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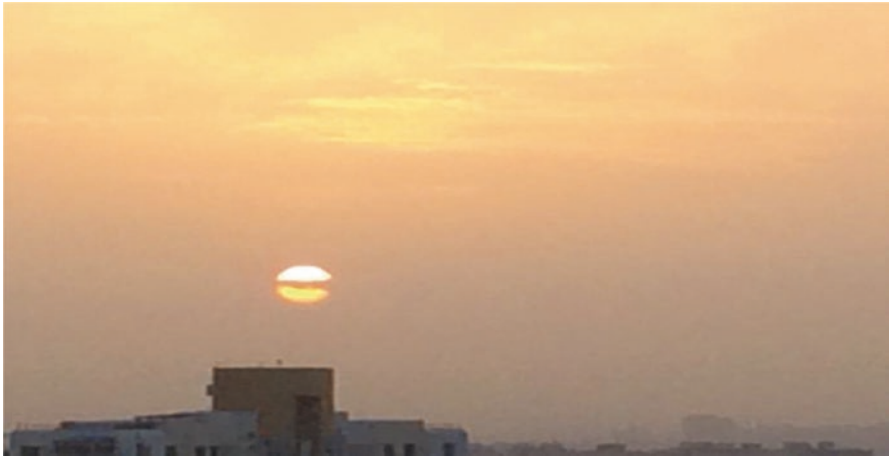

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Preface

Changes in the natural environment of the planet Earth, including its climate, have fascinated mankind all through the ages. The modern scientific understanding of natural processes that govern the functioning of the Earth system has provided sufficient knowledge to understand its present climate, including its evolution and future changes. The developments of the last few centuries have culminated into a system of monitoring and generation of global data sets, and enhancement in the basic theoretical understanding of complex processes involved in the science of Earth's climate. As a result of these efforts many holistic earth system models have evolved during the last few decades. These models have proven to be successful in generating plausible scenarios of future climates and highlighting the role of human interference in climate change. Realizing the role of anthropogenic influences on climate change, the last few decades have resulted in unprecedented activity and interest in the phenomenon of climate change in scientific, social, and political circles. This understanding and awareness has brought the issues of climate change impacts, mitigation, adaptability, and remedial measures at the forefront of all developmental activities with a focus on conserving the environment and the sustainability of natural resources. In spite of these accelerated developments, the major stakeholders with serious concern for their future as well as that of the generations ahead lack basic information and understanding on the subject to grasp and sensibly react to the issues in a broader perspective.

An academic career of almost half a century in the field of Earth system science has provided me an opportunity to be closer to many scientific ideas, deliberations, discussions, and differences of perceptions and goals at global and regional levels on climate change and other allied issues. It is, therefore, natural that the idea of writing a book as a basic source material on the subject suitable for a wide spectrum of scientifically oriented readers has always been in my mind. The opportunity to write this book acquired its renewed vigor after I joined the faculty at the Department of Atmospheric and Space Sciences at the Savitribai Phule Pune University. This has renewed my contacts with interested colleagues and students within and outside the university, and has created a sense of enthusiasm and confidence to take up this task as a joint effort. My coauthors, Dr. Pradeep Kumar, Dr. J.V. Revadekar, and

Dr. Narendra Singh have not only contributed in the subjects of their interest but also in every stage of the manuscript preparation. I may like to emphasize that in every sense this material is a joint contribution by all of us and this endeavor has enriched our joint research and teaching experiences.

