Linking ENSO and heavy rainfall events over Coastal British Columbia through a weather pattern classification

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Answer to the reviewer comments

Suggestions made by the two reviewers are gratefully acknowledged. We modified the text in response to the main criticisms.
In the following, we list all the reviewers' comments (in *italic and blue*) and we provide specific responses to these comments (in black) and the modifications brought to the manuscript (in *italic and black*).

1 REVIEWER 1

1.1 General comments and recommendation

The manuscript presents an analysis on the relationship between El Niño Southern Oscillations (ENSO) and characteristic weather patterns as captured by analysis geo-potential analysis from NOAA's Twentieth Century Reanalysis Project, and their influence in the magnitude of the precipitation events in the coastal region of Oregon, Washington State and British Columbia. The presented study is certainly interesting and the presented results and discussion are relevant. However, the motivation of the study should be better introduced, and the organization of the manuscript and, particularly, the presentation of the methodology require some re-organization. Therefore, I cannot recommend the publication of the manuscript in Hydrology and Earth System Sciences in its present form, and I encourage the authors to make major modifications.

1.2 Major comments

1) As mentioned above, the motivation of the study should be better presented in the Introduction, and the use of the chosen methodology should be better justified.

We modified the presentation of the study motivation in the introduction (section 1):

The aim of this paper is thus to define a WP classification based on a bottom-up approach introduced by (Garavaglia et al., 2010), which is useful for heavy rainfall analysis of the Coastal BC region and to use the WP approach to study the links between ENSOs and BC heavy rainfall events. More specifically, magnitude and frequency of heavy rainfall events will be quantified over different winter sets (all winter sets, Nino winter sub-sets and Nina winter sets).

Moreover, we agree that it is needed to clearly highlight what are the goal, the interests and the limits of our methodology compared to other methods. Thus, we added three paragraphs in the section 2.1:

The goal of this weather pattern classification methodology is to group days having similar atmospheric circulation pattern in a limited number of typical weather patterns. The weather pattern classification is thus defined at a regional scale and consists of the attribution of each observed day to one weather pattern. This regional weather pattern classification is then used at the local scale, for each daily rainfall series considered: the observed rainfall series is split into several rainfall sub-samples according to the weather pattern classification. This splitting is based on the hypothesis that rainfall events observed over a given area have different atmospheric geneses and thus that a rainfall series sampling based on days having similar atmospheric circulation patterns produces more homogeneous rainfall sub-samples than considering the observed rainfall series as a unique series (Garavaglia et al., 2010). Geopotential height fields are used for the definition of WP classification since they are interesting descriptors of regional rainfall patterns (e.g. Littmann (2000)).

The main advantage of this methodology is that it produces a rainfall-oriented WP classification, but days without any rainfall observations are also classified: the approach only needs a limited calibration period (typically 20-years) where both observed rainfall series and geopotential height fields are available over a given region in order to define several typical WP. The generated WP classification is finalized by using geopotential information. Then, it is possible to extend the classification beyond the calibration period by using only geopotential height fields. Since long geopotential height reanalyses exist, such as the National Oceanic and Atmospheric Administration (NOAA) 20th Century Reanalysis - a global 6 hourly geopotential height fields from 1871 to 2011 (Compo et al., 2011) - or as the EMULATE reanalyses - a daily mean sea-level pressure reconstruction over Europe for the 1850–2003 period (Ansell et al., 2006) - the classification could be extended over significantly long periods. Boé and Terray (2008) applied a similar methodology combining both sea level pressure fields with daily precipitation fields for defining WPs over France and studying the link between WP frequency evolution and anthropogenic forcing for example. Applications of such approaches are particularly interesting for climate change impact studies, since only the geopotential

height fields simulated by the General Circulation Models could be considered for predicting future WP frequencies for example.
The main limit of this methodology is that the WPs defined are only characterized by particular dynamical atmospheric situations (e.g. typical spatial distribution of low and high pressure systems over a given area) and not particular thermodynamic atmospheric situations (e.g. typical distribution of moisture amount over a given area). For example, considering dynamical and thermodynamical (such as moisture fluxes) description of atmospheric situations significantly improves the forecast performances (Obled et al., 2002), approach also included in statistico-dynamical downscaling methods (e.g. Beaulant et al. (2011)) or statistical downscaling methods (e.g. Mezghani and Hingray (2009)).
The weather pattern classification methodology is fully described and used in Garavaglia et al. (2010) for the definition of eight French WPs and in Brigode et al. (2012) for the definition of five Austrian WPs. It is summarised in the following four steps.

