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The Semi-arid Integrated Model (SIM)

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Abstract

The Northeast of Brazil is a semi-arid region, characterized by water scarcity and a high vulnerability of the natural resources and the social structures. The central question of the WAVES project is the analysis and modelling of the relationships between climate, water availability, agricultural and social processes (specifically migration) including the aspects of global change processes in the Brazilian federal states of Ceará and Piauí. A co-ordinated integration of knowledge in the individual disciplines of WAVES is a precondition to obtain these goals. For this purpose, the dynamics of the system and the external forces are implemented and interconnected in the Semi-arid Integrated Model (SIM) considering all relevant processes of the mentioned disciplines.
The model SIM gives a systematic, dynamic, quantitative and spatially resolved description of the causal relationships between climate - water availability – agriculture - quality of life - migration. The context of the descriptions is the internal dynamics of the regional processes and the reaction to global change processes, in particular to climate change. The discipline-specific partial models form the basis for the development of the integrated regional model, which is structured in a modular way.
Potential effects of different development strategies of social and natural systems will be evaluated by means of this simulation tool. The model allows to investigate the impact of climate change and variability and of further selected parameters. The results show that a regional integrated model can be a very suitable tool for complex and interdisciplinary studies.

Introduction

North-eastern Brazil is a semi-arid region that is characterised by water scarcity and vulnerability of natural resources, pronounced climatic variability and social stress situations. Climate conditions are characterized by moderate precipitation with high seasonality and high potential evapotranspiration. Limited availability of water is a result of these conditions and a major constraint for agricultural production, quality of life and development in the semi-arid tropics. This causes social responses like migration that primarily occurs in irregularly recurrent drought periods.
For understanding the problem, it is of importance to analyse the relationship between climate, water availability, agriculture and society. An integration of the knowledge of the individual disciplines of the WAVES-project is required. An integrated model is useful to investigate the impact of climate change and variability and of further selected parameters. With the model we are able to investigate how sensible the system reacts to climate change and variability

The Model

The development of an integrated model begins with an analysis of the most important processes. The WAVES project focuses on the assessment of relationships between water availability, the quality of life and migration in semi-arid North-eastern Brazil at a meso-/macro-scale in the context of global change, especially climate change. An analysis of the problem identifies the basic variables, processes, and external forces that should be accounted for in the integrated model.
The concept was derived starting at a rather aggregated level and become more detailed (top down approach). Figure 1 visualizes the systems analysis in medium detailed level with the internal variables that influence each other (central part of fig. 1) and external forces (outer parts) that have an impact on system but are not influenced by the system. It is important to select those internal processes, which are most relevant to describe the dynamic of the system and to include cross linkages and feedback processes, which could especially are significant

