EXPLAINING AND FORECASTING INTERANNUAL VARIABILITY IN THE FLOW OF NILE RIVER

Mohamed Siam[1], and Elfatih A. B. Eltahir[1]

1. Civil & Environmental Engineering Department, Massachusetts Institute of Technology, Cambridge, MA, USA

Introduction

The natural interannual variability in the flow of Nile River had a significant impact on the ancient civilizations and cultures that flourished on the banks of the river. Here, we analyze extensive datasets collected during the 20th century and define modes of natural variability in the flow of Nile River, identifying a new significant potential for improving predictability of floods and droughts. Through this study, we aim to:

(i) Identify, for the first time, a region in the southern Indian Ocean with strong teleconnection to the Nile flow.

(ii) Develop a new hybrid forecasting algorithm that predicts the Nile flow based on indices of the SSTs in the Eastern Pacific and Southern Indian Oceans

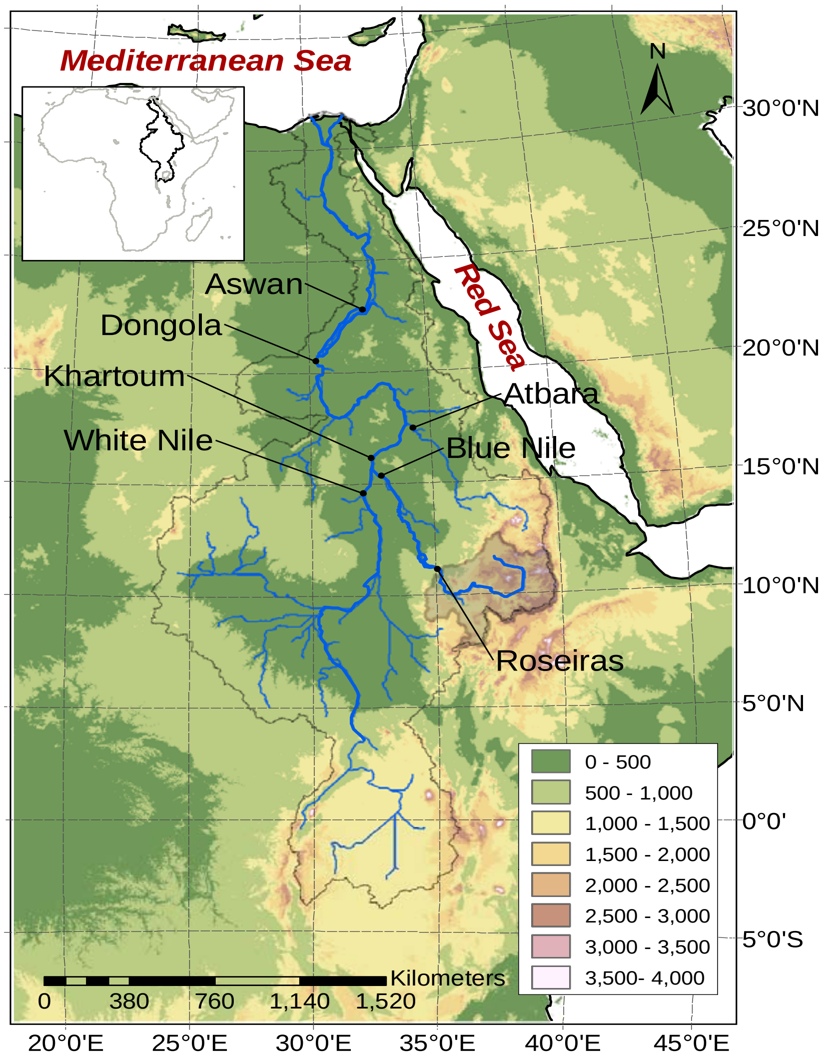
Data

In this analysis we use the following data:

i. Observed stream flows at Dongola from 1900 to 2000 extracted from the Global River Discharge Databse (RivDIS v1.1) (Vörösmarty et al., 1998)

ii. SSTs from (HadISSTV1.1) dataset on a 1-degreee latitude-longitude grid from 1970 to 2000 (Rayner et al. 2003).

