Regional ecohydrological modelling to study climate change impact on hydrology and crop yield in Brandenburg

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Objectives

Hydrological processes and crop growth were simulated for the current climate and a climate change scenario using the model SWIM (Soil and Water Integrated Model), which simulates hydrological processes, vegetation growth, erosion and nutrients at the river basin and regional scale. SWIM is coupled to the GRASS GIS and uses a simplified EPIC approach to simulate arable crops.

The objectives of the study were:

- to validate hydrological processes and crop growth at the regional scale, and
- to investigate the impact of climate change on hydrology and agriculture in Brandenburg (Fig. 1).

Modelling Procedure

The hydrological validation was performed in advance in three mesoscale river basins that belong to the state of Brandenburg: the Dahme, 575 km^2, the Nuthe, 1818 km^2, and the Stepenitz, 535 km^2 (Fig. 1).

After that, the crop module was validated regionally for the whole area of Brandenburg (Fig. 2 & 3). The validation was performed in three steps: Firstly, the distribution functions of crop yield were compared considering the full set of available survey data and the simulation results for 12 years (Fig. 2). Secondly, the spatial patterns of average yield values in the 12-year period (calculated and observed) were compared (Fig. 3). And thirdly, statistical evaluation of results was performed, applying the regional crop allocation scheme. The agreement was quite satisfactory.

Finally, a climate change impact study was performed, considering hydrological processes and crop growth. The CO_2 fertilization effect was studied considering: a) adjustment of the potential growth rate per unit of intercepted PAR by a temperature dependent correction factor (alpha) based on experimental data for C3 and C4 crops; and b) assuming a CO_2 influence on transpiration at the regional scale (beta factor), which is coupled to the direct CO_2 effect of Radiation Use Efficiency.

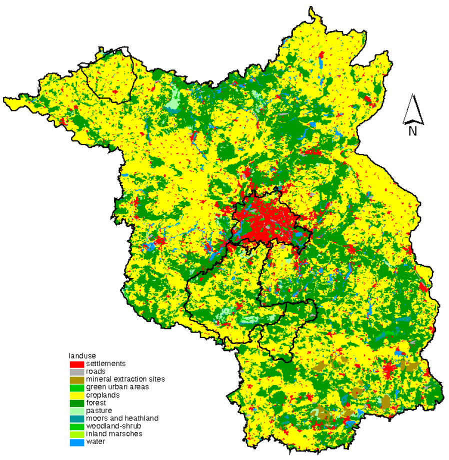

Fig. 1 *Land Use in the state of Brandenburg and the boundaries of three selected subbasins*

Scenario

Two transient 1.5 K scenarios of climate change for Brandenburg were developed in PIK (F.-W. Gerstengarbe and P. Werner): wet scenario W15 and dry scenario D15. Three periods were compared: 1981 - 1992 (control period A in Figs. 4), 2022 - 2030 (period B), and 2042 - 2050 (period C). The atmospheric CO_2 concentration for the reference period and two scenario periods were set to 346, 406 and 436 ppm, respectively.

According to the scenario W15, precipitation is expected to increase in Brandenburg: +5.2% and +11.7% on average in periods B and C, respectively. According to the scenario D15, precipitation is expected to decrease slightly in the period B (-1.7%) and quite significantly in the period C (-11.3%).

Climate Impact

According to the simulation results, under changing climate evapotranspiration is expected to increase quite significantly (Tab. 1, Fig. 5) for the scenario W15 (on average even more than precipitation), and moderately for the scenario D15. Groundwater recharge is increasing in some places and decreasing in others, on average it is practically the same for all periods for scenario W15. On the opposite, the decrease is notable for scenario D15 (-31.5% in the period C). According to scenario W15, runoff has also increasing and decreasing tendencies in different areas, but the overall trend is to increase. However it decreases significantly in the period C for scenario D15, responding to the decreased precipitation. This can be even more pronounced in some seasons, leading to a higher risk of droughts.

The crop yield was only slightly altered under the "climate change only" variant (I) of the W15 scenario for barley and maize, and it was reduced for wheat. This negative effect occurs mainly due to the higher evapotranspiration rates, and drier springs in periods B and C. The D15 scenario lead to the reduced crop yield for all the crops in this case.

The impact of higher atmospheric CO_2 (variant II) compensated fully or partly for climate-related crop yield losses, and resulted in an increased yield both for barley and maize in scenario W15 compared to the reference scenario. The negative changes were still preserved in scenario D15 for wheat and maize.

