Multivariate forecasting of water storage change for West-Africa using sea surface temperature and GRACE data

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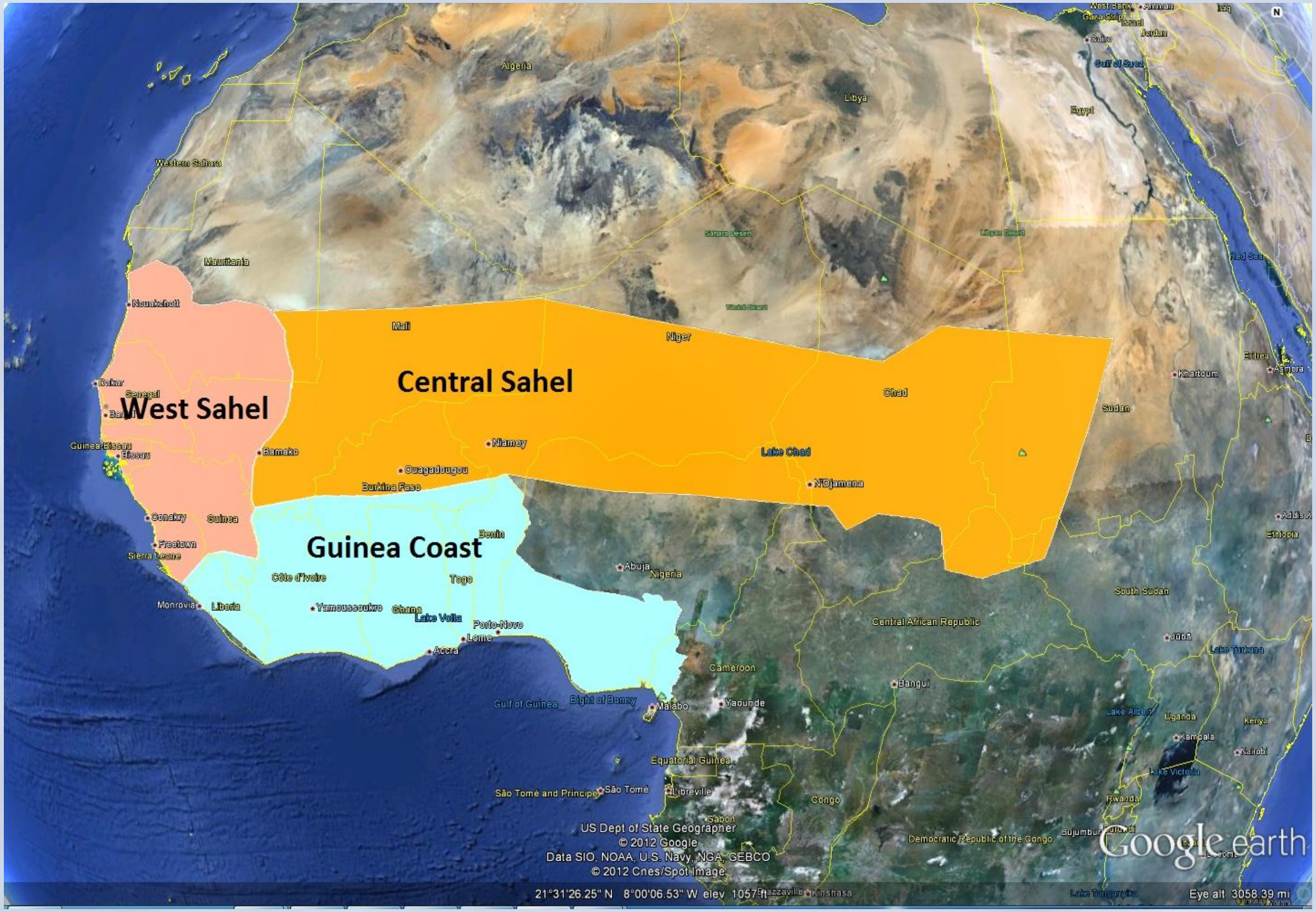
- West African countries are highly water-interdependent, with 17 countries sharing 25 trans-boundary river basins.



(According to: Fink et al., 2002)

- Drier conditions for the West Sahel and Central Sahel since the 1970s to at least 2000.

Rainfall Anomalies:

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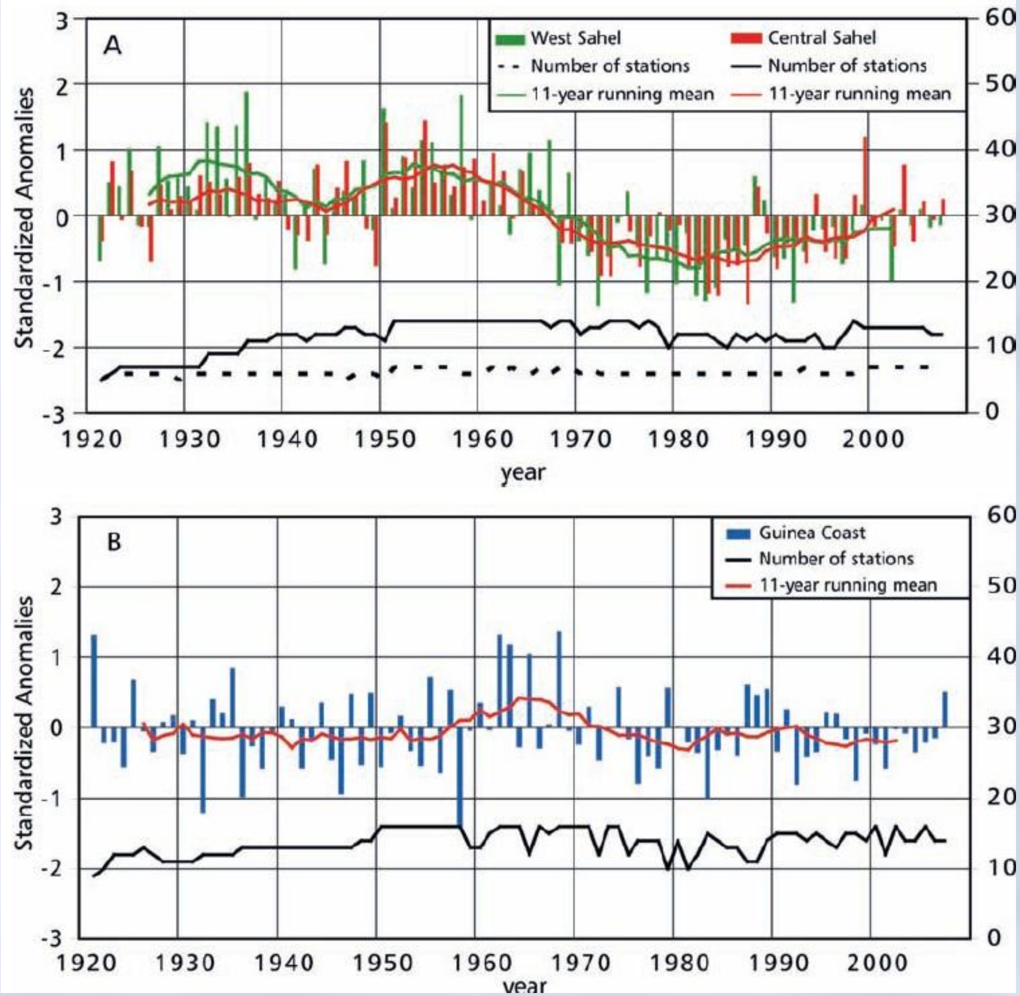


(Source: West African Atlas, Fink et al., 2002)

Knowledge concerning the hydrological cycle all in relation to climate change is essential for West African water resource management.

