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Climate of the Romanian Carpathians

Variability and Trends

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Foreword

Mountain regions are fragile spots in many aspects, and they have always represented a key environment for the well being of the human communities. Mountains provide a substantial range of ecosystem services, like protection, biodiversity, water storage and supply, food, and recreation. At the same time, various natural and anthropogenic threats have increasingly endangered the sustainable development of such areas, while conservation and management strategies have been reinforced consequently. As a result of natural factors and anthropogenic bias, the climate shapes actively the mountain landscape, both at large and finer scales, with considerable consequences on any activity.

The Carpathian Mountains or Carpathians stretch over seven European countries. Along the history, different political, social and economical changes have modified the natural background, but common features have been also preserved. There is a real need for high quality, homogeneous and consistent data bases to address environmental issues, with applications in many fields.

About one third of the Carpathians lie over the territory of Romania, and the geographical location and morphological characteristics lead to important climatic differences between various sub-units. Conducted by a dynamic and competent group of Romanian climatologists, this study is a thorough and attractive investigation into the climate of the Romanian Carpathians, focusing mainly on the observed characteristics and variability along 1961–2010, by means of weather station records from Meteo Romania (National Meteorological Administration), which were quality controlled and homogenized within the project Carpatclim (Climate of the Carpathian Region). The authors have adjusted and analyzed the input data according to the objectives expressed in the introductory chapter, and the outputs and results are outstanding. *The Climate of the Romanian Carpathians. Variability and Trends* is the first comprehensive climatological study covering the entire Romanian Carpathians. Such a complex synthesis addresses both fundamental science and applications, becoming a precious tool for students, large public, stakeholders and policy makers. It brings up-to-date science for climatologists and for all mountain practitioners exploiting climatic information and I am strongly confident in its short and long term value.

Bucharest, Romania
March 26, 2014

Norel Rîmbu

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Contents

Chapter 1
Introduction

Mountain regions are a key issue at global scale, their importance having been recognized at the United Nations Conference on Environment and Development (Rio de Janeiro, 1992) and further underlined by designating the year 2002 as International Year of Mountains (IYM). The global warming put critical challenges to mountain environment and related ecosystem services as mountain regions proved to be particularly vulnerable to climatic fluctuations. From many perspectives, the Carpathian Mountains have a decisive role for the Central and South Eastern Europe, shaping the landscape, or influencing the culture and human development. This book tackles mainly the climate characteristics and the observed trends in the Romanian Carpathians (1961–2010), but it also presents estimations regarding the climate projections through the next decades (2021–2050). It is designed to address the needs constantly expressed by a large variety of users, from students and mass media to policy makers, land planning actors, water managers, and economic operators.

After this introductory overview, the reader may spot the theoretical framework, which supported the structure and the development of the book, emphasizing the key position of mountain areas in environmental research, and reviewing the existent literature. It has to be mentioned that this book is the first comprehensive synthesis on the climate of the Romanian Carpathians.

Based on a rigorous selection of outputs from previous publications, the main characteristics of the studied area are thoroughly approached in Chap. 3. The Romanian Carpathians and their geographical divisions are placed within the European context, concise geomorphologic and geologic settings are described, and the most significant hydrology, vegetation, and soil features are presented.

Both the meteorological and ancillary data, and the methods used in this book are in fully concordance with the international practice and standards, and the spatial and temporal resolutions were used in a flexible way for responding in the best manner to the purposes of this work. Chapters 4 and 5 are dedicated to the ample description of the datasets, ground meteorological network and methods specific to various applications, such as homogenization, statistics, spatialisation,

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and climate change analysis. The use of homogeneous data, the significant number of variables, and the gridding procedures contain a high level of originality, at least for the studied area.

The main factors shaping the climate of the Romanian Carpathians are treated in Chap. 6. The influence of the geographical location, topography, and regional atmospheric circulation are approached quantitatively, and carefully described for each variable.

