A METHODOLOGY FOR EVALUATING CLIMATE MODELS AND REANALYSIS PRODUCTS USE OF STREAM FLOW TO DIAGNOSE ATMOSPHERIC AND SOIL WATER BALANCE

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Introduction

The hydrological cycle of climate models over major African basins is not well simulated. This requires that for any climate change study that aims to predict changes in future flows, climate models should be evaluated before their use. In this study, we present an evaluation method that systematically verifies the water balance of the land-atmosphere system in climate models and reanalysis products and tests their ability to represent the seasonal cycle of stream flow over large basins. Through this method, we aim:

(i) to determine how well reanalysis products and climate models represent the hydrological cycle over major African basins,

(ii) to determine whether horizontal resolution is a key aspect of climate models to properly represent the hydrological cycle over large basins.

This method can be used in the future to identify climate models that best simulate the hydrological cycle and are best candidates to study future changes in stream flow over such basins.

Evaluation Methodology

The atmospheric and soil water balance equations can be formulated after Peixoto and Oort (1992) as following:

$$\frac{\partial W}{\partial t} + \nabla .Q(u) = ET - P = -(\frac{\partial S}{\partial t} + R_{total})$$

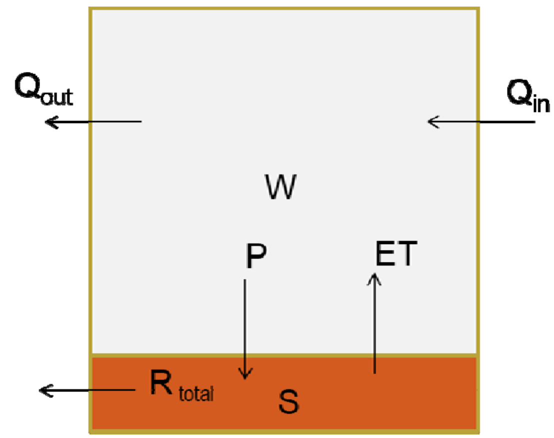


Figure 1: Schematic of Land-Atmosphere water cycle

Where:

$Q(u)_{in,\ out}$: Vertical integrated moisture fluxes

W: Atmospheric water vapor storage.

S: Soil water storage.

P: Precipitation

ET: Total evapotranspiration.

R_{total}: Total Runoff.

Over long timescales, such as monthly means, changes in atmospheric water storage can be neglected so that:

$$\{\ \overline{R_{total}}\ \} = -\{\ \nabla .\overline{Q}(u)\ \} - \{\ \frac{\partial \overline{S}}{\partial t}\ \} = \{\ \overline{P}\ \} - \{\ \overline{ET}\ \} - \{\ \frac{\partial \overline{S}}{\partial t}\ \}$$

Where the over bar and the bracket indicate the monthly mean and the spatial average of the variable respectively.

Data

In this analysis we use the following data:

(i) ERA-Interim reanalysis product (Dee et al. 2011, Berrisford et al. 2011)