Data:

- Direct (in-situ) observations ➡ data are sparse
- Remote sensing observations

Model:

- Climate models ➡ uncertain (FAO, 2008)

e.g. phase problem of rainfall predictions

- Hydrological models ➡ not accurate within inter-annual time scales (Grippa et al., 2011)

Motivation

Goal

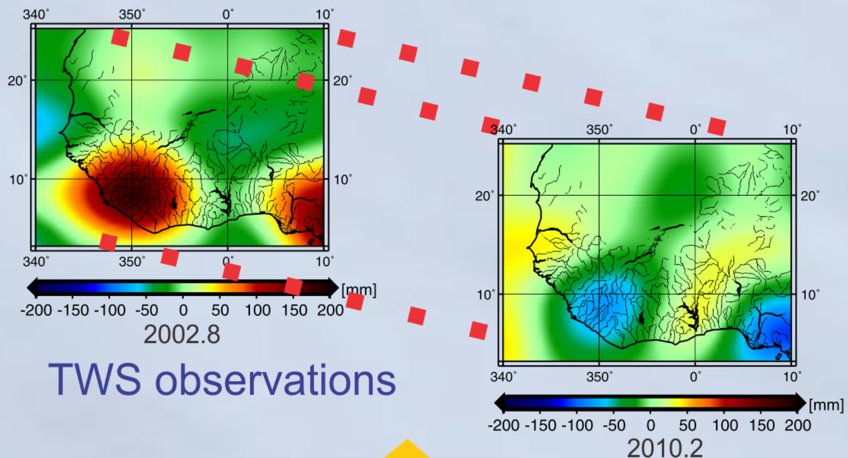
Forecasting Total Water Storage (TWS) variations of West Africa using remote sensing observations.

- Spatial scale: few-hundred kilometer
- Temporal scale: monthly based, up to a few years
- Why TWS? ⟹ GRACE provide accurate TWS
  - TWS is a key component of the hydrological cycle
  - It can be used for understanding the long-term effects of drought (Houborg et al., 2011)

The suggested method can be used for gap-filling of GRACE-TWS products over West Africa!

GRACE-TWS variations from GFZ centre, smoothed by Kusche et al. (2009)'s DDK2 filter

