Federal Ministry
of Transport, Building
and Urban Affairs

Navigation and Waterways in Germany – Meeting the Challenges of Climate Change

A Review

Climate change is an important and highly topical political issue. Around the globe, the effects of global warming are being observed or predicted for the near future. This includes e.g. the rise in sea level, changes in the atmospheric and oceanic circulation systems – in connection with an increasing frequency and intensity of extreme weather conditions, melting of polar ice masses and glaciers, heat records, drought, extreme flood and low water events of rivers. These events reveal that we have to cope with new challenges. On the one hand, we must apply preventive measures against rapid warming and its negative impacts – as far as this is possible for us; on the other hand we must be prepared for the foreseeable consequences as early as possible and adapt to them in a way such that core elements of the prosperity we have achieved are not endangered.

Climate change is not a new phenomenon but a well-known geological process. The reports presented by the Intergovernmental Panel on Climate Change (IPCC) show, however, that human activity has had an impact on the earth's atmosphere too. The warming currently observed is faster than the natural development would have suggested. Out of a sense of responsibility it is necessary to limit the human impact on the atmosphere. Therefore, the German Federal government is taking a leading role within European and global politics when it comes to promoting aims, measures and innovations to protect the climate. Therefore, in spring this year – under German EU Presidency – the European Council of Heads of State and Government paved the way for an integrated European climate and energy policy. This includes ambitious climate protection aims as well as aims for developing renewable energies and enhancing energy efficiency. With the Meseberg Decision of August 2007 for an integrated energy and climate programme, the German Federal government transposes the overall European decisions to the national level using a programme of specific measures. The implementation of the energy and climate programme will be oriented towards the climate aims in a continuous process lasting until 2020. The German Federal Ministry of Transport, Building and Urban Affairs (BMVBS) accompanies this with research and promotion measures in the fields of building and transport.

Independent of any climate protection measures, it is crucial to be prepared for the potential impacts of climate change on transport and infrastructure and to develop appropriate adaptation measures. The BMVBS takes up the challenges with its initiative "Meeting the Challenges of Climate Change".

The most recent (fourth) report of the Intergovernmental Panel on Climate Change documents that for Central Europe and Germany, several large knowledge gaps need to be closed. Due to this and the fact that effects of climate change have already become evident on the sea, coastal and inland waterbodies that could have an influence on navigation and waterways, the BMVBS has commissioned its scientific and technical authorities – i.e. the German Meteorological Service (Deutscher Wetterdienst, DWD), the German Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH), the German Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG) and the German Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW) – to investigate the bases of climate research and to interpret them as regards potential consequences for sea and inland navigation. This highly demanding and complex task can only be solved by the competent German Federal authorities working in a network – which again will be embedded in the relevant national and international research network.

This report is a basis for the necessary studies regarding climate change and its impacts in Germany. It informs interested experts on climate projections and possible changes in the waterbodies in order to be able to further guarantee and develop the performance of navigation and waterways in sea, coastal and inland areas as the most environmental-friendly mode of transportation. This will also help to achieve the climate protection aims that have been set.

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1 Introduction

Our planet's climate history – reconstructed primarily with core samples from deep-sea sediments and the huge continental ice masses – proves our climate's high variability within different periods. Here the changes between warm and cold periods stretching over millennia are superimposed by short-term variations encompassing periods from tens of years up to several hundred years.

It is without doubt that the climate system reacts in a highly sensitive way to the smallest changes in the energy balance and that CO_2 as a greenhouse gas plays a crucial role in these processes. It is also without doubt that global warming has developed much faster within the last decades than in the preindustrialised ages – as reconstructed by data from climate archives on preindustrialised ages (800,000 years have been documented).

Whereas earth temperature increased by a maximum of 1°C in 1,000 years in the past, already for the last decades a global warming of 0.6°C has been determined, with warming of 1°C for the Federal Republic of Germany. According to current climate forecasts, warming to values 2°C to 6°C above values measured in 1990 is probable by 2100. The last comparable warming occurred some 15,000 years ago, i.e. at the end of the last Ice Age – with a global rise in temperature of 5°C. However, this rise took place over more than 5,000 years whereas now a comparable rise within one century is probable. As documented in the 4th and most recent IPCC Report (Intergovernmental Panel on Climate Change – IPCC 2007) it is undisputed that man has contributed to this development. Around the globe, significant impacts of climate change are observed that might be strongly reinforced within the next decades. This is extensively dealt with in the recent WBGU (German Advisory Council on Global Change) report "Climate Change as a Security Risk" (WBGU 2007). Based on simulations, the German Institute for Economic Research (DIW) forecasts climate-induced costs for Germany of some EUR 800 billion by 2050 concerning almost all areas of life (Kemfert 2007).

Climate Protection

Protecting humans, their life bases and activities against dramatic negative effects of climate change has been taken up as a relevant political issue of highest priority around the globe. This becomes obvious by the fact that this issue is extremely present in the superior political levels and in the media. Here the German Federal government has taken a leading role – on a European as well as global level – when it comes to reducing climate-relevant man-made emissions quickly and efficiently and to limiting the amount of global warming to 2°C according to the EU objectives. Therefore the German Federal government initiated in 2006, under the overall responsibility of the German Federal Ministry of Education and Research (BMBF), the High-Tech Strategy on Climate Protection (BMBF 2006, 2007) in order to streamline research and innovation in the German economy and sciences and to attack the crucial challenges of climate change.

Within this context the BMBF – within the focus "klimazwei – Research for climate protection and protection from climate impacts" – promotes more than 40 new research projects with innovative ideas for dealing with climate change (BMBF 2004).

Adapting to the Climate Change

At the European and national levels, processes to work out adaptation strategies have been started. On 29 June 2007, the European Commission adopted a Green Paper that defines the basis for a consultation process with the member states and with the crucial stakeholder groups at the EU level (Commission of the European Communities 2007). The consultation deadline was 30 November 2007. The European Commission's Green Paper reveals that for this kind of strategy, in many aspects the Commission is still at the beginning of the process. Therefore it does not yet contain any detailed propositions regarding specific measures for the adaptation to the climate change. So a content-related aim is to identify the regional effects of climate change, to find out knowledge deficits, and to develop technical solutions for adaptation measures. It is now up to the Member States to compile information and experiences on programmes and activities, findings on climate-relevant regional risks and extreme events, on adaptation programmes and measures, and on scientific methods. In this context, the German Federal government has started, under the primary responsibility of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), to develop a German Adaptation Strategy to Climate Change (DAS) that should set the framework for gradual development of adaptation measures. It is indispensable to support the development of adaptation strategies by research at international and national levels. Therefore the High-Tech Strategy on Climate Protection promotes research with the purpose of adapting to the effects of climate change (BMBF 2007). The BMVBS will play a part in this process with its competences.

Experts from all over the world come to the result that the global climate projections currently available anticipate crucial changes as regards extreme weather conditions, in the oceanographic conditions (e.g. rise in sea level, waves) and in the water regime (e.g. in the landscape's water balances and in the flow regimes) (BMU 2007). Furthermore it has been found out that transposing global statements to regional scenarios related to specific river basins necessitates further activities in order to deal with adaptation issues more effectively (ICPR 2007).

In order to meet its responsibility regarding navigation and waterways, the BMVBS sees the need for further studies in sea, coastal, estuarine and inland areas in order to be able to develop reliable adaptation measures. The BMVBS sees an urgent task in identifying possible effects of climate change for its area of competence in order to enable timely development of adaptation strategies. On this well-founded basis, the effects of climate change can be considered appropriately with investment measures that may be necessary.

Sea Navigation as an Economic Factor

The climate changes projected in the IPCC scenarios (see Chapters 2, 3 and 4) would have perceptible effects on the German coastal areas and the related industries. Not only sea, coastal and recreational navigation, fishery and offshore areas with oil and gas production as well as wind energy plants would be concerned but also the protection of coasts, harbours and industrial plants and the navigability of large estuaries with access to inland and sea harbours. The inshore area is highly relevant for navigation and the related industries and service providers.

- According to the European Community (2006), maritime services and industries contribute up to 3 to 5 %, costal areas in total up to 40 % to the European gross domestic product.
- In the EU, 90 % of international trade and 40 % of domestic trade take place via the sea, with 3.5 billion tons of freight and 350 millions of passengers transported per year.
- In Germany, 450,000 persons work in the fields of maritime services and harbours and produce an added value of some 20 billion €.
- In 2006, in the German North Sea and Baltic Sea harbours alone, some 300 million tons of goods were handled, including 13.8 million standard container units (TEU — Twenty-Foot Equivalent Unit).
- According to the maritime traffic forecast as of 2007, this handling will increase to some 760 million tons by 2025.
- Within the same time period, container (TEU) handling will be more than quadrupled to over 45 million.

Such growth numbers provide positive employment impulses for many industries.

In sea navigation and harbour economy, timely adaptation and prevention strategies regarding the effects of climate change are of crucial importance. The North and Baltic Seas have a very high navigational density with intensive use of the sea, and climate changes as forecasted by the climate research will have extensive effects.

Inland Navigation as an Economic Factor

The challenges for the transport policy become obvious in the forecasts of the German Federal Transport Infrastructure Plan 2003. As an effect of Germany's and Europe's economic and social development, of EU East enlargement, and globalisation of the markets up to 2015, transportation demand between 1997 and 2015 will rise

- in freight transport in total by +64 % to some 600 billion tkm
- in inland navigation by +43 % to some 90 billion tkm

Regarding the inland navigation's transport volume, an increase by +27 % to some 300 million tons is expected. So inland navigation as a traffic mode is an indispensable element of the German and European traffic systems. Potential climate-induced limits to inland navigation (e.g. by an accumulation of extreme water levels) can be counteracted by appropriate adaptation strategies.

The BMVBS's Competence

Against this background, the BMVBS has started the initiative "Meeting the Challenges of Climate Change" and in a first step focussed on the requirements for navigation and waterways. With the National Meteorological Service of Germany (Deutscher Wetterdienst, DWD), the German Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie, BSH), the German Federal Institute of Hydrology (Bundesanstalt für Gewässerkunde, BfG) and the German Federal Waterways Engineering and Research Institute (Bundesanstalt für Wasserbau, BAW), the German Federal government has competent scientific and technical authorities which can – in a network with other partners – elaborate the bases for the development of adaptation strategies.

Exceptionally large goods transport (Photo: WSA Magdeburg / Surrounding district Wittenberge)

2 Climate Projections for Germany, Norwegian Sea and Baltic Sea

2.1 Climate Research in Germany

Already in the middle of the 20th century, experts had discovered that human impact on the global climate system and its changes would be a crucial problem in the future. International and national climate research programmes were subsequently drawn up around the globe. At universities, first – albeit still very simple from a physical point of view – global climate models were developed. The development of future scenarios on the basis of operational climate models – with atmosphere and ocean linked to each other – was started as a long-term research task in the 1970s. Nowadays, climate research is linked by the German Climate Consortium (DKK).

National Meteorological Service of Germany (Deutscher Wetterdienst – DWD)

The DWD is the Federal Republic of Germany's competent scientific and technical authority for the areas of weather and climate. In order to fulfill its statutory obligations (weather forecasts, climate monitoring and analysis for Germany and the oceans of the world) DWD has been developing and using numerical weather forecast models since the 1960s. With its national climate data archive, it possesses the most comprehensive quality-checked climate database in and for Germany. Its grid data archive is of special relevance for national climate research activities on monitoring of the current climate and its changes in course of time and for verification/validation of numerical weather forecast or climate models,. For this purpose, the climate data measured by the DWD at specific observation stations were interpolated based on skilled procedures to fine grids with a resolution down to 1 km.

DWD's impact models describe the climate impact on different areas, such as water, agriculture, energy, health and urban planning. On this basis, DWD provides the economy, research, politics, national, regional and municipal authorities as well as the public with data, products, expert reports and specialised advice. Input data for these impact models are climate data based on the observations (present and past) from the meteorological networks and on the results of climate model projections (future).

DWD contributes considerably to national and international research and observation programmes of maritime meteorology – with a special focus on North Atlantic, North and Baltic Seas and the Mediterranean Region. In this context there is a close collaboration with BSH.

One focus is the production and provision of the maritime-climatological database with defined quality standards. Via the archive of DWD's Global Collecting Centre for Maritime Climatological Data (GCC) access is possible to any worldwide available maritime meteorological data collected on site (maritime meteorological reports from ships, data from buoys and platforms as well as aerological data).

DWD's climate and weather observations are carried out according to the worlwide applied standards of the World Meteorological Organization (WMO), an international organisation of the United Nations.

Within the framework of WMO's World Weather Watch (WWW), DWD has access to all regularly worldwide exchanged observation data. Under auspices of the WMO, DWD hosts the Global Precipitation Climatology Centre (GPCC) as a German contribution to international climate research and monitoring and to the Global Earth Observation System of Systems (GEOSS) currently being developed.

Jointly with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), DWD hosts the European Satellite Application Facility on Climate Monitoring (CM-SAF). Since 1997, the DWD publishes the climate monitoring results for Germany in its annual Climate Status Report *(Klimastatusbericht, KSB)*.

The BMVBS's Higher Federal Authorities

in the field of waterways and navigation, i.e. the German Federal Institute of Hydrology (BfG), the German Maritime and Hydrographic Agency (BSH), and the German Federal Waterways Engineering and Research Institute

(BAW), along with their expertises regarding climate change and impact assessment, are presented in the appendix.

Water Authorities of the 'Bundesländer'
The Ministries and technical authorities at the level of the *Bundesländer* are dealing with the impacts of climate change, e.g. related to flood protection, low-water, water supply, groundwater formation or coast protection. The water authorities have always been relying on climate data, products and analyses of DWD and on its expert advice. Because climate change is becoming more and more evident, they are currently reinforcing their involvement in national and international projects – and this causes a need for extensive support work by the DWD.

Max Planck Institute for Meteorology – MPI-M
The impetus originating from universities mentioned above lead in year 1975 to the implementation of the Max Planck Institute for Meteorology in Hamburg (MPI-M) by the German Federal Ministry of Education and Research (BMBF). One research focus of MPI-M is the development of global and regional climate models. In this context the climate system is simulated by combined models for the processes of the atmosphere and of the ocean on the one hand and for the interactions with the land surface and with the ice-covered earth's surface on the other.

Assessing the regional consequences of climate change and its consequences for hydrological cycle and air quality is currently of special interest. In 2006, the Centre for Marine and Atmospheric Sciences (ZMAW) was established in Hamburg. The ZMAW is a union of six university institutes – amongst others the Centre for Marine and Climate Research of the University of Hamburg – and of MPI-M. Besides the series of its global climate models (currently ECHAM5), MPI-M runs its own regional climate model REMO and executes – within the MPI-M "Model and Data group" – the consortial runs of the Climate Local Model (CLM). There is a close collaboration between the DWD and the MPI-M in the field of development and validation of climate models.

German Climate Computing Centre (DKRZ)
The DKRZ maintains large databases with climate data containing above all the raw results (gridded fields) of climate projections as well as of relevant metadata. Besides this, it runs the climate simulation models in cooperation with the MPI-M. Currently the DKRZ maintains, with the participation of the DWD, a "Service Group Adaptation" (SGA) to support the projects in the BMBF research support focus "klimazwei" with data, products and expert advice. The SGA supports the use of the DKRZ's climate simulation results as well as the use of the DWD climate database.

Alfred Wegener Institute for Polar and Marine Research (AWI)
The AWI, member of the Helmholtz Association of German Research Centres, conducts interdisciplinary research on the earth's climate, biological and geological systems in the sea and on land – with a focus on the Arctic and Antarctic regions. Within the framework of polar climatology the AWI collaborates with the DWD, sometimes also with financial support, in projects of the German polar research programme.

Institute for Coastal Research of the GKSS Research Centre (IfK)
The GKSS's IfK, also member of the Helmholtz Association of German Research Centres, is an application-oriented, interdisciplinary research institute studying – applying model scenarios – the situation of the coast as a habitat and its sensitivities to changes in natural and human influences. Especially regarding wave modelling, the IfK works in close cooperation with the DWD. Furthermore, the GKSS plays a major role within the development of the CLM (Climate Local Model).

Potsdam Institute for Climate Impact Research (PIK)
The PIK, an institute of the Leibniz-Gemeinschaft, conducts research on global climate change and its ecological, economic and social consequences and on the Earth system's capacity for withstanding human interventions.

Its activities focus on the development of strategies for a sustainable development of humankind and nature. Concerning the description of observed climate and climate change in Germany, the PIK relies mainly on DWD data. The PIK also hosts the Climate & Environment Consulting Potsdam GmbH (CEC) which recently calculated several climate scenarios, commissioned by the German Federal Environmental Agency (UBA).

Institute of Marine Sciences (IFM-GEOMAR)

The IFM, part of the University of Kiel and also a member of the Leibniz-Gemeinschaft, conducts extensive fundamental research in the fields of ocean circulation and climate dynamics, focussing on studies of climate change. It possesses an advanced infrastructure with the only German manned research submersible in addition to several research vessels.

German Federal Environment Agency (UBA/FEA)

The UBA provides scientific support and advice to the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) in the fields of environmental and climate protection. The focus is on prevention of climate change risks and on mitigation of greenhouse gas induced damages. It has above all a coordinating function. For this purpose, the BMU has established in 2006 within the UBA the Competence Centre on Global Warming and Adaptation (KomPass) in order to gather information on climate adaptation in a centralised place. To complement this, the UBA finances selected studies conducted at universities and large research institutes. The UBA and the DWD have set up a cooperation agreement.

Universities

Various university institutes and many other public or private institutions study the extent of climate impact and of possible consequences of climate change. Often these studies are limited in time and funded as projects by promoting institutions (BMBF, DFG, EU, UBA, German *Bundesländer,* etc.).

There are almost innumerable projects of this kind. BMVBS's scientific and technical authorities monitor the most significant developments at the universities. Results and new methods or techniques resulting from this are taken on board – if they can be implemented.

