**CEDR Transnational Road Research Programme**
**Call 2012: Road owners adapting to Climate Change**

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# ROADAPT

# Guideline on the use of data for the current and future climate for road infrastructure

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Consortium ROADAPT:

Deltares, Netherlands

SGI, Sweden

EGIS, France

KNMI, Netherlands

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# ROADAPT
# Roads for today, adapted for tomorrow

# Guideline on the use of data for the current and future climate for road infrastructure

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**Author) this deliverable**:
J. Bessembinder (KNMI, Netherlands)

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# Executive summary

**Aim of these guidelines**
The aim of this document is to give background information and guidelines for tailored and consistent climate data and information for studies on the impact of the current and future climate for transnational road networks in Europe, suitable for National Road Authorities (NRA's). The document can be used by: NRA's to judge the climate information that they receive from e.g. (impact) research institutes, consultancies, and by impact researchers and consultancies to select the most appropriate datasets and methods for a certain application.

The questions most relevant for NRA's are answered in this guideline with reference to the paragraphs with more detailed information.

**What are the steps in using climate data in a quick scan of climate threats for road infrastructure and in more detailed studies?**
In the RIMAROCC approach (Fig. 3.1) in step 2 the risks and threats are identified. Table 3.1 gives an overview of relevant threats for road infrastructure taken into account in the ROADAPT-project and the related climate parameters. This table can help in collecting relevant climate data for studies on the possible vulnerability to climate change of road infrastructure. Especially in step 3 of the RIMAROCC approach (risk analysis) climate data are used to determine the risks in the current and future climate. Fig. 3.2 shows the steps in the use of climate data within this RIMAROCC step 3:

- Determine threats and related climate variables, the reference period and the relevant time horizon;
- Collect data on the current and future climate for these climate variables and check the quality and usefulness of the data;
- Determine which projections/climate scenarios to use with the help of the suggestions in this report;
- Perform additional processing, if needed, to get the data with which the risk analysis can be performed.

Weather extremes affect the road infrastructure and its functioning. The weather is variable from day to day, year to year and from decade to decade. To deal with extremes knowledge about the current climate (averages and the return times of extremes) should be achieved. The climate changed already and it will change further in the future, but it is not known exactly how much. To deal with this variation and uncertainty also knowledge about the future climate is needed.

Generally, NRA's will not take themselves all the steps of the quick scan or detailed studies. Collection and processing of climate data will mostly be outsourced to researchers or consultancies.

**What is climate and climate change? What are ensembles and what is downscaling?**
Climate is the average weather in a given area over a longer period of time. A description of a climate includes information on e.g. the average temperature in different seasons, rainfall, and sunshine. Also a description of the (chance of) extremes is often included. Climate change is any systematic change in the long-term statistics of climate variables such as temperature, precipitation, pressure, or wind sustained over several decades or longer (Fig. 2.2, Par. 2.1.1 and Par. 2.2.1). Climate change can be due to natural external forcings (changes in solar emission or changes in the earth's orbit, natural internal processes of the climate system) or it can be human induced (Par. 2.2.2).

An ensemble is a group of parallel model simulations used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty. Since climate model output is often spatially too coarse for impact studies downscaling is needed. Downscaling covers all techniques that increase the spatial or temporal scale (Par. 5.1.1).

**How to describe a climate?**
The classical period used for describing a climate is 30 years, as defined by the World Meteorological Organization (WMO). An overview of the periods that are used to describe the current climate in several European countries is given in Table 2.1. Causes of differences in climate are described in Par. 2.2.2. Only the larger scale differences (spatial resolution > 10 km) are included generally in the climatologies in Table 2.1.

**Can climate change be detected within 5-10 years?**
Since climate is variable and often described with data from about 30 years, this means that significant climate change is not detected within 5-10 years or even longer (Par. 5.1.1).

**What are the observed and projected climate changes for Europe?**
Table 2.2 gives an overview of observed changes in Europe (1951-2013) for the climate variables related to threats for road infrastructure (Table 3.1). Table 2.3 gives an overview of projected changes of these climate variables, as described in the most recent assessment report of IPCC (2013). In many countries in Europe the IPCC climate change information is translated into more detailed *regional climate change scenarios*, since the IPCC information is often not detailed enough to estimate the impacts of climate change in a particular region. Table 2.4 gives an overview of where information on regional climate scenarios of various European countries can be found.

**How to deal with uncertainties?**
In discussions on climate change inevitably the uncertainties on the future climate are discussed. Uncertainty is any departure from complete deterministic knowledge of the relevant system (Par. 2.3.1). Uncertainties can be due to imperfect knowledge about the climate system or the socio-economic system causing the emission of greenhouse gasses and/or it can be due to intrinsic variability in the climate system. The relative importance of these uncertainties for different time horizons is indicated in Fig. 2.13.

The sources of uncertainties give indications on how one can deal with them (Par. 2.4):
- Natural variability cannot be reduced, but it can be quantified with the help of statistics. If not enough data are available, than monitoring is a way to get more information;
- Uncertainty due to lack of knowledge of a system can be reduced by doing more research to better understand the system. In the meantime scenarios can be used (no probability per scenario!) to study the effect of known uncertainties.

**Which datasets with information on the current climate are available?**
Data on the current or past climate to describe the reference situation for vulnerability assessments can be obtained from different sources:
- Surface based observations: mainly from ground-based weather stations;
- Observations form remote sensing (e.g. radar, satellites);
- Model simulations: re-analysis and climate model data.

All sources have advantages and disadvantages (Table 4.1). Ground-based observations from weather stations are used most often for describing the current climate, for extreme statistics and for detecting climate change. However, with the increase of the length of the observational period, also remote sensing methods become more valuable. Data from model simulations (re-analysis) are useful when observational data are missing. Links to several databases for the current climate are given in Table 2.1, Table 4.2 and in Par. 4.5. They include links to climate normals, time series, climate indices, and re-analyses.

**Which period to use as a reference to describe the current climate and to capture natural variability?**

Depending on the purpose of the vulnerability study and on the presence of information on impacts the period 1961-1990, 1981-2010 or even other periods can be used. In view of climate change, 1981–2010 normals are considered as better descriptions of the current climate than 1961–1990 normals. In the case of cross-border projects, it is important to keep in mind to use the same reference period for the whole region of interest (Table 2.1 and Par. 4.1).

A period of 30 years is generally used to capture the main part of the day-to-day and year-to-year natural variability of a climate. Design events, reference years, etc. do not capture this variability or only partly. For yearly and seasonal averages a period of 30 years is enough. For extremes that occur on average once per year up to once per 10 years generally 30 years is also enough. For rarer extremes generally longer periods with observations have to be used.

**How to check the quality of the climate data?**

Quality control is to verify whether a reported data value is representative of what was intended to be measured and has not been contaminated by unrelated factors. In case of limited quality the reference climate cannot be described sufficiently for vulnerability studies. Factors that affect quality are:

- Missing data;
- Data errors/inconsistencies;
- Inhomogeneity: changes or trends in climate data due to non-climatic factors.

Par. 4.3.1 gives more information on the quality of climate data and Table 4.3 gives suggestions on how to check data quality of climatological time series. One can assume that the quality of climatological normals, statistics of extremes and derived climate indices produced by the NMHI's and other providers that comply with WMO-standards is of sufficient quality. However, time series always have to be checked for their quality. Metadata from weather stations or other sources of climate data can be useful to detect data quality problems (Par. 4.3.3).

**How to check the usefulness of the climate data?**

Although the quality of climate data may be good, still the usefulness and readiness for the intended use (validity) may be limited due to:

- Limited length of data sets or limited temporal resolution;
- Limited spatial coverage of data sets or limited spatial resolution;
- Limited accuracy;
- Presence of trends;
- Different format;
- Something else measured than required;
- Presence of biases (systematic deviations compared to observations).

Par. 4.3.2 gives more information on the usefulness of climate data. Table 4.4 gives some methods for solving data quality and validity problems. Which method is most appropriate in a certain situation, depends on factors such as the availability of other data sets and time available for processing. With the help of the tables and text in Par. 4.4 with advantages and disadvantages per method a selection can be made.

**Which methods are available to generate climate time series when no observations are available?**
When only a few observations are missing in a time series, estimations of these observations generally can be made by interpolation, using data from nearby stations or by using relations with other climate variables that were measured (proxies; Par. 4.4.1). When time series are missing partly or completely for a location, the use of proxies, neighbouring stations or re-analysis datasets (simulated climate in the past with a weather model integrating observational data) is an option (Par. 4.4.3).

**How to get consistent climate data with similar quality for all regions of Europe?**
Although observations of national meteorological institutes have to comply with international standards of WMO, there are some inhomogeneities between countries and measuring networks. When the required accuracy of the data is not extremely high, the existing inhomogeneities will not hamper cross border analysis of vulnerability of road infrastructure.

The European Climate Assessment & Database (ECA&D) is an effort to collect observational data form all European countries, and make them comparable for European wide analyses. Currently it is the dataset with the largest coverage in Europe. In case of cross border projects, this database is a good starting point for a quick scan. Re-analysis datasets are also an option to get consistent data for the past and current climate in Europe. It requires more expert knowledge to transform these data into maps and graphs, but time series are available for the whole of Europe. This makes re-analyses datasets less ready to use for a quick scan, but useful for detailed vulnerability studies (Par. 4.4.2).

**How can climate scenarios be used?** (Par. 2.4)
Climate scenarios are plausible representations of the future climate constructed for investigating the potential consequences of human induced climate change. Often a set of climate scenarios is constructed in such a way that they span a considerable part of the possible future climate. Given the objective of most **impact, adaptation and vulnerability studies** (exploring the range of possible impacts and searching for robust adaptation measures), it is useful to use a set of climate scenarios. By comparing the results of the various climate scenarios one can also determine how robust various adaptation measures are.

Ideally, the results of the impact, adaptation and vulnerability studies mentioned above play a role in the **formulation of policies and strategies**. In this phase often a choice for one or more climate scenarios is made as the basis for policies, although this is not necessary. The choice for one or more climate scenarios for policy making depends also on many factors that are not related directly to climate science (e.g. relevance for society, financial aspects). The IPCC does not indicate which of the underlying emission scenarios or representative concentration pathways (related to possible socio-economic developments) is more likely than the others. For policy making, in most cases it is better to ask which climate scenario is **most relevant** for the user, and not which one is most probable. Par. 2.4.2 gives examples of use of climate scenarios in policy making.

**Which climate model data and climate scenarios are available?**
Table 5.1 gives sources of climate model data for the future (and past) for Europe that include data from more than one Global Climate Model (GCM) or Regional Climate Model (RCM) and that can be used for vulnerability studies. Some climate model data are only available for non-commercial research and educational purposes.

Table 2.4 gives information on where information on regional climate scenarios for various European countries can be found. Table 2.5 gives more information on some of these scenarios and Fig. 2.12 compares the ranges of precipitation and temperature change that are spanned for winter and summer by a limited number of climate scenario sets.

**Which time horizon to use in vulnerability studies?**
The time horizon used in a vulnerability study should take into account (Par. 5.1.2):

- The expected life cycle of the structure (it should still function sufficiently at the end of its life cycle);
- The time until maintenance or replacement of existing structures (how fast can you adapt).

**How to determine climate change from climate model data?**
For a fair comparison, the results from the climate model projections for the future should be compared with the results from the climate model projections for the current climate and not directly with observational data for the current climate, due to the bias in climate model data (Par. 5.4.1).

As a consequence, to generate climate data as input for vulnerability studies on climate change, one generally needs three types of climate data:

- Observed climate data for your region of interest;
- Climate model data simulated for the same period covered by your observed data;
- Climate model data simulated for the future.

**Can one projection or scenario be used for impact analysis?**
The user of climate projections or climate scenarios should not trust in the results of only one climate projection or scenario for impact or vulnerability analyses, as there is no such thing as 'best GCM', 'best RCM' or 'best climate scenario'. Therefore, it is advisable to make use of a group of projections (ensemble) or a set of climate scenarios. Depending on which uncertainties one wants to take into account a different ensemble should be selected (Table 5.2).

**Which methods are available for downscaling?**
Downscaling is a general concept that embraces various methods for increasing (especially) the spatial resolution. There are two fundamentally different approaches to this:

- Dynamical downscaling makes use of a Regional Climate Model (RCM) having higher spatial resolution;
- Statistical or empirical downscaling uses observations on both scales to estimate the link between them.

Par. 5.4.3 describes various statistical downscaling techniques. Fig. 5.9 presents schematically the relation between downscaling techniques, bias correction (Par. 5.4.4) and methods to generate time series for the future (Par. 5.4.5).

**Which downscaling method to use?**
Empirical or statistical and dynamical downscaling techniques all have their advantages and

disadvantages. The advantages and disadvantages mentioned in Par. 5.4.3 may help in making a selection. RCMs require substantial computational resources. Therefore, hardly ever simulations can be made specifically for a project on road infrastructure and one has to rely on available downscaled projections (about 25 * 25 km nowadays). As long as climate models still have large biases, it cannot be said that empirical downscaling methods are less preferred.

Be aware that the downscaling methods themselves also cause new uncertainties. To see the effect, it is recommended to use both empirical and dynamical downscaling techniques.

**Why should model biases (systematic deviations compared to observations) be removed before use in impact models?**
Many impact models contain one or more non-linear relations with climate variables and they are often calibrated with observational climate data. Climate model data always contain biases (systematic deviations from reality). Therefore, using uncorrected climate model data may result in overestimation or underestimation of the impacts (e.g. Fig. 5.5).

**How to determine model bias?**
Model bias (systematic deviation between the model output and observations) can be determined by comparing the **statistics** of observational records for a certain period (often 30 years) with the simulated climate for the same period in the past (Par. 5.4.2).

**Which method to use for removing biases (systematic deviations compared to observations)?**
Depending on the aim of the impact or vulnerability study, other bias correction methods may be most suitable for representing the relevant climate parameters correctly. This also means that a bias correction performed for one impact or vulnerability study is not necessarily suitable for another study!

In most cases, climate extremes cause threats to road infrastructure and these extremes do not necessarily change in the same way as the averages (even the sign of change is sometimes different). In that case, more advanced methods for bias correction should be used. Dalelane (2014) gives a summary of various bias correction methods and techniques and some advantages and drawbacks (Par. 5.4.4).

**Which methods are available to generate time series for the future from climate model information?**
Basically there are 3 main methods for generating time series (hourly, daily, etc.) for the future from GCM's or RCM's (Table 5.3):

- Delta-method: applies climate change signals from climate model(s) to historical time series;
- Direct method: corrects for biases in climate model output with the help of observational historical time series;
- Stochastic weather generators: uses statistical properties/relations between climate variables to generate time series. For the future climate change signals from climate model(s) are used to adapt these relations (Par. 5.4.5).

**Which method to use for generating time series for the future?**
Which method is best or can be used depends among others on the requirements for the impact or vulnerability study, available climate data and available time.

Table 5.3 describes various characteristics of these methods (advantages and disadvantages) and this may help in the selection of the method. As long as climate models still contain large biases it cannot be stated that the direct methods is better than the other methods (Par. 5.4.5).

**Where can I find answers to questions related to climate, climate change and the use of climate data?**
Chapter 6 contains many questions grouped into categories with links to where answers to these questions can be found (in this report or on websites or in other documents). When you cannot find the answer to your questions, contact a local expert (e.g. at the national NMHI or at a research institute or climate service provider).

At the start of the ROADAPT project in 2013 several NRA's had questions about the recent cold winters (2009/2010 until 2011/2012) in Europe (Par. 6.7).

**How extreme were the recent cold winters?**
The winters of 2009/2010 and 2010/2011 were relatively cold in northern Europe (for Fennoscandia belonging to the 25% coldest winters; 2011/2012 within the 25-75% range)) but they were not cold on a global scale or on the scale of the North Atlantic and Europe. In the past clearly colder winters occurred in Fennoscandia and also several cold winters in a row were observed. Year-to-year variability in winter temperature is large on a regional scale (and often underestimated).

**Are the recent cold winters in northern Europe and the reduced trend in global temperature rise in contradiction with climate change?**
Fig. 6.4 shows that the global temperatures since 1998 are still within the simulated range of the global temperature including natural variability. On the basis of many studies IPCC concludes that about half of the reduction in temperature trend since 1998 is due to internal variability. The other half can be attributed to external forcings such as the sun and volcanic eruptions. The anthropogenic contribution to climate change is masked by these effects. So, occasionally colder periods are not in contradiction with global warming.

**Will cold winters as in the recent past occur as often in the future?**
Recent theories about possibly colder winters due to the decrease of Arctic sea ice show weak or no connection with observations. Although there are many questions left about the causes of the recent cold winters, at the moment it seems more probable that the occurrence of cold winters will decrease, although year-to-year variability remains large.

# 1 Introduction

Infrastructures are the backbone of our society. Citizens, companies and governments have come to rely on and expect uninterrupted availability of the road network. Extreme weather is an important factor for the reliability and safety of the road network. In the same time. it is generally understood that the climate is changing and that this will have significant effects on the road infrastructure. Since road infrastructure is vital to society, climate change calls for timely adaptation.

Although there are considerable uncertainties involved in both the projections of future climate change and related socio-economic developments and in estimations of the consequences of these changes in transportation needs, there is a constant need for decisions and development of the road transport system. As stated in the CEDR 2012 Climate Change DoRN: '*Road authorities need to evaluate the effect of Climate Change on the road network and take remedial action concerning design, construction and maintenance of the road network*.'


**Figure 1.1.** UK floods 2014: The River Afton in New Cumnock, Ayrshire, broke its banks after heavy rain overnight causing major flooding in the area and blocking a main road (Photo: James Williamson; Source: http://www.dailymail.co.uk/news/article-2530915/Get-ready-MONTH-bad-weather-After-floods-storms-driving-rain.html).

The ROADAPT project (*Roads for today, adapted for tomorrow*) is part of this CEDR Call. ROADAPT has an integral approach following the RIMAROCC (Risk Management for Roads in a Changing Climate) framework that was developed for ERA NET ROAD in 2010. ROADAPT aims at providing methodologies and tools enabling tailored and consistent climate data information, a good communication between climate researchers and road authorities, a preliminary and fast quick scan for estimating the climate change related risks for roads, a vulnerability assessment, a socio economic impact analysis and an action plan for adaptation with specific input from possible adaptation techniques related to geotechnics and drainage, pavements and traffic management.

Output of the ROADAPT project are guidelines that address all these topics. In the main guidelines an overview of all topics is provided. In five following parts the specific topics are addressed in detail. These five parts are:
A. Guidelines on the use of climate data for the current and future climate
B. Guidelines on the application of a QuickScan on climate change risks for roads
C. Guidelines on how to perform a detailed vulnerability assessment
D. Guidelines on how to perform a socio economic impact assessment
E. Guidelines on how to select an adaptation strategy

This report deals with part of the aim related to A (Guidelines on the use of climate data for the current and future climate). In Bessembinder (2014) an inventory of users' requirements is presented and in this report guidelines for the use of climate data for the current and future climate are elaborated. Also information from the parallel CliPDar[1] project is used in this report.

## 1.1 Aim

The aim of this document is to give background information and guidelines for tailored and consistent climate data and information for studies on the impact of the current and future climate for transnational road networks in Europe, suitable for National Road Authorities (NRA's).

This document can be used by:

- *NRA's*: to get an overview of available climate data, advantages and disadvantages of methods to process climate data, how to select a reference period and how to check quality of climate data and possible differences in climate data between countries. Generally, NRA's will not collect, process and interpret climate data and information themselves. However, some background information will help to judge the climate information that they receive from e.g. (impact) research institutes, consultancies. Moreover, the information may help in promoting consistency in the use of climate data among European countries;
- *Impact researchers and consultancies*: This group will generally use (collect and interpret) the climate data for vulnerability assessments. Sometimes they will also process the climate data. This document gives them a first introduction to climate and climate change and an overview of available data and processing methods. Some have considerable background knowledge on climate and climate change, but not all people working on climate impacts know a lot about the climate data themselves. This document can help in selecting the most appropriate datasets and methods for a certain application.

## 1.2 State of the art on delivering climate services in Europe

The challenge of climate services to society is to bridge the gap between scientific knowledge to knowledge that is usable for policy makers, infrastructure designers and impact researchers. A typical road-owner or road engineer in Europe will not be helped by scientific papers, but will need information such as the return times of extreme rainfall or snowfall in

[1] CliPDaR: project title 'Design guideline for a transnational database of downscaled climate projection data for road impact models (Matulla & Namyslo, 2014).

the current climate and possible changes in the future. A dialogue is needed to match supply and demand. In earlier projects on climate change and infrastructure and road networks this dialogue was started already. As part of the ROADAPT project a workshop was held and documents on the NRA-requirements were studied. The results are described in Bessembinder (2014).

The Global Framework on Climate Services gives the following (broad) definition of Climate Services in the Report of the High-Level Taskforce (WMO, 2011a) (http://www.wmo.int/hlt-gfcs/downloads/HLT_book_full.pdf:

> *'Climate services encompass a range of activities that deal with generating and providing information based on past, present and future climate and on its impacts on natural and human systems. Climate services include the use of simple information like historical climate data sets ……… also making use of climate projections according to different greenhouse gas emission scenarios and time frames. Included as well are information and support that help the user choose the right product for the decision they need to make and that explain the uncertainty associated with the information offered while advising on how to best use it in the decision-making process.'*

On a national scale in Europe many climate services have been developed. The cooperation between these initiatives is not mature yet, as they are often led and financed by national governments, serving national adaption policies. There is a lot of attention for Climate Services at the national, European and international scale. Some international projects and developments are:

- Global Framework on Climate Services (GFCS; www.gfcs-climate.org/);
- Climate Services Partnership (CSP): a platform for knowledge sharing and collaboration worldwide (www.climate-services.org/);
- JPI-Climate: European initiative to coordinate climate research funding (www.jpi-climate.eu/). Module 2 analysed inventories on users requirements and initiated the Climate Knowledge hub to get overview of the climate service providers in Europe (www.climate-knowledge-hub.org/);
- European Climate Assessment and Database (ECA&D): observations in Europe and tools to calculate and present trends, extremes (eca.knmi.nl/);
- Climate-Adapt: initiative of the European Commission and helps users to access and share information (http://climate-adapt.eea.europa.eu/);
- Regional Climate Centres: Centres of Excellence that assist WMO Members to deliver better climate services and products and to strengthen their capacity to meet national climate information needs (www.wmo.int/pages/themes/climate/regional_climate_centres.php);
- EU-projects related to Climate Services[2]: among others ECLISE (www.eclise-project.eu/), CLIMRUN (www.climrun.eu/), EUPORIAS (www.euporias.eu/), IS-ENES (http://climate4impact.eu/impactportal/general/index.jsp).

The above initiatives seek to improve the international cooperation and develop common methodologies to serve users of climate information.

[2] There are many more EU-projects that contribute to providing better climate services. Here only a few are mentioned that focus also explicitly on the contact with users.

**Figure 1.2** The road was flooded and damaged during a period of heavy rain in year 2000. (Source: SRA in Falemo & Lind, 2010).

## *1.3 Delimitation of the work*

This document answers the questions mentioned in the proposal of ROADAPT (see executive summary and green boxes in this report). Within the time frame of ROADAPT it is impossible to describe all available datasets and methods. In this document we give an overview of the most important datasets and methods and we will refer to other documents, websites and databases with more (detailed) information. Where relevant and possible guidelines are given or the advantages and disadvantages of datasets and methods are presented. This will help in making a choice. Information collected in the CliPDaR-project is also included or is referred to (Matulla & Namyslo, 2014a).

This guideline is limited to the provision of climate data, information and knowledge and does not provide information on weather[3], nor on impacts. However, other partners in the ROADAPT project provide information on (tools to determine the) impacts of climate and climate change (Bles et al., 2014). Table 3.1 gives an overview of relevant threats for NRA's and the related climate variables.

It appears that there are few international guidelines or recommendations on the use of climate data for international road networks. It is not the objective of ROADAPT to harmonize existing guidelines or develop harmonized guidelines for the use of climate data. However, at several locations in this document guidelines are given for the use of climate data in cross-border projects and the information in this guideline is meant to assist in getting more uniform cross-border results of climate change risk assessments.

## *1.4 What can you find in this report?*

This guideline gives an overview of existing definitions, methods for using and processing climate information for projects related to road infrastructure, and it gives recommendations for use of climate data and methods.

[3] See Par. 2.1 for the difference between the definitions for climate and weather.

For many people not working in climate science, it is difficult to get overview of the available knowledge on climate and climate change. Therefore, in Chapter 2 first an introduction is given to climate and climate change. More detailed information and guidelines for the collection, processing and use of climate data for the current and future climate can be found in Chapters 4 to 5 (see also the links at the end of these chapters or contact an expert[4]). Chapters 2, 4 and 5 start with a summary in which the questions in the ROADAPT project proposal for the work package on climate services are answered. These chapters also contain guidelines on the use of climate data (e.g. which reference period to use, how to check the quality of climate data).

- If you want an introduction to climate and climate change, go to Chapter 2;
- If you want a description on how to use climate data in a quick scan or detailed study on the risks of climate change for road infrastructure, go to Chapter 3;
- If you want an overview of the most important existing methods and tools to check and process climate data for the current, past or reference climate, go to Chapter 4;
- If you want an overview of the most important existing methods and tools to check and process climate data for the future, go to Chapter 5;
- If you have a specific question, go to the Chapter 6. A large number of questions, grouped into categories, is presented and it is indicated were you can find the answer to these questions. Part of the answers to these questions can be found in Chapter 2-5. For the rest of the answer the reader is referred to websites or other documents.

[4] Expertise is often available at the National Meteorological (and Hydrological) Institutes. Also other providers of climate data often have expertise on methods and tools.

# 2 General information on climate

## Summary and main questions

Weather extremes affect the road infrastructure and its functioning. The weather is variable from day to day, year to year and from decade to decade. To deal with these extremes knowledge about the current climate (averages and the return times of extremes over decades) should be known. The climate changed already and it will change further in the future, but it is not known exactly how. To deal with this variation and uncertainty also knowledge about the future climate is needed. This chapter gives a first introduction to climate and climate change. The questions most relevant for NRA's are answered here with reference to the paragraphs with more detailed information.

**What is climate and climate change?**
Climate is the average weather in a given area over a longer period of time. A description of a climate includes information on e.g. the average temperature in different seasons, rainfall, and sunshine. Also a description of the (chance of) extremes is often included. Climate change is any systematic change in the long-term statistics of climate variables such as temperature, precipitation, pressure, or wind sustained over several decades or longer (Fig. 2.2 and Par. 2.1.1 and 2.2.1). Climate change can be due to natural external forcings (changes in solar emission or changes in the earth's orbit, natural internal processes of the climate system) or it can be human induced (Par. 2.2.2).

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The classical period used for describing a climate is 30 years, as defined by the World Meteorological Organization (WMO). An overview of the periods that are used to describe the current climate in several European countries is given in Table 2.1. Causes of differences in climate and causes of climate change are described in Par. 2.2.2. Only the larger scale differences (spatial resolution > 10 km) are included generally in the climatologies in Table 2.1.

**What are the observed and projected climate changes for Europe?**
Table 2.2 gives an overview of observed changes in Europe (1951-2013) for the climate variables related to threats for road infrastructure (Table 3.1). Table 2.3 gives an overview of projected changes of these climate variables, as described in the most recent assessment report of IPCC (2013). In many countries in Europe the IPCC climate change information is translated into more detailed *regional climate change scenarios*, since the IPCC information is often not detailed enough to estimate the effects of climate change in a particular region. Table 2.4 gives an overview of where information on regional climate scenarios of various European countries can be found.

**How to deal with uncertainties?**
In discussions on climate change inevitably the uncertainties on the future climate are discussed. Uncertainty is any departure from complete deterministic knowledge of the relevant system (Par. 2.3.1). Uncertainties can be due to imperfect knowledge about the climate system or the socio-economic system causing the emission of greenhouse gasses and/or it can be due to intrinsic variability in the climate system. The relative importance of these uncertainties for different time horizons is indicated in Fig. 2.13.

The sources of uncertainties give indications on how one can deal with them (Par. 2.4):

- Natural variability cannot be reduced, but it can be quantified with the help of statistics. If not enough data are available, than monitoring is a way to get more information;
- Uncertainty due to lack of knowledge of a system can be reduced by doing more research to better understand the system. In the meantime scenarios can be used (no probability per scenario!) to study the effect of known uncertainties.

**How can climate scenarios be used?** (Par. 2.4)
Climate scenarios are plausible representations of future climate constructed for investigating the potential consequences of human induced climate change. Often a set of climate scenarios is constructed in such a way that they span a considerable part of the possible future. Given the objective of most **impact, adaptation and vulnerability studies** (exploring the range of possible impacts and searching for robust adaptation measures), it is useful to use a set of climate scenarios. By comparing the results of the various climate scenarios one can also determine how robust various adaptation measures are.

Ideally, the results of the impact and adaptation studies mentioned above play a role in the **formulation of policies and strategies**. In this phase often a choice for one or more climate scenarios is made as the basis for policies, although this is not necessary. The choice for one or more climate scenarios for policy making depends also on many factors that are not related directly to climate science (e.g. relevance for society, financial aspects). The IPCC does not indicate which of the underlying emission scenarios or representative concentration pathways (related to possible socio-economic developments) is more likely than the others. For policy making, in most cases it is better to ask which climate scenario is **most relevant** for the user, and not which one is most probable. Par. 2.4.2 gives examples of use of climate scenarios in policy making.

At the end of this chapter a number of links is given to glossaries, databases and websites with more detailed information on the subjects treated in this chapter.

## 2.1 What is climate?

### 2.1.1 Some definitions

**Weather:** is the state of the atmosphere, mainly with respect to its effects upon life and human activities, e.g. temperature, precipitation, humidity, cloudiness, visibility, wind. Weather consists of the short-term (minutes to days) variations in the atmosphere (http://glossary.ametsoc.org/). Several of these states may be threats to road infrastructure and its functioning.

All meteorological institutes and many commercial weather providers provide weather forecasts for the coming days/weeks and often they compare the forecasts with the long term average (climatic normals). Fig. 2.1 gives an example of the meteoalarm-website in which warnings and alerts on extreme weather of many countries in Europe are combined in a consistent way.

**Climate:** is the average weather in a given area over a longer period of time. A description of a climate includes information on e.g. the average temperature in different seasons, rainfall, and sunshine. Also a description of the (chance of) extremes is often included. The description of a climate provides insight in the occurrence of weather events that are threats to road infrastructure and its functioning.

**Variability, day-to-day variation, year-to-year variation:** is the temporal variation of the atmosphere–ocean system around a mean state due to natural internal processes within the climate system (internal variability: e.g. the different position of high and low pressure areas, differences in air circulation) or to variations in natural forcings (e.g. solar intensity, volcanic eruptions). As the mean state often the average over a recent 30-year period is used (Par. 2.1.2 'How to describe a climate'). The term climate variability is sometimes used also for variations due to human induced forcings (e.g. changes in land use, increase greenhouse gasses; IPCC, http://glossary.ametsoc.org/).

In the case of extreme events often the question is raised whether it is due to climate change. However, one extreme event can never be attributed to climate change. Due to climate change the probability of a weather event might change, but this does not mean that a certain weather event cannot already occur today.

**Definition: what is climate?**
**Climate** is the average weather in a given area over a longer period of time. A description of a climate includes information on e.g. the average temperature in different seasons, rainfall and sunshine. Also a description of the (chance of) extremes is often included (Par. 2.1.1).

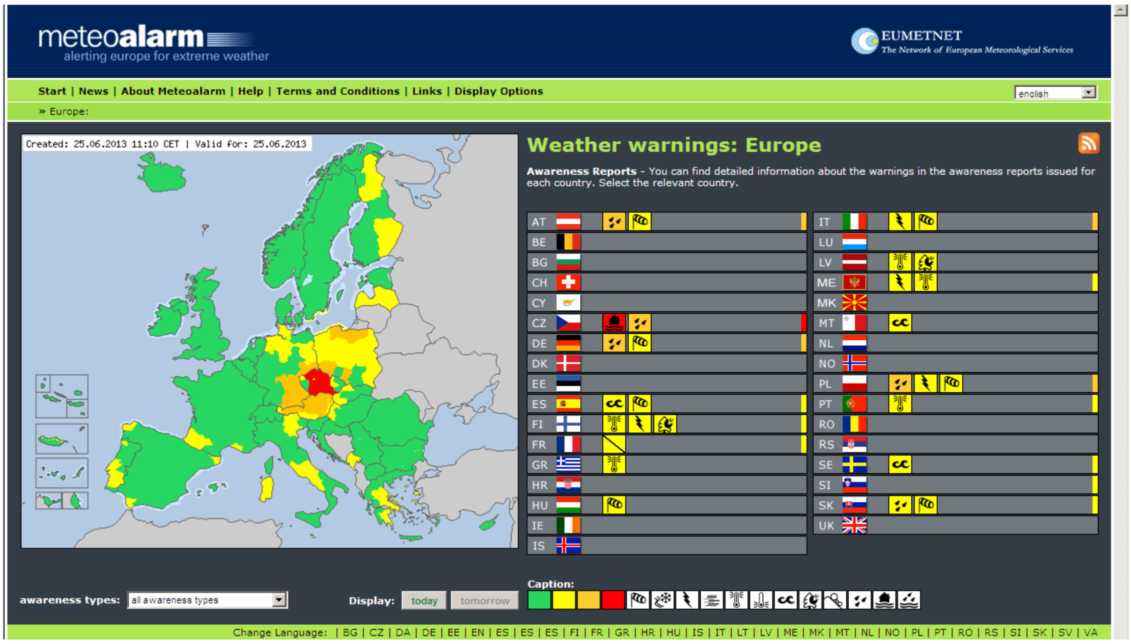


**Figure 2.1** Screen shot of the Meteoalarm website: www.meteoalarm.eu/index.php?lang=en_UK.

### *2.1.2 How to describe a climate?*

The classical period used for describing a climate is 30 years, as defined by the World Meteorological Organization (WMO). The relevant quantities are most often surface variables such as temperature, precipitation and wind (http://glossary.ametsoc.org/; IPCC).

Meteorological institutes are obliged to make a new description of the climate of their country (and regions within the country) every 30 years. The next period for which this has to be done is 1991-2020. Currently the period 1961-1990 is used in several countries to describe the current climate, although several countries in Europe also make a new description of the climate every 10 years (after 1961-1990, the periods 1971-2000 and 1981-2010 were used). An overview of the periods are used in several European countries is given in Table 2.1.

The variability of a climate is described with the help of statistics. For several climate variables a period of 30 years is enough to describe *most* of the variability, e.g. year-to-year seasonal averages, day-to-day variability. Even without climate change due to increased greenhouse gasses the climate would not be completely the same for each period of 30 years, due to internal variability and natural forcings. For some climate variables a period of 30 years is not enough to describe the largest part of natural variability, e.g. extremes in wind or precipitation (rarer than once in 10 years). Especially extremes pose threats to roads. To describe them well at least periods of 30 years with climate data are needed. By definition extremes are rare, and therefore it is also more difficult to detect significant changes in extremes.

As a result of climate change there is also discussion on whether the past 30 years or the period 1961-1990 give a good description of the current climate. Temperature has increased considerably over the past decades. Therefore, the change of having higher temperatures than the 1981-2010 or 1961-1990 averages ('normals') is higher than having lower temperatures than these normals. In its new assessment report IPCC (2013) uses periods of 20 years to describe a climate (1986-2005 as a reference for the current climate).

**Overview: how to describe a climate?**
The classical period used for describing a climate is 30 years, as defined by the World Meteorological Organization (WMO). Meteorological institutes are obliged to make every 30 years a new description of the climate of their country (and regions within the country). An overview of the periods that are used to describe the current climate in several European countries is given in Table 2.1.

### *2.1.3 Causes of spatial differences in climate*

Differences in climatology between and within regions and countries are caused by:

- (Relatively) large scale processes due to, among others, latitude, air circulation patterns, land-sea gradients, differences in altitude, large scale differences in land cover. These differences are in most cases reflected in the observations (depends on the density of the observational network). For example, the average temperature in coastal areas in summer is generally lower and in winter higher compared to inland regions; at higher altitudes the temperatures generally are lower than for lower altitudes;
- Local surface characteristics (on a scale of meters to several kilometres), such as the presence of buildings or vegetation. These local characteristics are more important for some climate variables than for others. Rainfall is less affected by the presence of

buildings and vegetation[5] than for example temperature and wind. These very local differences are often not described in the climatologies mentioned in Table 2.1, since most weather stations are located in rural areas and on locations with a relatively open landscape. Urbanization changes many characteristics of the local climate, notably the replacement of cooling trees with concrete and asphalt that heat up during the day but cool only slowly at night. Buildings and structures also change the ground-level wind flow (www.wmo.int/pages/themes/climate/statistical_depictions_of_climate.php).

### 2.1.4 *Descriptions of the current climate*

Table 2.1 refers to descriptions of the current climate in various countries in Europe, including the links to the websites with the information. As indicated in Par. 2.1.2 different periods can be used to describe the current climate. As can be seen in the table this is also the case in Europe, although the period 1981-2010 is most commonly used.

**Table 2.1** Some examples of descriptions of the climate from European countries. Also indicated is which periods are used to describe the current climate ('normals'; last checked September 19, 2014).

| Country | Web site | Current climate described with [A] |
|---|---|---|
| Austria | www.zamg.ac.at/cms/de/klima/klimauebersichten/klimamittel-1971-2000 | 1971-2000 |
| Belgium | www.meteo.be/meteo/view/fr/360955-Normales+mensuelles.html | 1981-2010 |
| Denmark | www.dmi.dk/klima/klimaet-frem-til-i-dag/danmark/ www.dmi.dk/en/klima/climate-changes-over-time/denmark/ | 1961-1990 |
| France | www.meteofrance.fr/climat-passe-et-futur/climat-en-france/le-climat-en-metropole# | 1981-2010 |
| Finland | en.ilmatieteenlaitos.fi/normal-period-1981-2010 | 1981-2010 |
| Germany | www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop?_nfpb=true&_pageLabel=_dwdwww_klima_umwelt_klimadaten_deutschland&T82002gsbDocumentPath=Navigation%2FOeffentlichkeit%2FKlima__Umwelt%2FKlimadaten%2Fkldaten__kostenfrei%2Fkldat__D__mittelwerte__node.html%3F__nnn%3Dtrue | 1981-2010 |
| Ireland | www.met.ie/climate-ireland/30year-averages.asp | 1981-2010 |
| Netherlands | www.klimaatatlas.nl/ | 1981-2010 |
| Norway | www.senorge.no/index.html?p=klima | 1971-2000 |
| Portugal | www.ipma.pt/resources.www/docs_pontuais/ocorrencias/2011/atlas_clima_iberico.pdf | 1971-2000 |
| Sweden | www.smhi.se/klimatdata | 1961-1990 |
| Switzerland | www.meteoswiss.admin.ch/web/en/climate/swiss_climate/Normperiode_1981_2010.html | 1981-2010 |
| UK | www.metoffice.gov.uk/public/weather/climate/city-of-london-greater-london#?tab=climateStations | 1981-2010 |

[A] Many countries also present the 'normals' for 1961-1990 and/or 1971-2000.

[5] But rainfall is affected by differences in altitude (lee-side effect), and not all spatial differences in a mountainous area (on a scale of kilometres) will be included in the descriptions of the climate in Table 2.1.

## 2.2 What is climate change?

### 2.2.1 Some definitions

**Climate change:** is any systematic change in the long-term statistics of climate variables such as temperature, precipitation, pressure, or wind sustained over several decades or longer. It can refer to changes in the mean and/or the variability of its properties. Climate change may be due to natural external forcings or it may be human induced (anthropogenic; http://glossary.ametsoc.org/; IPCC, 2007). Fig. 2.2 presents, in a schematic way, different examples of climate change.

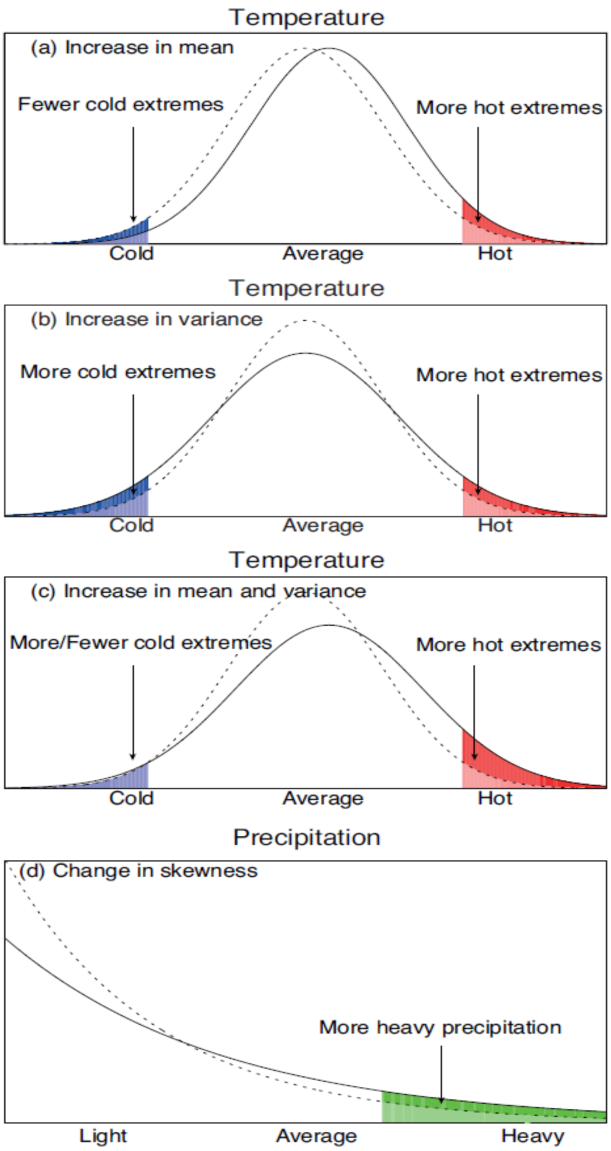


**Figure 2.2** Schematic presentation of climate change (dashed line=current climate, solid line=future climate): the mean can change (a); the probability of extremes can change (b) or a combination of these changes can occur (c). Panel d shows an example for precipitation where the number of days with light rainfall decreases and the number of days with heavy rainfall increases (Source: IPCC, 2013).

**Greenhouse effect:** the heating effect exerted by the atmosphere upon the earth because greenhouse gasses (water vapour, $CO_2$, etc.) absorb and reemit infrared radiation (http://glossary.ametsoc.org/). Naturally, there are greenhouse gases in our atmosphere, including $CO_2$ and water vapour. Due to the presence of these natural greenhouse gases,

the earth is about 33 ° C warmer than without these gases. As a result, the average global temperature is around 14 ° C and not around -19 ° C (*natural greenhouse effect*; IPCC, 2007). The natural greenhouse effect is enhanced due to the increase of greenhouse gases in the atmosphere due to human activities (*enhanced greenhouse effect*). Since the pre-industrial era (about 1860), the concentration of $CO_2$, $CH_4$ and $N_2O$ by human activities increased significantly (IPCC, 2007, 2013).

**Mitigation**: efforts to reduce or prevent emission of greenhouse gases. Mitigation can mean using new technologies and renewable energies, making older equipment more energy efficient, or changing management practices or consumer behavior. Efforts underway around the world range from high-tech subway systems to bicycling paths and walkways. Protecting natural carbon sinks like forests and oceans, or creating new sinks through silviculture or green agriculture are also elements of mitigation (www.unep.org/climatechange/mitigation/).

**Adaptation:** anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, or taking advantage of opportunities that may arise. Examples: using scarce water resources more efficiently; adapting building codes to future climate conditions and extreme weather events; building flood defences and raising the levels of dykes; choosing tree species and forestry practices less vulnerable to storms and fires (ec.europa.eu/clima/policies/adaptation/index_en.htm). Adaptation is what ROADAPT is working on.

**Definition: what is climate change?**
**Climate change** is any systematic change in the mean and/or extremes in the long-term statistics of climate variables such as temperature, precipitation, pressure, or wind sustained over several decades or longer (Fig. 2.2).

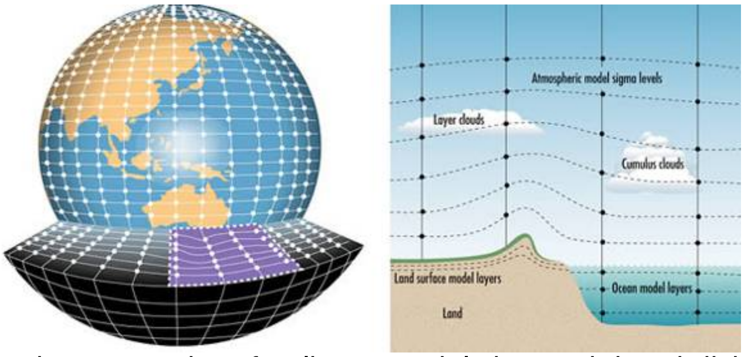


**Figure 2.3** Schematic presentation of a climate model: the earth is subdivided in many grids in horizontal and vertical direction: the climate model simulates the climate for each grid.

**Climate model:** A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties.

The climate system can be represented by models of varying complexity. Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) provide a representation of the

climate system that is near the most comprehensive end of the spectrum currently available (IPCC, 2007). Climate models approximate the real world and, therefore, models cannot represent the real world perfectly (Fig. 2.3). Many of the processes taking place in the atmosphere and the ocean take place on scales that are too small to be adequately captured by the grid box system (Fig. 2.3). An obvious example is the formation and dissipation of clouds, which clearly occur on scales much smaller than 200 by 200 km or 100 by 100 km. Processes such as these have to be incorporated into models in a manner that relates them in a very approximate way to the properties of the grid boxes (*parameterization)*.

**Emission scenario:** A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socioeconomic development, technological change) and their key relationships (http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=welcome).

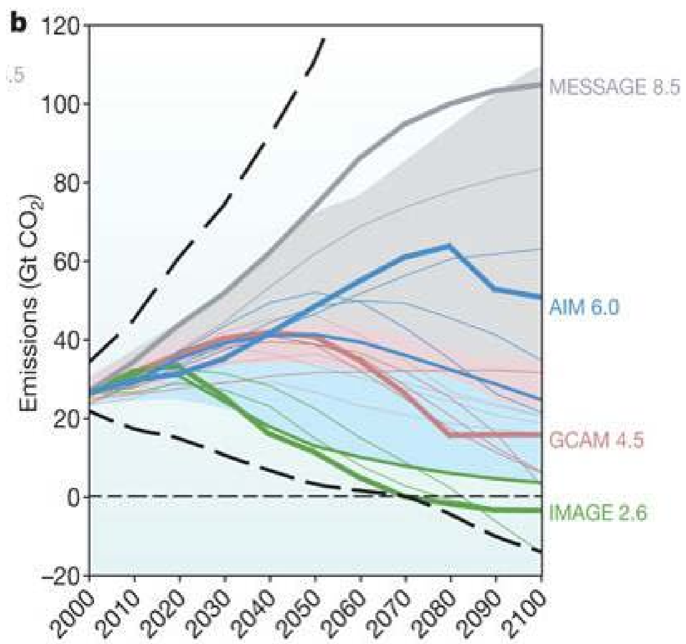


**Figure 2.4** The four RCP representative concentration pathways: 2.6, 4.5, 6.0 and 8.5 (source: Moss et al., 2010).

**Concentration scenarios:** are used as input to a climate model to compute climate projections. In the IPCC report from 2007 the SRES scenarios were used (Special Report on Emission Scenarios (SRES), Nakićenović & Swart, 2000). Concentration scenarios were derived from the SRES emission scenarios (Fig. 2.5). In the fifth IPCC assessment report (2013) RCP's (Representative Concentration Pathways, Fig. 2.4 and 2.6)) are used (http://tntcat.iiasa.ac.at:8787/RcpDb/dsd?Action=htmlpage&page=welcome). The RCP's are not new, fully integrated scenarios (i.e., they are not a complete package of socioeconomic, emissions, and climate projections). They are consistent sets of projections of only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as input for climate modelling. Central to the process is the concept that any single RCP can result from a diverse range of socioeconomic and technological development scenarios (www.wmo.int/pages/themes/climate/emission_scenarios.php).