Predictands

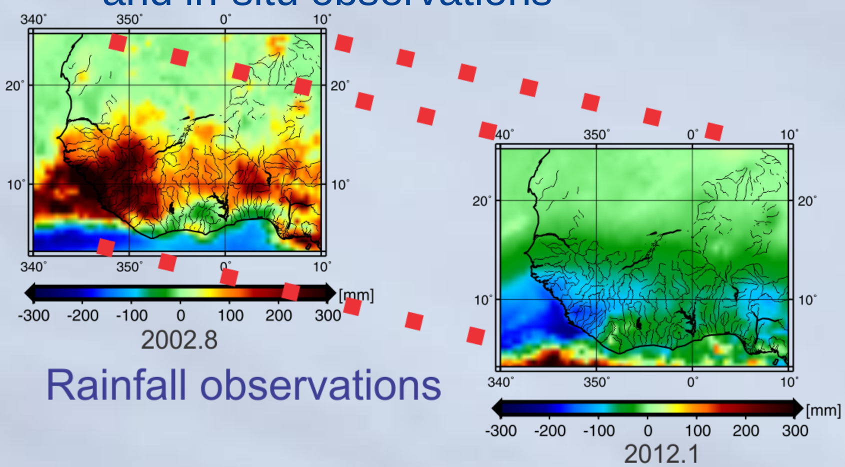


Forecast

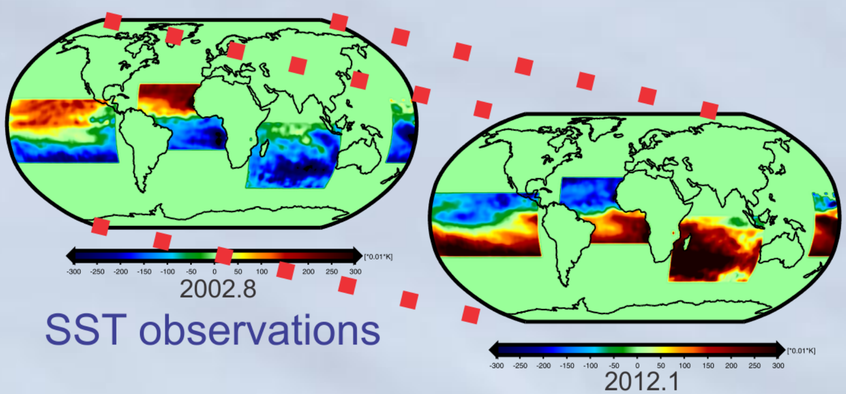
Relation

Predictors

TRMM-V7, a combination of satellite and in-situ observations

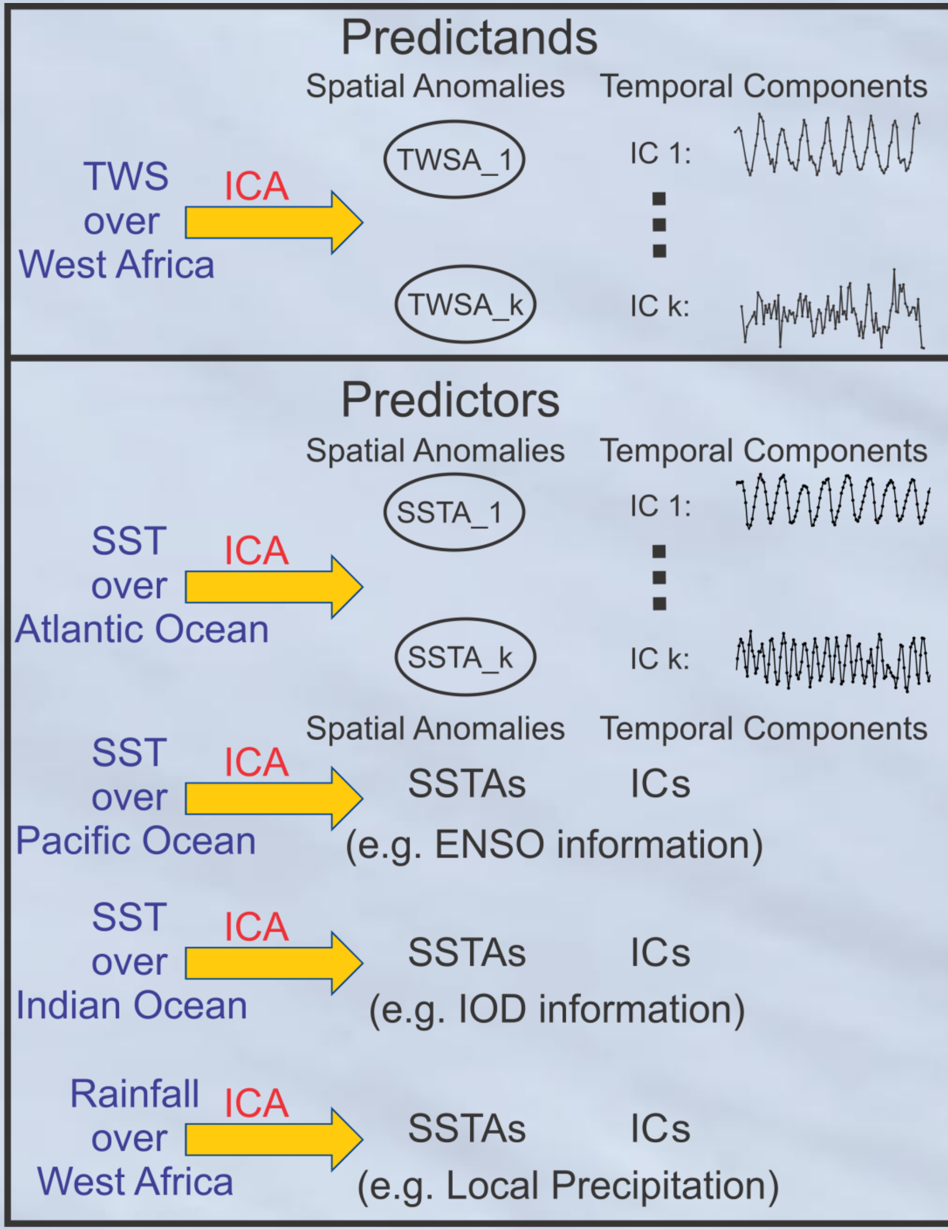


Reconstructed Reynolds SST from NOAA

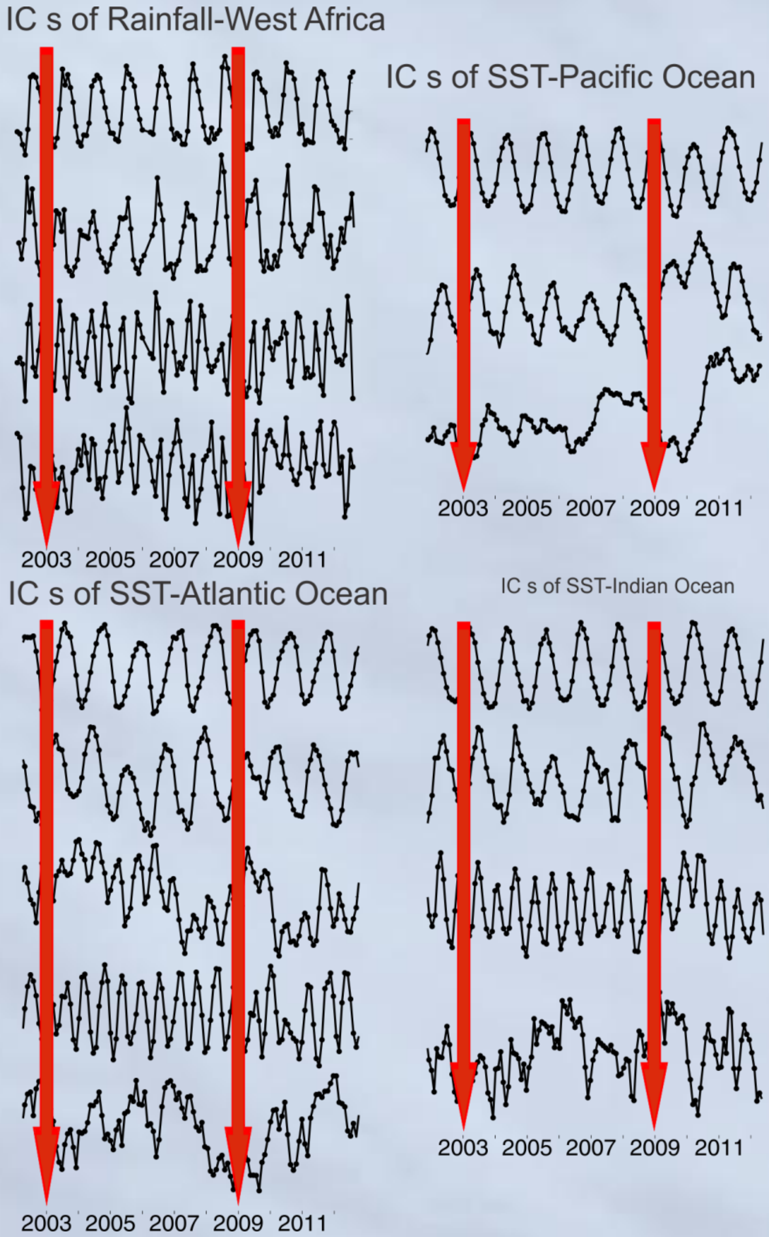


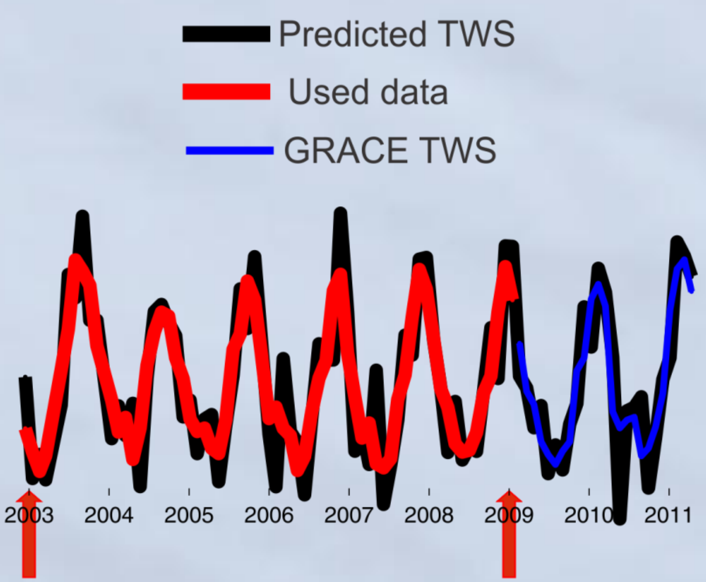
Multivariate Statistical Forecasting

- Using the higher order statistical method of Independent Component Analysis (ICA) for transforming predictands and predictors(Forootan and Kusche, 2012a)
- The forecast model is univariate in the “Predictand Space”.
- The forecast model is multivariate in the “Predictor Space”.



Modeling Concept





- Statistical modeling: Relating predictors and predictands, using an AutoRegressive (AR) Process

2-Steps ICA Algorithm for Transformation

Step1: PCA

$$F(t,s)_{n\times m} = \mathrm{P\Lambda E}^T$$

Step2: Rotation

$$F(t,s)_{n\times m} = F(t,s)_{n\times m} = \mathrm{PR\Lambda R}^T\mathrm{E}^T = \mathrm{AS}^T$$

Selected: diagonality of 4th-order cumulants

(Forootan and Kusche, 2012a,b)

Error estimation

A Monte Carlo error estimation can be used to estimate the uncertainties of the derived independent components.