On 19 October 2007, the University of Hamburg (UHH) was awarded – within the framework of the Initiative for Excellence *(Exzellenzinitiative)* organised by the Federal and *Länder* governments and announced by the German Research Foundation (DFG) – the green light for extending its competence centre for climate research. Together with its non-university partners, i.e. the Max Planck Institute for Meteorology, the GKSS Research Centre Geesthacht, the German Climate Computing Centre (DKRZ) supported jointly by them, and with the BMVBS's scientific and technical authorities located in Hamburg – i.e. BSH, DWD and BAW – the UHH is developing its Centre for Marine and Atmospheric Sciences (ZMAW) into a "Climate Campus Hamburg" and an international competence centre for climate research.

German Climate Consortium (DKK)

Under the guideline "research for society, economy and environment" the DKK will bring together non-university research institutes and universities that are conducting high-profile research in the fields of climate change, impact and protection. This network founded in October 2007 aims at streamlining scientific expertise in different research disciplines in order to provide a platform for integrated research projects. The objective is to develop activity-oriented results of the climate research for the society, economy and environment sectors. The German Climate Consortium (DKK) will represent core parts of the German climate and climate impact research. It should contribute toward coordinating the diverse and high-profile German climate and climate impact research. The DWD and the BfG will be partners in this network too.

"The range of the results from different climate models is up to 4 °C within one single emission scenario."

2.2 What are Climate Scenarios and how Reliable are the Statements?

"Climate scenario" means the calculation of future climate change by means of a climate model, where the future development of the greenhouse-relevant emissions – the so called "emission scenarios" (emission of greenhouse gases) – is given at each time step.

The climate calculated in this way for a period in the future is called "climate projection". Contrary to weather forecast, the term "forecast" is not used for climate simulations since the emission scenario used is applied hypothetically and also because the climate system's behaviour is not sufficiently well known.

In order to grasp the potential range of future climate change, several global climate projections are conducted – in international coordination – each time applying different emission scenarios and also applying different global climate models.

The results are interpreted, described and published on a regular basis by the Intergovernmental Panel on Climate Change (IPCC). The IPCC recently published its 4th Assessment Report (AR4) "Climate Change 2007" (IPCC 2007).

2.2.1 Global Climate Models

Global models appropriate to climate projections are based on physical and chemical relationships solved by numerical means. The atmospheric component of the climate models is closely related to the global weather forecast models. The latter are mostly used in a modified form as the basis for a climate model.

However, contrary to the weather forecast models, climate models are combined e.g. with ocean and vegetation models in order to consider non-meteorological components of the climate system too. But the models are based on many simplifications and assumptions so the results bear a degree of uncertainty.

Figure 2.1 shows the differences between the simulation results of the various climate models. According to the emission scenario given in the models, the differences by the end of the 21st century can amount up to a range of 3 °C to 4 °C. This means that the uncertainty has about the same order as the signal describing the temperature change.

Independent of this, the IPCC comes to the conclusion that the total range of +1.1 °C to +6.4 °C – resulting from all models applied and taking all relevant emission scenarios into account – for the change of the globally averaged surface temperature during the period 1990 to 2100 has, at least within the last 10,000 years, never occurred (IPCC 2007). This assessment confirms the results of the 3rd IPCC Report released already in 2001 (IPCC 2001).

Emission Scenarios

Nowadays the so-called SRES Emission Scenarios (Special Report on Emissions Scenarios) presented by the IPCC are primarily used as a basis for the climate scenarios. They comprise a total of four scenario families providing an assessment of the future emission development and of the resulting greenhouse gas concentrations.

Here the difference is basically made between the economic and demographic development and the degree of globalisation. The impacts of political agreements to limit climate-relevant trace gas emissions (such as the Kyōto Protocol) are not considered in the scenario calculations.

- The A1 family (divided into the scenarios A1FI, A1T and A1B on the basis of the ratio of fossil energies used) assumes a faster economic growth and a rather homogenous world with increasing cultural and social contacts between the different regions of the world. Differences in the per capita income reduce more and more, and the technological development progress is fast and efficient. The global population will peak in the middle of the current century.

- The A2 scenarios describe a very heterogeneous world oriented towards economy. Population growth continues at undiminished speed, and per capita incomes converge only in some regions and only at a very slow pace.

- Like the A1 family, the B1 scenarios anticipate fast globalisation, albeit under the assumption of economic structures transforming into a service and information technology oriented society. Here, an extensive introduction of clean and resource-efficient technologies is relevant for the evolution of greenhouse gas concentrations.

- Analogous to the A2 family, the B2 scenarios describe a way of thinking and acting that is very much regionally oriented, albeit with a much higher emphasis on environmental and social interests than in the A2 scenarios. In the AR4 they have not been taken into account.

Global Climate Models in Germany

One of the models considered in the IPCC results recently published is the ECHAM4 model of the Max Planck Institute for Meteorology (MPI-M). Compared at an international level with other global models, it is classified as average quality. But right now, climate projections based on the new ECHAM5 model are already available.

Regarding the physical content, the new ECHAM5 model is much closer to reality than its predecessor – and in an international comparison, it is at the top of the global climate models. Important improvements are, amongst others, the consideration of relevant land sur-

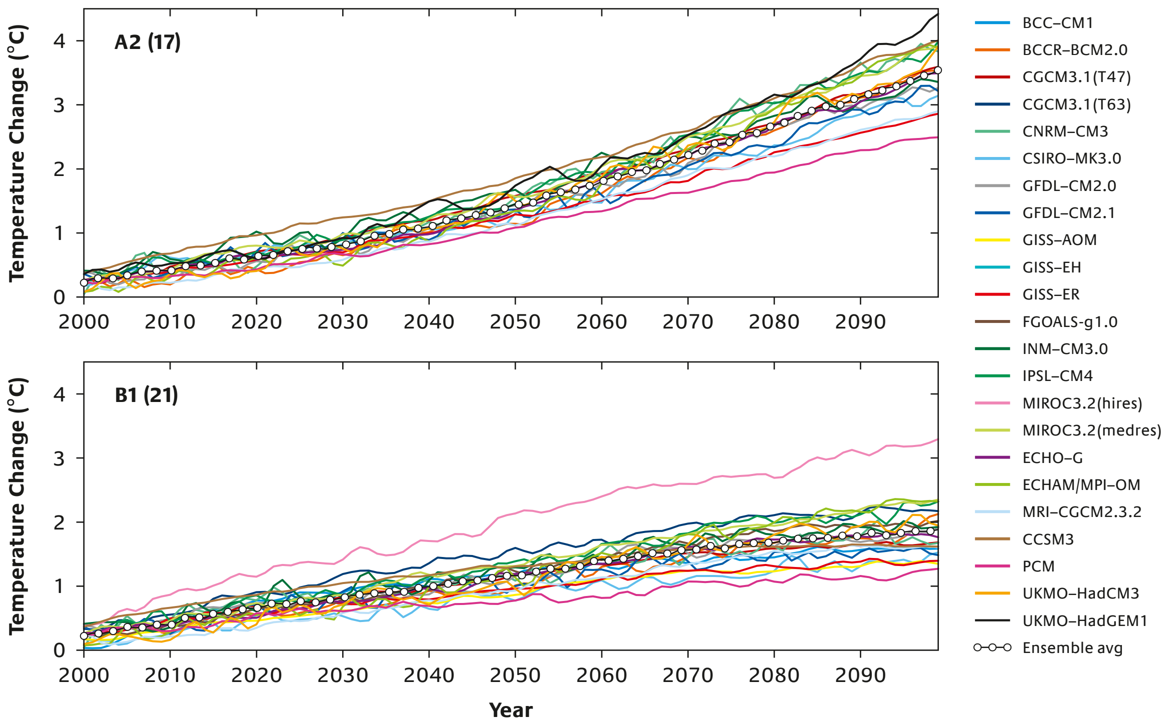


Figure 2.1: Change of the projected global mean temperature from 2000 to year 2100 compared to the observed recent climatic mean for 1980–1999 (IPCC 2007), choice of global climate models using the SRES scenarios A2 and B1

"The spatial resolution of the global models must be enhanced in order to obtain reliable regional statements on the impacts of climate change."

face processes and a database of the earth's surface qualities. Additionally, the calculation of cloud formation processes has been revised.

A crucial difference to the previous model is the more precise description of the initial state of the climate system when initialising the model. Therefore, on a global average, ECHAM5 simulations no longer bear any significant temperature differences compared to the data observed within the period monitored, i.e. the past 40 to 50 years. With ECHAM4, when simulating the period under revision, another remarkable divergence occurred: i.e. the actual climate was presented too warm by the ECHAM4 model.

Additional information is obtained due to the higher resolution of the new ECHAM5 model. Whereas the MPI-M had conducted the scenario calculations for the IPCC with the previous ECHAM4 model using a horizontal resolution of about 2.8° (approx. 300 km), recent simulations with ECHAM5 were produced with a grid point distance of about 2° (approx. 220 km). In ECHAM5, the vertical resolution was increased to 31 instead of the previous 20 layers.

2.2.2 Regional Climate Models

The spatial resolution of the global models for application in impact models and thereby for determining the effects of climate change are insufficient. Therefore, regionalisation procedures are applied. By them, the global projections are converted "downwards", i.e. "downscaled" to smaller grid elements of up to 10 km × 10 km, in individual studies even below. For this, two basically different procedures are available: deterministic or numeric regional climate models on a physical basis and downscaling models with a statistical basis.

(1) The deterministic regional climate models simulate the thermodynamic processes in the atmosphere due to physical laws, comparable to weather forecast models. Given the geographical limitation (Europe, Germany), it is possible to reduce the grid width and to improve the model physics.

Such models are nested in the result fields of the global models. This means they receive the meteorological impulse and boundary conditions of the global model, but can use, within their own model field, a topography with a higher resolution (terrain structure and properties) as well as their more complex physical simulations, such as for cloud formation. The group of these climate models – briefly called "regional models" – includes two models run in Germany which are both based on numerical weather forecast models developed by the DWD.

- The *regional model REMO* has been maintained and applied at the MPI-M in Hamburg for many years. Initially it was based on DWD's "Europe Model" (EM). Besides the necessary modifications for the application as a climate model, the MPI-M developed or replaced the physical parameterisations, too.

- The *climate local model CLM* was developed by the Consortium for Small-scale Modelling (COSMO) in collaboration with various university institutes, the GKSS and the DWD on the basis of the current regional weather forecast model LM of the DWD. The new names of the LM weather forecast models are COSMO-DE and COSMO-EU. So far, CLM is the only climate model in Germany providing in particular a "non-hydrostatic" component enabling, theoretically, applications with very small grid widths (e.g. 100 m). The CLM is maintained by this Consortium, coordinated by the Brandenburg University of Technology (BTU) Cottbus. This enables expert exchange between the CLM user community and the DWD. Changes applied to the model are disclosed and implemented by both sides. The BMBF and the "Service Group Adaptation (SGA)" declared the CLM and the climate projections based on it to be a reference for the projects within the BMBF's promotion focus "klimazwei".

Producing climate projections with the deterministic regional models requires complex calculations and is time-consuming. At the current state, it is possible to calculate climate projections with the following properties, starting from the current model versions:

- CLM: resolution approx. 20 km for Europe, data up to 2100
- REMO: resolution approx. 50 km for all Europe, data up to 2100
- REMO: resolution approx. 10 km for Germany, data up to 2100

(2) The statistical downscaling procedures include the "STAR" models of PIK and the *WETTREG procedure* of CEC. Both models are based on a new composition of standardised weather periods of the actual climate. The standardisation has different bases: with STAR the only basis is the regional temperature distributions observed, with WETTREG it is assignment of the large-scale weather conditions to the weather close to the soil.

To produce regional climate projections, the frequencies of the standardised weather periods are derived from the global climate projections and transferred into regional fields via statistical relationships. Due to the calibration with observational data, regional statistical models are applied only on land surfaces.

Producing reliable statements for the marine area bears specific difficulties. In this context, the impact of the changing wind climate is of particular relevance. For this, however, it is necessary to study the changing atmospheric circulation in the entire North-East-Atlantic/European region. Mostly, the model areas of the existing well-known regional models are insufficient for this or have only a relatively low resolution; this necessitates a marked extension. Here, regionally different grid widths are possible.

2.3 Bases for Determining the Climate Change

2.3.1 Data Evaluation

Within the topic of climate change and water, almost all meteorological variables are of predominant importance and most of the problems need to be considered in a complex context: precipitation, snow cover, evaporation, radiation, air temperature and atmospheric humidity have an impact on the water balance above the land surfaces. The distributions of atmospheric pressure with the resulting wind situations are important conditions for the weather types classification and for wave dynamics as well as tidal height at the coasts.

For making statements on ice cover, information on the water temperature is necessary. Another important parameter in the hydrologic cycle is the soil moisture, derived from precipitation, vegetation, soil properties, air temperature, atmospheric humidity, radiation and wind, which determines the actual evaporation. Therefore a comprehensive and well quality controlled meteorological data archive is the basis of high-quality climatologic analyses.

National Climate Data Centre – NCDC

In its National Climate Data Centre (NCDC) the DWD archives current as well as historical time-series from Germany – sometimes dating back to the 18th century – taken at up to 4,500 observation stations (see Figure 2.2 for precipitation).

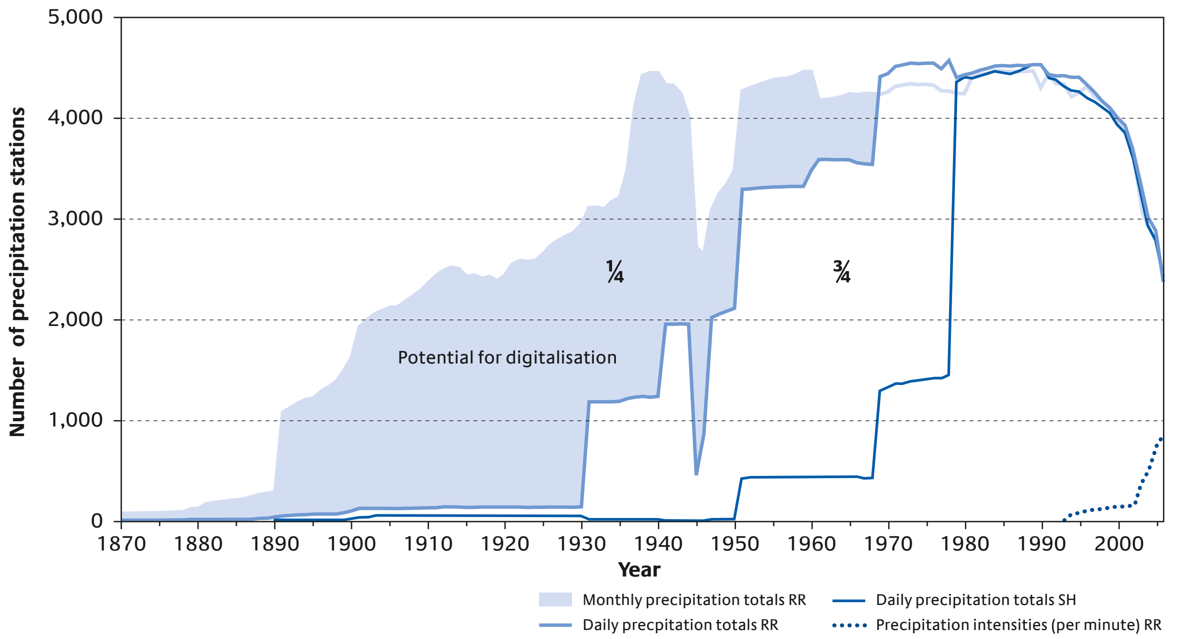


Figure 2.2: Development (1870–2006) of the number of precipitation stations (total precipitation RR and snow depth SH) in the national climate database of DWD. ¾ of all documents on daily data are already available in digital form. For ¼ of the data, only monthly values are available, daily values need to be digitised subsequently (Graph: DWD).

“The existing climate data series must be made entirely available for modelling future discharges.”

The DWD currently possesses the following meteorological parameters for the German territory in daily and monthly resolutions taken at stations on the ground: precipitation, air temperature, air pressure, atmospheric humidity, duration of sunshine and wind speed. Furthermore the DWD collects data from the free atmosphere, temperatures in the ground, radiation data as well as phenological data and data on weather types classification. They are all managed in a modern climate database.

Whereas the number of measurement points decreased with the automatisation of the observational networks in the early 1990s, the time-related information density increased. Nowadays, precipitation data are sometimes available with a temporal resolution in minutes, and this enables the analysis even of extreme precipitation intensities.

After an intensive quality control, gridded data were deduced for the entire German territory from the point values observed at the stations. These grid data can be used as reference data sets in addition to the original station time series. Any areal mean values can be deduced from the grid data.

For validating regional climate models, the following reference data sets are currently available at the DWD for the area of Germany:

Climatological Data Averaged over Several Decades

- Mean values of air temperature, precipitation and sunshine duration in the periods 1961–1990 and 1971–2000 in a 1 km × 1 km grid
- Mean wind speeds in the period 1961–1990 in a 1 km × 1 km grid
- Mean wind speeds in the period 1981–2000 in a 200 m × 200 m grid

Monthly Data

- Precipitation since 1901 in a 1 km × 1 km grid
- Air temperature, mean maximum and minimum air temperatures since 1901 in a 1 km × 1 km grid
- Duration of sunshine since 1951 in a 1 km × 1 km grid
- Global radiation, grass reference evaporation and climatological water balance since 2000 in a 1 km × 1 km grid

Daily Values

- Precipitation (only *Länder* in West Germany) since 1931 in a 30 × 60 seconds grid
- Precipitation (Germany) since 1951 in a 30 × 60 seconds grid

Besides the grid maps for the German territory the DWD can provide global products, too.

