Status report 2004

Sub-project A1: Regional Climate Simulations

TASK: COUPLED CLIMATE-HYDROLOGY SIMULATIONS
Gerlinde Jung, Harald Kunstmann, Rebekka Neumann (IMK-IFU)

Background
The Volta Basin is a basically agriculturally dominated, climate sensitive region. Even small changes in the water balance can have a strong influence on living conditions of the people. To estimate the effect of a possible anthropogenic influence on the water balance in the Volta Basin (400,000 km²), regional climate simulations and coupled hydrological simulations were performed.

Method
In a first step, a linear trend analysis of temperature, precipitation and discharge time series of Burkina Faso was performed to get an insight into existing present trends. This analysis included the investigation of the significance of the trend in performing the Mann-Kendall test, as well as the judgement of the stability of a certain trend using the reverse arrangement method was applied.

To go a step further, possible future climate changes were investigated. Therefore regional climate simulations were carried out, using the nonhydrostatic mesoscale meteorological model MM5, fully coupled to a 1D SVAT model, consisting of 4 layers up to 2m depth, to account for soil properties and soil-atmosphere feedback mechanisms. Optimal parameterisations were derived and model validation was performed (Kunstmann and Jung, 2005b). The scenario IS92a ("business as usual") of the global climate model ECHAM4 (2.5x2.5°) was dynamically downscaled to a final resolution of 9x9 km² for the Volta Basin. Two 10-years time slices were simulated: The years 1991-2000 for present day climate, the years 2030-2039 for future climate.

To investigate the impact of atmospheric change on terrestrial water balance, the distributed, physically based hydrological model WaSiM (Schulla and Jasper, 2000) was coupled in a one-way approach to the regional climate model. For the hydrological simulations, a horizontal resolution of 1x1 km² was chosen, allowing detailed analysis e.g. of changes in evapotranspiration, the different runoff components (direct runoff, interflow, and baseflow), and groundwater recharge.

Results
Trend analyses of the northern part of the Volta Basin (Burkina Faso) show a clear trend towards increasing temperatures and a weak trend of a decrease in rainfall. The analysed discharge time series don’t show clear trends. Only a weak trend towards a decrease in discharge for the dry season can be observed (Jung et al., 2005). This most probably underlies strong anthropogenic influences, which can not be evaluated.
The regional climate simulations show an increase in annual precipitation for the whole region, but the signal of precipitation change shows a strong spatial (-20% to +50%) and temporal heterogeneity (-20% to +20%) (compare Fig. 1). Remarkably, a delay in the onset of the rainy season and a general shortening of the rainy season could additionally be delineated. Fig. 2 shows a clear increase in temperature, ranging from 1° in the maritime South of Ghana up to 1.6° in the Sahelian North of Burkina Faso. In case of surface runoff, here calculated by the SVAT model included in MM5, a nonlinear response to the precipitation input signal could be observed (Fig. 3) (Kunstmann and Jung, 2005a).

Fig. 1: Mean monthly precipitation [mm] and precipitation change [%] 1991-2000 vs. 2030-2039

Fig. 2: Temperature Change [°C] 2030-2039 vs. 1991-2000
Fig. 3: Mean monthly infiltration excess [mm] and change [%] 1991-2000 vs. 2030-2039

It could be shown that WaSim is capable to reproduce observed runoff satisfactorily (results are shown in section sub-project A2) which in turn enables coupled regional climate – distributed hydrology simulations for the entire catchment.

Outlook

Analyses of changes in the hydrological balance (in particular surface runoff, interflow, baseflow and ground water recharge) will be derived from the coupled climate-hydrology simulations. Furthermore selected variables calculated by both the SVAT model (as a part of MM5) and WaSiM (e.g. evapotranspiration and surface runoff) will additionally be compared and analysed.
Background

The scientific challenges in the hydrological and regional climate simulations within the GLOWA Volta Project are demanding large scientific computing resources. For the hydrological modelling, inverse modelling and Monte-Carlo simulations for sensitivity studies for certain parameters are performed. The regional climate modeling with MM5 demands a huge amount of parallel computing power in order to perform a 10 year simulation for West Africa on a regional scale.