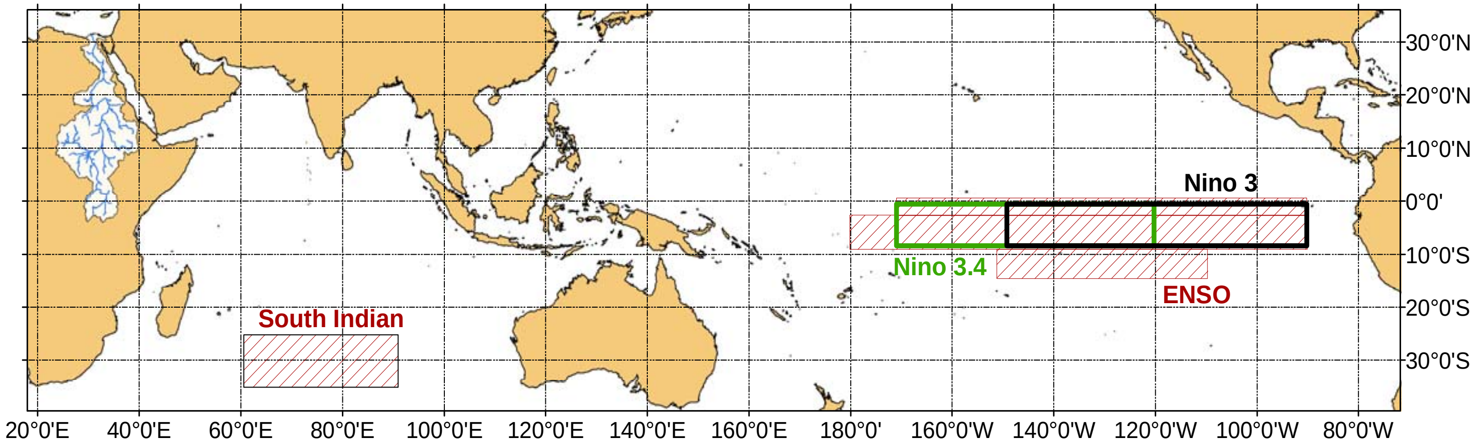
Study Area



Topographic map of the Nile basin showing the outlet of the Upper Blue Nile basin (shaded in gray) at Roseiras. The White and Blue Nile join together at Khartoum then form the main branch of the Nile that flows directly to Dongola in the North.

Relation between Nile flow, ENSO, and Indian Ocean SSTs

Based on extensive correlation analysis of the Nile river flow at Dongola and the observed SST in the Indian Ocean, we identify a region over the Southern Indian Ocean (60ºE-90ºE and 25ºS-35ºS) (Figure below) as the one with the highest correlation between SST and the Nile flow. This correlation is especially high for river flow (accumulated for July, August, September and October) and SST during the month of August. We introduce a new index defined as the average SST over this region of the Southern Indian Ocean (SIO index hereinafter) during August.



World map showing areas that cover the ENSO and North and South Indian Ocean SSTs indices. The Nino 3 and 3.4 are outlined in blue and green respectively. The whole Nile basin is outlined in black.

Relation between Nile flow, ENSO, and Indian Ocean SSTs

The North and middle of the Indian Ocean have also exhibited a high correlation between their SST and the Nile flow. However, the additional variability explained by the SST over the North and Middle Indian Ocean, when combined with the ENSO index, is negligible (not shown here). On the other hand, the addition of the SIO index to ENSO index enhances the explained variability in the flow of Nile river. Here, we define 0.5°C as the threshold between non-neutral and neutral years based on ENSO index. This value is about two-thirds of one standard deviation of the anomalies of ENSO index. Similarly, 0.3°C value is used as a threshold between non-neutral and neutral years in the SIO index.

Table 1: Summary of the coefficient of determination (R^2) between the average Nile flow from July to October and different combination of indices of ENSO and SIO.

