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Time series transformation tool: description of the program to generate time series consistent with the KNMI '06 climate scenarios

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Contents

Summary

Parallel to the development of the KNMI'06 climate scenarios[1] in 2006 a tool was developed to generate temperature and precipitation time series for the future (http://climexp.knmi.nl/Scenarios_monthly/). These time series are often needed for climate impact and adaptation models. The aim of this time series transformation tool is to adjust a historical precipitation or temperature time series (on a daily basis) in such a way that the newly generated time series for the future is consistent with one of the four KNMI'06 climate scenarios for a selected time horizon.

Until now, no official report was available with a description of all aspects of the KNMI transformation tool, although there are an elaborate user online guide and some popular-scientific publications (e.g. Bakker and Bessembinder, 2007). Within the COM28-project ("Climate data") this transformation tool was used regularly. As part of this project, the present background report is written, that gives a description of the tool together with an overview of its development and the analyses performed by KNMI to determine its limitations and advantages.

After the first release on internet in 2006, the transformation tool was further developed and improved. In Chapter 2 an extensive description is given of the functioning of the current and previous versions of the transformation tool. Chapter 3 gives an overview of the differences between the various versions of the temperature and precipitation transformation tool. Chapter 4 explores the characteristics of the various versions of the transformation tool. It describes e.g. the effect of changing the method to remove and add wet days and the effect of using other reference periods than the standard period of 1976-2005.

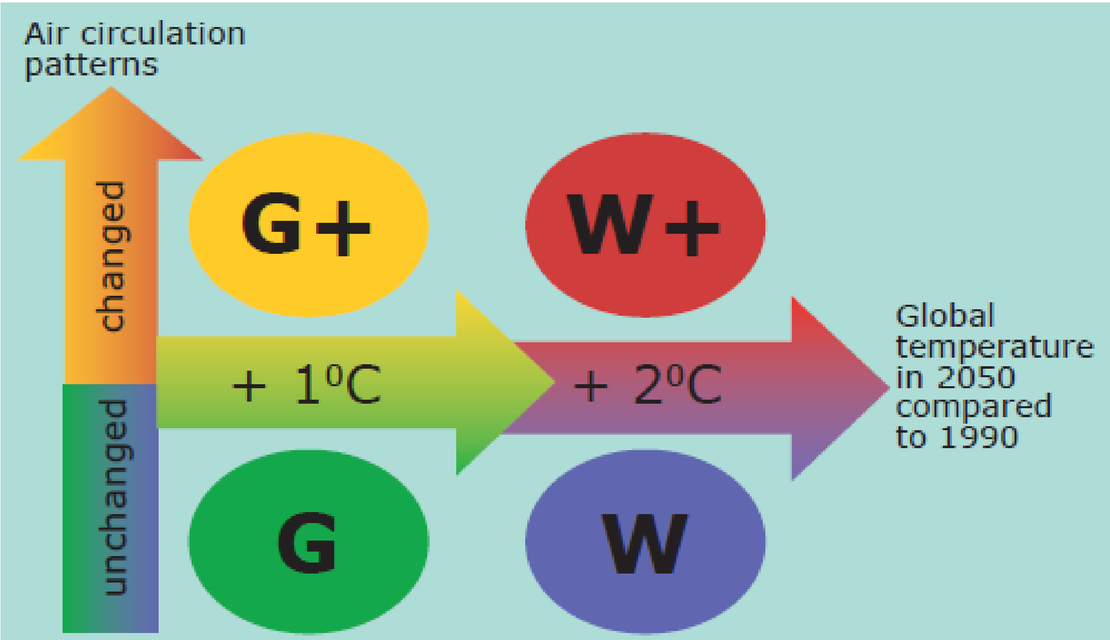
Chapter 5 describes the advantages and limitations of the current time series transformation tool and it gives information on alternative methods for generating time series for the future. The chapter indicates on which points the transformation tool could be improved or extended and whether it is useful to develop (further) other methods to generate time series for the future. Desired points for improvement and extension are closely linked to user requirements, which are also discussed shortly. Several projects are ongoing or will start that include already several of the desired and possible developments. A few examples are: "Theme 6: Climate projections" of the Knowledge for Climate programme, the project "Kritische Zone" of the National Model and Data Centre, and the activities for the next generation of the KNMI climate scenarios.

[1] Generally this term is used, also in this report, whereas "climate change scenarios" would be more correct.

1. Introduction

KNMI’06 climate scenarios

In May 2006, the KNMI’06 climate scenarios[1] were published (KNMI, 2006; Van den Hurk et al., 2006; 2007). Figure 1.1 gives a schematic overview of these four climate scenarios. Together with these scenarios a table with change coefficients was provided for the summer and winter season for the time horizons 2050 and 2100, compared with the reference period 1976-2005[2].



G	Moderate*	1°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
G+	Moderate +	1°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds
W	Warm	2°C temperature rise on earth in 2050 compared to 1990 no change in air circulation patterns in Western Europe
W+	Warm +	2°C temperature rise on earth in 2050 compared to 1990 + milder and wetter winters due to more westerly winds + warmer and drier summers due to more easterly winds

Figure 1.1 Schematic overview of the four KNMI’06 climate scenarios and the legenda.

Tailoring climate information

These tables with change coefficients are often not sufficient for climate impact and adaptation research. In 2004 the “tailoring-project” started as part of the “Climate changes spatial planning” programme[3]. This project aimed at providing tailored climate data related to climate change for impact and adaptation researchers. For this objective KNMI developed a time series transformation tool (often called transformation tool) before the publication of the KNMI’06 scenarios. Climate indices, e.g. number of summer

[2] http://www.knmi.nl/climatescenarios/knmi06/index.php;
[3] Climate changes spatial planning” programme (CcSP): http://klimaatvoorruimte.klimaatonderzoeknederland.nl/nl/25222969-Klimaatscenario%27s.html, project CS7.

and tropical days in summer, number of frost days in winter, have been derived from the time series generated with this first version. These indices have been published together with the launch of the KNMI'06 climate scenarios data[4]. Also the transformation tool itself was put on the internet in order to give users the possibility to generate additional time series and data themselves.

Aim of the time series transformation tool

The aim of the transformation tool is:

- To adjust a historical precipitation time series or a historical temperature time series on a daily basis in such a way that the newly generated time series for the future is consistent with one of the four KNMI'06 climate change scenarios and the selected time horizon.

In other words: the tool applies the changes in averages and variability as prescribed by the selected KNMI'06 climate scenario and selected time horizon to a given historical time series for temperature or precipitation.

The transformed time series give information on averages, variation between days, the probability of extremes, etc. for a plausible **climate** in the future. The transformed time series **do not give predictions of the weather** in the future on a specific day or in a specific year.

User requirements and further development

With the original version of the transformation tool (denoted as version 0.0) it was only possible to transform winter and summer data. Soon after its release, professional users, especially water managers, asked for a tool for "year-round" time series. This "year-round" version has been developed as part of the "tailoring-project" mentioned before. The first version is from January 2007 (version 1.0). A modified version (1.1) was released on the internet (http://climexp.knmi.nl/Scenarios_monthly/) in the summer of 2007 and version 1.2 has been available since April 2008 until now (April 2012).

Since version 1.0 the transformation tool has been used in many projects within and beyond the CcSP programme. In the data delivery project in CcSP (COM28[5]) it was used regularly to generate time series for the future. The wide use is probably stimulated by the following facts:

- The online availability of the tool makes it very easy to generate time series for the future. The easy access also promoted consistency in the time series used for impact and adaptation studies (which makes it easier to integrate results from these studies).
- It is the only method generally available6 that can generate time series for the Netherlands in a short time for the KNMI'06 climate scenarios: within a few seconds a time series is generated (see also advantages and limitations of the various methods to supply time series for the future in Chapter 5).
- There was relatively much support for users: guidance material at the internet, and a help desk at KNMI (which was frequently used).

Aim of this report

Until now, no official report was available with a description of all aspects of the KNMI transformation tool, except for the information on the internet and some popular-scientific presentations and publications. This report aims to give this description together with an overview of the development of the tool and the analyses performed by KNMI to determine the limitations and advantages of the tool.

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[4] http://www.knmi.nl/klimaatscenarios/knmi06/gegevens/index.html;

[5] http://klimaatvoorruimte.klimaatonderzoeknederland.nl/nl/25222969-Klimaatscenario%27s.html: COM28;

[6] We are not aware of other tools that also generate time series consistent with the KNMI'06 scenarios. See also Chapter 5.

Outline of this report

In Chapter 2 the tool is described in detail. In Chapter 3 a description is given of the development and various versions of the tool and in Chapter 4 an overview is given of the various analyses performed by KNMI related to the limitations and options of the tool. Chapter 5 presents conclusions, recommendations and points of discussion. It also describes briefly other methods to generate time series for the future and their advantages and disadvantages.

2. Description of the time series transformation tool

2.1. General

The KNMI'06 scenarios indicate that the change in the median differs from that in the high percentiles. The transformation tool takes this into account in the generation of time series for the future (see Figure 2.1).

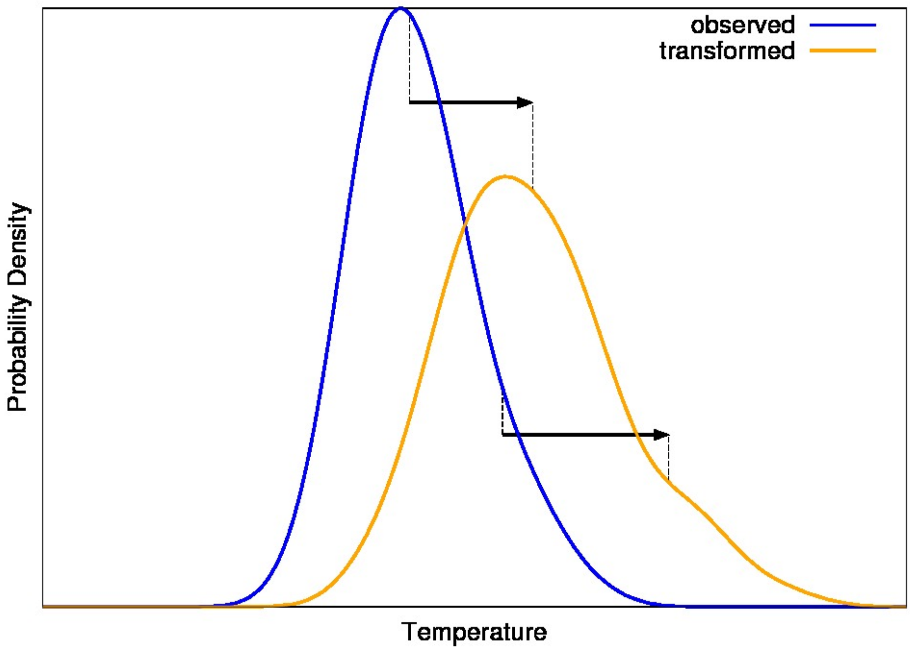


Figure 2.1 Schematic representation of the change in the probability density function (PDF) for temperature during the transformation in which the median changes less than the higher percentiles.

The transformation tool (http://climexp.knmi.nl/Scenarios_monthly/) transforms historical time series by applying a certain change (or "delta") to daily values. The application of change-factors is also referred to by many other names as the Delta method[7] and perturbation of time series (KMI/KU Leuven/KNMI, 2009).

The transformation tool version 0.0 uses changes in percentiles[8] per season (see Tables 3.1 and 3.2), whereas the brochure on the KNMI'06 climate scenarios (KNMI, 2006) presents changes in average temperatures or precipitation per season and changes in extreme events with certain return times. From version 1.0 on, the changes in the transformation tool were determined on a monthly basis (see Annex 1). The average changes in the months June-August and in the months December-February equal the changes in summer and winter, respectively, as mentioned in the brochures on the KNMI'06 scenarios (KNMI, 2006 and 2009a; Van den Hurk et al., 2006) and on the website[9].

[7] Usually limited to average changes;

[8] Note that the change in precipitation amounts that are exceeded once in 10 years is not the same as the change in the 99th percentile, and that temperatures that are exceeded once a year are not the same as the change in the 90th percentile;

[9] http://www.knmi.nl/klimaatscenarios/knmi06/samenvatting/index.html.

2.2. Temperature

For temperature, a pragmatic linear percentile scaling is applied to transform[10] a historical time series into a time series representative of one of the four climate scenarios. The 90th, 50th and 10th percentiles are determined from the observations ("current climate") and are denoted as $T^c{}_{90}$, $T^c{}_{50}$ and $T^c{}_{10}$ respectively. Then, the future percentiles ($T^f{}_{90}$, $T^f{}_{50}$ and $T^f{}_{10}$) are calculated by adding the change factors (ΔT_{90}, ΔT_{50} and ΔT_{10}, Eq. 2.1) that belong to the selected scenario and time horizon. This is applied for the winter and summer season (in version 0.0) or for each calendar month (from version 1.0 on) separately.

$$
\begin{aligned}
T^{\mathrm{f}}_{90} &= T^{\mathrm{c}}_{90} + \Delta T_{90} \\
T^{\mathrm{f}}_{50} &= T^{\mathrm{c}}_{50} + \Delta T_{50} \\
T^{\mathrm{f}}_{10} &= T^{\mathrm{c}}_{10} + \Delta T_{10}
\end{aligned}
\qquad \text{(eq. 2.1)}
$$

Each value of the temperature in the transformed temperature time series, T^f ("future climate") is derived from the reference time series T^c using a scaling relation that is based on the distance of T^c to the median:

$$
T^{\mathrm{f}} = T^{\mathrm{f}}_{50} + \alpha\left(T^{\mathrm{c}} - T^{\mathrm{c}}_{50}\right) \qquad \text{(eq. 2.2)}
$$

In which T^f is the transformed value of the temperature in the historical time series T^c, and α is a scaling factor that is different for values smaller or higher than the median of the reference time series:

$$
\alpha = \begin{cases}
\dfrac{T^{\mathrm{f}}_{90} - T^{\mathrm{f}}_{50}}{T^{\mathrm{c}}_{90} - T^{\mathrm{c}}_{50}} & T^{\mathrm{c}} > T^{\mathrm{c}}_{50} \\[2ex]
\dfrac{T^{\mathrm{f}}_{10} - T^{\mathrm{f}}_{50}}{T^{\mathrm{c}}_{10} - T^{\mathrm{c}}_{50}} & T^{\mathrm{c}} < T^{\mathrm{c}}_{50}
\end{cases}
\qquad \text{(eq. 2.3)}
$$

This procedure implies that the changes for values higher than the 90th and lower than the 10th percentile are linearly extrapolated from the changes between the 50th and 90th or the changes between the 50th and 10th percentiles. An example is given for the 99th percentile:

$$
\Delta T_{99} = \Delta T_{50} + \beta\left(\Delta T_{90} - \Delta T_{50}\right) \qquad \text{(eq. 2.4)}
$$

In which β is:

$$
\beta = \frac{T^{\mathrm{c}}_{99} - T^{\mathrm{c}}_{50}}{T^{\mathrm{c}}_{90} - T^{\mathrm{c}}_{50}} \qquad \text{(eq. 2.5)}
$$

In the transformation tool the changes of the 10th, 50th and 90th percentiles are given explicitly for 2050 and 2100, compared to the climate around 1990. The transformation

[10] The first (slightly erroneous) description is given in the scientific report (Van den Hurk et al., 2006).

tool automatically calculates ΔT_{10}, ΔT_{50} and ΔT_{90} for intermediate time horizons, based on linear interpolation between 1990, 2050 and 2100.

The method to transform temperature time series, as described above, has not changed between versions (with the exception of version -1.0; see also Table 3.2). Between version 0.0 and 1.1 there was a change in the time resolution of the change coefficients (from season to calendar month). In the beginning of 2008 some small errors were detected in the change coefficients and corrected in version 1.2 (Annex 5).

2.3. Precipitation

The transformation of precipitation time series consists of two steps. First, the observed wet day[11] frequency (F^c) is adjusted based on the relative change ΔF. Next, the changes for wet day amounts are applied.

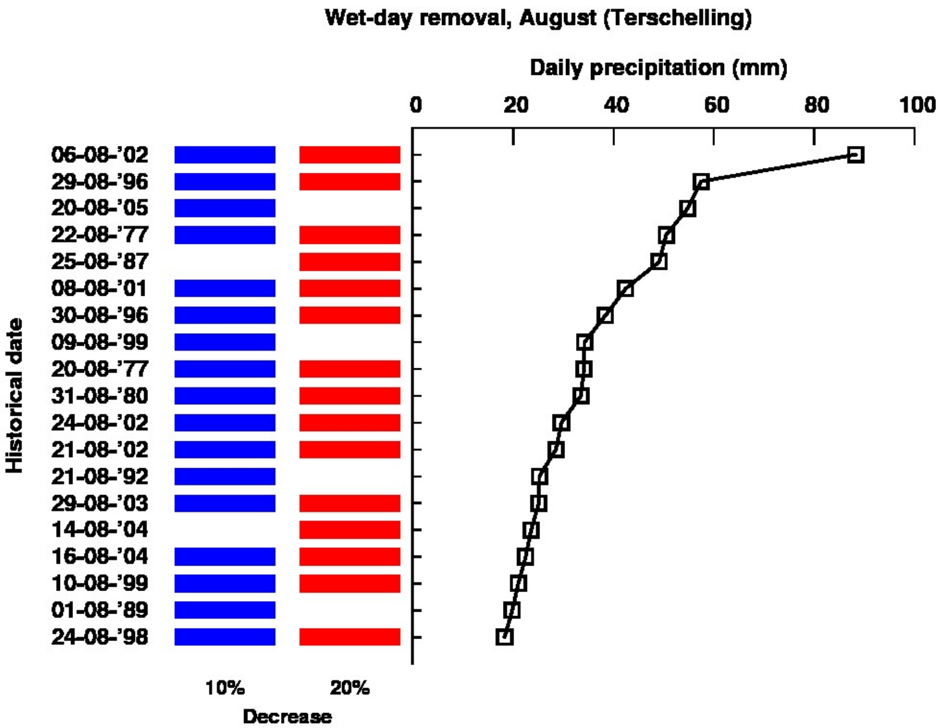


Figure 2.2 Example of the removal of wet days according to the statistical ranking method (version 1.1 and further), for the month of August in the period 1976-2005 for the station West-Terschelling (S496). Horizontally the daily amount of precipitation in the reference time series is given ("dagsom (mm)"). Vertically the highest 19 precipitation events (together with their historical dates on which they occurred: "Historische datum") are ranked with the highest amount on top. The column with the blue blocks shows which days are dried in case of 10% decrease ("10% afname") in wet day frequency, the column with red blocks represents a 20% decrease ("20% afname") in wet day frequency.

Removal of wet days / Drying wet days

In the case that $\Delta F<0$, wet days have to be "dried" or "removed". This is applied by setting the precipitation amount to zero. The selection of the wet days to be removed has changed over the various versions of the transformation tool:

- **Versions 0.0 and 1.0**: the wet days were removed by chronology. This means that e.g. in the case of a reduction of 10% of wet days in the calendar month of August, each 10th wet day was dried (after putting all wet August days in the reference period in chronological order). The first wet day removed was wet day number $(1/|\Delta F|)/2$,

[11] A wet or precipitation day is defined here as a day with ≥ 0.05 mm of precipitation.

rounded down[12] and starting from the first wet day in the chronological order (in case of the reference period 1976-2005 this was the first wet day of the particular season or calender month in 1976).

- **Version 1.1**: the removal of the wet days was based on the ranking of the amounts of precipitation in increasing order (see Figure 2.2). This was done to avoid clear changes in the probability density function (PDF) of the daily amounts (Figure 2.3) prior to the transformation of daily precipitation amounts. The first wet day removed was wet day number $(1/|\Delta F|)/2$, starting from the wet day with the lowest rank of the precipitation amount[12] (ranking method).
- **Version 1.2 and 2.0**: The same procedure as described for version 1.1 was used with the following additional selection criterion for drying days; only days that are at the beginning or the end of a wet period are available for drying. This criterion ensures a better maintenance of the temporal correlation. Removal of wet days starts at the lowest amounts. This means that after removal of wet days new wet days are available at the beginning or end of a wet period (Figure 2.4).

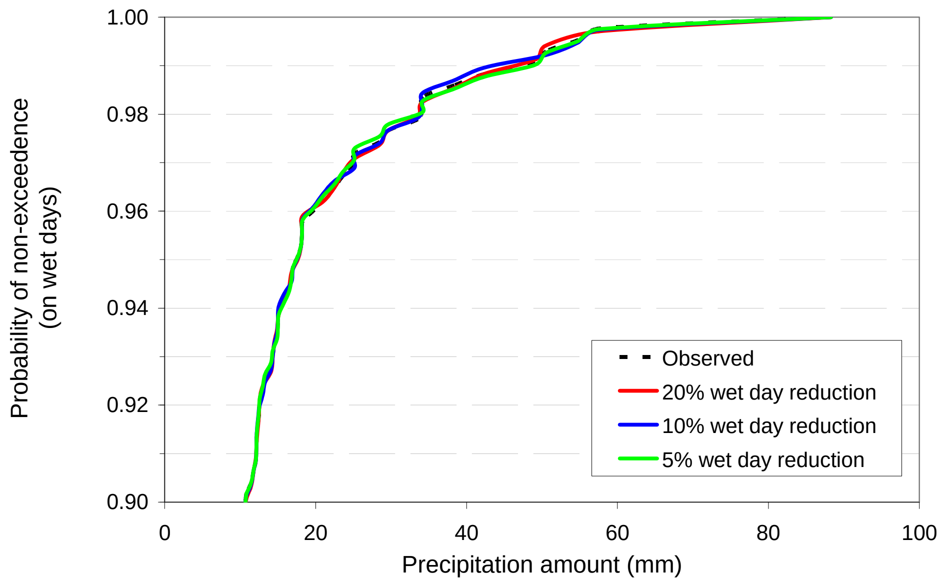


Figure 2.3 Example of the effect of the removal of wet days according to the statistical ranking method (version 1.1), for the month of August in the period 1976-2005 for the station West-Terschelling (S496) on large percentiles of the resulting daily precipitation. Horizontally the daily amounts of precipitation are given, vertically the non exceedance probabilities.

[12] A "counter" was defined. Each time it surpasses a threshold on a certain day, this day is "dried".

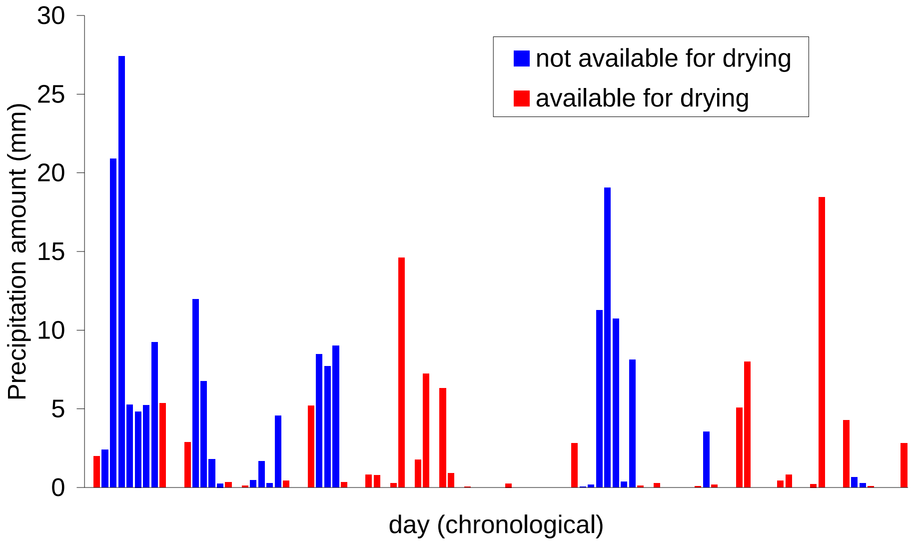


Figure 2.4 Schematic representation of the removal of wet days according to the ranking method (version 1.2 and 2.0). The red lines represent days that are at the beginning or the end of a "wet period", and therefore are available for drying.

Adding of wet days / Wetting of dry days

In the case that $\Delta F>0$, dry days have to be "wetted" or wet days have to be "added". In all versions, the dry days are selected by chronology and the added precipitation amounts are based on the last wet day preceding the newly wetted day. Two minor changes exist between the various versions:

- **Version 0.0 and 1.0**: the dry days to be wetted were selected by chronology. This means that e.g. in case of a decrease of 2% of dry days in the calendar month of December, each 50th dry day was wetted (after putting all dry December days in the reference period in chronological order). The relative change in dry days (ΔF_{dry}) is calculated from ΔF and F^c by $\Delta F_{dry}=-(\Delta F * F^c) / (1-F^c)$. The first day to be wetted was dry day number $(1/|\Delta F_{dry}|)/2$, rounded down[12] and starting from the first dry day in chronological order. The precipitation amount assigned to the new wet day is equal to the amount of the last wet day preceding the newly created wet day.
- **From version 1.1 on**: from this version on, the selection is based on the number of preceding **wet** days rather than on the preceding dry days. Therefore, a wet day counter is increased by $|\Delta F|$ with each wet day in the chronological order. The first dry day after the counter exceeds unity is turned into a wet day (and the counter is decreased by 1). This procedure automatically ensures that every new wet day succeeds an already existing wet day (no isolated wet days are created). This ensures a better maintenance of the temporal correlation. Note that the procedure allows "wetting" of two or more succeeding days if the preceding wet period is long enough (because the counter is not reset to zero, but decreased by 1 after wetting a dry day). The new precipitation amount is associated with the preceeding wet day. If the amount of this day is the xth-percentile of the distribution P_{pre} of the amounts of precipitation on wet days directly *preceeding* the *"wetted"* day, then the new wet day is assigned the xth-percentile of *all* wet days for that calendar month. Because the amount of precipitation on wet days near the end of a wet period tends to be relatively low, replacement of the percentiles from P_{pre} by percentiles from the distribution of all wet days in that calendar month, has an increasing effect on the variance of the new precipitation amount (i.e. with respect to the previous versions, adding wet days does not change the distribution of wet days).

Adjustment of the precipitation intensity on wet days

Subsequently, a change of the precipitation intensity on wet days is applied to the precipitation time series P^{c*} (with adjusted F) by a percentile scaling technique that uses a power-law rather than a linear transformation function (Leander and Buishand, 2007). The precipitation in the new time series P^{f} is calculated from the (wet day frequency adjusted) reference precipitation P^{c*}. The reference precipitation P^{c*} is adjusted in such a way that it represents the changes according to the selected KNMI'06 climate scenario and time horizon.

