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Fundamentals of Meteorology

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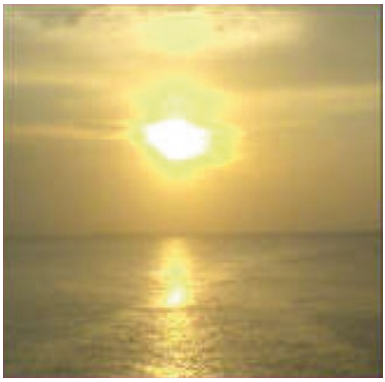
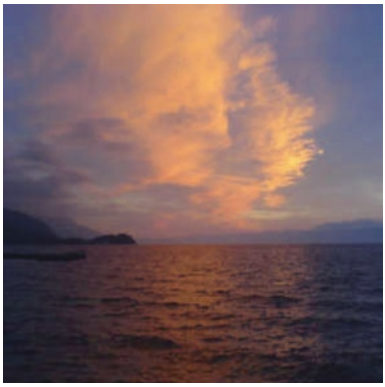
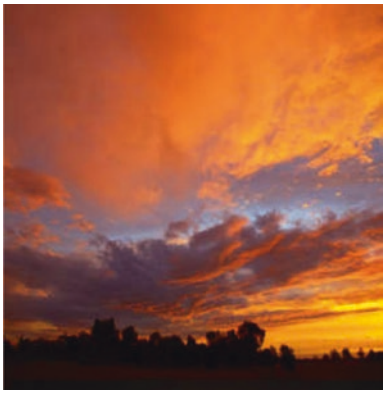
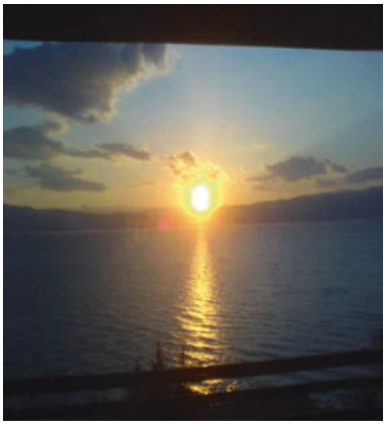
Preface









This book is dedicated to our planet's atmosphere, our great challenge and inspiration. It is just an extended arm of our great fascination, "Meteorology." The book opens the doors to the achievements made in this new millennium, making linkage between contemporary science, technology and society, and the pathways how meteorology contributes to the development of science. *Fundamentals in Meteorology* incorporates all significant eras, from ancient times to the present days. It explores important atmospheric phenomena and physical processes from a local to global scale and from seconds to years. In addition to the general topics, our novel book incorporates other important ones such as the atmospheric boundary layer, atmospheric waves, atmospheric chemistry, optics, and electricity.

As the weather keeps changing time to time and from place to place, sudden worsening of its conditions can change our mood, especially when it is unfavorable,

unstable, and severe. But when the sun and the blue sky reappear, the rays of happiness return our confidence, which is a sufficient reward for this modest work. Finally, we invite you to join us on a journey through the atmospheric space and bear witness to these wonderful events occuring within our atmosphere and even beyond.

Wien, Austria — Vlado Spiridonov
Belgrade, Serbia — Mladjen Ćurić

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Finally, we would like to thank our families for their unreserved support, patience, and understanding throughout the years for this hard and delicate work such as writing a book.

Thank you.
By authors

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About the Authors

Mladjen Ćurić was born in Zabljak, Montenegro. He completed his Bachelor in Hydrometeorology l in Belgrade and was awarded top marks. Dr. Ćurić graduated in meteorology from the University of Belgrade, where he also completed his post-graduate study and Ph.D. thesis. From 1977 to 1980, he attended Colorado State University, Fort Collins, USA, through several study visits; Imperial College, London, England; Manchester University, England; and The Meteorological Office, Bracknell. From 1972 to 1978, Dr. Ćurić was appointed as Teaching Assistant, Department of Physics and Meteorology, Belgrade University, and since 1990 he has been a Full Professor at the Institute of Meteorology, Belgrade University. From 1979 to 1982, Dr. Ćurić was Director of the Institute of Meteorology, University of Belgrade. From 1982 to 1984, he was Vice Dean in the Faculty of Physics, University of Belgrade. Dr. Ćurić was also nominated as a Member of the Executive Committee of the International Commission on Clouds and Precipitation-IAMAP from 1988–1996. Since 1990, he has been a Member of the Executive Committee of the National Association of Environment Protection. Dr. Ćurić was Vice Dean at the Faculty of Physics from 1996 to 1998 and from 2004 to 2007.