2) Section 2 is very difficult to follow for a reader not familiar with the used methodology. I miss (1) a brief conceptual description of the methodology of Garavaglia et al. (2010), (2) some introduction on the available datasets, and (3) the specific objectives of the presented Methodology. I suggest re-organizing and combining sections 2 and 3, to specifically mention what are the datasets used in each of the steps and how each dataset has been used.
We re-organized both section 2 and section 3, in order to clearly highlight the different parts of the methodology used and which data sets are used for the different methodology parts.

We added an introduction at the beginning of the section 2 describing the general methodology used in this study. Moreover, the section 2 is now divided in three parts: the first part describing the methodology used for the WP definition (section 2.1), the second part describing the MEWP rainfall probabilistic model (section 2.2) and the third part describing the methodology used for the quantification of ENSO influence on rainfall characteristics (section 2.3).
This section aims at presenting the methodology used in this study. The methodology used for the WP definition is presented in the section 2.1, the Multi-Exponential Weather Pattern (MEWP) rainfall probabilistic model is described in the section 2.2 and the methodology used for the quantification of ENSO influence on rainfall characteristics is presented in the section 2.3.

A small introduction of the Multi-Exponential Weather Pattern (MEWP) rainfall probabilistic model has been added in the section 2.2.
The Multi-Exponential Weather Pattern (MEWP) probabilistic model (Garavaglia et al., 2010, 2011) *has been applied on each rainfall series in order to compute a Cumulative Distribution Function of daily rainfall amount for each series up to extreme return period. This rainfall probabilistic model is based on a seasonal and weather pattern sub-sampling of rainfall series and thus used a regional weather pattern classification previously defined. An exponential law is used to model each of the considered sub-samples (one sub-sample for each season and each WP). Finally, a global MEWP distribution is defined for each rainfall series as the combination of all the different exponential laws. The combination is weighted by the frequency of each WP central rainfall observations.*

We added an introduction at the beginning of the section 3 describing the available datasets. Moreover, the section 3 has been reorganized, in order to clearly group the data set used for the WP definition (section 3.1) and the data set used for the quantification of ENSO influence on rainfall characteristics (section 3.2). We hope that it improves the clarity of this section and its link with the methodology described previously, since these two sections have the same organization: (i) methodology /data sets used for WP definition and (ii) methodology / data sets used for the quantification of ENSO influence on rainfall characteristics.
This section aims at presenting the two datasets used in this study. The first dataset, used for the Coastal BC WP definition and described in the section 3.1, consists of 177 daily rainfall series available

over the 1983-2003 period and 338 daily geopotential height grid points available over the 1871-2008 period. The second dataset, used for the quantification of ENSO influence on rainfall characteristics and described in the section 3.2, consists of 45 daily rainfall series available over the 1951-2001 period and an index describing the ENSO characteristics of each observed winter over the 1871-2008 period.

3) There is a general lack of justification of some of the elections made throughout the study and the discussion of the expected impact of these elections is also missing:

a. Line 25 page 11737 – Line 3 page 11738: Why is the geopotential height used to identify Weather Patterns?

The geopotential height fields are often used for defining weather pattern classification, and several studies showed that geopotential heights are useful for describing regional rainfall patterns and heavy rainfall events (e.g.Littmann 2000). This was noted page 11739, in the lines 12 to 15:

The 1000 hPa fields are strongly correlated to the rainfall ones since they describe the pressure situation on the ground and catch the local patterns, while the 700 hPa fields give information at a larger scale and catch the synoptic systems and movements.

Since we agree that it would be better to briefly introduce this idea before going deeper into the classification methodology, we add the following sentence in the section 2.1:

Geopotential height fields are used for defining weather pattern classification since they are interesting descriptors of regional rainfall patterns (e.g. Littman 2000).

b. Lines 6-10 page 11738: why top 20% days are selected as rainy days? By choosing this threshold, what is the cut-off value of recorded rainfall?

The 20% threshold is an arbitrary threshold typically within the 10 to 25% range representing the balance between number of rainy days and precipitation magnitude of rainy days. Note that considering a 10% threshold and considering a 25% threshold have been done but are not showed in the paper since it does not imply significant difference in the defined WP classification. The idea of this 20% threshold is to identify days which have been particularly rainy on average over a given area. This sub-population of rainy days is then used for defining rainy day classes. The top 20% day selection is similar to select days where more than 8.1 mm have been observed in average over the considered area. We added this cut-off value in the text and described this threshold as an arbitrary threshold in the section 2.1.1:

… The top 20% days are selected as “rainy days” in this study and correspond thus to days where the spatial rainfall average over the considered area is greater than 8 mm. This 20% threshold is an arbitrary threshold typically within the 10 to 25% range representing the balance between number of rainy days and precipitation magnitude of rainy days.

c. Lines 10-12, page 11739. The use of the 700 hPa and 1000 hPa geopotential fields are justified based on the results obtained in France and Austria. Can these results be extrapolated to the use of the same information over BC?

