A MECHANSIM RELATING THE INDIAN OCEAN SSTs, ENSO AND NILE FLOW

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Introduction

A significant fraction of the interannual variability in the Nile River flow is associated with ElNiño Southern Oscillation (ENSO). Fluctuations of the Indian Ocean (IO) Sea Surface temperature (SST) are also associated with the Nile flow. Here, we investigate the intermediate role of IO SSTs in the teleconnection between Nile flow and ENSO. Through this study, we aim to:

(i) Show the connections between the Nile flow, ENSO and IO SSTs using the partial coherency analysis.

(ii) Present a mechanism that connects the Nile flow to ENSO and IO SSTs by modulating the Indian Summer monsoon circulation.

Data

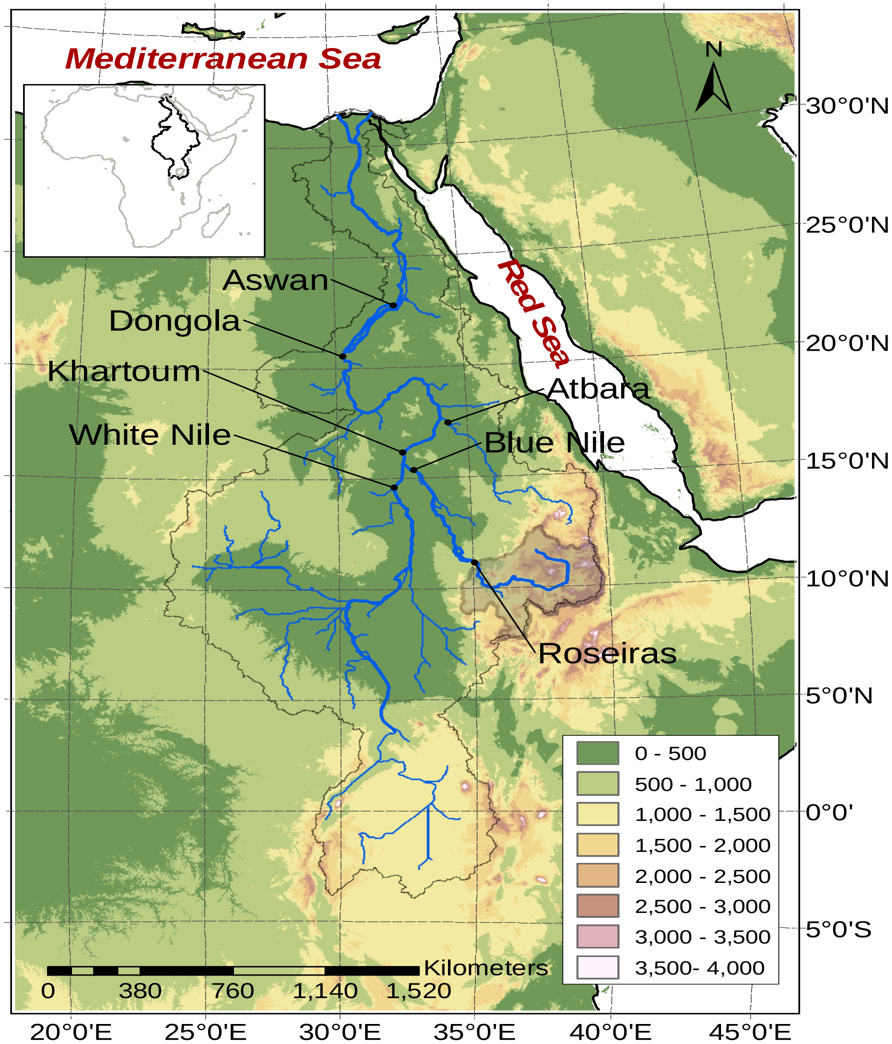
In this analysis we use the following data:

(i) Observed stream flows at the Dongola from 1871 to 2000, which is an index of the rainfall over Ethiopia.

(ii) Monthly SSTs from (HadISSTV1.1) dataset on a 1-degreee latitude-longitude grid from 1871 to 2000 (Rayner et al. 2003), from which the monthly anomalies over thee Eastern Pacific (6^{o}N-2^{o}N, 170^{o}W-90^{o}W; 2^{o}N-6^{o}S, 180^{o}W-90^{o}W; and 6^{o}S-10^{o}S, 150^{o}W-110^{o}W) are used as an index of ENSO.

