United Nations Educational, Scientific and Cultural Organization

International Hydrological Programme

GRAPHIC

Groundwater Resources Assessment under the Pressures of Humanity and Climate Change

UNIVERSITÉ DE RENNES 1

GEOSCIENCES Rennes

Assessing climate variability in large aquifers

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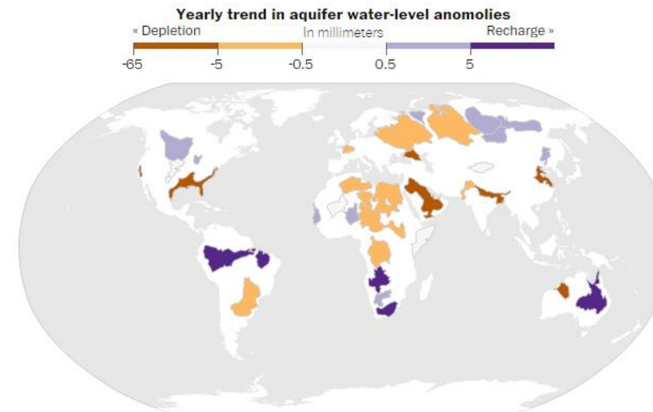
Context

The Washington Post

New NASA data show how the world is running out of water



Source: Water Resources Research

The New York Times

SCIENCE

World's Aquifers Losing Replenishment Race, Researchers Say

TECHNOLOGY

The Earth's Evaporating Aquifers

The Atlantic

NASA satellites are tracking the planet's underground fresh-water supply.

Context

- **Potential impacts of climatic oscillations on large aquifers dynamics have still not been largely addressed**
- **Large aquifers are often transboundary**
- **Badly managed groundwater resources could lead to potential intra and inter-States conflicts**
- **Lack of data, capacity and knowledge to assess the dynamics of large aquifers in the ground**

Challenges in a data-scarce setting

- **Need to be innovative**
  - *Use of gravity data supplied by satellites can provide a means to monitoring large scales changes in groundwater storage*

- **Need to validate satellite observations with ground data**
  - *Satellites will not replace monitoring networks*

- **Satellite time observations are limited in time**
  - *Need to “reconstruct” past groundwater level fluctuations in order to assess the impact of climatic oscillations and anthropogenic activities*

Main objective

- **Assess the impact of climate variability in large aquifers recharge <u>despite the lack of data</u> as a means to support sound management strategies**

- **Study within the framework of the UNESCO Groundwater and Climate Change (GRAPHIC) programme – www.graphicnetwork.net**

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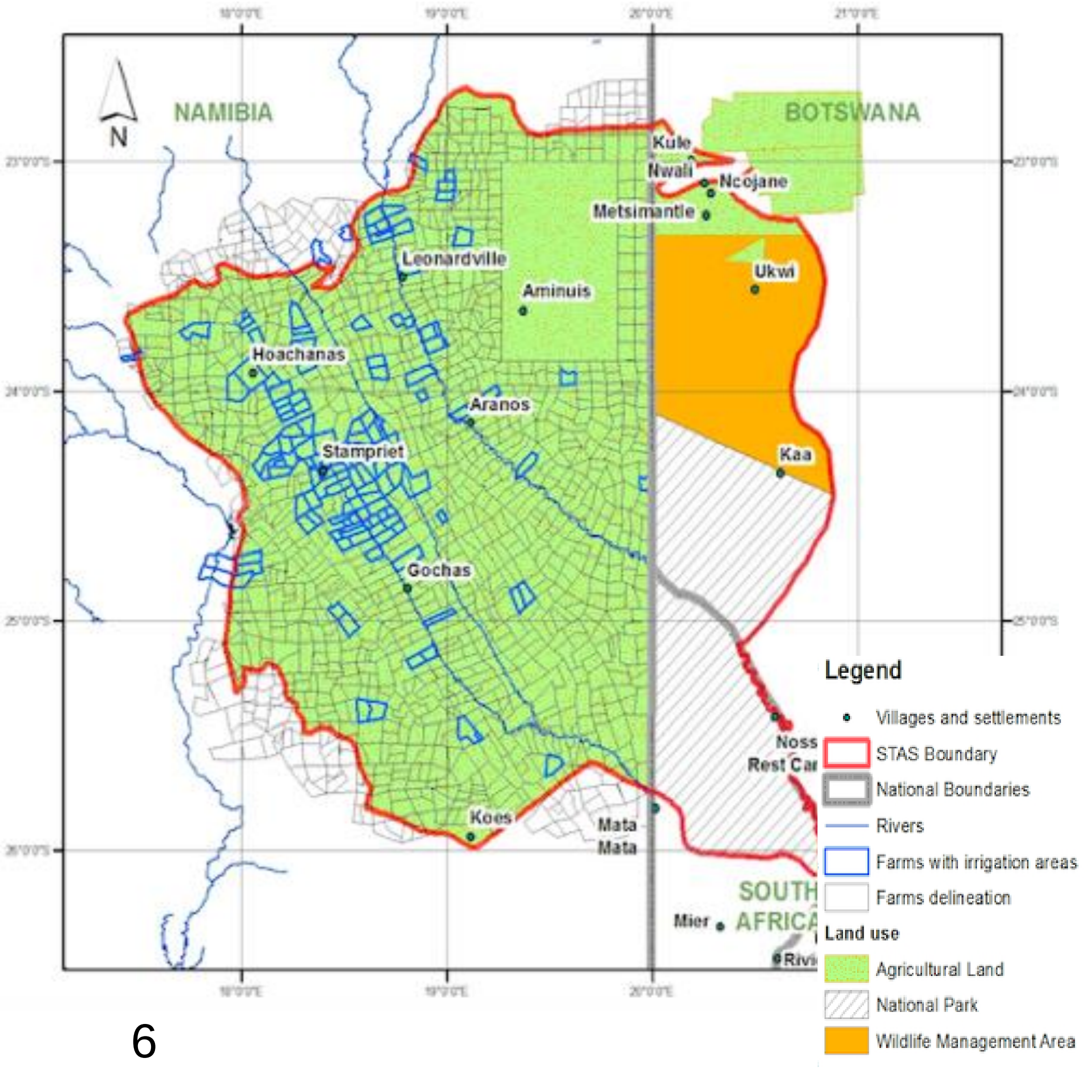
Starting point