Temporal vs. Spatial ICA

Temporal ICA: Rotation of PCs

$$x = \mathrm{P}_k\mathrm{R}$$

Spatial ICA: Rotation of EOFs

$$x = \mathrm{E}_k\mathrm{R}$$

(see Forootan et al., 2012)

2-Steps ICA Algorithm for Transformation

Step1: PCA

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Temporal vs. Spatial ICA

Temporal ICA: Rotation of PCs

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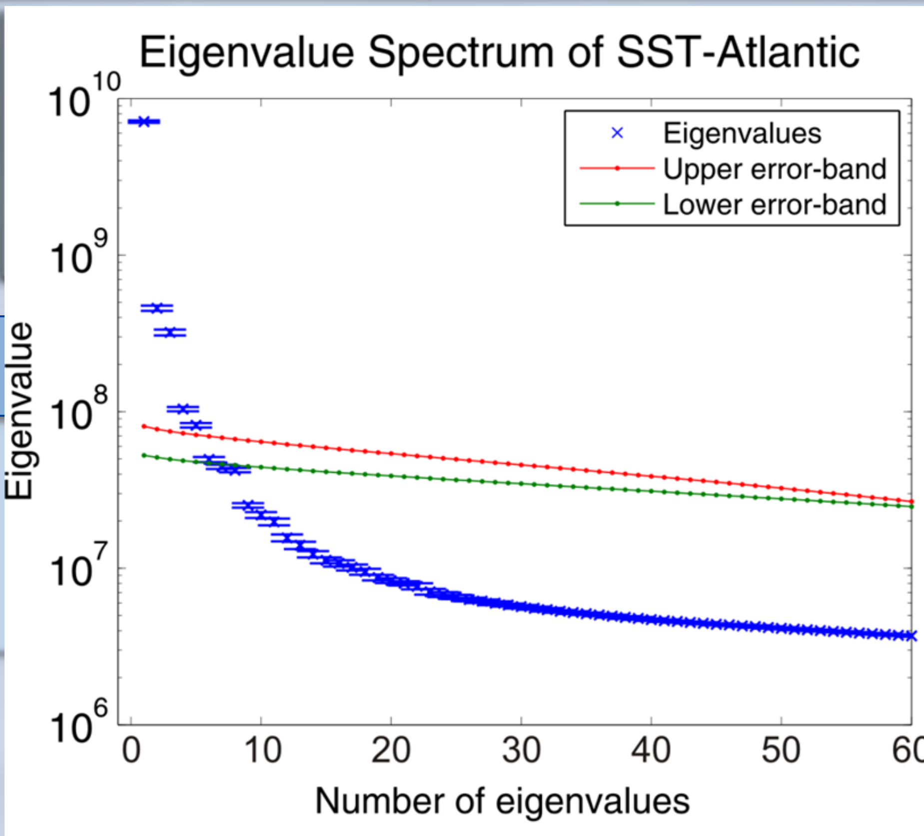
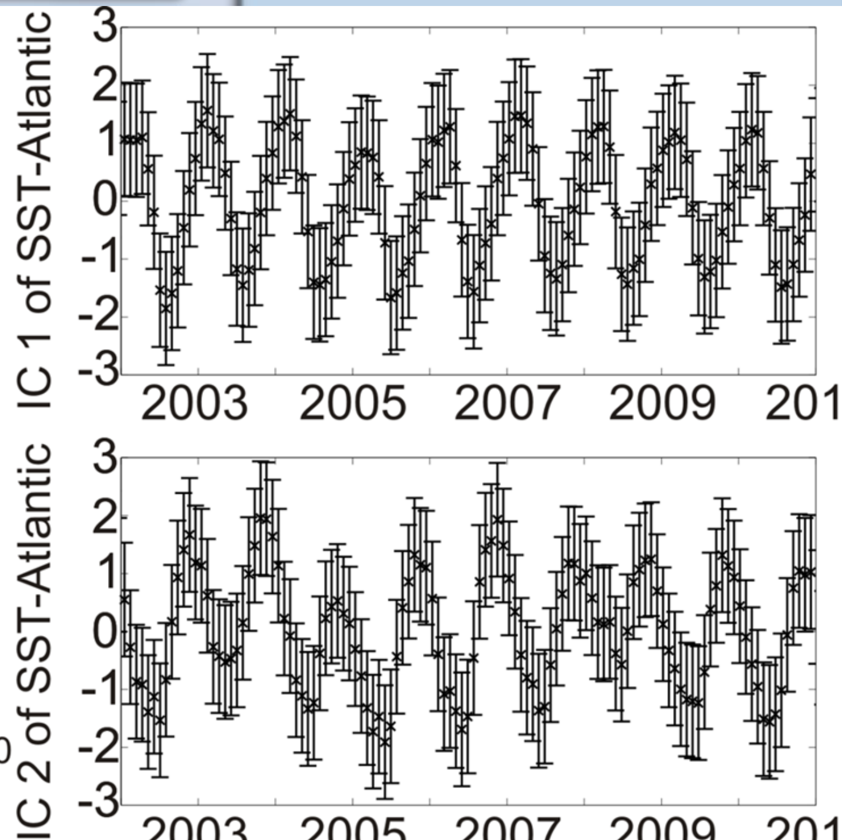
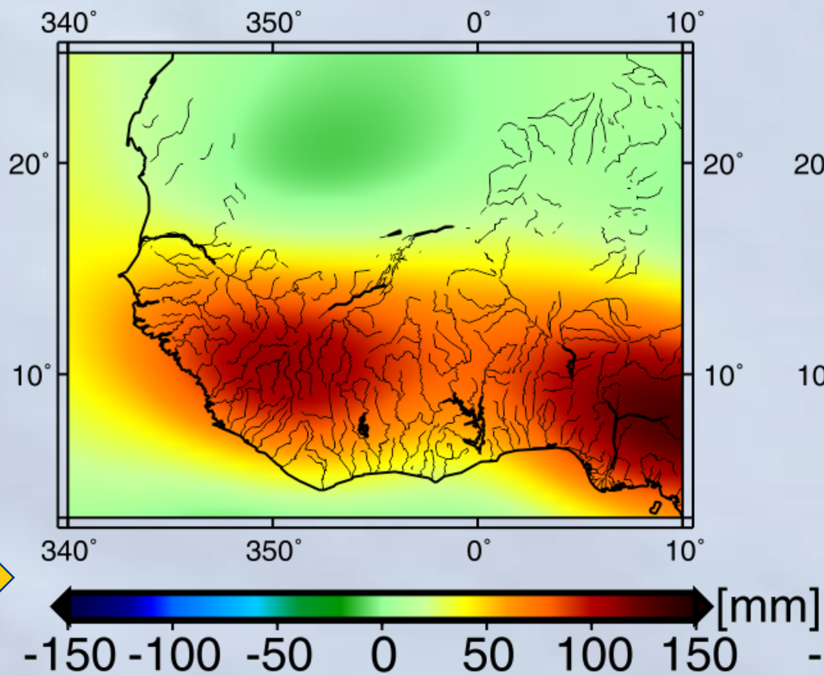




