Reply to Interactive comment on "Multi-scale hydrometeorological observation and modelling for flash-flood understanding" by D. Archer (Referee)

I. Braud et al., April 2014

In the following, the reviewer comments appear in black italic and our answers are provided in blue.

General

This paper gives a clear account of the monitoring philosophy to document the variability of active hydrological processes between and during flash floods from the hillslope scale to the regional scale. Although a suitable event has not yet occurred that will provide a comprehensive test for the developed network, the ambitious network and programme at all scales and at all stages of the hydrological cycle already provides suitable material for publication.

Answer: We tank Dr. D. Archer for this positive appraisal of the paper content.

However, I am concerned about the absence of a clear definition of a flash flood. The paper makes a distinction between 'normal' and 'extreme' behaviour in floods (p1876 C257 line 20). Does this imply that all extreme floods are flash floods? How would the authors distinguish between normal floods and flash floods given that there are many definitions of 'flash floods' (eg Douvinet and Delahaye, 2010). For example, did all 144 rain events having daily precipitation amounts greater than 190 mm during the 1958–94 period in southern France listed by Jacq (1994) generate flash floods – or did intense rainfall events of short duration of much lower total rainfall also generate flash floods on small to medium catchments. Is a flash flood characterised by the magnitude of its peak or by the rapidity of its onset (ie the rate of rise of the hydrograph)? (p 1874 line1). How rapid does the onset of the flood need to be categorised as a flash flood? Does the intense rainfall of the Mediterranean region require a different definition of a flash flood from those in more temperate areas as described by Douvinet and Delahaye ?

Answer: These questions about the definition of a flash flood are very interesting and we agree with the reviewer that a clear definition of what we mean with "flash flood" must be included in the revised manuscript. Although several papers address flash floods, only few of them provide a definition of flash floods. Gaume et al. (2004) cite an IAHS-UNESCO-WMO (1974) definition of flash floods: "*sudden floods with high peak discharges, produced by severe thunderstorms that are generally of limited areal extent*" which is quite vague. In a further study compiling flash flood data across Europe, Gaume et al. (2009) write "… *extreme flood events induced by severe stationary storms have been considered as flash floods. This relatively broad definition includes almost all the past events reported as flash floods in Europe, except dam break floods. The duration and spatial extension of the area affected by such floods depend on the causative storm and hence on the climatic setting. Most generally, the storms inducing flash floods lead to local rainfall accumulations exceeding 100 mm over a few hours (or more than 50 mm in less than 3 hours in northern France) and affect limited areas: some tens to some hundreds of square kilometres. Larger scale and longer lasting stationary storm events may, however, occur in some meteorological contexts, especially in the Mediterranean region. As an example, an area larger than 3000 km2 received more than 300 mm rainfall within about 12 h on the 8th and 9th of September 2002 in the Gard region of France (Delrieu et al., 2004). On the basis of these considerations, it has been decided that the most extreme floods in watersheds of an area of less than 500 km2, generally induced by short duration storms (i.e. less than 24 h) should be considered as flash floods*."

The definition we retain in our study is close to the Gaume et al. (2009) one, even if the catchments we consider are somehow larger (up to 2000 km^2). This definition includes a wider set of events than the one proposed by Douvinet and Delahaye (2010), which consider what is also called "storm overflow runoff", where the main processes are the combination of intense rainfall of short duration, high intensities and surface runoff with often erosive power. This type of flash floods is also characterized by their violent onset (in less than 1h) and high values of specific peak of discharges (up to $1m^{-3}.s^{-1}.km^{-2}$). The flash floods we are considering include this type of events but are not restricted to it. As mentioned by Gaume et al. (2009), the generating rainfall can also be long lasting rainfall (about 24h with moderate intensities but leading to accumulative rainfall of several hundreds of mm), which is quite specific of the Mediterranean region (see Delrieu et al, 2005 for a summary of their typical characteristics). In terms of dominant processes, the runoff can be explained by surface runoff in agricultural areas. In forested areas, due to the high infiltration capacity, estimated to be of several hundreds of mm/hr (e.g., Ayral, 2005), hortonian surface flow is seldom observed and sub-surface flow represents a significant contribution to the flood discharge (for example in the Valescure catchment in the paper). Hence the involved mechanisms are broader than those observed by Douvinet and Delahaye (2010) in the sedimentary areas. In terms of magnitude, Gaume et al. (2009) show that their European flash floods sample was characterized by specific peak discharge ranging from about 0.5 to 40 m3/s/km2. A specific peak discharge of this range is also considered necessary to speak about flash floods in our context, in addition to a quick rise of the flow (in a few hours).