- The Global Precipitation Climatology Centre (GPCC) run by the DWD can provide time-series of monthly precipitation on the global land surfaces in a grid of 0.5 degrees of geographical length/width (resolution approx. 50 km) for verification of the global climate projections.
- Furthermore, the DWD branch in Hamburg manages comprehensive global archives of specific maritime meteorological data.

Time-related Extension of Climate Data Series for Germany

As shown in Figure 2.2, the availability of digitised time-series with daily data from Germany decreases markedly from about 1970 backwards. So due to a lower spatial density the quality of the precipitation analyses decreases too. Time-related inhomogeneity also influences statements on current precipitation trends. Due to the high variability of precipitation, longer data series than e.g. for the air temperature are necessary for producing reliable trend analyses.

Currently, additional daily data (area marked in blue in Figure 2.2) are available on paper or microfilm only and need to be digitised in order to be made available. This would also mean an in-depth quality assurance of the newly digitised data and of the data already available. This activity would, especially for the period before 1970, cause significant extensions and improvements of the DWD's climatological database and enhance the quality of the derived reference datasets.

Space-related Completion of Climate Data Series for River Catchment Areas

The requirements of the water-related projects exceed – as far as their technical specifications are concerned – by far the basic data and products available in the DWD. Within the framework of BfG's ongoing project KLIWAS (Consequences of climate change for navigable waterways and options for the economy and inland navi-

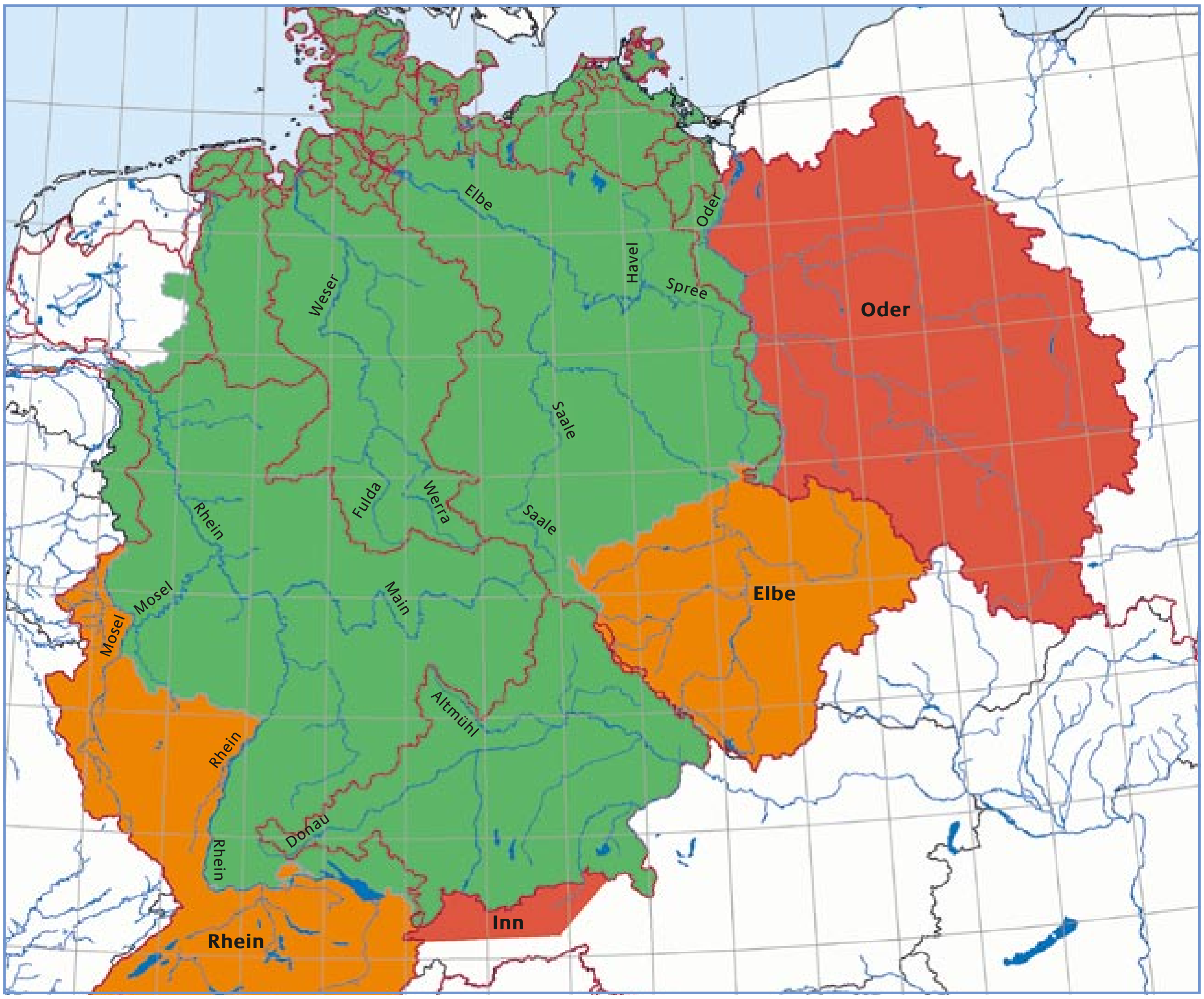


Figure 2.3: Germany and the hydrological catchment areas of the Rivers Rhine, Inn, Elbe and Oder draining to Germany
(Graph: DWD)

gation) the reference datasets of the DWD should be extended. Up to the middle of 2008 the following grid data are required and will be provided for the period 1951–2006 for the entire catchment area of the River Rhine:

- Daily precipitation data
- Monthly data on air temperature, relative air humidity, wind force, global radiation and duration of sunshine

In order to meet these requirements, observational data from the neighbouring riparian states France and Switzerland need to be acquired and integrated in the analysis process. Respective data will also be necessary on the parts of catchment areas of the Rivers Danube, Elbe and Oder located in foreign countries and relevant for Germany (see Figure 2.3). Comparable climate data from the countries Austria, Czech Republic and Poland need to be acquired and integrated into the overall data processing (database, analysis, visualisation). Figure 2.3 shows the catchment areas of the rivers draining to Germany.

Global Collecting Centre for Marine Climatological Data – GCC

Via the archive of DWD's Global Collecting Centre for Marine Climatological Data (GCC) access is possible to any meteorological data available around the world as well as maritime data collected on site (marine climatological data, data from buoys and platforms as well as aerological data). Data series go back until the first half of the 19th century (see Figure 2.4). For the period between 1820 and the Second World War there is a need for extensive data extension which should be edited and

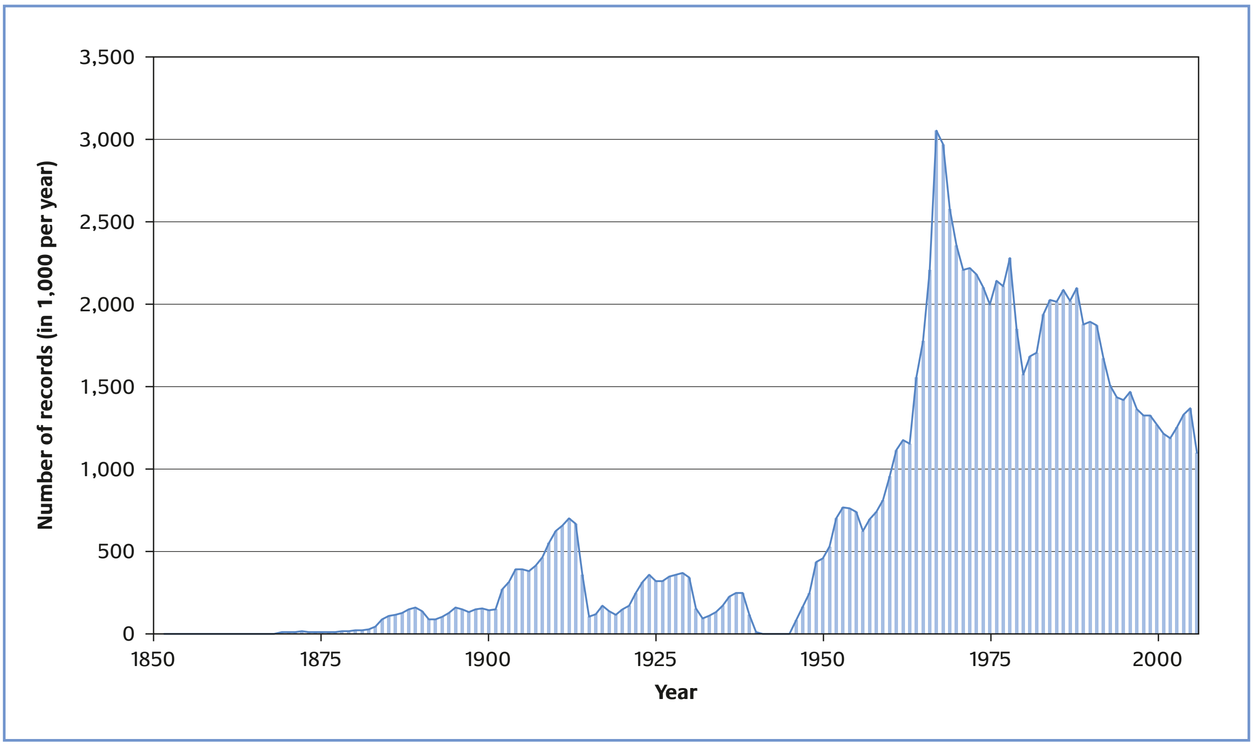


Figure 2.4: Development (1850–2006) of the amount of marine climatological data available at the Global Collecting Centre for Marine Climatological Data (GCC); Maritime meteorological data archive as of 12/31/2006 (Graph: DWD)

integrated within the framework of the HISTOR project. Data material on the European marginal seas and on the North Atlantic is best, compared to that for all the other oceans.

Together with the BSH's oceanographic data archives, there is a comprehensive database for deducing atmospheric-oceanographic reference datasets required for the project on the German coastal areas, the North and Baltic Seas and the North Atlantic.

GCC is one of the leading centres – in an international comparison – regarding the development and application of maritime-meteorological test procedures so that for the deduction of the necessary reference datasets, observational data of the highest quality can be used.

2.3.2 Contributions from Other Projects

For the topic of climate modelling and climate impact research, comprehensive results from numerous projects – ongoing and concluded – are available that can be used to assess the climate impact on navigation and waterways. So the experiences and products from the EU projects ENSEMBLES and PRUDENCE (Prediction of Regional Scenarios and Uncertainties for Defining European Climate Change Risks and Effects) ought to be integrated.

For coasts and estuaries and for navigation-related issues, the results of HIPOCAS (Hindcast of Dynamic Processes of the Ocean and Coastal Areas in Europe), KRIM (Climate Change and Preventive Risk and Coastal Protection Management on the German North Sea Coast, Schuchardt and Schirmer 2007) and MERSEA (Marine Environment and Security for the European Area) will be of particular interest. Significant impact can also be expected from BALTEX (The Baltic Sea Experiment) and from the projects of North and Baltic Sea countries.

There are innumerable relevant studies, and a review of the available research results will require major efforts. This as well as collecting and making available meteorological, oceanographical and ecosystem-related reference datasets for the North and Baltic Seas and for the North-East Atlantic will be an important task in the future and contributes to the research programme on navigational and coastal interest within the framework of the BMVBS initiative (see Chapter 5). For inland areas, the KLIWA project (Climate change and consequences for water management) can provide very valuable contributions.

Climate Trend Analyses of the KLIWA Project

The DWD has been collaborating with the German *Länder* Bavaria and Baden-Württemberg in the KLIWA project (Climate change and consequences for water management) since 1999. The development of new regional climate change scenarios allowed, for the first time, the formulation of well-founded statements on regional climate change impacts for Southern Germany. First, within the KLIWA project, meteorological and hydrological observational data from more than 350 measurement stations in the observation area were analysed for the period 1931–2000, and trends were determined.

In this context, the long-term behaviour of flood discharge, of mean discharges, of areal mean and extreme precipitation, of air temperature, of evaporation and duration of snow cover for the time-series in the 20th century has been analysed.

The analyses for Southern Germany revealed remarkable changes in particular regarding precipitation:

- significant decrease of areal precipitation in the summer half-year
- mainly significant increase of areal precipitation in the winter half-year
- regionally marked increase of strong precipitation in the winter half-year
- increase of westerly weather patterns with high precipitation over Southern Germany in the winter half-year

The findings so far gained within KLIWA and other regional projects still bear major uncertainties since often they have been insufficiently validated. So far, the conclusions deduced from these studies on the effects

Extreme weather conditions: over 15 m high waves caused damage at the FINO measurement platform near Borkum on the German coast (1 November 2006, hurricane "Britta") (Photos: BSH).

of climate change on the hydrological cycle in Germany are not really appropriate for deducing specific political measures or even for initiating investment measures as options for adaptation.

However, with the progress in climate research and an improvement in modelling instruments and reference datasets, the current findings will inevitably further improve.

The methodological instruments of KLIWA could be a model for a study on the effects of climate change on navigation and waterways or on the water management covering the entire German territory as well as parts of the catchment areas of the Rivers Elbe, Oder and Rhine situated in other countries. In this context, the DWD is the only place in Germany to provide the necessary observational database, the necessary analysis methods and the expertise required to evaluate the results.

3 Possible Consequences of Climate Change on Navigation and Waterways

3.1 Boundary Conditions

Rivers, their catchment areas and the coastal region are subject to many uses – some of which are competing – as described in Chapter 1. The use as a federal waterway for navigation is only one of these forms. In order to fulfil this function, it is a prerequisite that certain conditions guaranteeing safe, easy and economical operation are provided in a reliable way. Sufficiently deep and wide channels which are as stable as possible as well as moderate and predictable flow velocities are necessary. In order to guarantee these boundary conditions – subject to a natural variability – as well as possible, comprehensive management of the waterways is required. This includes

- Operation (regulating traffic, providing information systems, placing navigation marks, making available berths and harbours)
- Maintenance (keeping the hydraulic engineering structures and building materials as well as the channel in the originally approved state of the plan) and
- Development of the federal waterways (modifications for adaptation of capacities or for enhancing navigational safety and erosion control that are subject to plan-approval procedures).

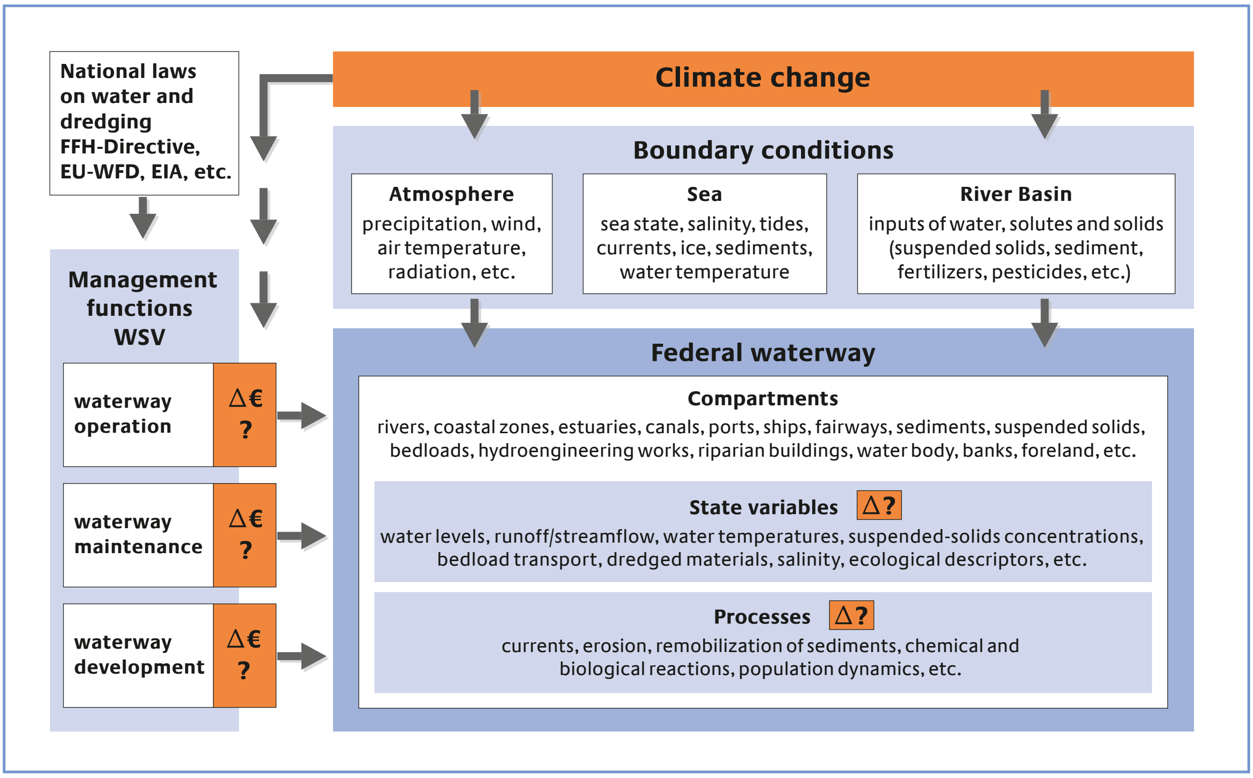


Figure 3.1: Federal waterways: compartments, state variables, processes and boundary conditions from atmosphere, sea and land surfaces as adjacent systems; the amounts of change currently unknown for the state variables of the system and for potential management costs under the impact of projected climate change scenarios are marked in orange (Graph: BfG).

To answer the question concerning which impacts the modifications due to the range of projected climate scenarios explained in Chapter 1 could have on the financial efforts for operation, maintenance and development, it is first of all helpful to consider the federal waterways with their elements.

Figure 3.1 shows schematically the climatic dependency within the system “federal waterway”; its current state at each point can be described by variables (such as water level, discharge, temperature, suspended-solids concentration, bed-load management, salinity, specific ecological descriptors, etc.). These are, in turn, interlinked in a complex and dynamic way in space and time, i.e. they change continuously (e.g. currents, erosion, sediment remobilisation, chemical and biological reactions, population dynamics, etc.).