The assumption that stomatal control of transpiration is taking place at the regional scale (variant III) lead to further increase in crop yield, which was larger for maize than for barley and wheat.

Conclusions

Our regional ecohydrological modelling demonstrated the principal ability to simulate consequences of climate change for crops and hydrology based on regionally validated model. In respect to the scenarios used, both the hydrological processes and the crops in Brandenburg appear to be quite sensitive to climate change, with some regional differences.

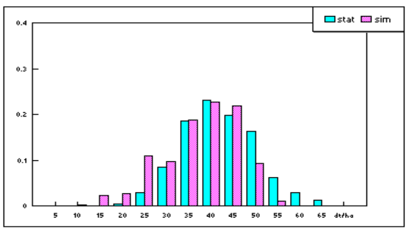

Fig. 2 *Comparison of the distribution functions for two sets of crop yield data (winter barley): simulation results (sim) and survey data (stat), 1981 - 1992.*

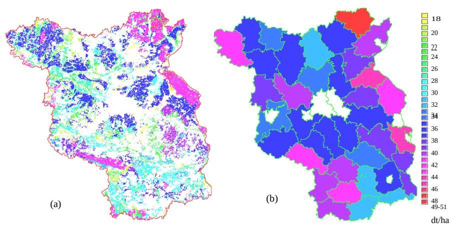

Fig. 3 *Spatial patterns (a) of the simulated winter barley yield in hydrotopes of the Brandenburg (average values 1981-1992); and (b) average winter barley yield in the districts of Brandenburg from the survey data for the same period.*

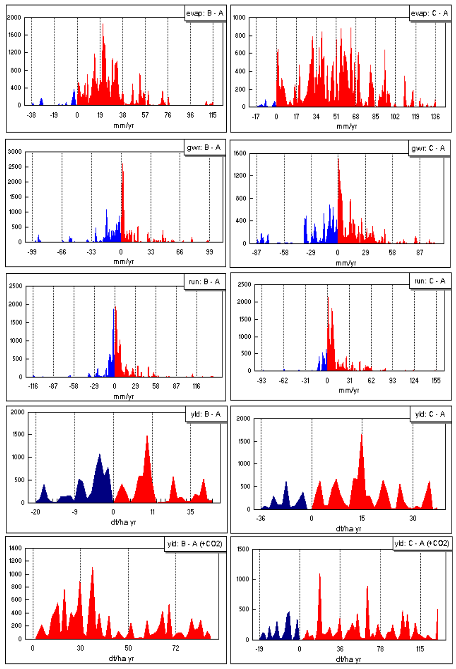

Fig. 4 *Histograms of the difference maps for evapotranspiration (evap.), groundwater recharge (gwr), runoff (run), and crop yield (yld. - winter wheat with the CO_2 fertilization effect and without) comparing the simulation results for the control period A and scenario periods B and C in scenario W15*

Table 1. *Climate change impact in hydrological processes and crop yield in Brandenburg, considering wet W15 (blue) and dry D15 (red) scenarios: climate change only (I), in combimation with adjustment of net photosynthesis (factor alpha:II,III) and transpiration (factor beta: III) to higher CO_2, comparing two scenario periods B and C to a reference period A*

Simulation experiments		Hydrological flows / crop yield	Change to the reference scenario A, % — Whole area, period B, W15	Whole area, period B, D15	Whole area, period C, W15	Whole area, period C, D15	Cropland, period B, W15	Cropland, period B, D15	Cropland, period C, W15	Cropland, period C, D15
I	Climate change only	evapotranspiration	+9.5	+5.7	+15.4	+4.9	+10.0	+5.7	+14.9	+6.1
		gr-water recharge	-3.2	-12.2	+7.0	-31.5	-4.2	-12.1	+8.6	-32.4
		runoff	+7.0	-1.9	+17.2	-22.6	+6.6	-3.6	+20.0	-31.3
		winter barley yield					+ 1.9	- 4.7	- 1.2	-8.0
		winter wheat yield					-6.2	-14.3	-10.3	-17.6
		silage maize yield					+2.2	-7.1	+3.7	-12.0
II	Climate change combined with factor alpha	winter barley yield					+8.7	+1.9	+10.5	+3.7
		winter wheat yield					+0.6	-7.5	+1.5	-5.8
		silage maize yield					+5.7	-4.0	+9.4	-7.0
III	Climate change combined with factors alpha and beta	winter barley yield					+9.5	+2.7	+11.3	+4.6
		winter wheat yield					+1.1	-7.1	+2.0	-5.2
		silage maize yield					+16.3	+6.4	+24.6	+8.4

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