Hydroclimatic Variability in Africa's Transboundary River Basin Using +50 Years of Extended Terrestrial Water Storage

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November 23, 2022

Abstract

Information concerning the types, patterns, and intensity of hydroclimatic variability is needed in various sectors, including water resources planning and climate change adaptation, among numerous others. In transboundary river basins, the nature of hydroclimatic variability frequently is a critical input in the treaties governing water resources allocation to competing parties and sectors. Yet, the pattern of hydroclimatic variability across Africa's Transboundary Rivers Basins (ATRB) remains poorly investigated owing primarily to lack of access to required data. To the extent that such studies exist, they often have been conducted at different times using different data sets and reference periods, making comparisons across the continent difficult. In this paper, we make use of NASA's Gravity Recovery and Climate Experiment (GRACE) satellite data to extend the Terrestrial Water Storage (TWS) +50 years prior GRACE era using the unique Generalized Additive Model for Location Scale and Shape (GAMLSS) approach on the Global Land Data Assimilation System Version 2 data (GLDAS V2). The results revealed a downward trend of the TWS over Africa with a decrease rate of 0.14 cm/yr. The spatial patterns of TWS in ATRB showed a significant decreasing trend for Nile, Niger, Chad, Volta, and Congo River Basins, compared to the insignificant trends for Zambezi, Okavango, Limpopo and Orange River Basins. The spatial trends in annual TWS is primarily related to the regional variation in the precipitation trends. The largest negative trend in precipitation were observed over West Africa and Sahel region. The dry trend over south Africa were intervened by wet records. The nature of these hydroclimatic patterns are explained by the significant reduction in the total precipitation and the increasing demands on water resources.

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AGU 100 ADVANCING EARTH AND SPACE SCIENCE
FALL MEETING
Washington, D.C. | 10-14 Dec 2018

Citation: Hasan et. al (2018), Hydroclimatic Variability in Africa's Transboundary River Basins Using a +50 Years of Extended Terrestrial Water Storage, Abstract [H51M-1474*] presented at 2018 Fall Meeting, AGU, Washington, D.C., 10-14 Dec.

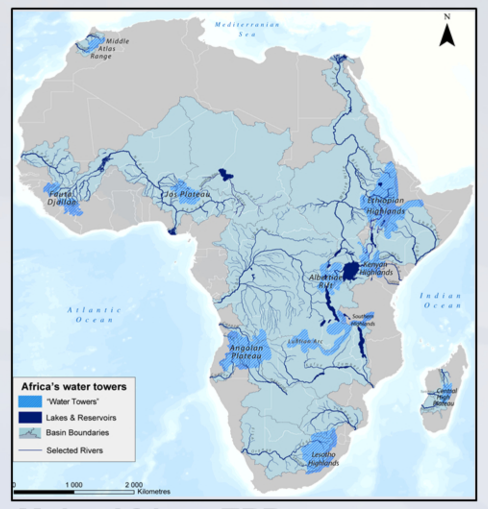
OBJECTIVES

Information concerning the types, patterns, and intensity of hydroclimatic variability is needed in various sectors, including water resources planning and climate change adaptation, among numerous others.

In transboundary river basins (TRBs), the nature of hydroclimatic variability frequently is a critical input in the treaties governing water resources allocation to competing parties and sectors.

In this paper, we make use of GRACE data to extend the TWS a +50 years prior GRACE era using GAMLSS approach on GLDAS-Noah V2 estimates.

The hydroclimatic nature of extended TWS across nine African TRBs (Nile, Niger, Chad, Volta, Congo, Zambezi, Okavango, Limpopo and Orange) were explained using trends, abrupt shifts, as well as the dominant modes of variability using wavelet analysis.