Any writing in the subject with an intended wide spectrum of readership will not be able to fulfill its purpose unless it contains specific examples from a climate-sensitive target area. The authors have selected the region of Western Himalaya, possessing a unique weather system, large forest cover, extensive mountain ranges with rivers, glaciers, and snow cover as well as a highly fragile ecosystem for detailed discussion and illustrations. Western and Central Himalaya, the highest and largest mountain ranges of the world, are the major source of fresh water to many countries of the South Asian region. The weather and climate of Himalaya plays an important role in the atmospheric general circulation systems which affect the large population living in the region and its biodiversity and abundance of flora and fauna. Himalaya plays an important role in the establishment and sustainability of large-scale monsoon systems over South Asia. The book also very briefly discusses the monsoonal climate of the Indian region to illustrate the relevant features of regional climate with bearings on Himalayan weather and climate. The mountain ecosystem over the region is very delicate and highly susceptible to even minor changes in their complex environmental parameters, with a high degree of dependence on changes in global and local climate factors. Many scientific studies and reports, particularly the IPCC reports on mountain glaciers, have highlighted the irreversible nature of the impact of climate change on the mountain regions especially the melting of snow and an accelerated pace of retreating glaciers. The subject of Himalayan climate is very timely and of wider interest. It is expected that the topic will find general acceptance among climate scientists, meteorologists, water resource scientists, and wide a spectrum of social scientists and policy makers.

To fully incorporate certain recent studies and make the subject material more useful for understanding climate change impacts on a smaller region, we have downscaled our discussion to a subregion designated as Central Himalaya. Due to the limitations of specific long period station data to represent an inhomogeneous terrain, we depended on the data from few stations as well as the grid point data from global analysis sets for illustrations. The major part of Central Himalaya, mainly represented by the state of Uttarakhand, is considered and used in the discussion of climate change impacts, remedial measures, and adaptation policies. These sections are included primarily to provide some guidelines to policy makers for due consideration of climate change impact as one of the factors in their decision-making process. These sections specifically deal with core sectors such as water, agriculture, glaciers, forests, biodiversity, and natural disasters. In the process of writing on many facets of the subject, the information has been scrutinized from research papers, reports, documents, and electronic media on public domain.

We sincerely wish that the reader interested in the subject will find the contents of the book useful and informative. This is just a beginning as far as the Himalayas are concerned. The next generation of climate scientists will enlarge the climate change information base with an advantage of long period high resolution data over the Himalayas at their command, and further efforts will continue.

Pune, Maharashtra, India
January, 2017

Govind Ballabh Pant

Acknowledgements

Writing of a Book on the subject encompassing Himalayan dimensions and complex subject of climate change turned out to be much more of a challenging task than we initially perceived it to be. Complexity of the science of climate change coupled with limited and restricted data on many parameters, over the region selected for the study, increased the challenge. A group of four authors contributing on their expertise relevant to the subject in simple language to a broad spectrum of readers with varying interest has its own problems of consistency and balance, which we believe to have been reasonably achieved. Support and guidance from many institutions and individuals as well as the references and quotations from numerous reports and research results constitute the back bone of this book. Individual's acknowledgement apart, we thank all those whose work is cited in or ideas are used as inputs. We are especially thankful to all those publishers of research material who granted the copy right permissions.

First of all, the authors are pleased to thank the Vice-Chancellor of Savitribai Phule Pune University for providing an opportunity to Dr. Pant to be associated with the Department of Atmospheric and Space Sciences while he worked on this project. The most important support has been given by the Director General of Meteorology, IMD, New Delhi; Director, IITM, Pune and the Director, ARIES, Nainital. The authors are grateful to them for their encouragement to the author who joined this team from their respective organizations and made use of the accessible data from the archives of their institutions for analysis and studies incorporated in this book.

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Contents

Chapter 1
Climate and Climate Change: An Overview

1.1 Introduction

Climate is usually defined as the long-term aggregate weather conditions over a place which displays large variability in space and time. It is often said "Climate is what you expect and Weather is what you get." Climate of the Earth has distinct records of changes in the past and possesses potential to change in future on various temporal scales. The variability and change in the climate may occur due to natural reasons as well as those related to the anthropogenic (man-made) activities within the Earth system. Many changes in climate have been detected in the data relating

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to the evolution of geomorphic features and life on the Earth within a time span extending back to the geological periods. The climate on these time frames is referred in a broader sense like; the colder/warmer periods or the wetter/dryer epochs, than the precise definition of climate of the recent past. The archeologists and historians have attributed many episodic changes in human civilizations and their settlements to major climate shifts like persistent droughts and floods, glacier surges, and the advances and retreats in desert margins across many parts of the globe. The climate induced abrupt changes in the human civilizations of the past might have occurred through the routes of environmental stress on basic needs of life: food, water, and shelter, as well as the consequences of natural disasters.

