Assessment of the Skill of Seasonal Meteorological Forecasts in the Eastern Nile

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Abstract

Warnings issued several months ahead of a flood or a drought event can trigger action plans to mitigate the risks and enhance preparedness. An early warning system that relies upon forecasting systems can provides the necessary information. The numerical weather models give a short term weather forecast for about three days. Even with the increasing power of supercomputers, the forecast skill of numerical weather models extends to about only six days. The European Center for Medium range Weather Forecasting (ECMWF) has a dynamical seasonal forecast model gives seasonal forecasts which predict the average weather up to one year ahead. In this paper, an effort is done to skill the 51 ensembles, generated by ECMWF and enhanced by the Bias Correction Methods, using the hydrological models in Nile Forecasting System (NFS). Each ensemble is a seasonal forecast from May to November during the years (2005-2011). The results produce 51 simulated flow ensembles which are analyzed to assess the most accurate ensembles in rainfall prediction. The results show that the ensemble mean is on average better than any individual ensemble member.

Keywords: NFS, Meteorological Seasonal Forecast, Skill Score.

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1. INTRODUCTION

Prediction of the weather is very essential in the hydrological applications. The short term weather forecasts which are exported from the Numerical Weather Models are limited to one or two weeks however the accuracy of the forecast decrease due to the length of the prediction period. The dynamical seasonal forecast models, such as the system run operationally at the European Center for Medium – Range Weather Forecast (ECMWF), consist of ensembles of integrations of coupled General Circulation Models (GCMs) of the ocean and atmosphere, similar to the models used to make the weather forecast.

A problem in seasonal forecasting is the lack of data for a thorough verification. The skill of seasonal forecasts depends very strongly on the season and the region, (Oldenborgh, 2003). Due to this lack of data, the skill of the seasonal forecast became more difficult. The scientists try to skill these data on specific locations and by using the hydrological models, through the evaluation of the flow forecasted using such that data.

Demirel, 2015, found the uncertainty from ensemble precipitation forecasts has a larger effect on seasonal low-flow forecasts than the uncertainty from ensemble potential evapotranspiration forecasts and initial model conditions. Seibert and Trambauer, 2015, found that the seasonal forecast can provide useful information for drought early warning systems and water managers. The dynamic multi ensemble seasonal forecast for the Limpopo river basin with ECMWF S4 seasonal forecasts, found that the higher skill in predicting low flows and high flows than in predicting near normal conditions and the predictive skills of these forecasts are higher than using the climatology (DEWFORA project D4.8,2013).

The aim is to skill the ECMWF seasonal forecast in flow prediction over the Eastern Nile. The prediction flow ensembles will be evaluated reference to the observed flow in order to define the optimum ensemble which gives reasonable flow forecast. The Nile Forecast System (NFS) is applied with (ECMWF) meteorological seasonal forecast data to produce forecasted flows at key locations in the Eastern Nile.

2. STUDY AREA

The Eastern Nile Region covers a large portion of the Nile Basin (Figure 1). The region encompasses three major sub-basins of the Nile: the Sobat in the south, the Blue Nile in the middle, and the Atbara in the north. Together, the contribution of the three sub-basins to the total annual Nile flow is about 85%. Most of that flow is generated in the Western Ethiopian highlands during the rainy summer season (July-September) with some minor contribution to the Sobat from South Sudan. The Eastern Nile region is characterized by heavy rainfall and steep slopes in the headwater areas of the mountains and less rainfall and mild slopes in the Sudanese plains near the outlets of the three rivers. In this study, the focus is on the Blue Nile and the Atbara sub-basins which are described briefly in the coming sections in terms of their hydrology, climate, and water resources utilization.