His professional and scientific interest are the fundamental topics in meteorology, that is, dynamics of atmosphere, cloud physics, applied meteorology and

hydrology, weather modification, and environment protection. Dr. Ćurić is the author of several books and author and co-author of more than two hundreds papers, mainly in international reviewed journals (*Journal of the Atmospheric Science*, *Quarterly Journal of the Royal Meteorological Society*, *Tellus*, *Journal of Applied Meteorology*, *Atmosphere-Ocean*, *Theoretical and Applied Climatology*, *Atmospheric Research*, *Meteorology and Atmospheric Physics*, *Journal of Geophysical Research*).

Vlado Spiridonov was born in Skopje. He completed primary school in Grigor Prlicev, secondary school in Rade Jovcevski Korcagin, and high school at the Institute of Physics, the Faculty of Natural Sciences, St. Cyril and Methodius University, Skopje. Dr. Spiridonov received specializing Sci., M.Sc., and Ph.D. degrees from the Institute of Meteorology, Physical Faculty of the University of Belgrade.

In 2004, the National Research Council of Canada granted a Postdoctoral Fellowship to Dr. Spiridonov at Meteorological Service of Canada, The Air Quality Modelling Branch.

In the same year, the Government of the Republic of Macedonia appointed Dr. Spiridonov as Director General of the Hydrometeorological Service and the Permanent Representative of the Republic of Macedonia to the World Meteorological Organization.

In April 2007, he was appointed as Assistant Professor in Meteorology at the Faculty of Natural Sciences and Mathematics, while in 2012 he became Associate Professor in Meteorology, and still continuing, at Ss Cyril and Methodius University in Skopje. Dr. Spiridonov is a Faculty Member in the National Council of Climate Change in Macedonia as well as the Representative of the Commission of Atmospheric Science at the World Meteorological Organization.

From 2017 to 2019 Dr. Spiridonov was a Visiting Professor of Meteorology at the University of Vienna, Faculty of Earth Sciences, Geography and Astronomy, Department of Meteorology and Geophysics, as a proxy for General and Theoretical Meteorology. He has made a significant contribution in developing and promoting education and learning platforms by implementation of innovative approach and

novel solutions in academic practice at UNIVIE. His research activities and valuable scientific publication record within a 2 years were highly acknowledged by the Department of Meteorology and Geophysics.

He has participated in several international scientific conferences, organized international events and symposiums, and has given presentations, scientific lectures, and invited talks to plenary sessions and seminars worldwide.

Dr. Spiridonov has published many scientific papers in international journals, five books, and has won several awards (e.g., Innovation of the Year-2000 in Macedonia, Gold medal with mention at EUREKA-2000 exhibition in Brussels, a Genius Prize by Hungarian Association of Innovations, and GRAND PRIX in 2002 on 4th GENIOUS International Invention Exhibition in Budapest for the invention associated with fog dispersal method).

His present research is related to the development of a new storm alert system using a non-hydrostatic mesoscale forecast model, a Cloud Resolving Model, and suitable diagnostic tool for calculation of severe weather indices. Many sensitivity studies indicate that this novel method shows good performance in more accurate evaluation of severe storms and the local-scale hazards impact over area of interest as valuable information for severe weather alert worldwide.

Chapter 1
Introduction

Meteorology belongs among the oldest scientific disciplines. It has a long-lasting history that reaches back to the distant past of the human civilization. From the beginnings of life, people have been trying to adapt to the atmospheric behaviour, to create a more comfortable life, and to control those conditions that endanger or make life uncomfortable. There is no doubt that today meteorological science has a tremendous importance around the world. Every day, people are faced with various manifestations of weather. Depending on weather conditions, they adapt their planned activities. Weather manifestation is closely related to the status of the atmosphere, which has a wave nature. The scientific discipline that examines atmospheric phenomena, atmospheric structure, composition, atmospheric features and phenomena, and the important processes that occur in a thin surrounding layer of the atmosphere-troposphere, water, and air including the future state of the atmosphere is referred to us as *"meteorology"*. Basically, meteorology examines the physical processes that occur in the atmosphere. Hence, this scientific discipline is often referred to as the *"Physics of the Atmosphere"* (see Spiridonov 2010; Spiridonov and Ćurić 2011; Andrews 2010; Salby 1996). Meteorology as an interdisciplinary science cuts across a various number of natural disciplines. Thus, there is a great interest in meteorology, especially in the last two to three decades, when the global community is facing with global warming and climate change with extreme weather events. During this period many comprehensive textbooks, scientific publications, and studies were dedicated to this contemporary and interdisciplinary science (e.g. Andrews 2010; Ackerman and Knox 2007; Ćurić 2006; Lutgens and Tarbuck 2009; Salby 1996; Anthes 1996).