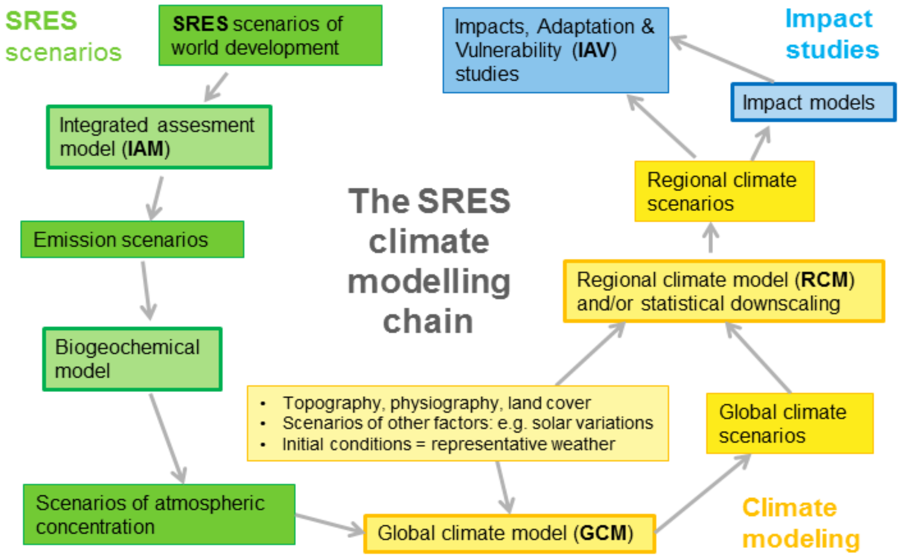


**Figure 2.5** The SRES chain of scenarios and models. (Image source: SMHI Rossby Centre, climate4impact.eu/impactportal/documentation/backgroundandtopics.jsp?q=Scenarios). In RCP's the 'scenarios of atmospheric concentration' are the starting point and the arrows towards 'SRES scenarios' are reversed.

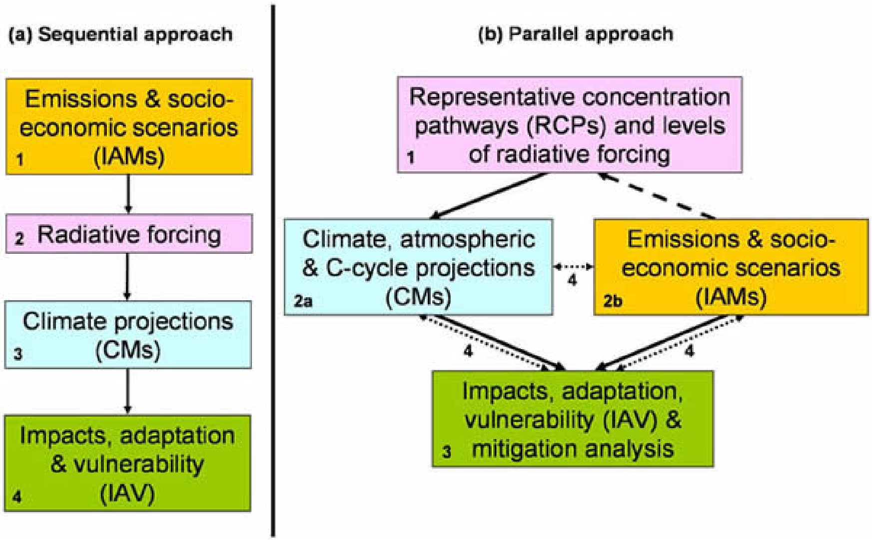


**Figure 2.6** Approaches to the development of global scenarios: (a) previous sequential approach; (b) parallel approach for RCP's. Numbers indicate analytical steps (2a and 2b proceed concurrently). Arrows indicate transfers of information (solid), selection of RCPs (dashed), and integration of information and feedbacks (dotted). Source: Moss et al. (2008).

**Climate projection:** is a projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/concentration/radiative forcing scenario used, that *may or may not* be realized and are, therefore, subject to substantial uncertainty (IPCC, 2007).

**Climate prediction:** A climate prediction or *climate forecast* is the result of an attempt to produce an estimate of the actual evolution of the climate in the future, for example, at seasonal, interannual or long-term time scales. Since the future evolution of the climate system may be highly sensitive to initial conditions, such predictions are usually probabilistic in nature (IPCC, 2007). It can be discussed whether climate predictions can be given for time horizons beyond 10-20 years ahead (this will be discussed in Chapter 5).

**Climate scenario:** is a plausible and often simplified representation of the future climate (Fig. 2.7), based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of human induced climate change, often serving as input to impact models. Climate model simulations for the future (projections) often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate. A *climate change scenario* is the difference between a climate scenario and the current climate (IPCC, 2007). Often a set of climate scenarios is constructed in such a way that they span a considerable part of the possible future.

In many countries in Europe the IPCC climate change information is translated into more detailed *regional climate change scenarios*, since the IPCC information is often not detailed enough to estimate the effects of climate change in a particular region. Table 2.4 (Par. 2.2.5) gives the links to the regional climate scenarios of various European countries.

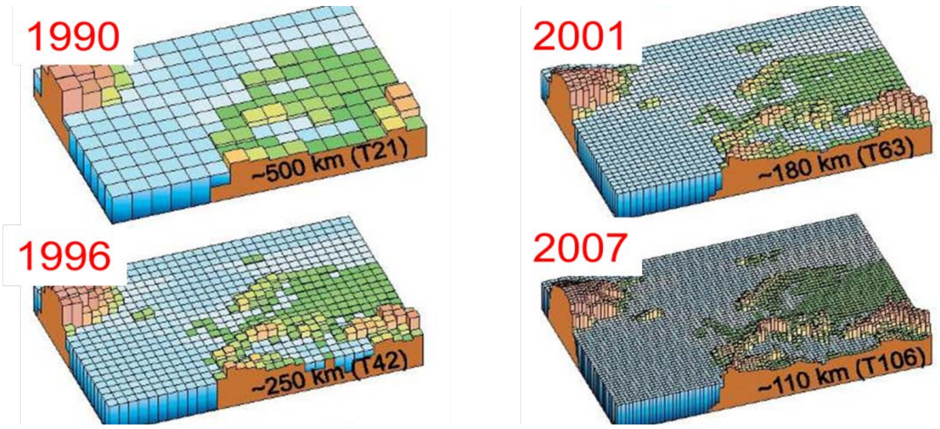


**Figure 2.7** Evolution of spatial resolution in Global Climate Models used for IPCC assessment reports (Source: www.wmo.int/pages/themes/climate/climate_models.php).

**Note!**

- Often the term 'climate change' is used to refer to human induced (anthropogenic) climate change;
- The term 'climate scenario' is also regularly used for climate projections. In that case individual climate projections are considered as climate scenarios;

- Some people use the terms 'projection' and 'prediction' interchangeably, whereas others make a clear distinction between them (as in the descriptions above);
- Most climate scenarios are in fact climate change scenarios, since they mostly give the changes (e.g. increase in temperature, percentage change in precipitation). However, several of these climate change scenarios are also translated into descriptions of the future climate (climate scenarios). For example compare the KNMI'06 climate change scenarios (www.klimaatscenarios.nl/knmi06/) with the descriptions of the future climate given on the website (e.g. www.klimaatscenarios.nl/knmi06/gegevens/neerslag/index.html) and in the 'climate sketchbook' (www.knmi.nl/klimaatmaatwerk/ro/Klimaatschetsboek.pdf);
- Not all climate (change) scenarios include consistency between the various climate variables: they do not indicate which combinations of changes of climate variables are possible. In these cases simply the average change or range of possible change per climate variable is indicated. This is e.g. the case for the IPCC climate change scenarios;
- Climate (change) scenarios are not long term weather predictions: they do not give information on the weather on a specific date in the future; they only give information on the average weather on dates in the future, and information on the chance that extreme weather will occur.

### *2.2.2 Causes of climate change*

The climate system is dynamic and climate has changed since the origin of earth. The causes of climate change can be divided into two main groups:

- Natural causes (e.g. variations in solar activity, the earth's orbit around the sun, volcanic eruptions). Of these, the two factors relevant on timescales of contemporary climate change are changes in volcanic activity and changes in solar radiation. In terms of the Earth's energy balance, these factors primarily influence the amount of incoming energy. Volcanic eruptions are episodic and have relatively short-term effects on climate. Changes in solar irradiance have contributed to climate trends over the past century but since the Industrial Revolution, the effect of additions of greenhouse gases to the atmosphere has been about ten times that of changes in the Sun's output (www.climatechange.gc.ca/default.asp?lang=En&n=65CD73F4-1#X-201208011007431);
- Human actions (e.g. changes in land use and emissions of greenhouse gases, aerosols; often called anthropogenic). Due to changes in land use the climate can change, usually on a regional scale (e.g. conversion of land for forestry and agriculture, urbanisation, the development of a large scale irrigation project). In addition to other environmental impacts, these activities change the land surface and emit various substances to the atmosphere. These in turn can influence both the amount of incoming energy and the amount of outgoing energy and can have both warming and cooling effects on the climate. The dominant product of fossil fuel combustion is carbon dioxide, a greenhouse gas (www.climatechange.gc.ca/default.asp?lang=En&n=65CD73F4-1#X-201208011007431). Since the pre-industrial era (approx. 1860), the $CO_2$ concentration of about 280 ppm (parts per million) increased to about 391 ppm in 2011 (IPCC, 2013).

**Causes of climate change**
Climate change can be due to natural external forcings (changes in solar emission or changes in the earth's orbit, natural internal processes of the climate system) or it can be human induced (Par. 2.2.2).

### 2.2.3 Description and detection of climate change

As mentioned before, even without human induced climate change the climate of one 30-year period is not exactly the same as the climate of another 30 years period due to natural variability. The weather that we got during the past 30 years is to a certain extent random. It could have been as well somewhat lower/higher for all climate variables. Therefore, it is difficult to indicate which part of the change in the past is due to natural variability and which part is due to the increased emission of greenhouse gasses, especially for relatively short periods of 50-60 years. For longer periods it is easier to see whether the change is in line with the long-term trend (Fig. 2.8).

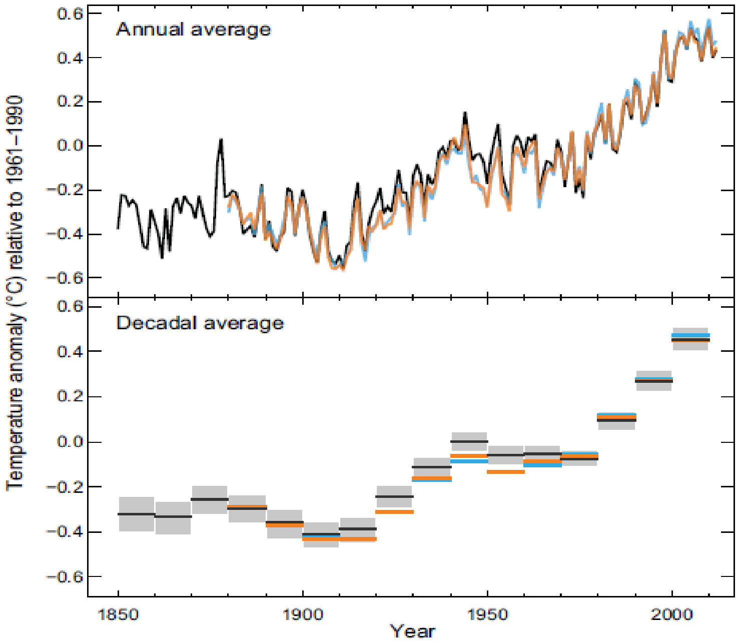


**Figure 2.8** Observed globally averaged combined land and ocean surface temperature anomaly 1850-2012 based on different datasets. Upper panel: yearly average temperature; lower panel: average temperature per decade (grey band= natural variability of 10-year periods; IPCC, 2013).

One of the approaches used to see whether the observed climate change can be attributed to natural variability or also to the increase of greenhouse gasses due to human activities, is to simulate climate with the help of climate models with and without increased greenhouse gas concentrations (Fig. 2.9) and within all cases the known natural causes (e.g. solar activity, el Niño, volcanic eruptions). For a large part of the past century the observed global temperature is within the blue area in Fig. 2.9 (the natural variability of a climate without increase of greenhouse gasses). However, in the second half of the last century the observed global temperature cannot be explained anymore by natural causes alone[6]. We can only explain the observed global temperature by including the effect of increased greenhouse gasses.

[6] Figures 2.9 and 2.10 present the long term average temperatures and not the year-to-year variation in temperatures. Therefore, the levelling off of the temperature since 1998 cannot be observed in these figures. Figure 6.4 does show the year-to-year variation in temperature.

On a global level warm periods in one region are generally averaged out by cold periods in other regions. Therefore, the bandwidth for natural variability is much smaller at a global level than e.g. for a region such as Europe (Fig. 2.10): on the scale of Europe the average temperature can be explained much longer by natural variability alone. However, also at the end of the past century the observed average temperature can only be explained when we take into account the effect of the increase of greenhouse gasses.

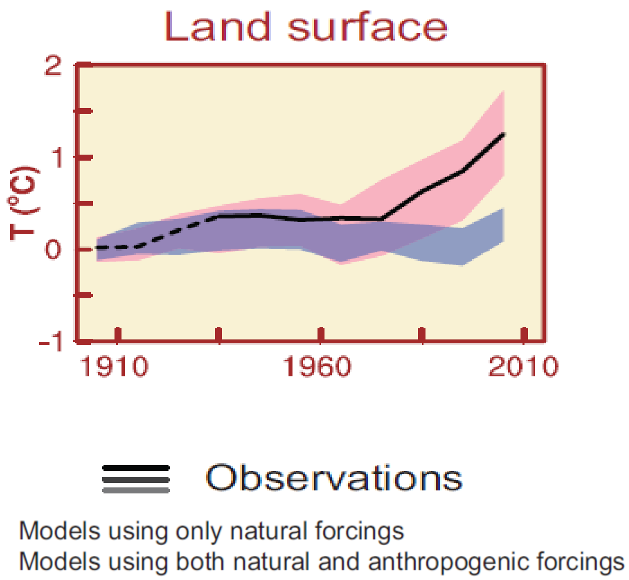


**Figure 2.9** Global temperature increase in the past century: comparison of observed and simulated climate change. Anomalies are given relative to 1880–1919 (IPCC, 2013).

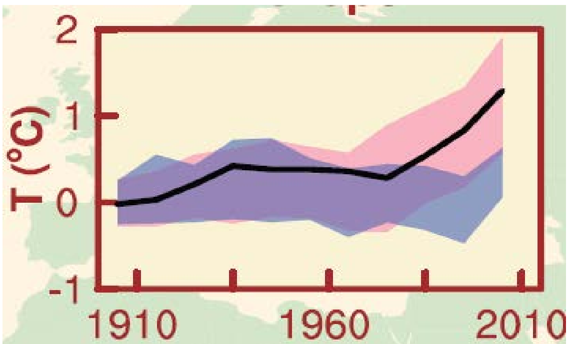


**Figure 2.10** Temperature increase in Europe in the past century: comparison of observed and simulated climate change. Anomalies are given relative to 1880–1919 (for legend see Fig. 2.9; IPCC, 2013).

**Table 2.2** Summary of present knowledge regarding critical climate parameters for climate change analysis in the transport sector: observed trends in Europe over the period 1951-2013[A] (Source: ECA&D, Annex 2).

| Climate parameter | Observed change (+:increase,-:decrease, ?=not clear, 0: no change)[E] | Significance of observed trend (5% level) |
|---|---|---|
| **Precipitation/drought** | | |
| Average amount of rainfall per year (mm/y) | North: +<br>South: - | North: many stations with sign. Increase; south: decrease less clear |
| Average amount of rainfall per season (mm/season) | DJF / MAM / JJA / SON<br>North: + / +/- / + / +/-<br>South: -/0 / 0/- / - / 0 | In general: north increase and south decrease, but many stations with non-sig. change |
| Maximum rainfall intensity in heavy showers (mm/h) | + | Hardly in the South, many stations without significant change |
| Extreme rainfall events (long periods with rain, mm/d) | North: +<br>South: - | Many stations without significant change |
| Average snowfall (cm/y or cm/season) | -/0<br>(except east of 40E) | Significant decrease in days with 1 cm snow for several stations |
| Heavy snowfall in 24 h (cm/d or cm/h) | -/0<br>(except east of 40E) | Significant decrease in days with 50 cm snow in some parts of alps and Scandinavia |
| Drought (consecutive dry days) | +/- | Most stations not significant trend, no distinct pattern |
| **Sea level** | | |
| Sea level rise (cm/y)[B] | + | Significant over past century |
| **Temperature** | | |
| Average temperature (˚C) | + | Significant for most of Europe and all seasons |
| Heat waves (number) | + (WSDI) | Significant for most of Europe and all seasons, except northern Scandinavia |
| Hot days (number of consecutive days with temperature above 30 ˚C) | + | Significant for most of Europe and all seasons, except northern Scandinavia [D] |
| Maximum temperature (highest temperature per year; ˚C) | + | Significant for most of Europe and all seasons, except northern Scandinavia |
| Daily temperature range (DTR; ˚C) | DTR: DJF - (mostly); JJA +(mostly) | Many stations without sign. changes |
| Number of frost days (min. temperature < 0 ˚C) | - | Significant for most stations |
| Frost-thaw cycle (number of days with T=0 crossings) | ? | But significant decrease in frost and ice days |
| **Wind** | | |
| Max. daily wind speed (storm surges; m/s) | ? | Some stations with significant decrease in number of days with > 6 Bft |
| Max wind speed (wind gusts; m/s) | +/- | For a few stations significant changes |
| Wind direction | # days: East +/0; North -/0; South +/0; West +/0 | In some part Europe significant changes, but over short period |
| **Other climate variables** | | |
| Days with fog (number of days/y)[C] | - | Significant changes |
| Lightning (number of days/y) | ? | No overview available |

[A] Maps for the trends for 1951-2013 were generated through the ECA&D website, and trends in this table were based on this period. Also maps for 1979-2013 were generated, and in most cases the trends were stronger for this period;
[B] Source: IPCC, 2013;
[C] Source: Oldenborgh et al. (2010) for the period 1976-2006 for most of Europe;
[D] Based on number of days with at least 25 ˚C, information on number of days with at least 30 ˚C not available;
[E] DJF=December-February; MAM = March-May; JJA = June-August; SON = September-November; 40E = 40˚ Easter length; WSDI = warm spell duration index.

### 2.2.4 Observed trends

Average global temperature has increased with 0.85 °C (0.65 to 1.06) over the period 1880–2012 (IPCC, 2013). Table 2.2 gives a summary of the knowledge on observed changes regarding critical climate parameters for road infrastructure. This table is partly an update of Table 2 in the RIMAROCC-report (Bles et al., 2010). Fig. 2.11 shows the observed trends in average temperature over the period 1950-2007 for the four seasons as a factor of the increase in global temperature. For a considerable part of Europe the temperature has increase 1.5 to more than 2.0 times faster than the global average over this period.

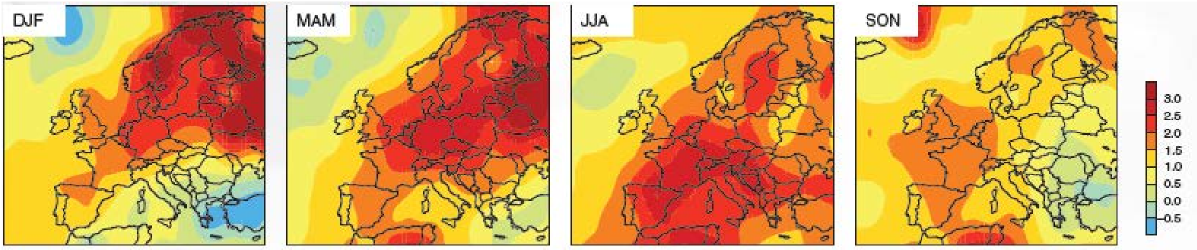


**Figure 2.11** Observed trends in average temperature over the period 1950-2007 (local temperature increase per degree global temperature increase) in the meteorological seasons: December-February (DJF), March-May (MAM), June-August (JJA) and September-November (SON). Data: CRU/Hadley Centre. (Van Oldenborgh et al., 2009).

### 2.2.5 Projected changes

Projections for the future are made with the help of climate models (and sometimes for the coming 10-20 years by extrapolating trends). For the IPCC reports Global Climate Models (or Global Circulation Models; GCM's) are used. These climate models use concentration scenarios as input. Since the start of climate modelling the spatial resolution has increased considerably (Fig. 2.7). This means that by now spatial differences and smaller scale processes can be simulated in a more realistic way.

Table 2.3 gives a summary of the projected changes regarding critical climate parameters for road infrastructure in Europe, based on IPCC (2013).

Most countries in Europe produce climate scenarios or projections for their own country (often called r*egional climate scenarios*), often using the same basic information (RCM projections) from large European projects such a PRUDENCE and ENSEMBLES, but all with their own methods to construct climate scenarios. Table 2.4 gives an overview of where information on the regional climate scenarios of various European countries can be found. Table 2.5 gives some characteristics of the various sets of climate scenarios.

**Table 2.3** Summary of present knowledge regarding critical climate parameters for climate change analysis in the transport sector: projected changes for Europe (IPCC, 2013).

| Climate parameter | Projected change for time horizon 2080-2100 compared to reference 1986-2005 (+=increase, -=decrease, 0=no change ?=not clear) | | | Certainty of projection |
|---|---|---|---|---|
| **Precipitation/drought** | | | | |
| Average amount of rainfall per year(mm/y) | North | + | | Likely |
| | South | - | | |
| Average amount of rainfall per season (mm/season) | | Dec.-Febr. | June-August | Likely |
| | North | + | +/- | |
| | South | ? | - | |
| Maximum rainfall intensity in heavy showers (mm/h) | + | | | Very likely over most mid-latitude land |
| Extreme rainfall events (long periods with rain, mm/d) | + | | | Very likely over most mid-latitude land |
| Average snowfall (cm/y or cm/season) | -/? | | | Likely, due to increase of temperature[A] |
| Heavy snowfall in 24 h (cm/d or cm/h) | -/? | | | Likely, due to increase of temperature[A] |
| Drought (consecutive dry days) | North | +/0 | | Likely |
| | South | + | | |
| **Sea level** | | | | |
| Sea level rise (cm/y) | + | | | Very likely: 2050-2100 |
| **Temperature** | | | | |
| Average temperature (˚C) | + | | | Virtually certain |
| Heat waves (number) | + | | | Virtually certain |
| Hot days (number of consecutive days with temperature above 30 ˚C) | + | | | Virtually certain |
| Maximum temperature (highest temperature per year; ˚C) | + | | | Virtually certain |
| Diurnal temperature range (˚C) | ? | | | Not known |
| Number of frost days (Min. temperature <0 ˚C) | - | | | Virtually certain |
| Frost-thaw cycle (number of days with T=0 crossings) | - [B] | | | Virtually certain |
| **Wind** | | | | |
| Max. daily wind speed (storm surges; m/s) | ? | | | |
| Max wind speed (wind gusts; m/s) | + | | | Often related with heavy rainfall in current climate |
| Wind direction | ? | | | Not known |
| **Other climate variables** | | | | |
| Days with fog (number of days/y) | -/0 | | | Depends especially on air quality |
| Lightning (number of days/y) | ? | | | Often related to heavy rainfall in current climate |

[A] In the northern part of Europe precipitation is likely to increase. This could also result in more heavy snowfall, however at the same time temperatures increase. With higher temperatures more precipitation occurs in the form of rainfall and less as snow;
[B] On the long term the number of days with frost-thaw will decrease everywhere, however in some regions it may also increase first. This depends on whether the winter temperature is close to 0 ˚C in the current climate (than decrease in the coming decades) or whether it is far below 0 ˚C (than first an increase may occur).

**Table 2.4** Regional climate scenarios/projections and their names in various European countries: links to the websites (source: among others Dalelane, 2014; links last checked September 19, 2014).

| Country | Website with regional climate scenarios[A] |
|---|---|
| Austria | klimawandelanpassung.at/ms/klimawandelanpassung/de/klimawandelinoe/kwa_zukunftsszenarien/ |
| Belgium | CCI-HYDR for Flanders: www.kuleuven.be/hydr/CCI-HYDR.htm |
| Denmark | en.klimatilpasning.dk/knowledge/climate/denmarksfutureclimate.aspx<br>www.dmi.dk/klima/fremtidens-klima/klimascenarier/<br>www.dmi.dk/klima/fremtidens-klima/danmark/<br>www.dmi.dk/fileadmin/Rapporter/DKC/dkc12-04.pdf |
| France | DRIAS: www.gip-ecofor.org/gicc, www.drias-climat.fr/<br>www.meteofrance.fr/climat-passe-et-futur/changement-climatique/projections-climatiques/les-projections-climatiques-regionalisees |
| Finland | ilmasto-opas.fi/en/ilmastonmuutos/suomen-muuttuva-ilmasto/-/artikkeli/74b167fc-384b-44ae-84aa-c585ec218b41/ennustettu-ilmastonmuutos-suomessa.html;<br>ilmasto-opas.fi/en/datat/mennyt-ja-tuleva-ilmasto#DoubleMapTimelinePlace:vertailu |
| Germany | DWD Klimaatlas: www.dwd.de/klimaatlas/<br>KLIWAS: www.kliwas.de/<br>WettReg2010: www.cec-potsdam.de/Produkte/Klima/WettReg/wettreg.html<br>CSC Klimasignalkarten: www.climate-service-center.de/031443/index_0031443.html.de |
| Ireland | www.epa.ie/pubs/reports/research/climate/STRIVE_48_Fealy_ClimateModelling_web.pdf |
| Nether-lands | KNMI'14: www.climatescenarios.nl/<br>(former set: KNMI'06) |
| Norway | met.no/Forskning/Klimaforskning/Klimascenarier/<br>www.senorge.no/index.html?p=klima |
| Portugal | www.ipma.pt/pt/oclima/servicos.clima/index.jsp?page=cenarios21.clima.xml<br>siam.fc.ul.pt/ |
| Spain | www.aemet.es/es/elclima/cambio_climat/escenarios |
| Sweden | www.smhi.se/klimatdata/Framtidens-klimat/Klimatscenarier/2.2252/2.2264<br>www.mistra-swecia.se/ (phase II to be completed in 2015) |
| Switzerland | CH2011: www.ch2011.ch/ |
| UK | UKCP09: ukclimateprojections.defra.gov.uk/ |

[A] Each country and organization uses its own methods to construct regional climate scenarios. Therefore, they cannot be easily combined. In Chapter 5 some more information is given on this.

**Overview: observed and projected trends**

Table 2.2 gives a summary of the knowledge on observed changes in Europe (1951-2013) regarding critical climate parameters for road infrastructure (Table 3.1). Table 2.3 gives an overview of projected changes of these climate variables, as described in the most recent assessment report of IPCC (2013).

In many countries in Europe the IPCC climate change information is translated into more detailed *regional climate change scenarios*, since the IPCC information is often not detailed enough to estimate the effects of climate change in a particular region. Table 2.4 gives an overview of where information on the regional climate scenarios of various European countries can be found.

Table 2.5 shows that none of the countries uses the same regional scenarios. Each country or group uses a different method, different ensemble, different reference period, different time horizon, etc. Therefore, the projections for the future, and the range of the possible futures spanned may differ per country. Fig. 2.12 gives an example of the differences in ranges for future temperature and precipitation changes that are spanned by some of the above climate scenario sets. The ranges are rather difficult to compare, since the reference periods and time horizons also differ between countries (Dalelane, 2014). From this figure it may appear that the climate scenarios are very unreliable. However, *climate scenarios are not predictions for the future*. They are tools to deal with the uncertainties about the future climate. Depending on the purpose, the users requirements, the information used or available, different climate scenarios may be created. In Chapter 5 some more information is given on how one can deal with the differences in climate scenarios between countries.

**Table 2.5** Regional climate scenarios/projections in various European countries: some characteristics (source: a.o. Dalelane, 2014).

| Country | Scenarios | Reference period | Time horizons | Ensemble | Basic information from | Regional differentiation |
|---|---|---|---|---|---|---|
| Belgium CCI-HYDR | High, mean, low | 1961-1990 | 2071-2100 | Multi-model, multi-emissions | PRUDENCE | Only for precipitation 50*50 km |
| France: simulateur climatique | A2 and B2 | 1960-1990 | 2050-2100 | Multi-emissions, one model | ARPEGE-model | Administrative regions, zones |
| Germany, KLIWAS | 8 runs (RCMs) | 1961-1990 | 2000-2100 | Multi-model, A1B | ENSEMBLES | 25*25 km and river basins |
| Germany, DWD Klimaatlas | 15th, 50th and 85th percentile | 1961-1990 | 2021-2050 | Multi-model, A1B | ENSEMBLES + German RCM | 25*25 km |
| Netherlands KNMI'14 | 4 scenarios, driving variables: global temperature and circulation patterns | 1981-2010 | 2030, 2050, 2085 | Multi-model, Multi-emissions | CMIP5 + Ensemble of EC-Earth-RACMO2 | Yes, only difference found for temperature |
| Netherlands KNMI'06[A] | 4 scenarios, driving variables: global temperature and circulation patterns | 1976-2005 | 2050, 2100 | Multi-model, multi-emissions | AR4, PRUDENCE | no |
| Switzerland CH2011 | A1B, A2, and RCP3PD | 1980-2009 | 2020-2049 | Multi-model (RCM's), multi-emissions (GCM) | ENSEMBLES | Averages over 3 regions |
| UK | B1, A1B and A1FI | 1961–1990 | 2020s, 2050s & 2080s | Perturbed physics ensemble, multi-emissions, one model | Model Hadley Centre | 25*25 km, administrative regions, river basins |

[A] new set will be published at the end of May 2014 with some other characteristics

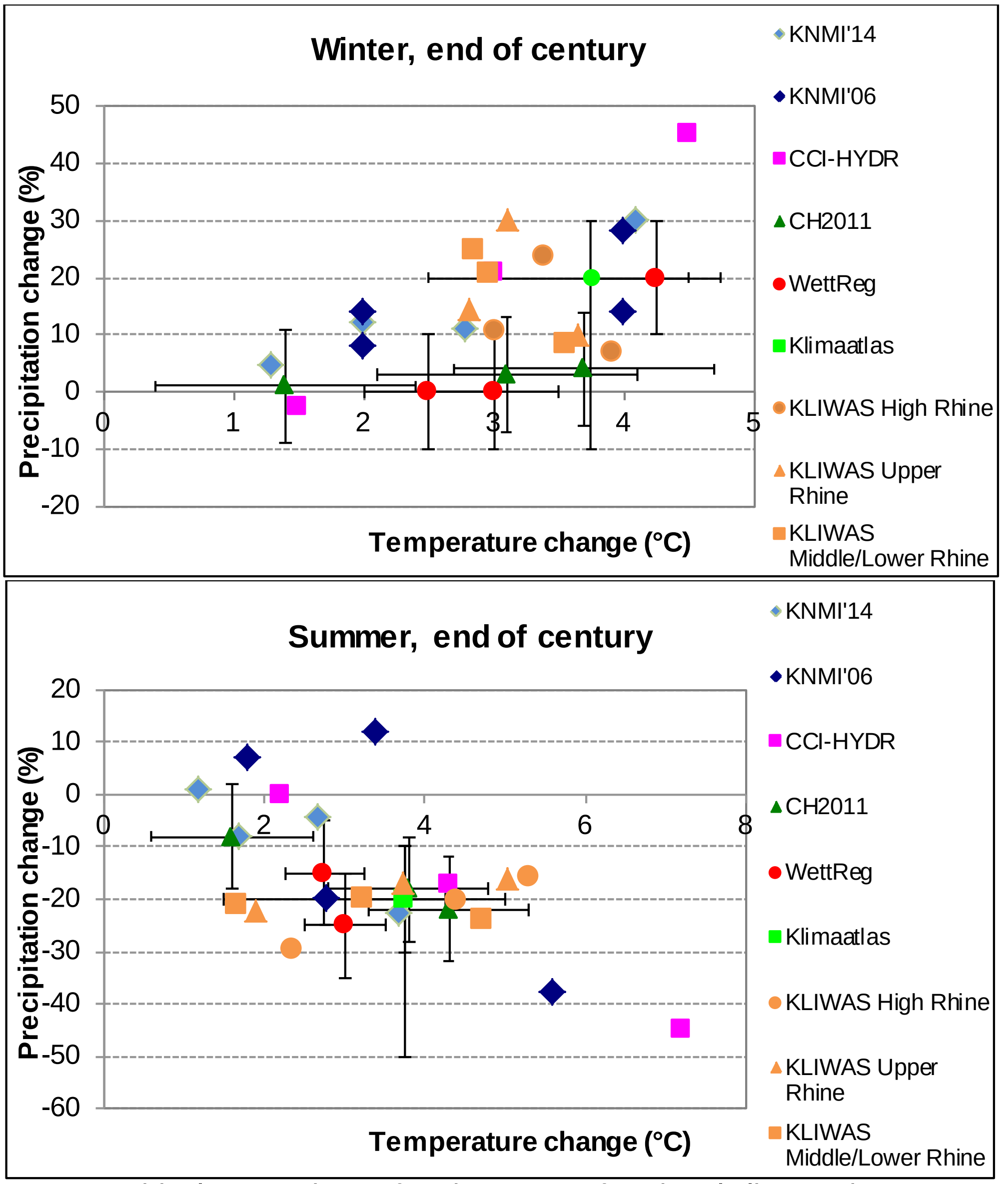


**Figure 2.12** Graphical comparison of various sets of regional climate change scenarios in Europe: changes in regional average temperature and regional average precipitation in winter (upper panel) and summer (lower panel) for the end of century (up to 2100: reference period + 60-110 years; the names of the climate scenario sets are mentioned in Table 2.4[7]; Modified from: Dalelane, 2014).

## *2.3 Uncertainties in climate data*

In discussions on climate change inevitably uncertainties on future climate are discussed too. However, there are many different types of uncertainties in observed data, in climate models, in impacts models and in the policy context. Uncertainties can be epistemic (imperfect knowledge) and/or stochastic (intrinsic variability in the climate system) (Walker et al., 2003;

[7] KNMI'06 = former generation of the KNMI'14 climate scenarios; the names after KLIWAS refer to regions within the Rhine basin.

Dessai & Hulme, 2004; Janssen et al., 2005). Besides this, the term uncertainty is often used differently in different sectors and disciplines, or other words are used for the same (e.g. range, variability, lack of knowledge). The word uncertainty often means something different to scientists than to others. For many people it means ignorance and it has a negative connotation for them, whereas this is not the case for climate scientists (Sommerville & Hassol, 2011).

Communication between climate scientists, impact researchers and policy makers is often hampered by misunderstandings about the phenomenon of uncertainty in (climate) science (Van der Sluijs, 1997; Funtowicz, 2006). Often the focus is on statistical and quantitative methods for risk assessments. This may lead to a tendency to ignore other relevant uncertainties that cannot or not as easily be quantified (Dessai & Van der Sluijs, 2007). Therefore, we give a short introduction to uncertainties in climate data in this paragraph.

### *2.3.1 Some definitions*

**Uncertainty** is any departure from complete deterministic knowledge of the relevant system (based on Walker et al., 2003). Uncertainty is not simply a lack of knowledge, because an increase in knowledge might lead to an increase of knowledge about things we don't know, and thus it may increase uncertainty.

**Variability, day-to-day variation, year-to-year variation** See in Par. 2.1.1.

**Range** refers to a set of possible outcomes. In the case of climate it can refer to the difference between the highest and lowest values for e.g. temperature that can be obtained in the current climate or it can refer to the difference between the highest and lowest outcomes of e.g. temperature change in the future.

**Probability** (or likelihood) is a measure or estimation of how likely it is that something will happen (e.g. of more than 50 mm of rainfall on one day). Probabilities are often given in return times (once in 10 years a daily amount of 60 mm of rainfall or more) or percentages chance (between 0% chance = *will not happen* and 100% chance = *will happen*) (http://en.wikipedia.org/wiki/Probability).

**Risk** is often defined as the probability of something happening (e.g. a certain extreme weather event) multiplied by the resulting cost or benefit if it does. In the ROADAPT / RIMAROCC framework it is defined as a combination of probability of a threat happening and consequences for the road owner/operator.

**Robust systems:** a system keeps functioning well under a large range of possible future developments (related to natural variability and/or climate change and/or socioeconomic processes).
**Robust decisions:** these decisions result in measures that work well under a large range of possible future developments.

**Definition: uncertainty**
**Uncertainty** is any departure from complete deterministic knowledge of the relevant system (Par. 2.3.1).

Uncertainties can be due to imperfect knowledge about the climate system or about the socio-economic system causing the emission of greenhouse gasses and/or it can be due to intrinsic variability in the climate system. The relative importance of these uncertainties is indicated in Fig. 2.13.

### *2.3.2 Typologies of uncertainties*

Although the terms 'range' and 'variability' can often replace the term 'uncertainty', they do not cover all types of uncertainties. Therefore, we continue using this term in this paragraph and give a further specification or typology.

Various typologies can be made of uncertainties based on:

- Levels (indicate how difficult it is to describe or quantify uncertainty);
- Sources (what causes the uncertainties);
- Locations (for model-based analysis): (where?, in input?, in model? in output?)

(Based on: Dessai & Van der Sluijs, 2007).

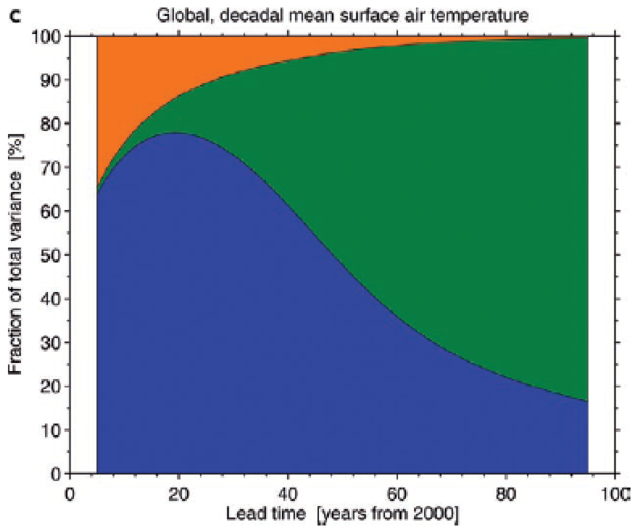


**Figure 2.13** Relative importance of uncertainties in climate modelling due to lack of knowledge on socio-economic-technological developments (emission uncertainty: green), due to lack of knowledge on the climate system (model uncertainty: blue) and natural variability (orange) (Source: Hawkins & Sutton, 2009).

Based on **levels of uncertainty** the following groups can be distinguished (Source: Walker et al., 2003, Janssen et al., 2005):

- *Statistical uncertainty*: this concerns the uncertainties which can adequately be expressed in statistical terms, e.g., as a *range with associated probability* (examples are statistical expressions for measurement inaccuracies, uncertainty on the temperature on e.g. July 1 2016);

- *Scenario uncertainty* this concerns uncertainties which cannot be adequately depicted in terms of chances or probabilities, but which can only be specified in terms of (a range of) possible outcomes. For these uncertainties it is impossible to specify a degree of probability or belief, since the mechanisms which lead to the outcomes are not sufficiently known. Scenario uncertainties are often constructed in terms of ‘what-if’ statements;
- *Recognized ignorance*: this concerns those uncertainties of which we realize – some way or another – that they are present, but of which we cannot establish any useful estimate, e.g., due to limits to predictability and knowability (‘chaos’) or due to unknown processes. A way to make this class of uncertainties operational in climate risk assessment studies is by means of surprise scenarios. Usually there is no scientific consensus about the plausibility of such scenarios while there is some scientific evidence to support them;
- Continuing on the scale beyond recognized ignorance, we arrive in the area of complete ignorance (‘unknown unknowns’) of which we cannot yet speak and where we inevitably grope in the dark.

In the case of **sources of uncertainties** a distinction can be made between uncertainties due to:

- (*Natural) variability:* often links closely to the statistical uncertainty;
- *Lack of (system) understanding*, inherent complexity: refers to the three other levels of uncertainties;
- *Varying perceptions, preferences* (ambiguity): articles on uncertainties in climate often focus on uncertainties in climate modelling, however, there are also considerable differences (and therefore uncertainties) in the interpretation, dealing with uncertainties, perception of risk related to climate change. No good typology exists for these uncertainties.

During the process of determining the impacts and possible adaptation strategies, uncertainties can occur at various **locations**, e.g. in the input data used for modelling climate, in parameters used in the model, impacts or adaptation measures, in the model structure used, etc. Often uncertainties are present at many different locations, but the importance for the final result may not be the same.

About some climate variables we can make statements with more certainty than about other variables. When using information on climate change, it is useful to take this into account. To give an impression, below the relative certainty about different climate variables is indicated. The relative certainty is based on (IPCC, 2007; Van den Hurk et al., 2006):

- Consistency between climate models (global and regional);
- Understanding why a particular change will occur;
- Good distinction between the change and the natural variation.

In general, the uncertainty in the next lines increases from left (smallest) to right (highest):

Temperature < Sea level < Precipitation < Wind
(in North west Europe) Precipitation in winter < Precipitation in summer
Averages < Once in 10 year extremes
Large scale < local scale

Starting from a particular emission scenario the uncertainty grows with every step that is necessary to derive different adaptation measures for climate change. This is schematically shown in the Fig. 2.14.

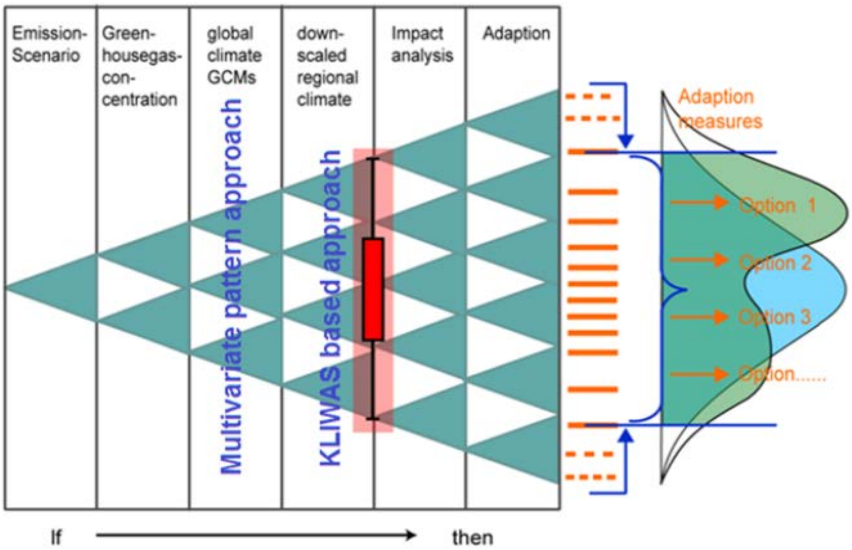


**Figure 2.14** Schematic propagation of uncertainties in deriving climate change adaptation measures (Source: Matulla & Namyslo, 2014a).

### *2.3.3 Differences in uncertainties between the current and future climate*

The importance of the various types of uncertainties differs for the current and the future climate (Fig. 2.13). In this paragraph some differences in the (relative) importance of various types of uncertainties for the current and the future climate are given.

**Table 2.5** (Relative) importance of various types of uncertainties for the current and future climate.

| Type of uncertainty | Current climate | Future Climate | Comment |
|---|---|---|---|
| Due to missing data | Yes | (Yes) | No observational data for the future, however, when data for the current climate are missing, than generally also uncertainty for the future |
| Natural variability | Yes | Yes | Most important factor for the current climate (besides uncertainties due to errors, missing data)<br>Also relevant for the future, however, in the future more sources of uncertainties |
| Uncertainty due to limited knowledge about socio-economic-technological developments (scenario and recognized uncertainty) | Not relevant | Yes | Especially relevant for the longer time horizons (Fig. 2.13) |
| Uncertainty due to limited knowledge about the climate system (scenario and recognized uncertainty) | Limited relevance | Yes | Especially relevant for the future, more important than limited knowledge about socio-economic developments for the period to about 2050 (Fig. 2.13).<br>Sometimes limited knowledge to describe the natural variability for the current climate |
| Ambiguity | Yes | Yes | Little information available on this, but probably important for the use of data on both current and future climate |

## 2.4 Dealing with uncertainties

Attitudes towards risks vary across people, cultures, time and experience. Some people have a risk-seeking attitude whereas others have a risk adverse attitude. Ultimately, which school of thought (top-down, bottom-up or a mixed approach) is pursued (Annex 1) or given more weight depends critically on the attitudes to risk and uncertainty of those actors involved in the adaptation process and the decision making environment where adaptation happens. Fig. 2.15 shows that some people only start adapting when there is almost 100% certainty that something will happen, whereas others already want to adapt when there is some suspicion or indication.

