

Interactive comment on “Hydrological drought forecasting and skill assessment for the Limpopo river basin, Southern Africa” by P. Trambauer et al.

Anonymous Referee #2

Received and published: 21 November 2014

Reaction to the interactive comment by Anonymous Referee #2

We would like to thank this referee for his/her interesting comments and suggestions that contributed to improve our paper and to clarify specific points. Hereby we present the authors reply (AC) to the referee's comments (RC).

RC: The paper presents hydrological seasonal prediction experiment using three different driving meteorological inputs (dynamic ECMWF seasonal forecast, ESP and ENSO conditioned ESP) for Limpopo River basin. The study in general follows correctly a common methodology applied for such studies, however does not provide detail information about some important steps of the whole process (see below). The text should be more inclusive to provide reader with all important information on methodology without simply referring to other existing studies; e.g. the results of NS criterion of hydrological model calibration should be stated (authors only refer to another study of the same team - P9978 "In these stations the performance of the hydrological model is found to be satisfactory based on evaluation measures and ranges proposed by Moriasi et al. (2007). These results are presented by Trambauer et al. (2014)."). In general, a text is understandable but some sentences are difficult to read and need overall grammar revision ("It is, however, unreliable, causing frequent droughts and floods also commonly occur in the rainy season."). In a whole, if revised for English and completed by missing detailed information I consider this study a valuable contribution to extended hydrological prediction system literature.

AC: As suggested, we included the results of the model performance. We added a Table (see below) with the performance measure for the selected basins, basin area, mean annual observed runoff, and observed runoff coefficient (RCobs).

Table 1 Model evaluation measures for runoff for selected stations, ordered by basin size

Station number	Sub-basin area (km ²)	Mean annual observed runoff (m ³ /s)	RCobs (%)	R ²	NSE	RSR
24	342,000	96.9	1.7	0.92	0.90	0.32
1	201,001	39.5	1.2	0.69	0.57	0.65
18	98,240	12.2	0.7	0.68	0.62	0.62
20	12,286	14.8	5.3	0.70	0.65	0.59

The mentioned sentence ("It is, however, unreliable...") was modified to clarify to: "Moreover, rainfall is highly variable causing frequent droughts, though floods can also occur during the rainy season"

The manuscript was edited for English

Specific comments:

RC: P 9963-9965 Introduction does not provide literature review of existing studies (or operational implementations) on seasonal hydrological prediction systems.

AC: We have added a review of existing drought early warning systems in the revised manuscript, which reads:

"There are several Drought Early Warning Systems (DEWS) currently in existence in the world, though due to the complexity of drought these are arguably less developed than many

flood early warning systems. Grasso (2009) reports that only three institutions provide information on the occurrence of major droughts at the global scale; FAO's Global Information and Early Warning System on Food and Agriculture (GIEWS), the Humanitarian Early Warning Service (HEWS) operated by the World Food Programme (WFP), and the Benfield Hazard Research Centre at University College London.

In the United States the U.S. Drought Monitor (<http://droughtmonitor.unl.edu/>) was set up in collaboration between the US Department of Agriculture (USDA), NOAA, the Climate Prediction Centre, and the University of Nebraska. It provides insight to current drought conditions and impacts at the national and state level through an interactive map, presenting multiple drought indicators combined with field information and expert input. It also includes 6- to 10 day outlooks and monthly and seasonal forecasts of precipitation, temperature, soil moisture and streamflow. The National Weather Service's National Center for Environmental Prediction's (NCEP) also has a (multi-model) drought monitoring system, as well as a seasonal hydrological forecasting system running at the Environmental Modeling Center (Ek et al., 2010). Additionally, the North American Multi-Model Ensemble (NMME), which became an experimental real-time system in August 2011, is mainly focused on seasonal prediction of meteorological drought (Kirtman et al., 2013)

In Europe the European Commission Joint Research Centre (JRC) has established the European Drought Observatory (EDO, <http://edo.jrc.ec.europa.eu/>), which includes an interactive map viewer with drought-relevant information. It includes real-time maps of different drought indicators, including the Standardized Precipitation Index (SPI), snow and soil moisture anomaly, and vegetation productivity anomaly. These indicators are combined in an overall indicator that is used to provide warnings and alerts. A one week forecast of the expected soil moisture anomaly is also provided. The Beijing Climate Center (BCC) of the China Meteorological Administration (CMA) similarly monitors the development of drought across China, with maps on current drought conditions being updated daily on their website.

