Global Environmental Change: Challenges to Science and Society in Southeastern Europe

Vesselin Alexandrov · Martin Felix Gajdusek ·
C. Gregory Knight · Antoaneta Yotova
Editors

Global Environmental Change: Challenges to Science and Society in Southeastern Europe

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Preface

This book is the outcome of the conference “Global Environmental Change: Challenges to Science and Society in Southeastern Europe” organized by the Scientific Coordination Center for Global Change (SCCGC) at the Bulgarian Academy of Sciences jointly with the Austrian Science and Research Liaison Offices Ljubljana and Sofia (ASO). The event was supported by the Federal Ministry of Science and Research of the Republic of Austria in the framework of its SEE science cooperation initiative. Sponsorship was also provided from the Knight-Staneva Foundation for Sustainability and Future Environments (USA) and the EC FP6 ADAGIO project (www.adagio-eu.org).

The Conference celebrated the anniversary of the founding of the SCCGC in 1997 as National Coordination Center for Global Change (NCCGC). The idea for such a center evolved at the June 1997 Workshop “Global Change and Bulgaria” held in the American University in Bulgaria, Blagoevgrad, sponsored by the US National Science Foundation via the Center for Integrated Regional Assessment (CIRA) at the Pennsylvania State University. In examining the competencies Bulgarian scientists would bring to the study of climate change and its impacts, that workshop identified a number of research priorities and future strategies to be pursued. The workshop resulted in two publications, Глобалните промени и България[1] and *Global Change and Bulgaria.*[2]

The most important future strategy from the 1997 Workshop was the proposal to the leadership of the Bulgarian Academy of Sciences for formation of the NCCGC, with the recommendation that it be headed by Academician Dimitar Mishev, director of the Academy’s Solar-Terrestrial Influences Laboratory, and membership from a variety of institutes and other organizations. In July 1997, the NCCGC came into being and operated under that title until the death of its president, Academician Mishev, in 2003.

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[1] 1999. Sofia: National Coordination Center for Global Change, Bulgarian Academy of Sciences, 370 pp. (Todor Hristov, C. Gregory Knight, Dimitar Mishev, Marieta P. Staneva, editors; in Bulgarian). ISBN 954-90485-1-9.

[2] 2000. Sofia: National Coordination Center for Global Change, Bulgarian Academy of Sciences, 350 + viii pp. (Marieta P. Staneva, C. Gregory Knight, Todor N. Hristov, Dimitar Mishev, editors). ISBN 954-90485-2-7.

During that interim, one of the research priorities was initiated, namely a study of the 1982–1994 Bulgarian drought as an analog of future climate change, realized as a project coordinated in Bulgaria by Professor Ivan Raev of the Forest Research Institute and in the US by C. Gregory Knight of the Pennsylvania State University, with funding from the US National Science Foundation via CIRA. That project also resulted in two books, Засушаването в България: съвременен аналог за климатични промени[3] and *Drought in Bulgaria: A Contemporary Analog of Climate Change.*[4]

The NCCGC played an important role in the creation of the Industrial Transformation Science Plan of the International Human Dimensions Programme in 1998–1999. The Centre also co-sponsored a workshop on Integrated Regional Assessment of Climate Change held in Budapest in 1999 and hosted the Sofia workshop on Human Dimensions of Global Change in 2000.

Subsequent to the death of Academician Mishev and by decision of the Board of the Bulgarian Academy of Sciences, NCCGC became the SCCGC in 2003 with Professor Ivan Raev as president. The SCCGC continues until the present as a consultative and advisory body on global change issues in Bulgaria with the presidency having been handed from Professor Raev to Associate Professor Vesselin Alexandrov, director of the Meteorology Department of NIMH, in May 2006.

