A New Hydrometeorological Decision Support System for Sustainable Water Management in the Volta Basin

(S1 and S2)

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Background

- Volta Basin: water management problems & weak infrastructure
- Increasing pressure on water resources due to population pressure
- Sustainable water management strategies require hydrological modeling
- … and hydrological modeling requires meteorological input …

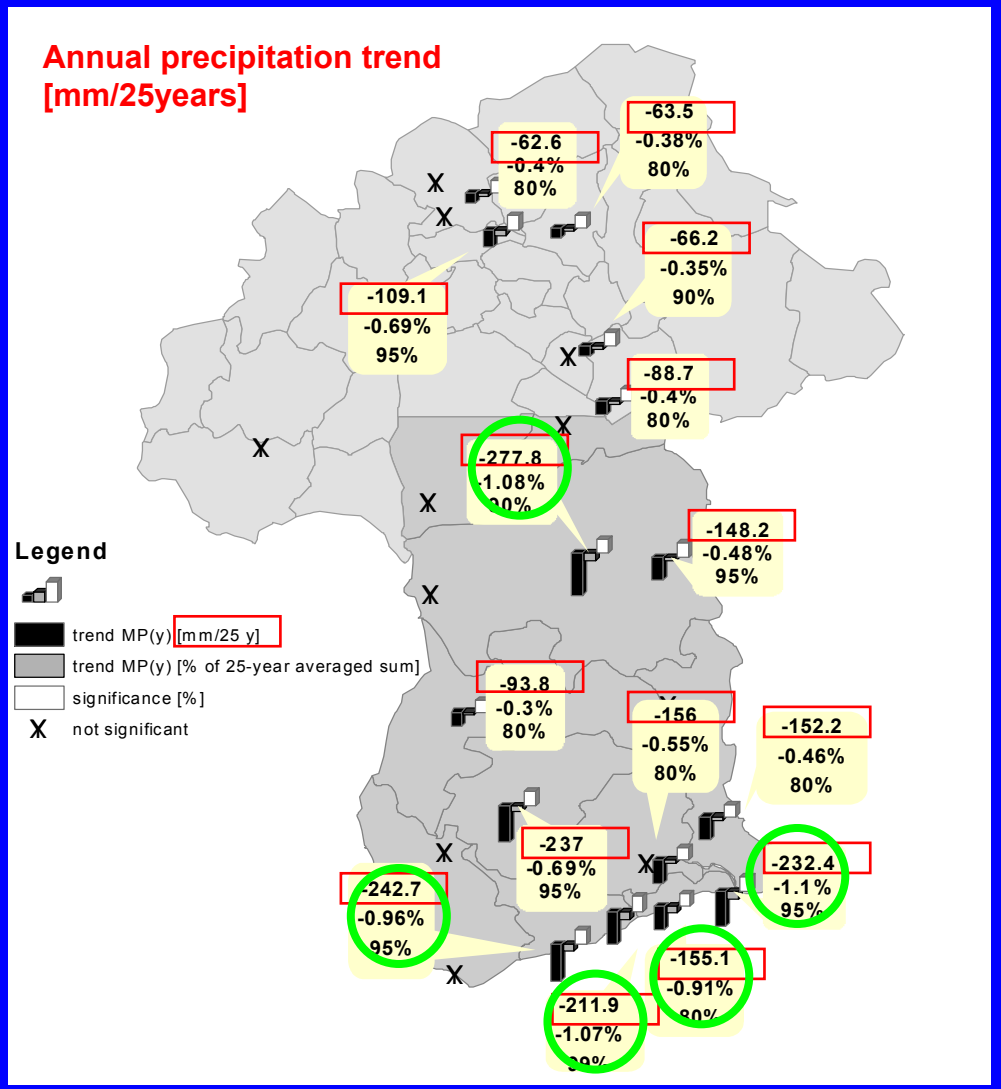
General Problems

- Limited observation networks, particularly for precipitation
- Observation information only available with delay
- Global warming changes statistical behavior of meteorological variables (e.g. temporal and spatial distribution of precipitation)

Technical/model based solutions for Decision Support must account for both atmosphere & terrestrial hydrology

Focus: Hydrometeorological Decision Support Volta Basin

Footprints of Climate Change in the Volta Basin



Significant decrease of annual precipitation in specific areas

≈ 25% precipitation decrease in last 25 years!

Challenge:
Scientifically sound information under weak infrastructure

Water Management Problems in the Volta Basin/West Africa

Hydrometeorological Decision Support for specific questions:

- How does climate change impact water availability in the Volta Basin?

  ⇒ Identification of future water availability gaps (drought risks)

- What are the current natural water stocks and -fluxes in the catchment?

⇒ Near-real time distributed identification of natural water balance

What are the rains in the next 5 days?

⇒ Operational numerical weather prediction

- How can the current onset of the rainy season reliably estimated?

⇒ Vital for correct sowing dates and sustainable livelihood

Atmospheric Science in Hydrological Decisions Support

Hydrometeorological Decision Support

Long term planning

Spatial distribution of **climate change** induced changing water availability

ECHAM4 - MM5 & WaSiM

Short/mid term planning

Operational
1) Weather forecast (NWP)
2) Model based water balance information system

GFS - MM5 *hindcasts* & WaSiM

GFS - MM5 *forecasts*

Special planning

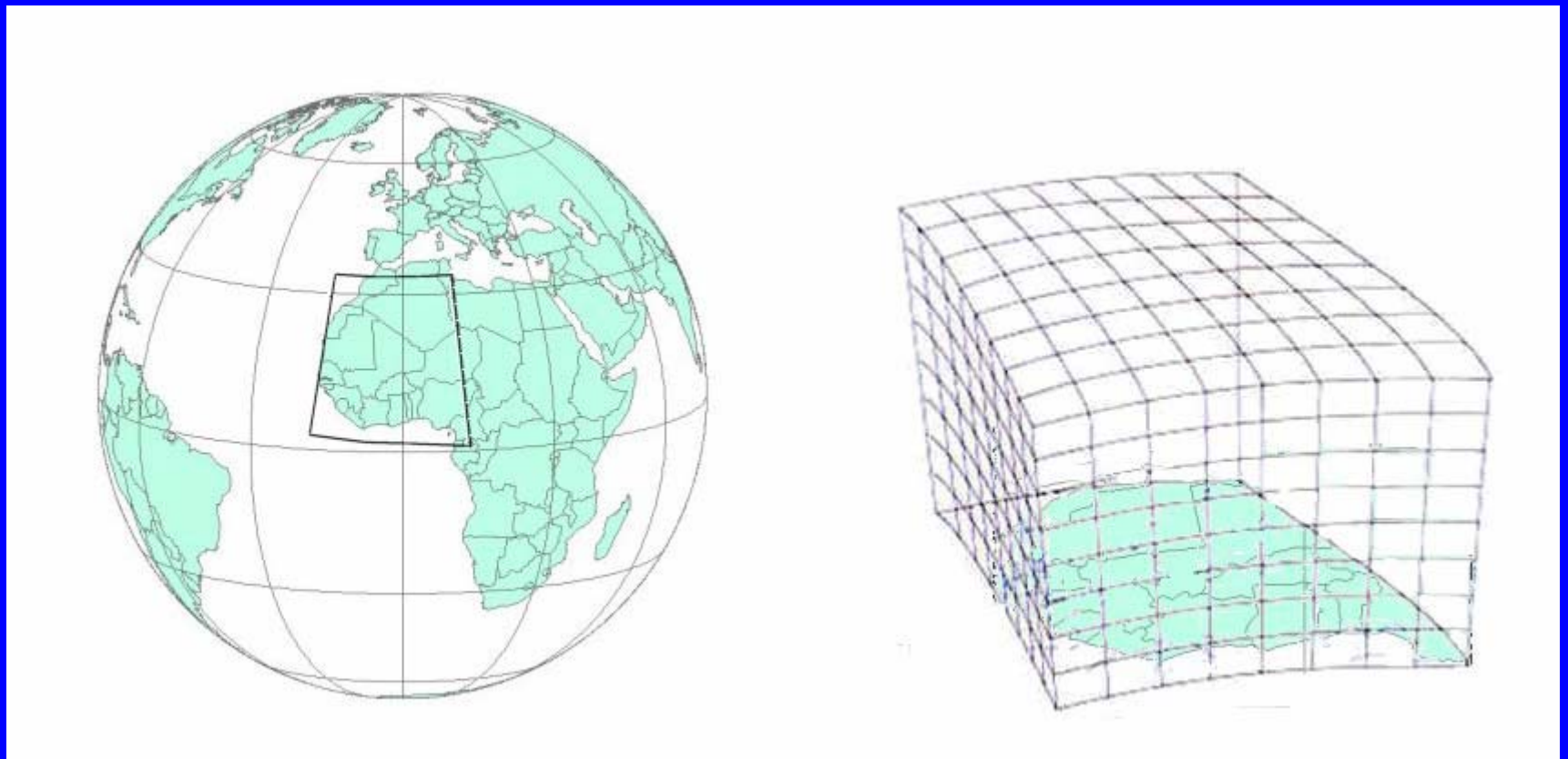
Prediction of current regional **onset date** of rainy season

- circulation patterns
- *linear discriminant* analysis

Coupled meteorological-hydrological DSS

Pure meteorological DSS

Atmospheric Modeling



Dynamic downscaling of global atmospheric fields
by mesoscale meteorological models
⇒ Provides all required meteorological variables for hydrology

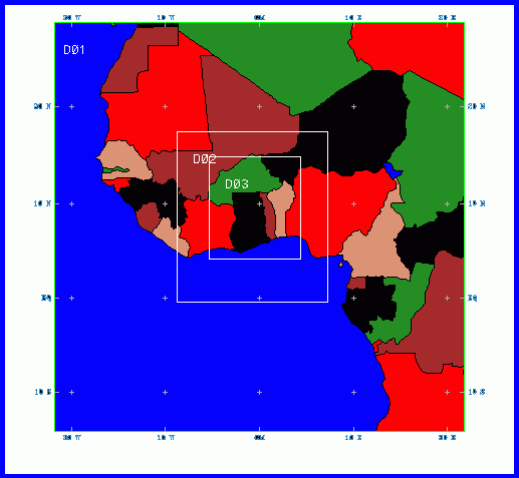
Decision Support (1):

Delineation of spatial and temporal distribution of changes in water availability Volta Basin through coupled regional climate-hydrology simulations

Impact of Regional Climate Change on Water Availability

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Radiation

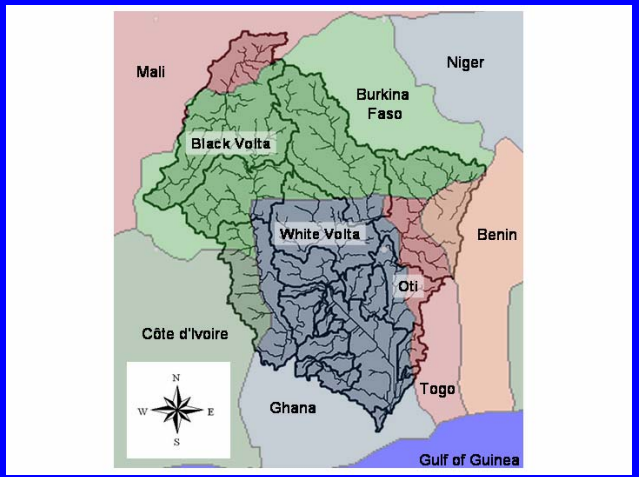
ECHAM4 & MM5
Scenario IS92a
2030/39 vs.
1991/2000



2.8° → 9x9 km² Resolution

Distributed
Hydrological Model
WaSiM

- Orography
- Land use
- Soil properties
- Aquifer properties
- Flownet structure



1x1 km² Resolution

Evapotranspiration

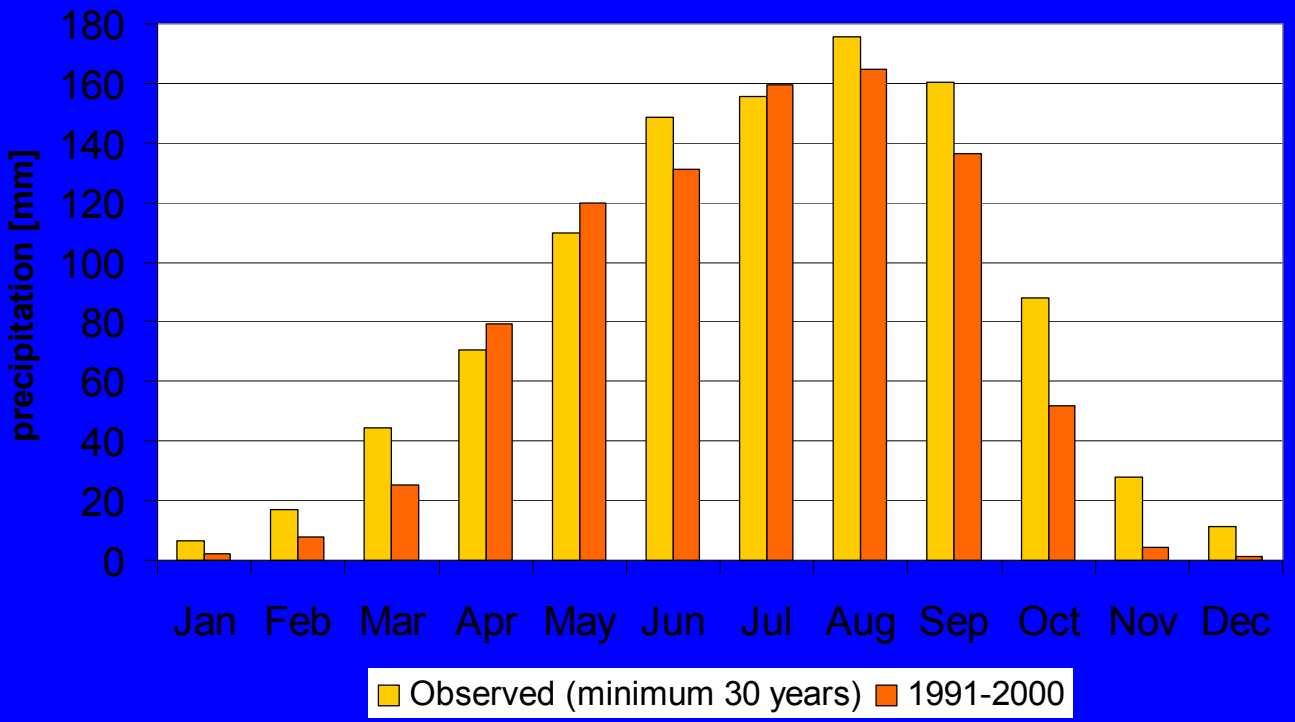
Infiltration

Surface runoff

Groundwater flow

Validation Regional Climate Simulations

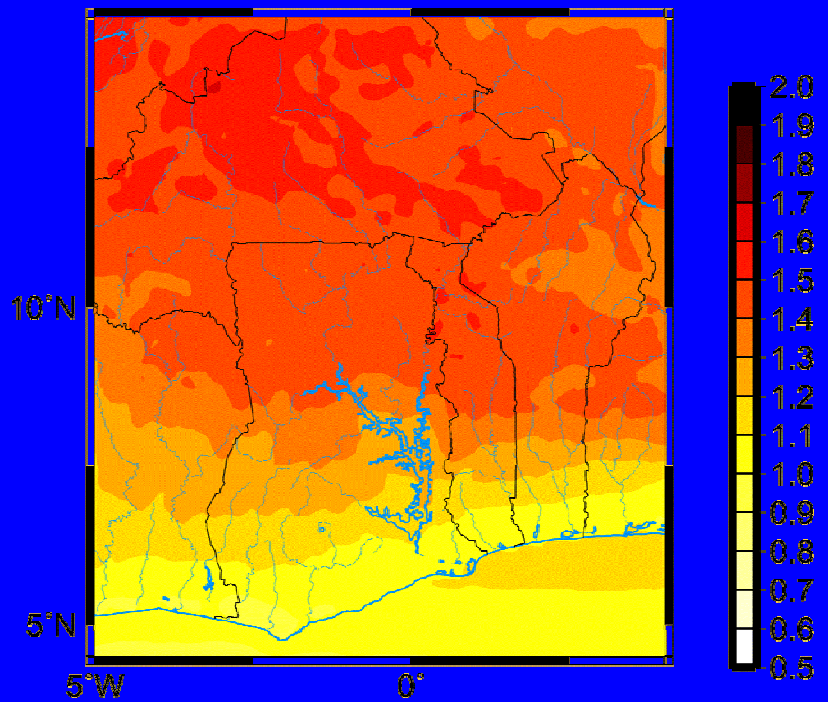
Simulated (1991-2000) vs. interpolated station data



