The Effect of Global Warming on Rainfall and Temperature in an Alpine Catchment

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Abstract The objective of this paper is to analyse possible impacts of climate change on rainfall, temperature and water resources and to discuss consequences for water management strategies. Within a European research project (ENV4-CT95-0128) several regions in Europe with completely different climatic conditions have been analysed to study possible impacts of climate change. Here, in this paper a basin in the Austrian Alps has been selected to analyse possible climate impacts in a vulnerable environment.

Methodology

The applied methodology consists of several steps including

- the linkage between observed large scale air pressure distributions with local observations (downscaling),
- generation of local time series of precipitation and temperature for different GCM-outputs,
- simulation of the response from hydrological systems
- and finally the analysis of changes in the outputs to identify consequences for water management strategies.

In this paper the terms large scale, regional and local are used corresponding respectively to an area larger than Europe, regions with an area of about 100 000 km^2 which are represented by a few grid cells in a GCM, and to observation networks in river basins with an area of a few thousand square kilometres. Subsequently these steps (Fig. 1) are briefly described.

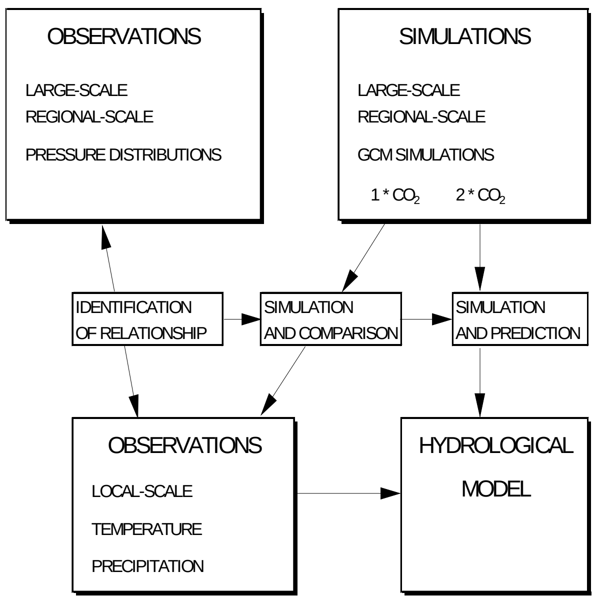


Fig. 1: General downscaling approach

Due to the unreliability of the GCM outputs describing the spatio-temporal distribution of rainfall and temperature, only the large scale pressure fields obtained from the GCMs are used for deriving changes in hydro-meteorological variables at the basin scale.

The pressure fields are characterised by the spatial distribution of the geo-potential heights given at a large grid and the observations are available for a local observation network. In general, the different downscaling approaches (Matyaszovsky et al. 1993; Bardossy, 1995; Diernhofer and Nachtnebel, 1998) can be described by relating a probability distribution function F of a local climate random variable y with the CP-type and regional variables like air pressure, the gradient ∇p, and pressure height $\overline{p}$.

$$F(y) = \sum_{i=1}^{I} w_i F_i(y)$$

$$F_i(y) = G(y \; | CP_i, \nabla p, \overline{p})$$

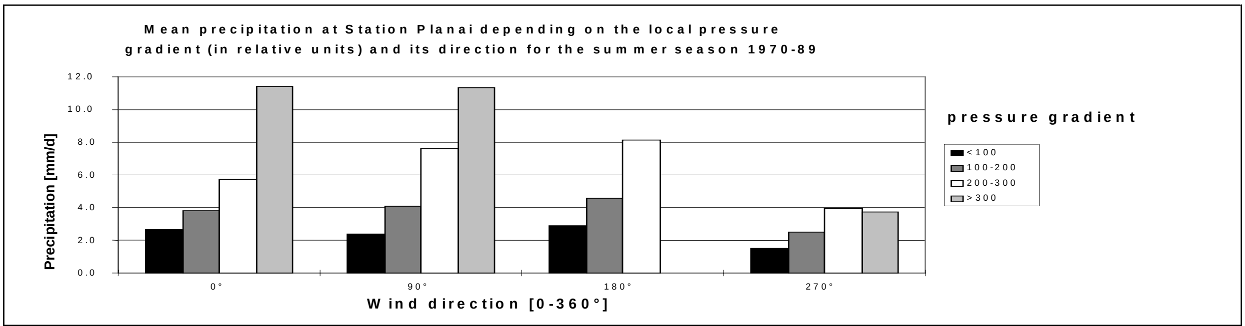
y	local surface climate element
i	indicator for CP-type
I	number of pressure pattern types
w_i	weight or probability of occurrence of CPi
G	multi-variate distribution function
Fi	marginal distribution given CP etc.
CP_i	large scale pressure pattern type i
∇p	regional pressure gradient
$\overline{p}$	regional average pressure
F	mixed distribution of local surface climate element

