Propagation of precipitation uncertainties

in distributed water balance assessments

of a data sparse semi arid environment

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Motivation

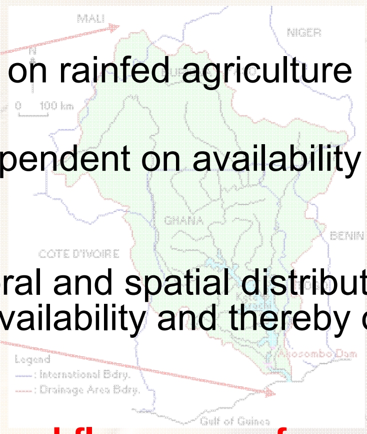
- Scientifically sound **decisions in sustainable water management:** usually based on hydrological modelling
  ⇨ can only be accomplished with **meteorological information**.

- 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**



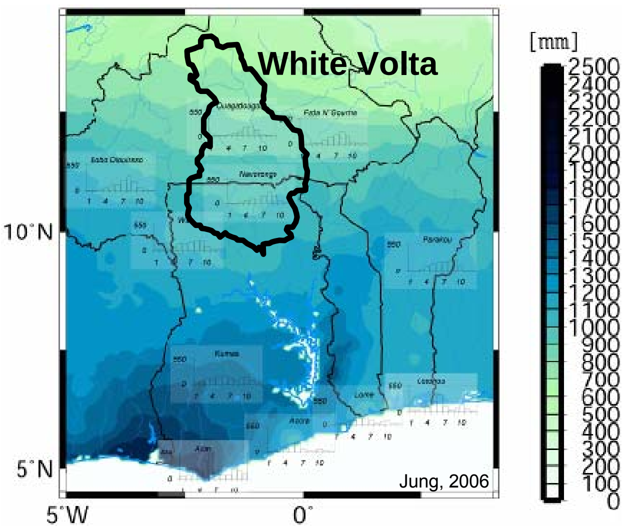
Volta Basin

Challenge West Africa

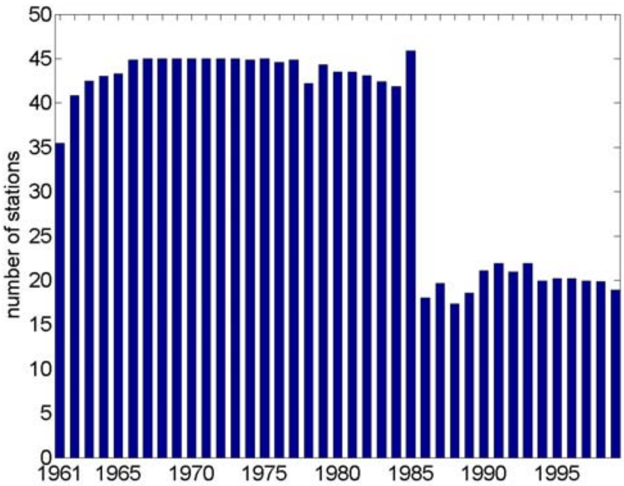
Required:
Scientifically sound information
under weak infrastructure

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



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

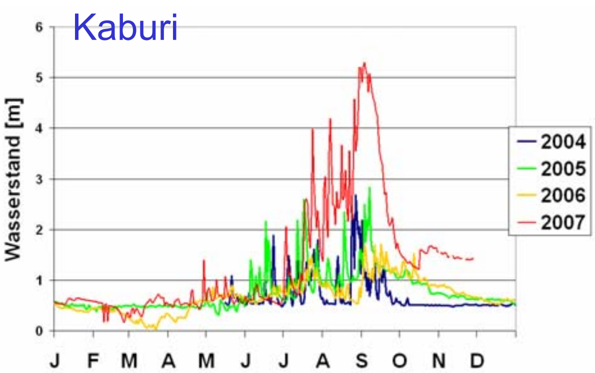
Overall Objective Research White Volta

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

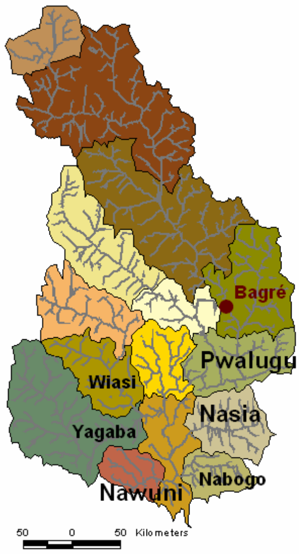


Hydrological Model WaSiM: Concept

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

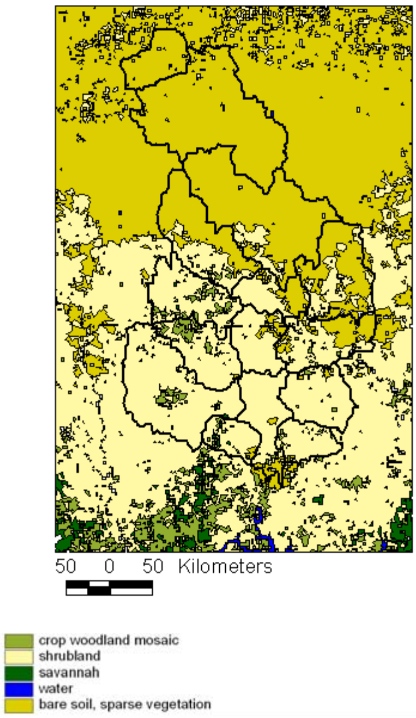
Conceptual approaches for lateral runoff aggregation
- Traveltime approach folded with linear storage
- Discharge routing: cinematic wave