The regional and temporal climatic patterns of the Romanian Carpathians during the present climate (observations and measurements), and for the future decades are consistently tackled in Chaps. 7, 8, 9 and 10. The analysis uses homogeneous datasets, satellite products, and outputs of Regional Climate Models, addressing mainly the average state of the climatic elements, but carefully exploring the extremes as well. The result is a comprehensive, thorough, and synthetic document on the climatic background and perspective of the area. The characteristics of the solar radiation, air temperature, precipitation, wind and snow are analyzed statistically, emphasizing the mean state, and the extreme situations, specific to each geographic division of the studied area.

The future projections of the temperature and precipitation are treated in the Chap. 10, based on the results of several European projects. It is revealed that a drier climate may be expected to set up over in the Romanian Carpathians, as a result of higher temperature during all the seasons and relatively stable precipitation amounts.

The book *Climate of the Romanian Carpathians. Variability and trends* comes to cover with high quality, relevant climatic information a territory of multiple scientific, economic, and natural interests. It has been based on sing the experience and the results of previous work developed by the authors themselves, but also the outputs of other scholars. Despite their national coverage, the outputs contain a definite regional, transnational and trans-disciplinary dimension, due to the direct impact of the Romanian Carpathian Chain on other environmental or societal factors like hydrology, atmospheric dynamics, and economy.

The significant technological and scientific progress in data acquisition, homogenization, and sharing was an essential support for our task, and we would like to express our gratitude to all those who believe they deserve it. We hope the reader will find this book useful, and a good starting point for future approaches.

Chapter 2
Theoretical Background

Abstract The chapter is organized in two sections. The first section overviews the main impulses, initiatives and achievements in global and European environmental research targeting mountain regions since the early 1970s until 2012 (the Rio +20 Conference). This section also highlights how the growing significance of the climate change issue in global environmental research agendas and of the potential climate change impacts in mountain environments, has promoted mountain regions to a next stage of importance, as they are currently widely recognized as "early indicators of climate change". The main achievements of the Mountain Research Initiative in promoting the research in the Carpathian region and building opportunities for future collaborations targeting this region are also emphasized. The second section outlines the main contributions to the knowledge of the climate and weather of the Romanian Carpathians. The survey of the Romanian specialist literature shows a general lack of comprehensive studies carried out on the Romanian Carpathians as a whole, only a few aiming at revealing the regional patterns of a distinct climatic feature, usually derived from short period of observations of less than 10 years.

2.1 Mountain Regions: Key Issues in Environmental Research

Joint scientific-political initiatives on mountain environmental research date back to the early 1970s. One of the first initiatives of global environmental research in mountain regions was the Project 6 of the United Nations Educational, Scientific and Cultural Organization (UNESCO) on Man and the Biosphere (MAB), focusing on the "Impact of Human activities on Mountain Ecosystems". This project proved to bridge the natural and social sciences by addressing four key-impacts on mountain environments (land use alternatives, large-scale technology, human settlements, tourism and recreation activities) and also, to contribute to the development of methods, transdisciplinary approaches and collaborations (UNESCO 1973). The final declaration of the UN Conference on Human Environments (June 1972, Stockholm) provided also a great stimulus for subsequent

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mountain research initiatives, even if mountain issues have been addresses indirectly. These early global impulses strengthened the opportunities during the 1980s, the 1990s and at the beginning of the twenty-first century, for setting up organizations, cooperation initiatives and conventions targeting different mountain regions, most of them still operational today e.g. the International Centre for Integrated Mountain Development (1983), the African (1986) and Andean (1991) Mountain Associations, Consortium for Sustainable Development of the Andean EcoRegion (1992), the Alpine (1991) and Carpathian (2001) Conventions.

