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RIVER-FLOW PREDICTIONS FOR THE SOUTH AFRICAN MID-SUMMER USING A COUPLED GENERAL CIRCULATION MODEL

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There are limited sources of streamflow data available in South Africa. These include simulated streamflow for catchments across South Africa and measured river-flow at specific rivers around the country. Given that a number of studies has been done on the prediction of simulated streamflow, and only one recent study on a limited number of measured river-flow stations, there is a need for a measured national river-flow dataset that previous results of streamflow prediction can be compared against. This study demonstrates the seasonal-to-interannual predictability of river-flow over the summer rainfall areas of South Africa by using various fields from a coupled general circulation model as predictors in statistical post-processing system.

Keywords: Seasonal Streamflow, Hydrology, Climate

INTRODUCTION

There are limited sources of streamflow data available in South Africa, the most notable, used in previous streamflow prediction studies over South Africa (Landman *et al*. 2009, Olivier 2012), being the simulated streamflow from the Agricultural Catchments Research Unit (ACRU) agrohydrological modeling system. This multipurpose model has key weather input of daily rainfall as well as monthly minimum and maximum temperatures and key output of runoff for 1946 quaternary catchments with post processed accumulated streamflow which was used in the aforementioned previous streamflow prediction studies (Schulze *et al.* 1997). The only dataset of point measured river-flow is the data available from the Department of Water Affairs (DWAF) Hydrological Information System. Although the number of flow-gauging structures in South Africa are numerous (782 by the end of 2007, Wessels and Rooseboom 2009) they generally suffer from inconsistency of data availability between stations with regards to time, i.e. numerous stations do not report for the same time period.

The aforementioned recent studies that have been done on the statistical prediction of simulated streamflow in South Africa for the mid-summer period (December-January-February, DJF) were based on the assumption that the ACRU simulated streamflow (accumulated) is a true representation of reality. A more recent study by Malherbe *et al.* (2013) has taken the step to illustrate the predictability of actual measured river-flow data, albeit on a limited region and a limited number of stations. Malherbe *et al.* (2013) used a predictor field of 850 hPa geopotential heights over an extended SADC region from a global coupled general circulation model (CGCM) as this variable has been found to be one of the best predictors of rainfall in South Africa (Landman and Goddard 2002). The assumption is then that rainfall is the main contributor to streamflow variation, though Whitmore (1971) and Schulze *et al.* (1997) have suggested that on average only 9% of streamflow variation can be attributed to rainfall in South Africa with evaporation playing the larger role.

This paper is an extension of the Malherbe *et al.* (2013) paper regarding river-flow prediction, to the extent of enlarging the area of interest to the entire summer rainfall region and evaluating additional model output fields. Here we downscale the Southern Hemisphere 500 hPa geopotential height fields and 2 m temperature fields of a CGCM to a measured streamflow dataset for the summer rainfall region and verify the results over a 15 year test period. By including 2-meter temperature from the CGCM as predictor for statistical downscaling, the results may incorporate some aspects of evaporation.

DATA AND METHOD

Measured river-flow data are obtained from the Hydrological Information System (HIS) (DWAF 2013) of the Department of Water Affairs (DWAF). This system provides river-flow data for all the drainage regions in South Africa with multiple river flow-gauge data available for each drainage region. A comprehensive overview of flow-gauging structures in South African rivers is given in Wessels and Rooseboom (2009).

The raw data were obtained and processed into a national dataset with only including stations that indicated to be operational for the entire period of the model hindcast (1983-2009). Some quality control was added according to the quality control codes available from DWAF to obtain a high quality dataset. Nationally the amount of flow-gauge measurements that survived the temporal criteria is 455. However, when an additional criteria of a minimum of 90% of data availability (affected by the quality control) is added, the number of reliable river-flow measurements

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drops to 127 nationally and 65 stations for the area of interest.