In **versions 0.0 and 1.0** the following transformation was used:

$$P^{\mathrm{f}} = \begin{cases} P^{\mathrm{c}*} & P^{\mathrm{c}*} < 0.05 \\ a\left(P^{\mathrm{c}*} - 0.05\right)^{b} + 0.05 & P^{\mathrm{c}*} \geq 0.05 \end{cases} \qquad \text{(eq. 2.5)}$$

P^{f} = daily precipitation amount in the future;

$P^{\mathrm{c}*}$ = daily precipitation in the reference time series (observations, but adapted for a change in the wet day frequency);

a,b = coefficients (depending on climate scenario, time horizon and calendar month).

In these versions the coefficients a and b were determined per station in an iterative process in such a way that the relative changes in the mean precipitation on wet days (ΔP_{mean}) and the 99th percentile on wet days (ΔP_{99}) are consistent with the selected climate scenario and time horizon. However, in version 0.0 the coefficients were determined on a seasonal basis, and in version 1.0 on a monthly basis. The value 0.05 was used as a threshold to distinguish between wet days (with ≥ 0.05 mm) and dry days (with < 0.05 mm).

In **versions 1.1 and 1.2** the following transformation was used:

$$P^{\mathrm{f}} = \begin{cases} P^{\mathrm{c}*} & P^{\mathrm{c}*} < 0.05 \\ a\left(P^{\mathrm{c}*} - 0.05\right)^{b} + 0.05 & 0.05 \leq P^{\mathrm{c}*} \leq P_{99}^{\mathrm{c}} \\ \left(1 + \Delta P_{99}\right)P^{\mathrm{c}*} & P^{\mathrm{c}*} > P_{99}^{\mathrm{c}} \end{cases} \qquad \text{(eq. 2.6)}$$

P^{f} = daily precipitation amount in the future;

$P^{\mathrm{c}*}$ = daily precipitation amount in the reference time series (observations, but adapted for a change in the wet day frequency);

P_{99}^{c} = threshold value (the 99th percentile on the basis of 13 Dutch stations);

a,b = coefficients on the basis of 13 Dutch stations (depending on climate scenario, time horizon and calendar month);

ΔP_{99} = relative change of the 99th percentile of wet day amounts according to a specific scenario

The values for a, b and the 99th percentile were based on a time series in which the daily data of 13 Dutch stations (Figure 3.3) for the period 1976-2005 were concatenated ("pooled" into a single long series). Therefore, the values of the coefficients a, b and P_{99}^{c} do not depend on the particular time series of an individual station. The values are given explicitly for the time horizons 2020, 2030, … , 2100. This also means that the change in the time series of an individual station does not have to be completely consistent with the chosen climate scenario and time horizon.

In **version 2.0** the same transformation (equation 2.6) was used as in version 1.1 and 1.2, but *a*, *b* and P_{99}^{c} are determined differently. In this version the amount of precipitation (in mm/day) for P_{99}^{c} was estimated by multiplying P_{mean}^{c}, the average precipitation on wet days, with a fixed ratio (*d*) per calendar month. The ratios were determined on the basis of historical data (Figure 3.4). In version 2.0 the coefficients *a* and *b* were determined again iteratively per station, as in version 1.0.

In the versions 1.0 and higher of the transformation tool the changes of the average precipitation on wet days, the 99th percentile and the wet day frequency are given explicitly per calendar month for 2050 and 2100, compared to the climate around 1990. Changes for time horizons between 1990 and 2050 and between 2050 and 2100 are obtained by linear interpolation.

3. Development of successive versions

3.1. Overview of characteristics and requirements

In this chapter a short description is given of the historical development of and changes in the various versions of the transformation tool for precipitation and for temperature. For each version some projects are mentioned in which the version is used (see also Annex 4 for an overview of the projects that used the transformation tool). The procedure of transformation is described in detail in Chapter 2. Tables 3.1 and 3.2 present the differences between the versions.

Table 3.1 Overview of differences between the versions of the **precipitation** transformation tool.

		Version					
		-1.0	**0.0**	**1.0**	**1.1**	**1.2**	**2.0**
		Mar. 2006	May 2006	Jan. 2007	July 2007	Apr. 2008	Feb. 2009
Period	Winter (DJF) + Summer (JJA)		X				
	Year-round	X		X	X	X	X
Changes per	Season		X				
	Calendar month			X	X	X[13]	X[13]
	10 days	X					
Removal of wet days[14] based on	No wet day removal	X					
	Chronology per calendar month		X	X			
	Ranking per calendar month				X		
	Ranking per calendar month + beginning/end wet period					X	X
Transformation on the basis of changes in[15]	P_{mean}	X	X	X	X	X	X
	P_{99}		X	X	X	X	X
	Wet day frequency		X	X	X	X	X
Change of percentiles > P_{99}	Extrapolated		X	X			
	Same change as P_{99}				X	X	X
Determination of 99th percentile in the transformation	Calculated for observations per station		X	X			
	Determined on the basis of observations of 13 "pooled" stations				X	X	
	Fixed ratio for P_{99}/P_{mean} based on observations						X
Determination of coefficients *a* and *b* in transformation[16]	Per station		X	X			X
	General (on the basis of 13 stations)				X	X	

[13] Corrected values, compared to the earlier versions (Annex 5);
[14] Adding of wet days took place by selecting dry days by chronology, before version 1.1 by counting the dry days, from version 1.1. on by counting the wet days;
[15] P_{mean} = mean precipitation on wet days; P_{99} = the 99th percentile (1% of the values is higher);
[16] See equation 2.5.

Table 3.2 Overview of differences between the versions of the **temperature** transformation tool.

		Version[17]			
		-1.0 Mar. 2006	**0.0** May 2006	**1.0/1.1** Jan. 2007	**1.2/2.0** Apr. 2008
Period	Winter (DJF) + Summer (JJA)		X		
	Year-round	X		X	X
Changes per	Season		X		
	Calendar month			X	X[18]
	10 days	X			
Transformation on the basis of changes in[19]	P_{10}		X	X	X
	P_{50}	X	X	X	X
	P_{90}		X	X	X

Important requirements during the development of this transformation tool were:

- It should produce time series at a daily basis, especially for temperature and precipitation;
- The time series produced should represent the climate change of the four KNMI'06 scenarios[20] (it should provide time series that are consistent with these scenarios);
- It should be able to produce time series for various time horizons;
- It should be easy to use, promoting consistency in the methods used to generate time series for the future[21];
- It should be easy to adjust the tool for the next generation of KNMI climate change scenarios, if they provide similar type of change coefficients.

3.2. Transformation of data in winter and summer

Version 0.0 (May, 2006)

This version of the transformation tool was developed to translate the information from the KNMI'06 climate change scenarios into climatological information for various locations in the Netherlands. Data generated with this version[22] were, for instance, used for the estimation of changes in extreme precipitation amounts (Figure 3.1) and changes in climate indices (e.g. the number of warm and tropical days in summer and frost days in winter). This information was partly published in the scientific report on these climate scenarios (Van den Hurk et al., 2006) and partly on the website of the KNMI'06 climate scenarios under "detailed data": http://www.knmi.nl/klimaatscenarios/knmi06/gegevens/ in May 2006. Also the transformation tool itself was put on the internet in May 2006 to enable users to generate additional time series and data themselves.

[17] Between version 1.0 and 1.1 no changes occurred in the temperature transformation. The same is true for versions 1.2 and 2.0 of the temperature transformation;
[18] Corrected values, compared to the earlier versions;
[19] P_{10} = 10th percentile (90% of the values is higher), similar for P_{50} and P_{90};
[20] http://www.knmi.nl/climatescenarios/knmi06/index.php;
[21] For the climate scenarios for the Netherlands developed in 2000 also one or more methods were developed to generate time series for the future by other organisations than KNMI. However, those methods were not easily accessible;
[22] The description of version 0.0 of the transformation tool for precipitation in the Scientific Report (Van den Hurk et al., 2006) contains some errors. In Chapter 2 of this report the correct description is given.

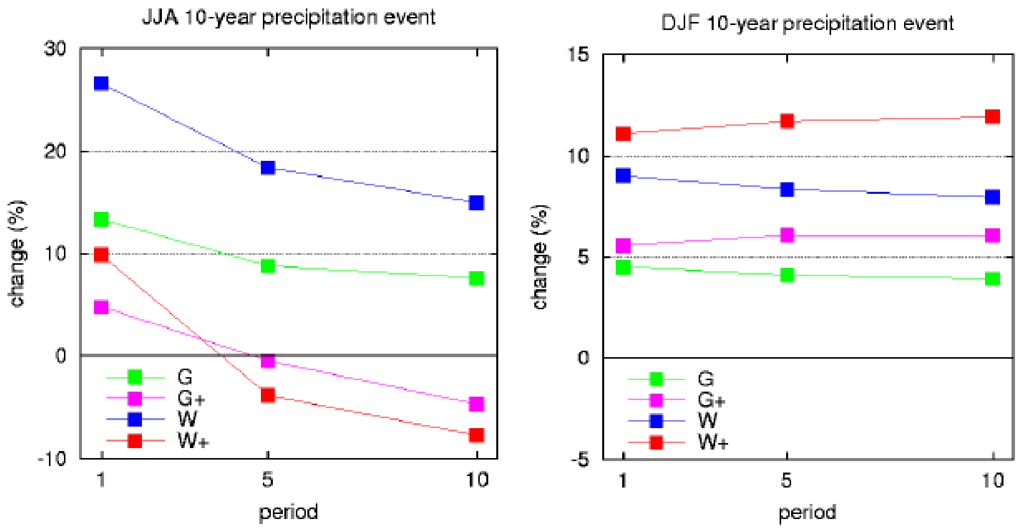


Figure 3.1 Relative changes (%) in precipitation intensity for 1-day, 5-day and 10-day precipitations sums with a return period of 10 years for each of the KNMI'06 scenario's. Left: summer (JJA); Right: winter (DJF). Calculations are based on observations for 13 stations in The Netherlands (Source: Van den Hurk et al., 2006).

Used in:

- The estimation of changes in extremes consistent with the KNMI'06 climate change scenarios (Van den Hurk et al., 2006);
- First estimation of climate indices consistent with the KNMI'06 climate change scenario's like the number of summer and tropical days, rainfall in winter, number of days with 10 mm or more on the website[23].

3.3. Preliminary year-round versions

Version -1.0 (March, 2006)

Prior to the publication of the KNMI'06 climate scenarios, preliminary data on climate change throughout the year were provided to RIZA and RIKZ, in order to give them the opportunity to do fast and preliminary analyses of impacts with the KNMI'06 scenarios for flood defenses and fresh water supply. For this purpose, changes in means for the 36 decades of days[24] year-round were supplied for precipitation (relative change), temperature (absolute change) and reference evapotranspiration (relative change). For spring and autumn linear interpolation between the values for summer and winter was used (Figure 3.2 "Preliminary (March 2006)").

[23] Currently this website (http://www.knmi.nl/klimaatscenarios/knmi06/gegevens/neerslag) contains data generated with version 1.2 of the precipitation transformation tool and version 1.2/2.0 of the temperature transformation tool;

[24] For this purpose each months is divided in 3. The first 2 periods contain always 10 days and the third period contains the remaining (8, 9, 10 or 11) days.

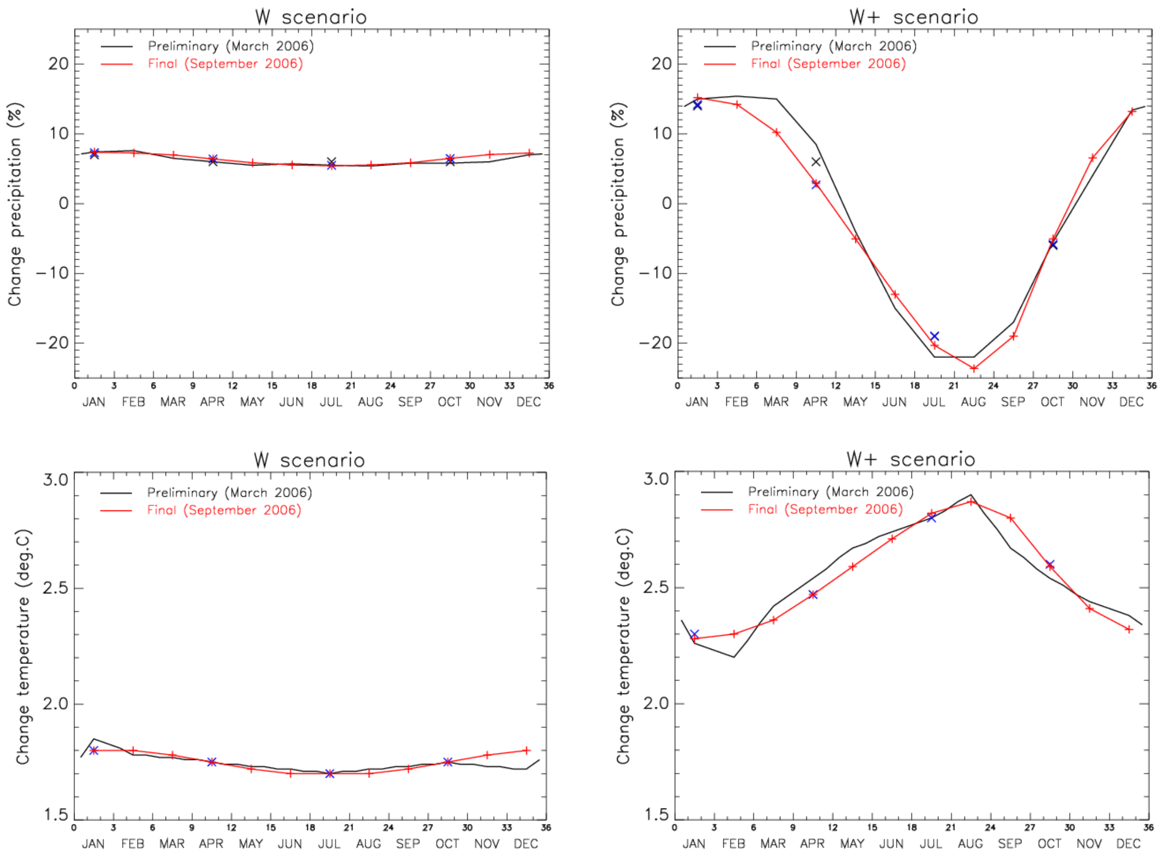


Figure 3.2 Changes around 2050 compared with 1976-2005 in average monthly or 10-day average precipitation (top) and average temperature (bottom) throughout the year in version -1.0 ("preliminary version March 2006") and version 1.0 (January 2007, but based on the document "KNMI'06 scenarios: interpolation to monthly changes" from G. Lenderink, September 2006; see Annex 1). Values for the scenarios W and W+ are shown. The values for G and G+ are 50% of the values for W and W+, respectively.

This version was never published on the KNMI website nor were data generated with this method for the KNMI website.

Used in (among others):

- Several climate change impact studies on changes in mean and extreme discharges of the rivers Rhine and Meuse (Van Deursen, 2006; Te Linde, 2007; De Wit et al., 2007[25]);
- Study on impact of climate change on cooling capacity of major water bodies in the Netherlands (Kallen et al., 2008).

Version 1.0 (January, 2007)

Soon after the on-line publication of version 0.0 for only winter and summer, users from especially the water sector asked for the development of such a tool for "year-round" time series. This was done as part of the "tailoring-project" (CS7).

For this year-round version 1.0 interpolation methods have been developed (Annex 1). These methods deviate slightly from the preliminary interpolation used for version -1.0 (see Figure 3.2). The methodology was applied to derive monthly change factors[26].

[25] Fully based on publications (Te Linde, 2007 and Van Deursen, 2006);
[26] In 2008, it appeared that some of the derived monthly change factors were incorrect (slight deviation from the correct values; Annex 5). These were adjusted in version 1.2.

This version 1.0 has not been published on the KNMI website[27], nor data were generated with this method by KNMI, however it has been sent to a limited number of users between January 2007 and the publication of the next version 1.1 in the summer of 2007. Soon after the development it appeared that this version produced unrealistically large changes for a number of stations on some days with extreme precipitation in the historical time series (Figures 4.3 and 4.4).

Used in (among others):

- One of the CS7-tailoring pilots on agro-hydrological impacts for the Betuwe (Droogers et al., 2008);
- Study on extreme summer rainfall in 2006 and in future (Groen, 2007).

3.4. Enhanced wet-day adjustment

Version[28] 1.1 (July, 2007)

The procedure as used in version 1.0 for precipitation appeared to result in extreme changes (sometimes more than 100%) for already extreme observed precipitation amounts (Figures 4.3 and 4.4). Since such changes are unrealistic and may hamper hydrological simulations, various options were considered to overcome this problem. Finally, it was decided to set the relative change of events rarer than the 99th percentile per calendar month to the relative change of this 99th percentile per calendar month.

In addition, the procedure to adjust the wet day frequency (*F;* a wet day is defined as a day with ≥ 0.05 mm) was changed. In version 1.1, wet days were selected for "drying" on the basis of their rank of their precipitation amounts rather than on chronology (for more information see Chapter 2). This was done to minimize changes in the probability density function (PDF) of the remaining wet day amounts.

Figure 3.3 The 13 precipitation stations[29] used to determine the coefficients in the transformation of precipitation.

[27] A hidden version (with no links from other KNMI-web pages) was available some time before the publication of version 1.1;

[28] The temperature transformation has not changed between versions 1.0 and 1.1;

[29] The 13 precipitation stations used are (Figure 3.3) 11=West Terschelling; 25=De Kooy; 139=Groningen; 144=Ter Apel; 222=Hoorn; 328= Heerde; 438=Hoofddorp; 550=De Bilt; 666=Winterswijk; 737=Kerkwerve; 745/770= Axel/Westdorpe; 828= Oudenbosch; 961=Roermond.

The 99th percentile of wet days per calendar month (P_{99}) in version 1.0 was estimated on the basis of a small number of large observations in the time series of interest. Therefore, the value could be strongly influenced by coincidental high observations. Less spatial variability in P_{99} was preferred, and for that purpose it was decided to derive one general transformation on the basis of 13 precipitation time series (Figure 3.3) as made available by ECA&D in 2006 (Klok and Klein Tank, 2008).

This version was published on the KNMI website in the summer of 2007.

Used in (among others):

- Provincial climate effect atlases (Stuyt et al., 2007; KNMI/Alterra/DHV/VU, 2008)[30].

Version 1.2 (April, 2008)

In April 2008 a slightly adapted version of the transformation tool was published on the internet[31] (version 1.2). The interpolation to monthly values as developed for version 1.0 appeared to be incorrectly applied. The differences, however, are very small (Annex 5). Errors in the absolute temperature changes are less than 0.10 °C and the errors in change factors for precipitation are usually less than 1%. The largest errors (~3.5%) are found for the change factors for P_{99} (May and October) in the W scenario. Also the procedure to change the number of wet days (*F)* in the precipitation series was adapted. The adjustment of *F* in versions 1.0 and 1.1 caused a serious decrease of the autocorrelation. Since the KNMI'06 climate scenarios do not have any statements about changes in autocorrelation, we tried to avoid a large change in the autocorrelation structure (for more detailed information see also Chapter 2).

In 2008 the transformation coefficients were recalibrated with the combined time series[32] of the 13 stations in the Netherlands, rather than with the slightly different ECA&D data that were used in version 1.1. The coefficients, however, hardly changed by the application of the complete time series data (not shown).

Used in (among others):

- In different peer reviewed jounal papers; about the salanisation of artificial lakes in the Netherlands (Bonte and Zwolsman, 2010); about climatic extremes and their influence on arable land (Schaap et al., 2011); about the affect on vegetation (Bartholomeus et al., 2011a,b,c);
- Climate Sketchbook ("Klimaatschetsboek Nederland"; KNMI, 2009b)[30];
- Study on the effectiveness of the application of meteorological standard years in hydrological simulations (Bakker et al, 2009; 2011).

Version[33] 2.0 (February, 2009)

In 2008-2009 KNMI worked on a project together with KMI (Royal Meteorlogical Institute of Belgium) and KU-Leuven (Katholieke Universiteit Leuven) to produce climate scenarios for Flanders (KMI/KU Leuven/KNMI, 2009). In Flanders no official climate scenarios are available. Flanders is contiguous to the Netherlands and in the analyses for the KNMI'06 climate scenarios also data from the climate projections for a large part of Belgium (including Flanders) were used. Therefore, the KNMI'06 scenarios could also be used for Flanders. However, in Flanders the range in yearly average precipitation is larger than in the Netherlands, and also the yearly amplitude is somewhat different. The coefficients in the precipitation transformation tool (implemented from version 1.1 on) were tuned to 13 Dutch stations. Therefore, the precipitation transformation tool should be tuned to the

[30] http://www.knmi.nl/klimaatscenarios/maatwerk/ro/;
[31] Data under http://www.knmi.nl/klimaatscenarios/knmi06/gegevens/index.html for temperature and precipitation are generated with this version (checked April 2011);
[32] See also Annex 3 "A3.5. Changes per April 10, 2008";
[33] The temperature transformation has not changed between versions 1.2 and 2.0.

climatological conditions in Flanders. At the same time a slightly different approach was developed. This was necessary since the variation over the year in average and extreme precipitation differs between the coastal and inland areas (also in the Netherlands[34], but more pronounced in Flanders).

The estimation of the 99th percentile (P_{99}) of the daily precipitation per calendar month in this version differs from that in version 1.2 and before. For every calendar month, the ratio P_{99}/P_{mean} is relatively stable throughout the Netherlands, although the monthly mean precipitation can differ. The same is true for Flanders, but the ratios differ slightly from those in the Netherlands. Therefore, in this version P_{99} was estimated by multiplying P_{mean} by the fixed ratio per calendar month[35]. The coefficients *a* and *b* in the transformation procedure were determined iteratively per station, as in the version 0.0 and 1.0 (for more details see Chapter 2).

This version has not been published on the KNMI website until now (the publication of this report).

Used in (among others):
- Climate scenarios for Flanders ((KMI/KNMI/KU Leuven, 2009);
- Delta Model (Homan et al., 2011a; Homan et al., 2011b).

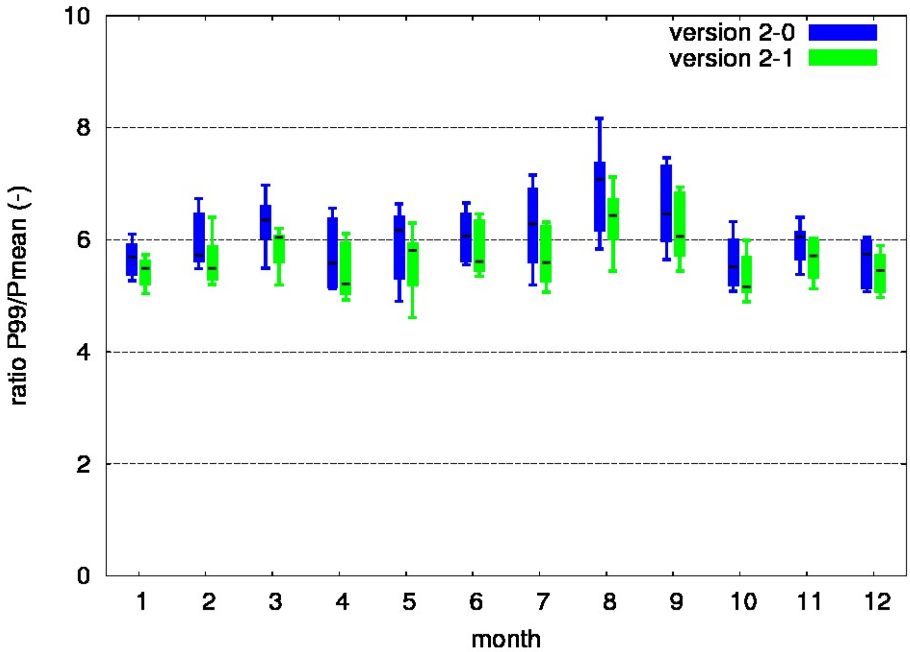


Figure 3.4 Ratio (*d*) between P_{99} and the average rainfall on wet days (P_{99}/P_{mean}; y-axis) per calendar month (x-axis) for the period 1976-2005 for 13 stations in the Netherlands. The boxplots represent the range of the ratios for 13 stations per calendar month. The black horizontal lines indicate the median value, the vertical blocks represent the values between the 25th and 75th percentiles and the thin vertical lines represent the values between the 10th and 90th percentiles.

Version 2.1 (2012)

During the writing of this report a small error was detected in the way the 99th percentile was determined (April 2011): rather than determining the 99th percentile a slightly higher percentile was determined[36]. This will be corrected in the future version 2.1. Figure 3.4

[34] In earlier versions, before version 2.0, this difference is yearly cycle in the Netherlands was neglected;
[35] The version for Flanders differed in the ratios used per calendar month. Within the Netherlands or Flanders everywhere the same ratio was used per calendar month;
[36] In the temperature transformation the same error may occur, but the effect will be less pronounced than in the precipitation transformation.

shows the effect of this error on the ratio between the 99th percentile and the mean precipitation on wet days (P_{mean}). Since this is a future version it has not been used yet in any project, nor has it been published on the internet.

3.5. Special versions

"Multisite" versions

For several of the above mentioned versions a "multi-site" version was made. These versions can read time series of many stations at the time as input, but transform each time series independently. These "multi-site" versions were not published online, but they were used to produce e.g. the datasets for the climate sketchbook and the Delta model.

Transformation of temperature for the WX-scenario

At the end of 2008, after the publication of "De toestand van het klimaat 2008" (KNMI, 2008) with information about the faster temperature increases in western Europe compared to the data in the KNMI'06 climate scenarios, a more extreme climate scenario was developed for the energy sector. This WX scenario is only valid for a time horizon until 2020-2030, and was based on an extrapolation of historical trends in temperature only. Version 1.2 with adapted input files was used to generate temperature time series for this scenario. It was not made available online for a broad public.

4. Exploring the various versions

In this chapter the various analyses that were performed during the development of the transformation tool are presented. Most analyses concern the precipitation transformation. In each section it is mentioned which versions are compared (see Table 3.1 and 3.2).