Method

The software tools used for the modelling and simulations are capable to run under the linux operating system, such that the only reasonable solution to fit all these different demands in computing resources is the use of a custom built-to-order Linux-Cluster. The system itself has to fulfill certain properties: Scalability, high performance of MPI-parallelized MM5 simulations and a reasonable price/performance ratio for the none-parallelized computing tasks in hydrology and inverse modelling.

After benchmarking the performance of some commodity computer systems, the INTEL XEON processor based systems have shown for the MM5 simulations in combination with INTEL's linux FORTRAN compiler the best performance against AMD ATHLON and OPTERON processor systems. In the second stage, the benchmarking was extended to MPI-Linux-Cluster systems for performance and cost evaluation. The currently installed system at IMK-IFU has more than 200 processors in total. The MM5 benchmark simulations in 2003/2004 have shown for MPI configurations up to 16 processors competitive results on an INTEL dual XEON system for double gigabit ethernet communication compared to the much more expensive Myrinet-2000 MPI intercommunication. By saving up to one fourth of the total cost by using gigabit ethernet rather than the much faster and higher bandwidth Myrinet-2000, this money could be invested to increase to total amount of computing nodes, such that the overall performance could be increased while maintaining the best price/performance relationship.

The final system is briefly shown in Fig. 4. It is based on two failover master servers with a shared file system and a shared local raid-system. All the compute nodes are connected via gigabit ethernet for the service network (file system, input/output, internet, etc.) and via a separate gigabit ethernet network for the pure MPI communication. Due to security reasons and robustness, the use of a common parallel file system on all compute nodes was not realized. The system is completely based on open source software for the cluster installation and management (C3, OSCAR, GANGLIA) as well as for the MPI libraries (LAM-MPI and MPI-CH). The job queuing system is realized with the free OpenPBS system with the maui scheduler.

With this configuration, the optimal solution for MPI-simulations as well as a large number of single processor tasks with respect to price/performance was realized.
Results

Regional Climate Simulation with MM5 V3.5

Comparing MPI Software Performance on a Linux-Cluster
MM5 V3.5 - 136x121x25 Grid, 20 Sec. Time Step
1 Month Simulation on 32 Processors

Fig. 4: Technical setup of the LINUX cluster at IMK-IFU

Fig. 5: Comparison of performance a) number of processors, b) MPI/Compiler version
Sub-project A2: Hydro-Meteorological Monitoring System

TASK: OPERATIONAL MODEL BASED WATER BALANCE MONITORING
Sven Wagner, Harald Kunstmann, Gerlinde Jung, Rebekka Neumann (IMK-IFU)

Motivation
The coupled operational meteorological and hydrological hindcasting system is part of the proposed Decision Support System (DSS). This system provides basin wide estimations of water and energy balances and it will allow water management authorities to monitor (in a coarse manner) the actual ongoing water balance in the catchment through the entire year, thereby getting scientifically sound information on river runoff, evapotranspiration, soil moisture content or groundwater recharge. To improve the quality of the land surface data input for this coupled meteorological and hydrological system, we investigate the possibilities of using satellite derived land surface data, which are more realistic than the values of the standard tables used in the meteorological and hydrological model. A further issue is that all input parameters for the hydrological simulations contain uncertainties. The effect of these uncertainties on the results of the simulations will be investigated using the Monte Carlo method.

Methods
- Coupled deterministic hydro-meteorological modelling

For the hydrological simulations the model WaSiM-ETH (Water balance Simulation Model developed at the ETH Zurich) is used. WaSiM is a fully distributed catchment model using physically based algorithms and parameters for the simulation of the different processes. In the project WaSiM-ETH is currently used in 3 scales: the complete Volta catchment (basin size 400,000 km², mainly applied in subproject A1), the White Volta catchment (basin size 94,000 km², subdivided into 6 subcatchments) (Fig. 6) and the Atankwidi catchment (270 km²). For the first two setups the horizontal grid spacing is 1 km and the time step 1 day. For calibration, the hydrological year 1967/1968 (March 1967 to February 1968) was chosen, due to data availability and the small amount of anthropogenic influences on river runoff (e.g. dams, irrigated areas) at that time.