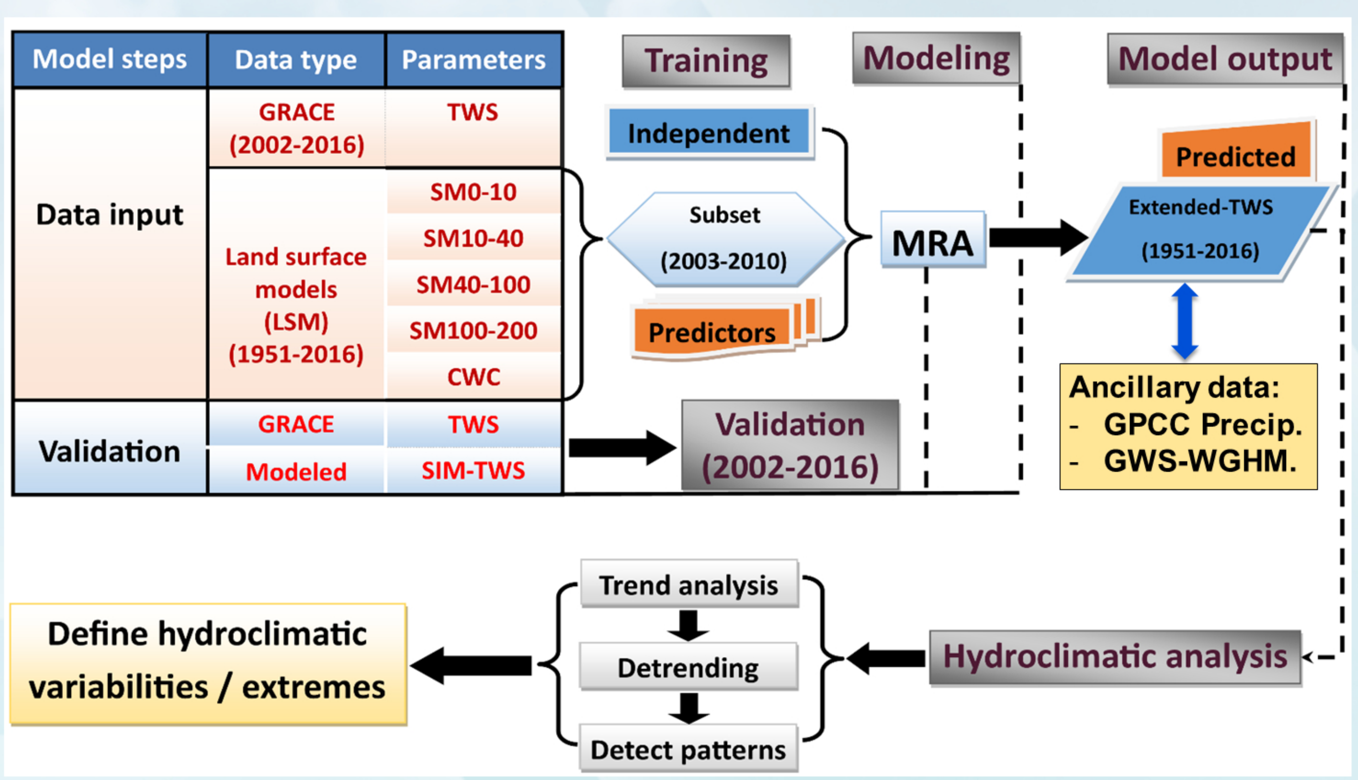
Major African TRBs

Basin	Area (km²)	Length (Km)	Q (m3/s)	Shared by	Pop (mi) (2015)	Climate
Nile	3,254,555	6,853	2,800	Eritrea, Sudan, Ethiopia, Egypt, Tanzania, Congo DR, Rwanda, South Sudan, Uganda, Burundi, Kenya	300	SA
Congo	4,014,500	4,700	41,200	Angola, Tanzania, Central African Republic, Congo Republic, Congo DR, Rwanda, Gabon, South Sudan, Burundi, Cameroon, Malawi, Zambia	77	H
