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THE GLOBAL ENGINEERING CONFERENCE ON SUSTAINABLE DEVELOPMENT AND WORLD FEDERATION OF ENGINEERING ORGANISATIONS EXECUTIVE COMMITTEE MEETINGS.

15th - 18th October 2024, Kigali, Rwanda

Theme: Engineering Innovations for a Sustainable Future

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Groundwater storage dynamics in the Lake Chad Basin revealed by GRACE and a multi-sensor signal separation approach

by
Marie Grâce MUTIMUCYEYE (MEng)

PRESENTATION OUTLINE

- Introduction
- Background and problem statement
- Research Objectives
- Datasets and Methods
- Results and Discussions
- Conclusions and Recommendations

Introduction

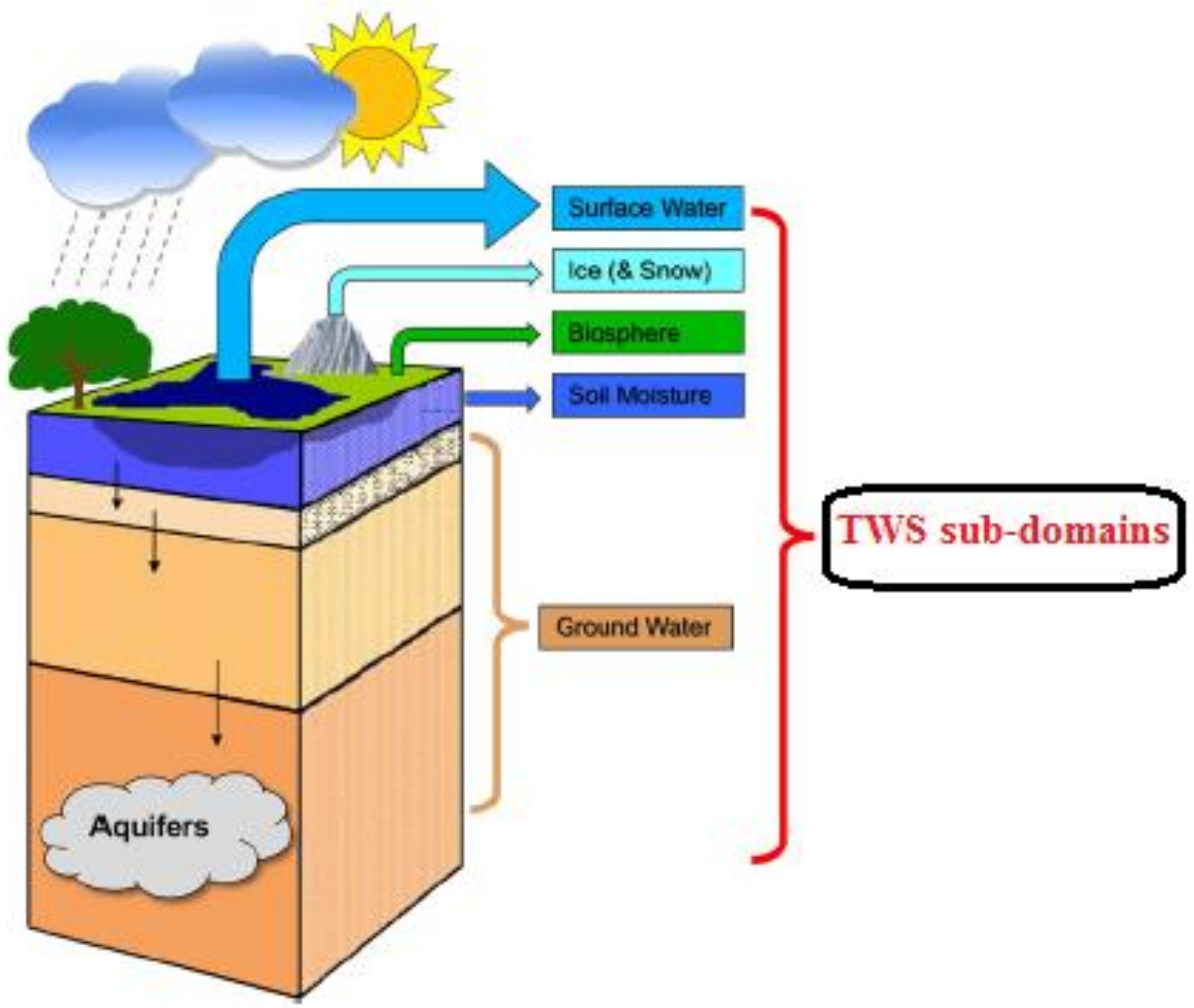

Figure: TWS components [Modified from Cazenave and Chen (2010)]

➢ What and where is groundwater?