To summarize, we retain the following criteria for the definition of a flash flood. The rise of the hydrographs should be very short (a few hours or less for catchments of 1-100 km2 and less than 24h for catchments of about 1000 km2). To be considered as flash floods, the events must also have a significant peak discharge larger than 0.5 m3/s/km2.

Concerning the specific comment about Jacq (1994) study, we can provide the following elements. The inventory proposed by Jacq (1994) only concerns rainfall events. The document does not mention the associated damages or if they triggered flash floods. In addition, the inventory only deals with local gauge measurements, which is different from catchment rainfall. We would also like to underline the following points: 1/ intense rainfall events exhibit a high rainfall spatial and temporal variability; 2/ flash floods most often occur in ungauged catchments, so it is not always easy to know where a flash flood has occurred for a given event. It is likely that a flash flood occurs only in some part of a given catchment. Indeed, a rapid onset of the flood and a high peak discharge are more likely in small catchments than in larger ones. For instance Fig.14c shows that, during the November 9-10 2012 event, the specific discharge was larger than 0.5 m3/s/km2 for the small 3.9 km2 catchment but not for the larger ones.

Were any of the events in autumn 2012 considered to be flash floods? If they were 'normal' was this because they did not produce exceptional peak flows or because they did not have rapid onset?

Answer: In autumn 2012, there was no significant event with rainfall larger than 150mm in 24h in the study catchments (Ducrocq et al, 2013) over the period September 5 to November 6 2012. In addition, before the 9-10 November event which is discussed in the paper, soil moisture was not high enough to induce a significant hydrological response. As illustrated in Fig. 14c, the catchment response was quick (a few hours), but the specific peak discharge was too low for the events to be considered as flash floods, except for some small catchments where it reached values larger than 0.5 m3/s/km2. But in any case, the response was not exceptional.

Given the availability of historical data (at least on rainfall) did they consider or calculate the risks of not getting a suitable event during the period of the project? Given the limited spatial extent of many flash floods is there particularly a risk that no events may occur on the three small catchments (Valescure, Tourgueille, Gazel) for many years.

Answer: This question is interesting. For the preparation of the HyMeX 2012 Special Observation Period, a statistical analysis was performed to select the period with the highest probability of getting a rainfall event larger than 150-200 mm over the whole Western Mediterranean, but the same kind of study was not conducted for the study catchments. Nevertheless, the Valescure and Tourgueille catchments are instrumented since 2003 and 2008 respectively. In Valescure, significant events with specific peak discharge larger than 0.5 m3/s/km2 were observed each year, with a maximum in October 2006 with a value of 3.2 m3/s/km2, which also destroyed the gauging station. In Tourgueille, the November 2011 event also destroyed the gauging station. The Gazel catchment has only been installed in 2010. In 2013, the 23rd October 2013 event, mentioned in section 4.3 of the paper also significantly affected the Gazel catchment, with a two-peak rainfall and a rise of the water level from 0.2 to 0.6m for the first peak and 0.2 to 1.4m for the second peak. So up to now, we have already registered in the various catchments (both historically and since 2012) interesting flash flood events in the small catchments. As the experiment is lasting two more years, we are confident that we will record other interesting events. In addition, as most of the experimental set up involves continuous measurements, we also record interesting events (not necessarily flash floods) during the whole years. These events also provide interesting insights on the active processes in various hydro-climatological contexts.

Specific comments

P 1879 line 9 et seq. With respect to hillslope monitoring, different network arrangements are made for the Gard and the Ardèche catchments on the basis of what are 'thought' to be the dominant modes of surface runoff. You should give some basis for this judgement or 'thought'.

Answer: The answers to those questions are indeed provided in the introduction of section 2.2 p. 1878, and are based on previous experimental studies in the area, with similar geological and/or land cover. But it should be made clearer on p. 1879 and in the text.

