Integration of NFS with Regional Climate Model to Simulate the Nile Basin Hydro-climatology

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Abstract
Many development projects involving Nile waters are currently underway, or being studied. These projects will lead to changes in land-use patterns and water distribution and availability. It is thus essential to assess their impacts on regional hydrological processes, water resource management and sustainable development.

This paper seeks to establish a basis for evaluation of such impacts within the Blue Nile and Sobat River sub-basins, using a Regional Climate Model – RegCM3 - to simulate the interaction between the land surface and climatic processes. Specifically, we present the results obtained from application to these sub-basins of RegCM3 and the Nile Forecast System (NFS). (NFS) is a hydrologic distributed rainfall runoff model of the Nile Basin. The interaction between climate and hydrological processes on the land surface has been fully coupled. Rainfall patterns and evaporation rates have been generated using the RegCM3, and runoff pattern have been simulated using NFS.
The paper presents validation results over the Blue Nile and Sobat basins, for the period 1990 to 2006. The Climate Research Unit (UK) and NASA Goddard Space Filight Center GPCP (USA) observational datasets for precipitation and temperature were used to evaluate the model results. Stream flow predictions were assessed using historical gauge records. Precipitation, temperature and evaporation were selected as the variables to be used in the hydrological processes simulation.

Key words: Nile River, hydrological process, Regional climate modeling, GIS, NFS

1. INTRODUCTION

Although many researchers have attempted to address the impact of climate change on Nile flows, using GCM and other scenarios, few studies use models capable of simulating key characteristics of the Nile. Mohamed, A.S (2003) recommended that effort should be devoted to calibrating one or more regional climate models (RCMs) and linking it to a hydrologic model. This is expected to improve climate impacts assessments studies by increasing the accuracy of precipitation and runoff estimates obtained from climate models, and by enabling a better consideration of local climate features.

Mohamed et al. (2005) presented results of a regional climatic-hydrologic model (RACMO) of the Nile Basin. For the first time, the interaction between climate and hydrological processes, on the land surface, has been fully coupled. Given the extremely low runoff coefficients in the catchment, the results obtained were considered to be satisfactory. Nevertheless, the study claimed to validate the RACMO model for the entire Nile using observation data from two stations, only.

The objective of this paper is to demonstrate the applicability of the RegCM3 regional climate model over two important stream flow-generating regions of the Nile Basin – the Sobat and Blue Nile Sub-basins. It is expected that, this research will be useful for perceiving a better understanding to the climate change impacts on the hydrology of the Nile Basin, due to its ability to link changes in precipitation, temperature, and land use in this region.

RegCM3 was developed at The Abdus Salam International Center for Theoretical Physics (ICTP) (Pal et al., 2003). The model is available at (W[5]). RegCM3 is an updated version of RegCM2 (Giorgi et al., 1993a, b). The model is a primitive equation, hydrostatic, compressible, limited-area model with sigma pressure vertical coordinate. The soil-vegetation atmosphere interaction processes are parameterized

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w[5] http://www.ictp.it/~pubregcm

through the BATS scheme (Biosphere-Atmosphere Transfer Scheme; Dickinson et al., 1993). The radiative transfer scheme of NCAR CCM3 (Community Climate Model 3; Kiehl et al., 1996) is used in RegCM3 (Giorgi and Mearns, 1999), which includes the forcing effects of different greenhouse gases, cloud water, cloud ice and atmospheric conditions.

By comparing the output for precipitation with different observation data sets, it is found that the model succeeds in simulating the seasonality of flow. Also, while the model is successful in accurately simulating historical streamflow at stations located along the Blue Nile (90% correlation with the observed data), it does tend to overestimate dry season rainfall over the Sobat Basin (0.68% correlation).

2. EXPERIMENTAL

RegCM3 includes updates to the previous RegCM2 model, with notable improvements in model physics that generally lead to better performance in regional climate simulations. Atmospheric radiative transfer in the model is computed using the radiation package from the NCAR CCM3. Surface processes are represented via the Biosphere-Atmosphere Transfer Scheme (BATS). Planetary boundary layer computations employ a non-local formulation and the Grell mass flux scheme is used to describe precipitation. The domain encompasses the Sobat and Blue Nile sub-basins at a horizontal resolution of 60 km. The model is run at its standard configuration of 18 vertical sigma layers and model top layer at 100 hPa.

Observed sea surface temperature derived from the OISST data of NOAA is used in the simulations. The lateral initial and time-varying boundary conditions are taken from the NCEP/NCAR 40-Year Reanalysis Project historical data sets for 1990 to 2006 (16 years). An exponential relaxation technique is used for the boundary conditions with 6-h updates. The experiment is run using the serial version of the model.