A recent coupled modeling system developed at the South African Weather Service (SAWS), that utilizes the ECHAM4.5 atmospheric general circulation model (Roeckner *et al.* 1996) and coupling it to the Modular Ocean Model version 3 (MOM3; Pacanowski and Griffes (1998)) with a Multiple Program Multiple Data (MPMD) procedure (Beraki *et al*. 2013), will be utilized to provide large-scale predictors to be downscaled to measured river-flow over South Africa. Coupled models have been shown to outperform atmospheric models forced with prescribed sea-surface temperatures over South Africa (Landman *et al.* 2012).

A model output statistics (MOS; Wilks 2011) canonical correlation analysis (CCA) approach will be used to project the various CGCM-based predictors to the new river-flow data. Various regions will be used for the different model predictor fields but a common region will be used for the response variable (river-flow) which will be concentrated over the summer rainfall region as this study aims to show the prediction of mid-summer river-flow. The 850 hPa geopotential height fields will be restricted to an extended SADC region (20N-50S, 20W-70E) mainly in an effort to capture important summer rainfall-bearing systems. The 500 hPa geopotential height fields will be extended across tropical areas of the Southern Hemisphere (0S-30S, 0W-360W) in order to capture those tropical climate drivers influential over the summer rainfall period. These fields have been found to be captured skillfully by the CGCM used here (Beraki *et al.* 2013). The 2-meter temperature field will be restricted to the same domain as used for the measured streamflow area (22S-30S, 24E-32E) of interest namely the summer rainfall region of South Africa.

The downscaling performance of the three large-scale predictor fields will be tested probabilistically since seasonal forecasts are inherently probabilistic. For this purpose the relative operating characteristic (ROC; Wilks 2011) scores and Reliability diagrams (Hamill 1997) will be assessed for each case.

RESULTS AND DISCUSSION

Downscaling was done retro-actively by applying the CCA option of the Climate Predictability Tool of the International Research Institute for Climate and Society (IRI; http://portal.iri.columbia.edu/portal/server.pt) to the CGCMs seasonal output fields and the seasonal river-flow measurements. The retro-active analysis used 12 years of data for the training of the statistical model and retro-actively forecasting for the next 15 years for verification. Figure 1 shows the area average ROC scores in a diagram for each of the three predictors used.

