Analysis of the state of knowledge on climate changes so far and on the impact of climate change on the water regime in the Rhine watershed - Literature evaluation -

State beginning 2009

Summary

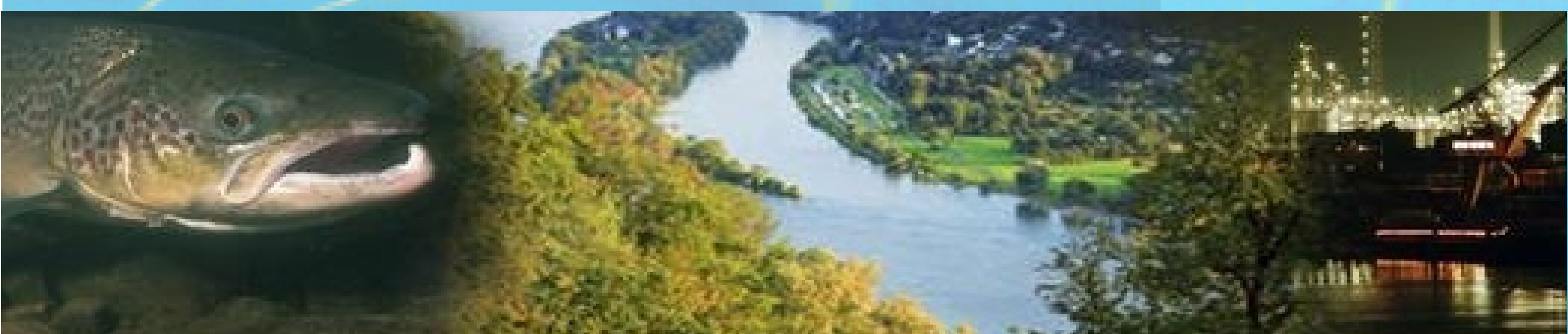
IKSR
CIPR
ICBR

Internationale Kommission zum Schutz des Rheins

Commission Internationale pour la Protection du Rhin

Internationale Commissie ter Bescherming van de Rijn

Report No. 174



Imprint

Publisher:
International Commission for the Protection of the Rhine (ICPR)
Kaiserin-Augusta-Anlagen 15, D 56068 Koblenz
P.O. box 20 02 53, D 56002 Koblenz
Telephone +49-(0)261-94252-0, Fax +49-(0)261-94252-52
Email: sekretariat@iksr.de
www.iksr.org

Translation: Karin Wehner

ISBN 3-935324-79-0

HYDRON
UMWELT und WASSERWIRTSCHAFT

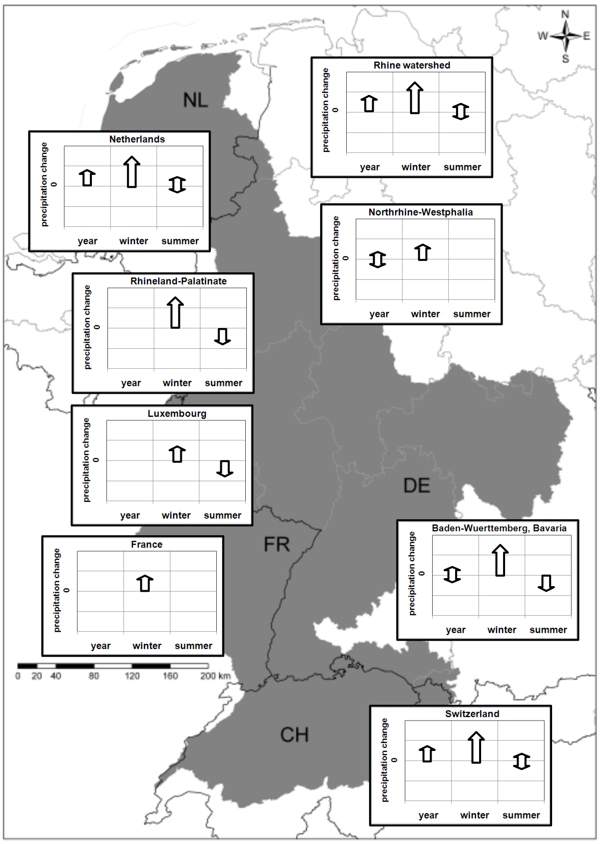
HYDRON Ingenieurgesellschaft für
Umwelt und Wasserwirtschaft mbH