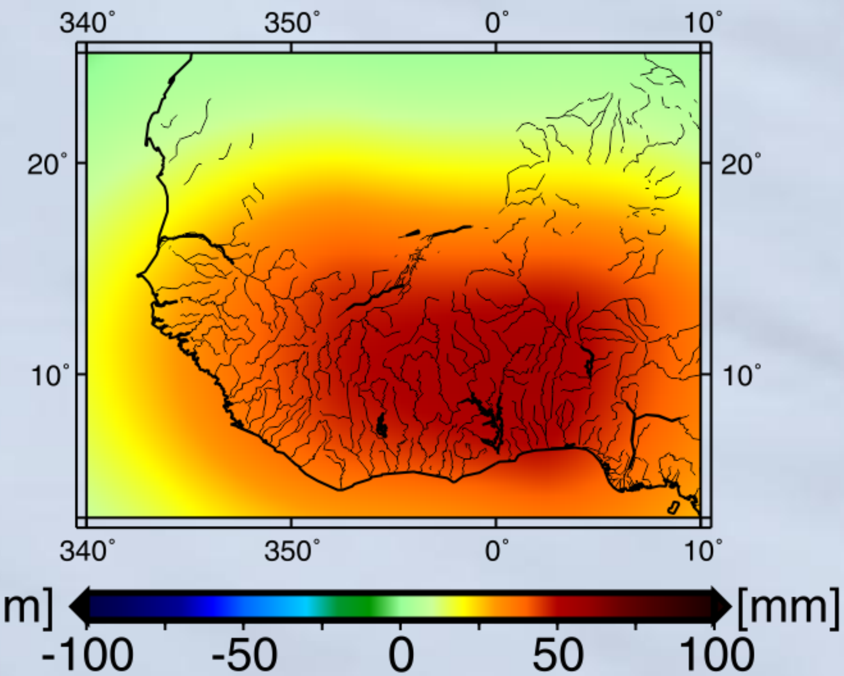
ICA Results - TWS

ICA of TWS

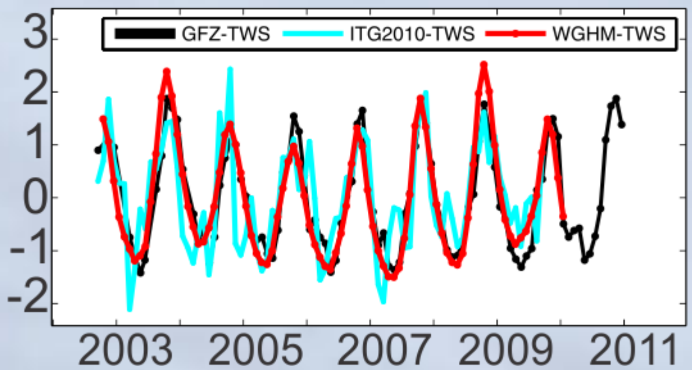
Spatial pattern of IC 1-GRACE



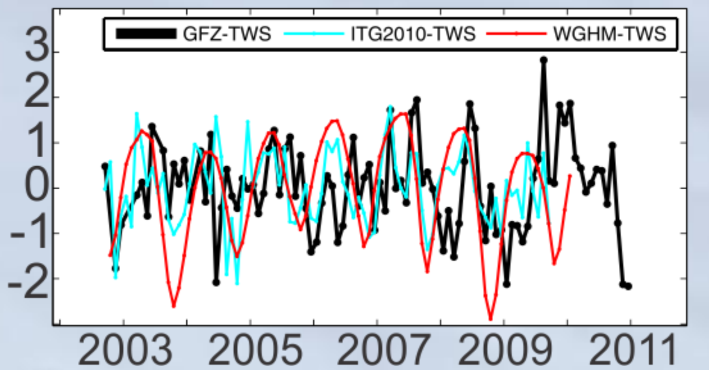
Spatial pattern of IC 2-GRACE



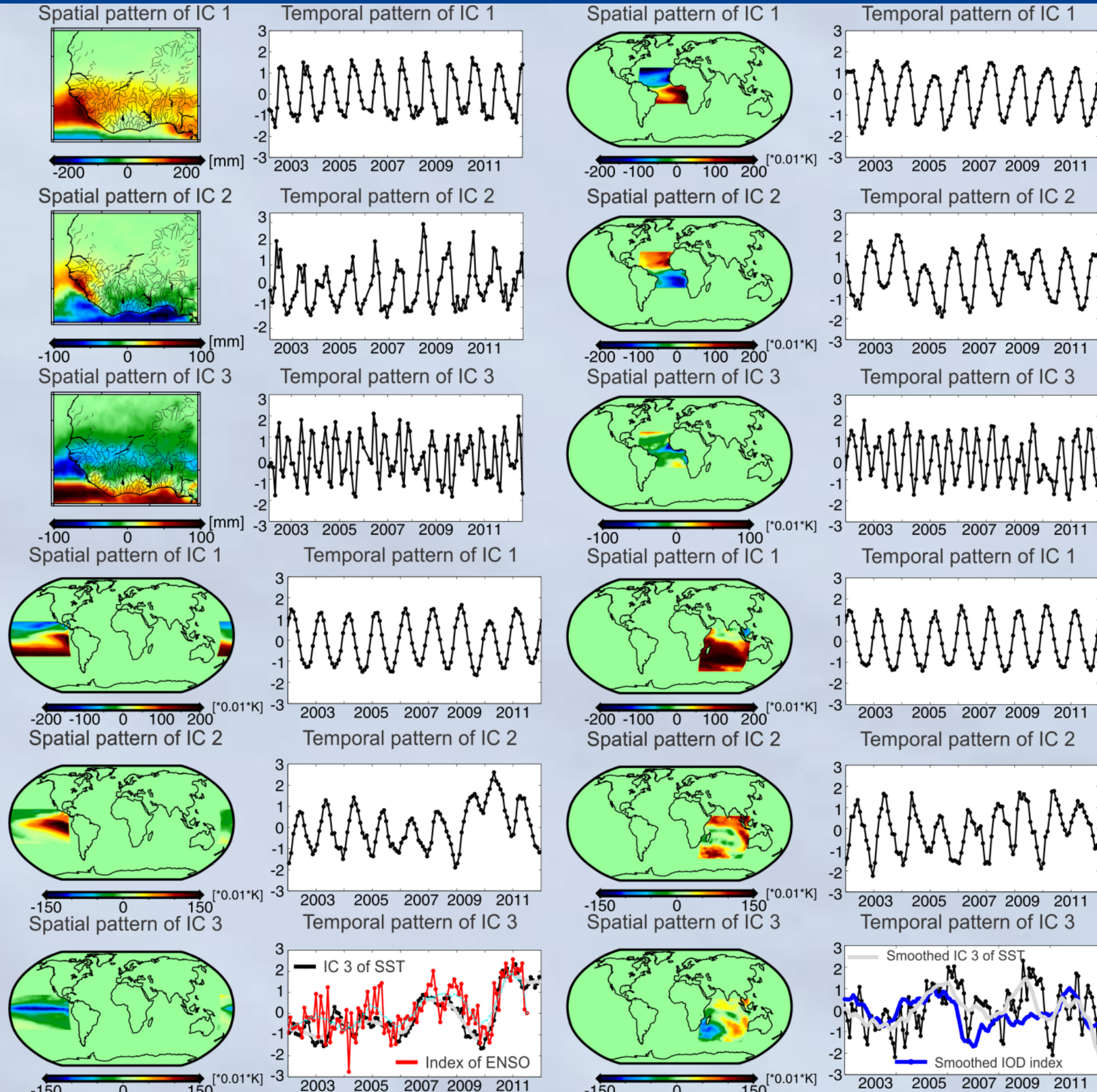
Temporal pattern of IC 1-GRACE



Temporal pattern of IC 2-GRACE



ICA Results - TWS



Highly correlated with the annual variability of TWS (TWS-IC1)