Mountain research got a decisive impulse in 1992 at Rio de Janeiro, during the UN Conference on Environment and Development ("the Rio Earth Summit"), as a follow up of the 1972 UN Conference in Stockholm. The world's mountain regions gained significance as they were considered a priority altogether with other global change issues (e.g. climate change, desertification, deforestation). The awareness on the growing impact of human activities on mountain environments has increased significantly, further encouraging the interactions between science and politics. Recognising and emphasizing the global importance of mountain ecosystem services and goods, the Agenda 21 addressed the overall sensitivity of mountain ecosystems within its 13th Chapter, entitled: "Managing Fragile Ecosystems: Sustainable Mountain Development" (UN 1992). It is worth mentioning that the UNESCO recognized the importance of mountain regions several years before the 1992 Rio Summit, by promoting the contribution of these regions in several global programmes (MAB, United Nations University, World Climate Research Programme, International Geosphere-Biosphere Programme and DIVERSITAS: International Programme on Biodiversity Science) or specific programmes devoted to mountains (e.g. World Glacier Monitoring Service).

A wide range of efforts have been undertaken to promote mountain regions for creating opportunities for regional and global cooperation. On November 10th, 1998, the UN General Assembly declared the year 2002 the "International Year of Mountains" (IYM), as a living proof of the importance of mountain regions for the mankind. The IYM concept emphasized the activities related to the conservation and sustainable development of mountain regions. Its objectives aimed at promoting the interdisciplinary and integrated research on mountain ecosystems, the cultural heritage of mountain communities and peace initiatives in such areas, under international cooperation of neighbouring countries. The IYM proclaimed the day of 11th of December as the "International Mountain Day" (IMD), which has been celebrated since 2003. Proposing different themes yearly, the IMD aims to increase awareness on mountain regions issues and to develop partnerships for the sustainable development of these regions.

Later, during the World Summit on Sustainable Development held in Johannesburg (South Africa) in 2002, the concepts of IYM have been strengthened. In response, the Food and Agriculture Organisation (FAO) established in 2002 the International Partnership for a Sustainable Mountain Development. This partnership was designed to promote and support the national and international research initiatives on mountain regions, to strengthen building capacity and to implement strategies for the sustainable development of mountain ecosystems. These objectives were targeting particularly developing countries and those with a growing economy.

After 1992, mountain regions have received growing attention from three international global environmental change organisations – the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP) and the Global Terrestrial Observing System (GTOS). The joint forces of the IHDP, IGBP and GTOS programmes created the basis of a new research programme – the Mountain Research Initiative (MRI), funded by the Swiss National Science Foundation (SNSF). The objectives, approaches and research activities of the MRI were altogether defined in 2001, recognising that 'mountain regions may experience the impacts of the rapidly changing global environment more strongly than others' (Becker and Bugmann 2001; Dexler 2008). This initiative aimed at promoting and coordinating global change research in the mountain regions worldwide, focusing on the monitoring of environmental change in mountain environments, investigation of the consequences of these changes for both mountain and lowland regions, as well as on the sustainable management of land-use and natural mountain resources at local-to-regional scales. The MRI along with other specific global programmes targeting mountain regions worldwide such as the Global Observation research Initiative in Alpine Environments (GLORIA) and the Global Mountain Biodiversity Assessment (GMBA), stand as evidence of the continuation of efforts for further promotion of research initiatives.

MRI has produced in 2005 a valuable science-oriented compendium entitled "Global change in mountain regions – An overview of current knowledge", which provided an overview of research contributions focusing on the detection, understanding and prediction of global change impacts in worldwide mountain regions (Huber et al. 2005). This publication created the basis for a FP6 cooperation within the GLOCHAMORE (GLObal CHAnge in MOuntain REgions) Project, with a further support of the UNESCO MAB programme, which aimed at elaborating an integrated and implemental research strategy to improve the understanding of causes and effects of global change in mountain regions worldwide. The MRI core activities are currently oriented to promote and implement the GLOCHAMORE strategy, through the initiation and support of regional networks of global change researchers.

Networking on mountain issues advanced significantly after the Rio Earth Summit in 1992, providing a solid base for the future European research activities (Dax 2002): Mountain Forum (1996), Euromontana (1996), European Mountain Forum (1998), the Alpine Convention (Convention on the Protection of the Alps) (2003), Charter for the Protection of the Pyrenees (1995), the Carpathian Ecoregion Initiative (1998), the Carpathian Convention (2003), Forum Carpathicum (2010).