Stampriet Transboundary Aquifer System (STAS) – Botswana, Namibia, South Africa



Stampriet Transboundary Aquifer System

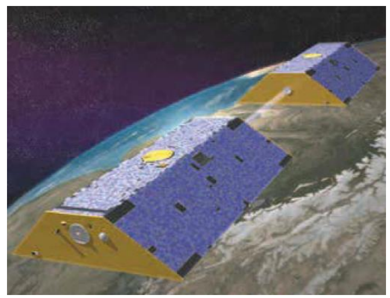
- **Semi-arid climate**
- **Area: 86 000 km^2 (=size of Switzerland)**
- **Rainfall: 150-300 mm/yr**
- **Groundwater is only reliable source of water (i.e. no surface water)**
- **No long-term groundwater depletion observed**

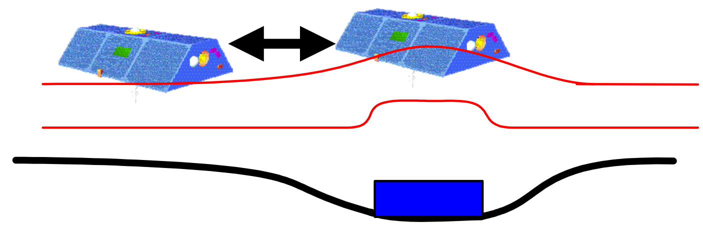
- **Main economic activities:**
  - *Agriculture and livestock (highly climate change dependent)*
- **70% of abstraction occurs from shallow and more vulnerable aquifers**

Methods and Data

1) Gravity Recovery and Climate Experiment (GRACE)

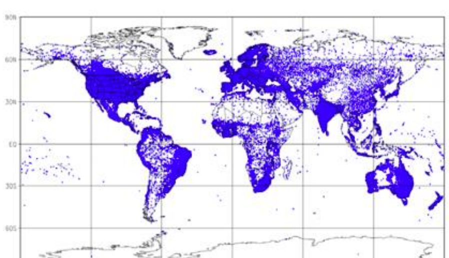
- *First satellite mission able to monitor total water-storage changes (including groundwater) remotely*
- *Launched in 2002*
- *Data available in $0.5^{o}x0.5^{o}$ grid in monthly basis*



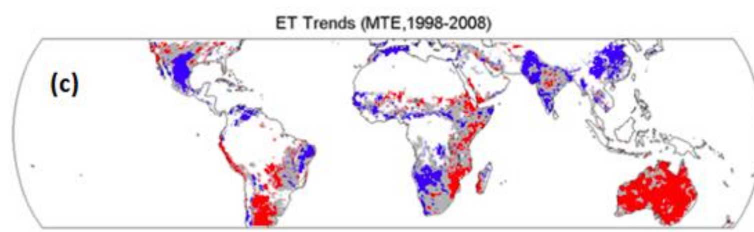


2) Simplified water balance model

- *Two variables: Precipitation and Actual Evapotrasnpiration*
- *Using only global datasets for precipitation and evapotranspiration*
- *Data available $0.5^{o}x0.5^{o}$ grid in monthly basis since 1982*