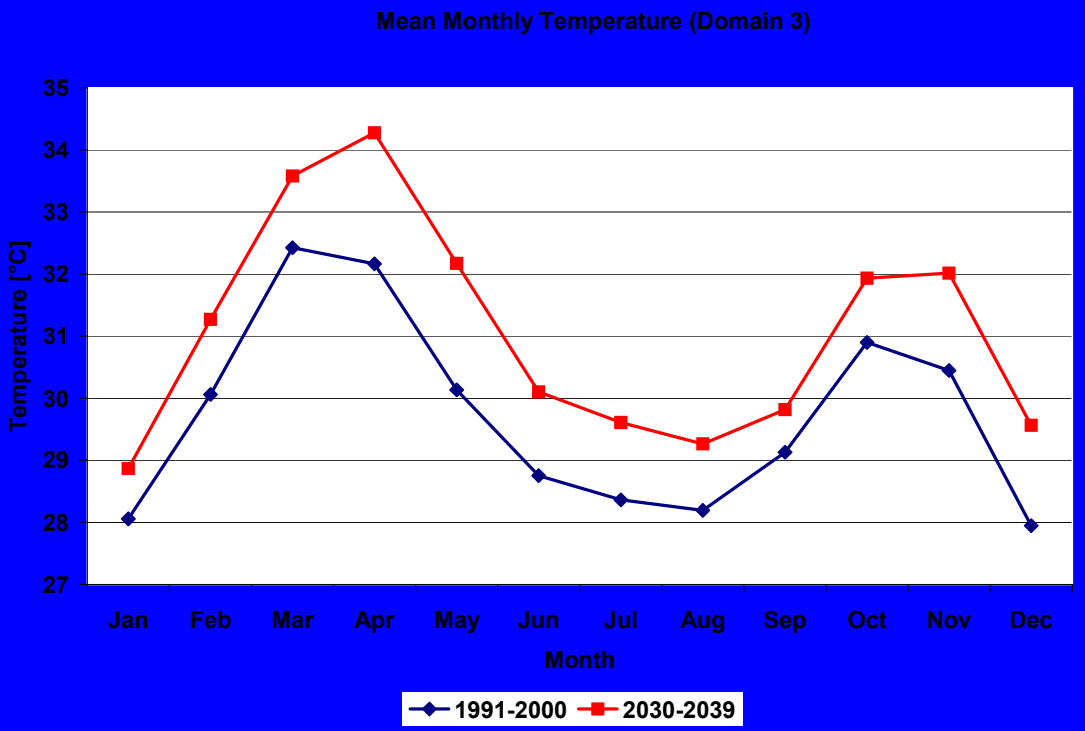
⇒ Reasonable simulation of annual cycle

Impact of Regional Climate Change on Water Availability

Results: temperature change [°C] 2030-2039 vs. 1991-2000

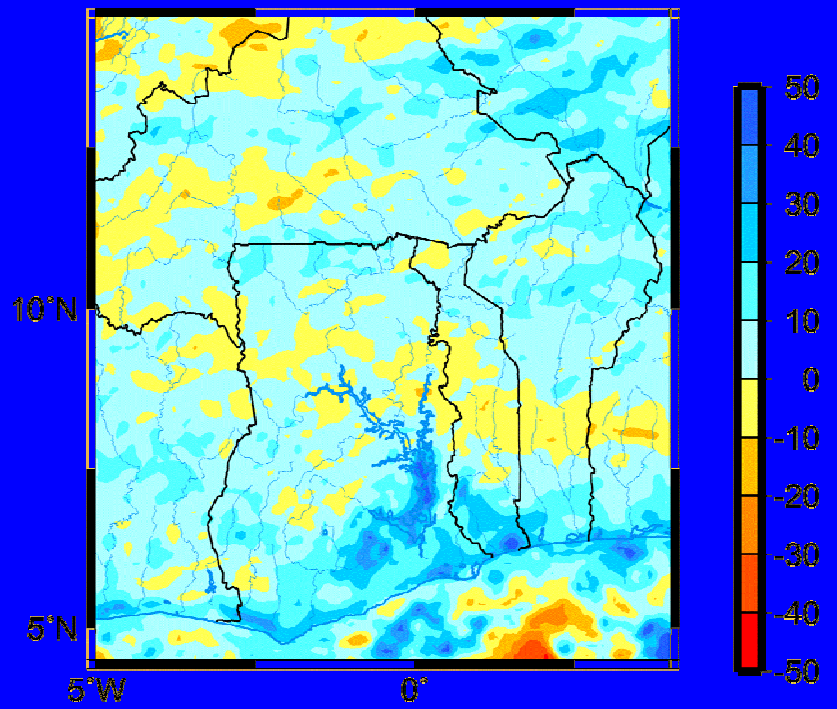


Change in annual mean temperature [°C]

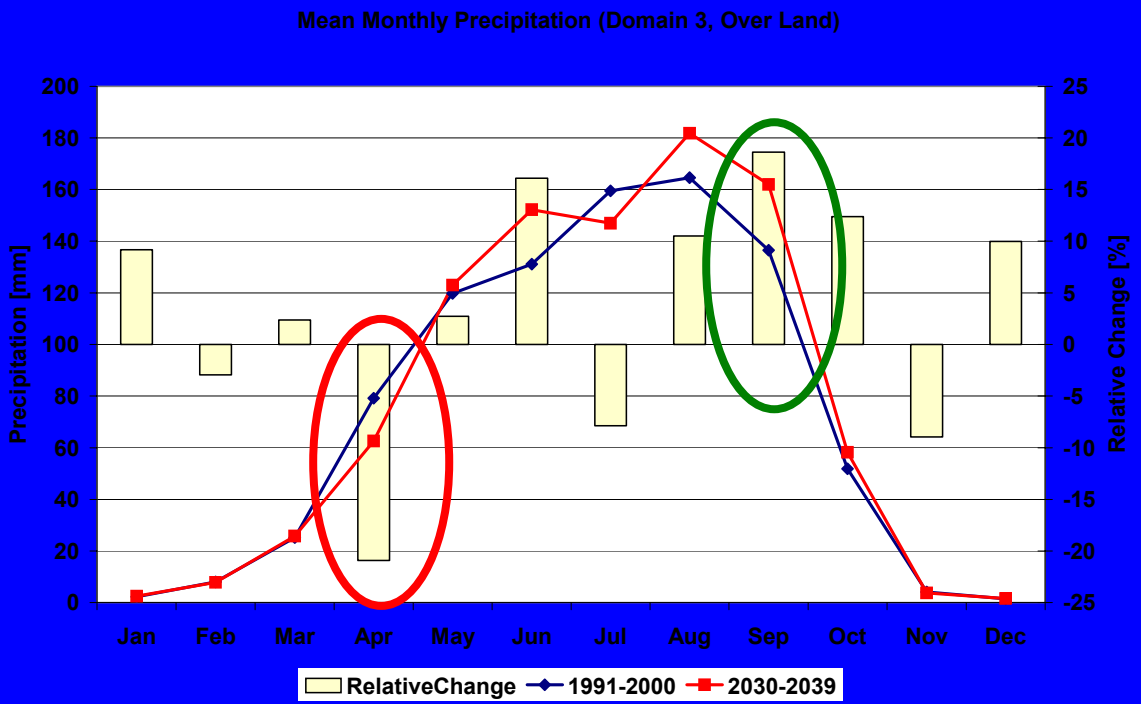


Impact of Regional Climate Change on Water Availability

Results: precipitation change 2030-2039 vs. 1991-2000



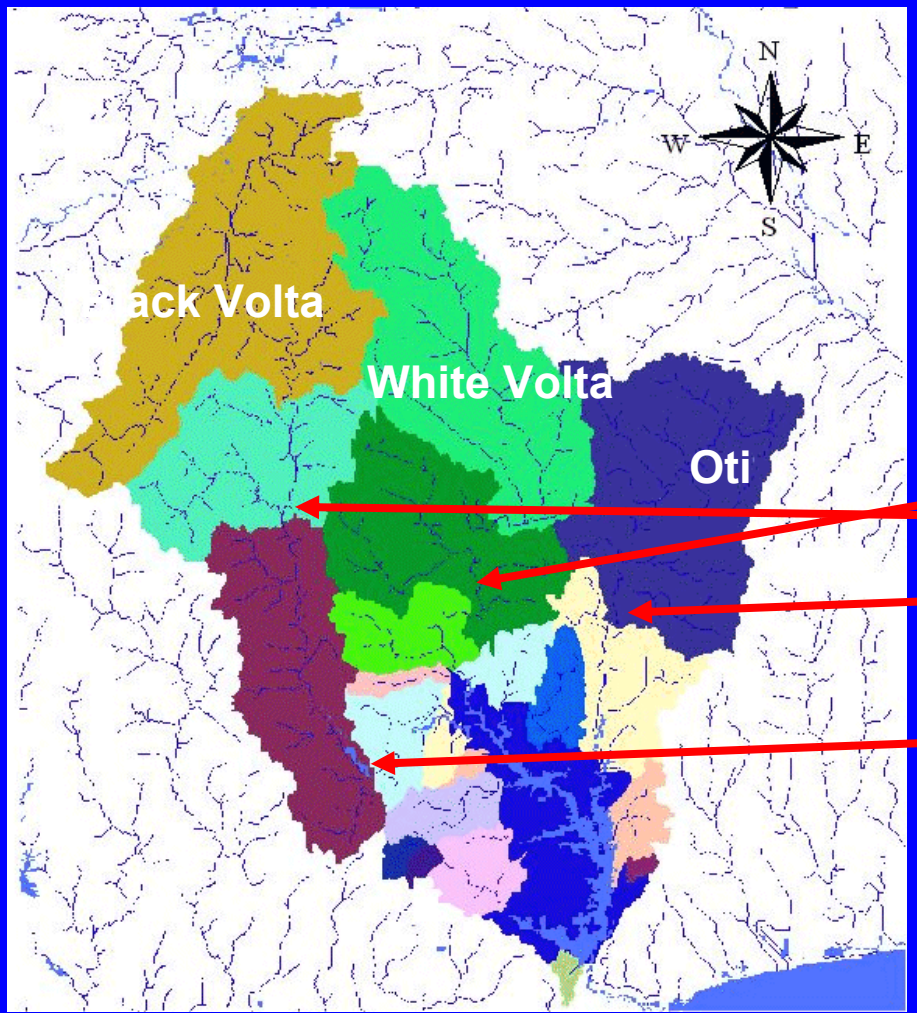
Mean annual precipitation change [%]



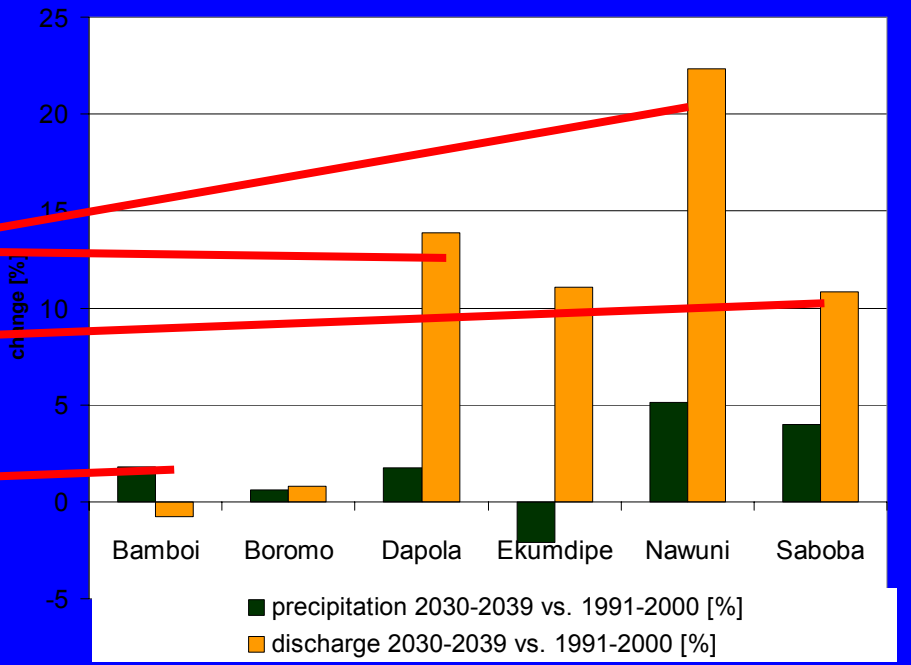
Decreased precipitation at cessation of rainy season

Impact of Regional Climate Change on Water Availability

Results: precipitation change 2030-2039 vs. 1991-2000

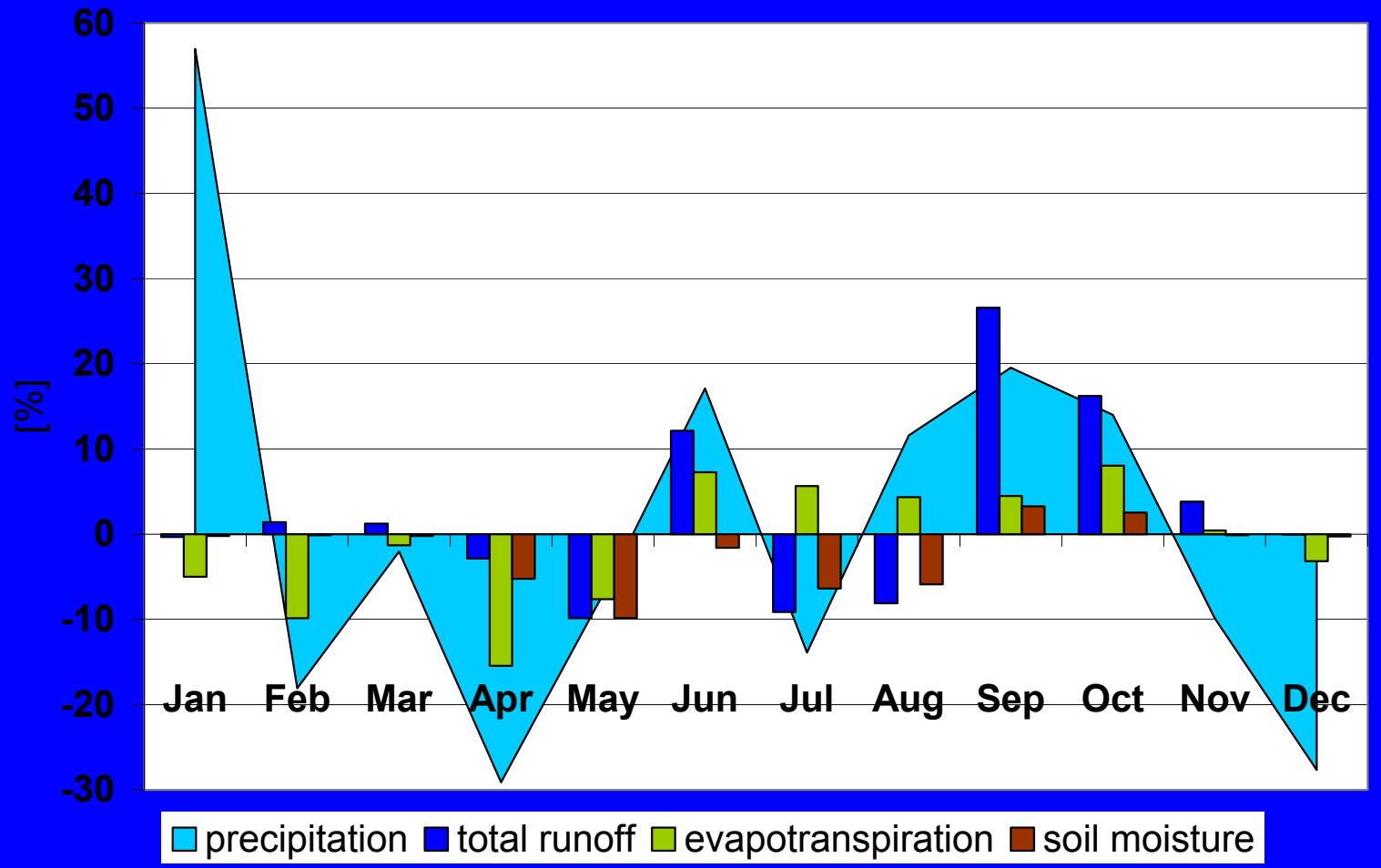


Nonlinear response of change in discharge to change in precipitation



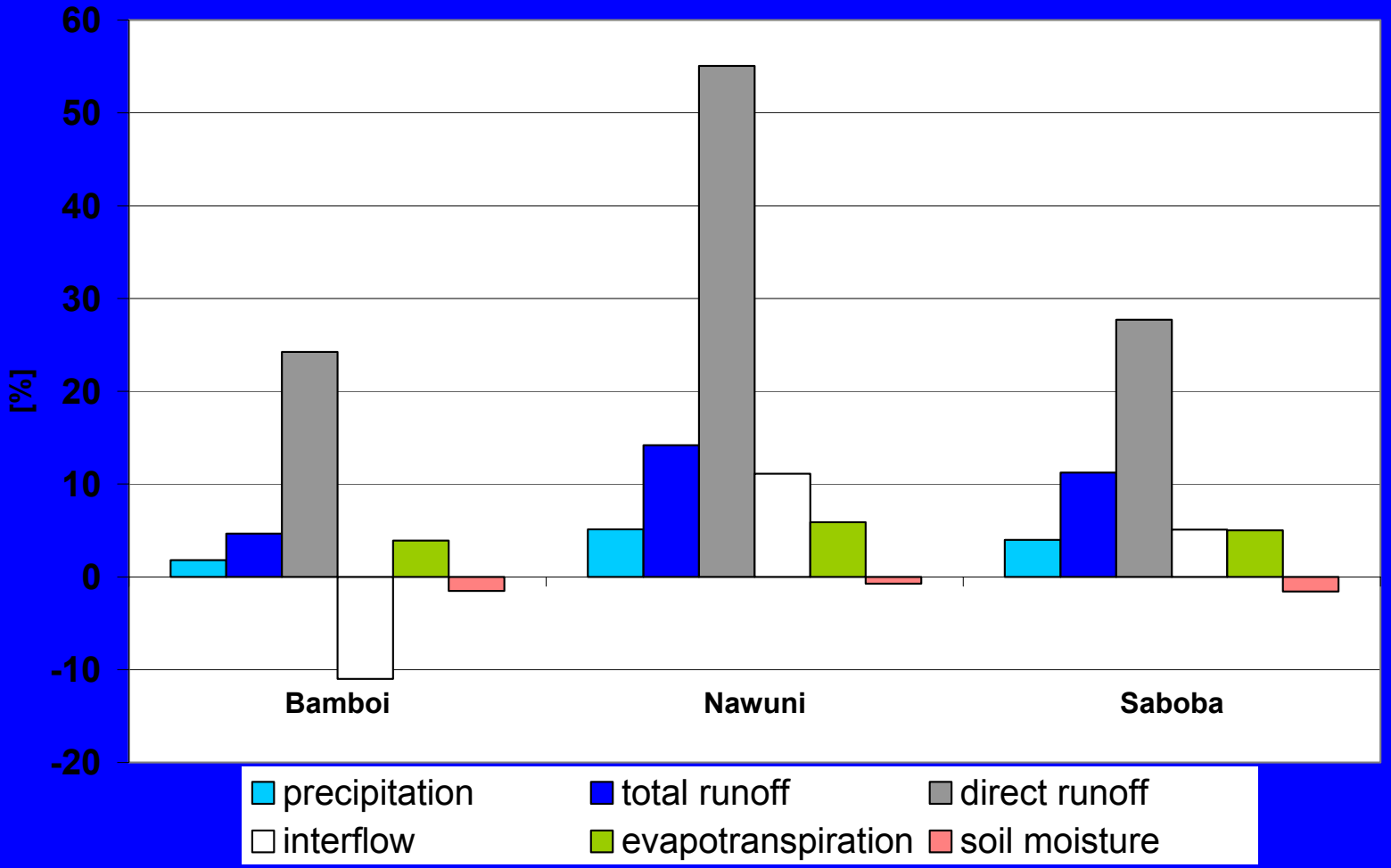
Impact of Regional Climate Change on Water Availability

