Response to Anonymous Referee #1
Received and published: 4 March 2020

The referee comments are in italics, and the author responses have been written in blue

Synopsis:The paper analyses trends of precipitation in the Alpine region since 1900 in a dynamical downscaling simulation. They use the regional climate model MAR at 7 km resolution, driven with ERA-20C boundary conditions, for the Alpine region. The focus is on extreme precipitation events and their seasonal changes. They first evaluate climatological features such as altitude gradients and then assess trends. They find seasonal, regional and altitude-dependent patterns of trends. Trends are mostly only significant when considering the entire centennial time period. The paper is interesting and scientifically sound, though not ground-breaking. It fits into the scope of the journal and hence I recommend publishing the paper after revisions have been taken into account.

We acknowledge the referee #1 for his/her supporting comments. Her/his comments are answered below.

Major points:

Structure: The paper could be shortened and made more accessible. For instance. The Introduction is long and talks at length about aspects such as the North Atlantic Oscillation etc. These aspects are not taken up later in the paper. I suggest to remove all parts that are not addressed later in the paper (or, alternatively, to revert to these aspects in the discussion part).

The introduction has been shortened by around 20 lines, by excluding all the introductive parts that are out of the scope of the article. The conclusion has also been slightly shortened.

Trends: An important question regarding the trends reported is the trend in the driving data set, i.e. ERA-20C. Please report the trends in this data set. If this data set is drying out unrealistically or has other shortcomings, this might affect the final results and its interpretation. Interpretation: It seems the authors interpret their findings mostly in terms of a regionally closed moisture budget (e.g. when they discuss different moisture availability as a function of altitude), although they are not very clear about it. They do not address or discuss things like atmospheric rivers or the like. I think they should discuss their findings more broadly and more specifically. Also, perhaps they could give the reader some feeling about the change in moisture advection in ERA-20C or in MAR. Sometimes it is not clear whether they refer to a model diagnostic or their interpretation (e.g.,when they write about moisture availability).

We acknowledge the first referee for these useful comments. The analysis has been completed with a description of the circulation changes (wind and moisture) at the scale of Western Europe in ERA20-C. The climatology of the vertically integrated moisture and the vertically integrated moisture flux from ERA20-C is shown in Figure 1 from this response, highlighting that most of the moisture is related to Westerlies bringing moist air masses from the Atlantic in all seasons.

The presence of the mountains induces lower vertically integrated moisture in the Alps compared to surrounding areas. Overall, the vertically integrated moisture is stronger during warm areas and periods, in particular during the summer, when the warm atmosphere is able to contain large amounts of water vapour. A longitudinal gradient is found over the continental areas, with drier air masses in the Eastern continent during winter, spring and autumn (Figure 1-a-b-d), whereas large amounts of atmospheric moisture are found in Eastern Europe in summer (Figure 1c). Interpretations of the seasonal vertically integrated moisture in the atmosphere is delicate in the sense that atmospheric moisture is driven both by temperature and winds.