2.1 Model Configuration

Table (1) and Figure (1) illustrate the domain and configuration selected for the experiments. The model uses the Global Land Cover Characterization (GLCC) data sets for vegetation and land-use. The GLCC data set is derived from 1 km Advanced Very High Resolution Radiometer (AVHRR) data spanning April 1992 to March 1993, and is based on the vegetation/land cover types defined by BATS (Biosphere Atmosphere Transfer Scheme). The 20 vegetation/land cover types and associated parameters are presented in Figure (2) each grid cell of the model is assigned one of twenty land use categories. More information regarding GLCC data sets can be found at (w[1]). The elevation data used is from the United States Geological Survey (USGS). Land-use and elevation data files are used at 2 minute resolution. More information available at (w [2]).

The Optimum Interpolation Sea Surface Temperature (OISST) weekly mean data, available at (w[3]), is used to specify the model sea surface temperature (SST).The National Center for Environmental Prediction (NCEP) Reanalysis, or NNRP1, data sets (2.5 degree grid) provided initial and boundary conditions, available at (w[4]).

Table 1 Configuration used in defining the RegCM3 domain in the study

Item	Value
No. of Grid Points in y direction	40
No. of Grid Points in x direction	44
No. of Vertical Levels	18
Grid Point Separation in km	60
Central Latitude (Geographical coordinates)	35 E
Central Longitude (Geographical coordinates)	11 N

w[1] http://edcdaac.usgs.gov/glcc/glcc.htm
w[2] http://www.ictp.trieste.it/ pubregcm/RegCM3/globedat.htm
w[3] http://www.cdc.noaa.gov
w[4] ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis/

Map Projection	Rotated Mercator
Boundary Conditions	NRRP1
SST	GISST

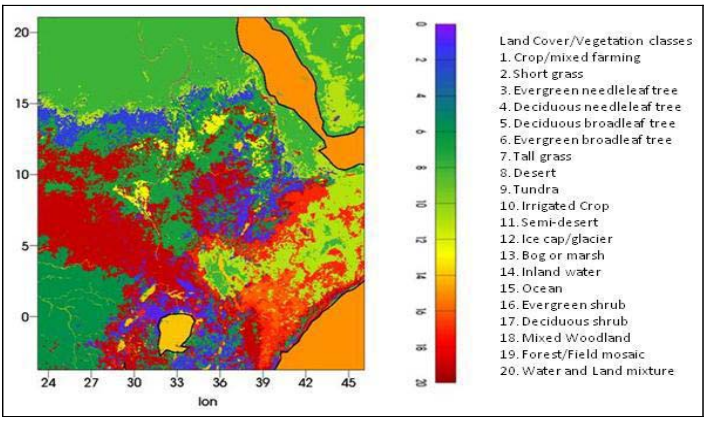

Figure 1 Domain overlaid with land use (Source: USGS)

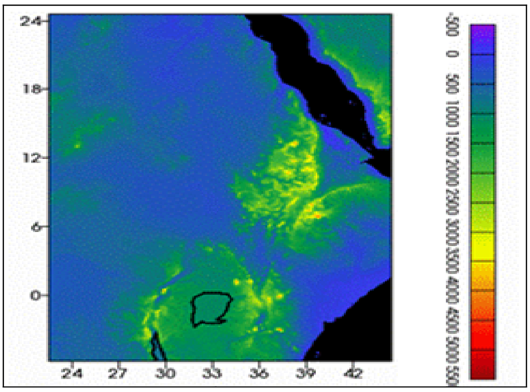

Figure 2 Digital Elevation Map used in the topographic simulation, scale in meters above sea level (Source: USGS)

2.2 Model Calibration

The model output include several parameters; radiation, atmosphere and surface. In this paper we only discuss and present the surface data output as they are of primary interest for the considered processes: precipitation, evaporation, ground temperature, and subsequent hydrological simulation. The different output parameters were compared with global observation data sets. The used observation data sets are: The Climate Research Unit (CRU) High Resolution Global Data, for climate parameter over land at 0.5 degree resolution, which is available at (w[5]).

The Global (GPCP) data sets provided by Precipitation Analysis Laboratory for Atmospheres, NASA Goddard Space Flight Center.

3. ANALYSIS

Using Grads capabilities, the selected climatologically parameters are appended for the entire simulation period. The average daily data, for different seasons, are produced for the period January 1990 – December 2006. The comparison between simulated and observed parameters is illustrated in the next section.

w[5] http://www.cru.uea.ac.uk/cru/data/

3.1 Precipitation

Figure (3) presents the seasonal values of the average daily precipitation for the simulated and observational (CRU and GPCC) data sets, for December-February (DJF), March–May (MAM), June–August (JJA), and September–November (SON). The model showed a good spatial and seasonal performance over the Blue Nile, however, it overestimated the rainfall over the Sobat sub-basin during the dry season. In addition, the rain fall pattern showed a spot of rainfall extending towards the southeast which is not present in the observation data. In general, the model displayed a good performance in simulating precipitation over the Blue Nile and Sobat sub-basin.