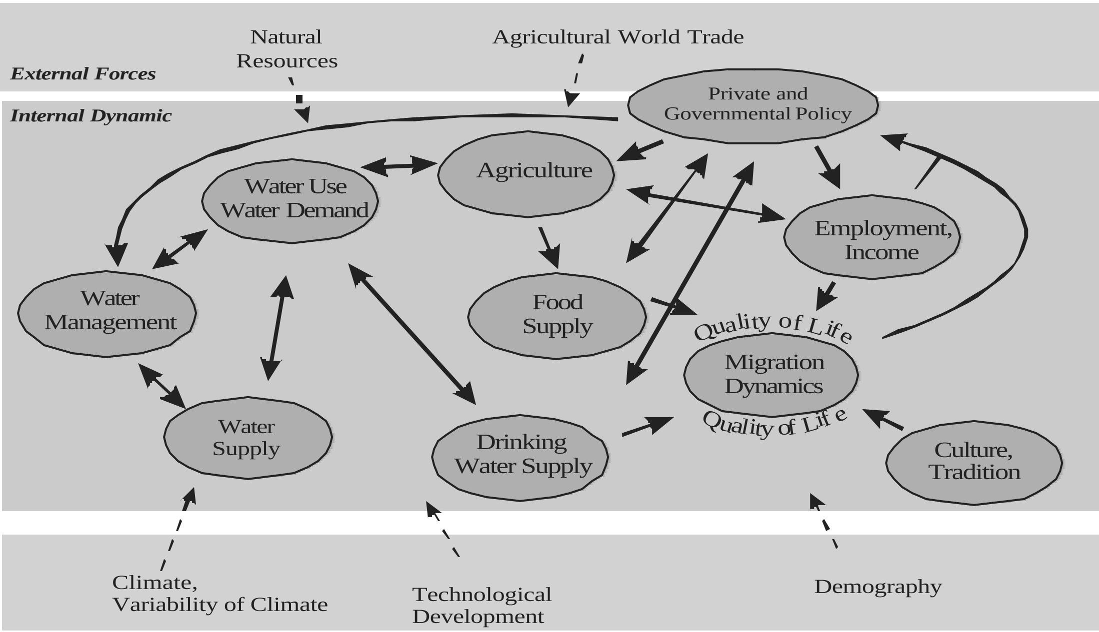

Figure 1 Systems analysis of relations between water availability and impacts on socio-economy.

for long-term dynamics of the system. Due to the context of global change processes we rather focus on long-term changes than on processes just explaining heterogeneity at the micro-scale. In this context, integrated models generally show a mix of deductive (top-down) and inductive (bottom-up) approaches. In the WAVES project the poor availability of data on many themes at the targeted scale is a limiting factor.

According to the main question of the project the systems analysis (Figure 1) shows the availability of water and the migration dynamics and their connecting processes. Physical water availability is changed by the climate and depends on natural resources and water use. Migration dynamic is mainly controlled by the life quality. Different endogenous indicators like employment and income as well as external forces like technical development influence life quality.
Central connection between these is the agriculture. Due to the water use for irrigation it depends from the water availability and gives the food supply and determines the income for the rural population

Based on the systems analysis the Semi-arid integrated model SIM was constructed (Fig 2). The most important processes were transformed in quantitative process-based dynamic descriptions. The model consists of different partial models and some integrating parts that were constructed for connecting the processes in a consistent way. The modules are mainly based on contributions from the various working groups in the WAVES program.
Some of the partial models have been presented in this workshop in a detailed way.