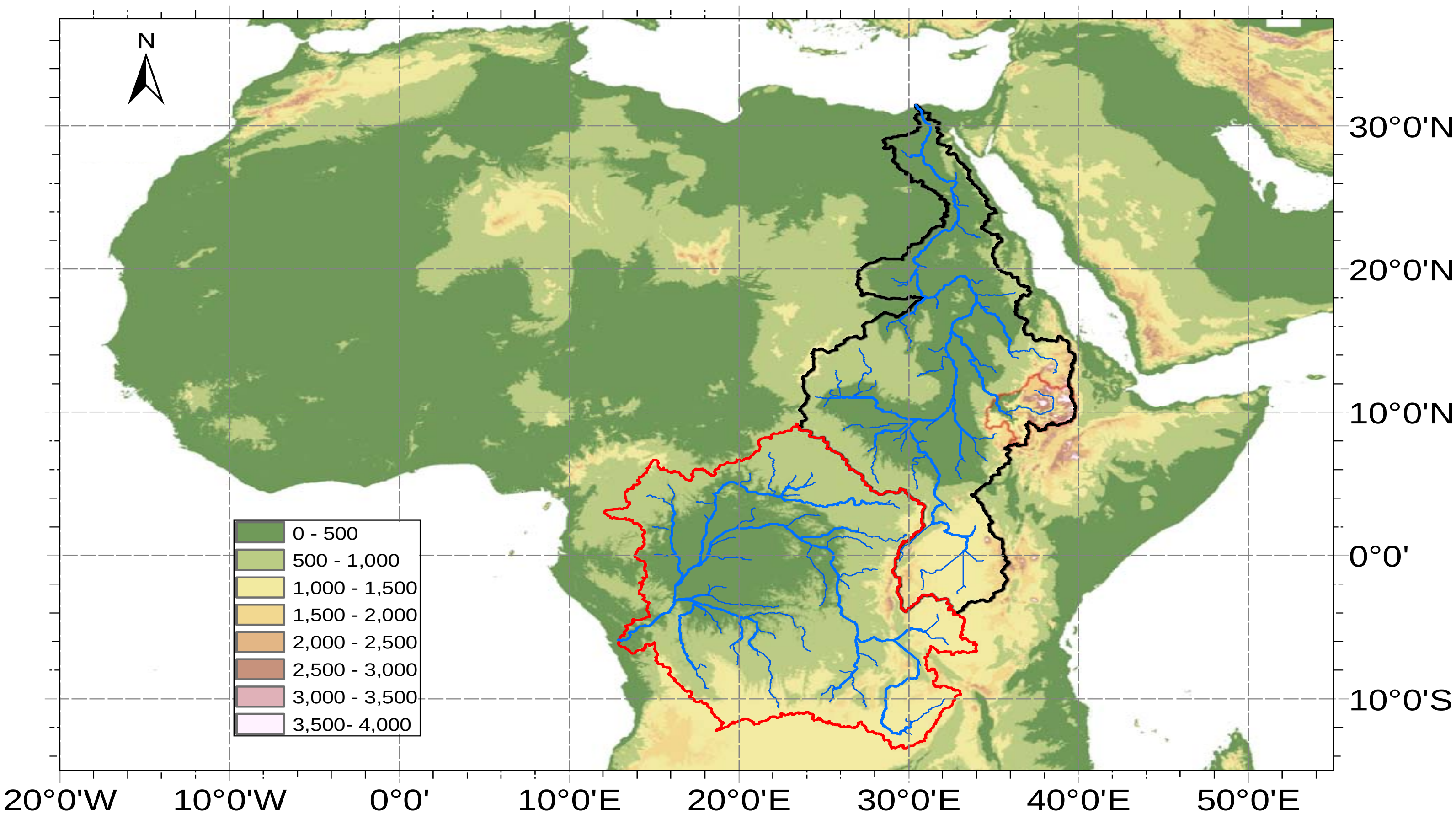
(ii) the global land atmosphere model based on the UK Met Office Hadley Center HadGEM1 (Johns et al. 2006) at four horizontal resolutions: N48 (270 km), N96 (135 km), N144 (90 km) and N216 (60 km) forced with 24-year AMIP2 data

(iii) Derived global evaporation dataset (Zhang et al. 2010)

(iv) CRU TS 3.1 precipitation dataset (Mitchell and Jones, 2005)

(v) RivDISv1.1 observed stream flows at the outlets of the Congo and Upper Blue Nile basins (Vörösmarty et al. 1998; 1996).