3.2 Temperature

Figure (4) presents the seasonal values of the average daily simulated temperature, as well as observed temperatures from the CRU data. The observed and simulated spatial variations are in good agreement; however, simulated temperature values were overestimated by 2-6 degrees during all seasons.

3.3 Evaporation Rates

To determine the river flow and the evaporation at different stations; the Nile Forecasting System is used to perform the hydrological simulation. The NFS is a real-time distributed hydro-meteorological forecast system designed for Forecasting Nile flows at designated key points within the Nile. Of major interest is the inflow of the Nile into the Aswan High Dam, Egypt. The system is hosted at the Nile Forecasting Center (NFC) of the Ministry of Water Resources and Irrigation (MWRI), Giza, Egypt, which kindly provided a copy of the NFS software version 5.1 (NFC, 2007) for this research.
The core of the NFS is a conceptual distributed hydrological model of the whole Nile system including soil moisture accounting for hill slope and river routing, lakes, wet- lands, and man-made reservoirs within the basin. The main inputs to this model are the rainfall and potential evapo-transpiration. The system relies on satellite-based (ME-TEOSAT) methods to estimate rainfall merged with gridded (to the METEOSAT grid) gauge estimates from freely available sparse gauge data. All rainfall data is stored in the Nile Basin Hydro-meteorological Information System (NBHIS) which also holds flow records at all key river gauges.

The total monthly values of evapo-transpiration simulated with RegCM3 are shown in Figure (5). These results can be compared with the total monthly potential evaporation for the Sobat sub-basin produced using actual climate data that was fed to the NFS hydrological model, as an input, as shown on Figure (6). The actual evaporation ranged between 110 in August and 170 mm/month in March. The RegCM3 simulation for the Sobat basin captured the maximum values of evaporation during March and April, which ranged between 160 and 200 mm/month. By contrast, the model did not reproduce the minimum values for evaporation accurately, which actually occur in August but are simulated during December.

3.4 Flow

To validate the use of RegCM3 predictions for exploring eventual changes in streamflow, the simulated rainfall estimates are routed using the NFS to generate basin runoff and daily stream flows at different station along the Sobat Sub-basin and the Blue Nile. Figure (7-a) presents the NFS-simulated flow at the Akobo station as well as the actual observed flow. The model appears to correctly capture the flow seasonality and to simulate the peak and low flow profile, but there are some abnormal storms which do not exist in the actual data, especially during 1999 and 2001 flood seasons. There are a number of possible explanations for this extreme output, which may be due to errors in the input data used for running the RegCM3, in the NFS rainfall-runoff model itself, or in the routing of flows in the Sobat sub-basin, where overbank spills and complicated hydraulics are features of the seasonal swamps. The Root Mean Sauer Error (RSE) is estimated as 0.30. The errors bars between the actual and simulated data is presented in figure (8-a), the correlation coefficient between observed and simulated flows is 0.68.
Figure (7-b) presents the NFS-simulated flow at the Deim station as well as the actual observed flow. The model appears to capture correctly the flow seasonality and to simulate the peak and low flow profiles, as shown on the figure. The model is simulating well the Blue Nile at Diem station. The Root Mean Sauer Error (RSE) is estimated as 0.803. The error bars between the actual and simulated data are presented on figure (8-b); the correlation coefficient between observed and simulated flows is 0.90.