The FEWS Net for Eastern Africa, Afghanistan, and Central America reports on current famine conditions, including droughts, by providing monthly bulletins that are accessible on the FEWS Net webpage. However, a drought forecast is not provided. Other drought warning systems over Africa include the Botswana national early warning system (EWS) for drought (Morgan, 1985) and the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES). In the latter a drought early warning system is being adapted to identify climate and water supply trends in order to detect the probability and potential severity of drought (RIMES, 2014).

Advances regarding drought early warning systems in Africa in the last few years are remarkable. There is an increasing availability of drought monitoring and forecasting tools for decision making that can provide real time monitoring and forecasting of drought across the continent. The Land Surface Hydrology Group at Princeton University, USA, has recently established an African Flood and Drought Monitor (<http://stream.princeton.edu/>) with support from the International Hydrology Program of UNESCO. The system provides near real time monitoring of land surface hydrological conditions based on the Variable Infiltration Capacity (VIC) model. The monitor is updated every day at 2 days behind real time. The database provides the daily conditions of precipitation, temperature, wind speed, soil moisture, evaporation, radiation, and different components of runoff in the continent, as well as historic hydrological records in Eastern, Southern and Western sub-regions up to 10 antecedent years, and derived products such as current drought conditions. They also provide precipitation, temperature and SPI forecast (Sheffield et al., 2014). Recently Barbosa et al. (2013) developed a Pan-African map viewer for drought within the framework of the DEWFORA project, following the main features of the earlier developed EDO. The African Drought Observatory (ADO) is a web application hosted by JRC (<http://edo.jrc.ec.europa.eu/ado/ado.html>) that provides historical and near-real time

monitoring information, as well as seasonal forecasts describing meteorological, agricultural and hydrological droughts (Barbosa et al., 2013)."

RC: P 9966 There were four stations evaluated in the study. Two of them representing smaller area have provided generally less satisfactory results. A bit surprisingly the best result has not been gained for the closing profile of a study basin (P 9979/5-10). This is not discussed and authors do not attempt to explain it. With respect to this I miss more detailed information about sub-basins (area, general geographical conditions etc.). Such information might be interesting (and supporting) for interpretation and discussion of results.

AC: A table with extra information on the basins considered (area, mean annual runoff, and observed runoff coefficient) was added, see Table 1 above. Regarding the lower skill of the largest basin, we included a possible explanation in P 9979/8:

"The lower skills for the station with largest contributing area for FS_S4 may be due to the shift from an arid to a more tropical climate in the downstream part of the basin, which means that the persistence of initial conditions would be expected to be lower."

RC: P 9968 A method of deriving of precipitation data is not sufficiently described and validated (a critical impact of meteorological input is obvious from gridded pattern of fig. 7). A way how monthly precipitation data are converted to daily time series for model simulations remain unexplained.

AC: The precipitation data (both reanalysis and re-forecasts) are obtained at a daily time step. No conversion from monthly to daily time series was needed. In P 9968, L7 we added "at a daily time step" after "with the ERA-Interim forcing meteorological data". The monthly time-scale is used only for the correction of the monthly means of ERA-Interim and for the climatological mean correction of S4 forecasts. In this study we did not focus on the detailed evaluations of this data, or further refinement, as our intention was to use available and documented datasets to force the hydrological model. The point that the reviewer raises is indeed very important, but such evaluation would take the paper to another focus on the evaluations of precipitation forecasts on the region.

RC: P 9969 Information about initializations dates and lengths of simulations is quite confused in this section and in results description. I would propose to include a figure with overview of forecast periods during the year and its relation to Limpopo river flow regime.

AC: A figure was added as suggested. The text was clarified and now reads: "In the hindcast, the first forecast of each season is issued in August and includes the seasonal (6-months) forecast from August to January. The forecast is updated at the beginning of each month from September to February. The last forecast of the season is issued in February, covering the period from February to July (see Fig. 4). All simulations are done at a daily time step."