(iii) Atmospheric variables (zonal and meridional wind speed) at different pressure levels from ERA-Interim (Berrisford et al. 2011).

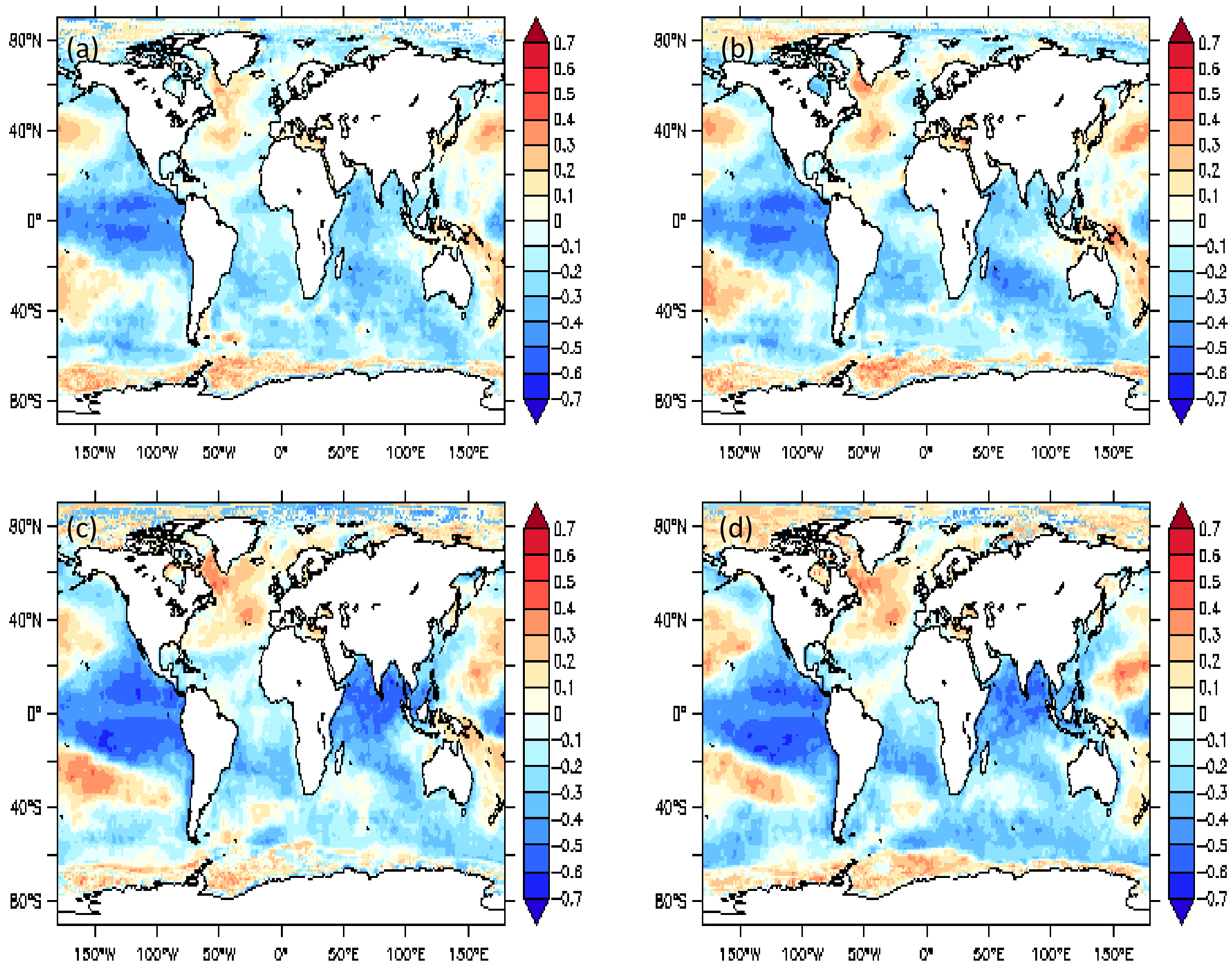
Study Area



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.