Haid-und-Neu-Straße 7
D-76131 Karlsruhe
Germany

Tel. +49 (721) 860 181 0
Fax +49 (721) 860 181 29
www.hydron-gmbh.de

Analysis of the state of knowledge on climate changes so far and on the impact of climate change on the water regime in the Rhine watershed

- Literature evaluation, state beginning 2009 -



Client: Secretariat of the International Commission for the Protection of the Rhine

Editing: Dr.-Ing. Kai Gerlinger

State of report: Final version 30.04.2009

Extended summary

<u>Nature of the task and approach</u>

With a view to evaluating the regional impact of climate change in the Rhine watershed, the ICPR expert group KLIMA commissioned a compilation of investigations on climate change. The survey consists of three parts:

- Survey over the general, up-to-date investigation on climate change.
- Survey over the present state of knowledge on climate change and the hydrological regime so far.
- Evaluation of future impact of eventual climate change on the hydrological regime.

Only precipitation and air temperature, the parameters considered to be of particular importance for the hydrological regime, are being considered. The focal points for the assessment of the hydrological regime are runoff (average runoff, floods and low water regime) as well as water temperature.

The survey of the state of knowledge is based on the documents the delegations furnished. All in all, 110 documents were furnished and surveyed. Due to the large scope of available literature on climate change, this survey cannot pretend to be comprehensive.

The investigations cannot be directly compared with one another, as different methods of assessment and different periods are being considered. Also, results are summarized, resulting in a loss of differentiation in time and space. The evaluation of the investigations or conclusions are not part of this survey.

<u>Present investigations on climate change</u>

The survey of the general on-going investigations on climate change reveals that in particular the projects "RheinBlick2050", KLIWAS and ACER establish projections for climate and runoff for the entire Rhine watershed

In Switzerland, investigations are among others made under the overall responsibility of the Advisory Authority on Questions of Climate Change. The German Länder Bavaria, Rhineland-Palatinate and Baden-Wuerttemberg co-operate in the KLIWA project on the impact of climate change on water management. Furthermore, Baden-Wuerttemberg and Rhineland-Palatinate investigate into the effects of climate change on the runoff of the Rhine as far as the Worms gauging station. Hesse and Northrhine-Westphalia are carrying through further projects on climate change concentrating on the Länder.

In the Netherlands, several projects on aspects of climate change are being conducted (e.g. "Kennis voor Klimaat"), also taking into consideration adjustment strategies (e.g. within the project "Klimaat voor Ruimte" or in the form of on-going work of the Delta Commission.

Analysis of climate changes so far

As far as precipitation is concerned, monitoring data show that, in all regions of the Rhine watershed, an increase of the sum of precipitation in winter can be assumed (fig. 1). On the other hand, in large parts of the Rhine watershed (above all in the south), the sum of precipitation in summer is stated to decrease. Partly, this decreasing precipitation is however not significant. All depending on the extent of decreasing precipitation in summer, the sum of the annual precipitation does not change (e.g. Baden-Wuerttemberg and Bavaria) or it increases (e.g. Switzerland, Netherlands). However, this rise in the annual precipitation is always less than that of precipitation in winter. The main reason for the increase of precipitation, in particular in parts of the watershed outside parts of the alpine watersheds with distinct relief is the increasing occurrence of humid atmospheric circulation patterns.

Investigations into monitoring data of air temperature lead to obvious findings in all regions of the Rhine watershed (fig. 2). During the past 100 years, a considerable rise of the air temperature has been recorded (about +1.0°C to +1.6°C). On the other hand, the rise of temperature in summer is less significant (ca. +0.6°C to +1.1°C). This leads to a mean annual rise of temperature in the Rhine watershed between +0.5°C and +1.2°C, which is slightly above the global mean value of +0.56 to +0.9°C/100 years.

Due to rising temperatures, glaciers are retreating in Switzerland. Additionally, investigations into snow parameters such as average depth of snow reveal a negative trend. However, with increasing altitude, trends are less distinct.

The results of independent investigations show that, in the Rhine watershed, climate change is already detectable in temperature and precipitation monitoring data.

