Downscaled climate change projections over northeastern South Africa: Implications for streamflow

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Abstract

The study assesses the impacts of anthropogenic forcing on seasonal streamflows over northeastern South Africa by using both dynamically and statistically downscaled multi-decadal climate change projections. The statistical model approach is to build linear links between observed present-day climate of flows and mid-tropospheric atmospheric circulation and then use the developed relationships to provide guidance on future-climate streamflows. Both CCAM raw runoff (as a proxy for streamflows) and statistically downscaled streamflows indicate a decreasing trend over northeastern South Africa. Statistical analysis on simulated data is done based on four 30-year periods (1981-2010, 2011-2040, 2041-2070, 2071-2100) from which parametric distributions are calculated and interpreted.

Key words: Streamflow, Perfect prognosis, Climate change, Statistical downscaling

1. Introduction

Climate change impacts on a number of human and natural systems. One of the most fundamental sectors impacted by climate change is water resources. Water in turn has an impact on several systems such as human health, agriculture and biodiversity. A comprehensive assessment and understanding of the long-term impacts of climate change on water resources is therefore vital. This information, if applied in planning processes and decision making can potentially minimize the adverse impacts of climate change on several interlinked sectors. The observed changing climate over southern Africa (Hughes and Balling 1996; Kruger and Shongwe 2004; New et al. 2006; Kruger 2006) continues to raise concerns on the future climate change and impacts over the region.

2. Data and method

The study makes use of the six-hourly output from a Regional Climate Model (RCM) run at a resolution of about 0.5° x 0.5° lon/lat, covering both historical (1979-2010) and future periods (up to 2100). Observed streamflow data obtained from the Department of Water and Sanitation's Hydrological Information System (HIS), are for the Limpopo Water Management Area (WMA), Olifants WMA, Levuvhu/Letaba WMA and Inkomati WMA. The RCM used in this study is the conformal-cubic atmospheric model (CCAM), whose simulations are available at a C64 stretched grid (approximately 60km) within South Africa and has 18 vertical levels. From the CCAM simulations, 500 hPa geopotential height fields are used. Both control (driven by the NCEP-based CCAM reanalysis) and future (forced using the CMIP4 GCMs) simulations are considered. The control run of the CCAM is performed by applying a multiple-nudging approach with low-resolution NCEP reanalysis data as the boundary forcing in order to produce "reanalysis" data at a resolution of about 60 km over southern Africa. The runs forced with the CMIP4 data are produced over the period 1951 to 2100, subsequently creating an ensemble of 6 projections. More details on the CCAM RCM configuration can be obtained from Engelbrecht et al. (2011). Additional RCM output for some of the aforementioned climate variables may be obtained for the Coordinated Regional Downscaling Experiment (CORDEX) data (Nikulin et al. 2012).

The approach is to first identify the high flow season over the area and then to assess the potential climate change impact on these flows. The peak season of streamflow over the area is identified as January-February-March (JFM) as shown in Fig. 1.

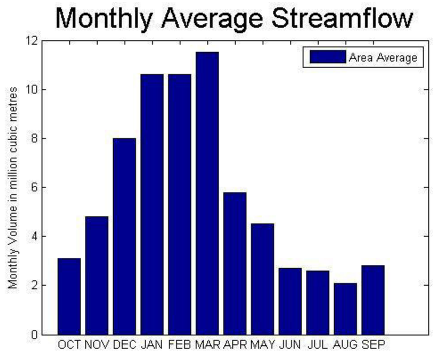

Figure 1: Monthly average streamflow data for northeastern South Africa (observed data from 31 stations)

After identifying JFM as the peak season for streamflow over the area model output statistics (MOS; Wilks 2011) is applied to estimate the statistical relationship between climate model simulations and the observed streamflow through a perfect prognosis approach (Landman and Goddard 2005). The perfect prognosis equations are created by canonical correlation analysis (CCA) of the Climate Predictability Tool (CPT). These statistical equations are developed for the JFM season, and the sets of equations form the basis for the statistical downscaled climate change projections (Landman et al 2013). The downscaling is done by first using CCAM Reanalysis for the 500 hPa as the predictor and station streamflow data as the predictand. This statistical model's validation is performed to test model skill and hindcast analysis (Fig. 2) to further test the developed statistical relationship.

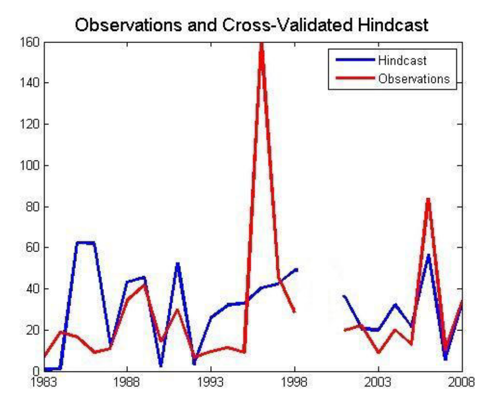

Figure 2: Observations and cross-valiated hindcast, area average for northeastern South Africa.