Connection between Nile, Indian Ocean SSTs and ENSO

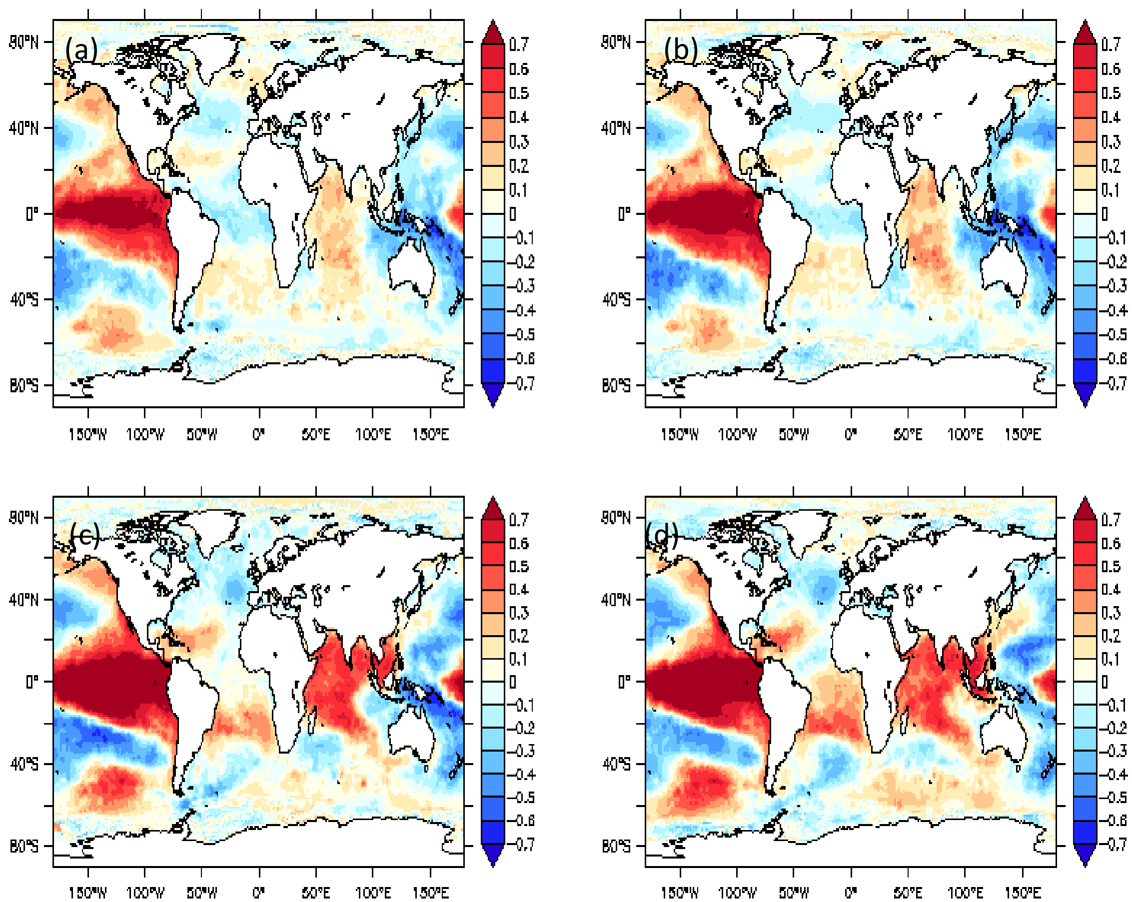
The figures below reveal that the correlation between the Nile flow and the global SSTs is primarily dependent on the correlation between ENSO and those SSTs. Therefore, most of the global SSTs cannot explain any additional variation of the Nile flow . However, the high correlation (R^2~0.38) between July-October mean Nile flow and South Indian Ocean SSTs in august compared to the correlation between ENSO index and SSTs over the same region (R^2~0.2) reflects that the south of Indian Ocean may have an independent role from ENSO in shaping the variability of the Nile flow.



Correlation (R) between average Nile flow during (July to October) and average monthly SST: a) July, b) August, c) September and d) October.

