Propagation of precipitation uncertainties

in distributed water balance assessments

of a data sparse semi arid environment

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Motivation

- Scientifically sound **decisions in sustainable water management:** usually based on hydrological modelling
  ⇨ can only be accomplished with **meteorological information**.

- Particularly in developing countries where **observation networks are coarse**, spatial interpolation is afflicted with **uncertainties**.

- Spatial variability of **rainfall**:
  often **major source of uncertainty** for water balance estimations

Challenge West Africa

- Sufficient water resources are life-blood of West African economies

- 70% of inhabitants in West Africa depend on rainfed agriculture

- Socio-economic development strongly dependent on availability of rainfall

- Changes in amount, variability and temporal and spatial distribution of rainfall have significant impact on water availability and thereby on socio-economy

- **Estimation of water resources, stocks and flows, are of crucial importance for decision making**

Volta Basin
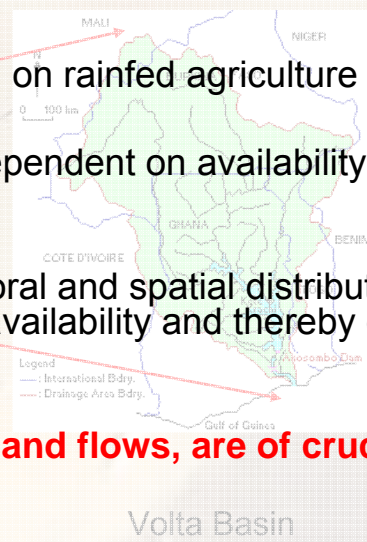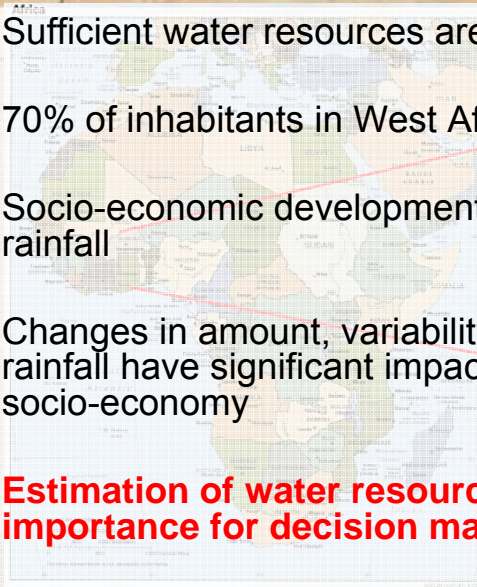
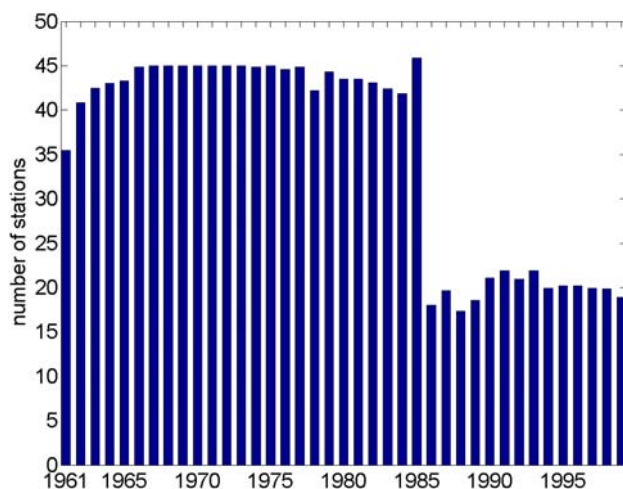# Challenge West Africa

Required: Scientifically sound information under weak infrastructure

Area of Investigation: White Volta/West Africa

- 94000 km², upstream of Lake Volta

- Flat topography

- Semiarid climate: rainy season May - October
  dry season November – April

Jung, 2006
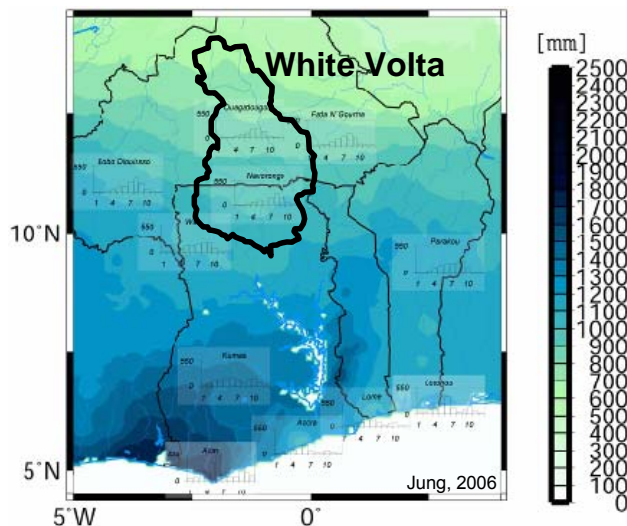
Data Sparse Environment White Volta

Precipitation:
- 1 station/6,000km² 1961-84

- 1 station/15,000km² 1985-2001

Wind, humidity, pressure
- ≈ 1 station/30,000km²

Discharge:
- Only available in Ghana

Overall Objective Research White Volta

Development of methods for distributed, model based water balance estimations in data sparse environment

- Application of near real time atmospheric models to provide meteorological fields for hydrological modeling

- Integration of remote sensing data for land surface properties in hydrological models

- **Impact of uncertainties arising from precipitation interpolation on water balance estimates**

Measurement Campaign: Start in May 2004

Hydrometeorological Network
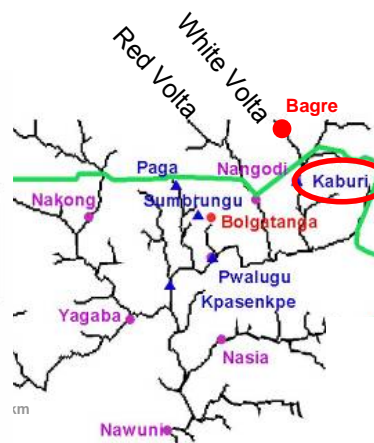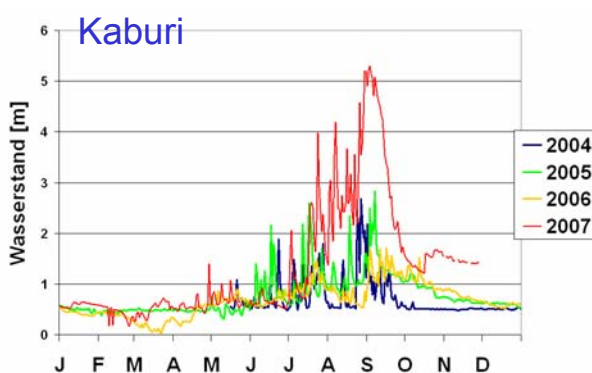
Hydrological Model WaSiM: Concept

