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

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AGU 2012, 3-7 Dec 2012, San Francisco, CA, USA
• West African countries are highly water-interdependent, with 17 countries sharing 25 trans-boundary river basins. (According to: Fink et al., 2002)
Introduction

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

Rainfall Anomalies:

(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-anual time scales (Grippa et al., 2011)
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!
Multivariate Forecasting of Water Storage

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

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

Reconstructed Reynolds SST from NOAA

Rainfall observations

SST observations

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6 December 2012
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”.

- 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”.
Statistical modeling: Relating predictors and predictands, using an AutoRegressive (AR) Process
2-Steps ICA Algorithm for Transformation

**Step 1: PCA**

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

**Step 2: Rotation**

\[ F(t, s)_{n \times m} = F(t, s)_{n \times m} = PRAR^T E^T = AS^T \]

Selected: diagonality of 4th-order cumulants
(Forootan and Kusche, 2012a,b)

**Temporal vs. Spatial ICA**

Temporal ICA: Rotation of PCs

\[ x = P_k R \]

Spatial ICA: Rotation of EOFs

\[ x = E_k R \]

(see Forootan et al., 2012)

**Error estimation**

A Monte Carlo error estimation can be used to estimate the uncertainties of the derived independent components.
2-Steps ICA Algorithm for Transformation

Step1: PCA

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

Step2: Rotation

Temporal vs. Spatial ICA

Temporal ICA: Rotation of PCs

\[ x = P \epsilon R \]

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ICA Results - 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

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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%
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:**


Fit of the Model

Covariance matrix of the forecast, using degree 1 for IC1-TWS and degree 3 for ICs-SST

Fit of Simulation

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<th>Degree of A(q) for predictant</th>
<th>1</th>
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<th>3</th>
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Degree of B(q') for predictors
Fit of the Model

Covariance matrix of the forecast, using degree 1 for IC2-TWS and degree 3 for ICs-SST

Fit of Simulation

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<tr>
<td>3</td>
<td>51.4%</td>
<td>59.2%</td>
<td>68.3%</td>
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Degree of B(q') for predictors

IC 1 of SST-Atlantic
IC 2 of SST-Atlantic
IC 3 of SST-Atlantic
IC 4 of SST-Atlantic
IC 5 of SST-Atlantic
IC 1 of SST-Pacific
IC 2 of SST-Pacific
IC 3 of SST-Pacific
IC 1 of SST-Indian
IC 2 of SST-Indian
IC 3 of SST-Indian
IC 4 of SST-Indian
Multivariate Forecasting of Water Storage

Predictands

TWS changes

GRACE-TWS variations from GFZ centre, smoothed by Kusche et al. (2009)’s DDK2 filter
Multivariate forecasting of water storage

Predictors (Indicators)

Reconstructed Reynolds SST from NOAA

Monthly SSTs

SST observations

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

Monthly Rainfalls

Rainfall observations

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