Previous studies (e.g. Cosandey et Didon-Lescot, 1990; Tramblay et al., 2010) showed that sub-surface flow could be relevant for part of the Cévennes-Vivarais region (forested area and granite lithology like in the Valescure catchment). Infiltration/runoff field experiments (Ayral, 2005; Marchandise, 2007) showed that the infiltration capacity of the top-soil was very high (a few hundreds of mm/hr) in the forested and granite lithology, generally excluding surface runoff as an active mechanism. For shale lithology, at the field scale, Brunet et al. (2010) also show the existence of soil saturation at the interface between the soil and the bedrock, but only ephemerally at the soil surface (Le Bourgeois et al., 2012). In cultivated areas in the region (mainly vineyards) other studies have shown that surface Hortonian runoff may also be the dominant mechanisms (Hébrard et al., 2006; Nicolas, 2010).

P1879 line 11 and 20 The word 'exposition' in French does not mean the same in English. Presumably 'exposure' is intended P1879 line 22 'shaley' Better simply 'shale'. In fact better shale lithology' and 'granite lithology'. P1882 line 2 repetition of 'soil' p 1887 line 10 'succion' is French. English is 'suction'. P1889 line 2 Spelling 'trough'

Answer: Thank you for those spelling/English improvement suggestions, which will be included in the revised version of the paper.

P 1890 line 29 Each class is considered statistically homogeneous what facilitates the study of its properties along agregation (Lepioufle et al., 2012). I don't understand this sentence! Reword.

Answer: The sentence is reformulated at follows in order to provide more detailed information. "Each class is considered as statistically homogeneous. For each class, the spatial structure of rainfall is estimated jointly on all time steps relevant to the class. In case successive time steps are within a same class, information is also gained about the temporal structure of the rainfall".

P1892 line 9 'and a morphodynamical expertise of the site'. Please explain what this is.

Answer: We propose to modify the sentences as follows : "LS-PIV and SVR are non-contact techniques providing the flow velocity at the free-surface only, which requires the additional use of an appropriate depth-average to surface velocity ratio in order to compute discharge (see Le Coz et al., 2010, for a discussion of coefficient values). Also, a bathymetry cross-section profile must be determined based on pre and post-flood surveys. It is important to study the morphodynamical evolution of the stream during the flood in order to assess the additional discharge uncertainty due to possible bed changes."

P 1902 line 28 'Nevertheless, low maximum peak discharges are recorded, as compared to historical values in both catchments (maximum peak discharge at the Ardèche at Sauze St-Martin recorded at about 4500m3 s−1, and maximum daily discharge of 2510m3 s−1). So, what were the comparative discharges during the event in m3 sec-1 ?

Answer: The value of the observed discharge can be seen in Fig. 9c, but it should be explicitly mentioned in the text. The maximum peak discharge observed at Sauze-St-Martin on November 10 2012 was 434 m3/s, so about 10% of the maximum ever recorded.

Page 1903 'Figure 11 shows the simultaneous behaviour of the electrical conductivity (EC), isotopic composition _18O, Ca, Al and TOC concentration of the streamwater in the Valescure catchment (3.9 km2) during the 9–10 November 2012 flood event. You do not comment on the fact that EC, Al TOC and CA appear to rise well before the main increase in discharge and peak before the discharge peak. Why is this?

All this section seems to refer to 'normal' flood events rather than flash floods. Under my own definition of flash floods, infiltration excess as well as saturation excess surface flow will occur during extremely intense short period rainfall. In this case the proportion of 'new' water is likely to be much higher. Ie., there is an intensity threshold over which the results for the normal modelled floods may no longer apply.

Answer: In the original figure, we were displaying the discharge from one sub-catchment and not the discharge at the outlet, which was missing due to sensor failure. We have updated the figure (see below) and the figure now displays a reconstructed hydrograph at the outlet of the Valescure catchment. The reconstruction method is the following: the discharge of the four upstream sub-catchments have been summed up after a translation using a constant velocity of 2 m/s. For the downstream sub-catchment, a rainfall-runoff model, previously calibrated on the catchment has been used. The increase of COT, Al, the dilution of Ca and the variation of CE are now more coherent in time with the discharges. About 18O, there is also a good synchronization with the discharges at the beginning of the flood, till 0.00 pm on the 10/11, but the isotopic composition then appears to be independent from the discharge. This is due to the fact that the isotopic composition of the rainfall changes between 9 and 10 pm, from nearly -2.5‰ to -5‰. This latter value is very close to the one of the stream a few hours later, so that variations cannot be detected anymore after this moment. In respect with the evolution of the geochemical decomposition, it is expected that a flood of major magnitude would bring different contributions in surface or sub-surface water flows at the outlet of the catchment. This information will be used for calibrating the hydrological processes with multi-variables control, such as discharges of course, but also geochemistry.