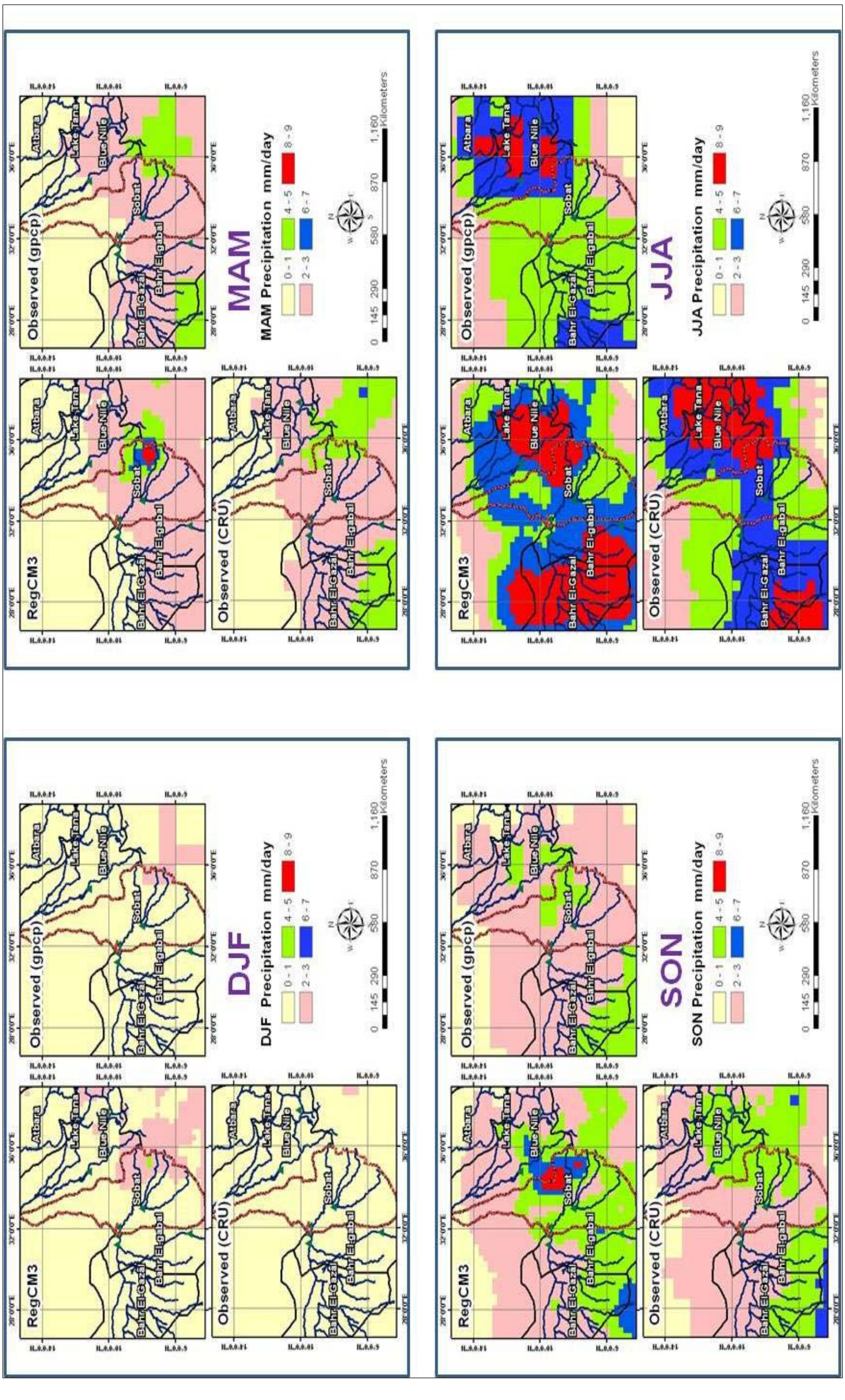

Figure 3 Comparison between simulated precipitation by RegCM3 CRU ,and CPCP data sets, for the different climatological seasons