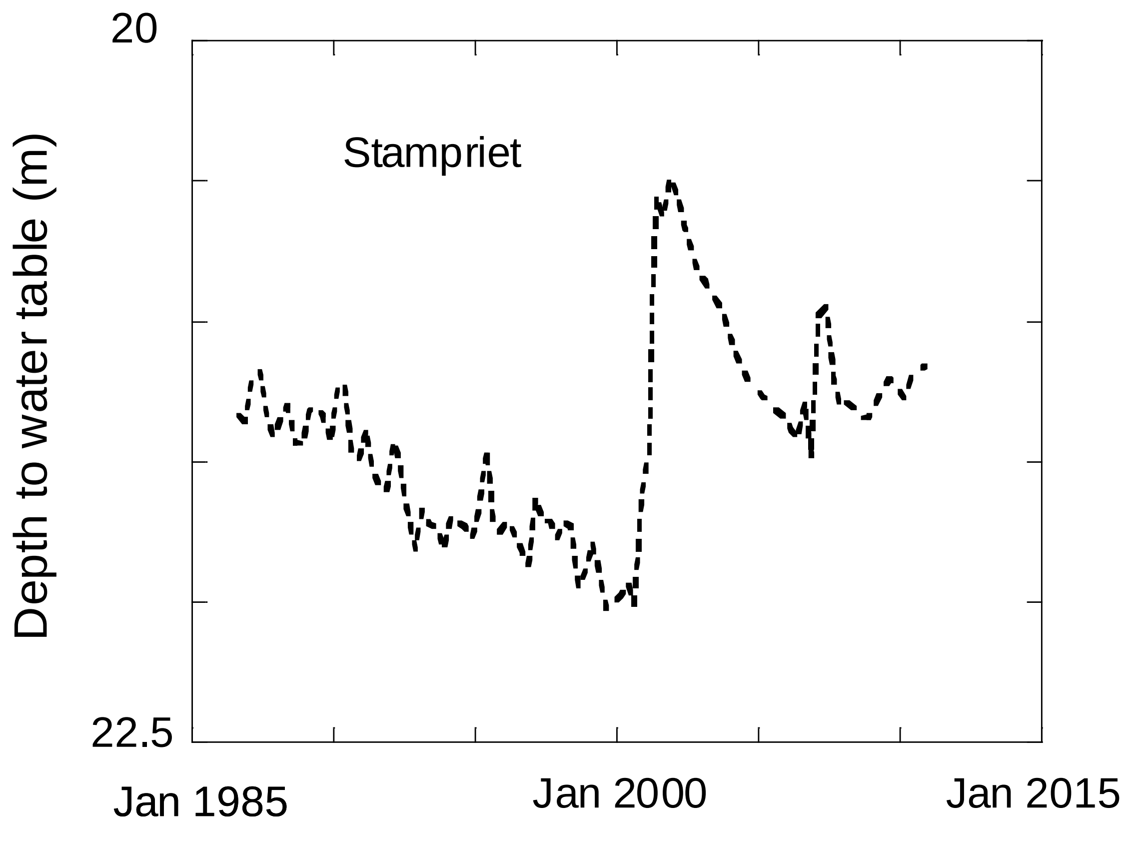
GPCC precipitation stations



1998-2008 - Actual evapotranspiration trends (Jung et al. 2010)

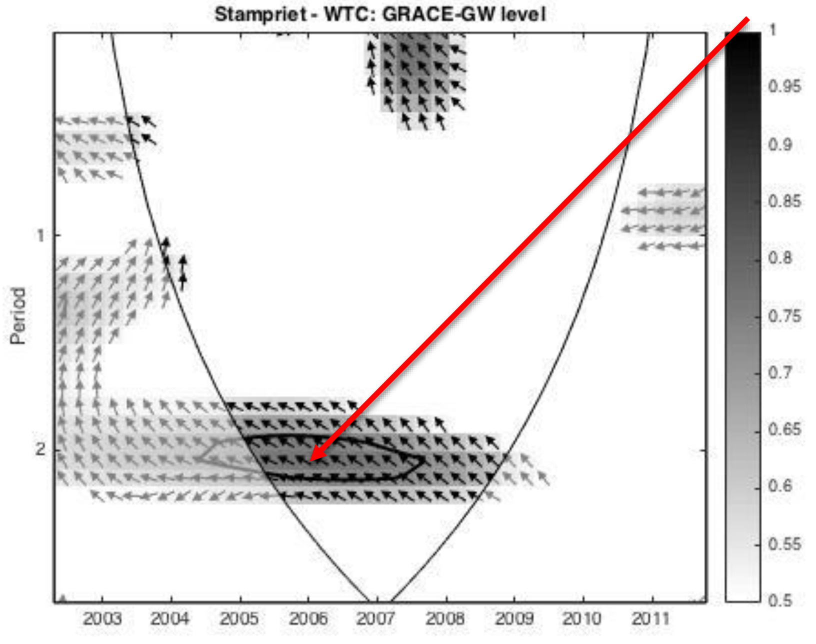
3) Reconstructed representative long-term observed groundwater level

- *Sandy Kalahari unconfined aquifers*



Gravity Recovery and Climate Experiment (GRACE)

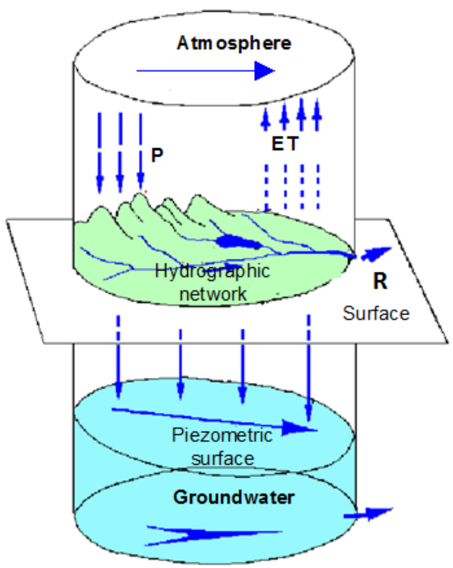
- **GRACE vs Observed groundwater level cross wavelet analysis (Grinsted et al. 2004)**
  - *2002 - 2011*
  - *Strong groundwater storage coherence in the 2 year period*



- **Main limitation:**
  - *GRACE observation timescale < some climatic oscillations*
  - *Need to "extend" GRACE time frame to the past with simplified models to "reconstruct" groundwater level fluctuations*

Simplified Water Balance Model

- **Mass balance equation applied at aquifer scale**
- **Assumption:**
  - *R = 0 contribution to storage as a linear trend. When estimating storage changes by integration of R, long-term trend is removed*



