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3.1.3 Intensification of the hydrological cycle – An important signal of climate change

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SUMMARY: *Future changes in the hydrological cycle may have important impacts on the society, e.g. with regard to flood risks, water availability and water quality. Although climate observations do not show consistent global trends in the hydrological cycle despite of the global warming in the past century, strong regional changes are possible. These changes may not only vary regionally but also seasonally. Even if for some regions the mean hydrological cycle may not change, a change in the intensity distribution of precipita-tion may have significant climate impacts.*

As reported by the Intergovernmental Panel on Climate Change (IPCC 2001), a mean increase of temperature by 0.09 K per decade was observed globally from 1951 to 1989. Up to 2004, this trend has continued. The increase of temperature varies depending on the region and season. SCHÖNWIESE reported in 2003 and 2004 that the warming is above average in Germany. If the temperature of the atmosphere increases, it should be assumed that the water cycle is intensified. However, it has not been possible until now to present clear statements on the changes in the water cycle as a consequence of climate change.

What is the water cycle and how can it be influenced by climate change?

The water on Earth is permanently moving in a cycle. In a simplified manner it can be said that water gets into the atmosphere through evaporation from the oceans and over the continents. The water vapour rises, forms clouds and the water falls back onto the Earth as rain, hail or snow. Part of the precipitation that falls over land remains on the vegetation and gets back into the atmosphere through evaporation. Part of the precipitation that reaches the ground evaporates, too. The remainder infiltrates into the soil where it penetrates down to the groundwater table or it flows downhill. This feeds the lakes and the rivers which finally transport the water back to the oceans.

The changes in the water cycle can be manifold. The capacity of the air to store water vapour increases with temperature following the Clausius Clayperon law. The generally recognised theory is that more water evaporates mainly over the oceans when the temperature of the atmosphere increases. This leads to more rain which is expected to fall predominantly over land. Furthermore, the processes according to which clouds and precipitation are formed in the atmosphere may change. This change largely depends on the amount, the distribution and the type of aerosols (which are small particles in the atmosphere), since these influence directly the formation of clouds, but also they can change the radiation properties of the atmosphere when it is free from clouds. Changes in the water cycle can also be caused by changes in the evaporation properties of the land surface and the plants which lead to interaction with the storage capacity of the soil.

If the water cycle is intensified this means that all of its components are enhancing, i.e. more evaporation, more precipitation and more run-off.

Have trends been observed in the water cycle during the past decades?

Observations on individual components of the water cycle made over the past decades indicate different trends. An analysis of satellite data (http://www.hoaps.zmaw.de) shows an increase of evaporation over the oceans from 1988 to 2002 (BAKAN, personal communication 2004). This contrasts with an observed decrease of evaporation over land as can be derived from numerous measurements of evaporation (RODERICK & FARQUHAR 2002). This decrease can be explained through a reduction of radiation reaching the ground leading to less enhanced evaporation. The reduction of radiation is caused by decreased translucidity of the atmosphere due to raising amounts of aerosols. Measurements show that the solar radiation that reaches the soil has reduced by more than 10% from 1958 to 1992 on a world-wide basis (STANHILL & COHEN 2001).

BENGTSSON et al. (2004) used a global re-analysis data set which had been elaborated at the European Centre for Medium Range Weather Forecast for the period 1958 to 2001 from available measurements of all kind as well as model calculations (UPPALA et al. 2005) to assess possible trends in the temperature of the atmosphere, the kinetic energy and the water vapour contents. The latter increased globally in average by 1.55 mm (i.e. about 6%) for each degree of increased temperature. This value agrees with the Clausius Clapeyron law.

Further components of the water cycle are the precipitation and the run-off. These vary extremely from region to region. No globally common trend can therefore be derived from corresponding observations.

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How could the water cycle be modified by possible climate change?

