Hydrol. Earth Syst. Sci. Discuss., 12, C3671–C3678, 2015
www.hydrol-earth-syst-sci-discuss.net/12/C3671/2015/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "South Asia river flow projections and their implications for water resources" *by* C. Mathison et al.

C. Mathison et al.

camilla.mathison@metoffice.gov.uk

Received and published: 15 September 2015

1 Authors reply to reviewer 3 comments

The authors would like to thank the reviewer for their comments on the manuscript. In the following pages the authors have replied to each comment and explained how the manuscript will be modified in light of these comments.

2 Reviewer 3

1. **Reviewer comment:** How is downscaling performed? The authors state that GCMs and ERA-interim drive the RCM but the details are missing. I assume GCMs provide coarse scale inputs to the RCM but the RCM perhaps requires finer scale forcing to produce 25 km outputs. Perhaps the RCM resolves the finer scale details but which details and how is not clear. A clear description of this downscaling strategy is needed in a step by step manner. Further, a justification for why driving RCM by a GCM can be called a downscaling exercise is needed.

   Authors reply: This should be addressed in the reply to comments from reviewer 1. A comparison of the driving GCMs and the RCMs is also completed in previous work by Lucas-Picher et al (2011) and Mathison et al (2013). Figure 2 of Mathison et al (2013) provides a flow chart showing the inputs, processes and outputs of an RCM. These references together with the other analysis of these simulations carried out as part of HighNoon are included in the text in the results section. These two references will also be added at the appropriate part of the methods section in order to aid the explanation of the use of RCMs to downscale GCMs. This is a widely used and accepted method of adding regional detail to larger scale models and is for example used in the IPCC reports.

2. **Reviewer comment:** I assume a comparison of streamflow at selected gauging stations based on 'downscaled' GCM via RCM with the observed (and ERA-interim-RCM derived streamflow) is supposed to be a validation of the performed downscaling exercise. However such a comparison is not convincing enough for it to be called validation. The authors may want to provide evidence that supports the robustness of the downscaling performed, perhaps based on better datasets available elsewhere (not limited to South Asia). Such validation need not be on observed streamflow but on other variables that the RCM simulates. Nonetheless, this does not disqualify the validity of the downscaling exercise itself – it

appears (based on my limited understanding of 'downscaling' implemented here) that RCMs introduce physics based constraints on the process of disaggregating coarse scale variables to finer scale 25km resolution.

Authors reply: Precipitation and evaporation are discussed as these variables are of direct relevance to the presented analysis on runoff. The representation of other variables by the RCMs such as temperature are discussed in the references at the beginning of the results section.

3. **Reviewer comment:** It is not clear if ERA-interim drives the same RCM as the GCMs? – should be HadRM3?

   Authors reply: HadRM3 is the regional climate model used throughout this analysis. This will be made clearer in the text.

4. **Reviewer comment:** Figure 3, cannot clearly see ERA-interim.. Need a different color

   Authors reply: This should be addressed from comments to reviewer 1

5. **Reviewer comment:** Page 5801 – not clear why the units of total annual precipitation is mm/day? Needs further clarification.

   Authors reply: This is a standard unit of precipitation used across climate science, it is relevant for use in analysis where the temporal averaging is over the month, season or year.

6. **Reviewer comment:** Figure 4, ERA-interim appears to be the same as GCMs while it is difficult to compare the 3 with the observed in Figure 5. I think the RCM constrained downscaling needs to be compared with a statistical/naïve downscaling method for example rule based or statistical disaggregation of coarse scaled GCM variables to 25 km and usingit to drive a hydrological model. In addition, these should then be compared with a control simulation of no downscaling, i.e.

the case of driving the hydrological model with the outputs of GCMs/ERA-interim. This can then highlight the value that RCM adds to the downscaling exercise. This will then also highlight whether we need RCM based (or any other) downscaling to arrive the conclusion that the region will see more high flow events in the future.

Authors reply: In the methodology references on the performance of TRIP using global models to provide the runoff are included. See reply to comment 9.

7. **Reviewer comment:** Page 5803: Why 1.5 stdev for GCM is used for the uncertainty bound? Why not the same of the observed? There may be other ways to further define these uncertainty bounds, e.g. based on a-priori knowledge about measurement errors etc.

   Authors reply: This comment is addressed in the reply to comments from the editor. Unfortunately GRDC could not provide an estimate of the errors in the gauges. This is mentioned in the text.

8. **Reviewer comment:** Line 20, page 5803: Ganges/Farakka gauging station is also sufficiently downstream in a basin where there is heavy GW extraction. Why is the same pattern not seen as in the Kotri gauge, where higher than observed simulations of GCMs and ERA-interim are attributed to the lack of extraction scheme in MOSES?

   Authors reply: There are significant differences in the patterns of precipitation from west to east across the Himalayan arc. The western most gauges like the Kotri gauge on the Indus are likely to be affected by western disturbances whereas the eastern most gauges like the Ganges will be more affected by the ASM. Estimates of extraction in the Ganges basin are also a much smaller proportion of the total flow for example the LPJml simulated extractions in Biemans et al (2013) suggest that extraction from the Indus basin is of the order 340$km^3 year^{-1}$ and the Ganges is in the region of $280 km^3 year^{-1}$. The Ganges

basin covers a much larger area than the Indus and therefore may not exhibit the same characteristics in river flow.