In 2007, in recognition of the 10th anniversary of the workshop that had led to the creation of the SCCGC, plans were begun to organize a conference on global environmental change issues in the region of Southeastern Europe in co-operation with the ASO. The conference was held in Park Hotel Moskva, Sofia, on 19–21 May 2008 with near 120 participants, including 36 from outside Bulgaria (Albania, Austria, Bosnia and Herzegovina, Croatia, Cyprus, Czech Republic, Finland, FYR of Macedonia, Greece, Latvia, Moldova, Montenegro, Serbia, Slovenia, Romania and USA), which reflected the interest in environmental change issues throughout Southeastern Europe and beyond. There were four plenary keynotes, eight thematic parallel and poster sessions during the conference.[5]

This book is a collection of papers presented in the conference as selected from presentations and respectively revised for publication. The editors and authors of contributions hope that the volume will be a way marker on the road of basic and applied research on climate change and other environmental issues as well as related

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[3]2003. Sofia: Bulgarian Academy of Sciences Press, 284 pp. (Ivan Raev, C. Gregory Knight, Marieta P. Staneva, editors). ISBN 954-90896-1-4.

[4]2004. Aldershot, UK: Ashgate Studies in Environmental Policy and Practice. 336 + xvi pp. (C. Gregory Knight, Ivan Raev, Marieta P. Staneva, editors). ISBN 978-0754642152.

[5]For further information refer to http://global-change.meteo.bg/conference_en.htm or refer to http://www.aso.zsi.at/bg/veranstaltung/2601.html (last accessed on September 4, 2009).

impacts in Southeastern Europe, and that it will also introduce some of the work done in this region to the global change community.

Vesselin Alexandrov
Martin F. Gajdusek
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Abbreviations

CEU	Central European University
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EU	European Union
GE	Global Environment
GEF	Global Environmental Facility
GIS	Geographic Information System
MoEW	Ministry of Environment and Water
MRDPW	Ministry for Regional Development and Public Works
NCSA	National Capacity Self Assessment
NGO	Non-Governmental Organization
NOPRD	National Operational Program for Regional Development
NSFRD	National Strategy for Regional Development
NTTA	Natura 2000 Assessment
OPs	Operational Programs
RCP	Rio Conventions Project
RDA	Regional Development Act
RDPs	Regional Development Plans
SA	Sustainability Appraisal
SD	Sustainable Development
SEA	Strategic Environmental Assessment
SEE	South Eastern Europe
SU	Sofia University
TP	Training Program
UD&SP	Urban Development and Spatial Planning
UNCBD	United Nations Convention on Biological Diversity
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

Introduction

Vesselin Alexandrov, Martin F. Gajdusek, C. Gregory Knight, and Antoaneta Yotova

Global change is the term used to encompass a multitude of environmental and ecological changes of different scale that have been noticed, measured and studied on the Earth. Global environmental change encompasses the study of issues such as climate change, biodiversity and species extinction, land use change, changes in the carbon and water cycles, air quality, etc. Global environmental change is as old as the Earth because physical, chemical and biological processes have been shaping and reshaping the planet's environment since its infancy 4.5 billion years ago. In recent time, however, humankind has become one of the major driving forces of environmental change on our planet by diverse activities resulting in climate change, loss of biodiversity, pollution, desertification and other consequences. In turn, both individuals and societies are also experiencing the impact of the changes in their natural environment upon their own social, economic and political situations.

In the region of South-Eastern Europe, changing weather patterns are creating droughts, floods, and forest fires. Severe droughts affected most socio-economic sectors in this region in the twentieth century. Since 2002, floods in Europe have caused a number of deaths, the displacement of about half a million people, and cost at least 25 billion Euro as measured by insured economic losses. In addition to wet weather conditions, poor river basin management contributes to flooding in South-Eastern Europe. Furthermore, water leakages from distribution networks are frequent in many South-Eastern European countries. It is common that more than one third of the supplied water is lost before delivery.

All countries in South-Eastern Europe are parties to the UN Framework Convention on Climate Change of 1992. Between 2004 and 2007, countries such as Albania, Bulgaria, Croatia, Former Yugoslavian Republic (FYR) of Macedonia and Montenegro ratified the Kyoto Protocol. Although the absolute and per capita contribution of the region to global greenhouse gas emissions is relatively small, there are significant opportunities for emission reductions. Countries can reduce their current high energy consumption and energy intensity, lower their reliance on coal for energy production, increase energy efficiency of the domestic sector, and invest in renewable energy resources such as solar, biomass, hydro, and wind.

Biodiversity is under serious threat in South-Eastern Europe, particularly in farmland, mountain regions and coastal zones. The loss of biodiversity happens primarily because of human activities leading to land use changes – including urban sprawl, infrastructure development, intensification and/or abandonment of the agricultural sector, as well as to acidification, eutrophication, desertification, overexploitation of natural resources, and climate change.

