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Discussions

Interactive comment on "High-Resolution Regional Climate Modeling and Projection over Western Canada using a Weather Research Forecasting Model with a Pseudo-Global Warming Approach" *by* Yanping Li et al.

Anonymous Referee #1

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Interactive comment on "High-Resolution Regional Climate Modeling and Projection over Western Canada using a Weather Research Forecasting Model with a Pseudo-Global Warming Approach" by Li et al. (2019) Summary

The authors perform two sets of simulations for the western Canadian domain via a dynamical downscaling approach. First, a control run (CTL) of the historical climate from October 1, 2000 to 30 September 2015 forced at the boundaries using 6-hourly 0.7 degree ERA-Interim reanalysis data was carried out. Subsequently, a pseudo-global warming (PGW) run of future climate following the RCP8.5 pathway was produced

for the same period as the CTL run but using temporally averaged fields from an ensemble of CMIP5 climate model simulations (2071-2100 relative to 1976-2005) and adding those to the initial and boundary conditions of the CTL experiment. The analysis is conducted at the convection-permitting scale (4-km) within the Weather Research Forecasting (WRF) model. The authors validate the CTL run against gridded observations in this region of Canada and found close agreement with reality although wet biases in precipitation are found as well as cold bias in spring air temperature particularly over the Rocky Mountains and towards the west coast. In terms of future climate, the PGW simulation shows more warming than CTL while precipitation changes are seasonally dependent. Increases are expected in the spring and fall while no change or decreases are anticipated in the summer months. The paper is generally well written and the authors made substantial efforts to verify the simulations. Please find below my major and minor comments for consideration.

Major comments

Objective of the study: performing a fine scale simulation (CTL and PGW) which captures convective cells at the 4km resolution shouldn't be the only objective of this paper. It is obvious that most of Canada has inevitably limited ground measurements which tend to not capture the effects of mountainous topography in areas such as the Rocky Mountains which are headwaters for most of the rivers flowing in either side of the Cordillera. As judged by the extensive verification of the simulations you carry out in the paper, it is possible that your study could explore the capability of the current generation of mesoscale atmospheric models such as WRF to reproduce precipitation and temperature features which are important for hydrology and water resources applications in western Canada. Simply, you have to also stress the need for improved forcing products given the data paucity in many regions of Canada.

Pseudo-Global Warming (PGW): what is the rationale behind employing the PGW downscaling approach instead of the continuous downscaling method often used in region experiments such as NARCAPP and CORDEX? You state in Section 2.2 that

‘The second simulation was a climate perturbation or sensitivity experiment following the Pseudo-Global Warming (PGW) approach used in Colorado-Headwaters work (Rasmussen et al., 2014, 2011). Climate projections from GCMs introduce large uncertainties because of the substantial inter-model variability among GCMs (Deser et al., 2012; Mearns et al., 2013), which can obscure the climate change response due to global warming. Using the PGW approach, rather than the intermodel variability, can isolate radiative forcing and its associated circulation as the sole reason for the regional climate response’. What the many disadvantages of the PGW method? See for example:

Sato, T., F. Kimura and A. Kitoh, 2006: Projection of global warming onto regional precipitation over Mongolia using a regional climate model, Journal of Hydrology, Volume 333, Issue 1, 30 January 2007, Pages 144-154.

Vasubandhu, M. and M. Kanamitsu, 2004: Anomaly Nesting: A Methodology to Downscale Seasonal Climate Simulations from AGCMs. Journal of Climate, vol. 17, Issue 17, pp.3249-3262

Added value of convection permitting downscaling: the overarching aim of this study is to provide high resolution modelling of mesoscale meteorology phenomena over the western Canadian region. However, the authors haven’t paid attention to the ‘added value’ of running WRF at 4km. For example, why should one trust the precipitation simulated by WRF at 4km compared to a low resolution output such as that of the Community Earth System Model (CESM)? This could have been the main stem of this study but it is not addressed here. I urge the authors to address this issue using any other available climate model products or observational products. For example, a validation could be made of WRF-resolved convective precipitation and other available products.

Validation of WRF CTL against observations: I am surprised by the agreement between the WRF CTL simulation and the observed data sets over the domain. The WRF

simulations in this study should inherit the biases from its forcing (ERA-interim) nudging was not involved in the downscaling procedure. In such cases, some form of bias correction is often applied to the WRF output. A related question is how good are the ANUSPLIN, NARR ($\sim$32km) and CaPA estimates relative to station observations over the study domain? These products are issued at $\sim$10 km, so you upscaled 4km WRF to 10 km and downscaled NARR to 10 km for direct comparison? I suppose several other station observations exist especially over the poorly gauged rocky mountain chains which could give us a better insight on the performance of WRF CTL in high elevation areas. Are mountain weather processes (especially in winter) well captured in the ANUSPLIN and CaPA data products? If not, this is a limiting factor to the verification you have shown in the paper.