This entire system is influenced by external factors, e.g. from the atmosphere via meteorological dimensions such as precipitation, air temperature, wind and radiation, from the land via inputs of water, solutes and solids, and from the sea amongst others by tide, waves, sea currents, sediment movements, water temperature, salinity and ice. As already mentioned and shown in Figure 3.1 on the left-hand side, the German Federal Waterways and Shipping Administration (WSV) is responsible for managing the German federal waterways.

If the boundary conditions change due to the climate change, the process dynamics within the system “federal waterway” change too; and in the end this would show up in changed spatial and time patterns of the state variables. It would, for example, be possible that the flow regime changes – and as a consequence it would be possible that changed sedimentation patterns, dredged material quantities and material load would arise. The related potential impact on the efforts (climate-induced additional effort “Δ€?” in Figure 3.1) for fulfilling the WSV’s abovementioned management function on the federal waterways, i.e. maintaining the usability function in a reliable way, is easily understandable. It is also becoming obvious that the objectives for other usability functions may need to be newly estimated within the framework of the statutory regulations.

The Chapters 3.2 and 3.3 will present – for both sea/coast and inland areas – the current state of knowledge, and potential impacts of climate projections on the abovementioned elements of the system “federal waterway” will be assessed. First, possible changes in several oceanographic parameters and changes in the water and solid matter balance are described, and then the related additional effects on the water quality and ecology will be discussed.

3.2 Sea Navigation and Sea Waterways

3.2.1 Oceanographic and Meteorological Boundary Conditions

The requirements placed on sea-going vessels and sea navigation as well as development, maintenance and operation of sea waterways depend on the oceanographic, hydrological and meteorological boundary conditions in the high seas and in coastal areas. Therefore, climate changes would first become apparent by a timely change in physical parameters, such as air and water temperature, ice cover, water level, wind force, wind direction, waves and precipitation. Thereby they have an immediate impact on sea navigation. The most important factors are given below – together with their potential modification due to climate change.

Global Atmospheric and Oceanic Temperature

Studying the effects of climate change on sea navigation in the North and Baltic Seas necessitates large-scale consideration. The harbours of these seas are linked to the global network via sea waterways. Sea navigation is therefore exposed to the effects of climate change on a global level. This relates, amongst others, to shifts in global atmospheric and oceanic circulation systems, to an increase in extreme wind and wave events, and to changing ice conditions.

The latter could, on the one hand, presents a risk e.g. through an increase of icebergs in the North Atlantic originating from massive discharges of ice from Greenland into the sea; on the other hand, they offer new possibilities such as establishing navigational routes in the case of year-round or seasonal ice-free Northeast and Northwest passages. This not only means a new coordination of the international sea-routes and commodity flows – including the related infrastructures – but, if necessary, it also means technical adaptations of the sea-going vessels as regards their ice class or cooling of cargo and engines.

The melting of polar ice masses would also be accompanied by a decreasing salt content of the seas. This could have strong impacts on the global heat transport as well as on the ecosystems.

Rising Sea Level

Global warming will provoke thermal expansion of the seawater, partial melting of inland ice, and thereby a rising sea level. Current IPCC scenarios result in a rise of less than 1 m by the end of the 21st century. Melting of the entire Greenland ice would cause a global rise in sea level by about 7 m. This would, however, require at least several centuries. Uncertainties regarding the rate and height of sea-level rise stem from still largely unknown the behaviour of the large ice sheets.

Water Exchange between North and Baltic Seas

Changes in the atmospheric circulation and thereby in the meteorological conditions (wind, temperature, precipitations) over Northwest Europe could result in impacts on the circulation in the North and Baltic Seas, the water exchange with the Northeast Atlantic, and the salt water intrusions from the North Sea into the Baltic Sea.

Tidal Currents

As a consequence of climate-induced changes in tidal water levels and velocity of translation of the tidal wave, the tidal currents would change at the coast and in the estuaries.

Normal Values of High and Low Tides, Tidal Range

A climate-induced rise in the mean sea level in the North Atlantic would cause a rise in the mean sea level of the coastal seas (especially in the bays and estuaries). Here, the tidal dynamics would be intensified with mean high tides mostly rising more than the mean sea level. All in-all, the climate change makes an increasing tidal range at the North Sea coasts more probable.

Tidal low water in the German Bight (satellite image 2 May 1998, DLR)

Episodic Extreme Situations
Climate-induced changes in the atmospheric circulation, in particular changes in cyclone tracks as well as intensifying west wind conditions, could cause extreme situations to occur more often. It is to be expected that not only the probability of extreme tidal water levels (storm surges) would increase, but also the probability of extreme wave conditions (intensity and directions).

Marine Salt, Sediment and Ice Transport
Modifications in foreshore and in estuaries currents would primarily have an impact on the sediment budget. This would cause a change in the dynamic balance existing between current, transport and morphology. Sedimentation and resuspension processes on the seabed and in the estuaries as well as erosion of the coasts, especially at the Frisian Islands and dwelling mound, would be the consequence.

Fluvial Discharge Rates Including Mixing Processes of Freshwater/Seawater
Reduced surface water inflow into the estuaries of the Rivers Ems, Weser and Elbe can cause climate-induced upwards shifting of the brackish water zone.

Groundwater Quality in Transitional Waterbodies
Upwards-shifting of the brackish-water zone into the estuaries can cause increasing salting of the aquifers (seawater to freshwater).

Morphodynamics
The mentioned effects of climate change on the coasts would in the end provoke a modified depth distribution of the waterbody's bed. In particular it needs to be taken into consideration that there is an interrelationship between the dimensions of current, waves and material transport and morphodynamics.

The abiotic system states influenced by climate change have an impact on the biotic processes and on the seas and coasts as natural landscapes and habitats. They must be regionalised for the system of sea waterways.

However, global projections deal first of all with the development of global mean values and with the deviation from these mean values in continental and oceanic areas. So far it is not yet possible to study in a sufficiently exact way the regional effects, e.g. on the German Bight, the Wadden Sea or the Sylt coast. Correspondingly, the reliability of the propositions that can be made so far on the effects of climate change on individual parameters and regions varies.

In coastal areas, sea waterways are subject to the influence of coastal seas, and are mostly part of estuaries; but the high seas need to be considered too. This is also true for the offshore constructions built. As explained above, changed hydrological and meteorological boundary conditions also have consequences for operation and maintenance of the sea waterways and of the constructions in or next to them.

Parallel to the development of the sea-going vessel size, the channels of sea waterways have been gradually extended since the invention of an effective dredging technique more than 150 years ago. Nowadays channels are to be seen as continuous constructions in the natural river and bay systems. So channels are a crucial element of inshore sea waterways. The projected climate scenarios may possibly imply changes here too.

3.2.2 Effects on Sea Navigation and its Infrastructure

Against the background of the forecasts on volume of goods transhipped in the German sea harbours that bear a significant growth potential – mentioned in Chapter 1 – it is of paramount importance to guarantee ease and safety of navigation as far as the effects of a possible climate change are concerned. This also concerns the cost-effectiveness and social acceptance of the traffic realised on sea waterways.

This means that, within the next years answers to crucial questions need to be worked on and provided in order to guarantee safe, cost-effective and ecological sea traffic for future generations too. To answer these questions will be the task of the technical and scientific authorities in collaboration with the climate research in the coming years.

From the current point of view, the most important questions regarding sea navigation are:

- Will the **degree of development of estuaries and harbour access routes** currently existing or aimed-at be changed by the climate change? If so, to what extent? Basically, a climate-induced rise of the average water level may allow for vessels with a larger draught. The effects of different climate scenarios on estuaries (in particular also in the view of creeping changes) are not yet sufficiently known.

- Will the **nautical conditions** in and along the channels change as a consequence of the climate projections? Would navigation management need to be adapted on a long-term basis? Do currently existing hydraulic engineering concepts need to be oriented towards the changed conditions on a long-term basis, e.g. due to changing morphodynamics especially in the tidal mud areas of river mouths (sediment deficits, very large sediment transport)?

- Will the usability of German landward-directed **sea waterways** be impeded by potentially more frequent storms and storm surges – making also the access to sea harbours more difficult?

- What costs are to be expected in the future in the coastal areas for **maintaining the sea waterways** by means of safeguarding the necessary channel depths?

- How large will the maintenance and repair efforts be in the future given the changes of wave-induced load on sea marks, sea-going vessels, offshore constructions (platforms, windparks, etc.), coastal and coast-protecting structures and harbour infrastructures, and on structures within the river (significant and maximum wave heights, heavy wind events)?

- To what extent will the **dyke safety** be influenced by climate change? How can the dyke safety existing nowadays, e.g. in the form of tidal barrages, measures to reduce storm surge peak water levels, etc., be retained in the future?

- What about the future **erosion on banks, revetments, underwater slopes and in forelands**? What will be the effects of higher load on quays, locks and barrages?

- Will the **use of estuaries by agriculture, fishery, industry and tourism be changed?**

- Which hydraulic engineering measures and long-term development concepts can be used to develop the tidal areas of the Rivers Ems, Weser and Elbe according to nautical, nature protection and economic criteria on a long-term basis, taking climate change into consideration?

- Can existing **shipping routes on the oceans** be newly optimized due to changes in the circulation pattern?
- Can an alleviation of the ice season (ice thickness, duration of icing) and in the end the disappearance of icing on the German coasts be expected on a long-term basis? And will this perhaps allow use of the Northeast Passage in the future – all-year or at least during a longer part of the year?
- Is an increased formation of icebergs to be expected in the area of the shipping routes in the North Atlantic, due to increased de-icing of the Greenland ice? And does this mean a higher risk for navigation?
- What consequences will a potential shifting of tourism from e.g. the Mediterranean region to the North and Baltic Seas have e.g. on ferry traffic, infrastructure and recreational navigation?

Answering these questions is the first step toward the development and design of necessary adaptation options, and is necessary in order to seize opportunities and to minimise risks.

3.2.3 Impacts from the Water Quality and Ecology Point of View

For the field of sea waterways it should be retained that climate change can cause changes in the chemical load, in the oceanographic, hydrographic, chemical and also ecological conditions. Here, in the sense of this review, it should be underlined that regarding these changes, a range from low to substantial is possible. To date it is still highly uncertain what the extent of these changes will be and what will be the consequences arising for sea navigation and the management of federal waterways. It must be observed intensively and accompanied by studies if, within the coming years, critical threshold values of the changes are reached or exceeded.

For the BMVBS it is important that climate-induced changes in the water quality and ecology will not be at the cost of maintenance and development projects for sea navigation. Therefore the evaluation methods for issues of waterbody quality and ecology must be able to distinguish in the future between the negative effects of climate change and the effects of maintenance and development of sea waterways.

Marine areas are a habitat with a high variety of ecological quality objectives. The stipulations of the United Nations Convention on the Law of the Sea (UNCLOS) on environmental protection in marine areas have been detailed and developed further by numerous agreements at a regional level. The contracting parties of the OSPAR Convention on the Protection of the Marine Environment of the North-East Atlantic (Oslo-Paris Convention) and of the Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention, HELCOM) have agreed on nature conservation and ecological targets by convening measures that should help prevent or remove pollution. Furthermore, all measures necessary to protect marine areas against the harmful effects of human activities should be applied in order to protect human health. The corresponding implementation for the German Federal Waterways and Shipping Administration (WSV) was assured by the Directive for Dredged Material Management in Federal Coastal Waterways (HABAK-WSV). Also the EU launched different directives obligating the member states to adopt the nature protection and ecological targets and, if they are not attained, to strive for them using appropriate measures, such as the FFH Directive (Fauna-Flora-Habitats Directive; Natura 2000 concept of nature protection areas), the EIA Directive on Environmental Impact Assessment, or the EU Water Framework Directive WFD.

The *Bundesnaturschutzgesetz (BNatSchG)* (German Federal Nature Conservation Act) and the *Umweltverträglichkeitsprüfungsgesetz (UVPG)* (Environmental Impact Assessment Act) apply to inland waterbodies and to the territorial sea of the Federal Republic of Germany (German territory). Besides the Environmental Impact Assessment (EIA), FFH-IAs (Fauna-Flora-Habitat Impact Assessments) are carried out in order to guarantee that

"The climate change has already caused changes to the sea that can be recognized and will have consequences for navigation and sea waterways too."

obligations stemming from International Law, European Community Law and Constitutional Law are met. Furthermore, the Environmental Risk Assessment (ERA), a voluntary administrative procedure, has been launched for the German Federal Transport Infrastructure Planning. And the marine habitat is of paramount economic importance for other uses described above which are connected to the aspects mentioned here and will increase further in the future (traffic, tourism, energy production, etc.).

Depending on the occurrence of different climate scenarios, sometimes enormous changes are to be expected for the marine ecosystem. This will also have consequences for the maintenance situation of sea waterways. The following deliberations illustrate the situation and its significance.

The global projections for the future climate, described in Chapters 2 and 3.2.1, and the hydrological parameters (low-water, flood, flow conditions, etc.) anticipate an increase in the frequency and intensity of hydrological extreme situations. In the cases of storm surges, longer phases of low inflow from inland and in the case of rising sea water level, a reinforced upstream transport of weakly loaded marine sediments into estuaries and river mouths would be expected. These rising quantities of solid matter in parts of the fairways would reduce the pollutant concentration in the dredged material. Due to more frequent extreme events that can be expected onshore too (see Chapter 3.3) within limited time periods, however, solid matter transport can also increase from the inland waterbodies into the coastal areas. This will then cause temporarily higher sediment inputs and accordingly higher load.

The abovementioned range of global temperature increase will be transferable in a similar manner to the average water temperature and enhance the activity of biological processes of microorganisms, plants and animals. As described also in the following chapter for inland areas, a generally stronger algae growth may enhance the quantity of organic material that would need to degrade, and this would reinforce oxygen depletion too. Furthermore, the higher the water temperature, the lower the dissolved oxygen in it. Longer intervals of oxygen stress for fish and other animal organisms would arise. Due to these coherences – briefly outlined – climate-induced impacts on the marine ecosystem, its organisms, water quality and its uses besides navigation, e.g. fishery, are expected. Furthermore, the consequences resulting for the maintenance of sea waterways, for the structures and for the materials used in shipbuilding must be checked.

Aspects for Maintenance

Part of the changes predicted for the hydrological conditions can provoke a stronger marine impact on the estuaries. And, due to the higher average water temperatures and the related lowering of oxygen content, occurrence of algae and bacteria can increase which prefer higher temperature ranges and lower oxygen concentrations. Examples of this would be dinoflagellates and vibrions which can sometimes provoke serious inflammatory diseases in humans and animals. Furthermore, increased blue-green algae populations are expected, which often produce toxic substances, so-called algae toxins. They can have a serious impact on the ecosystem and fishery. This includes a potentially toxic effect if humans have contact with seawater contaminated with algae toxins, its aerosols or with contaminated fish. With the shifting of bacteria occurring by nature in seawater towards this kind of rather heat-loving microorganisms, the possibility also increases that species will occur that can provoke diseases for man. Health risks for work in or along federal waterways would increase in parallel, due to contact with water, sediments or dredged material.

Therefore it needs to be checked to what extent climate-induced hazards for animals and humans, for fishery and for tourism would result.

Within the framework of maintaining sea waterways, concepts for managing fine-grained sediments need to be developed taking climate change into consideration and alleviating its consequences. A partial aspect of this is to limit the additional entry of nutrients by specific measures in order to eliminate the algae's basis for growth. In this context it also needs to be studied to what extent algae toxins can be found in sediments and dredged material.

The climate change will probably also have an impact on the composition of the species structure and food networks in marine areas and sea waterways. During longer periods with high summer temperatures, the critical limits of temperature and pollutant load and of oxygen deficiency may often be exceeded, especially in estuaries.

In the North Sea, restructuring of the ecosystem due to higher water temperatures has already been observed. Invasive heat-loving species could already become established. They were introduced with the sea-going vessel's ballast water or came by natural migration and have caused a changed range of species. The immigration of more southern species and the displacement of cold-loving fish species towards the North (codfish) have general consequences for the sea and coastal fish industry. Furthermore, the increasing warming causes a time displacement of phyto- and zooplankton flowering. This can provoke an inappropriate ratio between fish larvae occurrence and food supply.

It is not clear which species are concerned and what extent the changes will have in the future. The trend already observed nowadays of an increase in immigrating species may be reinforced due to the climate change. In order to limit this, the Ballast Water Convention was adopted in 2005.

The increase in flood and storm events can cause increased resuspension and thereby re-mobilisation of pollutant-loaded old sediments from existing dumping sites and lateral areas of the fairways. Increased nutrient and pollutant inputs into the coastal areas, provoked by stronger flood events, as well as increased resuspension could cause on the one hand a change in the pollutant distribution in the sediments currently to be dredged and on the other hand periods of enhanced oxygen depletion. Furthermore, rising temperatures and decreasing discharge quantities in summer may provoke an increase in algae and an extension of the growth periods. So not only would the amount of biomass coming into the estuaries of our rivers increase, but it would also occur over a longer time period. And this could have negative impacts on the oxygen balance.

An immediate impact on the future dredged material management – considering aspects of waterbody quality – could also stem from sediment inputs from the backshore caused by more frequent inundation events. Here shore protection by vegetation plays a role, but also the type of use. The vegetation in the tidal flats fulfils multiple functions for the balance of nature. Besides the function of habitat, these are, amongst others, filter functions for sediments and pollutants and a protective function against bank erosion. As in inland areas, non-endemic plant and animal species (animal invaders, neophytes) are already invading nowadays into existing biocenoses in backshore areas. With changed climate conditions, an increase in this trend is to be expected.

