

We would like to thank Lorenzo Marchi for reviewing our manuscript and for his constructive comments which will help us to improve the original manuscript. The revised manuscript will take into account all his suggestions.

Reply to General comments

Referee's opinion that the study fails to achieve its main objective: the author's objective is to find a relationship between the long-term fluvial evolution and the short-term river response in the study area. As the referee says, the sentence "bridging the gap between long- and short-term fluvial processes" may be misleading, because even if geologic and geomorphological context are broadly analysed, short-term processes exclusively focus on the geomorphological effects of the latest flood event. In order to solve this problem, the revised manuscript will be presented with the objective of relating long- and short-term processes, and this will be achieved by better documenting the 2013 flood (hydrological information and data), as well as the historic floods (collection of the available information). All this information is shown later in this document.

Referee's comment that long-term tendency is not demonstrated to be reflected in short-term processes: the referee suggests that in order to interpret the recent incisive evolution of the Garona River is necessary to introduce also information on the geomorphic effects of past flood events in the studied stretches. First of all, two more events will be added, corresponding to 1875 and 1907. Second, we collected the available information (e.g. precipitation and peak discharge) of the documented 6 past events. The data sources are (see new references which will be included in the revised manuscript): Archiu Generau d'Aran (1937), La Vanguardia (1963), Protección Civil (1988), Trutat (1989), Geli (2007), Sàez (2007), Aran Culturau (2013), Moreno et al. (2013), Pineda et al. (2013), Trapero et al. (2013) and García-Silvestre (2014). 1875 July 3: there is no detailed information, but it is said that the Garona River overflowed all along Val d'Aran. 1907 October: convective high intensity rainfall; 300 mm accumulated precipitation in Vielha. 1937 October 24: convective high intensity rainfall; highest peak discharge among all the historic flood events; peak discharge values of $360 \text{ m}^3\text{s}^{-1}$ in Bossòst, $400 \text{ m}^3\text{s}^{-1}$ in Les and $700 \text{ m}^3\text{s}^{-1}$ in Pont de Rei; Vielha was the most affected town (in study area A); main geomorphological effects were significant erosion and scouring, as well as 1.5 m accumulation in the alluvial fan at the confluence between the Nere and the Garona River. 1963 August 3: high precipitation in July and soil saturation; local intense summer storm; peak discharge value of $250 \text{ m}^3\text{s}^{-1}$ in Pont de Rei; Arties was the most affected town (in study area A); main geomorphological effects were erosion and scouring in Arties along the Valarties River and the Garona River, as well as 2 m accumulation in the Arties alluvial fan. 1982 November 6, 7 and 8: high precipitations during 3 days due to a persistent stationary system (200 mm in 48 h in Val d'Aran); precipitation values of 112 mm in Arties, 170 mm in Vielha and 162 mm in Bossòst; peak discharge value of $250 \text{ m}^3\text{s}^{-1}$ in Pont de Rei, almost the entire valley was affected; main geomorphological effects were erosion of the road along the Garona River, high energy (boulders >1m diameter were transported) of the Nere River and accumulation and filling of the Nere River alluvial fan channel in Vielha. In the revised manuscript (see also the end of this document) we will add a new table to summarize and compare these floods with the 2013 one and with the projected 25- and 100-year return period floods.

Referee's comment about the severity of the 2013 flood: even though it produced major losses, it was not a severe flood, but a quite smaller one (<50-year return period, according to the Administration available data, e.g.: CHE, 2014), that effectively shaped the channel

morphology, as it has been observed. We presume that if this intermediate flood produced such erosion, major floods will effectively enhance the processes and the morphology evolution, as it was described for the major historical floods (see previous paragraph). Related to this and answering the referee's suggestion to carry out a multi-temporal analysis of topographic maps and aerial photos, we considered this point. In fact, we carried out a geomorphologic analysis based on 1956 aerial photographs and we specially considered the channel. This analysis and mapping is exemplified in figs. 4, 5 and 6. On the other hand, we do not have aerial photographs of the 1982 flood. About detailed topographic maps, the first 1:5000 scale maps were produced at the end of the '80. Changes are not large enough to be detected from such maps (the changes are not detected when comparing the 1988 orthophoto, which does not present a complete covering of Val d'Aran, with the current map, except in 1 site upstream from Bossòst). There is not detail enough to compare maps and orthophotos in order to investigate in detail changes of the river channel morphology for the last 6 decades. Therefore, changes were analysed between the orthophotos pre- (2012) and post- 2013 floods and are summarized in tables 1 and 2.