The coarse ($\sim$80 km) grid spacing of ERA-interim: The region of Canada where you made the WRF simulations is topographically complex and challenging to model with a coarse DEM and grid spacing of ERA-interim to effectively capture the orographic effects in air temperature and precipitation. Such a coarse resolution could underestimate the complexity of topography in western Canada. Did you check to ensure that the highest peak of Rocky Mountains used in the WRF DEM is comparable to that in ERA-interim? This could also explain a lot of the biases you found in this study.

Sensitivity of various schemes and selection methods: the feeling I get after reading through this study and that of Liu et al, 2017 is that most of the schemes used in the model set up over the CONUS were simply repeated for the Canadian domain. This could be probabilistic to model water balance and energy exchanges in more snow dominated high latitudes using the same schemes as over the US. The follow up question is how you went about selecting the combination of parameterization schemes, planetary boundary layer schemes, and radiative transfer schemes for Canada north of 50o? Some results from the diagnostic test runs should be included as supplementary material. This is a study which involved model set ups and numerical experiments, thus the authors should elaborate on their modelling strategy by providing these details.

Liu, C., Ikeda, K., Rasmussen, R., Barlage, M., Newman, A. J., Prein, A. F., Chen, F., Chen, L., Clark, M., Dai, A., Dudhia, J., Eidhammer, T., Gochis, D., Gutmann, E., Kurkute, S., Li, Y., Thompson, G. and Yates, D.: Continental-Scale ConvectionPermitting Modeling of the Current and Future Climate of North America, Climate Dynamics, 49(1), 71–95, doi:10.1007/s00382- 016-3327-9, 2017.

Suitability for impact studies: ‘For many hydrological and agricultural applications, bias-correction of temperature and precipitation for RCM outputs often need to be reconciled with benchmarked parameters or criteria’ Are you recommending some form of bias correction be applied to the data before using it for impact analysis? The narrative throughout the paper is that WRF compared well with observations if not of some wet and cold biases over the mountain areas and along the coast. Based on your analyses, would you recommend that bias correction be applied to the WRF data for the whole domain or only over the regions mentioned above? Figure 3-11 indicate that WRF is quite biased compared to observations if you look closely at the mean error maps. A 4 degree cold bias has serious implications for snow hydrology.

Figure 8: taking an ensemble spread of ANUSPLIN, NARR and CaPA to compare WRF against isn’t correct. I see this in some studies in the scientific literature but it’s ill-informed. These observations are not climate model outputs that respond to the same forcing and can be perturbed to generate an ensemble. The purpose of the verification exercise is also to assess the skill of various observed products and where WRF stands in comparison. Simply computing the spread of the three observational data sets and comparing WRF against doesn’t make any sense. Consider comparing WRF against each of these products.

Minor comments

- It is not a wise thing to do by not providing continuous line numbers for the manuscript. I see this in a lot of manuscripts often submitted by newcomers to the field. - Abstract: the authors should consider reducing the length of the abstract. What do you mean

by ‘Due to this shift in precipitation intensity to the higher end in the PGW simulation, the seemingly moderate increase in the total amount of precipitation in summer for both the Mackenzie and Saskatchewan river basins may not reflect the real change in flooding risk and water availability for agriculture’? This kind of ambiguous statement isn’t suitable for inclusion in the abstract. Consider revising the abstract in simple terms without leaving the reader having to read the body of the manuscript in order to understand the abstract. - Change ‘and for studying climate impacts in hydrology, agriculture, and ecosystems’ to ‘and for studying climate impacts on hydrology, agriculture, and ecosystems’ - ‘The change in probability distribution of precipitation intensity also calls for innovative bias-correction methods to be developed for the application of the dataset when bias-correction is required’. This isn’t the crux of the paper and shouldn’t be the closing statement of your abstract. Rather you should highlight the importance of high resolution modelling compared to other mesoscale downscaling approaches which still parameterize convection.

Figures

- The mean error maps have a delta sign beside the colorkey. What does it represent? Some readers may take it to mean a change a precipitation or temperature between two periods.

- Write degree Celsius as (oC) in all figures.

- Figure 4: the colorkey to the left is not informative. You need a diverging color ramp with 0 at the centre to represent the ‘white’ color break. It is not possible to interpret the figure in its current form.

- Figure 6 and 7: the colorbreak labels are not informative. Use equal breaks for both wet and dry

- Figure 16: why a log and not a linear scale for daily precipitation?

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201, 2019.