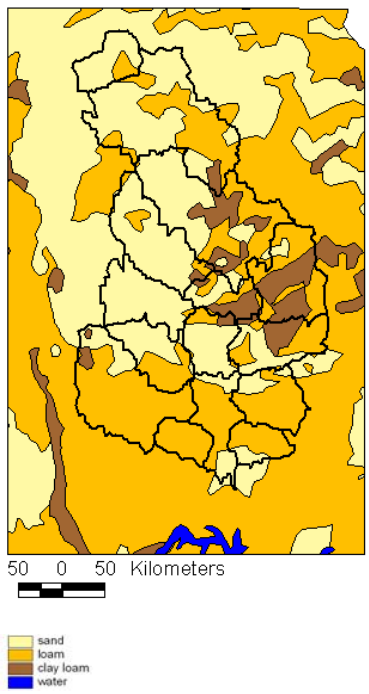
Setup White Volta
- Spatial resolution Δx : 1x1km²
- Temporal resolution Δt: 24h
- Subdivision into 15 sub-catchments



Hydrological Model WaSiM: Setup

Example: Spatial land use and soil information



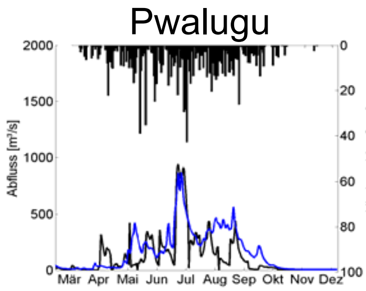


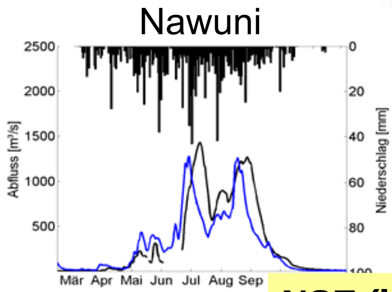
Calibration/Validation

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

Calibration:

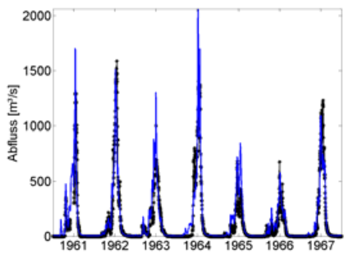
1968

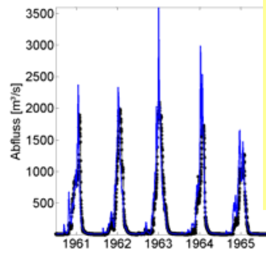




Validation:

1961-1967

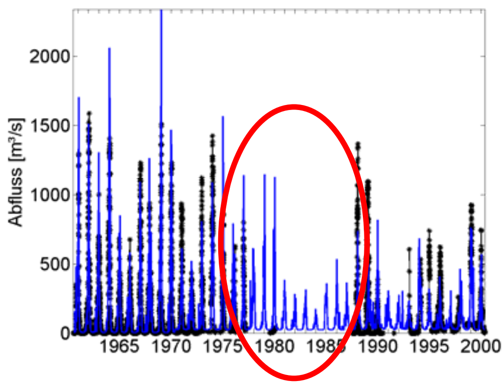




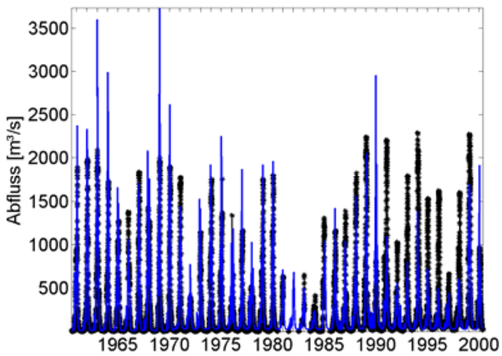
NSE (log):
Pwalugu: 0.47; 0.68
Nawuni: 0.72; 0.81

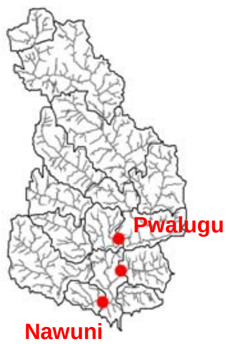
Long Term Simulations

Pwalugu:



Nawuni:

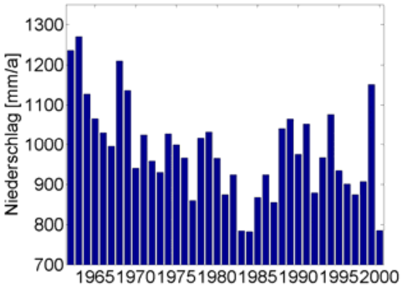




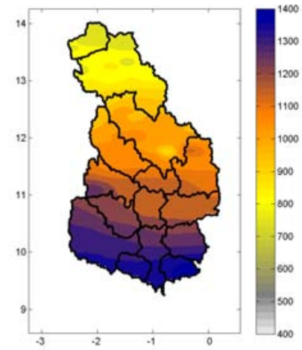
NSE (log):
Pwalugu: 0.55
Nawuni: 0.70

Long Term Simulations

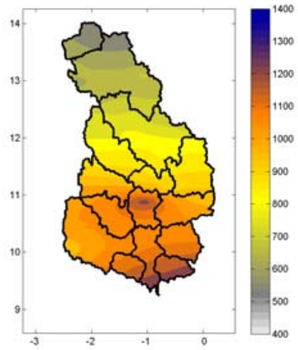
Annual Precipitation [mm]



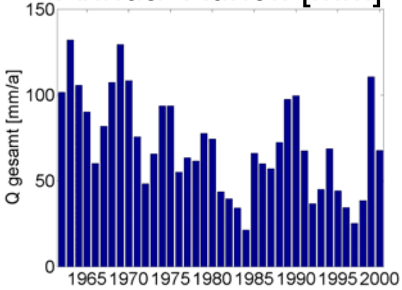
1961-1970

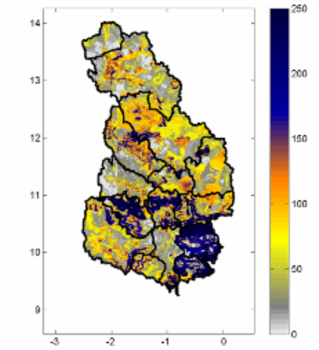


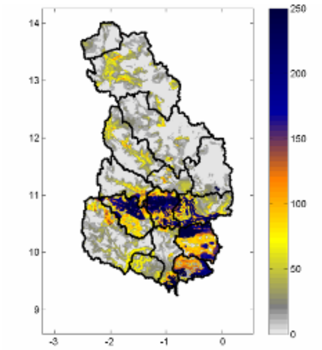
1981-1990



Annual Runoff [mm]