Analysis of changes of the hydrological regime so far

Due to rising temperatures and increased precipitation and little snow storage in winter, the monthly average runoff data for the entire Rhine watershed in the winter half-year are higher than what they used to be. This may be seen in connection with the "Western low-pressure circulation pattern", a large-scale circulation pattern significant for the generation of floods which, in winter, occurs distinctly more often and over a distinctly longer period of time.

However, in the summer half-year, the mean runoff in the southern Rhine watershed is decreasing. Due to the re-distribution of runoff from the summer half-year to the winter half-year, the waters with a glacial-nival regime are experiencing reduced variability within the years. Thus, the annual average runoff remains constant.

Towards the mouth of the Rhine, the reduction of mean runoff tends to be less in the summer half-year. Therefore, in this region, the average annual runoff increases due to higher runoff in the winter half-year. Thus, with climate change, these waters with pluvial regime experience increased variability within the year.

For many gauging stations in the Rhine watershed, investigations show an increase of mean flood runoff in winter. On the other hand, the trend for the annual maximum runoff (HQ values) is less obvious. At the gauging stations in Rhineland-Palatinate, Northrhine-Westphalia and Baden-Wuerttemberg no significant change of the HQ values are to be stated over wide areas.

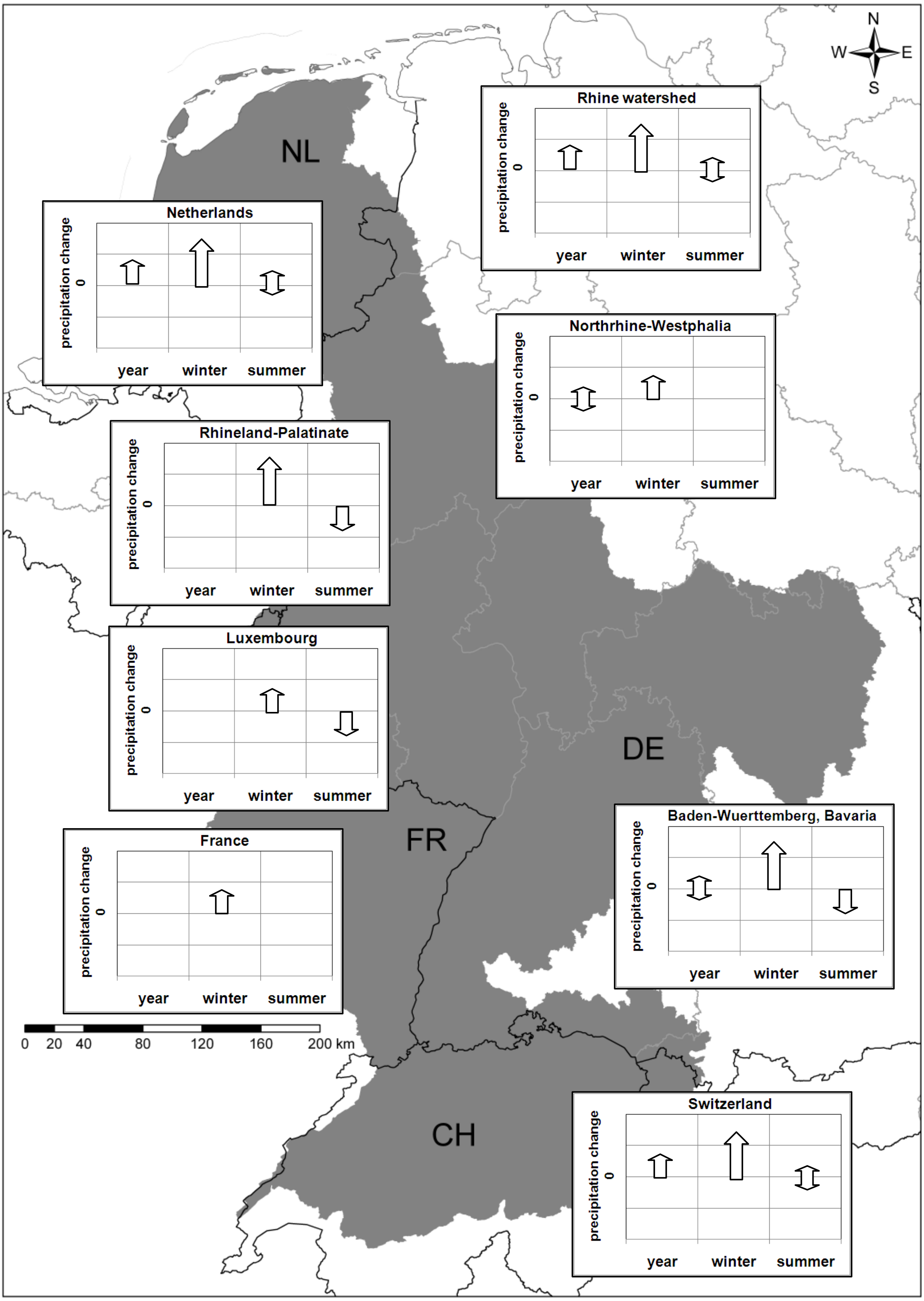


Figure 1: Changes of precipitation regime in the Rhine watershed in the 20th century for the hydrological winter and summer half-year as well as for the entire year (schematic representation based on heterogeneous data (Bader & Bantle 2004, Begert et al. 2005, KLIWA 2005c, KLIWA 2008a, KNMI 2008, LUWG 2007, LÖBF 2006, Pfister et al. 2004))