Niger	2,117,700	4,180	5,590	Mauritania, Algeria, Chad, Guinea, Nigeria, Sierra Leone, Ivory Coast, Mali, Niger, Cameroon, Burkina Faso, Benin	130	SA
Chad	2,434,000	950	1,290	Chad, Libya, Sudan, Central African Republic, Algeria, Niger, Cameroon, Nigeria	30	SH
Volta	407,000	1500	1,200	Ghana, Togo, Ivory Coast, Mali, Burkina Faso, Benin	29	SH
Zambezi	1,390,00	2,570	3,400	Angola, Tanzania, Malawi, Congo DR, Zimbabwe, Namibia, Mozambique, Botswana, Zambia	32	SH
Okavango	530,000	1,700	475	Namibia, Zimbabwe, Angola, Botswana	0.9	SA
Limpopo	415,000	1,750	170	Zimbabwe, Mozambique, Botswana, South Africa	14	SA
Orange	973,000	2,200	365	Lesotho, Namibia, Botswana, South Africa	20	SA

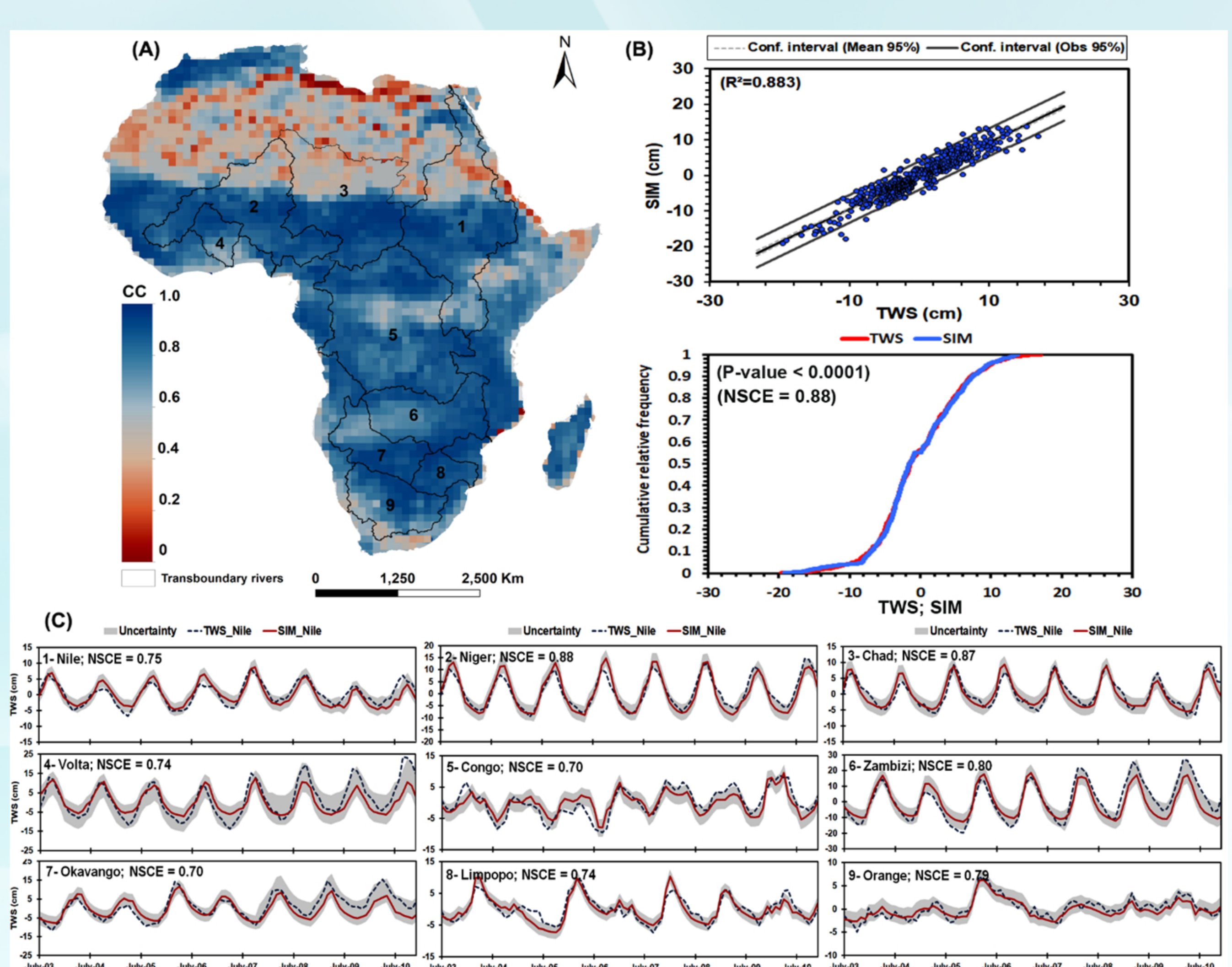
Basic info summary of TRBs.