The choice to apply the same methodology developed for France and Austria (i.e. using 700 hPa and 1000 hPa) over coastal BC has been mainly motivated by looking to the literature: Casola and Wallace (2007) used 500 hPa geopotential height fields for the definition of four weather regimes over the Pacific-North American sector and Neiman et al. (2011) examine 500 and 925 hPa geopotential heights for identifying atmospheric situations responsible for flooding in Western Washington.

Note that, as stated page 11743 at the lines 24 to 26, 500 hPa geopotential height fields have also been used for the weather pattern definition and no significant differences have been identified in terms of identified weather patterns.

d. Section 2.3. The section requires significant re-organization for a better understanding of the objective and how the analyses have been performed.

This section has been re-organized for a better understanding of the goals and the methodology used for analyzing the influence of ENSO on WP frequency and on the MEWP rainfall probabilistic model parameters.

e. Line 5, page 11743: How were the 177 stations selected? Are these all the available stations?

Yes, the 177 stations selected are all the available stations for the 1983-2003 period.

The 177 stations finally selected are coming from three rainfall data sources: (i) Environment Canada precipitation series, (ii) BC HYDRO precipitation series and (iii) some Northwestern Washington State precipitation series. The Environment Canada dataset is composed by relatively long series but mainly located in low elevation valleys and thus non-representative of the higher elevation precipitation patterns. BC HYDRO series have shorter temporal coverage (mainly beginning in 1983) but located in higher elevation area. Finally, Washington State series have similar elevation distribution as Environment Canada ones but provide important information for the understanding of Southern BC rainfall pattern. Finally, 177 stations have been selected for the definition of Coastal BC weather pattern, looking to data availability for the 01/01/1983 to 31/12/2003 period which is the time period when most data from three sources are available. The data quality has been checked, looking to statistically abnormal trends for each series compared to the nearest ones and looking to aberrant data.

f. Line 18 page 11743: Please, make explicit the criterion used to select the domain where Weather Patterns have been defined. Why 338 points?

As stated in the lines 19 to 23, the final domain used for defining the weather patterns has not been chosen with an explicit criterion, but by looking at a catalogue of historical storms synoptic situations and identifying a large domain which catch the low pressure / high pressure areas of these historical storms synoptic situations.

Note that we tested different geopotential height field domain sizes and positions for the definition of weather patterns, as we did for Austria in Brigode et al. (2012), but we did not found significant differences in the final weather patterns defined. Nevertheless, it could be an interesting perspective for further work. We thus added this perspective in the text, in the section 3.1.2:

Since no optimization procedure has been applied in order to select the final geopotential space size and position, it could be an interesting perspective for further research, by applying the methodology introduced by Brigode et al. (2012) for example.

g. Why were 5 WPs used in the study? How was this number selected?

The definition of the final number of classes is certainly the most difficult task when applying a classification method in general. Different criterion exist for choosing objectively the number of classes, but the final number is usually a mixture between the assessment of these numerical criterion and subjective choice motivated by the goal of the classification (having a classification with a limited number of classes for example) or thanks to expert analysis.

In our case, intra-class inertia has been the objective criteria for making the final class number choice. We thus add a figure in the section 4.2 showing the evolution of intra-class inertia when different number of classes are considered.

Figure 4 presents (a) the dendogram, (b) the evolution of the intra-class inertia and of (c) the 1-order intra-class inertia differences with the number of rainfall classes. Each difference Dn (plotted in the Figure 4(c) has been estimated as the absolute value of the difference between the intra class inertia estimated for (n+1) rainfall classes and the inertia estimated for (n) classes. Note that good classifications are characterized by high intra-class inertia values, and thus that a peak of intra-class inertia value for (k) classes followed by a significant loss of intra-class inertia value for (k+1) classes means a good classification of (k+1) classes. The change in intra class inertia clearly suggests the choice of four rainfall classes (highlighted with four red boxes in the dendogram presented in Figure

4a): moving from three to four rainfall classes leads to a limited intra-class inertia decrease, while moving from four to five rainfall classes leads to a large intra-class inertia decrease. Finally, the rainy days classification is composed by four rainfall classes and of one supplementary non-rainy class constituted at this stage of the 80% less rainy days (with spatial average below 8.1 mm in this case).