For the coupled system, the meteorological modelling is conducted with the mesoscale meteorological model MM5. MM5 will run with four nested domains having horizontal resolutions of 81x81 km² (61x61 gridpoints), 27x27 km² (85x67 gridpoints), 9x9 km² (157x121 gridpoints) and 3x3 km² (253x142 gridpoints) respectively and 26 vertical layers extending up to 30 mbar. The boundary conditions for the largest domain are provided by global ECMWF 40 years Re-Analysis data. The boundary conditions of the following domains are provided by the next larger domain. For the White Volta Basin, which is covered by the forth model domain the coupled hydro-meteorological simulations are performed.

The WaSiM setup for the entire Volta Basin is used in coupled climate-hydrology simulations that are performed within the framework of sub-project A1.
• **Stochastic hydrological modelling**

For this task, the Monte Carlo method is applied to investigate the impact of uncertain model parameters (e.g. different storage coefficients, anisotropy) on the water balance (e.g. runoff, evapotranspiration, groundwater recharge, etc.). If more than one parameter is investigated simultaneously, *Latin Hypercube Sampling* is applied. Hydrological simulations with WaSiM-ETH are performed for each set of random variable. The entirety of simulation results is then analysed statistically. This includes the calculation of mean, standard deviation and skewness for every day, as well as frequency distributions on selected dates.

• **Assimilation of remote sensing into the atmospheric and hydrological modelling**

With the integration of remote sensing, distributed and more realistic fields of land surface properties (e.g. albedo, LAI, land use) will be obtained. So far land surface property values are taken from standard tables as functions of land use. It is investigated if the assimilation of these satellite derived land surface properties into the atmospheric and hydrological modelling improves the quality of the results. For the remote sensing MODIS data will be used, which will be provided from the DLR in Oberpfaffenhofen.

• **Operation of a dense observational network for precipitation and surface runoff**

For the calibration and validation of the meteorological and hydrological models a dense observational network for precipitation and surface runoff was installed in spring 2004 in the Upper East region in Ghana. Gage readers read the total rain three times daily and the water level is recorded automatically at least every hour. Furthermore two *HydroArgos* systems were installed in October 2004, which transmit daily the hourly recorded water levels by satellites to an internet platform, so the ongoing water levels at these sites are always available. Fig. 7 shows the locations of the measures in the Upper East region. The measurement campaign is conducted in close collaboration with the *Hydrological Service* in Ghana.

**Results**

• **Coupled deterministic hydro-meteorological modelling**

Fig. 8 and Fig. 9 show first results of the WaSiM calibration, exemplary the surface runoff of the White Volta at the gage Pwalugu and of the Oti River at the gage Saboba. It can be seen that the model is able to reproduce the runoff behaviour in the catchment and it additionally calculates relevant parameters of the water balance (e.g. evapotranspiration, base flow). Before the simulations, the parameters and empirical values had to be adapted to the conditions in West Africa, because WaSiM-ETH was developed for Central Europe. Further calibration steps are necessary.

Fig. 10 is an example of the output of MM5, the modelled precipitation sum of domain 2 in 1968. The model calculates between 1000 and 1600 mm accumulated rain in the White Volta catchment. These simulation results will be passed to the hydrological model and the quality of the coupled simulations investigated.
• Stochastically hydrological modelling

[…]

• Assimilation of remote sensing into the atmospheric and hydrological modelling

[…]

• Operation of a dense observational network for precipitation and surface runoff

Since May 2004 the additional installed rain and water level gages are in operation.

**Outlook:**

The coupling of the meteorological and hydrological model will provide basin wide estimations of water and energy balances. The atmospheric model will then provide the necessary meteorological input (e.g. temperature, precipitation, wind, relative humidity) for the hydrological model. This coupled system will be applied for different catchments (White Volta, Upper East) and for more current time periods and the period of the ongoing measurement campaign.

**Figures:**

![Fig. 6: Volta catchment and White Volta catchment (framed with bold black lines) and subcatchments as set up for the hydrological simulations.](image-url)
Fig. 7: Overview of the locations of the measures in the Upper East region. The blue triangles show the gages installed in 2004, the purple dots the locations of discharge measures of the Hydrological Service in Ghana.

