HIGH RESOLUTION CLIMATE SIMULATIONS AS AN TOOL FOR CLIMATE IMPACT AND ADAPTATION ANALYSIS

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1 INTRODUCTION

The earth's climate has changed during the last decades mainly as a result of human activities. It is expected that the climate change will be going on during this century with significant impacts on ecological, economical and biological systems, and on human health.

Designing adaptation strategies requires a fundamental understanding of regional climate change which will develop differently in many areas of the world compared to global climate change. Global climate scenarios, however, are too coarse to account for regional phenomena like detailed height dependent temperature distributions, orographically induced precipitation or mesoscale thermally driven wind systems. Even with the most powerful computers, it is still not possible to simulate the earth's climate for periods of many years at a resolution which allows us to resolve its regional aspects. So-called downscaling techniques have to be applied to infer the regional climate from a global simulation. The most rigorous among these techniques is the dynamical downscaling or nesting technique in which a limited-area of the globe is represented at a very high resolution with a mesoscale model whereby the needed lateral boundary conditions are provided by a corresponding global model.

At IMK-IFU a regional modelling system has been developed and applied to downscale global climate scenarios. It simulates the regional aspects of global climate change and the impact on air pollution and water balances in river catchments. As the models generate time series of the relevant meteorological, chemical or hydrological variables (e.g., maximum and minimum temperatures, precipitation, intensity of insolation, concentration of air pollutants) results can be derived regarding intensities and frequencies of extreme and health hazard events like number of hot days or frost days, frequency and length of photochemical smog situations, and intensity of droughts and floods. In this paper some results of simulations for Southern Germany, Eastern Mediterranean and West Africa will be presented.

2 METHODS

The central part of the modelling system at IMK-IFU is the Penn State/NCAR meteorological community model MM5 (Grell et al., 1994). It is a non-hydrostatic mesoscale meteorological model with terrain-following height coordinates and a multiple nesting capability. The model simulates time dependent fields of wind, temperature, pressure, water vapor and liquid and ice phase cloud and precipitation compounds in the atmosphere. All of the model equations are formulated in either Lambert conformal, Polar stereographic, or Mercator projection map coordinates. This allows the model to be applied anywhere in the world. Included is a soil-vegetation-snow model which calculates the soil temperature and moisture stratification and determines the heat and moisture fluxes at the interface between atmosphere and soil. For vegetated surfaces, evaporation and the interception and re-evaporation is taken into account. A snow cover model treats the accumulation and melting of snow.

To simulate the flow field and the concentration fields of atmospheric pollutants the coupled meteorology and chemistry model MCCM (Grell et al., 2000) is applied. This combined model is based on MM5 and includes the RADM2 gas-phase chemistry scheme. The RADM2 mechanism (Stockwell et al., 1990) predicts 39 chemical compounds and describes 152 chemical reactions including 21 photolysis reactions. Emissions of biogenic organic compounds are simulated depending on the land use at each grid point and predicted temperature and short wave radiation.

The results of simulations with the regional models MM5 and MCCM can be used as input for impact models. At IMK-IFU besides various biological models the distributed hydrological model WaSiM (Schuller and Jasper, 2000) is applied. Driven with downscaled fields of global climate scenarios it can calculate the effect of climate change on surface and subsurface water balance of specific river catchments (e. g., Kunstmann et. al., 2004).

In this paper some results of regional climate simulations with the afore-mentioned modelling system will be presented. In all examples shown here two time slices each extracted from a global long term simulation covering some hundred years will be downscaled. One time slice represents present day conditions, the other possible future conditions. The selected global climate runs were produced by the global climate model ECHAM4 (Roeckner et al., 1996). They are driven by prescribed time dependent greenhouse gas concentrations. Until the 1990s observed values were applied, after that concentrations according IPCC emission scenarios were used.

The global fields simulated by ECHAM4 provide the needed boundary values for the regional simulations with MM5 and MCCM. In some experiments a repeated nesting to enhance the horizontal resolution was applied. In several steps, the information is downscaled to successively smaller domains with higher horizontal resolution.

The regional models simulate a continuous course of weather. The resulting output data are stored in intervals of one hour. These data are then used to calculate climate statistics or to provide the driving conditions for impact models. Comparing the differences of the calculations for the two time slices allows an assessing of future climate trends.

3 RESULTS

At first, results of a regional climate-chemistry simulation with MCCM for Southern Germany and the Alpine Region (Knoche and Forkel, 2004) are discussed. In this study the time slices 1991-2000 and 2031-2039 of a global climate scenario performed by ECHAM4 were selected. The emission scenario IS92a ('business as usual') which assumes an increase in atmospheric CO_2 concentration from 350 to 450 ppm between 1990 and 2030 was chosen. In two succeeding nesting steps the global fields with a resolution of about 250 - 300 km were downscaled to 20 km.