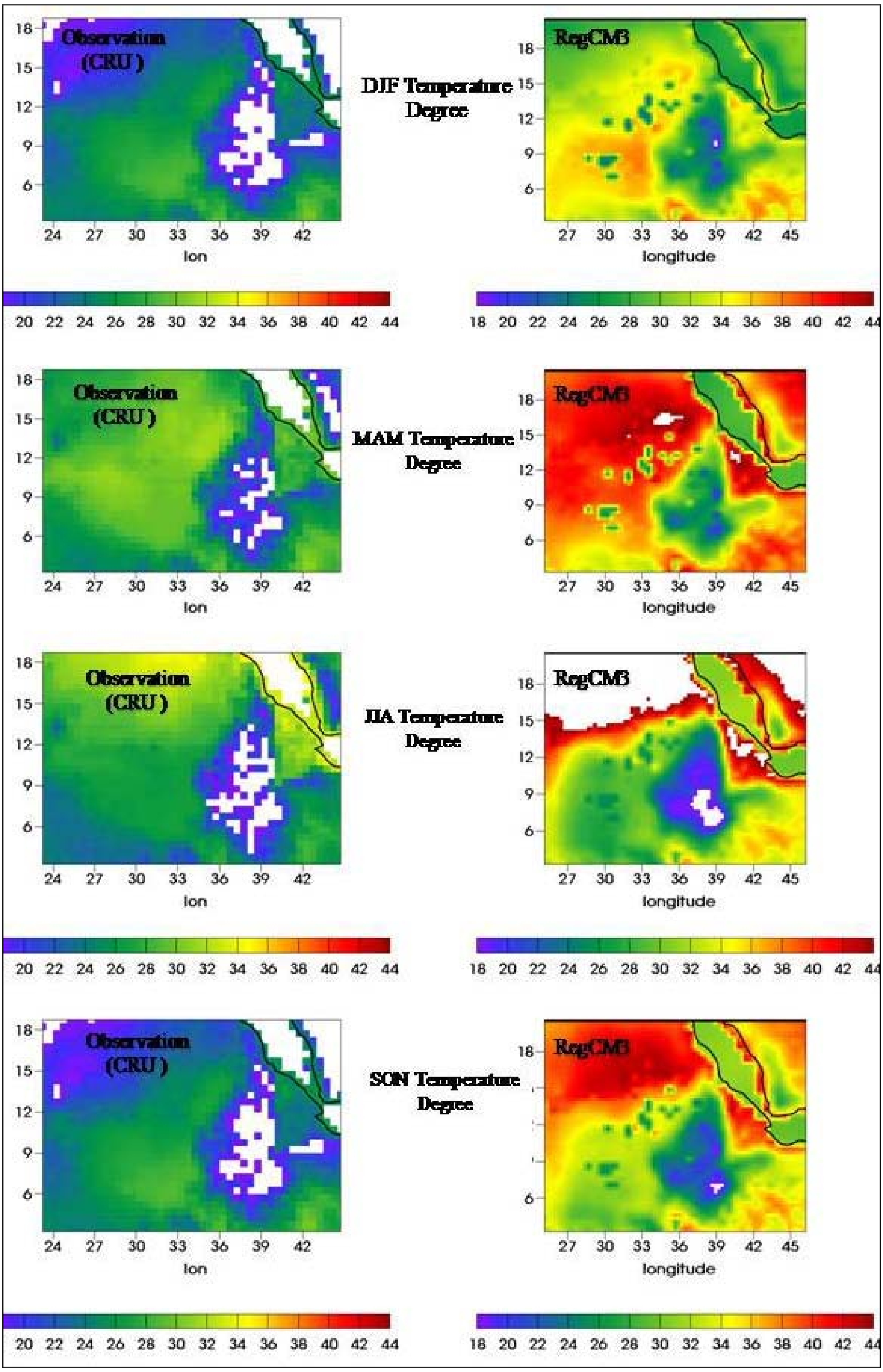

Figure 4 Comparison between the simulated temperatures y RegCM3 and CRU for the different climatological seasons