$$\frac{dS}{dt} = P - E - R$$

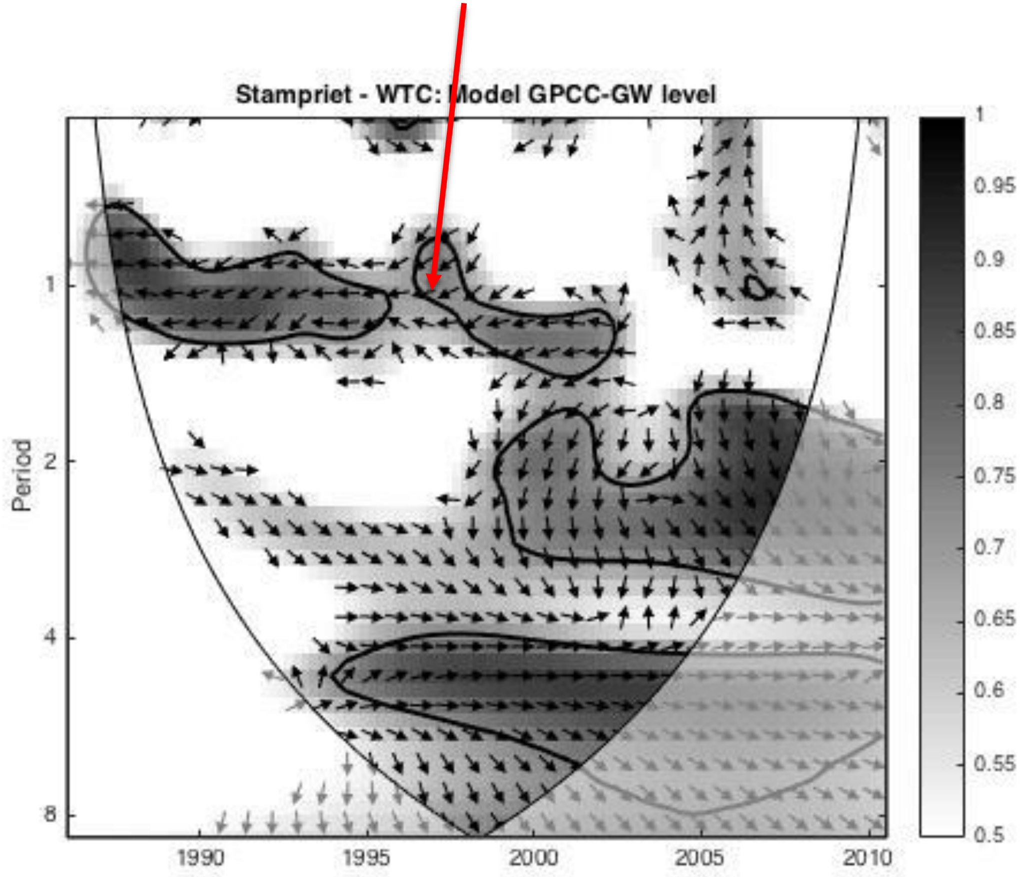
S	Total water storage change
P	Precipitation
E	Actual ET
R	Surface runoff

$$GWS_{model} \approx S_{model} = \int P\,dt - \int R dt - \int E\,dt \approx \text{detrend}\left(\int P\,dt - \int E\,dt\right)$$

- **Model allows extending evaluation time-frame to the last 30 years and therefore covers climatic oscillations cycles**

Simplified Water Balance Model

- **Model vs Observed groundwater level cross wavelet analysis (Grinsted et al. 2004)**
  - *1982 - 2010*
  - *Strong groundwater storage coherence in the 1 year period → good description of* ***<u>inter-annual storage variability</u>***