- The water found underground in the cracks and spaces in soil, sand and rock.
- It is stored in and moves slowly through aquifers.

❖ Groundwater is frequently poorly monitored and managed especially in the developing world,

❖ Mismanagement due to the fact that water often crosses political boundaries.

Background and problem statement

Figure: The GRACE mission provides total water storage

- ❑Gravity Recovery and Climate Experiment (GRACE) data can be used to derive spatially variable parameters for groundwater modelling,
- ❑ Only GRACE modeling approach is applied to estimate groundwater variations in ungauged basins.
- ❑ Groundwater estimation based on GRACE-derived total water storage (TWS) relies on the mass conservation approach in which TWS can be disaggregated into its sub-domains:

$$TWS = GWS + SMS + SWS$$

BACKGROUND AND PROBLEM STATEMENT CONT'D

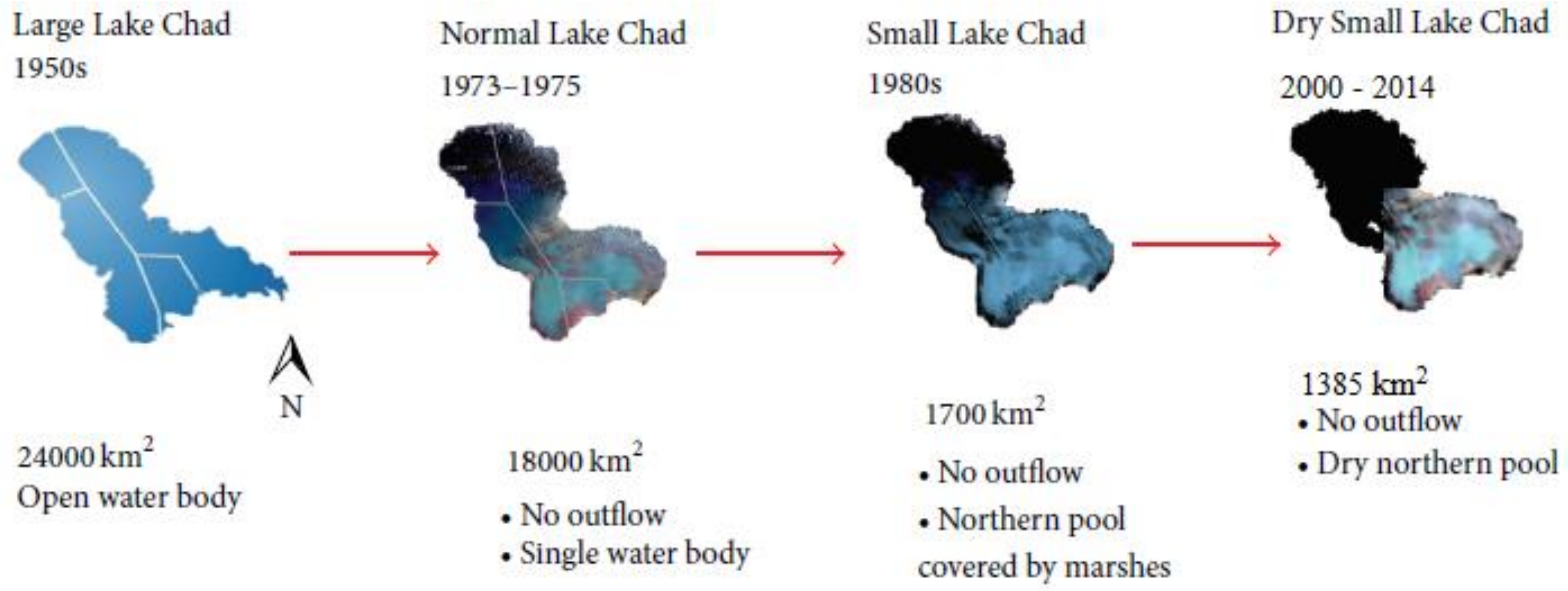

Figure: Landsat 5 images courtesy of NASA illustrating the shrinkage of Lake Chad from 1950 to 2014. Color blue represents water. [Modified from Okonkwo et al. 2014]