Physically based algorithms for vertical water fluxes & groundwater:
- Evapotranspiration: soil and vegetation specific (Monteith)
- Flow through unsaturated zone (Richards)
- Suction head & hydraulic conductivity (van Genuchten)
- 2-dim groundwater model dynamically
  coupled to unsaturated zone

Conceptual approaches for lateral runoff aggregation
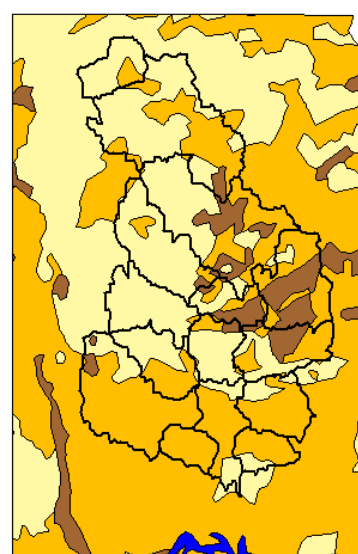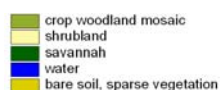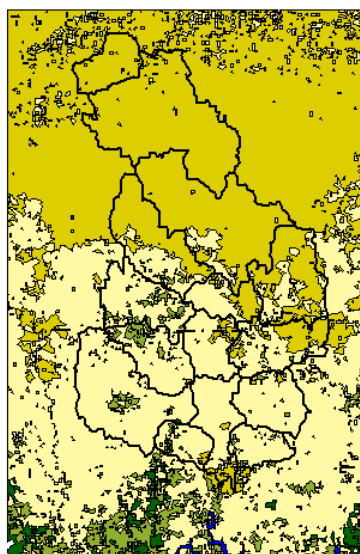- Traveltime approach folded with linear storage
- Discharge routing: cinematic wave

Setup White Volta
- Spatial resolution Δx : 1x1km²
- Temporal resolution Δt: 24h
- Subdivision into 15 sub-catchments

Hydrological Model WaSiM: Setup

Example: Spatial land use and soil information

crop woodland mosaic
shrubland
savannah
water
bare soil, sparse vegetation

sand
loam
clay loam
water

Slide 11 — Calibration/Validation

Calibration/Validation
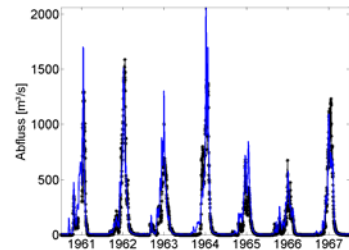
Historical data: 1968 & 1961-1967
• Data availability: meteorology & runoff for BF & GH
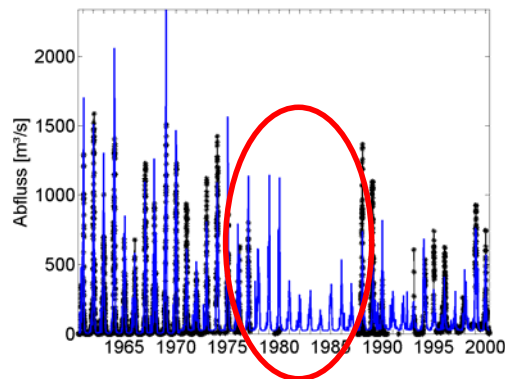• Small anthropogenic impacts

Pwalugu · Nawuni

Calibration: **1968**
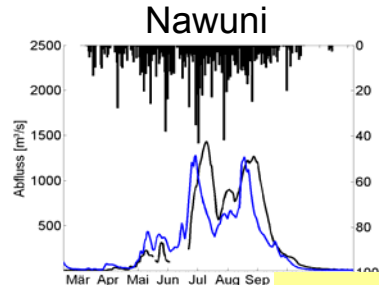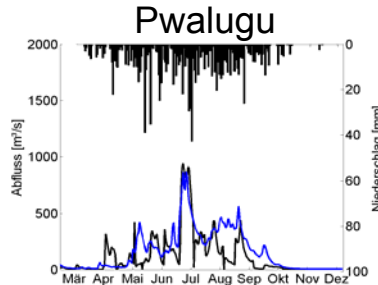
Validation: **1961-1967**
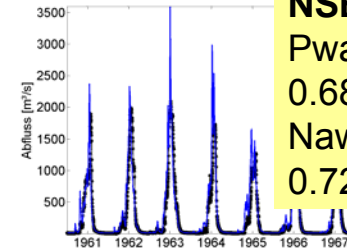
NSE (log):
Pwalugu: 0.47; 0.68
Nawuni: 0.72; 0.81

Slide 12 — Long Term Simulations

Long Term Simulations
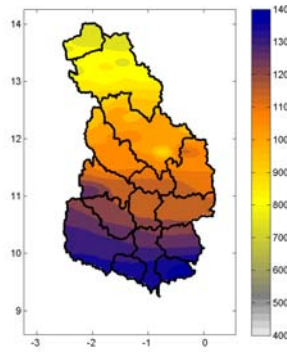
Pwalugu:

Nawuni:
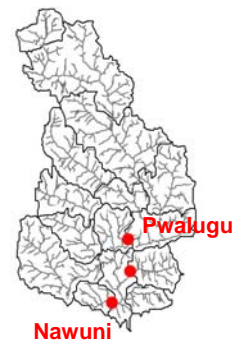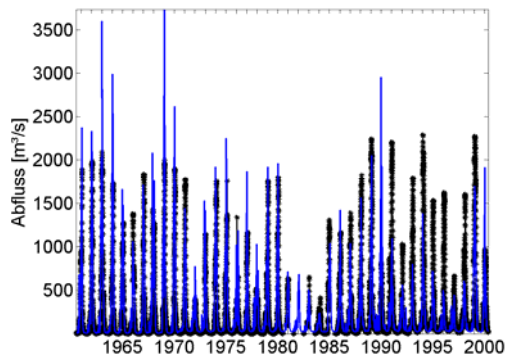
NSE (log):
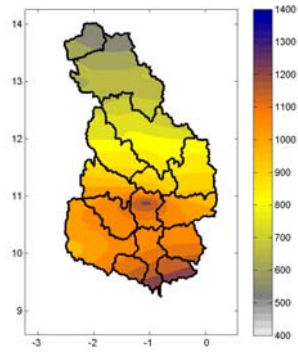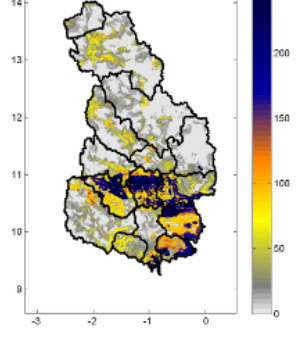Pwalugu: 0.55
Nawuni: 0.70