The countries of South-Eastern Europe have made substantial progress in developing legal and policy reforms in the area of environmental protection, most of it linked to EU accession or membership. However, the establishment of appropriate institutional infrastructures often remains a challenge. Countries of the region still face lack of sufficient resources and adequate administrative capacity for adoption and effective implementation of the multilateral environmental agreements. The quality of South-Eastern Europe's nature and environment is high but in order to preserve this status, the concept of sustainable development must be practically integrated into the mainstream economic and social development policies.

In the last decade, the environmental changes and awareness of their impacts on society, economy, and local and regional development have become important research topics in South-Eastern Europe. Global environmental change and its implications for the future development in the region are nowadays hot issues for politicians, and this impetus accelerates the introduction of specific adaptation and mitigation measures. Climate change is one of the most important public and society driven research topics but also one of the very first research issues requiring a real interdisciplinary, and therefore challenging, approach. During recent years, global change research and participation of researchers from South-Eastern Europe in the global change community have grown. Research networks in related fields emerged recently, driven also by diverse funding schemes, e.g. programmes of the European Union. The explicit societal demand challenges researchers and their science communication competencies on the research topics concerned. Thus, it became necessary to convene a meeting to assess the recent knowledge on global environmental change and related impacts in South-Eastern European countries. The international conference "Global Environmental Change: Challenges to Science and Society in South-Eastern Europe", held in May 2008 in Sofia, Bulgaria, aimed to respond this need. The particular interest on the region of South-Eastern Europe is because recently and in the future, this region will become increasingly sensitive to global changes. Beyond the work of scientists and actions of governments, civil society has a major stake in such changes, so the necessity for information exchange as basis for actions to address resulting stress as well as to exploit new opportunities is important task.

As main objectives of the above conference, different aspects of the environmental changes and their impacts are discussed in the next parts of this book. It starts with the four key-note lectures presented during the conference. In these chapters of the book, attention is paid to the possibility for numerical experiments with climatic models and to discovery of local and regional "signature" of the global climatic changes. The importance of a focused Balkan-region analysis of future climate change and climate change impacts on a more detailed regional basis than undertaken before is considered. Climate change scenarios based on high resolution climate models for Europe and the possible impacts of climate change due to changes in extreme weather and climate events for different sectors (agriculture, water resources, human health, built environment and infrastructure) are discussed. The last key-note chapter traces the history of the establishment of the Scientific Coordination Center for Global Change in Bulgaria aiming to ensure research projects, studies, publications and educational initiatives in the realm of global change and goal for sustainable development. Research results and lessons learned are viewed as road markers to assist decision makers and the public particularly in the face of climate change and planning for sustainability.

Global Change and Climate Change in South-Eastern Europe

In this part of the book, the chapters represent selected research on environmental changes at global, regional and local scales in the past, present and future including assessments of observations, indices and indicators, models, scenarios, trends, etc. In the first chapter, some issues which are important from the point of view of the current climate modelling attempts are considered, namely: (i) overview of the results achieved until the present time; (ii) discussion of the term predictability beyond complexity; (iii) consideration of an approach in analysis of the energy balance equation for the environmental interface and (iv) "chaotic" response of the environmental interface due to forcing by visible and infrared radiation. The aim of the second chapter is to estimate regional changes of different type of clouds associated with climate change in the south-eastern part of Europe. A statistical method of downscaling is applied to calculate how cloudiness change in parallel with the increase of hemispherical temperature with 0.5°K; the regression of local variables against the hemispherical mean temperature in the recent monotonously warming period of 1973–1996 is analyzed by the method of instrumental variables. The next chapter comprises recent achievements and updated research results on projected climate change in FYR of Macedonia in the twenty-first century, related to previously elaborated National Communications on Climate Change as an obligation under the UN Framework Convention on Climate Change. Then, authors from Bosnia and Herzegovina present the effects of climate changes, such as increase of average temperature about 0.7°C in the past 100 years and the annual sum of rainfalls with no severe changes, finding the existence of very warm and very cold short periods, and also their consecutive fast changes, over the country's territory. In the last chapter of this part, the historical archive of synoptic maps and NCEP/NCAR reanalysis data files are used for analysis and classification of the synoptic situations causing torrential precipitation over the territory of Bulgaria; the fields of air pressure and wind velocity are also considered. A negative trend in the annual and seasonal precipitation totals associated with an increase in the contribution of heavy rainfall events to the total precipitation is observed in the country as in some Mediterranean countries.