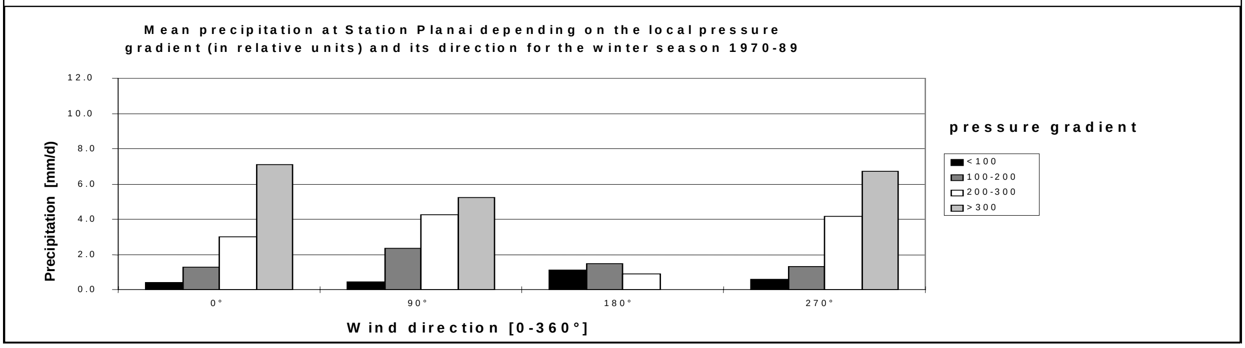
Utilizing a catchment model the meteorological input can be transformed into several output time series describing storage, runoff components including snowmelt, and also losses to the atmosphere (IPCC, 1998; Hebenstreit, 1995).

Application

The methodology has been applied to several mountainous basins in Europe (CCHYDRO, 1999) but here only some results from an Austrian basin will be given. The reason is, among other aspects, that mountains represent a very sensitive environment and that this region is also important with respect to economic consideration, like winter tourism and hydropower generation. The analysis of climatic characteristics in mountainous regions is complicated by the limited number of observations and by the complex terrain which is important for local meteorological processes.

For the downscaling a regional approach was used in which the air mass movement over central Europe was analysed using the 700 hPa geopotential heights. Then a stochastic downscaling to the basin scale was made by comparing the basin averaged rainfall with the geopotential gradient characterised by the direction and its gradient.