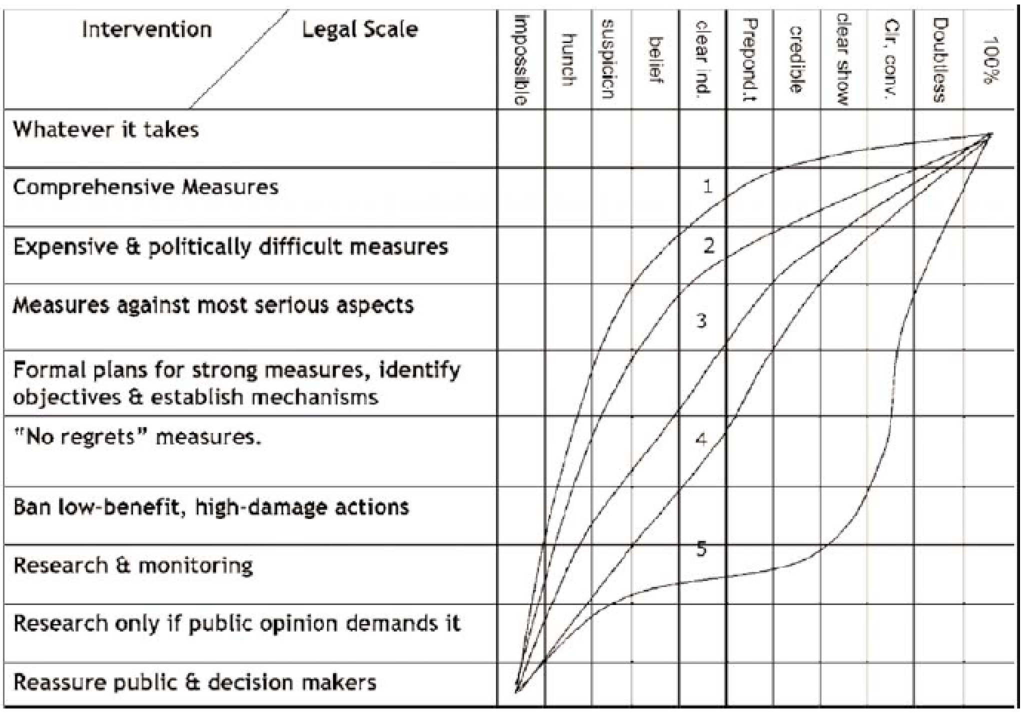


**Figure 2.15** Justified level of interventions (vertical axis) to address shared danger of severe and irreversible harm, as a function of the level of scientific evidence (horizontal axis) and the degree of risk aversion (numbered curves). Curves corresponding to different risk attitudes are represented as follows: 1. Environmental absolutist; 2. Cautious environmentalist; 3. Environmental centrist; 4. Technological optimist; 5. Scientific absolutist (Weiss, 2003).

The sources of uncertainties give indications on how one can deal with them:

- Natural variability cannot be reduced, but it can be quantified[8] with the help of statistics. If not enough data are available, then monitoring is a way to get more information;
- Uncertainty due to lack of knowledge of a system can be reduced by doing more research to better understand the system[9]. In the meantime scenarios can be used (no probabilities per scenario) to study the effect of known uncertainties.

[8] However, the presence of trends in climate variables may complicate the quantification: what is due to human-induced climate change and what is natural variability?

[9] More research can also lead sometimes to a wider range.

**Guideline: dealing with uncertainties**
The sources of uncertainties give indications on how one can deal with them (Par. 2.4):
- Natural variability cannot be reduced, but it can be quantified with the help of statistics. If not enough data are available, than monitoring is a way to get more information;
- Uncertainty due to lack of knowledge of a system can be reduced by doing more research to better understand the system. In the meantime scenarios can be used (no probability per scenario!) to study the effect of known uncertainties.

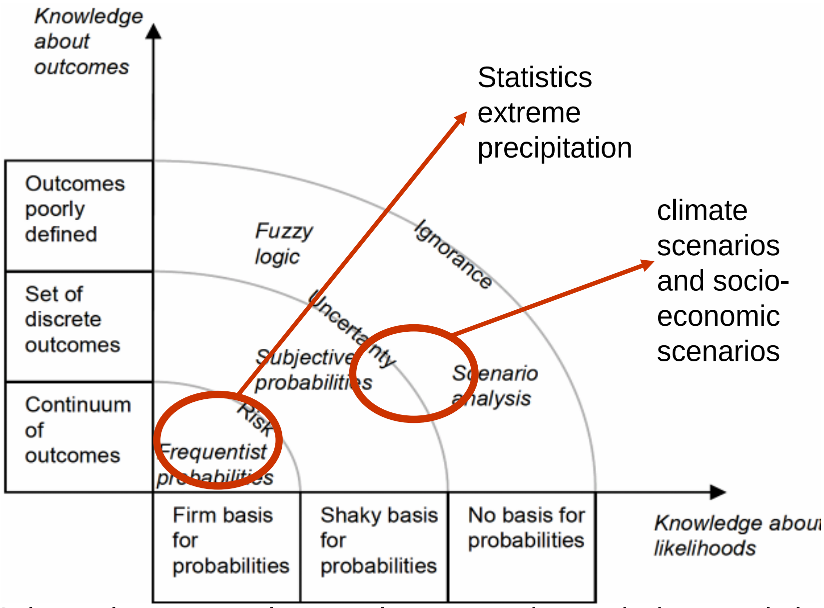


**Figure 2.16** Schematic presentation on when scenarios and when statistics can be used.

Figure 2.16 schematically indicates when different methods for future projections can be used. When there is a firm basis for probabilities and a continuum of outcomes, statistics can be used. In the case of climate statistics based on observations in the past can be used to make projections and even predictions for the near future. In this case the natural variability is the main source of uncertainties, which can be described with statistics. However, when we look further ahead, e.g. 2040, 2050, other types of uncertainties become important and probabilities cannot be determined very well or not at all. In these cases scenarios can be used.

### *2.4.1 Different purposes for using climate scenarios*

When using climate scenarios it is important to keep in mind the aim of your study. Below some guidelines for using climate scenarios for different purposes are given.

**Impact, adaptation and vulnerability studies**
Climate scenarios are often chosen in such a way that they span a considerable part of the possible future. Given the objective of most impact, adaptation and vulnerability studies, it is useful to use a complete set of climate scenarios. By comparing the results of the various climate scenarios one can determine also how robust various adaptation measures are.

Measures that work well for all scenarios are often of interest to policy makers. To explore the potential impact of climate change one can also look at potential *tipping points*, situations in which the current management or policy is no longer tenable (Kwadijk et al., 2010). In a second stage, one can then determine when these tipping points will be reached under the various climate scenarios.

**Policy and strategy**
Ideally, the results of the impact and adaptation studies mentioned above play a role in the formulation of policies and strategies. In this phase often a choice for one or more climate scenarios is made as the basis for the policies, although this is not necessary[10]. The choice for one or several climate scenarios can be determined by, inter alia:

- What is accepted by society (e.g. because of the costs now and in the future, or potential for behavioural change);
- What are the possible impacts/risks of climate change?;
- What are the possibilities to adjust a 'wrong choice' with later policies (can the drainage system of a tunnel be adapted when extreme showers increase more than taken into account during the design and construction?);
- What are the costs incurred in vain if the climate changes less than previously assumed, or what are the additional costs if climate change is stronger than previously assumed?
- How fast can further adaptation measures be implemented (e.g. raising of sea dikes takes more time and money than supplying extra sand to the beach to protect the coast);
- Which scenarios are considered more likely (e.g., if one assumes that the world will develop according to the IPCC A2 scenario, then a strong increase in temperature can also be considered more likely);
- Which scenarios are most relevant (e.g. industries that use surface water as cooling water, are likely to be more interested the scenarios with strong increases in (summer) temperatures, and consequently at greater risk of a shortage of cooling water).

As can be seen, the choice for one or more climate scenarios for policy making depends also on many factors that are not related directly to climate science.

**Guideline: using climate scenarios** (Par. 2.4.1)
Climate scenarios are often chosen in such a way that they span a considerable part of the possible future. Given the objective of most **impact, adaptation and vulnerability studies** (exploring the range of possible impacts and searching for robust adaptation measures), it is useful to use a complete set of climate scenarios. By comparing the results of the various climate scenarios one can determine also how robust various adaptation measures are.

Ideally, the results of the impact and adaptation studies mentioned above play a role in the **formulation of policies and strategies**. In this phase often a choice for one or more climate scenarios is made as the basis for the policies, although this is not necessary. The choice for one or more climate scenarios for policy making depends also on many factors that are not related directly to climate science (e.g. relevance for society, financial aspects).

[10] Another approach is *Adaptive management*: structured, iterative process of robust decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring.

### 2.4.2 *Probability and relevance*

The IPCC does not indicate which of the underlying emission scenarios or representative concentration pathways is more likely than the others. This is also not possible, since it would require knowledge about which socio-economic developments are more probable than others.

In most cases it is better to ask which climate scenario is *most relevant* for the user, and not which one is most probable. Some users are more interested in extremes, which are by definition rare and therefore less likely. For some users, a different time horizon is relevant than for others. Below some examples to explain that what is relevant may differ considerably between users:

- In cities flooding mainly occurs after heavy showers (in North-western Europe especially in summer). In that case the climate scenario with the largest increase in extreme summer showers is probably most relevant;
- Agricultural production is influenced by the availability of water in the growing season. In that case the climate scenario with the largest decrease in summer rainfall is probably most relevant;
- Drainage tubes often go into the ground for 40-80 years. When one wants a sewerage system to function adequately at the end of its life cycle, it is relevant to look ahead for 40-80 years;
- The economic depreciation period of many industrial installations is about 20 years. A time horizon of up to 2035-2040 is then relevant.

**Guideline: probability and relevance** (Par. 2.4.2)
The IPCC does not indicate which of the underlying emission scenarios or representative concentration pathways (related to possible socio-economic developments) is more likely than the others.

For policy making, in most cases it is better to ask which climate scenario is **most relevant** for the user, and not which one is most probable.

### 2.4.3 *Relationship with socio-economic scenarios of the IPCC*

Policymakers also use information on socio-economic and technological developments. These often provide clues for policies. Therefore, it is important to show how socio-economic scenarios (or related emission scenarios) are related to climate scenarios. In several countries in Europe a direct link exists between the climate scenarios and the SRES emission scenarios[11] (Par. 2.2 Table 2.5). If there is no direct link (such as in the case of the KNMI climate scenarios in the Netherlands), figures such as Fig. 2.17 can be used to make a link to socio-economic developments[12]: a global temperature increase of 2 ˚C at the end of the century compared to the reference period of 1986-2005[13] is possible with the Representative Concentration Pathways RCP4.5 and RCP6.0 (the horizontal red line in Fig. 2.17 goes through the boxes at the right). These RCP's link with certain socio-economic

[11] With the new RCP scenarios there is not a very direct link anymore with socio-economic scenarios. The RCP-approach assumes that certain pathways of concentrations of GHGs can be obtained with various socio-economic scenarios;
[12] In the Netherlands, the rise in global temperature in the KNMI'06 and KNMI'14 climate scenarios was used to link with (a range of) SRES or RCP scenarios, respectively, and as a result with the socio-economic scenarios behind it;
[13] At European level the aim is to limit the global temperature rise to 2 ˚C *relative to pre-industrial time*. From pre-industrial time until now (1880-2012) global temperature has increased already with about 0.9 ˚C.

developments. Per emission scenario there is a large range of possible temperature increases which overlap each other largely (Fig. 2.17). Especially for time horizons up to 2050 it is difficult to distinguish the various emission/concentration scenarios on the basis of global temperature increase. For time horizons up to 2020-2030 it is not useful to distinguish between the emission/concentration scenarios (vertical red line in Fig. 2.17; http://climate4impact.eu/impactportal/documentation/backgroundandtopics.jsp?q=SRES).

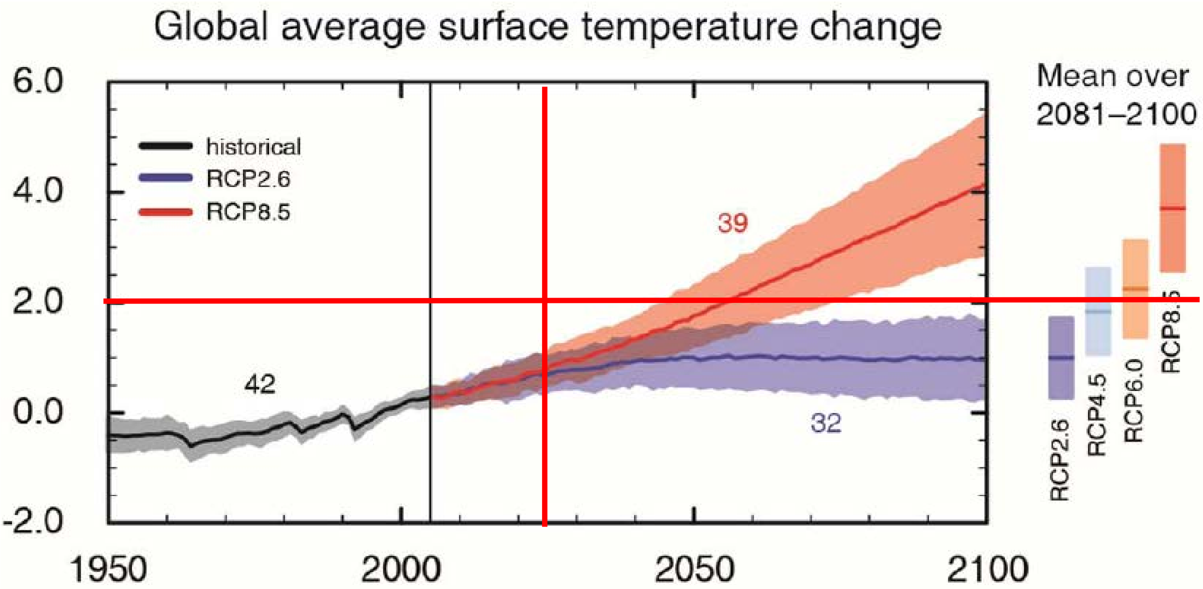

**Figure 2.17** CMIP5 multi-model simulated time series from 1950 to 2100 for change in global annual mean surface temperature relative to 1986–2005. Shading: measure of uncertainty for RCP2.6 (blue), RCP8.5 (red) and modeled historical evolution (gray). Vertical bars at the right: mean and associated uncertainties averaged over 2081−2100 for all RCP scenarios. Numbers: number of CMIP5 models used (IPCC, 2013). Red lines: see text.

There is no single most likely, 'central', or 'best-guess' scenario, either with respect to SRES or RCP scenarios or to the underlying scenario literature. Probabilities or likelihood are not assigned to individual SRES or RCP scenarios. None of the SRES or RCP scenarios represents an estimate of a central tendency for all driving forces or emissions, such as the mean or median, and none should be interpreted as such. The distribution of the scenarios provides a useful context for understanding the relative position of a scenario but does not represent the likelihood of its occurrence.

## *2.5 Some useful links*

The links below are checked and updated by October 2, 2014.

**General information on climate and climate change:**

- Course: *An Introduction to the Science of Climate and Climate Change*. http://reciprocatesite.conted.ox.ac.uk/;
- http://en.wikipedia.org/wiki/Climate;
- WMO: www.wmo.int/pages/themes/climate/index_en.php#,

www.wmo.int/pages/themes/climate/understanding_climate.php;

- Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification: http://koeppen-geiger.vu-wien.ac.at/shifts.htm.

**Glossaries**

There are a number of web pages which provide climate related glossaries. Below some sites in English are mentioned:

- Glossary of meteorology (American Meteorological society): http://glossary.ametsoc.org/wiki/Main_Page;
- WMO meteorological terms: www.wmo.int/pages/prog/lsp/meteoterm_wmo_en.html;
- Glossaries for IPCC reports: www.ipcc.ch/publications_and_data/publications_and_data_glossary.shtml (also some information in French and Spanish); www.ipcc.ch/report/ar5/wg1/ Annex III Glossary;
- NOAA: http://www.cpc.ncep.noaa.gov/products/outreach/glossary.shtml;
- EPA: www.epa.gov/climatechange/glossary.html;
- Wikipedia: http://en.wikipedia.org/wiki/Glossary_of_climate_change;
- Climate-adapt: http://climate-adapt.eea.europa.eu/glossary (largely based on IPCC);
- UKCIP: www.ukcip.org.uk/glossary/;

For those who seek the explanation for terms related to mitigation, adaptation to climate change and climate change policies, the following link may be useful: http://unfccc.int/essential_background/glossary/items/3666.php.

**Climate models**

Global climate models:

- http://climate4impact.eu/impactportal/documentation/backgroundandtopics.jsp?q=global_models.

Regional climate models:

- http://climate4impact.eu/impactportal/documentation/backgroundandtopics.jsp?q=regional_models;
- www.wmo.int/pages/themes/climate/climate_models.php.

**Scenarios:**

- SRES-scenarios: www.ipcc.ch/ipccreports/sres/emission/index.php?idp=0; http://climate4impact.eu/impactportal/documentation/backgroundandtopics.jsp?q=scenarios_different;
- RCP (Representative Concentration Pathways): www.ipcc.ch/pdf/supporting-material/expert-meeting-ts-scenarios.pdf;
- WMO: www.wmo.int/pages/themes/climate/emission_scenarios.php;
- IPCC definitions: www.ipcc-data.org/guidelines/pages/definitions.html; IPCC 2013 Fifth Assessment report: www.ipcc.ch/report/ar5/wg1/.

**Uncertainties**

- Digital reader of the autumn school on dealing with uncertainties: http://www.knmi.nl/klimaat/autumnschool2012/digital_reader.php. Collection of documents on terminology, types of uncertainties, dealing with uncertainties, communication of uncertainties;
- NUSAP - The Management of Uncertainty and Quality in Quantitative Information: www.nusap.net/;
- RIVM/MNP Guidance for Uncertainty Assessment and Communication, Tool Catalogue for Uncertainty Assessment: Van der Sluijs et al. (2004),

(www.nusap.net/downloads/toolcatalogue.pdf);
- IPCC: https://docs.google.com/file/d/0B1gFp6Ioo3akNnNCaVpfR1dKTGM/edit?pli=1.

**Descriptions of the current climate in Europe:**
- See last paragraph of Chapter 4.

**Projections of climate change in Europe**
- See last paragraph of Chapter 5;
- IPCC regional projections: www.ipcc.ch/report/ar5/wg1/;
- Climate scenarios for the various European countries: See Par. 2.2.5;
- www.wmo.int/pages/themes/climate/causes_of_climate_change.php, www.wmo.int/pages/themes/climate/climate_models.php.
- Climate change atlas (maps of projected changes for various climate variables for the RCPs (for various regions in the world): http://climexp.knmi.nl/plot_atlas_form.py.

**Databases with climate data**
- See also Chapter 4 and Chapter 5;
- ECA&D observational data for Europe: http://eca.knmi.nl/;
- Climate Explorer: http://climexp.knmi.nl/start.cgi?id=someone@somewhere;
- GHCN: www.ncdc.noaa.gov/oa/climate/ghcn-daily/index.php?name=data;
- National Meteorological (and Hydrological) institutes[14] (NM(H)I's collect climate data, in some countries all data are freely available, in others not): www.wmo.int/pages/members/members_en.html.

**Case studies/descriptions**
- http://climate4impact.eu/impactportal/documentation/guidanceandusecases.jsp?q=infrastructure_urban;
- http://climate-adapt.eea.europa.eu/data-and-downloads?searchtext=&searchsectors=INFRASTRUCTURE&searchtypes=MAPGRAPHDATASET.

[14] Also some other organisations collect climate data, however, they often do not have long records and/or only have information for a limited area.

# 3 The steps in the use of climate data

## Summary

In this chapter we describe the various steps in the use of climate data within:

- A quick scan of climate threats for road infrastructure (Par. 3.1; Bles & Woning, 2014a);
- Detailed vulnerability assessments for road infrastructure (Par. 3.2; ROADAPT, 2014b).

In the RIMAROCC approach (Fig. 3.1) in step 2 the risks and threats are identified. Table 3.1 gives an overview of relevant threats for road infrastructure taken into account in the ROADAPT-project and the related climate parameters. This table can help in collecting relevant climate data for studies on the possible vulnerability of road infrastructure to climate change. Especially in step 3 of the RIMAROCC approach (risk analysis) climate data are used to determine the risks in the current and future climate. Fig. 3.2 shows the steps in the use of climate data within this RIMAROCC step 3.

Generally NRA's will not take all the steps of the quick scan or detailed studies themselves. Collection and processing of climate data will mostly be outsourced to researchers or consultancies.

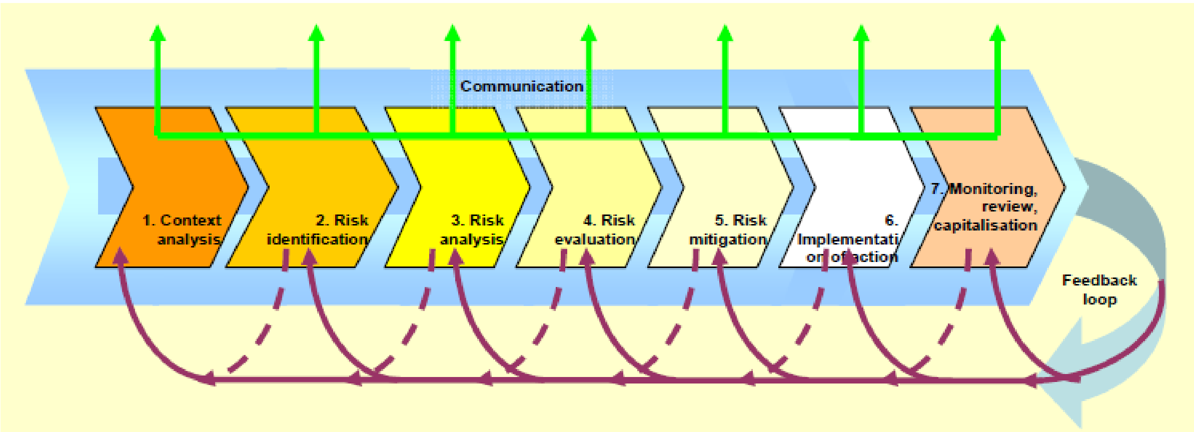


**Figure 3.1** Scope and steps of the RIMAROCC-approach (Bles et al., 2010).

## 3.1 Use of climate data in a quick scan

Fig. 3.2 gives an overview of the steps[15] one can follow in the use of climate data for a quick scan or detailed vulnerability assessment on the effect of climate and climate change on road infrastructure. This overview only includes the use of climate data, not the vulnerability analysis that will take place afterwards. In a quick scan one wants to gain preliminary insights on the risks and vulnerabilities due to climate change for a road network. Fig. 3.2 indicates in which paragraphs of this report one can find more detailed information on climate databases and methods.

[15] Largely based on http://climate4impact.eu/impactportal/documentation/guidanceandusecases.jsp?q=generic_work_flow1.

Generally, NRA's will not take all the steps of the quick scan themselves. Collection and processing of climate data will mostly be outsourced to researchers or consultancies. Table 3.2 indicates where NRA's can or have to play a role.

During the **quick scan** (Bles & Woning, 2014a) one wants to determine whether the occurrence of threats will increase or decrease due to climate change. For that reason one will have to determine the occurrence in the current or reference climate and in the future climate.

1. First determine on the basis of possible and existing threats, what are the relevant climate parameters (Table 3.1). Determine also the area of interest for the quick scan, the period of interest in the future (time horizon) and which period in the past will be used as reference for the current climate;
2. Since it is a quick scan one will focus on collecting climate data from rather easily accessible data sources (current climate: Table 2.1, Table 4.2 and Par. 4.5; future climate: Table 2.4, Table 5.1 and Par. 5.5) and sometimes only a qualitative assessment is possible. Before using the climate data, check what the quality of the data is (Par. 4.3 and Par. 5.3). Often derived data (climate normals, statistics) from NMHI's or research institutes will have sufficient quality for use in a quick scan and no quality check has to be done. When in doubt, one can ask an expert whether the data source can be used for the intended purpose). If there is no information on the required climate variable, one can sometimes use information on a different, but related climate variable (feedback loop in Fig. 3.2);
3. At this stage one has to make a selection of the projections or climate scenarios[16] that one wants to take into account (Par. 2.2.5). Not all available projections or climate scenarios have to be taken into account in a quick scan. To get an idea of the range of possible impacts for the threats under study, one has to select climate scenarios or projections that cover a considerable part of the possible changes in the relevant climate variable[17]. Generally, at least a worst case scenario should be included together with a more average and/or optimistic scenario;
4. Before using the climate data or information, sometimes some processing is needed (e.g. calculating the number of frost days from time series on temperature). Here again, since it is a quick scan the processing will only consist of relatively easy and fast methods with already available tools (Par. 4.4 and Par. 5.4). From climate scenarios often only changes are available in the main climate variables (e.g. temperature, precipitation). Processing is needed to get information about derived climate variables such as the number of frost days. Climate model projections generally have a coarse spatial resolution. Expert knowledge (climatologist, climate scientist) may help to translate information on the current and future climate to relevant information for road owners.

**Overview: threats and related climate variables**
Table 3.1 gives an overview of the threats for road infrastructure taken into account in the ROADAPT-project and the related climate variables. This table can help in collecting relevant climate data for studies on the possible impact of climate change on road infrastructure.

[16] For the differences between projections and scenarios, see Chapter 2;
[17] An example: in case of thaw select at least one scenario or projection that has a low increase in temperature and one that has a high increase in temperature.

After this, one will probably be able to do a qualitative or quantitative vulnerability analysis and say something on whether the threats will increase, decrease or not change due to climate change (the analysis and conclusions of the Quick scan). Be aware that changes in threats may also be due to changes in socio-economic developments[18] and that there is not always a clear and/or linear relation between the relevant climate variable and the threat[19].

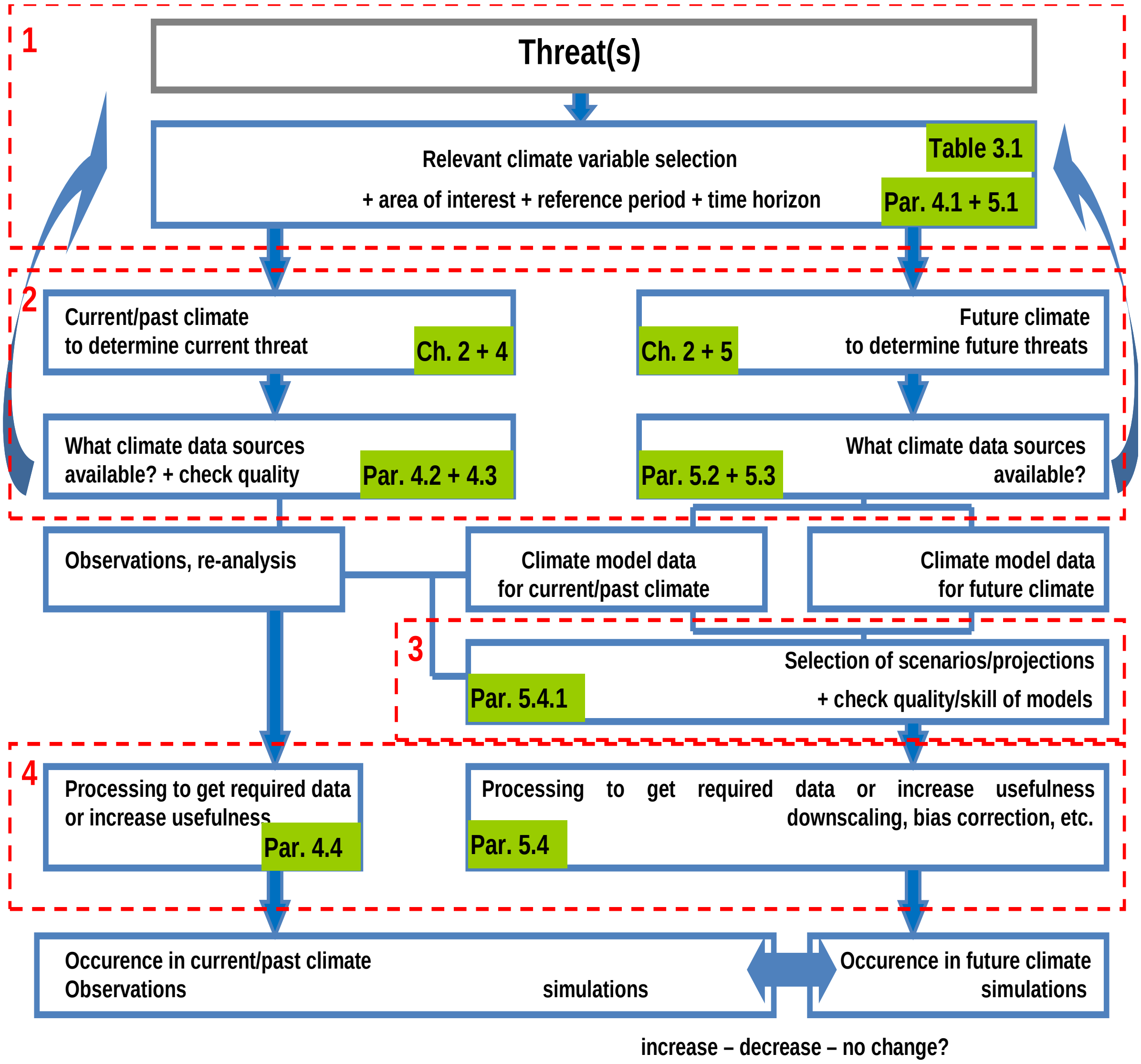


**Figure 3.2** Schematised steps in the use of climate data for climate change impact studies (red boxes refer to the steps in the text; for further explanation, see text).

[18] Regularly changes in threats are considered to be the effect of climate change, whereas they are (partly) due to other changes, e.g. the increase of water excess on roads may also be due to changes in land use along the road;
[19] An example: when the extreme rainfall increases with 10 %, there may hardly be an increase of excess water on the roads when the drainage system is clearly over dimensioned. The opposite may also be true: a relatively small change in climate may result in large changes in impacts, when the system is close to its thresholds.

**Guideline: the use of climate data in a quick scan or in detailed vulnerability assessments**
In the RIMAROCC approach (Fig. 3.1) climate data are used in steps 2 (risk identification) and especially in step 3 (risk analysis). Fig. 3.2 describes the steps that are generally followed during the use of climate data in a quick scan (Par. 3.1) and in more detailed assessments (Par. 3.2).

Generally NRA's will not take all the steps of the quick scan or detailed assessments themselves. Collection and processing of climate data will mostly be outsourced to researchers or consultancies.

**Figure 3.3** Quick scan meeting on the A24 motorway in Portugal, January 17 2014 (Ennesser, 2014).

**Table 3.2** Involvement of NRA's in the steps of the use of climate data.

| Step | Activity | Involvement NRA |
|---|---|---|
| 1 | Determine relevant climate parameters with the threats of interest | Yes |
| | Determine the area and time horizon of interest and the reference period | Yes |
| 2 | Collect climate data for the reference period and for the future | Only when different data sources are available, discuss how to make a selection |
| | Check quality of the climate data | No |
| 3 | Selection of the projections or climate scenarios | Yes, discuss the criteria for the selection |
| 4 | Process climate data | Only when different methods are available, discuss how to make a selection |

**Table 3.1** Threats and related climate parameters, imposing risks to the road infrastructure.

| Threat (main) | Threat (sub) | Climate parameter | Unit | Time resolution |
|---|---|---|---|---|
| Flooding of road surface (assuming no traffic is possible) | Flooding due to failure of flood defense system of rivers and canals, caused by snow melt, rainfall in catchment area, extreme wind | Temperature (in catchment area) | ˚C, days $T_{avg}$>0 ˚C | days |
| | | Extreme rainfall (long periods with rain in catchment area) | mm/days | days-week |
| | | Extreme wind speed | m/s | hours-days |
| | | Wind direction | degrees | hours-days |
| | Pluvial flooding (overland flow after precipitation, increase of groundwater levels, increase of aquifer hydraulic heads) | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | | Extreme rainfall events (long periods with rain) | mm/days | days-week |
| | Inundation of roads in coastal areas, combining the effects of sea level rise and storm surges | Sea level (rise) | cm | year(s) |
| | | Extreme wind speed(-> storm surge) | m/s | hours-days |
| | | Wind direction (-> storm surge) | degrees | hours-days |
| | Flooding from snow melt (overland flow after snow melt) | Temperature | ˚C, days $T_{avg}$>0 ˚C | days-weeks |
| Erosion of road embankments and foundations | Overloading of drainage systems crossing the road | Extreme rainfall events (long periods of rain) | mm/days | days-weeks |
| | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | | Thaw (for rapid ablation of snow) | ˚C | days |
| | Erosion of road embankments | Sea level (rise) | cm | year(s) |
| | | Extreme wind speed(-> storm surge) | m/s | hours-days |
| | | Wind direction (-> storm surge) | degrees | hours-days |
| | | Extreme rainfall events (long periods of rain) | mm/days | days-weeks |
| | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | Bridge scour | Sea level (rise) | cm | year(s) |
| | | Extreme wind speed(-> storm surge) | m/s | hours-days |
| | | Wind direction (-> storm surge) | degrees | hours-days |
| | | Extreme rainfall events (long periods of rain) | mm/days | days-weeks |
| | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| Landslips and avalanches | External slides, ground subsidence, affecting the road | Extreme rainfall events (long periods of rain) | mm/days | days-weeks |
| | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | | Drought (consecutive dry days) | consecutive days | multiple days-months |
| | Slides of the road embankment | Extreme rainfall events (long periods of rain) | mm/days | days-weeks |
| | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | | Drought (consecutive dry days) | consecutive days | multiple days-months |
| | Debris flow | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | Rock fall | Extreme rainfall events (long periods of rain) | mm/days | days-weeks |
| | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |

**Table 3.1** (continued)Threats and related climate parameters, imposing risks to the road infrastructure.

| | | | | |
|---|---|---|---|---|
| Landslips and avalanches | Rock fall | Frost-thaw cycles (nr. of days with temperature zero crossings) | nr. of days | days |
| | Snow avalanches | Snowfall | mm/day | day-weeks |
| | | Frost-thaw cycles (nr. of days with temperature zero crossings) | nr. of days | days |
| | | Temperature | ˚C | days |
| Loss of road structure integrity | Impact on soil moisture levels (increase of water table), affecting the structural integrity of roads, bridges and tunnels | Seasonal and annual average rainfall | mm/season, mm/y | season-year |
| | | Sea level (rise) | cm | year(s) |
| | | Extreme wind speed(-> storm surge) | m/s | hours-days |
| | | Wind direction (-> storm surge) | degrees | hours-days |
| | Weakening of the road embankment and road foundation by standing water | Seasonal and annual average rainfall | mm/season, mm/y | season-year |
| | (Unequal) settlements of roads by consolidation | Drought (consecutive dry days) | consecutive days | multiple days-months |
| | Instability / subsidence of roads by thawing of permafrost | Frost-thaw cycles (nr. of days with temperature zero crossings) | nr. of days | days |
| | Uplift of tunnels or light weight construction materials by increasing water table levels | Seasonal and annual average rainfall | mm/season, mm/y | season-year |
| | | Sea level (rise) | cm | year(s) |
| | | Extreme wind speed(-> storm surge) | m/s | hours-days |
| | | Wind direction (-> storm surge) | degrees | hours-days |
| | | Extreme rainfall events (long periods of rain) | mm/days | days-weeks |
| Loss of pavement integrity | Cracking, rutting, embrittlement | Maximum and minimum diurnal temperature | ˚C | days |
| | | Nr. of consecutive hot days (heat waves) | consecutive days | days |
| | Frost heave | Frost days | ˚C, nr. of days | days |
| | Aggregate loss and detachment of pavement layers | Frost days | ˚C, nr. of days | days |
| | Cracking due to weakening of the road base by thaw | Frost-thaw cycles (number of days with temperature zero crossings) | nr. of days | days |
| | Thermal expansion of pavements | Maximum and minimum diurnal temperature | ˚C | days |
| | | Nr. of consecutive hot days (heat waves) | consecutive days | days |
| | Decreased utility of (unimproved) roads that rely on frozen ground | Frost-thaw cycles (number of days with temperature zero crossings) | nr. of days | days |
| Loss of driving ability due to extreme weather events | Reduced visibility | Fog days | nr. of days | day |
| | Reduced visibility during snowfall, heavy rain including splash and spray | Snowfall or rainfall | mm/h, mm/day | minutes-day |
| | Reduced vehicle control | Extreme wind speed (worst gales) | m/s | hours-day |

**Table 3.1** (continued)Threats and related climate parameters, imposing risks to the road infrastructure.

| | | | | |
|---|---|---|---|---|
| Loss of driving ability due to extreme weather events | Reduced vehicle control | Extreme wind speed (wind gusts) | m/s | seconds-minutes |
| | Decrease in skid resistance on pavements from slight rain after a dry period | Drought (consecutive dry days) | consecutive days | multiple days-months |
| | Flooding of road surface due to low capacity of storm water runoff | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | Aquaplaning in ruts due to precipitation on the road, splash and spray | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | Decrease in skid resistance on pavements from migration of liquid bitumen | Maximum and minimum diurnal temperature | ˚C | days |
| | | Nr. of consecutive hot days (heat waves) | consecutive days | days |
| | Icing and snow | Snowfall | nr. of days, mm/d | days |
| | | Hail | nr. of days, mm/d | days |
| | | Frost days and rainfall | nr. of days, mm/d | days |
| Reduced ability for maintenance | Reduced snow removal planability | Snowfall | mm/day | day-season |
| | Reduced ice removal planability | Frost | nr. of days | days |
| | Impact on shoulder maintenance: increased vegetative growth | Temperature | ˚C | days |
| | Impact on road works: decreased time window for paving | Maximum and minimum diurnal temperature | ˚C | days |
| | | Nr. of consecutive hot days (heat waves) | consecutive days | days |
| Pollution aside the road after incapacity of storm water runoff system of the road | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| Susceptibility to wildfires that threaten the transportation infrastructure directly | | Drought (consecutive dry days) | consecutive days | multiple days-months |
| Damage to signs, lighting fixtures, pylons, canopies, noise barriers and supports | | Extreme wind speed (worst gales) | m/s | hours-day |
| | | Extreme wind speed (wind gusts) | m/s | seconds-minutes |
| Damage to energy supply, communication networks (e.g. pylons) and/or matrix boards by wind, snow, heavy rainfall and/or lightning | | Extreme wind speed (worst gales) | m/s | hours-day |
| | | Extreme wind speed (wind gusts) | m/s | seconds-minutes |
| | | Snowfall | mm/day | days |
| | | Extreme rainfall events (heavy showers) | mm/h | minutes-hours |
| | | Extreme rainfall events (long periods of rain) | mm/day | days-weeks |
| | | Lightning | nr. of discharges | hour to days |
| Trees, windmills, noise barriers, trucks falling on the road | | Extreme wind speed (worst gales) | m/s | hours-day |
| | | Extreme wind speed (wind gusts) | m/s | seconds-minutes |

## 3.2 Use of climate data in a detailed vulnerability assessment

After a quick scan one can decide to make a more detailed study of certain stretches of the roads or for the area. Basically the same steps are used for such detailed assessments[20] (ROADAPT, 2014) as in Fig. 3.2, but much more attention is paid to and time is invested in steps 2 to 4 (differences with the quick scan are underlined). The NRA's can be involved in the same way as in the quick scan (Table 3.2).

During the **detailed assessment** one also wants to determine whether the occurrence of threats will increase or decrease due to climate change. For that reason one will have to determine the occurrence in the current or reference climate and in the future climate.

1. First determine on the basis of the existing threats, what are the relevant climate parameters (Table 3.2). Determine also the area of interest for the quick scan and the period of interest in the future (e.g. time horizon) and with which period in the past one wants to compare this (reference period). If one has done a quick scan before the detailed study, most information for this step is already available. Where a quick scan normally focusses on all possible threats, a detailed study will generally focus only on one of the threats. This implies that a quick scan deals with many climate variables and a detailed study with probably only 1 or 2 variables;
2. In a detailed study more time is available for checking data quality, relevance and processing. Therefore, also data sources that could not be used during the quick scan can be used and for many climate variables quantitative data can be generated (current climate: Table 2.1, Table 4.2 and Par. 4.5; future climate: Table 2.4, Table 5.1 and Par. 5.5). Before using any climate data, check what the quality of the data is (Par. 4.3 and Par. 5.3). Often derived data (climate normals, statistics) from NMHI's or research institutes will have sufficient quality for use in a detailed study and no additional quality check has to be done for these data. A quality check is needed especially when time series (e.g. daily data on rainfall) are used[21]. In a detailed study more time is available for an elaborate quality check. When in doubt, one can ask an expert whether the data source can be used for the intended purpose). If there is no information on the required climate variable, one can sometimes use information on a different, but related climate variable (feedback loop in Fig. 3.2);
3. At this stage one has to make a selection of the projections or climate scenarios that one wants to take into account (Par. 2.2.5). There are many, however, not all have to be taken into account. Hardly ever there is enough time and money available to do climate model simulations for a detailed study, which means that a selection has to be made of existing climate model simulations. Generally, at least a worst case scenario should be included together with a more average and/or optimistic scenario. Since in a detailed study often more data sources can be used, the selection used in the quick scan has to be reconsidered. Often more projections and or climate scenarios will be taken into account. The use of a complete set of climate scenarios or even of an ensemble can be considered. To get an idea of the range of possible impacts for the threats under study, one has to select climate scenarios or projections covering a considerable part of the variation in changes in the relevant climate variable;
4. Before using the climate data/information, generally processing is needed (e.g. calculating the number of frost days from daily time series on temperature). From climate scenarios often only changes are available in the main climate variables (e.g. temperature, precipitation). Processing is needed to get information about derived climate variables such as the number of frost days. Since more time is available in detailed

[20] Based partly on the scheme for generic processing of climate data as used by IS-ENES;
[21] Although time series of NMHI's always will have been checked for quality, this does not mean that all problems with quality have been solved.

studies, the changes in climate variables in the future can be translated into time series for the future. From these time series quantitative information can be obtained on the occurrence of the relevant climate variables. Climate model projections generally have a coarse spatial resolution. Therefore, processing of climate data also often includes downscaling to higher resolutions *(*Par. 4.4 and Par. 5.4). Often help from experts (climate scientists) is needed for this processing.

After this one will probably be able to say something in a quantitative way on whether the threats will increase, decrease or not change due to climate change (the analysis and conclusions of the detailed assessment). Be aware that changes in threats may also be due to changes in socio-economic developments, and be aware that there is not always a clear and/or linear relation between the relevant climate variable and the threat.

**Figure 3.4** Flooding of road surface due to excessive rainfall (Source: K. Van Muiswinkel).

## 3.3 Example of use of climate data in a quick scan

To illustrate the use of climate data below an example is given for a case study on the A24 motorway in northern Portugal (Ennesser, 2014). Fig. 3.5 gives the location of the motorway.


**Figure 3.5** The location of the A24 motorway in the northern part of Portugal.

Below, first the text of the steps for the quick scan are shown in italics. After that it is explained shortly how and where the information is collected and how the information is processed.

**Step 1**
*Determine on the basis of possible and existing threats, what are the relevant climate parameters (Table 3.1). Determine also the area of interest for the quick scan and the period of interest in the future (time horizon) and with which period in the past one wants to compare this (reference period).*

Information on relevant threats, area of interest and time horizon was obtained from the stakeholders in the pilot project (through Y. Ennesser of EGIS):

- Relevant threats are among others flooding of the road surface due to extreme rainfall events (heavy showers) and susceptibility to wildfires due to drought. With the help of **Table 3.1** the relevant climate variables were determined
    - Flooding of road surface (pluvial): extreme rainfall events (heavy showers, long periods with rain are apparently less important for flooding of road surfaces in this area);
    - Susceptibility to wildfires: drought (consecutive dry days).
- Area of interest: Northern Portugal, A24 Motorway (Fig 3.5);
- Relevant time horizon depends on the threat, but 2050 is at least of interest;
- Reference climate: as reference the normals available in Portugal can be used: In January 2014 these were the 1971-2000 normals (no explicit information on required reference period from the stakeholders).

**Step 2**
*Collect climate data for the reference period and for the future. Since it is a quick scan one will focus on collecting climate data from rather easily accessible data sources (current climate: Table 2.1, Table 4.2 and Par. 4.5; future climate: Table 2.4, Table 5.1 and Par. 5.5) and sometimes only a qualitative assessment is possible.*

Available data through internet:

- Averages for temperature and precipitation for 1971-2000 for Vila Real: www.ipma.pt/resources.www/docs_pontuais/ocorrencias/2011/atlas_clima_iberico.pdf (**in Table 2.1**);
- Climatology of some extreme events (generated with ECA&D website[22]: link from **Table 4.2**): a rough estimate of the once per 10 year return level of extreme 1 day precipitation was made (Fig. 3.6) and of the maximum number of consecutive dry days occurring on average once in 10 years (Fig. 3.7).

[22] The European Climate Assessment & Database (ECA&D) is an effort to collect observational data from all European countries and to make them comparable for European wide analysis. For transnational vulnerability studies it is a useful starting point, as it presents reasonably consistent observations for all countries (see also Chapter 4).

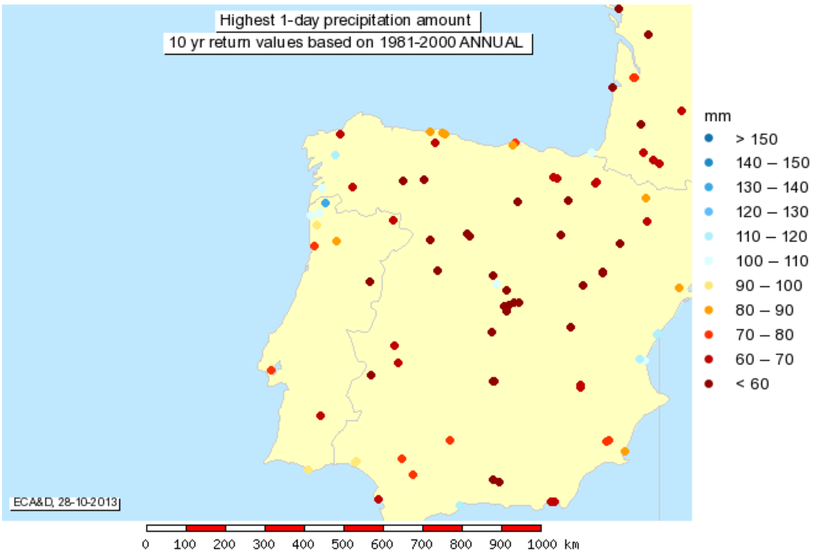


**Figure 3.6** Highest 1 day precipitation amount (mm) occurring on average once in 10 years for the period 1981-2000 (Source: ECA&D): in the northern part of Portugal[23] this is about 60 -70 mm in one day (varying from less than 60 mm to more than 80 m).

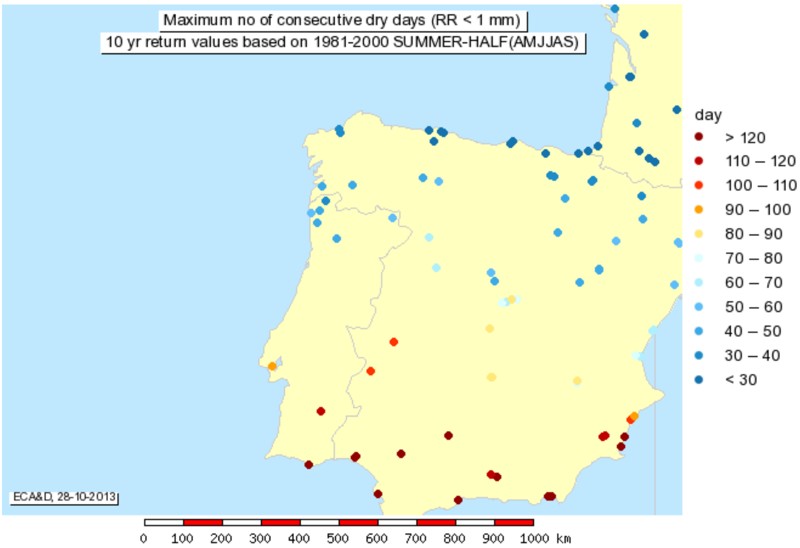


**Figure 3.7** Maximum number of consecutive dry days in the period April-September, occurring on average once in 10 years for the period 1981-2000 (Source: ECA&D).