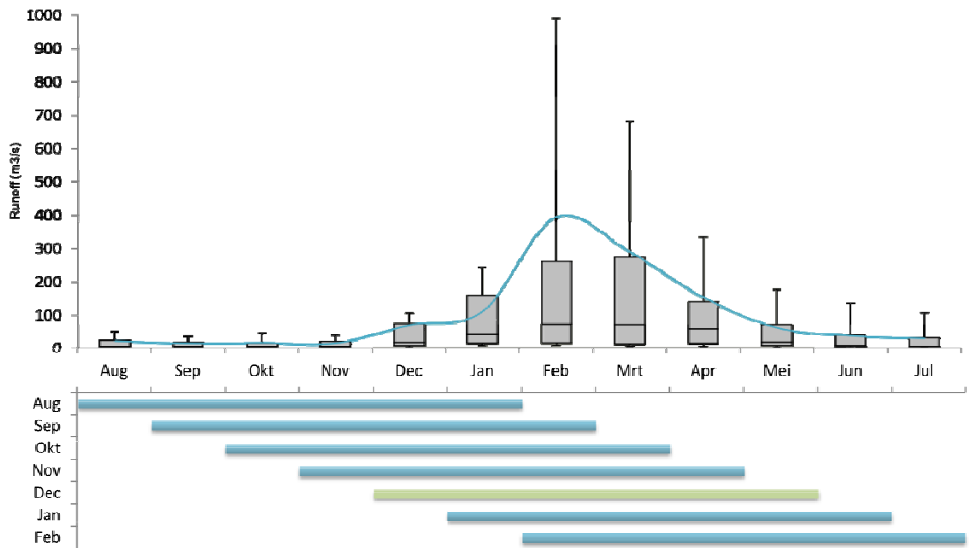


Fig. 4 Upper plot: Limpopo river flow regime for Station 24 at Chokwe. The blue line represents the average observed runoff, and the whiskers of the boxplots represent the 10th percentile and the 90th percentile. The lighter and darker shaded areas represent the main runoff period and high runoff period, respectively. Lower plot: Initialization dates and length of forecasts during the year. The forecast issued in December is highlighted as the one that captures the main runoff season.

RC: P 9971/18 Does "multi-annual mean" mean the same as "mean" long term climatology?

AC: Yes, "multi-annual mean" was changed for "climatological long term mean" to clarify.

RC: P 9971 According to a described precipitation bias correction the monthly mean correction factor is "linearly interpolated from monthly values to daily assuming it corresponds to day 15 of the particular month". This might suggest that interpolation has been done the way illustrated in fig. 1. Daily time series (a) is bias corrected on monthly basis (b). Let's suppose the correction factor (alpha) is 2.39 for a given month and 0,6 for a preceding and following months. If this number is applied to correct daily rainfall uniformly during the given month the corrected monthly precipitation total would equal to 255 mm (8,5 mm per day) while if interpolated according to description of authors the monthly corrected total would be 214 mm (7,1 mm per day) only (c). I believe that was not the case, only a method description should be more precise.

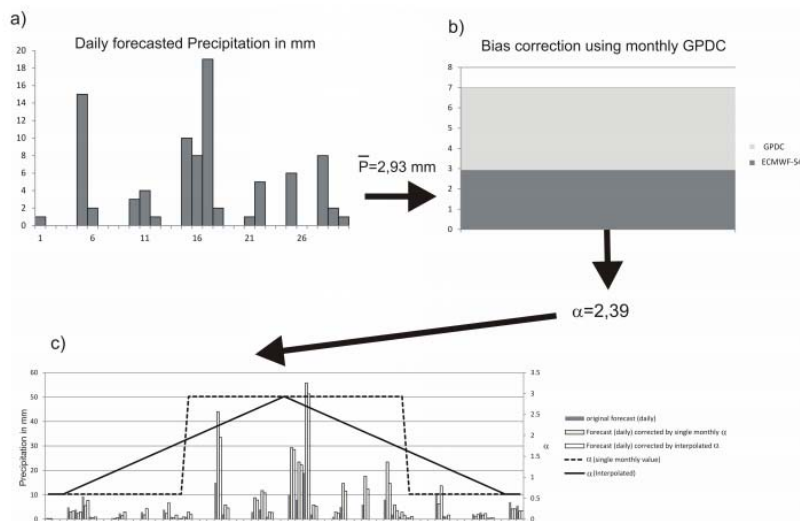


Fig. 1. Fig. 1 bias correction process (see text for explanation)

AC: The method described by the reviewer as "interpolated" was the one we used. The reviewer is right that it will not match the mean. However, the correction factor is only a long-term climatological value for each calendar month and forecast lead time, i.e. does not change from year to year. The decision of using a linear interpolation instead of a step function, as suggested by the reviewer, was to avoid "jumps" in the precipitation amounts, as we can see in the Fig.1. We did not evaluate the impact of using a different method for the bias correction, and we only applied a very simple correction. In our opinion, a more sophisticated bias correction would only be justified if we had good quality in-situ observations of precipitation, and this was not the case for the region.

