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SIMULATING GLOBAL FEEDBACKS BETWEEN SEA LEVEL RISE, WATER FOR AGRICULTURE AND THE COMPLEX SOCIO-ECONOMIC DEVELOPMENT OF THE IPCC SCENARIOS

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ABSTRACT

The Global Unified Meta-model of the BiOsphere (GUMBO) was used to simulate how the socio-economic conditions specified in the Special Report on Emission Scenarios (SRES) of the IPCC (Intergovernmental Panel on Climate Change) influence vulnerability to climate change. Input parameters are the consumer preferences, investment strategies, natural resources management and technological development associated with the SRES scenarios. From this input the characteristic SRES driving forces population growth, economic development and fossil fuel use were reproduced in GUMBO with the corresponding climate scenarios (temperature change, sea level rise and rainfall patterns). This article shows alternative pathways of development exist that yield the same SRES driving forces but that differ significantly in their vulnerability to sea level rise and water availability. It concludes that an assessment of the relative vulnerability of the SRES scenarios that takes into account the socio-economic characteristics of these scenarios, can challenge assessments based on climate change and the driving forces only. The assessment of alternative complex socio-economic conditions is an important addition to understand our world’s vulnerability to climate change. GUMBO offers a promising, flexible and fast environment for the assessment. The GUMBO model and documentation can be downloaded from www.uvm.edu/giee/GUMBO.

Keywords: Socio-economic Scenarios, Global Change Modelling, Dynamic Feedback

1 INTRODUCTION

This study simulates the dynamic feedback between different pathways of socio-economic development and climate change. It builds on the scenarios published by the Intergovernmental Panel on Climate Change (IPCC) in its Special report on emission scenarios (SRES) (IPCC, 2000). The SRES scenarios offer a well documented regime of plausible future for the world which provides a meaningful basis for impact assessments (Arnell et al, 2004). The four SRES scenarios are created in three successive steps: (1) qualitative storylines represent a diverse range of different socio-economic development pathways for the world, (2) the storylines are translated into quantitative driving forces, that are harmonised projections of the indicators population growth, economic development, technology, energy and land-use, and (3) greenhouse gas emission scenarios are calculated from the driving forces. So far most analyses of climate change use the driving forces to characterise the SRES scenarios (e.g., Parry, 2004, Alcamo, 2002; Kabat, 2003). Few use the socio-economic characteristics of the underlying storylines (Arnell et al, 2004). The goal of this study is to understand how complex dynamic socio-economic conditions influence our world’s vulnerability to climate change in the coming century. More specific this paper reports on the simulation of the dynamic feedback between sea level rise and water availability in agriculture and the world of two of the SRES scenarios. This paper explicitly takes a systems perspective in studying global change. The principles of
system dynamics allow studying interrelationships and patterns of change in how human activities are altering the Earth, impacting the life support system upon which humans depend (SDU, 2004; Steffen, 2004; Meadows et al, 1992). Emerging insights from system analysis are how differences flowing from different pathways of development are often more important than climate change itself in influencing the scale of global impacts (Parry, 2004) and how different human conditions and income level affect vulnerability and resilience to climate change (Turner, 2003; Parry et al, 2004).

To simulate the influence of the socio-economic characteristics of the SRES storylines on vulnerability to climate change this study uses the Global Unified Meta-model of the BiOsphere (GUMBO) (Boumans et al, 2002). GUMBO is a meta-model that incorporates a simplified version of several existing models at an intermediate level of complexity. GUMBO simulates the dynamic feedbacks among global change, human technology, economic production, welfare and ecosystem goods and services within the dynamic earth system. Since GUMBO treats our world as a closed system, the IPCC driving forces are endogenous variables, derived dynamically from model characteristics. Input parameters of GUMBO are changing socio-economic conditions including consumer preferences, investment strategies, natural resources management and technological development.