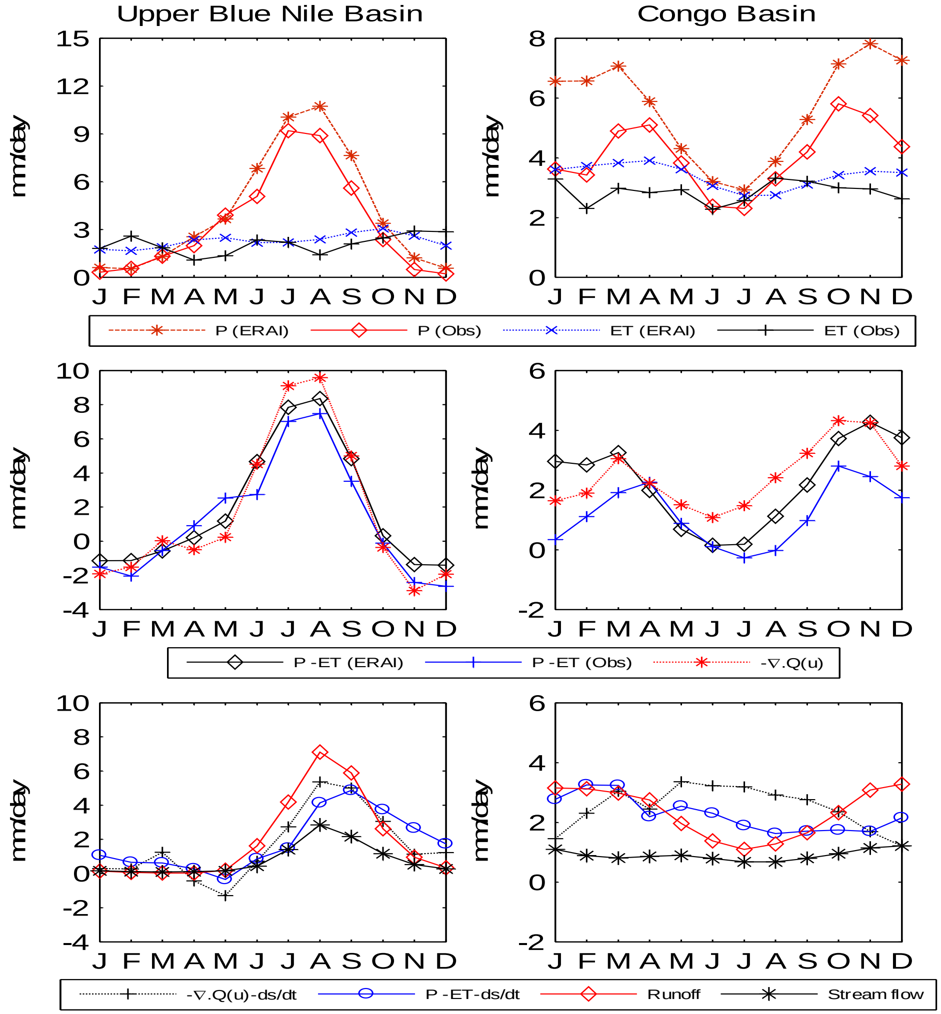
Study Area



Two different study areas with diverse climatic conditions and different complexity of topographical conditions are considered, the Congo and the Upper Blue Nile basins.