9. **Reviewer comment:** Page 5806, figure 7: How about a similar figure for rainfall, i.e. precipitation climatology both for downscaled and coarse scaled (original) products. This and comment 6 will clarify the role (and the value) of downscaling in revealing the pattern of increasing high river flows.

   Authors reply: The justification for using HadRM3 is given in replies to comments from reviewer 1 and above. The comparison between the driving GCM and the downscaling has been done in previous studies by Lucas-Picher et al (2011) and for the HighNoon ensemble; references for this analysis have been included in the text. Though a specific analysis considering if the downscaling has a role in the projections of river flows would be interesting it is not the aim of this analysis.

10. **Reviewer comment:** Figure 5 should be split into two. One which shows past to present and the other which shows future projections for the two GCMs for clarity sake.

    Authors reply: Although this was considered in the writing of the manuscript, it was decided that there was not sufficient justification for having 2 figures of 12 plots that showed the same variable. However, if two separate plots for historical and future are considered essential perhaps the separated figures could be included in supplementary information?

11. **Reviewer comment:** Do future streamflow projections incorporate plausible land cover land use change as well as socio-economic scenarios? – if not then the produced annual river flow projections via a complex MOSES land surface model are perhaps as good as downscaling climate projections and using them to drive a simple water balance model in representing plausible futures. This also touches upon comment 9. The authors may again want to clarify the value added of

using HadRM3 while responding to this commentwhy do I need such extravagant downscaling when it does not incorporate aspects of changing socio-hydrology of the basins – perhaps it provide an upper bound of sortsbut I doubt it.

Authors reply: The A1B scenario used in these simulations is one of the scenarios, the IPCC published as part of the Special Report on Emissions Scenarios (SRES) in 2000. The SRES scenarios were devised according to the production of greenhouse gases and aerosol precursor emissions. The A1 storyline and scenario family represents a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies. The A1B scenario represents this in a world where there is balance across energy sources i.e. a mixture of fossil fuels and non-fossil fuels. This scenario does not represent changes in landuse. Therefore the landuse remains fixed through the duration of these simulations. However this is still useful as this allows the effect of climate change to be examined in the absence of any adaptation to the changes. More detail on what the A1B scenario represents will be included in the text.

The justification for using HadRM3 is addressed in the reply to comments from reviewer 1.

12. **Reviewer comment:** Figure 9 and elsewhere: Need to state in the caption that the counts for the two GCMs appears in the upper right corner of the figures.

    Authors reply: This will be corrected in the revised manuscript.

13. **Reviewer comment:** Implications of river flow projections for regional water management: How confident can we be of stated water management implications when the RCM used is weak in terms of incorporating plausible socio-hydrological trajectories in the region? MOSES does not incorporate GW extractions, plausible land cover and landuse futures, regional land surface-atmosphere feedbacks, plausible socio-economic futures such as population, demography

and economic growth etc. These implications are probably as good as those that one would arrive at if only downscaled precipitation and temperature variables are used and run through a simple and static water balance model (by static I mean that its parameters that correspond to landcover etc. do not change). Please see comment 11 as well. Perhaps another control simulation may need needed for comparison where in downscaled climate variables are used to force a very simple water balance model (for example a single bucket model with a threshold).

Authors reply: HadRM3 is a physical model based on the same physics as the driving GCM but at a higher resolution. It incorporates a complex land-surface model that feeds back on the atmosphere and therefore regional atmospheric feedbacks are present and represented in this analysis. This will be made clearer in the text. The part of this comment that refers to landuse/landcover and socio trajectories is addressed by the reply to the reviewers comment 11 with reference to the A1B scenario used. Further justification for using HadRM3 is provided in replies to comments from reviewer 1.

14. **Reviewer comment:** Page 5815, line 22: The authors mention that increasing variability poses a challenge for the region but no analysis is provided to justify the claim that river flow will be become more variable in the future.

    Authors reply: The comment on increasing variability in temperatures and precipitation is related to the findings of the latest AR5 IPCC report for this region. I will add this reference at the appropriate point in the text.

15. **Reviewer comment:** Page 5816, lines 16-17: Same as the above. The authors mention temperature and variability in precipitation but no analysis is provided to back the claim. The paper will be stronger if additional analysis for variables that are downscaled and its variability is provided. This also connected to comment 1, where the need for clarifying the downscaling process through a detailed description of various involved variables (in addition to other) has been expressed.

Authors reply: The two GCMs used in this analysis are from the AR4 ensemble. This comment is in reference to the report on this ensemble, where it was found that there was a high variability in temperature and precipitation in this region. The reference to this report is given in the text.

16. **Reviewer comment:** Towards the conclusion, I am unable to see what the comparison between ERA and GCM downscaling tells us about the robustness of downscaling and simulation of river flows.

    Authors reply: In this analysis we aim to examine how useful RCM simulations are for understanding how river flows could change in South Asia in the future rather than justify the downscaling method. The aim of the comparison against observations is to demonstrate the RCM captures the regional patterns of precipitation and river flow. The analysis acknowledges the lack of observations and this is why the ERAint simulation is used as this is a reanalysis product that incorporates observations as well as modelling information. The justification for using this as a benchmark is addressed in the reply to comments from reviewer 1. If the lack of processes in the presented model limits the usefulness of the river flow projections then this is the driver for model development to include such processes in order to improve knowledge and understanding of water balance for this region.

17. **Reviewer comment:** I often encountered too long sentences, the authors may want to break them into smaller more digestible sentences.

    Authors reply: This should be addressed in the reply to comments from reviewer 1