2.1 The Blue Nile Basin

The Blue Nile has a total catchment area of about 314,000 km2. The river and all of its tributaries rise on the Ethiopian Plateau at elevations of 2,000 to 3,000m a.m.s.l. The Blue Nile leaves for about 935 km before reaching Roseires in Sudan near the border between Ethiopia and Sudan. The slope of the river changes drastically upon entering Sudan from 1.6 m/km to 15 cm/km. The river receives several tributaries on its way from Lake Tana to Roseires, which increase the flow tenfold. The total basin area up to Diem is about 182,000 km2 with annual average rainfall and PET (Potential Evapotranspiration) of 1,200mm and 1,400mm respectively. The mean discharge at Roseires/Diem for the period 1940-1982 is about 49.5 BCM. The river continues its journey to Sennar at a much milder slope for another 270 km where rainfall reaches 460 mm. There are no tributaries in this reach; therefore the flow at Sennar is about 2 BCM less than that at Roseires.

Between Sennar and the basin outlet to the Nile at Khartoum, the Blue Nile receives water from two major tributaries, the Dinder and the Rahad. Both of these rivers originate in the Ethiopian Highlands. Both tributaries run dry during the winter/spring months (January to May). The mean annual precipitation and PET for the Blue Nile basin between Diem and Khartoum are 550 mm and 2,157 mm respectively. The observed flow record at Khartoum has an average annual of 46 BCM. This is less than that at Diem because the irrigation diversions along the reach and losses from the Roseires and Sennar reservoirs outweigh the contributions of the Dinder and the Rahad.

2.2 The Atbara Basin

The River Atbara is the last tributary that joins the Nile. It originates in the Ethiopian Highlands to the north of Lake Tana. There is little consensus upon the area of the Atbara basin. The recent estimates using GIS delineation techniques based on recent digital elevation models gives an area of the basin more than 200,000 km^2. The upper basin has an average annual precipitation of 550 mm while the lower basin receives only about 200mm with a high potential evapotranspiration rate of about 2,300 mm. The total annual contribution of the Atbara, as measured at its mouth near the junction with the Nile is 10.95 BCM (El-Shamy, 2009). All of this flow comes from the upper basin as the lower reach is a source of loss due to the high evaporation rate and due to irrigation diversions and losses from the reservoir of Khashm El-Girba Dam.

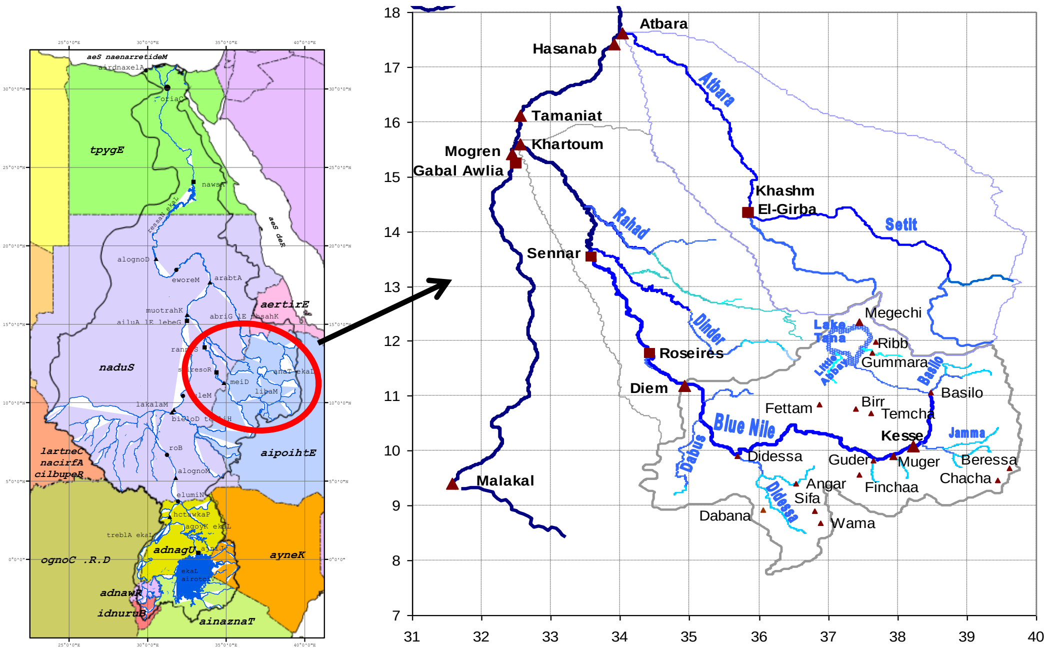


Figure 1: Nile Basin Map - Eastern Nile Region Marked *(Redrawn from Elshamy, (2006))*

3. NILE FORECAST SYSTEM (NFS)

The Nile Forecast System (NFS) is a near real-time distributed hydro-meteorological forecast system designed for forecasting Nile flows at designated key points along the Nile. The core of the NFS is a conceptual distributed hydrological model of the Nile system including soil moisture accounting, hillslope and river routing, lakes, wetlands, and man-made reservoirs within the basin. The main inputs to this model are the rainfall and potential evapotranspiration.