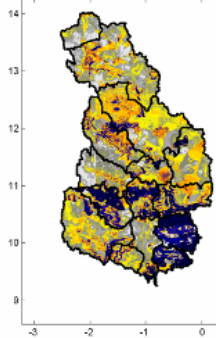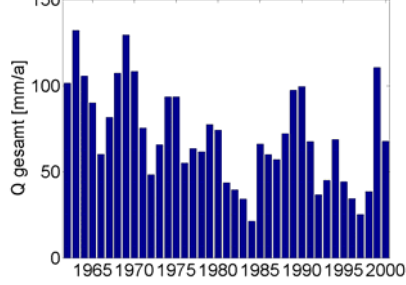## Long Term Simulations

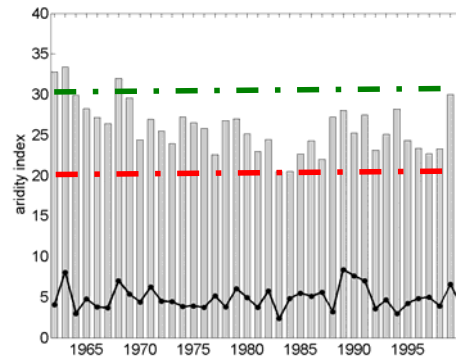Annual Precipitation [mm]   1961-1970   1981-1990
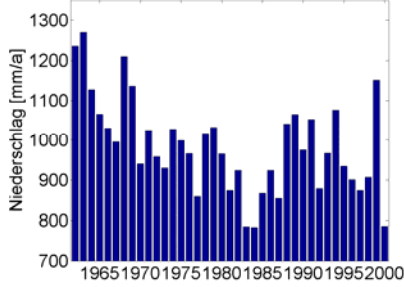
Annual Runoff [mm]
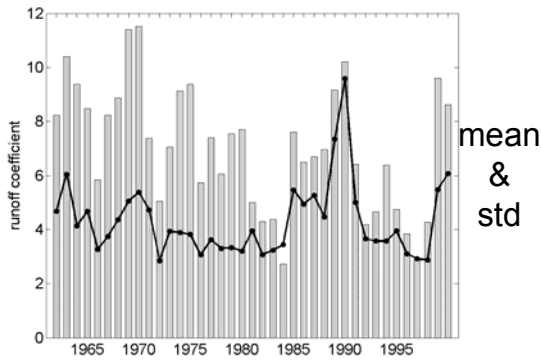

Long Term Simulations

Runoff coefficient:

$$RC = 100 * \frac{Q}{P}$$

mean & std

Overall: RC = 7% (2.7% – 11.5%)

Aridity index (de Martone):

$$dMI = \frac{P}{T + 10}$$

– · – 20-30: Irrigation often required

– · – < 20: Necessity of irrigation

Hydrometeorological Decision Support – Current Simulations

… through estimates on
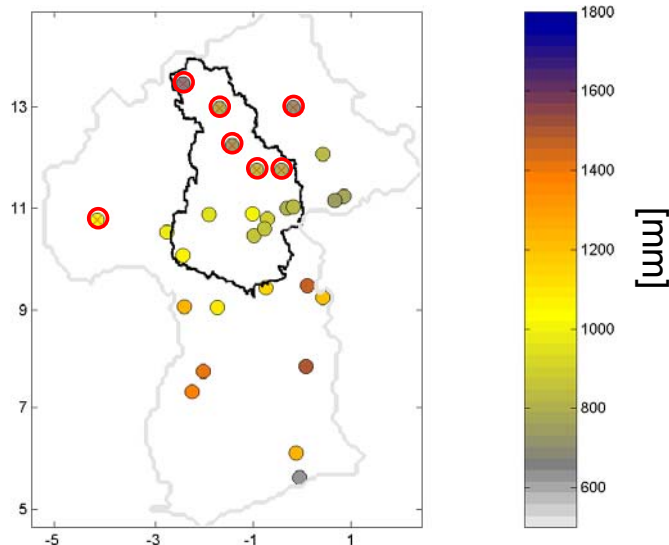temporal and spatial distribution of **current** water balance variables

ET_a | GW-Recharge | Piezometric Head
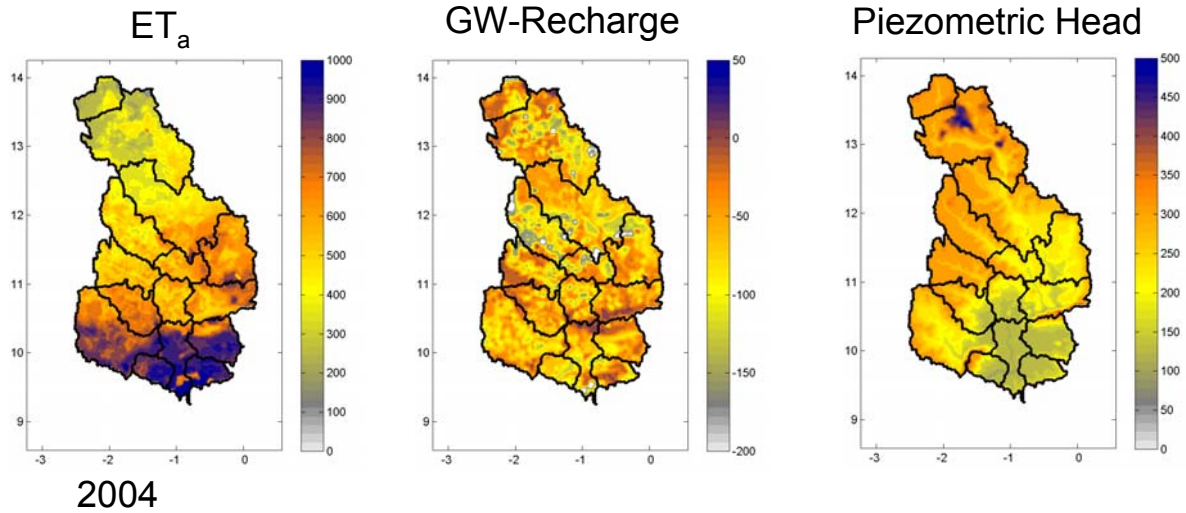
2004

Data Sparse Environment White Volta

Decision Support: Problem of temporal delay till station data are available

2004-2007

No data for Burkinabé part of catchments

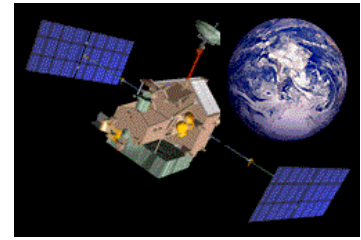⇨ Application of scaled TRMM* information at Burkinabé station locations

[mm]

* Tropical rainfall mission product 3B42, Δt=3h, Δx=0.25°

TRMM (1 Month Delay)