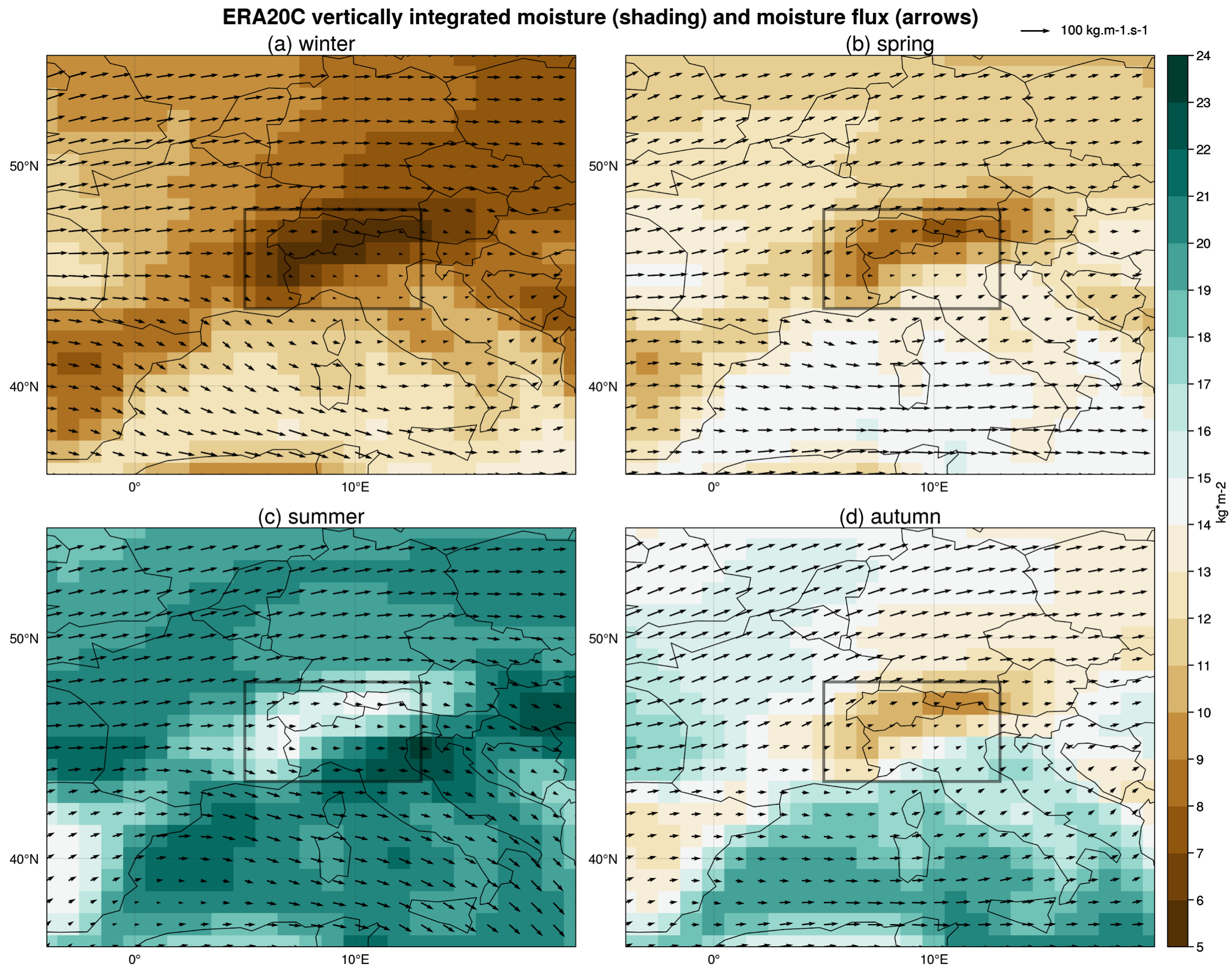

Figure 1: ERA20C climatology (1902-2010 average) of vertically integrated moisture (shading) and vertically integrated moisture flux (arrows). The rectangle highlights the domain of application used in this study. This figure has not been included in the revised manuscript.

Changes of atmospheric moisture are considered here for a better understanding of the precipitation changes over the Alpine area. The moisture trends (vertically integrated moisture and moisture fluxes) are shown in figure 2, a figure that has been included and described in the revised manuscript. The seasonal changes in precipitation simulated with MAR over the Alps (Figure 4 of the original manuscript, Figure 3 of this response) are strongly related to the seasonal changes of moisture in the ERA-20C reanalysis used as boundary conditions (Figure 2 of this response). The drying in the Po Plain is related to a drying that occured over a large part of the Mediterranean area, in particular over the French and the Italian Mediterranean coasts, that propagated inland especially during the summer, when southwestern winds transport moisture at the East of the continent (figure 2c). During the winter and the autumn, the moistening over Germany, Benelux and the North of France and Switzerland is related to an increase of western moisture fluxes that bring moisture from the Atlantic, in particular over the Northern flank of the Alps. The coarse resolution of ERA-20C does not allow a fine estimation of the precipitation changes over the Alps, contrary to what can be done with the MAR experiments at higher resolution. Conversely, the spatial features of the precipitation changes over the Alps simulated by MAR are largely related to the large-scale moisture fluxes driven by the ERA20C forcing.

