MECHANISMS OF THE IMPACTS OF CLIMATE CHANGE ON THE HYDROLOGY OF THE EASTERN NILE BASINS

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Introduction

The general circulation models (GCMs), are the primary tools for climate change studies. Here, we investigate the impacts of climate change on the hydrological cycle of the Eastern Nile basins (ENB) (Sobat, Atbara and Upper Blue Nile) using carefully selected GCMs. Through this study, we aim to:

i. Present mechanisms, which explain the changes in the rainfall over the ENB due to climate change.

ii. Develop new criteria to select suitable GCMs for climate change studies on ENB based on the runoff elasticity (percent change in runoff per percent change in rainfall) and the accuracy of simulation of the Sea Surface temperature and precipitation over the Indian Ocean.

Data

In this analysis we use the following data:

i. Observed stream flows at the Roseiras from 1970 to 2000.

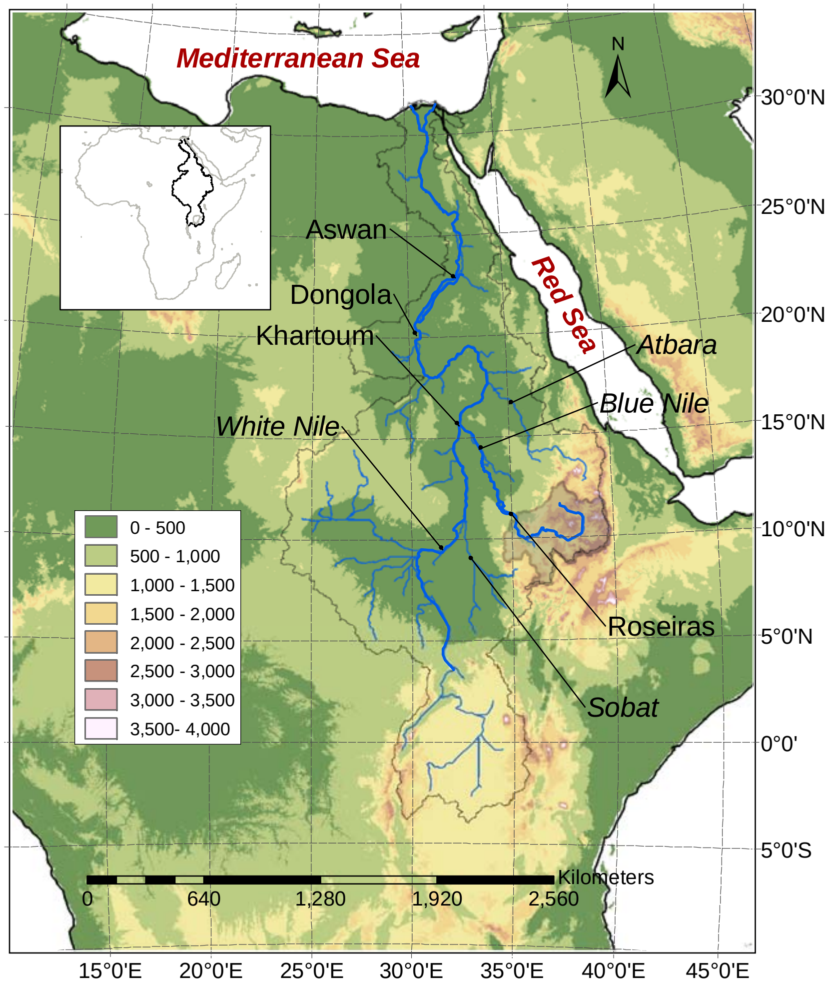
ii. Rainfall from 6 stations in the Upper Blue Nile basin (Combolcha, Gondar, Debremarcos, Wonji, Addis and Bahar) from 1970 to 2000.

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

iv. Precipitation, runoff, SST, zonal and meridional winds at different pressure levels from 8 CMIP5 GCMs for 1970 to 2000 and 2040-2070 using RCP8.5.

v. Rainfall from TRMM V7-3B43 from 1998 to 2012.

Study Area



Topographic map of the Nile basin showing the Blue Nile, Sobat and Atbara rivers.