From the outset of NFS development, it is decided to utilize satellite remote sensing technology in estimating rainfall over the basin. This is motivated by the scarcity and discontinuity of rainfall records within the basin in addition to the lack of direct monitoring control over rain gauges, as all basin rainfall occurs outside the borders of Egypt where the system is hosted. Therefore, the system grid is designed to match that of the satellite rainfall. Figure 2 shows the main components of the NFS.

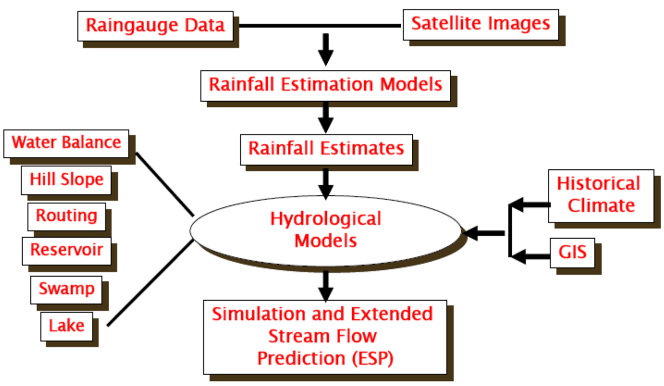


Figure 2: Schematic of the Nile Forecast System

The last evaluation of the NFS was in 2011. The evaluated criteria were Root Mean Squared Error (RMSE), the Mean Absolute Error (MAE), and the Nash-Sutcliffe (coefficient of) Efficiency (R^2). The evaluation showed that the NFS performance is generally satisfactory for the Blue Nile given the uncertainties in rainfall estimates and irrigation abstractions in addition to the fact that Lake Tana and the small swamps in some sub-basins are not explicitly modelled. Table 1 shows the evaluation results.

Table 1: Summary Statistics for Key Locations along the Eastern Nile, *(NFS Evaluation Report, 2011).*

Station	r	R^2	MAE (BCM)	RMAE %	RMSE (BCM)	RRMSE %	Mean Annual Volume (BCM)	
							OBS	NFS
Diem	0.96	0.92	0.77	1.52	1.38	2.72	50.74	50.80
Khartoum	0.94	0.88	1.01	2.25	1.70	3.80	44.80	42.23
Atbara	0.82	0.66	0.52	4.12	1.24	9.82	12.63	10.83

4. METEOROLOGICAL FORECAST DATASETS

The most recent seasonal forecasting system at European Center for Medium range Weather Forecasting ECMWF (System 4 - S4) was made available to the different modelling groups (DEWFORA 2011c). S4 issues 51 ensemble members with six months lead time. The atmospheric resolution is about 79 km with 91 vertical levels, and is fully coupled with an ocean model with a horizontal resolution of 1°. The initial perturbations are defined with a combination of atmospheric singular vectors and an ensemble of ocean analysis. Atmospheric model uncertainties are simulated using a 3-time level stochastically perturbed parameterized tendency (SPPT) scheme and the stochastic back-scatter scheme (SPS) that are also operational in the current ECMWF medium-range ensemble prediction system. The hind cast set is provided for calibration, covering a period of 30 years (1981 to 2010) with the same configuration as the operational forecasts but only with 15 ensemble members. Molteni et al. (2011) presents an overview of S4 model biases and forecasts performance, and Dutra et al. (2012) presents an evaluation of S4 in seasonal forecasts of meteorological droughts in several African Basins.