Results: Water balance change 2030-2039 vs. 1991-2000



Impact of Regional Climate Change on Water Availability

Results: Water balance change 2030-2039 vs. 1991-2000



Impact of Regional Climate Change on Water Availability

Results: Change in onset dates 2030-2039 vs. 1991-2000

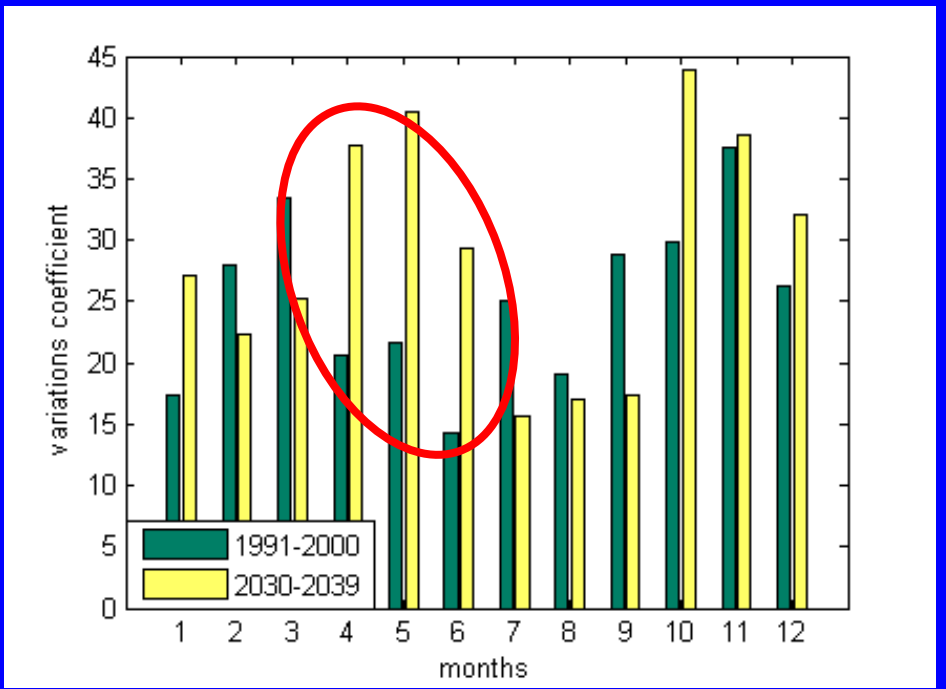
Change in Onset of Rainy Season

	Sahel	Guinea Coast
1991-2000 [DOY]	124	105
2030-2039 [DOY]	133	108
Mean change in onset date [days]	9	3

Definition of Onset: Stern et al. (1981)

⇒ **Delay in the onset of the rainy season**

Inter-annual variability



⇒ **Increase in inter-annual variability**

Recipe for DSS – Part 1:
Climate Change Adaptation

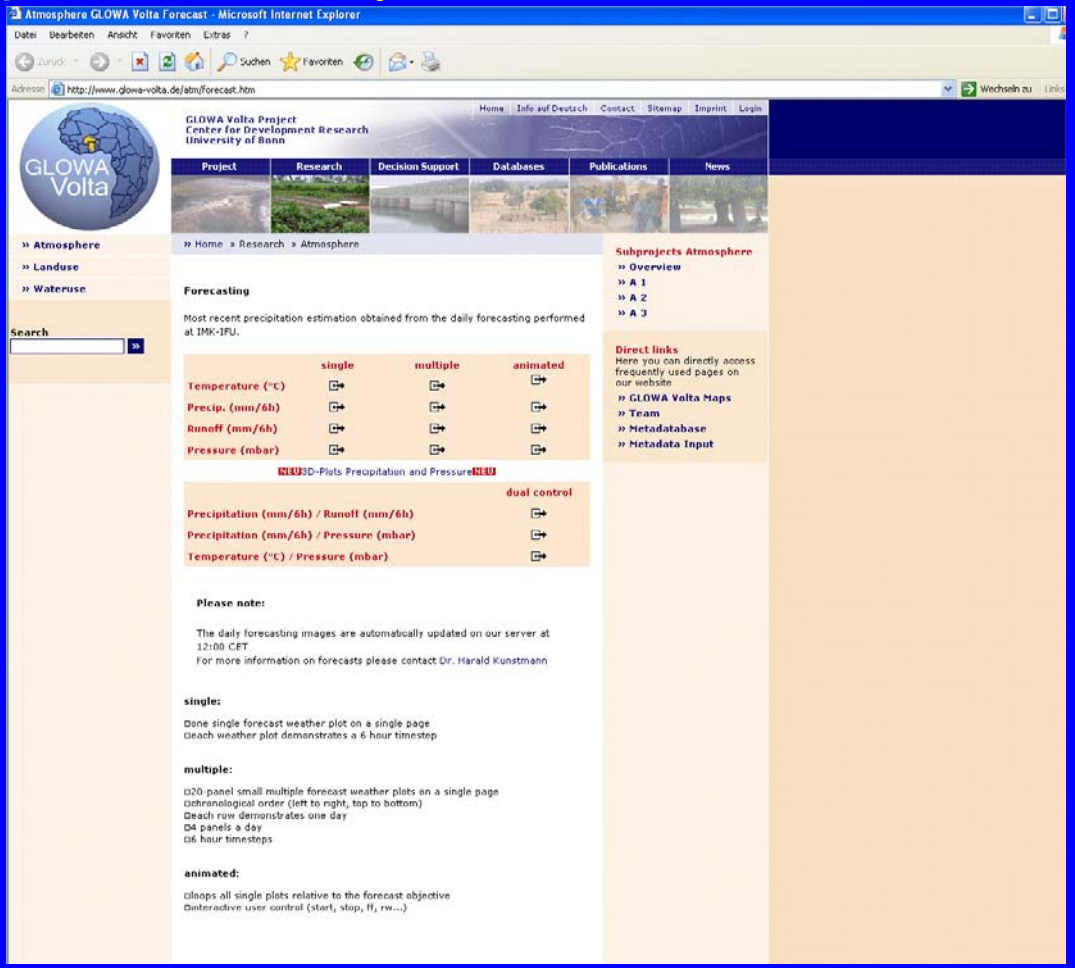
- Use climate change data set in 9x9 km² resolution
- Identify regions where changes in spatial or temporal distribution of water balance variables are expected
- Design adaptation and mitigation strategies

Decision Support (2):

Operational 5-day Numerical Weather Prediction (NWP)

Numerical Weather Prediction (NWP)

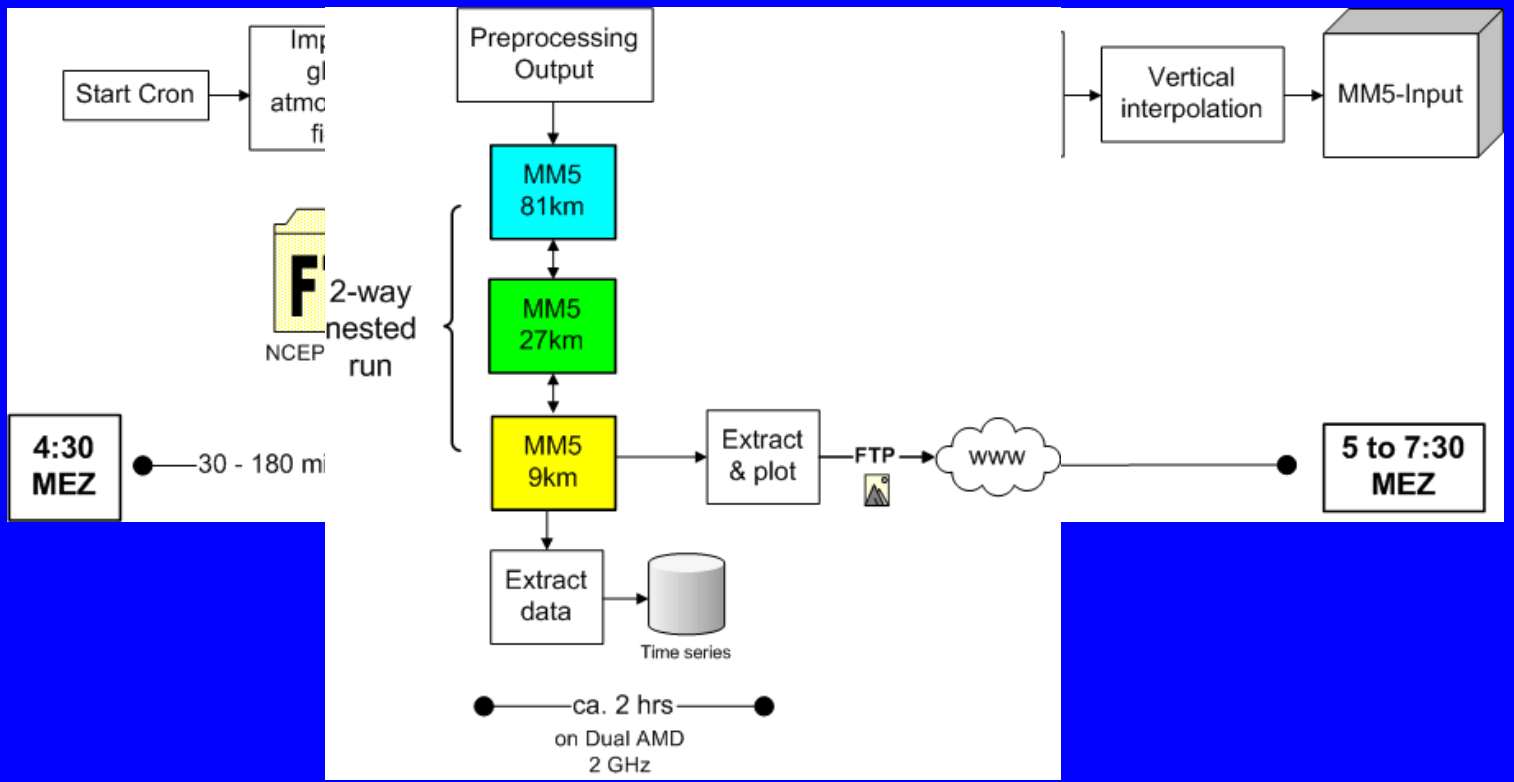
Operational 5-day Numerical Weather Prediction



http://www.glowa-volta.de/atm/forecast/atm.htm

Numerical Weather Prediction (NWP)

Operationalisation of atmospheric forecasting



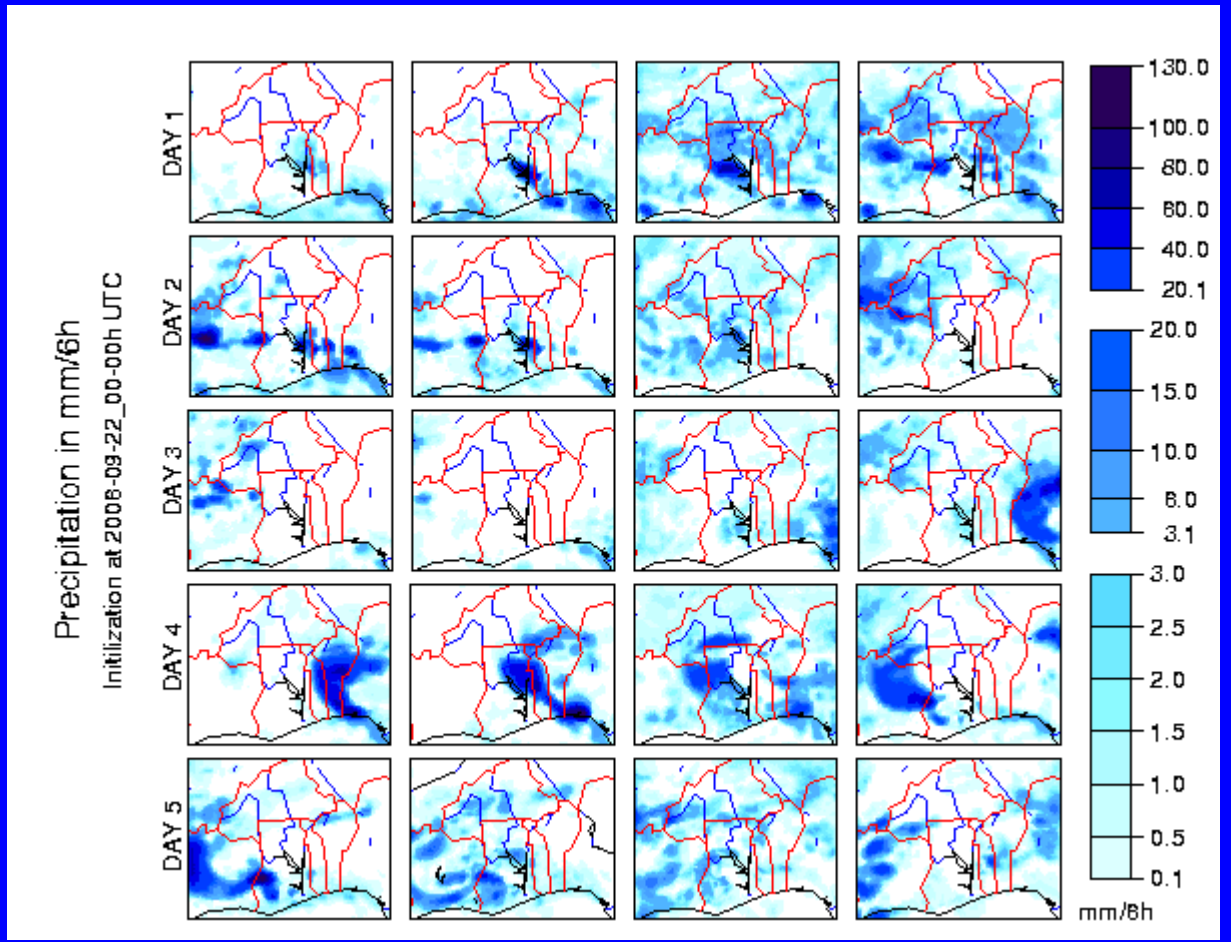
… using only public domain data sources …

http://www.glowa-volta.de/atm/forecast/atm.htm

Numerical Weather Prediction (NWP)

