Responses to Referee 1:

Please note, each comment of the referees is answered using italic letter and indented paragraphs.

General comment:

The authors thank the anonymous reviewer for his/her very constructive and helpful comments. We now clarified our definition of atmospheric river and its extent on the 9 and 10 Oct. 2011. Confusion about the role of Ophelia is now corrected. We have added isentropic PV in Figure. The reviewer asked several times to justify statements about the extremeness of some parameters when using the word "unusual" or "anomalous". We analyzed quantitatively the extremeness of those parameters (temperature, temperature increase, moisture) using Era-Interim as a reference and we now make quantitative statements in the text. A whole paragraph on the extremeness calculation has been included in section 3.1? We found all suggestions about formulation very helpful and corrected them point by point. Especially the first paragraph of the discussion has been strongly reformulated to meet all the suggestions.

Main Comments: 1). The paper does not correctly define an atmospheric river (AR), and as such I have doubts that an AR actually impacted the Alps during this event. ARs are located in the warm sector of extra-tropical cyclones within the warm conveyor belt.

Here we define atmospheric rivers following Ralph and Dettinger (2011). Following this definition, ARs must fulfill criteria of moisture transport intensity (or wind speed and integrated moisture) and shape (minimum length and maximum width). You are right that by using this definition a part of an AR could overlap with the low-level inflow section of a warm conveyor belt. However, in the present case additional trajectory analyses that were carried out for a companion paper by colleagues at ETH that investigates the moisture sources for the flood event show that the AR air parcels were moistened in the tropics and subtropics and then always stayed in the lower troposphere before arriving in northern Switzerland. Hence they do not fulfill the WCB criteria of rapid ascent to upper tropospheric levels.

We realized that it is difficult for the reader to identify the extent of the AR based only on the wind and integrated moisture fields shown in Figure 3 and we have therefore added a contour (violet) that encompasses all areas where the AR criteria are fulfilled. On 10 October the AR reached the Alps in the reanalysis data set.

Ralph, F. M., & Dettinger, M. D. (2011). Storms, floods, and the science of atmospheric rivers. Eos, Transactions American Geophysical Union, 92(32), 265-266.

At 00UTC 9th October (please see historical weather analysis charts here: http://www.wetter3.de/Archiv/archiv_ukmet.html) there was a warm front over the British Isles and a trailing cold front across the North Atlantic. The AR would be up against the cold front (in the warm sector), and as such the AR part of the storm does not reach Switzerland

Yes, fully we agree with your description of the AR extent on the 9 of October. Thank you for referring to the weather charts of MetOffice which offer an interesting framework to discuss figure 3. We notice even that the extent of the warm and moist airmass in fig. 3.e corresponds nicely to the fronts drawn by MetOffice on the 8th at 12UTC (the northern boundary of the AR is delimited by the cold front trailing across the Atlantic and the eastern boundary is delimited by the warm front over the British Isles). We agree that the AR did not reach Switzerland on the 9 at 00UTC (we argue that it occurred 1 day later).

(even over the analysis charts up to 18UTC 10 October 2011). There is evidence for AR conditions, but they are not near Switzerland, hence I believe your results/discussion/conclusions need to be revised.

It seems indeed that the surface warm front from the MetOffice charts never completely reaches the Alpine range on Oct. 10. There is however evidence from the reanalysis that in fact the warm and moist flow associated with the warm sector of the cyclone (the AR) did reach the Alpine range on oct. 10 (see for ex. the extent of the Atlantic moist plume –green to yellow coloring- on fig. 3.f). The airmass actually meets AR criteria till the Alpine range (see Figure below, violet contour) where the moisture transport suddenly drops due condensation and rainout of moisture.

Furter evidence is provided by satellite imagery (see for ex. www.sat24.com, or below an infrared slot at 10 oct. 06UTC). The AR is delimited by the presence of high clouds. And the satellite clearly shows that the intense precipitation event triggering the flood (10 oct. 00-12UTC) corresponds to the time when the southwesterly edge of the high clouds-delimited AR impacts on the Alpine range.

At 00UTC 9th October there is an upper level warm front (as shown by the open warm front symbols), which is probably a part of the ascending warm conveyor belt. In fact this upper level warm front is also seen in your Figure 3 – the blue line (at 00UTC 9Oct 2011) has a temperature inversion at about 675hPa, as the temperature starts rising with height here. This is probably a key part to the flood event.

Its influence on the flood event is difficult to quantify but we expect it to be rather low since 9 oct. 00UTC corresponds to a minimum of precipitation (between the snowfall and the rain on snow).

I also don't think that the storm formed from Hurricane Orphelia, as Hurricane Orphelia dissipated on 3rd October, a week before this flood event.

Thanks for pointing to that issue that indeed revealed some confusion. We analysed the synoptic situation in detail, also with the help of a companion paper that will be submitted soon. Ophelia underwent extratropical transition on 1 Oct and some remnant cyclonic circulation can be traced in the extratropics until 6 Oct on isentropic PV charts. At that time, the weak remnant circulation merged with an already well developed deep cyclone over Scandinavia (which can be seen in Figure 2a). Ophelia might thus have played a minor role in the formation of the cold front. This led to some confusion in the previous version. The AR did not originate from Ophelia. This is now corrected in the text.

It may help to look at a paper by Joos and Wernli (2012) with regard to your description of PV. Their Figure 1 shows a field of PV, which is more informative than just a red line.

Does the red line refer to the jet stream over the North Atlantic? It may be best to show maps of PV as in Joos and Wernli (2012).