- Trends in some extremes from the ECA&D website: highest 1-day precipitation per year (Fig. 3.9), number of days with at least 20 mm of rainfall (Fig. 3.8), number of consecutive dry days (no trend over de period 1951-2012 in the maximum number of consecutive dry days: results not shown). At the end of Annex 2 it is explained how trend maps can be generated with the ECA&D web site;
- Climate scenarios: http://siam.fc.ul.pt/, www.ipma.pt/pt/oclima/servicos.clima/index.jsp?page=cenarios21.clima.xml (Table 2.4), but little information on the change of extremes;
- Overview of what is done in Portugal related to climate change: http://climate-adapt.eea.europa.eu/countries/Portugal.

[23] Time series of Vila Real not included in the figures: no long homogeneous time series available for this station.

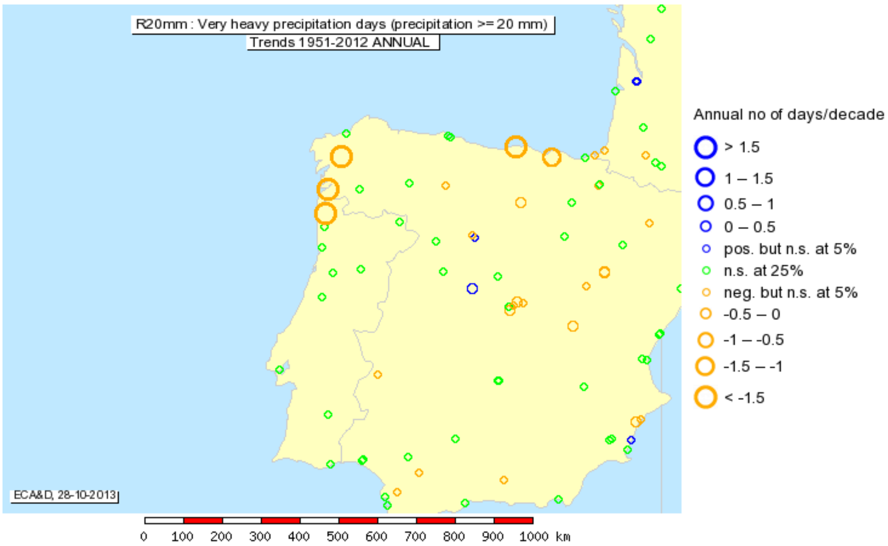


**Figure 3.8** Trend map of the number of days with at least 20 mm of rainfall per year over the period 1951-2012: for the area of the A24 motorway no significant trends (Source: ECA&D).

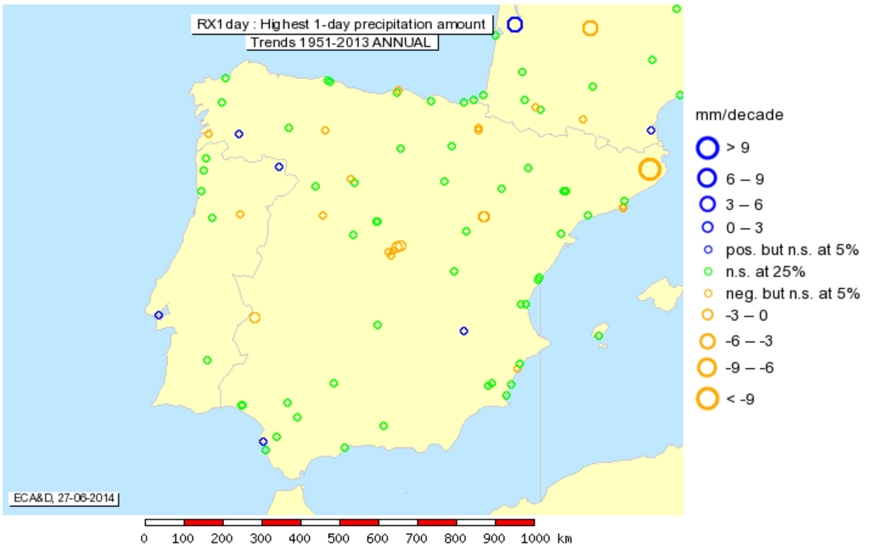


**Figure 3.9** Trend map of the highest 1-day precipitation sum per year over the period 1951-2013: for the area of the A24 motorway no significant trends although some decrease or increase (Source: ECA&D).

*Before using the climate data, check what the quality of the data is (Par. 4.3 and Par. 5.3). Often derived data (climate normals, statistics) from NMHI's or research institutes will have sufficient quality for use in a quick scan and no quality check has to be done. When in doubt, one can ask an expert whether the data source can be used for the intended purpose). If there is no information on the required climate variable, one can sometimes use information on a different, but related climate variable (feedback loop in Fig. 3.2).*

Check the quality of the climate data:

- Not necessary for the climatological data (average temperature and precipitation): in this case it can be assumed that the quality is checked by the provider (from IPMA and ECA&D);
- For trends from the ECA&D website we checked whether they are based on homogeneous time series. The information on the ECA&D website mentions that time series with large inhomogeneities are left out for the trend maps, which means that we can assume that the trends are not 'polluted' with non-climatic factors;
- For climate scenarios we checked whether the link in Table 2.4 refers to the most recent climate scenarios in Portugal (SIAM): a contact in Portugal for CCIAM (Centre for Climate Change Impacts, Adaptation and Modelling) confirmed that there are no more recent climate scenarios. The SIAM climate scenarios do not include the newest results of IPCC (2013), but the information from IPMA (Instituto Portugues do Mar e do Atmosfera) uses some information from the latest IPCC report.

**Step 3**

*At this stage one has to make a selection of the projections or climate scenarios that one wants to take into account (Par. 2.2.5). Not all available projections or climate scenarios have to be taken into account in a quick scan. To get an idea of the range of possible impacts for the threats under study, one has to select climate scenarios or projections that cover a considerable part of the possible changes in the relevant climate variable. Generally, at least a worst case scenario should be included together with a more average and/or optimistic scenario.*

In this case only some qualitative information can be given on the direction of change of the relevant climate variables:

- The available climate scenarios do not contain information on climate extremes, therefore it is difficult to select the scenarios with the highest and lowest changes for the relevant climate variables;
- From the IPCC (2013) it is known that summer precipitation will decrease in the Mediterranean region in all RCPs (Fig. 3.10 strongest decrease in annual precipitation for the highest RCP). In the Portuguese National adaptation Plan it is mentioned that "todos os modelos analisados prevêem redução da precipitação em Portugal Continental durante a Primavera, Verão e Outono' (all models project decrease in rainfall in spring-summer-autumn, and therefore increase of drought) as is also the case in the most recent IPCC report. Therefore, it is clear that drought will increase in the future, but it is difficult to give a quantitative estimate how much it will increase;
- It is also known that in many cases the extreme rainfall (heavy showers) will increase: the air can contain potentially more water vapor when temperatures increase, therefore, the maximum rainfall intensity can also increase even if the average rainfall will decrease (Lenderink & van Meijgaard, 2008; Lenderink et al., 2011). From this it seems most logical to assume that extreme rainfall, at least the heavy showers, will increase in the future. From the available information no estimate on the change in long periods with rain can be made.

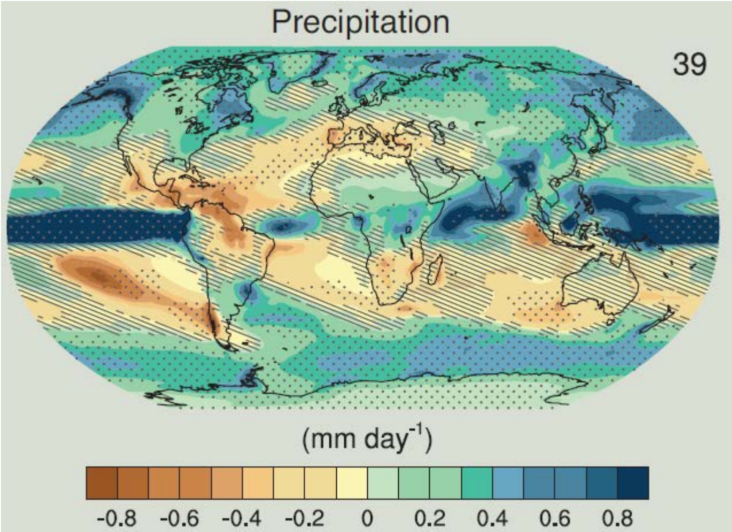


**Figure 3.10** Annual mean change in precipitation for 2081-2100 relative to 1986-2005 under RCP8.5. Hatching indicates regions where the multi-model (39) means change is less than one standard deviation of internal variability. Stippling indicates regions where the multi-model mean change is greater than two standard deviations of internal variability and where 90% of models agree on the sign of change (IPCC, 2013).

**Step 4**

*Before using the climate data or information, sometimes some processing is needed (e.g. calculating the number of frost days from time series on temperature). Here again, since it is a quick scan the processing will only consist of relatively easy and fast methods with already available tools (Par. 4.4 and Par. 5.4). From climate scenarios often only changes are available in the main climate variables (e.g. temperature, precipitation). Processing is needed to get information about derived climate variables such as the number of frost days. Climate model projections generally have a coarse spatial resolution. Expert knowledge (climatologist, climate scientist) may help to translate information on the current and future climate to relevant information for road owners*.

Processing of climate data:

- In this case study no further processing of climate data was done[24].

The above information on climate and climate change was used as input in the quick scan for the A24 motorway on its vulnerability for climate change. The result of the complete quick scan for which the above information was collected is described in Ennesser (2014).

[24] A tool that can be used for some simple processing is the Climate Explorer. At the end of Annex 2 an example is given of how the Climate Explorer can be used.

# 4 Current climate

## Summary and main questions

Although this document focuses on the effects of climate change for international road infrastructure, also information on the current climate is needed as a reference to see whether the impact of climate will change in the future. This chapter gives ample attention to the current climate and the data to describe it (more detailed information than in Chapter 2).

The questions most relevant for NRA's are answered here with reference to the paragraphs with more detailed information.

**Which datasets with information on the current climate are available?**
Data on the current or past climate to describe the reference situation for vulnerability assessments can be obtained from different sources:

- Surface based observations: mainly from ground-based weather stations;
- Observations from remote sensing (e.g. radar, satellites);
- Model simulations: re-analysis and climate model data.

All sources have advantages and disadvantages (Table 4.1). Ground-based observations from weather stations are used most often for describing the current climate, for extreme statistics and for detecting climate change. However, with the increase of the length of the observational period, also remote sensing methods become more valuable. Data from model simulations (re-analysis) are useful when observational data are missing. Links to several databases for the current climate are given in Table 2.1, Table 4.2 and in Par. 4.5. They include links to climate normals, time series, climate indices, and re-analyses.

**Which period to use as a reference to describe the current climate and to capture natural variability?**
Depending on the purpose of the vulnerability study and on the presence of information on impacts the period 1961-1990, 1981-2010 or even other periods can be used. In view of climate change, 1981–2010 normals are considered as better descriptions of the current climate than 1961–1990 normals. In the case of cross-border projects, it is important to keep in mind to use the same reference period for the whole region of interest (Table 2.1 and Par. 4.1).

A period of 30 years is generally used to capture the main part of the day-to-day and year-to-year natural variability of a climate. Design events, reference years, etc. do not capture this variability or only partly. For yearly and seasonal averages a period of 30 years is enough. For extremes that occur on average once per year up to once per 10 years generally 30 years is also enough. For rarer extremes generally longer periods with observations have to be used.

**How to check the quality and usefulness of the climate data?**
Quality control is to verify whether a reported data value is representative of what was intended to be measured and has not been contaminated by unrelated factors. In case of limited quality the reference climate cannot be describe sufficiently for vulnerability studies. Factors that affect quality are:

- Missing data;
- Data errors/inconsistencies;
- Inhomogeneity: changes/trends in climate data due to non-climatic factors.

Par. 4.3.1 gives more information on the quality of climate data and Table 4.3 gives suggestions on how to check data quality of climatological time series. One can assume that the quality of climatological normals, statistics of extremes and derived climate indices produced by the NMHI's and other providers that comply with WMO-standards is of sufficient quality. However, provided time series have to be checked for their quality. Metadata from weather stations or other sources of climate data can be useful to detect data quality problems (Par. 4.3.3).

Although the quality of climate data may be good, still the usefulness and readiness for the intended use (validity) may be limited due to:

- Limited length of data sets or limited temporal resolution;
- Limited spatial coverage of data sets or limited spatial resolution;
- Limited accuracy;
- Presence of trends;
- Different format;
- Something else measured than required;
- Presence of biases (systematic deviations compared to observations).

Par. 4.3.2 gives more information on the usefulness of climate data. Table 4.4 gives some methods for solving data quality and validity problems. Which method is most appropriate in a certain situation depends on factors such as the availability of other data sets and time available for processing. With the help of the tables and text in Par. 4.4 with advantages and disadvantages per method a selection can be made.

**Which methods are available to generate climate time series when no observations are available?**

When only a few observations are missing in a time series, estimations of these observations generally can be made by interpolation, using data from nearby stations or by using relations with other climate variables that were measured (proxies; Par. 4.4.1). When time series are missing partly or completely for a location, the use of proxies, neighbouring stations or re-analysis datasets (simulated climate in the past with a weather model integrating observational data) is an option (Par. 4.4.3).

**How to get consistent climate data with similar quality for all regions of Europe?**

Although observations of national meteorological institutes have to comply with international standards of WMO, there are some inhomogeneities between countries and measuring networks. When the required accuracy of the data is not extremely high, the existing inhomogeneities will not hamper cross border analysis of vulnerability of road infrastructure too much.

European Climate Assessment & Database (ECA&D) is an effort to collect observational data from all European countries, and make them comparable for European wide analyses. Currently it is the dataset with the largest coverage in Europe. In case of cross border projects, this database is a good starting point for a quick scan. Re-analysis datasets are also an option to get consistent data for the current climate in Europe. It requires more expert knowledge to transform these data into maps and graphs, but time series are available for the whole of Europe. This makes re-analysis datasets less ready to use for a quick scan, but useful for detailed vulnerability studies (Par. 4.4.2).

## 4.1 The current climate and the reference period

As mentioned in Par. 2.1 different periods in the past are used for describing the current climate. The period 1961-1990 (as requested by the WMO) is principally used for two different purposes:

- To describe the current climate;
- As reference period to describe climate change (due to natural and human causes).

WMO (2011b) advises to use the period 1961-1990 as a reference unless an update provides normals for a significantly greater number of stations (after 2020 when data for the period 1991-2020 become available, the period will be 1991-2020)[25]. Frequent updating carries the disadvantage that it requires recalculation of the normals, but also of the numerous datasets that use the normals as a reference. However, in view of climate change 1981–2010 normals are viewed by many users and National Meteorological Institutes (NMI's) as describing the current climate better than 1961–1990 normals. The most recent IPCC[26] report (2013) also uses a more recent period as reference (1986–2005). As can be seen in Table 2.1 many European countries provide normals for 1981-2010.

**Guideline: reference period**

Depending on the purpose of the study and on the presence of information on impacts the period 1961-1990, 1981-2010 or even other periods can be used. In view of climate change, 1981–2010 normals are considered as better descriptions of the current climate than 1961–1990 normals. In the case of cross-border projects, it is important to keep in mind to use the same reference period for the whole region of interest (Table 2.1 and Par. 4.1).

A period of 30 years is generally used to capture the main part of the day-to-day and year-to-year natural variability of a climate. Design events, reference years, etc. do not capture this variability or only partly. For yearly and seasonal averages a period of 30 years is enough. For extremes that occur on average once per year up to once per 10 years generally 30 years is also enough. For rarer extremes generally longer periods with observations have to be used.

In many sectors also 'standard years', 'reference years', 'design rain events'[27] etc. are used. The main advantage of these methods is the shorter computing time, however, it is not always clear how average/extreme these years or events are for the current climate (especially not in the light of climate change) and variability (especially year-to-year) cannot or hardly be taken into account.

[25] For predictive uses, National Meteorological (and Hydrological) Institutes are encouraged to prepare averages and period averages for more recent periods. The optimal period for average temperatures is often substantially shorter than 30 years, but the optimal period for precipitation is often greater than 30 years;
[26] IPCC = Intergovernmental Panel on Climate Change: www.ipcc.ch/;
[27] For these methods observations from events or years from the past can be used (until recently the rainfall in year 1967 was often used for simulating average hydrological conditions in the Netherlands, the year 2003 was used for a once in 10 years dry event), or years or events can be constructed with the help of observations from various observed events or years.

## 4.2 Climate data sources for the current climate

In most countries National Meteorological (and Hydrological) Institutes (NM(H)I's) have responsibilities for a very long time for national climate activities, including the making, quality control and storage of climate observations; the provision of climatological information; research on climate; climate projections and/or prediction; and the applications of climate knowledge. There has been, however, an increasing contribution to these activities from universities and private enterprises (WMO, 2011b).

There are over 11,000 weather stations around the world measuring land, air and sea temperatures, as well as satellites, ships and aircrafts that also take measurements. The stations all follow strict WMO standards[28] and 1040 of these stations have been selected to provide high quality climate data to quantify and detect global aspects of climate change[29]. The more stringent requirements on observation networks and systems for monitoring climate, including the detection of climate change, has led to the development of special networks at national (e.g. Reference Climate Stations), regional (e.g. Regional Basic Climatological Network) and global scales (e.g. the Global Climate Observing System - GCOS - Surface Network, GSN). (Source: www.wmo.int/pages/themes/climate/climate_observation_networks_systems.php)

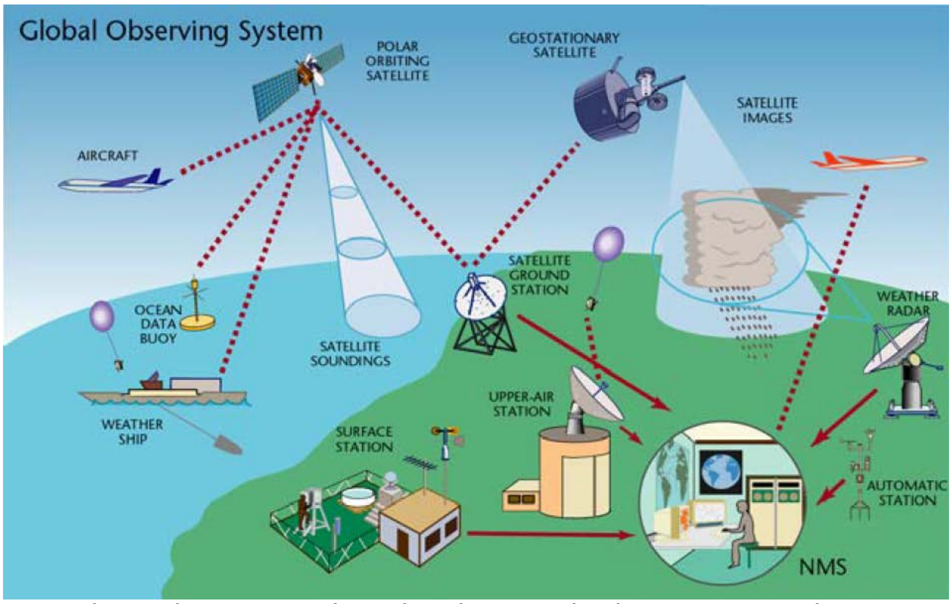


**Figure 4.1** Schematic presentation of various methods to measure the current climate (Source: WMO website). NMS=National Meteorological Station.

### *4.2.1 Climate data sources*

Data on the current or past climate can be obtained from different sources:

- Surface based observations (mainly from weather stations; all National Meteorological Institutes have a network; also included are measurements at ships) including derived climate indices and datasets (e.g. E-OBS: www.ecad.eu/download/ensembles/ensembles.php);

[28] WMO= World Meteorological Organisation. Reference to these standards: this also means that most weather stations are in rural areas, where the measurements can be considered representative for the surrounding area. See also Par. 2.1.3;
[29] Of course, other stations can also be used for specific purposes.

- Observations from remote sensing (air-crafts, radar, satellites, lidar; remote sensing data are calibrated with the help of observations from weather stations);
- Simulations: best known are the re-analyses in which the climate in the past is simulated with a weather model integrating as much as possible observational data.

### *4.2.2 Availability of climate data*

Not all data are freely available. Depending on the data policies per country, only data from a limited number of stations are freely available or data from all weather stations. WMO promotes the free availability of observational data, but for several reasons not all data are freely available (not yet; e.g. because of selling of data to cover costs of collecting the data). In Europe only a limited number of countries provide almost all their observational data freely (mostly through internet). ECA&D collected observational data in all European countries. Although the historical time series are not freely available for all countries, derived variables are available through the internet site (available for non-commercial use). Graphs, climatologies and trend maps are available for a large number of climate indices. The site also gives information on the quality of the underlying datasets.

Until some decades ago observational data from weather stations were not digitally available. In Europe many older climate observations have been digitised and most observations are now digitally collected. Applications of remote sensing data are sometimes available for free. The best know example is probably the data from the precipitation radar. The basic data for these applications generally can be obtained through the meteorological institutes. Re-analysis data can often be obtained through internet. NCEP data are freely available; ERA40 and ERA-Interim data are only available for non-commercial use.

**Table 4.1** Some characteristics of the 3 main groups of data for the current climate.

| Method | | Type | Advantages | Disadvantages |
|---|---|---|---|---|
| **Surface based obser-vations** | Weather stations | Point data | Often long time series<br>Global standards for measuring | Often only in rural areas<br>Should be checked for inhomogeneities |
| | Ships | Track data | Data from parts in the world where no weather stations are available | No long and continuous time series for the same location |
| **Remote sensing** | Radar/lidar/satellites | Area-average data | Data show spatial differences often on high resolutions | Relatively short time series until now<br>Other observations (surface based) needed to calibrate the dataset |
| | Aircrafts | Track data | Data from higher altitudes | No long and continuous time series for the same location |
| **Simula-tions** | Re-analysis | Area-average data | Also information for climate variables for locations where no measurements were taken, idem for periods in the past when no measurements were taken | May contain some biases<br>Quality depends on climate/weather model used and the observational climate data used<br>Often rather coarse spatial resolution |
| | Climate model simulations | Area-average data | Ensemble modelling can give more realisations for the current climate (better description of current climate) | Contain biases<br>Quality depends on climate model used<br>No direct link on daily/monthly basis with other observations[A] |

[A] The weather on e.g. April 1 2003 in a climate model cannot be linked to the weather on that date in reality. It can only be compared to the weather statistics for April 1.

**Table 4.2** Some links to databases with climate data in Europe (observations past-present, re-analysis; including the datasets mentioned in Matulla & Namyslo, 2013[A]).

| Database/ Source | Explanation | Area | Period | Link |
|---|---|---|---|---|
| ECA&D | Various climate variables (observations)<br>Time series (daily), indices, trend maps, etc.<br>Varying spatial resolution | Europe (also individual stations) | From 1946 –now | http://eca.knmi.nl/ |
| E-OBS | Temperature, precipitation, sea level pressure (observations)<br>Gridded dataset based on data in ECA&D<br>Daily data, spatial resolution depends on number of stations available | Europe | 1950-present | www.ecad.eu/E-OBS/ |
| GHCN | Global Historical Climatology Network<br>Various climate variables (observations)<br>Daily/monthly data, station data | world | variable | www.ncdc.noaa.gov/oa/climate/ghcn-daily/ |
| Climate Explorer | Various climate variables (observations, re-analysis and climate model data)<br>Time series, indices, trend maps, etc.<br>Tools for visualisation, statistical analysis, etc. | Europe, world (also individual stations) | Variable | http://climexp.knmi.nl |
| HYRAS | Precipitation, mean temperature, relative humidity, global radiation, sunshine duration and wind speed<br>daily data, 5 km grid | Central Europe | 1951-2006 | Rauthe et al., 2013 |
| KLIWAS | Air temperature, precipitation and global radiation<br>daily data, 5 km grid (Imbery et al., 2013) | Central Europe | 1960-2100 | www.kliwas.de |
| HISTALP | temperature, precipitation, pressure, hours of bright sunshine and cloudiness<br>Station based dataset, monthly data (Auer et al., 2007) | Greater Alpine Region/Central Europe | 1760-present | www.zamg.ac.at/histalp/ |
| EURO4M | Various climate variables (observations and re-analysis)<br>Gridded datasets | Part of Europe - world | Variable | www.euro4m.eu/datasets.html |
| NCEP/NCAR | Various climate variables (re-analysis)<br>2.5 degree resolution (Kalnay et al., 1996) | world | 1948-present | www.cpc.ncep.noaa.gov/products/wesley/reanalysis.html |
| ERA40 | Various climate variables (re-analysis)<br>2.5 degree resolution (Uppala et al., 2004) | world | 1957-2002 | http://data-portal.ecmwf.int/data/d/era40_daily/ |
| ERA-interim | Various climate variables (re-analysis)<br>Higher spatial resolution than ERA40<br>(Dee et al., 2011) | world | 1989–2008 | www.ecmwf.int/research/era/do/get/era-interim |
| 20th Century Reanalysis | Various climate variables (re-analysis)<br>(Compo et al., 2011) | world | 1879-2012 | http://portal.nersc.gov/project/20C_Reanalysis/ |
| Links to national meteo-services | Available information may differ per country (mainly observations or derived data) | per country | Variable, Normal periods | www.wmo.int/pages/members/members_en.html<br>www.eumetnet.eu/members<br><br>See also Table 2.1 |

[A] In this reference also the following databases are mentioned for Austria: StartClim (1960 – present, Station based) and DISTURBANCE (1980 – 2010, about 4 km). More datasets are available for some European countries.

### *4.2.3 Databases*

As can be seen in the Table 4.1, not all sources of climate data result in long time series. For studies on climate and climate change it is very important to have relatively long time series to describe a climate (minimum of 5-10 years to describe averages; for extremes often more than 30 years of data are needed; for climate change most often more than 30 years is used). In Table 2.1 links to the descriptions of the current climate (normals) of various European countries are presented. For climatological studies especially data from weather stations are used. Also the use of remote sensing data for these purposes becomes more and more valuable as the length of the times series from these sources increases.

**Figure 4.2** The impact of climate extremes is also influenced by the traffic load.

**Overview: data sources and data bases for the current climate**

Data on the current or past climate can be obtained from different sources:

- Surface based observations: mainly from ground-based weather stations;
- Observations from remote sensing (e.g. radar, satellites);
- Model simulations: re-analysis and climate model data.

All sources have advantages and disadvantages (Table 4.1). Ground-based observations from weather stations are used most often for describing the current climate, for extreme statistics and for detecting climate change. However, with the increase of the length of the observational period, also remote sensing methods become more valuable. Data from model simulations (re-analysis) are useful when observational data are missing. Links to several databases for the current climate are given in Table 2.1, Table 4.2 and in Par. 4.5.

## 4.3 Data quality and usefulness

Unlike observations taken to support the preparations of forecasts and warnings, the availability of continuous, uninterrupted climate records is the basis for many studies on climate and climate change. Prior to the description or use of a dataset, the data should be checked for accuracy and usefulness (validity). Accuracy refers to the correctness of the data, while validity refers to the applicability of the data to the purpose for which the values will be used (WMO, 2011b).

The objective of quality control is to verify whether a reported data value is representative of what was intended to be measured and has not been contaminated by unrelated factors. It is important, therefore, to be clear from the outset what the readings of a particular data series are meant to represent. Data should be considered as satisfactory for permanent archiving only after they have been subjected to adequate quality control (WMO, 2011b). Although quality control takes place before archiving of climate data by NM(H)I's, this does not mean that the data can be used for all other purposes without further quality control, since not all quality problems are solved.

Databases often contain information on the quality of data (although not always directly visible). The quality flags can indicate whether missing data have been added, original data have been corrected, etc. When the quality is checked, outliers are generally removed, but inhomogeneities not (see below for an explanation)!!! *The user of a dataset should never assume without confirmation that a dataset is accurate and valid, especially without relevant information from the quality control processes* applied during the assembling of the dataset. It is also important to know how the data have been collected, processed and compiled (WMO, 2011b).

> **Definition: quality of climate data**
> Quality control is to verify whether a reported data value is representative of what was intended to be measured and has not been contaminated by unrelated factors.
> Factors that affect quality are:
> - Missing data;
> - Data errors/inconsistencies;
> - Inhomogeneity: changes or trends in climate data due to non-climatic factors.
>
> Par. 4.3.1 gives more information on the quality of climate data and how to check it.

### *4.3.1 Factors affecting the quality of climate data*

Before using climate data the quality of the basic data has to be checked since low quality can affect the results of e.g. climate statistics and impact studies. Below the main factors that affect data quality are mentioned with some examples:

- Missing data (a few missing data or for longer periods): e.g. a day without measurement of precipitation may affect the monthly sum of precipitation;
- Data errors: they arise primarily as a result of instrumental, observer, data transmission, key entry and data validation process errors, as well as changing data formats and data summarization problems. Another form of data errors are inconsistencies (spatially; with other climate variables): e.g. the maximum temperature should be higher or equal to the minimum temperature on a day;
- Inhomogeneity: means changes/trends in climate data due to non-climatic factors, e.g. due to changes in site location (including changes in the surrounding area such as expanding urban areas that may cause the so-called Urban Heat Island[30]), in the observation procedure (including change of the person doing the observations, in measuring instruments, observation time, processing of data, etc.; see Figure 4.5 for an example). This includes temporal and spatial inhomogeneities: when different instruments or observation times are used in a region or on both sides of a border; mixing of data from different stations.

The above aspects refer especially to observational data, but also data from other sources (remote sensing, simulations, etc.) should be checked for quality.

[30] Urban Heat Island (UHI): urban areas generally have a somewhat higher temperature than rural areas, due to a different energy balance. With some wind the warmer air may be transported to the rural area near the city and affect temperature measurements over there.

**Figure 4.3** Frost heave (Source: Matulla & Namyslo, 2014a).

### *4.3.2 Usefulness of the climate data for the intended use*

Beside the above factors, there may be other factors that determine the validity (usefulness, readiness to apply, etc.) for users. Some examples:

- Limited length of data sets: to calculate extremes that occur once in 10 years, the datasets should have a minimum length of about 30 years;
- Limited temporal resolution: for some purposes such as urban water management precipitation data on 5-minutes resolution are requested. However, often the amount of data on this temporal resolution is limited or the data are not validated.
- Limited spatial coverage of data sets or limited spatial resolution: to calculate the differences in temperature between rural and urban areas also data from urban areas are needed, which are other missing;
- Accuracy: sometimes wind speed is measured in integers, when also values with decimals are needed;
- Presence of trends: when a strong trend is present in e.g. the temperature it may be more difficult to determine the natural variability in temperature;
- Different format: some applications require area-average data[31], whereas others require point data;
- Something else measured than required? E.g. air temperature at 2 m height is measured at weather stations, whereas the temperature at the road surface is needed;
- Presence of biases: Model simulations often contain considerable biases (systematic deviations compared to observations (Chapter 5). When a bias is too large, the climate data cannot be used directly, but should be bias-corrected. One could also consider the difference between the measuring location and the location of interest as a bias (e.g. most measurements are taken in rural areas, cities are generally somewhat warmer, therefore measurements from rural areas have a bias towards too low temperatures when used for urban areas).

The above examples are mainly based on measurements from weather stations, but validity of other sources of climatological data should also be checked before use.

**Note!**

All data sources have their advantages and disadvantages. E.g. precipitation measured at Automated Weather Stations often has a higher temporal resolution than at hand-measured stations, however the measured precipitation may be systematically higher of lower. Radar is

[31] In area-average data extreme daily rainfall is often lower and the number of days with rainfall is higher.

a very useful technique to measure spatial differences in precipitation, but it may be less accurate for measuring the local extremes.

**Definition: usefulness and readiness to apply**
Although the quality of climate data may be good, still the usefulness or readiness for the intended use may be limited due to:

- Limited length of data sets or limited temporal resolution;
- Limited spatial coverage of data sets or limited spatial resolution;
- Limited accuracy;
- Presence of trends;
- Different format;
- Something else measured than required;
- Presence of biases (systematic deviations compared to observations).

Par. 4.3.2 gives more information on the usefulness of climate data.

### *4.3.3 How to check the quality and usefulness?*

During the quality check, the intended use should be kept in mind. For some elements, missing data are much more critical than for others. For monthly extremes or event data such as the number of days with precipitation greater than a certain threshold, missing daily data may render a recorded time series useless. Total monthly rainfall amounts may also be strongly compromised by a few days of missing data, particularly when a rain event occurred during the missing period. On the other hand, monthly averaged temperature may be less susceptible to missing data than the two previous examples. For some applications data completeness is a necessity (WMO, 2011b).

Table 4.3 gives some suggestions on how to check the quality and usefulness of climatological time series. The suggestions in this table can be used in most cases also for indices, derived data, etc. *One can assume that the quality of climatological normals, statistics of extremes and other derived climate indices produced by the national climatological institutes is of sufficient quality*[32]*.*

Metadata from a weather station or other sources of climate data can be useful to detect inhomogeneities: e.g. when a station has been replaced, when new instruments have been introduced, etc. often inhomogeneities occur. Often statistical techniques are invaluable for detecting inhomogeneities, errors, and in some cases for suggesting what the 'correct' value should be (WMO, 2011b).

[32] The same is true for other climate service providers that comply to international standards such as from WMO.

**Table 4.3** Some suggestions on how to check the quality and usefulness of climatological time series that you want to use. *If you doubt or do not know whether you checked your data sufficiently, always ask an expert!*

| **Factor that may affect the quality/validity** | **What can you do?** |
|---|---|
| General | Ask the provider for information on the quality and validity for your project<br>Check the metadata for information on the quality (check also if all needed information is available, e.g. the dimensions in which the variables are given) |
| Missing data | Check whether all dates are in the time series<br>Check for missing data (generally indicated with -99)<br>Check whether it is easy to give good estimates for missing data |
| Errors/consistency | Check for strange outliers, taking into account the yearly cycle<br>Can the outliers be corrected in a reliable way (e.g. by using information from other stations or other climate variables)?<br>Some examples of checks: Is the maximum temperature is lower than the minimum temperature on some days? Is there rainfall on days with completely blue sky? Is the difference between neighbouring stations not too large (unrealistic) or between subsequent days? |
| Inhomogeneity | Visual check: look especially at points in time where changes in measuring location, instruments, etc. took place (see metadata)<br>Statistical checks: e.g. is the average or standard deviation of a climate variable significantly different before and after a change in measuring method[33] |
| Length of data set | Check what would be the recommended length of a data set for the intended use (for calculating the return times of extremes longer time series are needed than for calculating monthly averages) |
| Temporal resolution | Check what temporal differences are important for the intended use and what does this mean for the required resolution? |
| Spatial resolution/spatial coverage | Check what spatial differences are important for the intended use. Do we expect large spatial differences due to local surface characteristics and what this means for the required resolution?<br>Check whether the available data set covers your area of interest |
| Accuracy | Which level of detail of your data (decimals or not) is required for the intended use and check whether the data set has this level of detail |
| Presence of trends | Check whether there are significant trends in the climate variable of interest in the period that is used. If you want to describe the current climate this may be a complication. |
| Format of data | Compare current format with desired format<br>If necessary, can the format be changed easily without loss of accuracy, information, etc.? |
| Something else measured than required? | Compare the measured variable with the desired variable<br>If necessary, can the measured variable be transformed into the desired variable without too much loss of accuracy, information, etc.? |
| Presence of biases | Compare with a reference dataset (for model simulations)<br>Check whether you can expect large differences between the location of the measurements and the location of interest |

**Guideline: data quality**

On can assume that the quality of climatological normals, statistics of extremes and other derived climate indices produced by the NMHI's and other providers that comply with WMO-standards is of sufficient quality.

Metadata from weather stations or other sources of climate data can be useful to detect data quality problems (Par. 4.3.3).

Table 4.3 gives suggestions on how to check data quality of climatological time series.

[33] E.g. in the ECA&D database information is given on homogeneity of time series (http://eca.knmi.nl/FAQ/index.php#5).

## 4.4 Analysis and processing of data

The subject of this paragraph is closely related to what is discussed in Par 4.3, since quality control and improving quality of data often requires analysis and processing of data, respectively. Quality and/or validity control of climate data can also take place at different stages: at the 'raw' data, after quality control by the NM(H)I's, after processing into indices or maps, etc. In this paragraph those methods and techniques that where not treated explicitly in Par. 4.3 are presented.

Table 4.4 gives some solutions to the earlier mentioned problems with quality and validity. In the sub paragraphs some more information on the various methods is given. The list with methods is not complete, but gives a first introduction to the various methods that can be used.

**Table 4.4** Problems with data quality and usefulness and some solutions.

| **Cause limited quality** | | **Possible methods to overcome the problem** |
|---|---|---|
| **Missing data** | Indivi-dual days | Estimate from other climate variables (proxies)<br>Interpolation between days (not suitable for e.g. precipitation)<br>Use data from neighbouring stations as the basis for estimates<br>Use other data sources (e.g. from re-analysis) |
| | Longer time spans | Estimates from other climate variables<br>Use data from neighbouring stations as the basis for estimates<br>Use other data sources (e.g. from re-analysis) |
| **Data errors/inconsistencies** | | Correct the value when possible (then often the cause is clear)<br>Consider the data as missing and use the methods mentioned under 'Missing data' |
| **Inhomogeneity** | | Homogenization: use of nearby station, parallel measurements[34] if present, relation with other climate variable(s) and/or the statistical information on the difference with the unbiased period to determine bias and correct the biased data<br>In case of inhomogeneities over borders: use other dataset which does not have this problem (e.g. re-analysis)<br>If possible correct for the inhomogeneities over borders (comparable with bias correction)<br>Use of other dataset (if present) |
| | | |
| **Length of data set** | | Use other data sources to construct longer time series (e.g. from proxies, re-analysis, with weather generator) |
| **Temporal resolution** | | Interpolation of existing dataset[A]<br>Use other data sources if they can provide higher resolutions (e.g. from proxies, re-analysis)<br>Use of stochastic weather generator |
| **Spatial resolution** | | Interpolation of existing dataset<br>Use other data sources if they can provide higher resolutions (e.g. from proxies, re-analysis) |
| **Accuracy** | | Use other data sources that provide higher accuracy (e.g. from proxies, re-analysis, with weather generator) |
| **Presence of trends** | | Detrend the time series: determine trend and correct the time series for it |
| **Format of data** | | Adapt format, if possible (e.g. transform daily data to monthly data)[B]<br>Process data into desired data (if indices are needed) |
| **Something else measured than required** | | If possible, calculate/estimate the required data from the measured data |
| **Presence of biases** | | Bias-correction |

[A] This does not increase the real temporal resolution, however with the help of interpolation data can be presented on finer grid. Especially precipitation needs a sophisticated interpolation technique to avoid levelling off of extremes and too many rainy days (if one wants a data set with point-like data);
[B] Derivation of climate indices, calculation of extremes and their return times can also be considered as a form of changing the format of climatological time series.

[34] In case of relocation or new instruments often parallel measurements (at least during one year) are done at the old and new location or with the old and new instruments. With the help of the information from these measurements the time series can be homogenized.

**Guideline: how to solve problems with data quality and usefulness?**
Table 4.4 gives some methods for solving data quality and usefulness problems. Which method is most appropriate in a certain situation depends on factors such as the availability of other data sets and time for the processing. However, with the help of the tables and text in Par. 4.4 with advantages and disadvantages per method a selection can be made.

**Figure 4.4** Hindrance of traffic due to heavy snowfall (Source: Matulla & Namyslo, 2014a).

### *4.4.1 Adjusting data quality (missing data, errors, inconsistencies)*

Table 4.5 gives advantages and disadvantages of some methods to overcome missing data. Sometimes errors in data can easily be corrected when the cause of the error is known, e.g. when during processing the wrong dimension or conversion factors are used. When the maximum temperature is lower than the minimum temperature, the values for both variables may have been switched. If this seems logical e.g. after comparison with neighbouring stations or with other climate variables, this error or inconsistency can be easily corrected. When the cause of the error or inconsistency is not known or when it is not known how to correct the data, often the data have to be considered 'missing' and then the methods in Table 4.5 can be used to estimate the correct values.

Unrealistically large differences between neighbouring stations can also occur. When measured within one country or network they are generally due to errors (processing or problems with the measuring equipment). In case of such inconsistencies over borders or between measuring networks, they may also be due to e.g. differences in measuring methods/equipment. In this case we speak of inhomogeneities and not of errors. When the inhomogeneities are too large there are two options:

- Use other data sources (e.g. re-analysis; Table 4.1);
- Consider the data of one of the countries/networks 'biased' and use a 'bias-correction' (Table 4.6). However, it is difficult to distinguish the difference due to the different measuring methods from spatial differences, unless both methods are used at least at one location ('parallel measurements') during at least one year.

**Table 4.5** Some methods to overcome problems due to missing data: some advantages and disadvantages

| Missing data | | Advantages | Disadvantages |
|---|---|---|---|
| Indivi-dual days | Estimate from other climate variables (proxies) | Uses known relations between climate variables | Quality depends strongly on relation between the desired variable and the proxy |
| | Interpolation between days | For several variables there is a clear relation between the weather on neighbouring days (e.g. for temperature) | Not suitable when it is known that strong changes may occur from one day to another, e.g. for precipitation |
| | Use data from neighbouring stations as the basis for estimate | When stations are close to each other and within similar environments, generally there is a strong relation with the data from neighbouring stations | Depends on the distance between the stations<br>There may be a systematic difference between neighbouring stations, e.g. due to differences in altitude, in distance from the sea<br>For convective precipitation there may be large spatial differences on short distances |
| | Use other data sources (e.g. from re-analysis) | Possibility to check the quality of the reanalysis data by comparing with the available measured data | Re-analysis data may contain biases<br>Re-analysis data give area-average data, may be a complication for precipitation<br>Depends on the quality of the reanalysis |
| Longer time spans | Estimates from other climate variables (proxies) | Uses known relations between climate variables | Quality estimate depends strongly on relation between the desired variable and the proxy |
| | Use data from neighbouring stations as the basis for estimate | When stations are close to each other and within similar environments, generally there is a strong relation with the data from neighbouring stations | Depends on the distance between the stations<br>There may be a systematic difference between neighbouring stations, e.g. due to differences in altitude, in distance from the sea<br>For convective precipitation there may be large spatial differences on short distances |
| | Use other data sources (e.g. re-analysis) | Possibility to check the quality of the reanalysis data by comparing with the available measured data | Re-analysis data may contain biases<br>Re-analysis data give area-average data, may be a complication for precipitation<br>Depends on the quality of the reanalysis |

### *4.4.2 Correcting for non-climate related changes or trends*

As explained in Par. 4.3 changes and/or trends can appear in climate data sets due to non-climatic factors, e.g. due to changes in the surrounding area or the measuring method. This includes temporal and spatial inhomogeneities. Mixing of data from different types of weather stations with different measuring instruments can also be a source of inhomogeneities.

**Table 4.6** Some techniques for homogenization of climatological time series: some advantages and disadvantages.

| Method for homogenization | Advantages | Disadvantages |
|---|---|---|
| Use of parallel measurements | Measures exactly the differences/inhomogeneities | Generally only available in case of planned changes in measuring location or instruments<br>Limited time of parallel measurements: good for removing inhomogeneities in the averages, but maybe not for very extreme events |
| Use of statistical information on the difference between periods | Measures exactly the differences/inhomogeneities | Not possible when the inhomogeneity is caused by a gradual change (e.g. in environment of the measuring station)<br>The periods should be long enough to determine various statistical characteristics (averages, extremes, standard deviation, etc.) |
| Use of neighbouring stations | Longer period with measurements (compared to parallel measuring), therefore better possibilities to detect inhomogeneities in extremes | Systematic differences between stations (however, these can be detected with historical data)<br>Only possible when the neighbouring stations do not have inhomogeneities |
| Use relation with other climate variables | Uses information from the location itself | Only possible when the other climate variables do not have inhomogeneities<br>Depends on the relation with the other climate variable |

In case of derived data such as the E-OBS database, there can also be inhomogeneities due to differences in the density of weather stations used for the interpolation. E.g. it is known that the density is much lower in Spain (at least the number of stations that were available for constructing the E-OBS dataset) than in The Netherlands and Germany. Although WMO has developed recommendations for climatological measurements long ago, it is difficult to avoid small differences/inhomogeneities between countries, since within the recommendations still small differences in measuring methods are possible. For cross-border projects in Europe the free availability of all climatological data would also help in getting more consistency between countries.

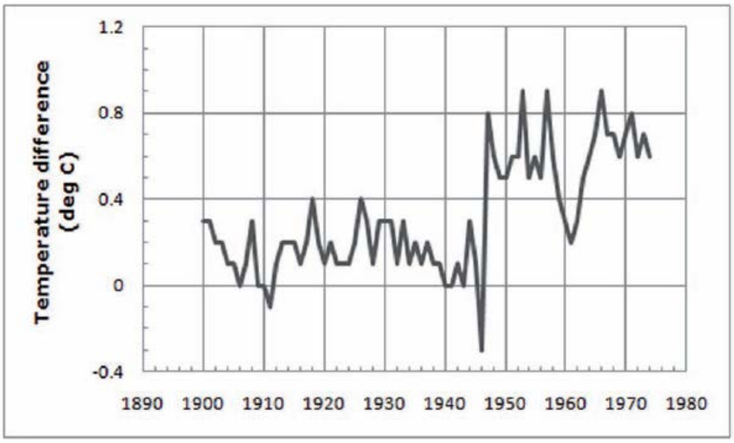


**Figure 4.5** Example of a dataset with inhomogeneity: changes/trends in climate data due to non-climatic factors (see also Par. 4.3.1; Source: WMO, 2011b).

When a dataset cannot be homogenized, possibly another data source can be used, e.g. model simulations. Simulations with climate models are generally not an option, since they contain biases that should be removed with measured data (that can be inhomogeneous), however, re-analysis data (simulations with a weather model and measurements) have much smaller or hardly any biases.

**Guideline: how to get consistent climate data with similar quality for all regions of Europe?**
Although observations of national meteorological institutes have to comply with international standards of WMO, there are some inhomogeneities between countries and measuring networks. When the required accuracy of the data is not extremely high, the existing inhomogeneities will not hamper cross border analysis too much.

European Climate Assessment & Database (ECA&D) is an effort to collect observational data from all European countries, and make them comparable for European wide analyses. Currently it is the dataset with the largest coverage in Europe. In case of cross border projects, this database is a good starting point for a quick scan. Re-analysis datasets are also an option to get consistent data for the current climate for Europe. It requires more expert knowledge to transform these data into maps and graphs, but time series are available for the whole of Europe. This makes re-analyses datasets less ready to use for a quick scan, but useful for detailed vulnerability studies (Par. 4.4.2).

### *4.4.3 Adjusting the length of a dataset*

Sometimes datasets are not long enough for e.g. analyses of extreme events[35]. Some techniques exist for making longer time series (Table 4.7). For some of these situations the use of an ensemble[36] (with more synthetic realisations of the same climate) might be a better option. Resampling techniques and statistical weather generators can also be used to generate more years with synthetic realisations of the same climate. Long observational time series may contain trends that hamper analyses. An ensemble for a shorter period created with e.g. a reanalysis can be useful for determining natural variability or the return times of extremes.

