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EDITORIAL

Focus on climate projections for adaptation strategies

Arnout Feijt[1], **Christof Appenzeller**[2], **Peter Siegmund**[1] **and Hans von Storch**[3]

[1] Royal Netherlands Meteorological Institute, the Netherlands
[2] Federal Office of Meteorology and Climatology MeteoSwiss, Switzerland
[3] Meteorological Institute of the University of Hamburg, Germany

E-mail: feijt@knmi.nl

Abstract

Most papers in this focus issue on 'climate and climate impact projections for adaptation strategies' are solicited by the guest editorial team and originate from a cluster of projects that were initiated 5 years ago. These projects aimed to provide climate change and climate change adaptation information for a wide range of societal areas for the lower parts of the deltas of the Rhine and Meuse rivers, and particularly for the Netherlands. The papers give an overview of our experiences, methods, approaches, results and surprises in the process to developing scientifically underpinned climate products and services for various clients. Although the literature on interactions between society and climate science has grown over the past decade both with respect to policy-science framing in post-normal science (Storch *et al* 2011 *J. Environ. Law Policy* **1** 1–15, van der Sluijs 2012 *Nature and Culture* **7** 174–195), user-science framing (Berkhout *et al* 2014 *Regional Environ. Change* **14** 879–93) and joint knowledge production (Hegger *et al* 2014 *Regional Environ. Change* **14** 1049–62), there is still a lot to gain. With this focus issue we want to contribute to best practices in this quickly moving field between science and society.

Introduction

Adaptation to the conditions that climate poses on community is ongoing business in the Netherlands for centuries. Climate change introduces new challenges. Not anymore, is it enough to look back in time to know what meteorological conditions may occur in the future. The community has to rely on climate projections, climate model simulations and on scientists to obtain a glimpse of what may happen in the future. As stakes are high with respect to safety and economic value policy makers and scientists must understand each other well. In the aftermath of IPCC AR4 and in the onset of AR5 a cluster of projects were initiated in order to provide suitable information for climate adaptation to Dutch community and guide policy makers and impact scientists. Two projects are mentioned here explicitly because of their central role in this issue:

1) The KNMI'14 project that yielded a set of four new climate scenarios for the Netherlands, based on IPCC AR5 CMIP5 global projections. 2) The 'High Quality Climate Projections for Adaptation in the Netherlands' project that aimed to translate these scenarios into useful climate characteristics for a wide range of impact projections. This project was part of the governmental 'Knowledge for Climate' initiative and is further referred to as KfC-project. The first project was initiated in order to generate scientifically sound climatological projections for The Netherlands, whereas the second focused on providing stakeholders from a wide range of societal areas with much more useful information on characteristics of future climate. From the start these projects have been interacting intensively, which yielded a number of surprising results.

Climate scenarios

KNMI has chosen to present the new climate projections in the form of 4 scenarios, or storylines. A principal components analysis has been applied on 28 CMIP-5 models, which has resulted in 2 main drivers of climate change in the Netherlands, global mean temperature and large scale circulation, that span a large part of the range of possible future climates (van den Hurk *et al* 2014). One of these models, the EC-Earth model, is used to provide consistent time series of several meteorological parameters for all scenarios. The letter by Lenderink *et al* (2015) describes this exercise, which is by no means straightforward. This top-down scientific approach gives hard numbers for the individual climate scenarios which, however, may suggest a measure of predictability of climate change that is not justified. We are very much aware that there is large uncertainty involved in any of these model-based projections, due to the limited ability to mimic the climate system and the little we know about future societal developments. Part of the results on this topic were published as a PhD thesis (Bakker 2014). In a study to model uncertainty, van Haren *et al* (2015) showed that the ability to mimic summer drought in Europe significantly depends on model resolution.

An example of a more probabilistic approach are the Swiss CH2011 climate scenarios (CH2011 2011), which are based on multi-model projections. Probabilistic scenarios of expected changes were calculated for three different future pathways of anthropogenic emissions (Fischer *et al* 2012). Despite the mathematical formal probabilistic assessment the CH2011 report refrains from interpreting the resulting projection uncertainties in a strictly probabilistic way. Rather, selected percentiles were used to define a ≪lower≫, ≪medium≫, and ≪upper≫ estimate for a given emission scenario.