Climate scenario W+ for time horizon 2100 shows the largest changes in average precipitation and in the number of wet days per calendar month. Therefore, effects of differences in the transformation procedure are often largest in this scenario. This is why this scenario is used frequently in the analyses below. Scenario W shows the largest change in extreme precipitation in summer and is therefore also used frequently. In the analyses in this chapter in all versions the change factors, as applied in versions 1.2 and further, were used.

4.1. Reproduction of the KNMI'06 change factors

The transformation tool aims to apply the change factors of the KNMI'06 scenarios to observed daily time series for temperature and precipitation. After temperature transformation T^f_{90}, T^f_{50} and T^f_{10} are very close to the desired values. Also the change in wet day frequency equals the KNMI'06 change factors (not shown).

Yet, the changes in wet day mean precipitation and the 99th percentile deviate slightly from the desired values, ΔP_{mean} and ΔP_{99}. These discrepancies vary with the calendar months and the various versions of the transformation tool.

The desired change ΔP_{mean} is well captured by the versions 1.0 and 2.0 (Figure 4.1), since the coefficient *a* (equations 2.5 and 2.6) is explicitly set to match this change factor. Versions 1.1 and 1.2, however, use general coefficients *a* and *b*, that were centrally estimated from 13 precipitation stations. Therefore, the relative change sometimes deviates.

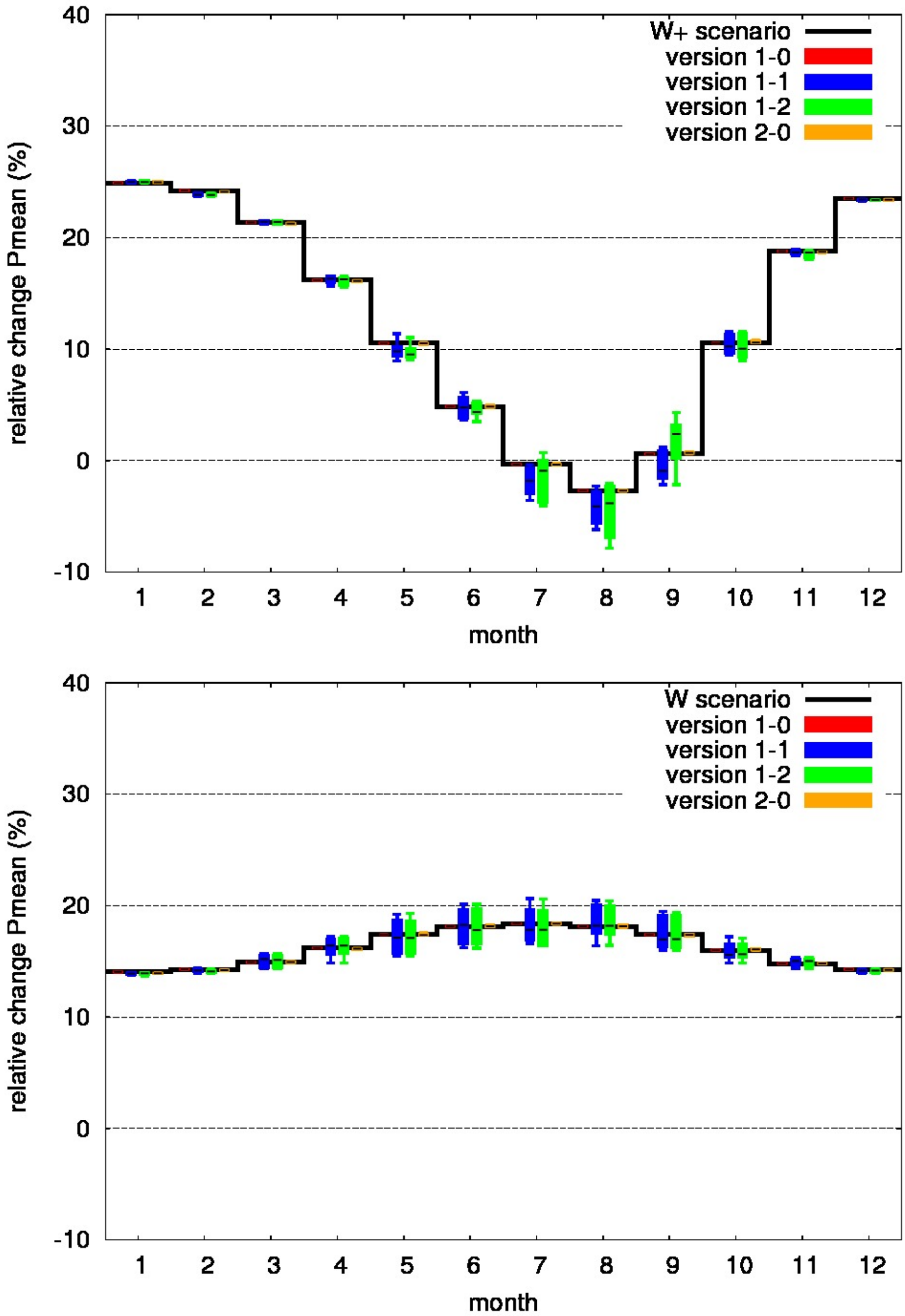


Figure 4.1 Relative change in the average precipitation on wet days (%) per calendar month for 13 stations in the Netherlands (Fig 3.3) for scenario W+ around 2100 (upper panel) and scenario W around 2100 (lower panel) compared to the historical period 1976-2005. The boxplots represent the range in the relative change for the 13 stations. The black line indicates the desired change according to the selected scenario. The black line segments in the coloured boxes represent the median of the relative change, the vertical blocks represent the values between the 25th and 75th percentiles and the thin vertical lines represent the values between the 10th and 90th percentiles.

The same applies for ΔP_{99}, although the relative change of P_{99} after transformation is systematically lower than the scenario values (as presented in Annex 5), especially in summer (Figure 4.2). This is mainly caused by the adjustment of the wet day frequency. This adjustment always slightly modifies the PDF of the precipitation amount on wet days, although it was designed to minimise this modification. Especially high quantiles, like the 99th percentile, are affected. Transformation according to the W+ scenario and time horizon 2100 generally lowers the 99th percentile ($P^*_{99} < P^c_{99}$) due to the large decrease in wet day frequency. As the coefficients *a* and *b* are estimated to change the original P_{99} by the desired change factor rather than P^*_{99}, the P^f_{99} is generally lower than the desired change factor (in the case of a large decrease of wet day frequency).

A second explanation is the incorrect estimation of the 99th percentile in all versions. As a result, ΔP_{99} is applied to a slightly too high quantile and the change in the correct P^c_{99} will, therefore, be slightly underestimated. This effect, however, is smaller than the previous effect.

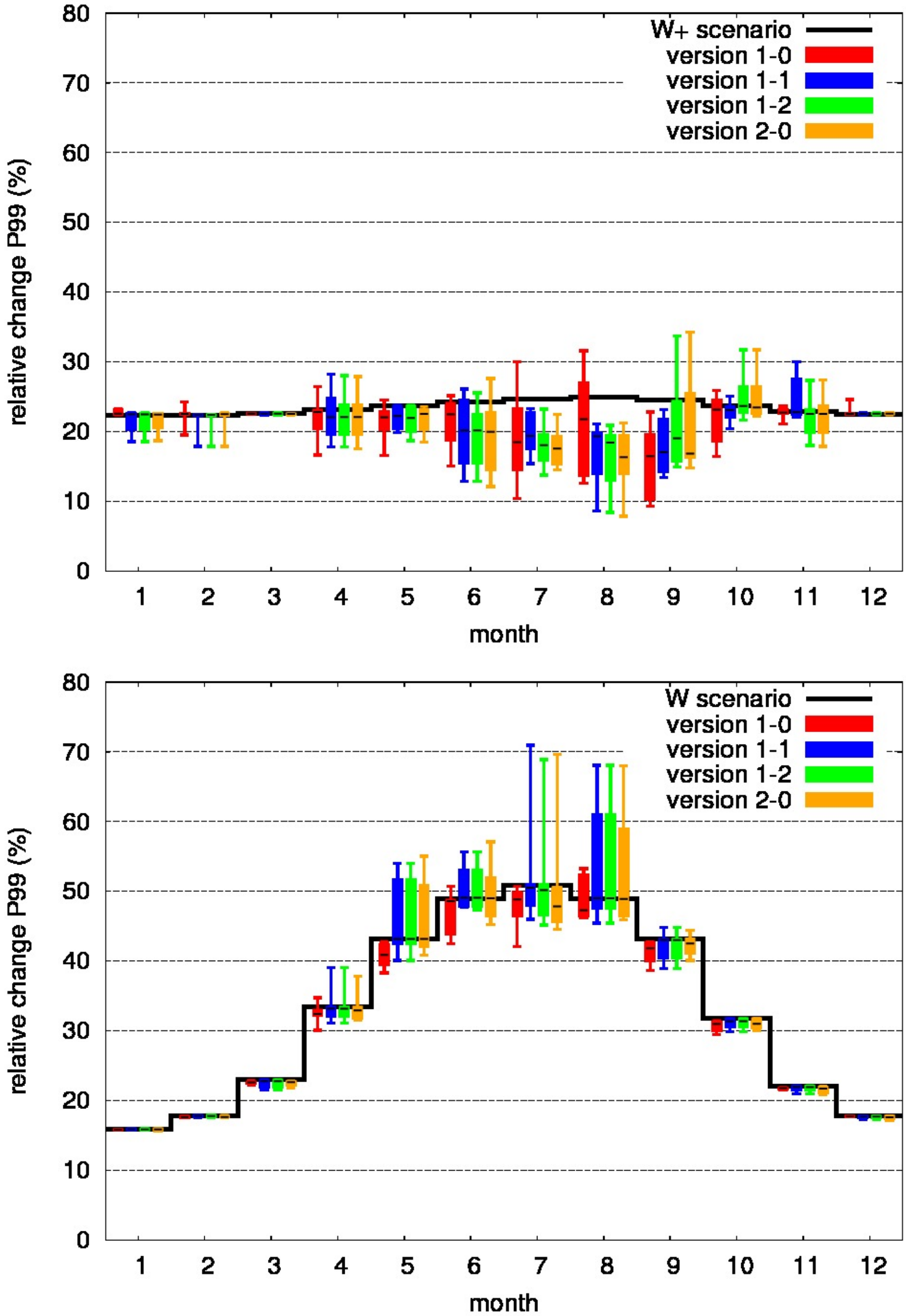


Figure 4.2 As figure 4.1, but for the relative change in the 99th percentile. Upper panel represents the W+ scenario around 2100 and lower panel the W scenario around 2100.

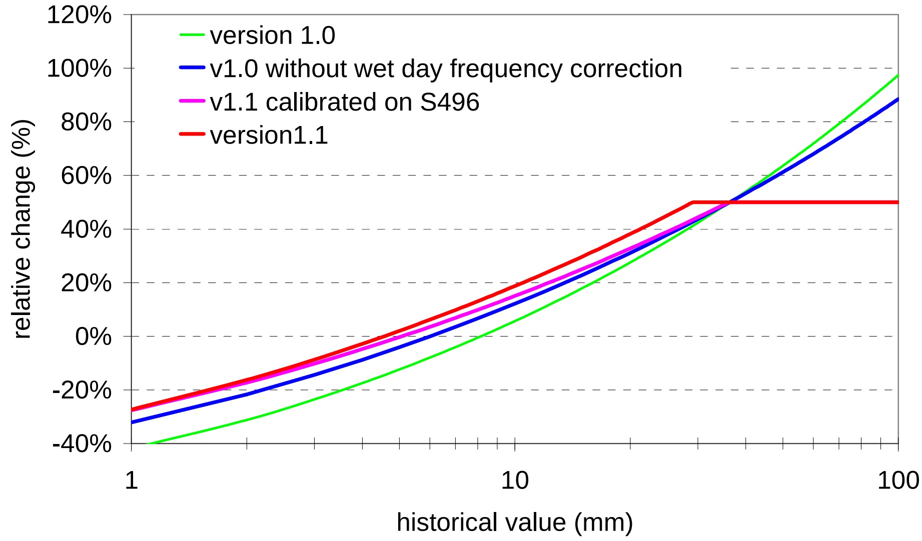
Change in monthly values for the precipitation transformation

In the beginning of 2008 some errors in the monthly coefficients were detected. In April 2008, version 1.2 with corrected values was published. In the tables in Annex 5 the change coefficients in versions 1.1 and 1.2 are compared. The differences for temperature are very small: only for a few cases the difference is 0.2 °C for 2050, but in most cases there was no difference. For precipitation the maximum error for the wet day frequency was 0.8% for the W-scenario around 2050, for the mean precipitation on wet days the maximum error was 0.4%, also for the W-scenario around 2050. For the 99th percentile the error was largest (maximum of 3.6% for the month of May in the W-scenario around 2050).

4.2. Controlling the change of the different percentiles

Limiting the relative change of precipitation larger than P_{99}

Version 1.0 showed sometimes very extreme changes in daily precipitation amounts larger than P_{99} (see Figure 4.3 and 4.4). Therefore, it was decided to limit the relative change of percentiles larger than P_{99} in version 1.1 and further.



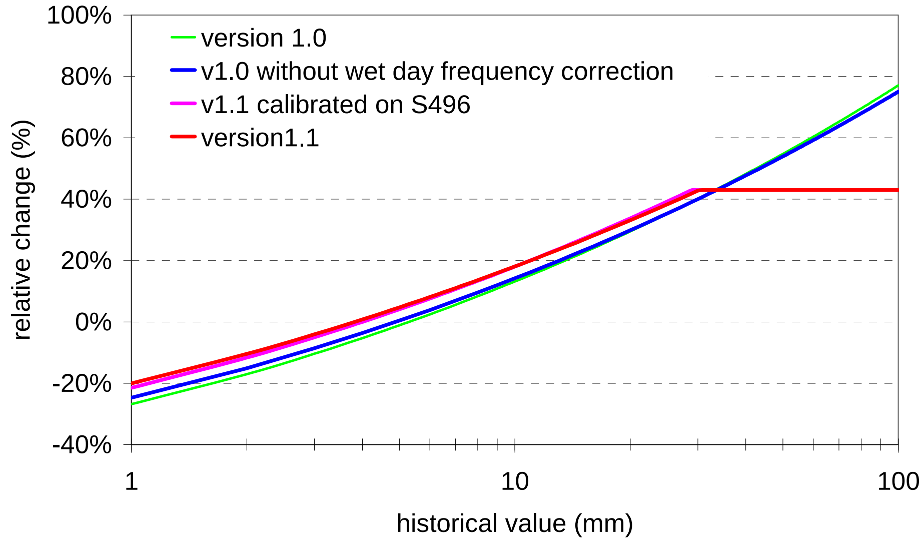


Figure 4.3 Relative change of historical precipitation per day in the months of July (upper panel) and September (lower panel) (1976-2005) for station West-Terschelling (code S496) for KNMI'06 scenario W around 2100 in four different versions of the transformation tool. Green = version 1.0; Blue = version 1.0 but without a correction for the wet day frequency (F); Pink = version 1.1 but with the coefficients calibrated for station S496 (and not the average of 13 stations); Red = version 1.1.

In Figures 4.3 and 4.4 the effect of this limitation is shown for two stations and two calendar months (compare the lines for version 1.0 and 1.1). As can be seen, this has potentially a large effect on the change of large observed precipitation amounts. Between version 1.0 and 1.1 a few more aspects were changed. Therefore, part of the differences may be due to these other changes between 1.0 and 1.1 as well. This is discussed in the following sections.

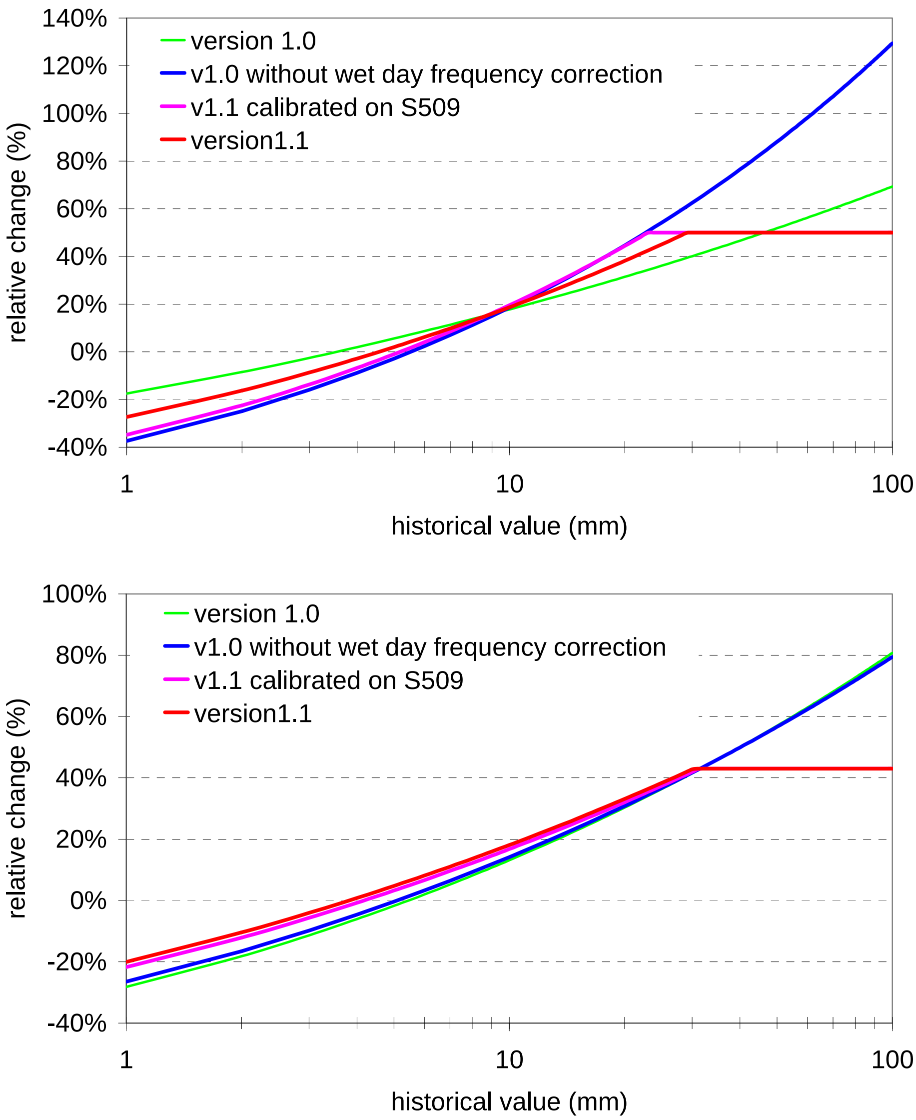


Figure 4.4 Relative change of historical precipitation per day in the month of July (upper panel) and September (lower panel)(1976-2005) for station Oudenbosch (code S509) for KNMI'06 scenario W around 2100 in four different versions[37] of the transformation tool. Green = version 1.0; Blue = version 1.0 but without a correction for the wet day frequency (F); Pink = version 1.1 but with the coefficients calibrated for station S509 (and not the average of 13 stations); Red = version 1.1.

[37] The difference between version 1.0 (green line) and version 1.0 without correction of the wet day frequency (blue line) for the months of July and September is due to the chronological removal of wet days, which can affect the probability density function.

Coefficients based on 13 stations in the precipitation transformation

In version 1.1 and 1.2 the coefficients *a* and *b* and P_{99} are based on the average of 13 stations in the Netherlands. Consequently, the time series per station do not represent exactly the changes in precipitation as mentioned in the KNMI'06 scenarios. In Figures 4.3 and 4.4 the relative changes in daily precipitation for two stations in two calendar months are presented (compare "version 1.1" and "v1.1 calibrated on S509/S496"). Station West-Terschelling is used because a very high precipitation sum of 91.0 mm was observed on July 19 in 2001. At Station Oudenbosch a very high precipitation sum of 95.3 mm was observed on September 14 in 1998. The figures show that the changes in daily precipitation values up to about 30 mm per day may differ between the two versions. Version 1.1 represents the changes with values for *a* and *b* based on the time series of 13 stations in the Netherlands. In "v1.1 calibrated on S509/S496" the values of *a* and *b* are determined iteratively for each station individually. In general, the differences are not very large. In the figures the difference is largest in July in Oudenbosch (max 7.5 %), but in September the differences are in all cases < 2.0 %.

4.3. The effect of the different versions of the wet day adjustment

Year-to-year variation

In versions 0.0 and 1.0 of the precipitation transformation wet days were removed, based on their chronological order. This means that in each year the relative change in the wet-day frequency (*F*) is more or less similar. From version 1.1 on the removal of wet days was based on the ranking of the precipitation amounts. By removing (and adding) wet days based on this ranking of precipitation amounts, the probability density function is hardly changed (Figure 2.3).

The year-to-year variation after transformation (Figures 4.5-4.7) mainly depends on the wet day adjustment. By removing or adding wet days based on the ranking method (versions 1.1 and higher), the change of number of wet days per year varies between years. In version 1.0, the "dried" days are almost equally distributed over the years. In version 1.1, the number of dried days varies slightly more between years than in version 1.0 due to the use of the ranking method. In versions 1.2 and 2.0 an additional criterion is introduced in the ranking method to preserve the temporal correlation structure: only removal of wet days at the beginning or end of wet periods. In dry years more rainy days satisfy this criterion. As a consequence, more days are "dried" than in the wet years. This makes that in most cases the year-to-year variation is enlarged in versions 1.2 and 2.0 compared to versions 1.0 and 1.1, especially in the case of a large change of the number of wet days (e.g. W+ scenario and time horizon 2100). For scenario W, where only a small number of wet days is removed in summer, the effect is very limited. Versions 1.2 and 2.0 have the same wet day adjustments (based on the ranking method + only removal at beginning of end of wet periods) and, therefore, almost similar year-to-year variation.

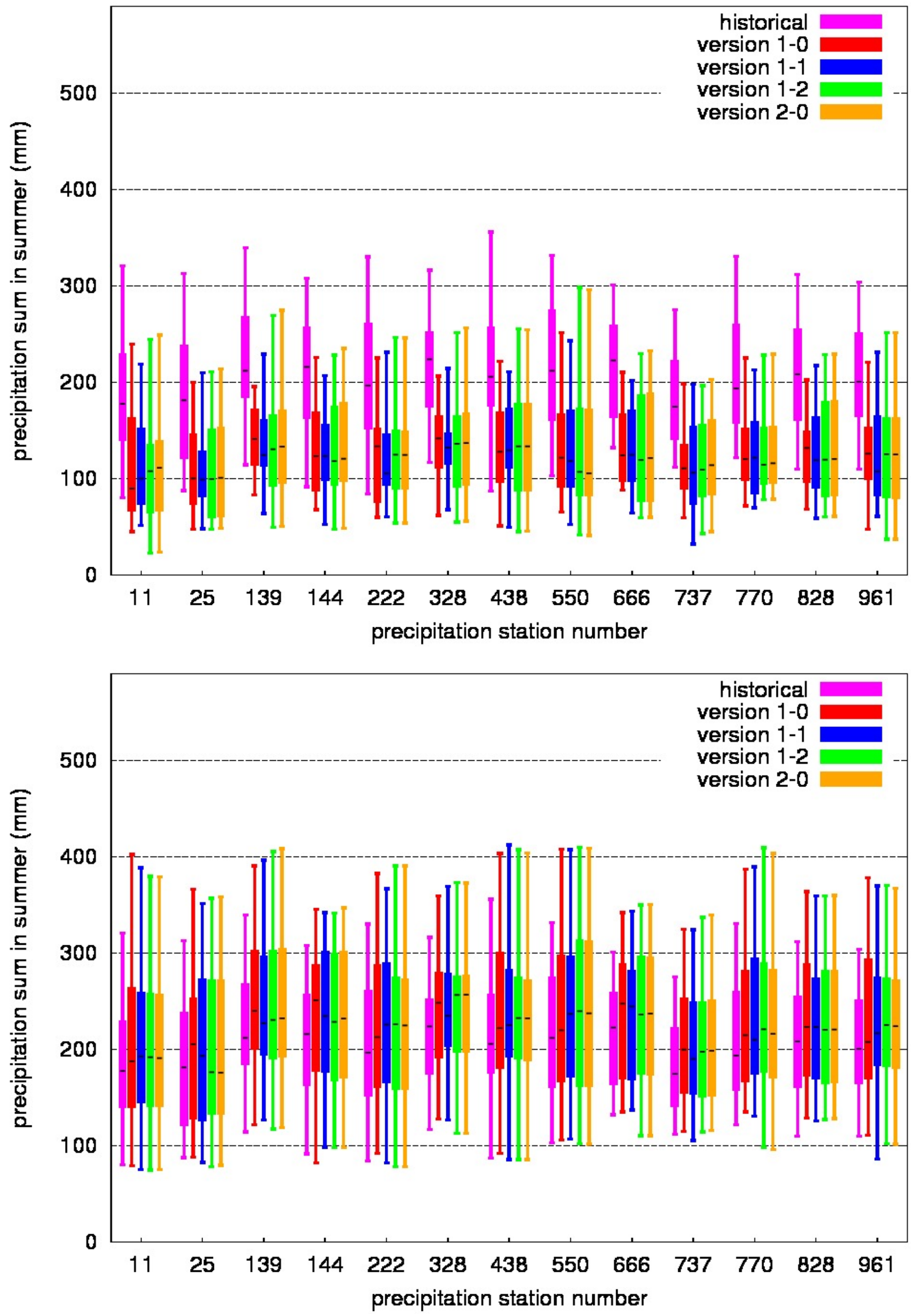


Figure 4.5 Year-to-year variation in total precipitation (mm) in the summer months June-August for scenario W+ around 2100 (upper panel) and for scenario W around 2100 (lower panel) compared to the historical period 1976-2005 (magenta boxes). The boxplots represent the range in 30 seasonal values: the black horizontal line presents the median value, the vertical coloured boxes represent the values between the 25th and 75th percentiles, and the vertical lines present the values between 5th and 95th percentiles. Presented is the range for 4 versions of the precipitation transformation tool for 13 Dutch stations (x-axis).