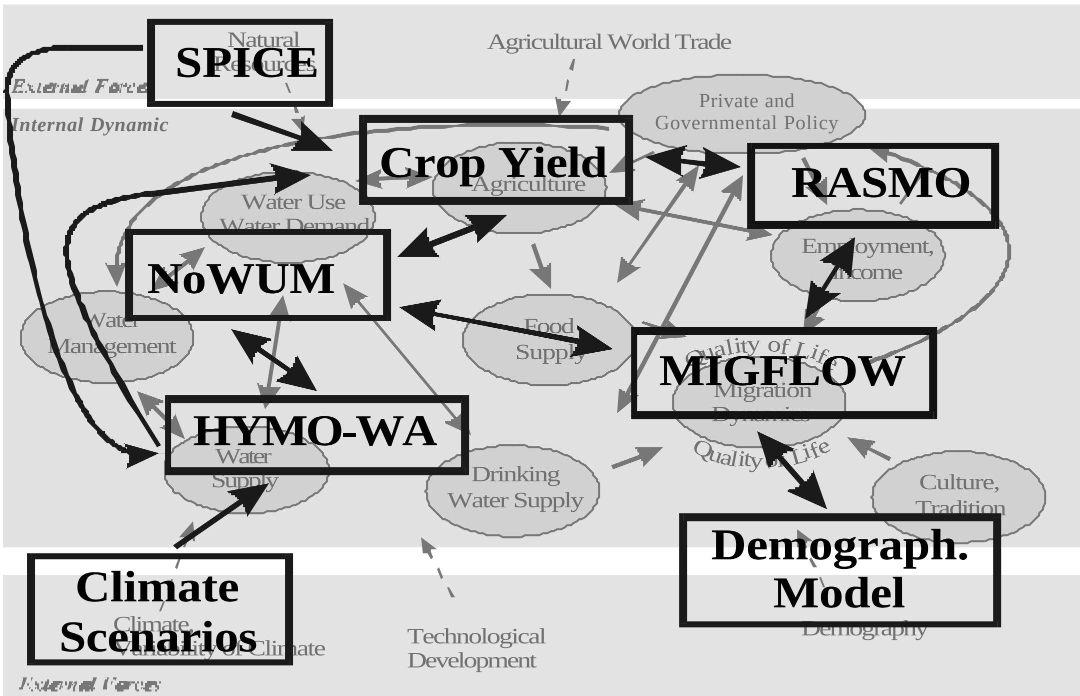

Fig 2: The implementation of the partial models into the systems analysis

The model calculates in a geographical explicit way using municipalities as smallest simulation units. Depending on the described process, the temporal resolution varies from one day to one year. The time horizon is about 60 years and we consider the area of the federal states of Ceará and Piauí (~470000 km²).

The main components of SIM are:

CLIMATE The CLIMATE SCENARIOS are the most important driving forces of the model. Analyses of long-term daily observation are the basis for a historical data set from 1921 to 1980, including daily values of rainfall, radiation and humidity. Downscaled data from Global Circulation Models are used to simulate scenarios in the future.

HYDROLOGY The large scale water balance model HYMO-WA accounts for river runoff, soil moisture and reservoir storage, with an explicit representation of the large water reservoirs. Considering the importance of lateral water flow for spatial patterns of soil moisture and runoff generation, modelling units are defined as terrain patches with similar characteristics referring to lateral processes based on a toposequence approach.
The Northeast Water use model NoWUM calculates the demand of water. It distinguished different water use sectors as for example animal breeding, household, industry, irrigation and tourism under consideration of their specific intensity and efficiency.

AGRICULTURE The CROP YIELD model estimates the production of the 14 main regional crops. According to a FAO approach it calculates the reduction of yield caused by a lack of water. It includes the quality of soil and different methods of cultivation. An agro-economical optimisation model (RASMO) maximises the income of the farmers under consideration of some restrictions (of available land, technical opportunities, and feed and food requirements) and calculates the best land use.

SOCIO-ECONOMY MIGFLOW calculates indicators to describe the quality of life that is mainly determined by the municipal income. Gradients in the life quality determine the migration between municipios. The model is linked to a demographic model resolving for age and gender.

Examples of modelling results

Present applications of the model focus on historic simulations for validation and studies of the sensitivity to climate variability and climate change.

Figure 3 gives two examples for the application and validation of SIM comparing observed historical data with simulated values.
The first example (Fig. 3a) shows the runoff at a station in Rio Jaguaribe basin (72000 km²) in Ceará, the largest and most important basin for water resources of this state. The figure shows monthly averages for the 60 years period of 1921 to 1980.The model satisfactorily represents the intraannual runoff variability.
In Figure 3b), the yield of beans in Ceará from 1947 to 1975 is shown. The slight systematic overestimation of simulated runoff in dryer years occurs probably because only those reductions caused by the lack of water and different soils are included. In the model version used here, further reductions caused by aeration and changes in the fraction of irrigated and non-irrigated areas are not considered.

