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The Cryosphere Discussions

Interactive comment on "Snowfall in the Alps: Evaluation and projections based on the EURO-CORDEX regional climate models" *by* Prisco Frei et al.

Anonymous Referee #2

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General comments

The paper "Snowfall in the Alps: Evaluation and projections based on the EURO-CORDEX regional climate models" by Prisco Frei, Sven Kotlarski, Mark A. Liniger, Christoph Schär aims to enlight the ability of the EURO-CORDEX models to represent snowfall over the Alpine region in the last decades and to provide future projections for the late 21st century.

The topic addressed by the paper is of interest for a broad community and within the scopes of the Journal. The paper is well written, with a proper language and in good English. The objective of the work clearly stated, the methods, the scientific results and conclusions presented in a clear and concise way.

However, the manuscript presents some inconsistencies in the methodology that needs to be addressed before pubblication.

First of all, in absence of a daily observational gridded snowfall dataset for the Alpine region the authors derive a dataset using daily temperatures and precipitation. They separate the snow fraction from the total precipitation using a fixed temperature threshold T*=2°C. While this method works fine with hourly data, it is probably weak when using data at daily scale. As the rest of the paper builds on the hypotesis that this snowfall dataset represents the ground truth (i.e. the hypothesis is used for the calculation of Richardson snowfall fraction fs,Ri ; for the bias correction of RCM snowfall fields) authors should provide some evidence that their snowfall dataset closely represent the real snowfall distibution.

In the Results (section 3.1) it comes really unexpected that the authors validate the RCM raw snowfall outputs by using 29 fresh-snow daily time series from MeteoSwiss stations. This dataset was not presented before and should be described in the "Observational datasets" section. Moreover this datasets is by definition "the" ground-truth, and I wonder why it comes out only at this point. It should be used for a detailed validation of the 2 km gridded snowfall product that you derive from temperature and precipitation fields. How the 2km gridded product compares to the fresh snow observations? Does it represent properly the snowfall climatology (mean, extremes) in correspondence of the stations? Does it represent the altitudinal gradient of mean/extreme snowfalls intensities? This information on the quality of the gridded reference dataset should be provided as it is necessary to set the basis for the whole methodology.

Finally the RCM bias correction methods is calibrated on the area of Switzerland only and then applied to the whole Alpine region. This is justified by the authors with the lack of information on snowfall beyond the borders of Switzerland. Indeed previous efforts were made to derive a gridded snowfall dataset for the Alpine Region: HISTALP dataset provides monthly snowfall over the full Alpine domain, since 1800, at about 10 km spatial resolution, i.e. resolution comparable to the RCM gridsize (12 km). I

believe this manuscript should include the HISTALP dataset in the analysis, in order to provide a comprehensive view on the reference datasets. In particular I would suggest to discuss i) how HISTALP compares with the stations and the 2km gridded dataset in the Swiss Alps; ii) if it is a good quality reference for validating the RCM snowfall outputs at monthly (or longer) time scales over the Swiss domain.

Specific comments

- P 7 L254: “We apply this regression to relate the surface temperature T to the snow fraction fs by accounting for the topographic subgrid variability. At each coarse grid-point k, the Richards method-based snowfall fraction fs,RI for a given day is hence computed as follows ... First, we estimate the two parameters C and D of Equation 4 for each single coarse grid point k by minimizing the least-square distance to the fs values derived by the Subgrid method via the reference snowfall SSG (local fit).”

The method used to separate snowfall with the temperature threshold T*=2°C is effective with hourly data but it is crude when using daily data as it returns snowfall fraction fs=1 or fs=0 in a given day. This can be far from the reality, expecially at middle elevations (throughout the snow season) but also at high elevations in spring and autumn. The fs,RI depends on the C and D, and the latter are estimated assuming that fs is a good estimator of the solid precipitation fraction. But as said above fs is characterized by unknown uncertainty. You should prove that fs closely reproduce the real snowfall fraction, before applying your method for deriving fs,RI and your snowfall reference dataset. Minimum requirement is to provide a quantification of this error, using fresh snow manual observations in the 29 manual stations.

- P9 L317-321: “the initial snow fractionation temperature T*=2°C of the Richards separation method (see Sec 2.5) is shifted to the value T*a for which the spatially and temporally averaged simulated snowfall amounts for elevations below 2750 m a.s.l. match the respective observation-based reference."

With this temperature correction you basically report the RCM snowfall to your refer-

ence. So, also in this case, before applying this procedure you need an evaluation of the error on your snowfall reference. Moreover, can you give details on how you calculate spatial and temporal averages, i.e. which domain/ time range?

- P9 L327: “Note that, as the underlying high-resolution data sets are available over Switzerland only, the calibration of the bias correction methodology is correspondingly restricted, but the correction is then applied to the whole Alpine domain.“

HISTALP dataset provides gridded snowfall monthly fields for the Alpine region at about 10 km spatial resolution (Chimani et al 2011), it should be included in the analysis and discussed in comparison to your reference/manual observations in Switzerland

Chimani, B., Böhm R., Matulla C., Ganekind M.: Development of a longterm dataset of solid/liquid precipitation Adv.Sci.Res,6,39-43, 2011http://www.adv-sci-res.net/6/39/2011/asr-6-39-2011.html

- P10 L338-341: "EURO-CORDEX simulations ... are compared against observations derived from measured fresh snow sums from 29 Meteo Swiss stations with data available for at least 80% ofÂăthe evaluation period. For this purpose a mean snow density of 100 kg/m3 for the conversion from measured snow height to water equivalent is assumed."

