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The effects of an increase in CO_2 on the hydrology of forests

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Abstract

The possible impacts of a climatic change associated with an increase in CO_2 on the hydrology of forests is evaluated by applying sensitivity analysis and a climatic scenario to a one-dimensional model. Water consumption of forests is affected by changes in plant physiology and meteorological environment. Changes in species composition are not taken into account. Increase in CO_2 leads to a decrease of stomatal conductance, resulting in a decrease in transpiration of 10-30%. The evaporation of rainfall interception by the canopy is increased due to a higher leaf area index and higher temperatures. Application of a wet scenario shows an increase in total interception, but the ratio between interception and precipitation decreases. Simulating a small increase in leaf area increases the evapotranspiration only weakly and the higher precipitation in the scenario is mainly passed on to drainage. Drought damage in summer should reduce, but winter discharge may strongly increase.

1. INTRODUCTION

Forests are not only important in the global carbon balance but have also a relevant influence on local and regional hydrology. A change in the concentration of CO_2 as well as a possible climatic change will have direct and indirect effects on the water use of plants, including trees. The direct effect of CO_2 increase will be most significant on the photosynthesis. Besides, forest are strongly coupled to the atmospheric conditions because of their roughness. Changes in the atmosphere will affect forests stronger than other vegetation types.

The aim of this study is to estimate the consequences of a climate change with an increase of atmospheric CO_2 concentration for the water balance of forests.

2. SIMULATION OF THE FOREST WATER BALANCE

A one dimensional model was developed to simulate the water balance. The model, derived from the model by Dolman et al. [1], is devided in three main parts. Transpiration through the leaves is simulated using the Penman-Monteith equation, which contains the stomatal conductance. Interception and evaporation of rainfall by the canopy is modelled according to the Gash-Rutter [2] approach. And thirdly, the soil is considered as a simple bucket and water exceeding the field capacity is drained. Transpiration is calculated on a hourly time basis, whereas interception and soil water content are calculated with a daily time step.

Transpiration of forests is strongly determined by the stomatal conductance. As stomata are sensitive to changes in the CO_2 concentration, a model simulating the responses of stomata is essential [3]. The correlation between stomata, meteorological variables and plant physiological processes is evident, but the exact mechanistic process of stomatal functioning is still unknown. This situation has resulted in several possible empirical simulation models. In this study the model developed by Leuning [4] was chosen. To incorporate the effect of soil moisture deficit on the stomatal conductance, the soil moisture function of Stewart [5] is used in combination with the Leuning model. The model describes a relation of stomatal conductance with the assimilation rate and air humidity deficit. To simulate the assimilation rate the biochemical model of Farquhar et al. [6] is used.

2.1 Climate scenario

The influence of the main model parameters on interception and transpiration were analyzed by sensitivity analysis. To integrate the results with results of other groups with in the National Research Program, the scenario KNMI-2 as described by Können [7] was applied. The amount of precipitation increases strongly (with a yearly of average 13%) as compared to climate scenarios described by IPCC.

In order to apply the scenario, an estimation must be made of the forest parameters in a changed climate. Changes in the parameters are derived from studies to responses of trees in a changed climate. An excellent review is given by Ceulemans and Mousseau [8]. The reaction of trees depends on species and nutrient environment with the possibility of the tree to develop sinks for the extra carbon. A general trend is the increase of growth and, with some exceptions, of the water use efficiency, but the increase is limited when no sinks are available. With limited nutrients, which is the case for many forests on sandy soils, the increase of biomass will be concentrated in the roots. Therefore, in the scenario a modest increase of 5% in leaf area index (LAI) of the canopy is applied. The onset of leaf growth and leaf fall are not changed. Also the nitrogen content is not changed to keep the approach simple. Most species show a decrease in stomatal conductance caused by both smaller stomatal opening and lower stomatal density. In this study doubling of CO_2 resulted in a decrease of stomatal conductance of 31%. Based on Morison [9], who compared the stomatal conductance of various species under ambient and double CO_2 concentrations, these changes are regarded as realistic. Although, variations due to varying species composition and forest site may be large.