5. METHODOLOGY

The methodology steps starts with: 1) obtaining the meteorological seasonal forecast from ECMWF together with some necessary "pre-processing" of the data of the rainfall and PET, so the average rainfall for the 51 ensembles became close to the real time rainfall estimation time series in Nile Forecast System (NFS).

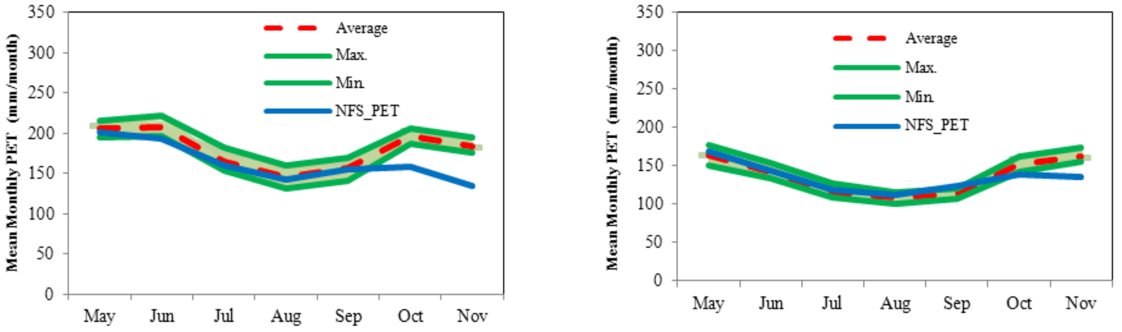
2) The simulation program in the NFS has been run for each ensemble (0-50), to produce a daily time step from the first of May till the end of November for each year (2005-2011) according to the rainfall forecasting time series. The number of runs is one run for each year and 7 runs for each ensemble, so the total numbers of the runs is 357 runs so a script is written to loop over all ensembles and run the simulation program for each year.

3) Finally the statistical criteria, Root Mean Square Error (RMSE), Nash Sutcliffe (R^2), and Mean Absolute Error (MAE), are used to evaluate the results of each simulated flow ensemble reference to the observations at key locations in the Eastern Nile (Diem, Khartoum, and Atbara) to get close to simulated flow ensemble to the observed flow, which pointed to the best rainfall prediction ensembles (0-50).

6. BIAS CORRECTION METHODS OF SEASONAL FORECASTS

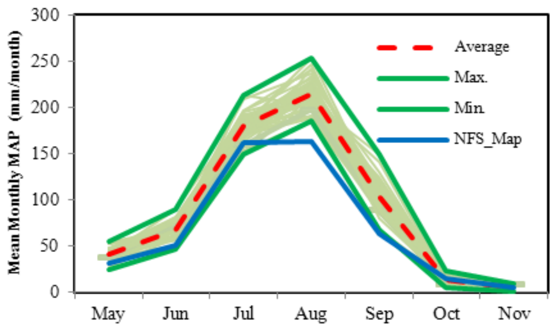
The method to bias correct precipitation is based on monthly means, by applying a multiplicative correction factor. The correction factor was calculated by comparing the mean climate of the forecasts and an observed mean climatology of the real time rainfall data in NFS (for each calendar month). Figure 3 and figure 4 show the change in the PET and the precipitation over the eastern Nile basins. The rainfall in the three basins (Atbara, Diem, and Khartoum) was over estimated which affect the simulation flow. This region (Eastern Nile basins) is very highly sensitive to the change of rainfall;

however the small change in the rainfall in this area leads to more change in the flow. After using the bias correction Method, the average rainfall for the 51 ensembles became close to the real time rainfall estimation time series in NFS.