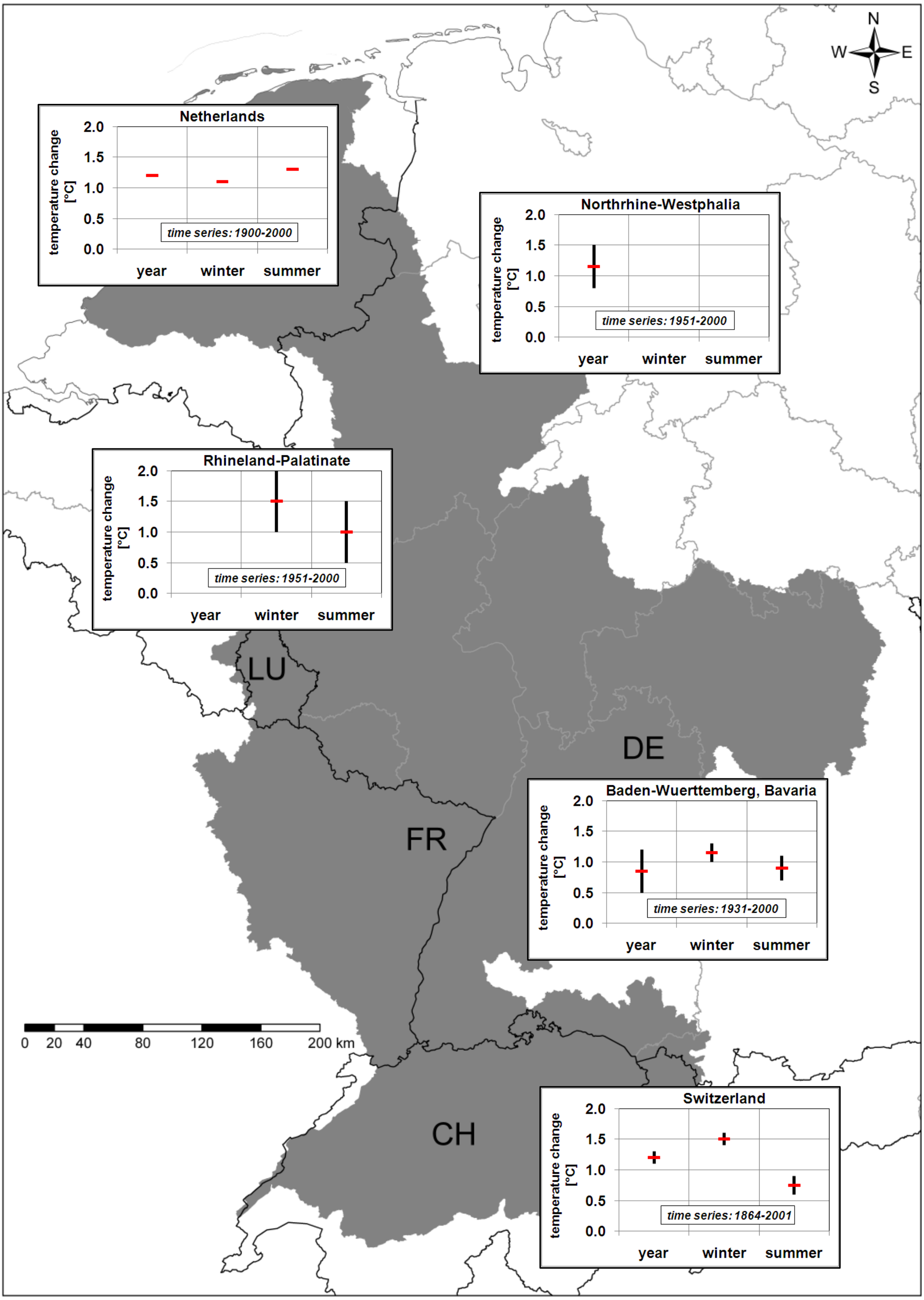


Figure 2: Changes of air temperature (average, minima and maxima) in the Rhine watershed in the 20th century for the meteorological winter and summer and for the entire year (based on heterogeneous data (Bader & Bantle 2004, MeteoSchweiz 2008, KLIWA 2005a, KLIWA 2008a, KNMI 2008, LUWG 2007, LÖBF 2004))

The analysis of floods is in particular complicated by man-made interference (e.g. river training) and the accidental character of individual events.

During low water periods, among others, the construction of storage reservoirs and water transfers make it difficult to interpret data. It may at least be stated that the increase of the sum of winter precipitation and reduced snow storage imply higher average runoff in the winter half-year, leading to significantly more low water events at gauging stations with a glacial-nival regime. Gauging stations with a pluvial regime register a tendency but no significant increases of low water parameters.

Largely, the natural water temperature is governed by the same factors of influence as air temperature. Thus, climate change has also contributed to rising water temperature. The observed rise of water temperature by about +1°C to +3°C is largely influenced by factors such as discharge of cooling water and urbanisation.

Assessment of the impact of possible climate changes

The assessment of climate changes is based on emission scenarios aimed at defining the future concentrations of greenhouse gases, such as CO_2. Such emission scenarios have been drafted within the Intergovernmental Panel of Climate Change (IPCC).

Based on emission scenarios, global circulation models (GCM) are used for calculating and projecting future climate. The GCM simulate the complex three-dimensional processes in the atmosphere. In most cases, an ocean model is coupled (coupled atmosphere-ocean-models).