Fig. 8: Comparison of modelled and observed discharge at the gage Pwalugu (White Volta):
Fig. 9: Comparison of modelled and observed discharge at the gage Saboba (Oti):

Fig. 10: Simulated dynamically downscaled (27x27 km²) accumulated precipitation in August 1968 [mm]
TASK: REMOTE SENSING LATENT AND SENSIBLE HEAT FLUXES
Andreas Marx, Harald Kunstmann (IMK-IFU)
Dirk Burose, Arnold Moene (Univ. Wageningen)

Problem
As infrastructure is weak in West Africa, areal validation of water balance variables is only feasible when applying remote sensed products.

Methods
Three methods to estimate sensible heat flux H for the Ghanian part of the Volta Basin were applied: (1) the surface energy balance algorithm (SEBAL, Bastiaannssen, 1998), (2) Large Area Scintillometer (LAS, De Bruin et al., 1995), and (3) mesoscale meteorological simulations (MM5, Grell et al., 1994). Satellite derived H (Fig. 11 a) was computed using NOAA-AVHRR images for December 2001 when cloud conditions permitted. These data were compared to LAS and MM5 simulation results. For the satellite derived H, an uncertainty analysis based on Gaussian Error Propagation was performed for the following intermediate steps: uncertainty due to different methods to estimate surface temperature, uncertainty in quality of input data (satellite scenes), and uncertainty in coefficients to estimate LAI. For LAS data, uncertainty due to input data was computed.

Results
The comparison of satellite derived H (Fig. 11 a) of Las data showed good agreement with an RMSE of 39 W/m² for the Tamale site (Fig. 11 b). Due to an overestimation of MM5 latent heat flux, the comparison of satellite derived H to MM5 showed a disagreement with an RMSE of 167 W/m² for the Tamale site.

The computation of uncertainties in satellite derived H due to uncertainties in intermediate steps showed relative uncertainties of 21% for the Tamale site and 32% for the Ejura site. It could be shown that uncertainty in LAS data is much lower with 8% for the Tamale site and 7% for the Ejura site.
Fig. 11: a) SEBAL estimated sensible heat fluxes using NOAA-AVHRR-16 (DOY 347, 2001); circles indicate test sites Navrongo, Tamale and Ejura; b) Comparison of SEABL estimates sensible heat fluxes (using ground based net radiation $R_n$) to LAS data (Marx et al., 2005)

**Outlook**

As Gaussian error propagation was shown to be a powerful tool in analysing uncertainty of satellite derived heat fluxes, a complete uncertainty analysis is envisaged.
Sub-project A3: Onset of the Rainy Season

TASK: STATISTICAL ANALYSIS OF THE ONSET OF THE RAINY SEASON

Patrick Laux, Harald Kunstmann (IMK-IFU)

Motivation

The determination of the onset of the rainy season in West Africa (Ghana) is still an unsolved issue which is of prime importance for sustainable water management in the Volta Basin. In West Africa, as in most parts of the tropics, crop choice, crop yields, actual sowing and sowing dates in particular, strongly depend on temporal and spatial distribution of rainfall and the onset dates. Within the last decades, a shift in the onset of the rainy season was observed, especially in the early 1980s. Due to temporal irregularities in rainfall distribution, prediction of the onset is of crucial importance for the farmers. Its successful estimation directly influences daily farmers' life and regional food security. Planting too early may cause severe crop failure, whereas planting too late may reduce crop yields.

Methods

1.) A methodology based on linear discriminant analysis was build to attain the decision about wet season onset relying on previous years’ Ghanaian synoptical observation data. Therefore, one has to found predictor variables for each observation station which are highly reliable in representing the true onsets. These potential predictor variables are simple rainfall indices, which are describing rainfall amount ($VRI_x$) and number of wet days ($VRA_x$) 30, 25, 15, 10 and 5 days before the potential onsets.

Given a set of potential predictor variables $x_1, x_2, \ldots, x_p$, linear discriminant analysis looks for a linear combination $a'x = a_1x_1 + a_2x_2 + \ldots + a_px_p$ which discriminates as well as possible between real and false starts of the wet season. The set of constants $a_1, a_2, \ldots, a_p$ is chosen to maximize the ratio of between- to within- group variation of $a'x$.