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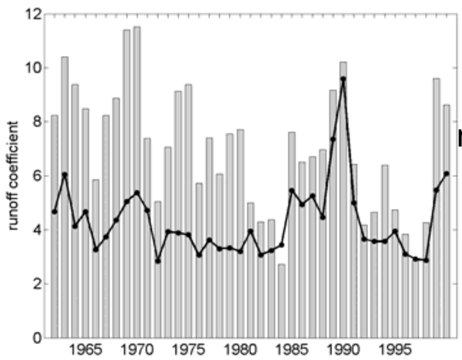
Long Term Simulations

Runoff coefficient:

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

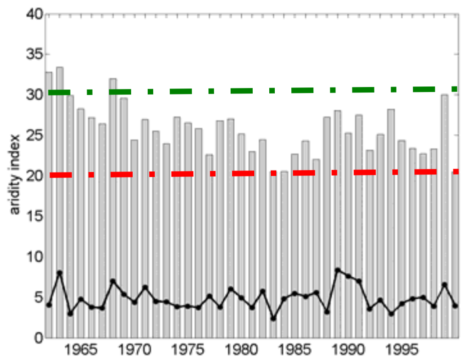


mean & std

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

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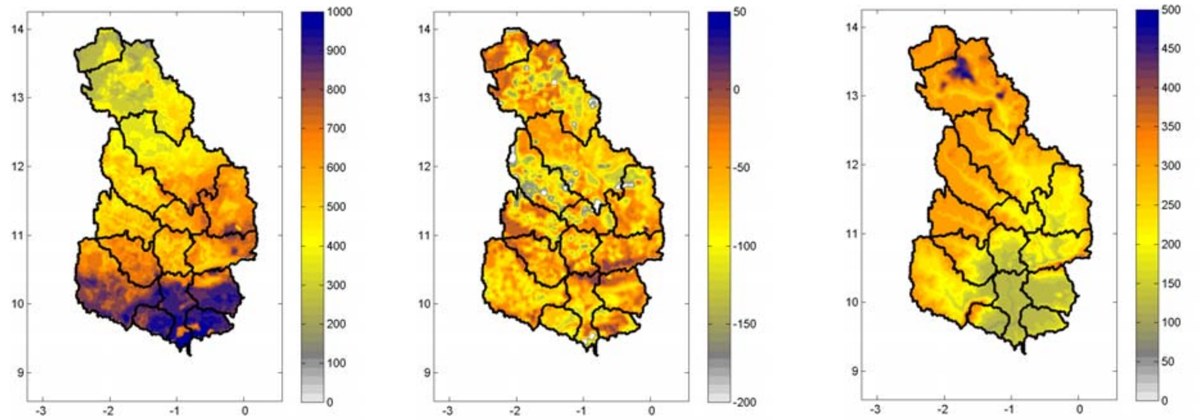
Hydrometeorological Decision Support – Current Simulations

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

ET_a GW-Recharge Piezometric Head



2004

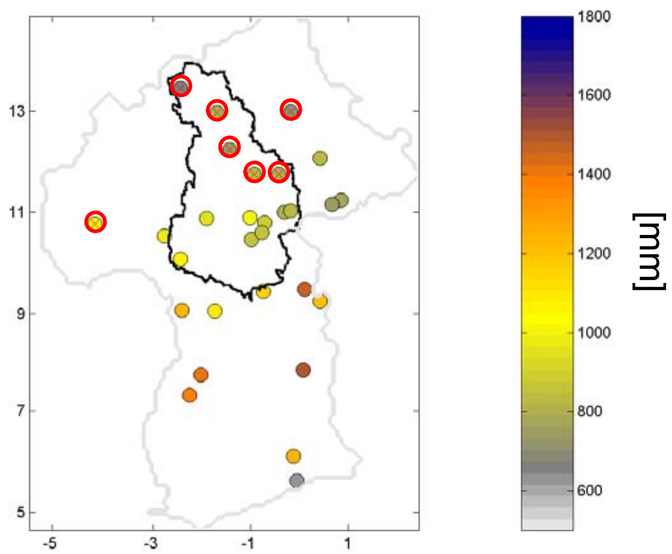
Data Sparse Environment White Volta

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

2004-2007

No data for Burkinabé part of catchments

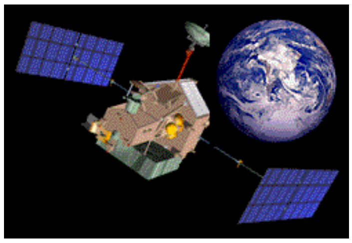
⇨Application of scaled TRMM* information at Burkinabé station locations



* 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

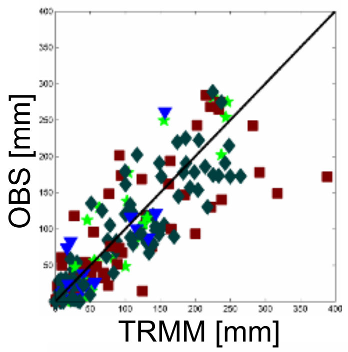
1. Combination of MW and VIR Daten
2. Scaled with observed monthly precipitation (3B-43:GPCC)

