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Climate change scenarios for impact studies in the Netherlands

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Abstract

Observed relations between meteorological elements in the present-day climate are used to transform an observed daily time series into representative daily time series of a possible future climate. For point precipitation the method needs reasonable guesses of the large-scale changes in the seasonal means of surface air temperature (or the combination of surface air temperature and surface air pressure). The transformation method is described and an example is given for De Bilt (the Netherlands).

1. INTRODUCTION

A climate change scenario can be defined as a meteorologically consistent picture of a possible future climate that can be used to study the response of environmental and social systems to future climate change. General Circulation Models (GCMs) are the natural tools for obtaining such a picture, since they synthesize existing knowledge of the physical and dynamical processes of the climate system and allow for many of the complex interactions between the various climate components. Nevertheless, impact studies generally need more detailed information about the present-day and possible future climate conditions for the site or region of interest than can be derived from the GCM simulations. The mismatch is caused by limited computer resources preventing global climate simulations with a gridmesh distance smaller than 100-200 km, combined with incomplete description of various atmospheric processes and interactions between the earth surface (land, ocean) and the atmosphere. As a result, the variability in GCM simulated climates at small spatial scales and short time scales is not adequately represented.

Over the last decades several methods have been developed to supplement the GCM simulations with a range of climate change scenarios at the appropriate resolution for impact studies (Giorgi and Mearns, 1991; Wilks, 1992). Four approaches can be distinguished:

1) transformation of a base-line climate series conform GCM predictions of large-scale changes in the seasonal means;
2) stochastic generation of local climate time series by adjusting the parameters in a time series model according to predicted changes in long-term means and variances;
3) stochastic generation of local climate series conditional on large-scale atmospheric circulation patterns (= statistical downscaling);

4) deterministic simulation of regional climates using a high resolution limited area model nested in a GCM (= deterministic downscaling).

The first approach has been followed to obtain daily precipitation scenarios in the KNMI Climate Scenario project. The KNMI method makes use of GCM predictions about large-scale changes in the seasonal means of the climate elements which are best reproduced in the GCM simulations, like surface air temperature and surface air pressure. Daily precipitation is transformed indirectly using relations in the present-day climate between precipitation, surface air temperature, surface air pressure and other important elements for impact studies (air humidity and solar radiation). The relations are modelled by weighted non-linear regression techniques (Buishand and Klein Tank, in press; Klein Tank and Buishand, 1993; 1995). Direct GCM predictions about changes in the seasonal means of precipitation are not used. One reason for this is that precipitation is poorly represented in the current GCMs. Another reason is that the application of GCM predictions about large-scale precipitation changes to higher resolution data (e.g. daily station data) may not be appropriate as a result of the high spatial variability of precipitation. Transformation of a base-line climate in the form of observed series is preferred to stochastic weather generators, because it is simple and it automatically provides a realistic variability on daily as well as longer time scales.

This paper focusses on the derivation of the KNMI precipitation scenarios. The results of background activities like the analysis of GCM climate simulations are not discussed here.

2. TRANSFORMATION OF OBSERVED PRECIPITATION SEQUENCES

The increase of the maximum concentration of water vapour with temperature (Clausius Clapeyron relation) causes fronts and other weather systems to produce more rain at higher temperatures. This effect explains part of the relation between mean precipitation amount R and surface air temperature T for wet days (threshold 0.1 mm) at De Bilt in Figure 1. A notable exception is the behaviour in the intermediate temperature regime, where the mean precipitation amount decreases with temperature. This is caused by a decreasing activity of large-scale precipitating systems at temperatures > 15°C. These systems become rare at $T >$ 18°C, but then convective showers become increasingly active and the mean amounts rise again.

KNMI Scenario 1 is based on Figure 1. It is obtained by transforming the precipitation amounts on wet days. The procedure is as follows:

1) apply a GCM-predicted change in seasonal mean temperature to all observed daily temperatures T;
2) determine for each wet day the resulting relative change in the mean precipitation amount R from Figure 1;
3) multiply the observed daily amounts by the calculated relative changes (multiplying factors).

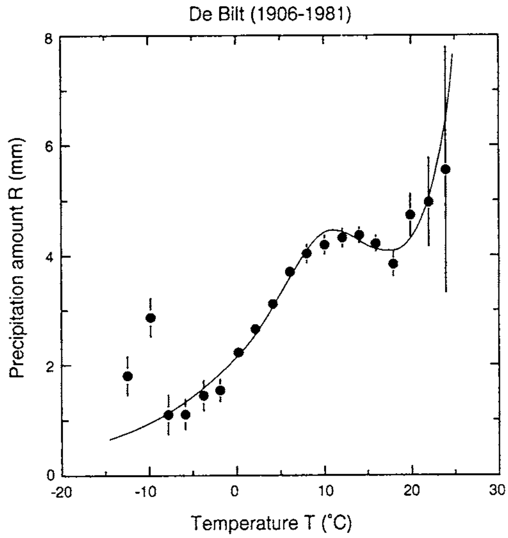

Figure 1. Mean precipitation amounts R (dots) at surface air temperature T class intervals of 2°C for wet days at De Bilt (1906-1981). The smooth curve represents the fitted regression relation; the error bars the standard deviations of the means. After Buishand and Klein Tank (in press).

