Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Advisory Board report : towards the KNMI '13 scenarios

Climate change in the Netherlands

De Bilt, 2012 | KNMI-publication 230

Advisory Board report : towards the KNMI '13 scenarios

Version 1.0

Date August 8, 2012
Status Final

Contents

1 Introduction

The members of the Advisory Board (Annex 1) for the next generation KNMI climate scenarios met in De Bilt, the Netherlands on 5 and 6 June 2012. These external experts have been asked by KNMI to provide independent feedback on the different aspects of the project that leads to the next generation KNMI climate scenarios for the Netherlands (called the KNMI'13 scenarios). The agenda for the meeting is attached as Annex 2. The discussion was structured on the basis of presentations and a panel discussion.

A scoping document (Annex 3) prepared for the meeting was distributed beforehand. This document describes the roadmap towards the KNMI'13 scenarios. The scoping document contains several pending questions for which KNMI sought advice from the Advisory Board members in particular. Discussion of these questions has led to the following comments and recommendations for the project.

2 Comments and recommendations

1) According to the Advisory Board, the KNMInext project (which aims to develop the KNMI'13 climate scenarios for the Netherlands), is a sound exercise not only from a technical point of view but also scientifically and intellectually. The KNMInext activities include a critical assessment of the results and a self reflection on the best way to present these. They go beyond generating the numbers on the basis of model projections alone. Expert judgement (also based on empirical evidence) is very much welcomed to augment the model derived scenario information (e.g. with respect to the scaling of precipitation extremes). Expert judgement also allows to keep the scenario structure for the end users relatively simple. The Advisory Board felt that the liaison with end users of the climate information pays off. There is a need to involve other disciplines than meteorologists and climatologists for integration of knowledge and providing the necessary context.

2) The Advisory Board concluded that a full probabilistic approach to climate projections at the regional scale is currently not feasible. The main reason is that the scientific developments in this area are currently only in its infancy. The limited model ensemble and limited number of emission scenario's or pathways which are available now make any probabilistic statement conditional. No such thing as a statistical significant scenario exists. Some fundamental concerns about the prospects of probabilistic climate predictions are raised. It is recommended to clearly communicate the point as to why the KNMI choice of discrete scenarios is preferable. These discrete scenarios come in the form of plausible descriptive sketches of the consequences of global warming for the Netherlands. Sketches that guide the users what to do when some climate future happens. At the same time, it is recommended to pay explicit attention to what can be told in a probabilistic sense already now, e.g. the likelihood of different magnitudes of global mean warming conditional on the different Representative Concentration Pathways (RCPs). Also, alert the users to what the potential of a probabilistic approach is.

3) The question whether the end result is "fit for purpose" should be addressed from the user perspective. It is all about providing the best assessment of future climate change in the Netherlands, given current scientific knowledge and constrained by the time and resources available. User requirements are important, but so is scientific credibility. There is often a tension between the two as users want more than scientists feel comfortable to provide. KNMI should be confident to defend what has been done, also against a harsh audience. Recognize and communicate that the scenarios are a snapshot of the current scientific knowledge. Details may change when new model data become available. KNMI should be transparent about the uncertainties and caveats, especially those that cannot easily be quantified. From the user perspective there

is a clear need for simplifications. In many cases climate is not the main driver of change. Often the adaptive capacity depends on other (e.g. socio-economic) scenarios too. Having too many scenarios in total can be avoided by selecting meaningful combinations.

4) The Advisory Board recommends to consider carefully whether KNMI wants to develop, provide and communicate one or more very extreme scenarios in addition to the more plausible scenarios currently planned. Such scenarios (which cannot be based on models alone) have been proven useful in the example of the Delta Committee scenario. The premises is that these additional scenarios are correctly framed as “upper limit” scenarios for vulnerability studies.

5) The Board encourages the KNMInext team to make the link to the emission scenarios and/or RCPs used for the IPCC-AR5 report as explicit as possible. It is likely that these scenarios will be widely used in the next few years. Even if no 1 to 1 relationship exists, there is a clear benefit of linking the KNMI scenarios for the Netherlands to the global story lines of future socio-economic development, climate policies and adaptation strategies. This will also make the communication about the scenarios as downscaled products of the findings in the new IPCC report more easy.

6) It is noted that the choice of a North Atlantic pressure pattern as the second steering variable for the structure of the four KNMI scenarios (besides global temperature rise as the first steering variable) is not straightforward. More work to understand the local drivers of the climate in the Netherlands is needed. A clear motivation for a pressure based pattern to replace the more straightforward strength of the westerly flow chosen in the KNMI’06 scenarios or another precipitation related steering variable is currently lacking. In addition, possible impacts of climate change in the Netherlands are connected to atmospheric conditions over other regions than the North Atlantic. For example, river flooding over the Rhine River is related to the conditions in the upstream area (including in the Alps). Also here, a clear link to the chosen pressure patterns has to be demonstrated.

7) The Board agrees with the suggested timing for scenario publication linked to the publication date of the IPCC-AR5 report from WG1. However, also noted is the potential complication with the WG2 release date of March 2014 because the WG2 report will include more regional information on Europe. Irrespective of the exact publication date of the scenarios, it is recommended to explain explicitly the added value of the AR5 information used for the KNMI’13 scenarios over the AR4 information used for the KNMI’06 scenarios.

8) A clear explanation for the added value of downscaling is required, e.g. to capture the coastal effects or small scale processes. Several different possible

avenues for downscaling are being explored by KNMI at present, but it is recognized that some might not work out. Therefore, there needs to be some flexibility retained in the plan and possibly an increase in the amount of effort spent on this topic.

9) The Board agrees that providing future weather like time series is a good addition for many impact studies. However, KNMI needs to be careful when providing (bias corrected) RCM output or high resolution GCM output directly to users. There are many caveats when a single RCM or high resolution GCM simulation is used to enrich each of the 4 anticipated KNMI'13 scenarios with a future weather like series of pictures. Showing contrasted results from different models might help to avoid overconfidence in one single projection. Probably the best way to bring this forward is to explore the possibilities for a "good practice" example working with one specific user group.

10) There has been some discussion on the added value of confronting model derived information with observed trends (appealing to the monitoring role of an NMHS such as KNMI). Explaining the differences (also related to comparing forced signals to natural variability) is a key element here which should be addressed in detail. Discounting one or more of the earlier KNMI'06 scenarios because the trends in the temperature observations are (much) stronger than extrapolation of the pathways for the scenarios for 2050 suggest is not recommended. One reason is that scenarios are no predictions and therefore it is fundamentally wrong to indicate probability of occurrence. Also, without robust attribution statements of what caused the observed trends, it would be dangerous to extrapolate the trends into the future even if the forcing was to remain in the same direction.

11) Given the international background of the Board, the advise on international cooperation is to explore what countries in Western Europe can do jointly with respect to climate scenarios partly because of their shared geographical position and/or culture. Already now, the scenarios developed in the countries bordering the Netherlands make use of the same GCM and RCM simulations. Among the other activities that can be handled jointly are facilitating access to generic products and defining best practice for (statistical) downscaling approaches and ways of user interaction.

12) On the request of the Advisory Board, the topic of Urban Heat Island (UHI) and Land Use / Land Cover (LULC) changes was added to the list of discussion items. KNMI needs to work with other groups in the Netherlands and abroad which have assessed these potential changes. Most analysis are in the form of case studies. A specific future task for KNMI could then be to develop long time series which will help to distinguish UHI/LULC signals from GHG signals. This work would benefit from active KNMI participation in regional reanalysis projects. Although it is recognized that this will be very much work in progress

next year, there is a clear need to include some information on this topical issue in the KNMI'13 scenarios.

13) The Advisory Board commended the KNMI for establishing a dialog with users. This is essential as both sides need some give-and-take and inevitably there are compromises. Part of the dialogue is required to obtain a better understanding of the way the climate change knowledge is perceived by the users. It is logical that the scenario products/services are similar to the observation based products/services which users are familiar with. This can help link the climate change information to their daily practice. Changes in frequency distributions of severe weather events are among the required products. So are tools for transformation of observational time series or weather generators. These tools should be accompanied with clear guidelines describing the caveats.

14) Finally, the Board notes that, in complex projects like this, things may not go as planned, people might leave or get diverted and take their expertise with them and the level of resources or the user-requirements might change. Hence KNMI is advised to reserve the right to change the approach to the production of the scenarios to react to such situations.