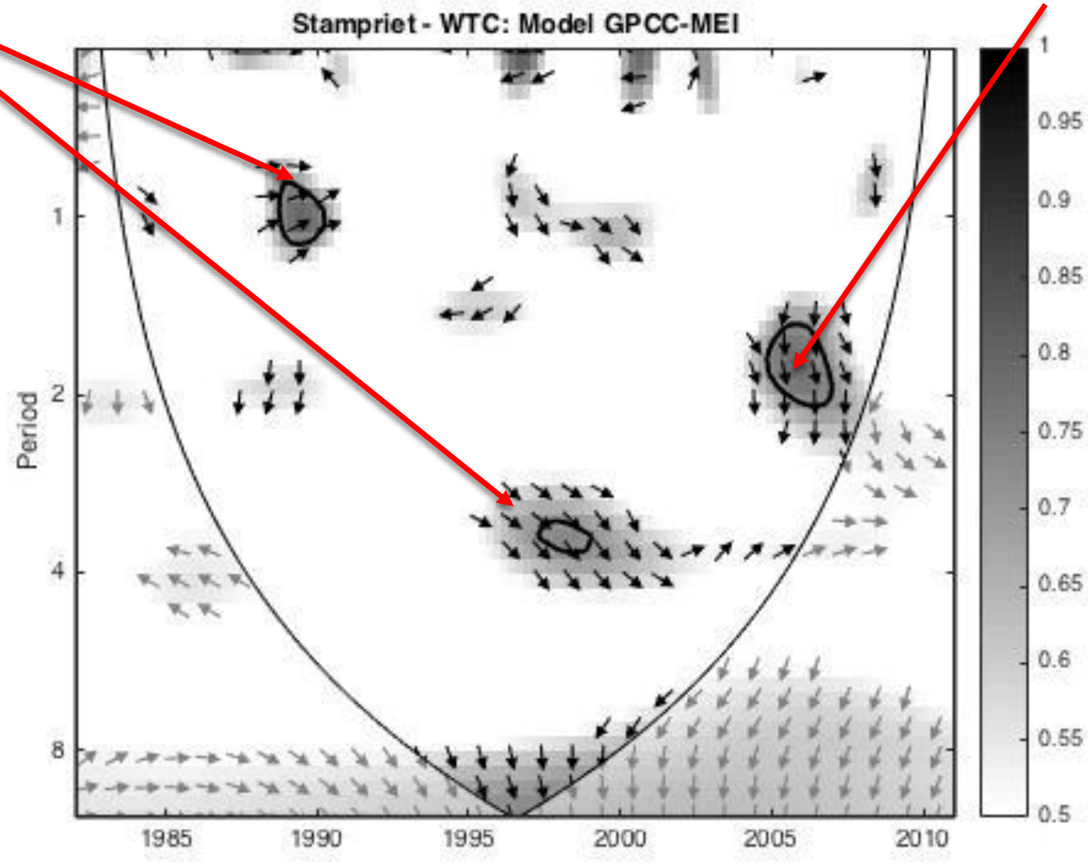


Simplified Water Balance Model

- **Model vs ENSO Index cross wavelet analysis**

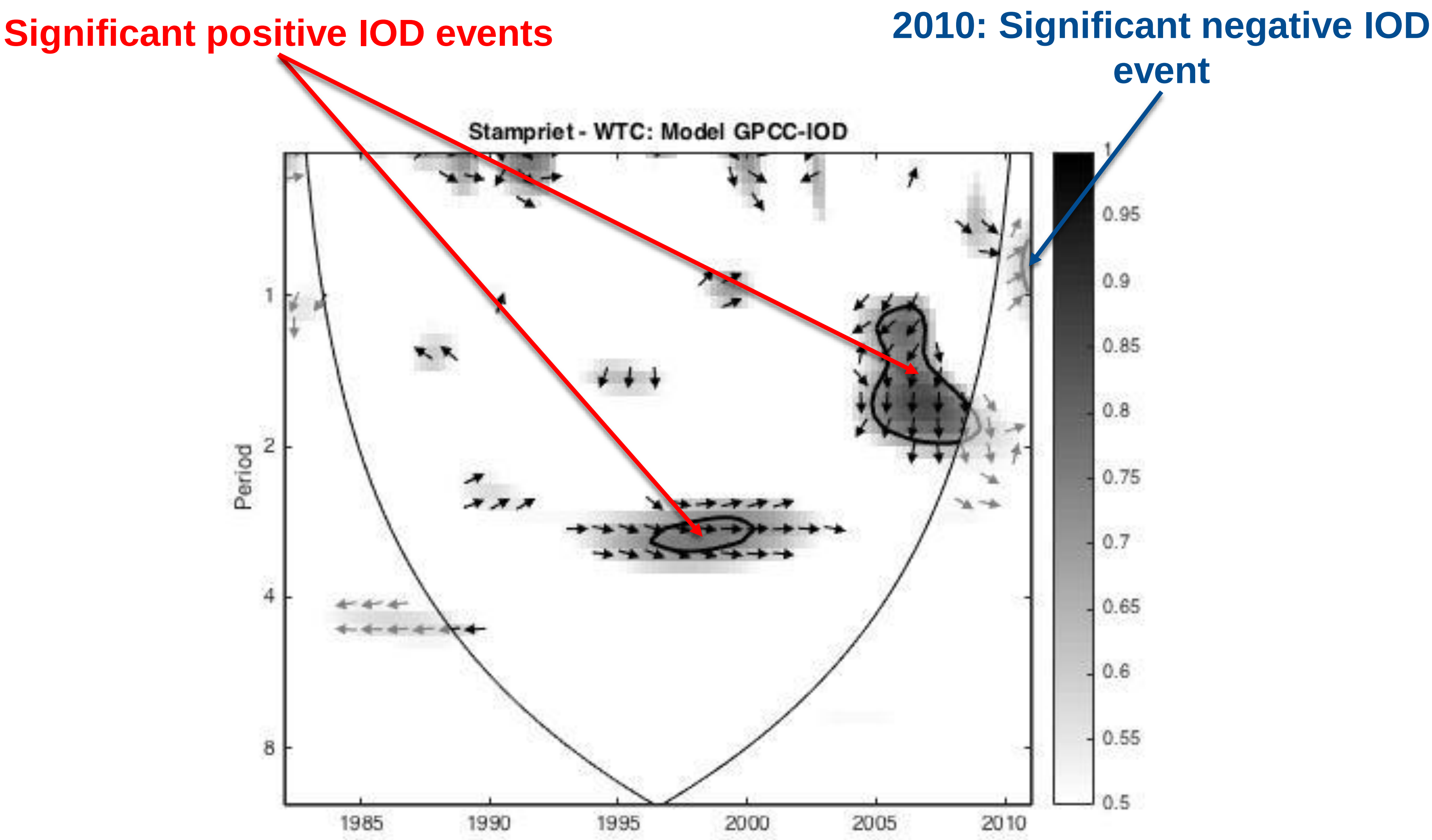
Strong El Niño followed by strong La Niña