The properties of the neophytes and animal invaders can have adverse effects, such as an increased production of allergens and phytotoxic substances, increased occurrence of mowed material and a more difficult accessibility of the banks. And many neophyte plant species do not provide sufficient erosion protection in winter. This may require additional protection measures at banks and dykes.

To estimate the extent of these potential changes in the backshore areas, on the one hand data on the statistical frequency of extreme events need to be provided by hydrology; on the other hand sediment inputs and pollutant load of the areas potentially concerned by erosion need to be recorded.

Technical Aspects

In addition to the abovementioned potential loads provoked by algae toxins, organisms that increasingly populate firm surfaces such as hydraulic engineering building materials or ship hulls could augment with increasing water temperature. This so-called "biofouling" can cause substantial economic damage.

Therefore many paints and building materials used for shipbuilding or near the water contain substances with a biocide effect. They should prevent the population as well as the microbial decomposition of the products and thereby enhance their durability or, in the case of ship paints, limit the "biological fouling". Due to the presumed stronger growth of the organisms, higher application quantities and frequencies of these biocides are expected. The relevance of these substances for sediment management becomes obvious in the example of tin organics whose use was prohibited because of their high level of toxicity and accumulability. An early detection of risks provides the time necessary to adopt measures and prevent costs.

Structures and shore protections to guarantee navigation in coastal waters and for coastal protection must resist strong weather conditions, but they must also provide long-term stability and safety. Here the properties of the hydraulic engineering building materials used (concrete, rip-rap, steel, etc.) are decisive. Stability and environmental compatibility of hydraulic engineering building materials are a function of water temperature, waterbody mechanism and hydrological stress. In the course of time, the materials are becoming mechanically worn out, some materials adsorb and emit substances. Climate change will have an impact on all these processes. So far, a systematic quantification of the medium-term and long-term action on hydraulic engineering building materials and of their impact on the environment (water, sediments, and biota) is still lacking. Only on the basis of these findings can it be estimated which materials and installation techniques are best suited to the respective applications and provide, at the same time, a high environmental compatibility.

A potential climate-induced change in species compositions surely brings up questions on nature protection and further environment-related evaluations. This is of particular relevance to requirements relating to the maintenance of federal waterways and compensation dimensioning.

On the other hand it is also possible that development and maintenance will intentionally be steered in a way that detrimental effects of climate change are mitigated. For example, shallow-water zones and connected backwaters can provide – given their high photosynthesis activity – a balance to higher oxygen depletion, provoked by climate or management, in deeper estuary sections and provide retreat areas for fish.

3.3 Inland Navigation and Inland Waterways

3.3.1 Potential Impairment due to Changed Water and Solid Matter Balance

Similar to coastal areas, the usability of inland waterways depends on the meteorological and hydrological situations in the river's catchment area. These may change due to the impact of the projected climate change.

The activities depend on atmospheric processes, such as precipitation and evaporation, as well as on terrestrial boundary conditions, i.e. river cross-sections, gradients, land use, soil condition and the retention capacity of the landscape. In estuaries, tidal water levels are additional factors that have an impact on the upstream freshwater and the brackish water regions.

The most important dimension for the use of waterways is the flow regime. The water yield and its seasonal distribution determine the navigable water depths and thereby not only the performance of the individual waterway but also of entire relations ("bottleneck" phenomenon). This is shown in Figure 3.2. Compared

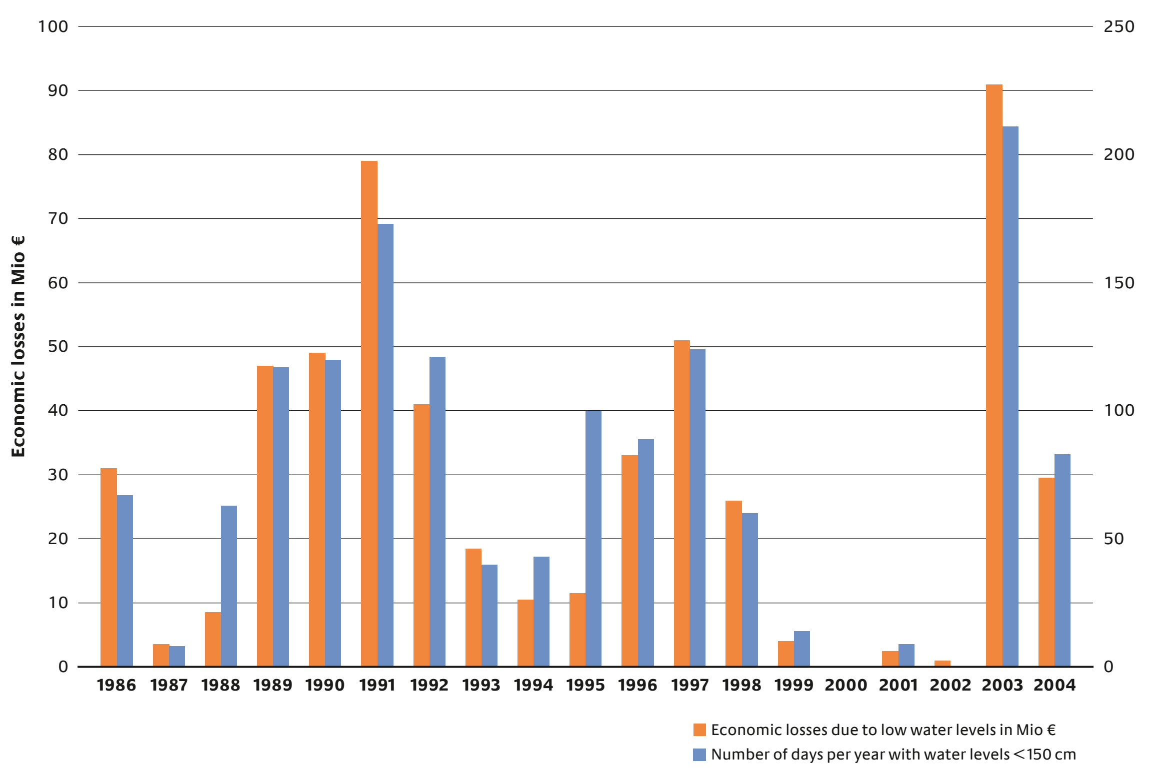


Figure 3.2: Economic losses associated with freight transport on inland vessels due to low water levels between 1986 and 2004 (left axis) compared to the number of days per year with water levels <150 cm at Kaub (River Rhine) gauging station (right axis); modified according to Jonkeren et al. (2007)

are the estimated losses caused to the national economy by lower water levels – according to goods transport on inland vessels at Kaub gauge station (River Rhine) between 1986 and 2004 – and the number of days per year with a water level <150 cm. This water level marks the threshold value for calculating the graded "Low Water Surcharge" (KWZ), a freight surcharge which the contractor can agree upon with its clients as a component of the transport contract for risk compensation during low-water periods.

So the discharge and its potential change are the core dimensions whose future development needs to be estimated (mean values, variability, and extreme values). This task has been dealt with since June 2007 by the KLIWAS project, with the BfG having the overall responsibility.

The trend resulting from the analysis of several past series of measurements could be indicative of the changes to be expected. To illustrate this, Figure 3.3 shows the normalized mean annual hydrographs of discharge at Cologne gauging station for four 25-year periods in the last century. All four periods were equally normalized with the mean annual discharge of the entire period 1901–2000.

The red graph shows the hydrological years from 1976 to 2000. It is clearly recognizable that the mean normalized monthly discharge in the winter months increased compared to the previous 25-year periods; the discharge

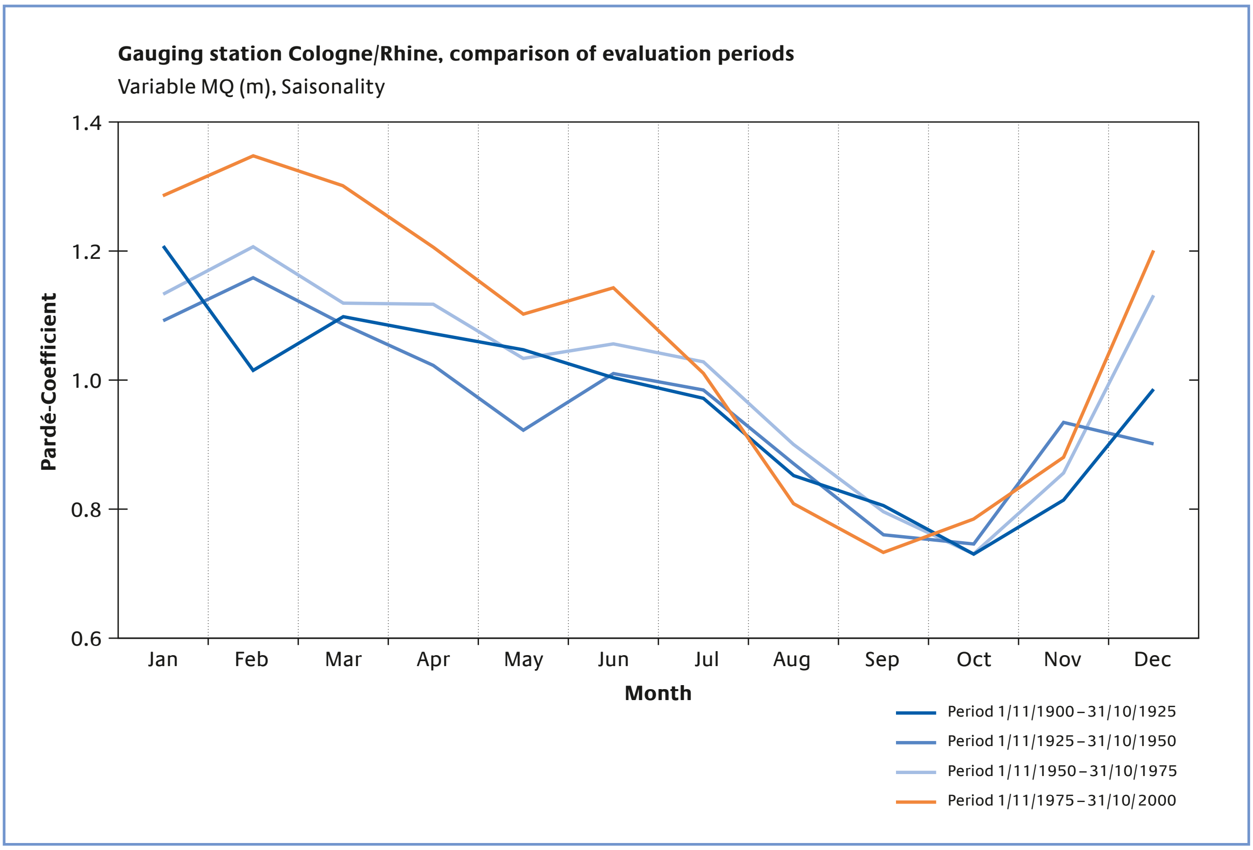


Figure 3.3: Characterisation of the flow regime; ratio of mean monthly discharges of the four 25-year periods presented and the mean annual discharge between 1901 and 2000 at Cologne/Rhine gauging station (based on PARDÉ 1920)

level observed in autumn, however, stayed more or less the same but expanded slightly in time. The month of lowest discharge amounts – highly important for navigation – has been shifted on average from October into September.

Similar regime changes could cause a more frequent and unfavourable superposition of extreme discharges from the various parts of the catchment area; and thereby they may provoke the occurrence of longer low-water periods, but also of more extreme flood events.

As mentioned above, the climate projections point to changes in the frequency and intensity of extreme weather periods and phenomena. Due to the expected warming it would still be anticipated that e.g. in the Alps and in higher parts of the low mountain ranges, only a smaller quantity of water can be stored in the snow cover in winter.

Thereby its buffer function would diminish and the flow regime would change accordingly. This would result in the higher discharges already outlined in winter and lower discharges in summer. The evidence for this trend is provided by individual calculations. Figure 3.4 shows the application of the climate projection of the global B2 scenario from the Third Assessment Report (TAR, IPCC 2001) using the model chain ECHAM4/OPYC (global climate model of the MPI-M), REMO (regional climate model of the MPI-M) and LARSIM (water balance model) at four gauging stations (columns). The B2 scenario is not followed any further in the AR4 (IPCC 2007), but comparative calculations have shown that the fundamental statements deduced from it are still valid: an increase is observed for almost all calculated future mean values of winter discharges, whereas for summer discharges, at three of the four gauging stations, a reduction of mean discharge values can be observed. In Figure 3.4, an orange bar is given additionally for the Cologne gauging station. It shows the range of the mean decade values of the last century (period 1891/2002). In winter, the mean discharges of these 11 decades deviate by a maximum of +13% and a minimum of –18% from the mean value of the reference decade 1990/1999, in summer by a maximum of +26% and a minimum of –13%. The comparison shows – for this scenario projection – that a shift in the mean discharges towards the more extreme periods of the last century may result in the future.

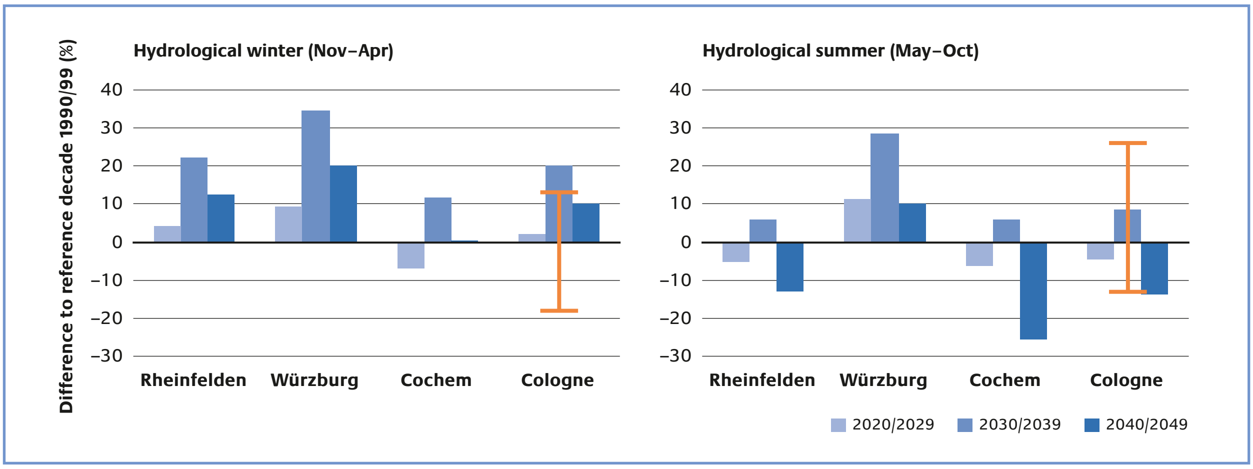


Figure 3.4: Estimation of the future changes [%] in mean discharge values of the winter and summer half-years for three decades at the gauging stations Rheinfelden (River Rhine), Würzburg (River Main), Cochem (River Moselle) and Cologne (River Rhine) compared to the reference decade 1990/1999. The orange bars – showing the margin of the mean decade values of the period 1891/2002 for the Cologne gauging station – are given for comparison purposes. Application of the climate projection from the global scenario B2 of AR3 (IPCC 2001). (Kempe und Krahe 2005)

"An offset towards more extreme discharges necessitates adaptation measures from users and operators of waterways."

The effects of a flow regime modified in this way would be complex and would affect various fields of inland navigation, including warehousing and logistics as well as industries depending on economical transport of bulk cargo.

The consequence would be a functional chain which would be activated by modified climate conditions or an increase in extreme weather conditions/periods. This functional chain would affect the cost-efficiency and reliability of waterway-bound transport as a result of modified fairway conditions for inland navigation, and thereby it would impair competitiveness, especially of industries depending on bulk cargo.

The dependency of inland navigation results from the available water depth which has a decisive impact on transport costs via the draught of the vessels (see Figure 3.2). An increase in the amount or frequency of extreme water levels would affect the reliability and safety of inland waterways as a traffic mode. The BfG has carried out in-depth studies of the recent low-water periods for all major German river basins (BfG 2006, BfG 2007, Belz et al. 2006a, Belz et al. 2006b). Analysing the long-term series of measurements shows in most discharge time-series a slightly increasing trend for discharges (m^3/s) in low-water situations, whereas this trend has moderated due to the low-water events in 2003 and 2006 (BfG 2007). In general, however, the proposition is valid that low-water extremes have moderated within the last decades and that as a consequence less restrictions for navigation due to the specific discharge have also been observed. However, this improvement is partly relativised by the use of vessel types of ever increasing dimensions and larger draught. For a sound estimate of the possible future development, extrapolations of discharge time-series from the past are insufficient on their own to represent the effect of boundary conditions changing rather quickly due to climate change.

The BMVBS's scientific and technical authorities are well-prepared for the necessary systematic analyses, in particular also due to their international network; because besides the national activities regarding the coordination required to deduce consistent climate projections for the German territory there is a further need for coordination with the respective working groups, in particular in the neighbouring countries.

For example, in the catchment area of the River Rhine, climate change scenarios have been drafted by working groups in Switzerland and in the Netherlands. Within the catchment area of the River Rhine there are also different hydrological model approaches. Since autumn 2007, the BfG has been compiling, in collaboration with the International Commission for the Hydrology of the Rhine Basin (CHR) within the framework of a 2-year project, common climate and discharge projections for the catchment area of the River Rhine and drafting discharge scenarios based on them.

As support for this task, there are good contacts to the Central Commission for Navigation on the Rhine (CCNR) and to the International Commission for the Protection of the Rhine (ICPR). A further network is given by the structural funding projects (EU INTERREG Programme). For example, within the framework of the INTERREG IIIB "Alpine Space" Project ClimChAlp, climate projections and adaptation options are finely-tuned collaboratively coordinated with the neighbouring alpine countries. For the mountain regions in East Europe, a corresponding project application was submitted in the current call for the EU's Seventh Framework Programme for research and technological development (RACE 2040). Within the framework of this project, the BfG plans to deal with the climate issue in the catchment area of the River Elbe in close cooperation with Czech scientists and offices. And with the Global Runoff Data Centre (GRDC), under the patronage of the World Meteorological Organization (WMO), the BfG makes an important contribution to international research programmes dealing with monitoring and modelling global climate change. From this context many contacts and an active exchange with international research have arisen. The results of these research programmes foster a continuous improvement in the combined global climate and ocean models important for regional climate modelling.