With the strong support of the scientific community, the Conference on "Global Change and the World's Mountains", held on October 2005, at Perth (UK), promoted the necessity for further investigations of global change effects on mountain ecosystems, recognising that "global change, and in particular global warming, has and will have serious impacts on policies, the biophysical environment, and the socio-economic conditions and livelihoods of people, particularly in fragile mountain environments, but also in the adjacent lowland areas" (Perth Declaration 2005).

The Millennium Ecosystem Assessment is another major global research effort initiated in the framework of IYM. Its synthesis report entitled "Ecosystems and Human Well-being" (Millennium Ecosystem Assessment 2005) was focused on the consequences of ecosystem change for human well-being. Mountain ecosystems are among the ten systems being evaluated within this assessment (chapter 24 "Mountain systems").

2.1.1 Mountain Regions and Climate Change

Documenting the main steps in the history of global mountain research, Messerli (2012) outlined that the growing significance of "climate change" for mountain water resources and of "biodiversity" and "ecosystem services" for both mountain and lowland populations. Schröter et al. (2005) emphasized the role of the scientific community in improving the awareness on the impacts of global environmental changes and climate change in particular, on the natural mountain ecosystems and their capacity to provide goods and services to the living in these regions and to the population of lowlands. Recent statistics have showed that 12 % of the World's population depends directly on mountain resources, while an even higher percentage uses precious mountain resources like water (FAO 2011).

Under the 2007 UN General Assembly Resolution 62/196 "the role of the scientific community, national governments and inter-governmental organisation is to collaborate with mountain communities in joint studies and address the negative effects of global climate change on mountain environments". Attempting to outline the need for coordinated adaptation strategies towards the expected climate change in the highly sensitive mountain environments of the world, the UNEP organised in 2008 at Padua (Italy) a Conference on "Mountains as Early Indicators for Climate Change". The conference goal was to provide support and to promote the exchange of up-to-date scientific research results concerning the changing climate signals and their effects in mountain regions worldwide. It was widely recognized that mountain regions are placed among the primary areas vulnerable to changing climate conditions.

Mountain ecosystems are emerging as vulnerable to climate changes (Beniston 1994; Sonesson and Messerli 2002). These regions were exposed to above-average warming during the twentieth century (IPCC 2007) and they are expected to be further exposed to climate warming and associated extremes over the twenty-first century. Nogues-Bravo et al. (2007) indicate that the average warming projected in mountain areas across the globe by 2055 is expected to range between 2.1 and 3.2 °C. Furthermore, Körner (2009) outlined that mountain regions are valuable early indicators of change in biodiversity.

Recognising the importance of mountain areas for the environment, society and economy of the European continent, where 36 % of its surface is mountainous, the European Environment Agency (EEA) outlined the vulnerability of mountain ecosystems to threats related to the land abandonment, intensifying agriculture, impacts of infrastructure development, unsustainable exploitation and last but not least, climate change and the related extremes (EEA 2010). EEA elaborated several reports (e.g. EEA 2008, 2009, 2010) addressing the environmental and climate change issues in various European mountain regions, including the Carpathians, which are considered a unique bio-geographic region (EEA 2008) of the continent. The overall findings of these reports suggested that the European mountain regions experienced severe climate change effects over the last decades, mostly expressed by glacier retreat, notable temperature increases, changes in precipitation regime and distribution.

The AR4 IPCC report (Trenberth et al. 2007) gave emphasis to mountain regions, reporting that these regions are particularly vulnerable to climate changes. IPCC outlined the importance of mountain glaciers which proved to be highly sensitive to temperature and precipitation oscillations, by considering them as the best terrestrial indicators of climate change.

The recognition of mountain regions among the highly vulnerable regions of the globe to climate change effects is also depicted in a distinct paragraph (94) within the Rio +20 Draft Agenda ("The future we want", January 10, 2012), which states: "We recognise that mountains are highly vulnerable to global changes such as climate change, and are often home to some communities including indigenous peoples, who although have developed sustainable uses of their resources, yet are often marginalised, sometimes with high poverty rates, exposure to natural risks and food insecurity. We recognise the benefits derived from mountains and their associated ecosystems. We also recognise the need to explore global, regional, national, and local mechanisms to compensate and reward mountain communities for the services they provide through ecosystem protection".