Moderate El Niño followed by Moderate La Niña



Simplified Water Balance Model

- **Model vs Indian Ocean Dipole (IOD) Index cross wavelet analysis**

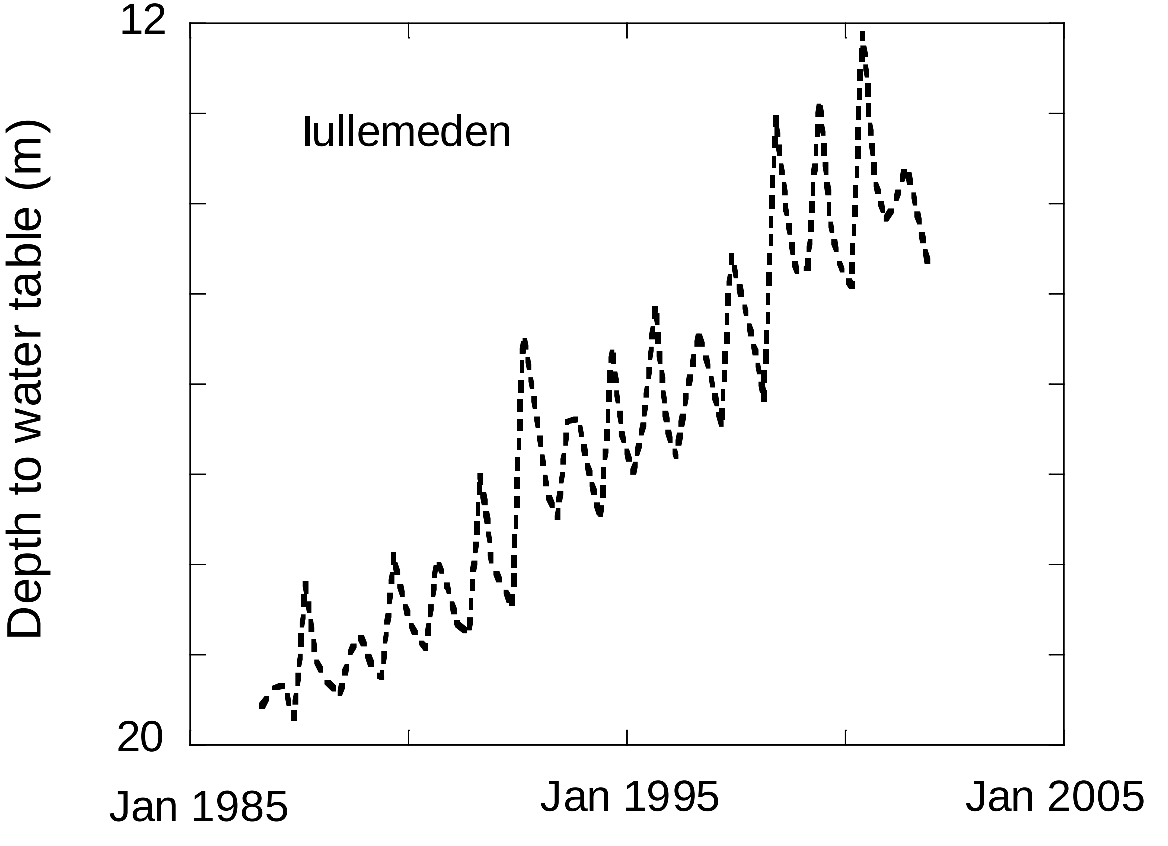


Simplified Water Balance Model

- **The aquifer is highly responsive to precipitation.**
- **Some preliminary observations:**
  - *Moderate to strong El Niño years (ENSO+): declining water table*
  - *Moderate to strong La Niña years (ENSO-): rising water table*
  - *Significant positive IOD events (IOD+): declining water table*
  - *Significant negative IOD events (IOD-): rising water table*

Application to other large aquifers

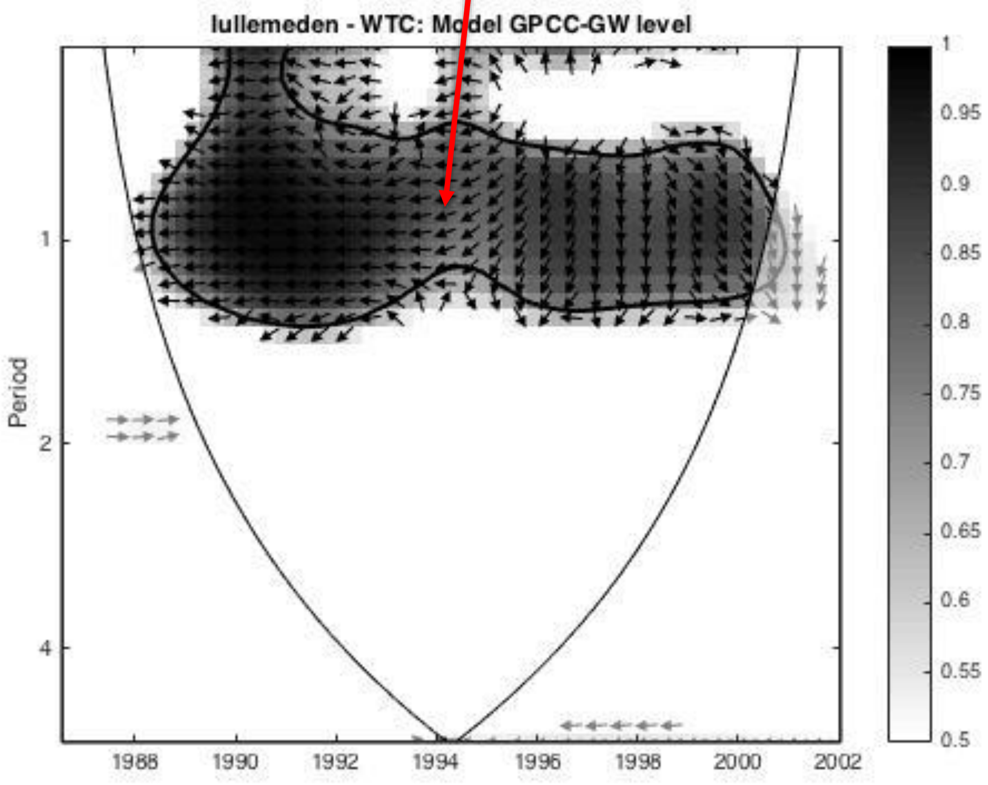
- **Iullemeden Basin**



Rising water table since 80s
(Leblanc et al. 2008)

