensity of the storm. Also, a practical methodology to build the storm, applied to a given case-study to validate it. For illustrative purposes, a comparison with most extended design storm in Mediterranean areas will be developed and discussed.

Page 4: Could Line 8-24 be moved up and then Lines 1-7 follow. As it stands you state you use a gamma function in Line 3 and then don't actually introduce it till line 25.

We agree with reviewer comment. Text at initiation of section-2 (page 4) of the manuscript can be improved, for a clearer reading. The following changes in the text are introduced in lines 2-7, which make the exposition better organized and clearer:

"The temporal pattern of rainfall intensities representing the design storm is expressed in terms of a continuous analytical function, of the form given in eq. 1:

$$i(t) = i_0 \cdot f(t) \quad ; \; t \geq 0 \qquad (1)$$

where t (min) is the elapsed time from the start of the rainfall episode (t=0), i(t) represents the rainfall intensity at instant "t", i_0 (mm/h) is the instantaneous peak rainfall intensity of the storm, and f(t) is a convenient non-dimensional, continuous and differentiable analytical function, which will be defined below."

Page 5: Not sure if another line can be added between equation 8 and 9 because I sort of missed this step.

Once again, we agree with reviewer comment, as minor changes in the text can help the reader to follow better the undergoing developments at that section.

LINES 7-11: (new re-written text):

"To do so, a final or residual value is established as a fraction η_1 of the maximum (eq. 7).

$$f(t_C) = \eta_1 \;\; ; \;\; 0 < \eta_1 < 1 \qquad (7)$$

where t_C (min) represents the total storm duration ($t_C > t_0$). Convenient η_1 values are shown in table 1. Introducing condition given in equation 7 into equation 2, yields to equation 8, which should be verified by $f(t_C)$.

Page 5, Line 24: I don't like the use of the word "easily".

The word "easily" will be removed in the revised manuscript.

Section 2.3: I understand the use of generic terms but I think you just use a delta t of 10 minutes so maybe it would make more sense to just employ that constant in this section (as you have in previous sections with eta1 of 0.05).

We understand comment by reviewer #1. In section 2.2 of the manuscript, as mentioned, the general expressions are obtained, and also particularized for the specific value $\eta_1 = 0.05$, which is later used in the application. This helps to illustrate the practical use of equations 14 and 19, with a very significant simplification of the expressions. But it should be remarked that this is not only done just for illustrative purposes, but also, and more importantly, to point out relevant properties (eq. 15 and 20). In particular, the latter one implies that the ratio i_0/P is directly proportional to the value of φ parameter.

In the same manner, in section 2.3 general expressions are obtained. But in this case, we consider that equations 22, 23 and 24 are clear enough as such, not being simplified in any way by substituting the particular value $\Delta t = 10$. Also, it should be noted that this substitution is not necessary at this point of the manuscript, and does not yield to any relevant property, as it was the case in previous section 2.2.

Page 8, Line 20: "not a" should be "no".

Yes, the correct word is "no".

Section 3.1.1 – A useful reference is Dunkerley, D. (2008), Identifying individual rain events from pluviograph records: a review with analysis of data from an Australian dryland site, Hydrol. Process., 22(26), 5024–5036, doi:10.1002/hyp.7122.

The following sentence will be added in the revised manuscript just before "Works by Restrepo-Posada…":

"Dunkerley (2008) presents an interesting review of the range of approaches used in the recognition of main events".

Page 9, Line 9: "Less" instead of "Lower".

Yes, the correct word is "less".

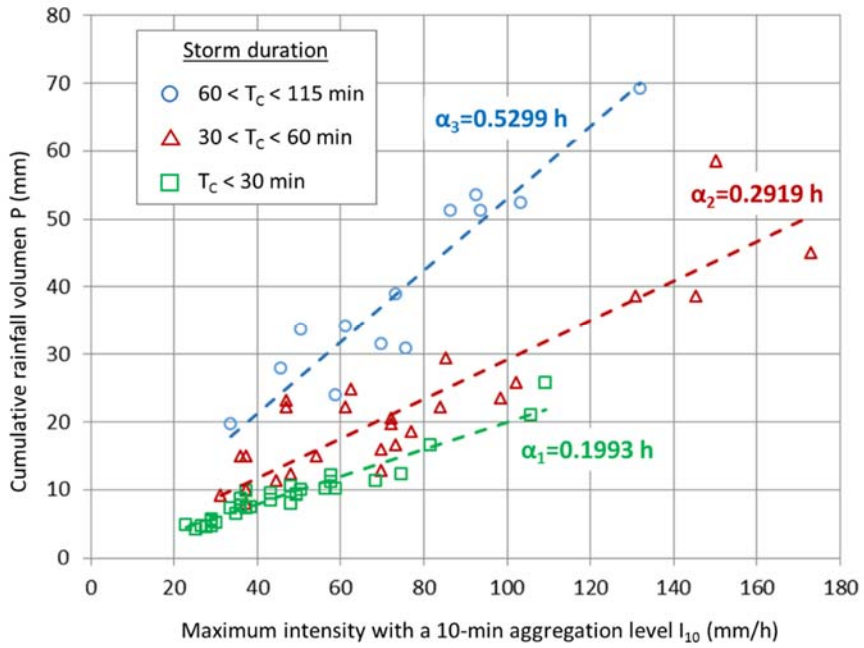
Section 3.2: I thought the relations were characterized by splitting the storms on critical duration (see Figure 2) not the ratio as stated in Line 5.