Environmental Impacts

The impacts of global, regional and local environmental changes on natural systems, such as water resources, forests, and ecosystems, are subject of this part of the book. The first two chapters present Joanneum research in the field of climate change – scientific and network activities in Austria and South-Eastern Europe. In the next chapter, a specific targeted research project CECILIA (Central and Eastern Europe Climate Change Impact and Vulnerability Assessment) is presented. The project's main goal is to provide climate change impacts and vulnerability assessment in targeted areas of Central and Eastern Europe. To assess the impact of climate change at the regional to local scale, very high resolution Regional Climate Models are run locally for targeted areas in order to capture the effects of the complex terrain of the region. Changes in weather patterns and extreme events are addressed within the project as they affect important economic sectors and welfare of individual countries in the region. The selected applications of the CECILIA outputs are supposed toward water resources management, agriculture, forestry, air quality and health. The next chapter discusses results of the regional studies and feedback gathered from experts and farmers which show in general that drought and heat are the main factors having impact on agricultural vulnerability not only in the Mediterranean region, but also in the central and eastern European regions. Another important aspect is that the increasing risk of pest and diseases may play a more important role for agricultural vulnerability than assumed before, however, till now this field is only rarely investigated in Europe. Review of climate change projections based on a range of emission scenarios extending up to the end of the twenty-first century is made in the next chapter. The study area covers South-Eastern European countries, such as Croatia, Bosnia and Herzegovina, Serbia, Montenegro, Albania and the FYR of Macedonia. The scenarios exhibit an anticipated increase in the annual air temperature higher than 5°C with very slight differences over the region. As result of the reduction in annual total precipitation rate, the study area could experience a general decrease in runoff. The demand for water could increase, especially in the summer. It could cause more keen problems, particularly for energy production from hydropower in countries like Albania that highly depend on hydropower. The state of climate changes in Serbia and their consequences: desertification, soil erosion, torrential floods, as well as the significance and effects of forests on their mitigation, are subjects of the next chapter. Erosion, erosion sediment and torrential floods cause numerous damages among which the damage brought to the environment is increasingly important. It is manifested as landscape degradation, mechanical and chemical pollution of water in watercourses and storages. With present climate changes, which have an unfavourable impact on the development of vegetation, the risk of intensified erosion processes is increased.

Impacts on Socio-Economic Activities

In this part of the book, the impacts of environmental changes on society and economy, for example impacts on human health, agricultural production, other industrial and economic sectors, are illustrated by selected chapters. Chapter 15 outlines the conceptual framework of the different types of climate change impacts and justifies the necessity of economic impact studies, especially on a local level. Results of a number of impacts studies at global, European and country level have been examined, not to give single values of damage or impact of climate change, but to explore plausible ranges of impacts. The chapter concludes with the expected results of a research project – CLAVIER (Climate Change and Viability: Impacts on Central and Easter Europe) aiming at filling the research gap concerning local level studies related especially to economic impact and vulnerability issues. The next chapter is devoted to the heavy rains in Albania which are amongst the greatest problems nowadays, especially on the low and coastal land. These zones very often are suffering from flooding caused not only by heavy rain but also by poor management of the urban infrastructure. Human factors are determinant in the frequent inundation of the coastal zones, as listed in the conclusion of the chapter. To analyze in details heavy rain and its social impact, the region around Lezha station as a representative for the coastal northern part of Albania is chosen. The threshold calculation for adverse weather phenomena identification and frequency distribution of meteorological variables is used as methodological tool. In Chapter 17 of this part, effects on the red blood cells in children exposed to air pollution are evaluated using the example of Nish in Serbia. The diagnosis of iron deficiency anemia is made using the pre-defined criteria. The air concentrations of black smoke, nitrogen dioxide, sulfur dioxide and lead in sediment matter are determined for the period from 1990 to 2000. The findings suggest that air pollution could have negative effects on red blood cells in children. Changes of water covered areas in Moldova during the transition period are analysed in the next chapter to reveal recent tendencies and find possible solutions of adaptation to climate change. "Spontaneous" concentration of reservoirs and ponds around big cities is found as a distinct feature of recent change. At the same time, the water-covered area diminished more drastically in initially water-scarce regions. As a result, adaptation measures must be territorially and typologically differentiated in order to achieve maximum effect and diminish social vulnerability of the population. Chapter 19 shows an observed trend which may indicate that the climate is becoming more maritime in northeastern and especially southeastern Europe. Namely, starting from the mid 1980s, there is a continuous decrease in the average lead-210 content of ground-level air both in Finland and Bulgaria, but the decreasing trend is much stronger in Bulgaria compared to Finland. However, the source areas of air masses are not the only factor to determine the lead-210 content of the air. The effect of the precipitation causing wet deposition of lead-210 has to be studied too, as the changes in the precipitation amount can influence the average residence time of lead-210 in the air.