Global and regional climate models are nowadays used to estimate possible climate related changes in the water cycle. These models describe the physical processes in the climate system as precisely as possible and calculate e.g. the water vapour contents in the atmosphere, the evaporation, the precipitation and also the run-off globally as well as for individual regions of the Earth for today's climate and possible scenarios for the future. The following approach is then taken: First the models are used to re-calculate past decades. Their results are compared with observations of all kinds in order to evaluate the quality of the climate model. It is then assumed that the physical laws remain the same under changing climatic conditions. In order to calculate the future development of the climate, a change in greenhouse gases in the atmosphere which is influenced by human activity is prescribed. This follows scenarios agreed by IPCC for the development of the population and the economic growth of the world from today until 2100 which have been transposed into developments of greenhouse gases. These are input to the climate model simulations. Global climate model runs show only a small amplification of the water cycle, but extremely strong changes are observed in certain regions. Regional climate models which can take account for substantially more details of the regions are used to assess changes with more detail and precision. But initially, global IPCC simulations are carried out which are analysed directly on the one hand and which are used as input for the regional model calculations on the other.

Calculations of the water cycle can not only be influenced by the increase of greenhouse gases but also by changes in aerosols, as explained above. LIEPERT et al. (2004) discussed whether aerosols could possibly slow down the intensification of the water cycle in a warmer climate. Calculations with the global climate model of the Max Planck Institute for Meteorology show that interactions between a warming through greenhouse gases and both direct and indirect effects of aerosols and clouds could explain this observation. These show, as reported above, an increase of temperature during the last four decades despite of a reduction of solar radiation that reaches the soil. LIEPERT et al. (2004) show that the reduction of solar radiation by clouds and aerosols can only partly be compensated for by the increased long wave radiation of the warmer and more moist atmosphere. Thus the evaporation at the land surface is reduced despite of global warming which also leads to a decrease of precipitation. This means that both effects, the warming of the atmosphere through greenhouse gases and the influence of clouds and aerosols, compete which may lead to a decelerated or weakened intensification of the water cycle. However, it is commonly assumed that a strong warming through greenhouse gases will predominate over the aerosol effect in the long run.

What's the story that regional climate models tell about the hydrological cycle in Europe?

Even today global climate models provide information only at a relatively coarse spatial scale. Therefore high resolution regional climate models are nested into the global calculations for the investigation of the impact of potential global climate change on specific regions. The results of these investigations depend on both the quality of the global and regional models and the choice of the climate scenario. In order to give a probability, e.g. for the intensification of the hydrological cycle over Europe, several models from the different European climate research institutes are used, such as it was done in the EU project PRUDENCE (http://prudence.dmi.dk). Focusing on Germany, this was also done in the BMBF project QUIRCS (http://www.tu-cottbus.de/meteo/Quircs/home.html) within the German climate research program DEKLIM (http://www.deklim.de).

Following the climate change scenario A2 that projects a relatively strong future increase of greenhouse gases until the year 2100 (IPCC 2001) and a subsequent global mean temperature increase of about 3.5°, numerous simulations were conducted within PRUDENCE. An analysis of their results for different river catchments shows significant differences between the projected changes over northern and central Europe for the time period 2071–2100 compared to the current climate (1961–1990). For the Baltic Sea catchment, a projected precipitation increase of about +10% is shown for the annual mean (*Fig. 3.1.3-1*), with the largest increase of up to +40% in the winter, while a slight reduction of precipitation is projected for the late summer (*Fig. 3.1.3-2a*). Evapotranspiration will increase during the whole year with a maximum increase in the winter (*Fig. 3.1.3-2b*). These rises in precipitation and evapotranspiration will lead to an increase of river discharge into the Baltic Sea of more than 20% in the winter and early spring (*Fig. 3.1.3-2c*). Here, the seasonal distribution of discharge is largely influenced by the onset of the snowmelt in the spring.

For the catchments of Rhine, Elbe and Danube, a different change in the water balance components is yielded. While the annual mean precipitation will remain almost unchanged (see *Fig. 3.1.3-1*), it will increase in the late winter (January-March) and decrease significantly in the summer. The evapotranspiration will rise during the whole year, except for the summer, with a maximum increase in the winter. These changes lead to a large reduction of 10 to 20% in the annual mean discharge (*Fig. 3.1.3-1c*). Especially for the Danube, the projected summer drying has a strong impact on the discharge (*Fig. 3.1.3-3c*) that is reduced up to 20% throughout the year except for the late winter (February/March) when the increased winter precipitation (*Fig. 3.1.3-3a*) causes a discharge increase of about 10%. These projected changes in the mean discharge will have significant impacts on water availability and usability in the affected regions.