In Scenario 1 only the effect of a prescribed atmospheric warming is taken into account. The relative changes in Steps 2 and 3 assume implicitely that the atmospheric circulation changes according to its present-day dependence on T. More flexible scenarios can be obtained by prescribing also a change in the atmospheric circulation. In Scenario 2 the daily mean surface air pressure P is included in the analysis for this purpose. Figure 2 presents the relation between R, T and P for wet days at De Bilt. The procedure for transforming precipitation amounts on wet days into a consistent scenario (Scenario 2) for the case of both a prescribed warming and a prescribed change in surface air pressure (atmospheric circulation) is similar to that for Scenario 1, but now Figure 2 is used instead of Figure 1.

In Scenario 1, it is assumed that the number and the sequence of wet and dry days in the future climate time series remains the same as in the observed record. Since the occurrence of a wet day is linked to the atmospheric circulation, Scenario 2 with a systematic change in P must account for a change in the sequence of wet and dry days. This was done as follows:

1) assign probabilities of rain to each day using Figure 3;
2) compute for each season the change in the number of wet days from these probabilities in the present-day and future climate;
3a) if the number of wet days in a season decreases by n: assign n wet days in the series as dry on the basis of their probability of rain, e.g. using a Monte-Carlo method.
3b) if the number of wet days in a season increases by n: assign n dry days in the series as wet on the basis of their probability of rain and determine their amounts using Figure 2.

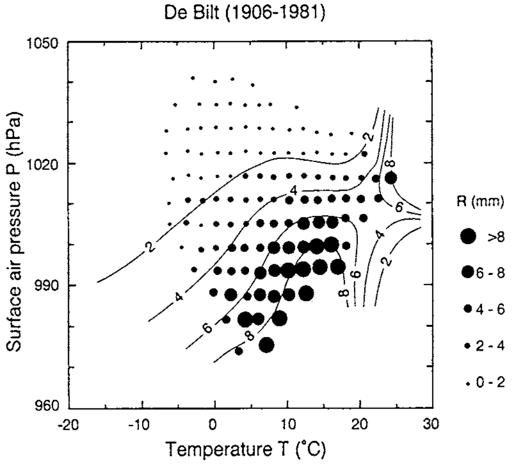

Figure 2. Mean precipitation amounts R (dots) at surface air temperature T class intervals of 2°C and surface air pressure P class intervals of 6 hPa for wet days at De Bilt (1906-1981). The isolines represent the theoretical mean amounts from a fitted regression model. After Buishand and Klein Tank (in press).

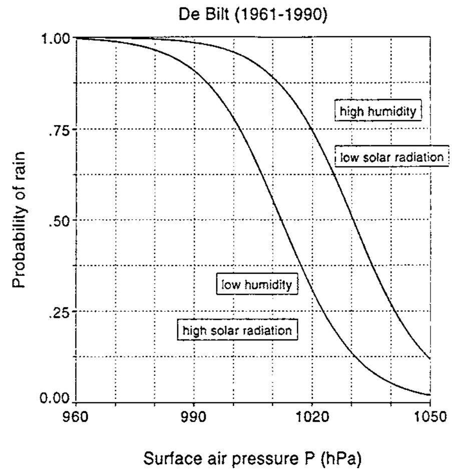

Figure 3. Fitted logistic regression relations for the probability of rain at De Bilt (1961-1990).

3. EXAMPLE FOR DE BILT

The daily precipitation amounts in the 1961-1990 record of De Bilt were transformed by the above methods. The prescribed changes in T and P were taken from the Canadian Climate Centre GCM predictions of large-scale changes in the seasonal means (Table 1; 2×CO_2 - 1×CO_2 experiment). Figures 4 and 5 illustrate the effects of the transformation on the July 1962 precipitation data for Scenarios 1 and 2, respectively. The multiplying factors (Scenarios 1 and 2) and the probabilities of rain (Scenario 2) are also shown. Note that in Scenario 2 two wet days (6 and 21 July 1962) were assigned dry.

Table 1
Predictions of the large-scale changes in the seasonal mean temperature and surface air pressure over Western Europe for the 2×CO_2 Canadian Climate Centre GCM experiment.