Annex 1

Members of the Advisory Board

Advisory Board:

1: Prof. dr. ir. Bert Holtslag (Wageningen University; chair)
2: Ir. Florrie de Pater (IVM)
3: Prof. Dr. Arthur Petersen (PBL)
4: Dr. Serge Planton (Météo France)
5: Dr. Christoph Appenzeller (MeteoSweiz)
6: Prof. Dr. Hans Von Storch (Helmholtz Zentrum Geesthacht)
7: Prof. Dr. Hans Moser (Bundesanstalt für Gewässerkunde)
8: Prof. Dr. Mat Collins (University of Exeter; provided written input)

KNMInext staff (selection of staff involved):

9: Prof. Dr. Wilco Hazeleger
10: Dr. Jules Beersma
11: Dr. Geert Lenderink
12: Dr. Albert Klein Tank

Annex 2

Advisory Board Meeting for the KNMInext Climate Scenarios

Date: 5-6 June 2012
Meeting venue: KNMI, De Bilt, The Netherlands

Tuesday 5 June: Buys Ballot room		
12:30	Lunch	
13:00	Hein Haak (Director Climate)	Welcome
13:10	Bert Holtslag (Chair, WUR)	Introductions around the room; meeting goals; task of the Advisory Board; review of the agenda; reporting plans; practicalities
13:30	Albert Klein Tank	Introduction KNMInext scenarios (short history; user profile; boundary conditions; international context; current status and future plans)
13:50	Bart van den Hurk	GCM analysis and scenario framework (drivers for climate change in the Netherlands; CMIP5 and EC-Earth results; future weather)
14:10		Discussion
14:30	Geert Lenderink	RCM downscaling for the Netherlands (RACMO simulations; sampling model output; spatial gradients; scaling studies)
14:50		Discussion
15:10	Afternoon break	
15:40	Geert Jan van Oldenborgh, Jules Beersma, Caroline Katsman	Forum discussion on: representing uncertainties; link with Dutch Delta Committee scenario; links with socio-economic, land use and spatial development scenarios; requested scenario variables and quantities; derived products including time series; assessment of past and current trends
17:30	Chair and AB members	Closed session for AB members
18:00	Close	
18:30	Drinks followed by Diner	Restaurant “De Witte Zwaan”, Dorpsstraat 8 3732 HJ De Bilt, +31 30 221 01 25

Wednesday 6 June: Buys Ballot room		
09:00	Chair and AB members	Feedback from previous day; shortlist of additional topics for discussion at 10:10
09:30	Janet Bessembinder	Scenario publication and user liaison (outreach plan; collaborative projects with users in the Netherlands; examples of tailoring)
09:50		Discussion
10:10	Chair and AB members	Additional topics from the shortlist (introduced by KNMInext project team members if necessary)
11:00	Morning break	
11:30	Rapporteurs	Summary of recommendations for the project
12:15	Chair	Reporting procedure and time schedule; Close
13:00	Lunch	

Annex 3

Climate change in the Netherlands

Towards the KNMInext scenarios

– Scoping document –

Royal Netherlands Meteorological Institute

Ministry of Infrastructure and the Environment

22 May 2012

Contents

1 Scenarios rather than predictions

1.1 Objective

This document describes the roadmap towards the next generation KNMI climate scenarios for the Netherlands. These KNMInext scenarios will update the current KNMI'06 scenarios published in 2006. The main deliverables will be a scientific report, brochure, and website. These deliverables together address both the professional user community and the general public. In addition, several scientific papers will be published.

The following sections of Chapter 1 deal with the process of scenario development and the wider context. Some preliminary results are provided in Chapter 2. At the end of each section some pending questions are highlighted for which we seek advice from the Advisory Board members. These items for discussion will be further articulated in the presentations on 5 and 6 June 2012.

1.2 Framing

KNMI climate scenarios are consistent, plausible and coherent pictures of the future climate of the Netherlands. They provide information for vulnerability studies and adaptation planning. The scenarios are intended to explore possible futures as guidance for informed decision making under uncertainty by local, provincial and national governments in the area of, among others, spatial planning, national security and water management. The scenarios also enable learning about the adequacy and effectiveness of policy options (Haasnoot and Middelkoop, 2012).

In response to user demands, KNMI climate scenarios consist of a limited number of discrete scenarios rather than a full probabilistic prediction framework. KNMI aims for one set of generic climate scenarios that suits a wide range of users. Based on the current knowledge these scenarios describe the bandwidth of likely future climates. This bandwidth is mainly provided by the range of climate model responses to external forcing in the CMIP5 project (http://cmip-pcmdi.llnl.gov/cmip5/). The generic scenarios facilitate integration and valid comparisons of subsequent risk, cost/benefit and vulnerability analyses. The provision of additional climate information tailored to individual customers is a KNMI task, but not part of the KNMInext project.

Although the construction of the KNMI scenarios follows a typical top-down information chain approach (from IPCC emission scenarios to a range of climate projections to a set of downscaling steps to statistical post-processing at the local level to potential impacts), the scenarios are designed to serve as a benchmark for bottom-up application in different sectors of society (Wilby and Dessai, 2010; Van den Hurk et al., 2012). This bottom-up procedure or "adaptation tipping point analysis" (Kwadijk et al., 2010) essentially follows a reversed chain of analysis (from potential impacts/thresholds that preferably need to be avoided to an assessment of corresponding climate characteristics that lead to these impacts to climate projections that determine whether or when these conditions can be expected). In this bottom-up procedure climate change is only one of the drivers for adaptation next to socio-economic and spatial development.

pending questions:

- Is the way KNMI frames the generic scenarios as discrete pictures of the future climate adequate and fit-for-purpose?

1.3 Time line, resources, and (inter)national context

The release of the KNMInext climate scenarios is planned for the autumn of 2013. This coincides with the publication of the WG1 report of the IPCC-AR5. The scenarios can be regarded as a translation of the newest future climate projections to the local scale of the Netherlands.

The KNMI scenarios form part of the baseline scenarios of the Delta Programme, which is the successor of the Delta Committee (see Section 1.6). Important decisions in water management are planned for the autumn of 2013. The preparatory calculations have used the KNMI06 scenarios, but the updated KNMInext scenarios will be taken into account when selecting preferential adaptation strategies in the Delta Programme process.

The estimated total effort spent on developing the KNMInext scenarios over a three year period (mid 2010 – mid 2013) is roughly 240 person months (or 20 person years). In addition to funding from the Ministry of Infrastructure and the Environment (under which KNMI resides), funding is used from several EU-projects and three national programmes: Sustainable Earth from the Netherlands Organisation for Scientific Research (NWO, 2012), Climate Changes Spatial Planning (CCSP, 2011) and Knowledge for Climate (KfC, 2011).

Unlike other countries who have recently developed national climate change scenarios (Jenkins et al., 2009; CH2011, 2011), KNMI has traditionally used the global temperature rise as a basis/driving variable, rather than emission scenarios. The motivation is that global temperature rise provides a better insight in the combined uncertainties about greenhouse gas emissions (and the socio-economic scenarios behind them) and the response of the climate system. The development of the KNMI scenarios resembles the approach followed in Australia (CSIRO, 2007; Whetton et al., 2012).

It has been recognized that the differences in scenario approach between countries in Europe sometimes limits the comparison of vulnerability studies and adaptation strategies. This is a complicating factor in particular for water management in the coastal zone and in the Rhine–Meuse delta. KNMI has close contacts with Belgian and German colleagues about mutual coordination of the climate scenarios for these basins (see e.g. Goergen et al., 2010). For Belgium, this has lead to a joint project, in which scenarios for Flanders are linked up with the KNMI'06 scenarios (Demarée et al., 2008). For Germany, the current situation is more fragmented. Activities are under way to devise a strategy to come to European Climate Services, including harmonized scenarios for Europe, e.g. as part of the EU-FP7 project ECLISE (http://www.eclise-project.eu/) or the JPI Climate (http://www.jpi-climate.eu/). However, this strategy won't be implemented before publication of the KNMInext scenarios in the autumn of 2013.

pending questions:

- How useful is aligning the timeframe of the KNMInext scenarios and the IPCC-WG1 reports?
- Should KNMI invest more in further integration of the scenarios from different countries, e.g. for the Rhine and Meuse river basins or for the North Sea area?