0.25°x 0.25°, 3-h, 50°S to 50°N

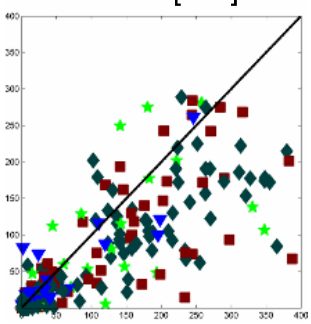
Validation TRMM - 2004

Validation with observations in Ghana

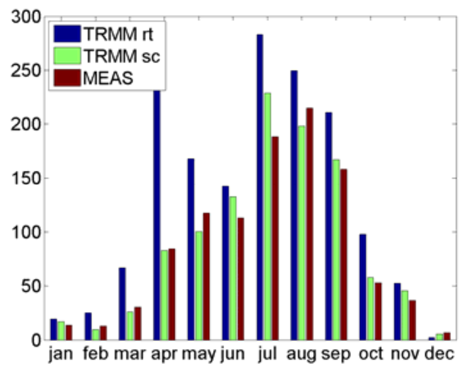
TRMM scaled:



TRMM unscaled:



Annual cycle:



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

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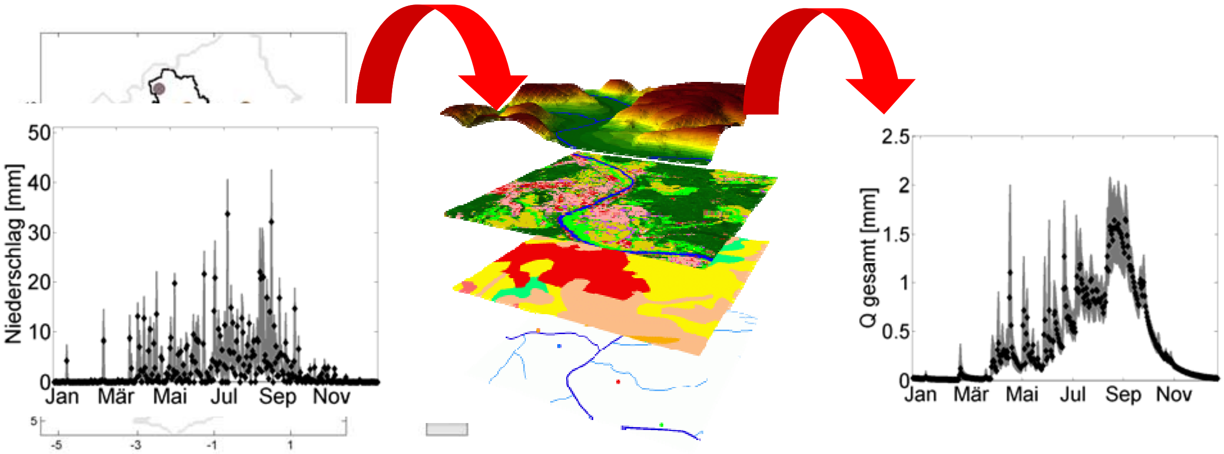
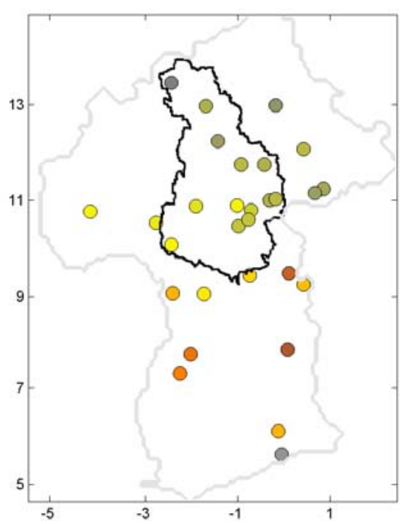
Central Question: Impact of Uncertainties from Precipitation Interpolation on Simulated Water Balances

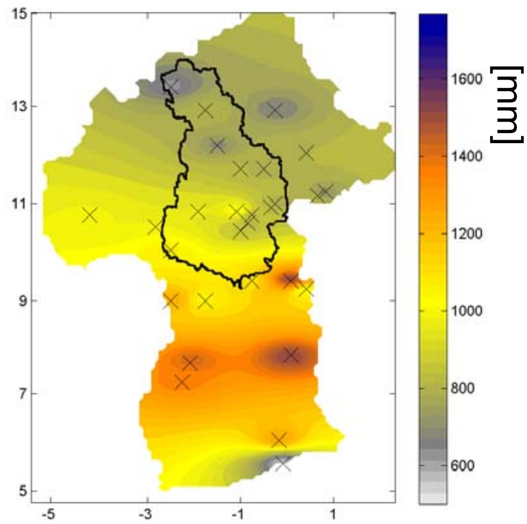


Geostatistical Interpolation Methods

General: Point Information ⇨ Spatial Information



⇨



IDW

Geostatistical Interpolation Methods

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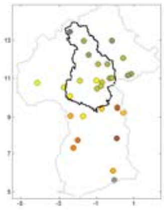
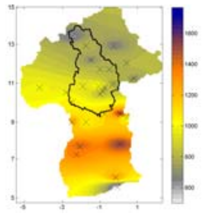


➔

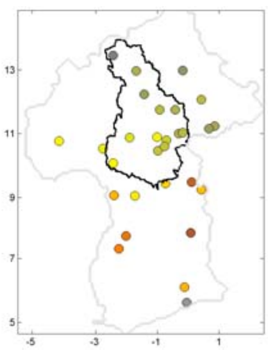


Methodologies

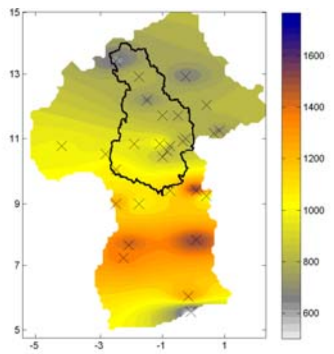
Spatial Interpolations	Simulations
• IDW, **Kriging**	• **Turning Bands**
• smoothing	• Conservation variability of obs.
⇨one field	⇨ many equally probable realisations