The key motivation for writing this contemporary textbook arrives from the need for comprehensive and systematic way of describing all the important atmospheric phenomena and processes that constitute the modern concept of meteorology. The purpose is to offer an advanced understanding and significant knowledge of the important topics relating to these natural environmental processes. Standard, theoretical, and experimental approach gradually adapts the reader into the subject and introduces the problems which emerge. Furthermore, the essential elements of

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mathematics are used, in order to easily present certain phenomena and processes in the atmosphere. We have tried to incorporate all important topics in the modern concept of the physics of atmosphere meteorology. The writing is primarily intended for students of the atmospheric and environmental sciences and physics of the atmosphere meteorology or those who attend the general course in meteorology. Yet again, this book is designed for a wider circle of readers, starting from primary, secondary, and higher education to all those interested in meteorology who want to find useful information, content, and interpretation of certain global phenomena and processes occurring in the atmosphere of our planet. With an exceptionally readable, comprehensive, and extensive illustrative and interesting approach with the standard appropriate mathematical concept, it describes the basic characteristics of the atmosphere, including weather, climate, and climate change. The book begins with the definition of the subject and the tasks of meteorology, methods of research, classification of meteorology, and the relation between meteorology and other sciences. It also contains chapters on the historical overview, structure and chemical composition of the atmosphere, energy and radiation in the atmosphere, the energy budget of the Earth, the basis of the thermodynamics of the atmosphere, air temperature, and its variations. The book covers all the major topics of atmospheric moisture processes (e.g. air humidity, condensation and formation of clouds, their classification as well as an explanation of the process of formation of precipitation). It also deals with chapters devoted to air pressure and winds, atmospheric statics, planetary boundary layer, atmospheric dynamics, turbulence, the global atmospheric circulation, air masses and fronts, cyclones, anticyclones, and tropical cyclones. The book also contains basic information about natural disasters related to weather, water and climate, atmospheric optical phenomena (photometers), and atmospheric electricity. Climate and climate change, complexity of climate system, climate models, the modern watching of climate change, greenhouse effect, and global warming are considered with a special attention. A chapter in this book is especially devoted to the methods and techniques of analysis and weather forecasting development and application of numerical weather prediction. The 25th novel chapter briefly introduces the readers in atmospheric chemistry, aerosols, and the factors affecting the pollution source of atmospheric gases and aerosols. The last chapter describes the meteorological measurements and observations, modern instruments and devices used to measure atmospheric phenomena, radar and satellite measurements, and observations of the atmosphere.

References

Ackerman, S. A., & Knox, J. A. (2007). *Meteorology: Understanding the atmosphere* (2nd ed., 528 pp). Brooks/Cole.

Andrews, D. G. (2010). *An introduction to atmospheric physics* (2nd ed., p. 237). Cambridge: Cambridge University Press.

Anthes, R. A. (1996). *Meteorology* (7th ed., 224 p). Pearson.

Ćurić, M. (2006). *History of meteorology (monography)* (pp. 563 (1, 2)). Belgrade: BIG Press.

Lutgens, F. K., & Tarbuck, E. J. (2009). *The atmosphere: An introduction to meteorology* (12th ed., 505 pp). Pearson.

Salby, M. L. (1996). *Fundamentals of atmospheric physics* (pp. 627 (4,5 11, 14)). San Diego: Academic Press.

Spiridonov, V. (2010). *Meteorology* (pp. 317). ISBN 976-9989-57-642-331, COBBIS.MK-ID 79389450.

Spiridonov, V., & Ćurić, M. (2011). *An introduction to meteorology* (pp. 241). ISBN 978-608-65175-0-2 COBISS.MK-ID 83607306.

Chapter 2
Meteorology as a Natural Science

Meteorology is the branch of science which studies the atmosphere of our planet; its structure, composition, and properties; the physical processes closely related to the Earth's surface, water, and air; various weather phenomena; weather and climate; and the future state of the atmosphere (Lindzen et al. 1990; Ackerman and Knox 2007; Ahrens and Henson 2016).