Operational 5-day Numerical Weather Prediction

Precipitation



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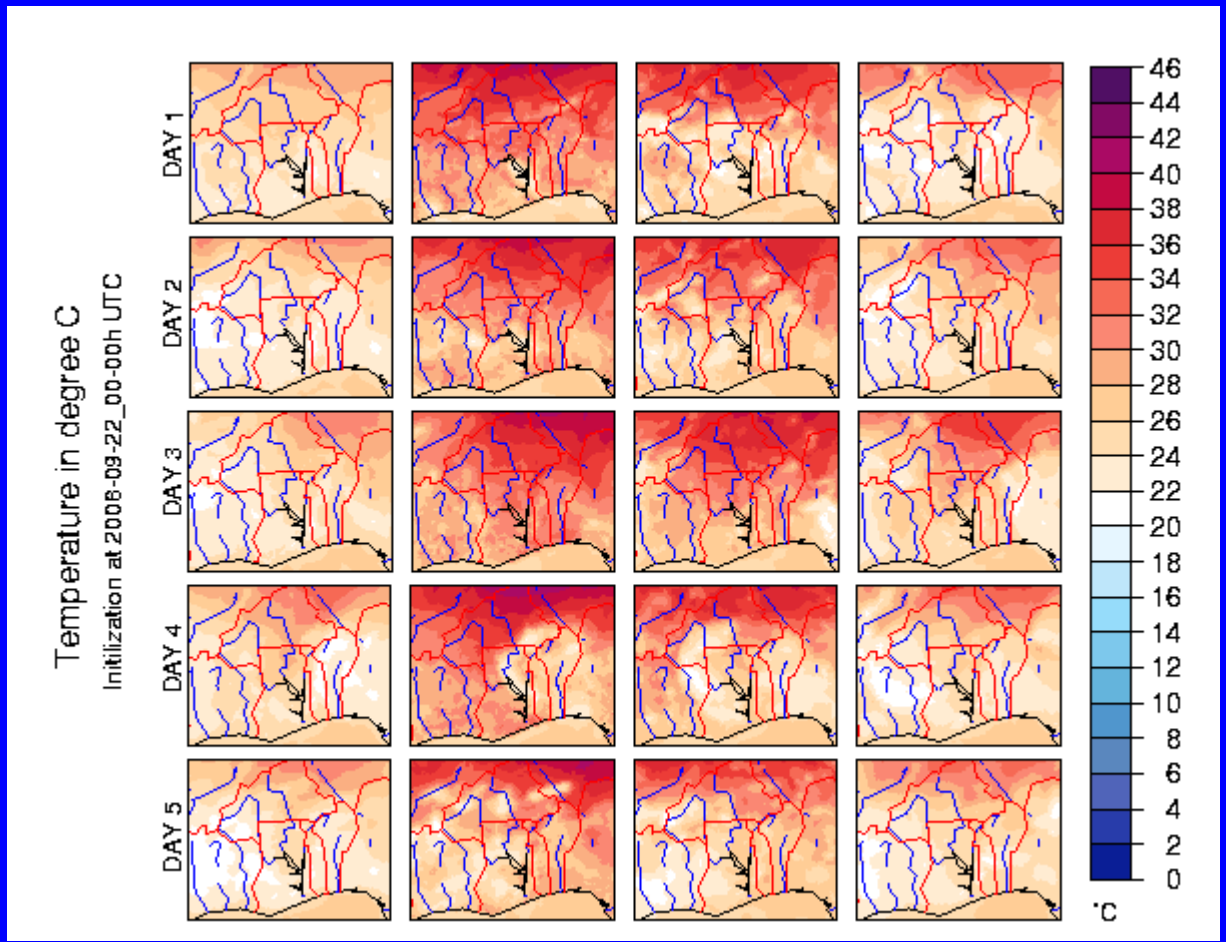
Numerical Weather Prediction (NWP)

Operational 5-day Numerical Weather Prediction

Temperature

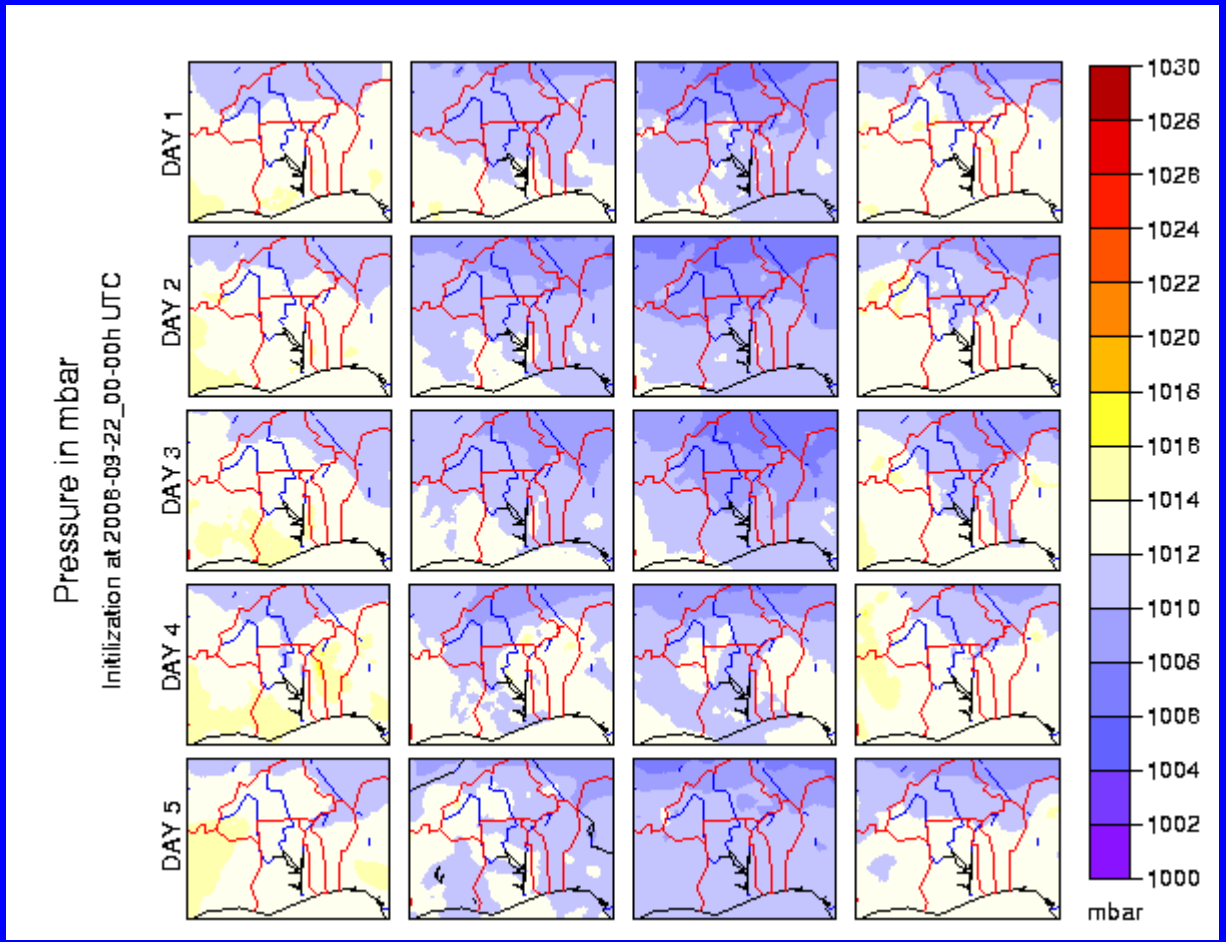


http://www.glowa-volta.de/atm/forecast/atm.htm

Numerical Weather Prediction (NWP)

Operational 5-day Numerical Weather Prediction

Pressure

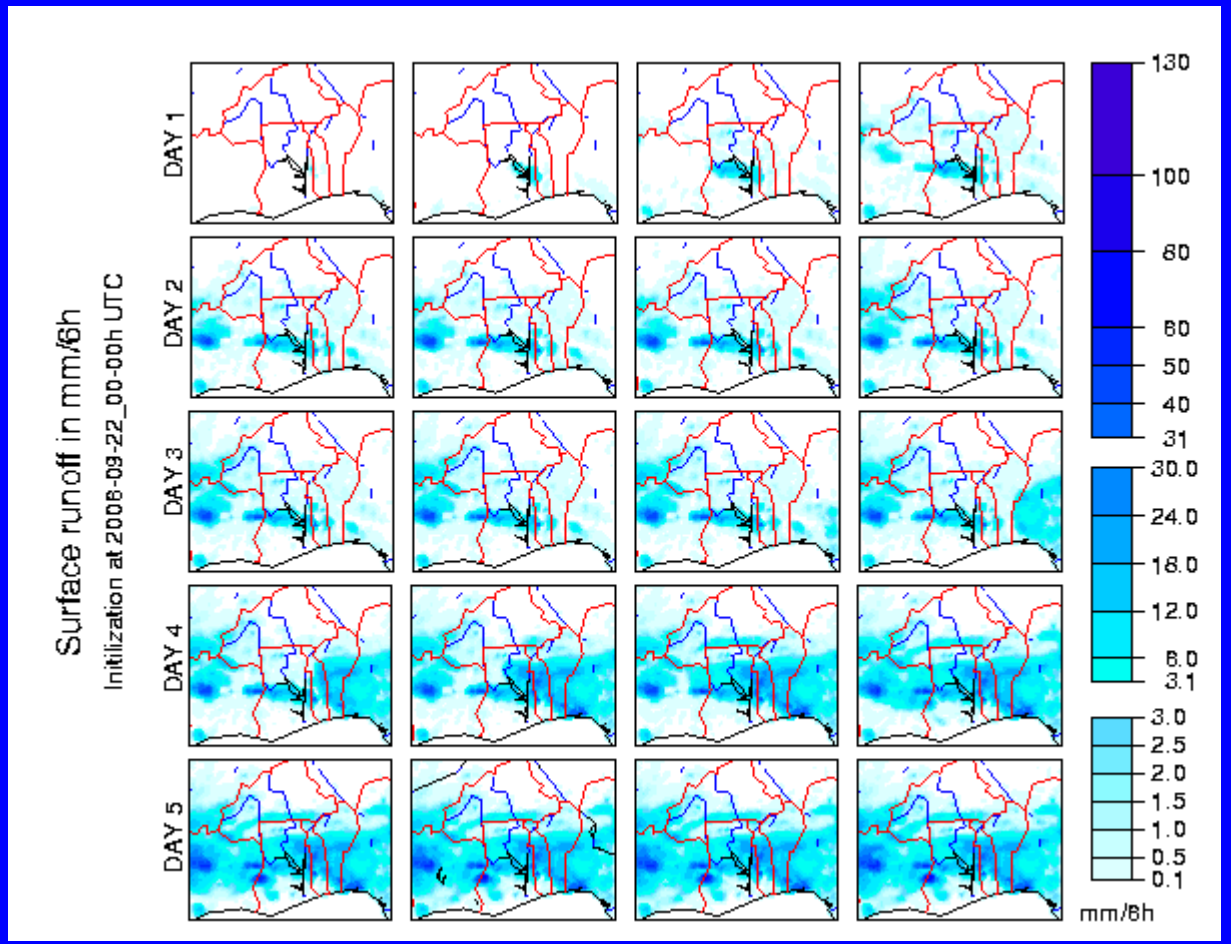


http://www.glowa-volta.de/atm/forecast/atm.htm

Numerical Weather Prediction (NWP)

Operational 5-day Numerical Weather Prediction

Runoff



http://www.glowa-volta.de/atm/forecast/atm.htm

Decision Support (3):

Model Based Operational Water Balance System

for the White Volta Subcatchment

through

Coupled Regional Atmospheric-Hydrological Simulations

Sven Wagner

Background

Objective:

Providing basin wide spatial and temporal distribution of natural water stocks and fluxes in near real time as central part of the hydro-met DSS

- Hydrological simulations: require meteorological input data

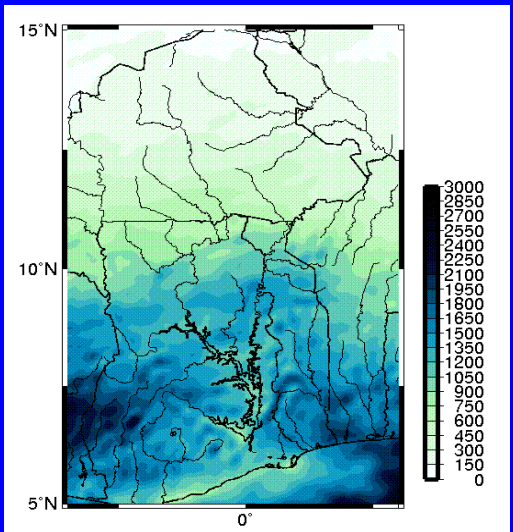
  1. dense observational network
  2. atmospheric model output

- Volta Basin: - Limited meteorological observation network
  - Observation information only available with delay!

Model Based Operational Water Balance System

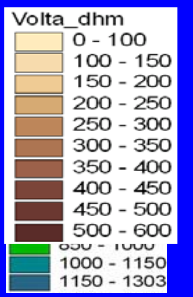
GLOWA Volta

Meteo-Model: MM5

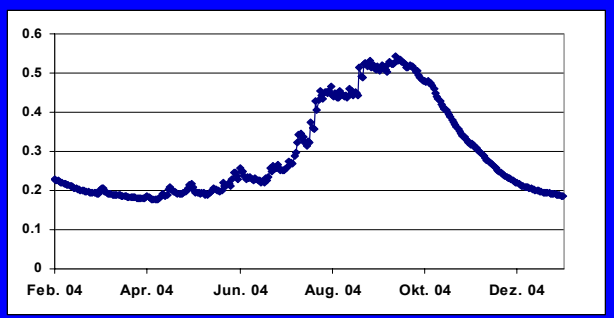


Modelbased
Monitoring
Terrestrial
Water Balance

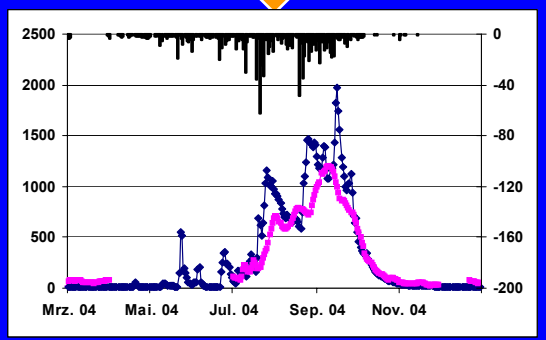
Hydro-Model: WaSiM



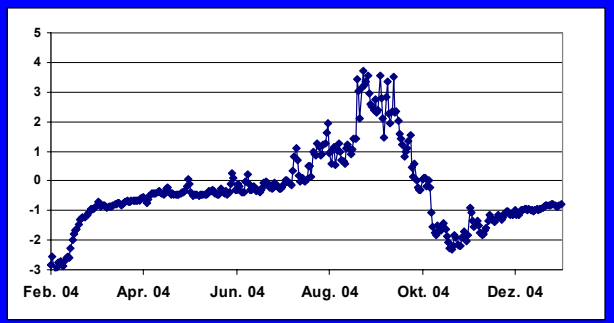
Evapotranspiration [mm/a]



Soil humidity



Surface Runoff [m³/s]



Groundwater Recharge [mm]

Operational Hindcast with Coupled Model System

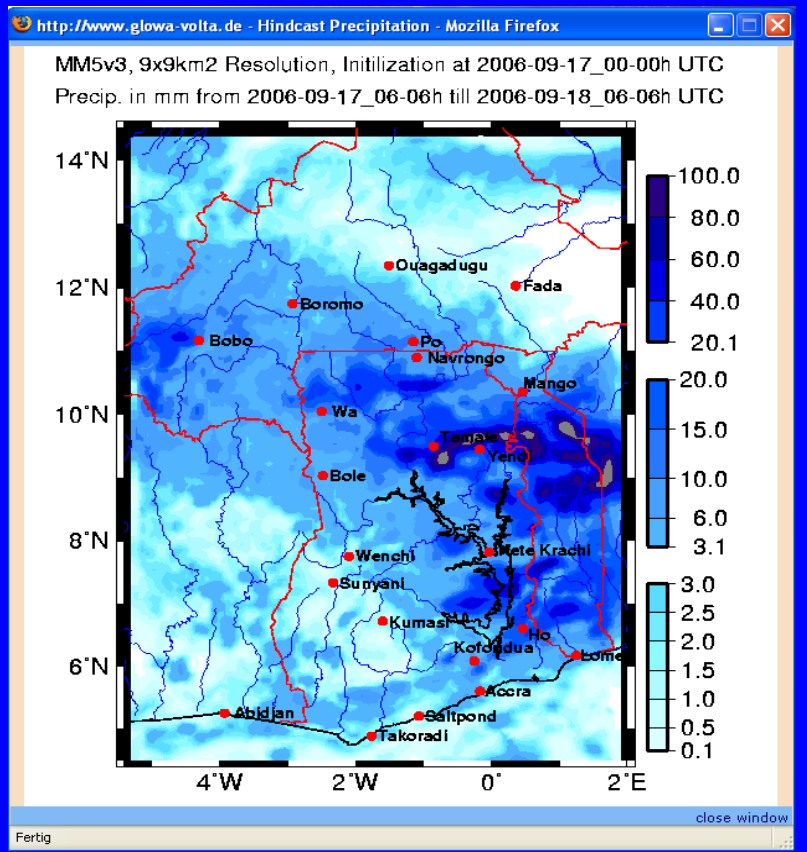
⇒ Transfer of coupled system in operational mode & simulating the water balance changes near real time

⇒ Atmospheric hindcast already operational:
http://www.glowa-volta.de/atm/hindcast/atm.htm

