Answer to Reviewer No. 2 of: Extreme runoff response to short-duration convective rainfall in South-West Germany, by Ruiz-Villanueva et al.

March 5, 2012

Introduction

We thank the Reviewer#2 for the revision of this manuscript. Accordingly with his/her general comments we introduced new elements in the revised version which are related to: i) assessment of runoff ratio, and ii) influence of storm motion on flood hydrograph. We also made clear that the section related to the analysis of storm motion represent a major step in the analysis of the influence of rainfall space-time variability on flood response, and provides a template for studies aiming to isolate the effect of storm motion on flood response.
We hope that this effort will improve the manuscript, by strengthening the weak points highlighted by this Reviewer.
We tried to answer here every comment in detail, although issues of typographical or editorial illustrations and tables are not incorporated here, but have been modified in the revised version of the manuscript.

General comments

Comment 1.1:
I find the title misleading: it deals with extreme runoff" and it turns out in the paper that the runoff is limited (p.10757, l.22). I think the title should reflect more accurately the content of the paper.

Response
As made clear in the paper, rainfall and runoff were extreme for this event. Examination of the quantiles corresponding to 1000-year recurrence interval indicates that the rainfall was well beyond a 100-year, but below a 1000-year event. This corresponds also to the return period of the field-estimated discharge. In spite of these very large values, we found that the runoff ratio is surprisingly low for this event. Text in the revised version should be able to remove this criticism.

Comment 1.2:
As highlighted in the evaluation section, I do not see what are the original and innovative contributions in this manuscript. The introduction is not clear about the scientific objectives of the paper.

Response
We agree with the Reviewer#2 that the original text was unclear about the main objectives of the work. We revised the text as follows:
“Two main questions are examined in this study based on the observational and modeling resources.
First, we aim to quantify the distribution of the values of event runoff ratios across the various subbasins surveyed during the post-event survey, and to compare these values with those obtained from the analysis of less severe flood events. Analysis of event runoff ratios may provide essential insight on how different landscapes ‘filter’ rainfall to generate runoff and how the observed differences can be explained by storm and catchment characteristics.

Second, we aim to analyse how the spatial and temporal distribution of the extreme rainfall, and more specifically storm motion, control flood response. This question has been rarely examined with reference to real flood events, essentially because of lack of a quantitative statistic relating the space–time properties of rainfall and drainage basin properties. For this purpose, we use the concept of 'catchment scale storm velocity' proposed by Zoccatelli et al. (2011) and based on the Spatial Moments of Catchment Rainfall. These statistics, which build on previous work by Viglione et al. (2010) and correspond in part to the catchment rainfall statistics reported in Smith et al. (2002, 2005), assess the dependence of the catchment flood response on the space-time interaction between rainfall and the spatial organization of catchment flow pathways. Moreover, we introduce a methodology to evaluate the impact of neglecting the storm velocity in flood modeling. This assessment bears important implications on the storm properties which should be monitored and forecasted for effective flash flood forecasting and more in general for flood risk management in the study area. "

Comment 1.3:

Sections 4-5-6: what are the main messages/results? The paper sounds very descriptive to me and lacks in-depth analyses. In addition, the processing of weather radar data presented is not new (see for instance Bouilloud et al., 2009); the use of high water marks to estimate the peak discharge has been described in previous studies by some of the authors; idem for the hydrological model. So what is the new information that the hydrological community should get from this manuscript?

Response

The three Sections have been revised in detail. Established techniques described in Section 4 and 5 are of interest due to their combination for the detailed analysis of an extreme events. Section 5 has been strengthened by adding analyses of other five flood events, which have been used to examine the performance of the model in simulating different more moderate floods. In Section 6 we aim to analyse how the spatial and temporal distribution of the extreme rainfall, and more specifically storm motion, control flood response. This question has been rarely examined with reference to real flood events, essentially because of lack of a quantitative statistic relating the space–time properties of rainfall and drainage basin properties. The use of the concept of 'catchment scale storm velocity' is central in this analysis. Moreover, we introduce a methodology to evaluate the impact of neglecting the storm velocity in flood modeling. This assessment bears important implications on the storm properties which should be monitored and forecasted for effective flash flood forecasting and more in general for flood risk management in the study area.

Comment 1.4:

Section 7: here also, what are the main results? This section is very descriptive, but there is no general (and transferable) message conveyed! The conclusion about the influence of storm motion has already been proposed in the past (Singh, 1997; Morin et al., 2006, to list a few).