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

Spatial Interpolation: IDW and Ordinary Kriging

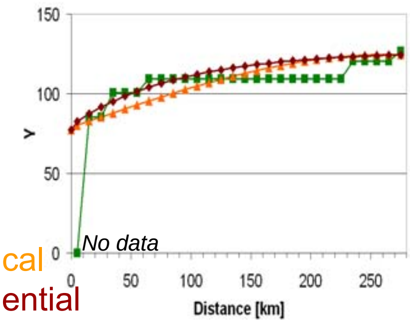


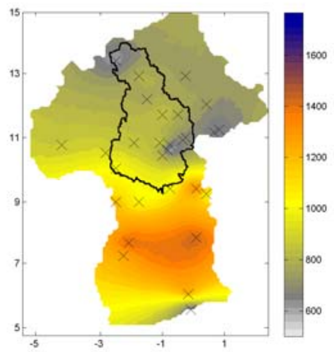
⇨ Inverse Distance weighting (IDW):



[mm]

⇨ Ordinary Kriging (OK):





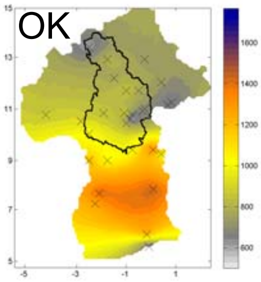
Variograms:
- experimental
- nugget & spherical
- nugget & exponential

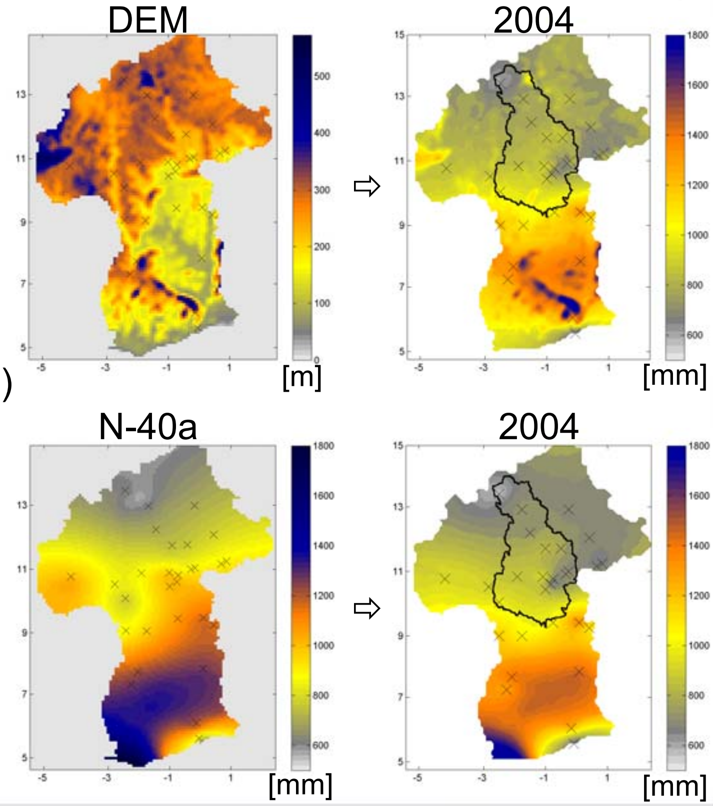
Spatial Interpolation: External Drift Kriging (EDK)

⇨ Suited additional information considered for interpolation

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

Applied External Drifts:
- Digital Elevation Model (DEM)
- Mean annual precipitation (40a)
- Latitudinal dependency
- LAI



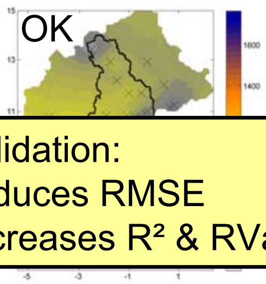


Spatial Interpolation: External Drift Kriging (EDK)

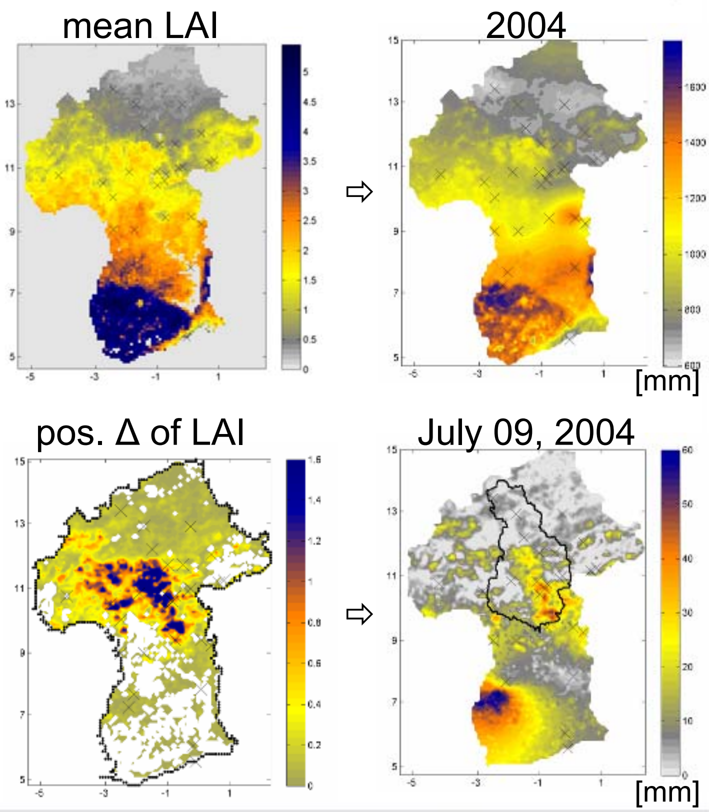
⇨ Suited additional information considered for interpolation

