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Non-Hydrostatic RegCM4 (RegCM4-NH): Model description and case studies over multiple domains
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Referee #2 (Citation: https://doi.org/10.5194/gmd-2020-435-RC2**)**

The paper "Non-Hydrostatic RegCM4 (RegCM4-NH): Model description and case studies over multiple domains" describes the extension of RegCM4 with a non-hydrostatic option. Three case-studies are presented which all feature heavy precipitation events in different parts of the world.

Response: Thanks to the Reviewer for the time she/he dedicated to review our manuscript. Below our responses to the comments.

General comments:

The paper could make a valuable contribution to the community, but it seems unfinished and needs major improvements.

1. The current manuscript needs a general language check. One can often find slips like additional blank spaces or inconsistent naming. Just to give one example: The term convection-permitting is used often in the text but sometimes with and sometimes without hyphen. It feels like the text has been written by many different people, which is not a bad thing at all, but it adds to the impression of being unfinished. Some sort of harmonization by one author would increase readability and consistency.

Response: Thank you to the Reviewer for her/his comment. We have corrected typos and slips. We did a language check, rephrasing wherever possible to better harmonize the text.

2. Another aspect that makes the manuscript look unfinished is the fact that some features of the model are explained in great detail, but others are completely left out. The title reads "Model description". I do not expect that all components are described in great detail, but at least a table listing all model features such as radiation scheme etc. with references where to find a description would be nice. Not everyone knows RegCM4 and searching all the other references for the bits an pieces is quit cumbersome. What is the time integration scheme?

Response: We have added Table 1 with a full list of physics parameterizations and references. The time integration scheme used by the RegCM model is the leap-frog one. This information has been added to the manuscript.

Specific comments:

Line 24: Delete "the" in front of the first RegCM. What does RegCM stand for? **Response:** The sentence relative to the Regional Climate Modeling system (RegCM) here (L24-27) has been opportunely rephrased.

Line 50: Do you mean "bias compared to observations"? **Response:** correction done

Lines 65-67: The mentioning of Grell et al. (1995) seems redundant in this sentence. **Response:** correction done

Line 68: Do you mean "same grid an variable structure as RegCM4"? **Response:** rephrased

Line 229-231: For the Texas case you used ERA-Interim directly. Can you also motivate this decision with spatial spin-up and the work by Matte et al. (2017; DOI: 10.1007/s00382-016-3358-2)?

Response: We appreciate the comment and we added some discussion in the text. In the Texas case study we nested the model directly in the ERA-Interim reanalysis with boundary conditions provided every 6 hours, given that such configuration was able to reproduce accurately the HPE intensity. In this case the model uses a large LBC relaxation zone which allows the description of realistic fine-scale features driving this weather event (even if not fully consistent with the Matte et al., 2017, criteria).

Table 1: Can you add the domain sizes. **Response:** done. Table 2 (1 in previous version) now also includes domain size information.

Figure 2: Numbers and texts around the sub-figures are too small. Is it possible to use a common label-bar and the same contour intervals? This would make it easier to distinguish different orographic features in the domains. In section 3.1 you describe the Russian River. Maybe it is worth to already indicate it here, as not everyone is familiar with California.

Response: We improved figures readability. Moreover we have indicated the area where the russian river is located with a red dot in the new domains figure (Fig. 3) and we have added a short description in the text.

Figure 3: Numbers are too small. What does the arrow length mean? I find it hard to compare the maps a) and b) with c). Can you either choose the same section in c) or at least indicate the regions of a) and b) in c) with a square.

Response: The panels (now Figure 4) have been modified accordingly. Unit vector has been added to give the measure of wind velocity based on arrow length. The whole figure has been replotted to improve its readability. A black square in panel “c” surrounds the same area as in panels “a,b”.

Line 271: Delete "the" in front of land. **Response:** The text has been rephrased accordingly to the new analysis.

Line 274: Do you mean "same variables from ERA5"? **Response:** yes. rephrased (now line 408).