In addition, the last statement about the influence of topography is not supported by any analysis/plot in the text.

Response

We modified the last three points of the conclusions as follows:

- “Even though the antecedent soil moisture conditions were relatively wet, small runoff ratios (less than 20%) characterized the runoff response at Rangendingen. Uncertainties in rainfall estimates and model simulations may affect these results. Anyway, it is shown that these values are in the range of values of runoff ratios computed for other less extreme floods recorded at Rangendingen. Also, the values reported for Rangendingen are in the range of those computed for other 8 surveyed catchments. Overall, this support the view that runoff ratio estimates obtained in this work are robust and may provide an indication for runoff generation triggered by short and intense rainfall in small to medium rural catchments in Central Europe. As such, these values are in the range of those reported for short duration flash flood events in other areas of Continental Europe (Zoccatelli et al., 2010).
- The distributed flood response can be reasonably well reproduced with a simple distributed hydrological model, using high resolution rainfall observations and model parameters calibrated at a river section which includes most of the area impacted by the storm. The model is capable of consistently reproducing the flood peaks at 8 sites (out of 17) estimated during the intensive post-flood survey. However, the response at three sites characterized by field-observed extreme response and very small catchment scales proved to be largely underestimated by the model. The nature of the error (either observational, or on the modeling side, or both) remains elusive. To examine the performance of the model in simulating different floods, the model was applied to five moderate flood events selected in the period 2002 to 2010. The model results shows that parameters identified on an extreme event may be transported to less extreme cases, when initial conditions are properly accounted for. It remains to be shown if the inverse, more useful, process of parameters identification on moderate events for use in extreme flood cases may be also successful. Anyway, the finding that event runoff ratios are relatively similar for short duration floods, irrespective of the rainfall depth, support this view.
- The Hilal organized system of thunderstorms was characterized by its rapid storm motion. We developed a methodology that affords isolation of the effects of storm motion on flood response. The rapid downbasin motion of the principal rain band was important, even though not dominant, in controlling the magnitude of the runoff response, by increasing the modeled flood peak by 13%. This suggest that fine space and time rainfall resolution is required in the study region to effectively monitor the storm characteristics which may be important for flood forecasting. “

Specific comments

Comment 2.1:

P.10740, l.14: “small runoff ratios": this is in contradiction with the title!

Response

See response to comment 1.1.

Comment 2.2:

P.10742, l.5-6: please provide a reference to strengthen the statement.

Response

We introduced the following reference: Uhlenbrook et al. (2002). This paper reports on the significance of meteorological input and the physiographic basin properties for runoff generation during extreme floods (recurrence intervals of greater than 10 years) for 29 mesoscale basins in southwest Germany.

Comment 2.3: P.10743, l. 22: what are the units mm a^{-1}?
Response
This has been corrected in the text.

Comment 2.4: P.10743, l.25 and p.10744, l.25: I think the units of the specific discharge should be m^3 s^{-1} km^{-2}.
Response
This has been corrected in the entire manuscript.

Comment 2.5: P.10746, l. 18: what are these "extremely high rain rates"? No values are provided... What make the authors think they are extreme?

Response
The reviewer is right, no values were provided in detail in that section, but this affirmation is based on the data provided later in the text (see p.10748):
"The analysis of the mean areal rainfall depth over the basin at Ragendingen provides a value of 85.6mm for the entire storm event, and of 55.5 mm for the 90 min corresponding to highest intensities. A statistical analysis based on the KOSTRA methodology (DWD, 2006) shows that the observed short-term rainfall corresponds to a 100-year recurrence interval. However, the recurrence interval of the entire event (85,6 mm in 10 hours) is more extreme. The 100-year rainfall of 9 hours duration according to DWD (2006) amounts to 63,6 mm, which corresponds to 67.6 mm for 10 hours. Examination of the quantiles corresponding to 1000-year recurrence interval indicates that the rainfall was well beyond a 100-year, but below a 1000-year event. This corresponds also to the return period of the field-estimated discharge".

Comment 2.6: P.10747, l.1-2: how do you take into account hail occurrence in the employed attenuation correction?

Response
In general, a reflectivity threshold (hail cap) parameter was used to identify hail contamination. However, owing to large attenuation by hail, it was difficult to recognise and isolate these situations. As a result, hail occurrence was not specifically accounted for in the attenuation correction. This clearly induces errors in the application of the MRT, due to the violation of the drop size distribution time-homogeneity assumption when hail is occurring. However, the MRT has been shown to be robust with respect to contamination of hail (Serrar et al., 2000).
We introduced the following text:
"It should be noted that hail occurrence may induce errors in the application of the MRT, due to the violation of the drop size distribution homogeneity assumption. However, the MRT has been shown to be robust with respect to contamination of hail in past studies (Serrar et al., 2000)."