ICA of Predictors

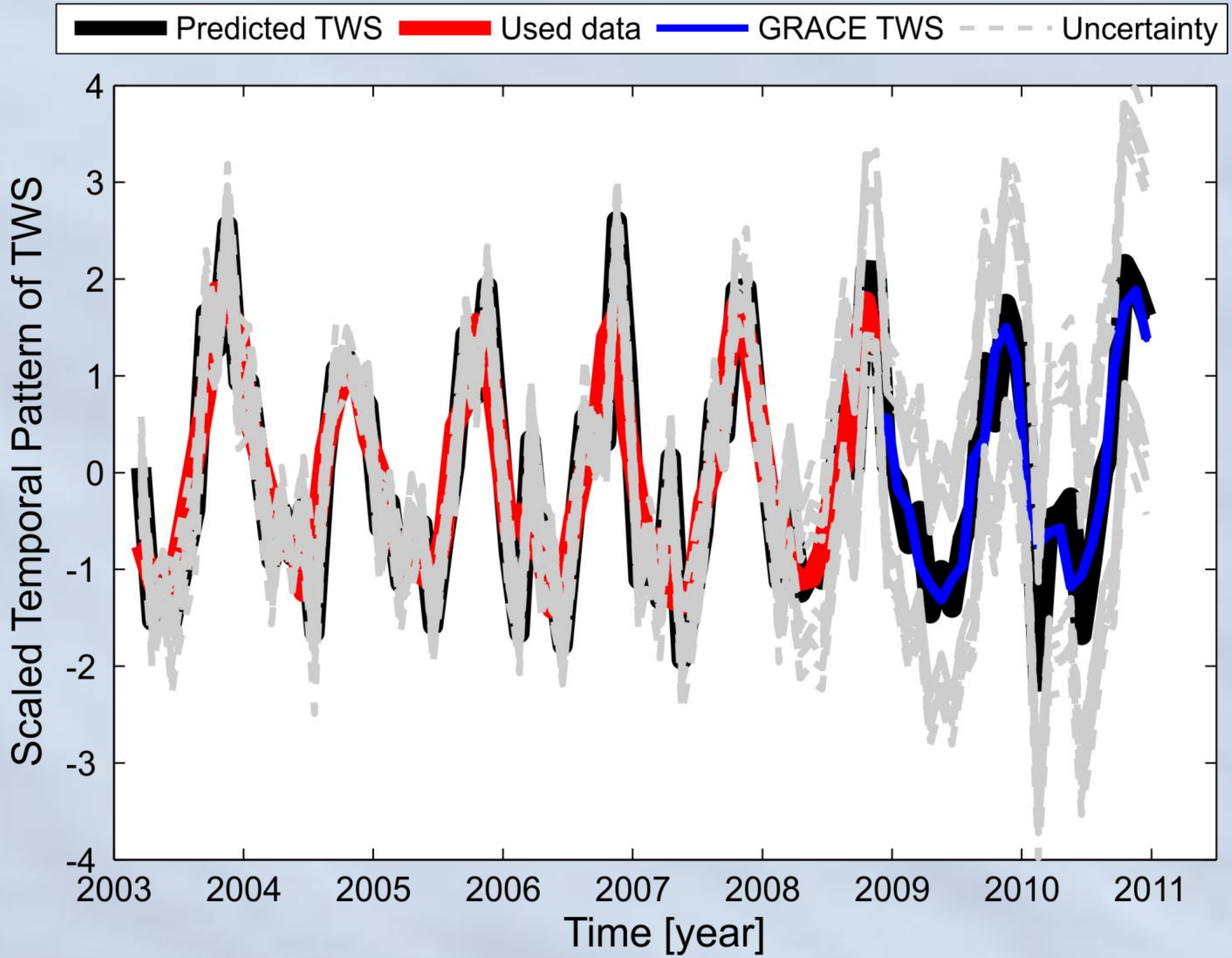
El Niño Southern Oscillation (ENSO)

Indian Ocean Dipole (IOD)

Forecasting Results

Simulation Fit: 92%

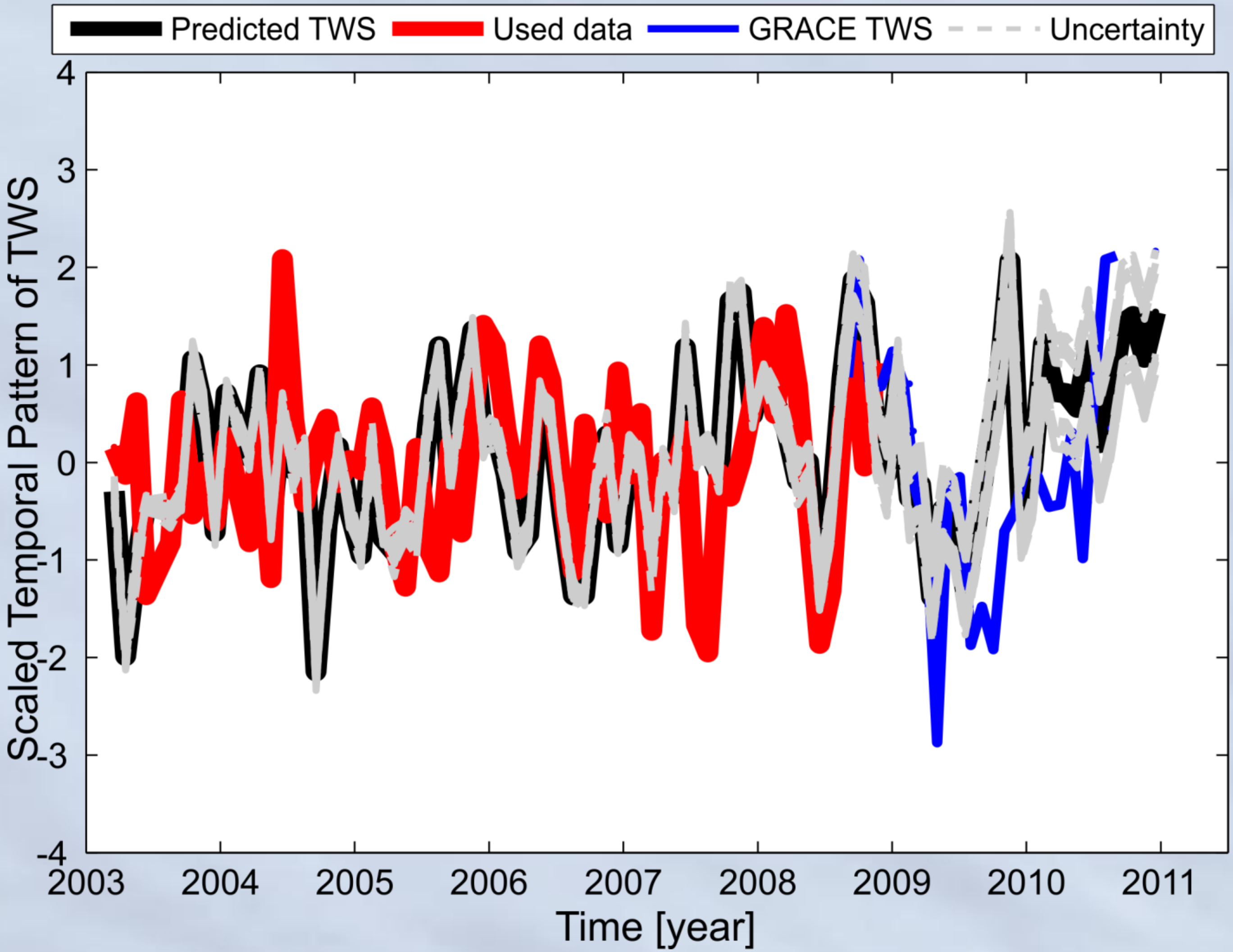
1-year Forecast Fit: 79%   2-year Forecast Fit: 63%



Forecasting Results

Simulation Fit: 83%

1-year Forecast Fit: 67%   2-year Forecast Fit: 58%



Summary & Discussion

- The amplitude of annual TWS variations over West-Africa is mainly correlated to SST variations of the Atlantic Ocean
- The long-term and inter-annual variability of West-African TWS is controlled with the ENSO phenomenon
- A Multivariate Statistical Forecast can be used for forecasting TWS over West Africa
  - Applying an Auto-Regressive (AR) algorithm,