An example of the use of proxies is the use of sunshine hours per day to estimate radiation. The Angstrom formula[37] describes the relation between both. The parameters in this formula differ per location and may differ throughout the year. With the help of parallel measurements (some years) of both sunshine hours and radiation the parameters can be determined and radiation can be estimated for the period where only sunshine hour data are available.

[35] Several methods are available for determining e.g. the return times of extreme events. Often Generalized Extreme Value analysis (GEV) is used. For extremes with long return times long times series are needed, otherwise the uncertainty range will be very large;
[36] In Chapter 5 more information is given on ensembles;
[37] For more information see http://www.fao.org/docrep/x0490e/x0490e07.htm#radiation.

**Table 4.7** Some methods to produce longer time series: some advantages and disadvantages.

| Adjusting length dataset | Advantages | Disadvantages |
|---|---|---|
| Use of proxies | Uses known relations between climate variables | Quality depends strongly on relation between the desired variable and the proxy and the time period on which the relation can be based |
| Use of re-analysis data | Possibility to check the quality of the reanalysis data by comparing with the available measured data | Re-analysis data may contain biases, depends on the quality of the reanalysis<br>Re-analysis data give area-average data, this may be a complication for precipitation<br>Re-analysis available only for limited time period |
| Use of neighbouring stations with longer time series | When stations are close to each other and within similar environments, generally there is a strong relation with the data from neighbouring stations | There may be systematic differences between the stations (due to differences in altitude, geographical position, etc.)<br>Depends on the distance between the stations<br>The observations may not be independent |
| Use of statistical weather generator (or resampling) | Very long time series can be generated | Time series with considerable length needed to determine statistical properties<br>In the case of resampling no higher/lower values than in the observed time series can be obtained |

**Guideline: which methods are available to generate climate time series when no observations are available?**

When only a few observations are missing in a time series, estimations of these observations generally can be made by interpolation, using data from nearby stations or by using relations with other climate variables that were measured (proxies; Par. 4.4.1). When time series are missing partly or completely for a location, the use of proxies, neighbouring stations or re-analysis datasets (simulated climate in the past with a weather model integrating observational data) is an option (Par. 4.4.3).

### *4.4.4 Adjusting spatial and temporal resolution*

**Spatial resolution**

When a (gridded) climate dataset is too coarse (e.g. 20 by 20 km grids) one can interpolate to get e.g. a 1 by 1 km grid. However, *when no additional spatial information is used during the interpolation, the spatial resolution of the original data set does not increase* (it does not give more information on spatial differences)! By using information on altitude, distance from the sea or other large water surfaces, wind direction, etc. it is possible to increase the spatial resolution. Sometimes datasets for other climate variables with higher spatial resolution can be used too to increase spatial resolution. Relatively little measurements are available to check the quality of the interpolation, although the availability of radar and satellite data for recent decades can be used for that. Sometimes datasets for other climate variables with higher spatial resolution can be used too to increase spatial resolution: the network for precipitation measurements is much denser in many countries than for the other climate variables. In theory this could be used for increasing the spatial resolution of other variables when there is a clear relation with precipitation. Temperature, humidity and wind generally show gradual changes over a distance[38]. For precipitation this is different, especially for convective precipitation[39]. Simple interpolation between a station with and without precipitation would result in precipitation for all points between these stations. For longer time series it would result in time series for interpolated points with a much higher number of rainy days and much lower extreme rainfall or less days with extreme rainfall[40]. During interpolation of precipitation data these effects should be avoided. Examples of adapted techniques are available (e.g. Soenario & Sluiter, 2010).

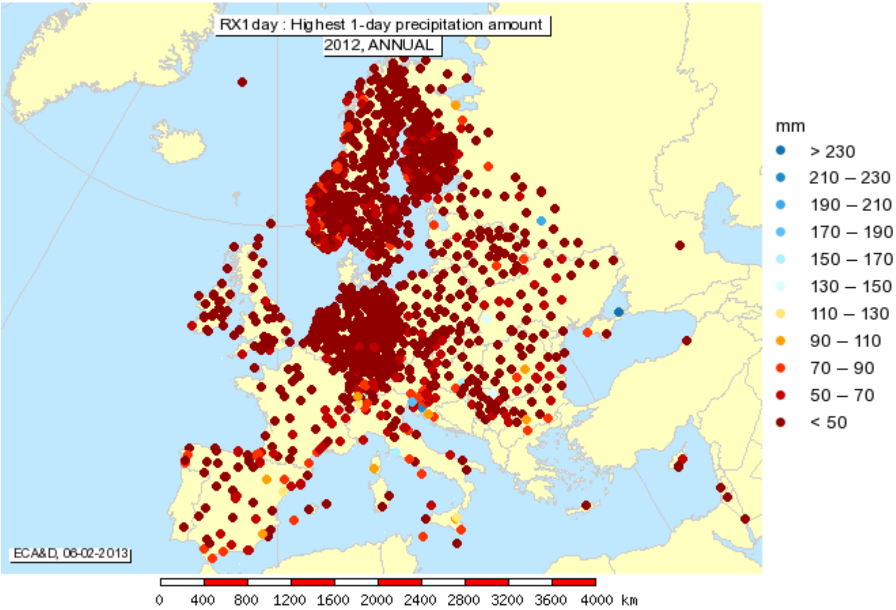


**Figure 4.6** Number of stations with information on the highest 1 day precipitation amount for 2012 in the ECA&D database: These stations are also used for the E-OBS gridded dataset: the spatial resolution is not the same for the whole of Europe since the number of available stations differs per region.

**Figure 4.7** Flooding of road surface after excessive rainfall.

[38] For the large scale. These variables can sometimes show spatial differences due to very local characteristics. The Urban Heat Island effect is a clear example of that.
[39] Convective rain, or showery precipitation, occurs from convective clouds. It falls as showers with rapidly changing intensity. Convective precipitation falls over a certain area for a relatively short time, as convective clouds have limited horizontal extent (http://en.wikipedia.org/wiki/Precipitation#Convection, 6-10-2014);
[40] To a much lesser extend this could also be true for radiation and cloudiness, which are related to rainfall.

In some cases re-analysis data can be used as an alternative when the existing spatial resolution of a data set is too coarse. However, the spatial resolution of existing re-analysis datasets is in the order of about 75 by 75 km[41]. Also regional climate model simulations could be used in some situations, although they are run often on relatively coarse resolutions (nowadays about 20 by 20 km). The main disadvantage of climate models simulations is that they simulate the climate and not the weather on specific days in the past. An example: if a climate model is good it will give the correct return time for dry years or cold winters, however, the cold winters and dry summers will probably occur in other years in the simulated runs than happened in reality.

**Temporal resolution**

For temporal resolution more or less the same things apply as for spatial resolution. Increase in temporal resolution can only be obtained when additional information is used; data sources with higher resolution may be used for this (e.g. radar, satellites, other stations). Climate model runs are often of limited value for increasing the temporal resolution. For resolutions higher than the daily level, often little information is available on the quality of climate model simulations.

Simple interpolation between daily values to get hourly values is in most cases useless, since most climate variables show daily cycles (temperature, humidity, radiation, wind) or are discontinuous over a day (precipitation). For the daily cycles a fixed average cycle can be applied. However, data sources such as radar, satellites and weather stations with higher temporal resolution may give information on deviations of this average daily cycle. In the case of precipitation there is no fixed daily cycle, but the mentioned data sources may still be useful to add information on the distribution of the precipitation over a day (especially rainfall radar data are useful for this).

Stochastic weather generators can also be used to increase e.g. the resolution form monthly to daily data. However, a lot of observation data at daily level are needed to determine the statistical relations in these generators.

**Accuracy**

In case of limited accuracy (e.g. wind speed in integer m/s values instead of values with decimals) also other data sources have to be used to increase accuracy. In theory proxies could be used, but for this purpose the relation between the climate variable and the proxy should be very strong to add accuracy. The use of re-analysis, climate models and weather generators has the same limitations as mentioned above for increasing the spatial or temporal resolution.

[41] For the ERA-Interim re-analysis at the equator.

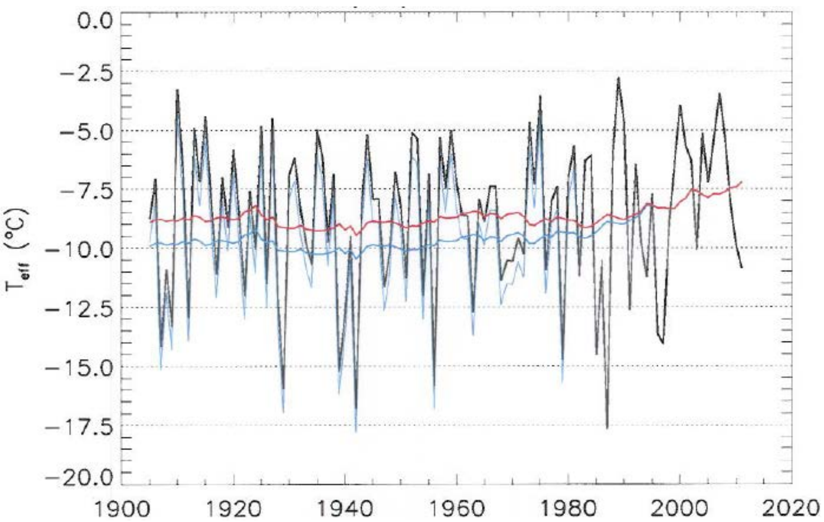


**Figure 4.8** Lowest effective temperature per winter for station De Bilt, the Netherlands. The effective temperature is the daily average temperature, corrected for wind speed. Black = yearly values based on observations; blue = 30-years moving average based on measured values of wind and temperature; red = 30-years moving average based on detrended values: the average temperature in winter in the period before 1976 is made equal to the average temperature in the period 1976-2005 (Wever, 2008).

### *4.4.5 Removing trends from time series*

When one wants to calculate return times of extremes such as the amount of daily precipitation that is exceeded once in 10 years or even rarer events, long time series are needed. Due to climate change (natural and human induced) time series of e.g. 100 years may contain trends in the averages and extremes. Statistics, however, often (implicitly) assume that the climate is stable, which means that no trends (at least not human-induced) should be present. For correct estimates of return times in the current climate, the basic time series should always be checked for trends and if present corrected for these trends: this is called detrending. Detrending consists basically of the following steps:

- Determine whether there are trends in the relevant climate variables. Relevant climate variables could be averages, extremes/percentiles, standard deviations, etc. or combinations of these variables. Trends in averages may not be the same as trends in extremes and trends in extremes are more difficult to detect;
- When there are significant trends, the trends should be removed using the statistical information on the magnitude of the trends and the time course of the trends (linear, exponential, etc.).

The detection of human-induced trends may be difficult to separate from natural variability[42]. Long homogeneous time series are needed to detect trends due to increase of GHGs. As stated before the use of 30-year periods often does not cover all natural variability, especially not for extremes. Detrending always includes the risk of decreasing the natural variability in a time series. Fig. 4.8 shows an example of detrending effective winter temperatures in the Netherlands.

[42] We do not want to remove natural variability, because this is a characteristic of a climate.

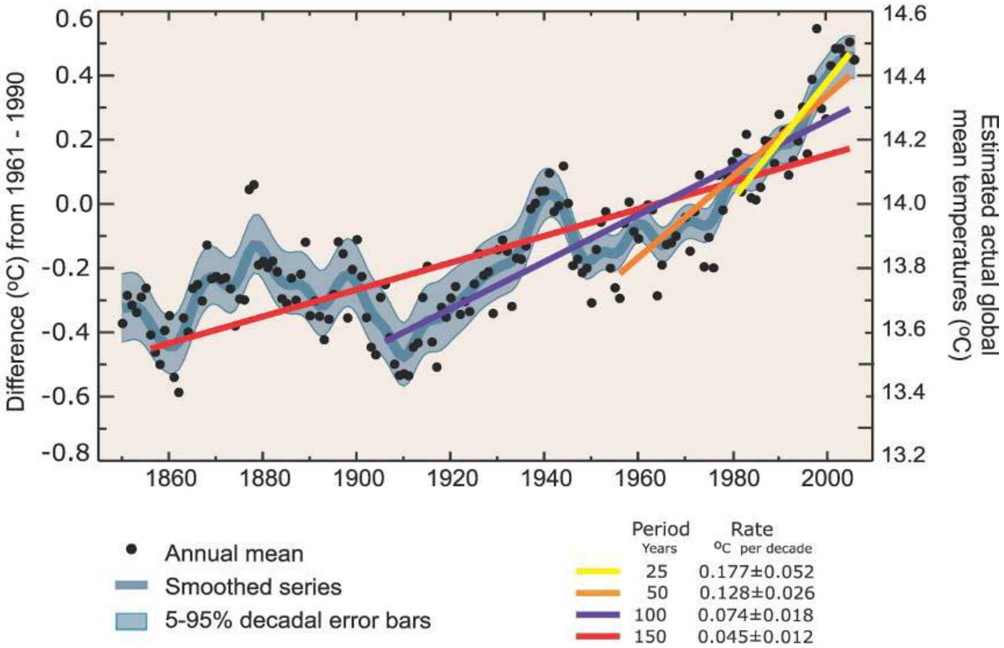


**Figure 4.9** Trends in global mean temperature and relation with length of period used: (linear) trends in long periods will mainly show human-induced effects, whereas shorter periods will show the combined effect of natural variability and human-induced effects (if one would look only at the period from 1998-now, one can also see a 'downward or no trend', but this is incorrect use and interpretation of climate data) (www.skepticalscience.com/global-warming-stopped-in-1998-intermediate.htm).

### *4.4.6 Changing (digital) format, making subsets/indices*

The formats in which many climate data[43] are delivered may not be the same as the formats or climate data which are used in the impact and adaptation modelling. Nowadays many climate/weather model data are delivered in a NETCDF-format; observation data from weather stations can be delivered in ASCII; sometimes observational data for precipitation are given in 0.1 mm instead of in mm. Some applications need gridded data, others need station data, the geographical projection used may differ. For several studies on ecosystems monthly or yearly values are used, whereas for road safety regularly precipitation is needed per 5-60 minutes.

**Changing (digital) format**

Formats often can be changed, although in some cases information may be lost: when changing the geographical projection some kind of interpolation of data is used. As discussed under increasing the spatial resolution this may lead e.g. to flattening off of precipitation extremes or inconsistencies when differences in altitude are not taken into account.

**Subsets/indices**

Indices or subsets can be produced from the basic climate data at e.g. daily or hourly resolution. Indices can be summations (e.g. yearly precipitation), averages (e.g. average season temperature), thresholds (e.g. number of days with higher/lower values). Within the ECA&D database many indices are predefined and calculated (http://eca.knmi.nl/indicesextremes/index.php; example in Fig 4.10). The processing of

[43] Time series of individual weather stations are often supplied as txt or ASCII files. For large spatial climate data sets, NETCDF is often used.

indices always includes some risks of including errors[44]. The ECA&D indices dictionary (http://eca.knmi.nl/indicesextremes/indicesdictionary.php) can be of help for producing indices that can be compared with other data sources. A core set of 26 indices follows the definitions recommended by the CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI) and additional indices are specifically defined for Europe. Note that new research (for specific applications such as road infrastructure) may lead to additional indices or changes in the indices definitions in the future.

When one needs other indices than predefined in ECA&D or when one wants to use other data sources, there are some tools available to do the processing. The Climate Explorer has several options to process data, including many statistical tests (which, however, require considerable knowledge on statistics to apply them well). Other tools are mentioned in the last paragraphs of this chapter. Processing datasets from individual weather stations can often be done within Excel or similar programmes. However, Excel is not sufficient for large gridded datasets.

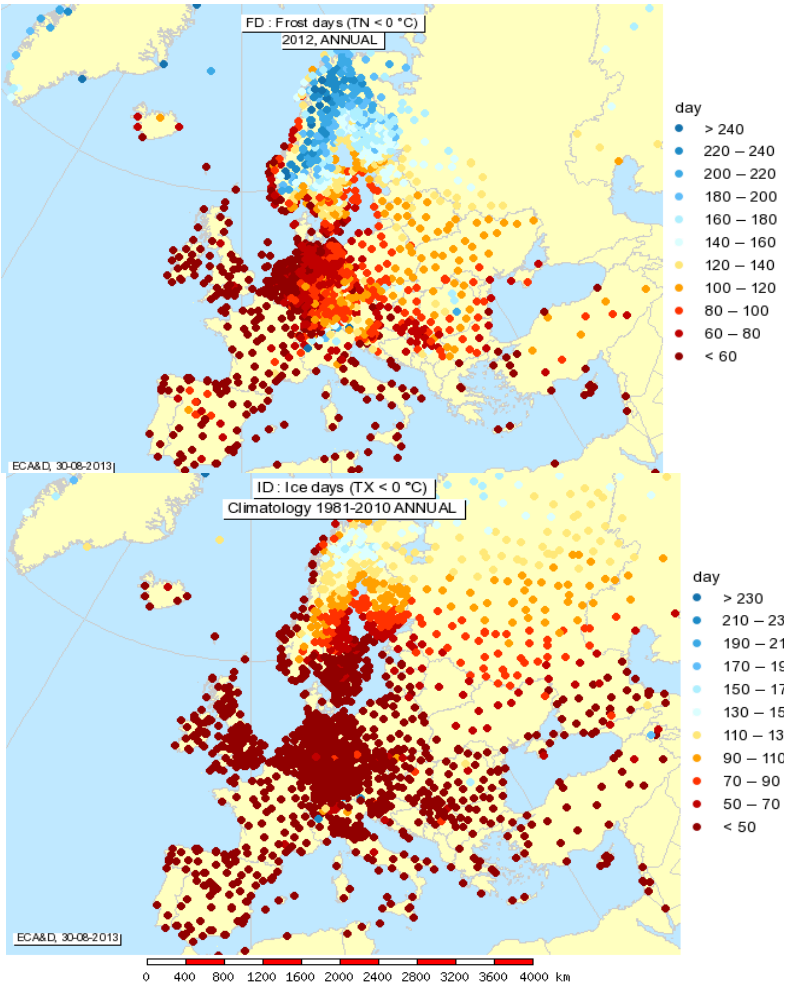


**Figure 4.10** Indices map: number of ice days (maximum temperature < 0 ˚C) in 2012 on weather stations in Europe (top) and the climatological average over 1981-2010 (lower panel) (Source: ECA&D database, 30-8-13).

[44] An example: ice days are defined as days where the maximum temperature is below 0 ˚C. When during the processing '≤' is used instead of '<' this will result in a different number of ice days.

**Something else available than required?**
In some cases, something else is measured than required:

- Wind speed was measured in the past in knots, but information is often needed in m/s;
- Wind speed is measured at 10 m height, but for wind turbines the wind speed at 100 m is needed;
- Air temperature is most often measured at about 2 m, whereas for road conditions the temperature at the road surface itself would be most useful.

Sometimes the measured information can be processed into the required information with or without additional climate variables. An example mentioned before is the estimation of radiation from sunshine duration; vapour pressure can be calculated from the relative humidity and the saturated vapour pressure at the given temperature, wind speed in knots can be transformed easily into m/s, etc. In other situations additional assumptions are needed, e.g. in the case of estimating the wind speed at 100 m height from data at 10 m height. The more relations with other climate variables are needed and the more assumptions, the higher the risk of loss of information or less accurate estimates.

### *4.4.7 Correction for systematic deviations compared to observations*

A bias is a systematic deviation of climate model output compared to observations (Fig. 4.11). To determine the bias of climate model output, a climate model run for the current climate is used and compared with observations. The term is used in case of model simulations, for weather as well as climate models. However, in the case of climate models the bias is generally larger, since simulation results are not constantly compared and adjusted with the help of measurements as in weather models (and re-analysis).

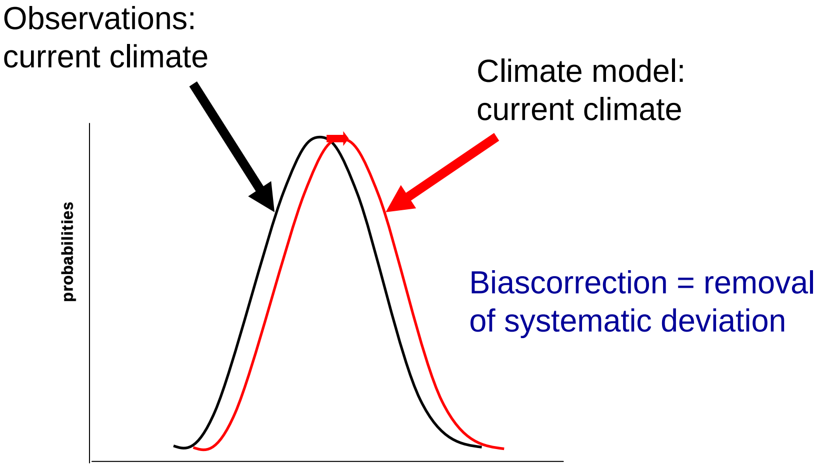


**Figure 4.11** Schematic presentation of climate model bias: the systematic difference between model output and observations.

When someone is interested only in the current climate, models are often not used, except sometimes re-analysis data (for which a weather model is used). In projects that are interested in the future, climate model results are used in most cases for the future *and* for the current or reference climate. Therefore, this subject is treated in more detail in Chapter 5. In Chapter 5 we will also treat bias correction of model data for the current climate and the differences with bias correction of model data for the future data. Bias correction (removal of the bias) is often needed before climate model data can be used in impact models, since many relations between climate and impacts are non-linear and impact models are often calibrated with observed climate data (for more information see Chapter 5).

### *4.4.8 Statistics*

As can be seen in the former paragraphs and chapters, statistics are used broadly in climate science, among others for calculating normals, for detecting trends, for quality control of measured data, for homogenization and detrending. It is a subject that is too broad to treat here comprehensively. WMO provides guidelines to use procedures for analysing climate data for climate change purposes as well as for other applications. This includes, inter-alia, analysis of extremes in a changing climate, the role of climatological normals in a changing climate and climate data homogenisation. Description of processes, methodologies and practices in climatology are provided within a the WMO guide to climatological practices. Also these documents are often not a comprehensive description of all methods, rather they treat key issues in the use of statistics for climate data (in the description of the current climate, trends, future climate). Several of these key issues have been treated shortly in the former paragraphs. In Par. 4.5 links are given to some important WMO documents on statistical analysis of climate data.

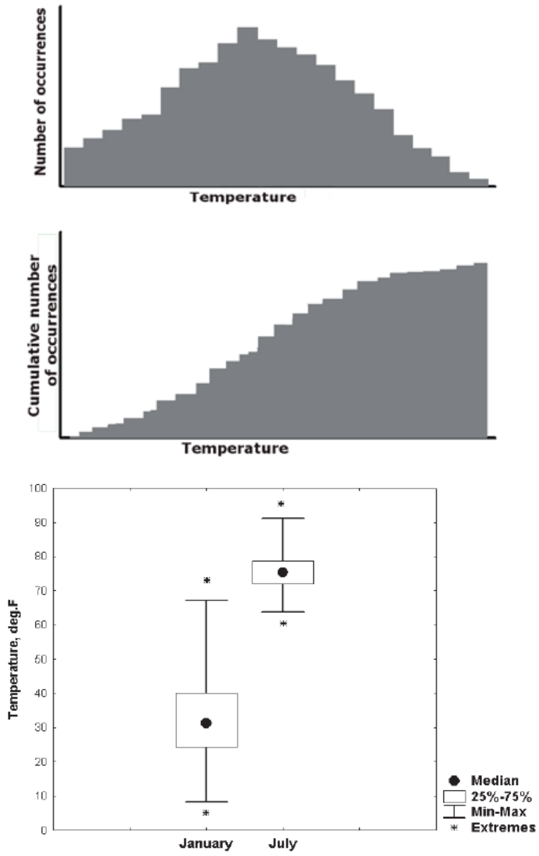


**Figure 4.12** Different ways to present statistical information on temperature. Top: Frequency distribution (histogram); Middle: Cumulative frequency distribution; Lower panel: box plot (WMO, 2011b).

When using statistics it should be realised that specific statistical assumptions concerning e.g. the consistency and homogeneity of the data or the nature of the dependence between observations, are implicit in all statistical analysis techniques. These assumptions should be clearly identified and assessed by the analyst, and the interpretation statistical results should be tempered by the extent to which the assumptions are satisfied (WMO, 2011b).

**Figure 4.13** Wildfire along road as a result of drought? (Source: K. van Muiswinkel)

## *4.5 Some useful links*

The links below are checked latest October 1, 2014.

**Climatological practices**

- WMO document on the analysis of extremes: A. M.G. Klein Tank, 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. www.wmo.int/pages/prog/wcp/wcdmp/wcdmp_series/documents/WCDMP_72_TD_1500_en_1.pdf
- WMO document on climatological normals in a changing climate: O. Baddour and H. Kontongomde (Eds), 2007. The role of climatological normals in a changing climate. WCDMP-No. 61, WMO-TD No. 1377. www.wmo.int/pages/prog/wcp/wcdmp/documents/WCDMPNo61.pdf
- WMO-document on climatological practices: WMO, 2011b. Guide to Climatological Practices. WMO-No. 100 (third edition). www.wmo.int/pages/prog/wcp/ccl/documents/WMO_100_en.pdf
- WMO some introduction on normals and problems with statistics: www.wmo.int/pages/themes/climate/statistical_depictions_of_climate.php (among others information on inhomogeneities)
- WMO Climate Data, Management and Exchange: www.wmo.int/pages/themes/climate/climate_data_management_exchange.php
- WMO, 2008. Guide to Meteorological Instruments and Methods of Observation. WMO-No. 8. www.wmo.int/pages/prog/gcos/documents/gruanmanuals/CIMO/CIMO_Guide-7th_Edition-2008.pdf
- World climate services programme. Climate Applications and Services: www.wmo.int/pages/prog/wcp/wcasp/seriespubs/index_en.html
- Courses for WMO-members: www.met-elearning.org/moodle_v2/

**Data sources**
See the links in Table 4.2. Here a few additional links are given.

- Links mentioned at the ECA&D website to Norwegian, German, Italian, Dutch and GCOS data: http://eca.knmi.nl/publications/index.php#other
- WMO: www.wmo.int/pages/themes/climate/climate_data_and_products.php. Links to websites with climate normals, world weather records, world weather and climate extremes, global surface temperature and precipitation data sets, and other datasets. Climate Normals can be found on the World Climate Data and Monitoring Programme (WCDMP) website
- NOAA: http://www.ncdc.noaa.gov/data-access/quick-links#ghcn. Contains a.o. information on climate normals for the period 1961-1990, Global Historical Climatology Network (GHCN-Monthly V.2), Monthly Climatic Data for the World
- Real climate: www.realclimate.org/index.php/data-sources/
- Global Precipitation Climatology Centre and Global Runoff Data Centre (Germany): through EURO4M-portal
- IPCC Data Distribution Centre: www.ipcc-data.org/observ/index.html

**Data quality, validity and processing**
See also the 'WMO Guide to climatological practices' under 'Climatological practices'

- International project on homogenisation www.homogenisation.org/v_02_15/. Two new software packages: HOMER (for monthly data) and HOM/SPLIDHOM (for daily data). The website also contains links to the results of the working groups: D.1. Inventory of existing homogenisation methods and benchmark dataset preparation; D.4. Methods for homogenisation of daily data; D.5. Presentation and release of the new common method.
- Domonkos, P, V. Venema, I. Auer, O. Mestre and M. Brunetti, 2012. The historical pathway towards more accurate homogenisation (www.euro4m.eu/Publications/Domonkos,%2011thEMS,%20The%20historical%20pathway%20towards%20more%20accurate%20homogenisation.pdf). Published in Adv. Sci. Res., 8, 45-52, 2012; doi:10.5194/asr-8-45-2012.
- Aguilar, E., I. Auer, M. Brunet, T.C. Peterson, and J. Wieringa (2003), Guidance on metadata and homogenization, *WCDMP*, No. 53, WMO-TD No. 1186, pp. 51. www.wmo.int/pages/prog/wcp/wcdmp/wcdmp_series/documents/WCDMP-53.pdf

**Visualisation**
Visualisation can play an important role in the understanding of the current climate, climate change and the (correct) interpretation of climatological data and it can play an important role in bridging the gap between climate (impact) scientists and decision makers. A lot has been written about it, and although it is not treated explicitly in the text belowe give some links that may be useful.

- IPCC visualisation tool: www.ipcc-data.org/ddc_visualisation.html
- ECA&D tools for visualisation of indices of extremes, climate normals, etc.: http://eca.knmi.nl/
- Climate Explorer tool: http://climexp.knmi.nl/start.cgi?id=someone@somewhere
- Autumn school on 'Dealing with uncertainties', day 3 also with presentations on visualisation of uncertainties: http://www.knmi.nl/klimaat/autumnschool2012/
- Nocke, Th., T. Sterzel, M. Bottinger & M Wrobel, 2012. Visualization of Climate and Climate Change Data: An Overview. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.157.2130&rep=rep1&type=pdf

# 5 Future climate

## Summary and main questions

For adaptation to climate change climate data are needed to investigate the effect of climate change and possible adaptation measures. Of course, no observational data are available for the future. Data and information on projected changes are obtained with the help of climate models or for the nearby future by extrapolating current trends.

**Definitions** (Par. 5.1.1)
An **ensemble** is a group of parallel model simulations used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty. Since climate model output is often spatially too coarse for impact studies downscaling is needed. **Downscaling** covers all techniques that increase the spatial or temporal scale.

**Which time horizon to use in vulnerability studies?**
The time horizon used in a vulnerability study should take into account (Par. 5.1.2):

- The expected life cycle of the structure (it should still function sufficiently at the end of its life cycle);
- The time until replacement of existing structures (how fast can you adapt).

**Which climate model data and climate scenarios are available?**
Table 5.1 gives sources of climate model data for the future (and past) for Europe that include data from more than one global climate model (GCM) or Regional climate model (RCM) and that can be used for vulnerability studies. Some climate model data are only available for non-commercial research and educational purposes.

Table 2.4 gives information on where information on regional climate scenarios for various European countries can be found. Table 2.5 gives more information on some of these scenarios and Fig. 2.13 compares the ranges of precipitation and temperature change that are spanned for winter and summer by a limited number of climate scenario sets.

**How to determine climate change from climate model data?**
For a fair comparison, the results from the climate model projections for the future should be compared with the results from the climate model projections for the current climate and not directly with observational data for the current climate due to the bias in climate model data (Par. 5.4.1).

As a consequence, to generate climate data as input for vulnerability studies on climate change, one generally needs three types of climate data:

- Observed climate data for you region of interest;
- Climate model data simulated for the same period covered by your observed data;
- Climate model data simulated for the future.

**Can climate change be detected within 5-10 years?**
Since climate is variable and often described with data from about 30 years, this means that significant climate change is not detected within 5-10 years or even longer (Par. 5.1.1).

**Can one projection or scenario be used for impact analysis?**
The user of climate projections or climate scenarios should not trust in the results of only one climate projection or scenario for impact analyses, as there is no such thing as 'best GCM', 'best RCM' or 'best climate scenario'. Therefore, it is advisable to make use of a group of projections (ensemble) or a set of climate scenarios. Depending on which uncertainties one wants to take into account a different ensemble should be selected (Table 5.2).

**Which methods are available for downscaling?**
Downscaling is a general concept that embraces various methods for increasing the spatial resolution. There are two fundamentally different approaches to this:

- Dynamical downscaling makes use of a Regional Climate Model (RCM) having higher spatial resolution;
- Statistical or empirical downscaling uses observations on both scales to estimate the link between them.

Par 5.4.3 describes various statistical downscaling techniques. Fig. 5.9 presents schematically the relation between downscaling techniques, bias correction (Par. 5.4.4) and methods to generate time series for the future (Par. 5.4.5).

**Which downscaling method to use?**
Empirical or statistical and dynamical downscaling techniques all have their advantages and disadvantages. The advantages and disadvantages mentioned in Par. 5.4.3 may help in making a selection. RCMs require substantial computational resources. Therefore, hardly ever simulations can be made specifically for a project on road infrastructure and one has to rely on available downscaled projections (about 25 * 25 km nowadays). As long as climate models still have large biases, it cannot be said that empirical downscaling methods are less preferred.

Be aware that the downscaling methods themselves also cause new uncertainties. To see the effect, it is recommended to use both empirical and dynamical downscaling techniques.

**Why should model biases (systematic deviations compared to observations) be removed before use in impact models?**
Many impact models contain one or more non-linear relations with climate variables and they are often calibrated with observational data for climate. Climate model data always contain biases (systematic deviations of reality). Therefore, using uncorrected climate model data may result in overestimation or underestimation of the impacts (e.g. Fig. 5.5).

**How to determine model bias (systematic deviations of reality)?**
Model bias (systematic deviation between the model output and reality) can be determined by comparing the **statistics** of observational records for a certain period (often 30 years) with the simulated climate for the same period in the past (Par. 5.4.2).

**Which method to use for removing systematic deviations?**
Depending on the aim of the impact study, other bias correction methods may be most suitable for representing the relevant climate parameters correctly. This also means that a bias correction performed for one impact study is not necessarily suitable for another impact study!

In most cases especially climate extremes cause threats to road infrastructure and the extremes do not necessarily change in the same way as the averages (even the sign of change is sometimes different). In that case more advanced methods for bias correction should be used. Dalelane (2014) gives a summary of various bias correction methods and techniques and some advantages and drawbacks (Par. 5.4.4).

**Which methods are available to generate time series for the future from climate model information?**
Basically there are 3 main methods for generating time series for the future from GCM's or RCM's (Table 5.3):

- Delta-method: applies climate change signals from climate model(s) to historical time series;
- Direct method: corrects for biases in climate model output with the help of observational historical time series;
- Stochastic weather generators: uses statistical properties/relations between climate variables to generate time series. For the future climate change signals from climate model(s) are used to adapt these relations (Par. 5.4.5).

**Which method to use for generating time series for the future?**
Which method is best or can be used depends among others on the requirements for the impact study, available climate data and available time. Table 5.3 describes various characteristics of these methods (advantages and disadvantages) and this may help in the selection of the method. As long as climate models still contain large biases it cannot be stated that the direct methods are better than the other methods (Par. 5.4.5).

## 5.1 The future climate and the time horizon

As indicated in Chapter 2 for different users different time horizons are relevant. But how is a time horizon defined in climate science, and e.g. what is the long term and short term? This is not trivial, since in other sectors these terms are often used with different meanings. Therefore, in this paragraph we pay attention to this. In Chapter 2 already some definitions of terms used in relation to climate change were given. In this Chapter we will give some more information on the methods used to analyse and process climate data for the future. Therefore, first some additional definitions are given of terms that will be used regularly in this chapter.

### 5.1.1 Some additional definitions

**Time horizon** When a time horizon is given as one year, it refers to the climate around that year. E.g. 2050 refers to the 30 or 20 years around 2050. In parallel with this definition the period 1981-2010 would describe the climate around the year 1995 and for the climate around 2010 we would need 1996-2025 or 2001-2020)[45]. Since climate is variable and often described with data from about 30 years, this means that significant climate change is not detected within 5-10 years or even longer. Therefore, in climate science 10 years ahead is considered 'short term', although for many users this is 'long term'.

[45] Sometimes also a different description is used: than (implicitly) the climate of 1990 is described with the period 1961-1990 (we do more or less the same for the 'current climate' for which we use the past 30 years to describe it).

**Guideline: can climate change be detected within 5-10 years?**
Since climate is variable and often described with data from about 30 years, this means that significant climate change is not detected within 5-10 years or even longer (Par. 5.1.1).

**GCM (General Circulation Model):** Numerical model representing physical processes in the atmosphere, ocean, cryosphere and land surface simulating the response of the global climate system to increasing greenhouse gas concentrations. GCMs depict the climate using a three dimensional grid over the globe (see also 'climate model' in Par. 2.2.1). GCMs may simulate quite different responses to the same forcing simply because of the way certain processes and feedbacks are modelled (source: Data Distribution Centre IPCC website).

**Regional Climate Model (or RCM):** The nested regional climate modelling technique consists of using initial conditions, time-dependent lateral meteorological conditions and surface boundary conditions to drive high-resolution RCMs (Fig. 5.1). The driving data are derived from GCMs (or analyses of observations: reanalysis) and can include GHG and aerosol forcing (IPCC, 2001). Currently many RCMs for Europe have a spatial resolution of about 25 by 25 km. As can be seen in the figure below 'regional' in RCMs refer regions as large as Europe or a large part of Europe.

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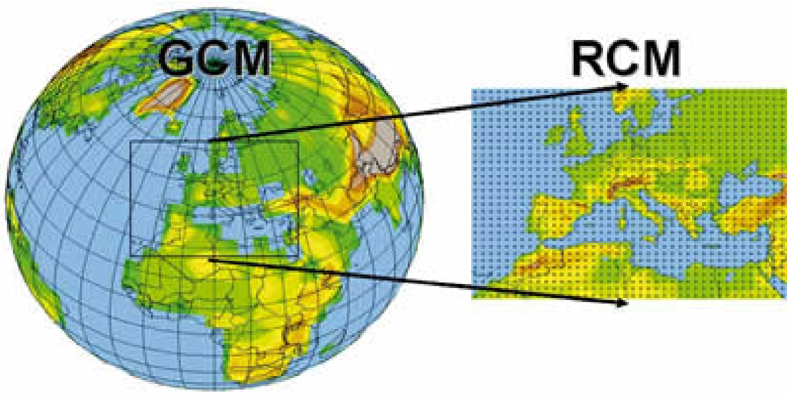


**Figure 5.1** Schematic depiction of the Regional Climate Model nesting approach (Giorgi, 2008).

**Ensemble:** A group of parallel model simulations used for climate projections and to characterize climate variability[46]. Variation of the results across the ensemble members gives an estimate of uncertainty. More information on the various types of ensembles is given in Par. 5.4. Fig. 5.2 gives an example of an ensemble.

[46] Ensembles are also used for weather forecasts. In that case a weather model is run with slightly different initial conditions or slightly different parameters.

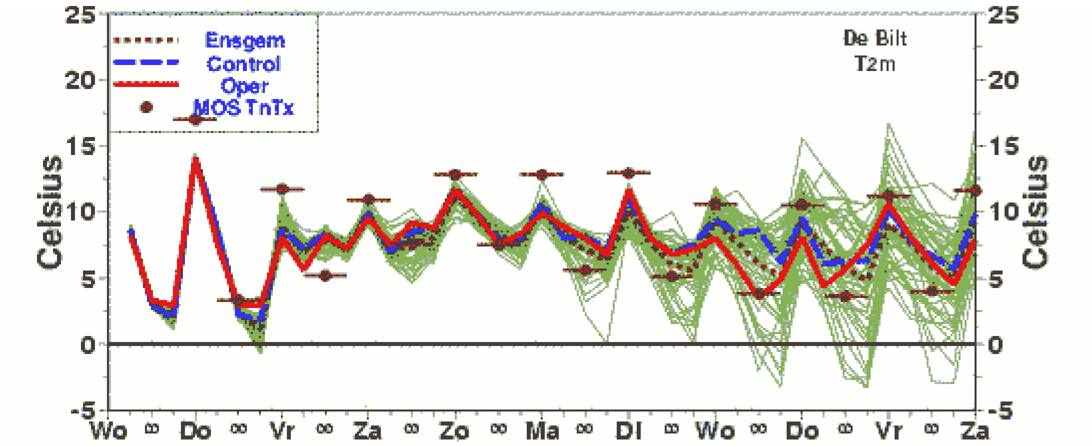


**Figure 5.2** Example of an ensemble: Ensemble forecast of ECMWF from March 13, 2014 for temperature for the Netherlands starting at Wednesday 12), as used on the KNMI-website (Source: ECMWF/KNMI).

**Model bias and bias correction:** See Par. 4.4.7.

**Downscaling:** covers all techniques that derive regional or local scale climate from the continental scale (large scale) evolution of the state of the atmosphere over several decades. The impact of climate change is mostly experienced at the regional or local scale, therefore it is necessary to have local scale climate change (Matulla & Namyslo, 2013a). More information is presented in Par. 5.4.

For most purposes the IPCC projections are still too coarse and more detailed information is needed. Various downscaling techniques can be used; one of them is dynamical downscaling with an RCM (Chapter 5). Fig. 5.3 gives an idea of the spatial resolution of various climate and weather models.

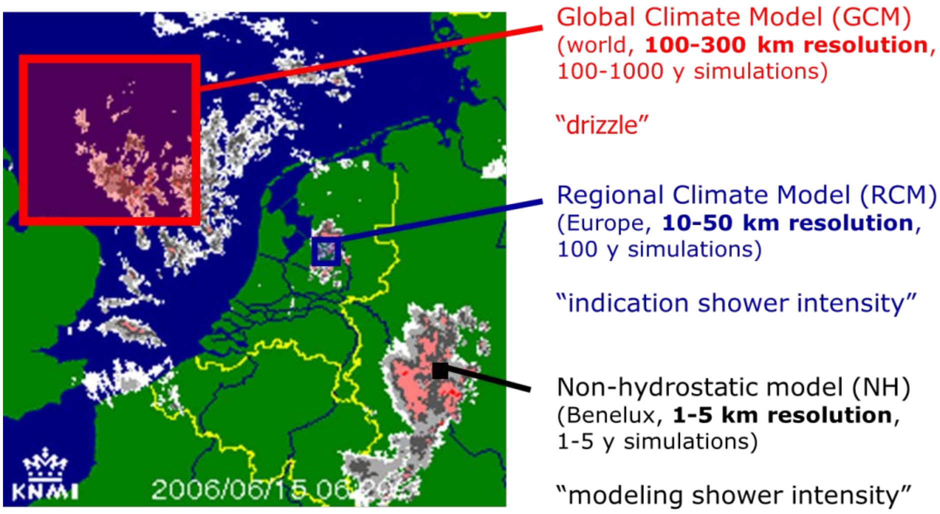


**Figure 5.3** Grid size in various climate and weather models and the type of processes that can be represented explicitly (Source: KNMI, Geert Lenderink).

**S2D predictions (Seasonal to decadal predictions):** Forecast of the weather/climate at seasonal to decadal time scales. Research on S2D predictions tries to improve forecast quality among others by better initialization of the simulation models and by increasing the spatial resolution. For large parts of Europe the skill[47] of weather models for more than some weeks ahead is not or hardly better than long term average climatology. However, in regions with e.g. El Niño and La Niña it is known that predictions on deviations from the long term average climatology have skill.

**Transient climate projections or scenarios:** Projections or scenarios in which the GHG concentration changes gradually and in which the gradual change of the climate is simulated (e.g. from 1950 to 2100).

**Definitions: ensemble and downscaling** (Par. 5.1.1)
An **ensemble** is a group of parallel model simulations used for climate projections. Variation of the results across the ensemble members gives an estimate of uncertainty.

**Downscaling** covers all techniques that increase the spatial or temporal scale.

### *5.1.2 What time horizon to use?*

To make a choice on the time horizon or time horizons to use in a climate change impact study, check for the following aspects:

- Life cycle of the adaptation measure/structure: when you construct something that has to last for a long time, take this into account and take a longer time horizon. E.g. the pipes of sewerage systems stay in the ground for 40-80 years (in the Netherlands). Also at the end of their life cycle they should be able to drain the water of intense precipitation events (expected to increase in most of Europe). The same is true for bridges and tunnels before they are replaced or adapted. Road coatings are replaced far more often (every 10-20 years or more often depending on the material and the traffic load) Therefore, the time horizon to take into account is the starting time of construction plus the expected life time (for a new sewerage system somewhere between 2050 and 2100);
- How fast can you adapt to changes: some adaptation measures take a lot of time and money before they are implemented (e.g. increasing dike height along coasts or rivers), whereas other adaptation measures may be implemented fast and/or cost relatively little money (e.g. take an alternative route in case of very local flooding of a road or tunnel). Sometimes it depends also on the life cycle how fast adaptation measures can be taken. When a structure is close to the end of its life cycle, the replacement can be anticipated and combined with adaptation.

**Guideline: which time horizon to use in vulnerability studies?**
The time horizon used in a vulnerability study should take into account (Par. 5.1.2):

- The expected life cycle of the structure (it should still function sufficiently at the end of its life cycle);
- The time until maintenance or replacement of existing structures (how fast can you adapt).

[47] Model skill: how well is a weather model able to forecast the weather? This is determined by comparing the forecast for a certain day with the actual observed weather on that day. In case of a climate model the skill is determined by comparing the statistics of various observed climate variables with the simulated climate variables (the difference is called the bias).

**Figure 5.4** Damage to road surfaces due to weather influences (Source: Matulla & Namyslo, 2014a).

## 5.2 Climate data sources for the future climate

In principle there are 2 ways of getting climate data or information for the future:

- *Extrapolations of observations*: long-term trends in the change of climate variables can sometimes be extrapolated to the future, but, in general, not more than about 10-20 years ahead, since trends in climate change are not necessarily linear. For extrapolation there should be some idea about the underlying cause of the observed trend[48]. Natural variation may also cause the climate change to deviate from observed (and projected) trends at time scales of 10-20 years ahead;
- *Climate model simulations for the future* (and current climate[49]): this is by far the most used data source, especially for time horizons beyond 2030. Climate model simulations for the future can be used in different ways (some more information on the methods is given later on in this chapter):
  - Model data can be used directly in impact and adaptation studies (but the bias is often too large for direct use, not recommended);
  - Climate model data can be used after processing (downscaling and bias correction);
  - Only the changes between the climate model simulations for the current and future climate are used to generate time series for climate variables for the future based on observational time series.

Table 5.1 gives some sources of climate model data for the future (and past) for Europe.

Individual NMHI's or research institutes also may have climate model data, however, Table 5.1 list some sources with data from more than one GCM or RCM. In Chapter 2 already an overview was given of the climate scenarios for several European countries.

[48] An example: the temperature in north-western Europe has increased in the past 50 years with a rate that is about twice the global temperature increase. It is thought that this faster increase is partly due to the air becoming cleaner (Van Oldenborgh et al., 2008). However, the air in north-western Europe cannot become much cleaner in the future and therefore, the increase in temperature may level off compared to global temperature rise;

[49] One often needs three types of climate data to produce datasets for the future for impact studies: 1. Observed climate data for the region of interest; 2. Climate model data simulated for the same period covered by your observed data; and 3. Climate model data simulated for the future.