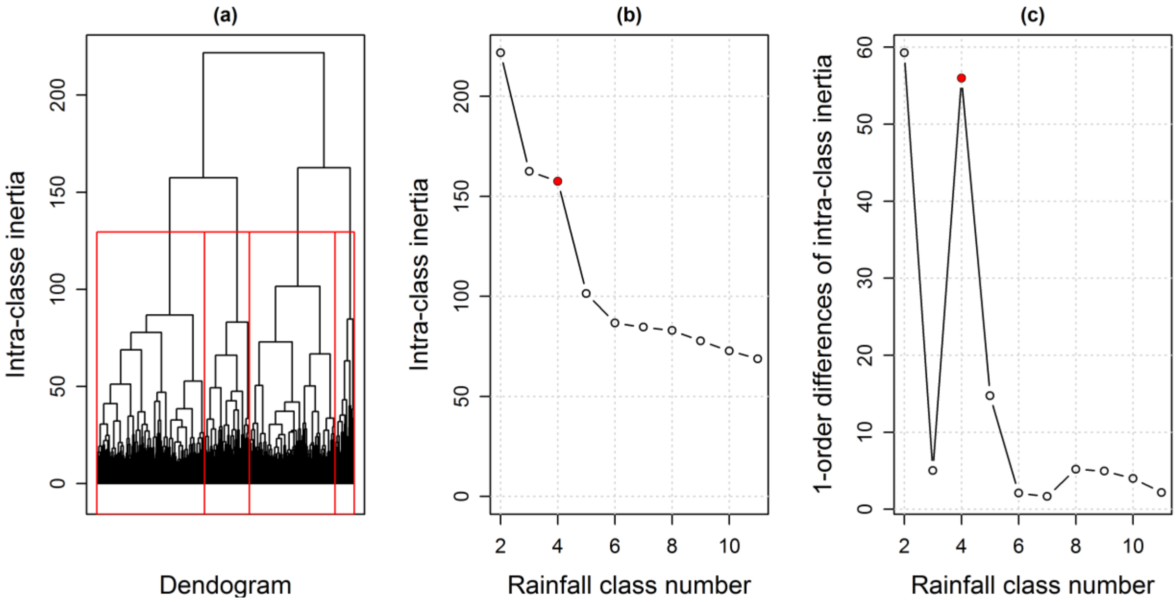

Figure 4. (a) Dendogram obtained from hierarchical Ascendant Classification of Coastal BC rainy days. (b) Intra-class inertia and (c) 1-order intra-class inertia differences evolution with the number of classes. Red boxes highlight the four rainfall classes identified and red points highlight their intra-class inertia.

1.3 Minor comments

1) Line 9, page 11738: 20 years corresponds to approximately 7305 days. However the total number of reported days adds up to 7660. Please, explain why.

The reviewer is right, we wrongly considered the 01/01/1983 – 31/12/2003 period as a 20-years period since it corresponds to a 21-year period constituted by 7670 days.

2) Lines 21-23, page 11739. This part of the description is unclear. If I understand correctly, the authors refer to the "non-rainy class" as defined in section 2.1.1 and to the "rainy classes" identified with the HAC method of section 2.1.2. I would suggest rewriting this part of the text to improve its clarity.

At this stage of the methodology, the observed days are either in one of the several (four in our case) "rainy classes" or in the "non-rainy" class. Note that since we used a 20% threshold for the definition of rainy/non-rainy days, the non-rainy class is constituted by 80% of all the observed days (days where less than 8.1 mm have been observed in average over the studied area) and the other 20% of all the observed days (days where more than 8.1 mm have been observed in average over the studied area) are separated within the different rainy classes. We rewrite this part for improving its clarity (section 2.1.3):

Once one geopotential space is defined, the centroids of the rainy classes and of the non-rainy class previously identified are calculated in this space, by estimating the four average geopotential fields of the days composing each rainy class. Note that at this stage of the methodology, the non-rainy class is constituted by 80% of all the observed days (the less rainy days in average over the studied area) while the rainy classes are composed by 20% of all the observed days (the most rainy days in average over the studied area).

3) Lines 7-9, page 11740. "The four distances between the four geopotential height fields". Is this the Euclidean distance?

The distances estimated are not Euclidean distances but Teweles-Wobus distances (Teweles and Wobus, 1954), which considered the synoptic circulations gradients. We modified the text for improving its clarity (section 2.1.4):

The final Teweles-Wobus distance between one particular day and one class centroid is defined as the sum of the four Teweles-Wobus distances between the four geopotential height fields (700 and 1000 hPa at 0 h and 700 and 1000 hPa at 24 h) of the day considered and of the centroid considered.

4) Section 2.1.4. The result of the re-assignment performed here can be in contradiction with the results of the HAC of section 2.1.2. How would this affect the definition of the Weather Patterns? Also, please, state more clearly that not only the "rainy days" (defined in section 2.1.1 as the top 20% rainy days) were used in the Weather Pattern classification.