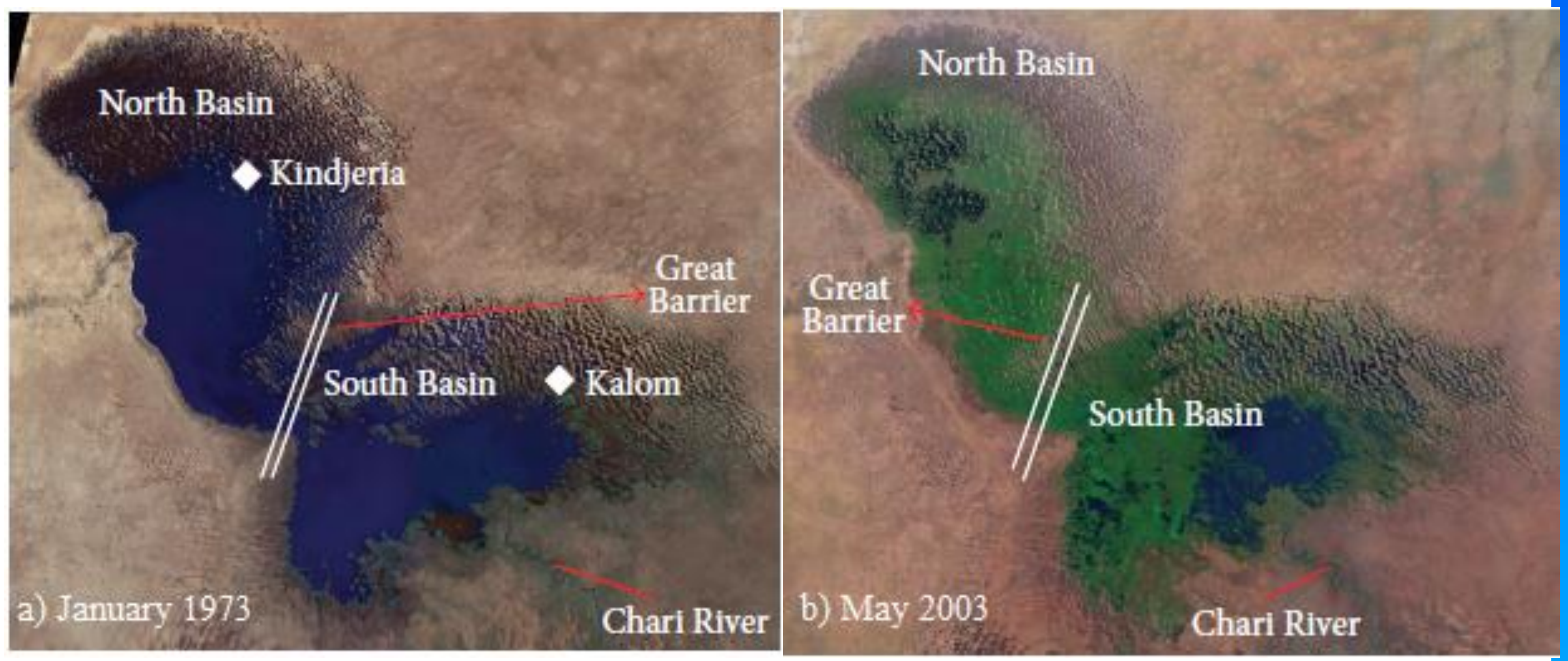

Figure: Lake Chad split into North and South basins, separated by great barrier. [Modified from Landsat 5 images; courtesy of NASA].

Research Objectives

- To invert GRACE synthesized gravitational potential at the satellite orbits into TWS fields at the Earth's surface and forward the gravitational potential at GRACE's orbit due to the soil moisture storages, and surface water storages based on point-mass modelling.

- To evaluate each inverted sub-domain of TWS- budget equation by applying empirical orthogonal functions.