APPROACH

$$f(TWS|\mu,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(TWS-\mu)^2}{2\sigma^2}}$$



MODEL PERFORMANCE

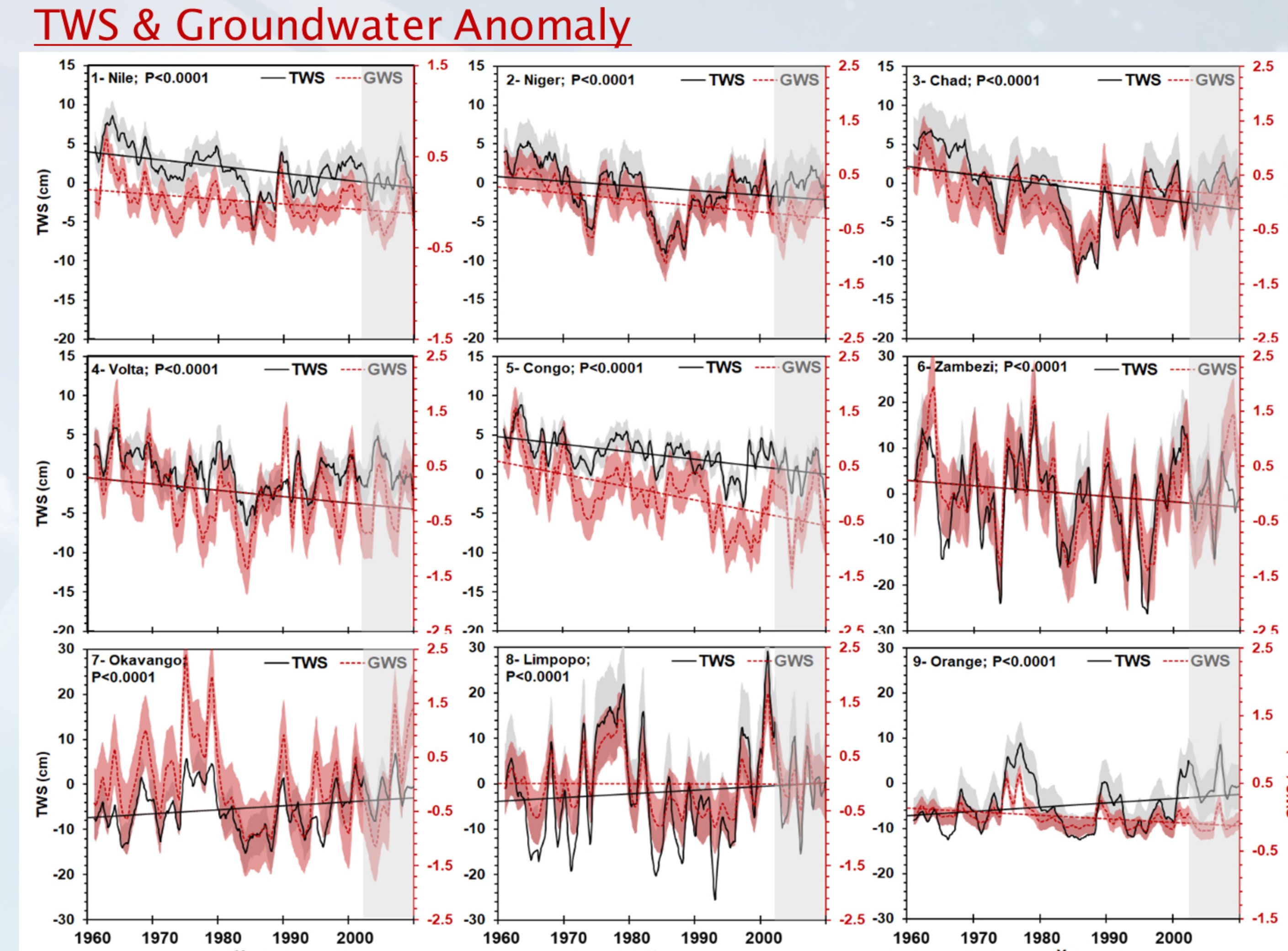


Spatio-temporal performance of the simulated TWS and CSR-M estimates between 2003 to 2010.

Using standard model evaluation criteria, including the Pearson correlation coefficient (R2), cumulative distribution function (CDF), the Nash Sutcliffe efficiency (NSCE) and model uncertainty, the results indicate a strong spatial agreement between the observed CSR-M and simulated TWS. Across the nine River Basins, a correlation coefficient of (R²= 0.88) is observed. A good density distribution and fitting are indicated by the cumulative density function (CDF) distribution. Time-series plots of the training period between the CSR-M and the simulated TWS between July-2003 and December-2010, the plot shows a good consistency of the model as indicated by the Nash–Sutcliffe efficiency test, the 95% uncertainty bounds are plotted.