2.2 Data

The model was calibrated on data of a decidiuos forest (*Quercus rubra*) located near Ede in the Netherlands and of the coniferous forest (*Pinus sylvestris*) of Thetford in England. The model had to be fitted on measured transpiration fluxes and soil moisture content because assimilation data were not available. The simulated variation in the

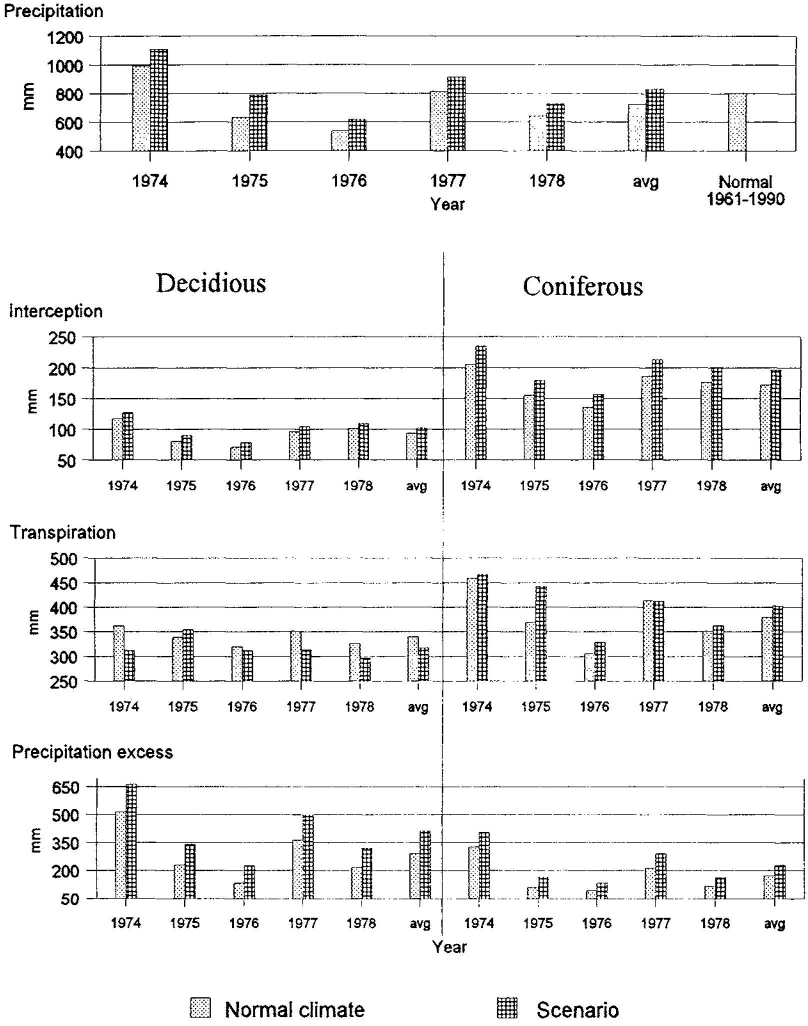

Figure 1. Yearly totals of precipitation, interception, transpiration and precipitation excess simulated with normal climate and scenario for both forest types.

assimilation rate with the Farquhar model was judged to be realistic.

To simulate the water balance over longer periods, the climate scenario study was conducted with a data covering the years 1974-1978, including dry and wet years. The variables were measured above grass and transformed to above forest conditions. The characteristics of Ede and Thetford forests were used to describe the modelled forests.

4. RESULTS AND CONCLUSIONS

Interception of rainfall is especially sensitive to changes in temperature, air humidity, windspeed and leaf area. With no change in the relative humidity when temperature increases, the small increase in leaf area index raises the interception with a small amount (see figure 1). Although precipitation increases strongly, the effect on interception is low. The ratio of interception and total precipitation is decreasing. This means that a larger part of the gross precipitation reaches the soil.

Using the physiological based model for stomatal conductance, transpiration appears to be sensitive not only to changes in temperature, air humidity and soil water availability but also the nitrogen availability and the photosynthetic capacity have a strong influence.

The available soil water determines the change in transpiration compared to the actual climate. Lower transpiration during winter and spring due to decreasing stomatal conductance, diminish water shortage during summer and the total yearly transpiration may increase. When water is not limiting transpiration decreases with 10-30%.

Taking the uncertainties of the applied scenario and used model into consideration, the results must be used with care. The increase in precipitation, especially high during winter, will drain almost completely to the groundwater. This means that frequent flooding can be expected in winter when evapotranspiration is low and the soil is already saturated. Summer droughts will decrease. The present policy to replace coniferous forests with deciduous forests to limit evapotranspiration, will further increase discharge in a greenhouse climate.

5. REFERENCES

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