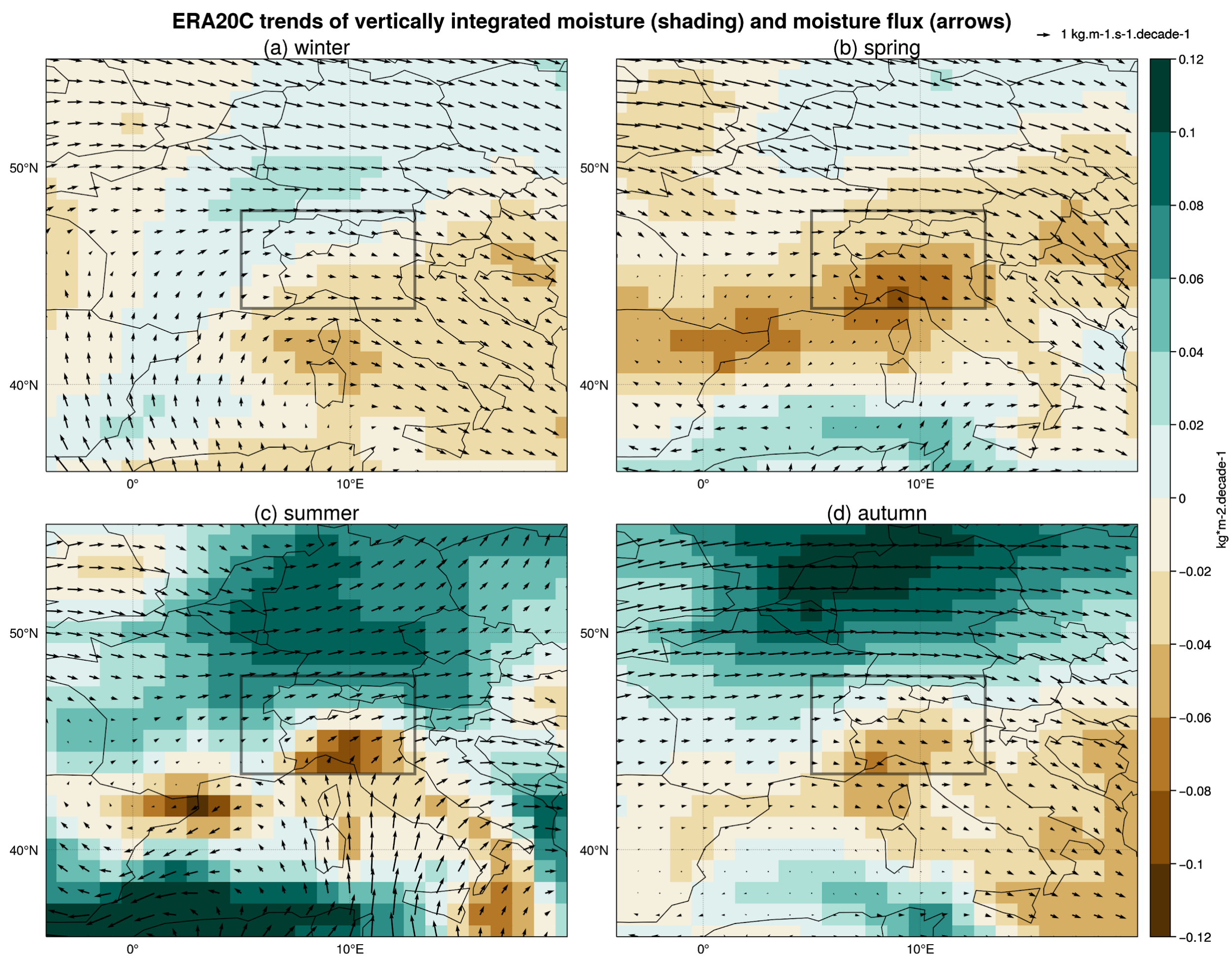

Figure 2: ERA20C linear trends over 1902-2010 of vertically integrated moisture (shading) and vertically integrated moisture flux (arrows). The rectangle highlights the domain of application used in this study. This figure is now Figure 5 of the revised manuscript.