Besides discharge, sediment balance and the state of the river bed are decisive for the waterways' navigability.

Large-scale changes – as far as time and space are concerned – have an impact on the channel depths and on the maintenance efforts necessary to guarantee the latter.

In this context, alluviation tendencies as well as large-scale and long-term deficitary riverbed developments require an active sediment management. Here, findings on the development of total bed-load and suspended solids load are of predominant importance.

Should the morphological conditions in inland waterways change due to the climate change, the question needs to be answered how the German Federal Waterways and Shipping Administration (WSV) would need to adapt its waterways management in order to stabilise the depth conditions of federal waterways. This initially requires a well-founded assessment of how much the transport system navigation/waterway is actually affected.

3.3.2 Impacts from the Water Quality and Ecology Point of View

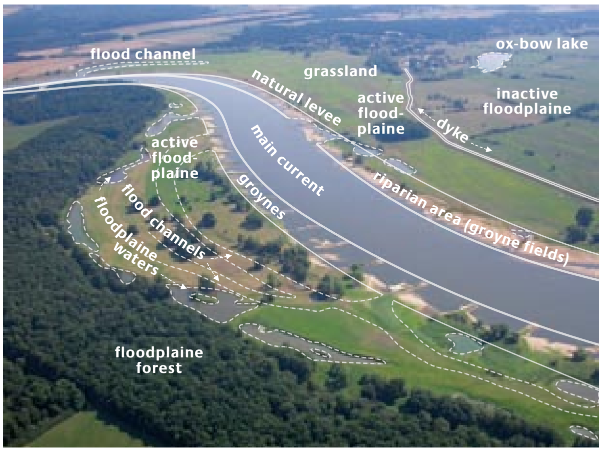
For deducing appropriate strategies to adapt to the climate change it is important to distinguish between the effects of maintenance and development projects and climate-induced changes in the waterbody quality and ecology. Therefore the future evaluation of the waterbody quality and ecology must be able to distinguish between the negative effects of climate change and the effects of maintenance and development of the federal waterways.

In inland areas – as in marine areas – the climate change will provoke changes in the hydrological conditions and in the ecological systems of the federal waterways. Here, in the sense of this review it should be underlined that regarding these changes, a range from low to substantial is possible. Climate change will also cause changed land use and adapted consumer habits among the population. This has an impact on the land-side inputs of contaminants/harmful organisms, on input from sewage treatment plants into the waterbodies, and on sediment management. The final extent of the changes as well as the consequences this will have for managing the federal waterways is still highly uncertain.

Like the shorelines and the sea, the federal waterways' waterbodies are highly important and valuable habitats. Crucial legal regulations for different environmental targets relevant to waterways are nature conservation laws, the Habitats / FFH Directive (Fauna-Flora-Habitats Directive; Natura 2000), the EU Water Framework Directive WFD, the EIA Directive on Environmental Impact Assessment, and, for the WSV's area of competence, the Directive for Dredged Material Management in Federal Inland Waterways (HABAB-WSV). Furthermore, the Environmental Risk Assessment (ERA), an administrative procedure, has been launched for drafting the German Federal Transport Infrastructure Plan. And the waterbodies are of paramount economic importance for other uses which are connected to the mentioned aspects and will further increase in the future (local recreation, tourism, energy production, etc.).

The expected increase in frequency and intensity of hydrological extreme situations as well as regional changes in discharge situations (low-water and flood events) are, at the same time, linked to phases – of regionally different strength – of low discharge in the waterways' catchment areas. Flood events will probably cause higher sediment inputs and corresponding (pollutant) load. On the other hand, material inputs from the catchment areas would be reduced during longer low-water periods. During low discharge, inputs from sewage treatment plants would have a stronger effect and algae growth will be fostered due to longer retention times. These changed quantities of solid matter would also change the pollutant concentration in the sediments and dredged material.

The range of global temperature increase will transfer, also in inland areas, to a similar extent to the average water temperature and enhance the activity of biological processes of microorganisms, plants and animals. A generally stronger algae growth may also enhance the quantity of organic material to be degraded, and this would reinforce oxygen depletion, with lower oxygen content at the same time. Like in marine areas, longer inter-



The system consisting of main current, river regulating structures and adjacent floodplain is the object under consideration (Photo: BfG)

vals of oxygen stress for fish and other animal organisms would arise. Due to these briefly outlined coherences, climate-induced impacts on the inland waterways' ecosystem, its organisms, water quality and use – beyond traffic aspects – are expected. It must be checked to what extent this will have consequences on the materials used in hydraulic engineering structures and shipbuilding.

Aspects for Maintenance

The climate change will also have an impact on the composition of species structure and food networks in inland waterways. Extreme events may even have a stronger impact on the smaller waterbodies of inland waterways than on sea waterways. In particular during longer periods of high summer temperatures, connected with low-water, the critical limits of temperature and pollutant load and of oxygen deficiency may be exceeded more often.

Already nowadays, oxygen deficits occur in several river sections and are determined in a decisive way by biological processes (algae production and decomposition of organic material). The degree and duration of this biomass production in turn depend on the discharge, temperature, light and nutrient content. So, similar to estuaries, a climate-induced increase in algae biomass is possible. In detail this would become unpleasantly apparent by reinforced daily oxygen dynamics and by an earlier occurrence and longer duration of oxygen deficits. This could also lead to conflicts with the energy industry, since oxygen deficits are often balanced by weir overflow (e.g. Rivers Neckar and Saar). This water would then no longer be available for energy production. Further conflicts may arise in the context of angling and cooling water for power stations.

The increasing extension of summer low-water periods and the stronger lowering of water levels would additionally restrict the bank habitats available for fish and invertebrates. So e.g. shallow-water zones and riprap at groynes, longitudinal structures and bank revetments are more difficult to populate if no sufficiently large subaquatic retention areas are available in critical time periods. Also backwaters which are still connected nowadays may lose their connection to the main current. This would have consequences for the populations in the waterbodies.

Here the long-term development needs to be analysed. By comparing the endemic species registration with potential invaders from the Mediterranean and Ponto-caspic area it must be established which species are concerned and what extent the changes may have. The trend – already observed nowadays – of invading animal and plant species is expected to increase in the coming years, along with phenomena such as the apparently complete disappearance of individual animal species or the mass appearance of animal invaders and neophytes. North-South or East-West waterways accelerate this exchange of organisms.

Endemic plant species with a multiannual growth and corresponding root system are a factor calculated for in the maintenance efforts. Their displacement by more competitive annual plants could be detrimental for the bank stability, especially in seasons of dynamic discharge. This may necessitate increased bank and dyke protection measures, and other potential disadvantages may materialise (allergens, phytotoxic substances, increased occurrence of mowed material, more difficult accessibility, and displacement of protected endemic plants). The system changes will also have an immediate impact on the future dredged material management. Estimation of their effects requires on the one hand data on the changes of these events, and on the other hand a comprehensive recording of the pollutant load of the areas that may be subject to erosion.

Technical Aspects

As mentioned above, many building materials used for hydraulic engineering or shipbuilding contain substances having a biocide effect. So far, for inland areas, there is no systematic quantification of the medium-term to long-term impact of climate change on building materials used in hydraulic engineering. A stronger growth of the organisms with increasing water temperatures would probably also require an increase in the biocide application quantities and frequencies. In addition to these and to the abovementioned potential load provoked by algae toxins, certain organisms could also strongly augment, such as zebra mussel or mud shrimp. They populate in particular firm surfaces, such as hydraulic engineering building materials or ship hulls, and can therefore cause substantial economic damage. Further examples of invading organisms occurring in masses are already known from the River Rhine and its backwaters (e.g. Asian clam *Corbicula fluminea*, Tiger shrimp *Gammarus tigrinus* and Killer shrimp *Dikerogammarus villosus*). A higher public awareness is achieved for big animal species or species of economic relevance.

A potential climate-induced change in the species number and composition surely brings up questions on nature protection evaluations. This is of particular relevance to requirements relating to the maintenance of federal waterways and compensation dimensioning. Adverse effects of the climate change can be moderated, for example, if shallow-water zones and connected backwaters provide a retreat area for organisms, given the high photosynthesis activity to be found here and in the case of a possible groundwater connection. Therefore, in deep sections of impounded reaches they provide a balance for an increased oxygen depletion.

4 Uncertainties in the Assessment of Climatic Consequences for the Waterbodies

Present Limits of Global Climate Models

The limits of global climate models (GCM) were compiled and assessed by the Intergovernmental Panel on Climate Change (IPCC) in its previous reports (IPCC 1996, 2001). They result primarily from the existing technical limitations of computer performance and memory capacity. This means the models have limitations with regard to spatial resolution and the realisable physical content.

The most recently published IPCC report (IPCC 2007) is based on calculations that were made in the period of time between approximately 2004 and 2006 with the models that were available at that time. These models can still only present an incomplete picture of the climate system – despite major developments in comparison to their forerunner models.

Plans already exist for the further improvement of sub-modules of the next generation of global climate models, or rather, to add to them complete sub-components of the climate system. For example, there are plans to also take into account land ice in the calculation of land surface processes. The introduction of a carbon circulation module and atmospheric chemistry will be aimed for as important additions to the overall system.

A shortcoming that continues to exist in the climate models is the lack of consideration of land use change, e.g. through vegetation that is adapting to the climate and alterations in land use by people and the reciprocal effect of these on cloud, precipitation and radiation processes.

An additional improvement in the information obtained is achieved through the higher resolution of the new ECHAM5 model. For the IPCC the MPI-M had carried out scenario calculations with the former version ECHAM4, still using a horizontal resolution of approx. 2.8° (approx. 310 × 200 km); recently, simulations were carried out with ECHAM5 with a grid point distance of around 2° (approx. 220 × 140 km). In ECHAM5 the vertical resolution was also raised to 31 layers instead of the previous 20.

The global climate models are not adequate for regional climate projections, as their resolution is too low. This is at present around 200 km, which means that the deductions that can be made at the level of a German *Bundesland* are not really reliable. At a grid resolution of 200 km the model does not even include the major low mountain ranges to an adequate degree. The result is that meteorological effects induced by mountain ranges, which can decisively influence a regional climate, can barely be reproduced by the model, or not at all.

Assessment of Climate Projections and their Uncertainties

The uncertainty of the climate projections has been expressed in the recently published 4th Progress Report of the IPCC (IPCC 2007).

The consideration of results of only one model, which have been obtained with varying boundary conditions, is, in itself, not sufficient for an assessment of uncertainty; rather, it is important to include different types of models as an ensemble.

In the assessment of uncertainty on a regional scale, it also has to be considered that uncertainties from the superordinate global model are passed on to the regional model. Furthermore, it has to be borne in mind that the statistical down-scaling processes are based on observation data of restricted reference data sets.

The calculated global warming for the period until 2050, for which all models – apart from some outliers – show a similar trend, is indisputable, in spite of the fact that the range of results is still considerable. However, there is a different picture for the variables for the water balance, for which the spread of results is of much greater significance. A first comparison of the results of ECHAM4 with ECHAM5 showed a clear tendency to lower precipitation for the German territory. Dutch studies on the predictions for large-scale climate models for Central Europe conclude that the predictability for various, important climate parameters is limited, particularly regarding changes in summer precipitation or the occurrence of cold winter or warm summer months (VAN ULDEN, VAN OLDENBORGH 2006).

On the basis of these existing results, it cannot yet be said to what extent and in which regions of Germany aridity and low water levels will lead to problems. The verification of climate projections is therefore of particular importance in the application area "water". In the coming years, increased attention should therefore be paid to problem specific verifications.

Uncertain Factors and their Propagation through the Model Chain

While conjectures regarding possible impacts of the expected climate changes on the factors influencing nautical conditions (such as discharge, water depth, flow velocity, sediment transport and the distribution of these in space and time, etc.) can be described by qualitative speculation, at present at most exemplary statements on the quantitative extent of potential changes are possible. Which changes will occur when and to what extent and, in particular, in which precise region they will occur cannot be stated with the required reliability at the present time.

The objective must therefore be the systematic development of regional scenarios for the factors which directly influence conditions in and around the waterways, in order to be able to assess the consequences for navigating conditions and the suitability of a variety of adaption measures.

To find a solution to this problem, it is necessary to deal with a whole series of uncertainties. A first major source of uncertainty lies in the varying global emission scenarios for further global development (SRES 2000), of which today no-one can know which will resemble the actually future conditions most closely. These are input in the global climate models, the results of which have just been published in the current fourth report of the IPCC (IPCC 2007, see also Chapter 2).

The multitude of models used, all of which obtain more or less different results, causes further ambiguity in the boundary conditions to be assumed for the navigation sector.

Figure 4.1 in the current IPCC report (CHRISTENSEN et al. 2007) depicts the uncertainty that results from the selection of the global climate model. It shows how many of 21 global climate models project an increase in mean precipitation in Central and Northern Europe in the next 100 years. The remaining number of models complementary to these 21, predict a corresponding decrease.

The further south one looks, the fewer models exits, which predict an increase in precipitation for this region. The white zones mark the regions for which approxi-

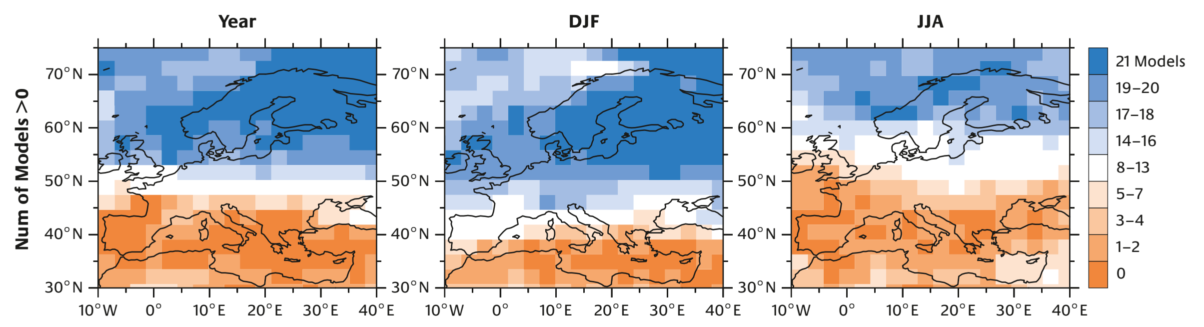


Figure 4.1: The number out of a total of 21 global climate models which, assuming the Multi-Model Data A1B scenario when comparing the years 1980–1999 and 2080–2099, project an increase in mean precipitation over Europe. (The remainder of the 21 models predict a decrease.) Left: annual mean; Centre: Winter mean for the months December, January and February; Right: Summer mean for the months June, July and August; Grid cell size approximately 2.7° × 2.7° (CHRISTENSEN et al. 2007, part of Fig. 11.5)

mately half of the global models that were used for the A1 B-scenario predict an increase in the mean precipitation. This distribution varies with season compared to the annual mean value (left): in winter (centre) and in summer (right), the white areas move northwards or southwards, respectively.

In addition, results from global climate models generally have a spatial resolution that is too low for obtaining specific information about the future regional conditions in one place. This is especially true for Germany and its river basins. Figure 4.2 illustrates the significance of the resolution. For example, it can be seen that only recently the spatial resolution permits a reasonably realistic representation of mountain ranges such as the Alps. However, the effects of small-scale structures as, for example, the Black Forest in its function as the water divide between the Rivers Rhine and Danube, still cannot be adequately represented. For this reason, regionally restricted models of higher resolution are subsequently run, nested into the global models.

Figure 4.3, however, clearly illustrates that even the resolution of such subsequently run regional models (such as REMO of the MPI-M) only recently could be increased to the point that individual river catchments can be assigned with adequate precision.

If one imagines, for example, the River Rhine at Basel, it is immediately clear that the precipitation data in the low resolution is not suitable for deducing regionally precise statements about the volumes of water precipitating on the various local river basins that rise in the Alps.