Under climate change conditions not only the absolute amounts of precipitation may change but also the precipitation intensities, i.e. the amount of precipitation within a certain time interval. This was investigated within the project KLIWA (http://www.kliwa.de) where the regional climate model REMO of the Max Planck Institute for Meteorology was used to simulate an IPCC B2 scenario until 2050. Until 2050, the projected increase in greenhouse gases is very similar in the two scenarios A2 and B2, and, thus, also the increase in the global mean temperature. But this REMO simulation was conducted with a considerably higher resolution than the A2 results presented above so that the influence of the topographically largely varying Alps on the formation of precipitation over the Rhine

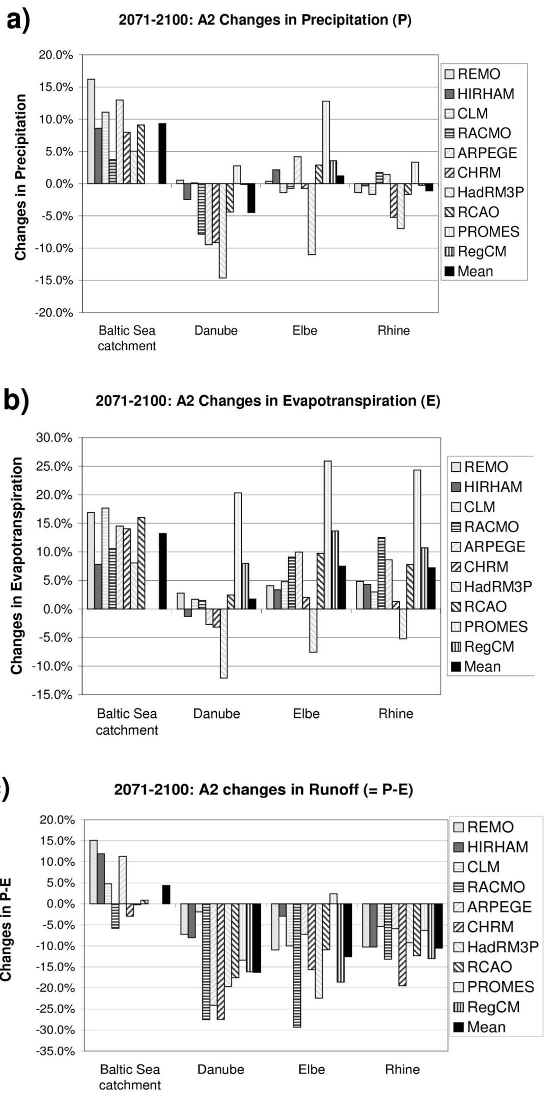

Fig. 3.1.3-1: Projected changes in a) precipitation, b) evapotranspiration, and c) discharge for the catchments of Baltic Sea, Danube, Elbe and Rhine.

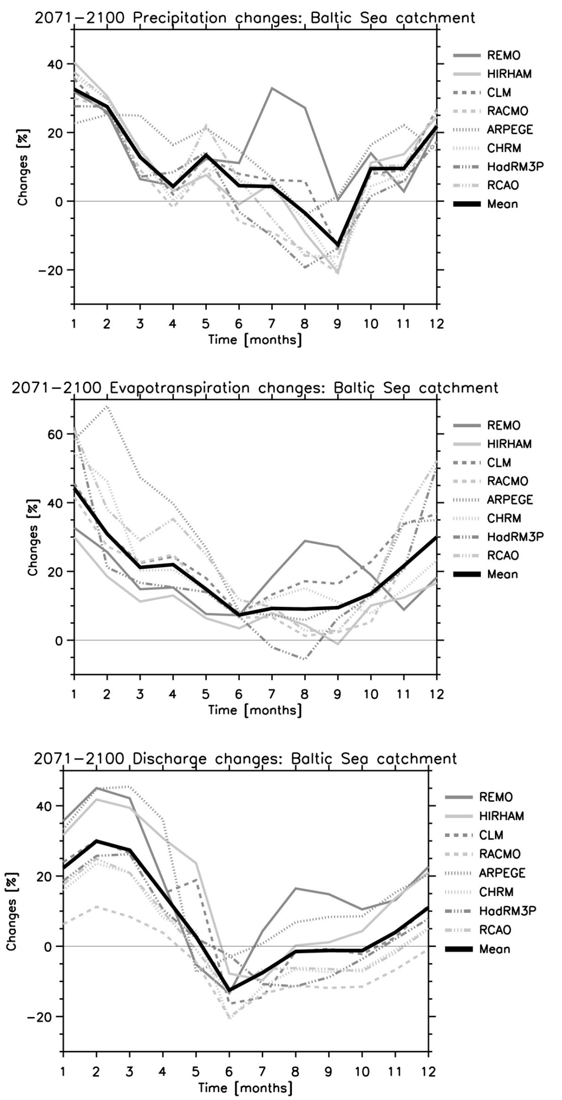

Fig. 3.1.3-2: Projected changes in the annual cycle of a) precipitation, b) evapotranspiration, and c) discharge for the Baltic Sea catchment.