Tropical Rainfall Measuring Mission

- Sub-, tropical precipitation
- MW and VIR sensors plus precipitation radar
- Mission of NASA and JAXA
- Start 1997, Orbit 400 km

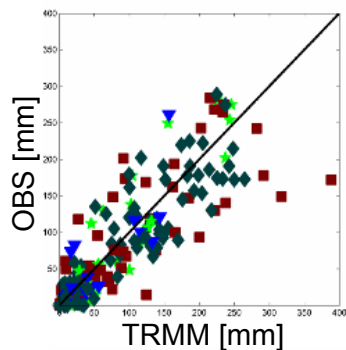### 3B-42 Product: TRMM Merged HQ/Infrared Precipitation
1. Combination of MW and VIR Daten
2. Scaled with observed monthly precipitation (3B-43:GPCC)
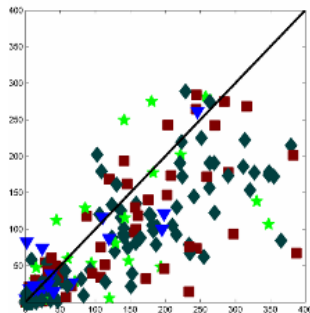
0.25°x 0.25°, 3-h, 50°S to 50°N

Validation TRMM - 2004
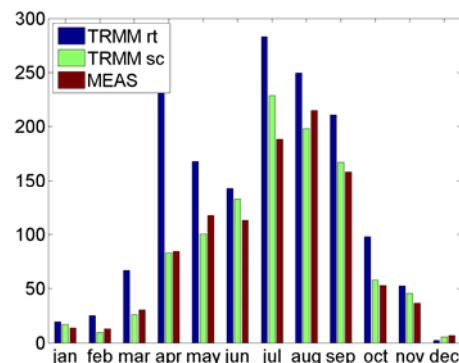### Validation with observations in Ghana
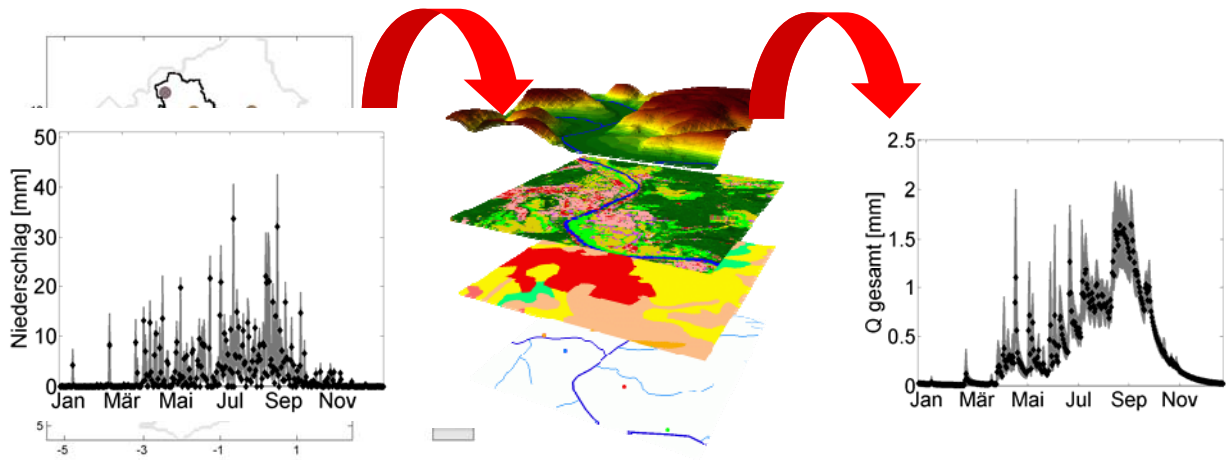
TRMM scaled:

TRMM unscaled:

Annual cycle:

Legend: stations along coast,
between latitude 7.5 & 8, 8.5 & 9.5, 10.0 & 11.5

Central Question:
Impact of Uncertainties from Precipitation Interpolation
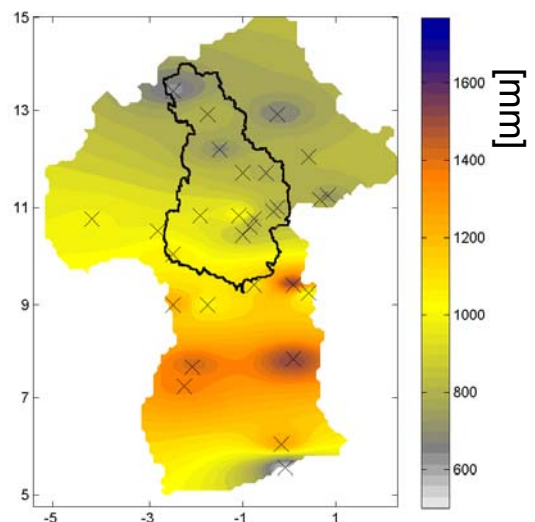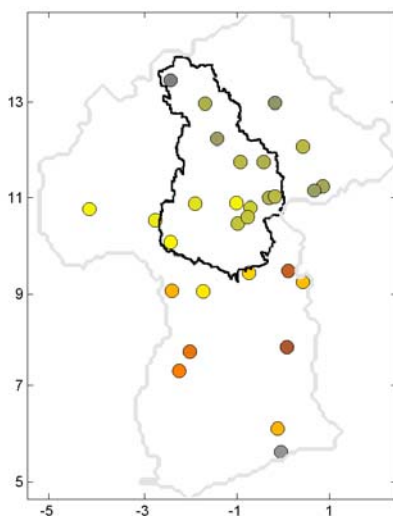**on Simulated Water Balances**

Geostatistical Interpolation Methods

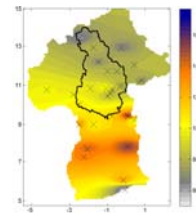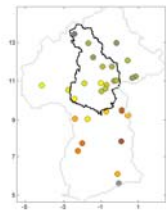General: Point Information ⇨ Spatial Information

IDW

Geostatistical Interpolation Methods

General: Point Information ⇨ Spatial Information
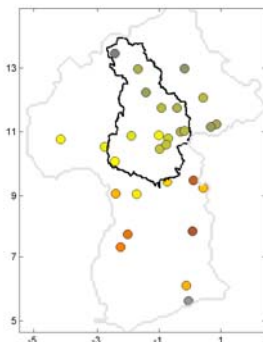
Methodologies

Spatial Interpolations

- IDW, **Kriging**
- smoothing

⇨ one field

Simulations

- **Turning Bands**
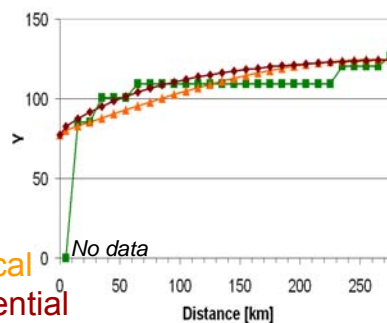- Conservation variability of obs.