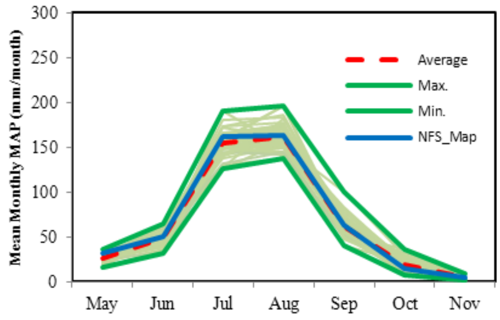


a) Atbara Station **b) Khartoum Station**

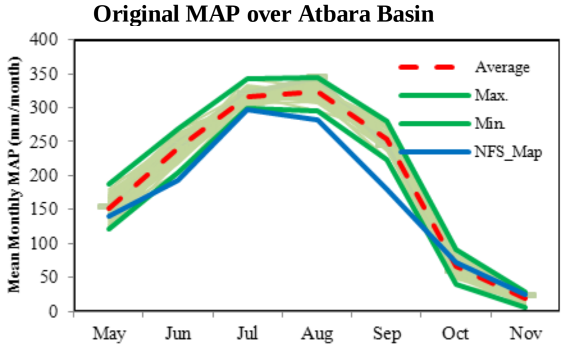
Figure 3: PET Calculated by the Forecasted Ensembles and Compared to the NFS fixed PET



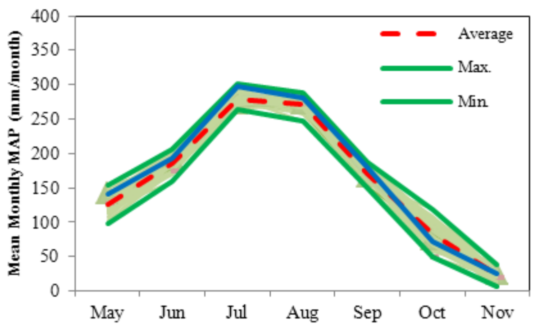
Original MAP over Atbara Basin



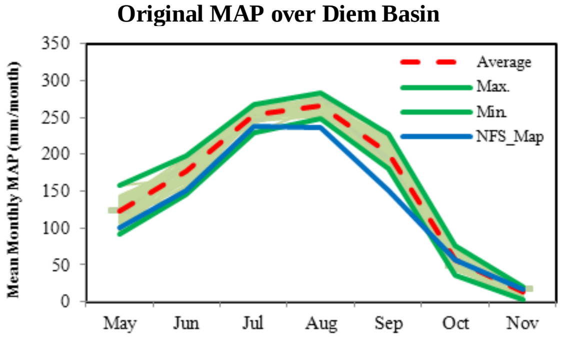
Corrected MAP over Atbara Basin



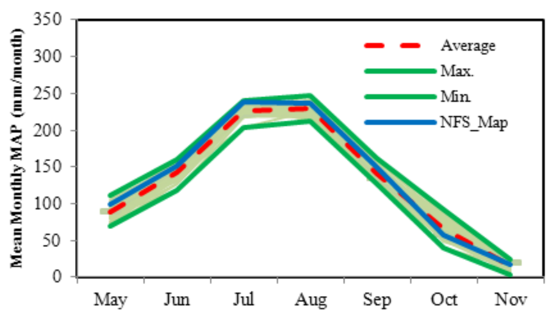
Original MAP over Diem Basin



Corrected MAP over Diem Basin



Original MAP over Khartoum Basin



Corrected MAP over Khartoum Basin

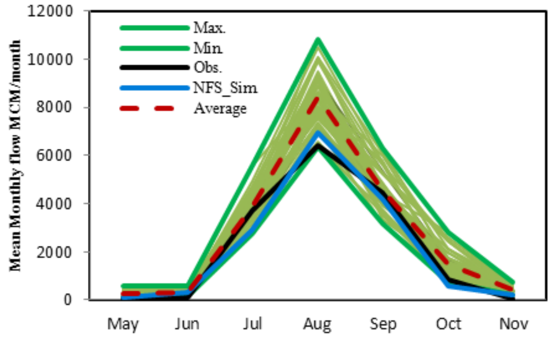
Figure 4: The Differences Between the Corrected Precipitation over the Eastren Nile by the Bias Correction Method and the Original Forecasted Precipitation