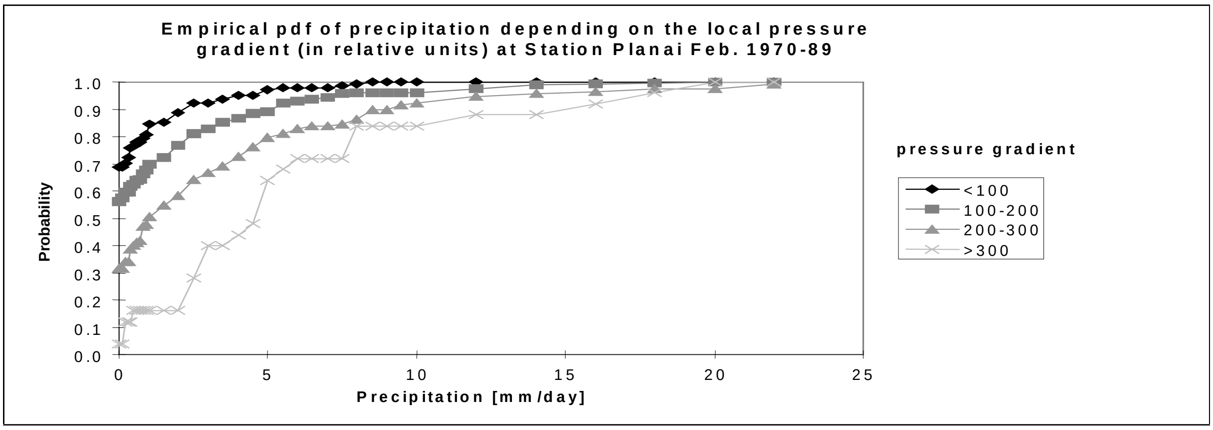


Fig. 2: Statistical relationship between air-mass movement and precipitation

It is obvious that there is a clear relationship between precipitation and both direction of air flow and magnitude of the gradient which is given in the three graphs in relative units. The procedure is calibrated for a period of about 40 years of observations. In a second step the validation is made for the GCM outputs for the 1*CO2-case and then the 2*CO2 scenario is used assuming that the statistically based relationship among the scales will still hold.

Without going into technical details the results for the 2*CO2 case indicate for temperature an increase especially in the fall and winter period (Fig. 5 and 6) while the rainfall time series does not reflect major changes (Fig. 3 and 4).

