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

Hydrol. Earth Syst. Sci. Discuss., 11, C6427–C6431, 2015

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

J.C. Peña, L. Schulte, A. Badoux, M. Barriendos, A. Barrera-Escoda

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.). This effects were eliminated partly in the present model. However, the frequency of floods did not change substantially. Finally, our regionalization show 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 17, line 8; page 18, line 27).

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 21, line 32, 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 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 it the different characteristics of the SNAO compared to the winter NAO, the SNAO 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 northwest Europe. This relation is more weakly in southern Europe and the Mediterranean characterized by cooler, wetter and cloudier conditions, especially in the east 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). This findings support our outcomes (p.22, L.21).

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 22-25: *"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 16-20: *"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 17-21: *"During this period an extra cooling occurred which was associated to 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 20CPR 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).

The most import issue is that we removed the cross-spectrum plot because is not important to the analysis. Furthermore, taking account that the coherency (figure 5a) 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.

Response to referees' comments (referee #2; 10/02/2015)

Hydrol. Earth Syst. Sci. Discuss., 11, C6427–C6431, 2015

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

J.C. Peña, L. Schulte, A. Badoux, M. Barriendos, A. Barrera-Escoda

REFEREE' COMMENTS:

General statements:

Referee #2:

Greetings to the authors of the manuscript "Influence of solar forcing, climate variability and atmospheric circulation patterns on summer floods in Switzerland", submitted to HESS.

The paper is carefully written, easy to follow and addresses very pertinent hydroclimatic questions. The authors use very well-known statistical methodologies for data analysis in the geosciences and rely on widely used data sources.

However, a number of critical issues require some attention:

Referee #2. Point 1:

Both the data and the methods should be taken with a "grain of salt". The reconstruction of geopotential height fields up to several centuries back is essentially a statistical extrapolation of XX century reanalysis data, under the assumption of stationarity. As such, the "atmospheric circulation patterns" identified for a climatology spanning several centuries are actually a loop of XX century cycles and may not fully capture the actual dynamics that might have taken place in the past. The reviewer understands that the authors had the best intention in using such reconstructions and knows that these had been produced with the best knowledge available to their authors, under assumptions that they had made clear themselves. However, these caveats should be clearly mentioned in this *manuscript, so that the reader is made aware that the statistical reconstructions and analysis of atmospheric data are not necessarily related to physical phenomena.*

Response:

In the paper we used the daily EMSLP grid taken from the 20th Century V2 Reanalysis Project (20CRP) and the monthly sea level pressure fields over the North Atlantic and Europe, generated by Luterbacher et al. (2002).

Generally, atmospheric reanalysis can be defined as a scientific method for developing a complete atmospheric dataset in order to analyse the evolution of the weather and climate over time. The method combines objectively observations and numerical models to generate a synthesized estimate of the atmosphere. Normally, it extends over several decades or centuries, covering the entire world from the surface to the stratosphere. Reanalysis products are used extensively in climate research: e.g. monitoring and comparing current climate conditions with those of the past, identifying the causes of climate variability and preparing climate predictions.

According to this definition, we can assume almost one difference between the two dataset used here. The 20CRP is based on the combination of surface and sea level pressure observations with a short-term forecast from an ensemble of integrations of an NCEP numerical weather prediction model using the Ensemble Kalman Filter technique to produce an estimate of the complete state of the atmosphere (Compo et al., 2011). In return, the Luterbacher grid were developed using principal component regression analysis based on the combination of early instrumental station series (pressure, temperature and precipitation) and documentary proxy data from Eurasian sites. The relationships were derived over the 1901–1960 calibration period and verified over 1961–1990. Under the assumption of stationarity in the statistical relationships, a transfer function derived over the 1901–1990 period was used to reconstruct the 500-year large scale SLP fields. Meaningful monthly reconstructions were available from around 1700 onwards, when station pressure series became available (Luterbacher et al., 2002).

