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Discussions

Interactive comment on "Analyzing the future climate change of Upper Blue Nile River Basin (UBNRB) using statistical down scaling techniques" *by* Dagnenet Fenta Mekonnen and Markus Disse

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We fully agree with the assessment of Anonymous Referee #1, Here we will give a short summary of our responses The disagreement among researchers on results of future precipitation has also been quoted in this manuscript (p1, l11). The question is, what is the new knowledge given in this article?

The reason for disagreement among researchers pointed out in this study was for the historical context, that the discrepancies could be due to the period and length of data analyzed and the failure to consider stations which can represent the spatial variability

of the basin and also errors induced from observed data. For the future context, apart from the above mentioned reasons, discrepancies could be due to the difference of GCMs and scenarios used for downscaling, the downscaling techniques applied (can be dynamical and statistical), selection of representative predictors, the period of analysis and spatial and temporal resolution of observed and predictor dataset and also Scale of study (ranging from one or more sub-basins of UBNRB, the whole Nile.

Since most of the studies were based on a single GCM and or scenario, the uncertainty in these predictions was not evaluated. Each general circulation model (GCM) has different temporal and spatial resolutions and assumptions describing atmospheric processes. High uncertainty is, therefore, expected in climate change impact studies if the simulation results of a single GCM are relied upon. Hence, in order to overcome the above shortcomings we introduce a new knowledge,

Firstly, we employed multi model approach (six different GCMs) which were used in the IPCC's Fourth Assessment Report (AR4) based on Special Emissions Scenarios SRES B1, A1B and A2 for three time windows , Atmospheric large scale predictor variables used for representing the present condition obtained from the National Centre for Environmental Prediction (NCEP) reanalysis data set, and GCM CanESM2, second generation Canadian Earth System Model that represents the IPCC Fifth Assessment Report (AR5). The result analysis revealed that, GCMs disagree on the direction of precipitation change as expected, two GCMs MIHR and GFCM21 result decreasing trend whereas a majority or four GCMs (NCCSM, Hadcm3, MPEH5 and MIHR) result increasing trend from the reference period in all three time periods. However, the multi model average indicates generally increasing trend for precipitation in the future and has a better agreement with the result of HadCM3(See pages 11 and 12).

Secondly, most studies were applied one statistical down scaling technique eg (Beyene et al., 2010) used Bias Correction and Spatial Downscaling technique (BCSD), (Kim, 2008) constructed the future climate variables by perturbing the corresponding base line data series with the predicted changes in a given GCM for each climate scenario, which means the uncertainties due to down scaling techniques were not evaluated. Moreover, because of the well known fact that GCMs are not very reliable in simulating precipitation, the error induced from the GCM output for precipitation will propagate the error of downscaling that makes the performance of down scaling techniques which are used directly the outputs of precipitation from GCMs (like BCSD and perturbing) to downscale precipitation more questionable. Hence, we applied two different widely used statistical down scaling techniques (LARS WG and SDSM) to evaluate the uncertainties due to down scaling techniques see section 5.6 (pages 14 and 15).

Thirdly, most of the previous studies e.g (Beyene et al., 2010; Elshamy et al., 2009; Kim, 2008), used CRU and other gridded data sets which are constructed based on the interpolation of a few stations in Ethiopia, which has the relatively less accuracy as compared with the station based data. Even studies that used observed station data, no more than 10 stations in most cases were used e.g. (Gebre and Ludwig, 2014) used one to three stations for one sub basin. Due to high spatial variability of UBNRB, incorporating only a few stations may not be reasonable for such a large area. However, we consider 15 stations for precipitation and 25 stations for temperature collected from the concerned governmental organization (Ethiopian Meteorological Agency). Moreover, this study focused on the whole Upper Blue Nile River Basin, whereas most studies were focusing either the entire Nile Basin (Beyene et al., 2010)or sub water sheds (Dile et al., 2013; Gebre et al., 2014)both studies focused on the water sheds located in Tana sub-basins of UBNRB .

The objective of the paper: As it is clearly stated on (page3, l14), is to analyze the possible future climate trend of Upper Blue Nile River Basin by applying widely used and more plausible statistical down scaling techniques (i.e, LARS-WG and SDSM) using multi-model approach. Furthermore, the relative performances of a multiple regression model (called SDSM) and a weather generator (called LARS-WG) were evaluated in terms of their ability to simulate the present climate variables of UBNRB and evaluation of climate model results for future precipitation and temperature were done and

discussed in detail under section 5.6 and section 6 (discussion and conclusion), to give a better understanding which of the two statistical down scaling performs best and which climate models give better representation of the present climate variables of UBNRB.

So, the objective of this study can be modified in such a way that to analyze the possible future climate trend of Upper Blue Nile River Basin by applying widely used and more plausible statistical down scaling techniques (i.e, LARS-WG and SDSM) using multi-model approach. Furthermore, to evaluate relative performance of downscaling methods and climate models.

The paper gives a lot of details and too many numbers make it very difficult to follow a clear story line that serves the key message of the paper. E.g.,evaluation is made at individual stations, and then for the whole catchment (p11, l23), and large differences were found among the models for the later. What does this mean for the overall uncertainty of the analysis?