1.4 Previous generation KNMI scenarios

After some pioneering first order assessments of climate change at the national level (Können, 2001), the most comprehensive KNMI scenarios to date have been published in 2006 (Van den Hurk et al., 2006; Van den Hurk et al., 2007). The KNMI'06 scenarios were based on an integrated assessment of state-of-the-art climate projections from CMIP3 GCM simulations prepared for the IPCC-AR4 (IPCC, 2007), downscaled data from a suite of RCMs (Jacob et al., 2007; Lenderink et al., 2007), local observations, and a regionalization exercise of the IPCC sea level rise scenarios (Katsman et al., 2008).

The KNMI'06 scenarios consist of four descriptive pictures of climate change in the Netherlands (Figure 1) expressed as a set of change factors for a number of relevant meteorological variables (temperature, precipitation, wind and sea level; Table 1). The change factors are for different statistical moments (allowing changes in the mean to be different from changes in the extremes) around 2050 and 2100 relative to the reference period around 1990 (1976-2005). Together, these four scenarios describe the range of most likely changes conditioned on the range of outcomes of CMIP3 models. The differences between the scenarios are indicative of the uncertainties. No quantitative likelihood statement has been assigned to the individual scenarios.

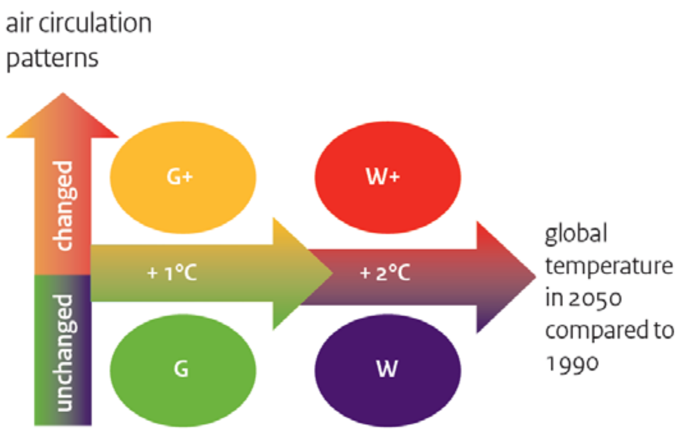


Figure 1: Classification of the four KNMI'06 scenarios.

		G	G+	W	W+
Global temperature rise		+1°C	+1°C	+2°C	+2°C
Change in air circulation patterns		no	yes	no	yes
Winter [3]	average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C
	coldest winter day per year	+1.0°C	+1.5°C	+2.1°C	+2.9°C
	average precipitation amount	+4%	+7%	+7%	+14%
	number of wet days (≥ 0.1 mm)	0%	+1%	0%	+2%
	10-day precipitation sum exceeded once in 10 years	+4%	+6%	+8%	+12%
	maximum average daily wind speed per year	0%	+2%	-1%	+4%
Summer [3]	average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C
	warmest summer day per year	+1.0°C	+1.9°C	+2.1°C	+3.8°C
	average precipitation amount	+3%	-10%	+6%	-19%
	number of wet days (≥ 0.1 mm)	-2%	-10%	-3%	-19%
	daily precipitation sum exceeded once in 10 years	+13%	+5%	+27%	+10%
	potential evaporation	+3%	+8%	+7%	+15%
Sea level	absolute increase	15-25 cm	15-25 cm	20-35 cm	20-35 cm

Table 1: Change factors in the KNMI'06 scenarios for the climate around 2050, compared to the baseline year 1990.

The scenarios differ in the degree of global temperature rise and the degree of change in atmospheric circulation patterns above the Netherlands. The W/W+ scenarios are characterised by a strong increase in the global mean temperature, whereas this increase is moderate in the G/G+ scenarios. In the G+/W+ scenarios, a change in the atmospheric circulation above the Atlantic Ocean and Western Europe leads to extra warm and wet winters, whereas the summers are extra warm and dry. In the G/W scenarios, the influence of circulation changes is small.

The four scenarios emphasize the location of the Dutch delta in a transition zone with a pronounced increase of wintertime precipitation projected for Northern Europe and a decrease of summertime precipitation projected for Southern Europe. Aspects of both features appear in the four scenarios for the Netherlands. Note that the uncertainty in the signature of this change in the transition zone is also related to the strong interannual variability of present-day seasonal precipitation and temperature in the Netherlands linked to atmospheric circulation conditions.

The present-day climate of the Netherlands is also characterised by gradients across the country. However, in the KNMI'06 scenarios no difference is made in the climate change signal between the different parts of the country. Neither are local features such as changes in the urban heat island effect included. The KNMI'06 scenarios assume that the regional differences and the urban heat island effects in the climate of 2050 and 2100 will be similar to the spatial differences that occur under present-day conditions. Since 2006, evidence for regional differences in climate change has grown, in particular in the precipitation climate between the coastal area and inland (see Section 2.4). The KNMInext scenarios will include spatial differentiation to a certain extent.

The KNMI'06 scenarios served a wide range of sectors vulnerable to summer droughts (e.g. agriculture), seasonal floods (e.g. water management), and wind storms (e.g. coastal defence). The climate variables included in the KNMI'06 scenarios were chosen in close cooperation with stakeholders from these vulnerable sectors. Examples are multi-day precipitation extremes which drive the high discharge levels in the Rhine and single day or even single event precipitation extremes as boundary conditions for water table management at the polder level and sewage design in urban areas.

The KNMI'06 scenarios received a legal status in the National Water Plan (NWP, 2009) in which the safety tasks for the national and regional water systems are regulated between the national and local governments. Also the Delta Committee / Delta Programme (see Section 1.6) and many other sector-specific applications use KNMI'06 as a reference.

pending questions:

- How important is continuity (in approach and/or outcome) from one generation KNMI scenarios to the next?

1.5 Representing uncertainties in the climate system

Like almost every prediction for the future also predictions of the future climate in the Netherlands are uncertain. There is uncertainty about socio-economic developments, solar activity, volcanic eruptions, model uncertainty, natural variability, uncertainty related to the downscaling of the projected changes from global to regional to local scale, etc. Also, potentially important processes in the climate system, such as the accelerated melt of ice sheets due to dynamical processes and the climate feedback mechanisms associated with biological and chemical processes, are difficult to quantify. The models used for KNMI'06 did not include these processes. The current generation climate models, which are used for the IPCC-AR5, and which act as input for the next generation KNMI scenarios, include these processes partially.

Consistent with our earlier approach, for KNMInext the choice has been made to develop a limited set of discrete scenarios to represent the uncertainties rather than probabilistic predictions. To account for known processes not included in the models, use will be made of subjective expert judgment in the scenario construction process. Expert judgement will also be used to deal with the limited sample of model simulations available for scenario development (see Section 2.3) and questions about model skill and model reliability (see Section 2.6). In an attempt to avoid the tendency towards overconfidence, KNMI involves a wide range of scientists and studies.

pending questions:

- Does KNMI rely too much on climate model projections for the scenarios rather than expert judgment?

1.6 Link with Dutch Delta Committee scenario

Intended as 'a reference for long-term (2100 and later) robustness tests of required measures and investments', the Delta Committee (2008; see also Kabat et al., 2009) issued an extreme climate scenario for local sea level rise at the Dutch coast. KNMI has contributed substantially to this work (Katsman et al., 2008; Katsman et al., 2011) in which a semi-objective procedure was followed by asking an international team of experts to provide a consensus view of the plausible high-end sea level change in 2100 and beyond (Vellinga et al., 2009).

For 2050, the Delta Committee makes use of the KNMI'06 scenarios, but for 2100 the Delta Committee emphasises the upper limit of the possible melting and calving of the ice sheets of Greenland and Antarctica. This limit is significantly higher than the most likely contribution that KNMI accounts for in the KNMI'06 scenarios. For the generic climate scenarios of KNMInext which are targeted at a wide range of users, the work of the Delta Committee represents useful input.

More importantly, the Delta Committee emphasised the gradual evolution of sea level rise over time, and recommended an adaptive approach, each time responding to the actual rise taking place. The Delta Committee further illustrates the use of subjective expert judgment in the scenario construction process.

pending questions:

- What lessons can be learned from the Delta Committee extreme scenarios?