Analysis of ERA-Interim Data

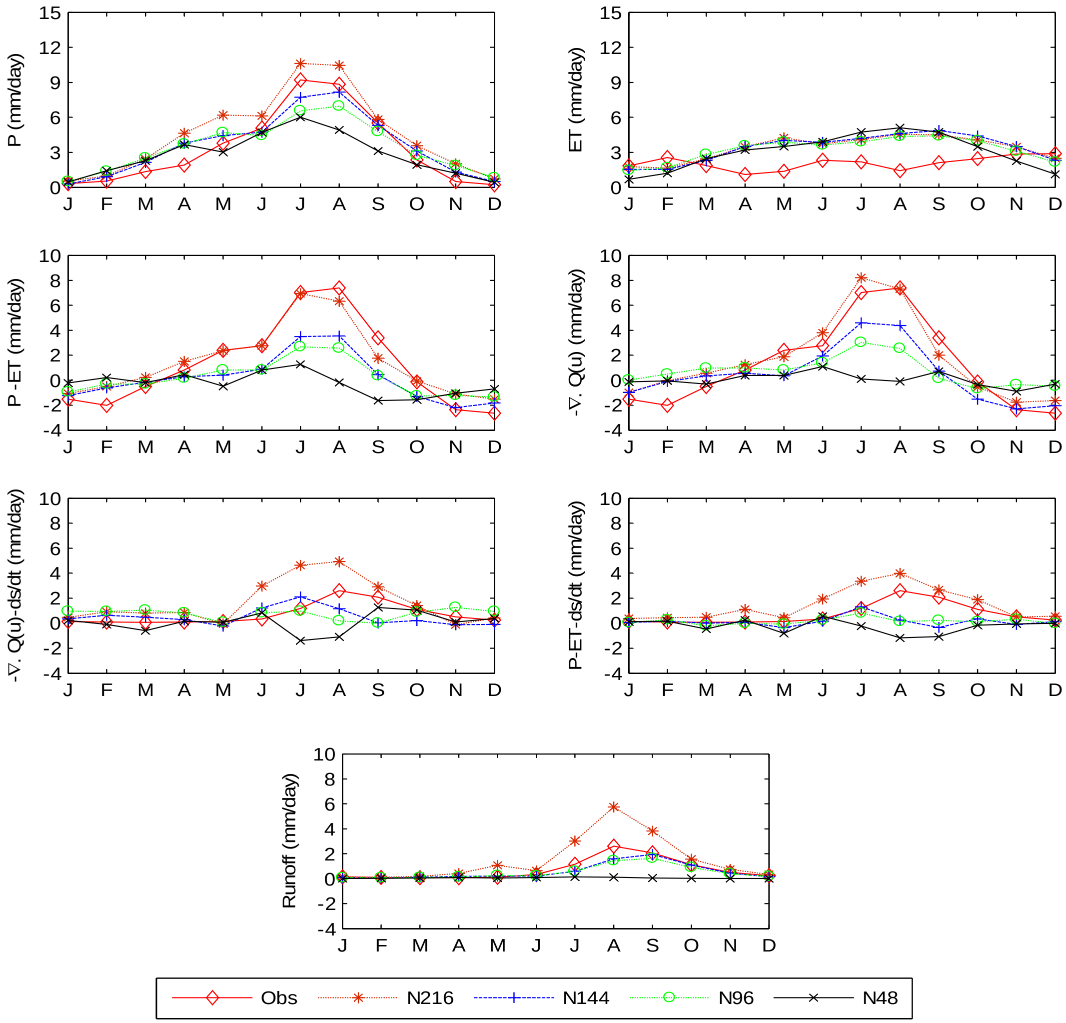
The average seasonal cycle for most of hydrological variables except the runoff of the Congo basin is well captured by the ERA-Interim data for both basins as shown in Figure below. The atmospheric and soil water balances are satisfied as the long-term averages of the convergence of moisture fluxes, net precipitation and simulated runoff are equal for the Congo basin and the Upper Blue Nile. However they are overestimated compared to the actual stream flow of the basins as shown in tables 1 and 2.



22-year mean seasonal cycle for different hydrological variables using the ERA-Interim data for the Upper Blue Nile and Congo basins.