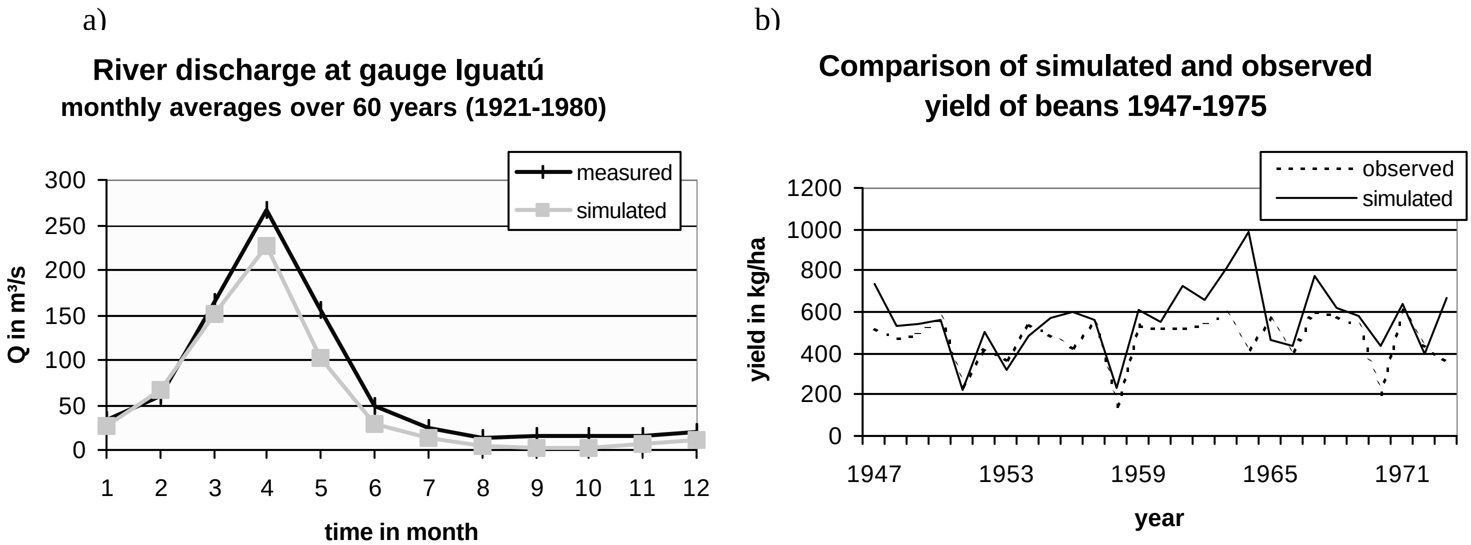

Fig. 3 Comparison of measured and simulated data a) runoff at station Iguatú b) yield of beans in Ceará

Preliminary sensitivity calculations are focused on the effects of climate changes according to a business-as-usual scenario of ECHAM 4 (Fig. 4). Figure 4a) shows the change of rainfall in a scenario based on results of the model ECHAM-4 for 2000 to 2050. The difference of

rainfall of the last 25 years and the first 25 years period shows a significant decrease of precipitation in most municipios of Ceará and Piauí.
The impact of this reduction of rainfall is shown in Figure 4b)-4d). Except of the climate data, external forces (e.g. land use, water infrastructure) were kept unchanged. Figure 4b) is a result of the connection of the water availability model and the water use model NoWUM. The relation between the availability of water and the water demand for the dry season in the year 2024 shows significant reductions. For the simulation period from 2000 to 2050 Figure 4c) shows the impacts of the climate scenario on agricultural GDP, under the assumption that all other external forces that are important for the simulation (e.g. prices) remain constant. The lower values for GDP are generally constant. In the second period of the simulation (2030 - 2050) the probability of a better economic return diminishes. This is caused by lower variability in precipitation, since the level of GDP is influenced by the yield and therefore by the rainfall. Emigration from sertoes from 2000 to 2050 is represented in Fig. 4d. High migration is caused by a lower agricultural income that is in turn caused by lower rainfall. The graph reflects the spatial gradient rather then the temporal. The line indicates an increasing migration in the simulation. These results are uncertain because description of life quality is not sufficiently represented in the model version used for the simulation shown here.

Conclusions

The Semi-arid Integrated Model successfully reflects the connection of climate, water availability, agriculture and migration.
Model application show the sensitivity of the region to climate change where the change of output variables is often even more pronounced than the expected change of the climate input variables demonstrating the non-linearity of the system.
Results indicate that climate change may have serious effects on northeastern Brazil, with appreciable reductions in river flow and agricultural GDP, if no counteracting policies are put through. Possible policy responses like improved water infrastructure, changes in the agricultural sector were not studied in this sensitivity study but will be considered in forthcoming integrated scenario runs. Moreover, it was shown that a regional integrated model could be a very suitable tool for complex and interdisciplinary studies. The present version of SIM still is in a development phase especially regarding the representation of socio-economic processes. Future applications will consider integrated scenarios of global and regional change with variations in regional policy interventions. These scenarios will be analysed as possible pathways of future development, considering aspects of sustainability.
It has been shown that common construction of integrated tools like integrated models or scenarios is a good way to harmonise an interdisciplinary project.

