Response to referees' comments (referee #1; 26/01/2015)

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‘Influence of solar forcing, climate variability and atmospheric circulation patterns on summer floods in Switzerland‘

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REFEREE' COMMENTS:

General statements:

Referee #1:

It is a lively discussed fact that floods occur in clusters which are separated by longer breaks of several decades. Based on a combined index of summer flood damage in Switzerland between 1800 and 2009 the authors study the connections between the floods, solar cycles, temperature and atmospheric circulation. They found four distinct periods with floods. In their analysis the authors use well-known and proven statistical methods. The paper is rather long. It is written in a comprehensible style, but there are still some open questions to be considered by the authors.

Referee #1. Point 1:

The first concerns the flood data set. It is a real merit to combine a precise flood database with flood damage data. Unfortunately the division of the research area into five administrative regions, even it was carried out with suitable statistical methods, hinders a more precise dynamic interpretation. Would it not be an advantage to distinguish precisely between the northern and southern slopes of the Alps?

Response:

We are in agreement with the referee because the final results show that the dynamics analyzed are well differentiated between the northern and southern slopes of the Alps.

But we have tried to take advantage of the large amount of information that was available at the municipal level and even at the basin level. Thus, we apply a well-known and proven methodologically statistical method to create our own regionalization that has allowed us to adapt the regionalization to the data structure and physiographic settings. Therefore, the resulting regional distribution is consistent with other regionalizations of Switzerland as we wrote in the original manuscript. In addition, we previously processed the data series based on a cantonal division to calculate the INU-index, but the results show local distortions due to the different characteristics of the cantons (e.g. topography, catchments, population densities, exposed settlements and infrastructures, etc.). These effects were eliminated partly in the present model. However, the frequency of floods did not change substantially. Finally, our regionalization shows consistency with the atmospheric dynamics.

Referee #1. Point 2:

Unfortunately the authors have not considered three recent papers providing important aspects of alpine flooding: Stucki, P. et al., 2012, Meteorol. Zeitschr. 21/6, p. 531 / Glur et al., 2013, Nature Scientific Reports, Article nr. 2770 (26.9.2013) / Wirth, S.B. et al. , 2013, Geophys. Res. Lett. 40, doi: 10.1002/grl.50741). The finding of the authors partly differ from those in these papers, and that not only related to the defined flood periods. The aforementioned papers agree with the authors of this paper that summer floods are strongly connected to cool summers, except for the two periods 1977-1990 and 2005 to present. But in their paper the authors also state that "the river catchments in the center and southern flank of the Alps are affected by atmospherically unstable areas defined by a positive SNAO". This is in contradiction with Wirth et al. (2013) who show that a low TSI (a so-called Grand Solar Minimum GSM) is attributed to a southerly position of the westerlies and positive precipitation anomalies in the NW Med. area. The same fact is also confirmed by the fundamental papers of Folland et al. (J. Climate 22 / 2009, p. 1082ff.) and Bladé et al. (Clim. Dyn. 2011, DOI 10.1007/s00382-011-1195-x).

Response:

We now include in the bibliography the paper of Glur et al., 2013 and the last two papers of Wirth et al., 2013. Furthermore the findings of these papers are included in our manuscript (see page 16, line 29; page 18, line 15).

Our findings are quite similar to those achieved by these authors. The southerly position of the westerlies and positive precipitation anomalies in the NW Med. area are explained by the SNAO pattern, as Bladé et al., 2011 has described. In our manuscript, page 20, line 19, we wrote:

"During these cold pulses the accumulation of snow and ice in the headwaters is significant, increasing the flood risk during warm years when melting processes contribute markedly to summer discharge. This flood pattern occurs in years dominated by positive SNAO phases when depressions are usually associated with the Atlantic cyclones that become more intense over the Mediterranean Sea, and follow a northeast to north-northeast track over the Alps. This path is known as Vb (van Bebber, 1898) and produces long-lasting, intense rainfall due to (1) the high water vapour content from the Mediterranean, (2) the orographic uplift of air masses and (3) the reinforcement suffered by negative anomalies of temperature and geopotential height that occurs at the lower and middle levels of the atmosphere.".

Folland et al. (2009) review the temporal evolution and surface impacts of the SNAO, despite the fact that the SNAO-like patterns have previously been identified by e.g. Barnston and Livezey (1987). Lack of analysis has led to disagreement in the scientific literature about the pattern. An important part of this confusion arises from the more northerly position and smaller spatial extent of the SNAO compared to its winter counterpart, with the southern node over northwest Europe, rather than the Azores–Spain region, and a smaller-scale Arctic node. In spite of the fact that SNAO has different characteristics than the winter NAO, it provides a similar paradigm for understanding the variability of seasonal climate. Bladé et al. (2011) describe the positive phase as a decreased pressure over Greenland and an increased pressure in north-western Europe. If it is compared to the winter NAO, the SNAO teleconnection is displaced northeastward, it is more zonally and meridionally restricted and the centres of action show a more southwest-to-northeast orientation, with more meridional advection over Northern Europe. This poleward shift explains the lack of correlation with the station used by the NAO index.

The SNAO is defined as the first EOF of July-August extratropical North Atlantic pressure at mean sea level (Folland et. al, 2009; Bladé et al., 2011). The positive phase of the SNAO is strongly associated with warm, dry, and cloud-free conditions over north-western Europe. This relation is more weakly in southern Europe and the Mediterranean characterized by cooler, wetter and cloudier conditions, especially in the eastern sector. Bladé et al. (2011) found that for the second part of the twentieth century, the relationship between the SNAO and Mediterranean precipitation is stronger than the relation established in Folland et al. (2009). These findings support our outcomes (page 22, lines 8 to 15).