CCAM multi-decadal projections from six climate models (CSIRO, GFDL20, GFDL21, MIROC, MPI & UKMO) are available from 1961 to 2100. These projections are then included into the statistical developed equations for downscaling. The downscaled data is then compared with CCAM raw model data to test if datasets are showing similar trends (Figs. 3 and 4). After verification, outputs are produced and data are analysed based on four periods namely; Present Day Climate (PDC) 1981-2010, Climate Change period 1 (CC1) 2011-2040, Climate Change period 2 (CC2) 2041-2070 and Climate Change period 3 (CC3) 2071-2100. The output is analysed and the analysis is based on area averages.

3. Results and Discussion

The statistically downscaled streamflow data shows a similar decreasing trend as the CCAM raw runoff trend (Figs 3 & 4). Rainfall is the main driver of streamflow over the area and the decreasing trends are in line with projected decreases of rainfall over the some parts of the sub-continent (Niang et al. 2014).

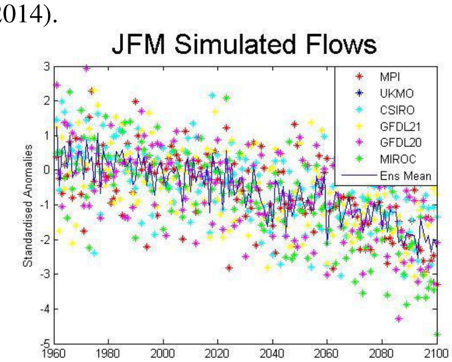

Figure 3: Area-averaged perfect prognosis stream flow from six models and ensemble mean for JFM (standardised anomalies).

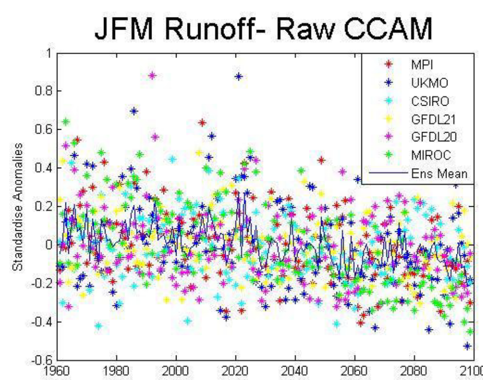

Figure 4: Area-averaged raw CCAM runoff from six models and ensemble mean for JFM (standardised anomalies).

Four theoretical distributions are fitted to the statistically downscaled data and they are the Gamma, Lognormal, Normal and Weibull distributions (Fig 5). These distributions are often used for analyzing rainfall and are subsequently developed here for streamflow. Negative log-likelihood estimates as well as the Kolmogorov-Smirnov test have found these distributions to adequately represent the statistically downscaled flows. All four distributions are subsequently fitted to the projected flows and all of them shift to the left for subsequently 30-year periods into the future (Fig 5).

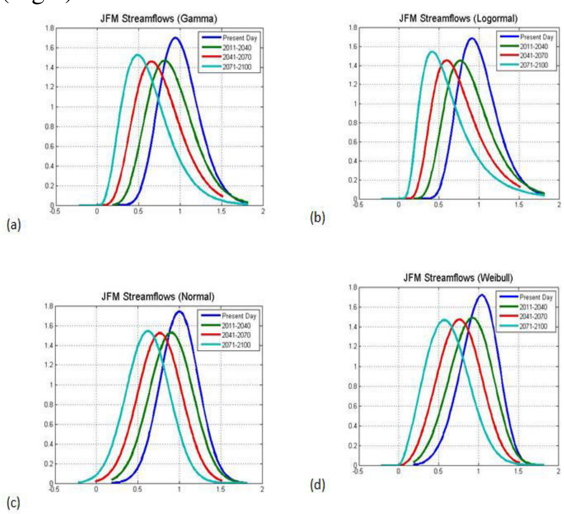

Figure 5: Gamma (a), Lognormal (b), Normal (c) & Weibull (d) Distributions for period 1981-2010, 2011-2040, 2041-2070 & 2071-2100.

4. Conclusion

The statistical downscaling procedure described here has been successfully applied in simulating streamflow by using mid-tropospheric atmospheric circulation as predictor in a perfect prognosis model. Both CCAM raw runoff and statistically downscaled streamflows indicate a decreasing trend over northeastern South Africa. The projected decreasing flows are in line with the expected consequence of projected decreases in rainfall over the catchment. Although rainfall is the main influence on streamflow, there are other factors such as ground water levels and the geology of the area, to name but two factors, which might affect the direct relationship between rainfall and streamflow. Such factors may have to be included for future downscaling studies.

5. References

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