7. RESULTS AND DISCUSSION

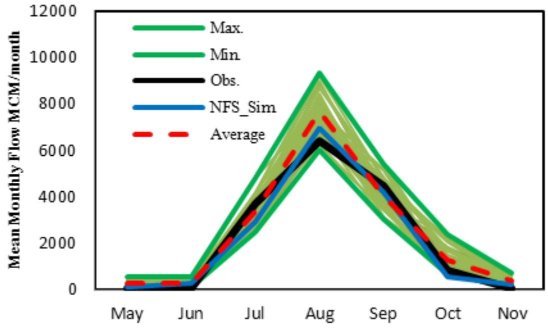
The results of this study are divided into two parts: part 1 using the rainfall forecast corrected by the bias correction method with the PET calculated from the outputs of the seasonal forecast for all ensembles. Part 2 use the same rainfall forecast with the (NFS) PET. The range of the forecasted PET is close to the NFS_PET except for October and November which are far from the NFS_PET (over estimate). This is clear in the Atbara basin, Figure 3a), and the differences is decrease in the Khartoum basin, Figure 3 b). It is expected that the differences in PET in October and November will affect simulation flow in these two months in Atbara and Khartoum sub basins.

Figure 5 shows the simulation flow range for all 51 ensembles compared to the observed flow and NFS simulation. For each sub basin, there are two cases; case 1 using the forecasted PET and case 2 using NFS_PET. It is found that when using the NFS_PET the simulation flow range is reduced; however the reduction in the PET for Atbara basin reduces the flow range width from 5 BCM to 4.5 BCM. For Diem using the NFS_PET. reduces the flow range width from 5.25 BCM to 5 BCM, while in Khartoum basin the reduction in the flow range width is 1.5 BCM.

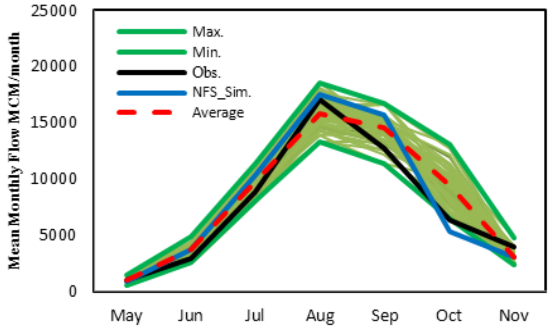
The results shows that, in case of using NFS_PET in Atbara basin the NFS simulation flow is close to the average simulated flow of the 51 ensembles and this does not occur in case of using the forecasted PET, the NFS flow become close to the lower limit of the range of the 51 ensembles. The results in the Blue Nile basins (Diem basin and Khartoum basin) shows some changes in the trend of the range of the 51 ensembles than NFS simulation flow in both cases especially in October and November, while in the rest of months it is seen that the NFS simulation is closer to the average range of the 51 ensembles in case of using the forecasted PET than in case of using NFS_PET. These give indication that at the months (May, June, July, August, and September the forecasted weather elements which are used to calculate the PET over the Blue Nile basin have succeeded in simulating the PET which is fixed in NFS. It is expected to get reduction in October and November flow simulation in both cases, because of the raise of PET in these months, but the rainfall which is slightly above the NFS flow simulation in October and November affects the results and raises the flow simulations range than the NFS flow.



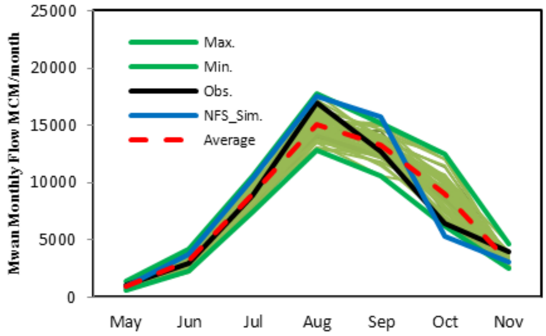
Simulation Flow at Atbara using forecasted PET