2.1 Definition of the Atmosphere

According to the AMS glossary of meteorology, Earth's atmosphere is a gaseous envelope gravitationally bound to our planet Earth (Fig. 2.1) (Glickman 2000). In order to determine its status and a behaviour at a given time, it is necessary to conduct observations at a different point, not only at the Earth's surface (surface observations) but also at a certain height above sea level (upper air observations). From here comes the necessity to organize a special meteorological station network and aerological observation, equipped with suitable instruments and apparatus. Moreover, there are special observatories for detailed observation and monitoring of certain electrical, optical, and sound phenomena, the turbulence in the atmosphere, and certain physical processes in clouds. Generally, in studying physics, the laboratory experiment appears as the primary used method. On the other hand, the meteorological laboratory is the atmosphere itself. In research applied in physics, conditions can be changed to introduce or eliminate certain factors in order to adopt some laws.

Unlike physics, in meteorology such changes are not possible because numerous secondary factors that affect a phenomenon or processes cannot be isolated. As the scientific discipline, meteorology has the following tasks:

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Fig. 2.1 The Earth's atmosphere

1. To identify and describe the processes that emerge in the atmosphere in a qualitative and quantitative manner
2. To explain these phenomena and based on the obtained data to establish the laws governing these processes
3. By applying these laws, to develop secure and reliable methods to predict their future development in a period
4. To develop effective methods for modifying natural atmospheric conditions based on personal needs, interdisciplinary application of meteorology in all economic sectors (e.g. energy, transport, health, environment, tourism), and other important activities

Meteorology is the contemporary natural science that is applied in various sectors (e.g. water management, industry, energy, agriculture, transport, health, tourism, etc.).

2.2 Methods of Research of the Atmosphere

In the current stage of development, meteorology as a natural science offers four methods of scientific research:

1. Method of observation in natural conditions
2. Method of experiments, which in a wider sense means laboratory measurements and research in natural conditions, so-called field experiments
3. Method of theoretical analysis based on the general laws of physics, the physical principles (Blake and Robson 2008), and exploitation of mathematical apparatus
4. Numerical methods for solving processes and phenomena considered a subject of meteorology (atmospheric models)

A wide application in meteorology has the experimental method of measurement and monitoring, in such cases when a specific data for scientific research purposes (Antarctica, Arctic, oceanographic observations, etc.) are required.

2.2.1 *Experimental Method of Research*

The experiment has a significant place in meteorology. Certain atmospheric phenomena, such as lightning, cloud formation, and polar lights, could be monitored in the laboratory conditions. In meteorology a huge amount of data that are subjected to processing and analysis could be collected through observation and experiment. In that view, the statistical method has the primary importance. It allows, by way of averaging, to exclude random sides of separate atmospheric phenomena and to separate primary direction with its characteristics. Statistical method of correlation represents statistical measure that describes the size and direction of a relationship between two or more meteorological variables. This method quantitatively expresses the extent of that relationship. However, statistical methods do not explain in more detail these relationships. For these reasons, the ultimate need is to apply an essential mathematical-physical analysis based on physical laws, specifically the physical and mathematical relations for description of the atmospheric behaviour.

2.3 Relationship Between Meteorology and Other Sciences

As a planet, Earth is consist of three substances: gas (atmosphere), liquid (hydrosphere), and solid (lithosphere). Physical-chemical processes that take place within them are now taught by independent studies. All these components are integrated under a common name known as *"geophysics"*. Consequently, meteorology is the group of geophysical sciences, and therefore it is closely related to other sciences of that group, such as Earth physics and oceanography. Since a long time ago, the linkage between meteorology and astrophysics, and more specifically between meteorology and physics of the Sun, is established and reinforced. Regardless of the numerous links to other sciences, according to the nature of task solution and methods used, meteorology is a physical science. It can be successfully developed only based on achievements in physics, more precisely, its main branches: mechanics, thermodynamics, hydrodynamics, aerodynamics, dynamics, and others. Therefore, there is no doubt that meteorology may rightfully be called physics of the atmosphere. According to the International Union of Geodesy and Geophysics (IUGG), meteorological science studies only a layer of the atmosphere in a shallow vertical space up to a height of 20 km. The rest of the atmospheric studies belong to so-called "*Aeronomy*". Aeronomy is the science of the upper part of the atmosphere, where dissociation and ionization are very important (Brasseur and Solomon 2005). This kind of division is obviously not appropriate because the processes in the atmosphere are interconnected. Thus, it is impossible to observe separately the wave motions that characterize the dynamics of the mesosphere and the lower thermosphere from the wave motions in the lower atmosphere, because these are interrelated motions. Or, atmospheric discharges in the troposphere result in spectacular electrical phenomena, such as blue jet, elves, and ring discharges (see Fig. 2.2).