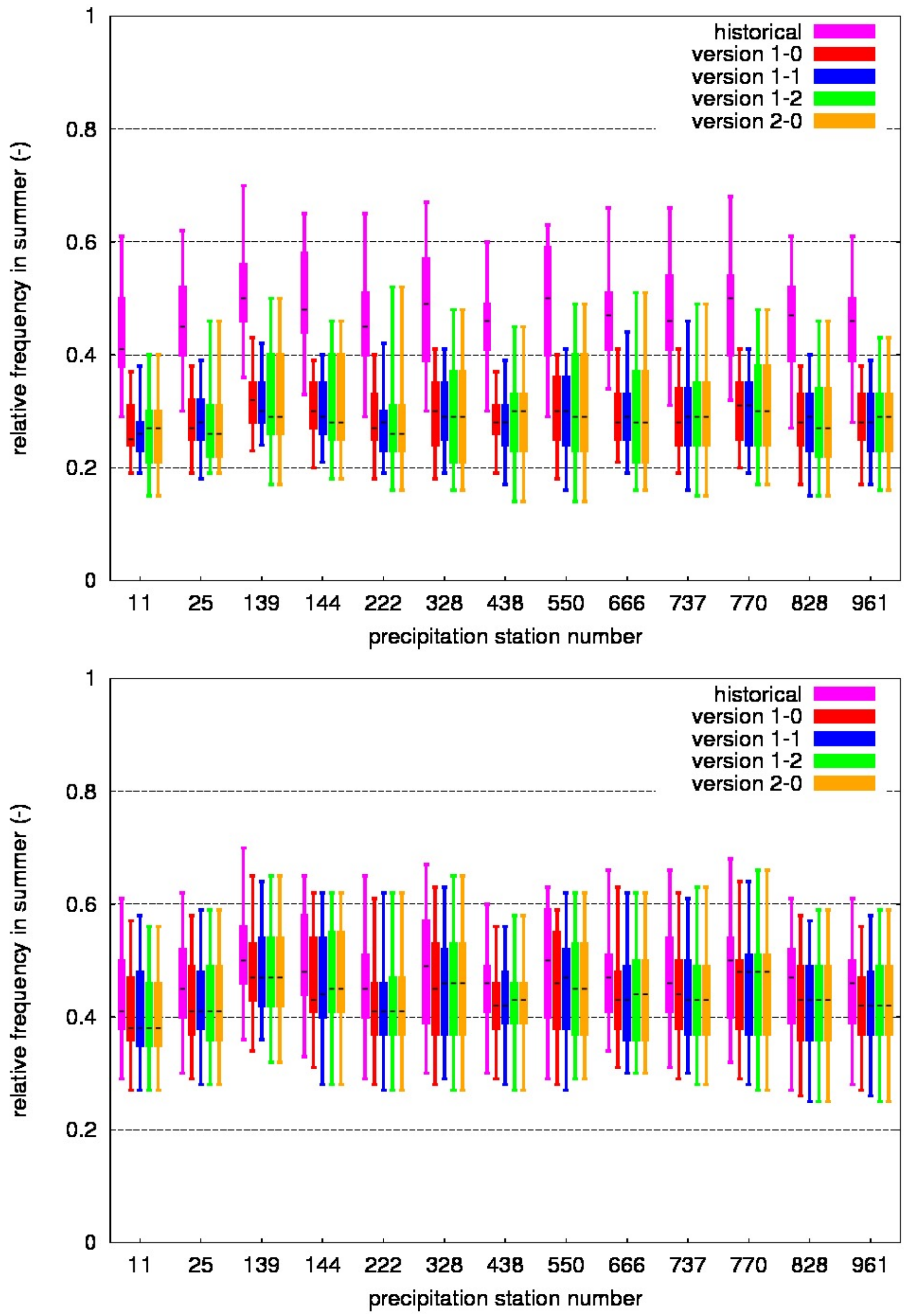


Figure 4.6 As figure 4.5, but for the year-to-year variation of the wet day frequency in the summer months June-August for scenario W+ around 2100 (upper panel) and for scenario W around 2100 (lower panel) compared to the historical period 1976-2005.

Figure 4.7 shows the effect of the wet day removal on the year-to-year variation of the maximum length of dry spells. For scenario W+ the mean and the variation in the longest dry spell per year increase considerably. This increase is largest for the transformation with versions 1.2 and 2.0 for most stations. For scenario W, where only a small number of wet days is removed in summer, the effect is very limited.

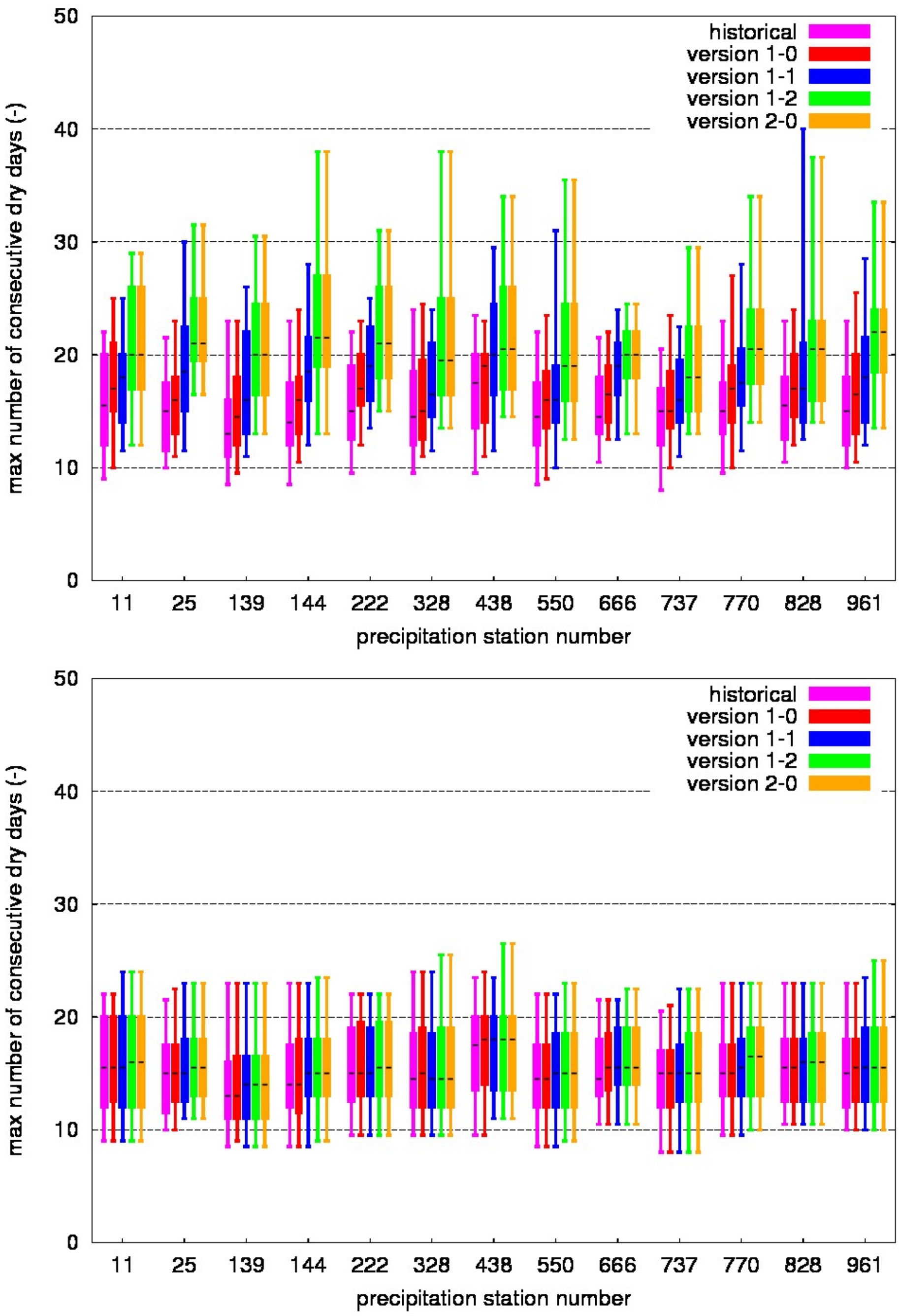


Figure 4.7. As figure 4.5, but for the year-to-year variation of the maximum length of a dry spell (number of consecutive days without precipitation per year for scenario W+ around 2100 (upper panel) and for scenario W around 2100 (lower panel).

In the case of chronological wet day removal (version 1.0), the increase of the length of dry spells is limited to a few days. Only if a single wet day between two dry periods is removed a considerable increase of the length of dry spells is possible. In version 1.1 it is possible that two or more successive wet days are dried. In version 1.0 this is not possible, except for situations where the last day of a month is dried and the first day of the next month. In versions 1.2 and 2.0, all wet day removals cause an extension of the neighbouring dry spell or even a merge of two dry spells. So, it is likely that the length of the longest dry spell per year increases as well. Therefore, both the mean and the variation of the maximum number of consecutive dry days per year increase in these versions. The increase is largest in the W+ scenario.

Temporal correlation

Figure 4.8 shows the lag 1 and lag 2 autocorrelation of daily precipitation in summer derived from the observed and transformed time series. Version 1.0 and 1.1 did not explicitly try to preserve the autocorrelation structure, which results in a huge decrease in autocorrelation (Figure 4.8).

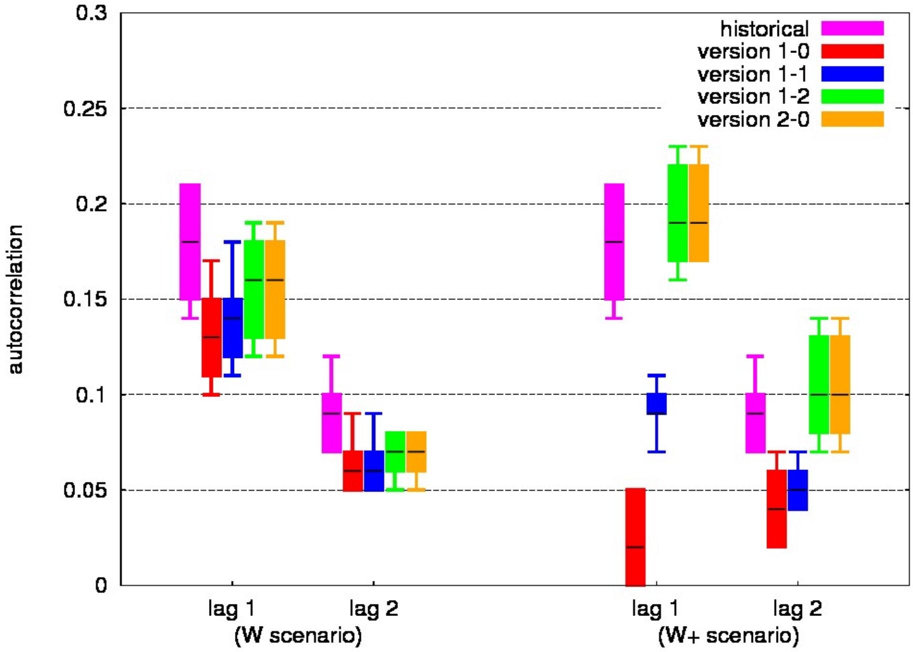


Figure 4.8 Boxplots of the autocorrelation of daily precipitation in summer (June-August), for the 13 Dutch precipitation stations for observed and transformed time series (W and W+ scenario and time horizon 2100). Shown is the correlation between two consecutive days (lag 1) and between days that are separated by one day (lag 2). The boxplots represent the range in autocorrelation of 13 stations: the black horizontal line presents the median value, the vertical blocks present the values between the 25th and 75th percentiles, and the vertical lines present the values between 10th and 90th percentiles.

For 2100, the W+ scenario gives a decrease in wet day frequency (*F*) of almost 40% in summer (31%, 40% and 45% for June, July and August, respectively). Chronological wet day removal (version 1.0) makes that a sequence of two successive wet days is hardly possible in the transformed series for scenario W+. This reduces the lag 1 autocorrelation to almost zero (Figure 4.8). The effect is less pronounced for longer lag times. The autocorrelation structure in version 1.0 is highly unrealistic. It shows that the chronological wet day adjustment is not suitable for time series transformation.

The wet-day adjustment in version 1.2 and higher is designed to change the autocorrelation structure as little as possible (no information is given in the KNMI'06 scenarios on the change of autocorrelation). The changes are indeed small compared to the historical period (Figure 4.8). In the W+ scenario, the autocorrelation slightly increases. This is caused by the fact that single wet days get scarcer after the wet day correction.

Spatial correlation

The transformation decreases the spatial correlation between stations, since this transformation does not take into account precipitation time series of other (nearby) stations. Figure 4.9 compares the spatial correlation of daily precipitation of 13 stations in transformed time series with the spatial correlation in the historical time series for 1976-2005.

Generally, the spatial correlation in version 2.0 is closest to the correlation of the historical time series, and version 1.0 shows, generally, the largest decrease in spatial correlation after transformation (Figure 4.9, left panels). Both decreases and increases of the wet day frequency (*F*) lead to a decrease of the spatial correlation between time series of different stations. In versions 1.0 and 1.1 all wet days are available for removal. Therefore, wet day removals are completely independent. In the versions 1.2 and 2.0, the wet days available for drying are limited to those at the beginning and end of wet periods. In the historical time series wet periods of different stations will overlap partly. This means that after the wet day removal this will still be the case. Therefore, the spatial correlation structure is better reproduced in these versions.

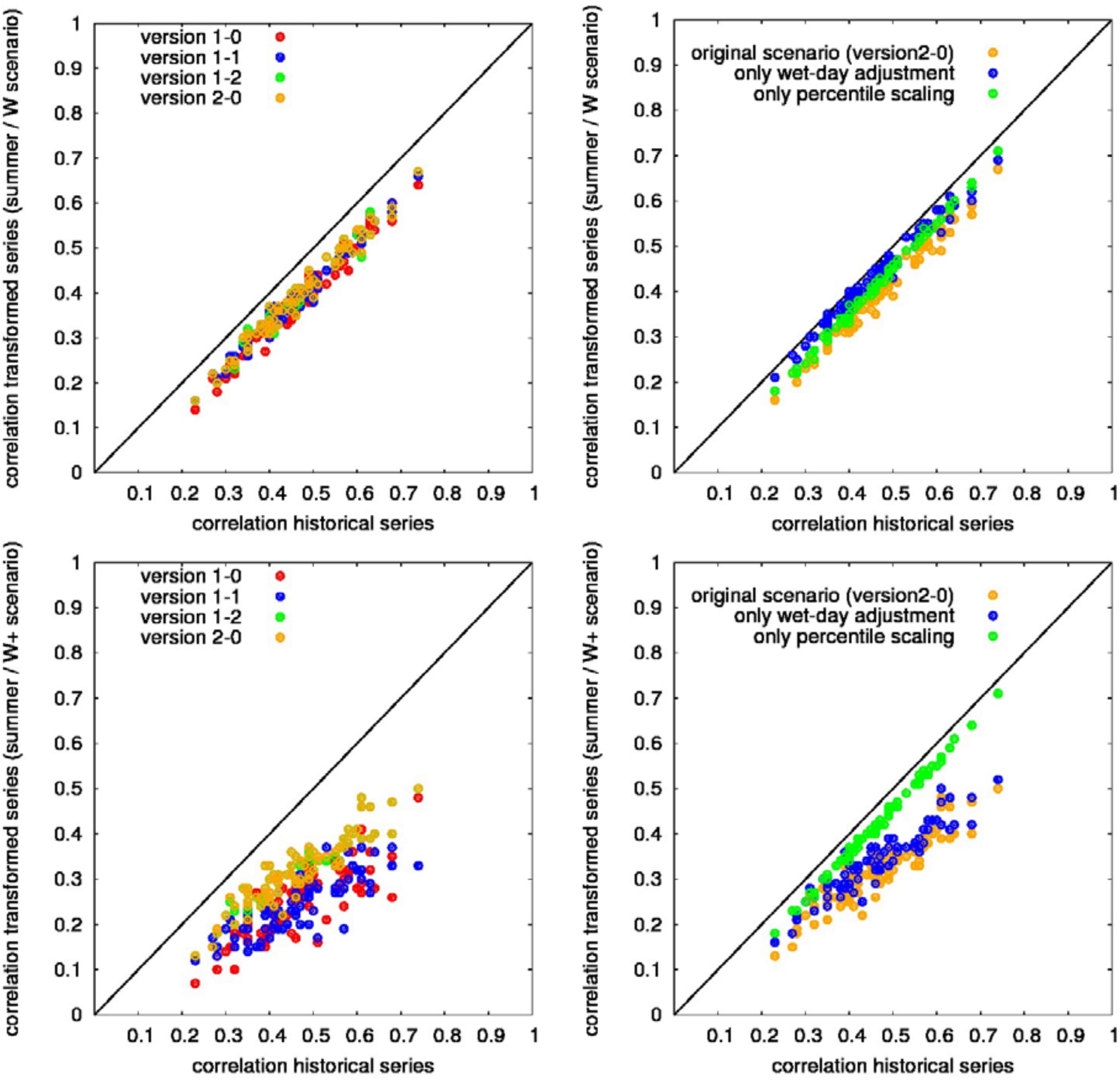
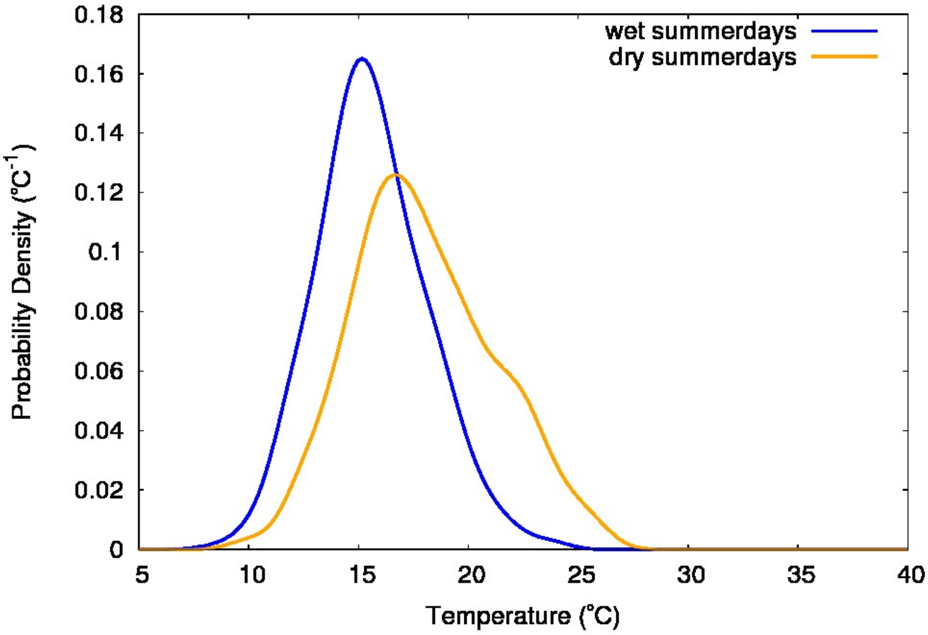


Figure 4.9 Comparison of spatial correlation between daily precipitation in summer (June-August) in observed (x-axis) and transformed time series (y-axis). Each dot represents a unique combination of 2 of the 13 investigated stations. Upper panels represent the W scenario and the lower panels the W+ scenario, all for the time horizon 2100. In the left panels the different versions of the transformation tool are compared (each represented by different colours). The right panels refer to version 2.0 with the individual contributions of both steps in the transformation: wet day adjustment and adjustment of the precipitation amounts (percentile scaling).

The adjustment of the precipitation amounts on wet days also contributes to the decrease in spatial correlation (Figure 4.9, right panels). The panels show the decrease according to transformation with version 2.0 (orange dots) and according to the individual contributions of both steps of the transformation tool (wet day adjustment (blue) and adjustment of the precipitation amounts on wet days (green)). For the W-scenario, the contribution of the adjustment of the precipitation amounts on wet days appears larger than the wet-day adjustment. For the W+ scenario, with a large reduction of the number of wet days, the effect of the wet-day adjustment is dominant.



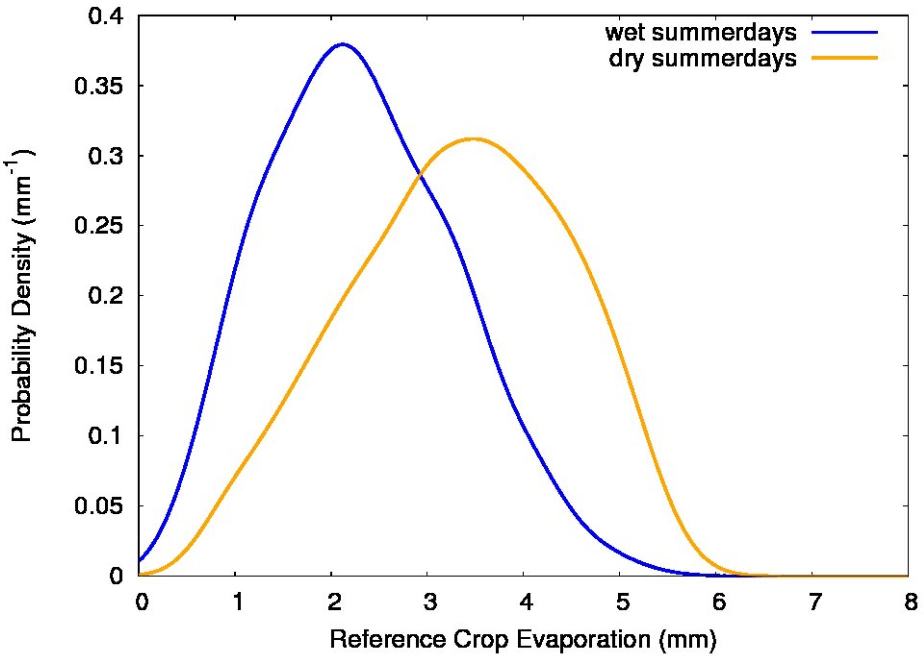


Figure 4.10 Probability density function of the mean temperature (upper panel) and the daily crop reference evapotranspiration according to Makkink (lower panel) in De Bilt on dry and wet days in summer (June-August) in the historical period 1976-2005.

4.4. Relation between climate variables

Dry days in summer are on average warmer and experience more potential evapotranspiration (*PET*) than wet days (Figure 4.10). Drying wet days during the transformation will, therefore, slightly shift and transform the probability density functions of the daily mean temperature (PDF-T) daily *PET* (PDF-PET) on dry days (Figure

4.11). Yet, this shift and transformation of the PDF-s due to the drying of wet days is very small compared to the effect of the adjustment of *T* and *PET* for time horizon 2100 according to the W+ scenario on the PDF-s (Figure 4.12). This means that the adjustment of wet days only has a limited effect on the relation between daily temperature, daily precipitation and daily crop reference evaporation. Note that the different versions of precipitation transformation give very similar results.

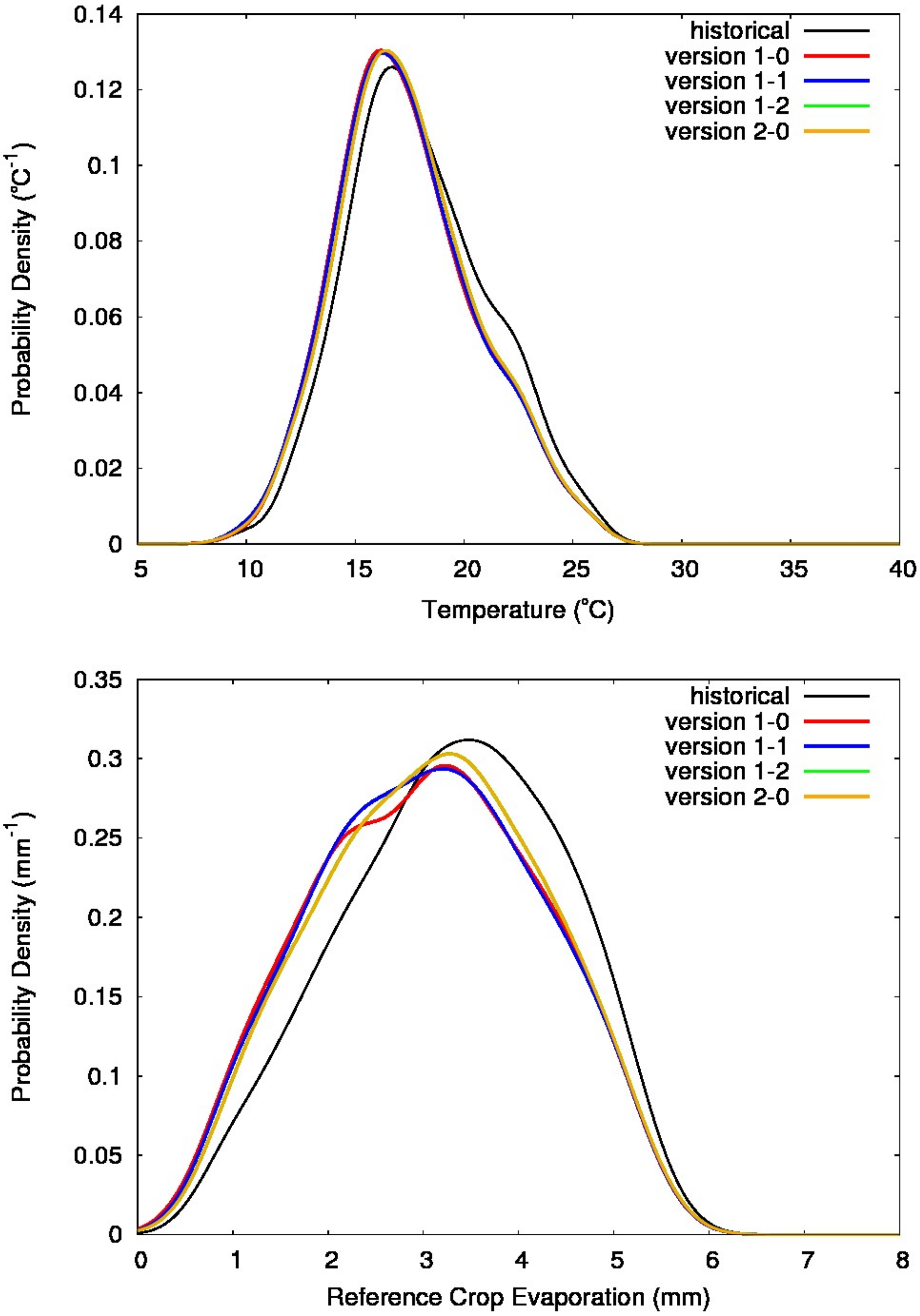


Figure 4.11 Probability density function of the mean temperature (upper panel) and the daily crop reference evapotranspiration according to Makkink (lower panel) in De Bilt on dry days in summer (June-August) in the historical period 1976-2005 and after transformation of the precipitation time series only according to W+ around 2100 (i.e. no transformation of *T* and *PET*). The wet day adjustment is performed according to the four versions of the precipitation transformation tool.