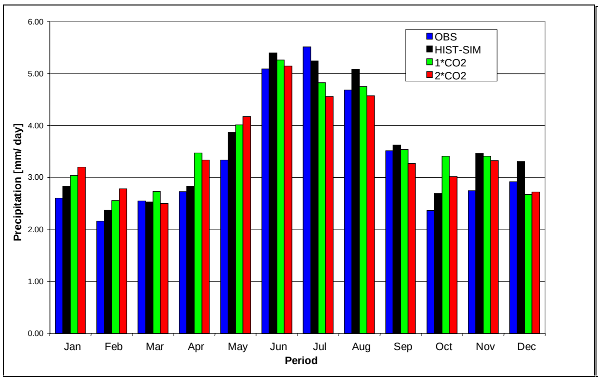


Fig. 3: Seasonal variation of mean daily precipitation

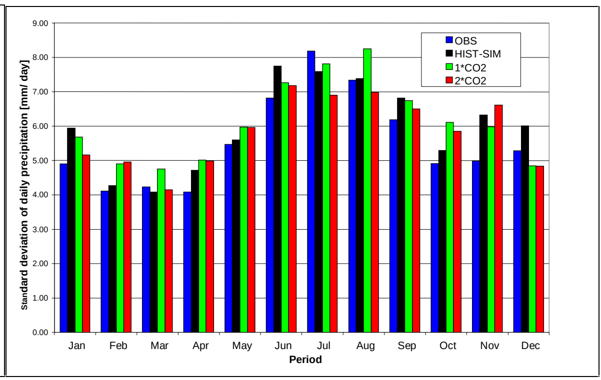


Fig. 4 Seasonal variation of the standard deviation of precipitation

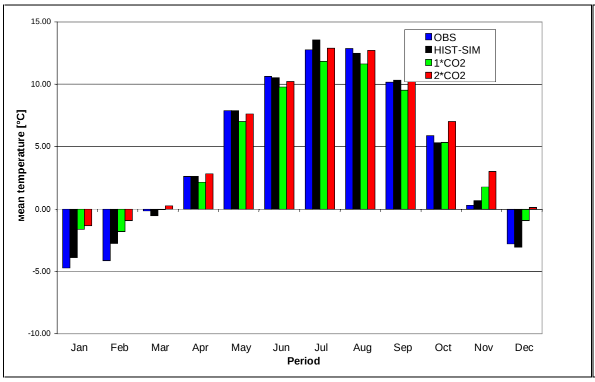


Fig. 5: Seasonal variation of mean monthly temperature scenario

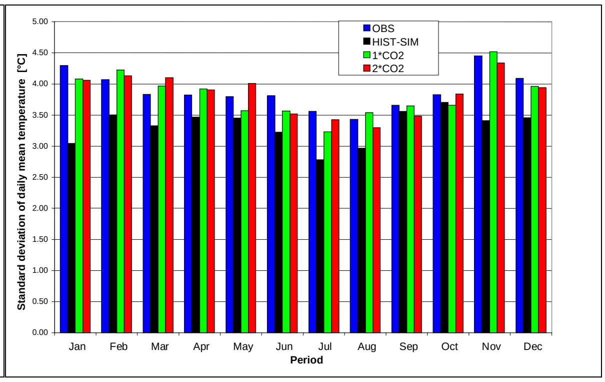
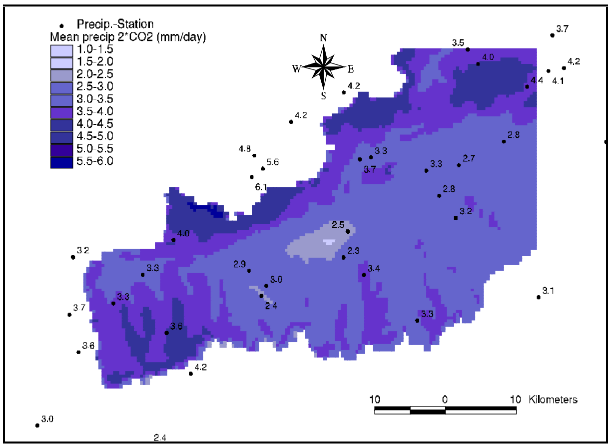


Fig. 6: Standard deviation of monthly temperature

The spatial structure of precipitation resulting from the downscaling of ECHAM-3 2*CO_2 scenario is displayed in Fig. 7 and 8. The differences between 2*CO_2 and historic observations are also calculated and show an increase especially in the mountainous region. The same fact can be stated for the differences between 2*CO_2 and 1*CO_2 scenario but not so pronounced. The result for temperature shows a much higher variability of changes for the map of differences between 2*CO_2 scenario and observations than that for the downscaled GCM results.



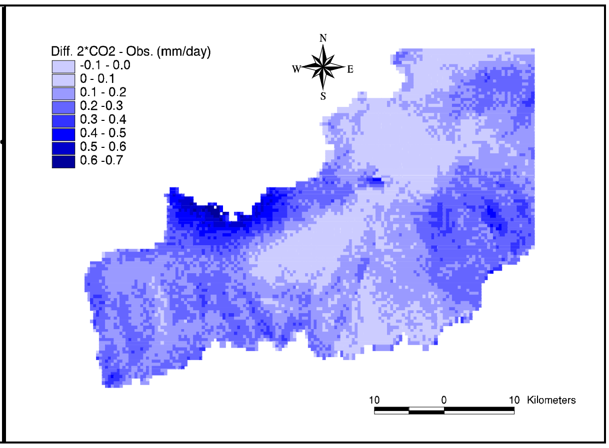


Fig. 7 Mean daily precipitation for the 2*CO_2 scenario

Fig. 8: Differences between mean daily precipitation for the 2*CO_2 and historical observations

With respect to floods the following conclusions can be drawn. There is a tendency to decreasing runoff and also to smaller floods. But considering local variability there is a probability of an increase of floods in some higher altitude areas. Especially the coincidence of rainfall driven floods and snowmelt events is becoming important. As can be seen from Fig. 9 the probability of coincidence is regionally completely different.