Connection between Nile, Indian Ocean SSTs and ENSO

From the below Figures, three different regions in Indian Ocean (North: 50ºE-70ºE and 0-15ºN; Middle: 50ºE-70ºE and 0-10ºS and South: 50ºE-80ºE and 20ºS-30ºS) are used to study the connections between IO SSTs, Nile flow and ENSO.

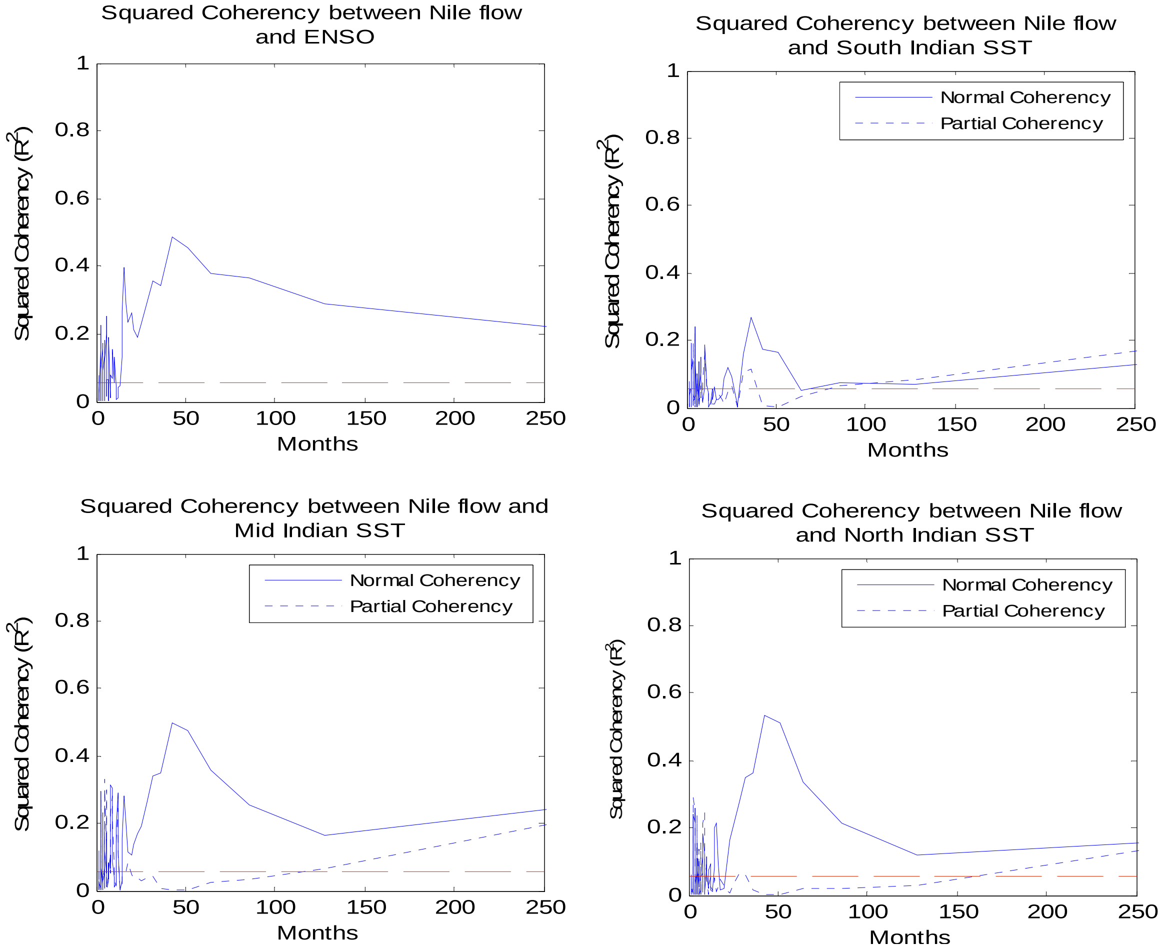


Correlation (R) between average ENSO index during (September to November) and average monthly SSTs: a) July, b) august, c) September and d) October.