From Global to Local and Vice Versa

The permanent direct and feedback links between global and smaller scale environmental changes and their impacts are discussed in this part of the book as illustrated by the selected chapters. Chapter 20 argues that in a changing climate, natural hazards are more frequent, and it would be reasonable to imply that social and economic risk is consequently increasing. Assessment of both – natural hazards and society vulnerability – belongs among the core work objectives of the Drought Management Centre for Southeastern Europe established in Slovenia. Historical assessment of drought occurrence and development of a drought monitoring system aim at establishment of regional products for estimation of climatological and actual natural hazards connected to drought. Some aspects of vulnerability have already been described for some of the countries in South-Eastern Europe. The next chapter states that one of the most important tasks of the signatory parties to the United Nations Convention to Combat Desertification (UNCCD) is to adopt National Action Programmes for combating desertification (NAP). The Romanian Government has adopted the first NAP in 2000. Following the previous experience with the limited implementation of this Programme, while confronting with the severe drought of 2007, it has been decided to proceed with its revision taking into account that (1) the political will and social impact of a revised NAP relates directly to the duration and intensity of the natural phenomenon (i.e., drought), and (2) bringing together a multitude of national authorities presumably concerned about drought and desertification incurs transaction costs which may easily exceed those required by the mere elaboration of NAP. Actions and measures proposed within this strategy may overlap with those provisioned by similar strategies (e.g., climate change mitigation/adaptation, water management, etc.), so that the critical issue of synergistic action comes again to the fore. The next chapter reports that the UNDP Country Offices in Albania, Bosnia and Herzegovina, Macedonia FYR, Montenegro, Serbia and the UN Administered Province of Kosovo have developed a regional demonstration programme around demand-driven projects in nine locations in the Western Balkans suffering from the legacy of polluting industries and requiring industrial renewal, environmental cleanup and new economic initiatives. The programme is to achieve improvement of the environmental situation and quality of life for citizens living in and around polluted areas through least-cost measures, improved local and national policy dialogue and supply of domestic professional services in the environmental management sector. While the main focus will be the physical works needed to mitigate the ecological problems, institutional strengthening and capacity building will be an important subject running throughout the programme. The last chapter presents the project "Integrating Global Environmental Issues into Bulgaria's Regional Development Process" initiated in 2006 by the Ministry of Regional Development and Public Works of Bulgaria and the United Nations Development Programme. The project's objective is to build capacities of respective ministries, district administrations and municipalities for mainstreaming global environmental issues into the formulation and implementation of regional and local development, as well as spatial planning policies. It is expected that by the end of the project, the beneficiaries shall have: adequate skills necessary for effective mainstreaming of global environmental issues into regional development policies; access to appropriate systems of training, mentoring, and learning in place to maintain a continuous skills upgrade of personnel; a comprehensive set of indicators that can be used to assess the impact of development and spatial planning at regional, district and municipal levels on the achievement of the UN Rio Conventions' objectives; access to data needed for reporting on progress in terms of impact on global environmental commitments; and models for update of regional development and spatial development plans and strategies.

We anticipate that the book chapters will be useful not only for experts and specialists in the field of global change and related impacts, but also for students and common people interested in environmental issues, especially in the region of South-Eastern Europe.

