Integrated Assessment of Water Stress in Ceará, Brazil, under Climate Change Forcing

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Abstract: Surface water is the main source of fresh water supply in Ceará, lying in the semi-arid Northeast of Brazil.

Keywords: Integrated assessment; Water stress; Climate change; Modelling

1. INTRODUCTION

Surface water is the main source of fresh water supply in Ceará, lying in the semi-arid Northeast of Brazil. The semi-arid climate goes along with a high intra-annual and inter-annual variability in precipitation, and in the same time the state's society is heavily dependent on water supply. This makes the region specifically vulnerable for unfavourable developments in climate.

Global circulation models (GCMs) are improving their skill to represent global and continental climate in present and recent history (IPCC, 2000) and their results are interpreted in regional impact studies.

Surface water storage is the main regional strategy to enhance water availability. The strategy is meant to serve both the goals of safeguarding water supply for vital water use, and of enabling a growth of water-demanding economic activities. The management of water storage infrastructure and water distribution is an important factor in determining water stress and its impacts. Tendencies towards participatory approaches in decision-making on water management, that emerge from Integrated Water Resources Management (IWRM, XXX) are being in introduced in Ceará over the last decade.

This paper describes the impact of climate change on the water balance of Ceará using the Semi-arid Integrated Model, SIM (Krol et al, 2001), as a case study for impacts on developing semi-arid regions. The state of the art in GCM results at the sub-continental scale for Northeast Brazil is assessed. Impacts on the water balance focus on water stress and stored water volumes. The representation of water management in SIM is evaluated, and the options to extend the integrated model are discussed.

2. CASE STUDY AREA

The study area can be characterised as a semi-arid environment with a short but intense rainy period and a long dry period (Gaiser et al., 2003). Rainfall in the rainy period is generally unreliable with droughts appearing at various temporal and spatial scales. Surface water is stored in small ponds and large reservoirs to distribute water availability over the year and into drought years. Groundwater availability is scattered with often problems of salinity in the dominantly crystalline area. In drought years, many groundwater wells lose capacity and show increasing salinity.
Surface water is mostly used for agriculture (irrigation and animal water use) and for water supply for the metropolitan area of Fortaleza (industrial and municipal use), over a canal inlet to the urban supply-system situated in the downstream part of the main river Jaguaribe.

Figure 1. Location of the study area of state of Ceará and the Jaguaribe Basin (marked orange), situated in the semi-arid 'drought polygon' in Northeast Brazil.

3. CLIMATE SCENARIOS

Complex physically-based climate models (as General Circulation Models, GCMs) show an increasing ability to simulate present day climate as well as historic trends over the last centuries at the global to continental scale (IPCC, 2000). They project significant global climate warming (1.4 to 5.8 degrees, 1990-2100) and precipitation increase to take place in the current century, under the assumption of a continuous increase in atmospheric greenhouse gas concentrations, as would be caused by a continued intensive use of fossil fuels.

Still, the skill of these models in representing climate at the scale of North-eastern Brazil (NEB) is modest. Of seven climate GCMs, whose climate change experiments were made available for climate impact assessments by the IPCC Data Distribution Centre (IPCC-DDC, 1999), only three are able to represent in their simulations the semi-aridness and strong seasonal cycle, that are characteristic for this region, see Figure 2. One of these three models has a serious flaw in representing global precipitation, hampering serious interpretation of its results on changes in precipitation. This lack in skill may be caused by the relatively coarse resolution of GCMs, 300 to 900 km, leaving 2 to 12 grid cells only to cover all of North-eastern Brazil. An alternative explanation may be the imperfect representation of regionally important physical processes. Either way, the lack in skill seriously affects the applicability of model results for impact assessments.