2.1.2 Mountain Research in the Carpathian Region

In response to the research priorities defined within the GLOCHAMORE research strategy, a MRI Europe network was established in 2007, for supporting, promoting and coordinating the research activities in European mountain regions. The MRI Europe endorsed in 2008 the SC4 network (Science for the Carpathians), with the purpose of connecting scientists and their research from the Carpathian countries, identifying key issues for the Carpathian mountain research and also, building opportunities for future collaborations with partners from outside the Carpathians. The launch of the S4C initiative created the base for the development of a comprehensive "Carpathians Research Agenda (2010–2015): Integrating nature and society towards sustainability" (Ostapowicz and Sitko 2009; Kozak et al. 2011). The departure point of this agenda resulted from the GLOCHAMORE strategy

(Björnsen Gurung 2006). The Carpathians gained substantial visibility after the launch of the Forum Carpathicum (2010, Kraków), an interdisciplinary conference devoted to the Carpathian region, with the purpose of identifying the status and emerging issues in the current and future research, which bring together scientists, practitioners and stakeholders.

In April 2009, during the International Conference on "Identifying the Research Basis for Sustainable Development of the Mountain Regions in Southeastern Europe", held in Borovets (Bulgaria), it was launched the South Eastern European Mountain Research Network (SEEmore). The SEEmore goal was to provide support for scientific networking, research coordination and collaboration in mountain regions of the South-Eastern Europe. Since commissioned, the SEEmore confronts challenges associated to the rapid transformation in land use, biodiversity and bio-productivity and tourism due to the global changes and particularly due to the local impacts of climate change.

European mountain regions were generally under the focus of large research projects, funded mainly within the European framework (FP) and Interreg programmes. The climate change impacts on European mountain regions proved to be a target topic of several completed or ongoing research projects: e.g. FP4 PACE (Permafrost and climate in Europe: climate change, mountain permafrost degradation and geotechnical hazard), 1997–2001; GLORIA (Global Observation Research Initiative in Alpine Environments), 2004–2011; FP6 CLAVIER (Climate Change and Variability: Impact on Central and Eastern Europe), 2006–2009; Interreg III CLIMCHALP (Climate Change, Impacts and Adaptation Strategies in the Alpine Space), 2006–2008; FP6 CIRCLE (Climate Impact Research Co-ordination for a Larger Europe), 2005–2009; FP7 ACQWA (Assessment of climatic change and impacts on the quantity and quality of water), 2008–2013; FP7 CIRCLE-2 (Climate Impact Research & Response Coordination for a Larger Europe – 2nd Generation ERA-Net – Science meets Policy) with CIRCLE-2 MOUNTAIN, 2010–2014 etc. It is worth mentioning that, the Carpathians have been rarely the target region in projects focusing on environmental or climate change issues. Other relevant EU projects tackling the climate variability and climate change impacts in the Carpathian Mountains region were: the TATREX Polish-Czechoslovakian Programme (1981–1982), Climate Changes and Variability in the Western Carpathians project, CARPIVIA (2010–2013) and CarpathCC (2010–2013).

The importance of the Carpathian region at European scale has been widely recognized since 2003, with the launch of the Carpathian Convention. Later, in 2007, the outputs of a bottom-up collaborative and consultative project were officially released, with the support of the UNEP's Division of Early Warning and Assessment (DEWA)/GRID-Geneva and the Regional Office for Europe (ROE), under the form of a comprehensive environmental assessment and future outlook addressing the entire Carpathian Mountains region (Carpathians Environmental 2007). This synthesis put together the results obtained throughout national climate research projects from seven European countries (the Czech Republic, Hungary, Poland, Romania, Serbia and Montenegro, the Slovak Republic and Ukraine).