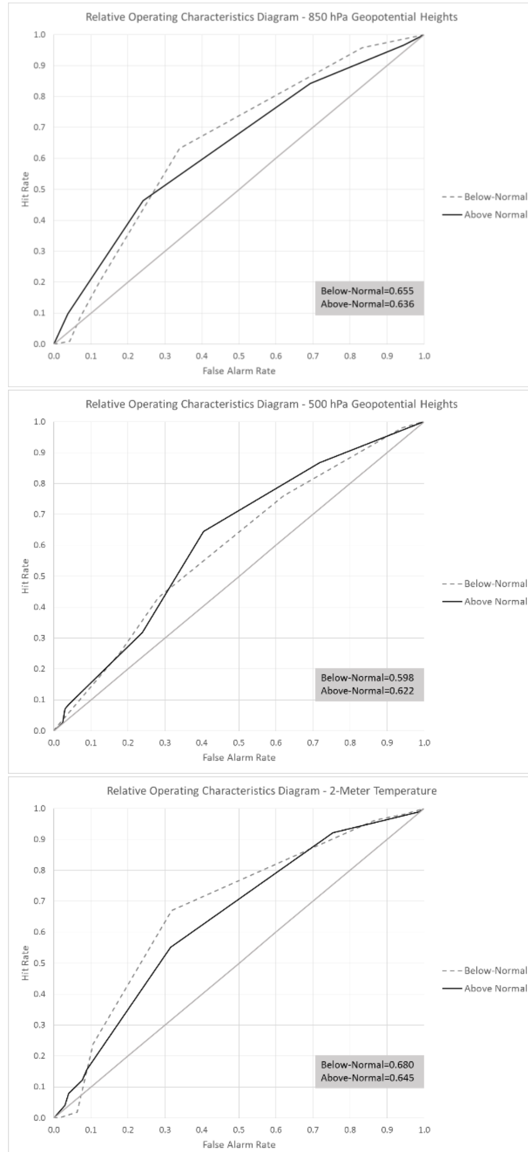

Figure 1: Relative Operating Characteristics diagrams for southern African 850 hPa geopotential heights (Top), Southern Hemisphere tropical 500 hPa geopotential heights (Middle) and 2-meter temperature (Bottom) predicting streamflow during mid-summer (DJF) at a 1-month lead (November initialized) for the summer rainfall areas of South Africa.

Figures 2 and 3 show the predictors' performance with regards to reliability for the above-normal (fig 2) and below-normal (fig 3) prediction categories.

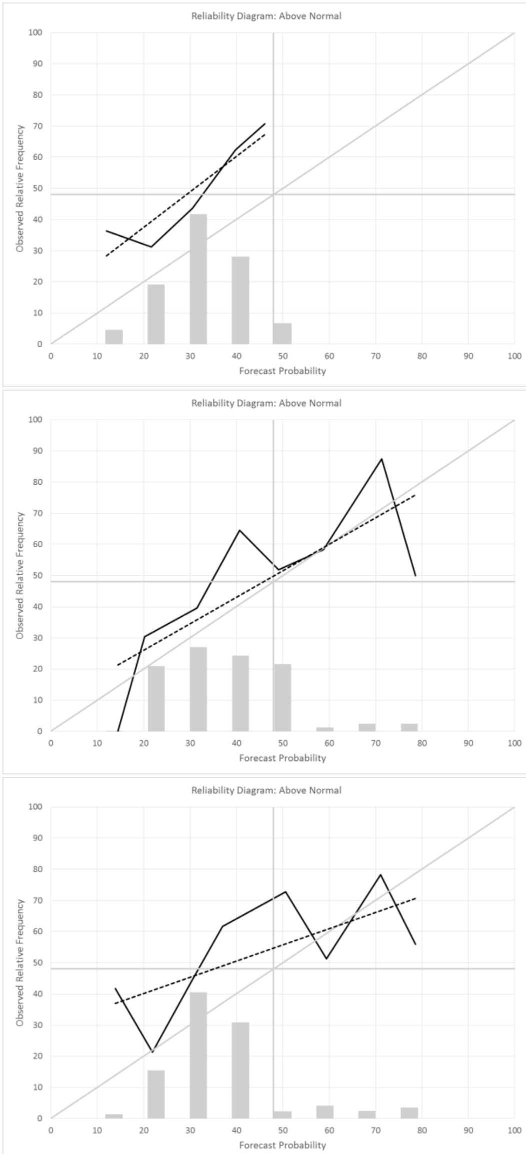

Figure 2: Reliability diagrams for predicting above-normal streamflow for southern African 850 hPa geopotential heights (Top), Southern Hemisphere tropical 500 hPa geopotential heights (Middle) and 2-meter temperature (Bottom) predicting streamflow in mid-summer (DJF) at a 1-month lead (November initialized) for the summer rainfall areas of South Africa.

