Preface

This publication on „Climatic Change and Water Resources in the Middle East and North Africa“ is dedicated to high-priority topics related to the impact of climate change on water resources in a water scarce region. Many aspects of climate change and its impact on the global hydrological cycle have been investigated, presented and published. However, the quantification of this influence is still very uncertain due to lack of understanding the complex system and the detailed interactions. Hence, process-oriented interdisciplinary research is necessary to overcome this problem.

The German-Arab Scientific Forum for Environmental Studies organizes every second year a scientific forum as a platform for the exchange of information and presentation of research findings. As a result of this scientific forum, many scientists have taken the opportunity to contribute to this book giving an overview about their research regarding this topic. Naturally this book is divided into three chapters:

- Global climate change- sources and impacts on the water cycle.
- Impact of climate change on water resources.
- Water resources and water management.

Global climate change due to greenhouse gases in the atmosphere is influencing the world water cycle resulting in changes in precipitation patterns, temporally and regionally. In the first chapter several authors present their research results dealing with this relationship.

First of all an overview about the dynamics of the climate systems in scope of the earth history is given and the influence of the temperature rise on the atmospheric circulation and thus on the global water cycle is discussed. However, for the prediction of the future development, observations of the regional precipitation trends are important. Hence, the regional climate trends in the Middle East and North Africa have been investigated either by applying climate models or statistical analysis.

The effects of climate changes on water resources in chapter two are also related to regions of the Middle East and North Africa. This chapter begins with a focus on climate changes and the resulting discharge conditions in the Arabian Peninsula in Quaternary, complimented by the paleo-climate for Holocen and Neolithicum. The impact of climate change on water resources in the region is discussed and a short term hydrologic drought in Lebanon is proposed as a superposition of climate and anthropogenic effects. It is assumed that changes in precipitation average and events will cause a higher number of floods in the future and require new management options for sustainable ground water exploitation.
The influence of the climate change on the world water cycle is distressed by increasing water demands due to population growth and urbanization. Thus, integrated water resources management has become an eminent steering mechanism in the optimization of solutions to this problem.

Chapter three of this book comprises 14 contributions related to this topic. New concepts in water management, in technologies of water exploitation or details of water resources management including water protection are presented and discussed. Other contributions focus on linked eco-hydrological processes in Lake Kinnereth, ecological effects in soils, the relevance of groundwater during droughts, groundwater degradation by sea water intrusion in the coast of greater Beirut, Lebanon, the desiccation of the Dead Sea and the interaction between population dynamics and water supply systems.

All topics of this book are complimentary and contribute to a comprehensive understanding of the interactions between global climate change, world water cycle and water resources. New and innovative water management concepts are necessary to overcome some of the problems that might arise within this development.

All over, a valuable and meaningful interdisciplinary mixture of topics has been combined in this book and is of great interest to many scientists.

In this context, I wish this publication a friendly and successful acceptance in the scientific world.

Aachen March 2008

Prof. Dr. Rafig Azzam
Changes to the earth's climate have a direct effect on the global hydrological cycle and hence on water. The rise of temperatures may exacerbate existing water shortages, impair water quality or enhance the frequency and intensity of floods and droughts. In particular countries in the transition zone from wet to dry arid climatic conditions have experienced water-related problems, such as uneven distribution of water resources and year-to-year variability. These changes in water resources and water-related extreme events are likely to affect social and economic developments.

Water resources are one of the highest-priority issues with respect to climate change impacts and adaptation in the Middle East and North Africa. While many aspects of climate variations and their impact on water resources have been presented and published, the information is still greatly dispersed and lacks a general overview. In order to support exchange on this issues the German-Arab Scientific Forum for Environmental Studies organised in 2006 a conference on this topic. The resulting report provides a broad overview of this important issue. It highlights the current knowledge about climate variations and change, discusses the impact on water resources systems, characterizes its predictability, and provides examples of its use in water resources management, planning, and design.

This book „Climatic Changes and Water Resources in the Middle East and in North Africa“ is the first to comprehensively present and discuss the results of scientific research on Impact of climate change on water resources in this regions from a variety of disciplines. The subject is described and discussed in three main chapters and different case studies. The three main chapters are (1) Climatic changes – their sources and effects on the water cycle, (2) Impact of climate change on water resources, (3) Water resources and water management.

