Answer to referee #1

We first wish to thank the anonymous referee #1 for his feedback and comments and his agreement on the importance of the data base and of the subject that this paper addresses.

We present in this paper the use of a variance based sensitivity analysis method applied to 10 large flash floods for 6 headwater catchments covering various physiographic conditions. A distributed hydrological model adapted to the simulation of Mediterranean flash floods is used and the temporal evolution of the sensitivity factors of the computed discharge to 5 parameters during the various phases of flood events is analysed.

Answer to general comments:

1) We agree that this approach is a local sensitivity analysis which aims to propose a framework and to analyse temporal dynamics of parameter sensitivity (TEPADS) for a functioning point in the parameter space of an event hydrological model.

   Concerning calibration for a given catchment, it is performed over several flash flood events with an optimization technique considering different starting points in the parameter space, as detailed in the revised manuscript (cf. specific comment n° 10). We think that using several flash flood events to constrain parameter values helps to reduce equifinality problem. But calibration problem for hydrologic models is still a difficult open question especially for event models and extreme catchments' behaviours such as flash floods.

   Concerning the optimality of the parameter sets: we do not pretend to have reached "the best parameter sets" for these catchments, the word optimal needing to be defined in function of the modelling goals, especially if modelling (and data) uncertainties and parameter values are considered variable in time. Nevertheless, performances of the model on the events considered in calibration and in validation are rather high over the six catchments of interest and may therefore be considered as sufficient for flash flood prediction purpose. Yet we would like to point out that the aim of this paper is not to test the predictive performances of the model, which would require a larger set of events under various conditions.

   The answer to the question of how sensitivities change for different parameter sets is not straightforward and further studies would be welcome for example with several parameter sets for one catchment. However, previous global sensitivity analysis studies already show that the model response is sensitive to C_Z (Bessière, 2008; Roux et al., 2011) which seems to indicate that sensitivity may change little for a different optimal parameter set.

2) We agree about the importance of a correct description of rainfall amount and spatial variability for flash flood simulation. We use a combined radar raingauge product with 1x1 km^2 spatial resolution and 5 minutes time step. Product reliability is not available but an important number of raingauge is used to correct quantitative precipitation estimation. Further investigations on model inputs would be interesting but more parameters would be required to consider uncertainty and correct rainfall amounts. The large sensitivity of the model to soil depth may be partly due to a misspecification of the rainfall input, however it is physically sound. Indeed, results show that estimated C_Z values are strongly correlated with the catchment geology (Table 2 in paper): for instance catchments developing on metamorphic substrates have estimated C_Z values around 4. This seems to stem from the soil depth used in modelling only accounting for soil horizons O, A and B. Horizon C is not taken into account whereas it may be hydrologically active.

Answer to specific comments:

1) Abstract: lines 1-15 rephrased in: "This paper presents a detailed analysis of 10 flash flood events in the Mediterranean region using the distributed hydrological model MARINE. Characterizing catchment's response during flash flood events may provide a new and valuable insight into the dynamics involved for extreme catchment response and their dependency on physiographic properties and flood severity. The main objective of this study is to analyze flash flood dedicated hydrologic model sensitivity with a new approach in hydrology, allowing model outputs variance decomposition for temporal patterns of parameter sensitivity analysis. Such approaches enable ranking of uncertainty sources for non-linear and non-monotonic mappings with a low computational cost. Hydrologic model and sensitivity analysis are used as learning tools on a huge flash flood dataset. With Nash performances above 0.73 on average for this extended set of 10 validation events, the five sensitive parameters of MARINE distributed physically based model are analyzed. p.1377 lines 5-10. Shortened and rephrased in: "The high variability of precipitations (Moussa et al., 2007) along with topography influence and spatial distribution of soil and land use properties makes hydrological processes largely variable both in time and space (Pilgrim et al., 1988)."

2) p. 1377, line 24 corrected: "among others for…"; p.1384, line 6 corrected: "were proposed"; p. 1386, line 15 corrected: "mainly develops.."

3) p. 1378, lines 12-15 and throughout the paper, rearranged in chronological order

4) p. 1378, line 21: reference about BATEA added (Kavetski et al., 2006)

5) p. 1380. Acronyms defined TEDPAS and TIGER, "TEPADS" corrected in TEDPAS throughout the manuscript

6) p. 1383 Eq. (4): the integrals range is between 0 and 1, indeed parameters are normalized by their variation range. Precised p. 1382 line 5 -6: "…inputs normalized by their variation range."