Part I
Keynotes

Chapter 1
Weather and Climate – Difficult Science Problems

Stoytcho Panchev and Tatiana Spassova

Abstract The classical physics with its fundamental principles and laws is in the basis of the contemporary weather and climate theories. The weather is defined as momentary state of the system Atmosphere–Land–Ocean (ALO). In this chapter, the development of the numerical method for deterministic weather forecasting is traced out and the main reasons leading to limited predictability are outlined. The climate is defined as a statistical ensemble of the ALO-system states for a long enough period of time τc ($\approx$30 years). The role of physics in the climate studies has two aspects:

1. Quantitative reconstruction of the past climate of our planet;
2. Development of theories and methods capable of reproducing the past climate events and of predicting future ones.

Special attention is paid to the possibility for numerical experiments with climatic models and to discovery of local and regional manifestation of the global climatic changes. The Bulgarian contribution to these current problems of physics and of the contemporary science in general, is also mentioned.

Keywords Climate · Numerical models · Weather

1.1 Introduction

About forty years ago, the great Russian scientist A. S. Monin (1969) published a book on physics and weather. Recently, he was a leading author of a review paper (Monin and Shishkov, 2000) on physics and climate. We share completely the ideas and concepts of this author concerning the crucial role of the physics in formulation and solution of the fundamental questions related to the weather and climate in cognitive and practical aspects. More precisely, we mean the classical physics with

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its general principles and laws, applied to the multi-component system Atmosphere-Land-Ocean (ALO) of the planet Earth. In this connection, we also mention the books of McIlveen (1992), Peixoto and Oort (1992) and Panchev (2003).

The study of the processes and the phenomena in the ALO-system goes in two main directions – instrumental observations (in situ and remote sensing) and theoretical (mathematical modeling on physical basis). Now, in the era of space satellites and powerful computers, both of them undergo unprecedented progress. Hereafter, we discuss some particular aspects in the development of theoretical studies.

1.2 The Weather

Under the term weather one usually understands the state of the low atmosphere (the "kitchen" of the weather) at the moment or for a short period of time, over a limited area. This state is characterized by a set of meteorological fields (or elements) which are functions of the space-time coordinates (x, y, z, t), such as: wind velocity, temperature, pressure, humidity, precipitation etc. Very often only one of them is used as main characteristic of the weather – people say: it is warm, cold, windy, rainy, etc.

One of the most important scientific and practical problems is the understanding of the laws governing the weather and their application for its forecasting. No doubt that these are fundamental laws of the classical physics of continuous media – hydrodynamics, thermodynamics, radiation, water phase transitions, etc., with extensive use of mathematical tools.

A century ago, in 1905, V. Berkness formulated the weather forecasting problem as a mathematical one for solving the system of partial differential equations (PDE) of the atmospheric thermo-hydro-dynamics at given initial and boundary conditions. Two decades later, L.F. Richardson realized (by hand!) the first (unsuccessful!) such a numerical weather forecast. Still 20 years later, the first electronic computer (ENIAC) was used by J. von Neumann for this purpose.

Meanwhile and next, the physical basis of the mathematical prognostic models was improved; the numerical methods for solving the equations were further developed; the volume and accuracy of the observational data gathered in the world set of meteorological stations and by remote sensing (i.e., by space satellites) methods increased many times and finally, the computers became much more powerful in memory and speed. It was logically to expect that the quality and duration of the meteorological forecasts will also increase proportionally. However, this was not the case!

An improvement was actually observed, but with a clear tendency towards "saturation" – the results did not correspond to the material and intellectual resources engaged into the problem. In other words, a "horizon of predictability" for deterministic forecasts exists. It was theoretically evaluated as 2 weeks and for now it has practically reached 1 week. There are at least five reasons for this:

– imperfect physics under the mathematical prognostic models;
– observational and other errors in the initial data;

– unknown boundary conditions for the regional models over limited area;
– inappropriate numerical schemes for discretization of the equations;
– the equations themselves – nonlinear partial differential, large number, multiparametric, etc.