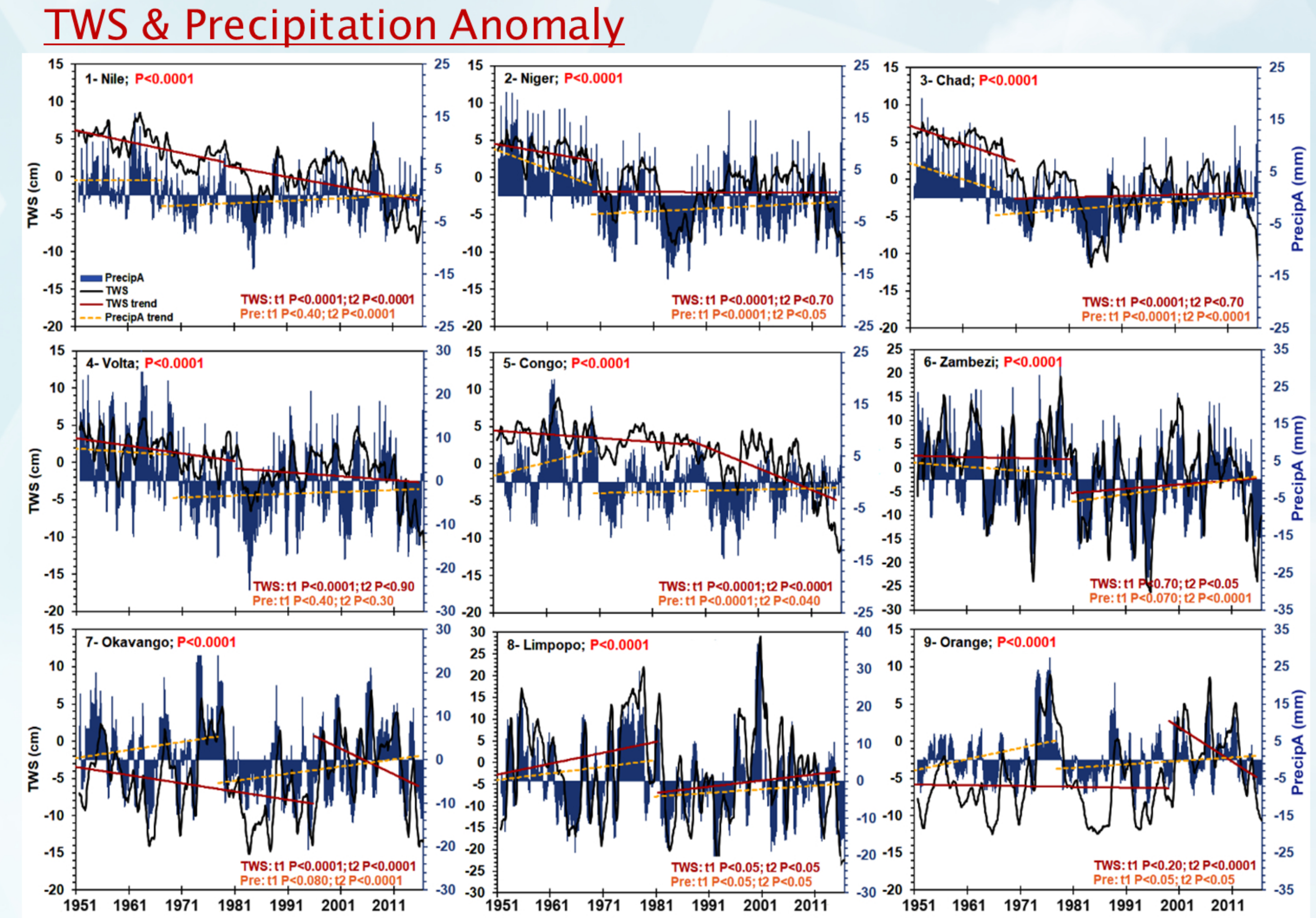
HYDROLOGICAL ESTIMATES

TWS & Groundwater Anomaly



There is overall good agreement of ~80% correlation between the extended estimated TWS and GWS anomalies derived from the WaterGAP Global Hydrology Model (WGHM) between 1960-2010.