This study has four main components. First the SRES scenarios were simulated in GUMBO. Secondly, alternative interpretations of the storylines were modelled. Thirdly, two climate stresses were simulated. Finally the vulnerability was assessed of the (alternative interpretations of) SRES storylines to the climate stresses. For the purpose of the iEMSs 2004 Conference this article focuses on the modelling aspects of the study. A more detailed discussion of assessment will be published separately. The analysis is limited to two of the four SRES scenarios. It proved possible to reproduce the SRES driving forces population growth, economic growth and energy use with their corresponding climate scenarios (temperature change, sea level rise and rainfall patterns) in GUMBO. Model parameters could be chosen to agree essentially with the different pathways of socio-economic development, investment strategies and technological development of the SRES storylines.

Alternative pathways of development could be defined within one SRES storyline that yield the same SRES driving forces but that differ significantly in their vulnerability to sea level rise and water availability. This study shows dynamic combination of environmental and social conditions exist that significantly enhance or reduce vulnerability. Results suggests that, taking into account the characteristics of the storylines, an assessment of the relative vulnerability of the SRES scenarios can challenge earlier assessments based on climate change and the driving forces only. The assessment of alternative multidimensional socio-economic conditions is an important addition to understand our world’s vulnerability to climate change.

2 BACKGROUND

2.1 The IPCC scenarios

To translate findings of climate change science into international politics the IPCC uses scenarios. These are published in the Special Report on Emission Scenarios (SRES) (IPCC, 2000). The SRES scenarios build on previous scenarios published by the IPCC (IPCC, 1992; IPCC, 1995), but do not include any policies or intervention; particularly there is no business-as-usual scenario. The IPCC scenarios of climate change are built in four discrete steps (see also Figure 1a):

1. Scenario panels created four qualitative SRES storylines that represent a diverse range of different development pathways for the world
2. The storylines are translated into quantitative SRES driving forces that are harmonised projections of the indicators population growth, economic development, technology, energy and land-use
3. Anthropogenic greenhouse gas emission scenarios are estimated from the driving forces
4. These emissions are used to drive climate models (General Circulation Models (GCMs)) to produce spatially explicit climate scenarios, including temperature change, sea level rise and precipitation.

The calculations do not include feed backs from the climate scenarios onto the SRES storylines or driving forces. Thus effects of climate change and climate variability on e.g. water resources, the economic system or ecosystem services remain largely unresolved.

The two storylines used in this study are (IPCC, 2000, 4-5; Mieg, 2002) (see also Table 1):

- A2: This storyline describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly.
- B1: This storyline describes a convergent world with rapid changes in economic
structures towards a service and information economy, with reduction in material intensity, and the introduction of clean and resource-efficient technologies.

2.2 **GUMBO**

**BOX: Model characteristics GUMBO:**

- Based on principles of system thinking (integration, feedbacks, strong sustainability)
- No spatial resolution; accounts for carbon, nutrient, water fluxes across 11 land covers and 4 capital stocks (natural, social, human, built capital). Apart from incoming solar energy all variables are endogenous.
- Draws concepts and data from many disciplines (Global Climate models, Atmospheric models, Sociology models, Economic models, Ecosystem models).
- Almost 1000 variables and 2000 parameters
- Programmed in Stella environment (run time under 30 sec for 200 years on average PC)
- Free available from (www.uvm.edu/giee/GUMBO)
- User can edit all model equations & parameters

GUMBO simulates the integrated earth systems and assesses the dynamics and values of ecosystem services. GUMBO is a meta-model in that it incorporates the simplified versions of several existing models at an intermediate level of complexity (Boumans et al., 2002). GUMBO is built upon the principles of system thinking (Meadows et al., 1992; Simonovic, 2002).

GUMBO simulates the dynamics of carbon, nutrients and water within the Atmosphere, Lithosphere, Hydrosphere, and Biosphere sectors, and across eleven land cover types covering the surface of the planet. GUMBO uses a one-year time step period, and is calibrated for the period of 1900-2000 for key variables for which quantitative time-series were available.