Reviewing the status of global change research in the Carpathians, Björnsen Gurung et al. (2009) identified the main gaps in the main research fields such as climatology, hydrology, land use and land cover change, forestry, biodiversity and conservation, tourism and ecosystem services. The authors emphasized the need of collaboration actions targeting the Carpathian Region as a whole. The recommendations to overcome the gaps identified in the field of climatological research were to "establish of a joint international climatological database of long-term data, to set up additional meteorological stations in high-elevation areas and to make data freely available for scientists".

In response to the need of a pan-Carpathian research initiative, the JRC Carpatclim project (2010–2013) is an example of effort meant to compile and share climate data on a joint platform, overcame the lack of a high-quality and unitary database for the entire Carpathian Mountains region, aiming also at providing comprehensive scientific information for future climatological studies in the region. The project produced and released on June 2013 an open-access digital climate atlas of the Carpathian Mountains region, available with a $0.1 \times 0.1°$ horizontal resolution. The project outputs were based on homogenized meteorological datasets from ten European countries (including Romania), covering the 1961–2010 period, using a standard methodology.

2.2 Weather and Climate of the Romanian Carpathians: A Literature Review

Scientific climatology has emerged once visual and instrumental observations were being used in line with the international methodology. The first Romanian climatologist considered to have made significant contributions to this science is Ștefan C. Hepites. The data yielded by instrumental measurements at weather stations, processed and published later were used to elaborate several climate works of localities, regions or of the whole Romanian territory.

The first climatological works signed Ștefan C. Hepites was published in the *Annals of the Romanian Academy* (*Analele Academiei Române* in Rom.) between 1895 and 1902, and republished under the title *Materials devoted to Romania's climatology* (*Materiale pentru climatologia României*, in Rom.), for example, *The climate of Sinaia Town* (Hepites 1896) (*Clima Sinaiei*, in Rom.), one of the first mountain climatology studies in this country. The author makes a series of considerations on the characteristics of the main climatic variables (i.e. air temperature, relative atmospheric humidity, atmospheric precipitation, atmospheric pressure, wind and nebulosity), briefly outlining the days when various meteorological phenomena were recorded (e.g. thunderstorms associated with hail or snow hail, fog, snowfalls, snow days) and included in the Miscellanea chapter. The study is based on the results of measurements performed at Sinaia Monastery station (879 m a.s.l.), between 1886 (when the station was set up) and 1895.

Other studies on the climate features of the mountain region, published between the 1921 and 1930 interval are due to Enric Otetelişanu. The author discusses the influence of pressure centers in various parts of Europe and their effect on the climate of all of Romania's regions, illustrating his considerations with temperature and precipitation data, and analyzing the effects of geographical factors on the country's climate, including the Carpathian Mountains. Having in view that the mountain relief covers one-third of Romania's territory, the meteorological observations conducted at different elevations did contribute, yet much later (since 1925), to emphasizing the influence of the Carpathian Chain on the climate of the whole country. In 1929, Constantin A. Dissescu elaborated two studies with focus on air frost phenomena in the alpine areas of the Carpathians Dissescu (1929a) and on temperature variation with elevation in the Bucegi Massif Dissescu (1929b), both published in the Monthly Meteorological Bulletins of the Central Meteorological Institute.

The first and most comprehensive Romanian mountain climate monograph was elaborated in 1951 by Ştefan M. Stoenescu, focusing on the Bucegi Mountains (the Southern Carpathians).

The implementation of the new measurement scheduled in 1960 explains the progresses made later in the area of scientific climate research.

Some synthesis works published during the 1960s and highlighting the general features of Romania's climate included referees to the Romanian Carpathian region: e.g. *The climate of Romania*, 1961–1962 (*Clima României*, 1961–1962, in Rom.), the first synthesis of the country's climate; Topor (1963); *The climatological atlas of the Romanian People's Republic*, 1966 (*Atlasul climatologic al R.S.R.*, 1966, in Rom.).