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

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

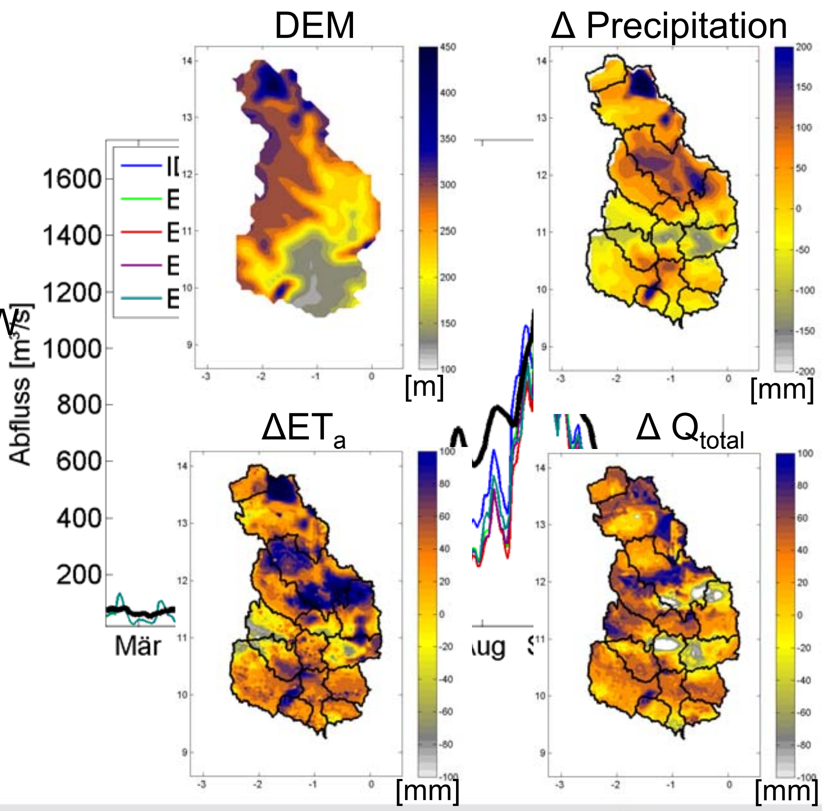


Cross validation:
- EDK reduces RMSE
- EDK increases R^2 & RVar



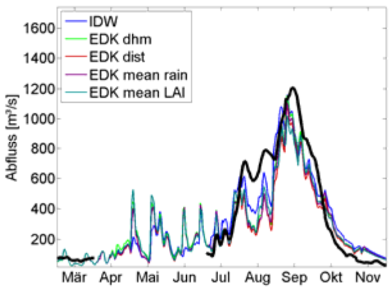
Impact Interpolation on Water Balance Estimates

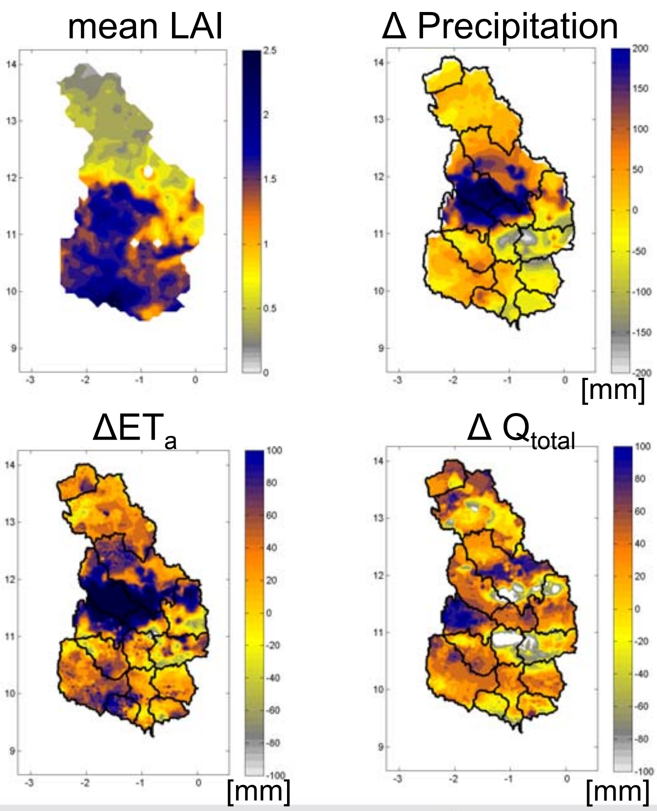
- Time series
- Spatial distribution:
  DEM
  ⇨ Difference EDK - IDW



Impact Interpolation on Water Balance Estimates

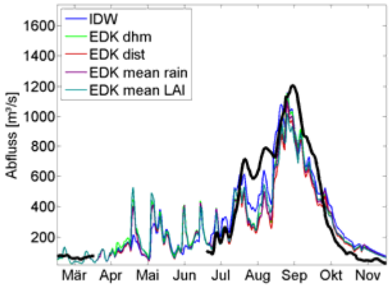
- Time series
- Spatial distribution:
  mean LAI
  ⇨ Difference EDK - IDW