The recommended approach to critically review regional performance in selecting model results to be used in assessments (IPCC-TGCIA, 1999) is often ignored, for instance in a specific assessment of plausible climate change in Brazil, including a focus on NEB (Hulme and Sheard, 1999). This can easily lead to inconsistent interpretations; for example, in one GCM, North-eastern Brazil turns from very arid into arid between 2000 and 2100, which by only using climate change output, would be interpreted as a transformation from semi-arid into sub-humid.

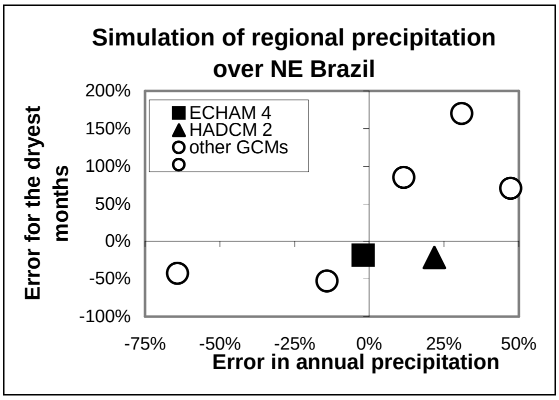

Figure 2. Simulation of precipitation in Northeast Brazil for the current climate by GCMs.

The two models involved, still reasonably allowing a regional interpretation of their results for North-eastern Brazil are ECHAM4 (Roeckner et al., 1996) and HADCM2 (Johns et al., 1997). Following the recommendations of IPCC-TGCIA (1999) we selected results from these models for our analyses. For an annual increase of greenhouse gases by 1% per year as of 1990, projections of precipitation changes over NEB (2070-2099 compared to 1961-1990) are –50% for ECHAM and +21% for HADCM.

Given the very small number of models meeting the minimal criteria adopted above for a direct regional interpretation of its climate change results, conclusions on likely precipitation changes in NEB, on median changes or probable ranges of precipitation change cannot be drawn. Still, in climate change studies for semi-arid North-eastern Brazil both the possibilities of a strong decrease in precipitation (-50%) and an appreciable increase in precipitation (+21%) should be considered as plausible to take place in the current century

Assessment of climate change impacts on e.g. surface hydrology and agricultural production for the states of Ceará and Piauí requires, at the coarsest, a resolution of climate data at the scale of sub-regions in Ceará and Piauí with marked differences in hydro-meteorological or agro-meteorological conditions, i.e. the scale of 10-100 km. This seriously hampers the direct (grid-cell based) regional interpretation of GCM-simulated climate change, whose resolution is much coarser. Indirect methods, using Local Area Models (LAMs) of climate or statistical downscaling of large-scale features to derive regional climate may overcome this problem. The latter method was applied in the WAVES project for the generation of regional climate scenarios (Gerstengarbe and Werner, 2001), as no LAMs are presently operational with sufficient skill for climate studies in the study region (Böhm, 2001). Future development of regional LAMs or GCMs with increased resolution could yield improved regional simulations of the climate of semi-arid north-eastern Brazil, as is hinted at by the fact that the 2 models with reasonable reproduction of regional and global climate exhibit the highest resolutions in the model set considered.

The downscaling method adopted combines observed daily historic climate data at the level of climate stations with long-term climate trends from GCM projections. Here the tendency in annual precipitation at the large scale was taken as the regionally most relevant trend. Simultaneously observed daily data on precipitation and temperature were used to interpret these tendencies into projections of these variables at the station level. Other meteorological variables like relative humidity and short-wave radiation were added using regression relations derived from the few available daily time series of a more complete set of meteorological variables. This resulted in climate scenarios at the level of the climate stations. Interpolation routines were used to transform these scenarios into a climate scenario defined at the level of municipalities. This additional step was necessary, as the municipality was taken as the common spatial unit used in the integrated simulations of hydrological, agricultural and socio-economic processes.

Results for the two selected GCMs show well-defined spatial patterns of precipitation trends, arising from station-specific correlations between local and large-scale precipitation amounts. The difference between the spatial patterns indicates that this correlation is different for anomalously dry years than for anomalously wet years. For a description of the methodology see Gerstengarbe and Werner (2001).