TWS & Precipitation Anomaly

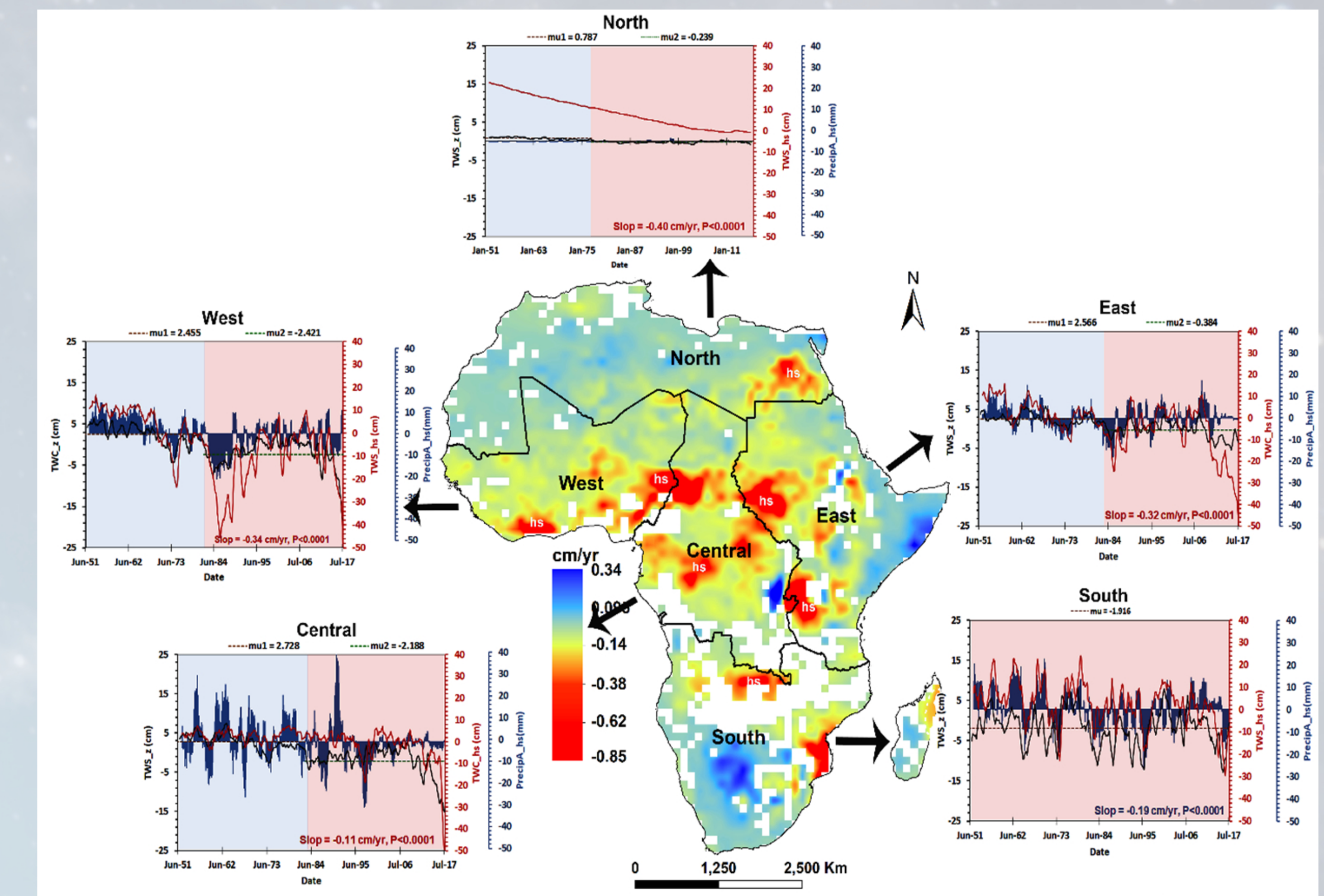


Basin	Change point year: PrecipA	Change point year: TWS	Trend: PrecipA_t1	Trend: TWS_t1	Trend: PrecipA_t2	Trend: TWS_t2
Nile	1969	1980		↓	↑	↓
Niger	1970	1970	↓	↓	↑	
Chad	1968	1972	↓	↓	↑	
Volta	1970	1982		↓		
Congo	1971	1989	↑	↓	↑	↓
Zambezi	1982	1982	↓		↑	↑
Okavango	1979	1997	↑	↓	↑	↓
Limpopo	1982	1982	↑	↑	↑	↑
Orange	1979	2000	↑		↑	↓

Extended-TWS and precipitation anomalies across the nine Africa's TRBs between 1951 to 2016. The coherence in the seasonality between TWS and precipitation anomalies is indicated by P-Value (in red font). The attached table is summarizing the direction of the trend before and after the change point of TWS and precipitation anomalies. The table only display the significant trend direction at a 95%.