The GCM are the initial data for the regional climate models with which regional assessments on climate change are possible (e.g. regional climate model WETTREG, REMO, STAR).

Available climate projections in the Rhine watershed often relate to the GCM ECHAM4 using the emission scenario B2. The comparative project PRUDENCE using different regional models and the drafting of four Dutch KNMI-scenarios use GCM ECHAM4 among others.

In the meantime, the calculation results of GCM ECHAM5 (emission scenarios A1B, A2 and B1) are available, driving WETTREG, REMO and STAR as well as the additional regional climate model CLM. In France, however, GCM ARPEGE is being used. Up-to-date climate projections are being expected within the EU project ENSEMBLES ("ENSEMBLE-based predictions of climate change and their impacts").

Scenario data for precipitation may also be generated by a precipitation generator providing new time series based on historic time series and re-organisation.

Climate projections made so far show an increase of the sum of winter precipitation for the next 50 to 100 years (figure 3). On the other hand, the sum of summer precipitation will decrease.

Until 2050, the sum of winter precipitation will rise by about +8% for Switzerland (deducted from PRUDENCE), by about +35% for Baden-Wuerttemberg (ECHAM4-WETTREG), by +20% for Northrhine-Westphalia (ECHAM4-STAR) and by about +4% to +11% for the Netherlands (all four KNMI scenarios).

On the basis of the same models, the sum of summer precipitation by 2050 will drop by -17% for Switzerland, -4% for Baden-Wuerttemberg, up to -20 % for Northrhine-Westphalia and -10% to -19% for the Netherlands (KNMI scenarios G+ and W+).