At this stage of the methodology, we have defined the average geopotential situations of each typical weather pattern (five in our case, described with 700 and 1000 hPa geopotential fields). These average situations are estimated as the mean geopotential heights fields of all the days which have been assigned to the different classes by the Hierarchical Ascendant Classification. Our final weather pattern classification is more than this definition of mean geopotential heights fields for each WP, it consist in a time series of weather patterns: for example, 1st January of 1950 is a weather pattern 1 (WP1) day, 2nd January of 1950 is a WP3 day, etc. To produce this final classification, the geopotential situations of each observed day is compared to the average geopotential situations of each weather pattern, in order to find which weather pattern is closest from the considered day, in terms of geopotential heights fields.

An example of this classification has been inserted in the text in order to illustrate this final step (section 2.1.4):

The final Teweles-Wobus distance between one particular day and one class centroid is defined as the sum of the four Teweles-Wobus distances between the four geopotential height fields (700 and 1000 hPa at 0h and 700 and 1000 hPa at 24h) of the considered day and of the considered centroid. This last step is illustrated in the Table 1, which shows the 20 Teweles-Wobus distances estimated between the five rain class centroids (Rainfall Class (RC) one to five) and the 16th October 2003 synoptic situation for the 1000 hPa geopotential height fields at 0h, the 1000 hPa geopotential height fields at 24h, the 700 hPa geopotential height fields at 0h and the 700 hPa geopotential height fields at 24h. Note that the 16th October 2003 days was classified as a member of non-rainy class (in the 80% of all the observed day considered as non-rainy) at the end of the Hierarchical Ascendant Classification step. The sum of the four Teweles-Wobus distances is minimal for the third weather pattern (233); the 16th October 2003 is thus attributed to the third weather pattern. This example highlights the major changes between the rainy days classification (Hierarchical Ascendant Classification step) and the final WP classification which are mainly due to the distribution of previous "non-rainy days" to rainy weather patterns. The 20% arbitrary threshold used for defining rainy days has no influence on this final step since all observed days are classified in terms of distance between average geopotential situations of the identified WPs and each day geopotential situations, grouping days having similar synoptic situations and not considering their observed rainfall fields.

	RC1	*RC2*	*RC3*	*RC4*	*RC5*
1000 hPa at 0h	*57*	*52*	*56*	*66*	*76*
1000 hPa at 24h	*52*	*53*	*48*	*58*	*78*
700 hPa at 0h	*74*	*75*	*70*	*79*	*92*
700 hPa at 0h	*65*	*68*	*59*	*70*	*94*
Distances sum	*248*	*248*	*233*	*273*	*340*

Table 1: Teweles-Wobus distances estimated between the 16th October 2003 synoptic situation and the five class centroids estimated for the 1000 and 700 hPa geopotential height fields at 0h and for the 1000 and 700 hPa geopotential height fields at 24h. In this case, the 16th October 2003 is finally attributed to the third weather pattern.

5) Lines 11-12, page 11740. A brief description of the approach introduced by Garavaglia (2010) is necessary. The definition of "centred rainy events" needs some further clarification. Similarly, in equation (1), could you please confirm that CR is the 24-hour rainfall averaged over the analyzed weather stations?

Since we agree that a brief description of the MEWP probabilistic rainfall model is needed, we added few lines on this model and on the centred rainy events definition and highlighted that CR sub-samples are defined for each rainfall series in the section 2.2:

The Multi-Exponential Weather Pattern (MEWP) probabilistic model (Garavaglia et al., 2010, 2011) has been applied on each rainfall series in order to compute a Cumulative Distribution Function of daily rainfall amount for each series up to extreme return period. This rainfall probabilistic rainfall model is based on a seasonal and weather pattern sub-sampling of rainfall series and thus used a regional weather pattern classification previously defined. An exponential law is used to model each of the considered sub-samples (one sub-sample for each season and each WP). Finally, a global MEWP distribution is defined for each rainfall series as the combination of all the different exponential laws. The combination is weighted by the frequency of each WP central rainfall observation.

Note that MEWP distributions are fitted on a sample of "centred rainy events", noted CR hereafter. The CR population is defined, for each rainfall series, as days having higher precipitation values than the previous and following days. Using this sub-sampling allows working on a distribution of (so-considered) independent events, which is much denser than annual maximums for example.

Moreover, note that seasonal MEWP distributions are defined, where seasons generally consist in grouping three or four continuous months of similar rainfall hazard values. In Coastal BC, the rainy season is mainly constituted by the winter months both for the common and the heaviest events. Heavy rainfall analysis has thus been limited in this study to a six winter months season, from October to March. This "long" winter season allows working on relatively long rainfall sub-populations.