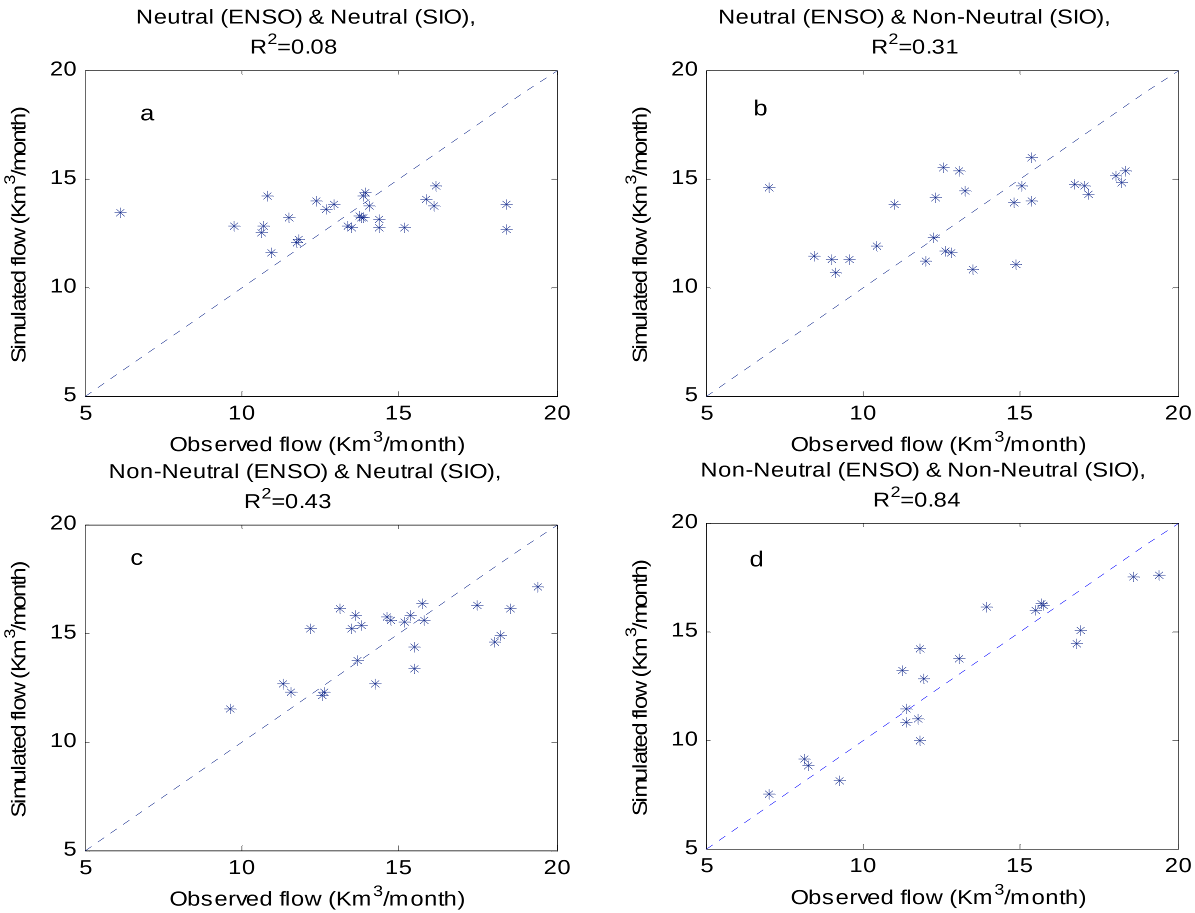
Mode		ENSO	SIO	ENSO, SIO	Number of events
ENSO index	SIO index				
Neutral	Neutral	0.04	0.03	0.08	29
Neutral	Non-Neutral	0.05	0.28^+	0.31^+	26
Non-Neutral	Neutral	0.4^+	0.02	0.43^+	26
Non-Neutral	Non-Neutral	0.64^+	0.6^+	0.84^+	19

$^+$ Values that are significant at 1% significance level

Modes of Natural Variability in the flow of the Nile

Four different modes are identified for describing the natural variability in the flow of Nile river and summarized in (Table 1). The ENSO and SIO indices do not explain a significant fraction of the interannual variability in the flow of river when they are both neutral. The variability of the Nile flow in such years can be regarded as a reflection of the chaotic interactions between the biosphere and atmosphere and within each of the two domains. The other two intermediate modes include non-neutral conditions in the Eastern Pacific and neutral conditions in the Southern Indian Oceans or vice versa. For these two modes, a significant fraction (i.e. 31% and 43%) of the variance describing inter-annual variability in the flow is explained. Hence, these modes point to a significant potential for predictability of the flow. Finally, indices of ENSO and SIO can explain 84% of the interannual variability in the Nile flow when non-neutral conditions are observed for both the Eastern Pacific and Southern Indian Oceans.

