

# Hoang et al. Mekong River flow and hydrological extremes under climate change

## Responses to Reviewer#1 comments

By Long Phi Hoang

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We highly appreciate Reviewer#1 for his/her dedicated reviews and constructive comments on the manuscript. We have addressed all comments and revised the manuscript accordingly, as described below.

**Comment:** The manuscript in discussion presents an assessment of the impacts of CMIP 5 climate change scenarios on extreme events of river flows through the Mekong River Basin. The study uses an ensemble of 10 scenarios, which were properly downscaled, biased corrected, and used to run a well calibrated and validated hydrological model. Overall, I think that this manuscript represents an important contribution to the understanding of hydrological impacts of climate change in the Mekong, providing also a robust and replicable methodology to be used in river basins elsewhere. As the authors clearly stated, this is one of the first hydrological studies in the Mekong using CMIP5 scenarios and thus of critical value to the hydrology community of this region. Among previous studies of climate change in the Mekong and similar river basins, in fact, this study sets a new bar of standards for comparative studies to follow. In general, the paper follows a clear outline, its justification is clear, methods well explained, and results sufficiently robust. There are, however, two major points that I suggest the authors clarify and expand on in the manuscript.

First, one of the primary justifications for this study –and the use of CMIP5 scenarios–is the large uncertainty associated with previous projections. The hope is that this new set of scenarios could show if CMIP5 models and scenarios have a better agreement among them and thus decrease uncertainty in climate predictions. This aspect, however, remained largely unresolved from the manuscript. I recommend that the authors assess and discuss in more detail if the new set of scenarios are actually alleviating the uncertainty issue in comparison to the previous assessments with CMIP3 scenarios, which is a finding that clearly could bring serious implications and challenges to water managers on the ground.

**Response:** We fully agree with Reviewer#1 that the CMIP5 versus CMIP3 uncertainties deserve better attention in the manuscript. We therefore further analysed our climate and hydrological impact signals and compare these to similar CMIP3-based assessments. We compared our results with four CMIP3-based assessments for the Mekong region, including Eastham et al. (2008), Kingston et al. (2011), Lauri et al. (2012) and Thompson et al. (2013). These studies include multiple GCMs and provide results that can be reasonably compared to our results. We have added a separate section (*5.1 Comparison: Impact signal and improvements in uncertainties*) to illustrate and discuss improvements in uncertainties relating to climate and hydrological impact projection. We also added *Table 4* to the manuscript present the cross-studies comparison.

Table 4. Comparing projected precipitation and discharge changes across studies. Signal agreement is indicated by number of GCM/scenarios projecting a reducing signal over the total GCMs/scenarios considered.

	<i>Eastham et al. 2008</i>	<i>Kingston et al. 2011</i>	<i>Lauri et al. 2012</i>	<i>Thompson et al. 2013</i>	<i>Hoang et al. 2015 (this study)</i>
<i>Annual precipitation change range</i>	0.5% to 36% (A1B)	-3% to 10% (up to 6°C warming)	-2.5% to 8.6% (A1B) 1.2% to 5.8% (B1)	-3% to 12.2% (2°C warming)	3% to 4% (RCP4.5) -3% to 5% (RCP8.5)
<i>Annual precipitation signal agreement</i>	Not available	3 out of 7	1 out of 10	3 out of 7	1 out of 10
<i>Annual discharge change range</i>	Not available	-5.4% to 4.5% (up to 6°C warming)	-10.6% to 13.4% (A1B) -6.9% to 8.1 % (B1)	-14.7% to +8.2% (2°C warming)	3% to 8% (RCP4.5) -7% to 11% (RCP8.5)
<i>Annual discharge change signal agreement</i>	Majority of GCMs show increasing trend	3 out of 7	3 out of 10	4 out of 7	1 out of 10

Our CMIP5-CMIP3 comparison shows that both the projection range and cross-GCMs/scenarios agreement on impact signal improve markedly in our CMIP5 assessment. In particular, our projected range for basin wide annual precipitation change is typically smaller than other CMIP3 assessments, implying better consensus in CMIP5 compared to CMIP3. Similarly, cross-GCMs/scenarios agreement on yearly discharge changes at Kratie also show best consensus in our assessment. Reduced uncertainties detected in our study are also in line with the expectations from Sperber et al., (2012) and Shabeh Uh et al. (2015) where the authors found a better representation of the summer monsoon under the CMIP5 models for the Mekong basin region. All in all, cross-studies comparison suggest reduced uncertainties and more robust impact signals out of our CMIP5-based GCMs/scenarios ensemble compared to earlier CMIP3-based studies. We have dedicated substantial text to sufficiently highlight this matter in the manuscript, mostly in the results and discussion sections.