Partial Coherency Analysis

The concept of partial coherency represents a generalization of the concept of partial correlation coefficient. Partial correlation analysis focuses on the relationship between two variables in the presence of a third variable . It quantifies the correlation between these two variables after controlling for the impact of the third variables. In this study, the two variables are the Nile flow and SSTs over the Indian Ocean, and the third variable is ENSO index. The partial correlation coefficient quantifies how much of the Nile flow variability, which cannot be explained by ENSO, can be explained by the SSTs in the Indian Ocean. However, the partial correlation coefficient does not show how this correlation is distributed over different frequencies. Here, we develop the concept of partial coherency, which describes how the partial correlation is distributed among different frequencies.

Partial Coherency Analysis



Squared Coherency between the Nile flows and SSTs in the Pacific (ENSO index) and the Indian Ocean. The straight dashed lines represent the 1% significance level of the correlation.

Partial Coherency Analysis

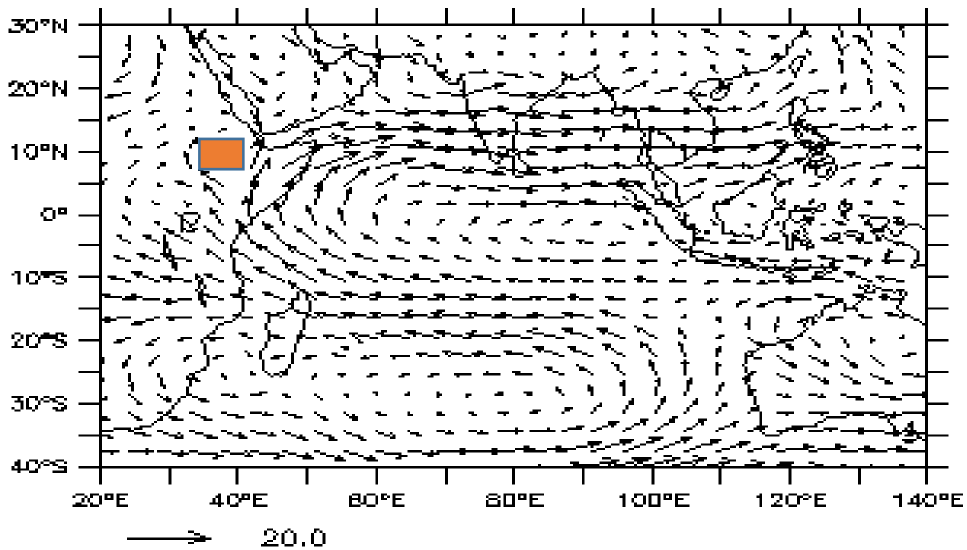
From the figures in previous slides, it be can concluded that:

1. At the 4-year time scale, SSTs over the North and Middle Indian Ocean cannot explain any of the flow variability that ENSO does not explain . The peak of the normal coherency at the time scale of 4 years can only be explained by the following: both the Nile flow and the SSTs in the North and Middle Indian Ocean respond to ENSO.

2. The SSTs in the South Indian Ocean explain some of the variability of the Nile flow, which is not explained by ENSO. Hence, only the South Indian Ocean has an independent role from ENSO on the Nile flow compared to the North and Middle India Ocean.

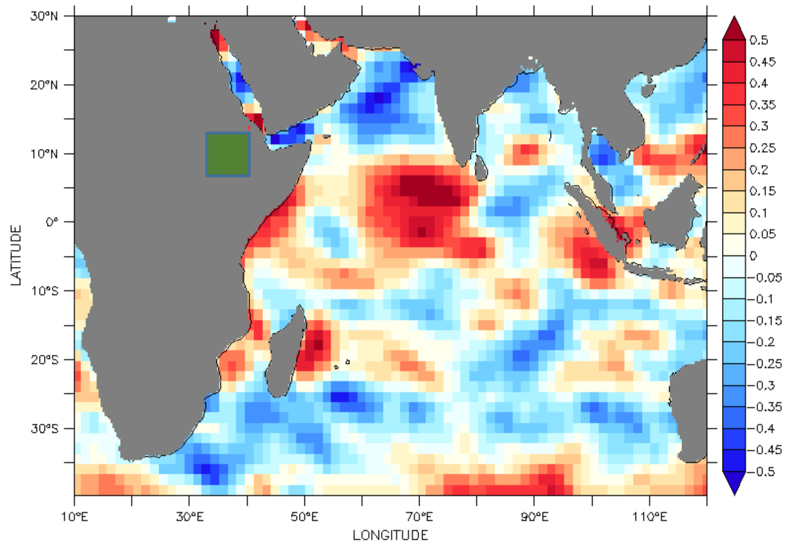
Mechanism Relating Nile to Indian Ocean SSTs and ENSO