Then, we can suppose that the uncertainty of both grids is approximately inversely proportional to the density of observations (Compo et al., 2011). The entire period that spans the 20CRP (1871-2009) is covered by atmospheric observations while Luterbacher grid that covers the period 1659-1999, the uncertainty is lower from 1780 when meteorological observations begin (Early Instrumental Period, EIP). For instance, the important work performed by the Meteorological Society of the Palatinate with a catalogue of extensive weather data (including pressure) for the period 1781-1792 taken by weather observers in 18 countries on the both sides of the North Atlantic realm.

The referee’s comments can be true for the Luterbacher grid for the period 1659-1800 with a low number of atmospheric observations and, essentially based on documentary proxy data. Note that we used this grid to reconstruct the SNAO for the period 1800-1870 and to analyse the flood period 1817-1851. Furthermore, the number of predictors for the transfer function used by Luterbacher et al. (2002) in our reconstructed period is around 50 in 1800 and approximately 100 in 1871 (see Fig. 1, page 548 in Luterbacher et al., 2002). We think that the number of predictors is significant for this period, although it is also a period reconstructed from the transfer function. Finally, remark that the correlation coefficient between the two grids is 0.89 for the common period 1871-1999 (in page 12, line 20 of the manuscript).

However following the recommendations of the reviewer, we have added this paragraph in the original manuscript (Page 7, lines 6-11): *“This grid was developed, under the assumption of stationarity in the statistical relationships, using a transfer function based on the combination of early instrumental station series and documentary proxy data from Eurasian sites. The function is derived over the 1901–1990 period and was used to reconstruct the 500-year large scale SLP fields (Luterbacher et al., 2002).”*.

Referee #2. Point 2:

On the so-called "Summer NAO":

This issue is also not the authors’ fault but is very critical to the paper:

Some geostatistical literature jumps into unfounded interpretations from statistical results without showing proper understanding about the physical processes. There, geospatial patterns are obtained and interpreted as being what they are not. One of them is the so-called "Summer NAO". The authors, who clearly strived to make a thorough analysis, have *clearly fallen victim of such ill-advised literature. However, now the authors have the chance to set the record straight prior to final publication. It would be a shame to see such interesting and well-written work marred by such a blunder that had not even been introduced by the authors in the first place.*

What is then the problem with the "Summer NAO"?

In a nutshell: the first principal component of the geopotential height field at 500 hPa (Z500) only represents the NAO if the analysis is performed for the Winter. In fact, that is the only season in which the NAO is the dominant circulation pattern. Over Summer the NAO is definitely not dominant. Instead, other processes take over. As such, it is their imprint, not of NAO, that is seen in the first principal component of the Summer climatologies of Z500.

In detail: There is a fundamental problem in the identification of the large scale atmospheric driver North Atlantic Oscillation (NAO). The authors mention a positive anomaly (high-pressure) centre over the North Sea (between Scandinavia and the British Isles), and a negative anomaly (low-pressure) centre over the Mediterranean. Actually, the centres of action of the NAO lie over the Atlantic, not over the North Sea or the Mediterranean Sea. The actual, physical high-pressure centre is the "Azorean High", over the North Atlantic area around the Azores archipelago, and the low-pressure centre is the "Icelandic Low", over the North Atlantic area around Iceland. The high-pressure centre close to Scandinavia is known as the Scandinavian High and represented by the Scandinavian Oscillation (SCO) Index. More on it can be found in a rich atmospheric science literature of rather quickly at major oceanic and atmospheric agencies, e.g. NCEP and NOAA http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml).

As noted before, when performing Principal Component Analysis for the extraction of EOF of the sea level pressure fields, the NAO pressure anomaly pattern will only be dominant during Winter (e.g. December to February, northern hemisphere). During Summer other patterns take over, e.g. the SCO. This is why the first EOF over Summer is no longer NAO-related, rather having completely different centres of action. Calling that "Summer NAO" is thus plain wrong.

This being said, the solution to this problem is within the authors' reach: first and foremost, the authors should remove the ill-named Summer NAO or SNAO, and then reinterpret the summer patterns in the light of mechanisms that actually play a dominant role at that time.

Again, it is very important to make it clear that these patterns are largely based on information statistically extrapolated from the XX-century, so that the results are put in the right perspective.