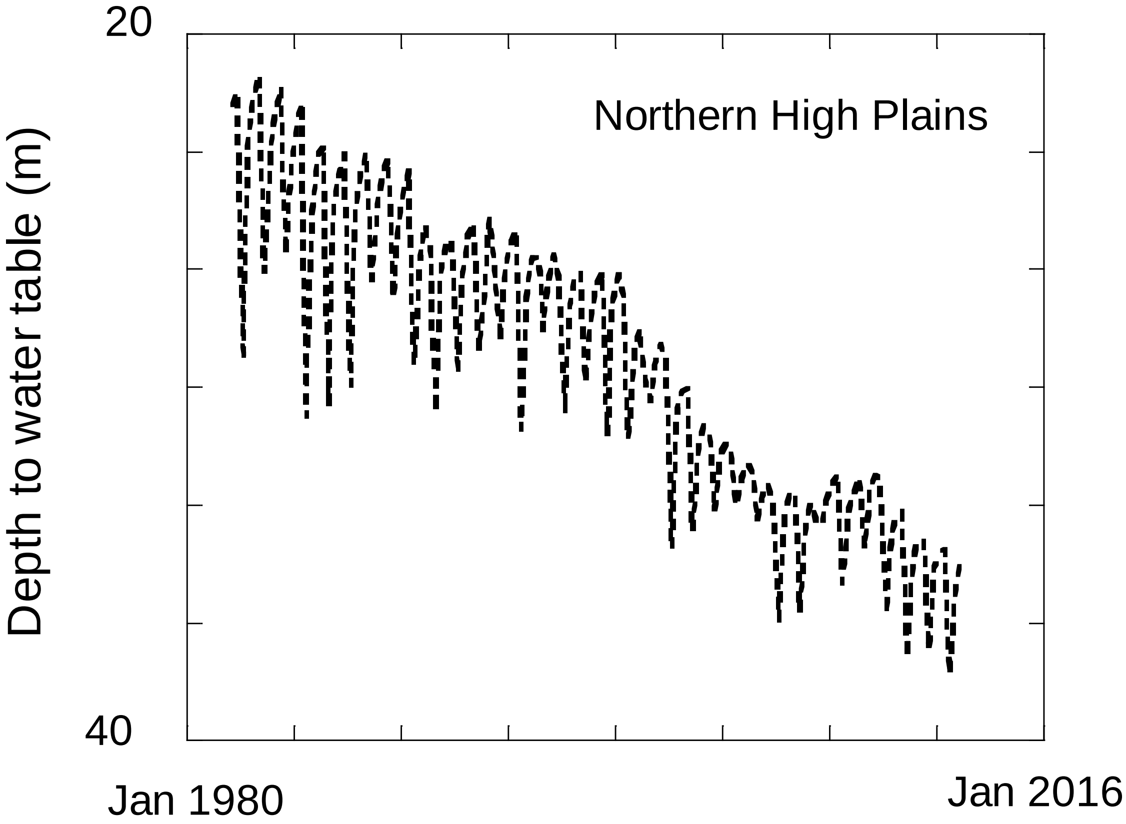
Application to other large aquifers

- **Model vs Observed groundwater level cross wavelet analysis**
  - *1986 - 2003*
  - *Strong groundwater storage coherence in the 1 year period → good description of* ***inter-annual storage variability***



Application to other large aquifers

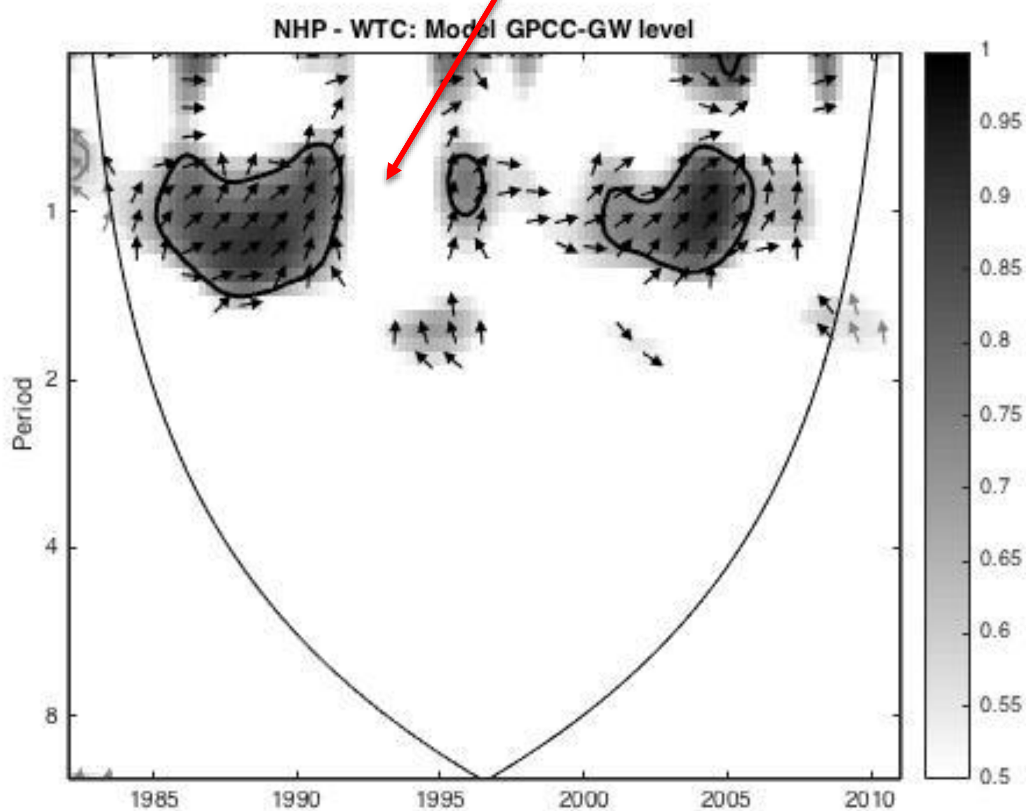
- **Northern High Plains (USA)**



Declining water table in large irrigation zones (USGS, 2016)