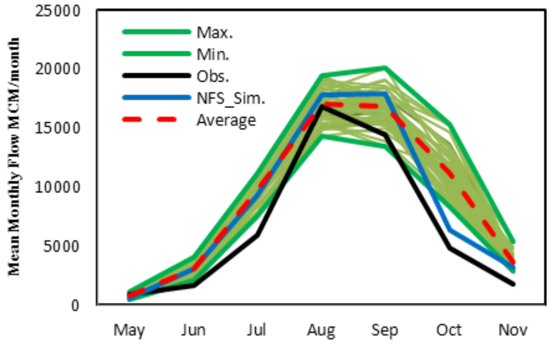
Simulation Flow at Atbara using NFS PET



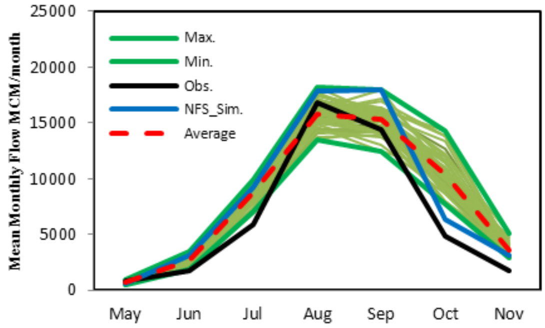
Simulation Flow at Diem using forecasted PET



Simulation Flow at Diem using NFS PET



Simulation Flow at Khartoum using forecasted PET



Simulation Flow at Khartoum using NFS PET

Figure 5: Simulations Flow in the Eastern Nile using the Forecasted PET Compared to Simulations Flow using NFS_PET

Table 2: Values of the Skill Scores for the ECMWF Seasonal Forecast Applied on the Eastern Nile Sub-Basins