Response:

Climate variability in Europe is strongly influenced by changes in the atmospheric circulation. This is absolutely exact in winter with a well-defined pattern, the North Atlantic Oscillation (NAO) exerting a decisive control over the European climate. There is a lot of climate literature taking this pattern as paradigm.

The atmospheric circulation variability in summer is less known. Summer climate in the North Atlantic-European sector possesses a principal pattern of year-to-year variability similar to the North Atlantic Oscillation in winter, although this pattern is weaker and confined to northern latitudes. It is the dominant large-scale driver of summer rainfall variability in Europe and the Mediterranean and exerts a strong influence on European summer climate. By analogy with the winter season, Folland et al., 2009 refer to this pattern of variability as the Summer North Atlantic Oscillation (SNAO) and the objective of these authors in their analysis was establish the SNAO as a key paradigm in understanding European summer climate variability and to explore its characteristics.

Folland et al. (2009) review temporal evolution and surface impacts, despite that the SNAO-like patterns have previously been identified (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 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 decreased pressure over Greenland and increased pressure in north-western Europe. If it is compared to the winter NAO, the summer NAO is displaced northeastward, 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 relative to winter explains the lack of correlation with the station based NAO indices.

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 northwest Europe. This relation is more weakly in southern Europe and the Mediterranean characterized by cooler, wetter and cloudier conditions, especially in the east 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).

Barnston and Livezey (1987) show similar leading SNAO pattern in July explaining similar hemispheric variance to winter pattern: 10% for the summer pattern and 12% for the winter NAO. Figure 1 shows this pattern for July (SLP anomalies and compare with Figure 6 of our manuscript) with temperature and precipitation hemispheric conditions.

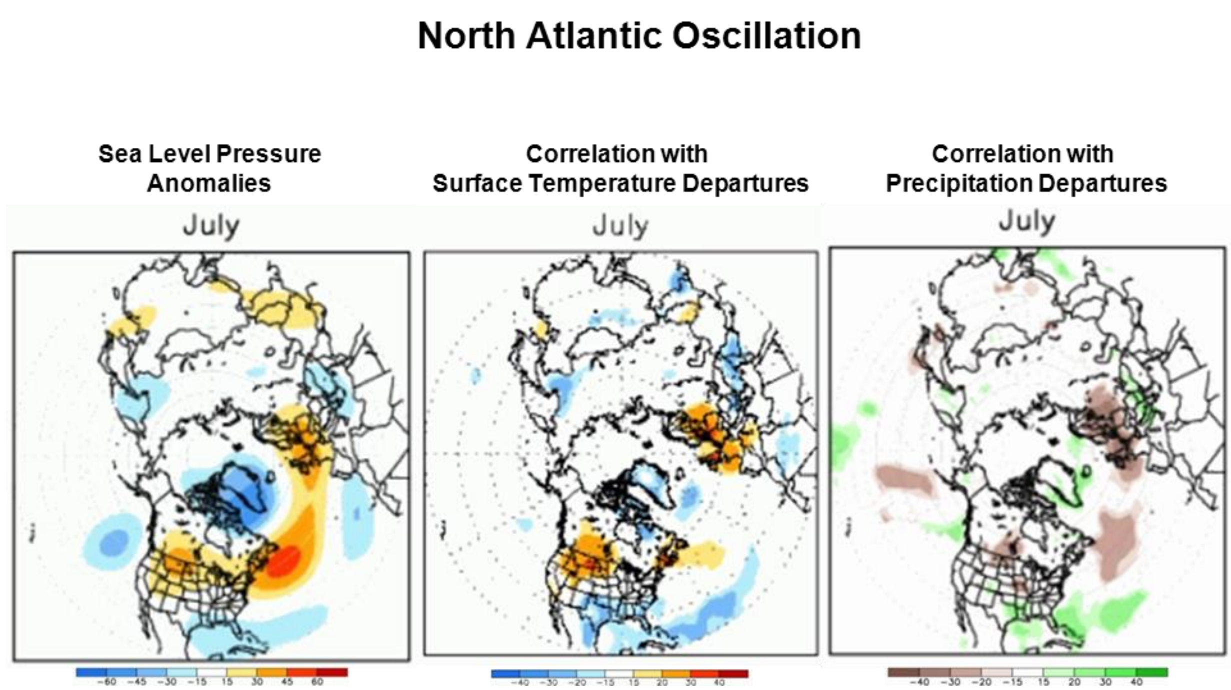

Figure 1. Source: ***http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml***

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 20CPR are partially solved. 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, the pattern associates the Mediterranean realm with the summer floods in Switzerland.