Figure 4: Numbers are too small. I would recommend to split the figure and treat each region separately. All cases use different observations or analysis products and one case does not have a corresponding hydrostatic run. Keeping everything in one figure is not helping the reader, but tends to confuse. What are the resolutions of the observations/analysis?

Response: Done. We have splitted Figure 4 in three different figures (figures 5, 7 ,11) and analyzed each case separately using several observational datasets as also required by the another referee.

Line 319: Is the comparison to ERA-Interim really fair given that the jump in resolution is rather extreme? One could even argue that the precursors are in ERA-Interim, because the downscaling captures the event.

Response: Thank you for the comment. In Figure 7, we now also show five other high-resolution observational datasets for comparison. We included the ERA-Interim because it's useful to see how the driving boundary conditions represent the rainfall event and it highlights the advantages of the high-resolution simulation, but it was not our intention to make an unfair comparison. We have rephrased opportunely and also added a discussion about the other observational datasets.

Line 329: "The RegCM4-NH simulation shows a more realistic temporal evolution than the RegCM4, ..." Did you mean ERA-interim instead of RegCM4? I thought there was no (hydrostatic) RegCM4 simulation. **Response:** Right. We have corrected the sentence (now line 498).

Line 360: Can you motivate the choice of 26°C for the lake temperatures with observations?

Response: This initial LST value was chosen following some previous studies. Talling (1969) shows for the Lake Victoria surface temperatures ranging from 24.5-26°C during the course of the year. Several studies have used RCMs to investigate the climate over Lake Victoria (Anya et al., 2006; Anyah and Semazzi 2009, Sun et al. 2015). They showed a significant relationship between lake temperatures and rainfall which varied depending on season. The value of 26°C (Tailing 1969, YIN X. and Nicholson S.E. 1998) was chosen based on preliminary sensitivity tests using different values of temperature ranging from 24°C to 26°C in order to evaluate the effect of lake surface temperature on RegCM simulation and on lake-atmosphere coupling in the representation of the spatial distribution and iIntensity of the precipitation over the Lake Victoria Basin (Sun et al 2015). The initial LST of 26°C has shown to produce the most realistic precipitation for the period analyzed. We have added this discussion in the manuscript.

Figure 6: Numbers are too small. Coastlines are very hard to see. What does the arrow length mean? **Response:** Done, We have changed the figure (now Figure 8) in order to make it more clear/comprehensible. Unit vector has been added to give the measure of wind velocity based on arrow length.

Line 374: Can you indicate the cross-section with a line in Figure 6 **Response:** We have added the cross section in Figure 8b.

Line 393: Replace "and this" with "which". **Response:** Done. The whole sentence has been rephrased (L 619-621).

Lines 394-395: This sentence is hard do understand. Do you mean that the maximum is captured but the pattern shifted to the south? Please rewrite.

Response: The sentence has been rephrased: "In particular, the 3 km simulation reproduces well the local rainfall maxima on the western side of the lake, although these appear more localized and with a multi-cell structure compared to CMORPH and TRMM."

Line 398: Delete "overall" **Response:** The whole sentence has been rephrased.

Line 399: Delete "that" **Response:** The sentence has been rephrased.

Section 4: The first paragraph needs a complete revision. I find many formulations hard to understand (e.g. the sentence from line 406-408). I can only find one conclusion that basically reads that non-hydrostatic models are better in simulating convection than coarser hydrostatic models. This is not new and obvious to me. I'm not saying that a model description paper needs ground braking conclusions. I rather like to encourage the authors to think about the possibilities the new system is opening up and how this system can add to the challnges around local climate change. The second paragraph is touching this topic and maybe the authors can expand on this. I would even wish for a short section in the main text on the performance of the model on climatic time scales.

Response: Sentence in lines 406-408 (now L 635-637) has been rephrased to clarify.
Findings from first long-term multi-model experiments at the convection permitting scale are discussed in the Introduction section documenting recent literature on the topic (Coppola et al., 2020, Ban et al., 2021, Pichelli et al., 2021). A second paragraph in the Conclusion section has been added.