As said before, I am surprised to see at this point of the paper that you have 29 fresh snowfall time series covering the 1970-2005 period. They should be presented before (section 3.1) & exploited much more than you do. These manned observations are the ground truth and they should be used to validate the snowfall gridded dataset that you derive from temperature and precipitation over Switzerland. Please provide a quality control of the snowfall gridded dataset prior to use it

- P10 L345-347: “The positive bias at high elevations might arise from the factÂăthat the very few observations were made at a specific location while simulated grid point values ofÂăthe corresponding elevation interval might be located in different areas of

Switzerland.“

Here you consider all Switzerland and you really mix very different areas far away one from another. Please discuss the case when only the gridpoints containing stations are considered, i.e. showing the spread of the models around the observed time series (i.e. in plots for the three - low, middle and high - elevation ranges?

- P14 L487: “In between is a transition zone with rather strong changes with elevation” . Can you explain why?

- P14 L494-6: Could it also be residual biases along the snowfall line?

- P16 L587-8: Given more precipitation at high elevation & temperatures more favorable to heavy snowfalls, why does the snowfall frequency decrease?

Technical corrections

- P2, L42: Climate models do not “simulate the anthropogenic greenhouse effect”, but the provide projections of the future climate in different scenarios, i.e. assuming different of rates of emissions of the greenhouse gases, land cover/use changes .. This sentence should be rephrased with more proper terminology

- P2 L50: “Although the snowfall fraction is expected to decrease at lower elevations during the 21st century”: here one or more citations is needed

- P2 L57: "Projections of future changes in theÂăsnowfall climate" -> "Projections of future changes inÂăsnowfall"

- P2 L63: I suggest to remove "of the projections"

- P3 L79: “Low”->“Lower”

- P3 L87: “coarse resolution RCM grid” : here “coarse resolution” is misleading as in the former lines you consider RCM resolution as “high”. I suggest to remove “coarse resolution”

- P3 L89: “a gridded observational snowfall product that could serve as reference for RCM evaluation does not exist”. This is true only for data at daily scale (see comment above on HISTALP)

- P3 L91: “Air” temperature

- P3 L94: “on the coarser (RCM) grid” -> “on the coarser RCM grid”

- P3 L113: “potentially leading to a reduction in overall snowfall amounts changes”: “changes” should be removed

- P4 L115: “here events > 1 mm/day”: please give a more a accurate definition of events, I assume “P>1 mm/day”

- P4 Section 2.1: Can you provide some information on the stations included in the two gridded datasets (precipitation & temperatures), i.e. how many are they? Are the same stations measuring both variables?

- P4 L139: “errors might be induced by . . .” I would also mention the uneven distribution of the stations and the under-representation of high altitudes.

- P4 L142: “in innerÂăAlpine valleys, where the presence of cold air pools is systematically overestimated” please provide a reference

- P5 L157: “The six RCM considered” -> They should be seven

- P6 211: “This method also allows for a more physically-based bias correction of simulated snowfall amounts (see Sec. 2.6).” This sentence is unclear here. I would move at the end of the paragraph: “. . . traditional bias correction approaches based only on a comparison of observed and simulated snowfall amounts in the historical climate would possibly fail due to a non-stationary bias structure, while the present method also allows for a more physically-based bias correction of simulated snowfall Âăamounts (see Sec. 2.6).”

- P7 L224 “coarse grid information” -> “fine grid information”?

- P7 L258 The two parameters C and D are defined as “point of inflection” and “growth rate” without giving other details. Please provide an explanation of the physical meaning.

- P8 L280: “For both indices Smean and Sq99, mean ratios across all elevation intervals are close to 1 (Fig. 2). At single grid points, maximum deviations are not larger than 1$\pm$0.1.” At single gridpoints the spread seems $\pm$0.3 for the binary method (Fig 2)

- P9 L316: “Pcorr approximately corresponds to the observation-based estimate” I would add “in the evaluation period”

- P10 L362 Fig. S1 -> Fig.S2

- P11 L372-377 : Can you provide more detail on the extent of the undercatch?

- P11 L388: “Bias of close to” -> Bias close to

- P13 L471 : between “effect” and “of” it seems there are too many spaces?

- P13 L485: “change sin” -> “changes in”;

- P13 L486: “in the upper part” -> “at higher elevation”

- P19 L692: “..”

- P19 L700: “snowfall-friendly temperature range” : Nice however I would say “temperature range more favorable to snowfall”

- Figure 1: What is the souce for this topography?

- Figure 6: The differences among these plots are not easy to see, I would recommend to show biases with respect to the reference.

- Figure 11: How low and high elevations are defined? Transition seasons are MAM and SON?

- Table 1: Caption “his study” -> “this study”. Moreover, please check the "*r1i1p1" below the table, which models does it refer to?

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