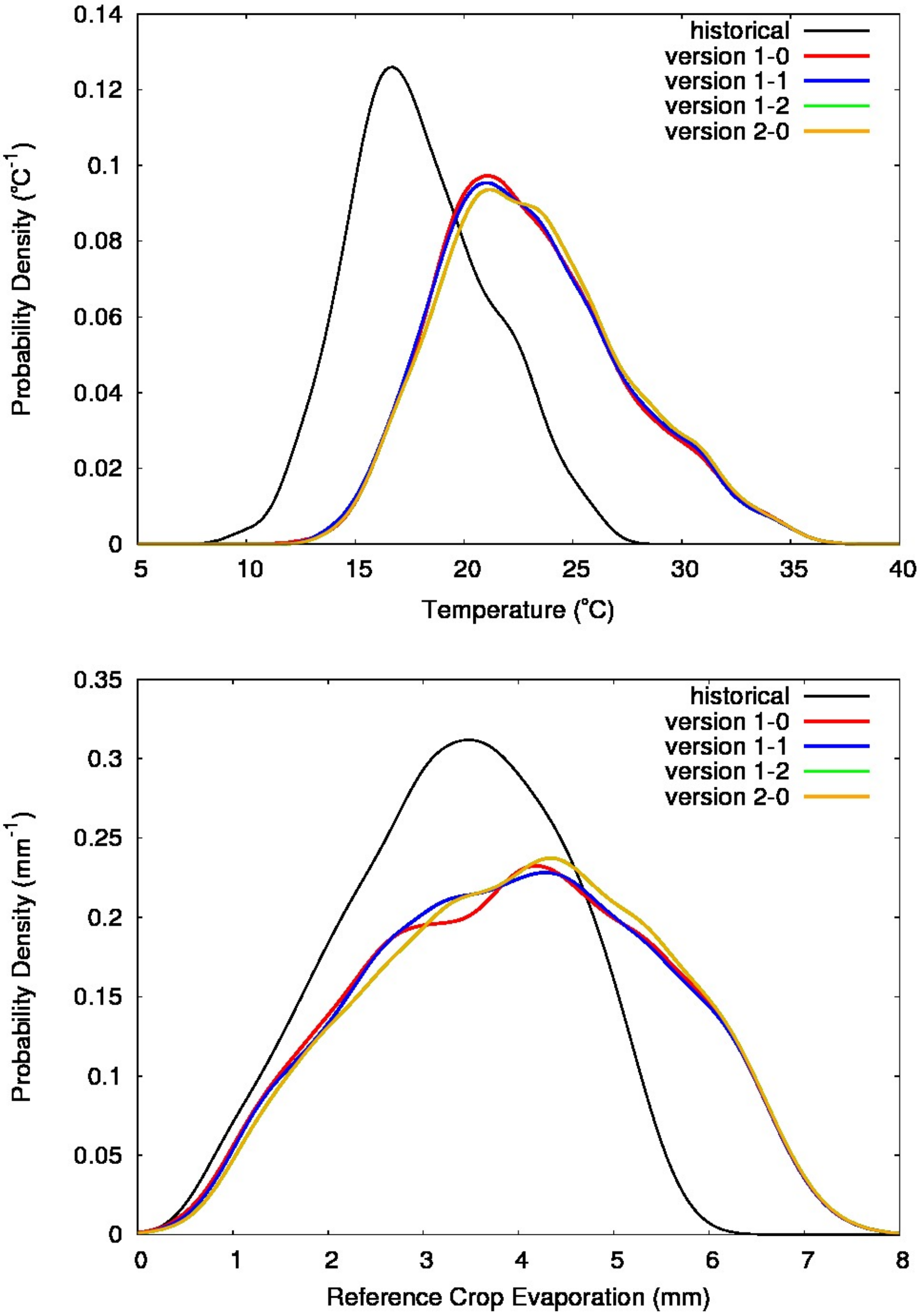


Figure 4.12 Probability density function of the mean temperature (upper panel) and the daily crop reference evapotranspiration according to Makkink (lower panel) in De Bilt on dry days in summer (June-August) in the historical period 1976-2005 and after transformation for the W+ scenario around 2100 of precipitation, *temperature and reference crop evaporation*. Four versions of the temperature and precipitation transformation tool are used.

4.5. Historical reference data

Estimating P_{99} from the average precipitation on wet days

For version 2.0 the ratio (d) of P_{99} and P_{mean} was determined per calendar month for the Netherlands and Flanders (KMI/KU Leuven/KNMI, 2009). Figure 3.4 shows the range of these ratios for the 13 stations used in the Netherlands. For Flanders slightly different ratios were used than in the Netherlands. By using a fixed ratio per calendar month the change of P_{99} may deviate from change factor belonging to the selected scenario and time horizon (Figure 4.2). For use outside the Netherlands, the ratios should be checked before[38]. For the Delta model version 2.0 was used, and it was checked whether the ratios in the river basins of the Rhine and Meuse[39] differed much spatially and whether they had to be adapted for use in these river basins (Homan et al., 2011a).

Figure 4.13 shows the ratio for the Rhine basin for the month of January (left panel) and for the month of July (right panel) - both on basis of the reference period 1961-1995 and area average data for precipitation. Both figures show that the ratio P_{99}/P_{mean} does not vary strongly within the river basin. Only in the extreme south-eastern sub region a clearly higher value in both January and July was found. The same was found for the other calendar months (not shown). In the Netherlands an average P_{99}/P_{mean} of 5.69 for the month of January is used, and for July a value of 6.20. In January most sub regions of the river basins have comparable or slightly higher values, but some sub regions also have slightly lower values. In July most sub regions in the river basins have values that are comparable or slightly lower than in the Netherlands. Large deviations are only found in the south-eastern sub region[40].

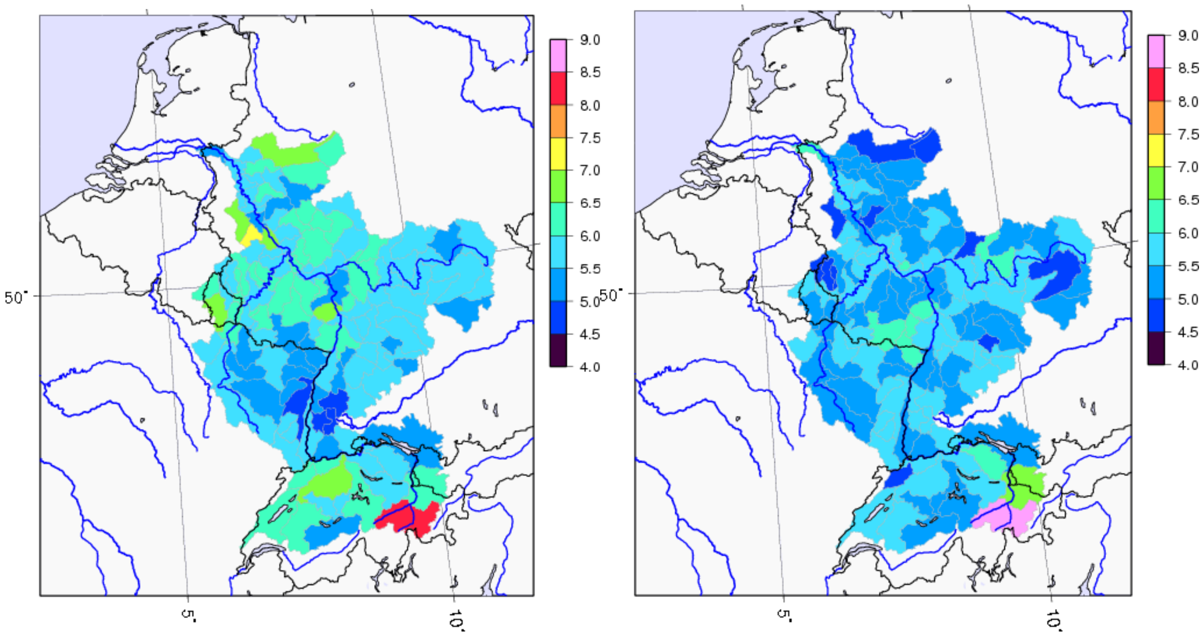


Figure 4.13 The ratio P_{99}/ P_{mean} for the sub regions in the river basin of the Rhine, for the month of January (left panel) and July (right panel).

Use of station data versus area average data

The KNMI'06 climate change scenarios do not explicitly state whether the precipitation change factors apply to point precipitation (as in observed time series) or area average precipitation (as in Regional Climate Model (RCM) output). Yet, the PDF of point precipitation differs from area-average precipitation and so, change factors could be different as well.

As an example, the average precipitation (arithmetic mean) of 3 stations in or close to the province of Zeeland (Kerkwerve, Westdorpe/Axel and Oudenbosch) has been transformed (with version 2.0), applying two different strategies. Note that the area-size is comparable to the typical grid size of RCMs used for the KNMI'06 scenarios. In the first strategy, the area-average (on a daily basis) was calculated prior to the transformation.

[38] It was not checked whether the ratios changed over time;
[39] The KNMI'06 scenarios were used in the whole river basin of the Rhine, although it is unlikely that they are also valid for Switzerland;
[40] Considering the results and the limited time available, it was decided to use the same ratios as for the Netherlands in the river basins of the Rhine and Meuse for the Delta model (Homan et al., 2011a).

In the second strategy, the individual time series were transformed prior to the area averaging.

Figure 4.14 shows the differences for both strategies. Shown are the quantiles of all summer data (wet and dry days) for the observed area-average and the transformed area-average according to the W+ scenario and time horizon 2100 for both strategies.

Averaging after the transformation (red line) reduces the decrease in the number of wet days: drying of wet days does not always occur on the same days for all stations. For the other strategy (transformation of area-average precipitation, blue line) it is implicitly assumed that drying of wet days occurs on the same day for the whole region. This causes the larger reduction in the number of wet days. This causes the difference in shape of the distribution on the left side of Figure 4.14 between the blue and red line. On the other hand, transformation of the area-average (blue line) gives much more extreme area-average rainfall events because all stations remain "wet" or all stations are "dried". This gives about 25% higher area-average precipitation for the higher quantiles (probability of non-exeedance ≥ 0.96).

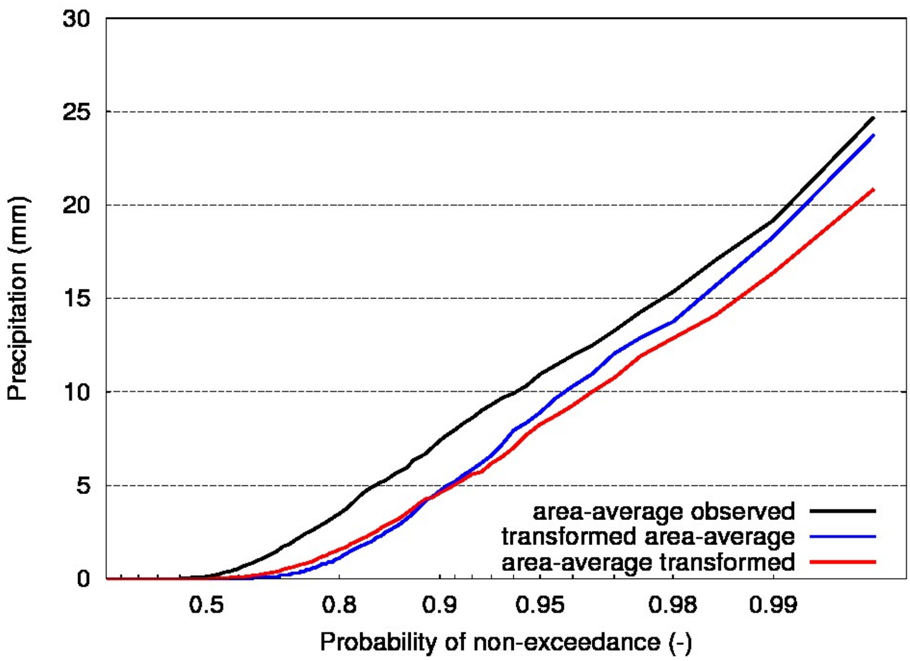


Figure 4.14 Quantiles of daily precipitation in summer (mm; June-August) of 3 stations in or close to the province of Zeeland (Kerkwerve, Westdorpe/Axel and Oudenbosch) for the historical period 1976-2005 (area-average observed) and transformed for W+ around 2100. Averaging before transformation = transformed area-average; averaging after transformation = area-average transformed.

Reference period: length and historical period

The KNMI'06 climate change scenarios provide a set of change coefficients for time horizons 2050 and 2100 with respect to the reference periode 1976-2005. Therefore, it is preferred to use reference time series that cover the period 1976-2005. Occasionally, studies deviate from this reference period as a consequence of owing to the limited data availability or the urge for longer time series, although the climatology of those alternative reference periods may be different (Table 4.1).

For instance, Homan et al. (2011a, b) applied an alternative reference period (1961-1995) to generate time series for the Delta model. This model needs both meteorological data for the Netherlands and for the river basins of the Rhine and Meuse. Since spatial correlation in data between the Netherlands and the river basins is very important in the

Delta model, the period 1961-1995 was used as the reference period. The effect of the use of this period was studied for 5 stations in the Netherlands. In the figures below the results of 1 station are shown. The other stations showed comparable differences between the reference periods 1961-1995 and 1976-2005 (Homan et al., 2011a).

Table 4.1 Average daily temperature and precipitation in De Bilt in various periods in the past.

Climate variable	Period	Mean	95% probability interval
Mean temperature per year (°C)	1976-2005	10.0	9.7-10.2
	1986-1995	10.1	9.6-10.5
	1971-2000[41]	9.8	9.5-10.0
	1961-1990[42]	9.4	9.1-9.6
	1941-1970	9.3	9.0-9.5
	1901-2005	9.4	9.3-9.6
Mean precipitation per year (mm)	1976-2005	857	800-919
	1986-1995	866	799-935
	1971-2000[37]	827	768-885
	1961-1990[38]	820	765-876
	1941-1970	812	769-860
	1901-2005	808	779-835

Figure 4.15 shows the average daily temperature per calendar month for the reference periods 1961-1995 and 1976-2005 and for the transformed time series based on these reference periods for station De Kooy. The differences in average daily temperature between the reference periods range from 0.1 to 0.6°C (Figure 4.16), which is much smaller than the projected absolute temperature changes. The transformation hardly affects the differences between both time series.

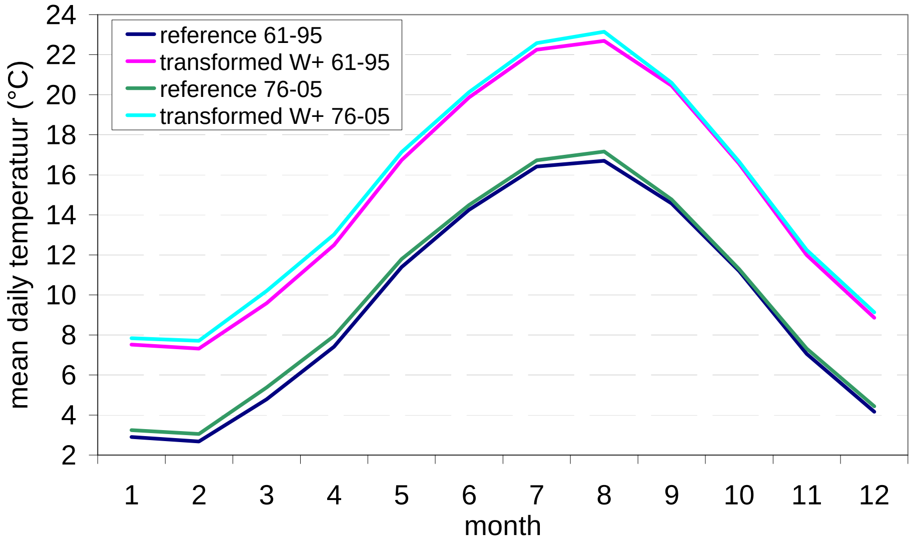


Figure 4.15 Average daily temperature (°C; y-axis) per calendar month (x-axis) for automatic weather station 235 (De Kooy). The dark blue and green lines represent the reference periods 1961-1995 and 1976-2005, respectively. The pink and light blue lines represent the transformed time series of the reference periods for the climate scenario W+ around 2100.

[41] Reference period, on which the "normals" were based up till the end of 2010, described in the "Klimaatatlas van Nederland" (Heijboer and Nellestijn, 2002);
[42] In the past, this period was often used to describe the climate in the year 1990.

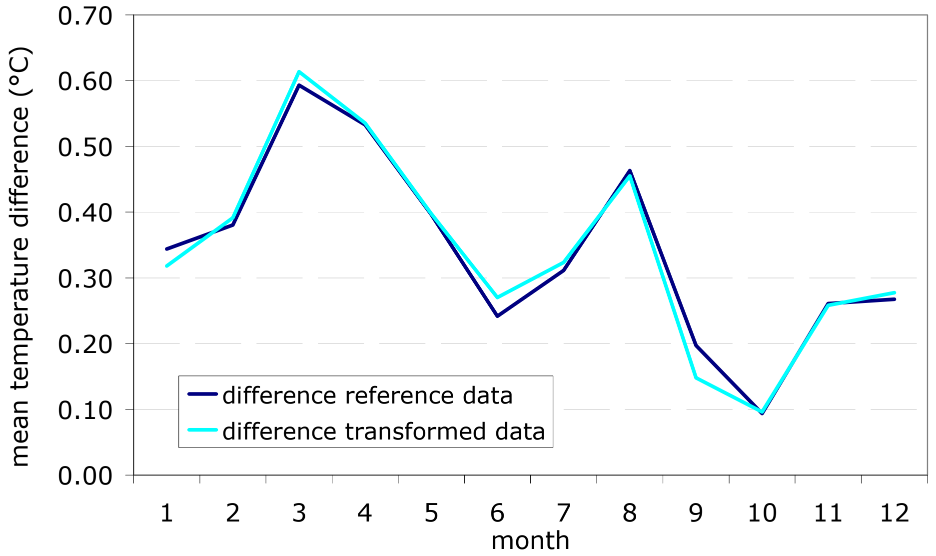


Figure 4.16 Difference in average daily temperature (°C; y-axis) per calendar month (x-axis) for station 235 (De Kooy) for the periods 1961-1995 and 1976-2005 (dark blue line), and the transformed time series for the climate scenario W+ around 2100 (light blue line).

Figure 4.17 shows the average precipitation per calendar month for the reference periods 1961-1995 and 1976-2005 and for the transformed time series based on these reference periods for precipitation station 10 (Hollum). The relative differences between the reference periods range from -12% to +17% and seem only slightly affected by the transformation (Figure 4.18). In the Netherlands the standard deviation of the average precipitation per calendar month is about 0.1 mm/day. Compared to this the differences in average precipitation per calendar month between the reference periods are not large.

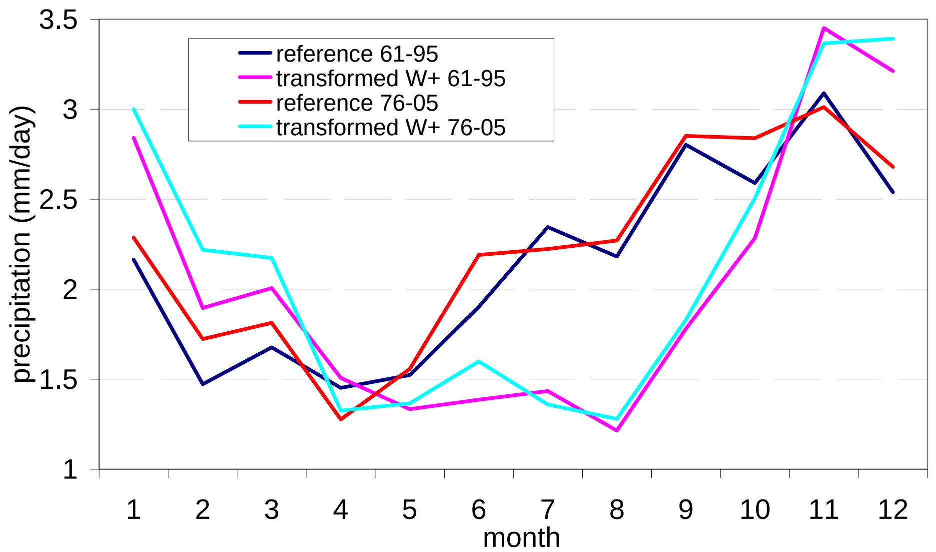


Figure 4.17 Average precipitation (mm/day; y-axis) per calendar month (x-axis) for station 10 (Hollum). The dark blue and red lines represent the reference periods 1961-1995 and 1976-2005, respectively. The pink and light blue lines represent the transformed time series of these reference periods for the climate scenario W+ around 2100.

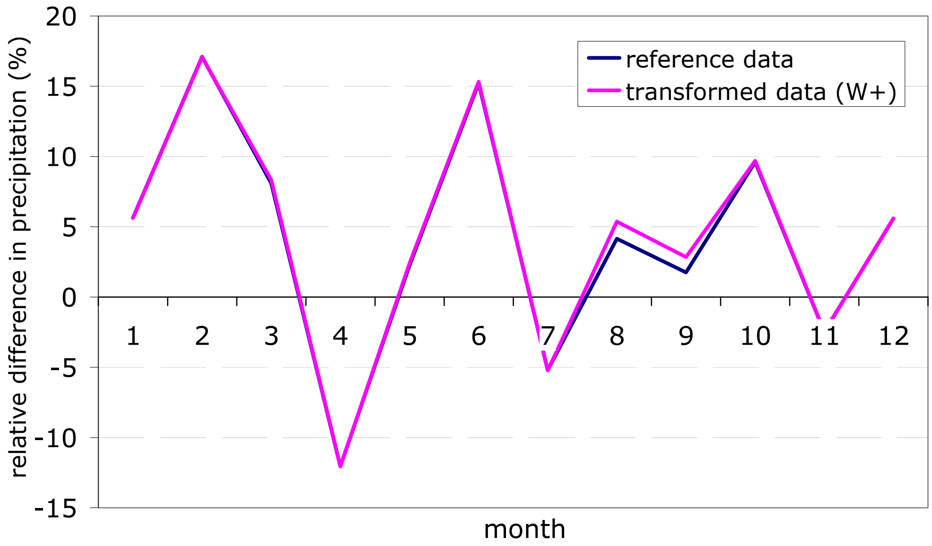


Figure 4.18 Difference in average precipitation (%; y-axis) per calendar month (x-axis) for station 10 (Hollum) for the periods 1961-1995 and 1976-2005 (dark blue line), and the transformed time series for the climate scenario W+ around 2100 (light blue line).

5. Discussion and conclusions

In this chapter a description is given of the main advantages and limitations of the current transformation tool (Section 5.1). In Section 5.2 we shortly discuss alternative methods for generating time series for the future, and in the last Section 5.3 we discuss the options for further development of methods to generate time series for the future in relation to user requirements and planned activities in various projects.

5.1. Advantages and limitations of the current transformation tool

Advantages

- The current transformation tools are the only methods available at the moment that can generate time series for the future in the Netherlands that are consistent with the KNMI'06 climate scenarios and that are easily accessible. Consistent with those scenarios it takes care of the fact that the averages can change in a different way than the extremes;
- They can generate time series for all time horizons between 1990 and 2100;
- The generated time series can often be used directly in impact models that use daily values as input;
- The generated time series show spatial and temporal correlation between different variables, due to the fact that the historical time series on which they are based, have spatial and temporal correlation (although by transformation the spatial correlation and the relation between variables may be reduced, since time series of each station are transformed individually);
- The transformation tool can be used to show what present-day extremes could look like in the future, as it directly modifies historical time series[43]. For instance, it can be used to show how the return period of a year such as 2003 may change in the future. Especially for communication and for policy makers this type of "example years" or "example weather events" are very useful;
- The generated time series can be used to generate indices such as the number of frost days, the number of days with more than 10 mm precipitation;
- The tool generates time series very fast and is easily accessible through the internet. Because of this, there is no need for other institutes or organisations to develop a method themselves to generate time series for the future in the Netherlands[43]. Therefore, it may promote consistency in the methods used for impact and adaptation studies to generate climatological time series;
- The time series transformation can be adapted easily to other regions or new scenarios. In case of new climate scenarios for the Netherlands with a similar tabular structure as KNMI'06, only the tabulated files with change coefficients[44] have to be updated or modified. In principle the transformation tool can also be used for other regions whenever the change coefficients used in the transformation tools can be provided for that particular region.

Limitations

- The time series for the various climate variables (temperature and precipitation) and stations are transformed independently in the current versions of the transformation tool. This reduces somewhat the spatial correlation of single (and multiple) variables and the dependency between climate variables;

[43] For some cases the current transformation tool is not the most appropriate method, e.g. when one wants to study the change in variability between years, when one is interested in extreme daily rainfall events. The KNMI'06 scenarios do not give information on changes in variability between years or on very rare events. The transformation tools try to adjust only those characteristics that are explicitly given in the scenarios.
[44] And for version 2.0 of the precipitation transformation tool also the ratios between the precipitation amounts for the 99th percentile and the average precipitation on wet days have to be provided.

- For the determination of the change coefficients in the KNMI’06 scenarios dependency between climate variables was taken into account (e.g. when precipitation and number of wet days decrease in the summer months, temperature increases more)[45];
- The length of the time series for the future depends on the length of the historical time series[46]. When long (synthetical) time series are available, also long time series can be generated with the transformation tool;
- Due to the way of removing wet days the most extreme daily precipitation in the time series for the future is sometimes lower than in the historical time series, although the climate scenario indicates that extremes will increase. (This is not necessarily an error in the transformation method, but is inherent to the rare nature of extremes, and occurs also in climate model simulations);
- The tool uses only the changes of a few points in the probability density function. For other points, especially those outside the range used, the changes can be overestimated or underestimated in the generated time series. This can e.g. be the case for historical days with precipitation amounts larger than the 99th percentile on wet days. However, change coefficients for these extremes were not provided in the KNMI’06 climate scenarios since it was not possible to estimate these changes reliably;
- The transformation tool does not explicitly control the year-to-year variation. So, the year-to-year variation in the transformed time series largely depends on the historical time series, but may be slightly changed (mainly due to the adaptation of the number of wet days);
- The tool is developed only for transformation of average daily temperature and precipitation. Although the temperature transformation can be used also for minimum and maximum temperatures, it does not cater for changes in the diurnal cycle.
- Some of the above limitations are more related to the limitations of the KNMI’06 scenarios (e.g. no information on change of diurnal cycle of temperature), than to the limitations of the transformation procedure itself.