Selection of GCMs: Runoff Elasticity

The runoff elasticity is defined as the percent change in runoff per percent change in the rainfall. It is important to choose GCMs, which have the right runoff elasticity in order to have the right changes in runoff for changes in the rainfall in the future.

The runoff elasticity (RE) is calculated as following:

$$RE = \frac{\partial \overline{R}}{\partial \overline{P}} x \frac{\overline{P}}{\overline{R}}$$

$$\overline{P} = \int f_p dp \qquad \& \qquad \overline{R} = \int g(p) f_p dp$$

Where:

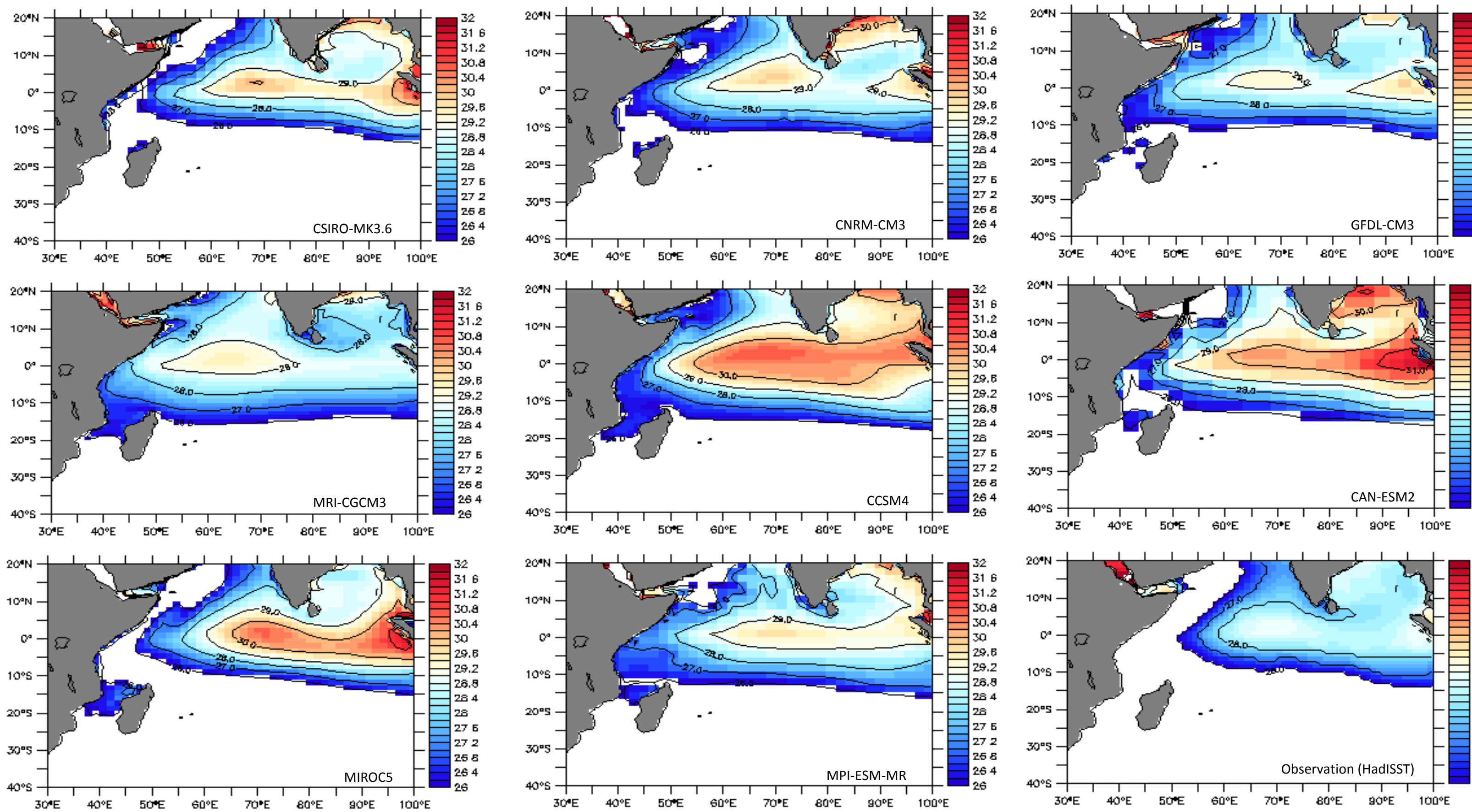
- $\overline{R}$: Climatological mean of the runoff over the basin.
- $\overline{P}$: Climatological mean of the rainfall over the basin.
- f_p : Probability density function of the annual precipitation.
- g(p) : Fitted relation between the annual rainfall and runoff.