The fundamental explanation, however, came after the 1960s from the theory of chaos – the crown of the classical physics (Panchev 2001). The ALO-system is nonlinear and extremely complex with a great number of feedbacks. Even the simplest mathematical models must be nonlinear. But such completely deterministic equations with parameters can generate highly irregular, nonperiodic, stochastic-like solutions with exponential sensitivity to the initial conditions, so that errors in the latter will grow very rapidly during the model runs. In other words, we have what is called "chaotic solutions". After some "term of predictability", the errors become large enough to completely compromise the forecast. The understanding of this fact results in the quite pessimistic conclusion – an ideal and unlimited in duration deterministic numerical prognosis could never be achieved even if most of the above mentioned factors were eliminated. This would be possible to some extent if there were some highly predictable effective reasons governing the weather. But this is not the case! That is why, the idea to use the solar activity is so debatable. Most probably, the ALO-system has its internal causes for the irregular weather variability and limited predictability.

During the last decade, our research interest is in the field of general theory of nonlinear (chaotic) dynamical systems and their various applications, including meteorological ones. A number of Bulgarian scientists and groups, mainly in the frames of international projects and programmes, have contributed to a better understanding of the planetary boundary layer physics and dynamics, the ocean dynamics, etc. This allows more correct formulation of the low boundary conditions in the numerical weather prediction described above. Now, several weather forecast models are in operational use in the Bulgarian hydrometeorological service – ALADIN, ARPEGE, MM5, etc. Results from other models are also used, such as the model of the European Centre for Medium-Range Weather Forecasts. Some of these models (ALADIN, for instance) have regional versions with smaller space and time steps, which better accounts for local terrain peculiarities and conditions, and allows to improve the weather forecast for the country.

1.3 The Climate

There are many definitions of climate in the popular literature. The physically rigorous definition for climate reads: "The climate of the Earth is a statistical ensemble from the states of the system ALO (called also Climatic System (CS)) for a long enough period of time τc". It is recommended by the World Meteorological Organisation (WMO) $\tau c = 30$ years because for such a period, the mean values of the climatic fields are relatively stable and representative. For time intervals $\tau < \tau c$, one speaks for climatic variability, while at $\tau > \tau c$ – about climatic changes (tendencies, trends). Moreover, the above definition permits to speak about "regional" and "local" climate, "climate of the ocean", "space weather and climate", etc. (Panchev 2003). In these cases, the interactions with other parts of the system must be considered. Evidently, it is not possible to distinguish sharply short-period ($\sim$1 year) climate variation from long-period weather fluctuations and for this reason, terminological mixing exists in the practice.

What is the role of physics in the problem of climate change? Quantitative diagnosis of the climatic changes during the geological history of the planet is impossible without knowledge of physical laws. Instrumental measurements have been made during the last few centuries only due to the physical and engineering achievements. Physical (radioisotope) methods ensure reliable data for climate description before this period. On such basis only, an acceptable explanation of the real climatic changes can be searched for. It is well known that long and short, irregular in time, glacial and interglacial periods have happened. Their "signatures" have been seen on the land, ocean bottom and glaciers, including the Antarctic ones.

The knowledge and the understanding of the climate history is a precondition for development of a reliable theory capable to predict climate future. In essence, the theory of climate is a statistical dynamics of the CS and is one of the most challenging theories at present. Two basic goals in development of this theory can be pointed out:

- Reproduction of past events in the climate history with or without inclusion of cosmic factors, i.e. solar activity;
- "Prognosis" for the future climate of the Earth accounting for new factors such as the anthropogenic greenhouse gas emissions. Here, the inverted commas stand to stress on the new meaning of the word prognosis concerning the climate consistent with the definition. One has to talk and write about climate perspectives with some probability or statistical moments, instead of climate prognosis.

Respectively, the modern climate theory goes in two main directions:

- Analysis and interpretation of the real climatic data;
- Development of mathematical models on physical background and numerical experiments with these models.

The first direction aims at identification of the physical and other factors influencing the climate and their quantitative representation. The second one aims at bringing the factors together in equations which is not unique operation. This is the reason for existence of a wide spectrum of models containing from one to several dozens of equations depending on the purpose of the model and the resources for its realization. The simplest, so called "point models", consist of up to three nonlinear ordinary differential equations of evolutionary type $da/dt = \dot{a} = b - c$. Two examples for such models are given in the Appendix (see also Panchev 2001). They tie globally averaged quantities such as temperature, CO_2 content, ice mass, etc. and are comparatively simple for solving and analysis. The "heavy" climate models, such as global circulation models, describe the CS as a whole and consist of large number PDEs. Only several national or world meteorological centres operate with such models (American, European, Canadian, Russian, etc.) because they require powerful computers, abundant collection of data as well as considerable intellectual and financial resources.