**Comment:** That brings me to the second major issue; while the authors briefly discussed some of the implications for water management, I thought that this discussion was a bit too general and short, given how crucial these findings are for the region. With the exception of a few comments, benefits and impacts to the water-dependent sectors that the authors mentioned in the introduction –fisheries, agriculture, and hydropower– were largely ignored from the discussion.

**Response:** We have substantially revised the discussion session to better address the implications for water management. In particular, we added one separate section (5.2 *Implications for water management*) to discuss impacts of discharge changes on flood risk, agricultural production, hydropower development and safety, and aquatic ecosystems in the lower Mekong region. We have also added the potentially important impacts of flow reduction in early wet season on the sediment and nutrient dynamics, following Reviewer#1's suggestion.

In addition to these general comments, there are a number of more punctual issues that I would like to bring to the attention of the authors:

**Comment -Abstract:** in the case that the manuscript is updated based on the two major comments above, be sure that those are incorporated in the abstract

**Response:** We have included additional text to the abstract and conclusion to better inform readers about (1) improvements in CMIP5-based projection's uncertainties and (2) implications of our findings for safety risks, water resources management and aquatic ecosystems.

Added text:

*“The scenarios ensemble, however, show reduced uncertainties in climate projection and hydrological impacts compared to earlier CMIP3-based assessments.”*

*“Climate change induced hydrological changes will have important implications for safety, economic development and ecosystem dynamics and thus require special attention in climate change adaptation and water management.”*

**Comment -11655 l. 26:** Higher precipitation amount per unit area

**Response:** Corrected to: *“This implies that the basin receives higher precipitation amount per unit area, owing to its dominant tropical monsoon climate (Adamson et al., 2009; Renaud et al., 2012)”*

**Comment -11656 l. 15:** None of the 3 references provided here actually documented ecosystem and/or agricultural productivity in the lower Mekong. Please correct

**Response:** Thank you for checking the manuscript very carefully! We have corrected and added more relevant references to the manuscript.

Revised text: *“Seasonal variation in river flow, especially the flood pulse occurring in the downstream deltas (i.e. the Tonle Sap Lake in Cambodia and the Mekong delta in Vietnam), supports a highly productive aquatic ecosystem and one of the world's major rice production area (Lamberts and Koponen, 2008; Arias et al., 2012)”*

**Comment -11656 l. 19:** Similar to the above, these two references do not relate to economic productivity of the Mekong. In fact, the Lamberts and Koponen (2008) reference will serve well in line 15 mentioned above

**Response:** We have added more relevant references to the manuscript.

**Comment -11657 l. 12:** What are the soil surface processes and associated methods used in VMOD? Such information was provided with regards to PET, so it is probably good to include here for consistency

**Response:** Following Reviewer#1's suggestion, we have added more details on soil surface processes and associated methods to the method section.

Added text: *“The soil is simulated as two distinctive layers and soil surface processes are simulated following Dingman (1994). After calculating the water balance, runoff is routed from cell to cell and finally into the river network.”*

**Comment -11657 I. 21:** A relatively outdated land cover map was used to run the model. Are there any justifications for the use of this map? There have been major land transformations in the Mekong in the past decade and I wonder if the authors carried out any sensitivity test –as they did for precipitation– with regards to this input.

**Response:** We selected the GL2000 land cover map in consideration of the calibration and validation period (1981-2001). The GL2000 provides land cover data that is most suitable to our time period of interest. Furthermore, we agree with Reviewer#1 that recent changes in the land use system, especially at the Lower Mekong countries, may have considerable impacts on river flows. We added our acknowledgements to this matter in the discussion and include this in our on-going complementary study, where future land use change, particularly agricultural land expansion is included. Regarding historic land use change, we did not account for this factor in our hydrological simulations due to unavailable data. Given the relatively robust performance of the model during calibration and validation, we believe that the modelling set up is reliable for our research purpose.