- To reconstruct groundwater storage considering its inversion in a least square sense given its spatial and temporal patterns (i.e., EOFs and PCs), based on a "tie-in" approach.

Datasets and Methods

❑ Satellite altimetry
- Water level
- TOPEX/POSEIDON (T/P), Jason-1 and Jason-2
- 10 days

❑ GLDAS-Noah model
- Soil moisture storage
  - NASA GES-DISC
- 30 days

❑ WaterGap Hydrological Model
- Groundwater storage
- Universities of Kasel and Frankfurt
- 30 days

❑ Monthly in-situ groundwater storage.

❑ Satellite gravimetry
- GRACE Level-2 Spherical harmonic coefficients
- CRS
- 30 days

❑ Satellite imagery
- Landsat 7 and 8 images
- USGS
- 16 days
- 30 m

Datasets and Methods cont

- The gravitational potential is calculated using Newton's integral for infinitesimal surface elements

$$\delta V(r,\varphi,\lambda,t) = GR^2 \sum_k \mu_k(t) \Delta\varphi_k \Delta\lambda_k \frac{\cos\varphi_k}{\ell_k}$$

- The application of principal component analysis (i.e., EOFs and PCs) for TWS sub-domains decomposition.

$$\mathbf{Z} = \mathbf{U} \cdot \mathbf{S} \cdot \mathbf{V}^{\mathrm{T}}$$

  - Tie-in approach in the inversion of groundwater storage by using least-square problem

$$\mathbf{X} = \left(\mathbf{J}^{\mathrm{T}}\mathbf{W}\mathbf{J}\right)^{-1} \mathbf{J}^{\mathrm{T}}\mathbf{W}\mathbf{L}$$

Tying loadings in least-squares

Results and Discussions

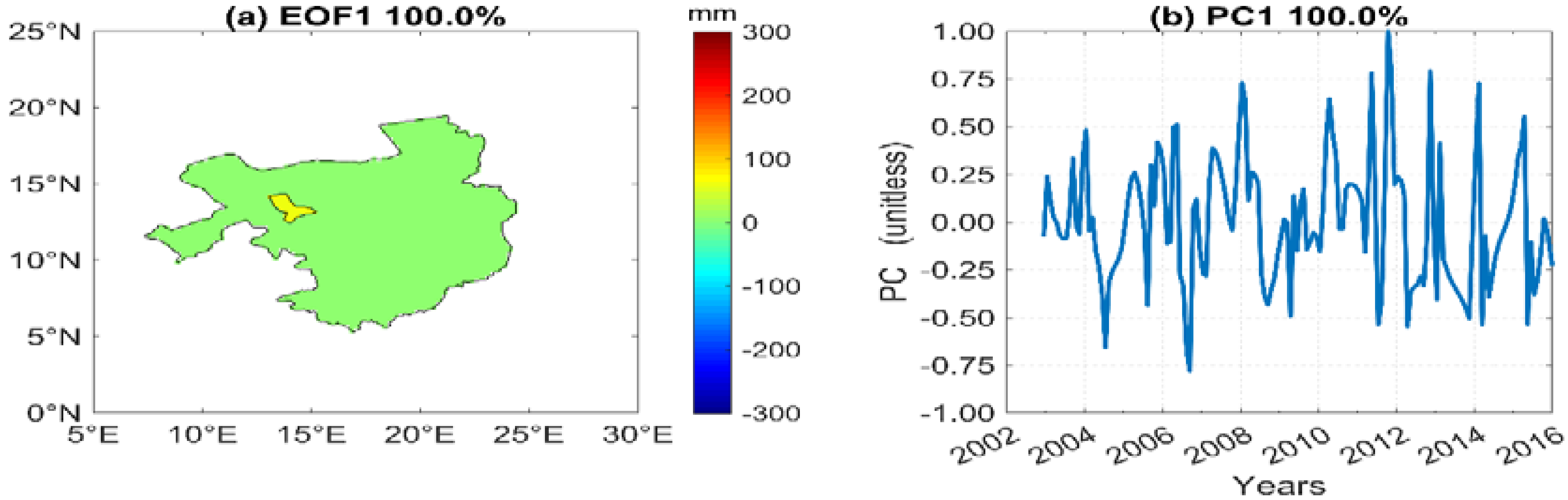

Figure: PCA decomposition of surface water storage variations over Lake Chad Basin