Selection of GCMs: Runoff Elasticity

Annual means of the hydrological variables for CMIP5 GCMs

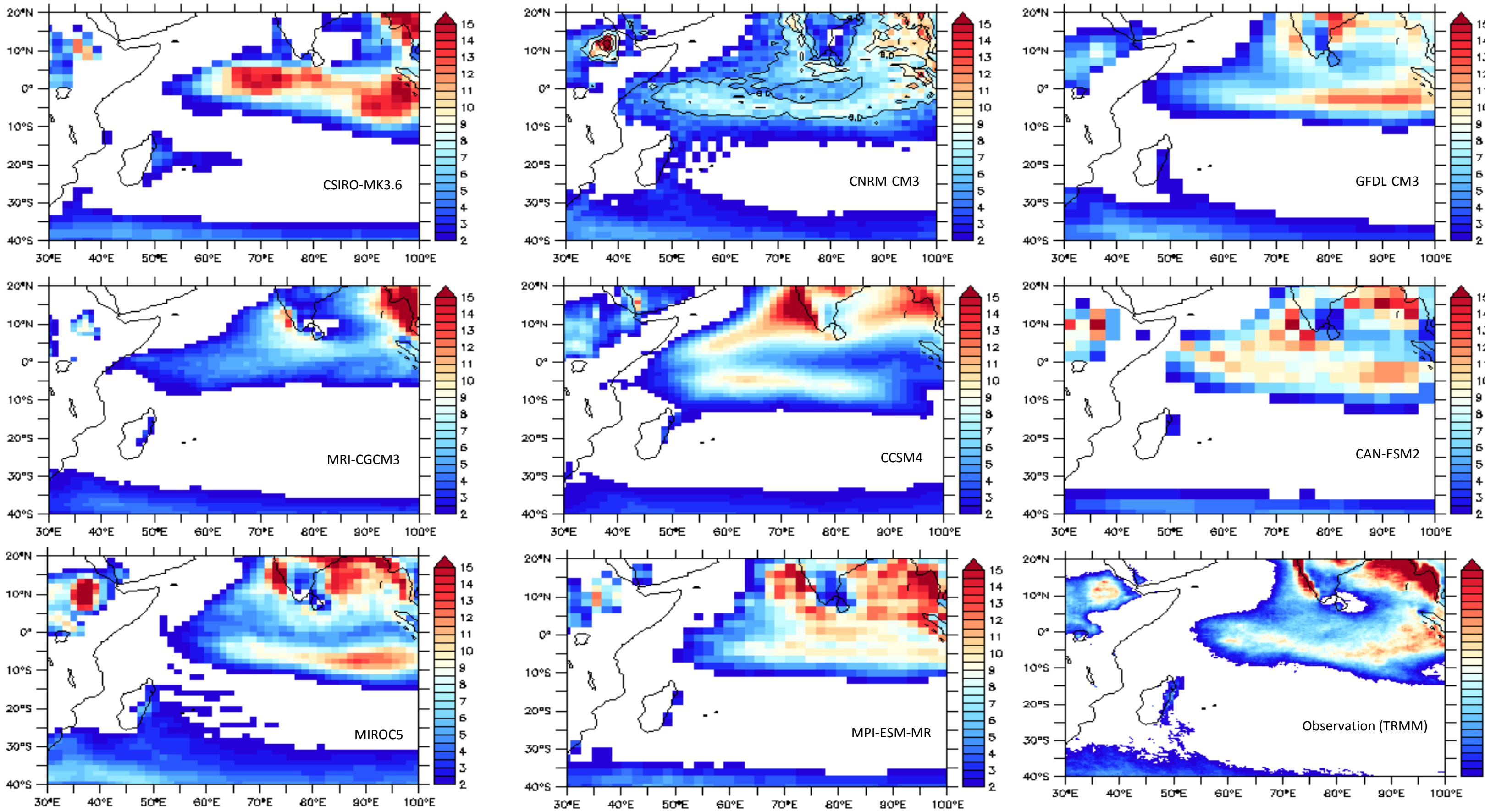
Model	Rainfall (mm/day)	Runoff (mm/day)	Runoff Elasticity
CSIRO-MK3.6	2.77	0.89	2.3
GFDL-CM3	2.85	0.46	1.2
MPI-ESM-MR	2.45	0.38	1.8
CAN-ESM2	2.87	1.05	2.2
MIROC5	5.67	2.56	1.83
MRI-CGCM3	1.84	0.21	3.8
CNRM5-CM5	3.53	1.16	2.3
CCSM4	3.2	0.64	2.2
Observation	2.9	0.72	1.6