5.2. Alternative methods to generate time series for the future

Most climate impact studies or climate adaptation studies need time series as input for their models, or indices derived from these time series. The transformation tool as described in this report has been used frequently in the Netherlands. However, there are also other methods for generating time series for the future, each with its own advantages and limitations. They can roughly be subdivided into three groups:
- Delta method: changes (or deltas) are applied to historical time series. The transformation tool is an example of this method;
- Direct method: output of climate models is used and if necessary bias-corrected;
- Stochastic weather generator: generate time series by means of statistical relations and properties.

Within each group various alternatives are possible, some of which are used by other countries (e.g. “perturbation” tool: KMI/KU Leuven/KNMI, 2009; weather generator[47] UKCP09: Jones et al., 2009). As indicated before, the KNMI transformation tool is an example of the Delta-method. In the simplest version of the Delta method, also denoted as the classical Delta-approach, only an average change is applied: the average change is applied to every daily value in an historical time series for e.g. temperature or precipitation. The (non-linear) KNMI transformation tool takes into account that extremes

[45] Actually, this limitation is associated with KNMI’06 scenarios rather than with transformation tool;
[46] For the Delta model (Homan et al, 2011b) the transformation tool was combined with the KNMI “rainfall generator” which recombines daily precipitation and temperature data to generate very long synthetic time series;
[47] The term “perturbations” is also used in the application of this tool, however in this case it refers to perturbations of the parameters of the weather generator.

may change differently than average values. Besides, in the precipitation transformation a change in the number of wet days is included.

Table 5.1 Future climate: methods to generate meteorological time series.

	Delta method	Direct method	Stochastic weather generator
Basic material	Historical time series	Output climate model	Statistical properties/relations between variables
Processing	Applies climate change signal to time series (transformation)	Corrects for biases[48] in climate model output	Adapts generator to climate change signal
Suitable[49] for KNMI'06 climate scenarios	Yes	No	Yes
Correlation (between variables, spatial and temporal)	Yes, limited by transformation and change values	Yes, limited by model biases and ways to correct for those	Yes, depends on method[50]
Different sequence of weather events than in observed time series?	No, hardly[50]	Yes	Yes
Possibility to generate information on"example" years (e.g. "2003")?	Yes	No[51]	Yes
Long time series possible (much more than 100 year for the same climate)?	No[52]	Yes	Yes[53]
Can be made available easily to a broad group of users?	Yes	No	Yes
Time needed to generate time series for the future	Little time	Much	Little time
Currently available for the Netherlands for the KNMI'06 scenarios?	Yes	No	No
Used in, among others[54]	COM21/COM27 (provinces): climate effect atlases and climate sketchbook CS7 (RIZA/ Waterdienst): hydrological standard year Deltamodel: time series for hydrological modelling GasTerra/NAM: Reduction in the change of extremely cold winters and hot days in summer	CS7 (Alterra): Time series for impact on crop production in Europe CS7/A7 (RIZA/ Waterdienst): long synthetic time series for extreme river discharges RheinBlick2050 project (D, F, CH, NL)	UKCP09: time series for the climate scenarios of the UK No examples available from CcSP projects

[48] Bias = a systematic deviation of climate model output compared to observations. To determine the bias of climate model output, a climate model run for the current climate is used;
[49] Suitable = can be adjusted such that time series are consistent with the KNMI'06 scenarios;
[50] Some parametric models use the spatial correlation of daily precipitation to fit the model. However, these models often underestimate the standard deviation and spatial correlation of monthly precipitation (Wilks, 1998; Mehrotra and Sharma, 2007) and are, therefore, unable to simulate drought over a large region adequeately;
[51] At present no, but work on this is in progress;
[52] Only possible if long synthetic time series are generated e.g. with the KNMI "rainfall generator", as is done for the Delta model. (Homan et al., 2011b);
[53] However, several weather generators show difficulties reproducing extreme events with return periods of 10 years or more (Jones et al., 2009);
[54] See also synthesis report CS7 of "Climate changes Spatial Planning" (Bessembinder et al., 2011b).

Table 5.1 gives an overview of the three groups of methods and their main advantages and limitations. From a daily perspective, each method will generate somewhat different time series, although they may represent the same changes in a limited number of climate characteristics as imposed by e.g. the KNMI'06 scenarios. The time series may differ in characteristics that are not explicitly given by these scenarios, although the particular characteristics may be important for impact analyses. This means that the methods to generate future time series themselves can be an extra source of uncertainty.

5.3. Directions and recommendations for the further development

In this section we recommend potential improvements and extensions of the transformation tool and whether it is useful to develop other methods to generate time series for the future. Desired points for improvement and extension are closely linked to user requirements, which are discussed first.

User requirements

In April 2011, a report on user requirements related to the next generation KNMI climate scenarios was published (Bessembinder et al., 2011a). This report indicates that users have interest in, especially, the following aspects related to generation of time series for the future:

- Transformation tools for other climate variables than precipitation and temperature, especially for reference evapotranspiration, (global) radiation, wind and humidity;
- Correlation between climate variables and neighbouring stations. Spatial correlation is asked for e.g. for determining the combined effect of low river discharges and drought in the Netherlands. It is not clear which temporal correlation is needed, probably not directly at the daily level, but more at the weekly of monthly level for most users;
- Inclusion of possible changes in year-to-year and intra-annual variation[55] in the transformation procedure;
- Methods to generate time series for larger areas than the Netherlands. This means that spatial variation in climate change can be included in the method to generate time series for the future.

Possible points of improvement or extension of the current transformation tool

- Further exploring the effect of applying change factors based on area-average changes from climatemodels to point data;
- The change factors provided with the KNMI'06 scenarios, which are used in the transformation tool, are ambiguous about the spatial scale for which they are valid. The change factors are derived from area-average climate model output, but they are generally interpreted as valid for point data. The existing documents about the KNMI'06 climate scenarios do not treat this problem. Yet, in section 4.5, it was shown that different interpretations can lead to very different future changes;
- Exploring alternative methods to remove wet days and their effect on spatial and temporal correlation. In Chapter 4 one can see that the method for removing and adding wet days has a clear influence;
- Exploring the possibilities to transform other climate variables conditional on (the changes in) precipitation. In the preliminary methods described in Annex 2 this was already done for global radiation and humidity;
- Combining different methods for generating time series for the future: e.g. a stochastic weather generator could be used to generate time series for other climate variables or for generating the temperature on days that were made dry;

[55] The options to fulfil this requirement also depend on which information will be provided in the next generation of KNMI climate scenarios.

- Estimating the percentiles in a consistent way (see Chapter 3 "version 2.1"). The temperature transformation may contain the same error as detected in the determination of the 99th percentile in the precipitation transformation tool version 2.0 and before;
- Developing a multi-site version of the transformation tool that can include spatial differences in climate change and that preserves the spatial dependence[56].

Use of alternative methods to generate time series for the future

As indicated in Section 5.2. there are 3 main groups of methods to generate climatological time series for the future. For each of the 3 main groups many variants exist (especially for precipitation).

In climate impact and adaptation research it is often important to determine the vulnerability of a system and the robustness of adaptation measures. This means that uncertainties about our future climate and the system under study have to be taken into account. The method to generate time series for the future also introduces uncertainties. Therefore, it would be interesting to have more than one method available for generating time series for the future. However, few users are aware of the uncertainty related to methods to generate time series and, therefore, it is hardly ever requested explicitly. First explorations of the effect of various methods for generating time series show a potentially large effect for extreme river discharges (Bakker, 2010), but effects on crop growth are probably less pronounced, since they are the cumulative result of a longer period (> 100 days).

The possibilities of stochastic weather generators for generating time series for the future are hardly investigated in the Netherlands. It might be interesting to do this, since stochastic weather generators have some interesting advantages (option to create long time series, often fast in generating time series, option to adapt year-to-year variation, temporal correlation etc.; see Section 5.2). A difficulty is that stochastic weather generators may not preserve some relevant statistical properties of present-day weather. This holds in particular for multi-site generators.

At KNMI we have some experience with bias correction of climate model output, but further research into bias correction of climate model output is still needed. When it is possible to generate climate model output consistent with one of the KNMI climate scenarios, the direct method is also an option to generate time series for the future. This would make it easier to generate time series for a wider area than the Netherlands, consistent with the next generation of climate scenarios for the Netherlands.

Activities in other projects related to the generation of future time series

In several other projects activities are planned or have almost finished that are related to generation of time series for the future. Below an overview is given:

- Transformation of hourly precipitation (project HSHL05/HSRR04 of the Knowledge for Climate-programme; will be finished in June 2011): a pilot version of a transformation tool for hourly precipitation, consistent with the daily transformation is currently under construction. The requirement that there should be correlation at the daily level is highly restrictive. Besides, the knowledge about possible future changes of hourly precipitation is very limited. Therefore, the status of the hourly precipitation tool is experimental;
- A comparison of "Delta methods" and "Direct methods" (CS7 of the CcSP-programme; will be finished in June 2011): in the last pilot project together with Alterra, time series with both a transformation tool and based on bias-corrected

[56] It is not clear whether the spatial dependence can be preserved completely, but probably it can be done in a better way that in the current versions of the tool (e.g. in the case of drying wet days, also dry the wet days from neighbouring stations).

climate model output are developed. The effect on the estimation of crop production will be compared;

- Regional distribution of climate change and generation of time series for other climate variables (NMDC "Kritische Zone" for the National Model and Data Centre; until the beginning of 2012): in this project it is investigated how the procedures for generating time series for other climate variables can be adapted;
- Development of methods and datasets for generation of time series for the next generation of KNMI-scenarios (within the "Theme 6" consortium of KfC and within the "KNMInext-project"): For the next generation KNMI climate scenarios probably again the transformation tool will be used to generate time series for the future, although the tool may be adapted (see above). At the same time it is investigated whether climate model runs can be generated that are consistent with the new KNMI scenarios. This would open up the option to generate also time series for the future by using the direct method. It is also investigated whether time series for the future can be generated that fit the requirements of various sectors at the same time. This could improve the efficiency of generating time series for the future and promote standardization in the use of climate data within impact and adaptation research.

Several of the desired and possible developments are already included in the projects mentioned above.

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Links

- http://climexp.knmi.nl/Scenarios_monthly (NL): Transformation tool version 1.2 (April 2012);
- http://climexp.knmi.nl (EN): Climate explorer (linked to the transformation tool, for downloading time series, visualisation tool, statistical processing, etc.);
- http://www.knmi.nl/climatescenarios (EN) http://www.knmi.nl/klimaatscenarios (NL) KNMI website on climate scenarios;
- http://www.knmi.nl/klimaatscenarios/maatwerk (NL): KNMI website: Examples of "Tailoring" projects (in several the transformation tool is used);
- http://knowledgeforclimate.climateresearchnetherlands.nl/highqualityclimateprojections (EN): Knowlegde for Climate, Theme 6 "High quality climate projections";
- http://klimaatvoorruimte.klimaatonderzoeknederland.nl/projecten (NL): For more information on the projects in which the transformation tool is used.

Annex 1. KNMI'06 scenarios: interpolation to monthly changes

Geert Lenderink, September 2006.

Introduction

The KNMI'06 climate scenarios (Van den Hurk et al. 2006, hereafter H06) provide seasonal means of the winter and summer changes of temperature and precipitation. For potential evaporation[57] only summer changes are given. For some of the other seasons preliminary values of the changes are given and no changes for each month are given. However, impact models often demand time continuous yearly time series. To meet this demand, this note describes a simple interpolation technique to obtain changes for each month. By aggregating the values for the individual months in spring and fall, it also provides the mean changes for spring (MAM) and fall (SON). These resulting seasonal mean values replace some of the preliminary values of spring and autumn in Table 9.3 of H06. We note that significant deviations from those values only occur for potential evaporation in winter and in spring. By construction the seasonal means for winter (except potential evaporation) and summer are not affected by the interpolation procedure. The method can be applied to all variables (indices) derived directly from the RCM downscaling procedure in Table 4.6 and 5.1 of H06.

Method

The method is based on a linear simple interpolation between the summer ΔX_S and winter values ΔX_W for each month i using:

$$\Delta X(i) = \alpha(i)\Delta X_W (1-\alpha(i))\Delta X_S$$

where $\Delta X(i)$ denotes the change of a particular index X in month i. The function $\alpha(i)$ is chosen universal for each scenario type; that is for each index X within a scenario W+/G+ (or W/G) it is the same. Figure A1.1 shows the interpolation functions we found after some experimentation, and the numerical values are given in Table A1.1. In the following we denote α used for the G/W scenarios as α_0 and α used for the G+/W+ scenarios α_+

[57] In the rest of this document called reference crop evapotranspiration.

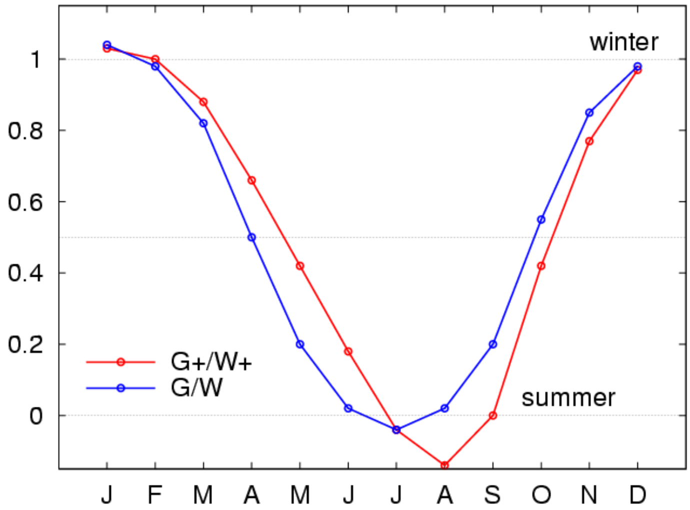

Figure A1.1 Interpolation function $\alpha(i)$ as a function of month i. Winter values are close to 1 and summer values close to 0.

Table A1.1 Numeric values of the interpolation function α (i).

I (month)	G/W	G+/W+
1	1.04	1.03
2	0.98	1.00
3	0.82	0.88
4	0.50	0.66
5	0.20	0.42
6	0.02	0.18
7	-0.04	-0.04
8	0.02	-0.14
9	0.20	-0.00
10	0.55	0.42
11	0.85	0.77
12	0.98	0.97

These interpolation functions are based on comparison with the GCM results (shown in Figure A1.2) and the RCM results (shown in Figure A1.4) and some common sense. The latter implies that the interpolation functions should be smooth in time. We also require the average values for spring and fall to be close to 0.5; that is, the average condition in spring and autumn should be (relatively) close to the average of summer and winter conditions. Far extrapolation is thus not allowed ($\alpha<<0$ or $\alpha>>1$) . The above restrictions imply that it is difficult, if not impossible, to cope with memory effects. For example, warm SSTs over the Atlantic and the North Sea cause relatively high temperature in fall. The opposite is the case in spring. This effect (for example illustrated in Figure 4) cannot or can only partly be represented by interpolation. Detailed results are discussed below.

Results

Scaling in the GCMs

Figure A1.2 show results of the selected GCMs for the change of temperature and precipitation per degree global temperature rise. In general, it is difficult to classify these GCMs in models that are representative for the "+" scenarios and model representative for the "no circulation change" scenarios. The GCMs cover a whole range of circulation responses, and also display a significant amount of natural variability even at a 30-years timescale. Roughly speaking, ECHAM5 and GFDL represent a "+" scenario in both winter and summer. MirocHi and CCC represent a "no circulation change" scenario (see Figs. 4.4 and 4.6 in H06 and Fig. 10 in Lenderink et al. 2007a). HadGEM has a weak circulation response in winter, but a significant one in summer. MirocM (low resolution version of MirocHi) has a moderate circulation response in both summer and winter. For precipitation, the GCMs basically follow the pattern of a relatively constant change during the year for the GCMs representative for the "no circulation change" scenarios, and a strong seasonality (with the highest values in winter and the lowest in late summer) for the GCMs representative for the "+" scenarios. For temperature, such a behavior is not clearly identifiable. GFLD and ECHAM5 are both representative for the "+" scenarios. GFDL follows the expected pattern with relatively high temperatures in late summer; however, ECHAM5 does not. MirocHi has a relatively large response in summer despite its relatively westerly circulation. This could be related to the Atlantic SSTs. For example, in summer those models that have a relatively low Atlantic SST (compared to the global temperature rise) temperature lag appear more prone to display a circulation change, and vice versa. For example, MIROCHi, which displays the weakest circulation change in summer, has almost no temperature lag, and GFDL has both the largest temperature lag and the circulation change (see Van Ulden and Van Oldenborgh, 2006). But we note that not all the GCMs results fit as nicely into this picture, and due to the limited number of models it is hard to establish the significance of this hypothesis.

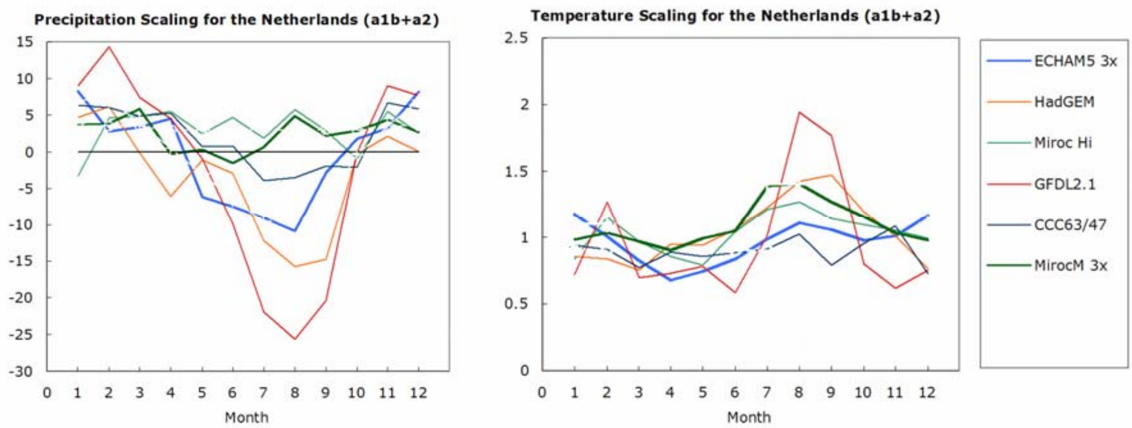

Figure A1.2 Change in mean precipitation and mean temperature in the selected GCMs. The change is normalized to a global temperature change of 1 °C. Results are averaged over the A1b and A2 emission scenario. ECHAM and MirocM contain the average of an 3 member ensemble.

Concluding from the GCM results, scaling appears to work reasonably well for precipitation both for the "+" and the "no circulation change" scenarios, but appears to be less appropriate for temperature most likely due to the importance of other factors like e.g. Atlantic SSTs. We note, however, that although scaling appears less appropriate for temperature, the total range of temperature change that is predicted by the 4 scenarios (G/G+/W/W+) is rather close to the range given by the GCMs (see Fig. 12 in Lenderink et al. 2007b). Thus, despite the above concerns, we will employ a simple scaling and interpolation method to derive scenario values for each month.

Interpolation results and comparison to RCM results

Figure 3 shows the interpolation results for mean temperature, precipitation and potential evaporation for the W and W+ scenarios. Values for mean winter and summer changes, ΔX_W and ΔX_S, are given in Table 1. These values correspond to the values in Table 4.6 for mean temperature and precipitation and Table 5.2 for potential evaporation in H06. The change in potential evaporation in winter has been changed from the preliminary value 0% in H06 (Table 9.3) to +3% in order to allow a better interpolation of the values in spring and autumn. Since absolute values of potential evaporation are low in winter, this has only small practical implications.

Table A1.2 Values of changes in the KNMI'06 W/W+ scenario's. The two values for potential evaporation in winter denoted with a * deviate from the preliminary values in H06 (Table 9.3).

	DJF		JJA	
	W	W+	W	W+
mean precipitation (%)	7.3	14.2	5.5	19.0
mean potential evaporation (%)	3*	3*	6.8	15.2
mean temperature (°C)	1.8	2.3	1.7	2.8

For the W scenario, there are no large difference between summer and winter values, in particular for mean temperature and mean precipitation. As a consequence, the impact on different interpolations on the outcome is not large. Conversely, given that differences in summer and winter values are not large, it is also difficult to derive the interpolation functions from the model results. Therefore, a simple, rather symmetric interpolation function was chosen. We note that since the RCMs represent a "+" scenario, no comparison with RCM results can be made. For the W+ scenarios there is a large difference between the increase in precipitation in winter and the decrease in summer. The interpolation function is slightly skewed in order to represent the phase lag in summer. This confirms with the GCM results in Figure A1.2 which show that on average the driest and warmest period is JAS (July-August-September) instead of JJA. It is likely that this phase lag is the consequence of progressive soil drying during the summer.

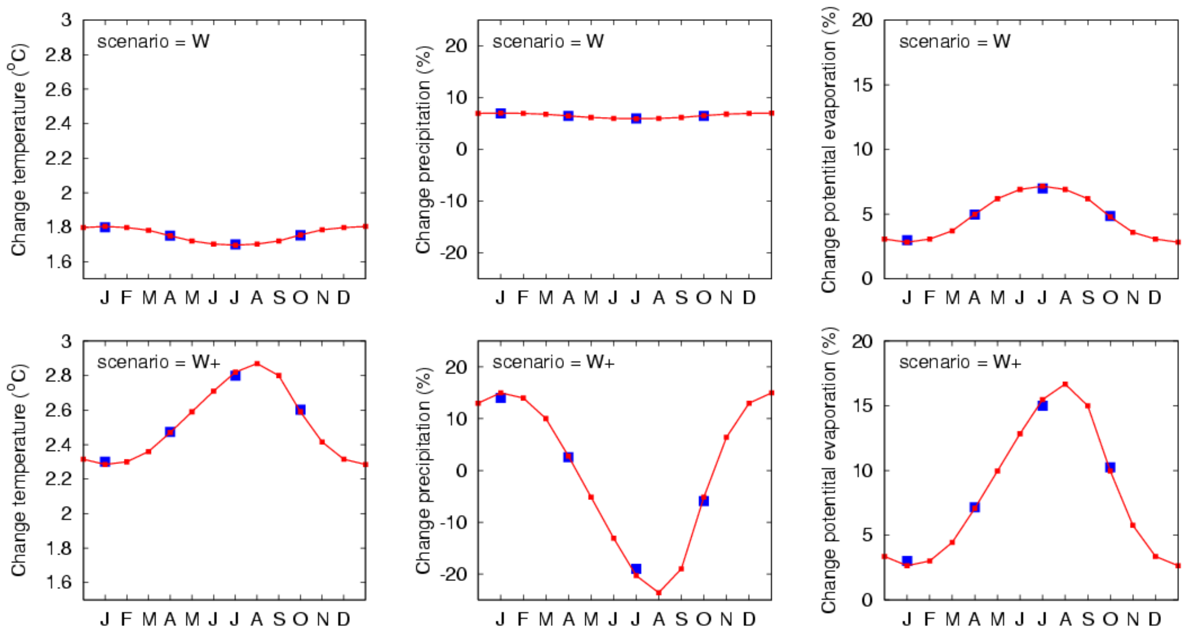

Figure A1.3 Time evolution of the change in mean temperature, mean precipitation and mean potential evaporation. Seasonal mean values are given by the blue squares.

Figure A1.4 shows a comparison with RCM results of the PRUDENCE integrations. All the RCM integrations are representative for the "+" scenarios as they have a considerable circulation change in both winter and summer. The integrations consist of two 30-years time slices, a control 1961-1990 and a future 2071-2100 period. Details of these runs can be found in H06. The global temperature response between control and future period is approx. 3.2°C, and the response in all RCM integrations is multiplied by 2 / 3.2 in order to represent the W+ scenario with 2 °C global temperature rise. Similar to H06 we give the two ECHAM4 driven runs a weight 4 and all HadAM3H runs a weight 1. In summer, all RCMs have a weight 1, excluding SMHI driven by ECHAM4 because of the very large summer response in that model. For autumn and spring we linearly interpolate these weights: in march a weight 3, April 2, and may 1 in both ECHAM4 driven RCM integrations. For precipitation, results of the interpolation are reasonably close to the interpolated ones. It is also clear that the interpolation function used for W+ improves on the symmetric one of W, in particular in late summer.

For temperature we use the same values for $\alpha(i)$. As discussed above, the results of the GCM indicate that a simple interpolation is problematic. The comparison with RCM results confirms this. In the RCMs the temperature response is relatively low in spring and relatively large in autumn, most likely as a consequence of the lag of the Atlantic temperatures. We note that the temperature response in late summer/early fall (August and September) in the RCMs exceeds our scenario values. Partly, this could be related to the strong tendency for drying in most of the RCMs in this ensemble. Intercomparison studies, like e.g. Van den Hurk et al. (2005) and Lenderink et al. 2007b, show that this strong tendency for drying in most RCMs is most likely artificial. Nevertheless, the RCM results contain a clear warning that if the soil dries out significantly in the future climate, temperatures in late summer may rise more than in the present scenarios.