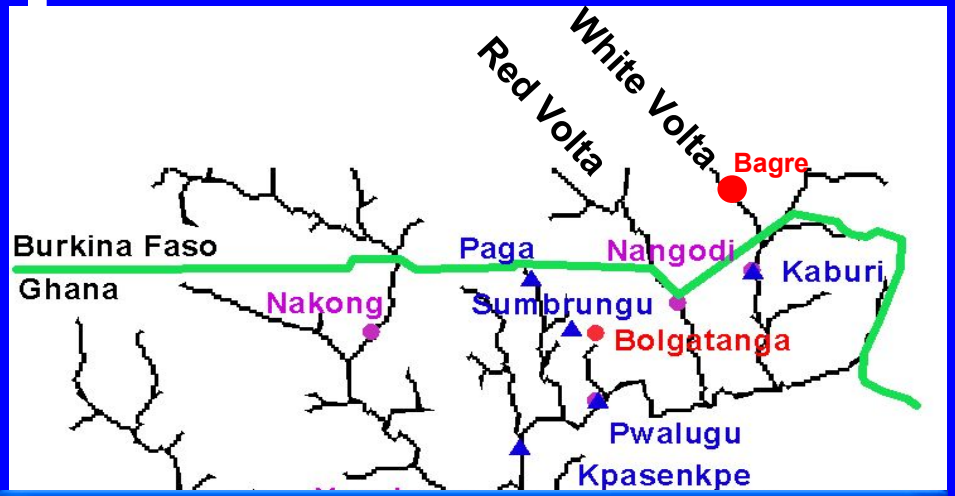
⇒ Operationalisation of atmospheric hindcasting with 48h delay

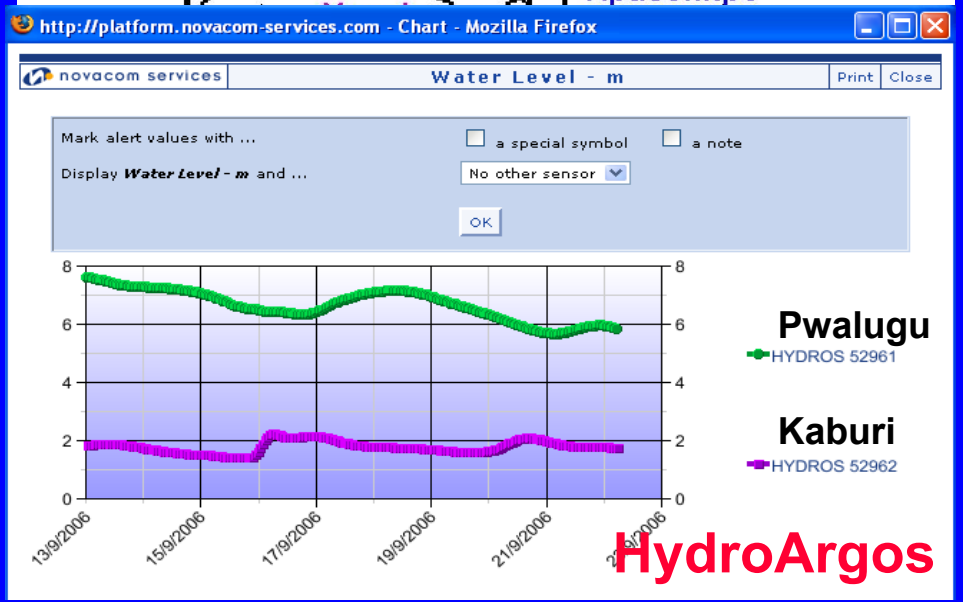
⇒ using only public domain data sources

Development & Setup :
ex-post hindcasting of coupled system for 2004 for White Volta catchment



Field Campaign 2004 with Hydrological Services Department





Kaburi
- HydroArgos, diver, manual
- Rain gauges, manual

Pwalugu
- HydroArgos, manual
- rain gauges, manual

Kpasenkpe
- diver, manual
- rain gauges, manual

Paga & Sumbrungu
- diver

Model System: Meteorological Model

Mesoscale Meteorological Model MM5 (Penn State/NCAR)

Characteristics:

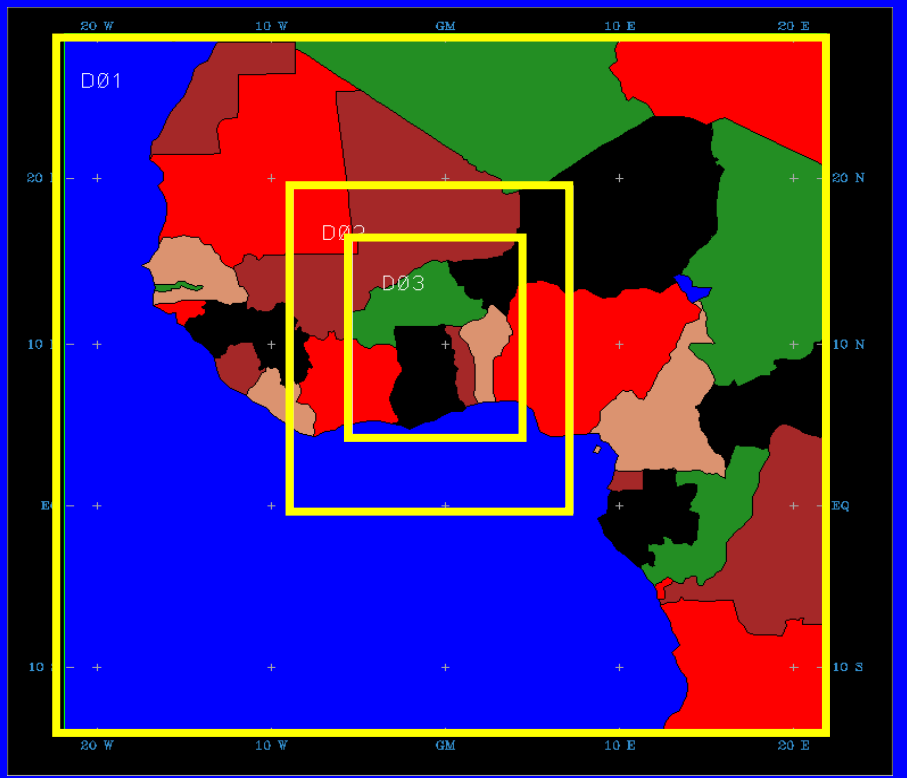
- Non-hydrostatic dynamics
- Multiple nesting capability
- Four dimensional data assimilation

Setup:

- Dynamical downscaling

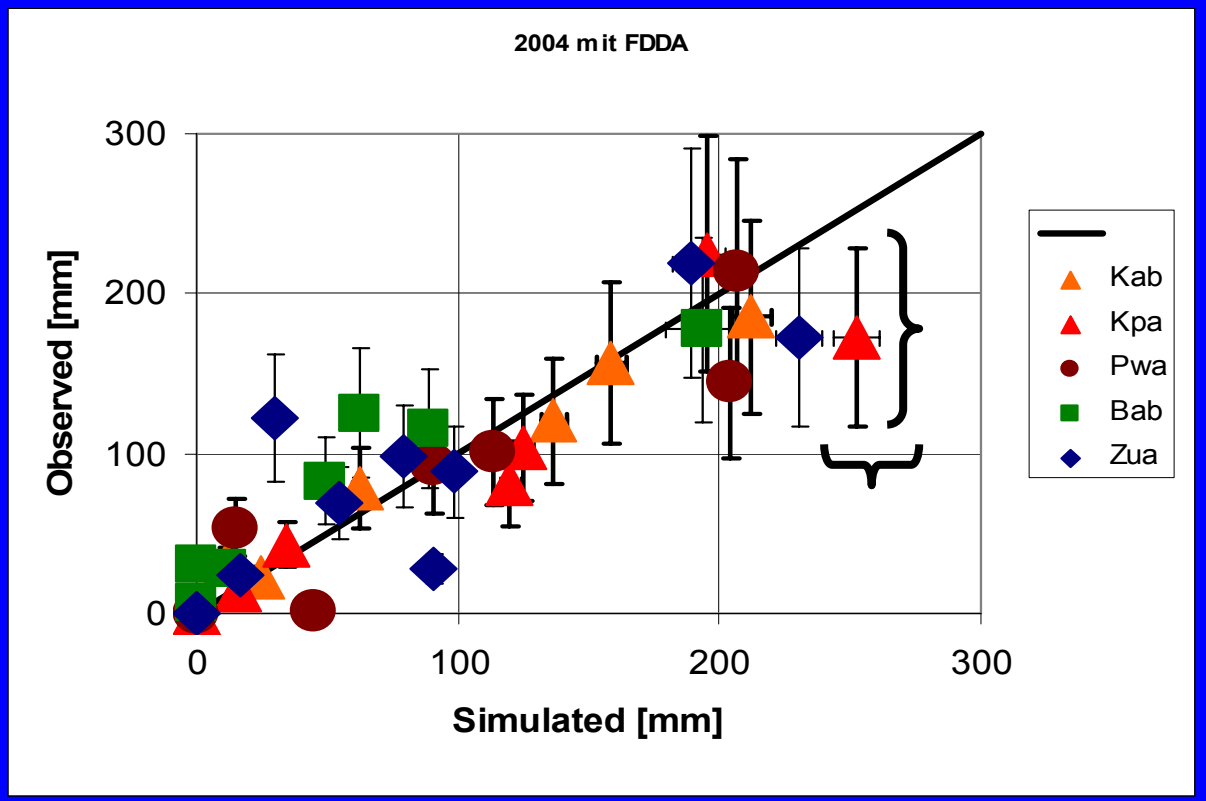
Domain1:	81 x 81 km²
Domain2:	27 x 27 km²
Domain3:	9 x 9 km²

- Vertical resolution: 25 layers up to 30hPa
- Period: 2004
- Global atmospheric fields: operational AVN–(NCEP) analysis
- Assimilation of radiosounding in domain 1
- One-way nesting (D1→D2→D3)

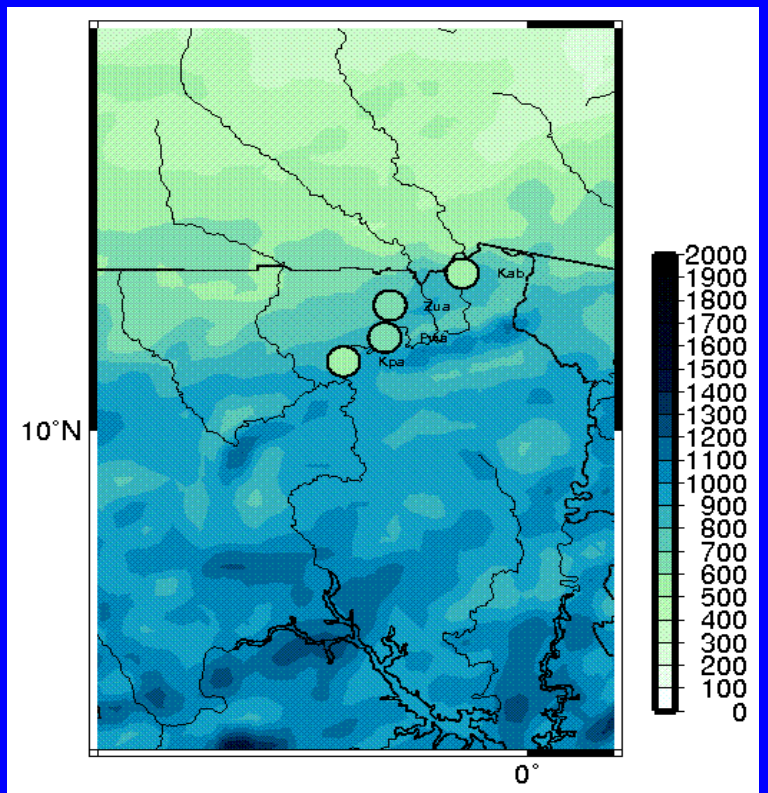


Validation Meteorological Model

Monthly sums [mm] in 2004



Precipitation sum: 06 – 10 2004

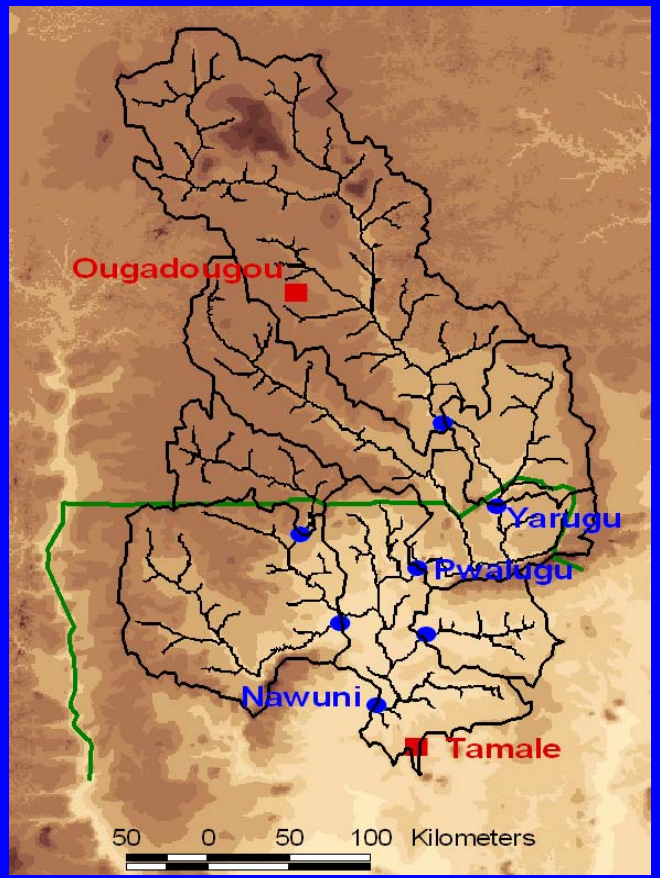


Variability between observation points

1-Way Atmospheric-Hydrological Modelling System

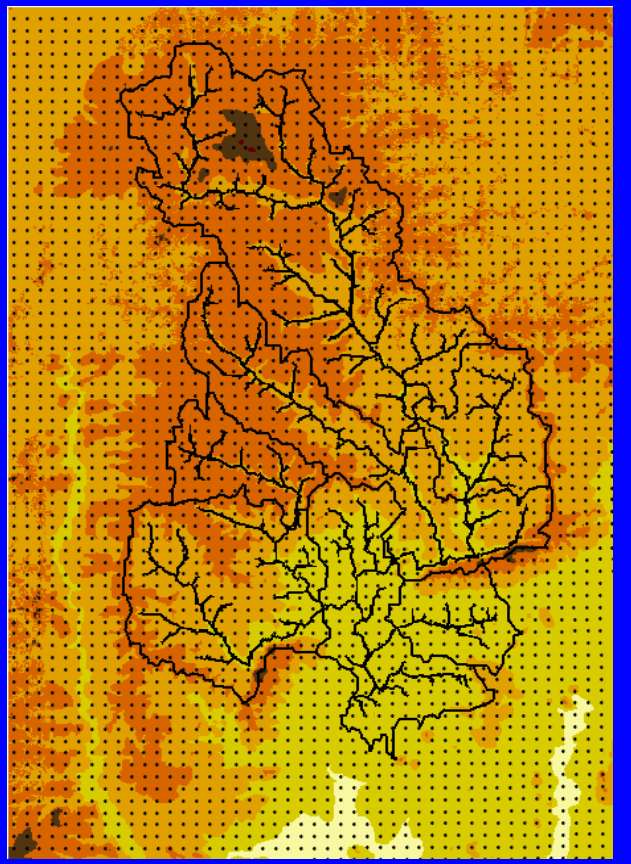
What is the performance of atmospheric model for hydrological modeling?