Results and Discussions cont'd

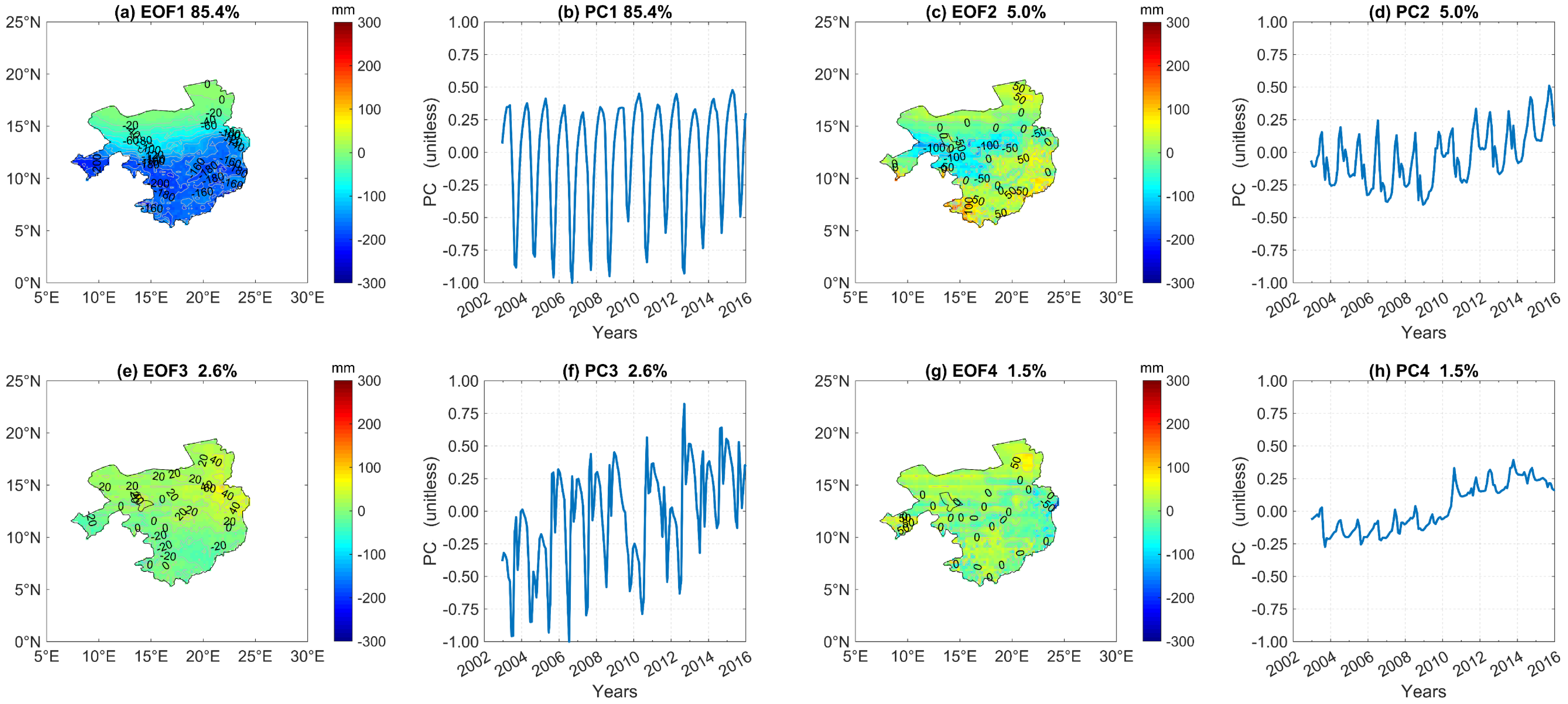

Figure: Evaluation of spatial and temporal patterns for soil moisture storage variations over Lake Chad Basin