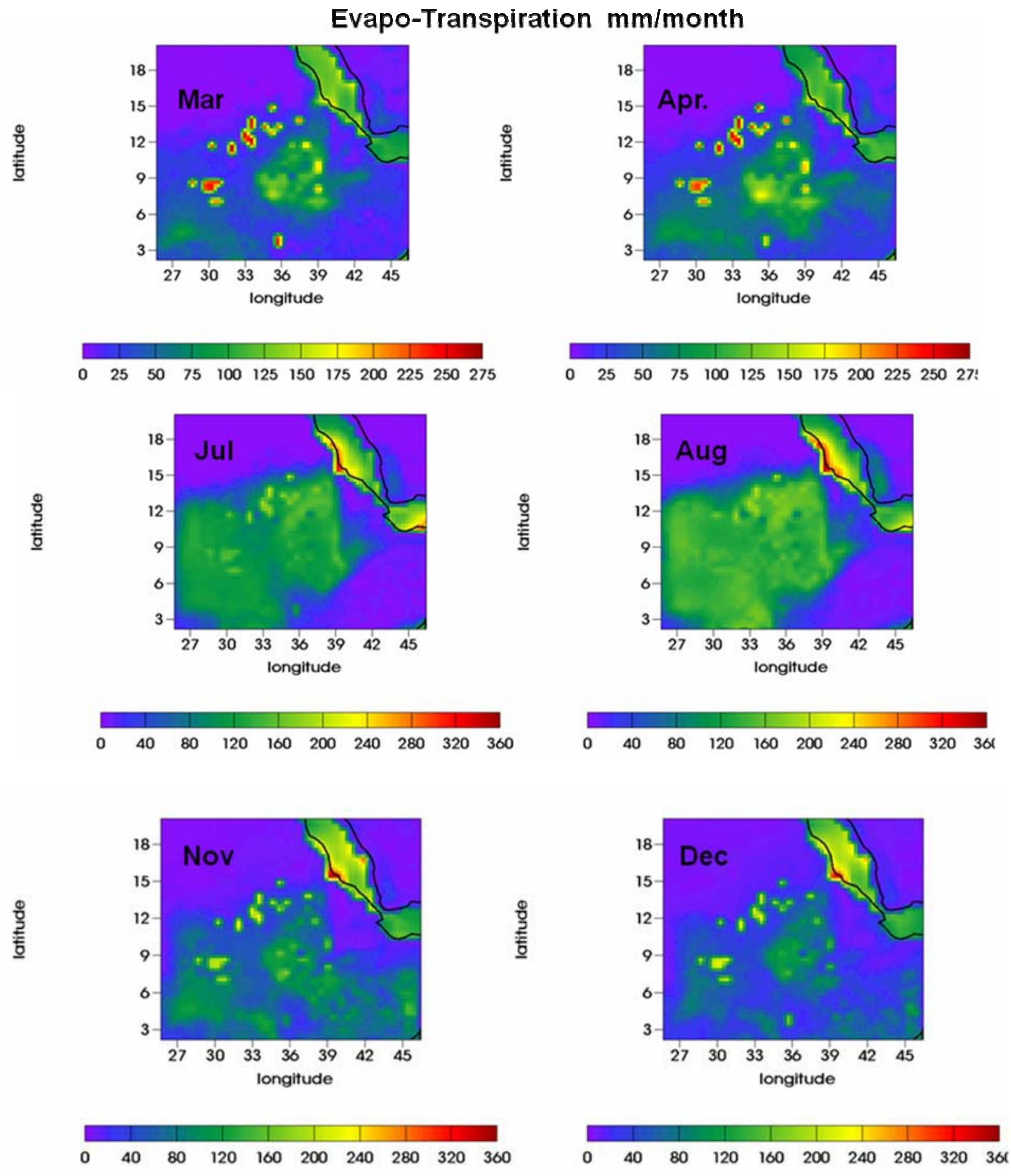

Figure 5 Simulated total monthly evapo- transpiration by RegCM3

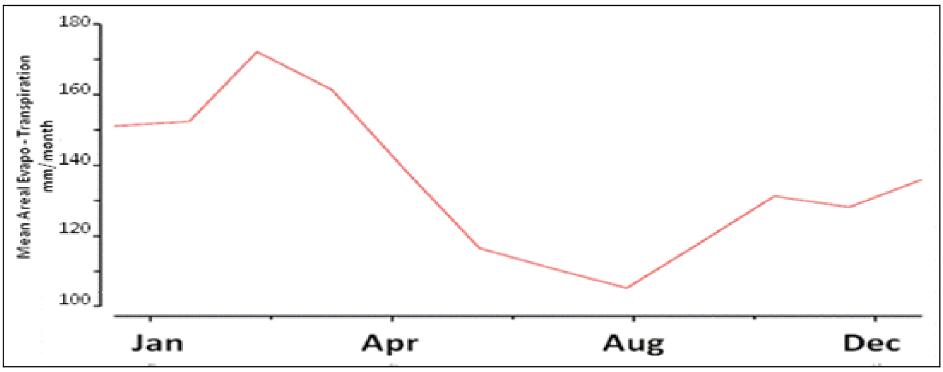

Figure 6 The mean annual evaporation as simulated by NFS over Sobat Sub-Basin.

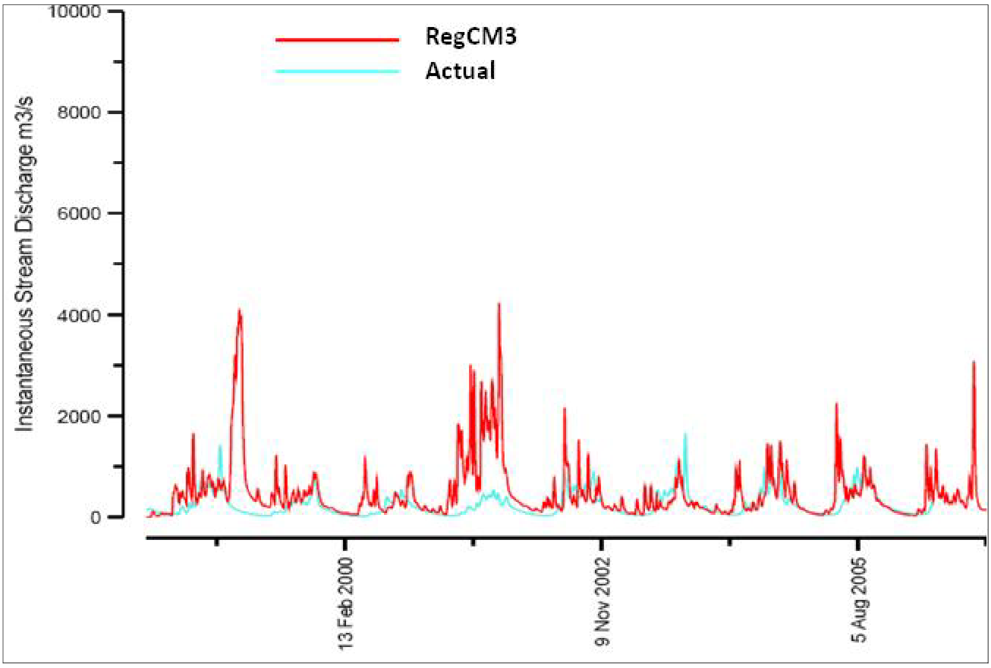

Figure7- a Simulated flow using RegCM3 versus actual flow for Akobo station (Sobat basin)