In the model, atmospheric processes attenuate solar radiation energy arriving at the Earth surface. The atmospheric exchange of carbon and nitrogen with terrestrial systems is regulated by vegetation growth, decay and burning on terrestrial systems. Producers, consumers and decomposers control these processes on ground, soil and water in the different land cover types. These conditions and processes result in the provision of goods and services, which are referred in the model as natural capital. Human-driven land cover changes have an effect on the provision and availability of natural capital, which in turn, is an important determinant of humans’ economy and social welfare. The dynamics of social interactions, the human economy and welfare are modelled within the anthroposphere sector of the model. In contrast to the larger biosphere, only a very small portion of materials is internally recycled within the Anthroposphere. Human population, knowledge, social institutions and investment rates drive the material and energy flux.

The atmosphere and anthroposphere are considered to be globally homogenous. The homogeneous nature of the atmosphere is justified by the fast exchanges in air masses between land covers. The homogeneous character of the anthroposphere, in turn, reflects the global economy where wealth and quality of life are not registered relative to land cover type. The other sectors (lithosphere, hydrosphere, and biosphere) are divided into 11 land cover types and the structure described is replicated for each land cover. In addition, there are sectors in the model for ecosystem services, land use, and the model’s database.

GUMBO is the first global model to explicitly account for ecosystem goods and services and factor them directly into the process of global economic production and human welfare development (Boumans et al., 2002). In GUMBO, the flow of ecosystem goods and services are explicitly combined with manufactured and human capital to produce human welfare (Costanza et al., 1997a). Such design is based on the strong sustainability concept, that is, on the concept that natural capital is essential for the creation and maintenance of the human, physical and social capitals aspects of the anthroposphere.

3 **METHOD**

There are four main components of the research. First the SRES scenarios were simulated in GUMBO. Secondly alternative interpretations of the storylines were modelled. Thirdly climate stresses were simulated. Finally the vulnerability was analysed of the (alternative interpretations of) SRES storylines to the climate stresses.

1. **Simulation of the SRES scenarios in GUMBO, including the driving forces and the associated climate change scenarios (temperature, sea level rise, precipitation)**

This study uses GUMBO to reproduce the SRES scenarios together with their climate scenarios in one modelling framework including feedbacks. This method differs from the IPCC simulations, that do not include feedbacks from the climate scenarios onto the SRES storylines or driving forces (Figure 1b). The socio-economic conditions described in the SRES storylines were used as an input to GUMBO (Table 1) and introduced by a change in model parameters after the year 2004. An interpretation of the storylines was selected that reproduces the driving forces of
the IPCC marker scenarios and the corresponding climate change scenarios. This article concentrates on the A2 & B1 scenario. A2 was chosen because the IPCC Task Group on Scenarios for Climate Impact Assessment has asked climate-modelling centres to give priority to the A2 (and B2) scenarios. B1 was chosen to complement the socio-economic and climatic conditions of A2.

To represent the IPCC climate change scenarios GUMBO was modified and recalibrated with recent insights from global change research. These modifications include recalibration of the carbon cycle using global estimates of atmosphere-ocean interaction and land-atmosphere interaction (IPCC, 2001). Characteristic carbon limitation factors were estimated for each land cover in GUMBO (CSCDGC, 2002). Since the potential interactions between CO₂, nutrients, water, weeds, pest insects and other stresses are largely unknown (Parry, et al., 2004) the limitation factors were calibrated against literature values of net biome production (Levy, 2004) and net primary production (e.g. Portela, 2004; Malhi, 2002). The water cycle was recalibrated using Cosgrove and Rijsberman (2002), with special attention to precipitation per GUMBO land cover type. For this recalibration climate scenarios of temperature and precipitation per GUMBO land cover type were estimated from the net sink for carbon that the terrestrial ecosystem represents.

2. Modelling of alternative interpretations of storylines that yield the same driving forces.

Two alternatives were simulated for each scenario. The leading input variable to mark the difference between the alternatives is agricultural production. Agricultural production was selected because recent impact assessments point at increased stress from climate change (e.g. Aerts, 2003; Parry et al., 2004). To yield the same SRES driving forces, the shift in agricultural production was balanced by changing other input parameters in line with the SRES storylines. Since the share of alternative energy sources is specified in the SRES scenarios, this was not used to construct alternative interpretations of a storyline.