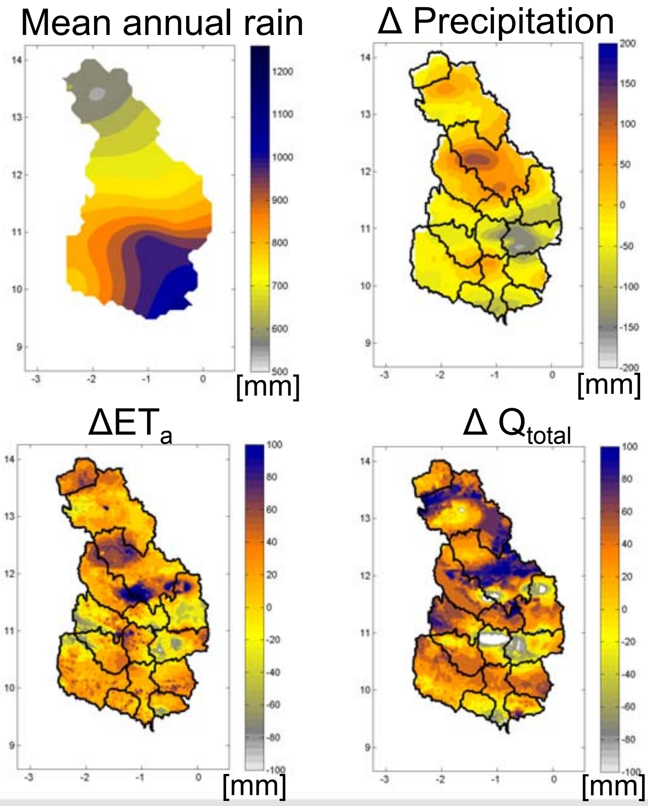




Impact Interpolation on Water Balance Estimates

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





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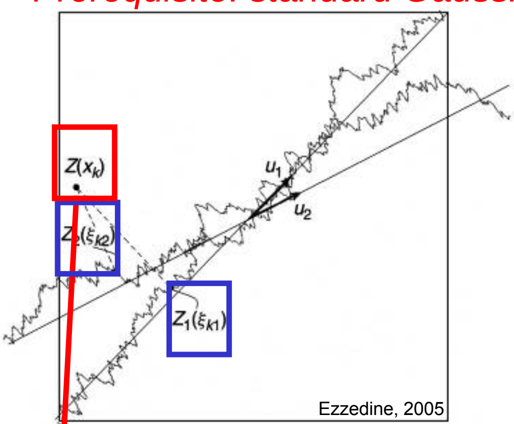
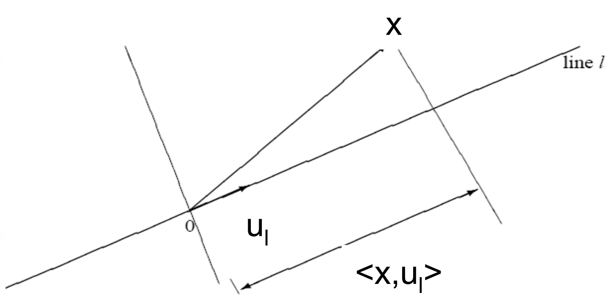
Spatial Interpolation: Turning Band Simulations

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



Ezzedine, 2005

Turning band lines and projections



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

$\boxed{Z_l}(u)$:

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

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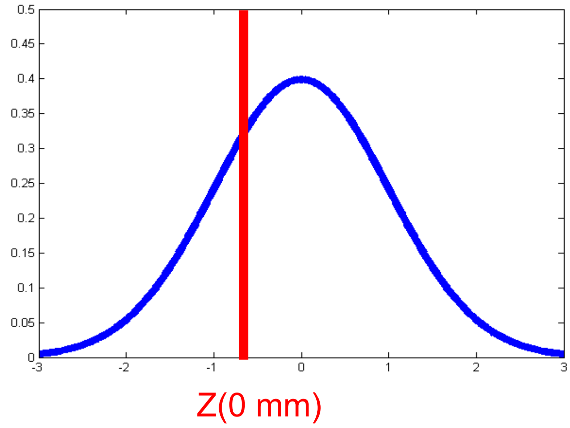
Normal score transformation

- Transform daily precipitation data to Gaussian distribution
- Problem: no negative precipitation exists
- Standard normal distribution: $Z = \frac{X - \mu}{\sigma}$

  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

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

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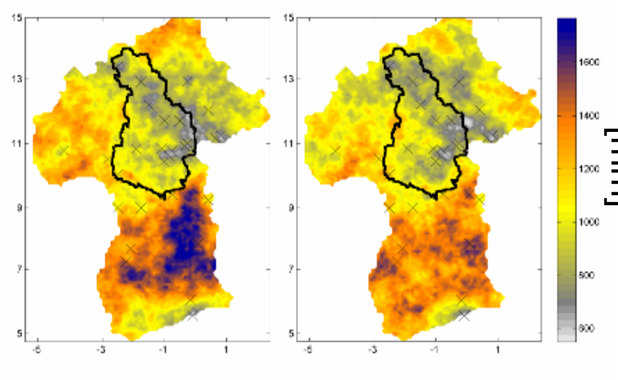
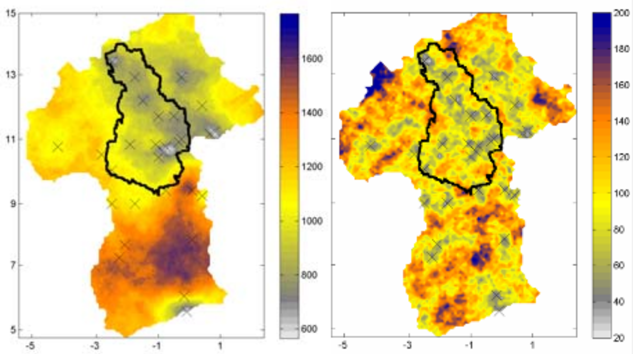
Conditional Simulations

Statistics:
Mean & standard deviation

Examples: Turning Band results





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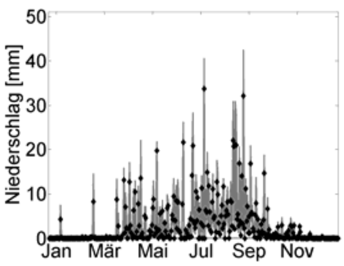
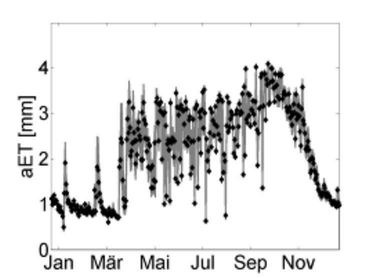
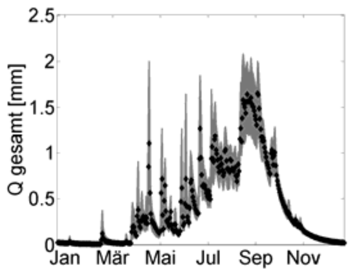
Uncertainties Propagated into Water Balance