These chapters are further split up into 26 sections. A total of 64 individuals from Germany, Israel, Italy, Jordan, Lebanon, Morocco, Palestine, Syria, Tunisia, and UK have made contributions to this book.

The editors would like to thank the authors and reviewers for their contributions and cooperation in terms of the successful completion of this book. Many thanks go to Prof. Dr. R. Azzam from the Department of Engineering Geology and Hydrogeology, RWTH-Aachen University and Dr. A. Margane from Federal Institute for Geosciences and Natural Resources (BGR), Germany for their support. We would further like to thank Prof. Dr. Broder J. Merkel from the Geology Department, University of Freiberg, Germany, Prof. Dr. Christian-D. Schönwiese from Institute for Atmosphere and Environment, J.W. Goethe University, Frankfurt, Germany, and Dr. A. Shaban from National Council for Scientific Research, Remote Sensing Center, Beirut, Lebanon.
We are especially grateful to Mrs. A. Oelschlager from Springer, who made this publication possible. We would also like to extend our gratitude to Mr. H.-H. Dülf er from the Institute for Atmospheric and Environmental Studies, Goethe University Frankfurt am Main.

Frankfurt am Main, Karlsruhe, March 2008

Prof. Dr. Fathi Zereini
Prof. Dr. Heinz Hötzl
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1 Global Climate Changes – Sources and Impacts on the Water Cycle

The Earth's climate has changed many times during the planet's history, with events ranging from ice ages to long periods of warmth. During the last centuries natural factors such as volcanic eruptions or the amount of energy released from the sun have affected the Earth's climate on a smaller scale. Beginning since the 19th century, due to human activities associated with emissions of carbon dioxide and other greenhouse gases the composition of the atmosphere has changed. The scientific community has reached consensus that this changes cause a warming of the atmosphere and therefore influencing the Earth's climate. Continuation of greenhouse gas emissions can result in additional warming over the 21st century up to 4.5 °C by 2100. This warming will have severe consequences for the water cycle of the world, because with the warming will come changes in precipitation patterns with increased risk of droughts and floods.

The assessment of the influences of climate changes on the global hydrological regimes and water resources are still very uncertain due primarily to the complex meshing systems as well as to an inadequate understanding of the water cycle in the oceans, atmosphere and biosphere. For assessing the effects water-balance calculations are necessary, including temporal and spatial changes in the relevant hydrologic parameters. Empirical knowledge would have to be replaced increasingly by improved process understanding. Overcoming this problem requires new ways in a field traditionally divided amongst several disciplines. In order to improve the assessment general circulation models are applied nowadays to simulate climate-change scenario and to evaluate possible future changes. Although there is variation between scenarios, the results suggest that average annual runoff will increase in high latitudes and in the equatorial regions, but will decrease in mid-latitudes and most subtropical regions. The selected scenario produces changes in runoff which are often closely related to the initial conditions, but there are important regional differences. The study also showed that different indications of the impact of climate change on water resource stresses could be obtained using different projections of future water use.

In this introductory chapter of the book several authors contribute to the basic relationship between climate changes and the world water cycle. In the first contribution Mosbrugger refers to the earth history providing abundant information on the dynamics of the climate systems. The geological past clearly indicates that global warming is typically linked with more humid conditions, which is in con-
contrast to several younger prediction and assumption. Schönwiese is focusing on climate change in terms of temperature rise and, in turn, with the resulting consequences for atmospheric circulation and the water cycle. Detailed global and regional precipitation trend analysis of the last hundred years show that there is no confident prove of increased intensity of the global water cycle, however, complicated precipitation trend patterns can be observed on a regional basis indicating the influence of other factors. In order to understand recent changes and to predict next developments in the Mediterranean region Born et al. (Marocco) and Suppan et al. (Near East) are applying regional climate modelling. The analysis points to a continuation of the trend of the last hundred years. Although differences in long-term variability between observations and model data can be seen, a change of climates towards warmer and dryer conditions can be assessed from the simulations. Arakadan refers by statistical analysis from precipitation data in Lebanon on a certain cyclicity, however, are in doubt, whether the observation period are enough to confirm the control of the prevailed climatic conditions by this cyclicity.
1.1 Climate Change and Water Cycle — Some Lessons from the Geological Past