Selection of GCMs: Simulation of the Indian Ocean SSTs and Precipitation



Average SSTs of August (1970-2000) for different CMIP5 GCMs compared to Observation (HadISST)

Selection of GCMs: Simulation of the Indian Ocean SSTs and Precipitation



Average Precipitation of August (1970-2000) for different CMIP5 GCMs compared to Observation (TRMM)

Mechanisms of Changes in Future Rainfall

In the previous section, we have investigated the accuracy of GCMS in simulating the runoff elasticity, SSTs and precipitation over the Indian Ocean. The accuracy in simulating the SSTs over the Indian Ocean is very important as the rainfall over the ENB is correlated with the SSTs in the Indian Ocean. From this analysis, we can select 3 GCMs (GFDL-CM3, MPI-ESM-MR and CSRIO-MK3.6) to study the impact of climate on the rainfall over the ENB as they are the best in simulating the above mentioned variables.

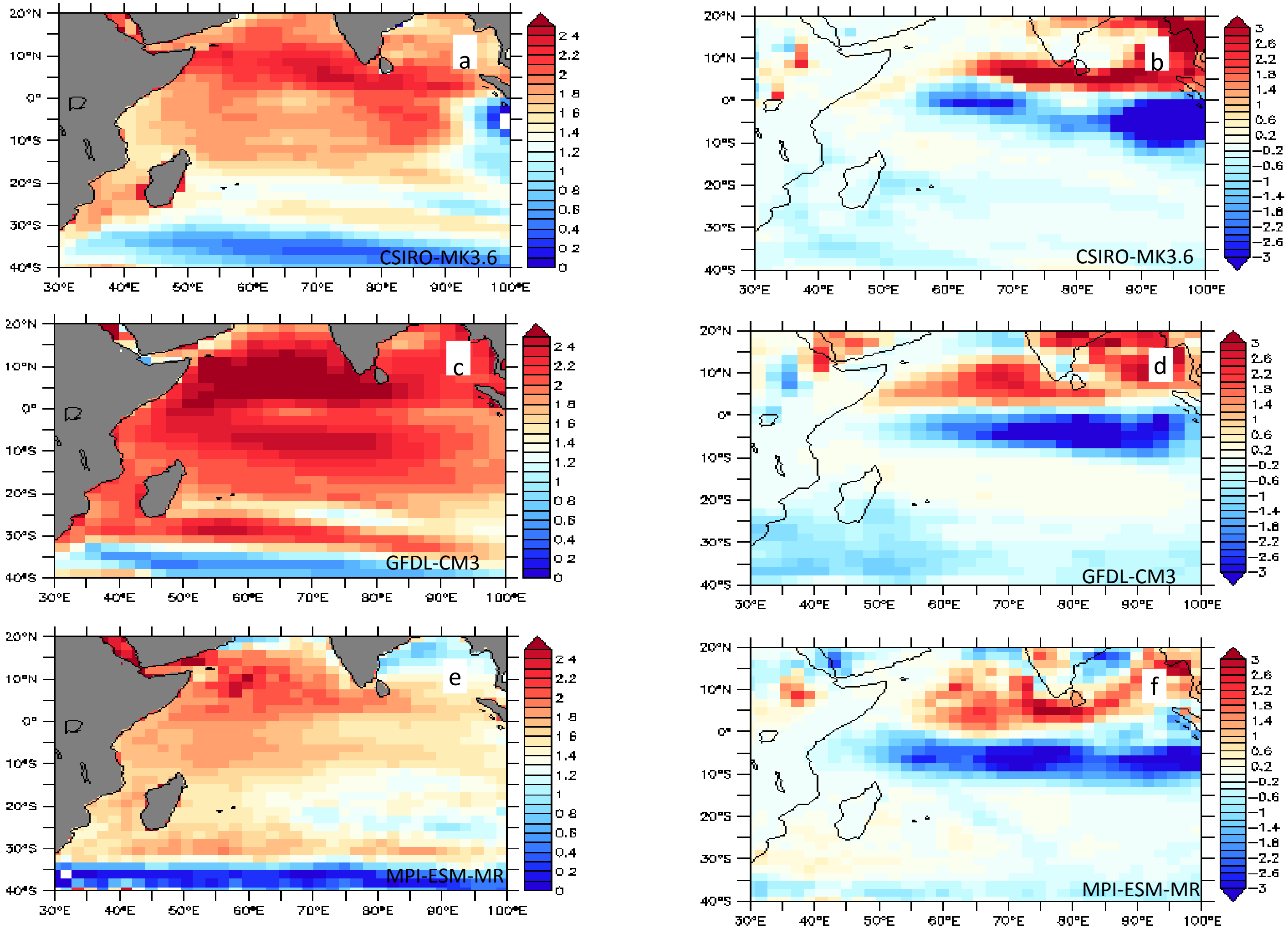
Summary of changes in the rainfall, runoff , convergence of air and specific humidity over the lowest 300 mb over the ENB during July and August (2040-2070) relative to (1970-2000)