Referee's comment about documentation of the flood of June 2013 and comparison with the 50-years return period inundation area: we agree with the reviewer that the comparison of inundation areas is of small significance as we presented it. Thus, we will remove Figure 15 in the revised paper. On the other hand, we will provide more detailed information of the event which will considerably improve the quantitative assessment and, therefore, will help to relate the 2013 flood with the regional context and evolution of the Garona River. The revised paper will include meteorological and hydrologic information of this event and a comparison of the peak discharge of the 2013 flood with the 25-year and 100-year return period flood discharges (provided by the Administration -National Flood Mapping System-) in order to justify that the last event was a $T < 50$ years flood (section 1.1 and 7.3). We collected data from different sources (see new references below which will be added in the revised manuscript): SNZCI (2011), Moreno et al. (2013), Pineda et al. (2013) and CHE (2014). Meteorological information: rainfall of 124.7 mm in 48 h in Vielha (101.2 mm in 24 h); unusual precipitation values not recorded since 1982. Hydrologic information: gauging stations were destroyed so there is not real-time discharge data (peak discharge values were estimated from flood evidences and/or hydrologic modelling; CHE, 2014); 40% of the flood discharge came from snow melting; 51 hm³ of water from snow melting in 10 days, which are high but not extraordinary values in the study area. Peak discharge of the 2013 flood: 100 m³s⁻¹ in Salardú, 233 m³s⁻¹ downstream the Arties dam, 154 m³s⁻¹ in Arties, 220 m³s⁻¹ in Vielha, 245 m³s⁻¹ in Aubert and 280-300 m³s⁻¹ in Bossòst. According to SNCZI, maximum discharge values calculated for 25-years return period flood events: 124 m³s⁻¹ in Salardú, 134-174 m³s⁻¹ in Arties, 200 m³s⁻¹ in Vielha, 204 m³s⁻¹ in Aubert and 257 m³s⁻¹ in Bossòst. Maximum discharge values calculated for 100-years return period flood events: 229 m³s⁻¹ in Salardú, 246-316 m³s⁻¹ in Arties, 368 m³s⁻¹ in Vielha, 380 m³s⁻¹ in Aubert and Bossòst m³s⁻¹ in Bossòst. Return-period of the 2013 flood event: $25 < T << 100$ -year flood. All this obtained discharge data allow us to prove that the last flood was an intermediate, not major, event. The peak discharge values are very similar to those corresponding to 25-year return period events. In CHE (2014) the 2013 flood is considered a < 50 -year flood. Therefore, the significant erosive effects (excluding some local effects due to bridges clogging and related eroded and flooded areas downstream from some protected ones), together with the geomorphological features related to the fluvial system (e.g. two generations of alluvial fans) are relevant to understand the short-term incisive tendency of the Garona River. Up to now, we do not dispose of detailed post flood topography to simulate the

2013 flood. We consider doing so in the future when this topography would be available, taking into account that the same discharges must be considered when using the pre and post flood topography.

Referee's comment about the presence of dams in the Garona River: there are not large dams in Val d'Aran. There are some small dams and water catchments along the Garona River study area, as well as some dammed small lakes in the head of some sub catchments. The latter do not have relevant influence in flooding events along the Garona River. The former can enhance incision just downstream, but this dam-related incision is local. The incision occurs more intensely downstream the dams (Fig. 14a), but also upstream (Fig. 14b), where no incision should be expected. These structures can be of significant importance during flood events particularly because they can trap vegetation, be clogged and even seriously damaged. A good example is the Arties dam, just upstream the Arties town, related to the Vielha hydroelectric power plant. This dam was built in 1947-1948 (before the first 1956 aerial photographs) and produced a decrease of the discharge due to capture water for the hydroelectric plant. In fact, the mean discharge value of the Garona River in Arties before building the dam was $5.7 \text{ m}^3\text{s}^{-1}$, which decreased to $0.5 \text{ m}^3\text{s}^{-1}$ with the presence of the dam (CHE, 2008). Moreover, this dam was broken during the flood event of 2013 because gates were not opened. This carried an increase of 47 % of the discharge value just downstream the dam. Flood peak discharge here was $233 \text{ m}^3\text{s}^{-1}$ (if the dam had been in operation peak discharge would have been $146 \text{ m}^3\text{s}^{-1}$). Anyway, at Arties the wave was already partly attenuated, as the discharge at this location (very close to the dam) was of $154 \text{ m}^3/\text{s}$. This high difference in water discharge in such a short distance proves that effect of the dam is not of significant importance for interpretation of the flood effects. All this information will be included in the final paper.