Intensive communication and interaction with stakeholders, about the meaning of the numbers and the uncertainties involved, is mandatory to prevent misinterpretation and stimulate proper use (van den Hurk *et al* 2013). This holds both for projections based on a probabilistic and on a storyline approach (Dessai and Porter 2013).

Stakeholder interaction

In the KfC-project project the interaction with the stakeholders was explicitly embedded as a separate 1Meuro work package and was started even before the plans of the scientific projects were completed.

The need for intense stakeholder interaction cannot be overestimated. It is a large effort even to come to develop a common language. For example, a significant problem in communicating the character of scenarios, i.e., descriptions of possible, plausible, consistent descriptions of future climate, to stakeholders is related to naming them ‘predictions’ and not, as would be more accurate, as ‘projections’. This is frequently done by media, civic society and even scientists. In a survey among climate scientists Bray and von Storch (2009) found that about one third of the surveyed scientists used the less accurate term ‘prediction’ instead of ‘projection’.

In separate meetings for policy makers and research institutes interactive sessions/workshops were held, which confirmed and detailed the main topics of concern of the stakeholders for a sustainable delta in the Netherlands. One of the main issues was extreme precipitation at timescales of showers (e.g. for sewer systems) to days (for the larger river basins). Surprisingly to many, the meteorological event with the largest financial consequences in our wet country would be long dry periods with high temperatures that boost evaporation and increase fresh water shortage. This finding was published in 2010 (Kwadijk *et al* 2010) as a result of a bottom-up study on vulnerability of society to changes. They defined the term adaptation tipping point by the condition that a (water) management strategy is not functioning anymore and, therefore, it is mandatory to change the strategy. Furthermore, the stakeholders called for spatial differentiation between the coastal area and more land inward, because even in a small country such as the Netherlands the influence of the sea causes distinct gradients in meteorological parameters.

Similar, the feedback on the Swiss CH2011 scenarios from the user community was very positive and the scenario data are widely used a.o. in quantitative impact assessments (CH2014 2014). But also many suggestions to improve the scenarios were raised. Some stakeholders asked for more localized and more specific climate information (Zubler *et al* 2014). Others argued that the three different emission scenarios together with the three uncertainty estimates are too complex to be used in their applications. Overall it became clear that an earlier and more direct involvement of the end-users community would have been beneficial, a topic that is taken up for the next Swiss climate scenario initiative.

Stakeholder influence

As a result of the contact with stakeholders, specific research topics were incorporated in the project plans to increase the knowledge about those meteorological phenomena that are thought to be the most relevant to Dutch society. As a response to the many requests from policy makers and impact scientists for information on future heavy shower events, there were specific studies into deep convection by analyzing observational records and large eddy simulations. To partly cover the requests for information on future periods of drought a technique was developed to simulate the corresponding meteorological conditions with our global climate model, EC-Earth, using so called singular forcing vectors. The method was adopted from operational weather forecasting. In order to obtain the requested differentiation between coastal and land inward areas, we investigated the added value of high resolution modelling for climate research purposes. To this end we used a very high-resolution weather model, Harmonie, that was at an experimental stage at that time, by embedding it in a regional climate model (RACMO) to study spatial patterns correlated to landscape features at higher resolution. RACMO in turn was embedded in the global EC-Earth model.

By listening to our stakeholders we were able to select and study and gain knowledge about those phenomena of high societal interest and most useful for them. Although our stakeholders did influence our project plans from the start and were consulted regularly during the course of the project, the way the project was organized as a whole was mainly a top-down science-led activity. The results of these studies are incorporated in the set of products that make up the KNMI'14 scenarios.