These indications of changes based on PRUDENCE and ECHAM4 apply to the emission scenario B2 which is comparable to the KNMI scenario G+. However, the differences between the emission scenarios A1B, A2, B1 and B2 are comparatively few until 2050. Only the KNMI scenarios show greater differences for precipitation.

ECHAM5-WETTREG simulates a comparable increase of the sum of winter precipitation by +19% to +30%, respectively a decrease of the sum of summer precipitation by -17% to -22% for Germany only until 2100.

As far as air temperature is concerned, the trend resulting from the analysis of monitoring data will continue in future. In winter, temperatures will rise distinctly (figure 4). Contrary to the analysis of monitoring data, the future rise of air temperature in summer will, according to some model calculation procedures, even exceed those in winter.

Until 2050, air temperature in winter will rise by about +1.8°C for Switzerland, by about +2°C for Baden-Wuerttemberg, by +2.4°C for Northrhine-Westphalia and by +1.1°C to +2.3°C for the Netherlands. Summer air temperature will by 2050 rise by +2.7°C for Switzerland, about +1.4°C for Baden-Wuerttemberg, +1.8°C for Northrhine-Westphalia and by +1.4°C to +2.8°C for the Netherlands. The same model runs were used as for precipitation.

With the model chain ECHAM5-WETTREG, comparable changes for air temperature are only found for the period up to 2100, as for the other models up to 2050 (rise in annual air temperature by +1.8°C to +2.3°C).

<u>Assessment of the impacts of eventual climate changes on the hydrological regime</u>

The results of the regional models may be used in order to investigate into the impact of climate change on the hydrological regime with the help of hydrological models. The models used to simulate runoff in the Rhine watershed were above all Rhineflow, HBV (both combined with the flood-routing model SOBEK), LARSIM and WaSIM-ETH (ASGi). Above all, the models SOBEK and LARSIM-WT may be used to simulate water temperature.

For the period until 2050, most of the hydrological model results using climate projections show a distinct increase of the average runoff in the winter half-year and lower average runoff for the summer half-year.

The maximum increase of the average runoff at the Lobith gauging stations amounted to +16% and the decrease in summer to -42% (model chain: KMNI'06 (scenario W+) → HBV and Rhineflow; until 2050).

The model chain ECHAM4 (emission scenario B2) → WETTREG → LARSIM (2021-2050) also points out distinct increases of the average runoff in winter at the gauging stations in Baden-Wuerttemberg. Thus, mean flood flow at the gauging station Rockenau/Neckar will in winter increase by about +40%, while mean low water discharges will remain unchanged during the summer half-year. However, these simulation results show great regional differences. E. g. at the gauging station Schwaibach/Kinzig, the reduction of average low water runoff in the summer half-year will amount to -16%.

The use of the regional model CHRM (driving model HadAM3H, emission scenario A2, period 2071-2100 compared to 1961-1990) with WaSIM applied to the gauging station Cologne results in a reduction of average discharge in summer and winter by -42% while mean discharges in winter rise by up to +14%.

A comparable result of future runoff changes are shown when applying the model Rhineflow (driving model HadCM3 (emission scenario A2; 2070-2099) and HadRM3H) at the gauging station Lobith with a decrease of the average discharge by -40% in summer and an increase of the average discharge of +30% in winter. Therefore, the discharge with a return period of 100 years (HQ_{100}) will increase by +10% to +30%.

Based on the results of the model ECHAM4 (emission scenario B2) → WETTREG → LARSIM (2021-2050) statistical investigations of extreme values have been made for changes of runoff in Baden-Wuerttemberg. As a consequence, an increase of the HQ_{100} value by +15% to +25% (regional differentiation) has been defined. The low water discharge with a return period of 100 years (NQ_{100}) distinctly decreases in the tributaries to Lake Constance and in the High Rhine area, while increases of the NQ_{100} values occur in other regions.

However, due to the assumptions concerning the emission scenarios and to uncertainties in the model chain from the global model via the regional model to the hydrological model, statements on future behaviour of average runoff are possible with greater certainty than statements on the maximal and minimal values, as e.g. the HQ value and in particular extreme values as the value for HQ_{100}.