1.7 Links with socio-economic, land use and spatial development scenarios

Climate models make use of projections of future emissions of greenhouse gasses and dust particles (aerosols). Associated with these projections are story lines of how the world population, economy and technology will develop. These socio-economic scenarios cannot be coupled one-to-one to the KNMI climate scenarios, but consistency between these scenarios is required. Because KNMI intends to cover a large part of the total uncertainty (emission plus model uncertainty) with the climate scenarios, global temperature rise will again be chosen as the starting point for the scenario classification rather than emission scenarios. The choice of global temperature instead of local temperature is motivated in Chapter 2.

By means of the global mean temperature, an indirect relationship between the KNMI scenarios and emission scenarios can be established. This involves estimating a "likelihood of occurrence" given future GHG emissions. For example, each of the four KNMI'06 scenarios may occur under each IPCC emission scenario for 2050. For 2100, the G/G+ scenarios (2°C global temperature rise) are most representative for a low B1 emission scenario under an average estimate for the climate sensitivity, whereas the W/W+ scenarios (4°C rise) are more likely under a high A1FI scenario.

A similar mapping exercise is foreseen for the KNMInext scenarios and the RCPs used for the CMIP5 simulations. The exact implementation of this coupling to the RCP's is not defined yet. A qualitative rather than a quantitative matrix is anticipated (e.g. 'Scenario A is most likely under RCP2.6 and less likely under RCP8.5'; Figure 2). It is logical that the statements are based on the spread of the scenario steering variables within the range of models constrained by a given RCP (see Section 2.3).

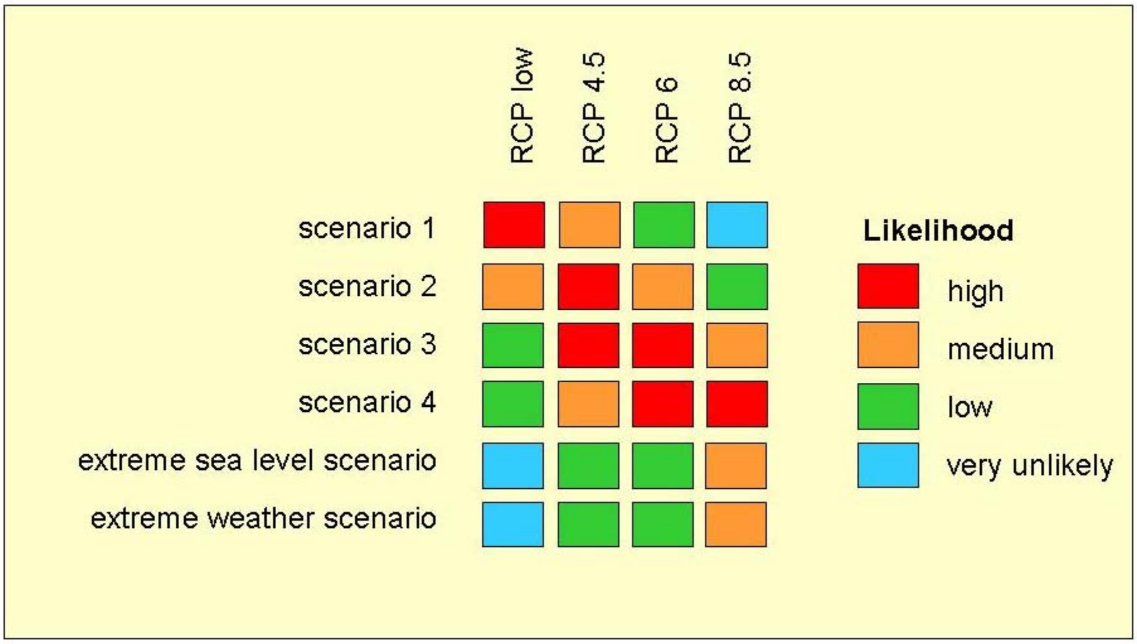


Figure 2: Sketch of the coupling between KNMInext scenarios and RCPs. Qualifications are indicative, for illustration purposes only.

pending questions:

- To what extent does KNMI need to quantify the link between the KNMI climate scenarios (which are based on global temperature rise) and emission scenarios/RCPs?
- How can the KNMI climate scenarios be linked to land use scenarios and spatial development scenarios?

1.8 Tasks

The KNMInext scenario development work consists of a large number of tasks. A detailed work plan has helped to structure the work and allows for monitoring of overall progress. In summary, the work consists of the following categories of activities:

1) User interaction;

2) Requested scenario variables and quantities;

3) GCM analysis and scenario framework;

4) RCM downscaling for the Netherlands;

5) Derived products including time series;

6) Assessment of past and current trends;

The results obtained so far for each category are discussed in Chapter 2.

2 Preliminary results

2.1 User liaison

Besides scientific progress, the set of KNMInext scenarios are further shaped by new or updated user demands for climate information. An inventory of these user demands has been made by consulting the most important user groups on several occasions as part of a systematic dialogue. Earlier this year, professional users of scenario information from different sectors were invited to workshops about the process towards the KNMInext scenarios on 14 February and 8 March 2012. Participants were asked to provide recommendations for the presentation of the new scenarios, for additional products and for examples of downstream application of the scenarios in their sector. The workshops were a continuation of the series of stakeholder workshops organized in the spring of 2010 which focused on the user needs. The next series of stakeholder workshops (about the outcomes and scenario presentation) are planned for the spring of 2013.

It is our experience that the consultation process results in a better mutual understanding, thanks to the personal communication between climate scientists and users of climate information. For climate scientists it has become clearer which climate data are needed in applications. They also gain understanding of the importance of climate data for various user groups and of the way climate information is conceived. For users it has become clearer which possibilities exist to generate fit-for-purpose climate data, what the advantages and disadvantages of probability distributions are, and in which way uncertainties are represented. User groups were also motivated to critically reconsider their list of requests, especially those requests which are difficult to comply with.

In addition to face-to-face contacts, a series of scenario newsletters has been issued in 2011 and 2012. Among others, these newsletters inform the user community in the Netherlands about the status of their information requests, and about the roadmap towards the next generation KNMI climate scenarios. Also, a user forum has been established which provides feedback on the KNMInext activities several times per year.

The most intense user contacts stem from the joint projects which have been run with users from different communities in the framework of the Climate Changes Spatial Planning (CCSP, 2011) and Knowledge for Climate (KfC, 2011) programs and with the water management community within our Ministry. A long history of joint research activities has led to clear articulation of the requirements and the possibilities for scenario information.

pending questions:

- Are the efforts of interacting with the user community adequate and efficient?

- What can KNMI gain from further intensification of user liaison and what additional mechanisms should KNMI explore to enhance user feedback?

2.2 Requested scenario variables and quantities

Traditionally, most users require scenarios for temperature, precipitation, wind and sea level. In response to more recent user demands, scenarios for additional variables such as humidity, visibility, solar radiation, evaporation and air quality are also being explored now. Instead of providing a table with change factors for the means and moderate extremes only, some users require time series and probability distributions (in particular of extremes) for the future climate or descriptions of extreme events under future conditions.

KNMI explores derivation of representative time series of 'future weather' from special climate model simulations that are associated with a particular climate scenario (Hazeleger et al., 2012). If successful (see Section 2.4), this will provide a more complete and consistent picture of the future climate, including year-to-year variations, and realistic realizations of for example long-lasting heat waves (relevant for health conditions), multi-day precipitation extremes (relevant for the peak discharges of the rivers Rhine and Meuse) and compound extremes such as coincident wind storms and high river discharge.

Statements about the probability distribution of a variable under future climate conditions may be provided in a meaningful way for some variables at large spatial scales. For example, the global temperature rise depends primarily on the emission scenario used and the climate sensitivity. These can be quantified on the basis of an ensemble of model simulations. For local changes in the Netherlands many more factors are important. Thus probabilities can be determined less easily. This holds in particular for statements about changes in the probability of rare events, which are frequently used in water management, among others.

In 2009 the KNMI'06 scenarios have been supplemented with probabilistic information about annual precipitation for durations of one hour up to 10 days for different return periods, both for the present-day climate and for 2050. Rather than probabilistic information about the change factor, the information provided constitutes probabilistic information under present-day and scenario conditions. The values for the present-day conditions have been derived from the historical record. The values for the 4 scenarios have been derived from transformed observational series (see Section 2.5). For KNMInext a similar approach is planned but providing a more complete set of extremes statistics (see e.g. Klein Tank et al., 2009). Ideally, these will be model based rather than derived from observations after transformation. Because computer power is still limited, expanding the number of model simulations to derive probabilistic statements comes at the expense of the spatial resolution of the model simulations and therefore at the expense of spatial detail (which is also much requested).