The first version of the paper was indeed created with such PV fields and then the authors decided for the sake of compactness to show only the 2 PVU line, which indicates where the dynamical tropopause, the strongest gradient of PV and the upper level jet stream are located. The 2 PVU line is therefore regarded here as the Rossby wave guide and thus as the relevant PV feature for weather-inducing atmospheric development. Included below is a Figure showing the full PV field. The panels in Figure 1 would become saml and unreadable if we include a third column showing the full PV field and an additional figure would be necessary. For this reason we have decided not to show the full PV field and only expand the explanations in the text.

We thank the anonymous reviewer for the numerous suggestions about formulation and terminology. We addressed them point by point (see below). We found that they all helped us to improve the paper.

2). The terminology needs to be rephrased and reconsidered in places. I will outline some of these in the specific comments.

Specific Comments: P2 lines 39-40: Why is it an anomalous cold front? Also, it is best to avoid terms such as “drastic” temperature increase. A large temperature increase sounds better.

The term “anomalous” is now removed, we now simply indicate that the cold front produced snow fall at low levels. Drastic replaced by “large”

P3 lines 84, 86-87: These are not correct terms. “Cold front system” and

“warm and moist northwest front” would probably be better as “extra-tropical cyclone” and “warm front” respectively.

Corrected in the text, thank you

P6 first paragraph: ERA Interim reanalysis has a 0.7 x 0.7 degree horizontal resolution. It is also a numerical weather prediction model frozen in time.

Now: “This reanalysis dataset results from a numerical weather prediction model frozen in time that is continuously forced by a complex assimilation of various observations of the atmosphere, ocean, and land surface. It is commonly used for the retrospective analysis of meteorological situations. The main atmospheric variables are available on a three dimensional grid (T255 horizontal resolution, interpolated to a 1 x 1° grid, 90 vertical layers) every six hours. “

P6 line 156 and throughout manuscript: What does cp. mean?

Now: cp. Is replaced by “see” , cp. stands for compare.

P10 lines 282-302: See general comment 1.

See answer to general comment

P10 line 283, P11 line 323: I would suggest changing the word “drastic”.

This word has been removed and replaced by “intensive” at the respective places.

P12 lines 350-352: This line does not make sense. Please rephrase.

Now rephrased as follows: “A positive dew point temperature is very important for snowmelt. If air with a positive dew point temperature is in contact with snow, and hence cooled to 0° C, it will be oversaturated and condensation will set in. ...“

P12 line 361: With respect to what criteria is the cold front anomalously cold?

Thank you for the remark, this indeed needed some clarification: The air was cold compared to the October Era-Interim climatology, it was however not extreme.

"Comparing the event with all October data in Era-Interim at the grid point upstream of the Loetschental (47°N, 7°E), we found that negative temperatures at 850 hPa occurred approximately 3 days per month in October during the 33 years considered."

P13 lines 367-394: I think your Figure 5 references should be Figure 4.

Yes indeed, thank you, it has been corrected.

Perhaps you should link to your discussion on the cavity circulation (a few pages later on) in lines 382-383?

Now we briefly mention that the small scale wind field induces the observed rainfall patterns and refer to later discussion of the cavity circulation.

P13 line 397: Can you explain your Figure 5 with the wind profiles in the paper? I was confused with these plots – it appears to me that the wind was coming from the southwest and not the northwest. The same applies to P14 line 404.

Thanks for the remark, the wrong figure was shown in this version the paper due to error when submitting, now this has been of course corrected. Indeed, in the version you had (a wrong day) the wind came from the south west, we apologize for that.

Now the figure caption is also more detailed and more clearly formulated.

P14 line 407: Very active cold and warm fronts. You need to show that they are active if you are going to use this terminology (I believe an active front is called an ana front – ana warm front).

"with the successive passage of two precipitation-producing fronts, a rapid rise of the snow line and exceptional amounts of moisture transported towards the Alps. "

P14 lines 425-427: Please rephrase this sentence.

"A cavity circulation implies upslope ascent on the lee side of the mountain crest as shown in Fig. 6. Such an upslope ascent and the associated adiabatic cooling, saturation, and cloud formation at low levels, can enhance snowmelt very efficiently through sensible and latent heat transfer to the snow."

P15 line 430: I don't think you want to use the word vaporized.

Now: evaporated

P15 lines 434-436: Can you get the measurements from the windward side?

There are unfortunately no stations on the windward side (now clearly formulated in the text)

P19 lines 572-575: This needs some rewording. Flood events can be both spatial and temporal; it doesn't have to be one or the other.

P19 line 577: Terminology – "unusual cold moist. . ..". How is it unusual?

P19 line 578: It should be ECMWF reanalysis data, or ERA-Interim reanalysis data.

P19 line 584: Terminology – "wet air masses".

Thanks, the first ten lines of the discussion have been reworded to account for the suggestions.

P20 lines 592-595: Lavers and Villarini (2013) showed that ARs caused extreme precipitation at long distances from the sea, so ARs don't just cause high rainfall near the coast.

Yes indeed. Thanks for this remark. The goal of the sentence was to emphasize that moisture was transported all the way until it reached the Alpine range. We agree that Lavers shows influence of ARs far inland.

The sentence is now reformulated to avoid confusion.

P20 lines 613-615: Please rephrase.

Now: ...snow events. Strong surface winds, warm temperatures and high humidity indeed proved to contribute directly to high snowmelt rates recorded in catastrophic rain-on-snow floods like in 1996 in the Pacific Northwest (Marks et al., 1998) and in northern Pennsylvania (Leathers et al., 1998).

P23 Conclusions: See Main comment 1.

See answer to general comment