Precipitation | **ET$_a$** | **Q$_{total}$**

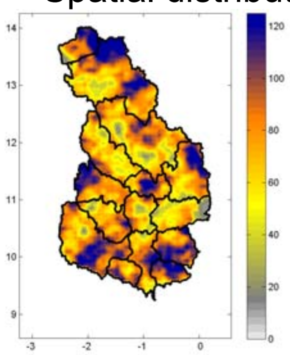
Time Series:

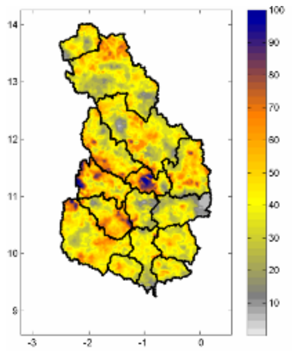


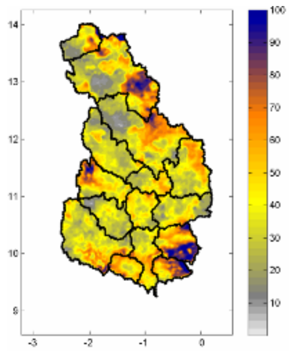




Spatial distribution: standard deviation

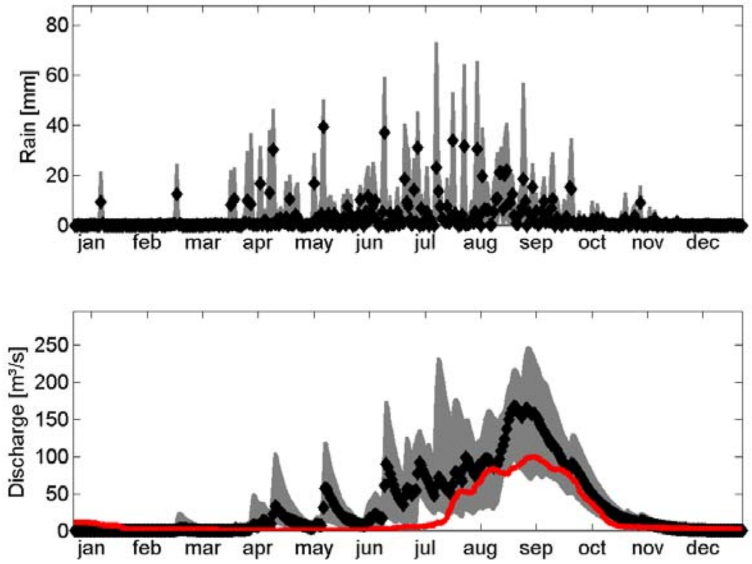






Karlsruhe Institute for Technology (KIT)
The Cooperation between Forschungszentrum Karlsruhe GmbH and University of Karlsruhe (TH)

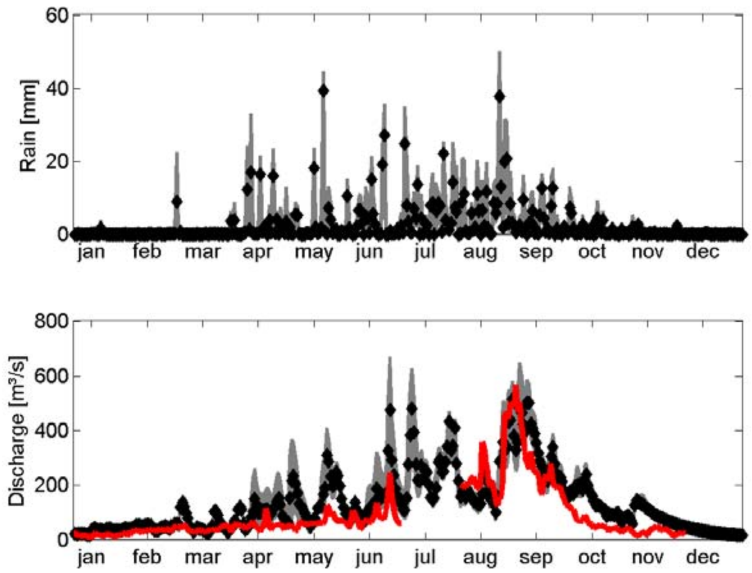
Uncertainties Propagated into Water Balance



2004

Gauge Nasia

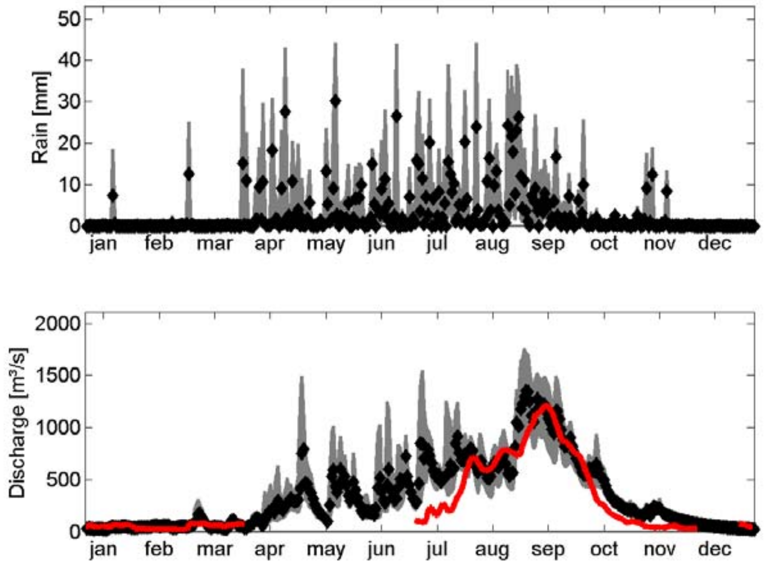
Uncertainties Propagated into Water Balance



2004

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 signifucantly 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