	Winter	Spring	Summer	Autumn
ΔT (°C)	+3.0	+2.3	+3.7	+3.4
ΔP (hPa)	-3.4	-1.1	+0.3	-0.1

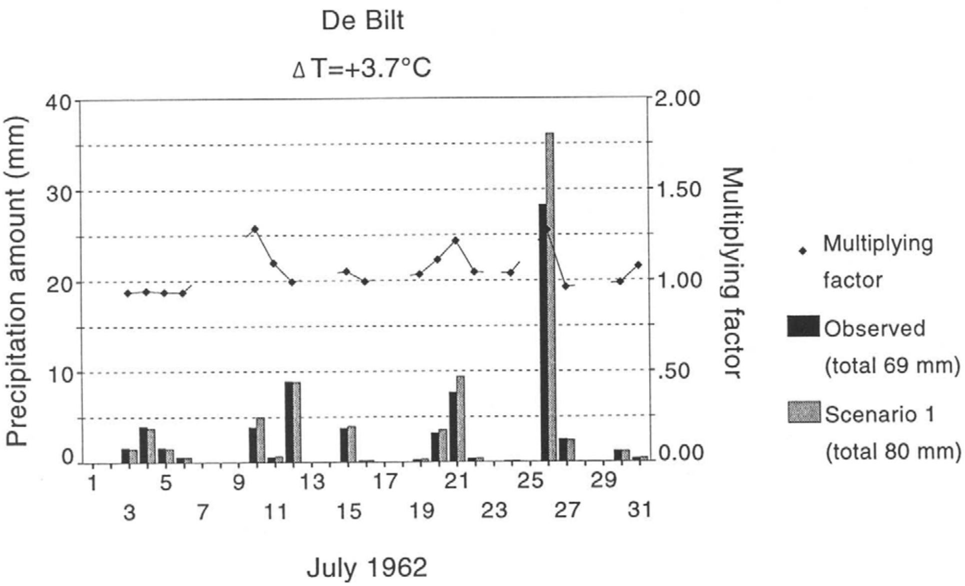

Figure 4. Precipitation amounts in the observed and transformed July 1962 month at De Bilt for Scenario 1. The solid squares represent the multiplying factors.

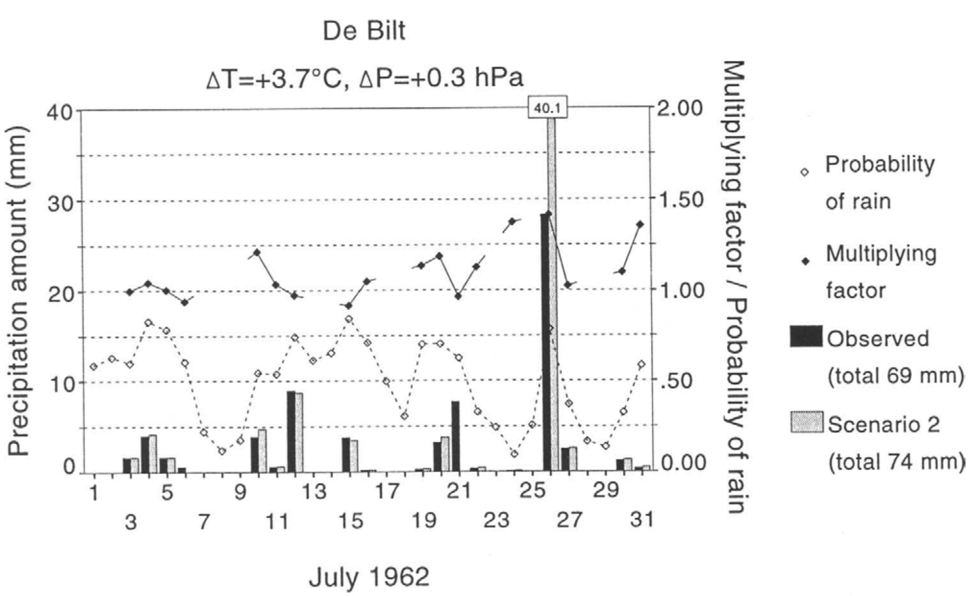

Figure 5. Precipitation amounts in the observed and transformed July 1962 month at De Bilt for Scenario 2. The solid squares represent the multiplying factors and the open squares the probabilities of rain.

The largest precipitation changes in the two scenarios occur in winter (+20% and +44% for Scenarios 1 and 2, respectively) and the smallest in autumn (+5% for Scenario 1) or summer (+8% for Scenario 2). The annual mean amount increases by 10% in Scenario 1 and 20% in Scenario 2. These values differ considerably from the precipitation changes as predicted directly by the GCM itself (+28% in winter, -26% in summer and no change on average over the year).

4. APPLICABILITY OF THE SCENARIOS

An attractive feature of the KNMI approach is that the scenarios and their updates can easily be implemented by impact groups. The transformed daily series have a realistic variability on daily as well as longer time scales. Extreme case scenarios for sensitivity studies can be constructed from past (extreme) episodes. Scenarios in the form of monthly, seasonal or annual time series can be obtained directly from the transformed daily series. The scenarios facilitate integration of NRP climate change impact studies.

After consulting the potential users a follow-up project is planned to construct a wider range of scenarios in which changes in air humidity and solar radiation are included.

5. REFERENCES

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