Referee #1. Point 3:

3.1. *The paper lacks of a clear mechanistic explanation, even this is a difficult task. The key question is whether the floods are really correlated with solar activity, temperature and SNAO. Based on Figure 9 this conclusion is at least justifiable for solar activity and temperature. Indeed periods with low solar activity, in many cases connected to a negative SNAO, often covary with volcanic events (e.g. during Dalton Minimum). Therefore, it is not absolutely clear whether the correlation with solar activity is real or not.*

Response:

We are in agreement with the referee. We have included in Figure 9 the volcanic eruptions and have added in the manuscript the following sentences:

Page 6, lines 17-20: *"Volcanic eruptions are investigated by mean volcanic sulphate deposition and converted to stratospheric volcanic sulphate injection (in Tg units) for the Northern Hemisphere over the past 200 years (1800-2000). These measures have been extracted from 32 ice core records that cover major part of the Greenland ice sheet (Gao et al., 2008)".*

Page 17, lines 4-8: *"To evaluate possible links between flooding and short-term external forcing fluctuations, the volcanic eruptions, SNAO, δ18O, 10Be and sunspot number have been plotted alongside the INU index for Switzerland (Fig. 9). All the proxy series are plotted as normalized values smoothed with an 11-year low-pass Gaussian filter, except the sunspot number record smoothed with a 22-year filter while volcanic eruptions and INU time series are not filtered."*

Page 18, lines 5-9: *"During this period an extra cooling occurred which was associated with the eruption of Tambora (1814) plus two eruptions in the years 1831 and 1835 (Fig. 9). Considering both forcings (solar and volcanic), the temperature anomaly for this period compared to the 1961–1990 mean was around -0.5 °C in the Northern Hemisphere (Gao et al., 2008) and -1.1 ºC for the Swiss Alps (Büntgen et al. 2006).".*

3.2. *I am also asking myself whether the SNAO is the best mode to define circulation changes because the Alps are situated in the transition area between the northern and the southern pole of this pattern (also mentioned by the authors). Another aspect concerns the area you defined for your PCA analysis. Was it not rather small? I have the impression it would possibly be better to correlate the flood frequencies with the Atlantic Multidecadal Oscillation (AMO) which is a rough representation of the triggering SSTs in the North Atlantic area.*

Response:

With regard to the domain selected in our paper, a lot of analyses restrict this domain avoiding the north of Africa (problems with the reanalysis products in this area), using the window (40º-70ºN; 90ºW-30ºE). We used the domain (30º-70ºN; 30ºW-30ºE) because the principal action centers are well defined for the European North Atlantic realm and we think that the problems with the reanalysis in the 20CRP are partially solved. To include North Africa is important because Folland et al. (2009) showed relationships between SNAO and the precipitation in the Sahel. This fact can be observed in Figure 11 of our manuscript: the strong low located in the North Africa for the years with positive phase of SNAO and INU > 2.5 SD, leading atmospheric instability in this area. Furthermore, this pattern associates the summer floods in Switzerland with the Mediterranean realm.

The variance explained by our reconstruction of SNAO pattern (roughly 40% of the EMSLP variance) is appreciably different to the variance explained of SNAO patterns presented in the literature. The variance explained by the summer pattern presented by Barnston and Livezey (1987) is 10% over the analysis domain; Folland et al., (2009) represents 28% of the 2-month mean variance over the analysis domain; and finally, for Bladé et al. (2011) the total of the explained variance is 34%. The different sizes of domains used may explain these differences in the variances.

Finally, Folland et al. (2009) state that SNAO variations are partly related to the Atlantic Multidecadal Oscillation (AMO; this index is related to natural changes in the thermohaline circulation) on interdecadal time scales. Thus, the warm and cold North Atlantic phase of the AMO roughly corresponds to a negative and positive phase

SNAO, respectively. Given this link we prefer to use the SNAO pattern because it shows with more precision the location of the atmospheric centres of action.

Referee #1. Point 4:

Finally, I recommend, for the conclusions, to answer the questions: What was known before? What is new (e.g. was it possible to explain the remarkable flooding gap in the 20th century?).

Response:

In the new manuscript we structured the section of conclusions according to the different findings and we add the following sentence:

"We presented a new flood damage index (INU) exploring the influence of external forcings on flood frequencies and links with the Summer North Atlantic Oscillation (SNAO). Our major findings are presented below."

[1….

2….

3….]

Referee #1. Formal aspects:

1) The font size in some figures is quite small.

We have changed the font size in the figures 4, 5 and 9.

2) I do not understand the different expressions on the y-axis of the figures 4a and 4b with almost the same curves (maybe a statistician would!).

We changed the expressions of the y-axis in the plots of spectral and cross-spectral analysis (figures 4 and 5) to make the plot more understandable.

The method to achieve the plots of the figure 4 is different: in figure 4a we have applied a Harmonic Analysis and it is the power spectrum, while in figure 4b we have applied an autoregressive first-order parameter. This parameter represents the amplitude of spectrum (in decibels) (see manuscript, page 8, line 27).

The most important issue of this point is that we have removed the cross-spectrum plot (Fig. 5a) in the original manuscript because is not important for the cross-spectral analysis. In addition, difficulties exist in interpreting the peaks owing to the absolute values of the periodicities detected in the original variables as pointed out in the original manuscript. Of much greater importance is the coherency (Schulz and Stattegger, 1997) taking account that it is a dimensionless number with $0 \leq \hat{C}^2_{xy} \leq 1$ for all f_k. A plot of $\hat{C}^2_{xy}(f_k)$ versus frequency is called the coherency spectrum (new figure 5a). Finally, in the context of paleoclimatic time-series analysis, the phase relation between two variables is of particular importance (Schulz and Stattegger, 1997). The units of the phase spectrum are degrees [-180º, +180º] (new figure 5b).