⇨ many equally probable realisations

Ex. Variogram: $\gamma(h) = \dfrac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(u_i) - Z(u_i + h)]^2$

Spatial Interpolation: IDW and Ordinary Kriging

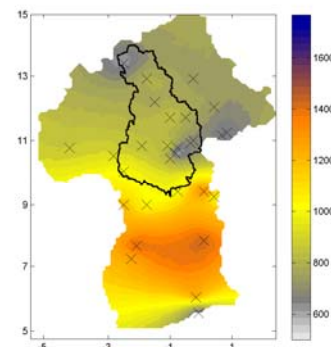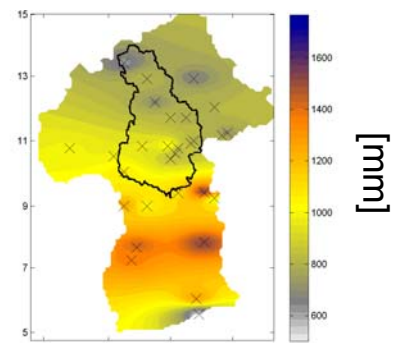

⇨ Inverse Distance weighting (IDW):

⇨ Ordinary Kriging (OK):

Variograms:
- experimental
- nugget & spherical
- nugget & exponential

No data

Spatial Interpolation: External Drift Kriging (EDK)

⇨ Suited additional information
   considered for interpolation

$$\sum_{j=1}^{N} \lambda_j \gamma(u_i - u_j) + \mu_0 + \boxed{\mu_1 \cdot Y(u_j)} = \gamma(u_i - u_0),$$

Applied External Drifts:

- Digital Elevation Model (DEM)
- Mean annual precipitation (40a)
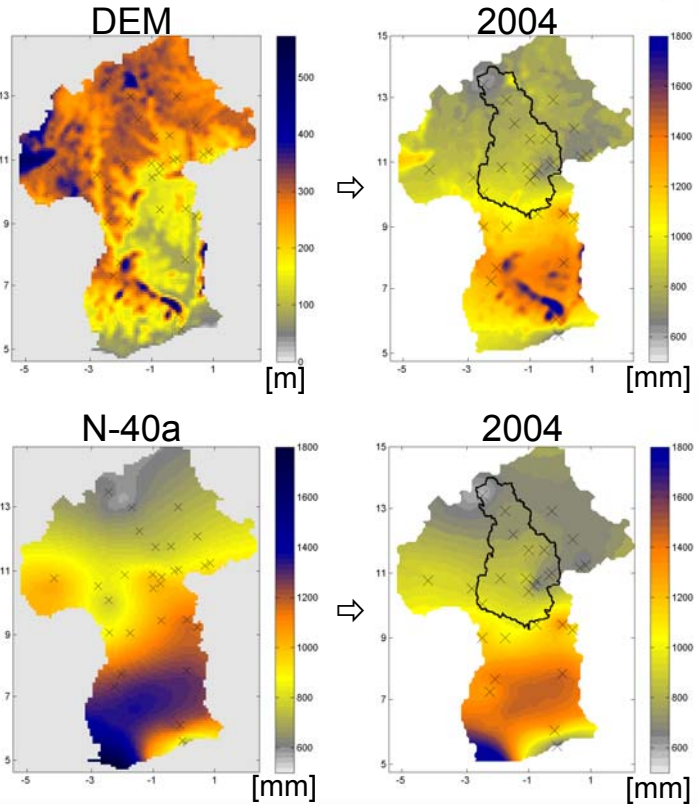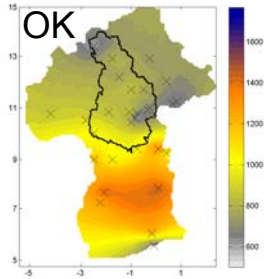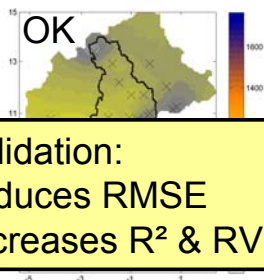- Latitudinal dependency
- LAI

Spatial Interpolation: External Drift Kriging (EDK)

⇨ Suited additional information
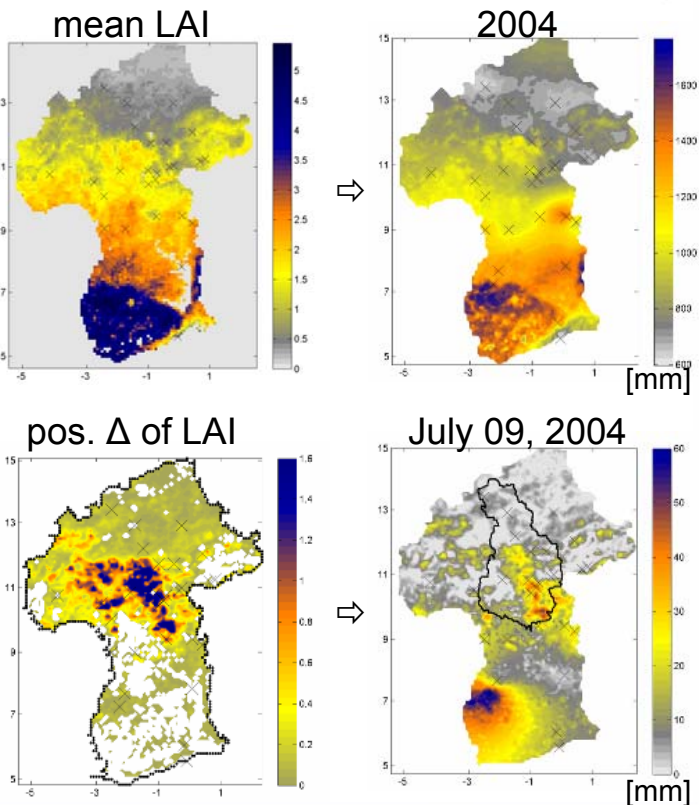   considered for interpolation

$$\sum_{j=1}^{N} \lambda_j \gamma(u_i - u_j) + \mu_0 + \boxed{\mu_1 \cdot Y(u_j)} = \gamma(u_i - u_0),$$

Applied External Drifts:

- LAI: MODIS, 8-day composites
  1. mean LAI
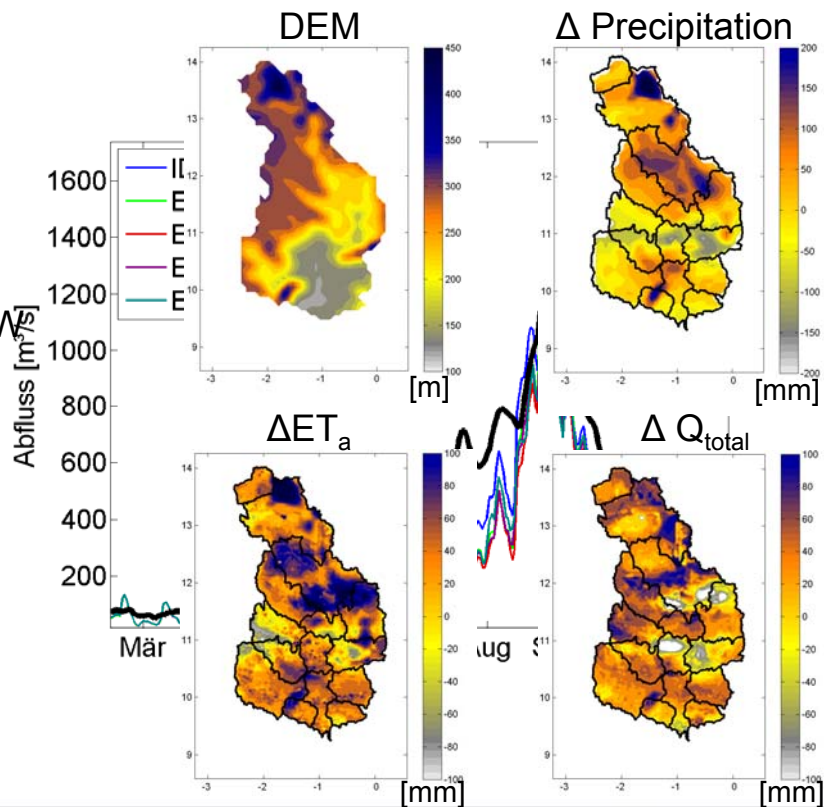 2. positive change of LAI

> Cross validation:
> - EDK reduces RMSE
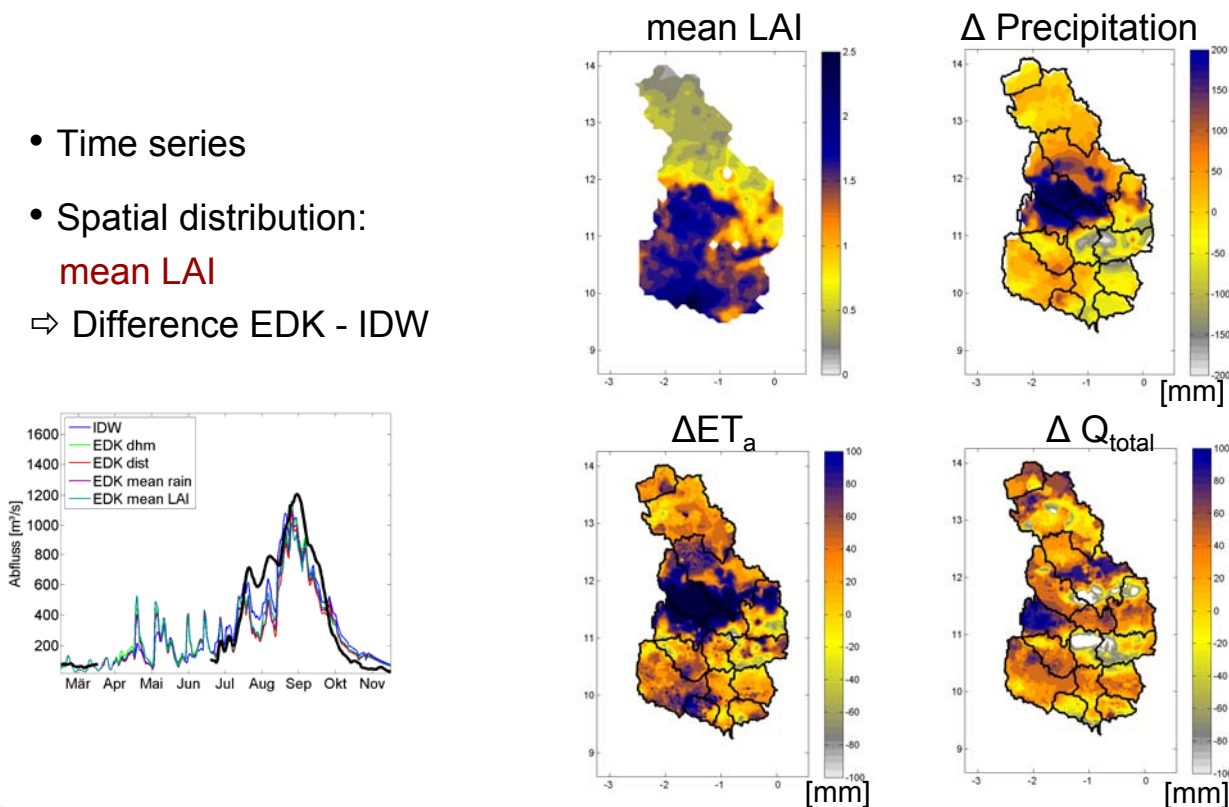> - EDK increases R² & RVar

Impact Interpolation on Water Balance Estimates

- Time series

- Spatial distribution:
  DEM
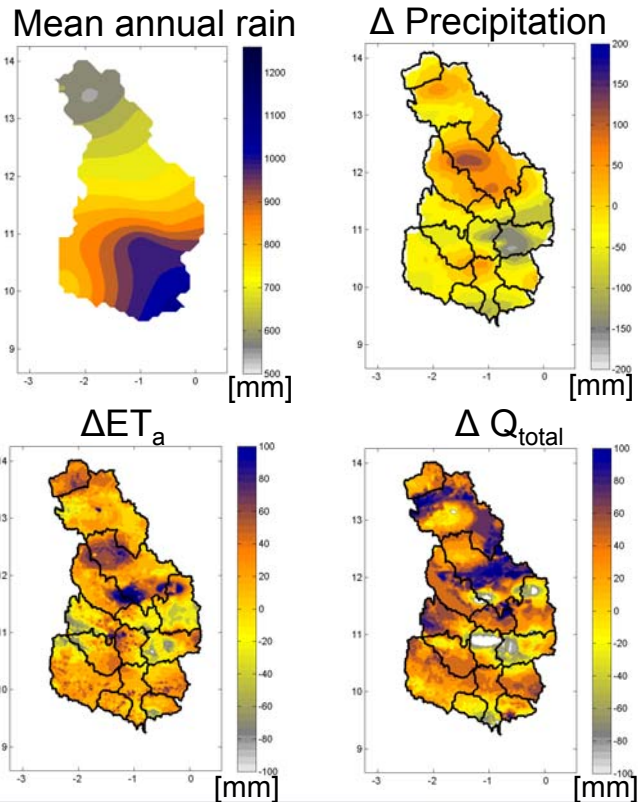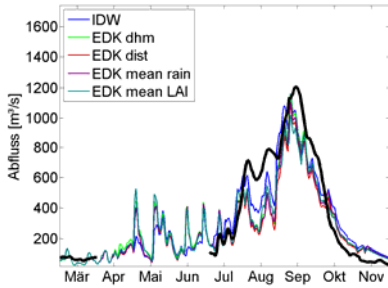
⇨ Difference EDK - IDW