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1.1.1 Introduction

Since the 4. Assessment Report of the International Panel on Climate Change (IPCC-4.AR), presented to the public in early spring 2007, there can be no doubt: global climate is changing, at least partly because of human activities. To predict the future climate change expected to occur over the next 100 years highly sophisticated climate models (or rather earth system models) are used. According to these models global warming will be between 1° and 6.3° C in 2100, depending on the scenario (Fig. 1.1.1). Meanwhile there is a considerable political movement –

![Multi-model Averages and Assessed Ranges for Surface Warming](image)

Fig. 1.1.1. Prediction of global warming until the year 2100 (from IPCC 2007).
strongly promoted by the Federal Government of Germany – to keep global warming until 2100 below 2° C although many scientists estimate that it is already too late to reach this goal.

The question arises how reliable all these model predictions are. In fact, the performance of these climate (or earth system) models is highly impressive when modelling the well-documented climate change that occurred over the last 150 years. On the other hand all models have their imperfections. For instance, recent climate models still suffer from insufficient representations of the cloud dynamics, of soil processes or of biosphere-atmosphere interactions (see for instance IPCC 2007). Moreover, all models have to use the technique of parameterization with the inherent problem that these parameterizations are adapted to certain situations and are valid only within specific boundary conditions. Hence, it is to be expected that model predictions for climate states far away from the present-day situation have higher uncertainties. It is therefore not surprising that today not a single climate (or earth system) model can simulate an extreme greenhouse world with almost no polar ice as it existed in the Eocene about 50 million years ago (see Figs. 1.1.2 and 1.1.3).

In fact, the past climate history is a strong tool to test and validate climate (earth system) models and their predictions for future climate change. Reliable climate models should be able to realistically simulate past climate states which are well different from the present-day situation. Moreover, the earth history provides us with climate states which are similar or analogous to the expected future climate (e.g. global warming due to high CO₂) and allow to validate model predictions. Thus, even when only interested in future climate change the climate history of the geological past may teach us some lessons. This will be briefly illustrated using four examples covering the natural climate dynamics of the last 50 million years.

![Global climate change over the last 60 million years](image)

**Fig. 1.1.2.** Global climate change over the last 60 million years as documented in the marine record (redrawn from Billups 2005 after Zachos et al. 2001).
1.1.2 Global warming, seasonality and rainfall

Over the last 60 million years the earth experienced a significant cooling well documented in the marine record (Zachos et al. 2001; Fig. 1.1.2). The Early Eocene period around 50 Ma ago represents the warmest periods with temperate deciduous forests up to 80° latitude north and (virtually) no ice at the poles. Then overall cooling starts, presumably linked to uplift of mountain chains and plateaus (such as the Himalayas and Tibet). An Antarctic ice shield developed near the Eocene/Oligocene boundary and North Hemispheric ice sheets appeared in the Upper Miocene around 6 to 8 Ma ago. In the Pliocene (5-2.5 Ma ago) cooling continued and the Quaternary (2.5 Ma ago to today) was characterized by rapid climatic changes between glacial and interglacial phases with the present-day Holocene representing the last interglacial.

More recently it became possible to reconstruct this Cenozoic climate also over land in quantitative terms. Fig. 1.1.3 illustrates the climatic changes in NW Germany over the last 50 Ma as represented by four different climate parameters, i.e. mean annual temperature (MAT), mean temperature of the coldest month (CMT), mean temperature of the warmest month (WMT) and mean annual precipitation. When comparing Figs. 1.1.2 and 1.1.3 it becomes evident that all in all the temperature change in NW Germany over the last 50 Ma largely follows the global climate change documented in the marine record. Both, the marine and the continental record show a similar overall cooling pattern with, for instance, a steep end-Eocene cooling, an end-Oligocene warming and a mid-Miocene temperature optimum followed by a gradual cooling.

The continental record, however, provides additional information concerning changes in seasonality and rainfall. As is evident from Fig. 1.1.3, the change in winter temperature is much more pronounced than the change in mean annual temperature, and the summer temperature changes are relatively small as compared to the mean annual temperature. Hence, the global climate cooling since the Early Eocene is more pronounced in winter temperature than it is in mean annual temperature or in summer temperature. Moreover, the precipitation data indicate that the overall Cenozoic cooling is linked with a reduction in rainfall.