6) Line 3, page 11741. To my understanding, the definition of Weather Pattern (WP) is not yet consolidated enough at this point of the manuscript. I would suggest emphasizing the definition of Weather Patterns in sections 2.1.3 and 2.1.4.

We tried to define more clearly the methodology and the final product of our weather typing approach in sections 2.1.3 and 2.1.4.

7) Lines 3-8, page 11742. It is the first time that the authors mention the bootstrap analysis. I would suggest introducing the motivation of the presented analysis before describing it.

We agree that clear motivation of the bootstrap analysis was not clearly written. We thus reorganized the considered section and highlighted the motivation of the bootstrap simulations:

2.3.1 Influence of ENSO on WP frequency and on MEWP parameters and distributions

Each observed winter (ONDJFM) will firstly be characterised as `Nino winter' or `Nina winter', according to SST Niño 3.4 Index (Trenberth 1997), described in section 3.2.2. Three winter sub-sets will thus be defined (All winters, Nino winters and Nina winters). The frequency of each WP is then estimated on the three winter sets and compared for each WP.

Then, more local tests will be performed to determine the influence of ENSO on rainfall characteristics over several Coastal BC rainfall stations. A MEWP distribution will be defined for each rainfall series considered and for each of the three winter sets (All winters, Nino winters and Nina winters). The MEWP distribution parameters are then compared for each rainfall station. Finally, the three MEWP *heavy rainfall estimations are compared for each station and each winter set considered, by looking at 1000-year return period precipitation values.*

2.3.2 Bootstrap simulations for testing the difference significance

The significance of WP frequency, MEWP parameters and MEWP heavy rainfall estimation differences between the three different winter sets has been evaluated by performing nonparametric bootstrap simulations, initially proposed by Efron (1979) and classically used in statistical characterization of uncertainty and sensitivity analysis. The idea is thus to evaluate ENSO influences on WP frequency, MEWP parameters and MEWP heavy rainfall estimations regarding to natural variability which is quantified by sub-sampling observed winters without consideration of their ENSO characteristics.

For testing the significance of the WP frequency difference between the three different winter sets, 1000 random winter combinations are generated among all the winters available over the period considered. Each of the 1000 random winter combinations is composed by the same number of winters, which is equal to half of the total number of winters of the period considered, i.e. for a given period composed of 20 winters, 1000 combinations of 10 winters will be generated. Note that the bootstrap simulation performed does not allow having a particular winter more than once in one combination of winters. WP frequency will be finally estimated on each of the 1000 combinations generated, in order to quantify the natural variability of WP frequency and thus to compare the frequency estimated on particular ENSO winter sub-sets compared to all the sub-sets (without consideration for ENSOs) generated by bootstrap simulations. Note that a similar methodology has been applied by Casola et al. (2007) for identifying the correlation between ENSO and the frequency of occurrence of four Pacific–North American winter WPs.

The same methodology is applied for each rainfall series considered in order to quantify the significance of MEWP parameter differences and MEWP heavy rainfall estimation differences. MEWP parameters will be defined for each station on 1000 random winter combinations, in order to quantify the impact of the natural variability (without consideration for ENSOs) on the MEWP parameters and distributions and thus to compare the parameters estimated on particular ENSO subsets with all the subsets generated by bootstrap simulations.

8) Line 11 page 11743: Should not "Western Washington" be referred to as "Washington State"?

We changed this part of the text (section 3.1.1):

Note that the stations used are located in the Coastal BC region (Canada) and also in the Western part of the Washington State (USA).

9) Line 18 page 11743: Please, use "grid spacing" instead of "resolution".

We changed this expression in the article version (section 3.1.2):

The geopotential height fields, provided by the Twentieth Century Reanalysis Project data set (Compo et al., 2011) from the National Oceanic and Atmospheric Administration (NOAA) are defined on a 2-degree grid spacing from 1871 to 2008 for both 700 and 1000 hPa.

10) Section 4.1. I neeeded reading the text several times to fully follow the discussion and Figure 3. I would suggest revising the text for clarity and state more clearly that each point in the panels of figure 3 corresponds to 1 station. In the panels of figure 3, would the 1:1 line help the interpretation of the results? I would also suggest making the same range for x and y axes for each panel. Page 11745, lines 19-25: Refering to concrete elemens of Figure 3 would help the reader to follow the discussion (e.g. "… also show an unclear signal…"; where?).