Finally, for questions related to investments it is important to know when the climate will have changed such that measures have to be taken or existing policies have become inadequate. For this purpose, transient scenarios are required rather than scenarios with a fixed time horizon (such as 2050 and 2100 in the KNMI'06 scenarios). In addition, there is demand for information on current trends, (natural) weather variability and decadal predictions for the coming 10 to 20 years. For KNMInext, information on the entire trajectory from now until 2100 will be provided, but for presentation purposes the near-future (the next 20 to 30 years) and far-future (around 2100) will be highlighted separately in the publications.

pending questions:

- How should KNMI deal with the strong demand for spatial details which we do not even know under present-day climate conditions?

- How should KNMI deal with the strong demand for more probabilistic information for risk management?

- Should KNMInext incorporate information about decadal predictions for the next 5-15 years?

2.3 GCM analysis and scenario framework

The KNMInext scenarios utilize the extensive results from the CMIP5 model ensemble which includes the KNMI global climate model EC-Earth. First analyses of these GCM simulations indicate that there is no reason to change the KNMI'06 approach drastically. What will change is that a new and more robust procedure is developed to extract the governing steering variables from the CMIP5 projections that can be translated into regional climate change indicators for Western Europe. Similar to the KNMI'06 approach, the steering variables are expressions of projected changes in global mean temperature and large scale atmospheric circulation. As before, the focus is on the broad picture of drivers for local changes in seasonal mean temperature and precipitation.

The steering variables in the KNMInext scenarios need to reflect a maximum spread of relevant local climate variables, linked to realistic change patterns in the model projections. The disadvantage of the KNMI06 steering variables "global temperature" and "strength of the west component of geostrophic wind over Western Europe" is that these variables are not optimally correlated to the local climate variability, and that many phenomena are not well described by the simplistic representation of the atmospheric circulation. An alternative approach is proposed for KNMInext.

The starting point remains that a two-axis matrix of scenarios is constructed, where the axes span a large portion of the local variability. Although the link between this two-axis structure and the (one-dimensional) RCP-chain is not straightforward, it allows more variations of local climate indicators than scaling with temperature alone. Experience with KNMI'06 is that this structure is well appreciated and understood. The additional advantage is that the main customers do not have to adapt to an entirely new scenario structure.

The two axes are marked by a temperature/climate sensitivity scale (the global climate feedback), and a local climate feedback scale. This local feedback can be induced by atmospheric circulation or aerosol/radiation/cloud interactions. The exact definition of the steering variables based on the CMIP5 model ensemble is different from KNMI'06.

A large number of CMIP5 simulations is now available via the KNMI Climate Explorer (climexp.knmi.nl). Spread over 4 RCPs up to 70 GCMs have been running between 1950 and 2100, with a large number of GCMs producing multiple ensemble members for each RCP. The total number of ensemble members is approximately 190. These have been used to define the steering variables in an optimal way. To allow inspection of the applicability of EC-Earth time slices for further high resolution downscaling, special attention is given to the position of the EC-Earth members in the GCM plume.

For temperature, the global mean temperature change explains a large fraction of variance of projected local temperature change (the grid point closest to De Bilt, 6°E, 51°N). The explained fraction of variance increases slightly when a temperature pattern in the Euratlantic region is used as steering variable. The projected changes are all defined as the difference between the projected seasonal mean temperature in 2071 – 2100 relative to the model projection for 1976 – 2005. In this pattern, in all seasons land warming clearly exceeds ocean warming, and a muted response in the NW Atlantic SST is evident. In JJA a N-S gradient in warming across the European continent is evident, whereas the high-latitude warming and a NE-SW warming gradient are most pronounced in the DJF and MAM seasons.

The close relationship between global warming and pattern strength implies that the role of changes in atmospheric circulation play a minor role in the local temperature response, which was already suggested by earlier analyses using CMIP3 model output. As a result, the choice of temperature steering variable is not critical. Choosing the global mean temperature is easy to explain, and makes coupling to RCPs straightforward. The choice of the pattern strength has the benefit that response features in the European surroundings affect to some extent the local temperature response, which may help in anecdotic explanation of the corresponding scenarios.

For the local feedback variable, the situation is more complex. A wide variety of local relevant climate indicators exist (such as mean temperature/precipitation, extreme (multiday) temperature/precipitation, drought duration/cumulative evaporation, extreme wind, etc.). Each of them is differently related to local feedbacks. A thorough analysis of all these possible mechanisms (and their interactions) has not yet been carried out.

The CMIP5 analysis results indicate that a fruitful approach is to derive the local feedback steering variable from the relationship between mean sea level pressure response and local precipitation response (as in KNMI'06). In all seasons a stronger local precipitation response is induced by a low pressure response North of the Netherlands, and a small to high pressure response in the South. The orientation of the pressure features varies across the seasons, but anomalous advection of moist Atlantic air is a key feature in all seasons. The strength of these pressure features is proposed to serve as our steering variable of interest. A formal analysis of the variance of the ensemble mean responses and individual ensemble members reveals that approximately 50% of the range in projected sea level response is related to natural variability (for global mean temperature response this fraction is less than 5%).

Haarsma et al. (2012a; 2012b) studied the mechanisms of the changes of sea level pressure in the CMIP3 and CMIP5 models. It appears that changes in tropical surface temperatures affect the entire troposphere and affect the westerly circulation through thermal wind balance. Also, using a barotropic model they could explain the respons of the meridional winds in the midlatitudes. The understanding of the physical mechanisms adds to the plausibility of the scenarios.

Two of the 70 GCM simulations concern the EC-Earth runs for RCPs 4.5 and 8.5. For each of these runs 8 members are available. In the time series of these simulations (Figure 3) one can clearly discern a considerable interannual variability of the strength of the steering variables. Also in the 30-yr filtered time series the (natural) variability is still present. This allows for selection of episodes representative of a relatively low or high value of the steering variable appropriate for further downscaling. For this, we need to take into account that EC-Earth shows a relatively mild response, both in temperature and in pressure. RCP8.5 clearly shows a summer drying signature, and warming is evident in all seasons and stronger in RCP8.5 (it tends to level off in the second half of the 21st century in RCP4.5).

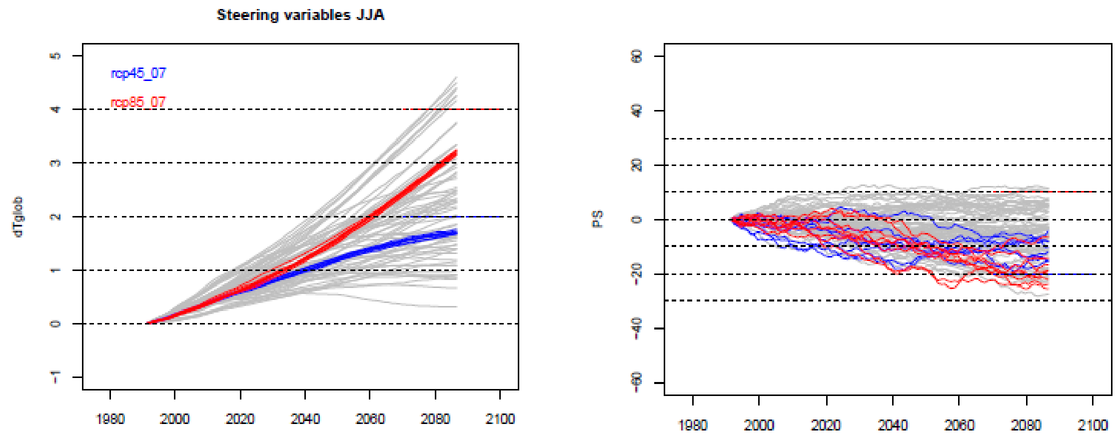


Figure 3: 30-yr running means of the steering variables global mean temperature response (left) and the strength of the mean sea level pressure pattern response (right) for 70 ensemble GCM projections divided over 4 RCPs (grey) and individual ensemble members of two EC-Earth projections for different RCPs (coloured). Plots are for summer (JJA).

The KNMI'06 scenarios describe only a small influence of climate change on the wind storm climate of the Netherlands. This picture is confirmed by new research (Sterl et al., 2009). Models provide evidence that the natural fluctuations in the wind storm climate are larger than the changes caused by the greenhouse effect.