**Comment -11658:** what is the justification for the calibration/validation period? The simulations were carried out from the early 1970s, time from which there are flow records that could have been used

**Response:** We restrained from going too far to the past (i.e. 1970s) in our calibration and validation exercises to make sure that measured data is available for all seven mainstream stations (Chiang Saen, Vientiane, Nakhon Phanom, Mukdahan, Pakse, StungTreng and Kratie). Additionally, land cover situation in the 1970s might be too different from our land use data around 2000. Given relatively good performance of the hydrological model over a 20-yr period for calibration and validation (as shown in Table 2), we believe that the model setup and parameterizations is sufficiently reliable.

**Comment -11658:** Was the calibration done manually only? No systematic/automatic routines?

**Response:** We only calibrated VMod manually (information added to manuscript). The autocalibration feature of VMod requires many runs and thus long computing time. Since the model set up and parameterizations for the Mekong basin have been proved very robust in an earlier study, i.e. Lauri et al., (2012), we believe that the model's performance is sufficiently reliable for our assessment.

**Comment -11661:** Despite the model performing very well in the lower stations, the discharge biased at Chiang Saen concerns me. There are a number of publications in recent years that have shown a significant increase in dry season flows at this exact location as a result of the construction of dams in the upper Mekong in China. Such effect could directly explain the discrepancies shown in the flood duration curves comparison in fig. 2. Based on the published evidence this seems to be a factor that the authors should considered or at least discussed about.

**Response:** We thank Reviewer#1 for this excellent comment and suggestion on possible linkages between the upstream Chinese dams and the biases in simulated discharge at Chiang Saen station. Recent studies including Adamson (2001), Lauri et al. (2012) and Räsänen et al. (2012) found substantial increases in dry season flow at this location due to hydropower dams operation. These increases are in line with the biases shown in our simulated river discharge where measured flow tends to be higher than simulated flow during dry season (shown in Figure 2). We have added our explanations and discussions regarding this matter to the manuscript and referred to recent supporting studies.

Added text: “*Low flow biases at Chiang Saen could be explained by unaccounted flow regulation by upstream hydropower dams during the dry season, as suggested by Adamson (2001), Lauri et al. (2012) and Räsänen et al. (2012).*”

**Comment -11663 I. 5:** Spatial variability in rainfall is mentioned here. That is a critical point that I suggest is discussed in more detail in the discussion. In particular, a reduction in rainfall in the lower Mekong could have serious implications for rainfed agriculture, which does occur in large areas.

**Response:** We agree with Reviewer#1 that rainfall reduction in parts of the lower Mekong can have substantial implications. We have added more text to further discuss the implications of rainfall reduction in some parts of the lower Mekong.

Added text: “*Lastly, rainfall reduction in some areas of the lower Mekong could damage agricultural production, especially rainfed agriculture.*”

**Comment -11664 I.8 :** Following up with implications to agriculture, the authors mentioned that one of the only projections for which all scenarios agreed was a reduction in flow in June. Flows during the early wet season are critical for both ecological and agricultural productivity, bringing the first flush of water and sediments critical for growth.

**Response:** Following Reviewer#1’s suggestion, we have added more text on the implication of flow reduction in June for agricultural activities.

Added text: “*Additionally, projected discharge reduction at the beginning of the wet season (i.e. in June) might have negative impacts on ecological and agricultural productivity. Flow alteration in the early wet season will likely change the sediment and nutrient dynamics in the downstream floodplains, which are very important for existing ecosystems and agricultural practices (Arias et al., 2012).*”

**Comment -Fig. 1:** For the readers that are not familiar with the Mekong, it would probably be helpful to show country boundaries

**Response:** We have added the country boundary to Figure 1.

**Comment -Fig. 5:** When printed in regular A4 paper, this figure is very difficult to read. I suggest using a much larger format. In addition, I felt that the ensemble mean lines was not showing a clear message; I recommend removing the mean lines from the discharge graphs in the first two columns, and in the third columns (% change), show also the error bars associated with the monthly difference among GCMs

**Response:** We thank Reviewer#1 for the useful and practical suggestions to improve Figure 5. We have enlarged this figure to improve readability. By enlarging the figure panels, the mean lines as well as the projection range are now more visible. We believe that the more visible projection range (i.e. shaded area) essentially illustrate the same information as the error bars, and thus we restrain from adding error bars to the figure. Due to limited space, we now moved the percentage change panel to the supplementary S2.