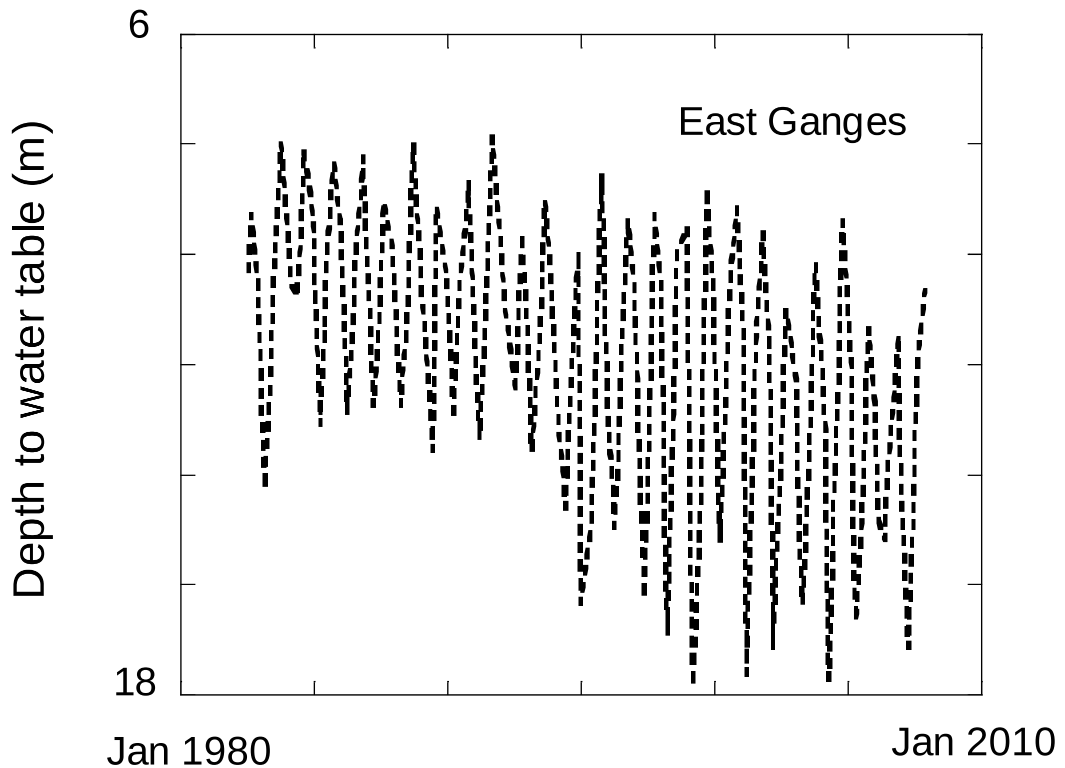
Application to other large aquifers

- **Model vs Observed groundwater level cross wavelet analysis**
  - *1982 - 2010*
  - *Strong groundwater storage coherence in the 1 year period → good description of* ***inter-annual storage variability***



Application to other large aquifers

- **East Ganges**



(Shamsudduha, 2011)

Application to other large aquifers

- **Model vs Observed groundwater level cross wavelet analysis**
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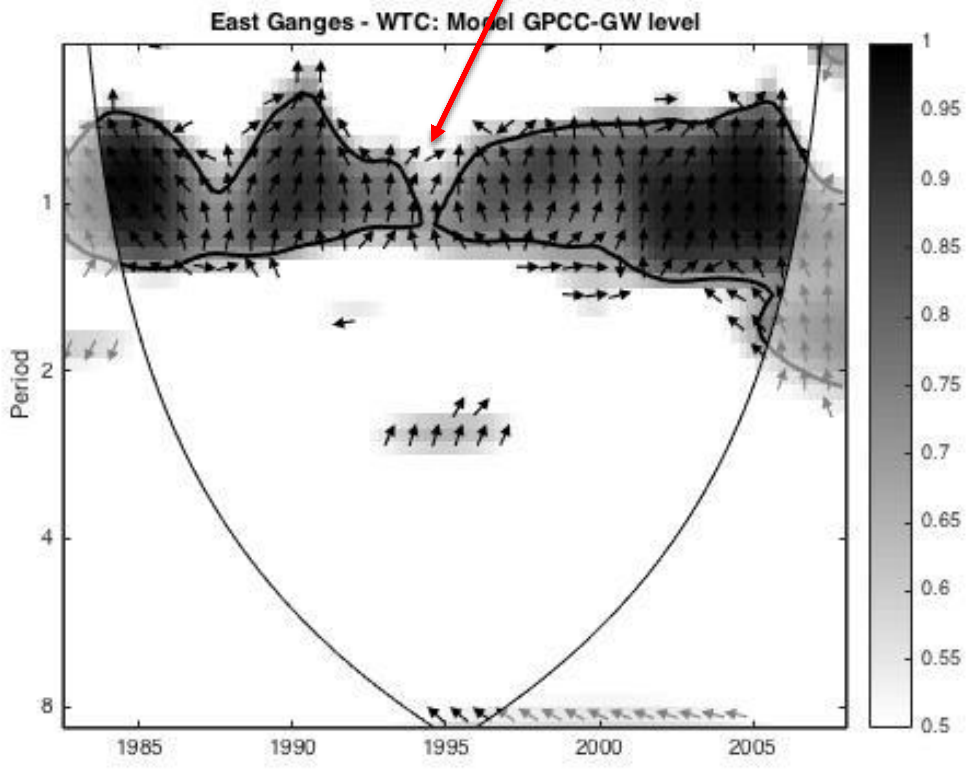

Conclusions and way forward

- **A 2-parameter (P, E) water balance model relying <u>only</u> global datasets has proven to be a quite robust and simple tool enabling to assess groundwater storage inter-annual variability in large aquifers.**

- **The model could allow identifying preliminary trends through teleconnections with climatic oscillations in data-scarce large aquifers.**

- **Model limitations: groundwater abstraction is not directly considered. However, evapotranspiration could indirectly provide information, e.g. land use changes.**

- **Shallow groundwater in the studied aquifers is highly responsive to precipitation. Further analyses need to be done to identify precipitation/evapotranspiration contribution.**

- **This work could support groundwater management and policy decision-making, especially in knowledge, capacity and data-scarce settings.**

- **Call for action: Strengthening links between Department of Water Affairs and Meteorological Agencies (at national, and regional level).**