Model	Rainfall		Specific Humidity		Convergence of air	
	Cont (mm/day)	2040-70 (%)	Cont (Kg/Kg)	2040-70 (%)	Cont (Pa/s)	2040-70 (%)
CSIRO-MK3.6	4.72	-3.0	0.004	21.4	-0.063	-3.3
GFDL-CM3	4.9	-12.2	0.006	27.9	-0.039	-23.1
MPI-ESM-MR	5.43	7.0	0.006	20.7	-0.047	5.5

Mechanisms of Changes in Future Rainfall

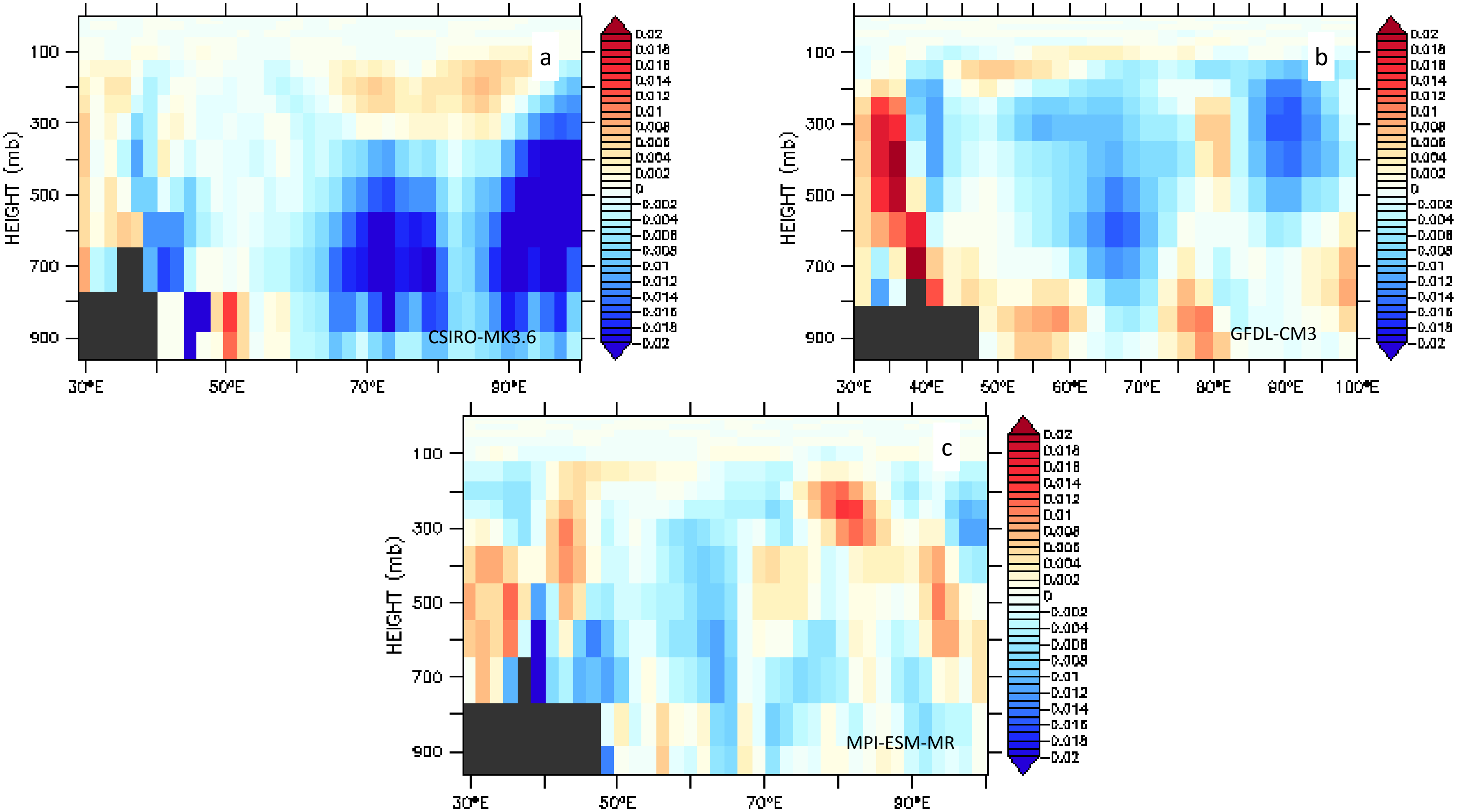
In the table of previous slide, we focus on the changes in July and August as the rainfall during these 2 months is responsible for almost 80% of the total Nile flow between July to October. It is also shown that the changes in the rainfall are relatively small. This can be explained as the moisture content over the basin has significantly increased over the basins, while the convergence of air has decreased for two (GFDL-CM3 and CSIRO-MK3.6) of the three GCMs.

Mechanisms of Changes in Future Rainfall



Changes in the mean SSTs (^{o}C) (a, c, e), rainfall (mm/day) (b, e, f) of August (2040-2070) relative to August (1970-2000).

Mechanisms of Changes in Future Rainfall



Changes in the mean vertical velocity (Pas^{-1}) between 5°N-15°N of August (2040-2070) relative to August (1970-2000).