In general, the global warming trend is reflected also in the regional simulations. The model predicts an increase of the near surface temperature in all months of the year (Figure 3), during the summertime up to more than 2 degrees. This leads to a significant increase of the number of the so-called summer days with temperatures above 25 degrees (Figure 1). Besides the warming the model simulates a decrease of precipitation and cloudiness in the summer months, especially in the south west of Germany. Consequently, the model predicts an enhanced insolation for the future (Figure 2). This is accompanied with an increase of UV-Radiation up to 20 mW/m^2 or 10 %.

Because MCCM includes a chemistry module the direct consequences for the near surface ozone distribution can be calculated. The model generally simulates an increase of mean ozone concentrations in Southern Germany during the summer months. As a consequence the frequency distribution of the mean daily maximum ozone concentration is shifted to significantly higher values (Figure 4).

For the Eastern Mediterranean the regional model MM5 has been applied to downscale a global climate run performed by ECHAM4 for the emission scenario SRES B2. This scenario is similar to the former used IS92a scenario. So far the time periods 1961-1966 und 2070-2075 have been simulated. In Figure 5 the mean annual precipitation distribution is shown. For the future climate conditions a pronounced decrease of precipitation, especially in the region around Israel is predicted.

A further example shows the regionalization of a global climate scenario for West Africa and the application of the hydrological model WaSiM. Here the same time slices (1991-2000 and 2031-2039) and the same global climate run (ECHAM4 with emission scenario IS92a) as in the first study are selected. In three nesting steps the global climate scenario has been downscaled by MM5. The resulting meteorological fields with a resolution of 9 km were then used as input for the hydrological model WaSiM. Figure 6 shows for 5 river subcatchments the different nonlinear response of simulated runoff change to precipitation change.

4 DISCUSSION AND CONCLUSION

The results of the simulations presented here are based on assumptions regarding the future emissions of greenhouse gases into the atmosphere. These will depend upon changes in the world economy and upon the success or failure of policies designed to protect the climate. It is plausible that

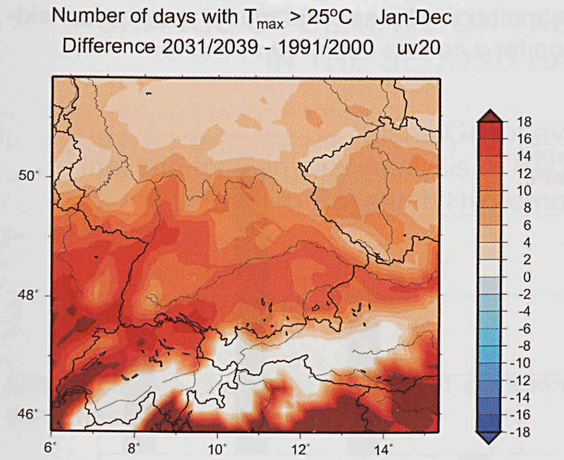

Figure 1: Difference between present day and future conditions for the number of days with temperatures above 25°C

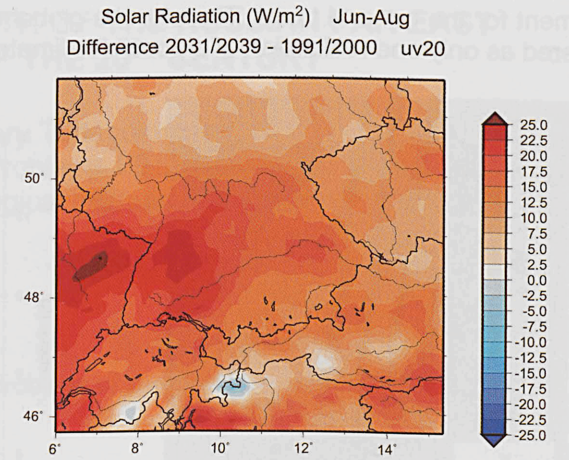

Figure 2: Difference between present day and future conditions for solar radiation

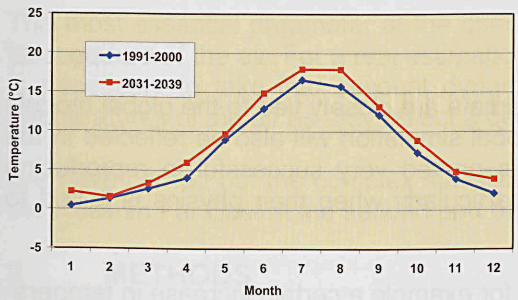

Figure 3: Simulated annual course of the mean temperature over Southern Germany.

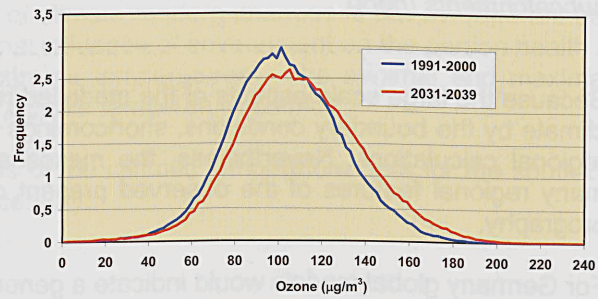

Figure 4: Mean frequency distribution of simulated mean daily maximum ozone concentration over southern Germany.