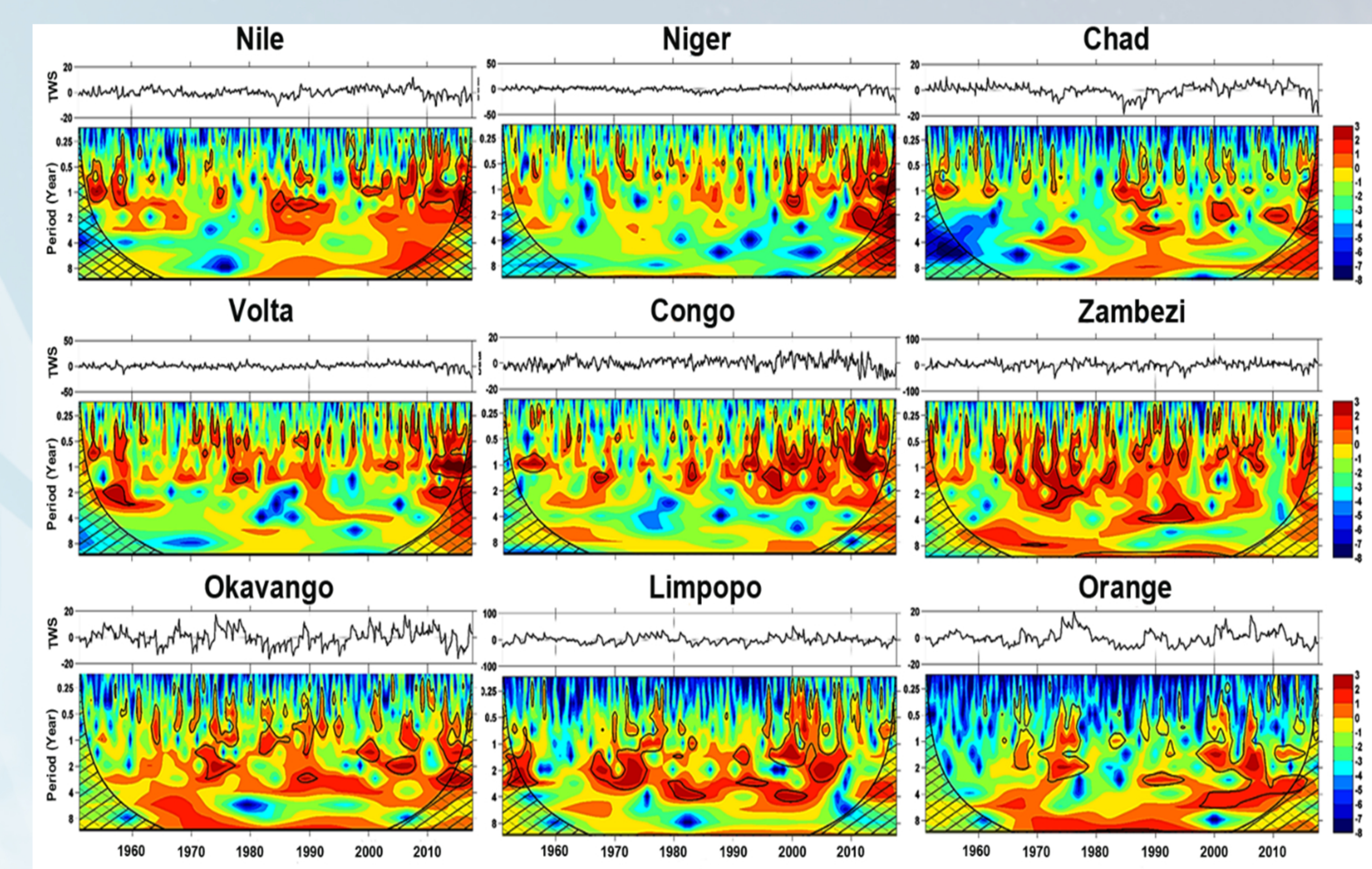
TREND ANALYSIS

$$TWS_{total} = TWS_{trend} + TWS_{cycle} + TWS_{seasonal} + TWS_{residual\ (stochastic)}$$



Spatio-temporal variation of the extend-TWS trend across Africa from 1951 to 2016. The trend map shows a number of hotspots that are marked by (hs), which are experienced substantial increase/decrease in the overall TWS trend. A time series average of TWS across five major geographic areas is also indicated. The results show a regional positive TWS mean between 1951 and early 80s (blue space) for North, East, West and Central zones, then a significant negative TWS trend is observed between late 1980s to 2016.

STOCHASTIC ANALYSIS



CWT for extended-TWS for the nine river basins. The power spectrum of the Nile, Niger, Chad, Volta and Congo river basins fluctuates in cycles between 1 to 2 years from 1951 to the 1980s. After 1980s the cycles extended up to a 4-year cycles especially during the late 2000s. The Zambezi, Okavango, Limpopo and Orange river basins fluctuate in cycles from 4 to 6 year cycles, where major cycles are shown from 1960s to late 2000s.