Mechanisms of Changes in Future Rainfall

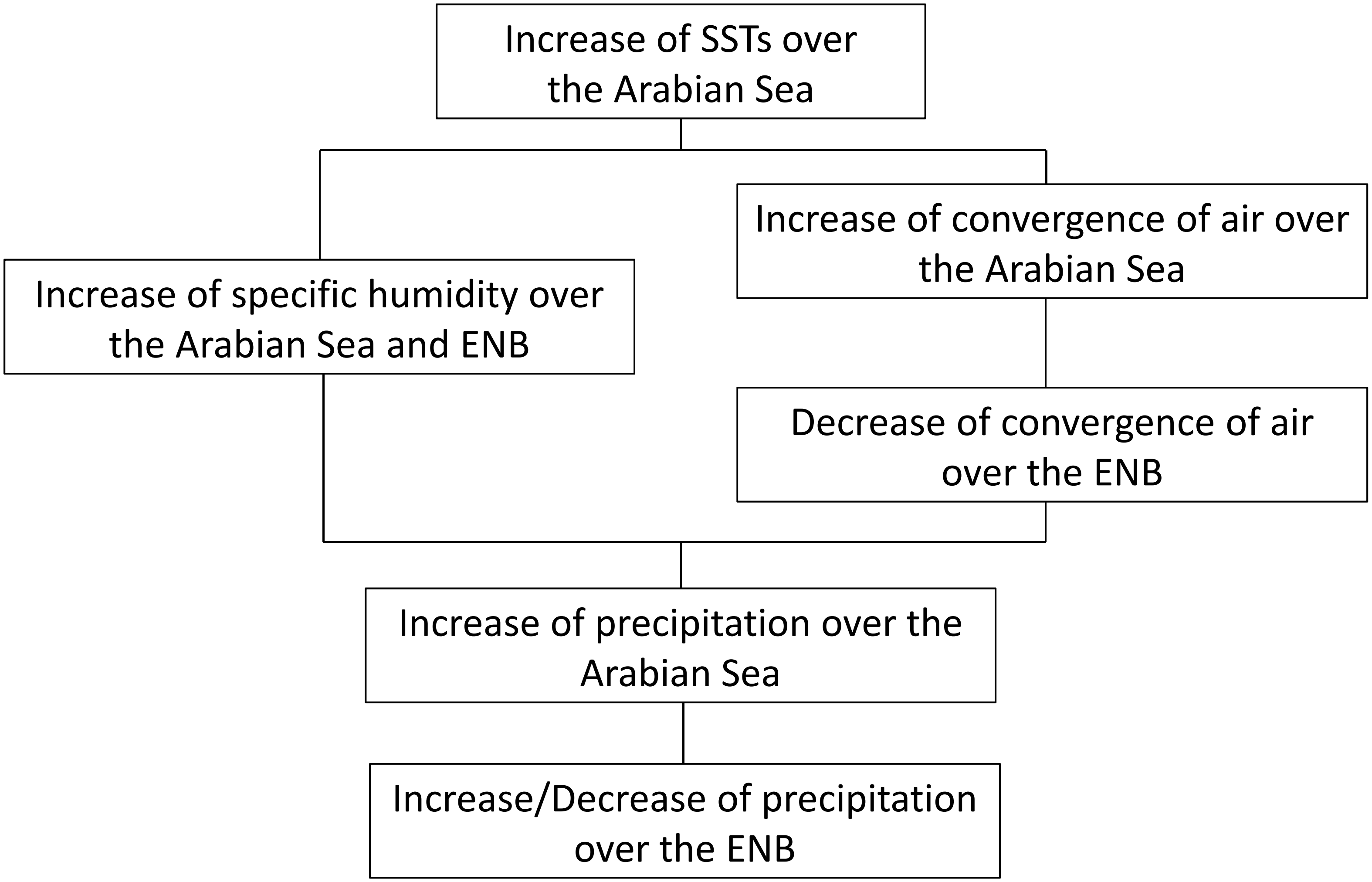
Table in slide 9 shows that there is a disagreement between the GCMs on the sign of change in the rainfall over the ENB. Here, we explain that the changes in the rainfall over the ENB is due to the competition of two different mechanisms:

1. As the SSTs increase over the Indian Ocean and based on the Clausius Clapeyron relation, the specific humidity over the Indian Ocean increases. This increase enhances the transport of moisture to the ENB and the specific humidity over the basin increases.

2. If the increase of the SSTs over the Arabian Sea is high and extending over a large a region, this may increase the convergence of air over the Arabian Sea and induce divergence of air over the ENB (Fig. 5).

The final impact on the rainfall over the ENB is depending on the magnitude of changes of these two mechanisms. (e.g., mild divergence and strong increase of the humidity over the ENB may lead to an increase in the rainfall and vice versa).

Mechanisms of Changes in Future Rainfall



Schematic diagram showing the mechanism of the impacts of climate change on the ENB.

Conclusions

1. In this paper, we propose two mechanisms which define the changes in the rainfall over ENB due to climate change. The first mechanism is the increase of the specific humidity over the basin due to warming, which tends to increase the rainfall over the basin. The second mechanism is the change in the convergence of air over the basin, which is directly related to increase of the convergence of air over the Arabian Sea. Application of these two competing mechanisms may help in explaining the differences between the different predictions of climate change impacts on the Nile hydrology.

2. Five out of eight of the studied GCMs do not accurately simulate the SSTs and precipitation over the Indian Ocean and also the runoff elasticity over the ENB. This suggests that these GCMs are not suitable to study the impacts of climate change on the ENB. Hence, we can reduce the uncertainty in the expected future changes in the hydrology of the ENB by not including these models in the climate change studies over this region.