4. CLIMATE CHANGE IMPACTS ON WATER SUPPLY INDICATORS

For the assessment of the effects of climate change on Ceará, the semi-arid integrated model SIM (Krol et al., 2001) was used. This model represents inter-linkages between climate, hydrology, water storage, agricultural production, and socio-economic impacts on the long term, considering regional development and external drivers of global change. The model bases on a systems analytical approach, where choices on

resolutions were made dependent on the spatial and temporal scales of the processes included. A minimum common resolution (municipality and year) was defined for data exchange, but finer where required.
This study considers simulations for one fixed scenario of regional and global developments, but with three different assumptions on climate change, referred to as the ECHAM scenario, the HADCM scenario and the Constant scenario. The reference scenario 'Globalisation and Cash Crops' (Döll and Krol, 2003) was taken. This scenario assumes a continuation of historic trends in demographic and economic development, an increasing on international markets with development focusing on the coastal region and the interior, where water resources are potentially available (especially the downstream river valleys and mountainous areas). Especially in these area water supply is enhanced through additional dam-construction. Agriculturally used area expands gradually; the irrigated area more than doubles.

In SIM, the larger reservoirs, with capacity over 50 Mm3, are simulated explicitly. The total water volume stored in these reservoirs at the beginning of the dry season (July 1st) shows a strong increase between 1995 and 2015, the period where a marked increase in storage capacity occurs in the scenario (by 7000 Mm3). Total storage capacity in Ceará and Piauí then reaches almost 22000 Mm3, of which 16400 Mm3 is installed in Ceará. Afterwards, in the HADCM scenario and the scenario with constant climate, the reservoirs show a variable degree of stored water, without a significant trend; for the ECHAM scenario, stored volume in Ceará shows a marked decline (Fig 3).

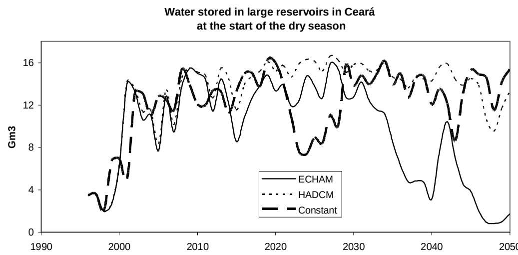

Figure 3. Volume of water stored in reservoirs in Ceará at the start of the dry season for the base scenario with 3 assumptions for climate change.

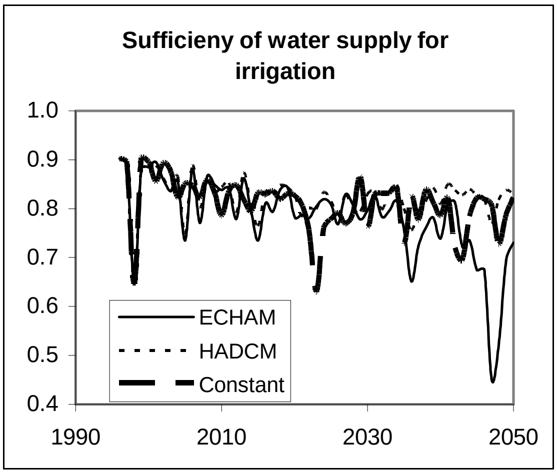

Figure 4. Relative sufficiency of water supply to fulfil the demands from irrigation in Ceará.