In statistical down scaling techniques, that we applied in this study, station level climate variables information of precipitation and temperature are required. These climate variables information can only be found in two ways. Either calculating the areal climate variable information from the observed stations and consider/use it as a single station. Or use directly the information of the stations in and around the catchment for further downscaling and then after calculate the areal average of the whole catchment using Thiessen polygon method. Both approaches were tried in this study and we found that the better agreement between the observed and simulated is in the latter case. Hence, we prefer to use a station level climate information for calibration and validation of our down scaling techniques and also for future prediction of climate change for reliable results. It is not the case that large differences among the models were found due to the fact that evaluation of the whole catchment was done after evaluation of individual stations. The contrary is true, the differences become smoothened (see Figure 4 and Figure 9 for LARS WG and SDSM respectively in the manuscript)and also Fig.1

constructed from the observed and simulated of precipitation.

Regarding to too many details and numbers, we will try to reconsider your comment and make some changes on the manuscript as necessary.

P1, l11, "However, a large uncertainty between different Global Circulation Models (GCM) and downscaling methods exist that makes reliable conclusions for a sustainable water management difficult." This is known for many years now, please give what is new that the reader is expecting from this paper.

Uncertainty due to GCMs is unavoidable, however, this can be minimized by applying multi-model approach and selecting best GCM that represents the existing conditions of the area. Therefore, in this study, we tried to see the uncertainties coming from different GCMs and due to different statistical down scaling methods by applying multi model approach and two different widely used statistical down scaling methods(LARS WG and SDSM) respectively see response for question 1.

P1, l14, LARS-WG, SDSM; give full name when appears for first time in manuscript: accepted The Abstract is not easy to follow. Try to mention the key message (objective) of the paper, and key results, without many details. Too many models, and too many numbers makes it difficult to grasp the main findings of the paper. Accepted and we will revise accordingly

P2, l15, climate change and climate variability mentioned on the same line. What is the difference between variability and change, please make critical discussion on this issue.

Climate variability – The way climate fluctuates yearly above or below a long-term average value. Common drivers of climate variability include El Niño and La Niña events, which are shifts of warm, tropical Pacific Ocean currents. El Niños give us hotter climate and drought, while La Niñas give us colder and flooding. Climate variability is already imposing a significant challenge to Ethiopia by affecting food security, water and

energy supply, poverty reduction and sustainable socio-economic development efforts. For example the impacts of past recurrent droughts (year 1972/73, 1984, 2002/03) are the most catastrophic and distressing events for the Ethiopian people. Moreover, currently this recurrent drought and flood persists and affecting the lives of more than 10 millions of people in Ethiopia.

Climate change is a long-term continuous change (increase or decrease) to average weather conditions (e.g. average temperature) OR the range of weather (e.g. more frequent and severe extreme storms). Both can also happen simultaneously. Long-term means at least many decades. The increasing water demand of upstream countries in the Nile Basin coupled with climate change impacts can affect the availability of water resources for downstream countries and in the basin. Previous studies which examined the impacts of climate change can affect multiple features of water resources, e.g., quantity and quality, high- and low-flow extremes, timing of events, water temperature, etc. All these aspects affect livelihoods in the basin but have not received attention in planning for future water allocation and design of water infrastructure yet.

p3, l8, there are more studies on Upper Blue Nile climate, e.g., Tesemma et al., 2010; Gebre et al., 2014, Beyene et al., 2010, among others

Yes, there are even more studies on Upper Blue Nile climate change but the results or outputs of the studies are not consistent due to the reasons mentioned above (Response 1)

Gebre et al. (2014), used multi model GCMs approach (five biased corrected 50km x 5okm2 spatial resolution GCMs) for RCP4.5 and RCP8.5 scenarios to down scale the future climate change of 4 watershed (Gilgel Abay, Gumara, Ribb and Megech) located in Tana sub Basin of UBNRB for the time period of 2030s and 2050s. The author used one to three meteorological stations for the observed data for each sub- basins. The result suggested that the selected five GCMs disagree on the direction of future prediction of precipitation but multimodal average monthly and seasonal precipitation result showed that in the future precipitation generally increases over the watersheds.

Beyene et al. (2010), also applied multi model GCMs approach (11 GCMs for A2 and B1 scenarios of CMIP3) and applied Bias Correction and Spatial Down scaling method, which uses percentile- percentile mapping for the whole Nile Basin. In brief, the method downscales monthly temperature and precipitation at the GCM spatial scale (regridded the climate variables to a common 2 degrees latitude by longitude spatial resolution to the one-half degree spatial resolution at which the VIC hydrology model was applied. The observed climatology for the historical run (1950-1999) was derived from the global gridded precipitation data set. The result obtained from the study suggested that predictions of mean temperature changes for the Blue Nile subbasin are 1.2 (1.2), 3.1 (2.6), and 4.1 (3.4) °C for A2 (B1) emission scenarios for the periods I(2010–2039), period II (2040–2069), and period III (2070–2099) respectively. Despite the variations in individual climate model predictions, over the entire Nile basin 8 (9) and 3 (6) of the 11 GCMs for the A2 (B1) global emission scenario predicted increases in precipitation for 2010-2039 and 2070-2099, respectively. Multi model average annual Nile basin precipitation changes in percentages of historical (1950-1999) precipitation are 115 (117), 98 (104) and 93 (96) for the A2 (B1) emissions scenario with observed for the time periods of I, II and III respectively. While, the multimodel ensemble average annual precipitation changes for the Blue Nile sub-basin expressed as a percentage of 1950-99 precipitation are 115 (117), 98 (104) and 106 (96) for the A2 (B1) global emission scenario and periods I to III, respectively.