Preliminary analysis results indicate that there is no clear change in wind storms over the North Sea area in the CMIP5 projections. The results are not much different from the wind storm analysis of CMIP3 projections (Sterl et al., 2009).

pending questions:

- Should KNMI base the scenarios on the newest CMIP5 simulations only or can we still use CMIP3 generation simulations?
- Do the GCM projections provide resolutions high enough for deriving information on the future wind climate in the North Sea area, and on the spatial gradients of change in the Rhine basin?

2.4 RCM downscaling for the Netherlands

The intention is to downscale several GCMs using the KNMI regional climate model RACMO in order to derive the relevant local change factors for each discrete scenario and provide the desired high resolution simulations of future weather. Computer resources allow for dynamical downscaling of a few GCM simulations only. KNMI has selected 8 simulations with the EC-Earth model which show clearly different characteristics in terms of the steering variables. Half of the simulations are for the RCP4.5 runs and the other half for the RCP8.5 runs.

In case no representative simulations can be found for each discrete scenario or the spread in the selected EC-Earth simulations turns out to be too narrow compared to the entire ensemble of all CMIP5 simulations, the first fall-back option is to select particular decades or years from the available RCM simulations on the basis of the values for the steering variables in these years. This sampling is complicated by the fact that consistency is required for different seasons and variables. The drawback of this approach is that subjective choices in the selection procedure may significantly affect the statistics of the required scenario quantities (in particular the extremes). The experience in KNMI'06 (Lenderink et al., 2008) shows that such a procedure is suboptimal.

The second fall-back option in case no GCM simulations for each discrete scenario can be identified for downscaling is to perturb the driving GCM. Attempts in this direction using SST perturbations have been promising, but unfortunately no adequate results have been obtained for all seasons and variables. A third fall-back option is the use of existing EU-FP6-ENSEMBLES simulations. In conclusion, finding the optimal GCM boundaries for downscaling corresponding to each scenario remains a challenge.

RCM simulations are also used to analyse the potential for spatial variation in the scenarios. In earlier work KNMI has shown that the temperature of the North Sea has a discernable influence on the precipitation distribution in the Netherlands. Observations show that the coastal area has on average become wetter during late summer and autumn compared to the inland area. Lenderink et al. (2008) provide evidence that, under certain air circulation patterns, up to 15% more precipitation can fall along the coast per degree Celsius temperature rise of the North Sea. These are mostly conditions in which cold and unstable air is transported over a warm North Sea. This effect is strongest up to about 30 km inland, and occurs in particular in the second half of the summer and in the autumn.

For the KNMI'06 scenarios, the starting point was one single value for the temperature and precipitation changes for the whole of the Netherlands. The climate models used for these scenarios did not include a realistic description of the local temperatures of the North Sea water. Also, the spatial resolution used for the scenarios was insufficient to distinguish coastal precipitation from precipitation inland. Work is underway to perform long climate simulations with RCMs in which the effect of the North Sea water is realistically simulated. The results of this work will feed into the KNMInext scenarios.

pending questions:

- Does the downscaling provide meaningful spatial detail or should KNMI focus attention more on RCM simulations that help understanding of local changes in severe weather and extremes?

- Should KNMI present the climate change signal and natural variability separately (if possible) or combined in representative time series for the future climate?

2.5 Derived products including time series

The KNMI'06 scenarios have been constructed by combining the results of different climate models. Therefore, no climate model exists for which the results exactly agree with one of the KNMI'06 climate scenarios. For KNMInext, we aim to identify at least (selected parts of) one downscaled model simulation for each scenario. There is no guarantee that this will be successful. And even if it is comparison with observations has shown that (downscaled) climate models often contain systematic errors in the quantities that matter for applications. These are large enough to make the simulated time series inadequate for direct use in impact studies.

Because many studies on the effects of climate change make use of meteorological time series of temperature, precipitation amount, etc. on subsequent days, and KNMI'06 provided a table of change factors only, time series for the future have been derived by adjusting local time series from the past. This was done in such a way that the transformed series match a chosen climate scenario for a selected time horizon (see e.g. Bakker et al., 2011). In the new time series, not only the seasonal averages are brought in agreement with the scenarios, but also the (moderate) extremes. A software program has been developed and made available through the Internet (climexp.knmi.nl/Scenarios_monthly/) which performs this transformation for daily values of temperature and precipitation. A full description of subsequent versions of this tool has recently been completed (Bakker and Bessembinder, 2012). Recently, a more advanced method has been developed which takes into account the projected changes in different quantiles of the distribution.

A consequence of the method used for time series transformation is that the time series for the future still contains many characteristics of the historical record. For example, the sequence of warm and cold days remains unchanged. The same holds for the sequence of dry and wet days, even though the change in the number of wet days has been taken into account. Using the tool has shortcomings for studies in which changes in for example the length of dry spells, multi-day precipitation extremes, or warm and cold spells are important. These shortcomings are recognized and their effect is described in detail in Bakker and Bessembinder (2012). Work is underway to further improve the time series transformation tool. Whether KNMI will keep this tool for its main customers or whether KNMI will recommend the alternative in the form of representative time series of 'future weather' derived from special RCM simulations is still an open question.

Another add-on request to KNMI'06 was information on sub-daily precipitation extremes. Sub-daily precipitation extremes are a high impact quantity leading to sewage problems, flash floods, and construction damage. In particular the urban environment is very sensitive to short duration precipitation extremes. For practical applications it was often assumed that the hourly intensities increase at the same rate as the daily amounts provided in KNMI'06. Subsequent analysis has shown that it is likely that this assumption is invalid for extreme showers during summer. Analysing a large data set of observed hourly precipitation both in De Bilt (Lenderink and Van Meijgaard, 2008) and in Hong Kong (Lenderink et al., 2011), the dependence of rare heavy precipitation events on surface dewpoint temperature turned out to be much stronger than generally obtained in RCM (and GCM) simulations. Not only the precipitation intensity can strongly increase with temperature, it is also likely that other phenomena that are closely linked to showers, such as hail, thunderstorms, wind gusts and tornadoes, will increase in strength and/or occur more frequently. More information on these sub-daily phenomena is foreseen in the KNMInext scenarios (based on empirical evidence, model simulations and expert judgment).

pending questions:

- Is the use of tools for time series transformation (or statistical weather generators) a fruitful direction to avoid complicated model bias correction procedures?

- How should KNMI deal with the demand for concurrent time series (e.g. the chances of coincident windstorms and high precipitation events)?

2.6 Assessment of past and current trends

The stronger focus on the near-future (coming 20-30 years) in the KNMInext scenarios makes that it is important to confront the projections with the observed trends. In addition, some of the projected trends are now large enough to be detectable in the observations. For these reasons, the KNMInext scenario work includes an assessment of observed change. Also, an assessment of observed (natural) variability and a comparison with model simulated variability becomes more important for earlier time horizons. Is decadal scale variability well represented in the models?

Based on observations, Van Oldenborgh et al. (2009) found that the temperature in the Netherlands and surrounding countries has increased twice as much as the global average over the past decades. Several causes for the stronger warming in the Netherlands can be identified. For winter, there is an increase in westerly winds (possibly related to ocean processes). For summer, there is an increase of incoming solar radiation due to a decrease in cloudiness, which is likely caused by drying over the continent, and due to a decrease in air pollution (less dust particles). These processes are not well simulated in climate models, and therefore the difference between the global temperature rise and the local warming in the Netherlands in the past 50 years was systematically underestimated in the CMIP3 ensemble. First results indicate that also in the CMIP5 simulations the local warming in the Netherlands is underestimated.

The stronger warming in the Netherlands is partly caused by factors that cannot be easily extrapolated into the future. The mechanisms behind the increase in westerly winds are not yet fully understood, and it is therefore unclear whether this trend will continue at the same rate. The same applies for the decrease in cloudiness. KNMI can be more certain about the decrease in air pollution. It is unlikely that the air will continue to become cleaner with the same rate of change. In the observations almost no decrease in the concentration of dust particles has been observed after 2000 (Vautard et al., 2009; Van Oldenborgh et al, 2010). A complicating factor is that the CMIP5 model calculations may use too low emission scenarios. As a result the temperature response may be overestimated.