The variance explained of our pattern (roughly 40% of the EMSLP variance) is appreciably different to the 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; for 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 domains used can 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. Figure 2 represents the AMO index (Parker et al., 2007) and the SNAO, filtered both series with a with a 25-year low-pass Gaussian filter. The Pearson coefficient shows a negative correlation of -0.62 (the filtering does not permit the estimation of statistical significance) between both time series. Another teleconnections are positive correlations with temperature over the African Sahel region suggest distant relationships between the SNAO and the West African monsoon in July and August. On interannual time scales, small but significant correlations with La Niña SST pattern in the eastern Pacific appear in high summer. An analysis of the atmospheric patterns associated with El Niño conditions in high summer shows no significant signal with the SNAO. Some locally significant correlations are found over northeast North America where higher-than-normal temperatures are related to the SNAO positive phase. Finally, Sun and Wang (2012) suggested connection between the SNAO and East Asian summer rainfall.

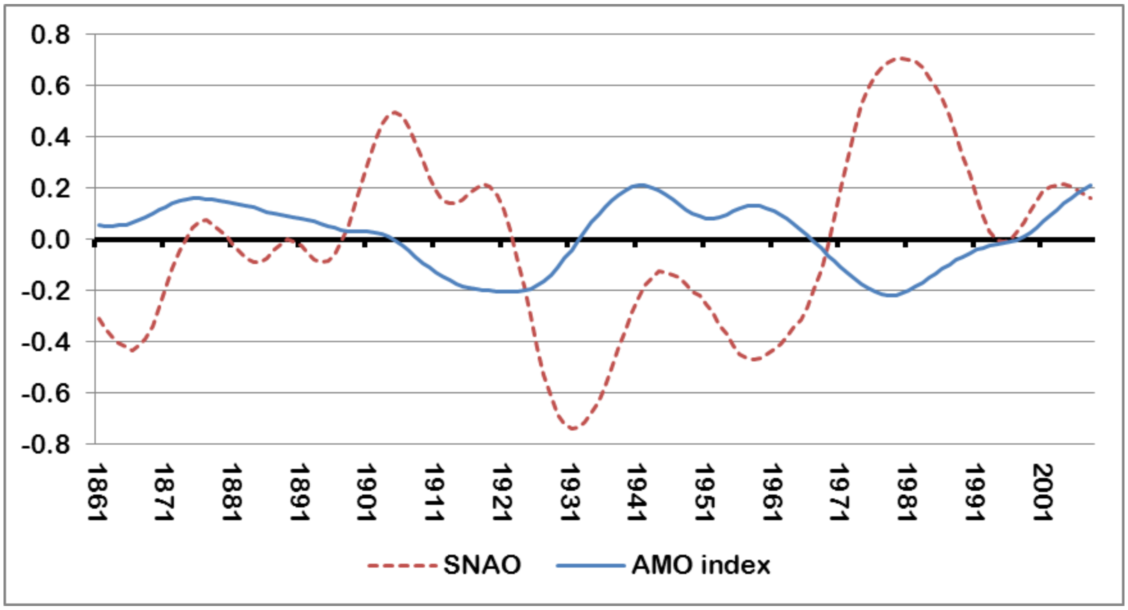

Figure 2. The SNAO versus AMO index filtered both series with a with a 25-year low-pass Gaussian filter. Source of AMO data: http://www.esrl.noaa.gov/psd/data/timeseries/AMO/.

The above described considerations about the SNAO have been impossible to express in our paper, given the extension of the manuscript with the objective to relate this atmospheric mode of the European sector of the North Atlantic to summer floods in Switzerland. The SNAO is perfectly defined in the climate literature, clearly distinguishing it of the winter NAO (Folland et al., 2009). On other hand, Bladé et al. (2011) presented an excellent analysis of the robustness of the pattern (see Figure 2 in the mentioned article).