Modes of Natural Variability in the flow of the Nile

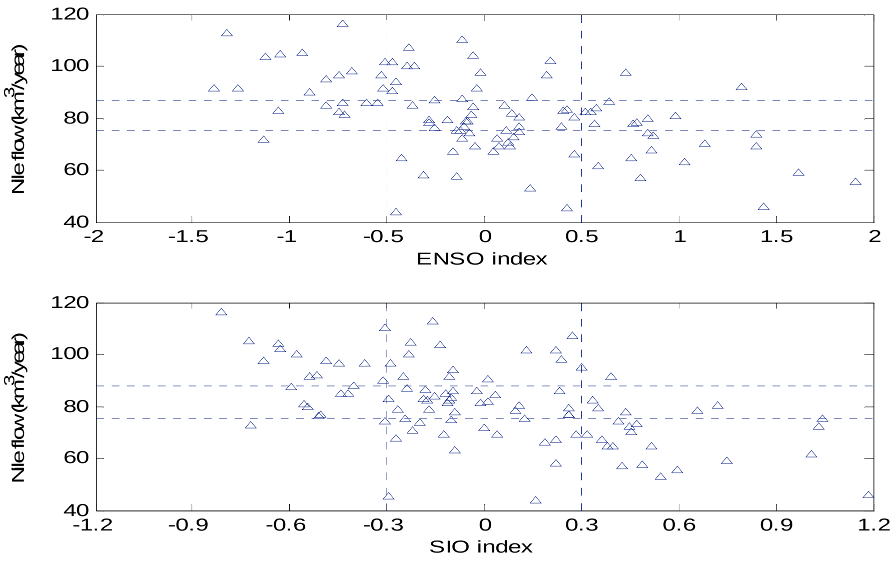


A comparison between the observed and simulated Nile flow showing the different modes of variability for the period from 1900 to 2000: a) Neutral ENSO and SIO, b) Neutral ENSO and Non-Neutral SSTs in SIO, c) Non-Neutral ENSO and Neutral SSTs in SIO and finally, d) Non-Neutral ENSO and Non-Neutral SSTs in SIO.

Hybrid Methodology for Prediction of Nile flow

A simple methodology based on discriminant approach that specifies the categoric probabilities of the predictand (Nile flow) according to the categories that the predictors (i.e. ENSO and SIO indices) fall into is proposed to predict the Nile flow (Figure below). The proposed method can be described in two main steps:

- Forecast of SST anomalies in the Indian and Eastern Pacific Ocean using dynamical models .
- Application of a forecast algorithm between the Nile flow (predictand) and forecasted SSTs (predictors).



Relations between the annual Nile flow and different indices for the period (1900-2000): a) ENSO, and b) SIO. The horizontal lines represent the boundaries for the "high", "normal" and "low" categories of the annual flow. The vertical lines represent the boundaries for the "Warm", "normal", and "cold" conditions for ENSO and SIO indices.

Hybrid Methodology for Prediction of Nile flow

The forecast algorithm is based on the Bayesian Theorem, which calculates the probability of occurrence of a specified flow category (Q_i) and given two independent conditions (A and B) as:

$$P(Q_i / A, B) = \frac{P(B/Q_i).P(Q_i/A)}{\sum_{i=1}^{3} P(B/Q_i).P(Q_i/A)} \qquad (1)$$