3. Simulation of two stresses from the climate system

Two climate stresses were selected to target the economic system and food / biome production respectively: (i) increasing the depreciation value of built capital with sea level rise and (ii) decreasing crop production with drought stress. The study aims to assess the relative vulnerability to these stresses and not the absolute vulnerability. The absolute strength of a climate stress is therefore less critical in the simulation. The impact of sea level rise on built capital was simulated by increasing the depreciation value of built capital proportional to sea level rise above a certain limit. This limit was
selected 20 [cm]. The impact of possible drought conditions was simulated by decreasing the drought tolerance of crops. In GUMBO this was realised by changing the groundwater limit below which crop production starts to decrease. Assuming no drought stress in 1990, the impacts of two different groundwater limits were assessed that were set at 5/3 and twice the 1990 groundwater level respectively. It is noted that drought stress in GUMBO is the combined result of water supply and water use.

4. Assessment of the relative vulnerability of (alternative interpretations of) SRES storylines to the climate stresses.

For each scenario two model runs are compared: one with and one without a particular climate stress. The relative vulnerability of the different SRES scenarios is assessed, focussing on a number of key GUMBO variables, including population, economic growth and ecosystem services.

<table>
<thead>
<tr>
<th>Storyline</th>
<th>A2</th>
<th>B1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elements of Storylines defining input parameters GUMBO</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pace &amp; direction of investment &amp; technological change</td>
<td>Slow; heterogeneous; focus on agricultural production</td>
<td>High; towards efficient resource use; clean technology; recycling</td>
</tr>
<tr>
<td>Environmental concern</td>
<td>Local; Directed towards easing soil erosion &amp; water pollution for agric.</td>
<td>High &amp; global, including taxation, regulation and reuse</td>
</tr>
<tr>
<td>Fertility rates</td>
<td>Slowly declining</td>
<td>Declining</td>
</tr>
<tr>
<td>Education and Health programs</td>
<td>-</td>
<td>High towards clean &amp; equitable development</td>
</tr>
<tr>
<td>Dietary patterns</td>
<td>-</td>
<td>Much lower meat consumption due to high food prices</td>
</tr>
<tr>
<td>Income gap &amp; Productivity Disparity</td>
<td>Maintained or increasing</td>
<td>Declining; Productivity increases</td>
</tr>
<tr>
<td>Social structures</td>
<td>Diversifying</td>
<td>High social consciousness</td>
</tr>
<tr>
<td><strong>Elements of Storylines reproduced in GUMBO variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy intensity of GDP</td>
<td>Declining 0.5-0.7 % per year</td>
<td>Declining significantly</td>
</tr>
<tr>
<td>Capital stock turn over</td>
<td>Slow</td>
<td>- (focus on quality &amp; services)</td>
</tr>
<tr>
<td>Resource availability</td>
<td>Low; emphasis on self-reliance</td>
<td>-</td>
</tr>
<tr>
<td>Equity</td>
<td>Decreasing</td>
<td>Increasing</td>
</tr>
<tr>
<td>Global interaction</td>
<td>Low; cultural pluralism &amp; protectionism</td>
<td>High</td>
</tr>
<tr>
<td><strong>Driving forces to be reproduced in GUMBO</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population growth</td>
<td>High; ~ 15 billion</td>
<td>Low; ~ 7.2 billion</td>
</tr>
<tr>
<td>GDP growth</td>
<td>Medium (and differentiated); 243</td>
<td>Medium - High; 328</td>
</tr>
</tbody>
</table>

4 RESULTS

Figure 2 illustrates the input variables found to capture the SRES Story lines and reproduce the SRES scenario A2 and B1 in GUMBO. Variables are shown relative to their maximum value in the simulations reported in this article.

Table 2 compares the values of the SRES driving forces and the corresponding climate scenarios that are reported by the IPCC with those simulated in GUMBO. The following observations are made when representing the SRES driving forces and the IPCC climate scenarios in GUMBO.