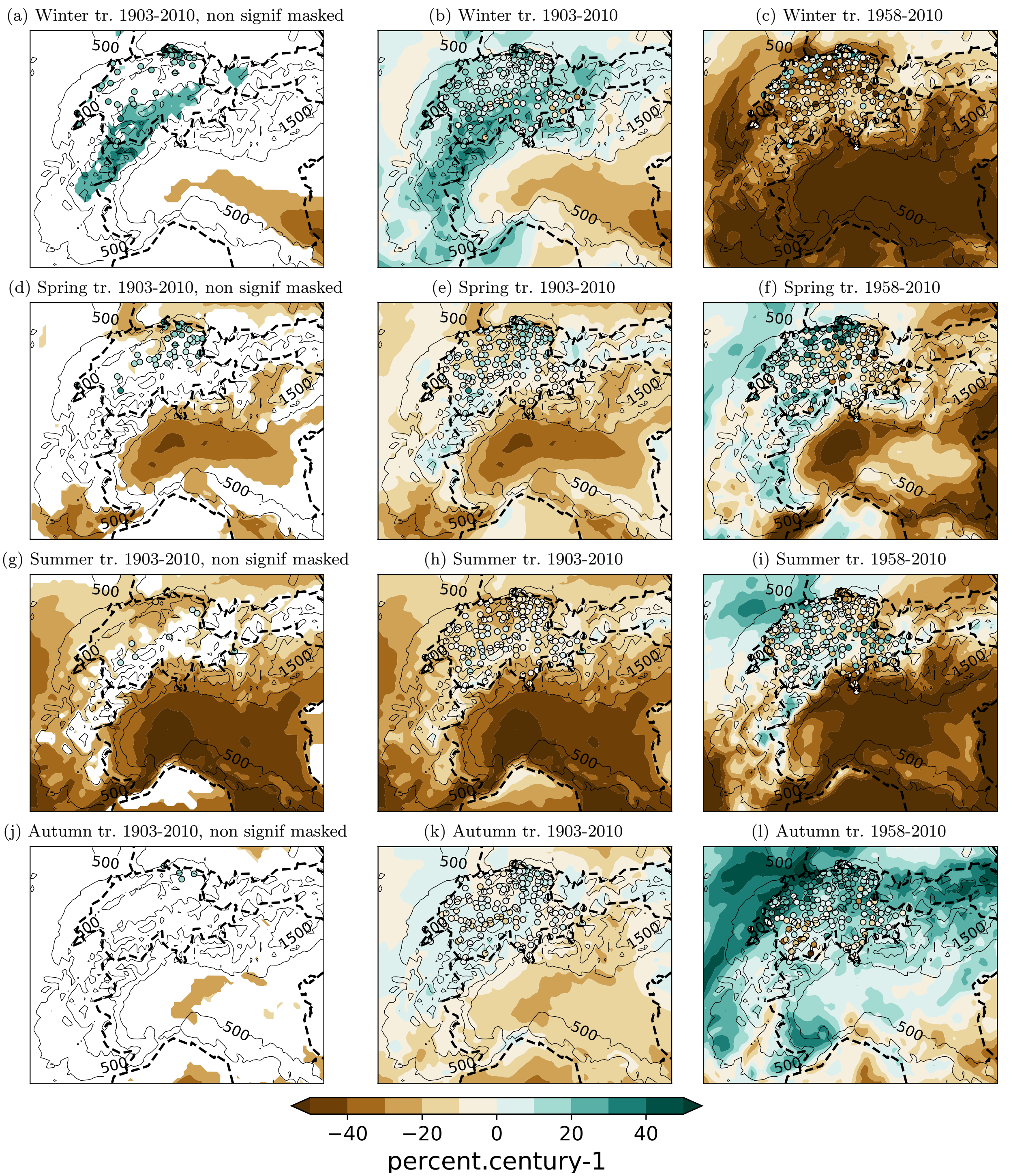

Figure 3: Seasonal linear trends (percent per century) of precipitation amounts in Winter (a-b-c), Spring (d-e-f), Summer (g-h-i) and Autumn (j-k-l), for the time periods 1903-2010 for (a-b-d-e-g-h-j-k) and 1958-2010 for (c-f-i-l). 1000 m-spaced black contours show the topography in the 7km-resolution model, starting from 500 m.asl and frontiers are denoted with the black dashed lines. In subfigures (a-d-g-j), the trend is masked when its p-value is below 0.05 (level of confidence is lower than 95%; white areas for the model outputs and station data excluded). This figure has replaced Figure 4 of the initial/discussion manuscript.

In the revised manuscript, the model diagnostics have been shown separately from the interpretations, either related to local-scale or to large-scale changes found in the ERA-20C reanalysis. Also, caution has been considered in the manuscript in the interpretations shown in the conclusion, in particular for the points concerning the moisture availability and the convective processes.

Minor:
L 24: longer and more intense?
L. 46: Danube: Alpine an non-alpine headwaters show quite different behaviour in some aspects. So, perhaps just at in brackets (Inn, Salzach, Saalach, etc.)
L. 50: make these
L. 54: has occurred and is expected to occur
L. 162: This is the first instance that a relation is made between the text and the paper. I suggest placing the paper in the context much earlier.
L, 165: I am missing what questions are actually addressed in the paper.
Sec. 2.3. For the sake of completeness, indicate the time resolution of all data sets (e.g. L. 239: is the gridded data set also monthly? Is SAFRAN daily?).
L. 310: 40-80% difference is huge!!
L. 315: Pattern correlation?
L. 319: Again, 20-80% is huge!
L. 366: I can hardly believe the bad correlation of HISTALP. Please double check.
L. 380: dependent
L. 426: twice significant
L. 449: Avoid qualifiers such as "dramatic"
L. 503: I do not understand this sentence.

Discussion: For trends in Rx1day I suggest the authors cite Scherrer et al. (2016),https://doi.org/10.1002/2015JD024634
L. 534: Just to clarify: stratiform precipitation is a separate diagnostic variable in the model?
L. 542: local convective precipitation locally?

We have considered all the minor comments in the revised version of the manuscript. In particular, we have double checked our analysis based on HISTALP and we have included *Scherrer et al. (2016)* in our references. A deeper analysis concerning the changes in convective versus stratiform precipitation, two separate diagnostic variables in our model, is provided in the response to referee #2.