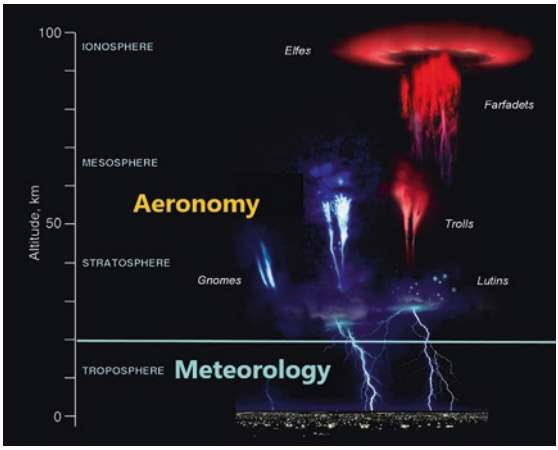

Fig. 2.2 The electrical discharges in the troposphere are related to that in stratosphere and mesosphere

2.4 Classification of Meteorology

Dynamic meteorology, physical meteorology, and applied represent three scientific branches focused on studying the fundamental principles, the atmospheric processes, and the application in various sectors.

Dynamic Meteorology. Dynamic meteorology studies the movements in the atmosphere using the laws of the dynamics and thermodynamics of the atmosphere. These basic laws applied to the atmosphere become very complicated, especially in situations where clouds are formed. The main task of this branch of meteorology is to provide a theoretical basis for understanding the effects of atmospheric movements on the weather and climate from the smallest to the largest. Within dynamic meteorology, a numerical weather forecast is being developed which solves the equations of the dynamics and thermodynamics of the atmosphere by numerical methods, since in most cases their solutions cannot be found by analytical methods. It is the science of dynamics of the atmospheric processes (Fig. 2.3). It is a fundamental discipline in meteorology where the complex meteorological processes and phenomena are interpreted in theoretical way using the fundamental principles of fluid dynamics and thermodynamics. The physical quantities that characterize the state of the atmosphere are temperature, density, pressure, etc.

Physical meteorology explains the physical processes in the atmosphere, such as solar radiation, absorption, reflection and scattering, and outgoing terrestrial radiation. It studies the cloud physics (see Fig. 2.4), aerosols, precipitation, atmospheric moist processes, and near surface processes such as mixing, turbulence, and friction.

Applied meteorology includes a wide range of individual scientific disciplines which deal with a specific application of meteorology in many sectors: transport, health, environment, agriculture, and water economy (Fig. 2.5). In the following

Fig. 2.3 Dynamical meteorology

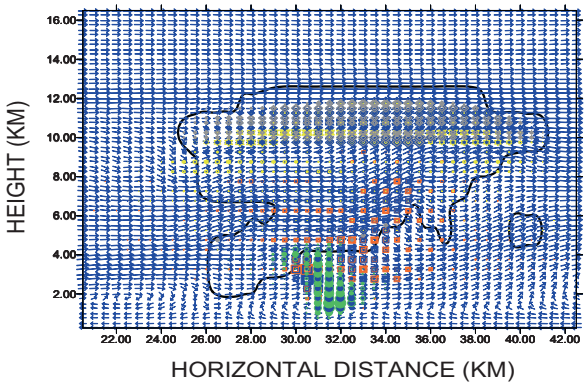

Fig. 2.4 Physical meteorology

text, a brief description of each individual branch of the applied meteorology is given.

Synoptic meteorology is a branch of applied meteorology whose name is derived from the Greek word synopsis, which is understood. This branch of meteorology aims to forecast the weather. Synoptic meteorology analyses processes in the atmosphere based on measurements and observations recorded on geographic maps for places where measurements are made at a point in time, so-called synoptic maps. The modern weather forecast is increasingly based on a numerical forecast, but still with the decisive role of man in interpreting the synoptic situation that arises based on drawn diagnostic maps and diagrams, products of different numerical models, and radar and satellite images. *Synoptic meteorology* is the science of weather prediction (e.g. Lackmann 2012; Barry and Carleton 2001; Bott 2012). The basic method is synoptic, and it consists of an analysis of atmospheric phenomena and processes with the help of special maps with a scale on which the data are caused by meteorological observations carried out at different points on Earth. These maps are called synoptically charts. The name derives from the Greek word "synopsis" which means "entry", thus enabling to obtain a representation of time over a wider region, drawn on the map, and to provide forecasts for future situations.