  Predictors: ICs of SST over the Atlantic, Pacific and Indian Oceans
  Predictors: ICs of rainfall over West Africa
  Predictands: ICs of GRACE-TWS over West Africa

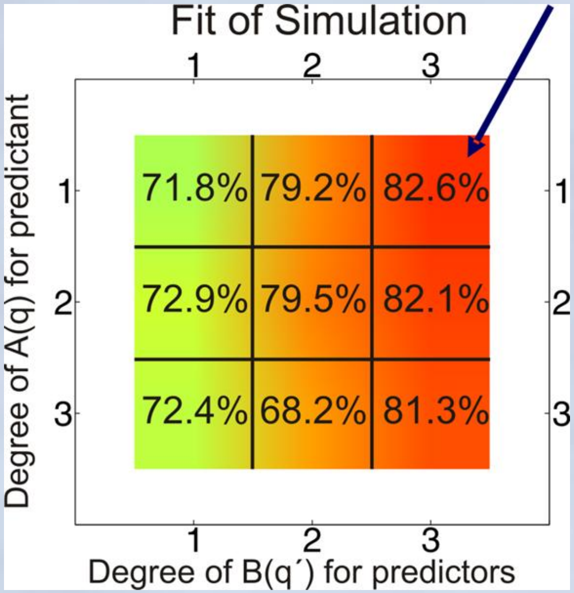
  - Results showed a reliable performance of the forecast up to two years
- The forecasting method can be used for gap-filling of GRACE-TWS over West Africa

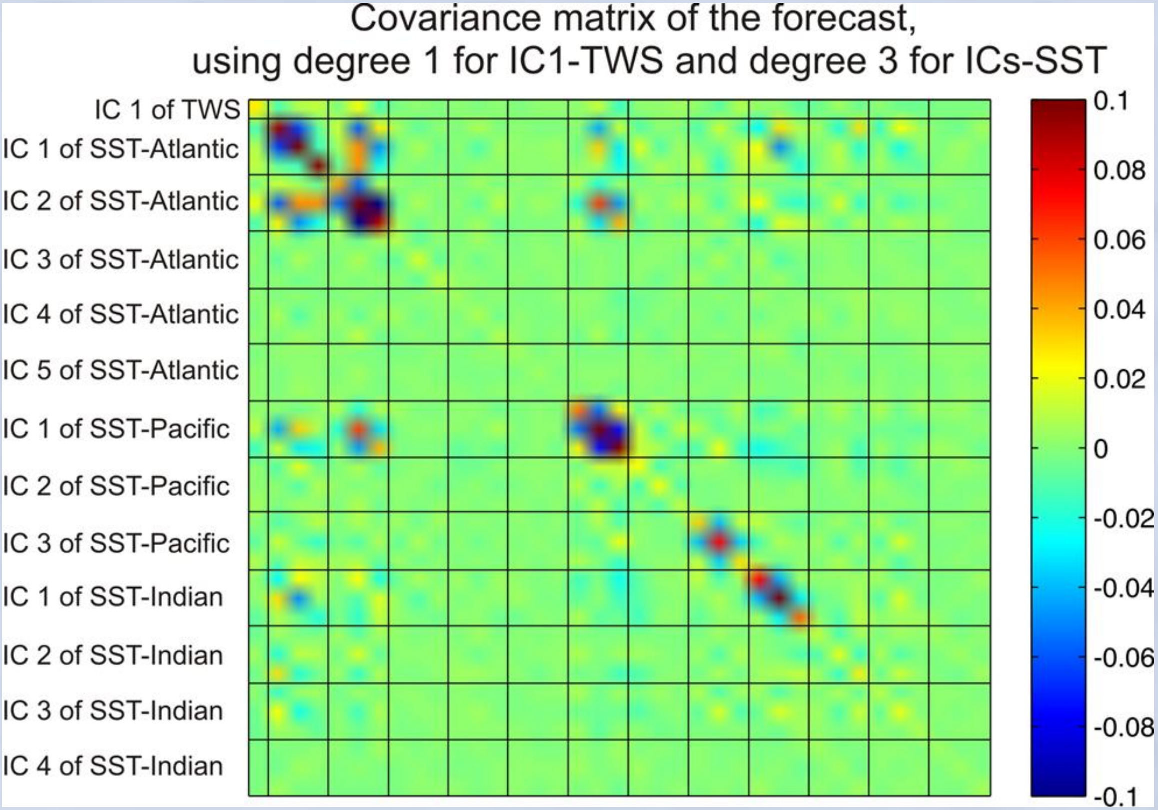
Thanks for your attention

- Main references:

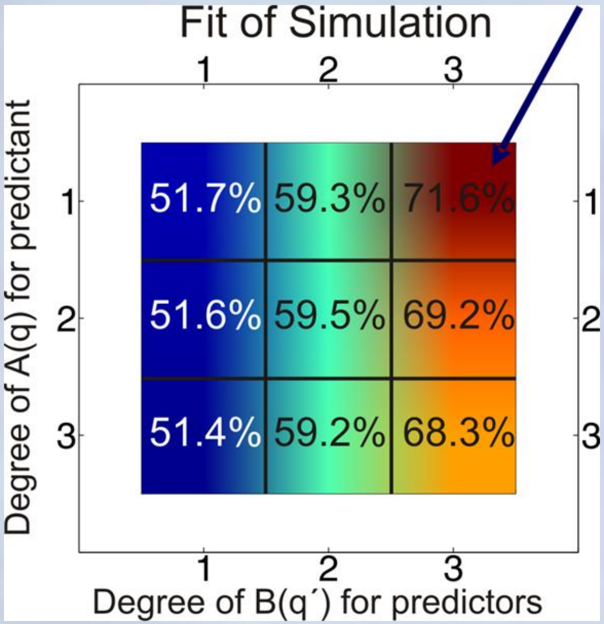
1. Forootan, E., Kusche, J. (2012a). Separation of global time-variable gravity signals into maximally independent components, Journal of Geodesy, Vol.86 (7), 477-497, doi:10.1007/s00190-011-0532-5.
2. Forootan, E., Kusche, J. (2012b). Separation of deterministic signals, using independent component analysis (ICA). Journal of Studia Geophysica et Geodaetica, doi: 10.1007/s11200-012-0718-1.
3. Forootan, E., Awange, J., Kusche, J., Heck, B., Eicker, A. (2012). Independent patterns of water mass anomalies over Australia from satellite data and models. Journal of Remote Sensing of Environment,Vol.124, 427-443, doi:0.1016/j.rse.2012.05.023.
4. Kusche ,J., Schmidt ,R., Petrovic, S., Rietbroek, R. (2009). Decorrelated GRACE time-variable gravity solutions by GFZ, and their validation using a hydrological model. Journal of Geodesy, Vol.83, 903–913.,doi:10.1007/s00190-009-0308-3