Section 1, referee's comment on missing references: We will follow your recommendation to include references that will improve the manuscript (see references at the end of this document). In terms of flood damages worldwide, we will include the suggested studies documenting flood events in different geographical regions (Jonkman, 2005; Barredo, 2007; Ashley and Ashley, 2008; Gaume et al., 2009). Concerning the referee's comment about the morphologic evolution of mountain rivers, we will include international literature on this topic but also on long-term landscape evolution, and will rephrase page 6381 lines 24-27, so that the revised version will say "Most of the previous works on fluvial systems exclusively deal with flood events, present processes, landforms or short-term river morphological evolution (Baker and Pickup, 1987; Beven, 1987; Montgomery and Buffington, 1997; Lenzi, 2001; Mao et al., 2009; Zanon et al., 2010), whereas other research lines focus on long-term geomorphologic and tectonic processes that shape the landscape (Dietrich et al., 2003; Oskin and Burbank, 2005; Bishop, 2007; Kirby and Whipple, 2012)". A literature review of fluvial geomorphology for river engineering and management has also been carried out (e.g. Schumm, 1977; Thorne et al., 1997; Kondolf et al., 2003), as well as considering frameworks for hydromorphological analysis with applications for risk mitigation (Rinaldi et al., 2014; Belletti et al., 2015; Gurnell et al., 2015). All these previous works will be considered in the revised manuscript (see reply to referee 2).

Section 1, referee's comment on the 2013 flood description: We have searched for quantitative information about the flood of June 2013. As mentioned before, we have collected some meteorological (precipitation) and hydrological (peak discharge, return period)

data on the event, which will be included in the introduction as a separate section (section 1.1) in the revised manuscript.

Section 1, Page 6381, lines 15-17: As mentioned before, we have obtained quantitative data on peak discharge of the 2013 flood event at different sites along the study area, confirming that the return period is between 25 and 50 years. This will be included in the new version.

Section 7.2, Page 6398, lines 27-28 and page 6399, lines 1-15: We agree with the referee that this long paragraph is not directly related to the present study, so we will remove the text and the revised manuscript will only contain a summarizing sentence relating climate and river response: "Traditional climatic theories related glacial periods with sedimentation and interglacial periods with entrenchment, but many authors have proved that a number of factors (e.g. sediment input, catchment morphometry, tectonics and anthropogenic actions) play an important role in fluvial dynamics (Vandenbergue, 1995, 2002, 2003)".

Sections 7.4, Page 6404, lines 9-24: Thanks for pointing out that these general comments are not directly related with the case study. However, we emphasize that erosion is an essential factor to be considered when designing engineering structures along the Garona River. Lines 9-24 will be removed and replaced by "In the study area, hydraulic structures must consider erosive power of the Garona River, especially for channelization dykes, bridges and dams".

Reply to Specific comments

Abstract, Page 6380, lines 3 and 4: The sentence will be rewritten as "Few studies have related flood events to the geologic, tectonic and geomorphologic context". We will pay more attention to international literature and some references related to this topic will be included (see references at the end of this document).

Section 2: The land use change is not significant in terms of the discharges of the Garona River. The basin is mostly forested, with some parts above the forest domain, and mostly unchanged since 1956. Population is mostly settled on the valley bottoms, and it increased specially along the river, what increased exposition to flood events. The new version will say "population is mainly settled along the valley bottoms (9993 inhabitants; IDESCAT, 2014). Land use has not changed significantly since 1956, except for valley bottoms, so the influence of land use change in fluvial evolution and discharge values is almost absent. Therefore, urban settlements only increased in valley bottoms during last decades, increasing exposition to flood events".

Section 4, Page 6386, line 9: ESRI will not appear in the revised version.

Section 5.1, Page 6388, lines 9.12: We agree that the sentence is too obvious and it will be removed.

Section 5.1, Page 6389, lines 11-29: Alluvial fans were formed after deglaciation when river and streams transporting high sediment loads decreased in gradient and energy at their confluence with the Garona River. Deposition is the natural result and alluvial fans were formed as both bedload and debris flow material accumulated. High slopes of the fans support this statement. This information about the origin of alluvial fans will be included in the revised manuscript.

Section 6.1, Page 6393, lines 12-13: We agree that the sentence is too obvious and it will be omitted.