Effect of Models Resolution

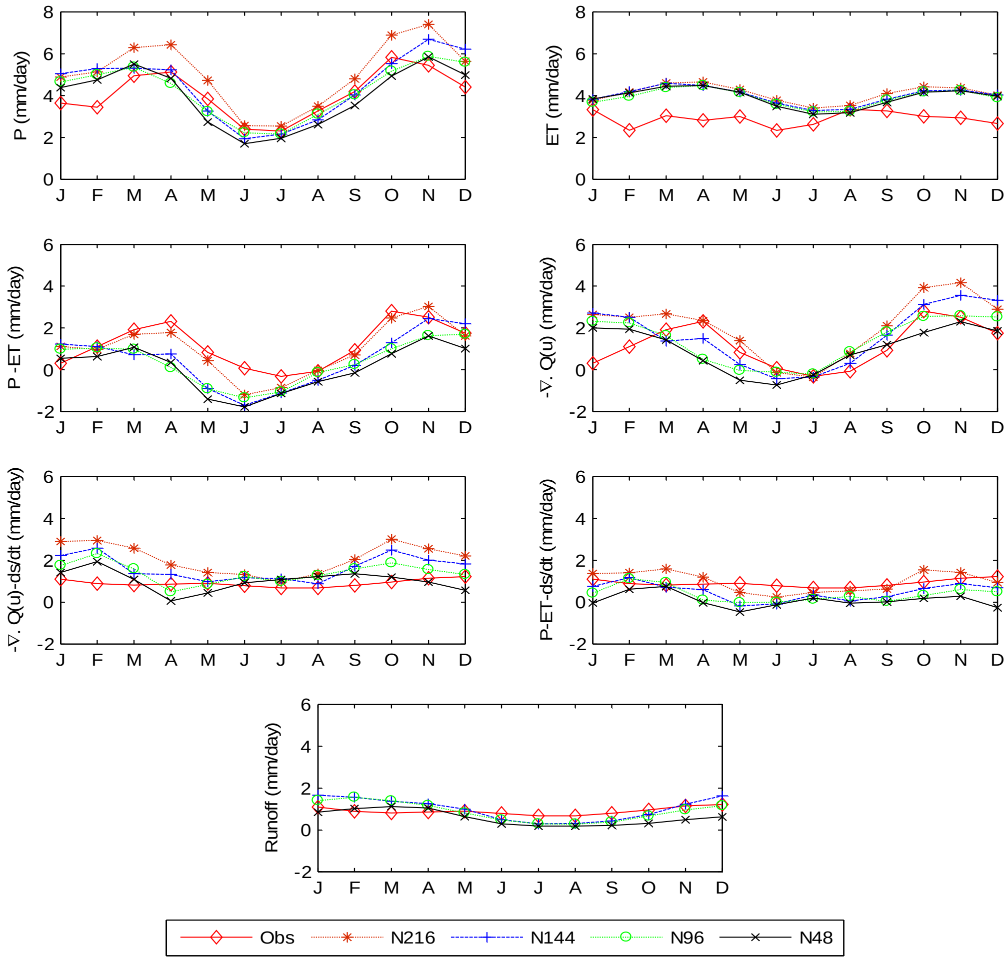
A horizontal smoothing method was applied on the moisture fluxes over the Upper Blue Nile before the calculation of the convergence. This step allows gradual changes in fluxes along the boundaries of the basin instead of sudden large changes induced by the steep topography of this region. This approach enhances the water balance over this region as seen in table 2.



Average seasonal cycle over 24 years for different hydrological variables using the HadGEM1 simulations data at different spatial resolutions for the Upper Blue Nile basin.

Effect of Models Resolution

Increasing the resolution systematically enhances the mean values of hydrological variables (Tables 1 and 2). However, the seasonal cycle is better simulated in high resolution models as seen in figures 4 and 5. The effect of the resolution on the Congo basin (4×10^6 km^2) is less significant compared to the Upper Blue Nile (2×10^6 km^2).



Average seasonal cycle for 24 years over different hydrological variables using the HadGEM1 simulations data at different spatial resolutions for the Congo basin.

Summary of Results

Table 1: The Congo basin results

Data	P	ET	R	P-ET	
N216	5.26	3.78	1.55	1.48	1.64
N144	4.6	3.58	1.13	1.02	1.27
N96	4.29	3.5	0.92	0.79	1.02
N48	3.94	3.49	0.57	0.45	0.44
ERAI	5.65	3.4	2.33	2.25	2.49
Obs.	4.06	2.83	0.9	1.23	--

Table 2: The UBN basin results

Data	P	ET	R	P-ET	
N216	4.5	3.04	1.48	1.46	2.67 1.66*
N144	3.53	3.05	0.47	0.48	1.55 0.49*
N96	3.36	2.89	0.49	0.48	1.85 0.73*
N48	2.75	2.76	0.06	0	2.8 0.04*
ERAI	4.09	2.27	1.93	1.82	1.61 0.7*
Obs.	3.3	2.08	0.72	0.92	--

* Convergence of moisture calculated using smoothed moisture fluxes

Conclusions

1. The proposed evaluation method investigates all the components of the hydrological cycle of climate models and reanalysis products. The use of observed stream flows for evaluation as a reference instead of other observed variables eliminates the uncertainties associated with them as it is considered the most accurate known hydrological variable.

2. Climate models and reanalysis products tend to overestimate all the variables of the hydrological cycle for the studied regions.

3. High-resolution models further increase the mean values of hydrological variables. However the representation of the seasonal cycle is significantly improved.

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