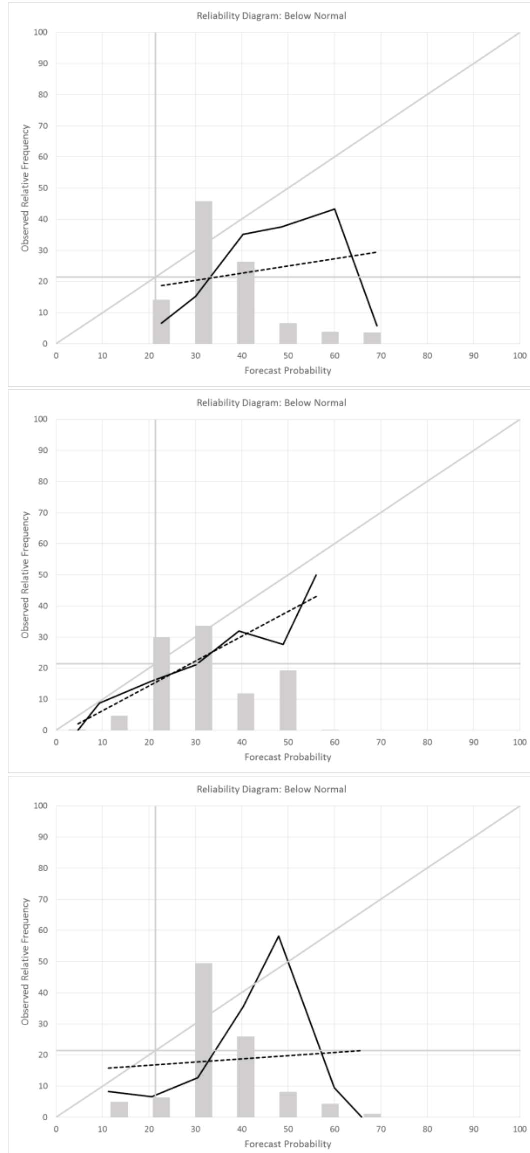

Figure 3: Reliability diagrams for predicting below-normal streamflow for southern African 850 hPa geopotential heights (Top), Southern Hemisphere tropical 500 hPa geopotential heights (Middle) and 2-meter temperature (Bottom) predicting streamflow in mid-summer (DJF) at a 1-month lead (November initialized) for the summer rainfall areas of South Africa.

All three predictors perform well overall for the area of interest with 850 hPa geopotential heights and 2-meter temperature performing marginally better than the 500 hPa geopotential heights when only considering the downscaling systems' ability to discriminate between high- and low-flows. When looking at the reliability diagrams though, the 500 hPa heights can be considered to be performing better due to its more even distribution of probability forecasts, especially for higher probabilities, rather than the heavily favored climatological forecasts from both the 850 hPa geopotential heights and the 2-meter temperature. A similar pattern of high-flows not being predicted often enough relative to the observed frequency and overconfidence of predicting low-flows is evident from the reliability diagrams in all cases. These results are similar to those found in Malherbe *et al.* (2013).

CONCLUSSIONS

This study have shown that even though there are minor differences in performance levels for using various predictor fields, that similar properties of probability forecasts arise from various predictors i.e. the underestimation of high-flows and the overconfidence in low-flows. In the particular case of the 500 hPa tropical geopotential heights, the improvement in sharpness of probabilistic forecasts poses some interesting questions on whether the increased sharpness is exclusively due to superior skill levels in 500 hPa geopotential heights in the tropics or whether the aforementioned influential climate drivers from the same fields contribute positively to the explanation of river-flow variation at a seasonal time-scale. This statement however needs further investigation although it does point towards the need to use skillful predictors, of which the extended SADC 850 hPa geopotential heights suffer a lack of in key areas (Beraki *et al.* 2013).

The seasonal prediction of river-flow (and simulated streamflow as in other studies) is still in its infancy and more in-depth studies are still needed especially in identifying the best model predictors, or even a combination of model predictors. The work however establishes a baseline skill which more sophisticated approaches (such as dynamical downscaling) would potentially be compared with.

Through findings of this paper as well as the previously mentioned studies on river-flow (streamflow) prediction, it is recommended that river-flow (single flow-gauge stations) as well as simulated or estimated catchment streamflow datasets be developed and updated regularly for use of various prediction applications. It is also recommended that the measured river-flow data be investigated at a daily time-scale in an effort to improve our understanding of the nature of river-flow and how it is affected by weather elements in addition to rainfall.

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