**Table 5.1** Climate model data sources for Europe: climate model output for the past and future[A].

| Type of data | Explanation | Area | Period | Link |
|---|---|---|---|---|
| CMIP5: GCM data | Most recent runs of a large number of GCMs, basis for IPCC AR5 | world | 1950-2100 or 1950-2050 | http://cmip-pcmdi.llnl.gov/cmip5/data_portal.html |
| EURO-CORDEX: RCM data, using CMIP5 | Most recent runs of a large number of RCMs for Europe | Europe ~ 27N – 72N, ~338W – 45E | Control: 1951 – 2005 (1981 – 2010, 1951-80) - Scenario: 2006 – 2100 (2041-71, 2011-40, 2071-2100) | http://cordex.dmi.dk/joomla/ |
| Climate Explorer: observations, re-analysis and GCM and RCM data | Time series for the past/current climate Climate model output for the current and future climate (many different climate models) Re-analysis model data Tools visualisation, statistical processing, etc. | Europe, world | variable | http://climexp.knmi.nl/start.cgi?someone@somewhere (data from projects such as ENSEMBLES, CMIP5 etc. included or will be included) |
| ENSEMBLES: GCM and RCM data (GCMs: CMIP3) | Older than CMIP5 and CORDEX Climate model data, time series Tools for processing data | Europe | 1951-2050 or 2100 | http://ensembles-eu.metoffice.com/data.html |
| IS-ENES GCM (CMIP5), RCM and other data (re-analysis, E-OBS) | Portal with access to various datasets like ESSENCE GCM data and downscaled data from CERFACS, CMIP5 data, NCEP, E-OBS, etc. | Europe, world | variable | http://climate4impact.eu/impactportal/data/basicsearch.jsp |
| KLIWAS RCM ensemble, | Bias corrected RCM's | Central Europe | 1960 – 2100 | www.kliwas.de/KLIWAS/DE/05_Datenmanagement/csw_node.htm |

[A] The results of climate models always contain biases. Biases are systematic deviations from the reality: systematically too high or too low values, bias in statistics, etc.

### 5.2.1 *Availability of the climate model data*

All model output in the CMIP5 archive is available for 'non-commercial research and educational purposes.' A *subset (about half)* of the data has also been released for 'unrestricted' use (http://cmip-pcmdi.llnl.gov/cmip5/terms.html). WCRP encourages modelling groups to provide their CORDEX data for both commercial and research purposes, but modelling centres may decide to restrict the use of their data to 'non-commercial research and educational purposes.' Users registering to access CORDEX output will be granted access to some or all of the data, depending on their affiliation.

In the project VALUE (Validating and Integrating Downscaling Methods for Climate Change Research) a network is established to systematically validate and improve downscaling methods for climate change research. The ENES-project is developing a portal to access climate model data for, among others, impact researchers (www.climate4impact.eu).

**Overview: available climate model data sources and climate scenarios**

Table 5.1 gives sources of climate model data for the future (and past) for Europe that include data from more than one Global Climate Model (GCM) or Regional Climate Model (RCM). Some climate model data are only available for non-commercial research and educational purposes.

Table 2.4 gives information on where information on regional climate scenarios for various European countries can be found. Table 2.5 gives more information on some of these scenarios and Fig. 2.12 compares the ranges of precipitation and temperature change that are spanned for winter and summer by a limited number of climate scenario sets.

## 5.3 Data quality and usefulness

Most factors mentioned in Chapter 4 are also valid for climate data for the future, directly or indirectly. Since historical observations are often used for determining biases or as the basis for constructing time series for the future, factors such as missing data, inhomogeneities, consistency can also be relevant for generating time series and indices for the future. In this paragraph we will treat some additional factors affecting data quality and validity.

### 5.3.1 Model skill and systematic deviations compared with observations

The quality of climate data for the future cannot be checked in a direct way (no observational data set available!). Therefore, the quality of climate model data for the future is checked in an indirect way. Climate model data from runs for the current/past climate are compared with observational data (for all relevant climate variables, which could be averages, extremes and variability). This gives an idea of the *skill* of a model to simulate the current/past climate. The skill indicates how well the current/past observed climate is simulated with the climate model (the deviation is called *bias)*. All runs for the current/past climate contain some bias, e.g. systematic differences between the simulated results and the observations (Fig. 4.11).

Climate model biases can be due to, among others:

- Limited spatial resolution in the climate model (horizontal and vertical);
- Simplified physics and thermodynamic processes;
- Numerical schemes (parameterisation);
- Incomplete knowledge of climate system processes.

A complication for this comparison between observed and simulated climate is that climate models produce area-average data, whereas most observations are point measurements. For determining the skill climate model data should be compared with area-average data, otherwise an incorrect impression can be obtained from the skill of the model[50]. Subsequently, it is assumed that the skill or bias for the future climate is the same as for the current climate[51]. *When the skill is good for the current climate, we generally have more confidence in the results for the future.*

There is a substantial and systematic difference in spatial scale and representativity between grid cell data and meteorological point measurements. Climate model data are in the form of

[50] For this purpose e.g. the E-OBS dataset is developed from point observations from a large number of stations in Europe and some countries outside Europe (www.ecad.eu/download/ensembles/download.php);
[51] This is not necessarily true, however, it is the only option to do.

*grid cell averages* (=area-average; essentially one number per grid cell, or divided per land surface tile), where the area of a GCM grid cell is in the range 10000–90000 km$^2$ (100–300 km resolution) and an RCM grid cell 100–2500 km$^2$ (10–50 km resolution). Meteorological measurements from weather stations are often *point measurements* that are strictly representative for a small area surrounding the measurement site. Depending on the spatial variability of the variable measured the representative area is more or less extended. For example, atmospheric pressure reduced to sea level is a spatially smooth variable and measurements taken at one point are representative for a relatively large surrounding area. Convective precipitation[52], on the other hand, is highly variable both in time and space. Translating spatial variability to uniform model grids results in smoothing local extreme values more than the less extreme values that are closer to the large scale average conditions. It is important to keep in mind whether the meteorological observation data are station data or whether they have been transformed into gridded observations data through some interpolation method (http://climate4impact.eu/impactportal/help/faq.jsp?q=resolution).

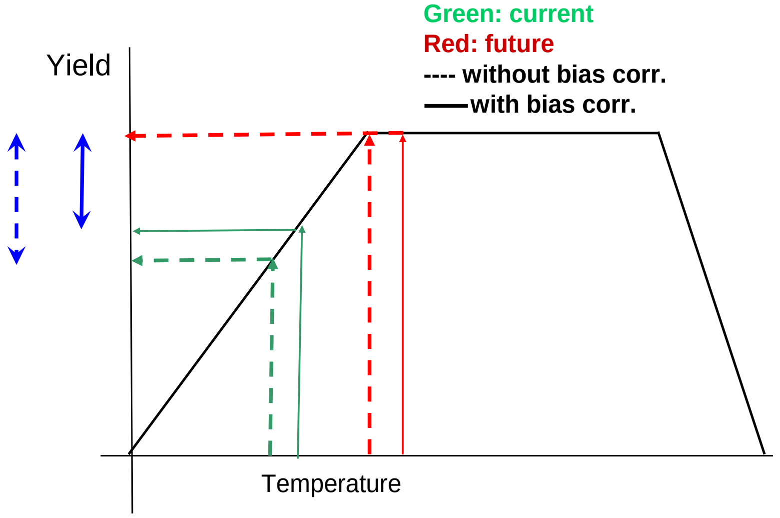


**Figure 5.5** Schematic example of the possible effect of climate model biases on the estimation of the impact of climate change. The climate model output has a systematically too low temperature.

**Why remove systematic deviations in climate model output before use in impact models?**

For most applications in impact studies, model biases have to be removed before climate model data can be used. Many impact models contain one or more non-linear relations with climate variables and they are often sensitive to the absolute values of climate variables. E.g. when a tunnel will flood in case there is more than 80 mm of precipitation within a day, and daily precipitation values are systematically too low in a ‘raw’ climate model run, than the number of events with flooding will be systematically underestimated when using the ‘raw’ model data. Regularly, it is assumed that if the bias is the same in the simulation of the current and the future climate, one can use the ‘raw climate model data’ in impact modelling and that the difference gives a good estimate of the change of impact. Fig. 5.5 gives an example where this is not the case: the model bias in the ‘raw climate model data’ affects the estimate of the impact. Due to the non-linear relations this effect may occur very often.

[52] Convective rainfall: the very local rainfall often observed especially in summer. Since this rainfall is highly variable the network of precipitation measurements is often more dense than for other climate variables.

Biases increase with altitude (Haslinger et al., 2012). Precipitation sums are largely underestimated (up to -20% south of the Alpine ridge) and overestimated (up to 40% North of the ridge). Differences are most pronounced within the complex terrain of the Alps where overestimations of 70% and more are to be found. Similar evaluations have been performed for heat waves (Vautard et al. 2013).

**Guideline: why should model biases be removed before use in impact models?**
Many impact models contain one or more non-linear relations with climate variables and they are often calibrated with observational data for climate. Climate model data always contain biases (systematic deviations of reality). Therefore, using uncorrected climate model data may result in overestimation or underestimation of the impacts (e.g. see Fig. 5.5).

### *5.3.2 Spatial and temporal resolutions*

Most global climate models have resolutions of about 100 km nowadays. This means it is difficult to compare model results directly with observations. A climate model will distribute the simulated precipitation equally within a grid box. The topography is also described as a mean value inside a grid box of a climate model. (http://climate4impact.eu/impactportal/help/faq.jsp?q=uncertainties_climate_models). The simulated area-average precipitation amount can be the same as in reality, but the intensities and spatial distribution can be very different.

Data from a GCM usually have a temporal resolution that ranges from 6-hourly data to monthly means (or other statistics). For a regional climate model (RCM) the temporal resolution is often 3-hourly (sometimes even higher resolution is saved) up to monthly values. For some variables also the highest and/or lowest value of any single time step during a day is stored. Common examples of this are daily maximum and minimum 2-metre temperature, and daily maximum wind speed at 10 metres (http://climate4impact.eu/impactportal/help/faq.jsp?q=resolution). Most evaluations of model skill or bias take place at temporal scales of daily up to yearly values. This means that the skill of sub daily values is often not known. Due to the limited amount of sub-daily observational data it is also difficult to determine this skill. An example of checking the model skill for hourly precipitation is given by Lenderink & van Meijgaard (2010).

### *5.3.3 Data format*

**Number of days per year in climate models**

In the simplified world that climate models represent the Gregorian calendar of 365/366 days is not always used. For historic reasons some GCMs have been set up to have a 'simpler' calendar. Some models omit the leap day and use a calendar of 365 days. And a few models use a 360 day calendar in which each month is assumed to be 30 days (http://climate4impact.eu/impactportal/help/faq.jsp?q=alternative_model_calendars).

**Data format**

All the input and output fields of climate models and pre-processor programs (e.g. the ones providing interpolated initial and boundary conditions) are stored in GRIB or NetCDF format.

- *GRIB format:* GRIB is a data format, commonly used in meteorology, to store historical and forecast weather data. GRIB means 'GRIdded Binary' and is designed for the international exchange of processed data, in the form of grid-point values expressed in binary form. The GRIB-code is part of the FM-system of binary codes of the World Meteorological Organization (WMO). The first edition is used operationally worldwide by most meteorological centres, for Numerical Weather Prediction output (NWP). A newer generation has been introduced and data is slowly changing over to this format;

- *NetCDF format.* NetCDF means Network Common Data Form. It is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. The University Corporation for Atmospheric Research (UCAR) maintains the NetCDF data format. NetCDF is commonly used in climatology, meteorology and oceanography applications. A wide range of application software has been written, which makes use of NetCDF files. For further information see the Unidata NetCDF guide.

(http://climate4impact.eu/impactportal/help/faq.jsp?q=climate_data_format).

**Maps, graphs, tables**

NRA's will not use climate model output directly, but derived products such as climate indices that are presented in e.g. maps, graphs or tables. This requires processing of the original data.

### *5.3.4 Uncertainties and ensembles*

As mentioned already in Par. 2.3.3 there are differences in the types of uncertainties in climate data for the current/past and future. The relevance of the various types of uncertainties is also different.

The use of an ensemble generally gives a better indication of uncertainties. As there is no such thing as 'best GCM', 'best RCM' or 'best climate scenario'[53] it is sensible to make use of a group of projections (an ensemble or set of climate scenarios). The user of climate projections or climate scenarios should not trust in the results of only one climate projection, but in the analysis of ranges of possible states of the climate system using a greater number of climate projections or scenarios (Matulla & Namyslo, 2013b). Depending on the type of ensemble different types of uncertainties can be studied better. Table 5.2 lists what can be varied to get an ensemble and the types of uncertainties that can be studied with these ensembles.

For the time horizon 2030 sometimes one scenario or projection is given, because differences between projections for this time horizon or not significantly different (e.g. for the KNMI'14 climate scenarios in the Netherlands a '2030' scenario is presented). However, this does not mean that there are no uncertainties about the climate around 2030. Natural variability (e.g. between years and between 30-year periods) can cause the climate around 2030 to be warmer/colder, dryer/wetter, etc. than in the projection. Therefore, also for this time horizon it is advisable to use an ensemble spanning most of the uncertainty for this time horizon.

[53] If someone assumes that the higher emission or concentration scenarios (RCP8.5, also regularly referred to as 'business as usual') are more probable, than climate scenarios with higher increases in temperature can be considered more probable. However, these are only conditional probabilities (see **Fout! De hyperlinkverwijzing is ongeldig.**). What are the best scenarios to use, also depends on which scenarios are most relevant (see Par. 2.4).

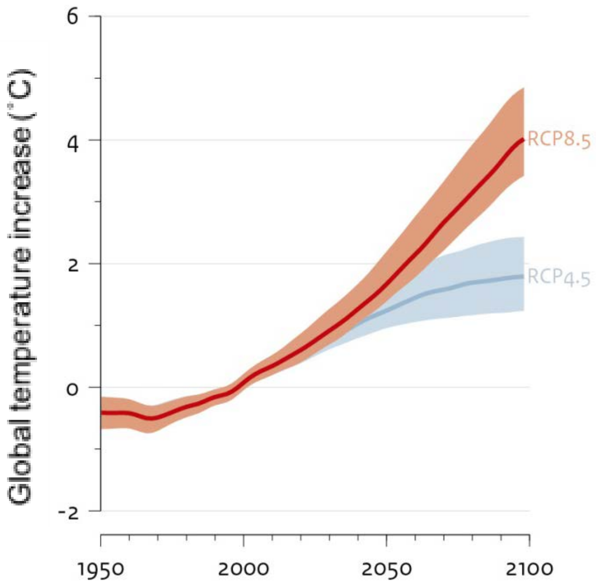


**Figure 5.6** Example of the relation between emission/concentration scenarios (RCP's) and projected global temperature increase (vertical axis). RCP8.5 is often referred to as a 'business as usual' scenario, RCP4.5 requires a strong reduction in emission of greenhouse gasses (and therefore considerable socio-economic and/or technological changes). When one assumes the 'business as usual' emission to be more probable, also the higher temperature increases become more probable (especially for the longer time horizons).

**Table 5.2** Various types of ensembles and the type of uncertainties that can be studied with them (combinations are also often used, but not mentioned in this table)

| What varies? | Which uncertainties can be studied? |
|---|---|
| Initial conditions (initial conditions ensemble) | Natural variability |
| Parameters in the model (perturbed physics ensemble) | Natural variability and/or the uncertainty due to the limited knowledge about the climate system |
| Emission/concentration scenarios | The uncertainty due to the limited knowledge about future emissions and related socio-economic developments |
| Models (multi-model ensemble) | The uncertainty due to the limited knowledge about the climate system |

Provided that the time necessary for computing is reasonable, the application of a greater ensemble of regional climate projections or a set of climate scenarios should be preferred as input for impact models (Matulla & Namyslo, 2013b). If the time available is limited a selection of the available projections or climate scenarios can be made as described shortly in Chapter 3: select at least two projections or scenarios that can be expected to span the range of possible outcomes for the climate variable of interest (and therefore for the impact of interest). Especially for the near future up to about 2030-2050, the different emission/concentration scenarios do not show as clear-cut differences as for longer term periods near the end of this century due to natural variability and uncertainties about the climate system (Matulla & Namyslo, 2013b). Up to about 2050 uncertainties related to the climate system itself are more important than uncertainties related to limited knowledge about future socio-economic developments (and related emissions/concentrations of GHGs; Fig. 2.13). As a consequence the use of an ensemble with various emission scenarios has less value for the near future (10-20 years ahead).

It is important to be aware of the uncertainties associated with the modelling of regional scale climate change projections. They result from several sources including the incomplete understanding of the forces and the atmospheric processes. Parameterizations, numerical schemes, imprecise data describing the orography, surface features are introducing further uncertainties. The overall effect of these uncertainties can be estimated by driving RCMs with reanalysis data (Matulla & Namyslo, 2013a). *When using a large ensemble, be aware that the frequency of the changes in climate variables resulting from the climate model runs is not necessarily the same as a probability distribution.* The ensemble can be biased towards certain climate models and therefore towards higher or lower values. When we assume that the used model is correct, the initial conditions ensembles and perturbed physics ensembles can be assumed to represent probabilities.

If more than one impact model is available then they should be used to compute even a moderate span of results. This should be done to describe the uncertainty on the impact level with respect to the given model chains (Matulla & Namyslo, 2013b).

**Guideline: can one projection or scenario be used for impact analysis?**
The user of climate projections or climate scenarios should not trust in the results of only one climate projection or scenario for impact analyses, as there is no such thing as 'best GCM', 'best RCM' or 'best climate scenario'. Therefore, it is advisable to make use of a group of projections (ensemble) or a set of climate scenarios. Depending on which uncertainties one wants to take into account a different ensemble should be selected (Table 5.2).

## 5.4 Analysing and processing of data (specific for the future)

Several of the methods described in Chapter 4 are also relevant for the future: use of proxies with known relation with the required climate parameter, adjusting spatial and temporal resolution, detrending (in the case transient climate model runs are used), changing format and calculating indices, etc. In this paragraph some methods most specific for the future are discussed.

### 5.4.1 The use of climate model data

Never compare the results of a climate model projection for the future (e.g. number of extreme rainfall events, number of thaw days) directly with observations for the reference period. Even after bias correction, the model results may still contain some bias. For a fair comparison the results from the climate model projection for the future should be compared with the results from the climate model projection for the current climate.

To determine the impact of climate change and adaptation options one generally needs three types of climate data to generate input for impact and adaptation studies:

- Observed climate data for your region of interest;
- Climate model data simulated for the same period covered by your observed data;
- Climate model data simulated for the future.

The first category of data one needs to determine the impact in the current or reference period. The first two categories of data one needs to assess how good the chosen climate models one wants to use for the future are able to reproduce the relevant climate variable in the current or reference climate for the area of interest (model skill or bias). Model skill or bias may differ for variables[54]; e.g. generally skill for temperature is better than skill for precipitation. Model skill will be different from one area to the next; e.g. skill is often less in mountainous areas compared to flat areas. At some stage one will need to correct the future climate data for such biases (since most impact models have non-linear relations with climate variables and are sensitive to the values of the climate variables, hardly ever the raw climate model data can be used). Climate model projections generally have a coarse spatial resolution. Therefore, processing of climate data also often includes downscaling to higher resolutions (see later on in this paragraph). Often help from experts (climate scientists) is needed for this processing.

For any given spatial and temporal resolution the numerical schemes used in climate models to simulate the climate put some limitations. Therefore, it is not advisable to analyse individual grid cells (http://climate4impact.eu/impactportal/help/faq.jsp?q=resolution).

The basis for bias correction is an observational data set (or sometimes re-analysis data). This observational data set has to be transferred to the grid of the climate projections. The data set should cover at least 30 years of observations. Before bias-correcting the data, gridded observations and model data should be compared Matulla & Namyslo, 2013a)

**Guideline: how to determine climate change from climate model data?**
For a fair comparison the results from the climate model projection for the future should be compared with the results from the climate model projection for the current climate and not directly with observational data for the current climate due to the bias in climate model data.

As a consequence, to generate climate data as input for vulnerability studies on climate change, one generally needs three types of climate data:
- Observed climate data for your region of interest;
- Climate model data simulated for the same period covered by your observed data;
- Climate model data simulated for the future.

### *5.4.2 Determining model skill and bias*

When comparing a reference period (e.g. 1981-2010) of a climate model dataset to meteorological measurements of the same period as mentioned in Par. 5.4.1 it might be tempting to carry out a point-by-point (date-to-date) comparison of the simulated time-series to the corresponding time-series of observations. This would normally result in a rather poor agreement and thus disappointment, which might lead to the conclusion that the climate projection has quality problems. Such a conclusion based on a point-by-point comparison is unwarranted, because it fails to take into account the influence of initial conditions of the simulation in relationship to slow modes of the natural climate variability[55]. The explanation to this point-by-point mismatch is as follows: the GCM or RCM simulations were initiated using initial conditions representing a possible weather situation at the start of the simulation period. But the exact state of the atmosphere and the oceans did not actually occur — it is

[54] In general, none of the climate models shows for all climate variables at the same time the smallest bias (or highest skill). Therefore, it is not possible to indicate one model that is the best for simulating all climate variables. When a model simulates the current climate well this is indeed an indication of the quality or skill of the model. However, it is no guarantee that the model will also simulate changes well. Therefore, more and more longer periods in the past are simulated to see how well a climate model simulates changes;

[55] In order to achieve any reasonable point-by-point temporal agreement climate model simulations have to be replaced by climate predictions.

only a situation that reasonably could have occurred in that year. For a more in-depth explanation see the paper by Jones and Nikulin (2009; http://climate4impact.eu/impactportal/help/faq.jsp?q=model_vs_observations).

The correct way to evaluate and analyse climate model results (determine their skill) is to focus on long enough periods. Usually this means 30-year periods, which can be either overlapping or consecutive. The length of the period depends on the variable, for some variables such as seasonal or annual temperatures a 20-year period may be sufficient, but for other variables like monthly precipitation longer periods should be used. Within each period the analyses should *focus on comparing statistics* between the climate projection and the corresponding observational record. In this way much of the natural variability is exposed as statistical measures of averages, spread, and frequencies. However, climate often shows multi-decadal variability. To fully remove the effect of multi-decadal climate variability the analyses have to be based on an ensemble of climate simulations, from different GCMs/RCMs and/or from several runs with different initial conditions of one GCM/RCM (http://climate4impact.eu/impactportal/help/faq.jsp?q=model_vs_observations).

**Guideline: how to determine model bias (systematic deviations of reality)?**
Model bias (systematic deviation between the model output and reality) can be determined by comparing the **statistics** of observational records for a certain period (often 30 years) with the simulated climate for the same period in the past.

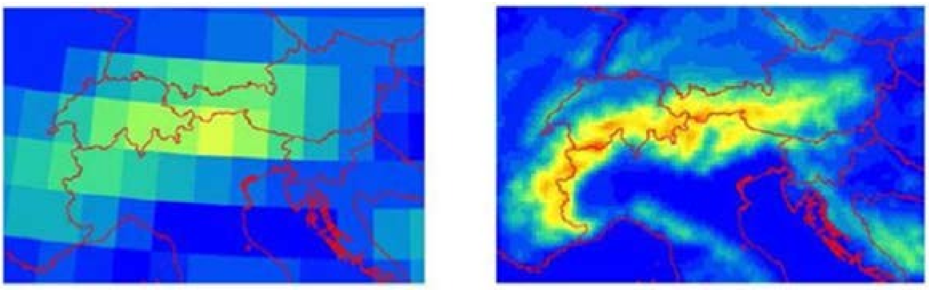

**Figure 5.7** Topography of the European Alps at a resolution of 100 km (left) and a resolution of 10 km (Matulla & Namyslo, 2013a).

### 5.4.3 Spatial downscaling

*Spatial downscaling* is a general concept that embraces various methods for *increasing the spatial resolution* (Fig. 5.7) and reduce some of the biases[56] in order to improve the usability of climate scenarios. Higher spatial resolution cannot be obtained by simply interpolating to a finer grid scale. Additional information has to be added to the GCM output in order to derive higher spatial resolution. Often, projections from comparatively coarse-resolution global climate models (GCMs) are implied, but also RCMs can be downscaled. Basically, there are two fundamentally different approaches to this:

- Dynamical downscaling makes use of a regional climate model (RCM) having higher spatial resolution (typically 10–50 km) over a limited area and which is 'fed with large-scale weather' from the GCM at the boundaries of the domain. A regional climate model is conceptually similar to a global climate model. RCMs explicitly calculate small scale processes unrecognized by GCMs and they generate physically consistent states of the

[56] Often downscaling and bias correction are combined, but not necessarily.

atmosphere that account also for features of the region (e.g. its topography and surface categories) in high resolution (e.g. Giorgi et al., 1991). Processes that are still too small to be captured by the RCM grid are again introduced by 'parameterization'[57]. The benefit of the high RCM resolution is achieved at the expense of computer resources and time. This kind of small scale climate change depiction is possible because of the restriction of the calculations to a limited geographical sector (Matulla & Namyslo, 2013a);

- Statistical downscaling, or empirical statistical downscaling (ESD), uses observations on both scales to estimate the link. A reference dataset (often one or several time-series of meteorological station data) is used to calibrate the climate scenario data. The main principle is to find a statistical relationship (linear or non-linear) between the observational dataset and a corresponding reference period of the climate model data. It is preconditioned that the functional relationship remains in effect under climate change.

**Overview: downscaling methods**

Downscaling is a general concept that embraces various methods for increasing the spatial resolution. Basically, there are two fundamentally different approaches to this:

- Dynamical downscaling makes use of a Regional Climate Model (RCM) having higher spatial resolution;
- Statistical or empirical downscaling uses observations on both scales to estimate the link between them.

Par 5.4.3 describes various statistical downscaling techniques. Figure 5.9 presents schematically the relation between downscaling techniques, bias correction (Par. 5.4.4) and methods to generate time series for the future (Par. 5.4.5).

The statistical downscaling techniques refer to methods in which sub-grid scale changes in climate are calculated as a function of larger-scale climate and can be broadly categorised into three classes (more detailed information on the various techniques in Matulla & Namyslo, 2013a):

- *Transfer functions* - statistical relationships are calculated between large-area and site-specific surface climate, or between large-scale upper air data and local surface climate.
- *Weather typing* - statistical relationships are determined between particular atmospheric circulation types (e.g., anticyclonic or cyclonic conditions) and local weather (e.g. Hess & Brezowsky, 1969, Lauscher 1972, Werner & Gerstengarbe 2011);
- *Stochastic weather generators* - these statistical models may be conditioned on the large-scale state in order to derive site-specific weather (www.cics.uvic.ca/scenarios/index.cgi?More_Info-Downscaling_Background). A comparison of weather generators is contained in Semenov & Barrow (1997).

Wilby and Wigley (1997) divided downscaling into four categories: regression methods, weather pattern-based approaches, stochastic weather generators, which are all statistical downscaling methods, and dynamical downscaling. Among these approaches regression methods are often preferred because of its ease of implementation and low computation requirements (Matulla & Namyslo, 2013a).

[57] HIRLAM (Dethloff et al., 1996) is tuned to reasonably picture the climate of the high latitudes and the Arctic. COSMO-CLM and REMO have often been applied to the mid-latitudes and tropical areas.

**Pro's and con's of dynamical and statistical downscaling**
The two approaches, dynamical and statistical downscaling are not quite interchangeable alternatives, and there are many technical aspects to consider if one needs to choose one of them. Both statistical and dynamical downscaling critically depend on two main assumptions:

- The large scale state of the atmosphere and its evolution affect the local scale weather development;
- The GCMs description of the reaction of the climate system to altered boundary conditions (so called 'projections') is complete and accurate (Matulla & Namyslo, 2013a)

Main advantages of dynamical downscaling (RCMs):

- Individual variables are physically consistent in time and space[58], and the different variables are internally consistent (but almost always bias correction is needed and this affects consistency between climate variables);
- The same fundamental physical principles are used in both an RCM and a GCM;
- An RCM provides for a large region a wealth of output data at high resolution compared to what can be obtained from a GCM (but for several applications the spatial resolution is still rather coarse, about 25 by 25 km in the most recent RCMs).

Main disadvantages of dynamical downscaling (RCMs):

- RCMs are very complex and require substantial computational resources, often at the same level as required for GCM simulations. Therefore, hardly ever simulations can be made specifically for a project on road infrastructure. However, large datasets covering many regions are made freely available by modelling institutes in Europe;
- Near the boundary of the RCM domain artefacts and spurious effects occur;
- While removing much of the GCM bias that is related to the coarse resolution, an RCM also adds its own biases to the output data. Therefore, in most cases a bias correction or statistical downscaling is needed to generate climate data for impact studies (based on http://climate4impact.eu/impactportal/help/faq.jsp?q=Downscaling).

Main advantages of empirical or statistical downscaling:

- The methods are computationally less expensive;
- Many different statistical methods are available, allowing for substantial flexibility;
- ESD typically includes bias correction as an integral part of the process.

Main disadvantages of empirical or statistical downscaling:

- A (calibration) dataset, typically a long meteorological record of high quality is required. Any quality problems in the calibration data will be transferred to the downscaled GCM/RCM data;
- The higher the requirements regarding spatial and temporal consistency, or inter-variable consistency are, the more complex and computationally demanding the statistical procedures become;
- The ESD approach requires/assumes stationary statistical relationship, the relationship must remain constant under climate change. (based on http://climate4impact.eu/impactportal/help/faq.jsp?q=Downscaling)

[58] Although this can also be disputed (Bakker, 2014).


**Figure 5.8** Flooding of highway A2 near 's Hertogenbosch in 1995 (Bles & Mens, 2010).

**Note!**

- Statistical downscaling is sometimes equated with **bias correction**. The reason is that in statistical downscaling the bias due to the different scales of the GCM output data and the reference dataset is lumped together with the true GCM biases (i.e. the model imperfections not related to scale issues). However, bias correction can equally well be applied to RCM data, in which case the focus is more on combined model biases of the GCM and RCM. As much of the scale transition is handled at the RCM modelling stage bias correction in this context is sometimes referred to as RCM calibration;
- A major source of difference – or bias – between GCM data and the observational reference dataset is the huge difference in spatial resolution. Because of this, and the history of development of these methods, 'downscaling' is sometimes equated with 'downscaling of GCM data'. Even though RCMs provide data at a much higher resolution than the GCMs, even higher precision is sometimes required. If this is the case statistical downscaling methods can equally well be applied to RCM data. In this case the term 'further downscaling' is sometimes used to distinguish this processing step from the dynamical downscaling achieved by the RCM (based on http://climate4impact.eu/impactportal/help/faq.jsp?q=Downscaling).

The downscaling technique can affect the representation of the relevant climate variables and therefore introduce uncertainty. Matulla & Namyslo (2013a) recommend for future studies to use ensembles made up by both dynamical and empirical downscaling techniques. The 'look up Table' in Matulla & Namyslo (2013a) gives an overview of studies where various downscaling methods have been applied to generate regional to local scale projections characterizing the possible future behavior of the target parameter under investigation. The table focuses on empirical techniques and the European continent.

Fig. 5.9 gives an overview of the relation between various downscaling techniques, bias correction and methods to generate time series for the future (Par. 5.4.5).

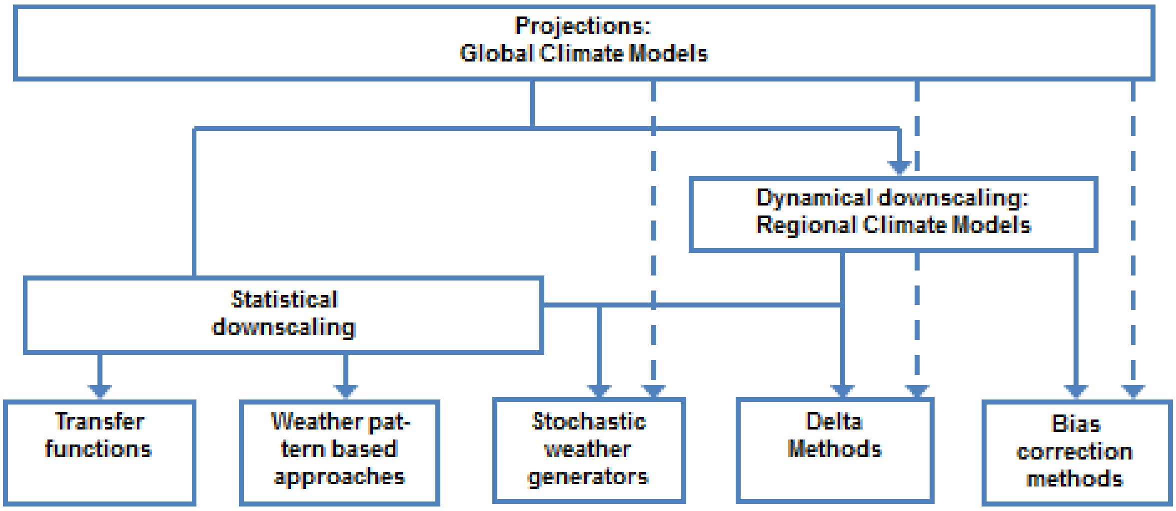


**Figure 5.9** Schematic presentation of the relation between downscaling techniques, bias correction and methods to generate time series for the future. GCM results are generally too coarse to be used directly in impact models. Therefore, downscaling methods are used. After dynamical downscaling generally an extra step is needed to make time series, since RCM's contain biases (dashed lines: also possible ways of generating time series, but used less).

**Guideline: which downscaling method to use?**
Empirical or statistical and dynamical downscaling techniques all have their advantages and disadvantages. The advantages and disadvantages mentioned in Par. 5.4.3 may help in making a selection. RCMs require substantial computational resources. Therefore, hardly ever simulations can be made specifically for a project on road infrastructure and one has to rely on available downscaled projections (about 25 * 25 km nowadays). As long as climate models still have large biases, it cannot be said that empirical downscaling methods are less preferred.

Be aware that the downscaling methods themselves also cause new uncertainties. To see the effect it would be recommended to use both empirical and dynamical downscaling techniques.

### *5.4.4 Correction for systematic deviations compared to observations in climate model output*

As pointed out in Par. 5.3.2 generally biases in climate model output (systematic deviations with reality) should be corrected for, before using climate model data in impact studies. The main assumption of bias correction methods is that *the bias behaviour of the model does not change with time*. Further it is important to realize that the quality of the observations database determines the quality of the correction and biases in circulation systems cannot be corrected for.

Downscaling methods also act to correct (part of) the bias, since they increase the resolution and therefore may reduce the bias due to the spatial resolution (http://climate4impact.eu/impactportal/help/faq.jsp?q=bias_correction). Fig. 5.10 shows what could be the effect of bias correction of climate model data. The bias is determined with the help of observational data and the climate model simulation for the present climate (e.g. in the mean, quantiles, etc.). For the future it is assumed that the climate model simulation contains the same bias. This assumption can be disputed, since biases are often not the same over the whole range of values of a climate variable, as shown among others in the ENSEMBLES project (Van der Linden & Mitchell, 2009)[59].

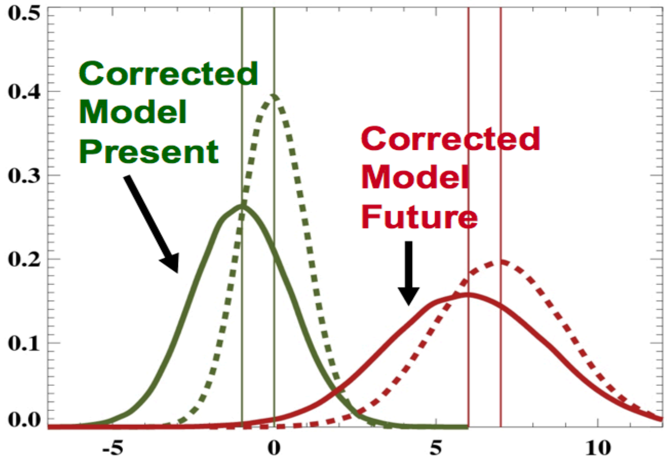


**Figure 5.10** Example of bias corrected data (continuous line) of raw climate model data (dashed line): the vertical axis presents the frequency of occurrence, the horizontal axis represents e.g. temperature.

The simplest way of bias-correction, applicable when a linear relation between model data and observations is evident, is the multiplication by a constant factor and/or the additive correction of a constant offset. This procedure is often adequate when one is interested in the yearly means of climate variables. When one wants seasonal or monthly means of climate variables this technique can be applied at seasonal or monthly scales, respectively. However, in most cases especially climate extremes cause threats to road infrastructure and the extremes do not necessarily change in the same way as the averages (even the sign of change is sometimes different). In that case more advanced methods for bias correction should be used. Often the changes in a few or a large number of quantiles are determined (e.g. for temperature in the 10%, 50% and 90% quantiles) and in the case of precipitation often also the number of dry/wet days is corrected for. Depending on the aim of the impact study, other bias correction methods may be more suitable for representing the relevant climate parameters correctly. This also means that a bias correction performed for one impact study is not necessarily suitable for another impact study. Dalelane (2014) gives a summary of various methods and techniques and some advantages and drawbacks.

In general, bias correction has certain drawbacks. Therefore, the concept of bias correction is not undisputed (Ehret et al., 2012):

- The individual bias-correction of one or more meteorological parameters interferes seriously with their physical consistency, an undesired side effect especially when dealing with complex multi-parameter impact models. Moreover, some typical model deficits are not possible to correct satisfyingly even by bias-correction procedures (e.g. biases in the circulation pattern or in wind direction);

[59] In most cases the climate change signals are derived from the uncorrected climate model data. It would be interesting to check whether the climate change signal will change after bias correction.

- Another effect of bias-correction is the possible change of climate signals, which occurs for instance in Quantile-mapping in case the correction coefficients for different quantiles of the distribution diverge considerably.

The implementation of bias-correction procedures requires a careful examination of both the quality of the resulting data series and the sensitivity of the impact model towards inconsistencies between the input variables (Matulla & Namyslo, 2013a).

**Guideline: which method to use for removing systematic deviations?**
Depending on the aim of the impact study, other bias correction methods may be most suitable for representing the relevant climate parameters correctly. This also means that a bias correction performed for one impact study is not necessarily suitable for another impact study!

In most cases especially climate extremes cause threats to road infrastructure and the extremes do not necessarily change in the same way as the averages (even the sign of change is sometimes different). In that case more advanced methods for bias correction should be used. Dalelane (2014) gives a summary of various bias correction methods and techniques and some advantages and drawbacks.

**Figure 5.11** Lofoten Islands, Hamnøy is often exposed to high tide and waves (Source: CEDR, 2012).

### *5.4.5 Producing climatological time series for the future*

Impact models often use climatological time series of e.g. daily values as input. Different methods exist for the generation of time series for the future after dynamical downscaling. Table 5.3 gives the 3 main groups of methods and some of their characteristics. The 'direct method' often is applied to dynamically downscaled data (RCM output), but it can also be used directly for GCM-data (without dynamical downscaling). The other two groups of methods are also indicated in Fig. 5.9.

More or less detailed methods can be used within these main groups: they can only take into account changes and biases in averages on a yearly basis (very simple methods) or take into account also changes and biases in averages and extremes and differentiated for various periods in a year, linear or non-linear relations[60]. Depending on the intended use more are less detailed methods are needed. E.g. when cold temperatures are important for road maintenance (e.g. frost-thaw cycles), it is important to check climate model data for biases in the representation of 0 ˚C crossings and to correct for biases. This means that e.g. biases of the 10%, 50% and 90% percentiles should be corrected for on a monthly or seasonal basis. In case of the use of a weather generator or the Delta-method changes in these percentiles on monthly or seasonal basis should be taken into account. Which method is best or can be used depends among others on the requirements for the impact study, the available climate data and available time. Table 5.3 describes various characteristics of these methods (advantages and disadvantages), which may help in the selection of the method.

**Overview: which methods are available to generate time series for the future from climate model information?**

Basically there are 3 main methods for generating time series for the future from GCM's or RCM's (Table 5.3):

- Delta-method: Applies climate change signals from climate model(s) to historical time series;
- Direct method: Corrects for biases in climate model output with the help of observational historical time series;
- Stochastic weather generators: uses statistical properties/relations between climate variables to generate time series. For the future climate change signals from climate model(s) are used to adapt these relations.

**Table 5.3** Future climate: main groups of methods to generate meteorological time series.

| | **Delta-method (also called transformation, perturbation)** | **Bias correction (also called Direct method)** | **Stochastic weather generator** |
|---|---|---|---|
| **Basic material** | Historical observational time series | 'Raw' time series from climate model(s) | Statistical properties/relations between climate variables |
| **Processing** | Apply climate change signal from climate model(s) | Correct for biases with the help of observational historical time series | Adapt generator with the help of climate change signals form climate model(s) |
| **Consistency between climate variables** | Yes, from historical time series.<br>Transformation often per climate variable and can affect consistency (especially in the case of large changes) | Yes, in 'raw' climate model output.<br>Bias in the various climate variables not the same, therefore bias correction affects consistency (especially in the case of large biases) | Yes, relation between climate variables determined on the basis of historical observational data<br>Difficult to get spatial consistency, depends on method |
| **Sequence of weather events?** | (Almost) the same as in the historical time series[61] | All kind of different sequences possible in the simulated climate | All kind of different sequences possible in the simulated climate |
| **Long time series possible (>100 y for same climate)?** | Only if long historical time series are available | Yes, depends on the number of simulated years with the climate model | Yes, depends on the number of simulated years with the generator |

[60] In the case of precipitation, in more sophisticated methods often the number of wet/dry days is adjusted;
[61] Can be adapted a little in some methods, e.g. remove or add wet days.


**Figure 5.12** Threats of snowfall: hindrance of traffic (Source: Matulla & Namyslo, 2014a).

**Guideline: which method to use for generating time series for the future?**
Which method is best or can be used depends among others on the requirements for the impact study, available climate data and available time. Table 5.3 describes various characteristics of these methods (advantages and disadvantages) and this may help in the selection of the method. As long as climate models still contain large biases it cannot be stated that the direct methods is better than the other methods.

## *5.5 Some useful links*

The links in this paragraph were updated last on October 1, 2014.

**Definitions/glossary**

- See links mentioned in Chapter 2

**Databases**

- See Par. 5.2
- COST-VALUE http://www.value-cost.eu/data
- IPCC Data distribution centre: www.ipcc-data.org/sim/index.html (monthly and period means of GCM runs)
- Climate change atlas (maps of projected changes for various climate variables for the RCPs (for various regions in the world): http://climexp.knmi.nl/plot_atlas_form.py

**Processing techniques**

- Links to tools mentioned on the ECA&D website (http://eca.knmi.nl/publications/index.php#other): RClimdex by the Meteorological Service of Canada, KNMI Climate Explorer by Geert Jan van Oldenborgh, the Netherlands, CAT at the University of Exeter, UK
- Stochastic Weather generators: www.ipcc-data.org/guidelines/pages/weather_generators.html
- IPCC guidelines: www.ipcc-data.org/guidelines/index.html
- www.cru.uea.ac.uk/projects/stardex/ (2005)
- www.cics.uvic.ca/scenarios/index.cgi?More_Info-Downscaling_Background
- www.cics.uvic.ca/scenarios/index.cgi?More_Info-Downscaling_Tools

**On the use of climate projections and scenarios**

- http://climate4impact.eu/impactportal/help/faq.jsp?q=scenarios_2030
- http://climate4impact.eu/impactportal/documentation/guidanceandusecases.jsp?q=generic_work_flow1

# 6 Frequently asked questions

This chapter contains a considerable number of Frequently Asked Questions. At the right side of the tables you find either the paragraph or table in this report where you can find the answer, or you are referred to a website where you can find the answer. If your question is not in this chapter, contact an expert.