Impact Interpolation on Water Balance Estimates

- Time series

- Spatial distribution:
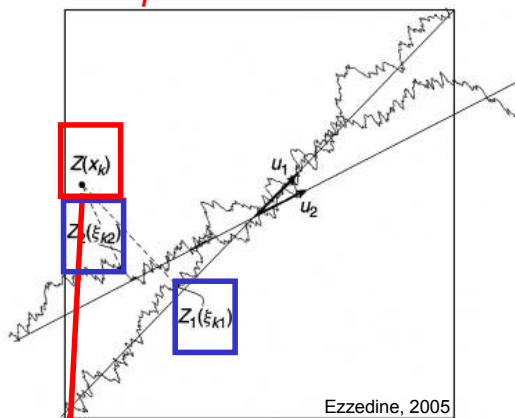 mean LAI

⇨ Difference EDK - IDW

Impact Interpolation on Water Balance Estimates

- Time series

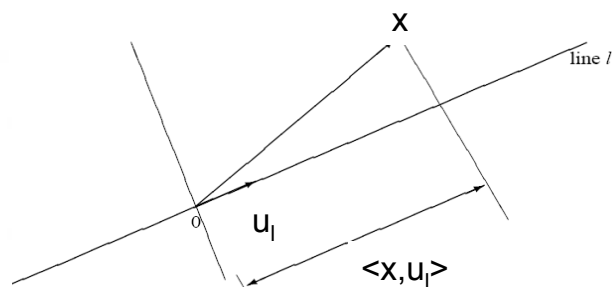- Spatial distribution:
  mean annual rain
  ⇨ Difference EDK - IDW

Mean annual rain

Δ Precipitation

ΔET$_a$

Δ Q$_{total}$

[mm]

Spatial Interpolation: Turning Band Simulations

- 1-D simulations ⇨ 2-D fields
- Unconditional
- *Prerequisite: standard Gaussian field Z(x)*

Ezzedine, 2005

Turning band lines and projections

$$Z(x) = \frac{1}{\sqrt{L}} \sum_{l=1}^{L} Z_l(\langle x, u_l \rangle)$$

$Z_l(u)$:

Random function with zero
mean & C(r) covariance function

Normal score transformation

- Transform daily precipitation data to Gaussian distribution

- Problem: no negative precipitation exists

- Standard normal distribution: $Z = \dfrac{X - \mu}{\sigma}$

  Using random numbers (normally distributed & X<=0mm) for Z(0 mm):

  → fill the curve left of Z(0 mm)

- Using transformed variable:

  - Calculate variograms

  - Perform turning band simulations

- *Creating conditional fields*

- Results are transformed back to

  original scale

Z(0 mm)
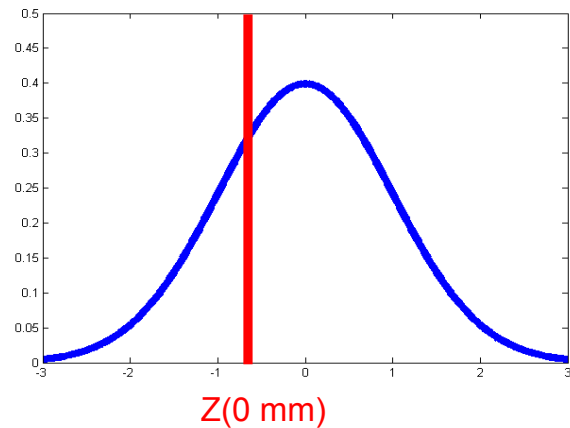
Conditional Simulations

$$Z_C(x) = Z^*(x) + (Z_S(x) - Z_S^*(x))$$

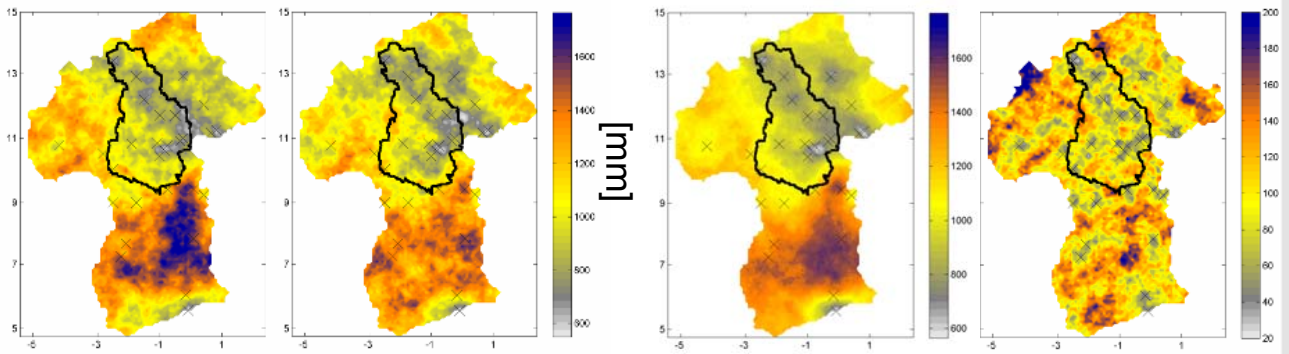$Z_C(x)$: Conditionally simulated value at point x

$Z^*(x)$: **Kriging** estimator of Z at x based on measurements

$Z_S(x)$: Unconditionally simulated value at point x (**TB method**)

$Z_S^*(x)$: **Kriging** estimator of Z_S at x based on unconditionally
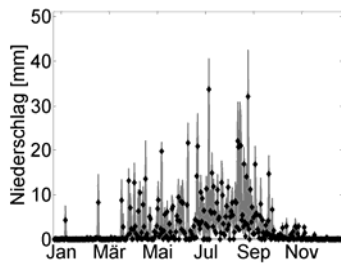simulated values at measurement points