The first sentence of this section (page 10 – lines 4-5) will be rewritten as follows:

"Three different sets of events were identified, according to their duration. As shown in figure 2, each of them can be characterized in terms of a representative value of the ratio:"

Figure 2: I don't think the colours and symbols match.

We agree, there is a mistake. Triangles and squares are mixed up. Figure 2 will be replaced by the following one:



Section 3.2: It would be nice to discuss in one line what the different alpha's mean in practice to the temporal pattern.

The following sentence will be added at the end of section 3.2. in the revised manuscript:

"Low α values typically correspond with storms with its peak intensity located short after the initiation of the storm, while higher α values are found for longer events and usually higher cumulative rainfall depths".

Page 11, Line 5: I don't like the use of the word "tackle" in general. I would prefer "undertaken" or something similar.

"tackle" will be replaced by "undertaking" in the revised manuscript.

Page 11, Lines 20-27: This seems to be just repeating the introduction. It also talks about storage not being important and then states it is important. I would probably just remove this paragraph.

We agree with reviewer #1. This paragraph will be removed in the revised manuscript.

Page 15, Line 10: You state the alternating block method overestimates the volume. But all these temporal patterns are statistical constructs anyway – so we don't know which is the truth.

The sentence "It is demonstrated … in excess." will be substituted in the revised manuscript by the following:

"Given a return period, the alternating block method combines in a single theoretical storm the most adverse statistics for several durations, which originally derive from different historical rainfall events. Conceptually, this is a worst-case storm ignoring actual rainfall patterns found in the rainfall registers, yielding to a volume overestimation.

Page 15, Line 19: "Most generally . . ." In Spain? In Europe? Around the world? This is not done Australia for example.

In the revised manuscript, "Most generally" will be replaced by "In many European and American countries".

Page 16, Line 23: I am still undecided if this is an advantage – counting three storms for every return period. Is it more that the advantage is you have a more robust definition of the return interval in that the depth and temporal have been incorporated into one variable?

In the revised manuscript "…with the advantage of counting with…" will be replaced by "…resulting in…"

New references

Resulting from reviewer #1 comments, suggestions, and critics, the following references will be added to the revised version of the manuscript:

Ball, J. E. (1994). The influence of storm temporal patterns on catchment response. Journal of Hydrology, 158(3-4), 285-303.

Di Baldassarre, G., A. Brath, and A. Montanari (2006), Reliability of different depth-duration-frequency equations for estimating short-duration design storms, Water Resour. Res., 42, W12501, doi: 10.1029/2006WR004911.

Dunkerley D. (2008). Identifying individual rain events from pluviography records: a review with analysis of data from an Australian dryland site. Hydrological Processes, 22 (26), 5024-5036.

Frances, F., R. García-Bartual and G. Bussi (2012): High return period annual maximum reservoir water level quantiles estimation using synthetic generated flood events, in "Risk Analysis, Dam Safety, Dam Security and Critical Infrastructure Management". Taylor and Francis, ISBN 978-0-415-62078-9. 185-190.

French, R., and Jones, M. (2012). Design rainfall temporal patterns in Australian Rainfall and Runoff: Durations exceeding one hour. Australian Journal of Water Resources, 16(1), 21-27.

Pilgrim, D. H. and Cordery, I. (1975). Rainfall temporal patterns for design floods. Journal of the Hydraulics Division, 101(1), 81-95.

Pilgrim D. H. (1987). Australian rainfall and runoff: a guide to flow estimation. Vol. 1. Institution of Engineers. Australia.

Walesh, S. G., Lau, D.H. and Liebman, M. D. (1979). Statistically based use of event models. Proceedings of the International Symposium on Urban Storm Runoff. University of Kentucky, Lexington, 75-81.