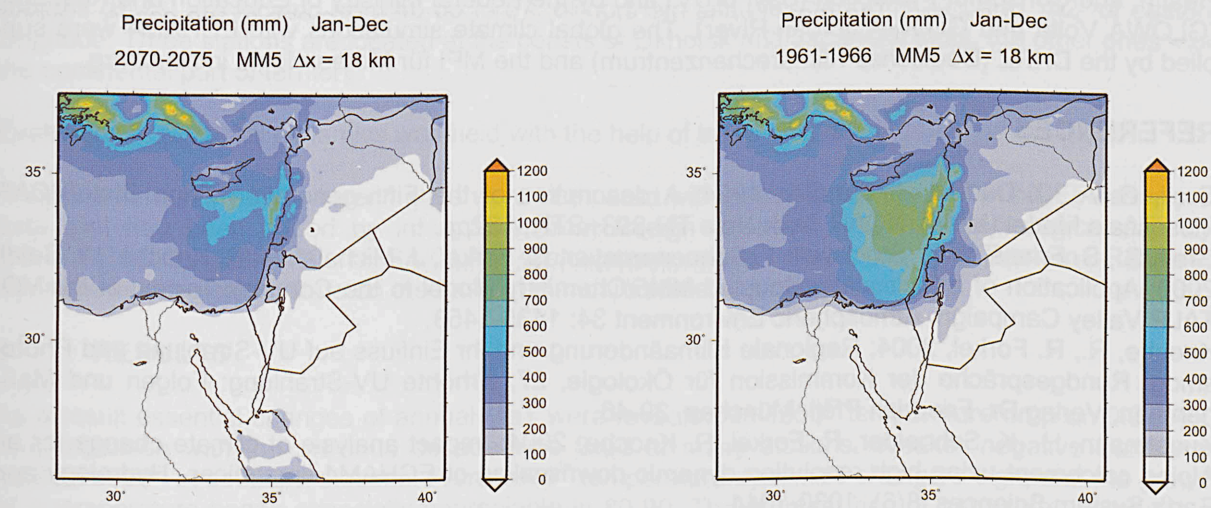

Figure 5: Simulated distribution of annual mean precipitation in the period 1961-1965 (left) and 2070-2075 (right)

even an ideal model might not provide a correct prediction if the assumptions made are not correct. Furthermore, an intercomparison of global climate models shows that the various models produce slightly different warming patterns for identical emission scenarios, although all models show agreement for the general trend. Therefore, a global climate simulation of a specific model may be considered as only one realization of a possible climate evolution for a certain emission scenario.

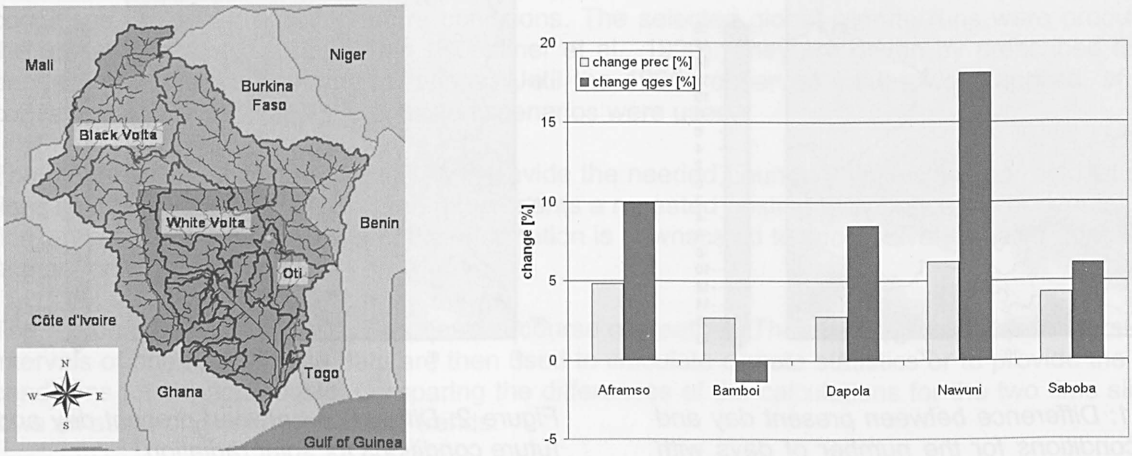

Figure 6: Volta Basin (West Africa) with subcatchments modeled by the hydrological model WaSiM (left). Simulated precipitation and runoff change between 1991-2000 and 2030-2039 for 5 selected subcatchments (right).

Because the large scale aspects of the modelled regional climate are closely tied to the global models climate by the boundary conditions, shortcomings of the global simulation will also be reflected in the regional calculations. Nevertheless, the mesoscale models proved very successful in reproducing many regional features of the observed present climate, particularly when their physics is linked to orography.

For Germany global models would indicate a general trend, for example a certain increase in temperature. However, using downscaling more pronounced and complex regional patterns are found. It could be also shown that data provided by the regional models MM5 and MCCM can successfully used as input for further calculations with models such as the hydrological model WASIM.

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