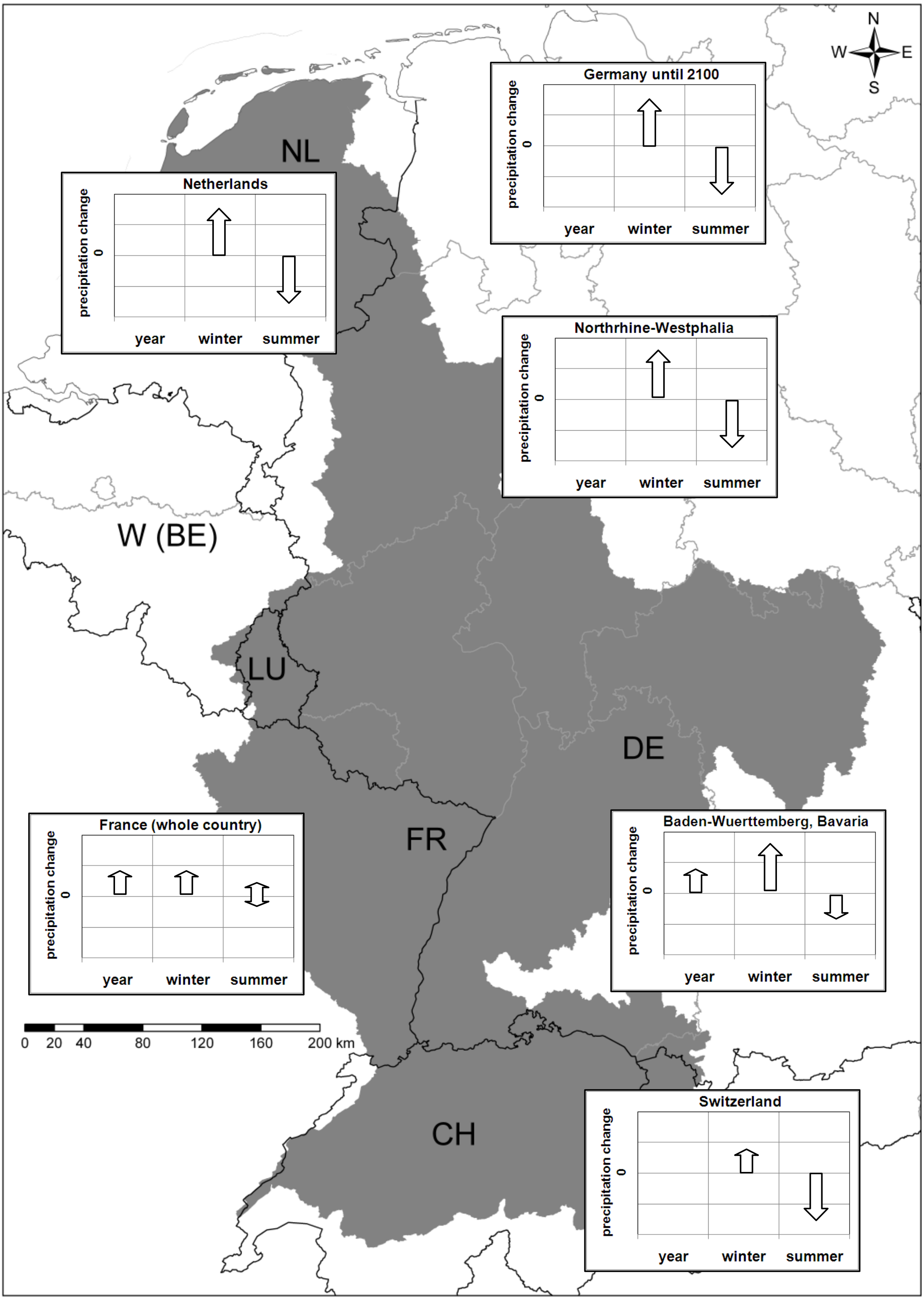


Figure 3: Possible future changes in precipitation in the Rhine watershed until 2050 for the hydrological winter and summer half-year as well as for the year (schematic representation based on heterogeneous data (Frei 2004, KLIWA 2006c, KNMI 2006, LÖBF 2006, ONERC 2008b, ONERC 2008c, ONERC 2008d, UBA 2007a))