General, non-context-specific results

The top down approach with respect to the choice of climate parameters has yielded a set of characteristics of climate that covers the requirements for a large group of users and is a coherent basis for products that are more context-specific. For instance, de Vries *et al* (2015) studied the projections of sea level rise for the coming decades. This information was generated without much user interaction. However, it is also basic information for context specific studies on the interaction between river discharges and sea level rise and on the consequences of salinization of the coastal areas for agriculture. These assessments require more user interaction. This also applies to the projections of large-scale wind fields by Sterl *et al* (2015). This is top-down basic information. It will require significant user interaction to differentiate further for specific purposes such as energy production or coastal defense. With respect to projections of air quality two different approaches were followed: one based on model runs (Manders *et al* 2012) and one on observations that are extrapolated into the future based on IPCC RCPs (Boers *et al* 2015).

In communication on climate change it is important to put the climate scenarios in perspective of observations of climate change. The KNMI'14 scenarios are presented in tables next to the climate normals, 30 year characteristics, of the periods 1951–1980 and 1981–2010 in order to put the projections into perspective. Also the spread in the 30 year averages is given as a first order estimate of natural variability. However, these estimates of natural variability have their limitations due to the limited extent of observational records and the limited knowledge we have about the climate system as a whole. Still, anthropogenic influence becomes clearer visible as the trend exceeds the range of estimated natural variability.

In present research this is the field of 'detection and attribution' (e.g., IDAG 2005). For detection, e. g., the determination whether present change is within the range of natural variability, scenarios may help to improve the skill by allowing enhanced signal-to-noise ratios. For attribution, e.g., the derivation of most probable causes for the 'detected' change, scenarios serve as a guide for selecting such causes.

While the methodology of 'detection and attribution' has been used widely for global quantities, considerably less activity has taken place on regional scales such as the North Sea region or even the Netherlands. Recent analyses of temperature and precipitation changes in the Baltic Sea region and in the Mediterranean Sea region have revealed that at least part of the recent change cannot be explained from natural variability, but that emissions of greenhouse gases alone cannot account for the recent change; instead other factors must be at work also (Bhend and von Storch 2009, Barkhordarian *et al* 2013). It has been suggested that a plausible additional factor would be the strong reduction of regional aerosol emissions since about 1980. This reduction could have accelerated the temperature trend (which is larger than what scenarios suggest) and decelerated trends in precipitation amounts. Unfortunately, no detailed quantitative estimates of the effect of reducing emissions of aerosols on temperature and precipitation are available, so that empirical models have to be used for testing the attribution hypothesis.

The wide variety of impacts

During the project, assessments were made of the vulnerability to climate change of areas like ecology, air quality and agriculture. For first order relations between meteorology and agriculture an Agro Cropping Calendar was developed (Schaap *et al* 2011). And Petr *et al* (2015) assessed climate impacts on ecosystem services in Scotland. To support decision making the concept of dynamic adaptive policy pathways was adopted and adapted.

The complicated interplay of factors that influence an ecosystem does not only include specific meteorological conditions, but also the timing and sequence of meteorological conditions. Each element of the ecosystem may react differently to the changing conditions and thus the coherence may be compromised, changing the ecosystem as a whole. Obviously, the methods to make climate projections for these impacts are as specific and complicated as the natural processes they describe. In many chains of impact models it is not known what the weakest link is, which hampers the quality of the assessment of climate change impact. van der Sluijs and Wardekker (2015) present and apply a method for the systematic critical appraisal of model assumptions that seeks to identify and characterize the weakest assumptions in a model chain. It yields a rich qualitative insight in model uncertainty and model quality.

In order to service the wide variety of impact studies and facilitate more coherent impact projections, a large effort was made to generate specific information for various societal areas based on common meteorological information (Bakker 2014). To further facilitate users of various areas the so-called transformation program was developed that enables users to 'transform' measured time series of meteorological parameters, that are used to dimension water system for current climate conditions, into time series for the future according to one of the 4 KNMI climate scenarios and for various time horizons. These tools are used frequently especially in water management.

An interactive approach to decision making was developed by Haasnoot *et al* (2015). They used a gaming environment in which water managers experienced the change of their water systems in time using transient (time-dependent) scenarios with realistic frequencies of occurance of extremes. The experience of being responsible for a water system in evolving climate conditions triggers a very different way of thinking, urgency and options for action than do tables and graphs of projections.