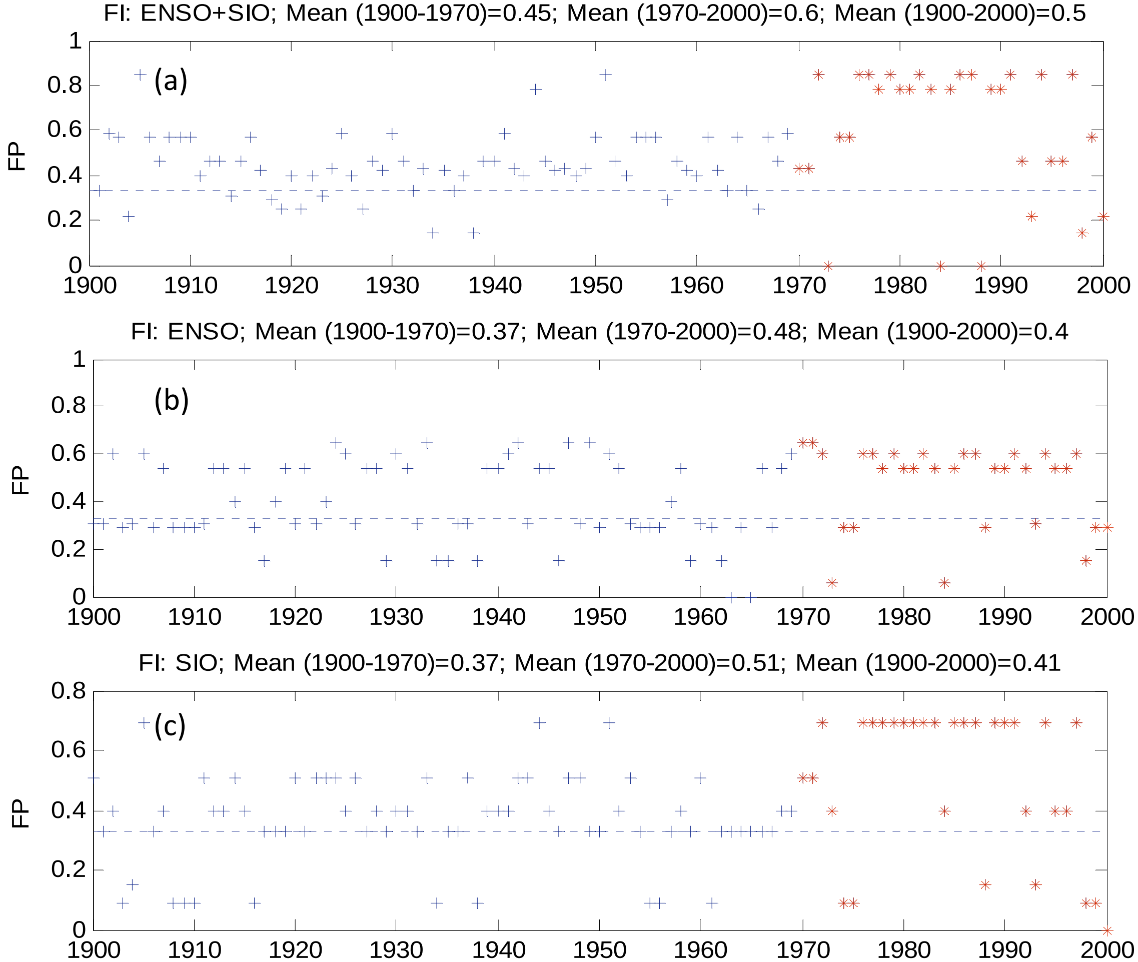
In order to evaluate the predictions of the Nile flow, we use a forecasting index (FI) defined as:

$$FP(j) = \sum_{i=1}^{3} P_r(i, j).P_p(i, j) \qquad (2)$$

$$FI = \frac{1}{n} \sum_{i=1}^{n} FP(j) \qquad (3)$$

Where FP(j) is the forecast probability in a certain year (j) and the FI is the average of the FP over a certain period, n. The prior probability Pr(i, j) is calculated using Eq.(1) for a certain year (j) and category (i=1, 2, 3) and the posterior probability Pp(i, j) is defined as [1,0,0] in low flow year, [0,1,0] in normal year, and [0,0,1] in a high flow year.

Hybrid Methodology for Prediction of Nile flow



Time series of the forecast probability using different indices: a) ENSO and SIO together, b) ENSO, and c) SIO. The period (1900-1970) is used for calculating the probabilities (shown in crosses) using Eq. (2) and (1970-2000) for validation (shown in stars).

Conclusions

1. We document that the SSTs in the Eastern Pacific and Indian Oceans play a significant role in shaping the natural interannual variability in the flow of Nile River.

2. Four different modes of natural variability in the Nile flow are identified and it is shown that during non-neutral conditions in both the Pacific and Indian Oceans, the Nile flow is highly predictable using global SST information. During those years with anomalous SST conditions in both Oceans, we estimate that indices of the SSTs in the Pacific and Indian Oceans can collectively explain up to 84% of the interannual variability in the flow of Nile.

3. Develop a new hybrid forecasting algorithm, using classical Bayesian theorem, to predict the Nile flow based on indices of the SST in the Eastern Pacific and Southern Indian Oceans. Applications of the proposed hybrid forecast method should improve predictions of the interannual variability in the Nile flow, adding a new a tool for better management of the water resources of the Nile basin.