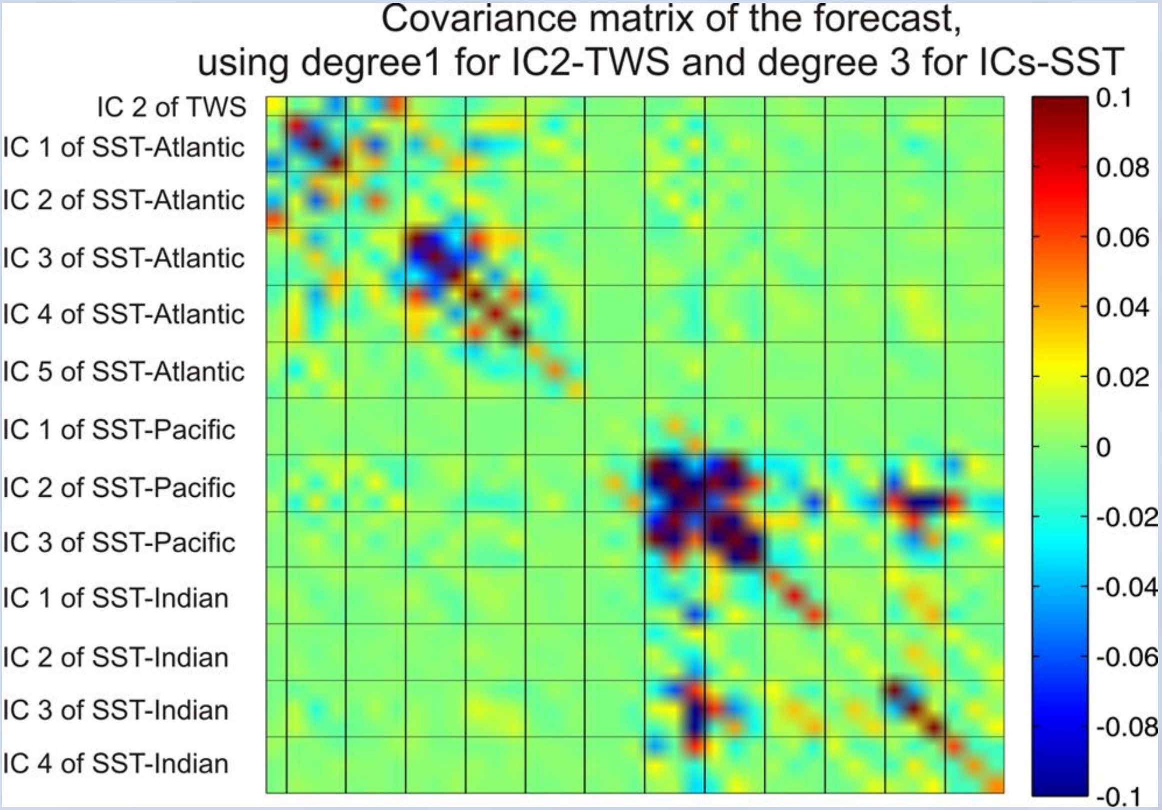
Fit of the Model





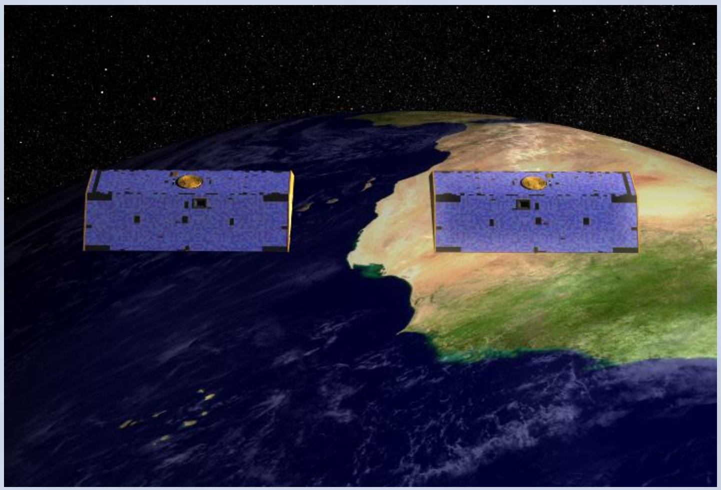
Fit of the Model

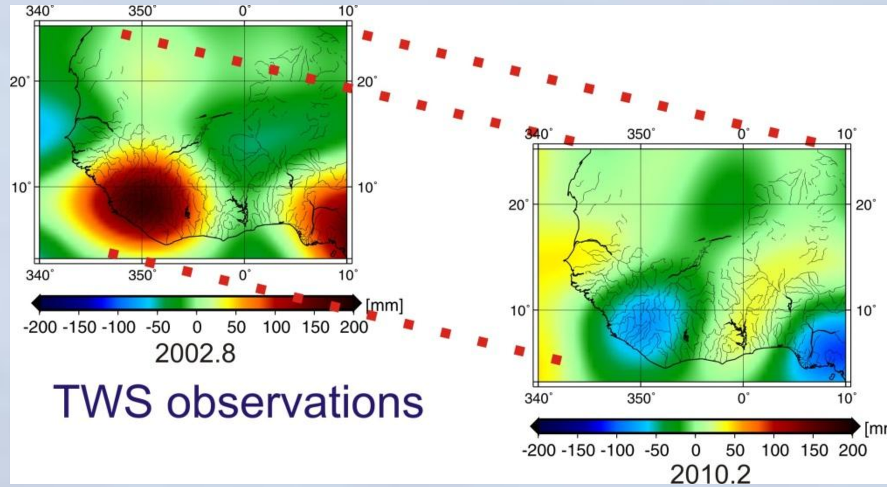




Predictands

TWS changes



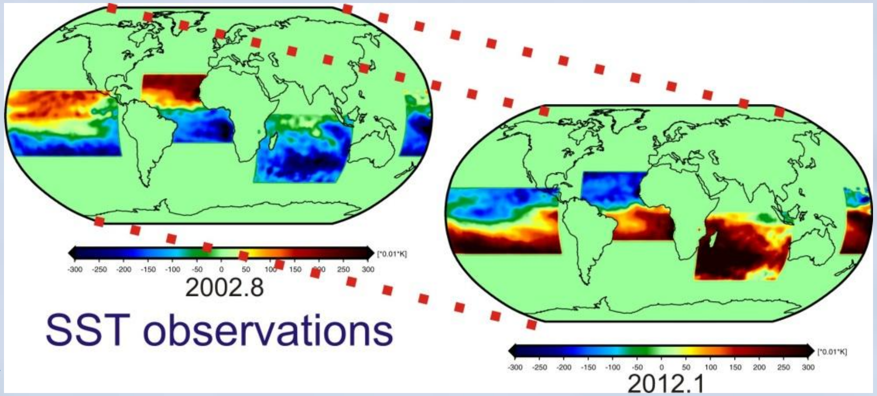


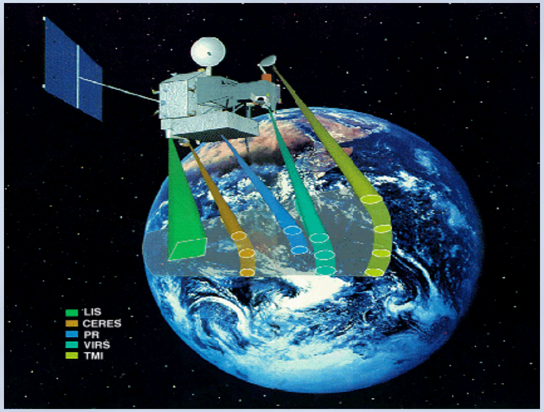
GRACE-TWS variations from GFZ centre, smoothed by Kusche et al. (2009)'s DDK2 filter

Predictors (Indicators)

Reconstructed Reynolds SST from NOAA

Monthly SSTs





TRMM-V7, combination of satellite and in-situ observations

Monthly Rainfalls