⇒ gridded meteorological fields in 9 x 9 km² treated as virtual met stations

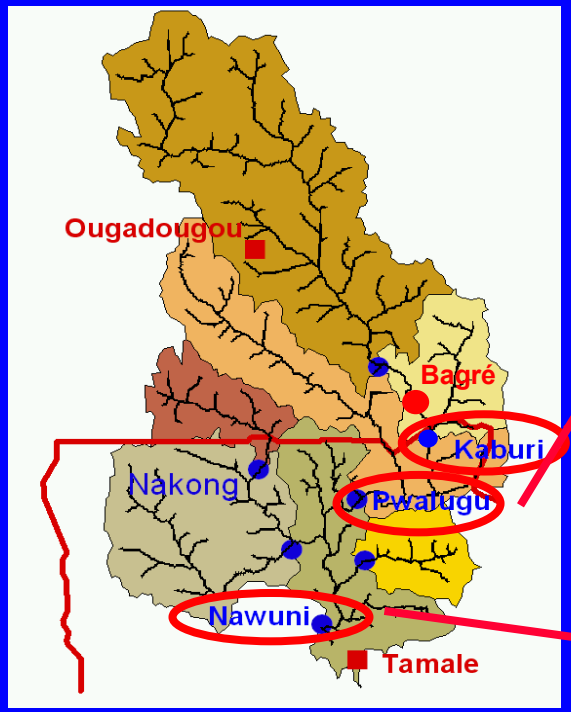


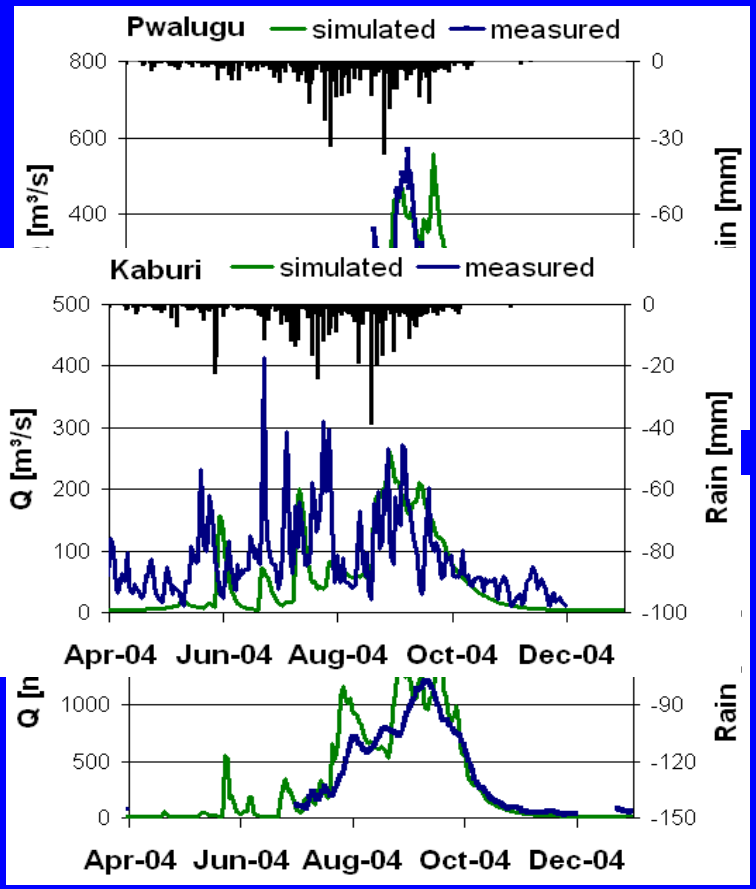
- Temperature
- Precipitation
- Wind
- Relative Humidity
- Global Radiation

Distributed Hydrological Model WaSiM



Validation Coupled Simulations

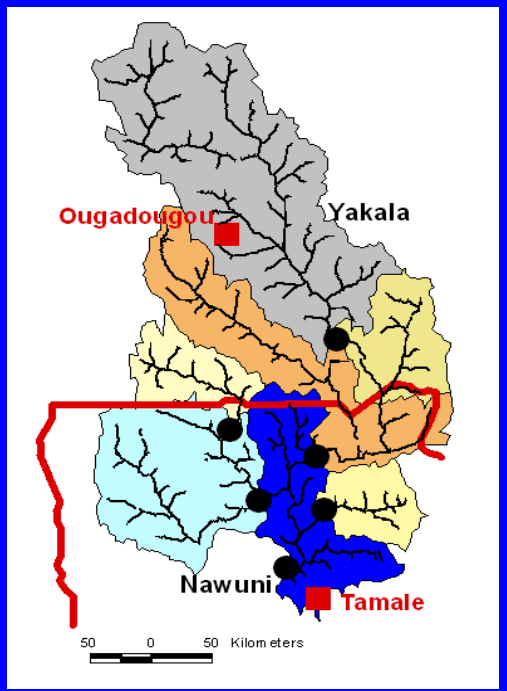




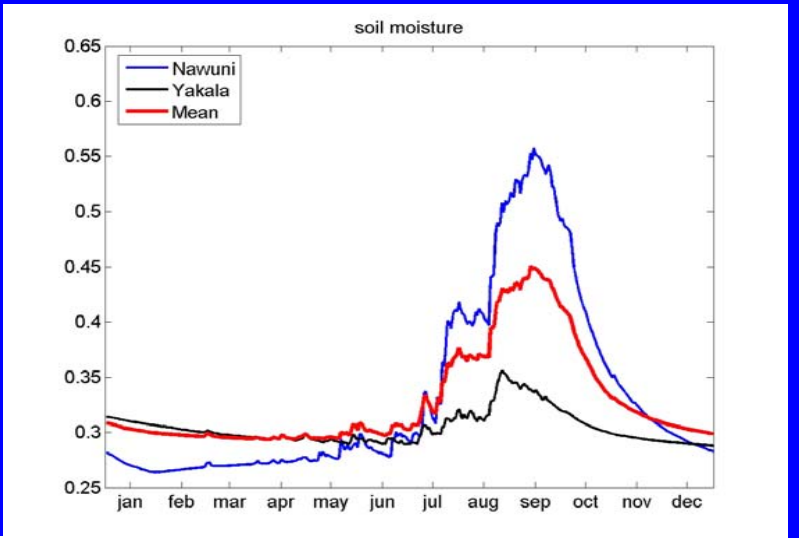
Coupled model system: reasonable results

Model Based Operational Water Balance System

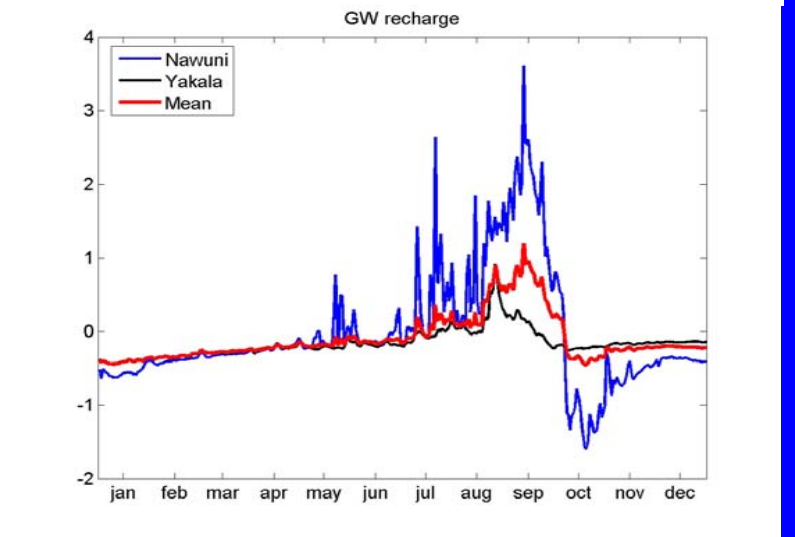
Quantification of water balance variables: time series



Relative soil humidity:



Groundwater recharge:

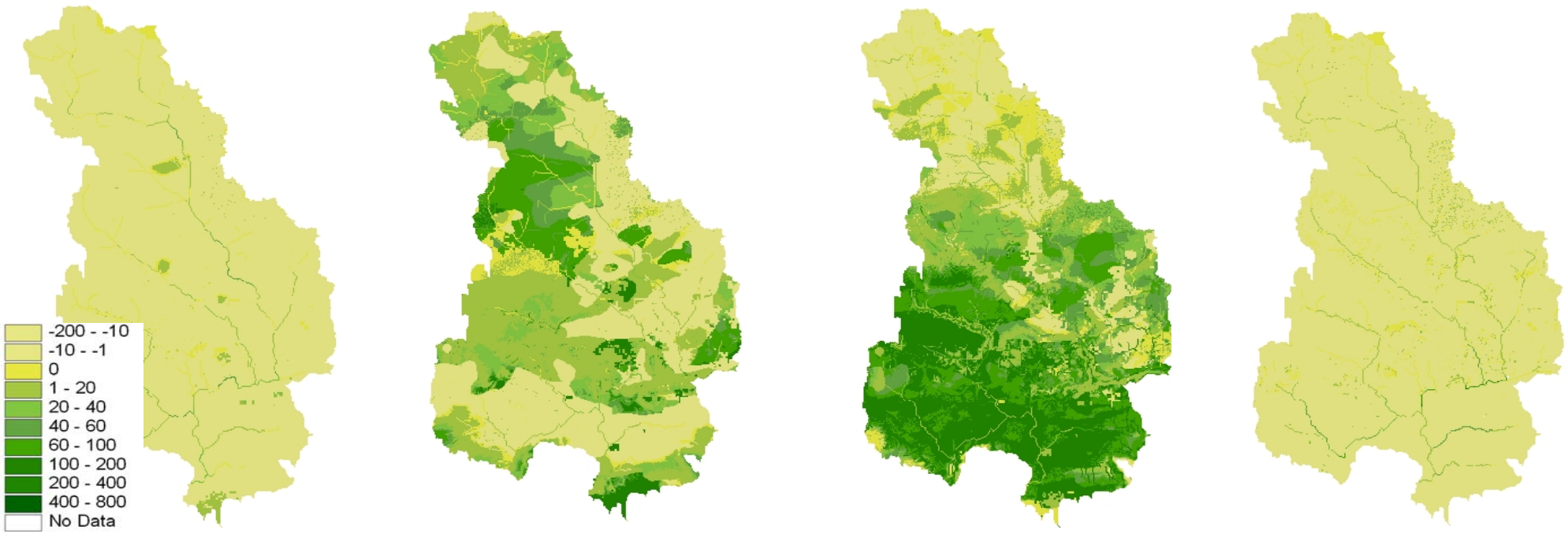


Model Based Operational Water Balance System

Quantification of water balance variables: spatial distribution

Groundwater recharge (monthly sums)

Apr 04 | Jul 04 | Sep 04 | Nov 04



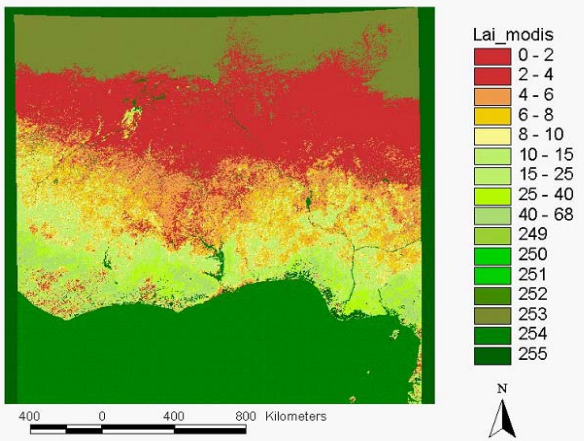
Assimilation of Satellite Derived Land Surface Properties

- Hydrological modeling requires land surface parameters (LAI, albedo, roughness length …)
- Standard literature values often inaccurate for specific areas
- Satellite remote sensing provides worldwide spatially information on land surface properties
  (e.g. MODIS entire earth every 2 days)

⇒ Use of satellite derived gridded land surface data in hydrological modeling

Can we improve the spatial estimations of Model Based Operational Water Balance System?

Example: LAI



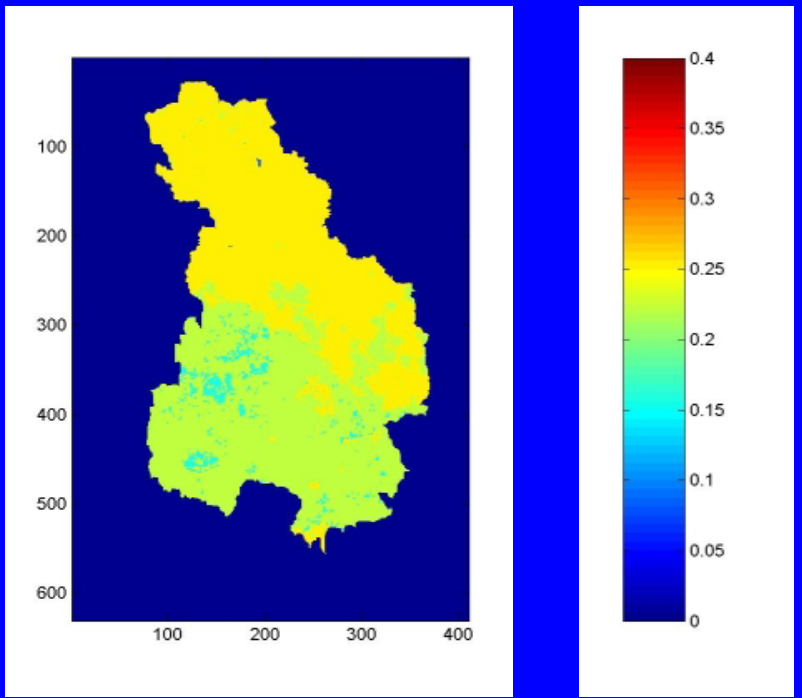
MODIS data were processed and provided by the Remote Sensing Group, University Würzburg: Tobias Landmann, Réne Colditz, Christopher Conrad

Albedo: Standard Literature Values vs. MODIS 2002

Aggregating to quarterly Albedo grids

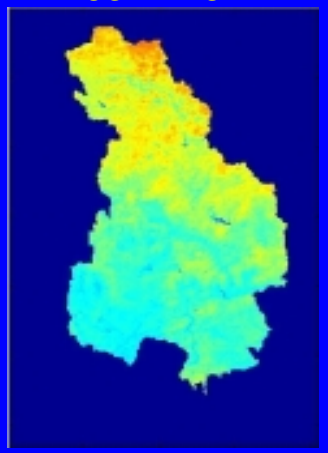
Standard literature

Albedo only depending on LU type

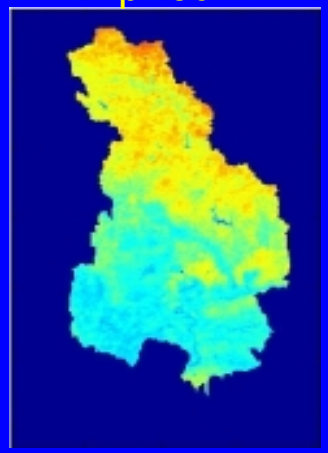


MODIS:

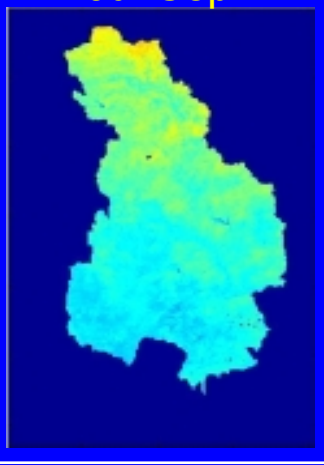
Jan-Mar



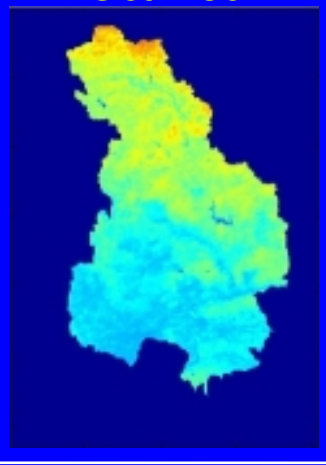
Apr-Jun



Jul-Sep



Oct-Dec

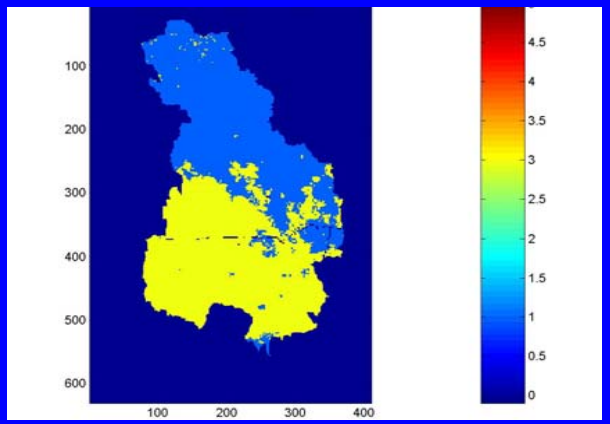


LAI: Standard Literature Values vs. MODIS 2002

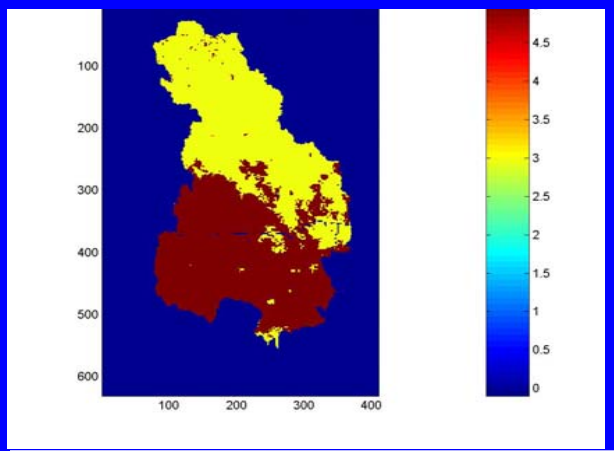
Standard literature:

LAI for 2 seasons

dry season: Nov - Apr



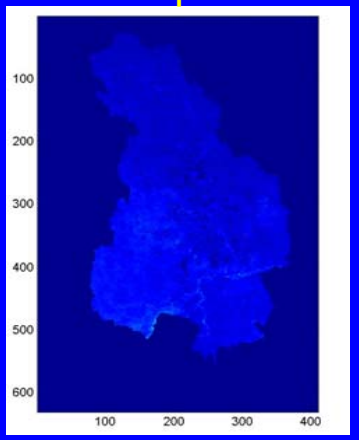
rainy season: Mai - Oct



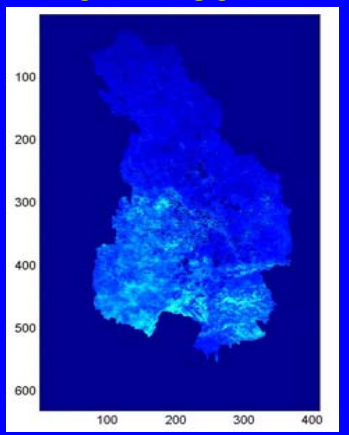
MODIS:

created season dependent grids

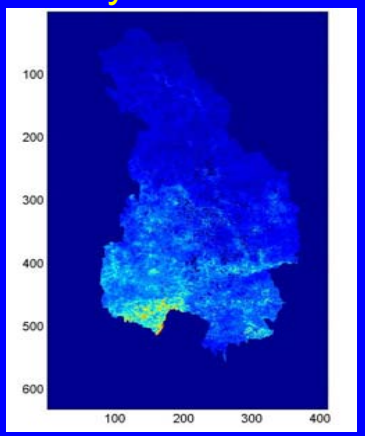
Jan - Apr



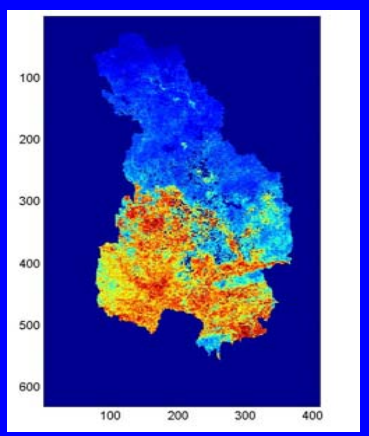
Nov - Dec

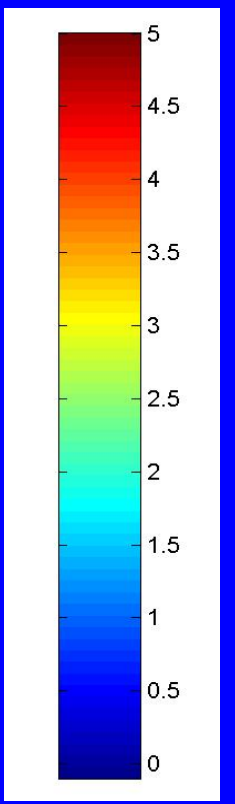


May - Jul

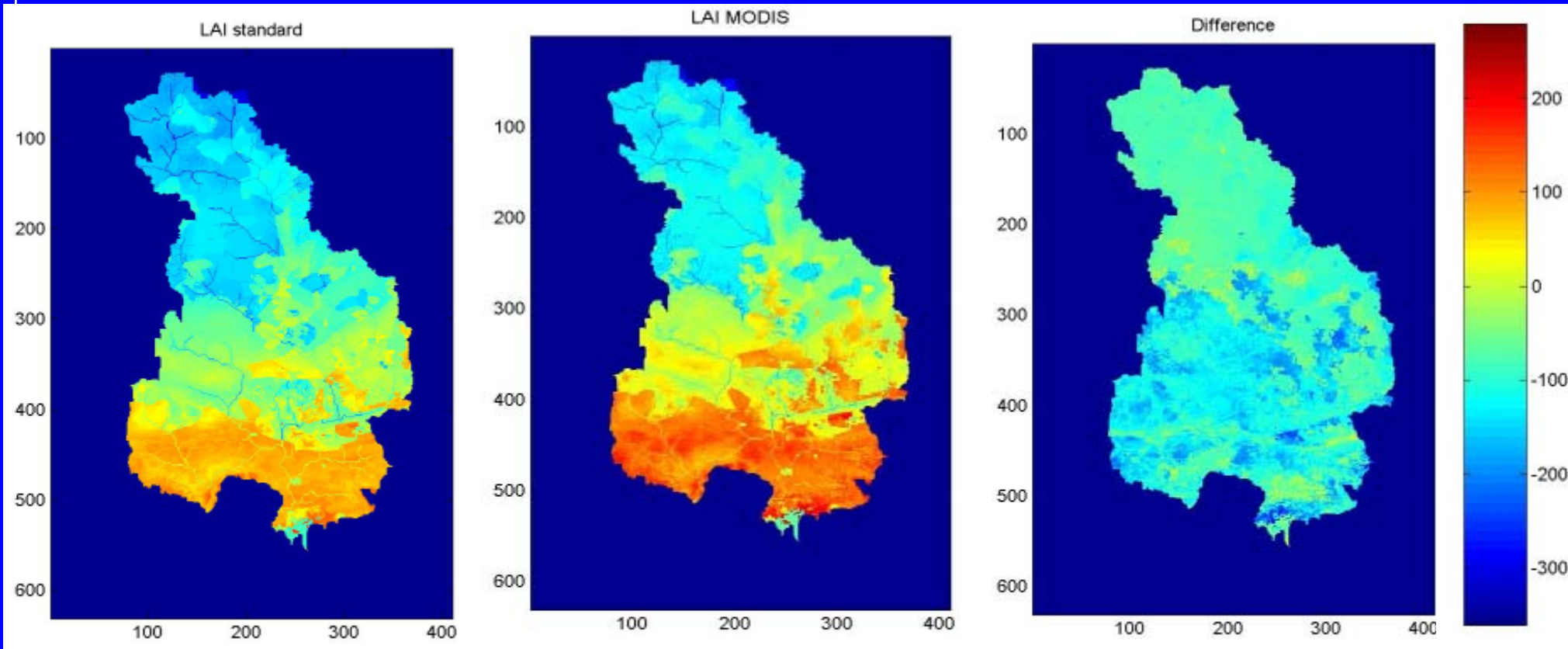


Jul - Oct





ET-Map for 2004 with Modified LAI



- **Assimilation of satellite derived land surface properties provides more "realistic" spatial information of water balance variables**
- **Improvement of Model Based Operational Water Balance System**

Recipe for DSS – Part 3:
Model Based Operational Water Balance System

- Coupled system simulates spatially distributed water balance (48h delay)

- Contemporary basin wide estimation of spatial and temporal changes of
  e.g.
  - discharge
  - evapotranspiration
  - soil moisture
  - groundwater recharge

- Important information for water resources management in the Volta Basin
  e.g.
  - irrigation schedules
  - water supply management
  - Volta Lake /dam inflow

Decision Support (4):

Techniques for estimating current onset of rainy season

Patrick Laux

Background

- 70% of inhabitants in West Africa depend on rainfed agriculture
- Determination of rainy season's onset plays major role for sustainable food production (crop failure ↔ lost vegetation time)
  ⇒ sowing date coincides with onset date
  ⇒ agricultural management (mobilization of manpower, seeds etc.)
- Large year-to-year onset variability

Objectives

1. The development of a reasonable onset definition for the Volta Basin on regional scale

2. The prediction of the major rainy season's onset for the ongoing season by means of
   linear discriminant analysis (LDA) &
   linear regression analysis (LRA)

3. Supplementary (probabilistic) information using
   Atmospheric Circulation Pattern Analysis (CPA)

Onset Definition

What are prominent requirements for onset definition?

1. Consideration of agricultural meaningful aspects
   (survival of seedlings, level of soil moisture > preparation of soils, etc.)

2. Easy to compute ⇒ practical usage

3. Data availability (long records ⇒ sufficient significance)

Onset Definition

Rainfall-alone definition:

ONSET = First day after **"regional threshold day Ω"**
(⇒ ensures survival of the seedlings), where:

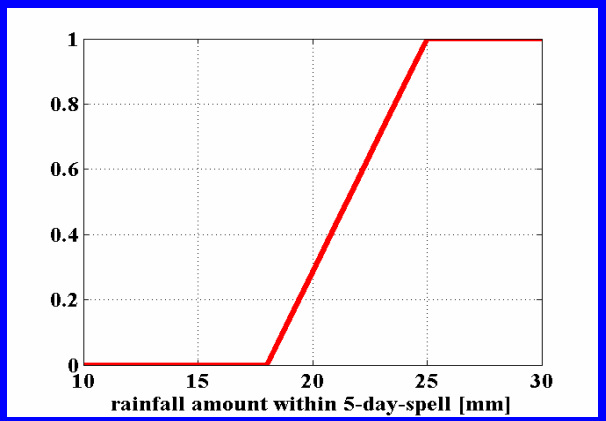
1. at least 25 mm of precipitation falls within 5 consecutive days
⇒ ensures soil moisture level

2. two or more days are wet (precip. > 0.1 mm) within 5-day-period
⇒ excludes one single heavy showers

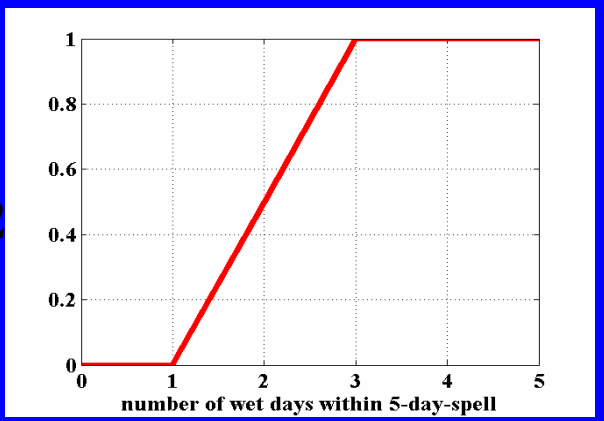
Onset Definition – Fuzzy-logic extension

Membership functions to ease restrictions of the definition

γ1



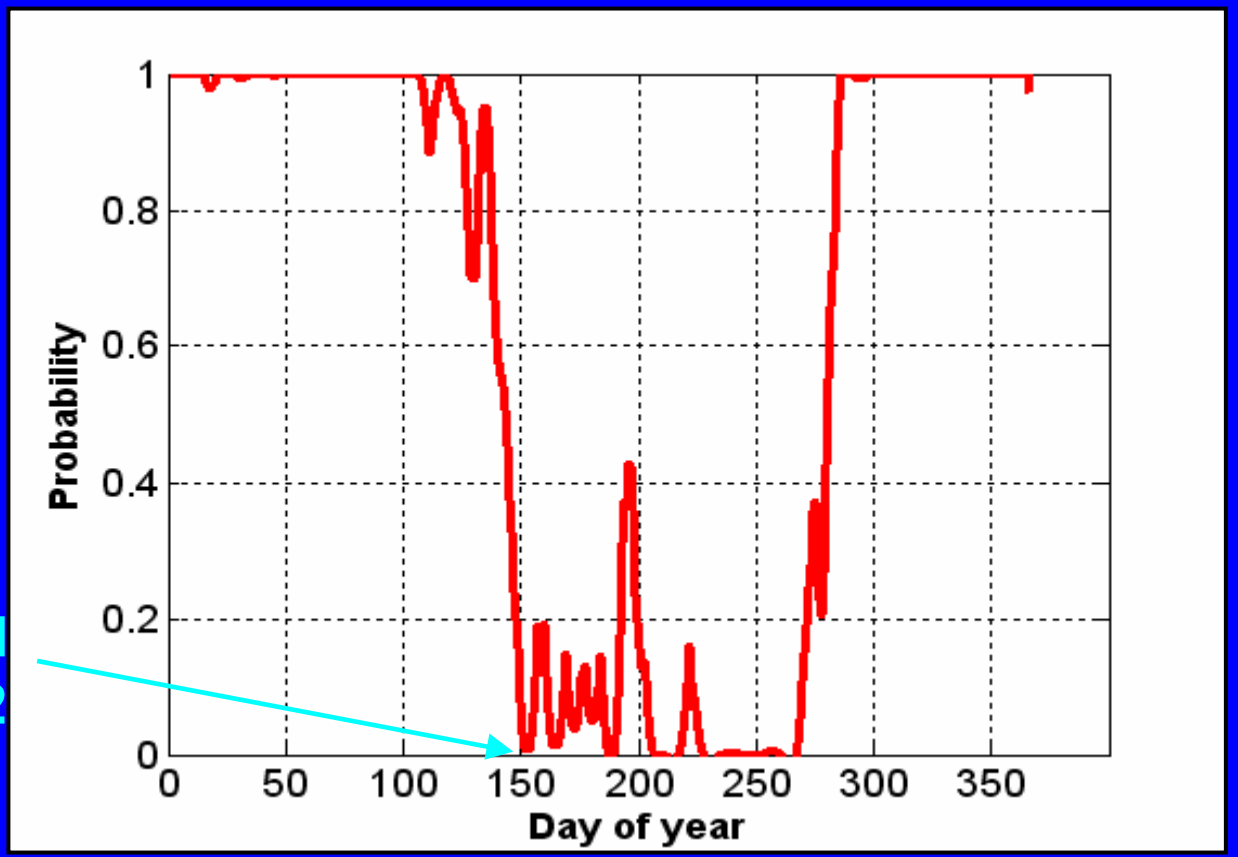
γ2



Membership grade = γ1 * γ2

Onset, if γ > threshold

Onset Definition



regional threshold day Ω at prob. 0.2

Probability of the occurence of a dry spell of 7 consecutive days within following month (exemplary shown for PC1)

Onset Definition - Regionalization

Rotated Principle Component Analysis (RPCA) in spatial mode

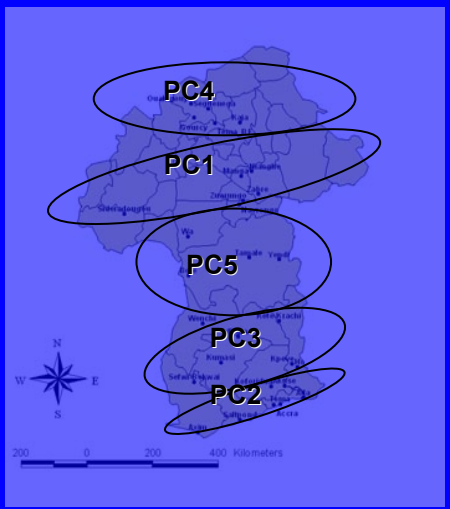
- 29 synoptic weather stations

5 PCs, explaining >60% of the daily precipitation variance

Spatial distribution of PCs:

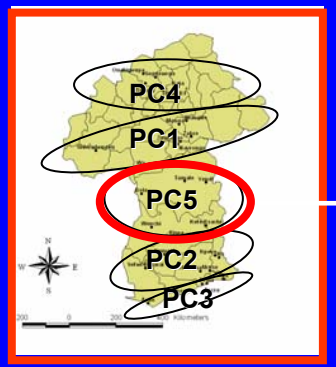
Correlation between PCs and observation sites

Mean values of all observation sites within a region

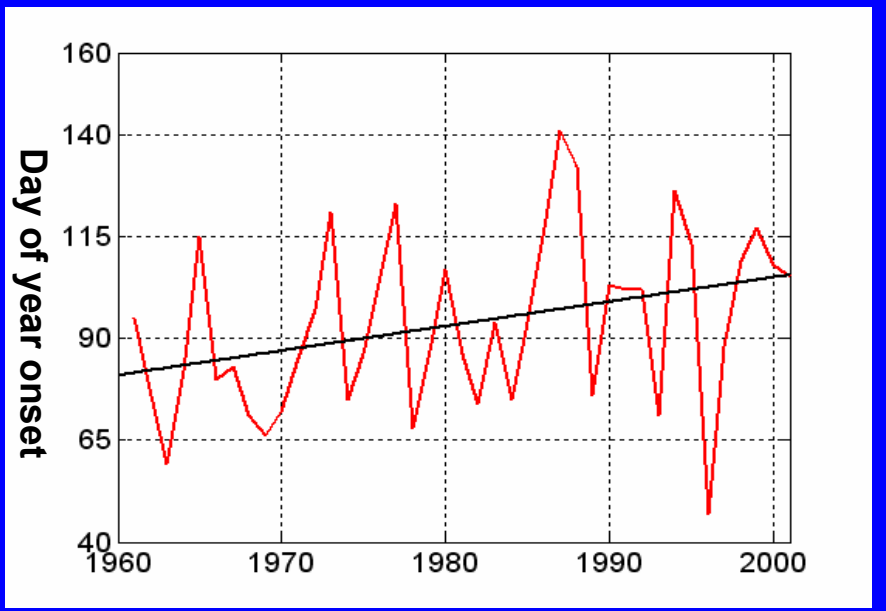


Regional Onset Definition

Onset Definition – Past Regional Onset Features



Regions



Trend

	Mean onset [Julian day]	Standard dev. [days]	Trend [days/year]	Signif. [%]
PC1	132	24	0.88	> 99
PC2	89	22	0.14	36
PC3	67	18	0.40	91
PC4	157	22	0.09	25
PC5	93	21	0.60	> 99

Delay of onset ≈ 34 days within the past 40 years!