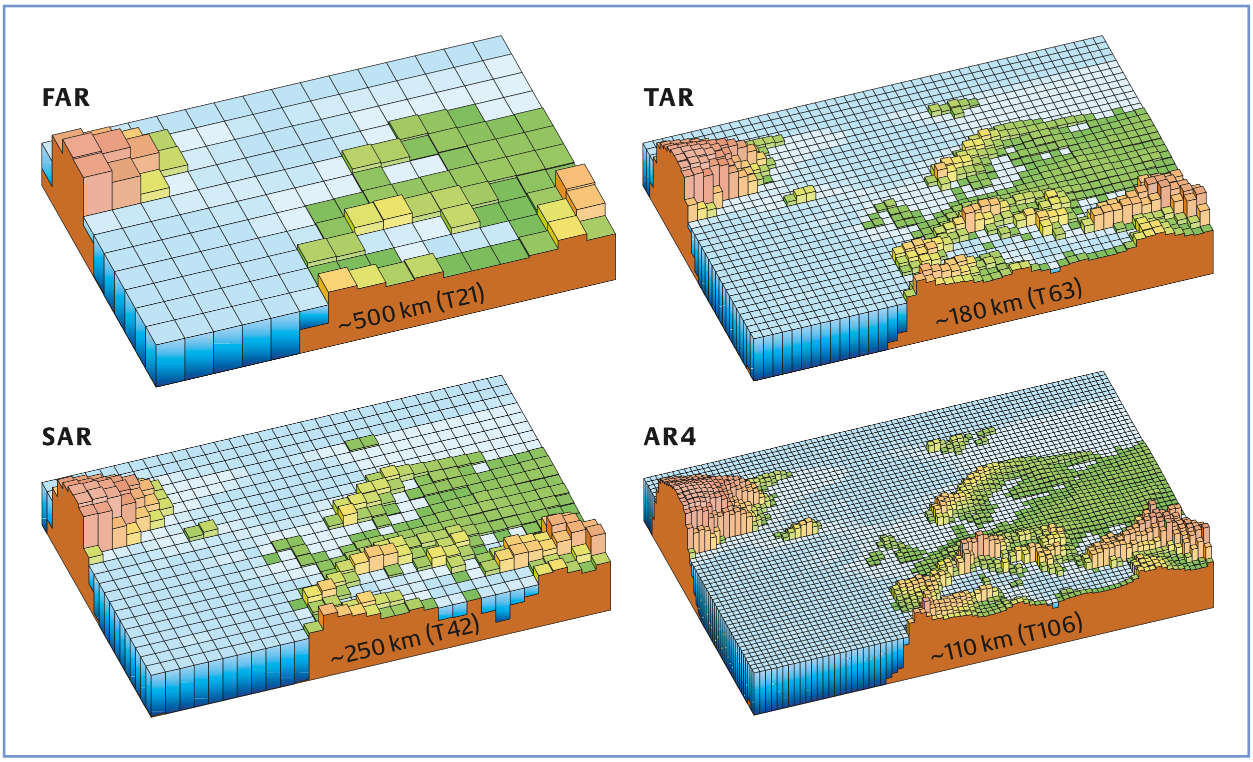


Figure 4.2: Improvement of the spatial resolution in the successive generations of climate models that was possible at the time of the respective IPCC reports; the example shows Europe in FAR 1990, SAR 1996, TAR 2001 and AR4 2007). This reveals how geographical details, such as the Alps, could only be realistically depicted in the most recent generation of models (Somerville et al. 2007, Fig. 1.4).

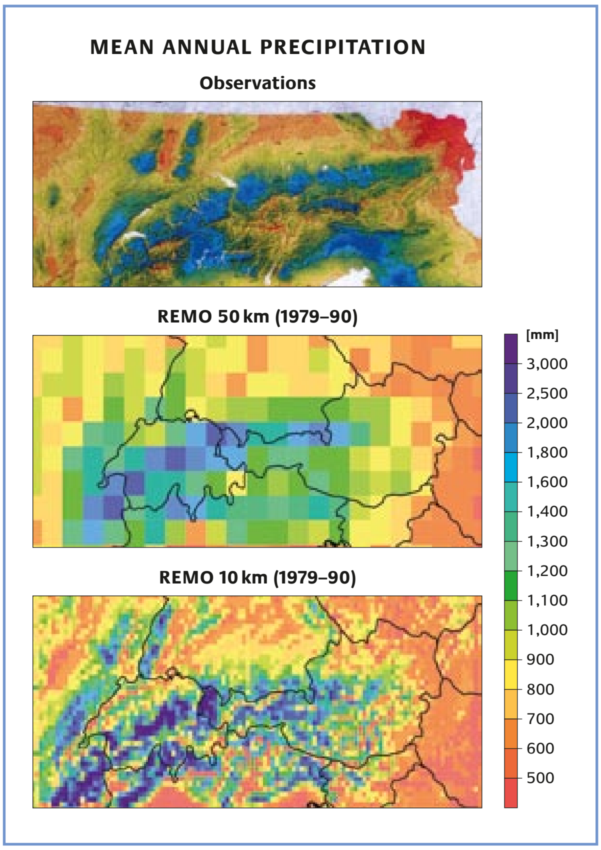


Figure 4.3: Different spatial resolutions of the versions of the regional climate model REMO **adapted to the available computing capacity;** the example shows the mean annual precipitation across the Alpine region (Max-Planck Institute for Meteorology).

The regional climate projections drive water balance models of the river basins. The results of these form the basis for morphodynamic models of bed-load and suspended matter budget. Their results in turn are incorporated into water quality models and also ecological models for vegetation and fauna. This hierarchical connection of models is termed as “model chain” (see Figure 4.4).

Additional assumptions must be made at every level of this model chain, which in turn can be termed as scenarios. Furthermore, different model approaches and data of varying quality are used, which in one way or another contain inaccuracies and/or uncertainties with regard to their absolute values and their differentiation in time and space.

Moreover, different models in general differ with regard to process representation and the options of interaction. Figures 4.5 and 4.6 show how, in this way, inaccuracies or statistical uncertainties, respectively, propagate and spread out while passing through the model chain, that is, the range of possible results increases along the model chain.

The statistical statements about frequencies, mean values and extreme values (e.g. related to low flow, floods or flow regime) that finally are deduced from the model results reflect these uncertainties.

It becomes clear that it is scarcely possible to make quantitative statements about the uncertainties at the subsequent link of the impact or model chain, if the information on the uncertainties is not presented at the preceding link of the chain. It is this essential to choose a systematic approach to deal with issues of the consequences of climate change for the navigation/waterway traffic system.

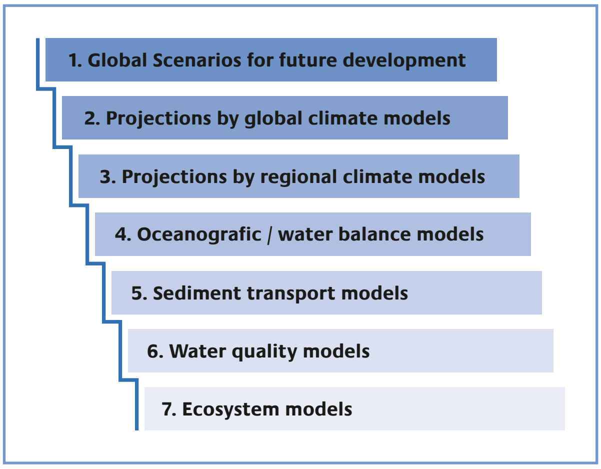


Figure 4.4: Hierarchical succession of the models (model chain)

Uncertainty Caused by Lack of Comparability of Results from Different Sources

The problem of comparability of different studies is closely linked to the model chain. Due to the numerous combination possibilities, every research project investigates only selected paths through the model chain, and many uncertainties are not systematically identified.

A single result that has been obtained by running on e path of the model chain may strictly speaking be compared only with another result in which only one aspect of the many assumptions that have been made is varied, as otherwise the changes in different target variables can no longer be unambiguously related to the causes. For a specific model run it is necessary that it is always viewed in the context of all assumptions at every stage of the model chain.

Because of the large number of combinations, however, the comparability of two analyses carried out by different groups is frequently not possible, as each group has concentrated on its own questions. There is a great deal of segmentation and a corresponding "bouquet" of scenarios and models. The direct comparability of resulting statements is therefore frequently not guaranteed.

The fact that computer capacity and model complexity as well as data and scenarios are undergoing constant development also means that the comparability of the results cannot be unconditionally guaranteed, even when these are based on the same scenarios and model types, as they may originate from different development generations.

The long-standing involvement of the BfG with the subject of climate change has shown that a systematic synthesis of the numerous research results from different institutions and working groups does not exist in Germany.

Admittedly, there are numerous individual studies, and some preliminary work has been carried out by the German *Bundesländer* (e.g. in projects such as: KLIWA, KLARA, BAYFORKLIM, INKLIM) as well as research projects funded by the BMBF, for example, GLOWA ELBE, Elbe-DSS, GLOWA DANUBE or on the climatology side, through the program DEKLIM. For the coastal area, the project "Climate Change and Preventive Risk and Coastal Protection Management on the German North Sea Coast (KRIM)" deserves mentioning. These and similar projects are also sources for current assessments of the impacts of

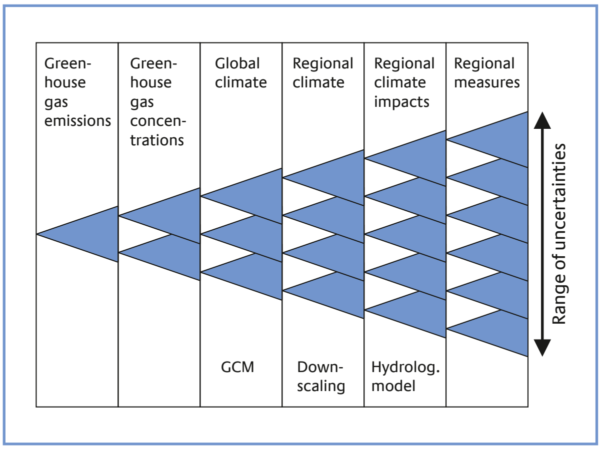


Figure 4.5: Decreasing statistical significance that arises from the transfer of global climate scenarios to regional climate impacts and measures (VINER 2002)

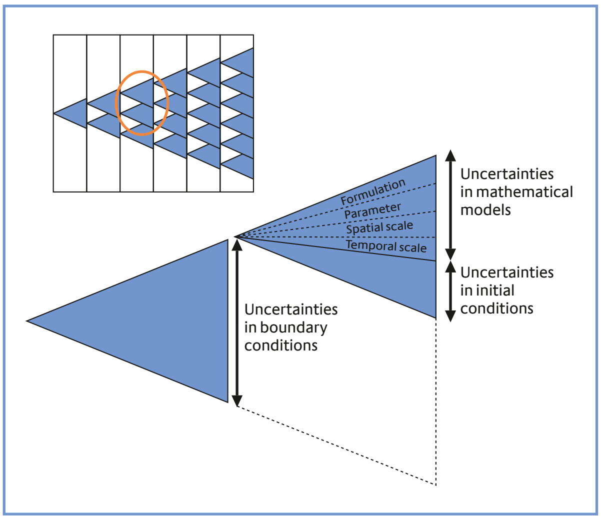


Figure 4.6: Reasons for uncertainties in the models of regional climate impacts (VINER 2002)

climate change. Furthermore, international studies and their assumptions (e.g. KNMI 2006) should also be noted.

Because of the many and varied combination possibilities of model components in connection with the ongoing development of results from the previous modules of the impact or model chain, that were already explained above, the results of climate impact research that have been achieved so far cannot easily be compared, especially when it is a matter of transboundary river basins. The lack of coordination between different working groups is an additional factor (see Chapter 2).

Uncertainty due to non-regionalised Scenarios

A distinction must be made between the protection of the climate from human influence, i.e. the problem issues that the IPCC is concerned with, and the estimation of the consequences of global climate change, i.e. the protection of people from impacts of climate change.

Whereas in the field of climate protection, climate change as a result of the man-made increase in the concentration of greenhouse gas emissions in the atmosphere is regarded in relation to a reference state merely by means of *global* scenarios (SRES 2000), in the second case, the *regional* influence of the socio-economic development must be more closely considered alongside the natural changes in climate.

In Germany, aspects such as population development, politics (cooperative behaviour of society) as well as the changes in land use may also be influential and, in the next one hundred years, could create new boundary conditions for federal waterways, quite independently of climate change.

A further task will therefore be to determine agreed local scenarios for the change of the variables mentioned in the German river basins, analogous to the global scenarios, as described in the IPCC Special Report Emissions Scenarios (SRES 2000), not only on the basis of the emissions, but also as a result of natural climate change and possible social developments.

Conclusion

Global projections are primarily concerned merely with developments on a global scale, in particular with the deviations for continental and oceanic regions of the possible future conditions in contrast to the present status, which have been determined over long periods. In view of the extension of the catchment areas of the federal waterways and German coastal regions, the results are only available in comparatively low resolution. Regional influences, e.g. on the German Bight, the Wadden Sea or on the coastline of Sylt, require data with a much higher resolution, and until now have been examined only very sporadically and not systematically. The same is true for inland areas. Accordingly, the reliability of results that have been achieved to date about the consequences of climate change for single parameters or regions varies considerably.

The encouraging message is, however, that the model results are becoming increasingly reliable, thanks to constant further development of the simulation models and in particular through the continued integration of further processes and continual improvements in the spatial and time-based resolution of simulations and measured data.

This is facilitated by the constant increase in calculating capacity and ever larger volumes of data material available for the parameterization, calibration and validation of simulation models. As already mentioned in Chapter 2, the current Version 5 of the global climate model ECHAM of the MPI-M can, for example, reproduce the measured climate history significiantly better than previous versions.

With the results of the most recent (fourth) IPCC report, worldwide coordinated up-to-date results are available, for starting the model chain (stages 2 and 3 in Figure 4.4). On this basis, coordinated regionalisation studies should now be started for the current and possible future status of the navigable waterbodies, taking account of the climate projections.

“Now the regional consequences for navigable waters must be studied on the basis of the most recent IPCC Climate Projections.”

To do so, the following methodical steps must be taken and gaps in knowledge filled:

- Compilation of suitable, special reference data sets (grid data) for the verification of the climate models in the application field of navigation and waterbodies
- Temporal and spatial expansion of the historic climate data base for the requirements in the application field of water through post-integration of historic climatic records that are still held in paper archives as well as acquisition and inclusion of climate data from the riparian states of Germany.
- Analysis of the observed climate change by means of a statistical evaluation of station-based time series and observation based grid data for the cross-border catchment areas of the Rivers Elbe, Oder, Rhine and Upper Danube as well as for the marine area covering the North Sea, Baltic Sea and the Northeast Atlantic
- Checking, verification and determination of the error range for the applied regional and global climate simulations by means of a comparison of model results with reference data in the control period, i.e. reliable analyses on the basis of measured or observed climate data
- Analysis and presentation of the range of uncertainty of the climate projections and the impact analyses that have been deduced from the latter by forming a practicable ensemble of the results of various climate models
- Integration of the method of the objective weather types classification of the National Meteorological Service of Germany (DWD) as well as methods for the calculation of evaporation and soil moisture from climate projection data
- Provision of climate scenarios for specific contents or regions, for the necessary studies of the possible effects in waterbodies in sea, coastal or inland areas, alongside with a specialised advisory service for users
- Identifying possible changes in oceanographic and hydrographic conditions (tide parameters, wave statistics) for different climate change projections and modelling of long-term changes
- Identifying possible changes in discharge characteristics and water level distribution in the individual inland waterways for different climate change projections, and modelling of long-term changes in hydrological conditions
- Additional validation of water level changes, with consideration of anthropogenic and tectonic influences
- Analysis of the implementation of meteorological oceanographic/hydrological climate projections and impact assessment with regard to the sediment budget and the bed development for the provision of required widths and depths of navigation channels
- Analysis of the development of the water hygiene situation and possible changes in pollutant patterns in sediments
- Modelling of the mass balances and algae development in the event of changes of temperature and flow regimes for analysis of the development of important ecological indicators (temperature layers, eutrophication and oxygen balance)
- Estimation of changes in vegetation from the point of view of the future maintenance and aspects of foreland protection
- Examination and assessment of possible changes in water characteristics with regard to future use of hydraulic engineering materials

From existing experiences of climate and climate impact research and the requirements for the control and management of a complex system, the urgent need for a systematically planned research programme is evident in order to arrive at comparable and thus reliable results that take account of all issues and interactions.

Only with these new results from global and regional climate models, which better reflect regional circumstances, in conjunction with systematic studies, better and more reliable analyses can be carried out for the navigable waterbodies. On this basis, it will be possible to make predictions regarding changes in oceanographic conditions, water availability in the waterways, sediment budget, the water quality and ecology, which, in turn, will form the basis for the development of solid and reliable adaptation options.

Fluctuations in water yield and in discharge affect navigability in stretches that are difficult to navigate (Photo: BAW).

5 Outlook

The climate change is ongoing. Based on the currently available global climate projections, far-reaching consequences for navigation and waterways may be expected. Parallel to the climate protection initiatives, the BMVBS is taking up the challenge of ensuring the efficiency of navigation and waterways for the future, taking account of potential climate changes, and has already initiated respective fundamental actions.

With its scientific and technical authorities – i.e. DWD, BfG, BSH and BAW for inland waters, estuaries and coastal waters – the BMVBS has excellent expertise in the fields relevant to this context, namely meteorology, oceanography, hydrology, hydrography, hydraulics, morphology, quality of waters, ecology and hydraulic engineering; furthermore these competencies are part of a national and international scientific network. The know-how available from the network is considered, and applied to attain further knowledge. Collaboration with other disciplines, in particular with the German Federal Ministry of Education and Research (BMBF) and the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), should enable synergies.

This review is a first, fundamental step in this direction. It shows that fundamental knowledge gaps still need to be closed in order to specifically identify potential consequences of climate change on navigation and waterways and in order to develop appropriate adaptation strategies.

For this purpose, a research programme was designed together with the BMVBS's technical and scientific authorities considering waterways and navigational interests. Within the next years, this is intended to reduce the existing knowledge gaps and uncertainties so that it will be possible to make reliable statements on climate impacts on navigation and waterways, and to develop adaptation options and strategies. The research programme encompasses the entire model chain – as far as methods and content are concerned – and its system has been planned accordingly:

- Defining scenarios of the future global development
- Considering up-to-date results of global climate models
- Determining regional climate projections
- Analysing available water yield in inland areas / analysing oceanographic, hydrographic and hydrological changes at coasts and seas
- Analysing bed load and suspended sediment transport and budgets
- Analysing water quality
- Analysing ecosystems
- Analysing hydraulic-engineering/technical adaptation options

The methodic approach serves toward specific enlargement of the existing knowledge base and Systematic application of the results from climate research. The questions and research deficits outlined in the Conclusion of Chapter 4 should be treated within the framework of the following structure:

- **Meteorological-hydrological Climate Projections:**
  - Validation and evaluation climate projections and provision of climate scenarios for navigation and waterways

- **Sea Navigation and Sea Waterways:**
  - Identification of changes in the sea and in the hydrological system of coast and sea as well as adaptation options
  - Identification of changes and degree to which the state of the waterbody is concerned (morphologically, qualitatively, ecologically) as well as adaptation options

Inland Navigation and Inland Waterways:

- Identification of changes of the hydrological system and adaptation options
- Identification of changes and degree to which the state of the waterbody is concerned (morphologically, qualitatively, ecologically) as well as adaptation options

Two sub-projects have already been launched as part of the programme:

ARGO: Regarding the changes of the sea and their consequences on navigation, the ARCO project (Array for Real-time Geostrophic Oceanography) has been initiated which helps to record oceanographic data in the North Atlantic by means of surface floats.