For the scenario development process it is important to note that the observations discussed above may indicate that the lowest temperature scenarios should be discounted. Whether KNMI will do this is still an open question.

For average precipitation and moderate extreme precipitation, there is evidence of change in Europe over the past decades too (Van Haren et al., 2012). The trends for the Netherlands are different for different parts of the country. The annual precipitation has increased by 30-35% along the coastline and by 10-25% in the east and south-east over the 100-year period 1910-2009 (Buishand et al., 2012). The number of days per year with high rainfall amounts shows an even stronger percentage increase in this period. Since 1950, the precipitation thresholds which are exceeded on average once per year in the Dutch records have increased by about 10%. For more extreme events (1x per 10 years and 1x per 100 years), no significant changes can be detected in the observations (yet). Similar trends are seen at stations in the border areas of Germany and Belgium.

Preliminary comparisons of precipitation trends with CMIP5 simulations show that in winter the underestimated trend in atmospheric circulation in the models results in too low precipitation increases in Northern Europe and too low decreases in Southern Europe. In summer, it is likely that an underestimated trend in sea surface temperature causes an underestimated precipitation increase along the coast line in the models. Although the observed local precipitation trends for the Netherlands are generally underestimated in the CMIP5 simulations (according to preliminary results), the trends in precipitation are in general agreement with the KNMI'06 scenarios but a more precise quantitative comparison is still pending.

Apart from the observed trends, it is important for adaptation purposes to note that, significant regional differences exist in extreme precipitation under current climate conditions. The spatial differences in extremes deviate from the differences in the total precipitation amounts in a year (Buishand et al., 2009). For the extreme daily precipitation amounts that are exceeded with a probability of once in 10 years, the differences between the most wet and dry parts of the country are currently almost as large as the changes in the KNMI'06 scenarios for 2050. Station and rain radar observations show no clear regional differences for extreme hourly precipitation amounts.

These regional differences across the country may open the possibility for analogues scenarios based on the present climate conditions elsewhere.

In addition to the in situ observations discussed above, KNMI makes use of satellite data to assess the trends in atmospheric composition (GHGs and aerosols) in the past decade(s) (see e.g. De Ruyter de Wildt et al., 2012). Current trends will be compared to the emission scenarios used as an input for the CMIP5 projections.

pending questions:

- Should KNMI discount particular scenarios (e.g the lowest temperature scenarios) because observational evidence about current trends (and assessment of future GHG/aerosol emissions) make some model projections less likely?

References

Bakker, A.M.R., B.J.J.M. van den Hurk, J.J.E. Bessembinder en T. Kroon, 2011: Reduced Climate forcings for large-scale hydrological scenario calculations, Env. Mod. and Softw., 2011, 26, 797-803, doi:10.1016/j.envsoft.2010.11.008.

Bakker, A. and J. Bessembinder, 2012: Time series transformation tool: description of the program to generate time series consistent with the KNMI'06 climate scenarios. KNMI Technical Report TR-326, De Bilt, The Netherlands. Available from: www.knmi.nl/knmi-library/knmipub_en.html

Buishand, T.A., R. Jilderda, J.B. Wijngaard, 2009: Regional differences in extreme precipitation. KNMI Scientific Report WR 2009-01, De Bilt, The Netherlands (in Dutch). Available from: www.knmi.nl/knmi-library/knmipub_en.html

Buishand, T.A., G. De Martino, J.N. Spreeuw and T. Brandsma, 2012: Homogeneity of precipitation series in the Netherlands and their trends in the past century. Int. J. Climatol., DOI:10.1002/joc.3471

CCSP, 2012: http://climatechangesspatialplanning.climateresearchnetherlands.nl

CH2011, 2011: Swiss Climate Change Scenarios CH2011, published by C2SM, MeteoSwiss, ETH, NCCR Climate, and OcCC, Zürich, Switzerland, 88pp. ISBN: 978-3-033-03065-7. Available from: http://www.ch2011.ch

CSIRO, 2007; Climate Change in Australia. Technical report. ISBN 9781921232947. Available from: http://www.climatechangeinaustralia.gov.au/technical_report.php

Delta Committee, 2008: Working together with water: A living land builds for its future. Findings of the Dutch Delta Committee 2008. Available from: http://www.deltacommissie.com/en/advies

Demarée, G., P. Baguis, L. Debontridder, A. Deckmyn, S. Pinnock, E. Roulin, P. Willems, V. Ntegeka, A. Kattenberg, A. Bakker, J. Bessembinder, G. Lenderink, 2008: Calculation of climate scenarios for Vlandres. INBO report INBO.FD.2007.5 (in Dutch). Available from: http://www.inbo.be/files/Bibliotheek/64/186064.pdf

De Ruyter de Wildt, M., H. Eskes, and K. F. Boersma, 2012: The global economic cycle and satellite-derived NO2 trends over shipping lanes, Geophys. Res. Lett., 39, L01802, doi:10.1029/2011GL049541.

De Vries, H., R.J. Haarsma and W. Hazeleger, 2012: Western European cold spells in current and future climate, Geophys. Res. Lett., doi:10.1029/2011GL050665

De Winter, R.C., A. Sterl, J.W. de Vries, S.L. Weber en B.G. Ruessink, 2012: The effect of climate change on extreme waves in front of the Dutch coast, Accepted by Ocean Dynamics.

Goergen, K., J. Beersma, G. Brahmer, H. Buiteveld, M. Carambia, O. de Keizer, P. Krahe, E. Nilson, R. Lammersen, C. Perrin and D. Volken, 2010: Assessment of Climate Change Impacts on Discharge in the Rhine River Basin: Results of the RheinBlick 2050 Project, Lelystad, CHR, ISBN 978-90-70980-35-1, 211p, Available from: http://www.chr-khr.org/files/CHR_I-23.pdf

Haarsma, R.J. and F.M. Selten, 2012a: Anthropogenic changes in the Walker Circulation and their impact on the extra-tropical planetary wave structure in the Northern Hemisphere, Clim. Dyn., 2012, doi:10.1007/s00382-012-1308-1

Haarsma et al., 2012b. Manuscript in preparation.

Haasnoot, M. and H. Middelkoop, 2012: A history of futures: A review of scenario use in water policy studies in the Netherlands. Environmental Science & Policy, 19-20, 108-120.

Hazeleger, W., B. van den Hurk, E. Min, A. Petersen, D. Stainforth, E. Vasileiadou, 2012: Tales of future weather; submitted to Nature Climate Change.

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Jacob, D., L. Barring, O.B. Christensen, J.H. Christensen, M. de Castro, M. Deque, F. Giorgi, S. Hagemann, M. Hirschi, R. Jones, E. Kjellstrom, G. Lenderink, B. Rockel, A.P. van Ulden en B.J.J.M. van den Hurk, 2007: An inter-comparison of regional climate models for Europe: model performance in present-day climate, Climatic Change, 2007, doi:10.1007/s10584-006-9213-4

Jenkins, G.J., J.M. Murphy, D.S. Sexton, J.A. Lowe, P. Jones, C.G. Kilsby, 2009: UK Climate Projections: Briefing report. Met Office Hadley Centre,Exeter, UK. Available from: http://ukclimateprojections.defra.gov.uk

Kabat, P., L.O. Fresco, M.J.F. Stive, C.P. Veerman, J.S.L.J. van Alphen, B.W.A.H. Parmet, W. Hazeleger and C.A. Katsman, 2009: Dutch coasts in transition. Nature Geoscience 2, 450 – 452, doi:10.1038/ngeo572.