Thus, if we read Fig. 1.1.3 backwards, i.e. from the present-day to the past, it teaches us some interesting lessons. First of all, over the last 50 Ma global warming is typically linked with an increase in rainfall, at least in temperate zones. Secondly, global climate change (i.e. warming or cooling) is generally more pronounced in winter temperature than in summer temperature. Correspondingly, warming induces a reduction in seasonality and cooling an increase in seasonality. We may expect that this same pattern holds true for the global warming occurring over the next 100 years.
1.1.3 Global warming and the Gulf Stream

Another possible lesson from the past concerns the future of the Gulf Stream. The Gulf Stream is a warm Atlantic ocean current that transports considerable energy
Vegetation distribution a) in the Upper Miocene (8-10 Ma ago) and b) today (from Micheels et al. 2007).

(about 1.4 petawatts) from the low latitudes of Florida and the Gulf of Mexico to the high latitudes of the North Atlantic. It is responsible for the considerable temperature difference existing between the West and East coast of the North Atlantic. For instance, Bergen in Norway and Prins Christian Sund in Southern Greenland are both located at around 60° latitude North, but Bergen enjoys a mild climate
with about $8^\circ$ C mean annual temperature whereas the mean annual temperature is $0.6^\circ$ C in Prins Christian Sund. Because the temperature gradient between Equator and North Pole is one of the drivers of the Gulf Stream several modelling studies predicted that global warming should lead to a weakening of the Gulf Stream and hence to a cooling of considerable parts of Europe (e.g. Rahmstorf 1997, 2003).

The Cenozoic climate history tells a different story. So far all proxy-data show that global warming also means warming of Europe; no past situation is known with a global climate warmer than today and a Western or Northern European climate cooler than today. This is clearly documented not only by the climate evolution in NW Germany over the last 50 million years (Fig. 1.1.3) but also by a global vegetation map of the Upper Miocene (8-10 Ma) shown in Fig. 1.1.4. The Upper Miocene is a phase with a considerably warmer climate than today (cf. Figs. 1.1.2 and 1.1.3) and the vegetation in Western and Northern Europe also clearly reflects a warmer climate.

Although past climate data indicate that a globally warmer climate also implies a warmer Europe, they say nothing about the strength of the Gulf Stream. In fact, it might well be that the Gulf Stream is indeed weaker in a globally warmer climate but that the effect of a weaker Gulf Stream is compensated by other processes such as a more intense latent heat transport, i.e. energy transport through the water cycle (Mosbrugger et al. 2005, Mosbrugger & Micheels 2007; see also below).

Thus, taking the lesson from the earth history seriously one would predict that the expected global warming will also lead to a warmer and all in all more humid Europe. It is interesting to note that meanwhile also modelling studies come to the same result and that recent measurements do not yet indicate a weakening of the Gulf Stream (Kerr 2006).

1.1.4 Global warming and forests

One of the most important mitigation strategies to compensate for the anthropogenic CO$_2$ emission is to plant forests since growing forests or biomass extract CO$_2$ from the atmosphere. Correspondingly, forests also play a major role in the emission trading business. Here again, the earth history may help to better understand the overall climatic effect of forests.

Fig. 1.1.4 shows the vegetation distribution of today as well as the vegetation distribution about 8 to 10 Ma ago, during a period of globally warmer climate (Figs. 1.1.2 and 1.1.3). A quantitative comparison reveals that during the Upper Miocene there existed about 25 % more forests than today (Micheels et al. 2007), the additional forests being located in particular in the high northern latitudes and in the subtropical zone. To investigate the climatic effect of these additional 25 % of forests a modelling study was performed (Mosbrugger & Micheels 2007).
In this study we first simulated the Tortonian (Upper Miocene, 10-8 Ma ago) climate with the AGCM ECHAM coupled to a mixed-layer ocean model and using the vegetation distribution of Fig. 1.1.4a (Mosbrugger & Micheels 2007). Then we repeated the same model experiment but with the present-day vegetation distribu-
tion (Steppuhn et al. 2006). The difference between the two runs is shown in Fig. 1.1.5a and directly reflects the effect of the additional 25% of forests on temperature and precipitation. Obviously, the additional forests cause a significant warming which in some regions such as Siberia may reach 4°C (Fig. 1.1.5a). The changes in the precipitation pattern caused by the additional forests are particularly interesting (Fig. 1.1.5b). In some regions precipitation increases by more than 100 mm/a, in others it decreases by the same amount but all in all there is a global increase in mean annual rainfall by 35 mm/a. Thereby a peculiar pattern becomes evident for the Atlantic: while precipitation in low latitudes decreases, precipitation in high latitudes increases. This obviously indicates that the latent heat transport was increased by the additional forests: more water evaporated in the low latitudes, more water precipitated in the high latitudes.