## 6.1 General questions on weather, climate and climate change

| Question | Answer or where can you find the answer? |
|---|---|
| **Current Climate** | |
| What is the difference between climate and weather? | Par. 2.1.1 Some definitions |
| What is natural variability of a climate? | Par. 2.1.1 Some definitions<br>Par. 2.2.3 Description and detection of climate change |
| How is a climate described? | Par. 2.1.2 How to describe a climate?<br>Par. 2.1.4 Description of the current climate |
| What is a trend? | Par. 2.2.3 Description and detection of climate change |
| What climate change is already observed? | Par. 2.2.4 Observed trends<br>Table 2.2 Observed trends in Europe<br>www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf (IPCC, 2013)<br>http://www.climatechange2013.org/images/report/WG1AR5_FAQbrochure_FINAL.pdf: **FAQ 2.2** Have There Been Any Changes in Climate Extremes? P. 9 |
| Where can I find information on the current climate for the following country: …..? | Table 2.1 Descriptions of the climate from European countries |
| **Future climate** | |
| What is climate change? | Par. 2.2.1 Some definitions |
| What is the difference between the greenhouse effect and the enhanced greenhouse effect? | Par. 2.2.1 Some definitions<br>www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-1-3.html: **FAQ 1.3** What is the Greenhouse Effect? |
| What causes climate change? | Par. 2.2.2 Causes of climate change |
| How do we know that humans have caused the climate to change? | Par. 2.2.3 Description and detection of climate change<br>http://www.climatechange2013.org/images/report/WG1AR5_FAQbrochure_FINAL.pdf: **FAQ 10.1** Climate is always changing. How do we determine the causes of observed changes? P. 43 |
| What is an emission scenario (SRES or RCP scenario)? | Par. 2.2.1 Some definitions |
| What is a time horizon (for climate scenarios/projections)? | Par. 5.1.1 Some additional definitions<br>Par. 5.1.2 What time horizon to use? |
| What is a climate model and which types do exist? | Par. 5.1.1 Some additional definitions |
| Why is there so much uncertainty about the future climate? | Par. 2.3 Uncertainties in climate data<br>Par. 2.3.3 Differences in uncertainties in the current and future climate |
| Why is it possible to give projections for the climate around 2050 and | http://www.climatechange2013.org/images/report/WG1AR5_FAQbrochure_FINAL.pdf: **FAQ 11.1** If You Cannot Predict the |

| | |
|---|---|
| beyond if the weather for the next 2 weeks cannot be predicted/forecasted well? | Weather Next Month, How Can You Predict Climate for the Coming Decade? P. 47 |
| Has climate change stopped since 1998? | www.climatechange2013.org/spm (IPCC, 2013)<br>In the period 1998-2012, the global temperature trend was significantly smaller than in previous decades. This is also called hiatus. The key question is whether the delay in the temperature rise is temporarily or permanently. According to the fifth assessment report of the IPCC in this period a number of natural influences offset the warming due to the increase of greenhouse gas emissions. Given the temporary nature of these natural influences, it seems unlikely that the delay in the warming continues in the long term<br>www.metoffice.gov.uk/research/news/recent-pause-in-warming |
| Is climate change the same in every region in Europe? | Table 2.2 Observed trends in Europe<br>Table 2.3 Projected changes in Europe |
| Why is it not possible to give only one projection for the future climate? | Fig. 2.12 and Fig. 2.14<br>http://www.climatechange2013.org/images/report/WG1AR5_FAQbrochure_FINAL.pdf: **FAQ 12.1** Why Are So Many Models and Scenarios Used to Project Climate Change? P. 51<br>There are many uncertainties; giving one projection would mask this. Proper decision making is not possible without information on the uncertainties. |
| What is the difference between climate projections, climate predictions and climate scenarios? | Par. 2.2.1 Some definitions |
| What are the projected climate changes for Europe? | Table 2.3 Projected climate change in Europe<br>Table 2.4 Climate scenarios in various European countries<br>www.ipcc.ch/report/ar5/wg1/: Annex I: Atlas of Global and Regional Climate Projections |
| Where can I find information on the future climate for the following country: ……? | Table 2.4 Climate scenarios in various European countries |
| Is this … event due to climate change? | www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-9-1.html: **FAQ 9.1**: Can Individual Extreme Events be Explained by Greenhouse Warming? (IPCC, 2007) |
| **Other or general questions** | |
| Where can I find more information on the climate system? | www.ipcc-wg1.unibe.ch/publications/wg1-ar4/faq/wg1_faq-1.1.html: **FAQ 1.1**: What Factors Determine Earth's Climate? (IPCC, 2007)<br>Par. 2.1.3 Causes of spatial differences in climate |
| What does IPCC stand for and what does this organisation do? | www.ipcc.ch/organization/organization.shtml<br>www.ipcc.ch/activities/activities.shtml |
| What is WMO and what does this organisation do? | www.wmo.int/pages/about/index_en.html |
| What do National Meteorological Institutes (NMI's) do /what are their tasks? | www.wmo.int/pages/about/nmhs_en.html |
| My question is not in this list. Where can I find an expert to answer my question? | In most cases you can find an expert at your national Meteorological institute (www.wmo.int/pages/members/members_en.html for a link to these institutes). Experts on climate and climate change can also be found and some universities and providers of climate services |

## 6.2 Climate data sources

| Question | Answer or where can you find the answer? |
|---|---|
| **Current Climate** | |
| How is a climate described? | Par. 2.1.2 How to describe a climate |
| What types of data sources on the current and past climate are available? | Par. 4.2 Climate data sources for the current climate |
| What is a reference period? | Par. 4.1 The current climate and the reference period |
| What is re-analysis? | Par. 4.2.1 Climate data sources |
| Where can I find information on the current climate for following country: …..? | Table 2.1 Descriptions of the climate from European countries or through the meteorological institute of each country (www.wmo.int/pages/members/members_en.html) |
| With which reference period is the current climate described in the various European countries? | Table 2.1 Descriptions of the climate from European countries |
| **Future climate** | |
| How is climate change detected? | Par. 2.2.3 Description and detection of climate change www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf p. 15-16 |
| What types of data sources on the future climate are available? | Par. 5.2 Climate data sources for the future climate |
| Where can I find information on the future climate for the following country: ……? | Table 2.4 Climate scenarios in various European countries |
| What climate scenarios are used in the various European countries? | Table 2.4 Climate scenarios in various European countries |
| What are the differences between the climate scenarios of the various European countries? | Table 2.5 Some characteristics of climate scenarios in European countries |
| How to get data/time series on wind, precipitation, …… for the future in ……… this region? | Par. 4.2.2 Availability of climate data<br>In most cases you can obtain climate data from the national Meteorological institutes (www.wmo.int/pages/members/members_en.html for a link to these institutes). |
| **Other or general questions** | |
| Where can I find tools to process and visualize climate data? | Par. 4.5 and Par. 5.5 Some useful links<br>Table 4.2 Some links to databases with climate data in Europe (observation past-present, reanalysis)<br>Table 5.1 Climate model data sources for Europe: climate model output for the past and future |
| My question is not in this list. Where can I find an expert to answer my question? | In most cases you can find an expert at your national Meteorological institute (www.wmo.int/pages/members/members_en.html for a link to these institutes). Experts on climate and climate change can also be found and some universities and providers of climate services |

## 6.3 Ranges and uncertainties in climate data

| Question | Answer or where can you find the answer? |
|---|---|
| **Current Climate** | |
| What is natural variability in a climate? | Par. 2.1.1 Some definitions |
| How can one distinguish between natural variability and trends due to climate change? | Par. 2.2.3 Description and detection of climate change |
| How large is the range of natural variability in the current climate? | Often information on extremes on the websites with climate normals (Table 2.1)<br>See also Par. 2.1.2 How to describe a climate?<br>And Par. 6.7 with an example on cold winters |
| What uncertainties exist in the climate data for the current climate | Par. 2.3.3 Differences in uncertainties between the current and future climate (Table 2.5) |
| How can I deal with ranges, uncertainties and/or natural variability in the current climate? | Par. 2.4 Dealing with uncertainties<br>Par. 2.5 see links under 'uncertainties' |
| **Future climate** | |
| Why is there so much uncertainty about the future climate? | Par. 2.3 Uncertainties in climate data |
| Why is it possible to make projections for the climate around e.g. 2050, when the weather for the next weeks/months cannot be predicted? | http://www.climatechange2013.org/images/report/WG1AR5_FAQbrochure_FINAL.pdf: **FAQ 11.1** If You Cannot Predict the Weather Next Month, How Can You Predict Climate for the Coming Decade? P. 47 |
| What uncertainties exist for the future climate? | Par. 2.3.3 Differences in uncertainties between the current and future climate (Table 2.5) |
| How can I deal with ranges, uncertainties and/or natural variability in the future climate? | Par. 2.4 Dealing with uncertainties<br>Par. 2.5 see links under 'uncertainties'<br>Par. 5.4 Analysing and processing of data (specific for the future) |
| **Other or general questions** | |
| Where can I find background information on uncertainties in climate data? | Par. 2.3. Uncertainties in climate data<br>Par. 2.5 see links under 'uncertainties', especially http://www.knmi.nl/klimaat/autumnschool2012/ (Autumn school 'Dealing with uncertainties') |
| My question is not in this list. Where can I find an expert to answer my question? | In most cases you can find an expert at your national Meteorological institute (www.wmo.int/pages/members/members_en.html for a link to these institutes). Experts on climate and climate change can also be found and some universities and providers of climate services |

## 6.4 Quality and validity of climate data

| Question | Answer or where can you find the answer? |
|---|---|
| **Current Climate** | |
| What determines the quality of a dataset? | Par. 4.3 Data quality and usefulness |
| What determines the validity or usefulness of a dataset? | Par. 4.3 Data quality and usefulness |

| | |
|---|---|
| What is inhomogeneity in climate data sets? | Par. 4.3.1 Factors affecting the quality of climate data |
| Is it possible to get a dataset at a 1 by 1 km spatial resolution? | The spatial resolution depends on the density of the observational network and the used downscaling techniques. The density of the ground based stations is much less than 1 by 1 km<br>See Table 4.1 for some characteristics of the main groups of data for the current climate<br>A grid size of 1 by 1 km does not necessarily have the same spatial resolution!!<br>Par. 4.4.4 Adjusting spatial and temporal resolution |
| Is it possible to get a data set with a temporal resolution of 1 hour, 5 min., ….? | Observational data at automated weather stations often have a high temporal resolution, but not all resolutions are always available through internet. Ask the relevant NMI for more information<br>Par. 4.4.4 Adjusting spatial and temporal resolution |
| **Future climate** | |
| What determines the quality of a dataset? | Par. 5.3 Data quality and usefulness |
| What determines the validity or usefulness of a dataset? | Par. 5.3 Data quality and usefulness |
| What is an ensemble and which types exist? | Par. 5.1.1 Some additional definitions<br>Par. 5.3.4 Uncertainties and ensembles |
| What is a bias in climate model data and what is bias correction? | Par. 5.3.1 Model skill and systematic deviations compared to observations<br>Par. 4.4.7 Correction of systematic deviations compared to observations<br>Par. 5.4.2 Determining model skill and bias |
| What is downscaling and which methods exist (statistical and dynamical)? | Par. 5.1.1 Some additional definitions<br>Par. 5.4.3 Spatial downscaling |
| Is it possible to get a dataset at a 1 by 1 km spatial resolution? | The spatial resolution depends on the density of the observational network and the used downscaling techniques. The density of the ground based stations is much less than 1 by 1 km and climate models are in general not run at such high resolutions<br>A grid size of 1 by 1 km does not necessarily have the same spatial resolution!!<br>Par. 5.4.3 Spatial downscaling |
| Is it possible to get a data set with a temporal resolution of 1 hour, 5 min., ….? | Observational data at automated weather stations often have a high temporal resolution. Simulation models often have a temporal resolution of one hour, but these data are often not saved/made available. Besides that, less knowledge is available on the model skill of these hourly data<br>Par. 5.4.2 Determining model skill and bias<br>Par. 5.4.5 Producing climatological time series for the future |
| **Other or general questions** | |
| What determines data quality and data validity? | Par. 4.3 Data quality and usefulness<br>Par. 5.3 Data quality and usefulness |
| Are climate data always quality checked? | No. Observational data have often undergone a basic quality check (e.g. missing data, outliers), but inhomogeneities in time series are often not removed. Climate model simulation data are often 'raw' data without bias correction.<br>Always look for or ask for information on data quality! |

| | |
|---|---|
| My question is not in this list. Where can I find an expert to answer my question? | In most cases you can find an expert at your national Meteorological institute (www.wmo.int/pages/members/members_en.html for a link to these institutes). Experts on climate and climate change can also be found and some universities and providers of climate services |

## 6.5 Methods for checking and improving quality and usefulness of climate data

| Question | Answer or where can you find the answer? |
|---|---|
| **Current Climate** | |
| How can one check data quality (missing data, errors, inhomogeneities, etc.)? | Par. 4.3.3 How to check the quality and usefulness? |
| How can one improve data quality (missing data, errors, inhomogeneities, etc.)? | Par. 4.4 Analysis and processing of data |
| How can one detrend a time series? | Par. 4.4.5 Removing trends from time series |
| How can one make longer time series when observational data are missing? | Par. 4.4.3 Adjusting the length of a dataset |
| How can one adjust the spatial or temporal resolution of a data set? | Par. 4.4.4 Adjusting spatial and temporal resolution |
| How can one correct for inhomogeneities? | Par. 4.4.2 Correcting for non-climate related changes or trends |
| **Future climate** | |
| How can one adjust the spatial resolution of a data set? | Par. 5.4.3 Spatial downscaling |
| How can one correct for climate model biases? | Par. 5.4.4 Correction of systematic deviations compared to observations in climate model output |
| How can one produce time series for the future? | Par. 5.4.5 Producing climatological time series for the future |
| **Other or general questions** | |
| My question is not in this list. Where can I find an expert to answer my question? | In most cases you can find an expert at your national Meteorological institute (www.wmo.int/pages/members/members_en.html for a link to these institutes). Experts on climate and climate change can also be found and some universities and providers of climate services |

## 6.6 Using climate data in impact and adaptation studies

| Question | Answer or where can you find the answer? |
|---|---|
| **Current Climate** | |
| Why should I use climate data for the current climate when I'm interested in the impacts in the future? | Par. 3.1 Use of climate data in a quick scan<br>Par. 3.2 Use of climate data in a detailed vulnerability assessment |
| Which period should I use as the reference period and to capture the natural variability? | Par. 4.1 The current climate and the reference period |

| | |
|---|---|
| Where can I find climate data for the current climate? | Par. 2.1.4 Descriptions of the current climate<br>Par. 4.2 Climate data sources for the current climate |
| How to check the quality of the climate data? | Par. 4.3 Data quality and usefulness |
| How to get consistent climate data with similar quality for all regions in Europe? | Par. 4.4.2 Correcting for non-climate related changes or trends |
| **Future climate** | |
| Where can I find climate data for the future climate? | Par. 2.2.5 Projected changes<br>Par. 4.2 Climate data sources for the future climate |
| Do the climate scenarios of the various European countries describe more or less the same range of climate change? | Fig. 2.12 (Dalelane, 2014)<br>Par. 2.2.5 Projected changes |
| How to check the quality of the climate data? | Par. 5.3 Data quality and usefulness |
| Why use ensembles? | Par. 5.3.4 Uncertainties and ensembles<br>Table 5.2 |
| Which time horizon should I use? | Par. 5.1.2 What time horizon to use? |
| Why should model biases be removed before using climate model data? | Fig. 5.5<br>Par. 5.3.1 Model skill and systematic deviations compared to observations |
| How to determine climate change form climate model data? | Par. 5.4.1 The use of climate model data |
| I am only interested in the period up to 2020/2030, what to do? | http://climate4impact.eu/impactportal/help/faq.jsp?q=scenarios_2030 |
| Why is it not possible to give one projection for the future climate? | Par. 2.3 Uncertainties in climate data |
| Which methods are available for making time series for the future? | Par. 5.4.5 Producing climatological time series for the future |
| **Other or general questions** | |
| What are the steps in using climate data in vulnerability assessments? | Chapter 3 The steps in the use of climate data |
| Which types of data do I need for impact or adaptation studies related to climate change? | First determine which threats you want to study. Than look in Table 3.1 which climate variables are relevant for these threats |
| What determines data quality and data validity? | Par. 4.3 Data quality and usefulness (current climate)<br>Par. 5.3 Data quality and usefulness (future climate) |
| How to deal with uncertainties? | Par. 2.4 Dealing with uncertainties |
| My question is not in this list. Where can I find an expert to answer my question? | In most cases you can find an expert at your national Meteorological institute www.wmo.int/pages/members/members_en.html for a link to these institutes). Experts on climate and climate change can also be found and some universities and providers of climate services |

## 6.7 Recurrence of cold winters

Recent winters in northern Europe were relatively cold (except for the winter of 2013/2014), seemingly contrary to expected climate change, and raising questions by road owners considering maintenance budgets. Cold winters are often combined with more snowfall and frost, and consequently higher maintenance cost (removal of snow, salting, repairing road surfaces). All this causes costs and expenditures and therefore future occurrence of cold winters is significant interest for road authorities as well as for asset management. Therefore, NRA's asked what is the probability of re-occurrence (repeating frequency) of cold winters and whether these winters are consistent with current climate change models?

To answer these questions we first look at the past[62]. How cold were the recent past winter compared with the climate normals? Fig. 6.1 shows the average winter temperature on a global scale, for Fennoscandia[63] and for the Northern Atlantic and Europe. As can be seen the winters of 2009/2010 and 2010/2011 were indeed relatively cold in Fennoscandia (belonging to the 25% coldest winters; 2011/2012 is within the 25-75% range)) but not cold on a global scale or on the scale of the North Atlantic and Europe. The figure also shows that in the past clearly colder winters occurred in Fennoscandia and also several cold winters in a row. The figure shows that variability in winter temperatures in Fennoscandia is very large. This variability is often underestimated by many people! On a global scale the variability is much smaller, since cold winters in one region are often compensated for by warm winters in other regions. The same but to a lesser extent is true for the North Atlantic and Europe as a whole.

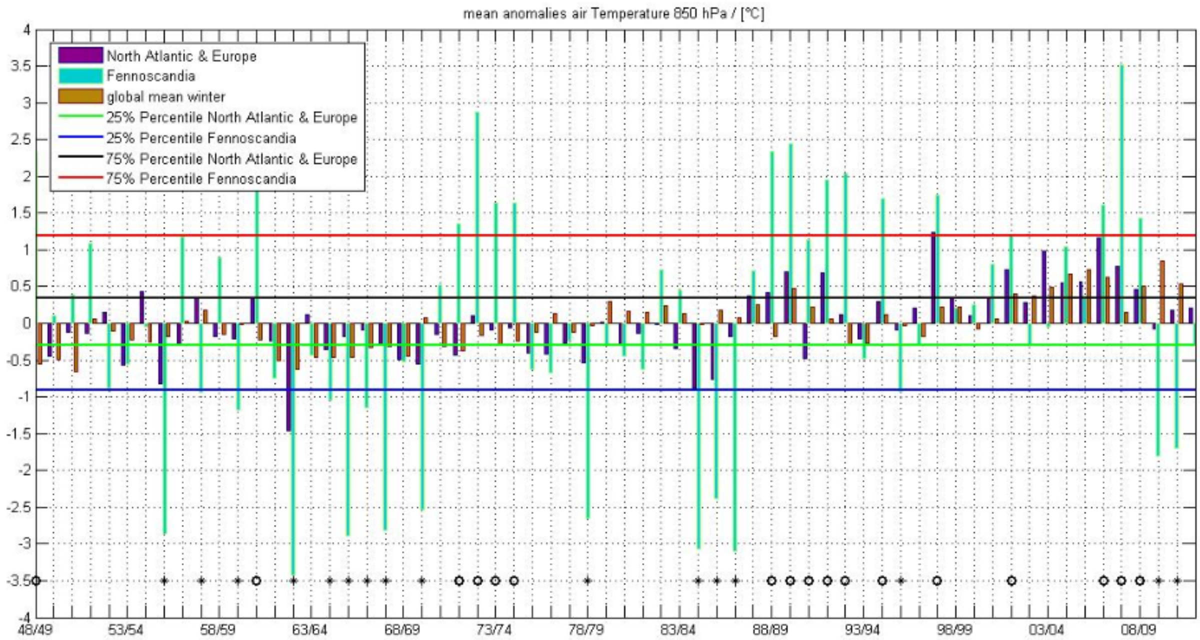


**Figure 6.1** Time series of winter temperature anomalies (to the period 1948-2012/13) averaged over (i) the North Atlantic and Europe (purple) as well as (ii) Fennoscandia (turquoise) and (iii) globally averaged. Horizontal lines indicate the percentiles below/above which winters are called very cold/warm. Asterisks/circles mark these very cold/warm winter seasons. Data retrieved from the NCEP/NCAR reanalysis data (Source: Matulla & Namyslo, 2014b).

Fig. 6.2 shows the spatial distribution of the anomalies of average winter temperature (December-February) from the reference period 1961-1990 for the winters of 2009/2010 (winter 2010) to 2012/2013 (winter 2013). As can be seen especially the winters 2009/2010 and 2010/2011 were relatively cold in a large part of northern Europe. This is in accordance with the information in Fig. 6.1.

For road maintenance not only the average winter temperature is of importance, but also snowfall or the number of days with snow cover. Fig. 6.3 shows the spatial distribution of the anomalies of number of days with at least 1 cm of snow cover for winter from the reference

[62] Information from the CliPDaR project on this subject is also included partly;
[63] Norway, Sweden, Finland and a small part of Russia

period 1961-1990 for the winters of 2009/2010 (winter 2010) to 2012/2013 (winter 2013). As can be seen in Fig. 6.2 and 6.3 far less weather stations have information on snow cover than on average temperature. The figures also show that there is some relation between snow cover and average winter temperature, but especially in the winters 2011/2012 and 2012/2013 in some part of Europe the number of days with snow cover was relatively large compared to the average winter temperatures[64].

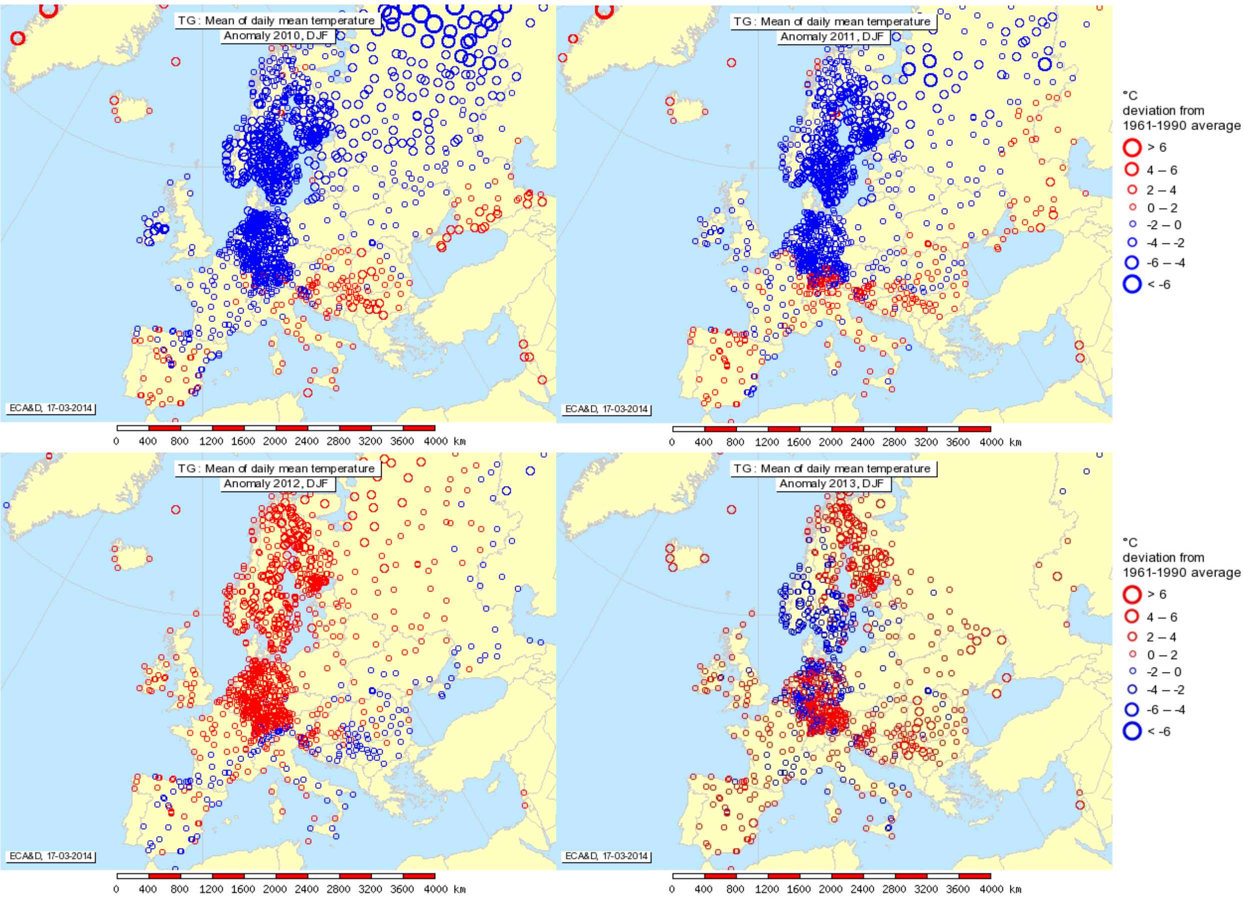


**Figure 6.2** Spatial distribution of the anomaly of average winter temperature (DJF) from the 1961-1990 period for the winters 2009/2010 (upper panel, left), 2010/2011 (upper panel, right), 2011/2012 (lower panel, left), 2012/2013 (lower panel, right) (Source: ECA&D).

[64] The average winter temperature can be relatively high due to e.g. a very warm December month, whereas it can be followed by one or two months with snowfall and low temperatures.

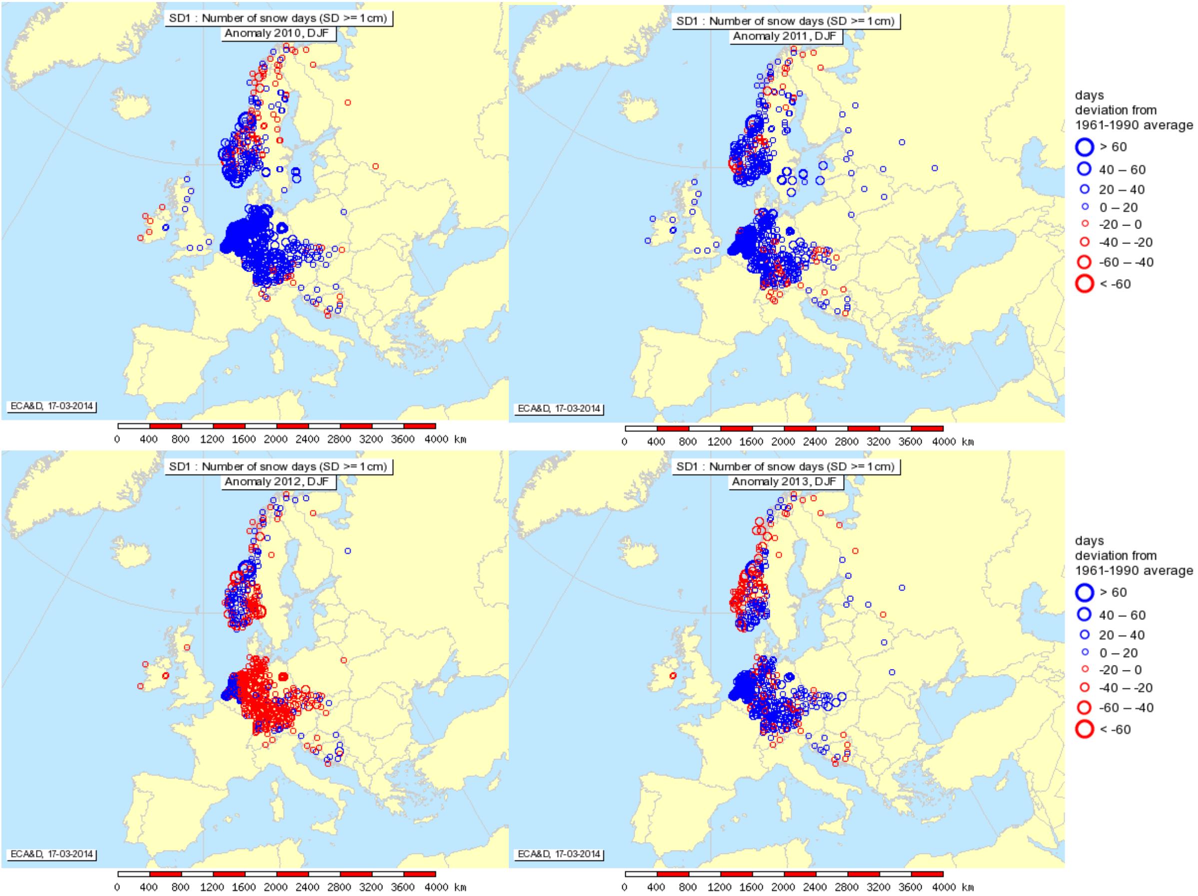


**Figure 6.3** Spatial distribution of the anomaly of the number of days with at least 1 cm of snow cover in winter (DJF) from the 1961-1990 period for the winters 2009/2010 (upper panel, left), 2010/2011 (upper panel, right), 2011/2012 (lower panel, left), 2012/2013 (lower panel, right) (Source: ECA&D).

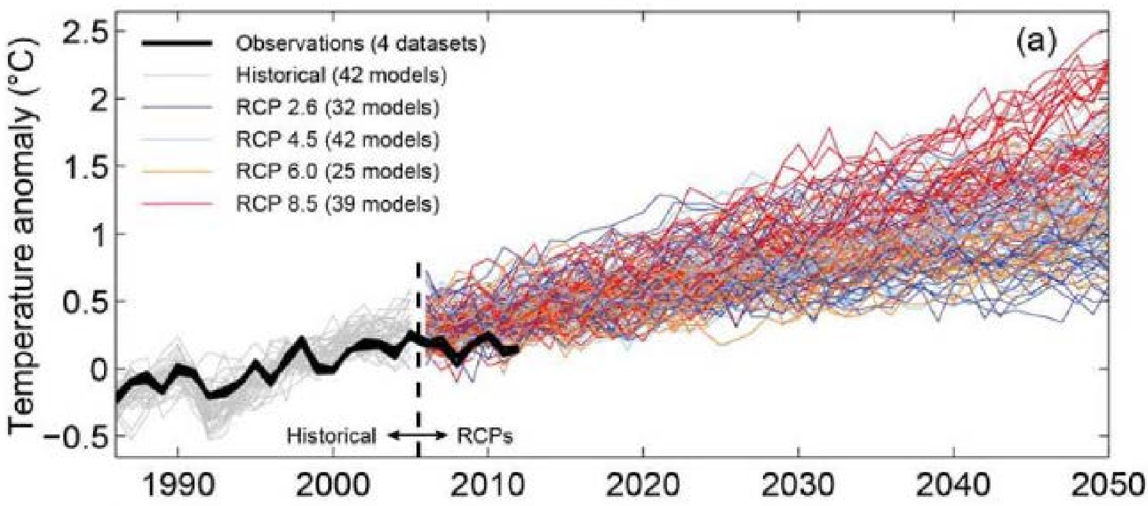


**Figure 6.4** Development of global average temperature (relative to 1986-2005). Thick black line: different observational data sets; coloured lines: GCM projections driven with various RCP's (IPCC, 2013).

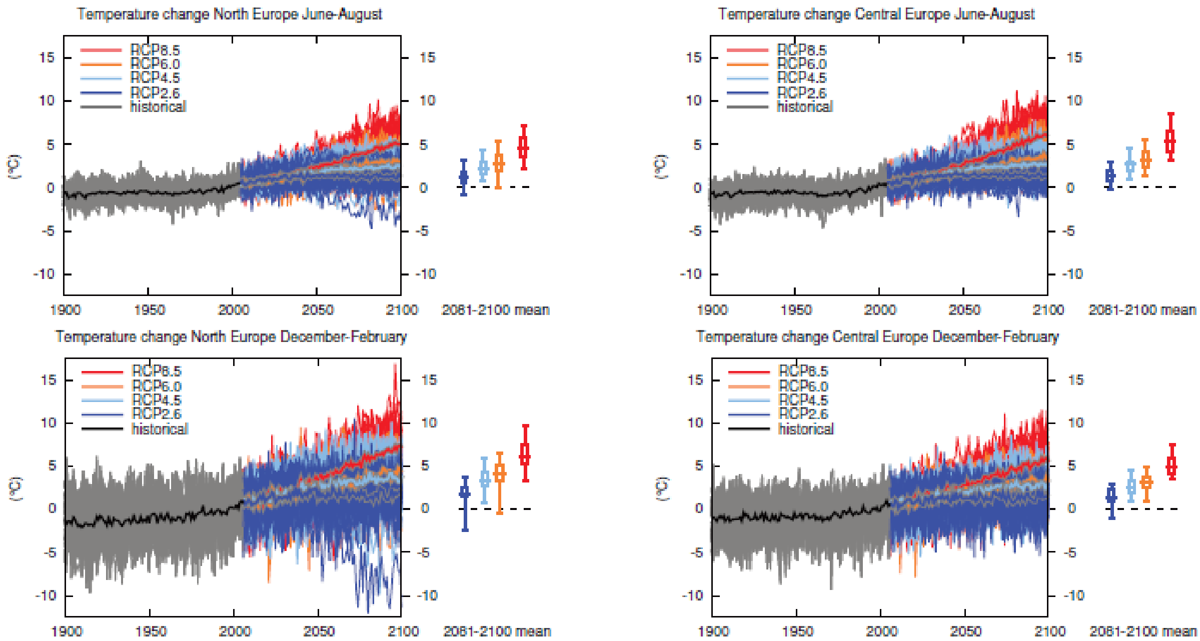


**Figure 6.5** Projected average temperature change in June-August (upper panels) and December-February (lower panels) in North Europe (left panels) and central Europe (right panels) (Source: IPCC, 2013 Annex I).

The trend in global average temperature rise is considerably lower since 1998. This is referred to as the temperature hiatus in the latest IPCC assessment report (IPCC, 2013). The question is whether this reduction in temperature increase is still within the natural variability, or that something else can be the cause, and whether the change in trend may be temporary. Fig. 6.4 shows the historical observations of the global temperature and a ensemble (multi-model and multi-RCP's) for the global temperature rise until 2050. The line with observations is still within the variability simulated by the model ensemble. On the basis of many studies IPCC concludes that about half of the change in temperature trend is due to internal variability. The other half can be attributed to external forcings such as the sun and volcanic eruptions. The anthropogenic contribution to climate change is masked by these effects. This means that the reduction in global temperature trend since 1998 can be temporary. So, occasionally cold winters are not in contradiction to global warming.

Petoukhov & Semenov (2010) published an article which reported a link between the amount of sea ice between Spitsbergen and Novaya Zemlya and cold winters in Europe. This issue is still under discussion. The strong reduction of sea ice in this area would be a reason that the winters are severe in northern Europe. However, this connection is very weak and not visible in the observations. In another study of Francis et al. (2012) it is concluded that the weather in winter will become more extreme (towards higher and lower temperatures due to increased meandering of the jet stream. More meandering leads to increased persistence of cold periods and of periods with very mild weather. In a study for the Netherlands increased persistence in winter temperatures from 1979 on was not observed, rather a tendency to decrease (although not significant), which means that no link with decreasing sea ice was observed. In addition, other modeling studies show different effects. Fig. 6.5 shows the projections of winter (and summer) temperature for Northern Europe and Central Europe. Most projections show an increase in winter temperature. Only a few show projections that are the same or slightly lower (related to the RCP's with the lowest increases of GHG's) than in the current climate. The figure also shows no clear decrease in year-to-year variability.

Although there are many questions about the causes of the recent cold winters, at the moment it seems more probable that the occurrence of cold winters will decrease, although year-to-year variability remains large.

**How extreme were the recent cold winters?**
The winters of 2009/2010 and 2010/2011 were indeed relatively cold in Northern Europe (for Fennoscandia belonging to the 25% coldest winters; 2011/2012 within the 25-75% range) but they were not cold on a global scale or on the scale of the North Atlantic and Europe. In the past clearly colder winters occurred in Fennoscandia and also several cold winters in a row were observed. Year-to-year variability in winter temperature is large on a regional scale and often underestimated.

**Are the recent cold winters in northern Europe and the reduced trend in global temperature rise in contradiction with climate change?**
Figure 6.4 shows that the global temperatures since 1998 are still within the simulated range of global temperature including natural variability. On the basis of many studies IPCC concludes that about half of the reduction in temperature trend is due to internal variability. The other half can be attributed to external forcings such as the sun and volcanic eruptions. The anthropogenic contribution to climate change is masked by these effects. So, occasionally colder periods are not in contradiction to global warming.

**Will cold winters as in the recent past occur as often in the future?**
Recent theories about possibly colder winters due to the decrease of Arctic sea ice show weak or no connection with observations. Although there are many questions left about the causes of the recent cold winters, at the moment it seems more probable that the occurrence of cold winters will decrease, although year-to-year variability remains large.

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# Annex 1. Approaches to climate change adaptation and interaction between socio-economic developments and climate change

**Approaches to climate change adaptation**
Climate data (for the current and future climate) can be used in different stages of the adaptation to climate change process, depending on the approach used. In the Top-down approach climate change is the starting point of the analysis. Climate data sets are produced to determine whether the system is vulnerable to climate change. In the bottom-up approach the current status of the system under study and its vulnerabilities are the starting point. Vulnerabilities or risks and thresholds are determined, of which climate or climate change can be one of the causes. Only in a later stage climate data are used to determine whether the thresholds will be passed in the current and future climate. Vulnerabilities due to other causes than climate change are also taken into account. Both approaches are schematically represented in Fig. A1.1. In the RIMAROCC approach especially the bottom-up approach is used (Berkhout et al., 2013), however it profits from the work that has been done in more top-down approaches (e.g. for the IPCC[65]).

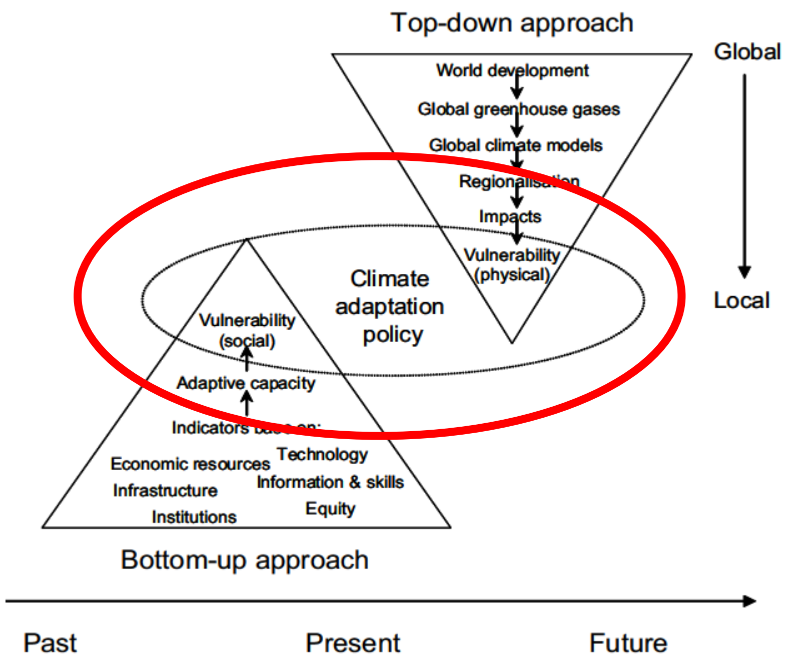


**Figure A1.1**. 'Top-down' and 'bottom-up' approaches used to inform adaptation to climate change (from Dessai and Hulme 2004; Dessai and vd. Sluijs, 2007: www.nusap.net/downloads/reports/ucca_scoping_study.pdf).

Society is often adapted to most of the extremes that occur. When climate changes and more often extremes occur that society cannot cope with, adaptation becomes necessary (Fig. A1.2).

[65] IPCC- Intergovernmental Panel on Climate Change: www.ipcc.ch/.

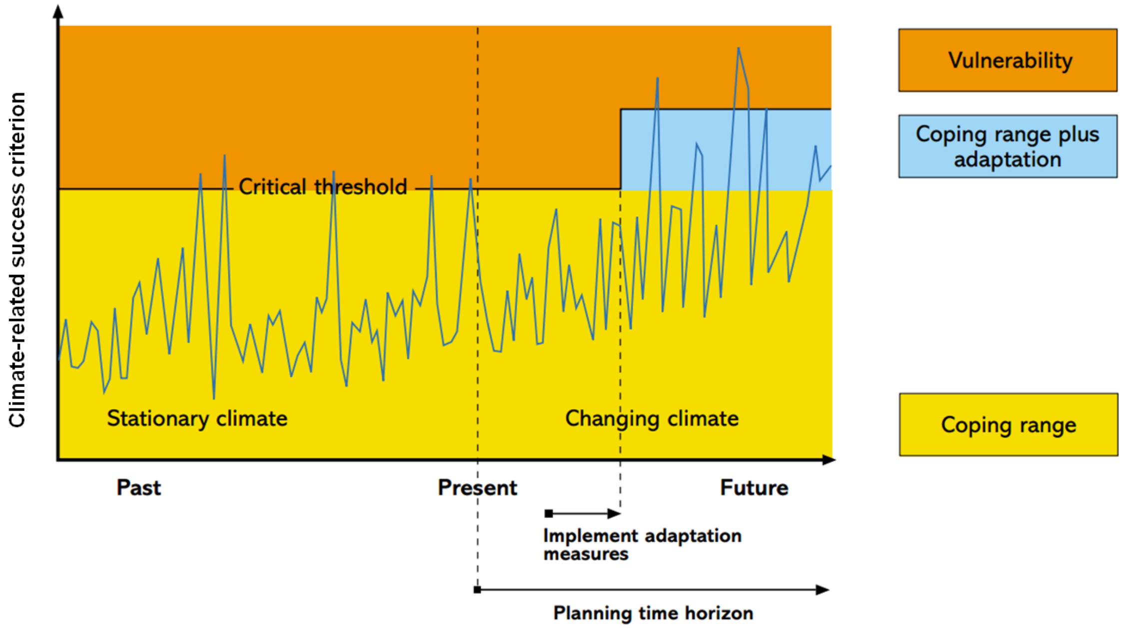


**Figure A1.2** Dealing with extreme weather events: when to take adaptation measures? (Source: EU, 2013, modified from Willows & Connell (2003)).

**Interaction between socio-economic developments and climate change**
Changes in vulnerability and risk of the road networks are not only caused by climate extremes (in the current or future climate). Even without climate change e.g. a stretch of road can become more vulnerable to extreme rainfall when e.g. the road will be used more intensely due to socio-economic developments (e.g. a new residential or industrial area near that road). Especially at a time horizon of 10-20 years ahead changes in socio-economic conditions (including changes in land use/cover and technological developments) may be more important for changes in vulnerabilities/risks than climate change.

To be able to take robust adaptation measures, it is useful to take this interaction into account and realize what are the causes of increased risks/vulnerabilities.

# Annex 2 Trend maps of relevant climate parameters

Below trend maps over the period 1951-2013[66] are shown. These maps were generated with ECA&D. Most information in Table 2.2 is based on these maps. Explanation of the indices can be found on http://eca.knmi.nl/indicesextremes/indicesdictionary.php. At the end of this Annex 2 it is explained how one can generate these maps.

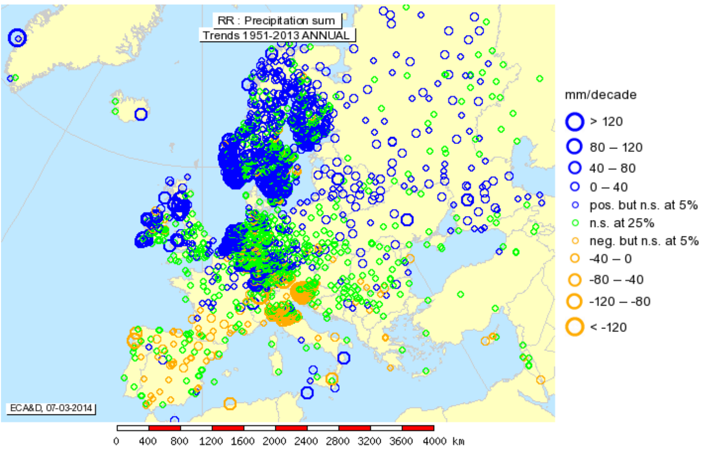


**Figure A2.1** Trend in average yearly rainfall (RR-annual) over the period 1951-2013 (ECA&D).

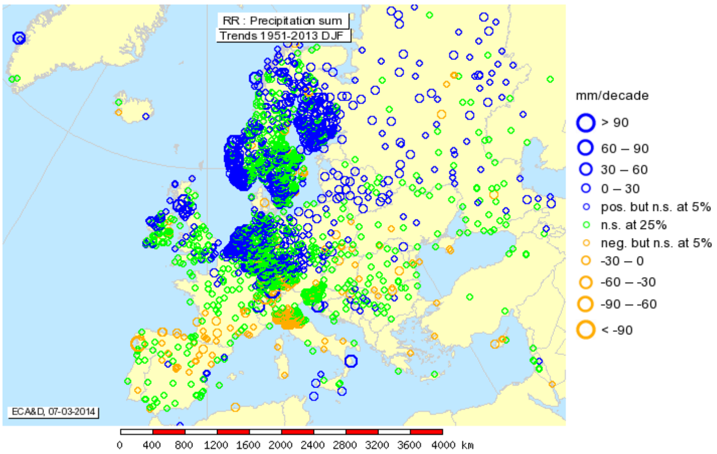


**Figure A2.2** Trend in average winter rainfall (RR-DJF) over the period 1951-2013 (ECA&D).

[66] For wind direction the period 1979-2013 was used, since hardly any reasonably homogeneous data are available for 1951-2013.