Conditional Simulations

Examples: Turning Band results

Statistics:
Mean & standard deviation

Uncertainties Propagated into Water Balance

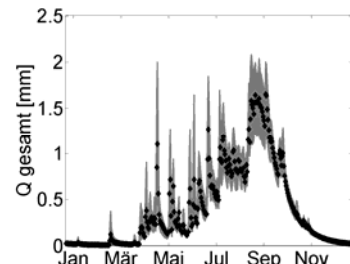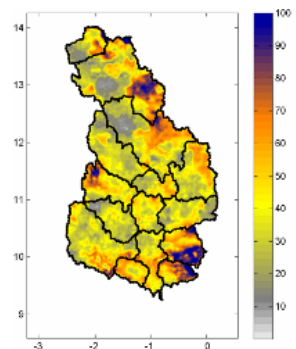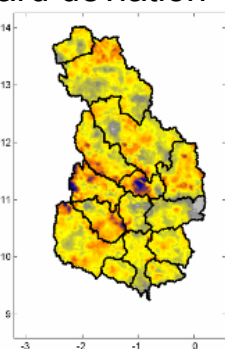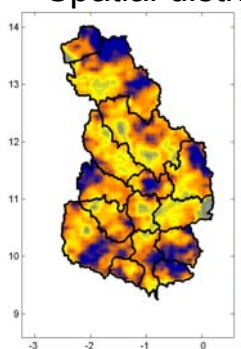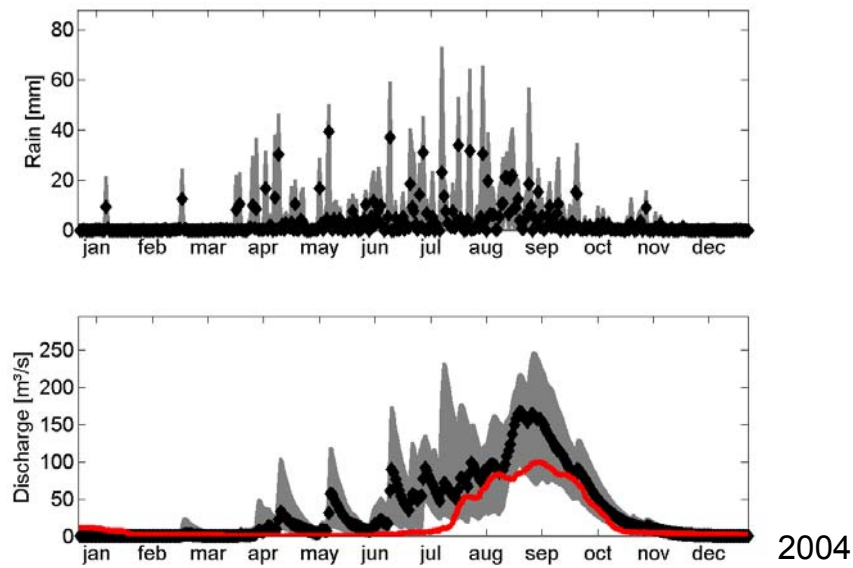**Precipitation**   **ET_a**   **Q_{total}**

Time Series:
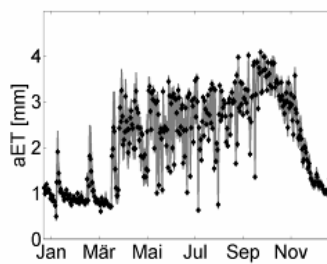
Spatial distribution: standard deviation

Uncertainties Propagated into Water Balance
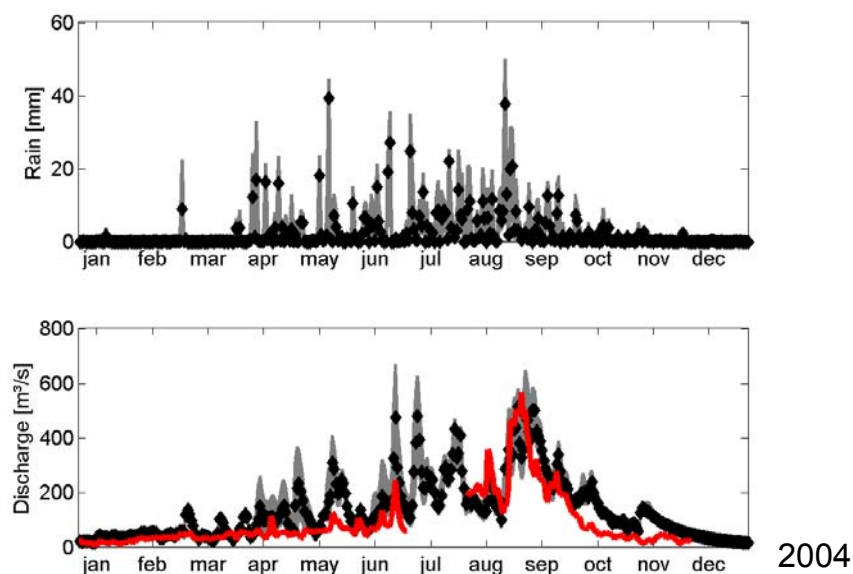

Gauge Nasia

Uncertainties Propagated into Water Balance

Gauge Pwalugu
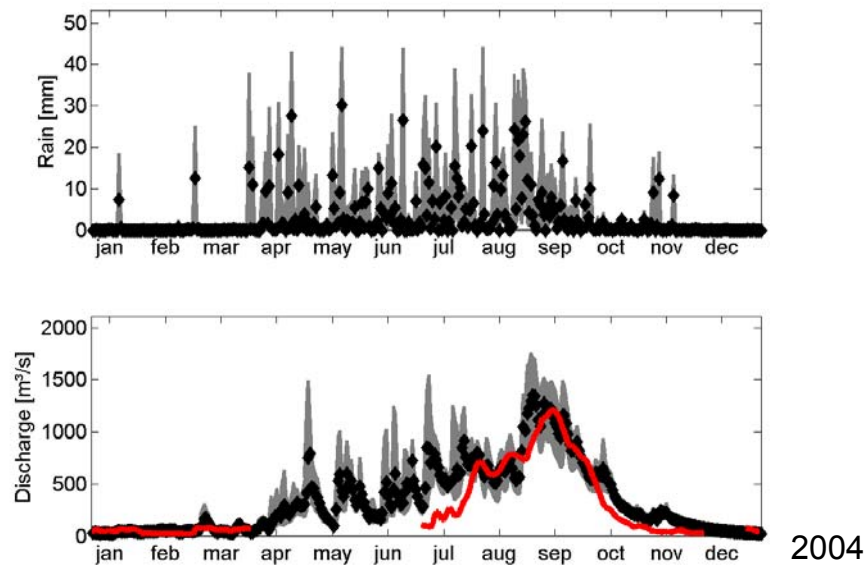
Uncertainties Propagated into Water Balance

2004

Gauge Nawuni

Summary

- Kriging methods outperform IDW interpolation
  (cross validation comparison)

- Use of external drifts increases variance of areal precipitation fields

- **Turning Band simulations:** uncertainty ranges of spatial & temporal distribution of water balance variables due to uncertainties in spatial distribution of precipitation; increase variance further

- Minor impact of spatial precipitation interpolation methods for spatially aggregated variables & corresponding time series.

- Interpolation method significantly affect spatial distribution of water balance variables

- **Turning Band method for precipitation assists in sustainable water management under uncertainties in data sparse environments**

Thank you for your attention