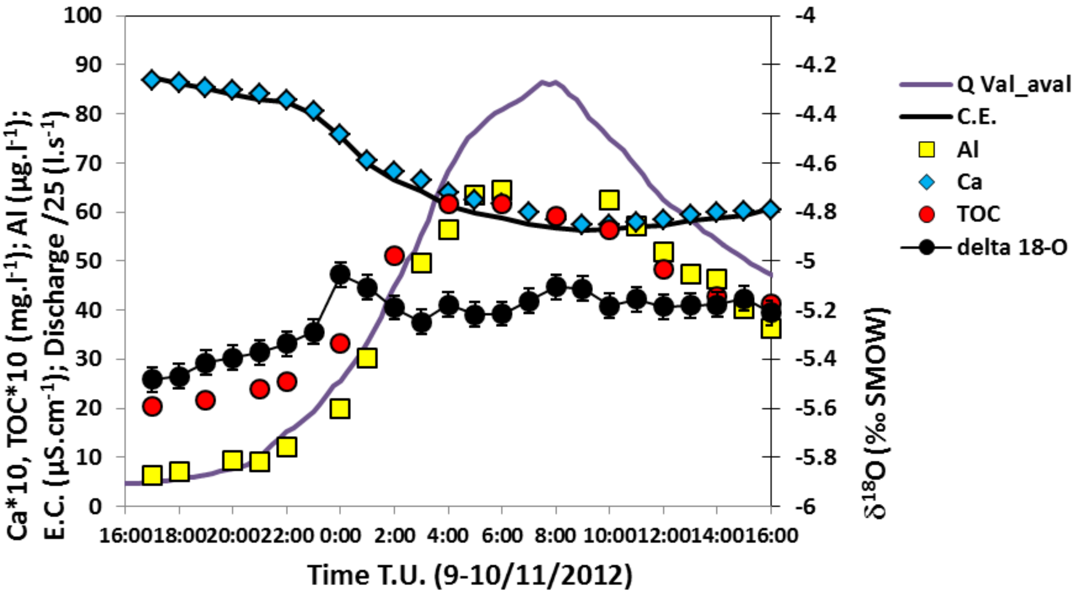

Figure 11 : (Left) Time evolution of the Valescure streamwater electrical conductivity (E.C.), Calcium (Ca), Aluminum (Al), Total Organic Carbon (TOC) and discharge (Q) during the 09-10/11/2012 flood. (Right) Valescure streamwater isotopic composition ($d^{18}O$).

References

Ayral, P. A.: Contribution à la spatialisation du modèle opérationnel de prévision des crues éclair ALHTAIR. Approche spatiale et expérimentale. Applicaton au bassin versant du Gardon d'Anduze, Biosciences de l'Environnement, Chimie et Santé, Université de Provence (Aix-Marseille), Aix-Marseille, 311 pp., 2005.

Brunet, P., Clément, R., and Bouvier, C.: Monitoring soil water content and deficit using Electrical Resistivity Tomography (ERT) - A case study in the Cevennes area, France, Journal of Hydrology, 380, 146-153, 2010.

Cosandey, C., and Didon-Lescot, J. F.: Etude des crues cévenoles: conditions d'apparition dans un petit bassin forestier sur le versant sud du Mont Lozère, France, Regionalisation in Hydrology, Ljubljana, 1990, 103-115,

Delrieu, G., Ducrocq, V., Gaume, E., Nicol, J., Payrastre, O., Yates, E., Kistetter, P. E., Andrieu, H., Ayral, P. A., Bouvier, C., Creutin, J. D., Livet, M., Anquetin, S., Lang, M., Neppel, L., Obled, C., Parent-du-Chatelet, E., Saulnier, G.-M., Walpersdorf, A., and Wobrock, W.: The catastrophic flash-flood event of 8-9 September 2002 in the Gard region, France: a first case study for the Cévennes-Vivarais Mediterranean hydrometerorological observatory, Journal of Hydrometeorology, 6, 34-52, 2005.

