Aeronomy of the Middle Atmosphere

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Aeronomy of the Middle Atmosphere

Chemistry and Physics of the Stratosphere and Mesosphere

Third revised and enlarged edition

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Preface

Since the industrial revolution, the chemical composition of the atmosphere has changed at a rate unprecedented in recent history. The concentration of carbon dioxide has increased by about 25% during the 20th century as a result of fossil fuel combustion, and is expected to further increase substantially over the next several decades. The level of methane is more than a factor 2 higher than a century ago, due in large part to agricultural practices. The aerosol load of the atmosphere has been perturbed by such practices as the intensive use of coal as a primary energy source. The release of nitrogen oxides, carbon monoxide and hydrocarbons, as a result of fossil fuel and biomass burning has led to enhanced abundances of ozone and other oxidants in the troposphere. Organic halogenated compounds including the industrially manufactured chlorofluorocarbons have become a dominant source of ozone-depleting chlorine and bromine in the stratosphere. The science of the ozone layer and its interactions with halogenated chemicals are the focus of this book.

These human-induced changes have led to significant perturbations in the Earth's global environment, and will further affect it in the decades ahead. Among these perturbations are the degradation of air quality with associated health effects, the acidification of precipitation with potential consequences for ecosystems, changes in the oxidizing power of the atmosphere and hence on the ability of the atmosphere to eliminate pollutants, changes in the Earth's climate in response to modified absorption and emission of radiation by atmospheric trace constituents, and stratospheric ozone depletion leading to enhanced levels of harmful solar ultraviolet radiation at the Earth's surface.

Ozone plays a central role in the Earth's environment. By absorbing DNA damaging ultraviolet light originating from the Sun, it protects living organisms including humans from lethal effects. It also strongly affects the thermal structure of the atmosphere, and maintains a dynamically stable layer, –the stratosphere–, between approximately 10 and 50 km altitude. Ozone, a greenhouse gas and a powerful oxidant, also influences the Earth's climate and plays a key role in the ability of the atmosphere to destroy several chemical compounds, including many primary or secondary pollutants.

The depletion of the stratospheric ozone layer captured the attention of scientists, policy makers, and the public, particularly in the 1970s, 1980s, and 1990s. Active research quickly provided an improved understanding of the mechanisms involved in the formation and fate of stratospheric ozone. Ozone depletion emerged as one of the most important environmental issues of the 20^{th} century as the evidence grew for substantial human influences on the ozone abundances over much of the globe. An international environmental agreement (The Montreal Protocol and its amendments and adjustments) now governs the global use of ozone-depleting halocarbons. In the 21^{st} century, interest remains strong in the science, the history, and the future of the stratospheric ozone layer.

The purpose of this volume is to provide to graduate students and research scientists a comprehensive view of the chemical, dynamical and radiative processes that affect ozone and other chemical compounds in the middle atmosphere. The title of this volume –Aeronomy of the Middle Atmosphere– has been chosen to highlight the topics covered in this book. The word “Aeronomy” is defined as the science dealing with planetary atmospheres with reference to their chemical composition, physical properties, relative motions and reactions to radiation from outer space (Chambers Dictionary). The field of aeronomy is therefore highly interdisciplinary, drawing on the fields of chemistry, physics, fluid dynamics, meteorology, statistics, mathematics, engineering, etc. The middle atmosphere is defined as the region extending from the tropopause (approximately 12 km) to the homopause (about 100 km altitude).

The book is intended to provide an overview in a manner understandable to persons familiar with college level chemistry and physics. After a general introduction presented in Chapter 1, Chapter 2 reviews basic concepts from physical chemistry, which are of relevance to atmospheric studies. Chapter 3 presents a highly simplified view of dynamical and transport processes above the tropopause, and Chapter 4 summarizes important aspects of radiative transfer in relation to the energy budget and photolytic processes in the middle atmosphere. Chapter 5 presents an overview of the key chemical processes, which influence the chemical composition of the middle atmosphere, while Chapter 6 discusses human-induced perturbations affecting ozone and other compounds. The chapter also presents a detailed discussion of ozone depletion, particularly the formation of the spectacular Antarctic ozone hole is provided in this chapter. Finally, Chapter 7 provides an overview of ionization processes in the mesosphere and stratosphere. Although the discussion focuses on the atmospheric layers ranging from 10 to 100 km, we have sometimes found it necessary to discuss processes occurring in the troposphere (surface to about 12 km altitude) and thermosphere (region above 100 km) in order to explain the roles of these neighboring regions.

Due to the large number of topics to be addressed in the present volume, we have found it impossible to provide a complete review of the available literature. We anticipate that the interested reader will regard the discussions as a starting point and find additional references by consulting publications cited here. The periodic international assessments of the state of the ozone layer, published by the World Meteorological Organization and the United Nations Environment Program, provide additional information.

When we wrote the first edition of this book in the early 1980's, we did not anticipate that the question of stratospheric ozone would soon receive so much scientific attention. The discovery of the Antarctic ozone hole sparked the rapid development of exciting scientific programs and new research understanding. Since the publication of the early editions of this book, new measurement techniques (including space platforms and instruments), more accurate laboratory methods, and more sophisticated atmospheric models have become available. Our understanding of the middle atmosphere, including the role of chemical transformations on the surfaces of liquid or solid particles and the complexity of the air motions, has improved dramatically. More importantly, the discovery and explanation of the Antarctic ozone hole has shown that human activities can lead to major changes in the chemical composition of the atmosphere not just locally and regionally, but at the global scale. The new edition of the present volume attempts to synthesize some of the most recent findings.

The review of critical portions of the manuscript by colleagues has certainly improved the quality of this volume. Material provided to us has also been of great help. We particularly thank S. Chabrillat, D. Edwards, R. Garcia, M. Giorgetta, H. Graf, C. Granier, M. Hagan, J. Holton, I. Karol, K. Kodera, E. Kopp, S. Madronich, E. Manzini, D. Marsh, M. Mlynczak, J. Orlando, T. Peter, W. Randel, A. Smith, Stan Solomon, X. Tie, G. Tyndall, S. Walters, X. Zhu. We deeply appreciate the assistance of R. Terrell Bailey, Paula Fisher, and Debe Fisher for the preparation of the camera-ready manuscript, of C. Granier for her proofreading of the manuscript, and of the Imaging and Design Center at the National Center for Atmospheric Research (NCAR) for their expert figure drafting. We also acknowledge the Atmospheric Chemistry Division at NCAR for supporting the preparation of this book.

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