The Indian Monsoon circulation is mainly composed of two anticyclonic circulation over the North and South of the Equator (Figure below). The anticyclonic circulation located over the South is responsible for increasing the convergence of air over the Upper Blue Nile basin, which is the main source of water for the Nile, by easterly winds, while the North anticyclone decreases it by the westerly winds. The intensity of the anticyclones is reflected in the magnitude of the relative vorticity: strong westerly and easterly flows correspond to high values of relative vorticity over the North and South Indian Ocean, respectively.

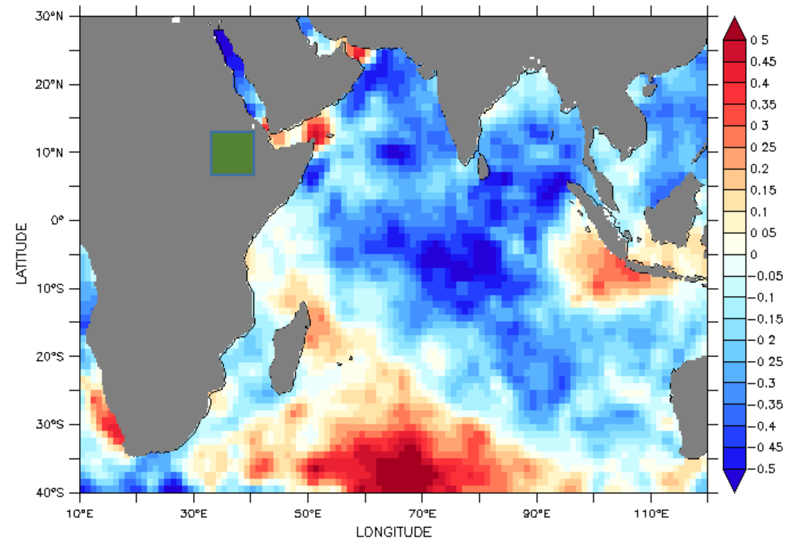


Average wind circulation during August (1979-2011) at 800 mb using ERA-Interim reanalysis product. The Upper Blue Nile basin (shaded in brown).

Mechanism Relating Nile to Indian Ocean SSTs and ENSO



(a)



(b)

Correlation (R) between the relative vorticity at 700 mb: a) over the Indian Ocean and averaged convergence of air in the lowest 300 mb layer over the UBN basin (shaded in brown) during July, and b) average relative vorticity over (60°E-80°E and 5°S-10°N) and SSTs in the Indian Ocean during July.

The magnitude of the relative vorticity over North and South Indian Ocean is negatively correlated with SSTs (Figure b). Thus, warming over the Indian Ocean decreases the anti-cyclonic circulation over the South IO and increases it over the North Indian Ocean by inducing westerly winds around the equator. The anomalous westerlies are induced following a Matsuno-Gill circulation forced by an increase in SSTs around the equator, particularly during El Niño years and reduce the convergence of air over the UBN.

Conclusions

1. SSTs over North and Middle Indian Ocean are just responding to the warming of the Pacific Ocean, particularly during El Niño events, by advecting warm water through the Indian Throughflow and South Equatorial current. Moreover, they do not impose any new significant variation on the Nile flow from ENSO. However, the SSTs over the South of Indian Ocean are less dependent on ENSO and explain some the variability of Nile flow that is not explained by ENSO.

2. The increase of the SSTs over the North and Middle of Indian Ocean, during ElNiño events, forces a Matsuno-Gill circulation over these regions, which enhances westerly winds and reduces the convergence of air over the UBN basin. Similarly, the increase of SSTs over the South Indian Ocean generates an anomalous cyclonic circulation that reduces the convergence of air, hence rainfall, over the UBN basin.