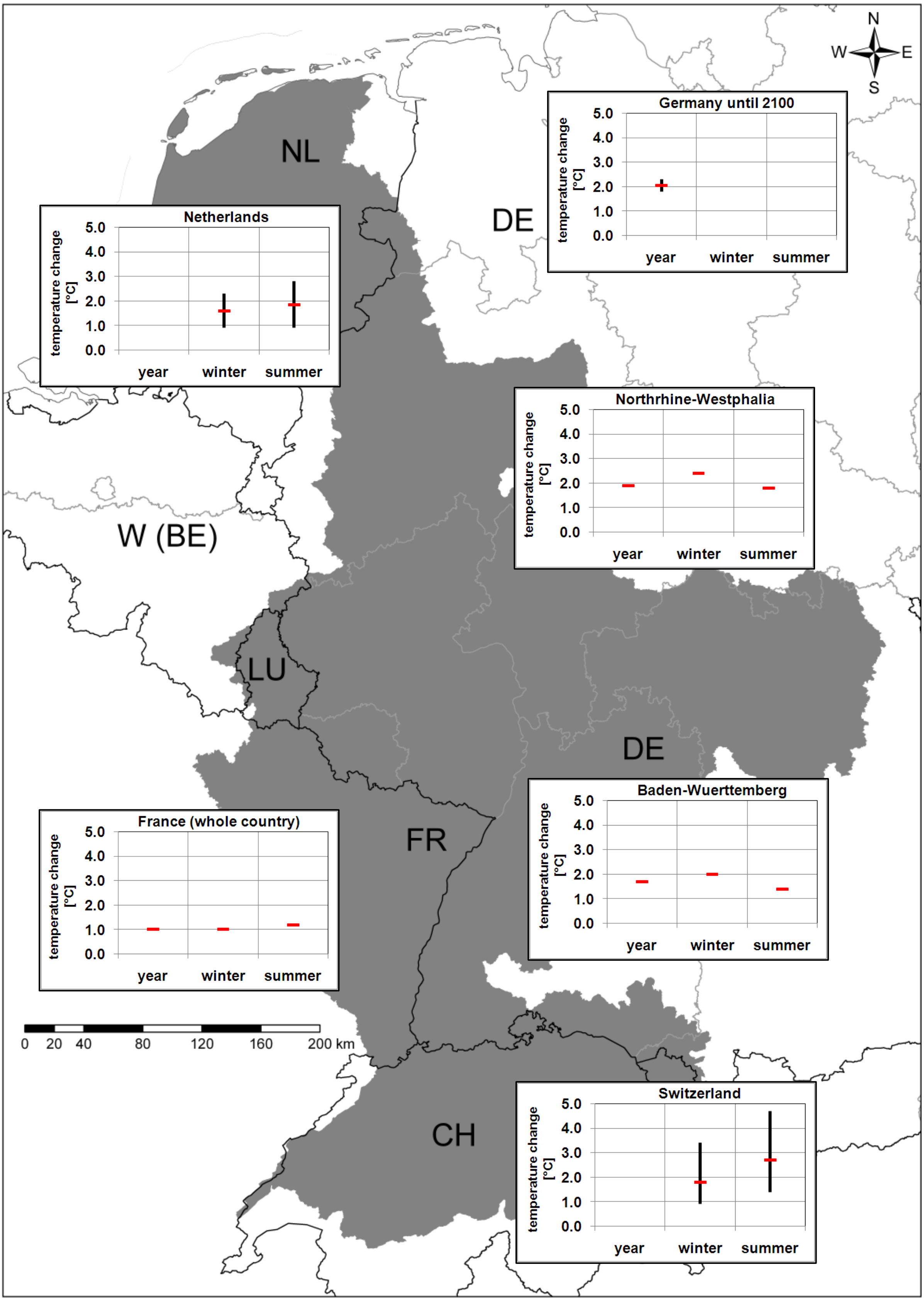


Figure 4: Possible future changes of the air temperature (minima, average and maxima) in the Rhine watershed until 2050 for the hydrological winter and summer half-year as well as for the year (schematic representation based on heterogeneous data (Frei 2004, KLIWA 2006c, KNMI 2006, LÖBF 2006, ONERC 2008b, ONERC 2008c, ONERC 2008d, UBA 2007a))