7) p. 1386, line 1-3, ok, supressed: "stream gauges and rating curves quality is good also for the catchments of interest."

8) p. 1386, lines 5-7. Ok, rephrased in: "Thus the French Mediterranean region rather frequently affected by intense rainfalls represents an interesting area for flash flood study in a regional manner (Garambois et al., 2012b) with contrasted catchments' properties, rainfall distributions and hydrological responses characteristics (Garambois et al., 2012a)

9) p. 1387, lines 18-21. Ok, rephrased in: "An estimation of uncertainty for soil moisture model outputs would be welcome but it remains a hard task given that a very good knowledge of soil properties and structure seems to be required."

10) p. 1388, lines 8-10. Sentence rephrased in: "Catchment parameter sets that will be used in this paper are given in Table 2." Table 3 and sentences added to explain calibration methodology: "For each catchment, model calibration is performed by estimating a parameter set over several flash flood events (Table 3), i.e. a cost function equals to 1-Nash is minimized over multiple flood events (called global Nash hereafter). The minimization technique is a BFGS (Broyden–Fletcher–Goldfarb–Shanno) algorithm considering multiple starting points in the parameter space. The

validation is performed on other available flash flood events and efficiencies are given in Table 3." We do not pretend to have reached "the best parameter sets" for these catchments, the word optimal needing to be defined in function of the modeling goals, especially if modeling (and data) uncertainties and parameter values are considered variable in time. Nevertheless, performances of the model on the events considered in calibration and in validation are rather high over the six catchments of interest (Table 3). Performance decrease is slight for the whole catchment set from calibration to validation with mean Nash values of 0.86 and 0.7 respectively (Table 3).

11) Ok

12) p. 1388, line 26. Explained: "…in other words catchment's spatial and temporal dampening effect".

13) p. 1389, line 8. Ok, corrected.

14) p. 1389, line 14. Ok, corrected.

15) p. 1390, line 21. Size of the parameter space precised (calibration window) in Table 2. Since it is a local sensitivity analysis method we only explored smaller values than 50%. Moreover too large sensitivity analysis window can deteriorate variance estimation quality or even convergence.

16) Notion of metamodel explained. p.1384, line 16. Sentences rephrased and added: "The method used in this paper is the State Dependent Parameter metamodelling method (Ratto et al., 2007a) which is based on recursive filtering and smoothing estimation to build an approximation of the computational model. Ideas and tools from signal processing and time series analysis are used to estimate the terms in the ANOVA-HDMR decomposition using a special recursive fixed interval smoothing algorithm that estimates the parameters in a State-Dependent Parameter (SDP) formulation of the input–output mapping (Ratto et al., 2007a).

17) p. 1390, lines 19-23. Rephrased in : « Figure 4 shows a limited influence of sampling range on temporal sensitivity index to C_Z which is yet the most sensitive parameter on average. $S_{i1}\_C_Z$ estimation differences are lower than 15% after model initialization and during hydrograph late recession, and lower than 5 % for the rest of the simulation especially when most hydrographs are peaking (t = 20h to 27h).

18) p. 1392, lines 1-11. We agree, table 4 and 7 have been rearranged in ascending order of specific peak flow for each event.

19) Table 1, corrected and precised: "Hsol is the spatially distributed soil depth estimated from pedologic data."

20) Table 4. Ok averages removed.

21) Table 4, Bransby formula added.

References:

Bessière, H., 2008. Assimilation de données variationnelle pour la modélisation hydrologique distribuée des crues à cinétique rapide. PhD thesis, Institut National Polytechnique de Toulouse, France. http://ethesis.inp-toulouse.fr/archive/00000710/.

Kavetski, D., Kuczera, G., Franks, S.W., 2006. Bayesian analysis of input uncertainty in hydrological modeling: 1. Theory. Water Resour. Res. 42, W03407. doi:10.1029/2005WR004368

Roux, H., Labat, D., Garambois, P.A., Maubourguet, M.-M., Chorda, J., Dartus, D., 2011. A physically-based parsimonious hydrological model for flash floods in Mediterranean catchment. Nat. Hazards Earth Syst. Sci. J1 - NHESS 161, 2567–2582.