Results and Discussions cont'd

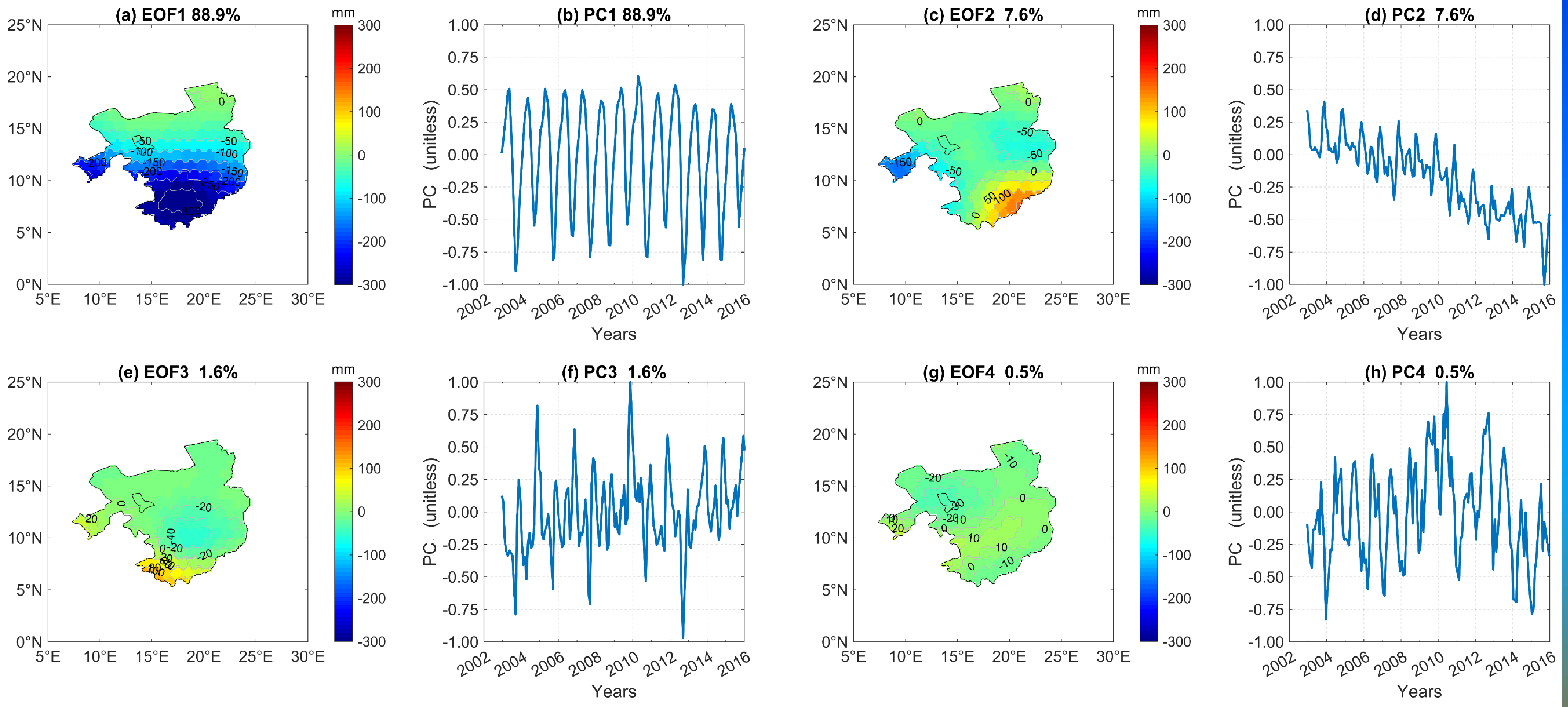

Figure: PCA decomposition for GRACE-TWS changes over Lake Chad Basin

Results and Discussions cont’d