**Population growth**

Two challenges had to be overcome to match the population growth of the SRES scenarios:
- to decrease population growth in the near future given substantial economic growth
- to sustain the world’s population at the end of the century under increasing pressure from waste, resource shortage and stress on food production.
Essential elements of the storylines are: the effect of education on fertility and raising the waste carrying capacity and waste assimilation capacity, as reported in B1. In addition the effect of GWP growth and food/capita growth on mortality had to be decreased. This signifies that GNP growth does only marginally benefit the poorest and inequality will increase as reported in the A2 storyline.

**GNP growth**

GNP growth is matched by growing labour participation and labour efficiency with increasing income and technology. The can be understood from increased appreciation of services and internalisation of the informal economy, as indicated in storyline B1. Labour participation was raised strongly in B1 to simulate high economic growth under falling population number and fossil fuel use. To match economic growth it had to be assumed that improved efficiency of resource use stimulates consumption, rather than decreases (income from) raw material use. This may be at odds with the shift from quantity to quality, reported in the B1 storyline. Finding satisfying assumptions to sustain economic growth as projected in the SRES scenarios proved a major challenge in the GUMBO simulation.

**Energy use**

For B1 the amount of available fossil fuel had to be increase by 30% and for A2 by over 400%. Substantial controls had to be installed, to realise that additional available oil is not consumed immediately, but gradually over time. This is realised in GUMBO by decreasing the rate at which new oil is found when human capital in the form of knowledge is invested in fossil fuel exploitation. The share of alternative energy sources was raised. To match the share of renewables of the SRES scenarios, it was assumed that new technology that is developed is directly used which may not be the case in all scenarios.

**Land use changes**

Preserving biome productivity is essential to realise the large terrestrial sink of anthropogenic carbon, estimated by the GCMs. It is governed by production limits (of water, carbon, nutrients, light and waste). In GUMBO climate change affects the production limits within a land cover type. Presently it does not directly influence land cover change, and the rates at which land covers change from one to another are held constant. Once more data becomes available on the influence of climate on land cover change, this may be a valuable extension of GUMBO. It was decided not to reproduce the land cover change scenarios of the IPCC since these do not exist for all scenarios and are increasing questioned (Levy, 2004, etc).

**CO₂ concentrations**

Global atmospheric carbon concentrations are well represented. Net biome production was calibrated to yield carbon uptake in line with the IPCC estimates of atmospheric carbon.

**Global average temperatures**

Global temperature change relative to 1990 is well represented. Temperature changes per land cover type are less well represented and deserve future attention.

**Global Mean Sea level rise**

Sea level rise is well represented in A2 and underestimated in the B1 scenario.

**Precipitation**

The trend in overall change in precipitation is well represented. Inter yearly variations are not modelled by GUMBO. Changes in precipitation per land cover are different from the GCMs results, especially for those land covers that change significantly in area. As GUMBO is not spatially explicit, GUMBO assumes that when the area of a land cover increases, the new area receives the average precipitation over land. This corresponds to the notion that e.g. cropland is now in the most suitable locations for agriculture, characterised by high precipitation. New cropland would be found in areas with less favourable conditions.

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### Table 2: Comparison of SRES and climate scenarios with GUMBO results