Douvinet, J., and Delahaye, D.: Specificities and risk due to 'flash floods' in the north of France (Parisian Basin), Geomorphologie-Relief Processus Environnement, 73-90, 2010.

Gaume, E., Livet, M., Desbordes, M., and Villeneuve, J.-P.: Hydrological analysis of the river Aude, France, flash flood on 12 and 13 November 1999, Journal of Hydrology, 286, 135-154, 2004.

Ducrocq, V., Braud, I., Davolio, S., Ferretti, R., Flamant, C., Jansa, A., Kalthoff, N., Richard, E., Taupier-Letage, I., Ayral, P.-A., Belamari, S., Berne, A., Borga, M., Boudevillain, B., Bock, O., Boichard, J.-L., Bouin, M.-N., Bousquet, O., Bouvier, C., Chiggiato, J., Cimini, D., Corsmeier, U., Coppola, L., Cocquerez, P., *Defer, E., Delanoë, J., Di Girolamo, P., Doerenbecher, A., Drobinski, P., Dufournet, Y., Fourrié, N., Gourley, J. J., Labatut, L., Lambert, D., Le Coz, J., Marzano, F. S., Molinié, G., Montani, A., Nord, G., Nuret, M., Ramage, K., Rison, B., Roussot, O., Said, F., Schwarzenboeck, A., Testor, P., Van-Baelen, J., Vincendon, B., Aran, M., and Tamayo, J.: HyMeX-SOP1, the field campaign dedicated to heavy precipitation and flash-flooding in the northwestern Mediterranean, Bulletin of the American Meteorological Society, in press, 2013.

Gaume, E., Livet, M., Desbordes, M., and Villeneuve, J.-P.: Hydrological analysis of the river Aude, France, flash flood on 12 and 13 November 1999, Journal of Hydrology, 286, 135-154, 2004.

Gaume, E., Bain, V., Bernardara, P., Newinger, O., Barbuc, M., Bateman, A., Blaskovicová, L., Blöschl, G., Borga, M., Dumitrescu, A., Daliakopoulos, I., Garcia, J., Irimescu, A., Kohnova, S., Koutroulis, A., Marchi, L., Matreata, S., Medina, V., Preciso, E., Sempere-Torres, D., Stancalie, G., Szolgay, J., Tsanis, I., Velasco, D., and Viglione, A.: A compilation of data on European flash floods, Journal of Hydrology, 367, 70-78, 2009.

Hebrard, O., Voltz, M., Andrieux, P., and Moussa, R.: Spatio-temporal distribution of soil surface moisture in a heterogeneously farmed Mediterranean catchment, Journal of Hydrology, 329, 110-121, 10.1016/j.jhydrol.2006.02.012, 2006.

Le Bourgeois O., Bouvier C. and Ayral P.A. : Caractérisation des propriétés hydrodynamiques d'un sol cévenol par modélisation inverse des humidités des sols. 37èmes Journées Scientifiques du GFHN, Paris, 22-23 Novembre 2012, 135-144, 2012.

Le Coz, J., Hauet, A., Pierrefeu, G., Dramais, G., and Camenen, B.: Performance of image-based velocimetry (LSPIV) applied to flash-flood discharge measurements in Mediterranean rivers, Journal of Hydrology, 394, 42-52, 2010.

Marchandise, A.: Modélisation hydrologique distribuée sur le Gardon d'Anduze; étude comparative de différentes modèles pluie-débit, extrapolation de la normale à l'extrême et tests d'hypothèses sur les processus hydrologiques, Ecole doctorale Terre, Eau, Espace, Université de Montepellier II, Montpellier, 234 pp., 2007.

Nicolas, M.: Etude expérimentale et numérique du ruissellement de surface: effets des variations d'intensité de la pluie. Application à une parcelle de vigne en Cévennes-Vivarais, Université de Grenoble, Grenoble, France, 04 Février 2010, 215 pp., 2010.

Tramblay, Y., Bouvier, C., Martin, C., Didon-Lescot, J.-F., Todorovik, D., and Domergue, J.-M.: Assessment of initial soil moisture conditions for event-based rainfall-runoff modelling, Journal of Hydrology, 387, 176-187, 2010.