KLIWAS: Given the longer periods of extreme water-levels in recent years – which are detrimental for inland navigation and transport volumes – the sub-project KLIWAS (Consequences of climate change for navigable waterways and options for the economy and inland navigation) was launched in June 2007. This project will be run jointly by the German Federal Institute of Hydrology (BfG, project coordination), the Max Planck Institute for Meteorology (MPI-M), the European Institute for Energy Research (EIfER), and the Development Centre for Ship Technology and Transport Systems (DST) in two phases over 4 years. Focal points are the preparation of climate and discharge projections for the Rhine basin until 2100, vulnerability analyses (status quo) of inland navigation and transport systems, including the loading industry, as well as the analysis and evaluation of adaptation options.

The results of the research programme will enable the BMVBS to fulfil its responsibility as regards climate impact on navigation and waterways and to take adequate decisions for the future on a solid basis. This should help prevent wrong adaptation strategies and misinvestments having far-reaching consequences. In the field of navigation and waterways, investments must last 30 to 50 years or even more. Therefore, the bases for such decisions should be established with care already now – also in the sense of sustainability.

Additionally, the research programme will provide crucial contributions – within the framework of developing and implementing the German Adaptation Strategy to Climate Change – in the following areas in particular: improvement of climate projections, climate change consequences on coastal and inland waters and use/choice of model chains (ensembles). These findings will also be an important impetus for the High-Tech Strategy on Climate Protection (BMBF 2007).

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National Meteorological Service of Germany (DWD)

The DWD (Deutscher Wetterdienst) is the national meteorological service of Germany responsible for providing services for the protection of life and property in the form of weather and climate information. One of its core activities, besides weather forecasting, is climate monitoring as well as the meteorological safeguarding of aviation and sea navigation and the issue of warnings of dangerous meteorological events. It also carries out important services for the Federal Republic and the *Bundesländer* and fulfils international obligations on behalf of the Federal Republic of Germany. As the reference for meteorology in Germany, it is the first contact partner for the entire public in all matters relating to weather and climate.

The DWD represents Germany in the World Meteorological Organization (WMO), a specialized agency of the United Nations. The president of the DWD is a member of the elected Executive Council of this international organization; employees of the DWD work in various important bodies of the WMO on a European and global context. Through its membership, the DWD is furthermore closely linked with the European institutions, for example, the European Organisation for the Exploitation of Meteorological Satellites, (EUMETSAT) in Darmstadt and the European Centre for Medium-Range Weather Forecasts (ECMWF). In addition, it is actively engaged in the network of the European weather services (EUMETNET). The international commitment of the DWD is an important precondition for the analysis of global climate change.

With its observation systems and analyses, the DWD provides a reference data pool for the assessment of climate change. Its capabilities include, in particular, the on-going recording, analysis and assessment of the spatial and temporal distribution of the climate. In this process, it relies on the comprehensive observation data from its meteorological measurement networks and observatories as well as on numeric simulation of the physical processes of the atmosphere. The DWD measurement network in Germany includes 175 meteorological watch offices and more than 2,000 additional automatic weather and precipitation stations. Vertical soundings of the atmosphere at 9 upper-air stations complete the service. For the comprehensive observation of precipitation, the DWD operates a radar measurement network. Finally, the influence of weather patterns on plant growth is monitored in Germany with the help of almost 1,400 phenological observers. On the ocean, weather observations are recorded on more than 2,000 merchant ships and research ships. Further data is obtained from buoys, aircraft and weather satellites. Four automated radiosonde systems are operated on ships under the supervision of DWD experts. In work that is shared internationally, the DWD makes a decisive contribution to the acquisition of maritime data on a global basis.

The DWD’s Global Precipitation Climatology Centre (GPCC) provides global precipitation analyses for climate monitoring and climate research. The centre is an international contribution by Germany to the World Climate Research Programme (WCRP) and to the Global Climate Observing System (GCOS). Furthermore, the DWD’s Global Collecting Centre for Marine Climatological Data supports global climate and oceanic programmes. As remote sensing methods are also gaining increasing importance in climatology, the DWD has in addition taken over central responsibility for the EUMETSAT Satellite Application Facility on Climate Monitoring (CM-SAF).

With regard to climate modelling, the DWD also has major competencies: its regional weather forecasting model is the basis for the regional climate model, CLM. Besides weather forecasting and climate monitoring, climate advisory services in the special application fields of environmental, agricultural, hydrological, medical, biological and maritime meteorology form are further main foci.

The DWD sees one of its most important tasks in the provision of advisory services concerning climate change on a political level and for the German Federal and *Länder* authorities and the business world.

German Maritime and Hydrographic Agency (BSH)

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

The BSH (Bundesamt für Seeschifffahrt und Hydrographie) is responsible for the operational water level, storm surge and ice forecasts for the North and Baltic Seas and is running, for this purpose, an operational forecast model as well as specialised model developments. These models also allow studying of specific issues of forecasted climate changes.

Since 2004, the BSH has been involved in the international ARGO project ("Array for Real-time Geostrophic Oceanography") in order to document – and to make available in real-time – temperature and salinity changes in the upper 2,000 m of the North Atlantic by means of free-drifting profiling floats. The BSH uses these data for efficient monitoring of the state and climate in the North Atlantic. Due to positive evaluation of the ARGO programme's functionality, ARGO will be hosted operationally at the BSH as of 2008. Currently the Federal Republic of Germany is participating in the international ARGO programme with 165 active floats.

Based on its observational and model data, the BSH has a comprehensive oceanographic data set, especially for the North and Baltic Sea regions and for the North Atlantic. Long-term observations are of special interest as they allow deduction and evaluation of climate changes:

- Data from the Marine Environmental Monitoring Network in the North Sea and Baltic Sea (MARNET)
- Marine physical data from ship and coast stations, platforms and groynes
- The comprehensive data sets from the annual comprehensive surveys of the North Sea (biology, chemistry, physics)
- Data from monitoring the North Atlantic with free-drifting profiling floats within the framework of the ARGO project (measuring temperature and salinity in the upper 2,000 m of the ocean, velocity fields)
- Temperature monitoring transects across the Atlantic in depths of up to 1,000 m from merchant ships along specified routes within the framework of the Ship-Of-Opportunity-Programme (SOOP)
- Remote sensing data from projects such as Coast-Watch or Marcoast (surface temperatures, chlorophyll, turbidity, water transparency, gelbstoff etc.), and data from the operational NOAA satellites
- The operational model system of North and Baltic Seas and its long-term data sets
- Long-term gauging time-series
- Long-term ice data time-series
- Historical ice data

German Federal Institute of Hydrology (BfG)

As a research institute, the BfG (Bundesanstalt für Gewässerkunde) is mainly responsible for the German federal waterways. Our task is to contribute to the efficiency and environmental compatibility of the traffic system.

We study

- water levels and discharges, geometry and the morphological state of the waterways. The studies and measurements also cover the floodplain, groundwater near the river, the developments in the catchment area, as well as the consequences of global climate change. In connection with appropriate simulation, prediction and forecast models we develop, on this basis, reliable statements on the impact of hydraulic engineering and water management measures and on the discharge development within the catchment area;
- the occurrence of contamination in the waterbodies and its effects on the aquatic ecosystems and on the use of the waterbodies. We apply our expertise in the disciplines of chemistry, biochemistry, ecotoxicology and radiology for navigation purposes when it comes to assessing the water quality of inland and coastal waters and in particular their solid matters and sediments. Data from a nation-wide measurement network and project-related surveys provide the basis for impact scenarios, forecasts and information for the public;
- the ecosystems in and along the German federal waterways, and develop concepts and measures for environmentally compatible water resources management. In this context we not only study the origin and extent of ecological change, but we also point out ways to minimise or compensate potential negative consequences of human actions and use. This requires answering complex ecological issues and an integrated and effect-oriented system analysis. In this way we develop environmental impact studies, landscape conservation plans or environmental concepts for waterways and their vicinity.

When Dealing with the Climate Change Impact Assessment:

- We "translate" existing climate projections into regionalised discharge forecasts for inland waterways. For coastal and estuary zones we calculate the most important oceanographic parameters. For example we assess the long-term fairway depth developments and the potential transport volumes. For this purpose we apply, amongst others, state-of-the-art precipitation-runoff models and morphologic-hydrologic models.
- Starting from these boundary conditions related to possible water quantities and in combination with modelling pollutant/material inputs we evaluate the ecotoxicological risks of climate change. This also includes the technical assessment of possible changes of the habitat "water" (oxygen content, algae, etc.), sediment quality as well as stability and environmental behaviour of hydraulic engineering materials using models.
- Process-based and rule-based approaches continue to be applied when the – partially feared – migration of new plant and animal species regarding their hazard potential for the population and regarding the waterways maintenance and operation have to be represented.

With these instruments and our long-term know-how we compile vulnerability analyses for inland and sea navigation and their transport systems, for the quality of our waterbodies, and for the social value of the waterways as an ecosystem.

German Federal Waterways Engineering and Research Institute (BAW)

The BAW (Bundesanstalt für Wasserbau) is the central – scientifically independent – institute of the German Federal Waterways and Shipping Administration for scientific/technical test and research work and for providing practice-oriented consultancy in the fields of structural engineering, geotechnical engineering, hydraulic engineering and information technology. It has more than 100 years experience in the field of waterways engineering, and develops integrated solutions. For a long time already, a focus of its work has been the development of waterways engineering measures which keep interventions minimised and hydrodynamics and navigational dynamics optimised.

The BAW works out fundamental contributions towards increasing the nautically usable water depths of inland waterways – which have been implemented gradually in past years taking into consideration the development of discharge and of the bed-load transport situation. For the entire range of issues (hydraulics, morphology, ship movement, bottleneck analysis, trafficability analysis, wave models for determining the bank load) the BAW applies hydro-numerical models of various dimensionalities (ID, 2D, 3D) developed for many waterways stretches.

The BAW studies all river engineering measures planned by the WSV regarding their effects on flood discharge and flood level, and optimises them if necessary. For several decades, the BAW has been intensively involved in the planning, scientific support and success control of bed-load management of the Rivers Rhine and Elbe. In this context, bed-load management benefits particularly from the results of the morphodynamic scenario calculations conducted in the BAW.

For several decades, the BAW has been working on and providing expert opinions on WSV measures at the North and Baltic Sea waterways (channel development and maintenance, hydraulic engineering measures for the improvement of maintenance and for stabilising channels) and on projects of third parties (e.g. River Ems storm surge barrier or the JadeWeserPort). For this purpose, the BAW possesses high-resolution three-dimensional models for all estuaries, including the German Bight and the Baltic Sea. The models describe the tidal dynamics, storm surges, waves, transport of marine salt and sediments and include the dynamics of soil topography too.

Due to studies undertaken on extensive development projects at the tidal Rivers Elbe, Weser and Ems in the last years, the BAW has built up very comprehensive knowledge on the alterable and vulnerable character of the conditions in sea waterways. This knowledge is based on theoretical bases, on mathematical modelling, on analysis procedures developed specifically for coastal dynamics, and above all on experience.

With its practical knowledge and existing methodological bases the BAW has the necessary instruments for developing hydraulic engineering and operational measures on the German federal waterways which are appropriate for the climate effects on navigation and waterways in inland and coastal areas and for counteracting the negative effects of climate change.

List of abbreviations

AR4 Fourth Assessment Report of the Inter-Governmental Panel On Climate Change – IPCC

ARGO Array for Real-time Geostrophic Oceanography, http://www.german-argo.de/

AWI Alfred Wegener Institute for Polar and Marine Research *(Alfred-Wegener-Institut für Polar- und Meeresforschung)*

BAW German Federal Waterways Engineering and Research Institute *(Bundesanstalt für Wasserbau)*

BAYFORKLIM Bavarian climate research program *(Bayerischer Klimaforschungsverbund)*

BfG German Federal Institute of Hydrology *(Bundesanstalt für Gewässerkunde)*

BMBF German Federal Ministry of Education and Research *(Bundesministerium für Bildung und Forschung)*

BMU German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety *(Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)*

BMVBS German Federal Ministry of Transport, Building and Urban Affairs *(Bundesministerium für Verkehr, Bau und Stadtentwicklung)*

BSH German Maritime and Hydrographic Agency *(Bundesamt für Seeschifffahrt und Hydrographie)*

CEC Climate & Environment Consulting Potsdam GmbH (located at the PIK)

CHR International Commission for the Hydrology of the Rhine Basin

CLM Climate Local Model

COSMO Consortium for Small-scale Modelling

COSMO-DE DWD's high-resolution regional weather forecast model for Germany

COSMO-EU DWD's high-resolution regional weather forecast model for Europe

DAS German Adaptation Strategy to Climate Change of the German Federal Government under the leadership of the BMU *(Deutsche Anpassungsstrategie an den Klimawandel)*

DEKLIM German Climate Research Program of the BMBF

DFG German Research Foundation *(Deutsche Forschungsgemeinschaft)*

DKK German Climate Consortium *(Deutsches Klima-Konsortium)*

DKRZ German Climate Computing Centre *(Deutsches Klimarechenzentrum)*

DWD National Meteorological Service of Germany *(Deutscher Wetterdienst)*

EC European Community

ECHAM Global climate model of the MPI-M

ECMWF European Centre for Medium-Range Weather Forecasts

EIA-Directive on Environmental Impact Assessment

Elbe-DSS Elbe Decision Support System. Research project funded by the BMBF

ERA Environmental Risk Assessment

EU European Union

EUMETNET Network of European National Meteorological Services

EUMETSAT European Organisation for the Exploitation of Meteorological Satellites

EU-WFD EU Water Framework Directive

FFH-Directive "Habitats Directive", Flora-Fauna-Habitats Directive

GCC Global Collecting Centre for Marine Climatological Data

GCM General Circulation Model

GCOS Global Climate Observing System

GEOSS Global Earth Observation System of Systems

GLOWA DANUBE Global Change at River Danube. Project within the BMBF promotion focus "Global Change and the Hydrological Cycle" *(Globaler Wandel des Wasserkreislaufs)*

GLOWA ELBE Global Change in the Elbe Region. Project within the BMBF promotion focus "Global Change and the Hydrological Cycle" *(Globaler Wandel des Wasserkreislaufs)*

GPCC Global Precipitation Climatology Centre

HABAB-WSV Directive for the Handling of Dredged Material Management in Federal Inland Waterways *(Handlungsanweisung für den Umgang mit Baggergut im Binnenland der WSV)*

HABAK-WSV Directive for the Handling of Dredged Material Management in Federal Coastal Waterways *(Handlungsanweisung für den Umgang mit Baggergut im Küstenbereich)*

HTS High-Tech Strategy on Climate Protection *(Hightech-Strategie zum Klimaschutz)* of the German Federal Government, under the overall responsibility of the BMBF, therefore also promotes research with the purpose of adapting to the effects of climate change

ICPR International Commission for the Protection of the Rhine

IFM-GEOMAR Institute of Marine Sciences, Kiel *(Institut für Meereswissenschaften)*

INKLIM Integrated Climate Protection Programme "INKLIM 2012" *(Integriertes Klimaschutzprogramm)*. Research project of the climate protection program of Hesse/Germany

IPCC Intergovernmental Panel on Climate Change

KLARA "Klimawandel - Auswirkungen, Risiken, Anpassung" (KLARA: Climate Change: impacts, risks, adaptation), integrated project of the Ministry of Environment and Transport of Baden-Wuerttemberg (Germany)

klimazwei BMBF's funding activity "Research for Climate Protection and Protection from Climate Impacts". http://klimazwei.de

KLIWA Climate change and consequences for water management *(Klimaveränderung und Konsequenzen für die Wasserwirtschaft)*. Project of the German *Länder* Bavaria and Baden-Württemberg with the DWD as a collaborating partner.

KLIWAS Consequences of climate change for navigable waterways and options for the economy and inland navigation *(Klimawandel – Auswirkungen auf die Wasserstraßen und Handlungsoptionen für Wirtschaft und Binnenschifffahrt)*, R&D project of BMVBS http://www.kliwas.de

KomPass Competence Centre on Global Warming and Adaptation, at the German Federal Environment Agency *(Kompetenzzentrum Klimafolgen und Anpassung)* http://osiris.uba.de/gisudienste/Kompass/

KRIM Climate Change and Preventive Risk and Coastal Protection Management on the German North Sea Coast *(Klimawandel und präventives Risiko- und Küstenschutzmanagement an der deutschen Nordseeküste)*. http://www.krim.uni-bremen.de/. Research project sponsored by the BMBF.

KWZ Low Water Surcharge *(Kleinwasserzuschlag)*

LARSIM Large Area Simulation Model

MPI-M Max Planck Institute for Meteorology *(Max-Planck-Institut für Meteorologie)*

PIK Potsdam Institute for Climate Impact Research *(Potsdam-Institut für Klimafolgenforschung e.V.)*

REMO Regional climate model of the MPI-M

SRES Special Report on Emissions Scenarios

TEU Twenty-Foot Equivalent Unit (= container unit)

tkm ton-kilometre (unit for freight transport)

UBA (FEA) German Federal Environment Agency *(Umweltbundesamt)*

UNESCO United Nations Educational, Scientific and Cultural Organization

WBGU German Advisory Council on Global Change *(Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen)*

WCRP World Climate Research Program

WMO World Meteorological Organization

WSV German Federal Waterways and Shipping Administration *(Wasser- und Schifffahrtsverwaltung des Bundes)*

WWW World Weather Watch

ZMAW Centre for Marine and Atmospheric Sciences *(Zentrum für Marine und Atmosphärische Wissenschaften)*

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