Ensembles	Diem				Khartoum				Atbara			
	R^2	RMSE	MAE	r	R^2	RMSE	MAE	r	R^2	RMSE	MAE	r
0	0.59	3.73	2.38	0.80	0.57	4.18	3.16	0.83	0.18	2.60	1.60	0.65
1	0.43	4.40	2.86	0.77	0.30	5.31	3.68	0.80	0.08	2.75	1.72	0.68
2	0.53	4.02	2.50	0.79	0.51	4.43	2.99	0.84	0.37	2.27	1.34	0.75
3	0.38	4.62	3.29	0.69	0.46	4.67	3.46	0.79	0.02	2.83	1.71	0.73
4	0.38	4.61	3.12	0.75	0.37	5.04	3.52	0.81	0.35	2.32	1.29	0.72
5	0.64	3.52	2.39	0.83	0.56	4.19	3.02	0.86	0.21	2.55	1.48	0.72
6	0.56	3.89	2.33	0.76	0.50	4.50	2.90	0.76	0.02	2.83	1.67	0.51
7	0.67	3.37	2.41	0.83	0.67	3.63	2.84	0.85	0.50	2.03	1.18	0.73
8	0.65	3.45	2.32	0.83	0.66	3.72	2.76	0.89	0.55	1.92	1.30	0.82
9	0.65	3.47	2.35	0.83	0.63	3.88	2.86	0.86	0.52	1.99	1.18	0.77
10	0.54	3.96	2.66	0.79	0.54	4.31	2.94	0.83	0.35	2.31	1.22	0.63
11	0.65	3.45	2.28	0.85	0.52	4.41	3.32	0.87	0.10	2.72	1.59	0.64
12	0.61	3.63	2.49	0.83	0.53	4.37	3.09	0.87	0.24	3.19	1.74	0.55
13	0.67	3.36	2.13	0.85	0.64	3.79	2.59	0.88	0.19	2.57	1.53	0.61
14	0.26	5.05	3.20	0.75	0.11	5.98	4.08	0.81	0.06	2.78	1.67	0.66
15	0.45	4.33	2.97	0.78	0.37	5.03	3.71	0.86	0.59	3.61	2.10	0.63
16	0.63	3.54	2.40	0.84	0.58	4.13	3.01	0.86	-0.06	2.95	1.65	0.53
17	0.60	3.70	2.27	0.81	0.56	4.20	2.83	0.84	0.08	2.98	1.67	0.56
18	0.12	6.19	3.22	0.60	0.34	7.35	3.98	0.63	0.36	3.34	2.04	0.53
19	0.46	4.30	2.86	0.72	0.40	4.90	3.49	0.75	0.14	2.65	1.51	0.61
20	0.73	3.02	2.08	0.86	0.70	3.47	2.64	0.87	0.29	2.42	1.29	0.71
21	0.52	4.05	2.76	0.77	0.37	5.03	3.46	0.77	0.35	2.31	1.33	0.71
22	0.49	4.19	2.68	0.73	0.47	4.64	3.16	0.78	0.32	3.29	1.84	0.67
23	0.62	3.61	2.43	0.81	0.55	4.28	3.22	0.83	0.30	2.40	1.40	0.71
24	0.69	3.26	2.12	0.84	0.72	3.35	2.46	0.86	0.30	2.39	1.22	0.64
25	0.57	3.86	2.61	0.83	0.45	4.71	3.38	0.87	0.01	2.85	1.63	0.60
26	0.45	4.35	2.56	0.72	0.40	4.93	2.91	0.73	0.15	3.07	1.50	0.63
27	0.62	3.59	2.15	0.81	0.57	4.16	2.75	0.80	0.27	2.44	1.40	0.63
28	0.58	3.79	2.56	0.82	0.47	4.61	3.30	0.88	0.03	2.90	1.61	0.77
29	0.42	4.47	2.69	0.76	0.39	4.95	3.28	0.82	0.14	2.65	1.70	0.70
30	0.52	4.04	2.74	0.76	0.58	4.09	2.86	0.83	0.12	2.68	1.42	0.61
31	0.57	3.84	2.83	0.83	0.48	4.57	3.58	0.89	0.07	2.76	1.47	0.63
32	0.61	3.68	2.59	0.82	0.45	4.68	3.38	0.82	0.30	2.40	1.36	0.70
33	0.48	4.22	2.54	0.73	0.53	4.34	2.75	0.78	0.09	2.73	1.71	0.66
34	0.40	4.53	2.69	0.74	0.37	5.04	3.25	0.78	0.15	2.63	1.52	0.67
35	0.67	3.34	2.24	0.83	0.66	3.71	2.61	0.85	0.51	2.00	1.19	0.74
36	0.34	4.75	2.71	0.72	0.33	5.18	3.32	0.78	0.26	2.46	1.38	0.72
37	0.71	3.13	2.07	0.87	0.72	3.38	2.59	0.92	0.26	2.46	1.30	0.69
38	0.54	3.98	2.83	0.78	0.38	5.01	3.61	0.78	0.49	2.05	1.37	0.81
39	0.67	3.35	2.08	0.84	0.66	3.70	2.48	0.88	0.27	2.44	1.41	0.69
40	0.50	4.16	2.65	0.80	0.27	5.43	3.75	0.82	0.13	3.05	1.91	0.76
41	0.01	5.83	3.57	0.65	0.07	6.57	4.25	0.73	0.17	2.61	1.60	0.72
42	0.13	5.46	3.12	0.68	0.03	6.26	3.80	0.73	0.22	2.53	1.57	0.74
43	0.76	2.86	1.80	0.88	0.76	3.10	2.28	0.92	0.22	2.52	1.38	0.63
44	0.61	3.65	2.24	0.84	0.55	4.25	2.97	0.87	0.25	2.48	1.38	0.62
45	0.32	4.84	2.92	0.78	0.10	6.02	3.87	0.78	0.12	2.68	1.61	0.65
46	0.60	3.68	2.67	0.82	0.53	4.34	3.31	0.86	0.93	3.98	1.86	0.60
47	0.56	3.88	2.31	0.79	0.61	3.97	2.71	0.86	0.10	2.71	1.58	0.70
48	0.05	5.69	3.12	0.63	0.02	6.28	3.66	0.70	0.08	2.75	1.73	0.64
49	0.71	3.16	2.19	0.85	0.71	3.43	2.53	0.87	0.94	3.99	2.03	0.44
50	0.61	3.67	2.24	0.83	0.55	4.25	2.98	0.88	0.03	2.82	1.75	0.67

8. CONCLUSIONS

The bias correction is a good method to correct the rainfall data forecasted from the Numerical Weather Models, however the ensemble mean is on average better than any individual ensemble member. Some of the simulated flow ensembles capture the lower year, which give indicator that this type of rainfall forecasted ensemble has succeeded to capture the climatology in this lower season.

It is recommended to apply the drought indexes to get information about the actual and simulated drought level to have overview comparisons among the 51 ensembles reference to the observations.

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