<table>
<thead>
<tr>
<th></th>
<th>A2 2050</th>
<th>A2 2100</th>
<th>B1 2050</th>
<th>B1 2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population number [billions]</td>
<td>IPCC 11.3</td>
<td>IPCC 11.1</td>
<td>IPCC 10.8</td>
<td>IPCC 10.6</td>
</tr>
<tr>
<td></td>
<td>GUMBO 11.1</td>
<td>GUMBO 11.0</td>
<td>GUMBO 10.8</td>
<td>GUMBO 10.6</td>
</tr>
<tr>
<td>GNP Per capita [US$]</td>
<td>IPCC 72.2</td>
<td>IPCC 61.1</td>
<td>IPCC 59.6</td>
<td>IPCC 59.6</td>
</tr>
<tr>
<td></td>
<td>GUMBO 72.2</td>
<td>GUMBO 61.1</td>
<td>GUMBO 59.6</td>
<td>GUMBO 59.6</td>
</tr>
<tr>
<td>Ecosystem Services [US$]</td>
<td>IPCC 10.0</td>
<td>IPCC 9.8</td>
<td>IPCC 9.6</td>
<td>IPCC 9.6</td>
</tr>
<tr>
<td></td>
<td>GUMBO 10.0</td>
<td>GUMBO 9.8</td>
<td>GUMBO 9.6</td>
<td>GUMBO 9.6</td>
</tr>
<tr>
<td>Gross National Product (GNP) [trillion US$]</td>
<td>IPCC 115.6</td>
<td>IPCC 115.6</td>
<td>IPCC 115.6</td>
<td>IPCC 115.6</td>
</tr>
<tr>
<td></td>
<td>GUMBO 115.6</td>
<td>GUMBO 115.6</td>
<td>GUMBO 115.6</td>
<td>GUMBO 115.6</td>
</tr>
<tr>
<td>Fossil Fuel [GtC]</td>
<td>IPCC 11.3</td>
<td>IPCC 11.3</td>
<td>IPCC 11.3</td>
<td>IPCC 11.3</td>
</tr>
<tr>
<td></td>
<td>GUMBO 11.3</td>
<td>GUMBO 11.3</td>
<td>GUMBO 11.3</td>
<td>GUMBO 11.3</td>
</tr>
<tr>
<td>Alternative Energy [EJ]</td>
<td>IPCC 17.0</td>
<td>IPCC 17.0</td>
<td>IPCC 17.0</td>
<td>IPCC 17.0</td>
</tr>
<tr>
<td></td>
<td>GUMBO 17.0</td>
<td>GUMBO 17.0</td>
<td>GUMBO 17.0</td>
<td>GUMBO 17.0</td>
</tr>
<tr>
<td>Fossil Fuel [trillion US$]</td>
<td>IPCC 54.0</td>
<td>IPCC 54.0</td>
<td>IPCC 54.0</td>
<td>IPCC 54.0</td>
</tr>
<tr>
<td></td>
<td>GUMBO 54.0</td>
<td>GUMBO 54.0</td>
<td>GUMBO 54.0</td>
<td>GUMBO 54.0</td>
</tr>
<tr>
<td>Net Ecosystem Prod. (carbon) [GtC]</td>
<td>IPCC 3.1</td>
<td>IPCC 3.1</td>
<td>IPCC 3.1</td>
<td>IPCC 3.1</td>
</tr>
<tr>
<td></td>
<td>GUMBO 3.1</td>
<td>GUMBO 3.1</td>
<td>GUMBO 3.1</td>
<td>GUMBO 3.1</td>
</tr>
<tr>
<td>Sea level rise relative to 1990 [m]</td>
<td>IPCC 0.16</td>
<td>IPCC 0.16</td>
<td>IPCC 0.16</td>
<td>IPCC 0.16</td>
</tr>
<tr>
<td></td>
<td>GUMBO 0.16</td>
<td>GUMBO 0.16</td>
<td>GUMBO 0.16</td>
<td>GUMBO 0.16</td>
</tr>
<tr>
<td>Temperature change relative to 1990 [oC]</td>
<td>IPCC 1.71</td>
<td>IPCC 1.71</td>
<td>IPCC 1.71</td>
<td>IPCC 1.71</td>
</tr>
<tr>
<td></td>
<td>GUMBO 1.71</td>
<td>GUMBO 1.71</td>
<td>GUMBO 1.71</td>
<td>GUMBO 1.71</td>
</tr>
<tr>
<td>Total precipitation [mm/yr]</td>
<td>IPCC 429.0</td>
<td>IPCC 429.0</td>
<td>IPCC 429.0</td>
<td>IPCC 429.0</td>
</tr>
<tr>
<td></td>
<td>GUMBO 429.0</td>
<td>GUMBO 429.0</td>
<td>GUMBO 429.0</td>
<td>GUMBO 429.0</td>
</tr>
<tr>
<td>Change In Precip. rel to 1990 [mm/yr]</td>
<td>IPCC 15.1</td>
<td>IPCC 15.1</td>
<td>IPCC 15.1</td>
<td>IPCC 15.1</td>
</tr>
<tr>
<td></td>
<td>GUMBO 15.1</td>
<td>GUMBO 15.1</td>
<td>GUMBO 15.1</td>
<td>GUMBO 15.1</td>
</tr>
<tr>
<td>Ocean Atmosphere Exchange</td>
<td>IPCC 0.7</td>
<td>IPCC 0.7</td>
<td>IPCC 0.7</td>
<td>IPCC 0.7</td>
</tr>
<tr>
<td></td>
<td>GUMBO 0.7</td>
<td>GUMBO 0.7</td>
<td>GUMBO 0.7</td>
<td>GUMBO 0.7</td>
</tr>
</tbody>
</table>