Katsman, C.A., W. Hazeleger, S.S. Drijfhout, G.J. van Oldenborgh and G.J.H. Burgers, 2008: Climate scenarios of sea level rise for the northeast Atlantic Ocean: a study including the effects of ocean dynamics and gravity changes induced by ice melt, Climatic Change, 2008, doi:10.1007/s10584-008-9442-9

Katsman, C.A., Sterl A., J.J. Beersma, H.W. van den Brink, J.A. Church, W. Hazeleger , R.E. Kopp, D. Kroon J. Kwadijk, R. Lammersen, J. Lowe , M. Oppenheimer, H.-P. Plag, J. Ridley, H. von Storch, D.G. Vaughan, P. Vellinga , L.L.A. Vermeersen, R.S.W. van de Wal and R. Weisse, 2011: Exploring high-end scenarios for local sea level rise to develop flood protection strategies for a low-lying delta - the Netherlands as an example. Climatic Change 109, DOI: 10.1007/s10584-011-0037-5

KfC, 2012: http://knowledgeforclimate.climateresearchnetherlands.nl

Klein Tank, A.M.G., F.W. Zwiers and X. Zhang, 2009: Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation. WMO-TD No. 1500, 56 pp. Available from: http://www.wmo.int/pages/prog/wcp/wcdmp/wcdmp_series/documents/WCDMP_72_TD_1500_en_1.pdf

Können, G.P., 2001: Climate scenarios for impact studies in the Netherlands. KNMI, De Bilt, Netherlands. Available from: http://www.knmi.nl/klimaatscenarios/vorig/Scenarios2001.pdf

Kwadijk, J. C. J., Haasnoot, M., Mulder, J. P. M., Hoogvliet, M. M. C., Jeuken, A. B. M., van der Krogt, R. A. A., van Oostrom, N. G. C., Schelfhout, H. A., van Velzen, E. H., van Waveren, H. and de Wit, M. J. M., 2010: Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. WIREs Clim Change, 1: 729–740. doi: 10.1002/wcc.64

Lenderink, G., A. van Ulden, B. van den Hurk, F. Keller, 2007: A study on combining global and regional climate model results for generating climate scenarios of temperature and precipitation for the Netherlands. Clim. Dyn. 29:157–176.

Lenderink, G. and E. van Meijgaard, 2008: Increase in hourly precipitation extremes beyond expectations from temperature changes. Nature Geoscience, 1, 511-514, Doi: 10.1038/ngeo262.

Lenderink, G., E. van Meijgaard and F. Selten, 2008: Intense coastal rainfall in the Netherlands in response to high sea surface temperatures: analysis of the event of August 2006 from the perspective of a changing climate. Climate Dynamics, Doi: 10.1007/s00382-00800366-x.

Lenderink, G., H.Y. Mok, T.C. Lee and G.J. van Oldenborgh, 2011: Scaling and trends of hourly precipitation extremes in two different climate zones – Hong Kong and the Netherlands, Hydrology and Earth System Sciences, 2011, 4701-4719, doi:10.5194/hessd-8-4701-2011.

NWO, 2012: http://www.nwo.nl/nwohome.nsf/pages/SPPD_5R2QE7_Eng

NWP, 2009: National Water Plan. Available from: http://english.verkeerenwaterstaat.nl/english/Images/NWP%20english_tcm249-274704.pdf

Sterl, A., H. van den Brink, H. de Vries, R. Haarsma, and E. van Meijgaard, 2009: An ensemble study of extreme North Sea storm surges in a changing climate. Ocean Sci. Disc., 6, 1131-1159, http://www.ocean-sci-discuss.net/6/1031/2009

Van den Hurk, B., A. Klein Tank, G. Lenderink, A. van Ulden, G. J. van Oldenborgh, C. Katsman, H. van den Brink, F. Keller, J. Bessembinder, Burgers, G., G. Komen, W. Hazeleger and S. Drijfhout, 2006: KNMI Climate Change Scenarios 2006 for the Netherlands. KNMI Scientific Report WR 2006-01, De Bilt, The Netherlands.

Van den Hurk, B.J.J.M., A.M.G. Klein Tank, G. Lenderink, A. van Ulden, G.J. van Oldenborgh, C. Katsman, H. van den Brink, F. Keller, J. Bessembinder, G. Burgers, G. Komen, W. Hazeleger and S. Drijfhout, New climate change scenarios for the Netherlands; Water Science and Technology, 2007, 56, 4, 27-33, doi:10.2166/wst.2007.533.

Van den Hurk, B. A. Klein Tank, C. Katsman, G. Lenderink, A. te Linde, 2012: Vulnerability assessments in the Netherlands using climate scenarios. In: Pielke et al., Vulnerability assessment encyclopaedia (in press).

Van Haren, R., G.J. van Oldenborgh, G. Lenderink, M. Collins en W. Hazeleger, 2012: SST and circulation trend biases cause an underestimation of European precipitation trends, Clim. Dyn., in press.

Vautard, R., P. Yiou and G.J. van Oldenborgh, 2009: The decline of fog, mist and haze in Europe during the last 30 years: a warming amplifier? Nature Geoscience, 2, 115-119, doi:10.1038/NGEO414

Van Oldenborgh, G. J., S. Drijfhout, A. van Ulden, R. Haarsma, A. Sterl, C. Severijns, W. Hazeleger and H. Dijkstra, 2009: Western Europe is warming much faster than expected. Clim. Past, 5, 1-12.

Van Oldenborgh, G.J., P. Yiou and R. Vautard, 2010: On the roles of circulation and aerosols in the decline of mist and dense fog in Europe over the last 30 years, Atm. Chem. Phys., 10, 4597-4609, doi:10.5194/acp-10-4597-2010.

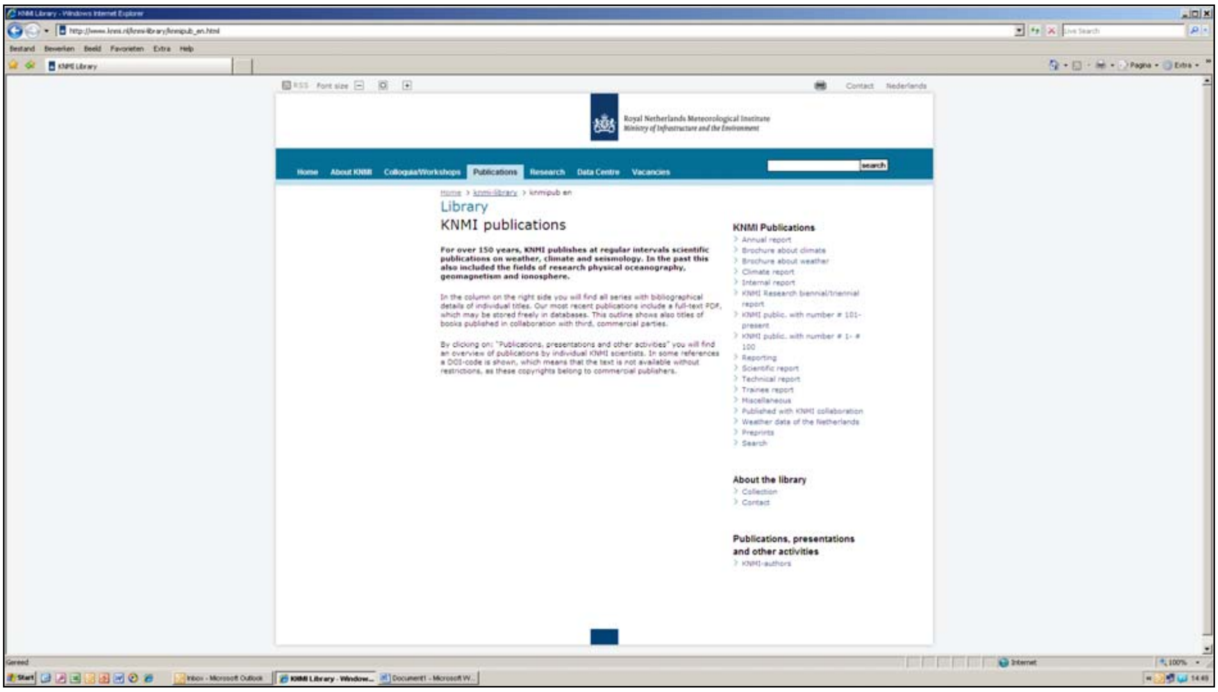
Vellinga, P., C.A. Katsman, A. Sterl and J.J. Beersma (eds.), 2009: Exploring high-end climate change scenarios for flood protection of the Netherlands. International Scientific Assessment carried out at the request of the Delta Committee, KNMI Scientific Report WR-2009-05, De Bilt, The Netherlands, Available from: www.knmi.nl/knmi-library/knmipub_en.html

Whetton, P., K. Hennessy, J. Clarke, K. McInnes and D. Kent, 2012: Use of Representative Climate Futures in impact and adaptation assessment. Climatic Change, submitted.

Wilby, R.L., and S. Dessai, 2010: Robust adaptation to climate change. Weather, 65(7), 180-185.

A complete list of all KNMI-publications (1854 – present) can be found on our website

www.knmi.nl/knmi-library/knmipub_en.html



The most recent reports are available as a PDF on this site.