Section 6.2, Page 6396, line 4: The term "impermeable" will be rephrased as "not erodible".

New references to be included in the revised manuscript

- Aran Culturau: Aiguats istòrics en Aran (II): 1963, Aran Nau, 62, 10, 2013.
- Archiu Generau d'Aran: Actes minicipaus de Vielha, Conselh Generau d'Aran, Vielha, Spain, 38-40, 1937.
- Ashley, S. T., and Ashley, W. S.: Flood fatalities in the United States, *J. Appl. Meteorol. Climatol.*, 47, 805-818, doi:10.1175/2007JAMC1611.1, 2008.
- Baker, V. R. and Pickup, G.: Flood geomorphology of the Katherine Gorge, Northern Territory, Australia, *Geol. Soc. Am. Bull.*, 98, 635-646, doi:10.1130/0016-7606(1987)98<635:FGOTKG>2.0.CO;2, 1987.
- Barredo, J. I.: Major flood disasters in Europe: 1950-2005, *Nat. Hazards*, 42 (1), 125-148, doi:10.1007/s11069-006-9065-2, 2007.
- Beven, K.: Towards the use of catchment geomorphology in flood frequency predictions, *Earth Surf. Processes*, 12 (1), 69-82, doi:10.1002/esp.3290120109, 1987.
- Bishop, P.: Long-term landscape evolution: linking tectonics and surface processes, *Earth Surf. Proc. Land.*, 32, 329-365, doi:10.1002/esp.1493, 2007.
- CHE, Confederación Hidrográfica del Ebro: Informe de la avenida del 17 al 20 de julio de 2013 en la cuenca del río Garona, Ministerio de Agricultura, Alimentación y Medio Ambiente, Gobierno de España, 73 pp., 2014.
- Dietrich, W. E., Bellugi, D. G., Sklar, L. S., Stock, J. D., Heimsath, A. M., and Roering, J. J.: Geomorphic transport laws for predicting landscape form and dynamics, in: *Prediction in Geomorphology*, AGU Geophysical Monograph, vol. 135, edited by: Wilcock P. R. and Iverson, R. M., American Geophysical Union, Washington DC, United States, 103-132.
- Gaume, E., Bain, V., Bernardara, P., Newinger, O., Barbuc, M. Bateman, A., Blaškovicová, 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, *J. Hydrol.*, 367, 70-78, doi:10.1016/j.jhydrol.2008.12.028, 2009.
- Geli, A.: Un dimenge espantós, *Aran Ath Dia*, 19, 4-19, 2007.
- Jonkman, S. N.: Global perspectives on loss of human life caused by floods, *Nat. Hazards*, 34 (2), 151-175, doi:10.1007/s11069-004-8891-3, 2005.
- La Vanguardia: La situación en los valles de Arán y Ribagorzana, available at: <http://hemeroteca.lavanguardia.com/preview/1963/08/07/pagina-/32674053/pdf.html>, last access: 16 December 2015, 1963.
- Lenzi, M. A.: Steep-pool evolution in the rio Cordon, northeastern Italy, *Earth Surf. Proc. Land.*, 26, 991-1008, doi:10.1002/esp.239, 2001.
- LOOP, Observatorio Limnológico de los Pirineos, and MoveLab, Laboratori d'Ecologia del Moviment: Noticias históricas de las riadas en la Val d'Aran, available at: http://holet.org/media/holet/references/general_references/IT-RI-ES.html, last access: 16 December 2015.
- Mao, L., Cavalli, M., Comiti, F., Marchi, L., Lenzi, M.A., and Arattano, M.: Sediment transfer processes in two Alpine catchments of contrasting morphological settings, *J. Hydrol.*, 364, 88-98, doi:10.1016/j.jhydrol.2008.10.021, 2009.
- Montgomery, D. R. and Buffington, J. M.: Channel-reach morphology in mountain drainage basins, *Geol. Soc. Am. Bull.*, 109 (5), 596-611, doi:10.1130/0016-7606(1997)109<0596:CRMIMD>2.3.CO;2, 1997.
- Oskin, M. and Burbank, D. W.: Alpine landscape evolution dominated by cirque retreat, *Geology*, 33, 933-936, doi:10.1130/G21957.1, 2005.

Protección Civil: Las inundaciones en la España Peninsular, Dirección General de Protección Civil, Ministerio de Obras Públicas y Urbanismo, Gobierno de España, Madrid, Spain, 1988.