What is the lesson from this case study? First of all, changing the vegetation and the terrestrial biomass does not only influence the atmospheric CO$_2$ concentration, it also impacts temperature and precipitation by influencing albedo and water cycle. An increase of forest cover may indeed induce additional warming and rainfall and enhance latent heat transport. Thereby it is important to note that the climatic effects of changes in vegetation are not restricted to those regions where changes occurred. This lesson needs to be considered in the emission trading business and in any improved version of the Kyoto protocol.

**1.1.5 Global warming and the arid zones**

A particularly crucial aspect of future climate change concerns rainfall and water availability. According to IPCC-4AR the global precipitation will slightly increase with significant regional differentiations; Fig. 1.1.6 shows the IPCC model projections for the A1B scenario. All in all, for the year 2100 models typically predict an increase in precipitation in the humid mid and high latitudes and a decrease in precipitation in the dry low latitudes (cf. Fig. 1.1.6); thereby the „aridisation trend“ is more pronounced in summer than in winter. This prediction of future climate causes particular concern among politicians and societies since it would cause – if it becomes reality – severe problems for millions of people living in a Mediterranean and subtropical climate.

On the other hand, model simulations concerning future precipitation patterns are well known to be less reliable than predictions of temperature patterns. Hence, it may again be useful to look back into the geological past: How did the semiarid and arid zones of today look like during time periods where global temperatures were higher than today? If we take once more the Upper Miocene as a rough analogue of the expected future climate then the answer is clear. As is evident from Fig 1.1.5, the vegetation of the Mediterranean and subtropical zones was much more humid in the globally warmer Upper Miocene than it is today, real deserts didn’t hardly exist. A recently published volume „Miocene Climate in Europe“ (Bruch et al. 2007a) gives further evidence that warmer climates in the Miocene were indeed
linked with more humid conditions in the Mediterranean (see for instance the contributions of Bruch et al. 2007b, Martinetto et al. 2007, Jimenez-Moreno & Suc 2007). For Northern Africa it is documented that an aridisation occurred during the
Miocene in parallel to the global cooling with the spreading of savannas and open woodland only in the Pliocene (Cane & Molnar 2001).

Thus, the geological past clearly indicates that global warming is typically linked with more humid conditions also in the semiarid to arid Mediterranean and subtropical zones. Hence, one might be sceptical if the above mentioned prediction about further aridisation of these regions will indeed hold true.

1.1.6 Discussion

The earth history provides us with a plethora of information concerning the dynamics of the climate system. Whenever we are interested in the future climate it makes sense to also have a look at past climates. They allow to test and validate our climate models and – equally important – they allow empirical access to climate situations that do not or not yet exist today. In this contribution I was particularly focusing on this last aspect – past climates may teach us lessons to better understand the future climate change. I briefly considered four examples, i.e. the effect of global warming on a) seasonality and rainfall, b) on forests and climate feedbacks, c) on the Gulf Stream and European climate, and d) on the arid and semiarid zones. For these four examples the lessons from the past are most relevant for understanding and managing future climate change and are only partly consistent with model results (this is particularly true for examples c and d). Thus they may point out particular weaknesses and uncertainties of model predictions.

On the other hand it is clear that the past can never directly be used as a perfect representation of the future: earth and climate history are indeed historical processes, past situations are never repeated identically in the future. Hence, although the Neogene was considerably warmer than today and can thus be considered an interesting analogue of the future climate we have to be aware of the differences: in the Neogene the palaeogeography was different, CO$_2$ was probably below 400 ppm (possibly with the exception of the mid-Miocene climatic optimum; Pagani et al. 1999, Kürschner et al. 2008), and there was no human impact on landuse and vegetation. Nevertheless a critical and intelligent use of the information provided by the geological past is strongly recommended.

References