During the recent decades, the widespread warming of the Earth's surface, ocean waters and melting of large volume of ice on global scale, reported by authentic observations, have established that there are causes for these changes beyond natural processes. The present knowledge and understanding on climate science confirms that these changes have enough potential to create an imbalance in the Earth's climate system. Continuous monitoring of many climatologically significant parameters during the last about a century, as well as, a better understanding of mechanisms involved in the evolution of climate and changes there in, have made it possible to distinctly visualize the contemporary climates. All timescales ranging from seasonal to millennium and beyond can be used in defining the climate depending on the context. However, to define the present day climate in terms of surface meteorological parameters the climatologists generally consider a period of 30 years to represent the climate.

The climate change is thus recognized as a phenomenon that is being experienced by the people all over the world as a process with high potential to create perceptible changes in the Earth's ecosystem. There are indications that the variability and trends in global and regional climates have started appearing as major threats to traditional subsistence agriculture, water resource, clean air, and human safety, thus causing widespread material and social insecurity. This concern may assume significant dimensions particularly over marginal geographic zones over the Earth's surface, where higher sensitivity to changing climate is distinctly displayed. Small islands, coastal areas, arid regions, mountains, and glaciated regions of the world are under the category of high sensitivity zones for climate change. Within these zones there will always be an assembly of vulnerable sections of society likely to be affected the most, primarily due to enhanced stress on natural resources and inadequate socioeconomic protection.

India experiences a large variety of climates all across its latitudinal and longitudinal spreads, with warm-humid tropical climate in the east to an arid climate in the west and in a similar manner tropical monsoon climate in the south to temperate climate of middle latitudes in extreme north. The large-scale ocean-atmosphere coupled systems like the monsoons of south Asia are potentially sensitive to major climate change episodes, thus making India as one of the highly vulnerable regions due to its dependence on monsoons for practically all socioeconomic activities. It is, therefore, logical to assume that the direct impacts of climate change may adversely

affect vital sectors such as biodiversity, forests, water resources, deserts, coastal regions, monsoons, mountains, and glaciers of the Indian subcontinent.

To deal with these adverse consequences of changing climate, a basic understanding on the subject is highly desirable for wide spectrum of educated society in the present day world. In view of this, an attempt is made in this book to cover the important basic scientific facts and other related issues pertinent to climate and its change. While dealing with issues relating to the social and environmental impacts of climate change, a balanced view is presented with supporting data and observations wherever possible. The subjects of vulnerability, impacts, mitigation, and adaptation are discussed as a regional case study for Himalaya and its subregion, the Central Himalaya (CH), keeping in mind the sensitivity of the region to changes in climate and a large number of concerned reader community.

The first few sections will deal with the story of the evolution of the science of climate change and its theoretical and observational foundation. A panoramic view of chronological developments in scientific and technological advancements in the field of theoretical basis of climate science as well as the observational methods used in the measurement of a large assembly of relevant parameters are also presented. The contemporary developments on these two important aspects have been complementary to each other and the growth in the recent past has been phenomenal.

As a follow-up on detailed discussion of climate and climate change, the second part of the book focuses on a highly significant region over the Asian land mass, the mighty Himalaya, primarily the Indian domain over the western sector, henceforth referred as the Western Himalaya (WH). This will cover an elaborate description of the climate of the Himalaya and its role in global climate, signals of regional climate change, and the probable impacts of global climate change on the overall mountain ecosystem. In the third part, a detailed description of climate change impacts will be described specifically for the CH region primarily represented by the state of Uttarakhand in the northern part of India.