Revised Figure 5:

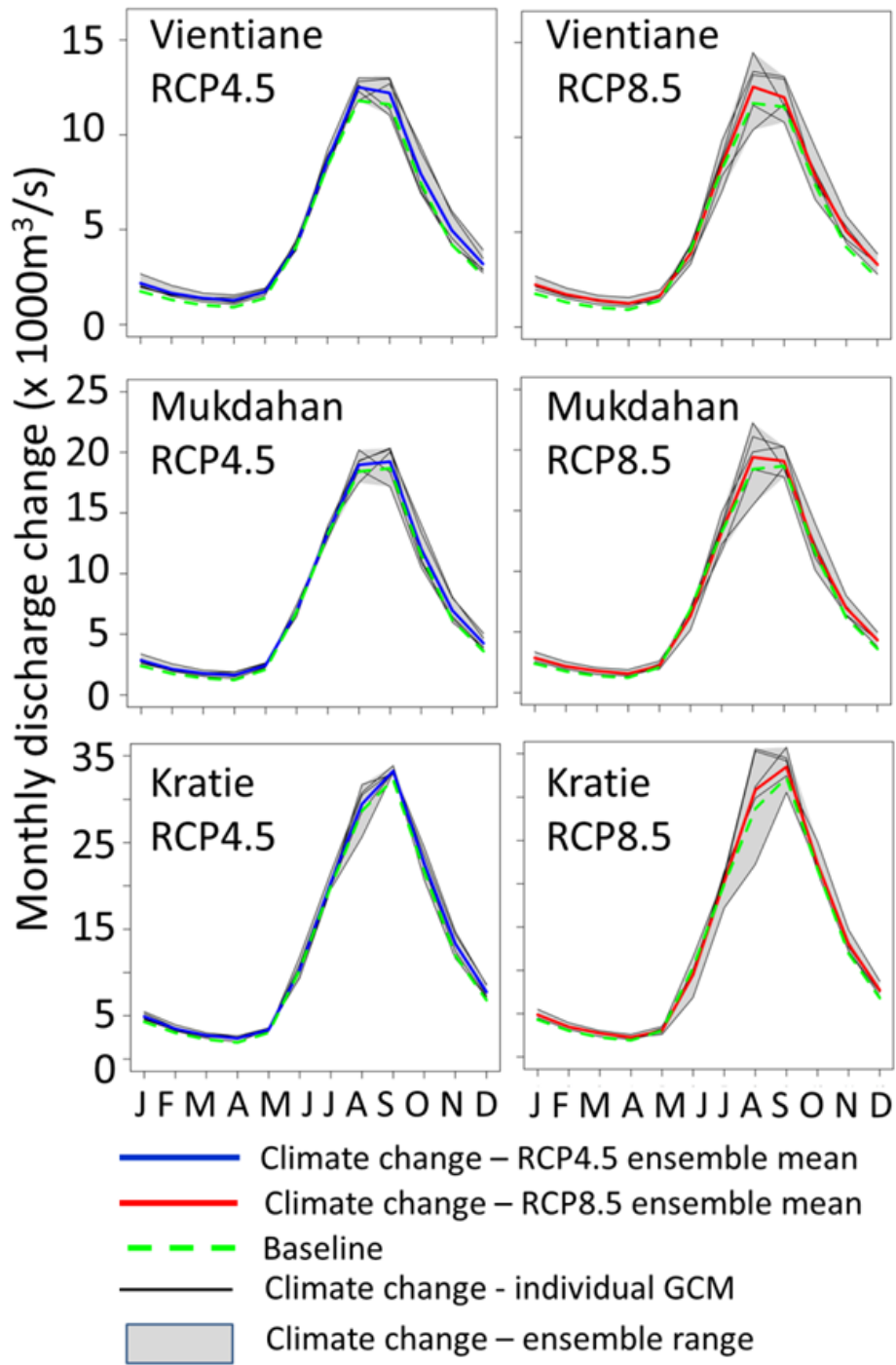


Figure 5. Projected monthly river discharge (left and middle panels) and relative changes (right panel) under climate change for 2036-2065 relative to 1971-2000.