5. WATER MANAGEMENT ISSUES

Water management issue play a key role in determining drought impacts. Ceará has a century-old history of water-management oriented towards drought relief and regional development.
Reservoir construction has had a central part in water management policies, with the object of guaranteeing water supply both for the dry season as for possible subsequent droughts (failure of the rainy season).
Water demand management and management connected to water distribution, especially in connection with stakeholder involvement, have emerged only recently. This is reflected by the small availability of historic data on water use and water distribution.
Options in water management that are being considered in strategic planning still involve the consideration of reservoir construction, next to connections of subbasins, combating subregional drought, strategic reservoir operation that could possibly gain efficiency by considering long-term precipitation forecasts, that have gained substantially in skill over the last decade, prioritization and distribution policies. Especially the latter two issues are also subject of discussion in water committees that are operational in Ceará. In this respect, Ceará is a front-runner in Brazilian water policy, by even partially implementing committees before the legal arrangements have been completed. Here new developments will emerge and experiences are to be gained over the coming decade.
Very different water management strategies can be distinguished between, from precautionary or even conservative to risk-seeking or profit-optimizing. It is presently unclear how water management in Ceará could be characterized or what tendencies in such a characterization could be expected. It does, however, have a significant

influence on the regional vulnerability to drought and to climate change.
At present, water management is only considered very coarsely in the integrated model SIM. The model includes responses to water shortage, but rather to safe-guard internal consistency in the model, than to realistically represent management; this was beyond the scope of the project in which the model was defined.
A consideration of these water management issues in the model is expected to yield more convincing simulations, in improving the consistency and allowing options to assess not only the sensitivity of the region to climate change but also the possible efficiency of water management options. Agent-based modelling offers an option to define algorithmic descriptions of water management strategies that can be directly implemented in the existing framework of the integrated model.

6. CONCLUSIONS

Global climate change will take effect on the climate of North-eastern Brazil. The direction of precipitation changes however cannot be determined with certainty. Both very significant precipitation losses and moderate precipitation increases should be considered plausible.

At current climatic conditions, surface water availability, showing the regional vulnerability. The impacts of precipitation losses, as projected by one of the climate models with best regional performance (ECHAM scenario), would be of big importance for the region, even enhancing the vulnerability.
For the state of Ceará, large scale reductions in the availability of stored surface water leads to an increasing imbalance between water demand and water supply after 2025, under the assumptions of the reference scenario, where future water demands are growing until 2025 but stabilizing then.
Agricultural production would also show negative tendencies after 2025 due to insufficiency of water supply to meet irrigation water demands.
For the climate scenarios with a constant or moderately increasing precipitation, no apparent tendencies in impacts are found.

In the climate scenarios, trends in precipitation are entangled with the natural variability, leaving long periods for tendencies to become statistically significant. This applies to tendencies in the impacts as well. Even for the climate scenario with the most marked trends, significance of impacts is found after 2025 only. Before, impact levels do not exceed the levels of impacts emerging from natural variability.
This should not discourage to consider possible climate change in preparing policies to increase drought resilience. Measures to increase resilience will largely rely on long-term policies. In discussions with responsible regional agencies, focus was on measures in water infrastructure and its management, water use efficiency improvements, and structural changes in the agricultural sector. All these items refer to long term changes, where possible climate change could have a significant influence. The present analysis suggests, that the efficiency of various measures under different future climatic conditions (which can be considered as the robustness of the measure) might be a more relevant criteria in selecting measures than optimising the measure for present climatic conditions.
Integrated modelling proved an important instrument in evaluating climate impacts. Feedbacks between trends in agriculture, water use, insufficiency of surface water supply have a relevant influence on model results, especially for the scenario with diminishing precipitation volumes. Such feedbacks would not be addressed by single thematic studies or direct sequential couplings of models.
Many uncertainties remain, not only in the possible future climate developments, but also in the regional responses to water shortage and trends in water use; descriptions of specific water use, water management, tendencies in (irrigated) agriculture and societal processes are based on scarce data, and other relevant themes are still lacking representation in the scenarios and models, e.g. planned adaptation strategies as the connection of large catchments to reduce impacts of sub-regional droughts. These uncertainties were partly studies for the isolated contributing models, see various contributions in Araújo et al. (2001), but an ample study of uncertainties in the integrated model is lacking. Here methods from agent-based modelling offer promising options, especially in representing user's responses to reduced water availability and in representing decision making on water distribution.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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