3 Different Utilities for DSS

Observed precipitation data prior to current day

Anomalies of atmospheric circulation fields

1. LDA

Pro:
- Rainfall data
- Onset yes/no (daily)

Contra:
- Time delay of data
- Current data needed

2. LRA

Pro:
- Decision in advance
- DOY with onset

Contra:
- Reliability (extrapolation, low R^2)

3. CPA

Pro:
- Includes atmospheric data

Contra:
- No classification (delivers only probabilities)

Solution 1: LDA

Model calibration:

1. Grouping data into the classes: dry season, transition, onset of the rainy season & rainy season

2. Choice of predictor variables: number of rainy days and rainfall amount 5,10, …, 30 days before onset, **γ** –values

3. Calculation of linear discriminant functions, which are discriminating between these four classes

Model validation:

Reclassification using discriminant functions

Solution 1: LDA

Results:

1. **γ**, precipitation amount 30 & 10 days before potential onset are parameters with most discriminative power for all regions
2. hit-ratio of classification

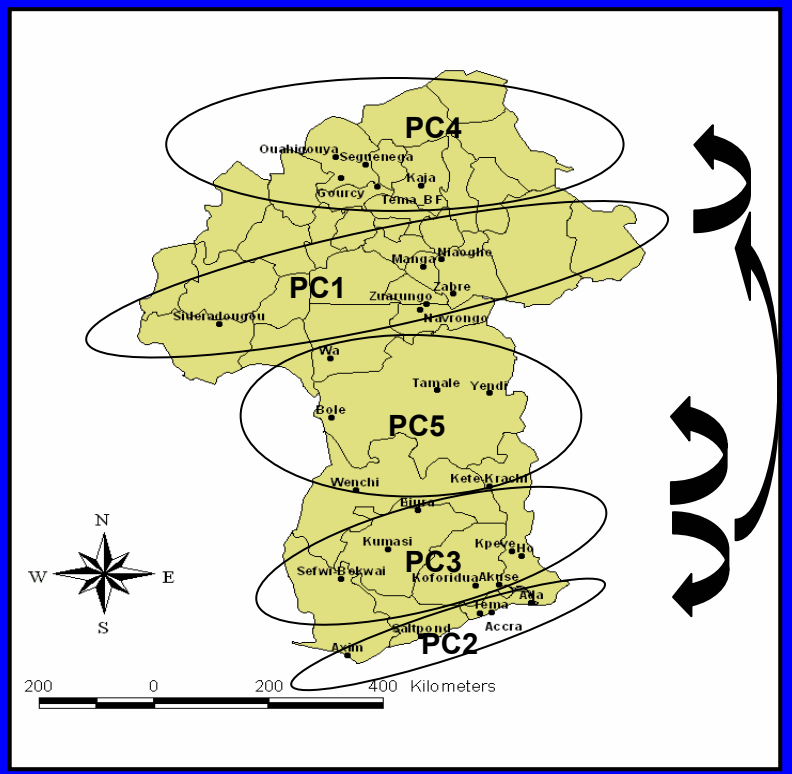
$\gamma = 0.5$		Class membership after application of linear discriminant analysis [%]			
		dry season	transition	onset	wet season
Predetermined Class Membership [%]	dry season	**83.37**	14.68	1.24	0.71
	transition	50.72	**38.10**	3.47	7.71
	onset	8.09	11.30	**70.91**	9.70
	wet season	5.38	6.95	8.43	**79.24**

Correct classification in 71% !

Solution 2: LRA

Model calibration:

- e.g.: Onset PC5 = f (Onset PC3)



Target PC	Independent PC	γ threshold target PC	γ threshold independent PC	Regression equation	r
PC5	PC3	0.35	0.3	**PC5 = 52.36 + 0.61 PC3**	0.52
PC2	PC1	0.3	0.85	**PC2 = 44.33 + 0.57 PC1**	0.46
PC1	PC3	0.2	0.2	**PC1 = 78.64 + 0.80 PC3**	0.57
PC4	PC1	1	0.8	**PC4 = 119.7 + 0.40 PC1**	0.47

Solution 3: CPA

Large Scale:

- Re-analysis data

NCEP (National Centers for Environmental Prediction)

Local (Regional) Scale:

- Historical meteorological observations
- Coordinates and elevation of climate stations

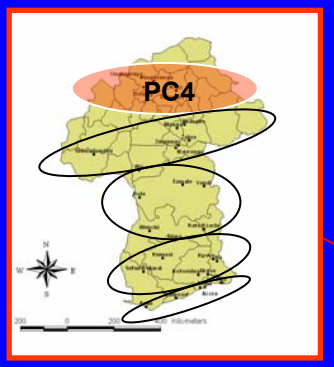
Meteorological Services Ghana and Burkina Faso

- Output of GCMs, e.g., GFS, AVN (current situation)

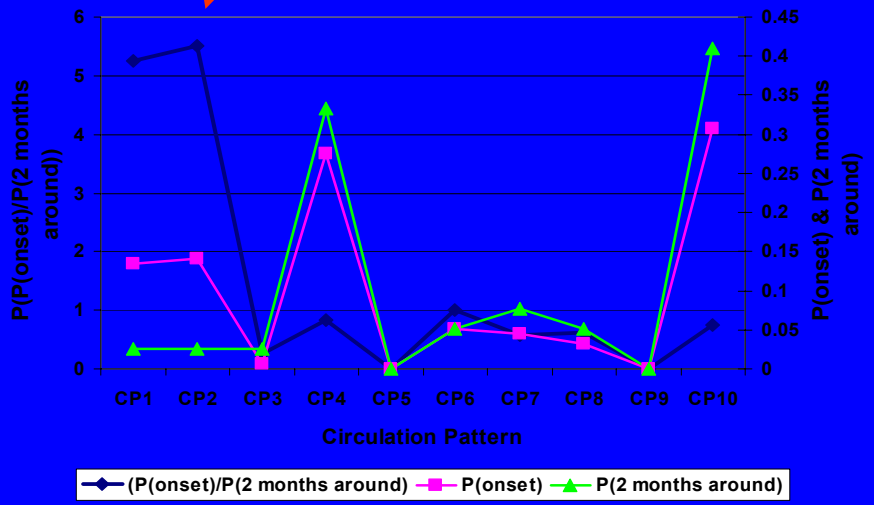
NCEP

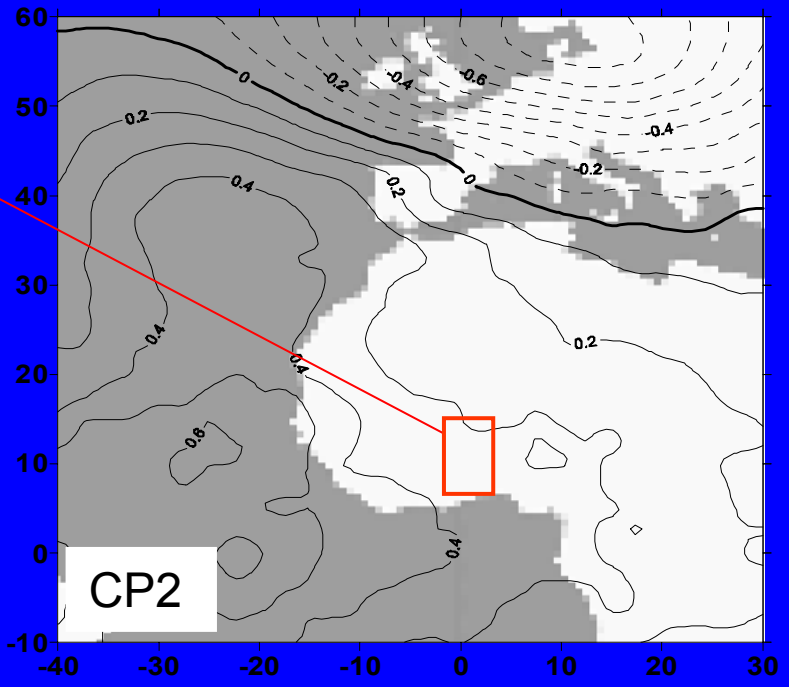
Solution 3: CPA

Example 1: Sea Level Pressure conditioned on PC4



More than 5 times higher relative occurence probability at onset dates



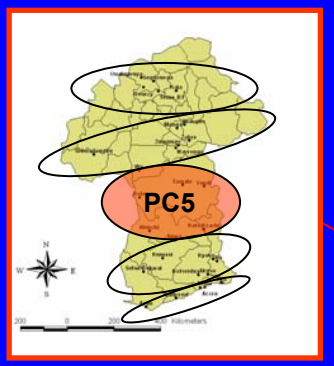


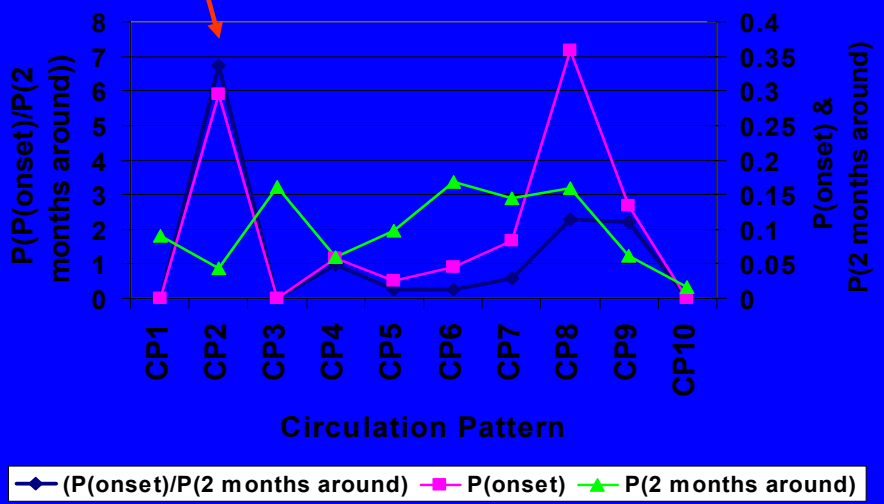
Mean SLP anomalies (1961-1999) corresponding to CP2, reliable for onset in PC4

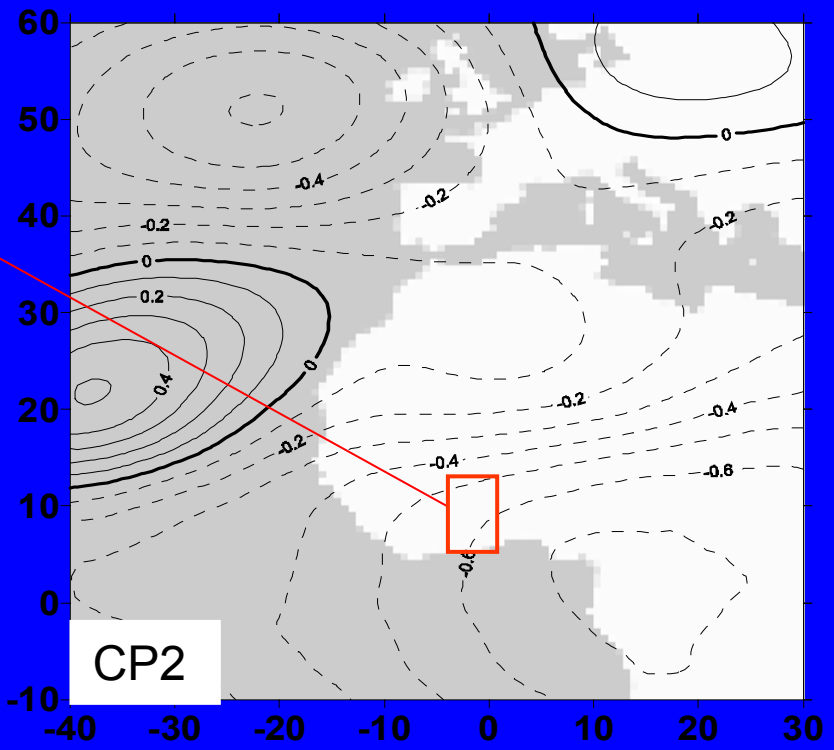
Solution 3: CPA

Example 2: Geopotential height 500hPa conditioned on PC5

About 7 times higher relative occurence probability at onset dates





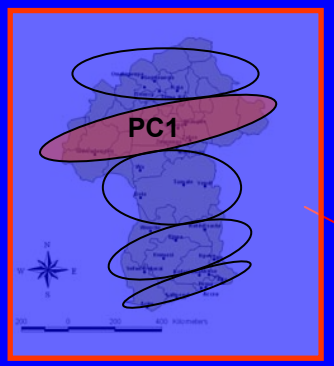


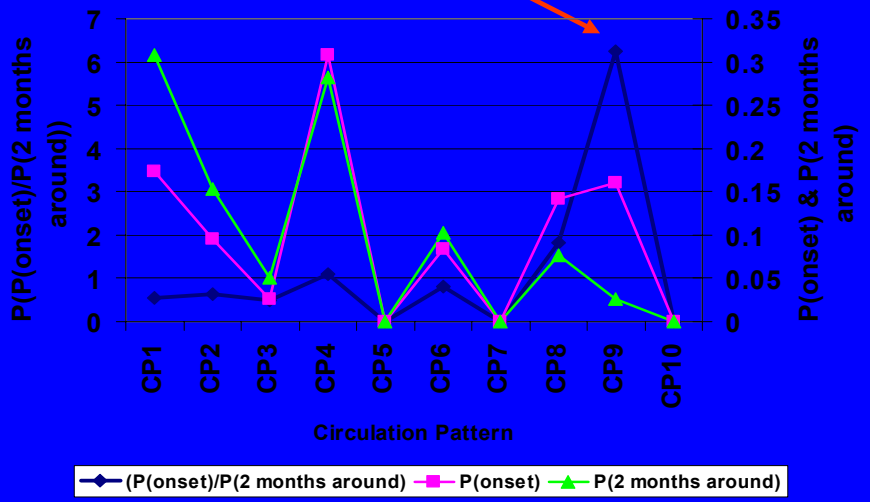
Mean GPH500 anomalies (1961-1999) corresponding to CP2, reliable for onset in PC5

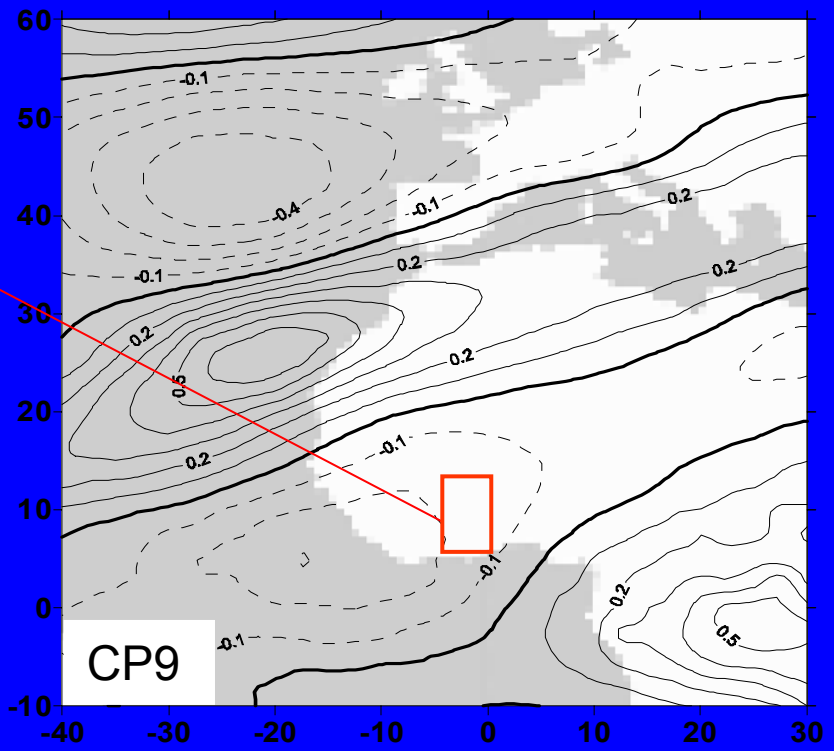
Solution 3: CPA

Example 3: horiz. wind 500hPa conditioned on PC1

About 6 times higher relative occurence probability at onset dates







Mean uwnd500 anomalies (1961-1999) corresponding to CP9, reliable for onset in PC1

Estimation Current Onset of Rainy Season

Recipe for DSS – Part 4: Onset of the Rainy Season

1. **LDA:** Take current **γ**, precipitation amount 30 & 10 days
   ⇒ calculate class membership (onset yes/no)

2. **LRA:** Take onset of region PC3
   ⇒ estimate onset dates of regions PC1, PC2, PC4, PC5
   ⇒ cross check with results of LDA

3. **CPA:** Take current GFS (AVN) fields (SLP, SST, Geopot., u etc.)
   ⇒ classification of circulation pattern (software provided)
   ⇒ check onset probability of this pattern (table provided)
   ⇒ decision onset (yes/no)

Reminder - Summary

Hydrometeorological Decision Support

Long term planning

Spatial distribution of **climate change** induced changing water availability

ECHAM4 - MM5 & WaSiM

Short/mid term planning

Operational
1) Weather forecast (NWP)
2) Model based water balance information system

GFS - MM5 *hindcasts* & WaSiM

GFS - MM5 *forecasts*

Special planning

Prediction of current regional **onset date** of rainy season

- circulation patterns
- *linear discriminant* analysis

Coupled meteorological-hydrological DSS

Pure meteorological DSS

Summary Hydrometeorological DSS

- Hydrometeorological decision support tool in S1 and S2 for:
  - climate change impact analysis
  - numerical weather prediction
  - near real time model based water balance monitoring
  - estimation of current onset of the rainy season

Next steps

- Identification of further questions & research needs (this meeting)
- Transfer to stakeholders from mid 2007 on possible
- Technical realisation at Kofi Annan Center to be prepared
- Identification of target persons to be trained in hydro.-met. DSS


Thank you for your attention