In general, in this study we can see that uncertainties due to spatial and temporal resolution (regridding from the resolution of GCMs to 0.5 degree spatial resolution and disaggregating from monthly to daily time scale) and also uncertainty due to global regridded precipitation data set.

P3, l13 to 15, “Therefore, the objective ....”, here you can explicitly mention the objective of the paper, and why it is different from previous published research? Is it evaluation of future climate over the Upper Blue Nile; Is it evaluation of the downscaling

methods? Why to do downscaling? Could the result be feasible to be used for hydrological analysis, e.g., to compute runoff ? discussing these points may allow to clearly define the objectives of the analysis

This issue is explained above. The result obtained from this study is feasible to be used for hydrological analysis and it is clearly mentioned on page 16 and 17, l33 (In general, the results of future climate change from multi model GCMs and applying two widely used downscaling techniques for all three climatic variables have shown that climate change will occur plausibly that may affect the water resources and hydrology of the UBNRB, so the outputs of canESM2 GCMs with new sets of emission scenarios downscaled by SDSM technique can be applied for further impact analysis with high degree of certainty).

P5, l11, why using IPCC 4th report (2007), and not IPCC 5th report (2013) ?

We used both versions (IPCC AR4 and AR5). IPCC AR4 (2007) GCMs as input for LARS WG but not AR5 (2013), because there is no any data set from CMIP5 incorporated in to LARS WG at the time of this study. However, we used both CMIP3 and CMIP5 (hadCM3 and canESM2 GCMs) respectively for SDSM (see page 5)

P5, l15, 6 best performed models, how selected? mention few lines about criteria, and selection process.

For the evaluation of a GCM’s model performance, the MAGICC/SCEGEN computer program tools are used. MAGICC is a coupled gas-cycle/climate model (MAGICC; Model for the Assessment of Greenhouse-gas Induced Climate Change) that drives a spatial climate-change SCENario GENerator (SCENGEN) (Wigley, 2008). Both software packages have been developed in the Climatic Research Unit (CRU), University of East Anglia, UK. MAGICC/SCEGEN has been one of the primary models used by IPCC to produce projections of future global mean temperature and sea level rise since 1990.The latest version, Version 5.3, which has a resolution of 2.5o × 2.5o latitude and which has been used in the IPCC_AR4 (IPCC, 2007)is employed in this study.

MAGICC combines a coupled gas cycle and climate model which helps the user to estimate the associated global mean temperature and then SCENGEN constructs a range of geographically-explicit climate change scenarios for the world by exploiting the results from MAGICC by combining observed data set and a set of GCM experiments. It uses temperature and precipitation data set for 20-year reference period, 1980-1999. The temperature data is from the European Centre for Medium-range Weather Forecasting's (ECMWF) reanalysis data set, ERA40, whereas the precipitation data is taken from the Climate Prediction Center (CPC) merged analysis of precipitation (CMAP). Both data sets are provided at 2.50 x 2.50 degree resolution.

A standard method for selecting models is on the basis of their ability to accurately represent current climate, either for a particular region and/or for the globe. The statistics used for model selection are pattern correlation (R2), Root mean square error (RMSE), bias (B), and a bias-corrected RMSE (RMSE-corr). To rank models this study used a semi-quantitative skill score that rewards relatively good models and penalizes relatively bad models as suggested by user manual. Each model gets a score of +1 if it is in the top seven and a score of -1 if it is in the bottom of seven both for the Globe and for Ethiopia. The analysis was done separately for precipitation and temperature and finally an average score value was taken for model selection as indicated on the Table 1,2and 3. The output of MAGICC/SCENGEN shows that some models perform better using the mean temperature data but poor using precipitation data and vise versa. GCM's which scores above 0 on average was selected for this study. However orange shaded GCMs which are found in the data set of MAGGIC/ SCENGEN were not found in the data set of LARS-WG, therefore excluded from the list.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-543/hess-2016-543-AC1-supplement.pdf

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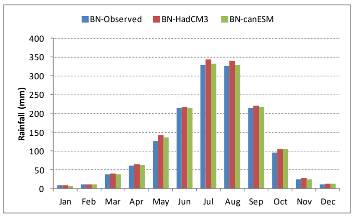

Figure 1: Observed and simulated for precipitation of UBNRB constructed using Thiessen polygon method from the stations

Fig. 1.