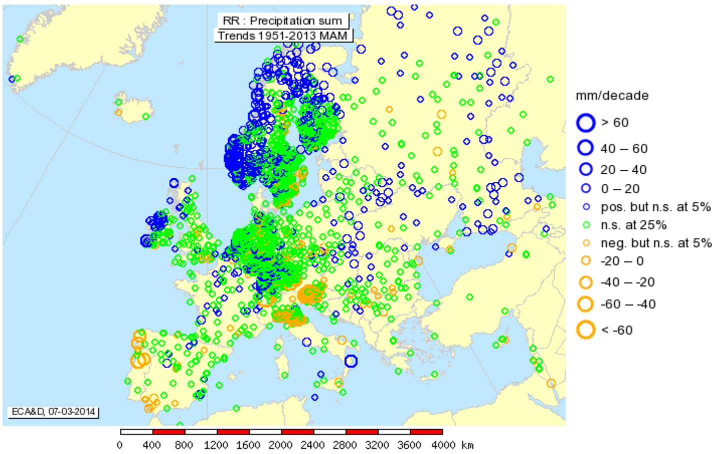


**Figure A2.3** Trend in average spring rainfall (RR-MAM) over the period 1951-2013 (ECA&D).

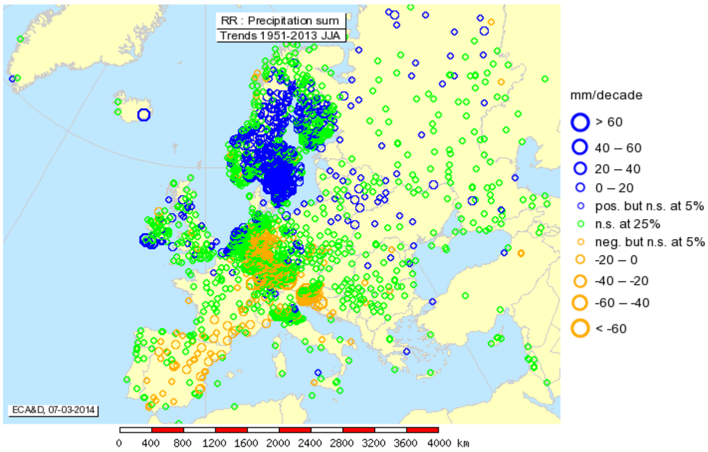


**Figure A2.4** Trend in average summer rainfall (RR-JJA) over the period 1951-2013 (ECA&D).

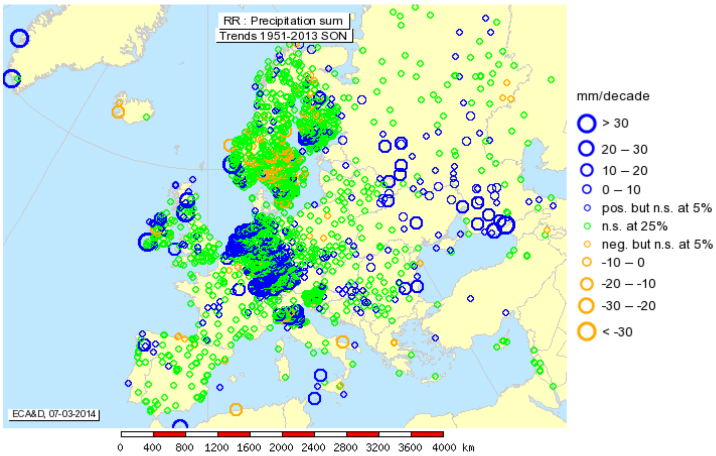


**Figure A2.5** Trend in average autumn rainfall (RR-SON) over the period 1951-2013 (ECA&D).

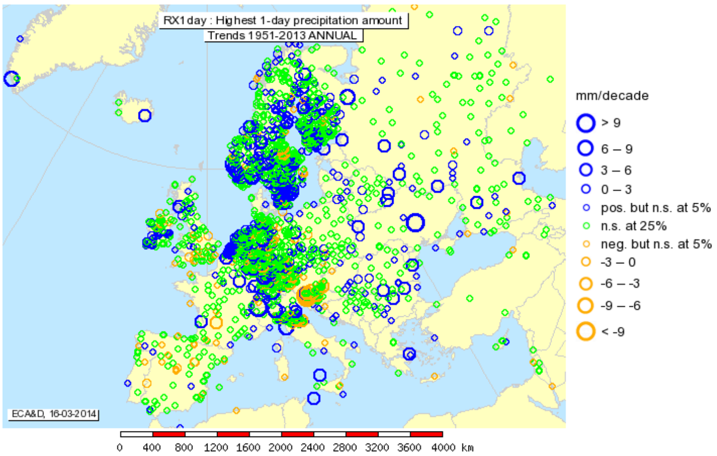


**Figure A2.6** Trend in highest 1-day precipitation amount per year over the period 1951-2013 (ECA&D).

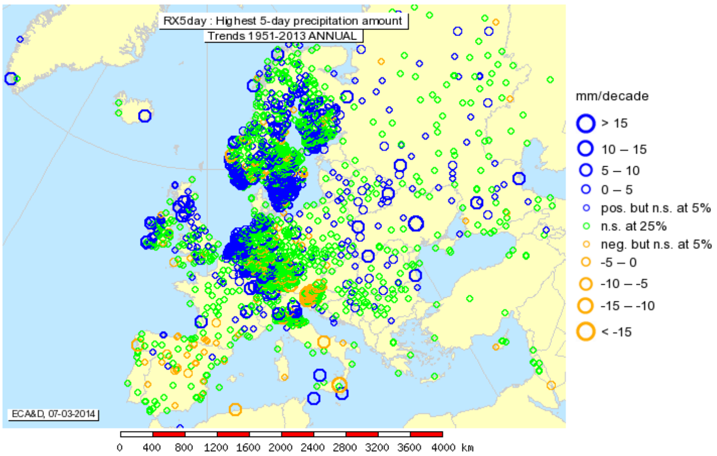


**Figure A2.7** Trend in highest 5-day precipitation amount per year over the period 1951-2013 (ECA&D).

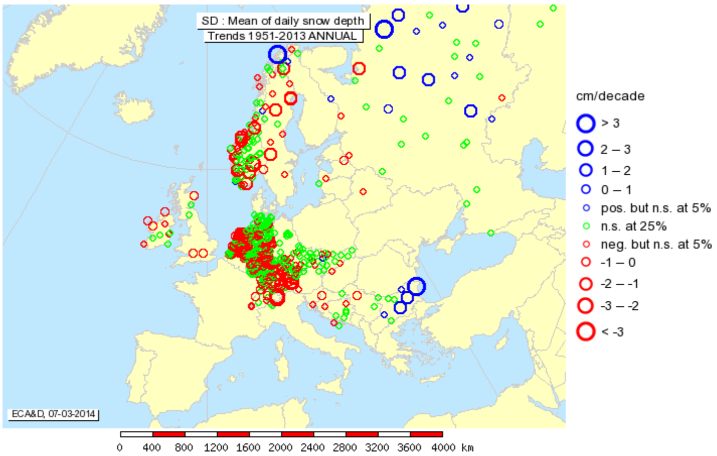


**Figure A2.8** Trend in mean of annual snow depth over the period 1951-2013 (ECA&D).

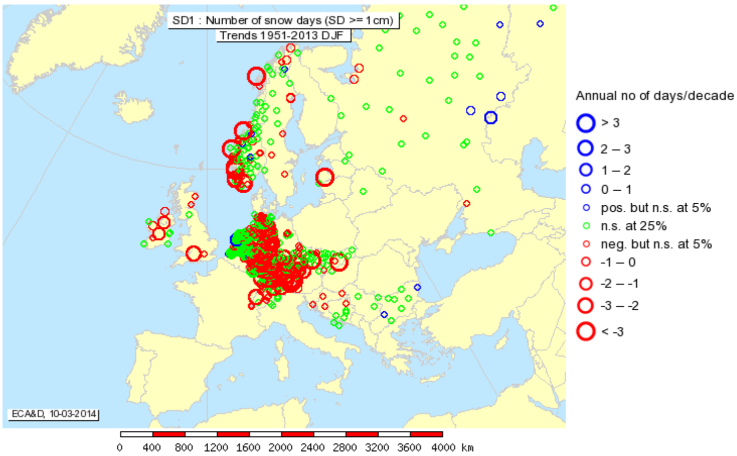


**Figure A2.9** Trend in number of days per year with snow depth of more than 1 cm over the period 1951-2013 (ECA&D).

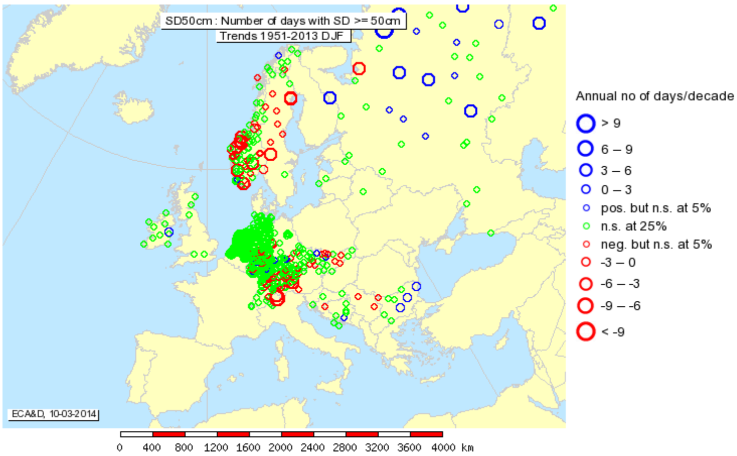


**Figure A2.10** Trend in number of days per year with snow depth of more than 50 cm over the period 1951-2013 (ECA&D).

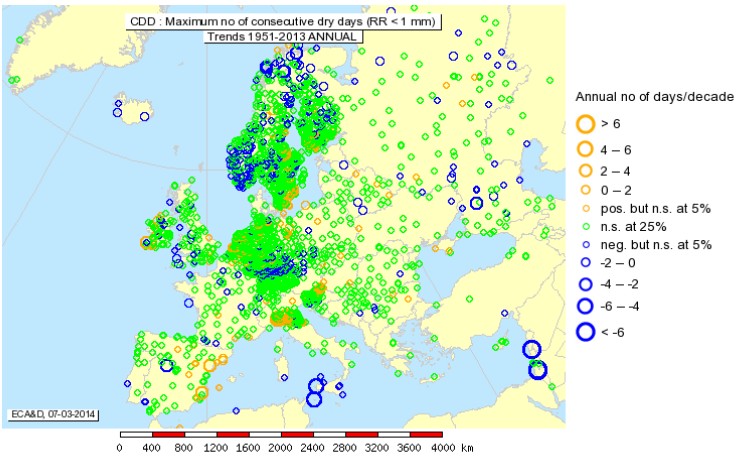


**Figure A2.11** Trend in maximum number of consecutive dry days (<1 mm) per over the period 1951-2013 (ECA&D).

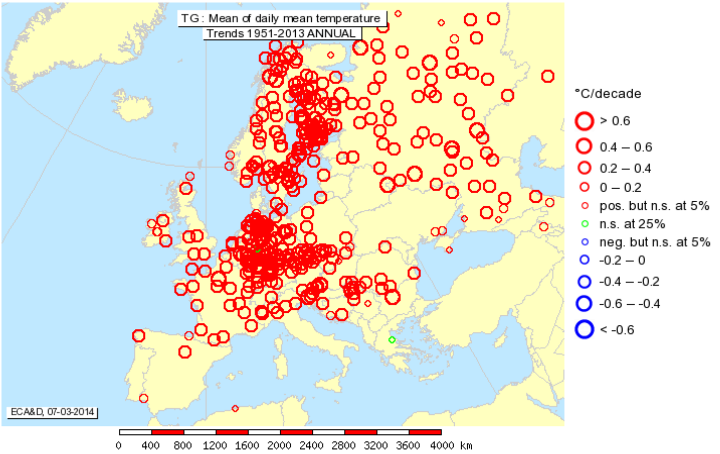


**Figure A2.12** Trend in average annual temperature over the period 1951-2013 (ECA&D).

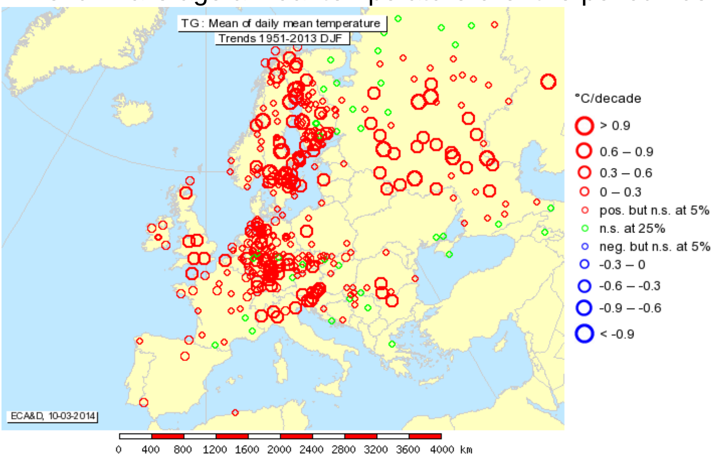


**Figure A2.13** Trend in average winter temperature over the period 1951-2013 (ECA&D).

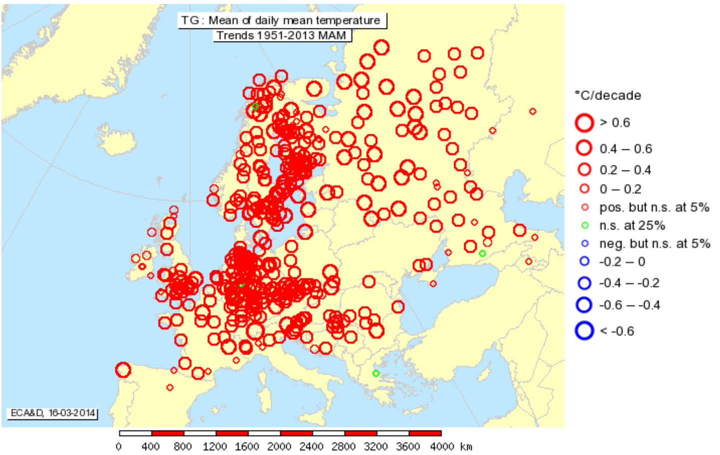


**Figure A2.14** Trend in average spring temperature over the period 1951-2013 (ECA&D).

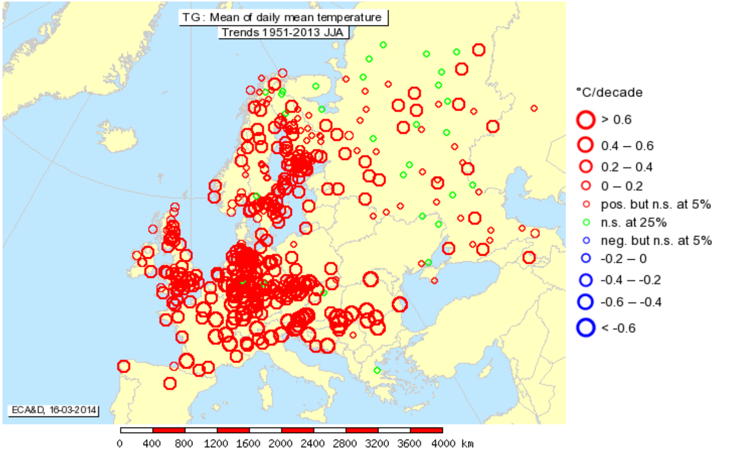


**Figure A2.15** Trend in average summer temperature over the period 1951-2013 (ECA&D).

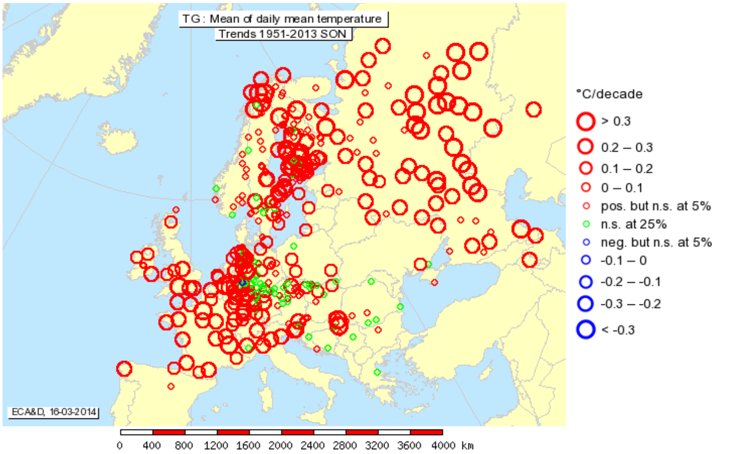


**Figure A2.16** Trend in average autumn temperature over the period 1951-2013 (ECA&D).

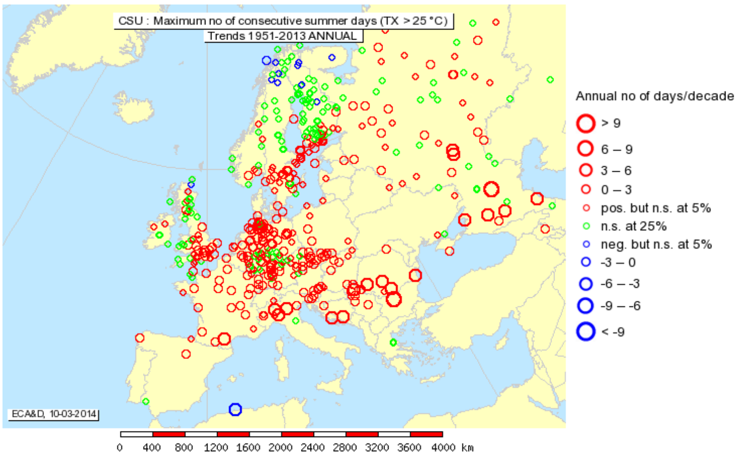


**Figure A2.17** Trend in maximum number of consecutive summer days (Tmax ≥ 25 ˚C) per year over the period 1951-2013 (ECA&D).

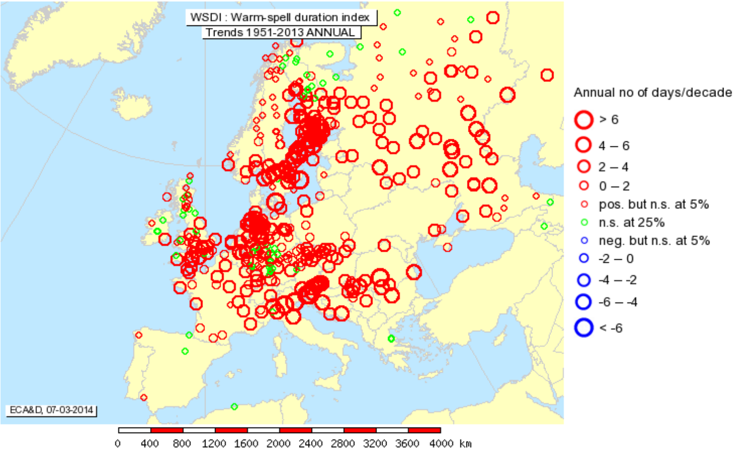


**Figure A2.18** Trend in the warm spell duration index per year over the period 1951-2013 (ECA&D).

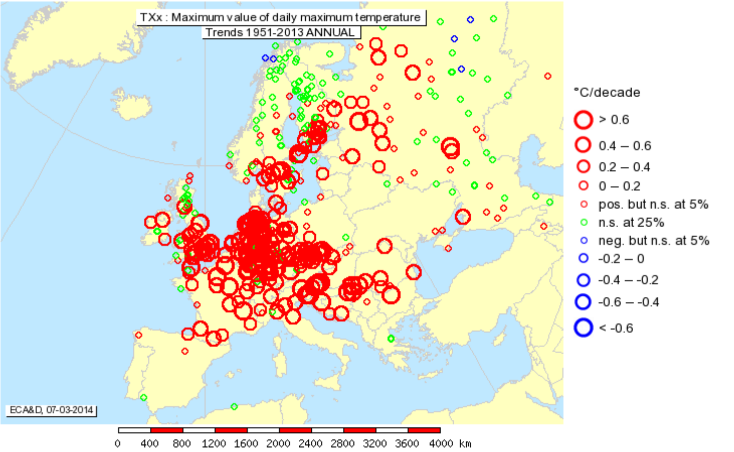


**Figure A2.19** Trend in the maximum daily temperature per year over the period 1951-2013 (ECA&D).

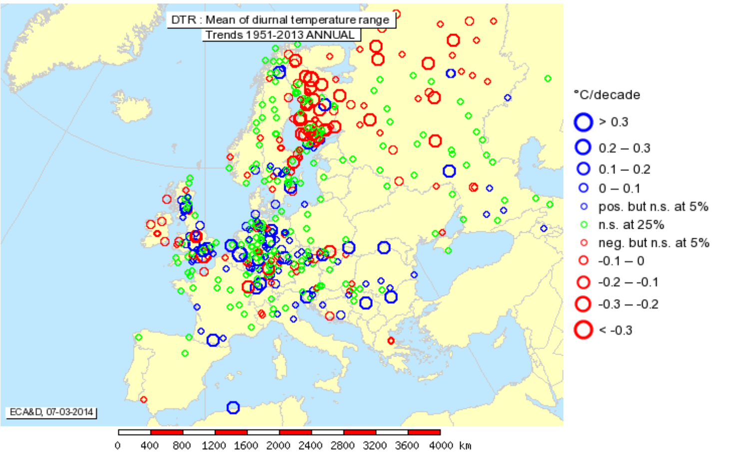


**Figure A2.20** Trend in the mean of the diurnal temperature range per year over the period 1951-2013 (ECA&D).

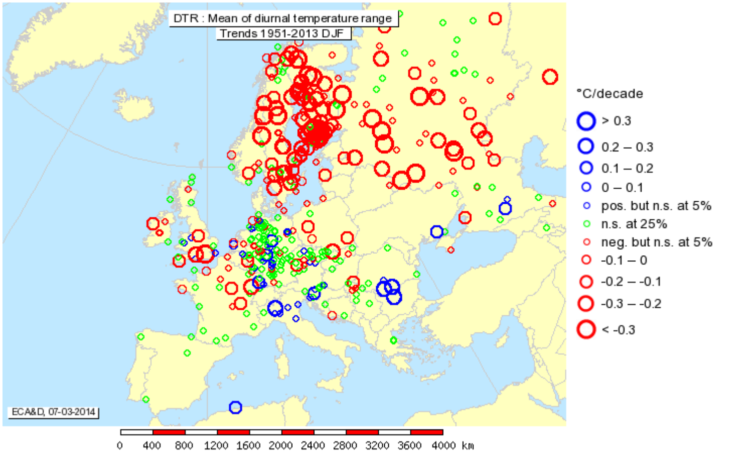


**Figure A2.21** Trend in the mean of the diurnal temperature range per winter over the period 1951-2013 (ECA&D).

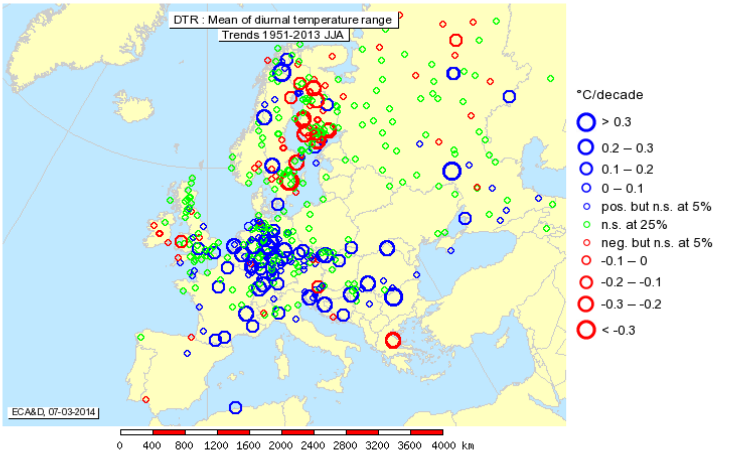


**Figure A2.22** Trend in the mean of the diurnal temperature range per summer over the period 1951-2013 (ECA&D).

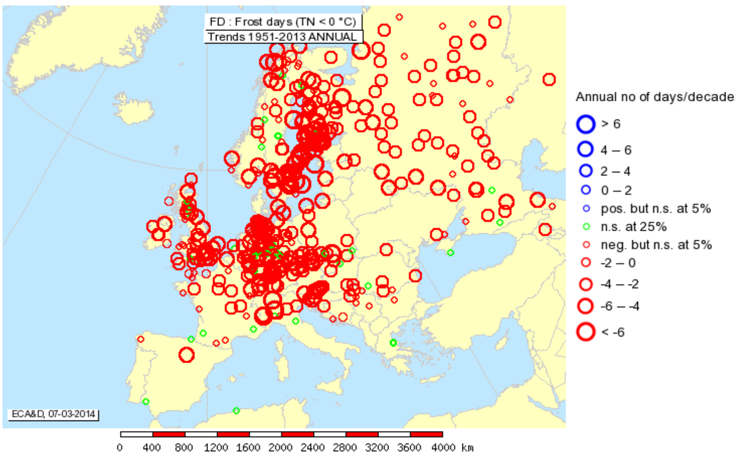


**Figure A2.23** Trend in number of frost days (Tmin < 0 ˚C) per year over the period 1951-2013 (ECA&D).

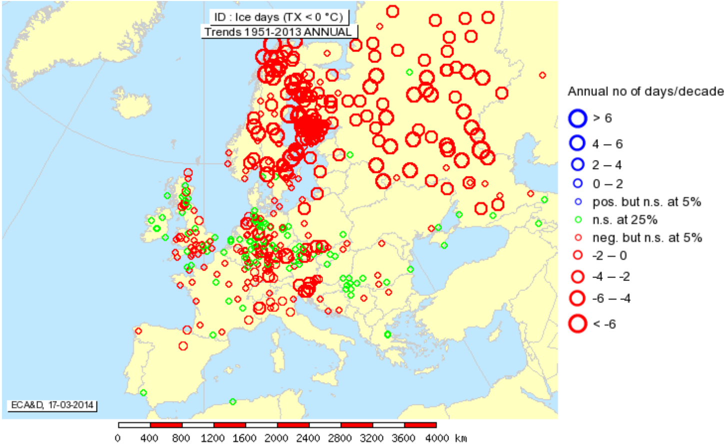


**Figure A2.24** Trend in number of ice days (Tmax < 0 ˚C) per year over the period 1951-2013 (ECA&D).

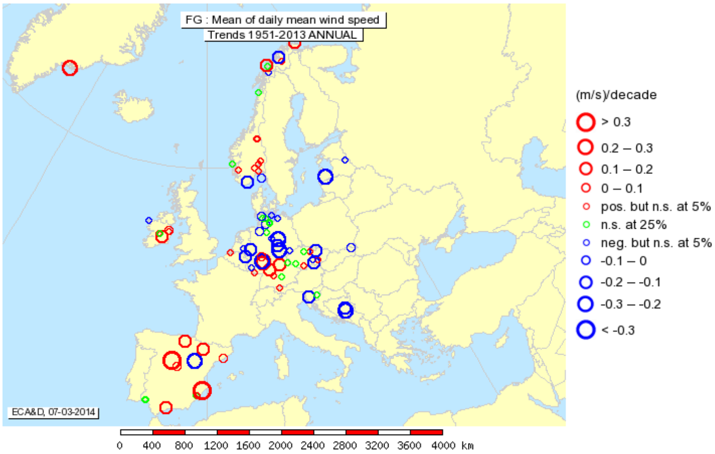


**Figure A2.25** Trend in the mean of the daily wind speed per year over the period 1951-2013 (ECA&D).

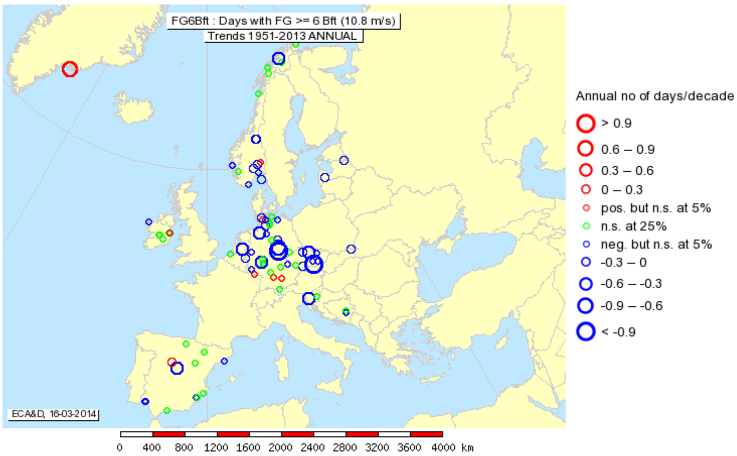


**Figure A2.26** Trend in number of days a wind speed of 6 Bft or more per year over the period 1951-2013 (ECA&D).

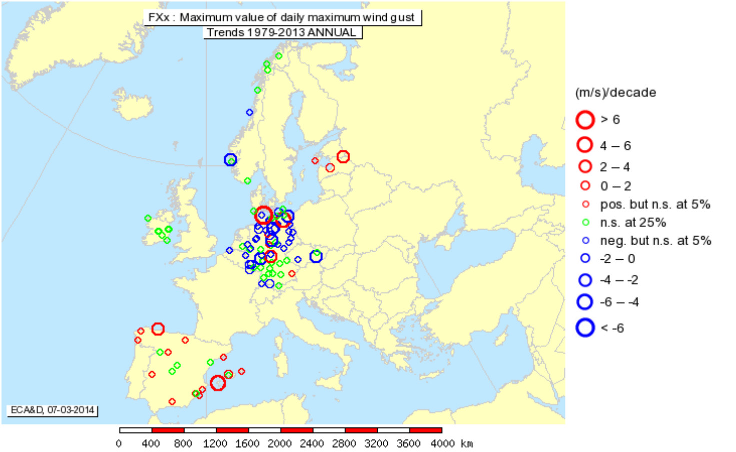


**Figure A2.27** Trend in maximum daily maximum wind gust per year over the period 1951-2013 (ECA&D).

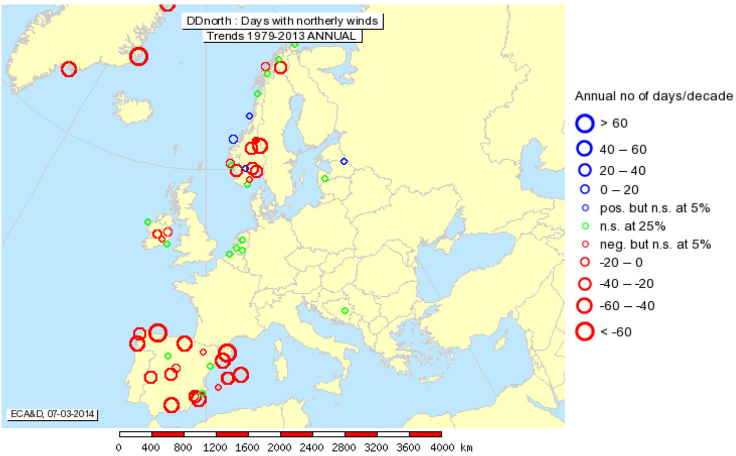


**Figure A2.28** Trend in number of days northerly winds per year over the period 1979-2013 (ECA&D).

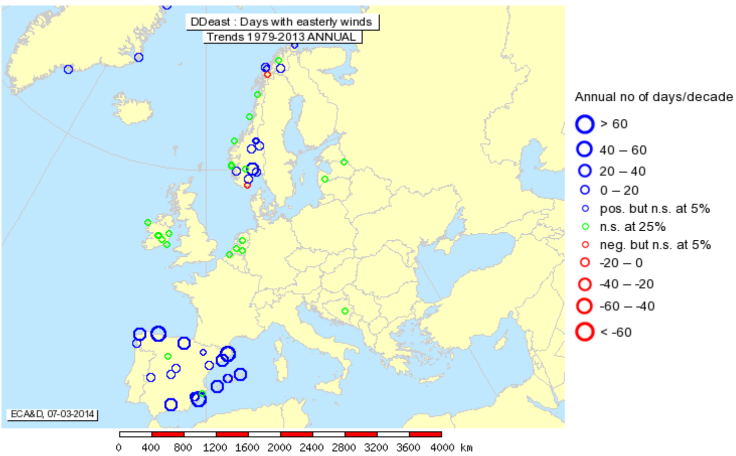


**Figure A2.29** Trend in number of days easterly winds per year over the period 1979-2013 (ECA&D).

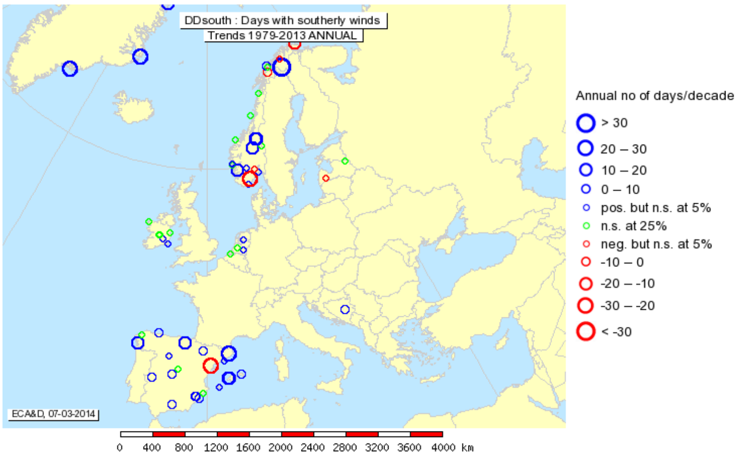


**Figure A2.30** Trend in number of days southerly winds per year over the period 1979-2013 (ECA&D).

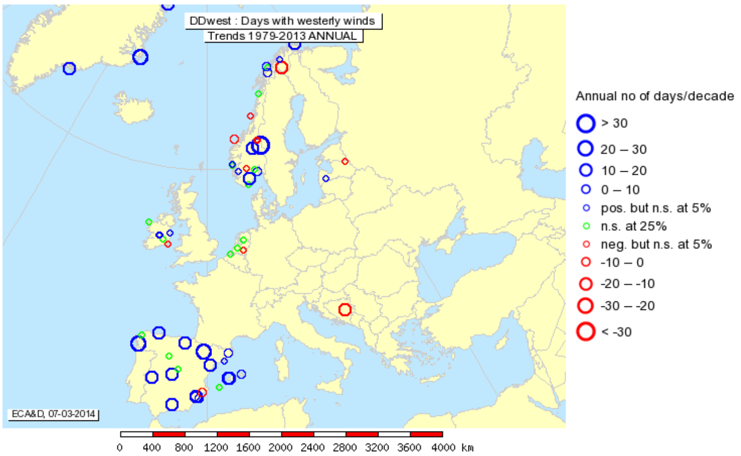


**Figure A2.31** Trend in number of days westerly winds per year over the period 1979-2013 (ECA&D).

## *A2.1 Generating trend maps yourself with the ECA&D database*

Use the following steps to create trend maps yourself:

- Go to: www.ecad.eu/;
- Select 'Indices of extremes' in the upper bar;
- Go to 'Trend maps' in the list on the lower half of the web page;
- Select the 'Index Category';
- Select an 'Index'. For an explanation of the indices one can go to www.ecad.eu/indicesextremes/indicesdictionary.php;
- Select the 'period' of interest (preferably use a longer period, e.g. 1951-2013). To see how robust the trend is or whether the trend has changed in the past decades, one can also create a map for a more recent period e.g. 1979-2013;
- Select the 'season';
- Then click on the map area and the trend map will appear.

The web page gives information on how to interpret the maps and the web page also offers the possibility to down load the map and data (see right top of the map) and to zoom in.

## A2.2 Example on how to use the Climate Explorer for processing of climate data

For the estimation of extreme rainfall return times with the help of the Climate Explorer the following steps can be followed:

- Go to http://climexp.knmi.nl/start.cgi?id=someone@somewhere;
- Go to *Select a time series*: select *Daily station data;*
- Select *Blended ECA&D* (database: contains some longer time series than *Pure ECA&D*) and the climate variable *Precipitation;*
- Go to *Select* and fill in the name **Paris** after *Stations with a name containing*;
- Click on *Get stations*;
- The following information is presented:

  Looking for stations with substring PARIS
  Found 1 stations
  PARIS-14E_PARC_MONTSOURIS (FR)
  coordinates: 48.82N, 2.34E, 75.0m
  ECA station code: 38 (get data)
  Found 129 years of data in 1886-2014

- Click on *Get data* to get access to the daily time series (you will get the screen in Fig. A2.32).

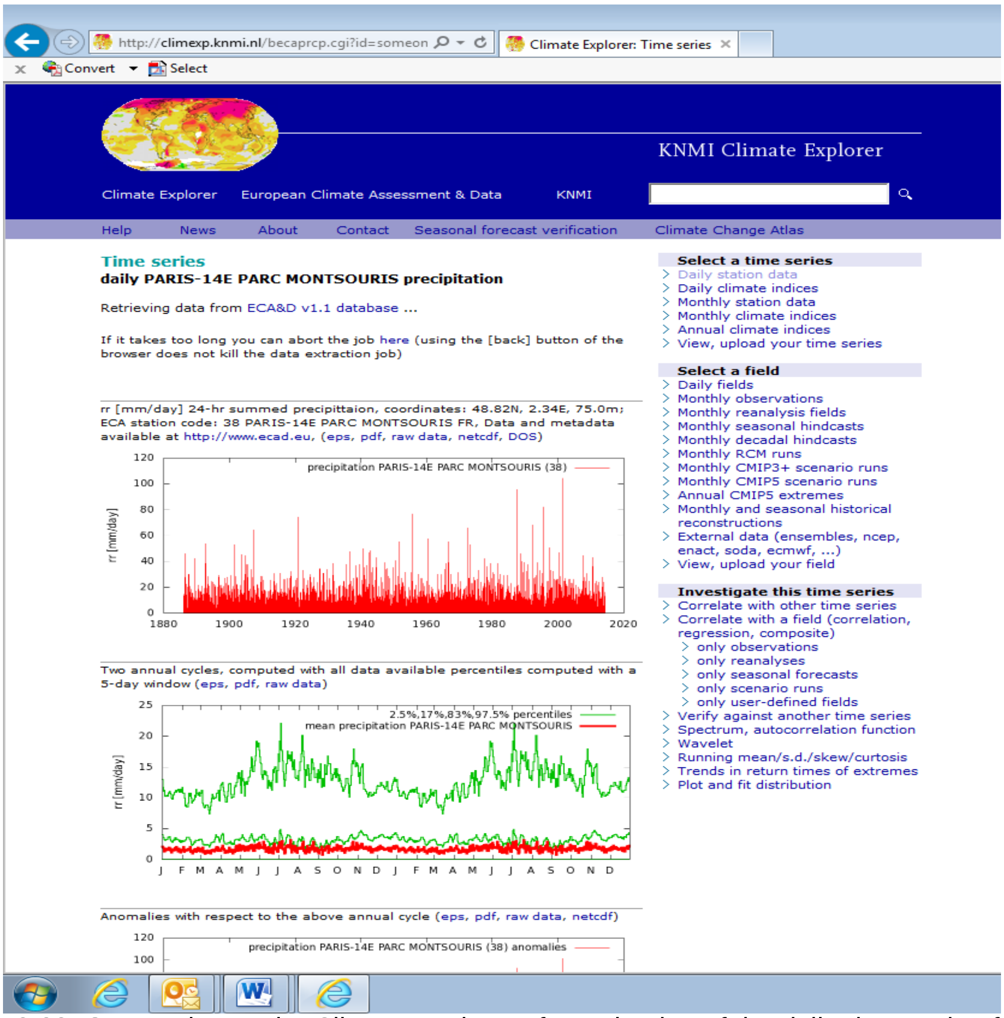


**Figure A2.32.** Screenshot to the Climate explorer after selection of the daily time series for Paris.

There are several ways for estimating the return times of precipitation extremes, but one is using the highest values per year. The get a time series of these highest daily rainfall events per year do the following:

- Scroll down the screen and go to *Create a lower resolution time series*;
- Select *New time scale: Annual (Jan-Dec)*;
- Select *New variable: max*;
- Select *Threshold: no cut*;
- Then click on *Make new time series* and you will get the time series as presented in Fig. A2.33.

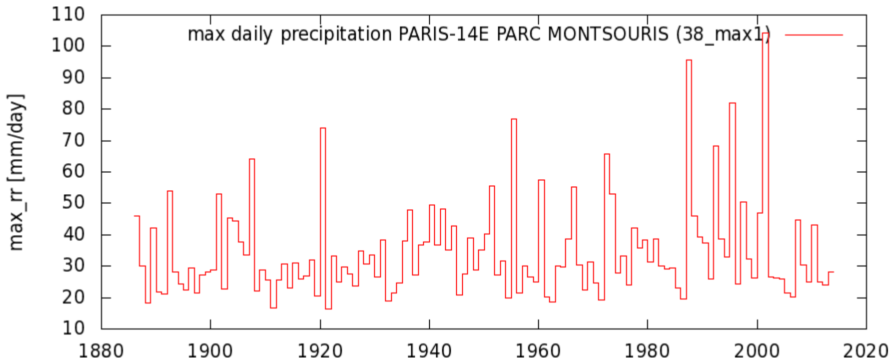


**Figure A2.33** Time series with the annual maximum daily rainfall for station Paris-14E Parc Montsouris, generated with the Climate Explorer.

To check whether the time series contains long term trends, take the following steps:

- Go to *Investigate this time series* and select *running mean/s.d./….* (in the menu on the right side);
- In the next screen change *Window* into **30** (for describing a climate we often use 30 years) and click on *Compute* and you will get the following figure (A2.34).

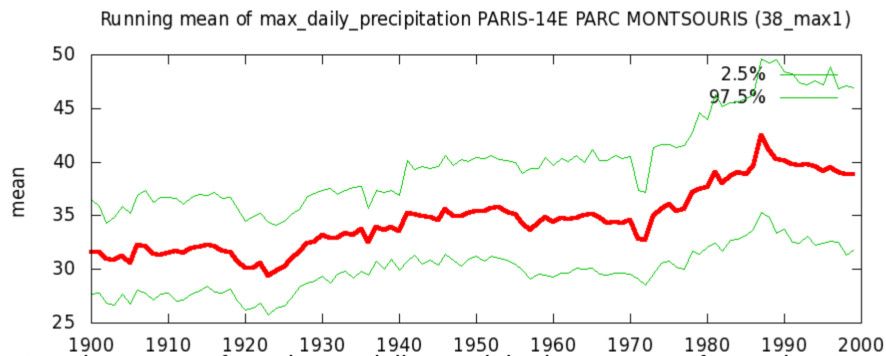


**Figure A2.34** Running mean of maximum daily precipitation per year for station PARIS-14E PARC MONTSOURIS, generated with the Climate Explorer.

As you can see there is a trend in the 30-year average yearly maximum daily precipitation. For estimating e.g. the maximum daily precipitation that is exceeded on average once in 10 years in the current climate it is not wise to use the whole time series from 1900 on. For estimating a return time of once in 10 years, at least about 30 years is needed (but preferably more). We can select the period this is often used to describe the current climate (1981-2010) in this time series in the following way:

- Go back to the screen that contains figure A2.33;
- Go to *Manipulate this time series;*
- After *Select years* fill in **1981** and **2010**;
- Then click on *select*.

To make a rough first estimate of the daily precipitation amount that is exceeded on average once in 10 years in the current climate, follow the next steps:

- In the screen after selecting the years 1981-2010 go to *Investigate this time series* and select *Plot and fit distribution*;
- In the next screen select for *Type of plot: Gumbel plot* (often used for precipitation extremes);
- Then select for *Fit: Gumbel or GEV* (this requires ample knowledge about precipitation extremes, using both may give you at least some indication of the daily amount of rainfall that may be exceeded once in 10 years and the uncertainty around this estimate);
- When you select the GEV fit you will get Fig. A2.35, when you select the Gumbel fit you will get Fig. A2.36. The GEV-fit gives an estimate of 65 mm (95% confidence interval is 47-95 mm; on the website look in the table above the figure) and the Gumbel-fit gives an estimate of 59 mm (95% confidence interval is 44-76 mm). As can be seen in Fig. A2.36 the highest observations are outside the 95% confidence interval, indicating that the Gumbel-fit is probably not the most appropriate method to use (and probably leading to some underestimation). However, the GEV-fit may result in overestimation and large uncertainty intervals when a few observations are much higher than the rest (as is the case here);
- Based on the above analyses the first rough estimate of the daily precipitation amount that is exceeded once in 10 year on this station is around 60 mm, with a large uncertainty range.

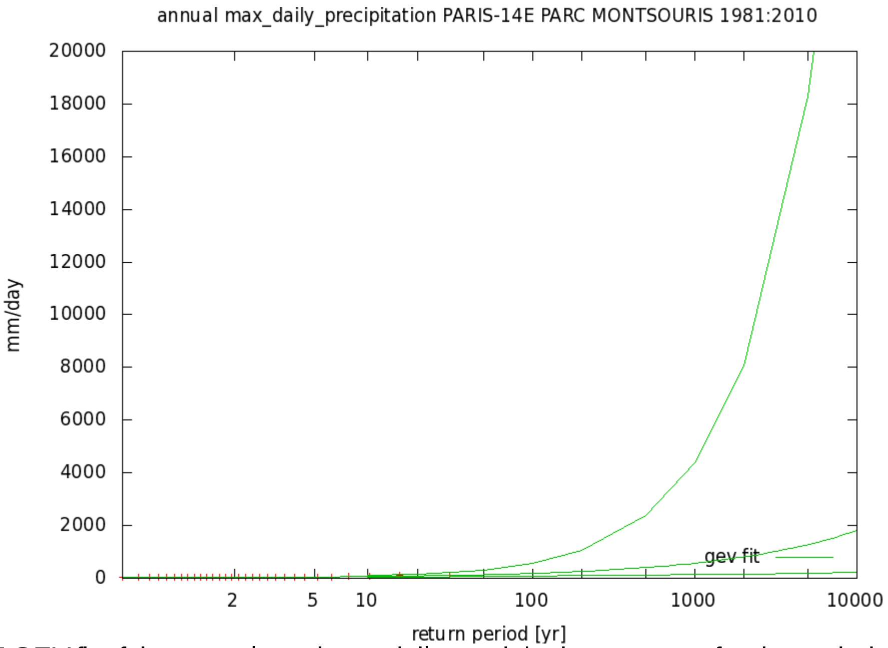


**Figure A2.35** GEV fit of the annual maximum daily precipitation amounts for the period 1981-2010 for station Paris-14E Parc Montsouris, generated with the Climate Explorer.

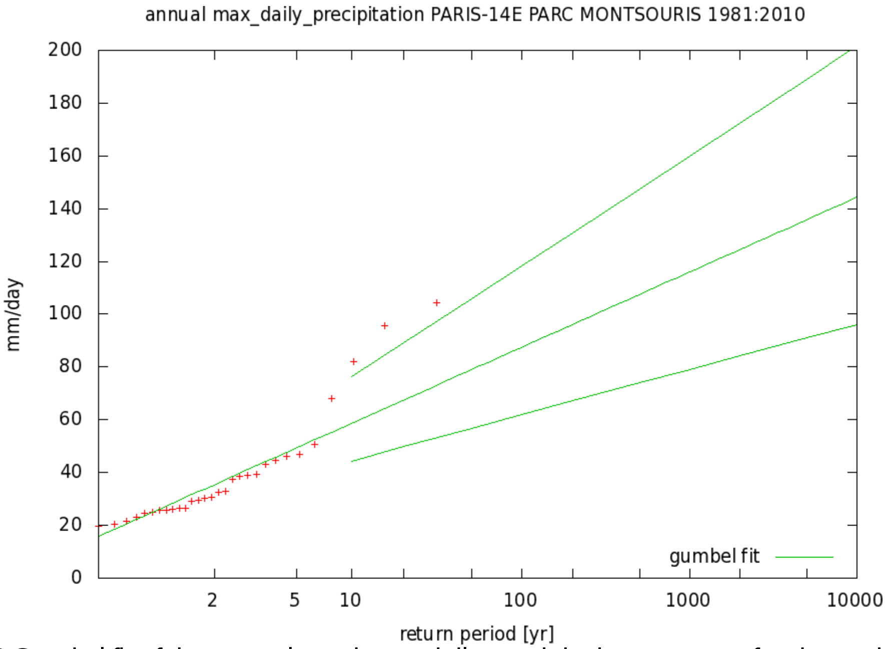


**Figure A2.36** Gumbel fit of the annual maximum daily precipitation amounts for the period 1981-2010 for station Paris-14E Parc Montsouris, generated with the Climate Explorer.

# Annex 3 List of abbreviations

The full titles and/or explanation of many of the abbreviations used in this document are presented below:

| | |
|---|---|
| A1B | Code for one of the SRES scenarios, the B stands for 'Balanced' |
| A1FI | Code for one of the SRES scenarios, the FI stands for ' Fossil' |
| A2 | Code for one of the SRES scenarios |
| AOGCM | Atmosphere-Ocean Global Circulation Model |
| | |
| B1 | Code for one of the SRES scenarios |
| B2 | Code for one of the SRES scenarios |
| | |
| CLIMRUN | Climate Local Information in the Mediterranean region Responding to User Needs (EU-project) |
| CliPDaR | Design guideline for a transnational database of downscaled climate projection data for road impact models |
| CMIP5 | Coupled Model Intercomparison Project Phase 5 |
| CSP | Climate Services Partnership |
| | |
| DJF | December - February |
| DWD | Deuthscher WetterDienst |
| | |
| ECLISE | Enabling CLimate Information Services for Europe (EU-project) |
| ECA&D | European Climate Assessment and Database |
| ECMWF | European Centre for Medium-Range Weather Forecasts |
| ENSEMBLES | EU-project on Climate Change and its Impacts (EU-project) |
| E-OBS | Gridded version of the ECA dataset |
| EPA | Environmental Protection Agency |
| ERA40 | ECMWF re-analysis (September 1957 through August 2002) |
| ERA-interim | ECMWF re-analysis (period from 1979 to present) |
| ETCCDI | Expert Team on Climate Change Detection and Indices |
| EURO4M | European Reanalysis and Observations for Monitoring (EU-project) |
| | |
| HISTALP | Historical Instrumental Climatological Surface Time Series Of The Greater Alpine Region ( |
| HYRAS | Central European high-resolution gridded daily data sets |
| | |
| IPCC | Intergovernmental Panel on Climate change |
| IS-ENES | Infrastructure project of the European Network for Earth System modelling |
| | |
| JJA | June - August |
| JPI-Climate | Joint Programming Initiative on Climate (of the EU) |
| | |
| GCM | Global Climate/Circulation Model |
| GCOS | Global Climate Observing System |
| GHCN | Global Historical Climate Network |
| GHG | GreenHouse Gases |
| | |
| KLIWAS | Auswirkungen des Klimawandels auf Wasserstraßen und Schifffahrt – Entwicklung von Anpassungsoptionen (Germany) |

| | |
|---|---|
| KNMI | Koninklijk Nationaal Meteorologisch Instituut (Royal National Meteorological Institute of the Netherlands) |
| MAM | March - May |
| NCEP/NCAR | National Centres For Environmental Prediction/National Centre for Atmospheric Research (USA) |
| NETCDF | NETwork Common Data Form |
| NMHI | National Meteorological and Hydrological Institute |
| NMS | National Meteorological Station |
| NOAA | National Oceanic and Atmospheric Administration (USA) |
| NRA | National Road Authority |
| NWP | Numerical Weather Prediction |
| PRUDENCE | Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects (EU-project) |
| RCC | Regional Climate Centre |
| RCM | Regional Climate Model |
| RCP | Representative Concentration Pathway |
| RIMAROCC | Risk Management for Roads in a Changing Climate |
| ROADAPT | Roads for today, adapted for tomorrow |
| SON | September - November |
| SRES | Special Report on Emission Scenarios (of IPCC) |
| UKCIP | United Kingdom Climate Impacts Programme |
| VALUE | Validating and Integrating Downscaling Methods for Climate Change Research (EU-project) |
| WMO | World Meteorological Organization |