The real starts (onset dates) are computed using the definition after STERN et al. (1981) in combination with fuzzy rules. This definition states that the wet season has started when, for the first time since 1st of March:

(a) a period of 5 consecutive days occurs in which at least 25 mm of rain falls;
(b) the start day and at least two other days within this period are wet;
(c) no dry period of 7 or more consecutive days occurs in the following 30 days.

Fig. 12 presents the mean value and the standard deviation of onset dates (Julian Days) for Ghana and a time period of at least 35 years applying the geostatistical interpolation technique known as Universal Kriging.

2.) A sophisticated methodology for automated objective circulation pattern definition and classification based on optimized fuzzy rules applied. These fuzzy rules are obtained using an optimization of the performance of the classification. For precipitation, the performance of the classification is measured by rainfall frequencies and rainfall amounts conditioned on the CP, so the main purpose is the definition of
wet and dry CPs (Bardossy et al., 2002). In this context the potential detection of CPs, which are significantly responsible for the start of the rainy season is intended.

**Results:**

Table 1 shows the analysis results, i.e. information about the number of real and false starts for 9 of the Ghanaian weather stations. The application of a restrictive definition, e. g. the definition after Stern et al. (1981), is found to be less suited, because it defines too less onset dates for all the stations. For this reason this definition is applied with fuzzy logic. The most frequent reliable predictor for discrimination is the number of wet days 30 days before the potential onset (VRA 30), which shows always the highest canonical correlation coefficients. It can be proofed that this method is generally applicable to estimate the onset using previous years’ data.

<table>
<thead>
<tr>
<th>Station</th>
<th>Real starts using all variables [%]</th>
<th>False starts using all variables [%]</th>
<th>Real starts using suited variables [%]</th>
<th>False starts using suited variables [%]</th>
<th>Suited variable(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kumasi</td>
<td>95,4</td>
<td>4,6</td>
<td>99,7</td>
<td>0,3</td>
<td>VRA30</td>
</tr>
<tr>
<td>Ho</td>
<td>94,3</td>
<td>5,7</td>
<td>98,8</td>
<td>1,2</td>
<td>VRA5, VRA30</td>
</tr>
<tr>
<td>Axim</td>
<td>98,3</td>
<td>1,7</td>
<td>99,2</td>
<td>0,8</td>
<td>VRA5, VRA10, VRA30</td>
</tr>
<tr>
<td>Saltpond</td>
<td>87,9</td>
<td>12,1</td>
<td>98,9</td>
<td>1,1</td>
<td>VRA10, VRA30, VRA20</td>
</tr>
<tr>
<td>Sefwi-Bekwai</td>
<td>90,7</td>
<td>9,3</td>
<td>99,0</td>
<td>1,0</td>
<td>VRA30</td>
</tr>
<tr>
<td>Kete-Krachi</td>
<td>96,6</td>
<td>3,4</td>
<td>99,7</td>
<td>0,3</td>
<td>VRA30</td>
</tr>
<tr>
<td>Koforidua</td>
<td>97,1</td>
<td>2,9</td>
<td>99,7</td>
<td>0,3</td>
<td>VRA30</td>
</tr>
<tr>
<td>Accra</td>
<td>87,6</td>
<td>12,4</td>
<td>99,5</td>
<td>0,5</td>
<td>VRA30</td>
</tr>
<tr>
<td>Bole</td>
<td>92,3</td>
<td>7,7</td>
<td>99,5</td>
<td>0,5</td>
<td>VRA25, VRA25</td>
</tr>
</tbody>
</table>

Table 1: Proportion of real and false starts derived from daily rainfall datasets in Ghana
Fig. 12: a) Mean Onset-Date (Julian Day); b) standard deviation of onset dates

**Outlook:**

Regarding to the discriminant analysis it has to be verified if current season data can be used to arrive at the decision whether the rainy season has already begun.

[...]
**Problem**

Short-term prediction of precipitation and temperature is an essential tool for facilitating decisions in water management and in particular agricultural planning. Decisions on sowing and harvesting depend on scientifically sound information on short term weather evolution.