Saèz, A.: Eth dramàtic precedent d'Arties, *Aran Dath Dia*, 19, 22-25, 2007.

SNZCI, Sistema Nacional de Cartografía de Zonas Inundables: Mapa de caudales máximos, available at: <http://sig.magrama.es/snczi/visor.html?herramienta=DPHZI>, last access: 18 December 2015, 2011.

Trapero, L., Bech, J., Duffourg, F., Esteban, P., and Lorente, J.: Mesoscale numerical analysis of the historical November 1982 heavy precipitation event over Andorra (Eastern Pyrenees), *Nat. Hazards Earth Syst. Sci.*, 13, 2969-2990, doi:10.5194/nhess-13-2969-2013, 2013.

Trutat, M.: Les inondations dans les Pyrénées Centrales. Extrait de bulletin de la société de géographie de Toulouse, *Arxiu Fons Melquíades Calzado*, Les, Spain, 28-34, 1989.

Zanon, F., Borga, M., Zoccatelli, D., Marchi, L., Gaume, E., Bonnifait, L., and Delrieu, G.: Hydrological analysis of a flash flood across a climatic and geologic gradient: The September 18, 2007 event in Western Slovenia, *J. Hydrol.*, 394, 182-197, doi:10.1016/j.jhydrol.2010.08.020, 2010.

Table: Data compilation of major historic floods in Val d'Aran, the flood of 2013 and the calculated 25- and 100-years return period floods. All data are related to the villages where they were collected or observed, and ordered downstream.

	1875/07/03	1907/10/22-25	1937/10/24		1963/10/03		1982/09/6-7-8			2013/06/18	Tr 25	Tr 100
	<u>Effects:</u> The Garona River overflowed all along the valley ^k	<u>Rainfall</u> (mm)	<u>Q</u> (m ³ /s) Highest recorded peak discharge ^h	<u>Effects:</u> Sediment removal from Alfonso XIII tunnel, at the Nere River headwaters ^b	<u>Q</u> (m ³ /s)	<u>Effects:</u> Local, intense summer storm on saturated soils (high rainfall in July) ^a	<u>Rainfall</u> (mm) (200 mm / 3 days) ^f	<u>Q</u> (m ³ /s)	<u>Effects:</u> Almost the entire valley affected ^d Erosion (road: 30 km length) ⁱ	<u>Q</u> (m ³ /s) (40% Q from snow melting) ^c	<u>Q</u> (m ³ /s)	<u>Q</u> (m ³ /s)
Salardú										92-130 (Tr>50) ^c	124 ^j	229 ^j
Arties						Valarties River overflowed. Erosion and scouring in Valarties and Garona rivers ^a Medieval bridge destruction. 2m accum. In Valarties alluvial fan in Arties ^a	112 ⁱ		Valarties River: bridge clogging ^d	233 just downstream the Arties Dam ^c 146-170 (Tr<50) ^c	134-174 ^j	246-316 ^j
Garós - Casarilh						Garós: Bargadera bridge destruction ^a Casarilh: erosion of 10 m of road ^a						
Vielha		300 ⁱ	80 Nere ^b	Nere River overflowed. Erosion and scouring (road: 2m depth and 150m length). 1,5m accum. at Nere alluvial fan (Vielha: Libertat street) ^b			170 ⁱ		Nere River: clogging at the confluence in Vielha and up to 1 m accum. ^d Joeu River overflowed ^d	230 (Tr<50) ^c	200 ^j	368 ^j
Aubert										245-260 (Tr<50) ^{c, g}	204 ^j	380 ^j
Bossost			360 ^h	Pont Vell bridge destruction ^b			162 ⁱ			280-339 (Tr<50) ^{c, g, h}	257 ^l	380 ^j
Les			400 ⁱ	La Lana bridge destruction ^b								
Pont de Rei	Bridge destruction (clogging) ^k		700 ^e		250 ^e			250 ^c				

^a Aran Culturau, 2013.

^b Archiu Generau d'Aran, 1937.

^c CHE, 2014.

^d Geli, 2007.

Saèz, 2007.

^e La Vanguardia, 1963.

^f LOOP, Observatorio Limnológico de los Pirineos, and MoveLab, Laboratori d'Ecologia del Moviment, last access: 16 December 2015.

^g Moreno, M. L. et al., 2013.

^h Pineda, N. et al., 2013.

ⁱ Protección Civil, 1988.

^j SNZCI, Sistema Nacional de Cartografía de Zonas Inundables, 2011.

^k Trutat, M, 1989.