RC: P 9974 and 9976 Resampling procedures have to be described in more detail.

AC: The resampling procedures were described in more detail. The explanations in P9974 and 9976 were expanded, respectively:

- "For each forecast start date, we construct an ensemble meteorological forecast of 30 members to be consistent with FS_ESP. The selection of the members is based on a resampling with replacement procedure given the probability assigned to each member. From the 30 possible ensemble members to be included, those with an ONI index closer to that of the forecast year, have a higher probability of being included in the ensemble. This means that some ensemble members are included more than once, and some are not included at all. "
- "The uncertainty of the ROCS is estimated by applying a bootstrap resampling with replacement procedure.
For the FS_S4 and FS_ESP forecasts, we randomly replace (allowing repetition) the original forecast and verification pair to produce a new sample of the same size as our original sample. We then calculate the ROCS from the new sample. We repeat this procedure to create 1000 new samples from which we generate an empirical distribution of the ROCS. The 90% confidence interval is estimated from the 5th and 95th percentiles of this empirical distribution."

RC: P 9976/20 Root stress indicator is used, however it is not defined. Is the Root stress the same as a modeled soil water deficit?

AC: The "root stress" (RS) is an indicator of the available (or the lack of) soil moisture in the root zone, which can be calculated for each grid cell. The RS varies from 0 to 1, where 0 indicates that the soil water availability in the root zone is at field capacity and 1 indicates that the soil water availability in the root zone is zero and the plant is under maximum water stress. This explanation was added in the manuscript.

RC: P 9978/1 The "mean runoff season" and "high runoff season" need to be defined.

AC: Instead of "mean", it should have said "main". By "main runoff season" we meant the season from December to May, which is the season with highest runoff. The "high runoff season" is the four months period, January to April, where the runoff is the highest during the year. These periods are presented in the new Figure 4.

RC: P 9984 Authors conclude that initial hydrological conditions (IHC) contributes to predictability up to 2 to 4 months but do not discuss these findings with Shukla et al. (2013) who have found shorter impacts of IHC.

AC: This statement is here clarified. We did not find that the initial conditions dominate the predictability up to 2 or 4 months, but that they contribute to the predictability. The higher skill of FS_S4 over that of FS_ESP during the wet season for every lead time suggests that the Meteorological forecast (MF) might dominate the hydrological drought predictability for every lead time, as reported by Shukla et al. (2013). However, we cannot make the same kind of conclusions as Shukla et al. (2013) as we did not apply the reverse ESP procedure, which

derives its skill solely from the perfect forecast. In our case FS_S4 derive its skill both from the IHC and meteorological forecast (MF). Our statement refers to some contribution of the IHC to the skill, given that when we examine the results of FS_ESP (which derives its skill only from the knowledge of IHC) we see some skill only up to 2, and in some cases 4 months. After that there is no skill at all from the IHC.

In the manuscript, P9984/17-25, it already states: "The higher skill of the FS_S4 and FS_ESPcond compared to that of the FS_ESP for every lead time is in line with the study of Shukla et al. (2013) who show that for the region of the Limpopo river basin the meteorological forecast dominates the hydrological predictability for the wet season for almost every lead time considered. Only for the 1-month lead time forecasts issued in October they found a higher influence of the hydrological initial conditions to some extent. Moreover, Yossef et al. (2013) indicate that for semi-arid regions the initial conditions do not contribute much to the skill given the high sensitivity of the runoff coefficient to rainfall variability."

RC: P 9982-9985 Station 24 (closing gauge of the basin) is in general predicted with less skill than upstream station 1 but physical explanation is not discussed.

AC: It is true that the skill is in general better for station 24 than for station 1. The lower skills for the station with largest contributing area for FS_S4 may be due to the shift from an arid to a more tropical climate in the downstream part of the basin, which means that the persistence of initial conditions would be expected to be lower. Also, given that this is mostly the case for the FS_S4 and not so much for the FS_ESP and FS_ESPcond, we can speculate the ECMWF S4 seasonal forecast might have a better skill for the northern (more arid) part of the basin (area corresponding to sub-basin draining to station1), than for the southern part of the basin. This is also reflected in the spatial analysis of skill presented in Figure 9.