**Method**

As CPU power has increased tremendously in the past years and state of the art internet connection allow fast transfer of large data amounts, numerical weather prediction can be performed with PCs at low costs. Behind this background, an operational numerical weather prediction for West Africa and the Volta Basin was developed. AVN global reanalyses in 2.5x2.5° resolution are retrieved automatically every day and after operational pre-processing chains dynamically downscaled to 27x27 km² resolution.

**Results**

The forecast is analysed with respect to temperature, precipitation, surface runoff (infiltration excess) and soil moisture/saturation. It is visualised and put on the GLOWA-Volta server where it can be viewed by any user connected to the internet.

![Internet presentation of 5-day numerical weather prediction](http://www.glowa-volta.de/atm/forecast.htm), example 2nd of February, 2005
Outlook
Where in phase 2 the focus is set on the operational setup and the graphical presentation of the numerical weather forecast, detailed validation is anticipated for phase 3.
Sub-project L4: Modeling Spatial and Temporal Upscaling of Erosion and Hydrological Processes

**TASK: DERIVATION OF EFFECTIVE LAND SURFACE PARAMETERS FOR SVAT MODELS**
Harald Kunstmann (IMK-IFU)
Joseph Intsiful (ZEF)

**Problem**
Mesoscale distributed hydrological models as well as process based regional climate models often use grid resolutions that are not able to account for detailed land surface heterogeneity (e.g. soil, vegetation and land surface properties). The impact of this subgrid-scale heterogeneity usually is not accounted for. Land surface information, however, often is available in higher spatial resolution than the specific model resolution (e.g. via satellite data) and the coarse model resolution is only due to limited CPU resources. If subgrid-scale effects shall be accounted for on grid-scale, aggregation techniques have to be applied that allow the derivation of effective model parameters.

**Method**
A new methodology was developed that allows the upscaling of land surface parameters of a Soil-Vegetation-Atmosphere-Transfer (SVAT) Model. Focus is set on the proper representation of latent and sensible heat fluxes on grid scale at underlying subgrid-scale heterogeneity. The objective was to derive effective land surface parameters in the sense that they are able to yield the same heat fluxes on the grid scale as the averaged heat fluxes on subgrid-scale. A combination of 1) inverse modelling and 2) Second-Order-First-Moment (SOFM) propagation or alternatively Monte Carlo simulation is applied for the derivation of effective parameters. The derived upscaling laws relate mean and variance (first and second moment) of subgrid-scale heterogeneity to a corresponding effective parameter at grid-scale. Explicit upscaling relations were exemplary derived for a) roughness length, b) albedo, c) emissivity, d) leaf area index, e) wilting point soil moisture, and f) minimal stomata resistance. It could be demonstrated that the SOFM-Method yields congruent results to corresponding Monte Carlo simulations. Effective parameters were found to be independent of driving meteorology and initial conditions.

The Monte Carlo approach has additionally been applied to the full MM5 model (Intsiful, 2004). Slight differences between the stand-alone SVAT model and the fully MM5-integrated SVAT model could be derived. It was additionally demonstrated that the geometrically averaging on subgrid scale provides a reasonable approximation for the majority of effective land surface parameters.

**Results**
Fig. 14: a) comparison between simulated and observed latent heat fluxes, b) dependency of grid-scale effective roughness on subgrid scale mean and standard deviation (Kunstmann, 2005)

Outlook
Beside mean (1\textsuperscript{st} moment) and standard deviation (2\textsuperscript{nd} moment), higher moments can be considered.
Sub-project L5: Land Use Change Prediction Model

TASK: LARGE SCALE VEGETATION MODELLING
Markus Erhard (IMK-IFU)

Background
Information on large-scale vegetation dynamic is needed for assessing changes in ecosystem services and the biochemical cycles in the Volta basin under climate and land-use change.

Method
According to the available input data we use a top-down approach to simulate vegetation dynamic in the region. Simulations should deliver:

- crop yield data to be used as input for economic modelling with GAMS,
- land surface parameters for climate (MM5) and hydrological modelling (WaSIM), and
- projections of vegetation dynamic due to climate and land-use changes and disturbance by fire.