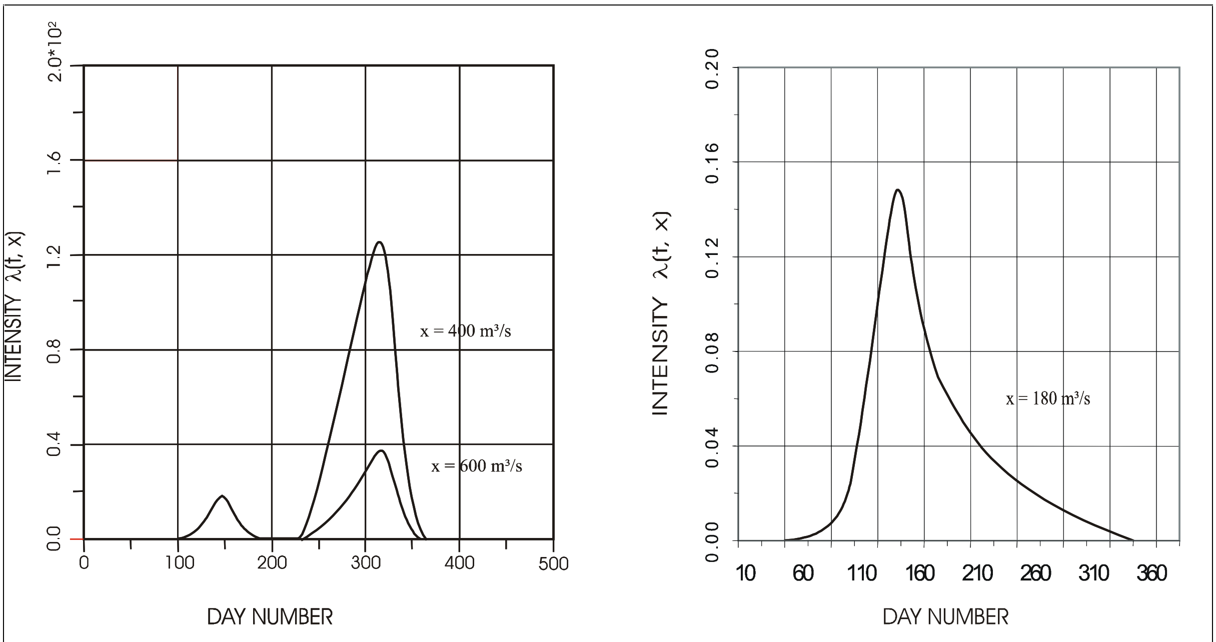


Fig. 9 Seasonal intensity of flood events in two alpine Austrian basins: Gail basin (left)and Enns Basin (right) (Nachtnebel and Konecny, 1987).

Summary and Conclusions

Under increased CO_2 concentrations the increase in temperature will lead to substantial changes in the seasonal runoff pattern. The model simulations indicate that the low flow period will then occur in late summer because of the increased evapo-transpiration. During the winter period the increase in temperature will reduce the storage of precipitation and will contribute to an increase in runoff. Both the number of days with snow cover and the period with continuous snow cover will be substantially reduced. Also the number of days with mean daily temperatures below the freezing point will be reduced under $2*CO_2$.

It is difficult to derive detailed conclusion with respect to flood frequency changes. In general, it can be said that an increase in the variance of the hydrological input will result in an increase of the respective model output and therefore the frequency of flood events might be increased. But hundreds of simulated time series indicate rather a decrease of flood probabilities because of larger evaporative losses and earlier snowmelt. However it should be noted that according to Fig. 9 small changes in melt water together with precipitation on snow cover may lead to increased floods.

Weak points in the approach are in the assumption that the statistical relationship between CP-types and local climate variables will hold also under increased greenhouse gas concentrations and also that the hydrological system parameters will not change. This is probably not true because the vegetation layer and the land use in the basin might also respond to climate changes as can be learnt from the past.

Another critical point is in the feedback mechanisms within basins which will are only weakly understood and rarely considered in modelling approaches. Due to an increase in temperature and the shift in rainfall patterns the vegetation will respond in the long-term to the modified environmental conditions. The efficiency of water uptake by plants will be increased under higher CO_2 concentrations and also the biomass production might increase. The timber line in alpine catchment will change and will have an impact on the hydrological processes.

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