1) Values from Levy, 2004
2) results Hadley General Circulation Model
3) results ECHAM4 Model General Circulation Model
SRES storylines A2 and B1. The Figure shows a reduction of agricultural production could be balanced by increased labour participation and healthcare development. In terms of economic growth, labour was substituted for agricultural production in the alternatives. Population growth is controlled by food production rather than healthcare and education.

Climate stresses were applied to the two alternative interpretations of the SRES scenarios A2 and B1 in GUMBO. Table 3 lists the values of characteristic GUMBO variables for the alternative interpretations relative to each other without additional climate stress (first row for each variable) and with an additional climate stress (row 2-4 for each variable). It illustrates that the vulnerability to climate stress differs between the alternatives. Alternative 2, of which the economy depends stronger on agricultural production and less on service and health care, is more vulnerable to drought stress. This is particularly true for B1, which does not ease soil and water pollution for agriculture as in A2.

The A2 scenario is found less vulnerable to drought stress than the B1 scenario, although it is characterised by high population growth, fossil use and climate change, suggesting growing stress on food production. In the underlying storyline this stress is recognised and mitigated through innovation and the local management of soil erosion and water pollution. Building the scenario from its storyline, adaptations to climate change have been implemented that are not included in assessments that build on the driving forces (e.g. Aerts, 2003; Parry et al., 2004). A more detailed discussion of the assessment will be published separately.

5 DISCUSSION

It proved possible to reproduce the SRES driving forces population growth, economic growth, energy use together with their corresponding climate scenarios (temperature change, sea level rise and rainfall patterns) in GUMBO. Model input parameters could be chosen to agree with the different pathways of socio-economic development, investment strategies and technological development of the SRES storylines. Exceptions are the absolute amount of accessible fossil fuel that had to be differentiated between scenarios to meet the scenario specific fossil fuel use. Improved efficiency of resource use was assumed to stimulate consumption to indicate a shift to quality goods.

Critical relationships that had to be estimated to harmonise the scenarios in GUMBO with the SRES scenarios include (i) the effect of carbon, water, nutrient and other limiting factors on net biome production to yield estimates of the global carbon sink, (ii) the impact of investment in knowledge on population growth, technological change, efficiency of resource use and energy production, (iii) the relation of income and labour participation and productivity.

Alternative pathways of development can be defined within one SRES storyline that yield the same SRES driving forces but that differ significantly in their vulnerability to sea level rise.
rise and water availability. This study shows dynamic combination of environmental and social conditions exist that significantly enhance or reduce vulnerability. It suggests that, taking into account the characteristics of the storylines, an assessment of the relative vulnerability of the SRES scenarios can challenge earlier assessments based on climate change and the driving forces only. The assessment of alternative multidimensional socio-economic conditions is an important addition to understand our world’s vulnerability to climate change. It is recommended to build on this “inverse” approach of vulnerability analysis to assess multi dimensional causes of critical outcomes. It could extend the merits of vulnerability assessments that investigate the impacts of multiple scenarios of one particular global environmental stress. GUMBO offers a promising, flexible and fast environment for this assessment.

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7 REFERENCES


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