Bottom-up studies

The term adaptation implies that there is a man-managed system that due to climate change has to be changed and adapted, in order to maintain its purpose. Man-made systems are often built using knowledge on the climate and its extremes. This knowledge may be implicit, for instance a system may be built similar to older versions that all have sustained through time. The knowledge can be explicit in terms of regulations about resistance to meteorological extreme events. Now that climate changes, these assumptions about climate need to be updated. The ultimate climate adaptation service would be to assess all these explicit and implicit assumptions for all these systems and update them. A large part of the stakeholder interaction concerns the discussions with the clients to find out what the impact of climate change is for their specific system and if it is possible to find numbers from the general top-down data set that would enable decision support. In many cases this works out fine. However, oftentimes a special study has to be made for the projection of a specific parameter. An example is the way that Lenderink and Attema (2015) made projections for local precipitation extremes, a parameter of high importance to water managers. The method combines insights from model experiments and observations. The other way around Reidsma *et al* (2015) did a bottom-up study to the impacts of climate change on (various types of) arable farming in the Netherlands. Although climate change may change the frequency of drought or excess of precipitation at a potentially delicate time of the season and thus has its impact on crop production, it was not found to be more important in farm development than other possible developments, such as genetic improvements or international policies. Their conclusion that it is mandatory to view the impacts of climate change in the context of other developments to weight the importance is valid for many societal areas.

Surprising results

The work done was on the interface between scientific research and dedicated climate services. This field has intrinsic tension because our clients are on a tight time schedule due to policy cycles and project plans whereas research is not completely predictable with respect to results and timing. Therefore, our plans were flexible in some aspects and there was some capacity reserved for new topics that could come up during the course of the project.

The first unexpected result came from studies on the development of tropical storms that may or may not reach the West-European shores towards the end of this century (Haarsma *et al* 2013). Another development was born from a severe water management problem that occurred in January 2012 in which KNMI was asked for advice. The problem was labeled a compound event problem, when two moderate extremes meet at the same time and location. Obviously, the water management strategies were well dimensioned to cope with the separate moderate extremes, one being a 1 in 10 year amount of precipitation in the coastal area. This amount of water should be discharged to the sea. However, a high sea level caused by a persisting north-westerly wind made this impossible, causing ground water to reach levels above ground level for about a month. Most water management regulations only take into account one type of extreme at the time and do not include occurrence of two or more unfavorable (meteorological) conditions at the same time. van der Hurk *et al* (2015) report on the efforts to use the model runs data base (Lenderink *et al* 2015) for assessment of this specific compounding event. This was done in close cooperation between researchers and stakeholders defining the possible methods and outcomes interactively. From the large data base of climate model runs, sections were selected that showed similarity to the compound event under study. These time slides were presented to the stakeholders visualized as if it were the weather forecast of tomorrow, thus showing how a critical situation that had recently occurred may turn out in a future climate. To our surprise this helped the stakeholders a lot in obtaining insight in the real consequences of climate change for their water management and in their adaptation options. A picture tells a thousand words and a realistic simulation tells a whole story of a possible future. It was an eye opener to both stakeholders and scientists. This concept which has been named 'future weather' has become popular among water managers and policy makers. It turns out to be a good example of joint knowledge production (Heggers *et al* 2014). It is a virtue of the set-up of the programme that it included intense stakeholder interaction and allowed for adjustments during its realization.

An assessment to compound events using high resolution modeling and the set of climate projections was done by Klerk *et al* (2015). They studied the coincidence of extreme river discharges from the Meuse and Rhine rivers and storm surges along the North Sea coastline. To date, in most flood risk analyses these two hazardous phenomena are considered independent, and the consequences of coincidence are considered severe. They conclude that indeed high water in the Rhine may coincide with a storm surge along the coastline, but this is of no consequence for coastal defense, because it takes 6 days for the river water to reach the coastline barrier.

Conclusions

Our experiences of the past 5 years show the importance of intense stakeholder interactions in impact and adaptation research. This goes far beyond telling and listening. So, it takes more time and effort than you might think even if you take this effect into account. It means assessing together. Stakeholders and scientists may value the research results completely differently. Furthermore, it is important to make the set-up of the research project flexible to anticipate on surprising promising intermediate results. This field of science is still young and surprises are sure to occur.

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