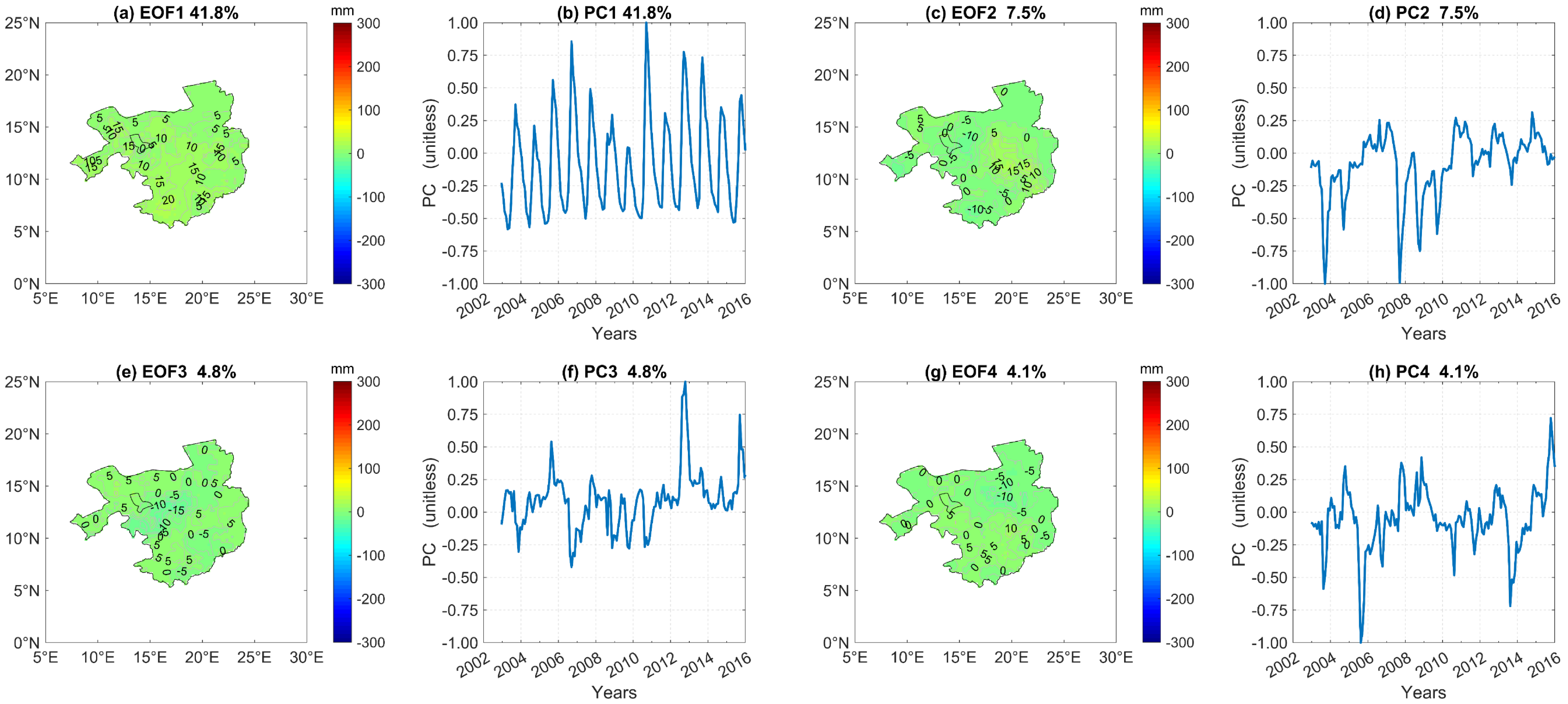

Figure: First four modes of EOFs and PCs resulting from PCA decomposition of WGHM groundwater storage