For completeness we have adapted some plots from Pichelli et al. (2021) to show the behaviour of RegCM-NH in terms of climatic simulations within the km-scale multi-model ensemble for a series of precipitation indices. We report below the box plots, Fig. R2-1(Fig. R2-2), of area-averaged precipitation indices (mean precipitation, wet-day(hour) intensity, wet-day(hour) frequency, heavy precipitation (P99 for day extremes, P99.9 for hourly ones)) across the 12 models ensemble at km-scale resolution used in the paper, highlighting with a black cross the position of RegCM-NH within the ensemble. The models common area of study and the sub-regions considered are reported in Fig. R2-3. The ensemble and RegCM-NH are compared with different observed dataset at the daily scale (Figure R2-1) and with the highest (space-time) resolution observations at the hourly scale (Figure R2-2). The model performance changes on a season and region base, showing a greater tendency to be in line with the rest of the ensemble (first and third quartile) in fall season, while often laying at the drier edge of the distribution in summer, although remaining within the 5th percentile.

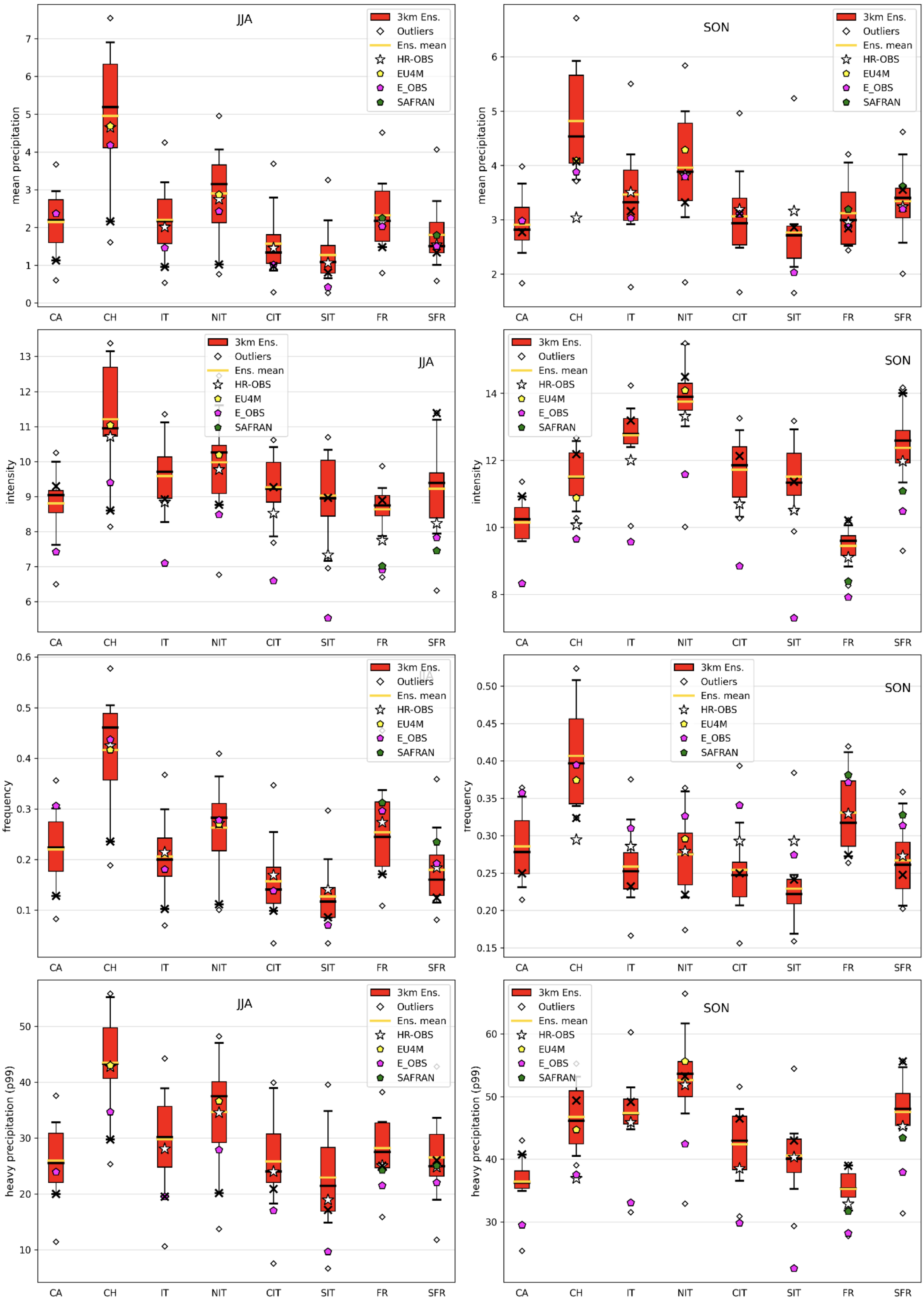
JJA
SON
3km Ens.
Outliers
Ens. mean
HR-OBS
EU4M
E_OBS
SAFRAN
mean precipitation
intensity
frequency
heavy precipitation (p99)
CA
CH
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Figure R2-1 Readapted from Pichelli et al. (2021) JJA (left) and SON (right) red box-plot representing the distribution of the convection-permitting models of their ensemble over different areas (CA: common domain as represented in Fig. R2-3 below, CH: Switzerland, (N/C/S)IT:(North/Central/South) Italy, (S)FR: (South) France) over the historical period 1996-2005. The distribution is represented within 5th and 95 percentile, for (from top to bottom) mean daily precipitation (mm/day), mean wet-day intensity (mm/day), wet-day frequency, heavy daily precipitation (p99, mm/day). RegCM-NH is represented by the black cross; outliers are represented singularly (open diamonds), ensemble mean (yellow line) is also reported and compared with the highest resolution observations (white star, RdisaggH (CH), COMEPHORE (FR), GRIPHO (IT)) over the same area and other dataset at coarser resolution where available (EURO4M-APGD (yellow pentagon), E_OBS 25 km (pink pentagon), SAFRAN reanalysis 8km (green pentagon).