An updated version of the LPJ-model (*Lund – Potsdam - Jena Dynamic Global Vegetation Model*; Sitch et al. 2003) was applied. Simulations are based on CRU 0.5 x 0.5° 20th century monthly climatology (New et al. 2000), down-scaled ECHAM4 data, and the IGBP global land cover map. Model results are expressing the climate impact on natural vegetation.

Results
Net ecosystem productivity show high inter-annual variation in the 20th century. Growing conditions are changing from year to year. Overall rate of carbon storage in the vegetation is very low. Carbon uptake is slighty increasing in the 21st century indicating better average growing conditions in this period up to 2090. In parallel inter-annual variation is increasing raising the risk of carbon loss by fires and droughts.

Crop yield was simulated for the years 1960 - 2000 with the LPJ crop module. show the trends for three different vegetation zones (from south to north: evergreen broadleaf forest, woody savannas and savannas). Yields represent potential yield or crop suitability as function of climate and soil conditions. Inter-annual variability is much lower than calculated for natural vegetation. Yields are slightly increasing due to land-use changes and better climatic conditions (see also Fig. 16).

Results show how vegetation may change over time in the Volta basin. Further efforts are necessary to improve quality and reliability of the data.
Outlook

Next steps in large-scale vegetation modelling are:

- spatial and temporal down-scaling of the model using GLOWA-Volta land-use and climate data
- validation of the crop module using measured yield data
- validation of the vegetation module using measured flux (Dano site) and remote sensing data (Modis)
- multi-scenario runs to investigate vegetation dynamics and crop suitability in the 21st century for risk assessments and model coupling
Subproject D1: Technical Integration of Socioeconomic and Environmental Modelling Subsystems

 TASK: COUPLED HYDROLOGICAL AND ECONOMICAL SIMULATION/OPTIMISATION

Markus Mast, Harald Kunstmann, Hella Ahrends (IMK-IFU)
Charles Rodgers (ZEF)

Problem

The 1st objective of the Coupled Hydrological and Economical Simulation is an optimized irrigation strategy with a guaranteed sustainable water balance. In detail the maximization of irrigated agricultural profit accounting for hydrological constrains like a minimum flow requirement in rivers and a maximum groundwater level drawdown (“red line”), more precisely the combination of both, should be achieved. The cultivated crops consist of dry season rice, wet season rice, tomato and onion.

Method

To simulate a sustainable water balance for the researched catchment Atankwidi between Burkina Faso and Ghana the Water Balance Simulation Model (WaSIM-ETH version 2) is applied. It is driven by a validated and calibrated data setup for the period of one year.

The economical model GAMS (by GAMS Development Corporation 1998) realizes the optimization of allocating water for irrigation and maximization of irrigated agricultural profit. The initial point is an equation summary that simplifies the problem to a single reservoir and irrigation system with no recursive surface area calculations. Such defined structural condition is solved by CONOPT3 a Multi-Method Solver with Automatic Dynamic Selection of Methods. This nonlinear programming routine has the goal of finding a solution that optimizes the objective function, possibly subject to constraints on the decision variables.

The communication between both models, the basic aspect of coupled models, is build up by PERL and C-shell programming (Mast and Kunstmann, 2005). These simple tools provide data exchange between template model input files and enable estimating and manipulating all forms of required data.

Fig. 17 shows the setup scheme of the coupled hydrological and economical simulation.
The objective proceeding is the withdrawal for irrigation out of a reservoir/gauge by observing the local hydrological conditions and possible agricultural profit. Due to crop prices, maximum crop yield, total fixed costs, inflow to reservoir etc. GAMS simulates an optimized water allocation and irrigated agricultural revenue. Relative to the GAMS output, pre-processing tools are preparing data for the usage in WaSiM-ETH adjusted with a defined reservoir and activated irrigation module. According to the hydrological modelling post-processing routines are scanning the WaSiM-ETH output by the predefined hydrological constraints. If the results fulfil the conditions of a sustainable water balance (e.g. min. flow requirement in river, max. groundwater level), the simulation will be closed. Is there an undershoot of a “red line” condition, withdrawal will be reduced and a new iteration is starting.

Outlook

Major task of the coupled hydrological and economical simulation could be the operation on predicted changes in climate or different climate scenarios to achieve an economically efficient water management with respect to environmental sustainability.
References