Results and Discussions cont'd

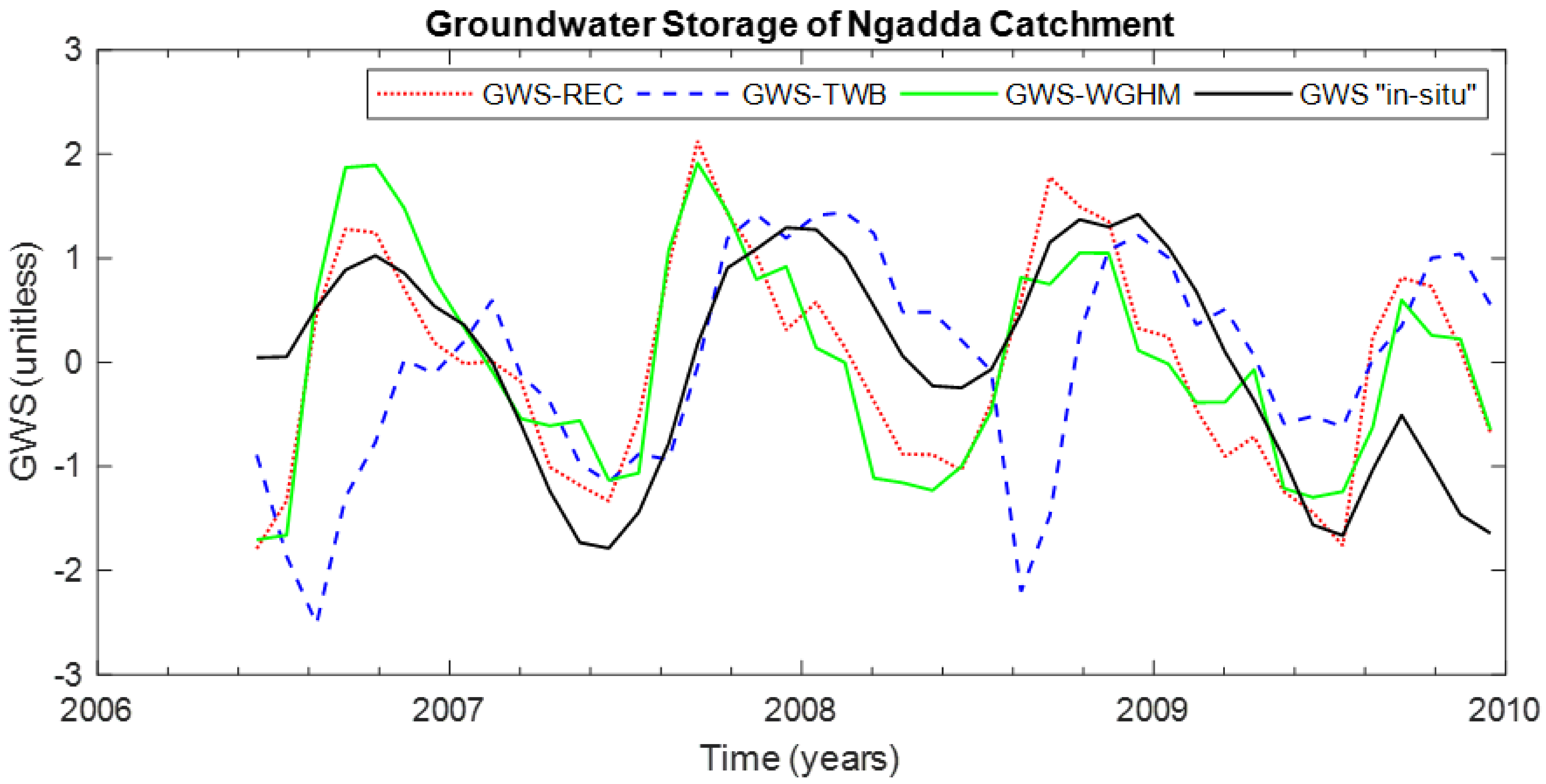

Figure: Comparisons between the in-situ (solid black line) and the evaluated groundwater series, that is, the reconstructed (red small dashed line), TWS-budget equation (blue dashed line) and WGHM (green solid line) groundwater series.

Results and Discussions cont'd

Table : Comparison between "in-situ" and the evaluated groundwater storage

Indices / Variables	Correlation coefficient (CC)	Standard deviation (SD)	Nash-Sutcliffe efficiency (NSE)
GWS-Reconstructed	0.60	0.89	0.21
GWS-TWS budget	0.28	1.20	-0.45
GWS-WGHM	0.56	0.94	0.12

- Improvement between the reconstructed and TWS-budget GWS is:
  - 114%, 26% and 147% for CC, SD and NSE respectively.

- **Reconstructed-GWS performed well in Lake Chad Basin comparing to TWS-budget GWS.**

Conclusions

- Results from PCA decomposition for each sub-domain of TWS, revealed that water storage in LCB is controlled by sub-surface water since surface water seems to be insignificant,

- The dominant mode of TWS and SMS exhibited the increase in wetness from the northern to the southern part of the basin with values ranging from 0 to -300 mm and 0 to -200 mm respectively,

Recommendations

- For altimetry-imagery derived SWS, satellite with high-quality images and DEMs are proposed for the extraction and delineation of surface area.

- Since this study was conducted on a single lake, future work could consider other surface water reservoirs in Africa such as east African great lakes where the surface water is significant.

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