The scientific works published in the periodicals of the Meteorological Institute (later Institute of Meteorology and Hydrology and currently the National Meteorological Administration) after 1960 stand proof to a fruitful scientific activity. Other researchers were dealing with some aspects, still topical today, such as the long-term variations of key climatic variables subject to change (air temperature and precipitation). Some of the remarkable works elaborated by Ştefan M. Stoenescu focused on climate oscillations and climate change in Romania (Stoenescu 1959, 1964), were actually the first approaches to these issues in this country. The endeavours of that period also had in view extreme phenomena, such as snowstorms (the severest twentieth-century event occurring in February, 1954), heavy rainfalls, snow avalanches, rime, sleet and glaze.

Climate research has been progressing in line with practical interests. The climatologists started to give more emphasis to the major influence of the underlying terrain on the characteristics of physical processes and boundary layer conditions (Topoglimatologia României. Bibliografie selectivă adnotată 1987). Interests in this area succeeded in advancing a new research direction in applied climatology both worldwide and in Romania, namely, topoclimatology. The first works on this topic were devoted to establishing the terminology specific to this new research direction in Romania. Vintilă Mihăilescu was the first in Romania to propose the term *topoclimate*, in a paper published in Russian (Mihăilescu 1957), defining it as "the climate of the contact zone of planetary covers considered over small areas, thus making it possible to analyze at local level the relationships between the physical phenomena in the atmosphere and the other components of the geographical complex or environment (firstly, landform and secondly, water, vegetation, etc.)". Later, together with Ștefan C. Stoenescu, elaborated the second edition of the *map of climate and topoclimate of Romania* (Mihăilescu and Stoenescu 1960), bringing concise data and quantitative indexes to sustain each individualized topoclimate. This map on the scale of 1:3,000,000 depicts the climatic potential of several topoclimatic units, among which the mountainous topoclimatic belt with its sub-belts: alpine, subalpine and the mountain proper.

Several contributions to this new research direction emphasized some aspects related to the topoclimatic features of some cities, spas and tourist resorts (e.g. Bogdan and Mihai 1977; Teodoreanu 1981, 1997; Bogdan and Niculescu 1996a) and the role of the subjacent topographic surface as a topoclimate generator (e.g. Niculescu 1993; Bogdan and Niculescu 1996b).

The Romanian Carpathians as a whole, or their three component units, have fairly seldom made the object of complex mountain climatology studies (syntheses). Regional climate studies, targeting smaller geographical areas within the Romanian Carpathians, were started mainly after 1960 and focused preferentially on certain climatic elements, or on the natural factors influencing them:

- **Air temperature regime** – e.g. Dissescu (1929a, b) and Șorodoc (1960), temperature distribution with altitude in the Bucegi Mountains; Stoenescu and Dumitrescu (1965), the frequency and daily average temperature in the Bârsa Depression; Dumitrescu et al. (1971), the frequency of positive minimum winter temperature in the Giurgeu, Ciuc, Bârsa, Făgăraș and Sibiu depressions; Bogdan and Mihai (1972), thermal amplitude in the Romanian Carpathians; Neacșa et al. (1972), the variation of thermal parameters in relation to topographic mountain features; Dobrea (1972), air temperature characteristics in the mountain sector of the Prahova Valley; Oprescu and Bogoriță (1976), air temperature distribution in the Lotru-Parâng Mountains (Southern Carpathians); Măhăra and Linc (1993), thermal anomalies in the Codru-Moma Mountains (Western Carpathians); Dragotă and Gaceu (2005), extreme temperatures in the Bihor and Vlădeasa Mountains (Western Carpathians); Gaceu (2004), air temperature distribution in the Bihor and Vlădeasa Mountains; Popa and Cheval (2007), early winter temperature recontruction of Sinaia area (Southern Carpathians) derived from tree-rings of silver fir; Cheval et al. (2011), July surface temperature gradient in the Romanian Carpathians, Croitoru et al. (2011), change-point analysis if temperature variability at high elevation sites etc.;
- **Precipitation regime** – e.g. Marcu (1967), the precipitation regime in the Postăvaru Massif and Bârsa Depression; Teodoreanu (1972), the frequency of 1-day maximum precipitation in the Southern Carpathians; Neamu and