We changed both the Figure 3 and its interpretation (section 4.2):

Fig. 3 presents the relative differences between rainfall characteristics of all the record periods (51 winters) and over the Nina winters (17 winters) and the relative differences between rainfall characteristics of all record periods (51 winters) and over the Nino winters (20 winters) estimated for each of the 45 rainfall stations. Four characteristics were estimated: (a) the average of winter precipitation values, (b) the frequency of the days when more than 20mm were observed, (c) the 0.70 *percentile and (d) the 0.95 percentile of the rainfall distributions. The blue and red histogramms represent for each of the four graphs the distributions of the (x) and the (y) axis values. Each point represents one of the 45 rainfall series.*

For the majority of the 45 Coastal BC rainfall series considered, the average winter amount of rain is higher during Nina winter compared to all winters since numerous points are in the left part of the Fig3.a and average winter amount of rain is lower during Nino winter compared to all winters since numerous points are in the bottom part of the Fig3.a. Thus, significant differences are observed in terms of average winter amount of rain over Coastal BC, with about 8% increase in rain during Nina winters compared to all winters on average over the 45 stations considered, and 8% decrease in rain during Nino winters compared to all winters on average over the 45 stations considered. The difference between Nino and Nina winters is less significant in terms of frequency of heavy rainy days (here days with 20mm or more observed). Nevertheless, a majority of points are in the bottom part of the Fig3.b, highlighting a lower frequency of heavy rainfall events during Nino winters compared to all the winters for the 45 considered stations. Finally, heavy (percentile 0.70) and extreme empirical quantiles (percentile 0.95) also show an unclear signal, with percentile values slightly lower during Nino winters compared to all winters and slightly higher during Nina winters compared to all winters, especially for the heavy rainfall event percentile.

11) Page 11749, line 28 – page 11750, line 8. Pointing at the specific panels of Figure 7 would help the reader understand the presented arguments.

In the new version of the paper, we pointed at the specific part of the Figure 7, now referenced as Figure 8:

Figure 8 compares the parameters of the 45 Nino MEWP distributions with the parameters of the 45 Nina MEWP distributions. It is organised as a table, with each column representing one Coastal BC WP and each line representing a parameter of the MEWP distributions. Each point represents one of the 45 rainfall series studied. Note that the first two lines (λ and u) are the parameters of the exponential distribution of each WP, while the third line (p) is the mean number per year of CR events of each WP for each station. Scale parameter value variability (plotted in the first line of the Figure 8) using different winter sets is significant (from -40% to +40%) but the impact of ENSO on this variability is not straightforward. Variability of the u parameters (plotted in the second line of the Figure 8) is slightly more limited (from -30% to +30%) but the ENSO impact on their values is also not clear. Nevertheless, WP1 u values (plotted in the second line, first column of the Figure 8) seem to be significantly higher during Nina winters than during Nino winters. Finally, the variability of CR frequency for each WP (plotted in the third line of the Figure 8) is limited (from -20% to +20%), but ENSOs seem to significantly impact their values: WP1 and WP2 CR events are more frequent during Nina winters (plotted in the second line, first and second columns of the Figure 8, respectively), while WP3 and WP4 CR events appear to be more frequent during Nino winters (plotted in the second line, third and fourth columns of the Figure 8, respectively), as shown for WP frequency in section 4.4.

12) Lines 9-10 page 11750: "noted P1000 hereafter, exprimed in mm". Should not "exprimed" be "expressed"?

We changed this sentence (section 4.5):

The estimations of 1000-yr return period precipitation values (noted P1000 hereafter, expressed in mm) were then compared.

13) Figure 7 and related discussion (page 11749-11750). By looking at the variability of the different paramenters separately, the authors implicitly assume that the role of the 3 fitted parameters is independent. How would the results change when one of the parameters is set constant? Could you please comment on this aspect and on how this could affect the interpretation of your results?

We do not assume that the parameters are independent since they are strongly not. For example, the scale parameter values are totally dependent on the quantile threshold values considered for the definition of the heavy rainfall events sub-population (0.70 quantile in this study) and thus on the u parameter values (0.70 quantile value in mm). Moreover, a sensitivity analysis (not showed in this study) showed that the MEWP extreme rainfall estimates are strongly influenced by the scale parameter values (λ parameters) and clearly less influenced by the frequency of rainy events (p parameters). Finally, our methodology has been built in order to quantify the influence of natural variability and variability induced by ENSO on extreme rainfall estimations and not to study the independence of the different MEWP parameters.

14) Section 5: I miss some discussion about how the presented results compare to findings by other authors (some of them introduced in section 1). As an example, in page 11736 the authors state "Kenyon and Hegerl (2010) did not find a clear, significant difference between El Niño winter extremes and other winters over BC". Some discussion on how this agrees or not with the obtained results would be interesting.