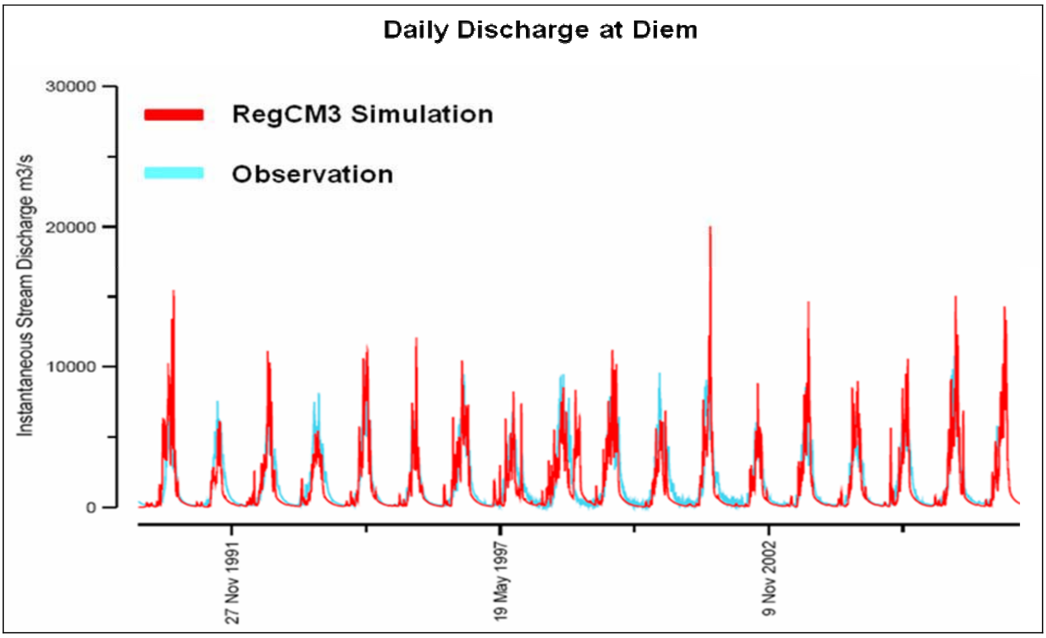

Figure7- b Simulated flow using RegCM3 versus actual flow for Diem station (at Blue Nile)

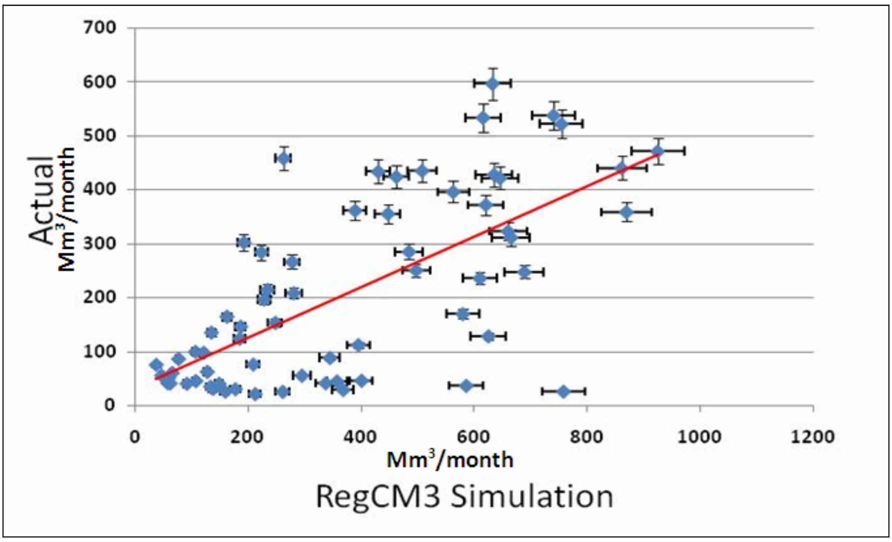

Figure8 - a Simulation versus actual flow
(error bars indicates the error percentage at Akobo)