However, another question is whether the winter NAO affects the summer floods in Switzerland. In this same issue “Hydrol. Earth Syst. Sci., 11, 2015”, we will publish another paper that relates floods records registered from sedimentary records for the last 3000 years in the Bernese Alps with several solar and climatic proxies. We suggest that the flood periods are associated with negative phases of the winter NAO from 1667 to 1820 cal yr AD. This relation is explained because the winter snow, the ice and the glaciers play a fundamental role in the generation of the flooding in Switzerland.

Moreover, in our manuscript we propose flood periods are associated with cool phases which is in agreement with the consulted literature (Schmocker-Fackel and Naef, 2010; Glur et al., 2013; Wirth et al., 2013). It can be found in the climate literature a significant number of papers linking these cold periods with phases of low solar activity (Wanner et al., 2011). The climate models show in these phases alterations in the atmospheric circulation due to hemispheric changes in heat air flux, ozone, humidity and cloudiness that provoke a shrinking of the Hadley cell, an expansion of the polar vortex and a southward shift of the western storm tracks. For the North Atlantic the results show a NAO-like pattern in negative phase (High et al., 2003; Gray et al., 2010). This pattern is correlated significantly with the winter season and no significantly with the rest of the seasons (Gray et al., 2010). Several authors have called this pattern as "paleo-NAO" (Wanner et al., 2008; Wirth et al., 2013). It is defined as annual or decadal state of the atmospheric circulation over the North Atlantic realm being the circulation dominant mode during the cool and low solar activity phases. This pattern affects the temperature and the precipitation, suggesting flood occurrence related to shifts of the Atlantic and Mediterranean storm tracks (Glur et al., 2013). Furthermore, atmospheric dynamics during winter season may also have a delayed influence on summer flood frequencies (Stewart et al., 2011). 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. Flood pattern occurs in years dominated by positive SNAO phase in the southern part of the Alps, while the negative phase is related to the northern side.

We add the following text at p. 3 L.18.

"Summer climate in the North Atlantic-European sector possesses a principal pattern of year-to-year variability similar to the North Atlantic Oscillation in winter, although this pattern is weaker and confined to northern latitudes. By analogy with the winter season, Folland et al., 2009 refer to this pattern of variability as the Summer North Atlantic Oscillation (SNAO)."

Referee #2. Point 3:

On calling EOF of the geopotential height field "atmospheric circulation patterns". In fact, per se they are not. Rather, as computed in the paper, they are geospatial patterns that explain the low-frequency statistical variability of the geopotential height field anomalies relative to the climatological average taken in the analysis (which is then directly related to atmospheric pressure field anomalies). These patterns can then be used to inform about the dominant wind patterns and thus circulation regimes. A proper name for these geospatial patterns is "teleconnection patterns", as this is ultimately about statistical teleconnections in the atmosphere, i.e. the identification of statistical properties that inform about the spatial coherence of a certain field.

Response:

Based on the definition given by the Climate Prediction Center of NOAA, a teleconnection pattern is:

“The term "teleconnection pattern" refers to a recurring and persistent, large-scale pattern of pressure and circulation anomalies that spans vast geographical areas. Teleconnection patterns are also referred to as preferred modes of low-frequency (or long time scale) variability” (***http://www.cpc.ncep.noaa.gov/data/teledoc/teleintro.shtml***).

We agree with the referee and we change in the manuscript *“atmospheric circulation patterns”* by *“modes of low-frequency atmospheric circulation”*.

Referee #2. Point 4:

On the general absence of physics behind the statistical analysis.

This is a recurrent problem in geostatistical and climatological studies, especially when teleconnection patterns are taken into consideration (e.g. NAO, SCO, EAWR, MJO, AMO, among others).

Purely statistical patterns are interpreted as being a physical signature, when they are not. Whilst addressing the fundamental processes behind would make for a completely new study, a brief word on potential mechanisms at play along with supporting physical arguments would be very welcome.

Response:

We think that this question has been answered in the point 2.

Referee #2. Point 5:

Correlation is not causation.