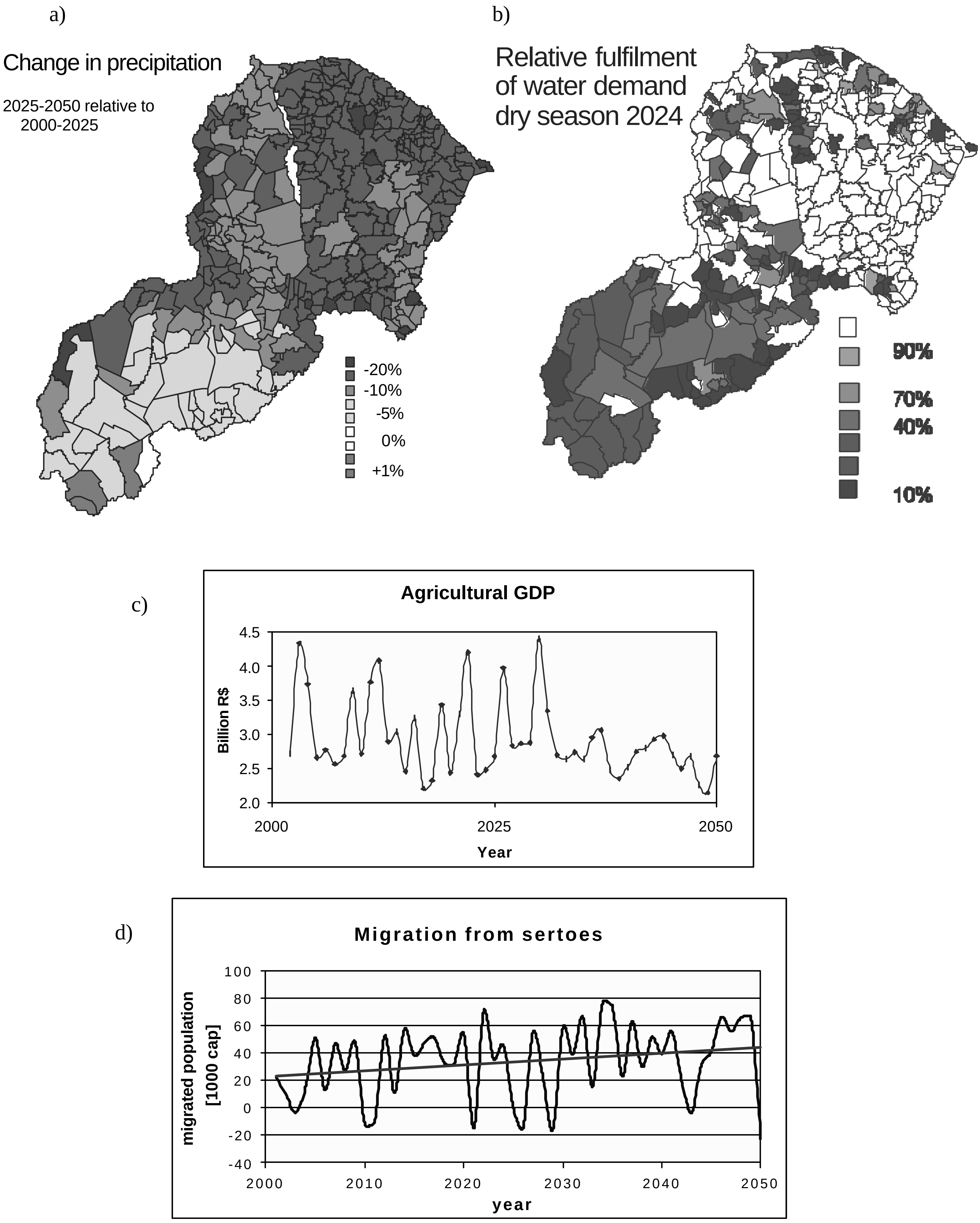

Figure 4 Example results of SIM for a climate change scenario, based on a GCM run: a) reductions in precipitation in Ceará and Piauí over the next 50 years; b) restricted fulfilment of water demand in the dry season of 2024, c) the mean annual agricultural GDP; d) migration from sertoes