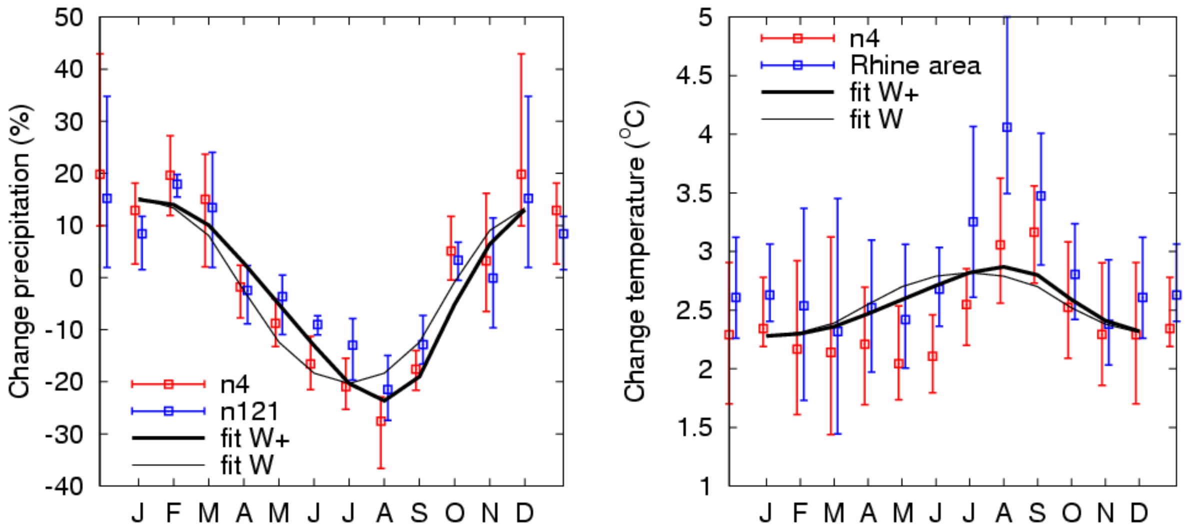

Figure A1.4 Change in precipitation and temperature in the RCMs (linearly rescaled corresponding to 2 °C global temperature rise) in comparison with the scenario values derived by the interpolation procedure. n4 denotes the small area near De Bilt, whereas n121 denotes the large area (used to derive the scenarios for precipitation) (see Fig. 4.9 in H06) and Rhine Area denotes the Rhine catchment area. Error bars denote 10 and 90th percentiles.

Seasonal mean values computed from the monthly mean value $\Delta X(i)$ are given in Table A1.3. By construction seasonal means of summer and winter are the same as those in Table A1.2. Seasonal mean precipitation amount in spring and autumn correspond to the preliminary values in Table 9.3 of H06, but the values for mean potential evaporation deviate slightly in spring.

Table A1.3. Seasonal values of change in mean precipitation (P_{mean}), wet-day frequency (F), precipitation on 1% wettest day (P_{99}), mean potential evaporation (PE_{mean}), mean temperature (T_{50}), temperature on 10 % coldest days (T_{10}), and 10% warmest days (T_{90}). Values with * deviate 1-3 % from the preliminary values in Table 9.3 of H06

	W				W+			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
P_{mean} (%)	7.3	6.4	5.5	6.4	14.2	2.7*	-19.0	-5.8
F (%)	0.2	-1.5	-3.3	-1.4	1.9	-5.5	-19.3	-10.9
P_{99} (%)	8.6	16.5	24.8	16.1	11.2	11.6	12.3	11.9
PE_{mean} (%)	3.0	4.8*	6.8	4.7*	3.0	7.2	15.2	10.4
T_{50} (°C)	1.8	1.8	1.7	1.8	2.3	2.5	2.8	2.6
T_{10} (°C)	2.0	1.9	1.8	1.9	2.8	2.6	2.2	2.4
T_{90} (°C)	1.7	1.9	2.0	1.8	1.9	2.5	3.6	2.9

Sensitivity

Finally as a simple sensitivity test, Table A1.4 shows seasonal means for MAM and SON for the W+ scenario when the α_o interpolation of the W scenario is used. Differences for mean precipitation are between 3-4 %. However, in general results are rather close to those obtained with α_+.

Table A1.4 Alternative "+" scenarios, denoted by W+*, for MAM and SON obtained by using the interpolation function $\alpha o(i)$ of the G/W scenarios compared to the standard values W+.

	MAM		SON	
	W+	W+*	W+	W+*
P_{mean} (%)	2.7	-2.2	-5.8	-1.3
F (%)	-5.5	-8.6	-10.9	-8.0
P_{99} (%)	11.6	11.7	11.9	11.7
PE_{mean} (%)	7.2	9.0	10.4	8.7
T_{50} (°C)	2.5	2.6	2.6	2.5
T_{10} (°C)	2.6	2.5	2.4	2.5
T_{90} (°C)	2.5	2.7	2.9	2.7

Conclusion

We discussed a simple method to derive scenario values for each scenario and each month. The method can be applied to all predicted changes from the RCM results (not those derived from the time series transformation). Although it is clear that the method has its limitations, it provides a simple means to produces seasonally dependent scenarios that are required for many impacts assessment studies.

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Van den Hurk B., M. Hirschi, C. Schär, G. Lenderink, E. Van Meijgaard, A. Van Ulden, B. Rockel, S. Hagemann, P. Graham, E. Kjellstrom and R. Jones, 2005. *Soil control on runoff response to climate change in regional climate model simulations*. Journal of Climate 18: 3536–3551.

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Annex 2. Transformation of other climate variables

Reference crop evapotranspiration according to Makkink

There is no transformation tool in the Netherlands for reference crop evapotranspiration (PET). However, at the transformation tool website information is given on how to transform data on reference crop evapotranspiration (often requested), and at KNMI a simple module is developed to transform historical reference crop evapotranspiration data with the "classical" delta method, in which an average change is applied to all daily values per calendar month.

In the KNMI'06 scenarios published in May 2006 information is given on the change in reference crop evapotranspiration in summer (JJA). In October 2007 a document with the monthly average changes in reference crop evapotranspiration was added to the transformation tool website (Table A2.1). Users are advised to apply these changes to each daily value of reference crop evapotranspiration per calendar month. This can be considered as "version 1.0" of the reference crop evapotranspiration transformation. The monthly values are also presented in the document of Lenderink (2006) on monthly changes (see Annex 1). Below the table with monthly changes per scenario is given.

Table A2.1 Average monthly changes (%) in reference crop evapotranspiration around 2050 compared to the reference period 1976-2005 for the 4 KNMI'06 climate scenarios (version 1.0).

	G	G+	W	W+
January	1.4	1.3	2.8	2.6
February	1.5	1.5	3.1	3
March	1.8	2.2	3.7	4.5
April	2.5	3.6	4.9	7.1
May	3	5	6	10.1
June	3.4	6.5	6.7	13
July	3.5	7.8	7	15.7
August	3.4	8.5	6.7	16.9
September	3	7.6	6	15.2
October	2.4	5	4.7	10.1
November	1.8	2.9	3.6	5.8
December	1.5	1.7	3.1	3.4

For 2100 (compared to 1976-2005 or "1990") twice the values in Table A2.1 are used. And for time horizons in between "1990" and 2050 and 2100 linear interpolation is used.

In March 2006 (version -1.0) also preliminary data on changes in reference crop evapotranspiration were provided to RIZA for estimating the effects of the KNMI'06 scenarios on hydrology and river discharges. The values used in that version are shown below in Figure A2.1.

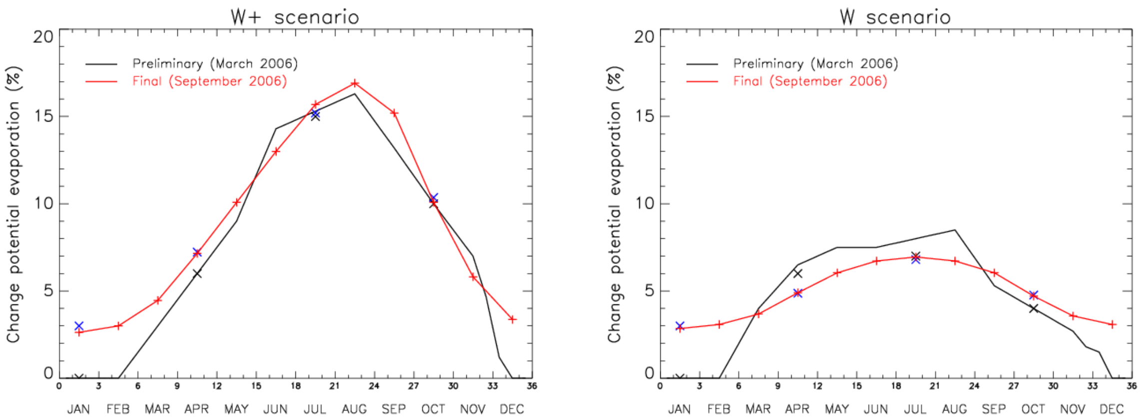

Figure A2.1 Monthly changes in reference crop evapotranspiration (Y-axis: change potential evaporation) in the KNMI'06 scenario's W and W+ (based on Lenderink, September 2006, Annex 1) and the preliminary changes as provided to RIZA in March 2006.

Version 1.0 is used in (among others):

- Delta model (Homan et al., 2011a and 2011b);
- Climate Sketchbook ("Klimaatschetsboek Nederland"; KNMI, 2009b)[30];
- Groene Hart study (Provincie Zuid Holland, 2011);
- Project Agri-Adapt (De Wit et al., 2009).

Effect of the reference period on transformed time series for reference crop evapotranspiration

In section 4.5 the results of various analyses are shown. Some of these analyses were also performed for reference crop evapotranspiration. Below some results for the study of Homan et al. (2011a) are presented. Figures A2.2 and A2.3 show, respectively, the average reference crop evapotranspiration (calculated with the Makkink method) and the difference between the reference data and transformed data per month for station De Kooy.

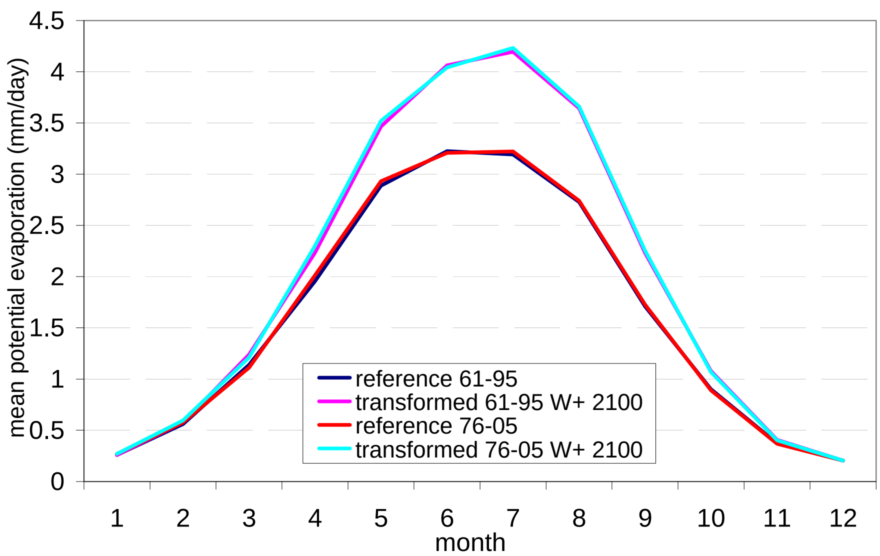

Figure A2.2 Average reference crop evapotranspiration (mm/day; y-axis: potential evaporation) per calendar month (x-axis) for station 235 (De Kooij). The dark blue and red line represent the reference periods 1961-1995 and 1976-2005, respectively. De pink and light blue lines represent the transformed time series of the reference periods for the climate scenario W+ around 2100.

For reference crop evapotranspiration there are hardly any differences between the reference periods 1961-1995 and 1976-2005 and between the transformed time series based on these reference periods. The differences are not larger than 0.06 mm per day for the reference periods, and the transformed time series for scenario W+ around 2100 show slightly larger differences. However, these differences are very small compared to the average daily reference crop evapotranspiration in the various months.

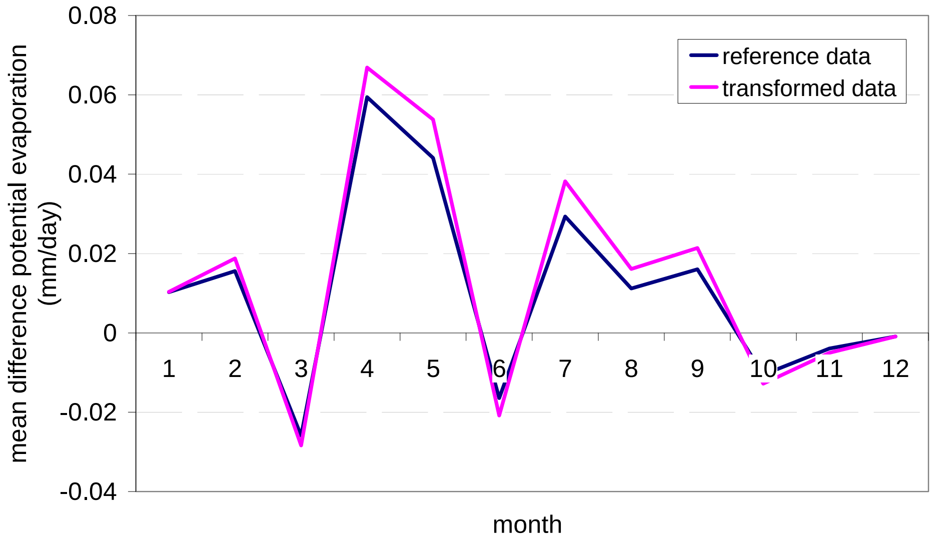

Figure A2.3 Difference in average reference crop evapotranspiration (mm/day; y-axis: potential evaporation) per calendar month (x-axis) for station 235 (De Kooij) for the periods 1961-1995 and 1976-2005 (blue line), and the transformed time series for the climate scenario W+ around 2100 (pink line).

Other climate variables

Like evaporation, there is no transformation tool available for other climate variables such as wind speed, global radiation, humidity. However, in the past sometimes requests for time series for these climate variables reached KNMI.

The following approaches/methods were advised until now:

- **Wind speed**: according to the KNMI'06 scenarios (KNMI, 2006, 2009b) wind speed hardly changes compared to the current natural variability. Therefore, it was regularly advised to use the historical time series unchanged for the future. In the case that a certain sector is very sensitive to changes in wind it was advised to use also the historical time series, but with the changes for the maximum average daily wind speed per year applied to all daily values (for a sensitivity analysis);
- **Global radiation (*Q*)**: The KNMI'06 scenarios do not supply information on changes in the global radiation. In the course of time three different approaches have been advised to obtain future time series:
    1. **Dependence on Δ*PET* [%]:** for a project on the estimation of future cooling capacity of the large rivers (Kallen et al., 2008) it was advised to determine the relative change factor **Δ*Q* [%]** from **Δ*PET*** for all 36 decades (of days) by the following equation: $\Delta Q = \max(0, \Delta PET - 8\%)$
    2. **Dependence on wet-day adjustment:** for a project on ecohydrological effects (Witte et al., 2009) it was advised only to change *Q* for days that had been "dried or wetted" by the transformation tool for precipitation. In the case

that a day was “dried”, the global radiation in the historical time series was replaced by the average global radiation on a dry day in that calendar month (only if the global radiation in the historical time series was lower than the average global radiation on a dry day in that calendar month). In the case that a day was “wetted”, the global radiation in the historical time series was replaced by the average global radiation on a wet day in that calendar month (only if the global radiation in the historical time series was higher than the average global radiation on a wet day in that calendar month).

3. **Application of the Makkink formula:** for the innovation project “Kritische Zone” of the NMDC (Nationaal Modellen en DataCentrum; Bakker, 2012) the Makkink formula was applied to determine future global radiation $\boldsymbol{Q^f}$ from future/transformed temperature $\boldsymbol{T^f}$ and evapotranspiration $\boldsymbol{PET^f}$.

- **Sunshine duration:** for sunshine duration the same relative change is applied as for the global radiation in Kallen et al. (2008) and Bakker (2012).
- **Relative humidity (*UG*):** Two approaches to determine future relative humidity have been advised since the lauch of the KNMI’06 scenarios:
    1. **Absolute change of the relative humidity (Δ*UG*) dependent on the relative change of global radiation (Δ*Q*):** for the cooling water project (Kallen et al., 2008) it was found that the **Δ*UG*** is proportional to **Δ*Q*** (only for the G+ and W+ scenario):

$$\Delta UG = -0.36 \Delta Q$$

    2. **Dependence on wet-day adjustment:** for the project on ecohydrological impacts (Witte et al., 2009) the same procedure was applied for global radiation and for relative humidity (see method 2 for future radiation)

Used in (among others):

- Project Agri-Adapt (De Wit et al., 2009);
- Study on impact of climate change on cooling capacity of major water bodies in the Netherlands (Kallen et al., 2008)
- NMDC innovatieproject, “Kritische Zone” (Bakker, 2012)

Annex 3. User guide on the internet

On the website of the transformation tool an explanation is given and some guidance in Dutch (http://climexp.knmi.nl/Scenarios_monthly/transtoelichting.cgi). Below the guidance is translated into English. The explanation of the tool is given in Chapter 3 of this report.

Table A3.1 Content of the website and translation in English.
http://climexp.knmi.nl/Scenarios_monthly/transtoelichting.cgi

Section (in Dutch)	Translation in English	Where to find the English explanation/translation?
Doel transformatie-programma	Aim of the transformation tool	Chapter 1 this report
Hoe werkt het programma?	How does the tool work?	Chapter 3 this report
Gebruik transformatie-programma (neerslag, gemiddelde, minimum-, en maximumtemperatuur)	Use of the transformation tool (precipitation, average, minimum, and maximum temperature)	This annex, see below under "A3.2. Use of the transformation tool (precipitation, average, minimum, and maximum temperature)"
Invoer: historische tijdreeksen (periode, kwaliteit, format)	Input: historical time series (period, quality, format)	This annex, see below under "A3.3. Input: historical time series (period, quality, format)"
Voordelen en beperkingen van getransformeerde tijdreeksen	Advantages and limitations of the transformed time series	Chapter 5 this report This annex, see below under "A3.4. Advantages and limitations of the transformed time series"
Wijzigingen per 10-4-2008	Changes per April 10, 2008	Chapter 2 this report This annex, see below under "A3.5. Changes per April 10, 2008"

How does the tool work?

Currently (October 2011) on the internet version 1.2 of the precipitation and temperature transformation is used. The explanation in the user guidance on the internet describes this version. In Chapter 2 of this report a more formal and elaborate description of the tool is given than on the internet.

Use of the transformation tool (precipitation, average, minimum, and maximum temperature)

Step 1
During the first step of the transformation tool on the web page you can indicate which climate variable you want to transform. The following options are available:

- Precipitation (= "Neerslag" in Dutch)
- Average daily temperature (= "Gemiddelde etmaaltemperatuur"in Dutch)

The average daily temperature is the average temperature between 0.00-24.00 Universal Time.

Many users of climate information are also interested in the **daily minimum temperature** and the **daily maximum temperature**. In principle, it is also possible to transform time series for the daily minimum temperature and for the daily maximum temperature, although the KNMI'06 climate scenarios only give changes for the average daily temperature. From observations in the past 25 years it appears that the minimum temperature and maximum temperature in the Netherlands increase more or less in the same way (IPCC, 2007). However, it is possible that the temperature amplitude will change in the future.

Cloud cover has a clear influence on the daily temperature amplitude. According to global climate models used in the Fourth Assessment Report of the IPCC, the Netherlands is located in a transition zone between Southern Europe, where cloud cover will diminish, and Northern Europe, where cloud cover will increase. On the basis of this information it seems justified to assume that the daily minimum and daily maximum temperatures in the Netherlands change in the same way as the average daily temperature in the KNMI'06 climate scenarios[58]. Time series for the future for daily minimum and daily maximum temperatures can be generated in two ways:

- First transform the average daily temperature time series. Then determine the change for each historical day (future – past) and add this change to the minimum and maximum temperatures of the same historical day. With this method the difference between minimum, maximum and average daily temperature remains exactly the same in the transformed time series;
- Transform the time series of the daily minimum temperature or daily maximum temperature directly with the transformation tool (use the option "upload time series"). In this case the differences between the daily average, minimum and maximum temperature in the future are not always the same as in the historical time series (it is even possible that in the transformed time series the minimum temperature on a certain day becomes higher than the maximum temperature on that day!). This is due to the fact that extreme maximum temperatures do not necessarily occur on the same day as the extreme average temperatures or as the extreme minimum temperatures.

The two methods can result in slightly different average and extreme minimum temperatures and maximum temperatures for the future. When you wish to use both minimum temperatures and maximum temperatures, you are advised to use the first method.

Step 2

During the second step you are asked to indicate for which station you wish to transform a time series. A number of stations in the Netherlands is available in the menu. When you want to transform another time series, there is an option in the menu to "upload" this time series yourself ("eigen reeks uploaden"). When you use other time series than provided by the menu, we advise you to read first the text under "Input: historical time series" in the guidance.

In the menu for **precipitation** the following stations are available (data in mm/day; 8.00-8.00 h Universal Time from ECA&D):

- West-Terschelling
- Den Helder/De Kooy
- Groningen
- Ter Apel
- Hoorn
- Heerde
- Hoofddorp
- De Bilt

[58] For the W+ and G+ scenarios in the summer this assumption is less justified, since we expect a clear increase in dry days, and therefore implicitly also a decrease in cloud cover.

- Winterswijk
- Kerkwerve
- Axel/Westdorpe
- Oudenbosch
- Roermond
- Upload own time series

In the menu for temperature the following stations are available (temperature in °C; 0.00-24.00 Universal Time; average daily temperature):
- Den Helder/De Kooy
- Groningen/Eelde
- De Bilt
- Vlissingen
- Maastricht
- Upload own time series

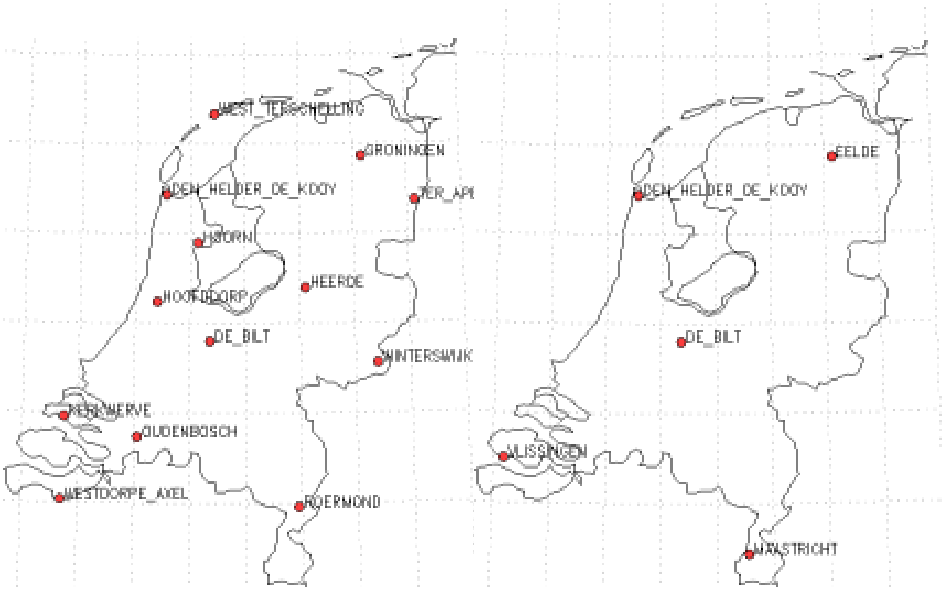

Figure A3.1 Locations of the precipitation stations (left; Google Earth) and temperature stations (right; Google Earth).

Step 3
Next, you are asked to select the KNMI'06 climate scenario for which you wish to transform the time series. The following options are available (for more information on the scenarios look at www.knmi.nl/climatescenarios/knmi06/):
- G
- G+
- W
- W+

To get a good picture of the effects of climate change, or to test the robustness of adaptation measures you are advised to use all four the KNMI’06 climate scenarios (see also www.knmi.nl/climatescenarios/suggestions/).

Step 4
In this fourth step you select the desired time horizon. On the website of the KNMI’06 climate scenarios only changes around 2050 and around 2100 compared to the period 1976-2005 are mentioned. However, with the transformation tool other time horizons can be chosen. The following options are available:
- 1990 (no transformation!)
- 2020
- 2030
- 2040

- 2050
- 2060
- 2070
- 2080
- 2090
- 2100

The tool uses linear interpolation between 1976-2005 (“1990”) and 2050 to generate the changes for 2020, 2030 and 2040. For the time horizons 2060, 2070, 2080 and 2090 linear interpolation of the change coefficients for 2050 and 2100 is used.

Step 5
By clicking on the button "Transformeer" (“Transform”), the desired time series will be generated. Automatically a window from the "Climate Explorer" will open. In the first figure the daily values of the transformed time series are plotted. Directly above this figure you will see the text "(postscript version, raw data, netcdf)". By clicking on one of these three options you can see the data file and save the transformed time series. When you use a PC and you want to use the option "raw data" to download your time series, it may occur that all data are shown in a sequence on you screen (and not for each date a new line). In the following way you can change the file into a file with a new date on each line with the temperature or precipitation in the future: go with your cursor to the text in the file, right click on your mouse and select “show source” (“bron weergeven" in Dutch). After this, the set up of the file will change and you can save your time series.

Step 6 (optional)
With the help of the "Climate Explorer" you can process and analyse your transformed time series. The "Climate Explorer" has many options, however, it is not very “user-friendly” for non-climate researchers.

At the lower end of the page in the "Climate Explorer" (the page that opens automatically when you transform a time series) you will find a block with "Create a new time series". With the help of the functions in this block you can process your transformed time series into a time series with e.g. yearly precipitation amounts, maximum daily precipitation amount per year, or the number of days per year with a maximum temperature above 25 °C. In the menu at the right side under "Investigate this time series" you will find options to analyse your transformed time series or your processed time series, e.g. make histograms, calculate averages and standard errors, calculate return periods for extremes. Of course, you can also use other programmes for these analyses.

Input: historical time series (period, quality, format)

Which period?

For a good description of the year-to-year variation we advise to use a historical time series of 30 years or more (see also section 4.5). The same length of period is used for the reference period for the KNMI’06 climate scenarios and in the transformation tool. The use of shorter or longer periods as input can result in systematic differences with the period 1976-2005 (and consequently for the future; in the table in Section 4.5 a few examples are shown).

Quality of the used historical time series

Before using a historical time series, it is advised to check the quality. If the historical time series contain errors, then also the generated future time series will contain errors. The quality of a time series is determined among others by:

- *The number of missing data*. The transformation tool can handle missing values: the standard notation assumed for missing values is -99.9, however, also values <-90 are considered missing. These values are not transformed in the future time series, and remain unchanged. However, it is not advised to use historical time series with many missing values;

- *The presence of inhomogeneities*. Inhomogeneities can be caused by changes in measuring methods, measuring locations, growing of trees around a measuring location, etc. They result in abrupt or gradual changes in average values, statistical properties, etc. In the past on KNMI stations relocations or changes in measuring methods took place. As a result many time series are not homogeneous. Sometimes inhomogeneities can be detected visually by plotting a time series: when you see an abrupt change this indicates an inhomogeneity. An example is given in Figure A3.2. Often inhomogeneities can not be detected visually. At the KNMI-website on "Klimatologie/Verleden weer" (Climatology/Past weather)[59] you can find information on the dates of relocations and introduction of new measuring methods (meta information). By checking whether the time series (e.g. averages, coefficients of variations) before and after these dates are significantly different, inhomogeneities can be detected.