The problem for "prediction", or more precisely "perspectives" of the climate for decades or 1–2 centuries ahead is already a problem not of physics (geophysics) only but multidisciplinary one. It has demographic and economic aspects related to the growth of human population on the planet and the increasing influence of the anthropogenic factor. The physical aspect is, to the great extent, understood and mastered. As to the other aspects, they are presented in the models in the form of scenarios, i.e. assumptions on how respective components will change in the future – staying uncontrolled or being limited by international protocols and agreements. Under such situation, various climate change models can be created accounting for both type of aspects and predicting the reaction of the CS depending on the initial data. Preliminary results concerning the future climate up to the end of the twenty-second century have been recently published (Dai et al. 2001a, 2001b, 2001c). The authors conclude that global warming of about 2–3°C could be expected, against less than 1°C increase at the end of the twentieth century, compared to the nineteenth one.

1.4 Conclusions

In the light of the above, a fundamental question arises: when and to what extent one can believe to the model perspectives for the climate? From theoretical considerations, the answer is: when the model can satisfactory reproduce past events from the climate history (McIlveen 1992). It is found that only internal mechanisms of the CS can explain qualitatively its observed behaviour. Moreover, the models predict more than one stationary climate, different from the present one, so that the CS can "jump" from one to another stationary state if the physical parameters of the system change above some threshold value (Monin and Shishkov 1979).

An important feature of the climate modeling research is the possibility for numerical (computer) experimentation. In such experiments, one can start by giving various initial conditions like absence or different configuration of the continents and oceans on the globe, different solar radiation by some reasons, different composition of the atmosphere, absence of biosphere, etc. Different climates will correspond to each of these cases. Hence, the life on the planet will react correspondingly.

Finally, the problem for detecting regional and local manifestations of the global climatic changes is not less difficult. Technically, it is similar to the problem to distinguish and separate the useful "signal" on the background of the "noise" of same order. This important problem, however, can be attacked by single scientists or small research groups. Bulgarian physicists-meteorologists also contribute to find solutions of this problem with regard to the climate in the region of South-Eastern Europe, the Balkan Peninsula and Bulgaria in particular.

As to the weather forecast models, all of them are being constantly improved and behave very well even for limited area and for a period from 1 week up to 10 days. However, this is correct for relatively stationary synoptic situations. In case of more dynamic non-stationary situations, the accuracy of these models is usually worse. For this reason, the extreme events are much more difficult to be exactly predicted in space, time and intensity. The development and improvement of the weather forecast models in this sense have to be encouraged.

Appendix

Below, examples for model equations of two dimensionless point climatic models are given. Even very simple, they could demonstrate quite rich spectrum of solutions' behaviour, respectively – quite different climates could result as their solutions.

(1) The Lorenz model (Lorenz 1984, 1990)

$$\begin{aligned} dX|dt &= Y^2 - Z^2 - aX + aF, \\ dY|dt &= XY - bXZ - Y + G, \\ dZ|dt &= bXY + XZ - Z, \end{aligned} \tag{1.1}$$

where $X(t)$, $Y(t)$ and $Z(t)$ represent the zonally averaged meridional temperature gradient (or equivalently, the intensity of the westerly wind current) and the amplitudes of the cosine and sine phases of a chain of superposed large scale eddies, respectively; aF and G stand for the symmetric and asymmetric external thermal forcing by the underlying earth surface (land and oceans); a and b are physical parameters.

(2) The Saltzman-Maasch model (Saltzman and Maasch 1988)

$$\begin{aligned} dX|dt &= -X - Y, \\ dY|dt &= -pZ + rY - sZ^2 - YZ^2, \\ dZ|dt &= -q(X + Z), \end{aligned} \tag{1.2}$$

where $X(t)$, $Y(t)$ and $Z(t)$ represent the global ice mass, the CO2 content and mean static stability of the world ocean (i.e. the Brunt-Vaisala frequency) whereas p, q, r, s are model parameters.

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