Comment 2.7: P.10747, l.10-15: the rain gauges that are used to calibrate the radar rain rate estimates should not be used for their evaluation. The text is not clear about this issue...

Response
In order to clarify this aspect, we modified the section as follows:
"Radar-rainfall estimates obtained in this way were evaluated by comparing them with rain gauge observations at the hourly aggregation scales (which were considered as reference values, Fig. 4). The statistical assessment was carried out in terms of Mean Absolute Error (equal to 0.48) and Correlation Coefficient (equal to 0.90). The mean error is null, due to the use of the event-cumulated raingauge data for bias correction. These results show that, given the constraint provided by the bias correction, the radar-rainfall estimates correctly reproduce the precipitation spatial and temporal repartition detected by raingauges at the hourly temporal resolution."

Comment 2.8: P.10750, Eq.2: The definition of T is not clear to me. The time is not a random variable, so its variance has no meaning...

Response
We introduced the following text to answer this point.
"The reader is referred to Zoccatelli et al. (2011) and Viglione et al. (2010) for the use of the $cov_t[\ ]$ and *var[ ]* operators."

Comment 2.9: P. 10751, l.20-22: the shift to the headwaters also corresponds to a strong decrease in the rain rate, so this is simply the rain system going out of the catchment, no?
Response
This indeed occurs between 17:00 and 17:30.

Comment 2.10: P.10751, l. 27: "..the spatial distribution of rain depth and intensities": storm motion is controlling the spatial distribution of rainfall intensities (in time), so this sentence is not clear to me.

Response
In order to clarify this part we modified the sentence as follows:
"According to the literature (Ogden et al., 1994; Singh, 1997), the downbasin storm velocity may have added to the severity of the storm, giving rise to a stronger flood peak than that of an equivalent stationary storm characterised by the same temporal rainfall distribution and by the same value of Δ_1".

Comment 2.11: P.10756, Eq.3: shouldn't it be As?
Response
The error is in the reference to A_s, which should be substituted by the catchment area A.

Comment 2.12: P.10756, l.23: more details are needed concerning the calibration of the model parameters.

Response
The model was implemented over the Starzel catchment at 15-min time step and using a 90 m grid size cell for the description of landscape morphology and soil properties. The

most sensitive model parameters (saturated hydraulic conductivity and flow velocity parameters) were manually calibrated based on the peak flood estimated in Rangendingen and on the information concerning the chronology of the flood collected in Rangendingen and in Jungingen. The manual calibration aimed to minimise i) the error in the time of the rising hydrograph, ii) the error in peak discharge and peak time, and iii) the error in the recession limb of the hydrograph. Information concerning the timing of the main hydrograph feature was based on eyewitnesses assessment. Uncertainty analysis of this kind of information based on multiple crosschecked interviews shows that the timing of specific flood hydrograph features may be accurate within ±20 min (Zanon et al., 2010).

Comment 2.13: Table 2: the units for the area should be added (km^2 I guess). The units for the unit peak discharge are strangely written...
Response
This has been corrected and a revised table is reported.

Comment 2.14: Figure 3: the exponent for s in the units is not correct.
Response
This has been corrected.

Comment 2.15: Figure 8: barely readable...
Response
This has been corrected and a revised figure is reported.

References

Bouilloud, L., B. Boudevillain, G. Delrieu, B. Galabertier, L. Bonnifait, P.-E. Kirstetter, and M.-L. Mosini (2009), Radar rainfall estimation for the post-event analysis of a Slovenian ash-ood case: application of the Mountain Reference Technique at C-band frequency, Hydrol. Earth Syst. Sci., 13 (7), 1349-1360.

Morin, E., D. C. Goodrich, R. A. Maddox, X. G. Gao, H. V. Gupta, and S. Sorooshian (2006), Spatial patterns in thunderstorm rainfall events and their coupling with watershed hydrological response, Adv. Water Resour., 29 (6), 843{860, doi:10.1016/j.advwatres.2005.07.014.

Singh, V. P. (1997), Effect of spatial and temporal variability in rainfall and watershed characteristics on stream flow hydrograph, Hydrol. Processes, 11 (12), 1649-1669.