As an introduction to the overall theme, following few paragraphs are devoted to present a concise view on the scientific basis and mechanism of climate change. It is well known that the natural changes in mean climate are primarily due to the internal dynamics of climate system as well as the changes in external forcings caused by the variability of energy input from the Sun. All planets of the solar system including the Earth and their satellites receive their energy from the Sun which is a radiant star located at the focus of orbital planes of these planets. The Sun emits its energy in the form of electromagnetic waves mostly in visible, ultraviolet, and infrared bands of the solar spectrum at an approximate surface temperature of 5778°K from a mean distance of 1496×10^5 km from the Earth.

The energy emitted by the Sun is enormous; however, a small fraction of it received by the Earth in the form of incoming solar radiation is the prime mover of all activities on the Earth including climate. This energy is defined by a term called the Solar Constant which is a measure of electromagnetic energy received from the Sun over a unit area on a plane perpendicular to the incident rays at a distance from

the Sun equal to the mean distance between the Sun and the Earth. Though, the term Solar Constant is traditionally used to denote net energy flux with a fixed long-term average value, it displays minor variations due to changes within the Sun, such as the occurrence of the sunspots. Recent satellite measurements suggest a mean value of 1361 Wm^{-2} to the Solar Constant for all practical purposes including the study of climate change.

Similarly, the planet Earth, the only astronomical object known to accommodate and sustain life, emits energy corresponding to the temperatures acquired by all of its components according to the fundamental laws of radiation. This energy is much smaller in magnitude compared to the energy emitted by the Sun by virtue of the equilibrium temperature of the Earth [estimated to be 288°K (15 °C)] being less than one order of magnitude to that of the Sun. The radiant energy emanating from the Earth lies entirely within the range of infrared part of electromagnetic spectrum commonly termed as outgoing longwave radiation (OLR) and have a mean outward flux of 390 Wm^{-2}.

The energy received from the Sun as incoming shortwave radiation (visible) and that emitted by the Earth's surface as OLR (infrared), and the fluxes of sensible (physically measurable) and latent heat (involved in phase change processes without changing temperature) energies have a balanced budget within the Earth system. As a result, under normal conditions the warmth bestowed on the planet will maintain a constant value, as net loss of heat energy to outer space is adjusted in such a manner that the Earth's surface would tend to acquire a mean equilibrium temperature. In case the balance requirements of incoming and outgoing radiations are not fulfilled, the Earth's surface temperature would also change accordingly so as to eliminate the imbalance. For the basic understating of a common reader, the general picture of the electromagnetic spectrum is displayed by Fig. 1.1 given here.

Any change in the equilibrium thermal state of the Earth over a period of time resulting into change in its surface temperature and all forms of its manifestations on the Earth system are synonymous with climate change. Therefore, the commonly used index to quantify changes in climate of the Earth is the change in the magnitude of global mean surface temperature averaged over long period of time with respect to a standard base value. A persistent increase in the value of this index noticed during the last few decades is popularly known as the Global Warming (GW). It is thus a pertinent question for us to seek logical and scientific answers to observed changes

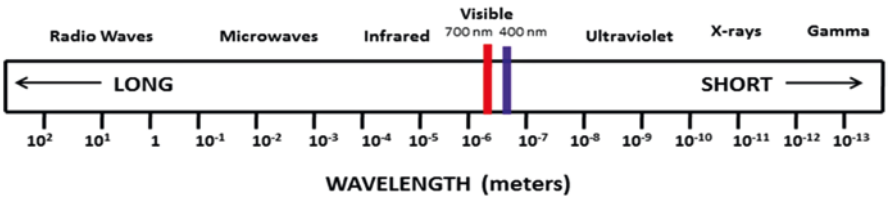

Fig. 1.1 Spectrum of solar radiation, colored portion representing the visible wavelengths that reaches up to the earth's surface