Finding some correlations between potential drivers (e.g. solar activity, atmospheric patterns) and floods is a worthy task and it is clear that the authors have taken it with care. However, it should be clearer to the reader that these do not mean that there is any causal link between the processes. Conversely, the absence of correlations does not necessarily mean that the processes are not related at all.

At most, correlations indicate the existence of a "statistical connection", which has the good use of assisting the researcher in formulating hypothesis to understand a certain problem. However, without a physical reasoning, correlations are just that: statistical connections. Therefore, care must be exerted when talking about "influences" when discussing correlations.

Response:

We are completely in agreement with the referee. In the original manuscript we warned of this fact (Page 17, line 31).

"However, it must be taken into account that the length of INU time series is relative short, covering 200 years, and linkages are based on only four flood periods and three flood gaps. Therefore, the relation between INU and the different climate proxies must be interpreted with caution and simple associations must not explain causal mechanism. Furthermore, it should be stressed that the INU signal includes uncertainties due to the integration of natural and anthropogenic variables. These reasons have to be borne in mind before discussing the following results".

Furthermore, we changed in the manuscript the word “correlated” by “links”, “associated” or “analyses” in page 4 (line 12), page 17 (line 21), page 18 (line 13) and page 19 (line 19).

Referee #2. Point 6:

On Vb tracks and floods of Mediterranean origin, p. 13867:

Actually, Vb are a local symptom of a broader synoptic situation generally coming from the Atlantic and then collecting additional moisture and energy from the Mediterranean (Blöschl et al. 2013: http://www.hydrol-earth-syst-sci.net/17/5197/2013/hess-17-5197-2013.pdf).

Response:

We agree to the referee. We change the sentence on page 21, line 3 of the original manuscript:

“This flood pattern occurs in years dominated by positive SNAO phases when depressions are usually associated with the Atlantic cyclones that develop or become more intense over the Mediterranean Sea, and follow a northeast to north-northeast track over the Alps.”

changed to:

“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 (Blöschl et al. 2013).”

Referee #2. Point 7:

New vs. known facts.

The paper would benefit from a clearer distinction between the knowledge revisited by the authors and their innovative contributions. Having extensively accompanied the relevant *literature, one can see how the authors innovated, but that might not be that clear to the less informed reader.*

Response:

We are completely in agreement with the referee. We add the following text and we have differenced each of the conclusions.

"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. *Despite regional climate differences within Switzerland, INU provides evidence that the 1817-1851, 1881-1927, 1977-1990 and 2005-present flood clusters are mostly in phase with paleoclimate proxies and North Atlantic dynamics. Moreover, these periods coincide with those identified in a range of studies concerned with the occurrence of floods in Switzerland and in the other river systems of eastern central Europe. The 20th century flood gap identified by the INU, reflecting the absence of extreme weather conditions, contrasts with the higher flood frequency of the last three to four decades, which has contributed to the increased perception of flood events.*
2. *The cross-spectral analysis shows that the periodicities detected in the coherency and phase spectra of 11 (Schwabe cycle) and 104 years (Gleissberg cycle) are related to a high flooding frequency and solar activity minima, whereas the 22-year cyclicity detected (Hale cycle) is associated with solar activity maxima and a decrease in flood frequency. We suggest that changes in large-scale atmospheric circulation (autogenic forcing) and solar activity (exogenic forcing) influence the occurrence of flood periods, although there is no general consensus as to how solar forcing has affected climate and flood dynamics in recent centuries.*
3. *The analysis of the modes of low-frequency atmospheric variability based on the standardized daily anomalies of sea level pressure shows that Switzerland is located close to the border between different modes of summer atmospheric circulation that are controlled by North Atlantic dynamics. Small shifts of this system border may*

introduce atmospherical instability over the Swiss river catchments. Very severe and catastrophic flood episodes are influenced strongly by positive (mostly central and southern basins) and negative SNAO (mostly the northern basins) modes, which include a range of synoptic patterns that generate severe floods. Finally we can state that the SNAO in negative phase controlled notably major floods during the last stages of Little Ice Age (1817-1851 and 1881-1927 flood clusters), while the positive SNAO prevailed during last four warmer decades (flood clusters from 1977 to present)".