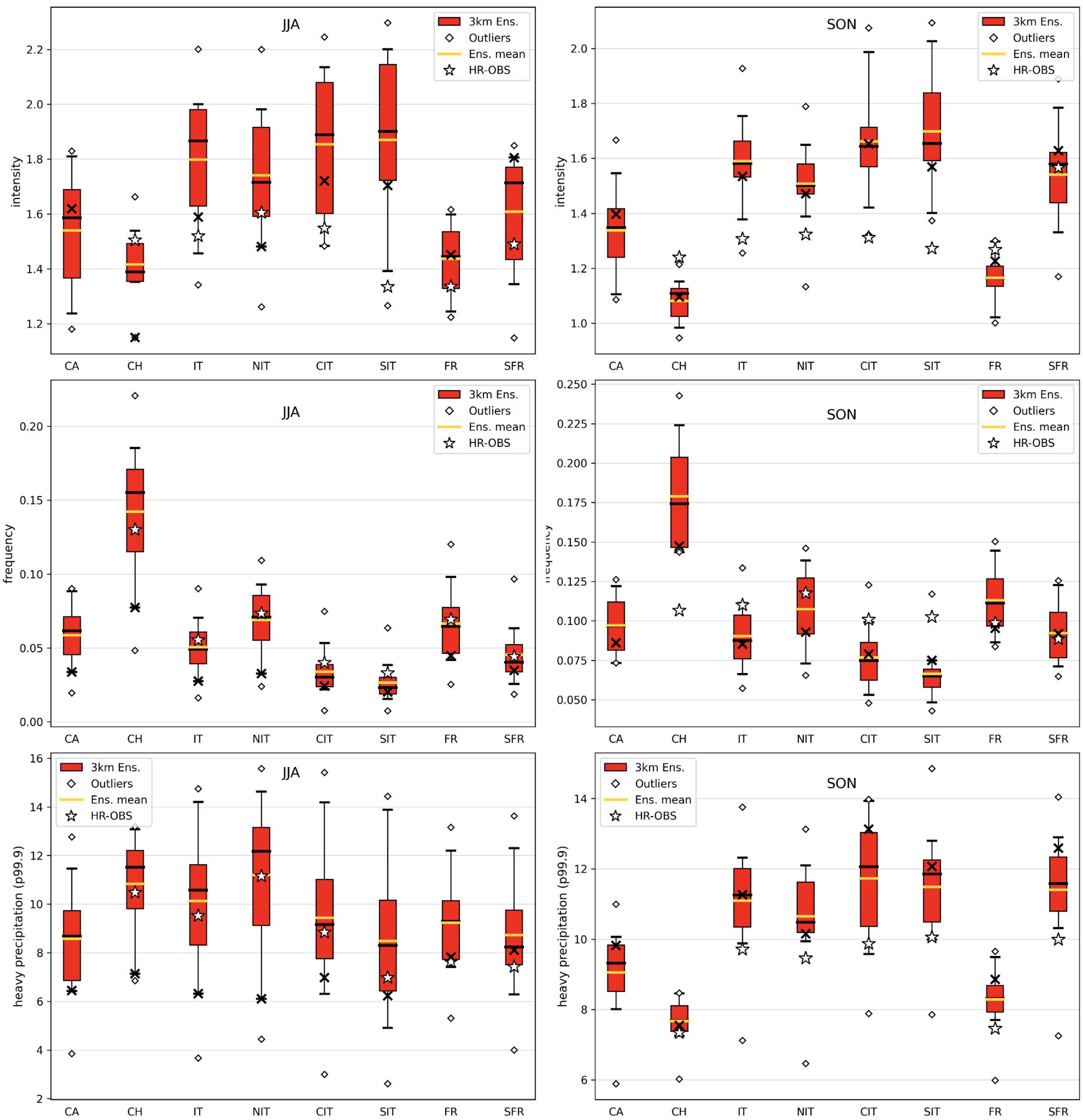

Figure R2-2 Readapted from Pichelli et al. (2021) Same as Figure R2-1 but for (from top to bottom) mean wet-hour intensity (mm/h), wet-hour frequency, heavy hourly precipitation (p99.9, mm/h). Only the highest resolution observed dataset is reported here (star, RdisaggH (CH), COMEPHORE (FR), GRIPHO (IT)).

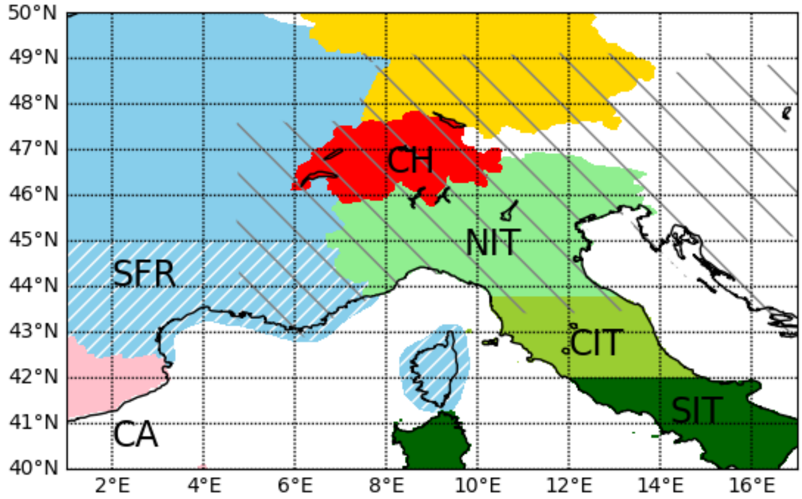

Figure R2-3 by Pichelli et al. (2021): Common domain (CA). Areas where observed dataset are available are in different colours: EURO4M-APGD (dashed grey), REGNIE (yellow), Spain02 (pink), RdisaggH (red), COMEPHORE (blue), GRIPHO (greenish). Sub-domain areas considered in the analysis are labelled: South France (SFR), North, Central, South Italy (N/C/SIT), Switzerland (CH) (Pichelli et al, 2021, their section 3 for dataset description).