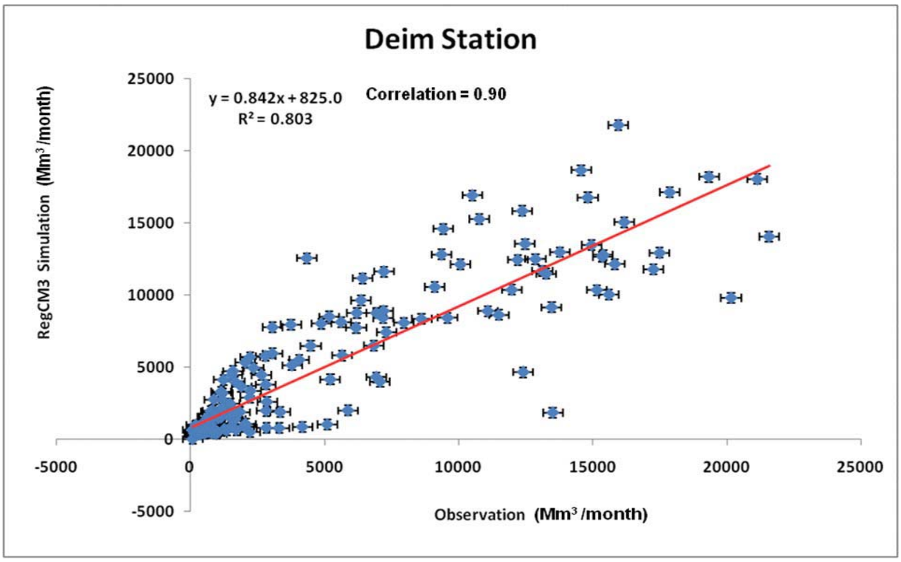

Figure8 - b Simulation versus actual flow
(Error bars indicates the error percentage at Diem)

4. CONCLUSION AND RECOMMENDATIONS

In general the RegCM3 can efficiently simulate the climatology of the Blue Nile, reproduce the spatial and temporal pattern of temperature, the seasonality and spatial pattern of precipitation, and provide inputs to the NFS model which accurately predicts stream-flow observed at Diem. For the Sobat basin, it was apparent that the model requires some adjustment and additional investigations. The model behavior can be summarized as follows:

- The spatial Pattern of precipitation is captured well by the model both in summer and winter. However, the model over-estimates precipitation at some regions during the dry season, especially in the Sobat basin.
- With regards to temperature, the model displayed a bias towards warmer conditions (2-6 degrees Celsius) over the entire studied domain, in all seasons.

- The multi-year flow simulation using RegCM3 output data that are fed to the NFS, showed a good performance in capturing the seasonality of flows in both the Sobat and Blue Nile basins (RSE_{Sobat} = 0.30, RSE_{BN} = 0.803). However, there are incorrect predicted extreme flows in the Sobat basin which do not exist in the actual data.

Following this preliminary modeling exercise, it is recommended to:
1. continue working with RegCM3 for a longer period, in order to detect the model bias and develop a mean to correct the model bias
2. apply and verify RegCM3 model over the entire Nile basin.
3. nest RegCM3 with GCM data for future prediction, and fully calibrate the model for the entire Nile Basin

5. ACKNOWLEDGMENTS

This work was conducted in collaboration with the departments of Ain Shams University, Faculty of Engineering and Planning Sector, Ministry of Irrigation and Water Resources, as part of PhD research to quantify the impact of land use change on the Nile climatology. The research is funded by START Network through START/PACOM Doctoral Research Fellowship
The authors acknowledge Dr. Mohamed Ezaat El-Shamey, Mr.Taha El-Kassem and Baker Badway from the Nile Forecasting Center of MWRI, Dr. Abd Alla Abd El-Rahman; Egyptian Metrological Authority for their effort and information provided to complete this research.
The reviewers are acknowledged for their questions and comments, which lead to improve the quality and readability of the paper.

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7. LIST OF ABBREVIATIONS

AVHRR	Advanced Very High Resolution Radiometer
BATS	Biosphere-Atmosphere Transfer Scheme
CRU	The Climate Research Unit
GLCC	Global Land Cover Characterization
GPCP	Global precipitation control points provided by Goddard Space Filight Center
hPa	unit for measuring height of atmosphere pressure
ICTP	Abdus Salam International Center for Theoretical Physics
NBHIS	Nile Basin Hydro-meteorological Information System
NCAR CCM3	National Center for Atmospheric Research Community Climate Model
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NFC	Nile forecasting center
NFS	Nile Forecast System
NOAA	National Oceanic & Atmospheric Administration
OISST	Optimally Interpolated Sea Surface Temperature
RCM	Regional Climate Model
RSE	Root Mean Sauer Error
SST	Sea surface temperature
USGS	United States Geological Survey

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