We agree that a discussion about other study results comparison was missing. We thus added discussion in the first part of the section 5:

El Nino Southern Oscillations influence significantly the frequency of occurrence of two Coastal BC WPs: WP2 is more common during Nina winters rather than during Nino winters and WP3 is clearly more common during Nino winters than during Nina winters. These changes are statistically significant, but the magnitudes of changes are small: WP2 is observed 22% of all days during Nino winters, whereas it is observed 27% of days during Nina winters, and WP3 is observed 17% of all days during Nina winters, whereas it is observed 22% of days during Nino winters. These results are consistent with findings of Casola and Wallace (2007), which showed that ENSO influence significantly the frequency of their four weather regimes defined over Pacific–North American Sector.

Empirical evidence of ENSO influence on rainfall characteristic has been observed. Significant differences are observed in terms of average winter amount of rain over Coastal BC, with about +8% rain during Nina winters compared to all winters on average over the 45 stations considered, and −8% rain during Nino winters compared to all winters on average over the 45 stations considered. A lower frequency of heavy rainfall events (here defined as days with 20 mm or more observed) during Nino winters compared to all the winters for the 45 considered stations seems to be observed.

Finally, heavy (percentile 0.70) and extreme empirical quantiles (percentile 0.95) seems to be slightly lower during Nino winters compared to all winters and slightly higher during Nina winters compared to all winters.

Within each WP, ENSOs seem to only influence the frequency of rainy events and not the magnitude of heavy rainfall events: WP1 and WP2 central rainfall events are more frequent during Nina winters, while WP3 and WP4 central rainfall events appear to be more frequent during Nino winters. MEWP heavy rainfall estimations do not show significant evolution of heavy rainfall behaviour between Nino and Nina winters: ENSO is not influencing significantly the 1000-year return period precipitation values estimated over the Coastal BC region through the MEWP rainfall probabilistic model. Natural variability seems thus to be predominantly explaining the differences of heavy rainfall values estimated through the MEWP rainfall probabilistic model over Coastal BC region.

These results are consistent with the findings of Feldl and Roe (2011) which showed that ENSO could influence differently mean rainfall values and the extreme rainfall quantiles and with studies that did not find a significant influence of ENSO on extreme rainfall values over Coastal BC region (e.g. Kenyon and Hegerl 2010 and Zhang et al. (2010)).

15) In many parts of the text, the authors refer to periods like 1951-2001 and 1983-2003 as 50-year and 20-year periods. Note that if the two extrenes are included these are 51-year and 21-year periods.

The reviewer is right, the 1951-2001 period is a 51-year period and the 1983-2003 period is a 21-year period.

16) Please, make all the panels of the figures larger (specially, Figures 3-7 and 9). The presented results and text are hardly visible.

We changed the text size in all the figures.

2 BIBLIOGRAPHY

Casola, J.H., Wallace, J.M., 2007. Identifying Weather Regimes in the Wintertime 500-hPa Geopotential Height Field for the Pacific–North American Sector Using a Limited-Contour Clustering Technique. Journal of Applied Meteorology and Climatology 46, 1619–1630.

Efron, B., 1979. Bootstrap Methods: Another Look at the Jackknife. Ann. Statist. 7, 1–26.

Feldl, N., Roe, G.H., 2011. Climate Variability and the Shape of Daily Precipitation: A Case Study of ENSO and the American West. J. Climate 24, 2483–2499.

Garavaglia, F., Gailhard, J., Paquet, E., Lang, M., Garçon, R., Bernardara, P., 2010. Introducing a rainfall compound distribution model based on weather patterns sub-sampling. Hydrol. Earth Syst. Sci. 14, 951–964.

Garavaglia, F., Lang, M., Paquet, E., Gailhard, J., Garçon, R., Renard, B., 2011. Reliability and robustness of rainfall compound distribution model based on weather pattern sub-sampling. Hydrol. Earth Syst. Sci. 15, 519–532.

Kenyon, J., Hegerl, G.C., 2010. Influence of Modes of Climate Variability on Global Precipitation Extremes. Journal of Climate 23, 6248–6262.

Littmann, T., 2000. An empirical classification of weather types in the Mediterranean Basin and their interrelation with rainfall. Theoretical and Applied Climatology 66, 161–171.

Neiman, P.J., Schick, L.J., Ralph, F.M., Hughes, M., Wick, G.A., 2011. Flooding in Western Washington: The Connection to Atmospheric Rivers. Journal of Hydrometeorology 12, 1337–1358.

Teweles, J., Wobus, H., 1954. Verification of prognosis charts. Bulletin of the American Meteorological Society 35, 455–463.

Trenberth, K.E., 1997. The definition of El Niño. Bulletin of the American Meteorological Society 78, 2771–2778.

Zhang, X., Wang, J., Zwiers, F.W., Groisman, P.Y., 2010. The Influence of Large-Scale Climate Variability on Winter Maximum Daily Precipitation over North America. Journal of Climate 23, 2902–2915.