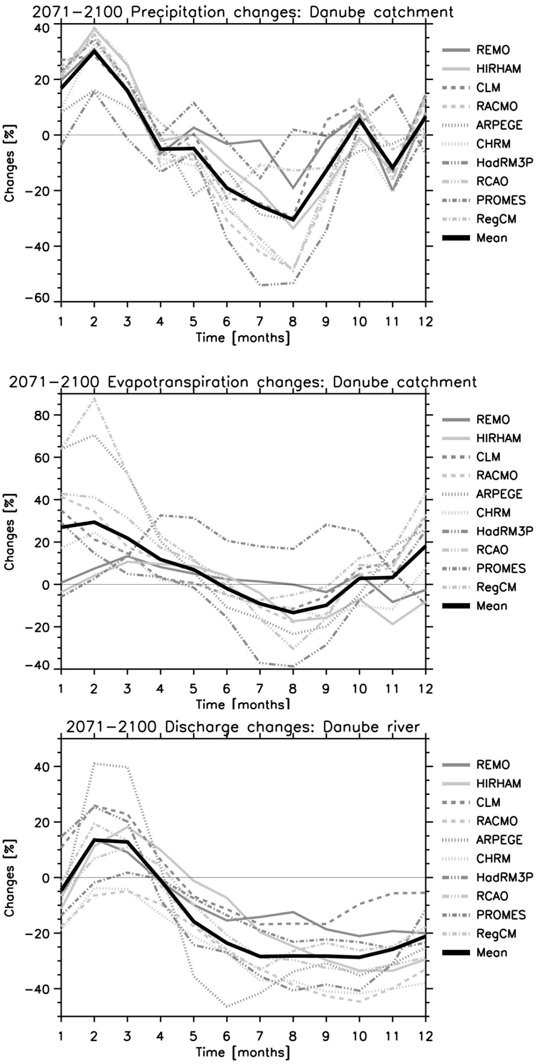

Fig. 3.1.3-3: Projected changes in the annual cycle of a) precipitation, b) evapotranspiration, and c) discharge for the Danube catchment.

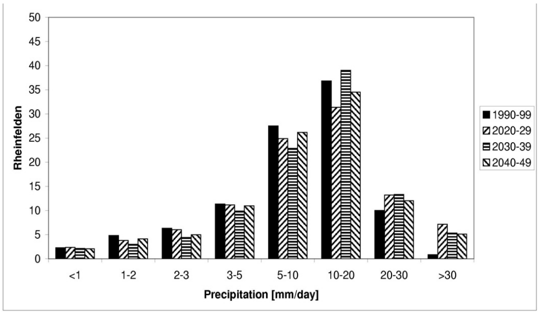

Fig. 3.1.3-4: Precipitation intensity classes for the Rheinfelden catchment.

catchment could be adequately calculated. The results show (*Fig. 3.1.3-4*) that the global warming until 2050 will lead to an increase of high precipitation events over the Alpine part of the Rhine catchment (until the water gauge station at Rheinfelden), especially in the summer. This climate change signal becomes clearly visible in the Pre-Alps, but a similar trend is seen in the high resolution simulations over large parts of Europe.

Conclusions

Despite the global warming in the past century observations do not show a consistent trend in the global water cycle. Experiments conducted with regional climate models show that the warming may regionally lead to strong changes in the hydrological cycle. These changes may have regionally as well as seasonally largely varying consequences. In addition to an intensification of the hydrological cycle, such as, e.g., predicted for the Baltic Sea catchment, global warming may also lead to a drying of certain areas, such as calculated for the Danube catchment. And even if the mean water cycle will not change substantially a shift in the precipitation intensity distribution may lead to significant regional climate impacts ♦

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