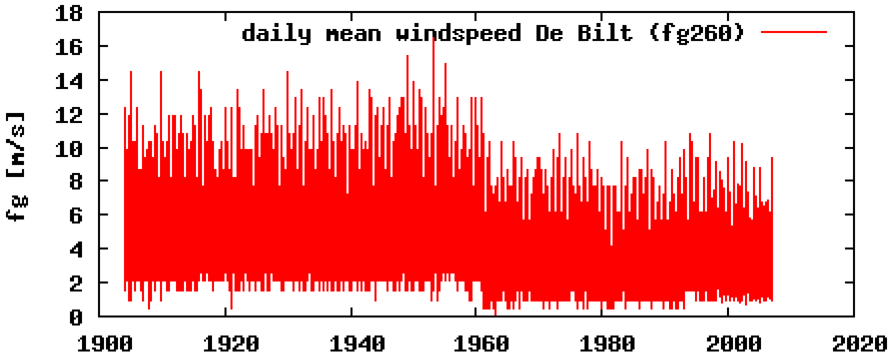

Figure A3.2 Average daily wind speed (m/s) in De Bilt. Clearly visible is the abrupt change in average wind speed in the beginning of the '60, caused by a change in measuring height and location (figure generated with the "Climate Explorer").

Through the KNMI-website ("Klimatologie/Verleden weer") all daily values of the KNMI-stations (with temperature and precipitation data for 0.00-24.00 UTC) and the precipitation stations (with precipitation data for 8.00-8.00 UTC) can be downloaded freely[60]. Time series can also be downloaded freely through the Climate Explorer (http://climexp.knmi.nl/start.cgi?someone@somewhere).

Format of the time series (input and output)

Table A3.2 indicates which formats of the historical time series are accepted by the transformation tool. The tool only produces the transformed time series in one format. On each line first the date is given[61], followed by the value for temperature (in °C; integers and decimals are separated by ".") or for precipitation (in mm/day; mm and decimals separated by "."). The dates in the input file can have different formats. For each date a new line is used.

[59] http://www.knmi.nl/klimatologie/metadata/stationslijst.html
[60] http://www.knmi.nl/klimatologie/daggegevens/download.html and http://www.knmi.nl/klimatologie/monv/reeksen/
[61] In some cases the output of the transformation tool that can be downloaded through the web pages of the Climate Explorer, presents more dates on one line: see Section A3.2 step 5.

Table A3.2 Example of a historical time series and a transformed time series. Average daily temperature for De Bilt: the historical time series can have four different formats, the resulting transformed time series only has one format.

Input: historical time series (year-month-day-hour and the day temperature in °C)	Output for scenario W+, time horizon around 2050 (year-month-day and the day temperature in °C)
19760101 5.0 19760102 5.6 ... 20051230 -1.2 20051231 4.5	20360101 7.13204 20360102 7.67656 ... 20651230 1.55491 20651231 6.78373
1976010100 5.0 1976010200 5.6 ... 2005123000 -1.2 2005123100 4.5	
1976 1 1 5.0 1976 1 2 5.6 ... 2005 12 30 -1.2 2005 12 31 4.5	
1 1 1976 5.0 1 2 1976 5.6 ... 12 30 2005 -1.2 12 31 2005 4.5	

In the transformed time series dates **around** the chosen time horizon are used.

Example: when a time series for the reference period 1976-2005 is transformed into a time series around 2040, the transformed time series will contain the years 2026-2055[62]. However, the transformed time series **do not give predictions** for the temperature or precipitation on a certain day in a certain year in the future.

Leap years

The current transformation tool does not check whether the leap years are correctly included in the transformed time series. This means that the transformed time series may contain 366 days in years that will not be leap years in the future. This problem does not occur when you use the reference period 1976-2005 and transform for the time horizons 2030, 2050, 2070 and 2090. Attention: the year 2100 is not a leap year!

Example: you use as reference period 1976-2005 and want to transform a time series for around 2040. The transformed time series contain the years 2026-2055. In the reference period e.g. 1988 was a leap year. This year is transformed into the year 2038 and contains 366 days in the transformed time series, whereas in reality 2036 and 2040 will be leap years[63].

[62] If a time series for the reference period 1961-1990, or 1971-2000 is transformed into a time series for around 2040, the transformed time series will also contain the years 2026-2055;

[63] If an impact model is sensitive to leap years, this problem can be overcome by subtracting 2 years of each date in the transformed time series.

Advantages and limitations of the transformed time series

(See Section 5.1 for the advantages and disadvantages.)

As a result of the limitations of the transformation tool the transformed time series are probably not so suitable for use in the following situations:

- To determine the chance in the future of specific sequences of events, e.g. heat waves (5 consecutive days with maximum temperatures of 25 °C or higher, of which 3 days have maximum temperatures of 30 °C or higher), number of consecutive days with more than 10 mm per day, a dry period of 30 days or more, a relatively warm end of winter and start of spring followed by sudden frost (as happened in February-March 2005 in the Netherlands). The sequence of temperatures and precipitation in the transformed time series is strongly based on the historical time series;
- To determine the year-to-year variation in the future. The year-to-year variation in the transformed time series is strongly based on the historical time series;
- Determining the joint occurrence of several climate variables, e.g. the number of summer days (maximum temperature of 25 °C or higher) with precipitation. The time series for precipitation and temperature are transformed independently. Therefore, the transformation tool does not know which wet days are removed in summer. On a dry day the temperature may increase faster than on a wet day (this is especially important for the G+ and W+ in summer);
- The time series present a picture of the climate around a certain time horizon in the future. The time series do not indicate how our climate may change from year to year (no prediction!).

At KNMI also other methods are available to generate time series for the future (e.g. with the help of output of climate models). There are also techniques available to estimate extremes with long return times (e.g. the “rainfall generator” or “Neerslaggenerator” in Dutch). For these methods and techniques you can contact the klimaatdesk@knmi.nl.

Changes per April 10, 2008[64]

(See Chapter 3 where the changes in the versions are explained)

In April 2008 also 4 of the historical precipitation time series in the menu were adapted. Until then the data from the stations West-Terschelling, Den Helder/De Kooy, Groningen and De Bilt from 2004 on were taken from the nearest precipitation station. From April 2008 on, all data from the historical time series for the investigated period 1976-2005 were from the stations West-Terschelling, Den Helder/De Kooy, Groningen and De Bilt. All data from Den Helder/De Kooy in the period 1976-2005 are from station De Kooy.

[64] In April 2008 a new version of the transformation tool was published on the internet. To inform the users a section on the changes between the version before April 2008 and from April 2008 on was added (see Chapter 2 and 3 for more information on the versions).

Annex 4. Overview of projects in which the transformation tool has been used

Since version 1.0 the transformation tool has been used in many projects within and beyond the CcSP programme. In the data delivery project in CcSP (COM28) it was used regularly to generate time series for the future.

Table A4.1 Overview of CcSP projects in which the transformation tool is used and in which KNMI was involved.

Project subject	CcSP project code (stakeholder)	Reference/link	Version transformation tool[65]
Ecosystems: ecohydrological effects in the Netherlands	A1 (VU/KWR)	Witte et al., 2009	P: 1.2 T: 1.2/2.0 PET: 1.0
Ecosystems: impact on butterflies	A2 (Alterra)	Cormont, 2011	T: 1.2/2.0 P: 1.2
Financial arrangements: water quality	A9 (wetterskip Fryslan)	Loeve et al., 2006	P: 1.0
Financial arrangements: hydrology in water board area	A9 (water board Rivierenland)	Immerzeel et al., 2007	River discharges: P/PET: -1.0 + changes 4 seasons Hydrology NL: P: 1.0
Energy: overview changes climate variables related to oil industry	A11 (Vereniging Nederlandse Petroleum Industrie (VNPI))	Bessembinder & Keller, 2008	P: 1.1 T: 1.0/1.1
Agriculture: impact analyses Northern NL	A21	De Wit et al., 2009	P: 1.2 T: 1.2/2.0
Fresh water supply: hydrological standard year	CS7 (Waterdienst, before that RIZA)	Bakker et al., 2009	P: 1.1 PET: 1.0
Water management water boards: time series for Quarles Ufford	CS7 (FutureWater, water boards)	http://www.knmi.nl/klimaatscenarios/maatwerk/water/index.html	Discharges: -1.0 P: 1.0[66] T: 1.0/1.1 PET: 0.0 + 4 seasons
Agriculture: time series for impact analyses crop yield in Europe	CS7 (Alterra)	http://www.knmi.nl/klimaatscenarios/maatwerk/natuur/index.html	Delta method[67]
Spatial planning: spatial information on climate and climate change in maps	COM21 (individual provinces)	http://www.knmi.nl/klimaatscenarios/maatwerk/ro/	P: 1.1 T: 1.0/1.1 PET: 1.0
Spatial planning: spatial information on climate and climate change in maps	COM27 (IPO: all provinces together)	KNMI, 2009b	P: 1.2 T: 1.2/2.0 PET: 1.0

[65] P=precipitation; T=temperature; PET=reference crop evapotranspiration.
[66] Probably used in this case study;
[67] The Delta method is used, however, not the current version of the transformation tool, since data were needed for the whole of Europe.

Tables A4.1 to A4.3. give an overview of projects in which the time series transformation tools are used. All projects in which KNMI was involved in some way are mentioned and some other projects of which we know they used the transformation tool. The tables also indicate which versions were used (as far as known).

Table A4.2 Overview of CcSP projects in which the transformation tool is used and in which KNMI was not involved directly (this means that the versions used are estimated).

Project subject	CcSP project code (stakeholder)	Reference/link	Version transformation tool[65]
Ecosystems: impact on habitat change species	A2	http://www.klimaatonderzoeknederland.nl/resultaten/klimaat-response-database	T: 1.0/1.1 or 1.2/2.0 P: 1.1 or 1.2
River discharges: extremes	A7 (Acer-project)	First estimates: Te Linde, 2007; De Wit et al., 2007; Van Deursen, 2006	P: -1.0 T: -1.0 PET: -1.0
Shipping: extreme river discharges	A8	First estimates river discharges: Te Linde, 2007; De Wit et al., 2007; Van Deursen, 2006	P: -1.0 PET: -1.0
Hydrology and water safety: impact on Zuidplaspolder	A14 (hotspot Zuidplaspolder)	De Moel et al., 2008; De Moel, 2008	P: 1.1 T: 1.0/1.1
Impacts climate change: Tilburg	A16 (hotspot Tilburg)	Schneider et al., 2007	P: 1.1 T: 1.1

Table A4.3 Some other projects in which the transformation tool is used[68].

Project subject	Stakeholder	Reference/link	Version transformation tool[65]
Urban water management: change in hourly extreme precipitation	TU Delft	Romero et al., 2011	P: 1.1 T: 1.1
Water management: change in extreme precipitation	DG Water	Groen, 2007	P: 1.1
River discharges: first estimates	RIZA/RIKZ	Te Linde, 2007; De Wit et al., 2007; Van Deursen, 2006	P: -1.0 T: -1.0 PET: -1.0
Fresh water supply and water safety: time series for estimating river discharges and hydrological parameters	Waterdienst/ Delta model	Homan et al., 2011a and 2011b	P: 2.0 T: 1.2/2.0
Nature: climate scenarios and time series for Flanders	Instituut voor Bos- en NatuurOnder-zoek, Flanders	KMI/KU Leuven/KNMI, 2009	P: 2.0 (Flanders) T: 1.2/2.0
Energy: reduction in chance extreme cold winters and high temperatures in summer	GasTerra/NAM	Wever, 2008	T: 1.0/1.1
Betuwe route: ice formation	Project organisation Betuwe route	Groen & Jilderda, 2007	T: 1.0/1.1
Cooling water capacity	Waterdienst	Kallen et al., 2008	T: -1.0 P: -1.0 PET: -1.0
Schiphol: temperature extremes	Hotspot Schiphol	Wolters & Beersma, 2012	T: 1.2/2.0

68 And in which KNMI was involved or contacted.

Annex 5. Overview of change coefficients in some versions of the transformation tool

Precipitation

Table A5.1 Change in wet day frequency (Δ*F;* %) per calendar month around 2050 compared to 1976-2005. Differences larger than or equal to 0.1 % are indicated in orange in the last four columns.

Month	Old coefficients (1.1 and before)				New coefficients (1.2 and later)				Differences between the 2 versions			
	G	G+	W	W+	G	G+	W	W+	G	G+	W	W+
1	0.15	1.27	0.30	2.54	0.17	1.22	0.34	2.54	0.0	0.1	0.0	0.0
2	0.10	0.95	0.20	1.90	0.07	0.90	0.13	1.90	0.0	0.0	0.1	0.0
3	-0.11	-0.32	-0.22	-0.64	-0.21	-0.36	-0.43	-0.64	0.1	0.0	0.2	0.0
4	-0.49	-2.65	-0.99	-5.31	-0.75	-2.67	-1.55	-5.31	0.3	0.0	0.6	0.0
5	-0.92	-5.20	-1.83	-10.40	-1.26	-5.19	-2.60	-10.40	0.3	0.0	0.8	0.0
6	-1.33	-7.74	-2.67	-15.48	-1.57	-7.71	-3.23	-15.48	0.2	0.0	0.6	0.0
7	-1.72	-10.05	-3.44	-20.15	-1.67	-10.02	-3.44	-20.15	0.1	0.0	0.0	0.0
8	-1.89	-11.13	-3.79	-22.27	-1.57	-11.07	-3.23	-22.27	0.3	0.1	0.6	0.0
9	-1.65	-9.65	-3.30	-19.30	-1.26	-9.60	-2.60	-19.30	0.4	0.1	0.7	0.0
10	-0.92	-5.20	-1.83	-10.40	-0.67	-5.19	-1.38	-10.40	0.3	0.0	0.5	0.0
11	-0.30	-1.49	-0.61	-2.98	-0.16	-1.52	-0.33	-2.98	0.1	0.0	0.3	0.0
12	0.05	0.63	0.10	1.26	0.07	0.59	0.13	1.26	0.0	0.0	0.0	0.0

Table A5.2 Change in mean precipitation on wet days (ΔP_{mean}; %) per calendar month around 2050 compared to 1976-2005. Differences larger than or equal to 0.1 % are indicated in orange in the last four columns.

Month	Old coefficients (1.1 and before)				New coefficients (1.2 and later)				Differences between the 2 versions			
	G	G+	W	W+	G	G+	W	W+	G	G+	W	W+
1	3.52	6.23	7.04	12.45	3.56	6.18	7.02	12.45	0.0	0.1	0.0	0.0
2	3.55	6.05	7.10	12.10	3.62	6.00	7.14	12.10	0.1	0.0	0.0	0.0
3	3.67	5.34	7.34	10.68	3.78	5.29	7.46	10.68	0.1	0.0	0.1	0.0
4	3.89	4.04	7.78	8.09	4.10	3.99	8.10	8.09	0.2	0.0	0.3	0.0
5	4.13	2.63	8.26	5.26	4.40	2.58	8.70	5.26	0.3	0.0	0.4	0.0
6	4.37	1.21	8.74	2.42	4.58	1.16	9.06	2.42	0.2	0.1	0.3	0.0
7	4.59	-0.09	9.18	-0.17	4.64	-0.14	9.18	-0.17	0.0	0.1	0.0	0.0
8	4.69	-0.68	9.38	-1.35	4.58	-0.73	9.06	-1.35	0.1	0.0	0.3	0.0
9	4.55	0.15	9.10	0.30	4.40	0.10	8.70	0.30	0.1	0.1	0.4	0.0
10	4.13	2.63	8.26	5.26	4.05	2.58	8.00	5.26	0.1	0.0	0.3	0.0
11	3.78	4.69	7.56	9.39	3.75	4.64	7.40	9.39	0.0	0.1	0.2	0.0
12	3.58	5.87	7.16	11.75	3.62	5.82	7.14	11.75	0.0	0.0	0.0	0.0

Table A5.3 Change in the 99th percentile (ΔP_{99}; %) per calendar month around 2050 compared to 1976-2005. Differences larger than or equal to 0.1 % are indicated in orange in the last four columns.

Month	Old coefficients (1.1 and before)				New coefficients (1.2 and later)				Differences between the 2 versions			
	G	G+	W	W+	G	G+	W	W+	G	G+	W	W+
1	4.06	5.58	8.11	11.17	3.98	5.58	7.95	11.17	0.1	0.0	0.2	0.0
2	4.30	5.60	8.60	11.20	4.46	5.60	8.92	11.20	0.2	0.0	0.3	0.0
3	5.27	5.67	10.54	11.33	5.76	5.67	11.52	11.33	0.5	0.0	1.0	0.0
4	7.05	5.79	14.11	11.57	8.35	5.80	16.70	11.57	1.3	0.0	2.6	0.0
5	9.00	5.92	18.00	11.84	10.78	5.95	21.56	11.84	1.8	0.0	3.6	0.0
6	10.94	6.05	21.88	12.10	12.24	6.09	24.48	12.10	1.3	0.0	2.6	0.0
7	12.72	6.17	25.45	12.34	12.72	6.22	25.45	12.34	0.0	0.0	0.0	0.0
8	13.53	6.23	27.07	12.45	12.24	6.28	24.48	12.45	1.3	0.0	2.6	0.0
9	12.40	6.15	24.80	12.30	10.78	6.20	21.56	12.30	1.6	0.0	3.2	0.0
10	9.00	5.92	18.00	11.84	7.95	5.95	15.89	11.84	1.1	0.0	2.1	0.0
11	6.16	5.73	12.33	11.45	5.52	5.74	11.03	11.45	0.6	0.0	1.3	0.0
12	4.54	5.62	9.09	11.23	4.46	5.62	8.92	11.23	0.1	0.0	0.2	0.0

Temperature

Table A5.4 Change in the 10th percentile (ΔP_{10}) per calendar month of the average daily temperature (in °C) around 2050 compared to 1976-2005. Differences larger than or equal to 0.1 °C are indicated in orange in the last four columns.

Month	Old coefficients (1.1 and before)				New coefficients (1.2 and later)				Differences between the 2 versions			
	G	G+	W	W+	G	G+	W	W+	G	G+	W	W+
1	1.00	1.41	2.01	2.81	1.00	1.41	2.01	2.82	0.0	0.0	0.0	0.0
2	1.00	1.40	2.00	2.80	1.00	1.40	2.00	2.80	0.0	0.0	0.0	0.0
3	0.99	1.38	1.98	2.75	0.98	1.36	1.96	2.73	0.0	0.0	0.0	0.0
4	0.97	1.33	1.93	2.66	0.95	1.30	1.90	2.60	0.0	0.0	0.0	0.1
5	0.94	1.28	1.88	2.57	0.92	1.23	1.84	2.45	0.0	0.1	0.0	0.1
6	0.92	1.24	1.84	2.47	0.90	1.15	1.80	2.31	0.0	0.1	0.0	0.2
7	0.90	1.19	1.79	2.38	0.90	1.09	1.79	2.18	0.0	0.1	0.0	0.2
8	0.89	1.17	1.77	2.34	0.90	1.06	1.80	2.12	0.0	0.1	0.0	0.2
9	0.90	1.20	1.80	2.40	0.92	1.10	1.84	2.20	0.0	0.1	0.0	0.2
10	0.94	1.28	1.88	2.57	0.96	1.23	1.91	2.45	0.0	0.1	0.0	0.1
11	0.98	1.35	1.95	2.71	0.99	1.33	1.97	2.66	0.0	0.0	0.0	0.0
12	1.00	1.39	1.99	2.79	1.00	1.39	2.00	2.78	0.0	0.0	0.0	0.0

Table A5.5 Change in the 50th percentile (ΔP_{50}) per calendar month of the average daily temperature (in °C) around 2050 compared to 1976-2005. Differences larger than or equal to 0.1 °C are indicated in orange in the last four columns.

Month	Old coefficients (1.1 and before)				New coefficients (1.2 and later)				Differences between the 2 versions			
	G	G+	W	W+	G	G+	W	W+	G	G+	W	W+
1	0.90	1.14	1.80	2.28	0.90	1.09	1.80	2.29	0.0	0.0	0.0	0.0
2	0.90	1.15	1.80	2.30	0.90	1.10	1.80	2.30	0.0	0.0	0.0	0.0
3	0.89	1.18	1.79	2.36	0.90	1.14	1.78	2.36	0.0	0.0	0.0	0.0
4	0.88	1.24	1.77	2.47	0.90	1.20	1.75	2.47	0.0	0.0	0.0	0.0
5	0.87	1.29	1.74	2.59	0.90	1.27	1.72	2.59	0.0	0.0	0.0	0.0
6	0.86	1.36	1.72	2.71	0.90	1.35	1.70	2.71	0.0	0.0	0.0	0.0
7	0.85	1.41	1.70	2.82	0.90	1.41	1.70	2.82	0.1	0.0	0.0	0.0
8	0.84	1.43	1.69	2.87	0.90	1.44	1.70	2.87	0.1	0.0	0.0	0.0
9	0.85	1.40	1.70	2.80	0.90	1.40	1.72	2.80	0.1	0.0	0.0	0.0
10	0.87	1.29	1.74	2.59	0.90	1.27	1.76	2.59	0.0	0.0	0.0	0.0
11	0.89	1.21	1.78	2.41	0.90	1.17	1.79	2.42	0.0	0.0	0.0	0.0
12	0.90	1.16	1.80	2.32	0.90	1.11	1.80	2.32	0.0	0.0	0.0	0.0

Table A5.6 Change in the 90th percentile (ΔP_{90}) per calendar month of the average daily temperature (in °C) around 2050 compared to 1976-2005. Differences larger than or equal to 0.1 °C are indicated in orange in the last four columns.

Month	Old coefficients (1.1 and before)				New coefficients (1.2 and later)				Differences between the 2 versions			
	G	G+	W	W+	G	G+	W	W+	G	G+	W	W+
1	0.85	0.92	1.69	1.85	0.79	0.98	1.69	1.85	0.1	0.1	0.0	0.0
2	0.85	0.95	1.70	1.90	0.80	1.00	1.71	1.90	0.0	0.1	0.0	0.0
3	0.87	1.05	1.74	2.10	0.84	1.10	1.75	2.10	0.0	0.1	0.0	0.0
4	0.90	1.24	1.80	2.48	0.90	1.27	1.85	2.48	0.0	0.0	0.1	0.0
5	0.94	1.44	1.87	2.89	0.96	1.46	1.94	2.89	0.0	0.0	0.1	0.0
6	0.97	1.65	1.95	3.29	1.00	1.66	1.99	3.29	0.0	0.0	0.0	0.0
7	1.01	1.83	2.01	3.67	1.01	1.83	2.01	3.67	0.0	0.0	0.0	0.0
8	1.02	1.92	2.04	3.84	1.00	1.91	1.99	3.84	0.0	0.0	0.1	0.0
9	1.00	1.80	2.00	3.60	0.96	1.80	1.94	3.60	0.0	0.0	0.1	0.0
10	0.94	1.44	1.87	2.89	0.89	1.46	1.84	2.89	0.0	0.0	0.0	0.0
11	0.88	1.15	1.77	2.29	0.83	1.18	1.75	2.29	0.1	0.0	0.0	0.0
12	0.85	0.98	1.71	1.95	0.80	1.02	1.71	1.95	0.0	0.0	0.0	0.0

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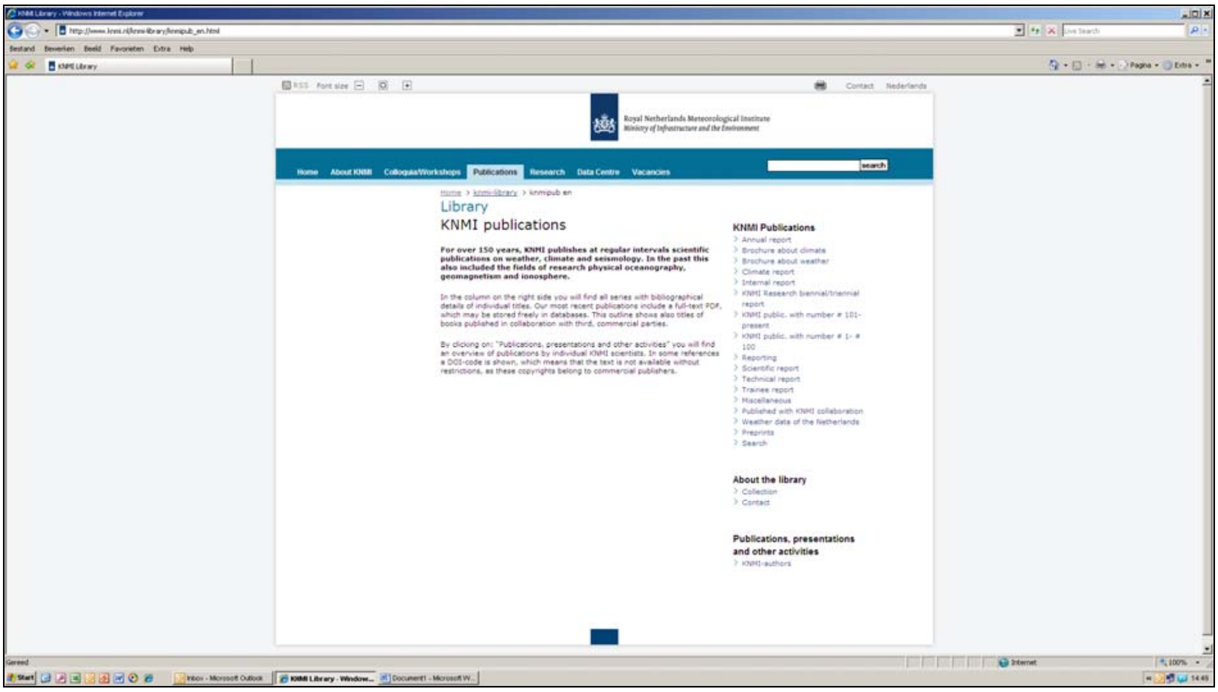

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