

Climate Change Science: A Modern Synthesis



PROBABLY THE MOST COPIED
IMAGE OF ALL TIME
TAKEN BY APOLLO 17 ASTRONAUTS ABOUT
MIDWAY
BETWEEN THE MOON AND EARTH
AND THE LAST
TAKEN BY MAN
FROM OUTER SPACE
AS OF
June 2012

G. Thomas Farmer • John Cook

Climate Change Science: A Modern Synthesis

Volume 1 - The Physical Climate

 Springer

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ISBN 978-94-007-5756-1 ISBN 978-94-007-5757-8 (eBook)
DOI 10.1007/978-94-007-5757-8
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2012956285

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*How inappropriate to call this planet Earth
when clearly it is Ocean*

Arthur C. Clark

Preface

This textbook, *Climate Change Science: A Modern Synthesis, Volume I: The Physical Climate*, is intended for the introductory college science student who perhaps has not had a science course since secondary or preparatory school. It is also intended to serve as a more advanced textbook for students who have had a basic science course in astronomy, geology, biology, physics, or chemistry and who want to better understand Earth's climate, how Earth's climate has developed, what affects it, and how it may change in the future. However, it presumes no background in any of the sciences. Basic scientific concepts are introduced and explained as they become necessary for understanding the current topic. It constitutes Volume I of a two-textbook treatment of climate change science designed for a 1-year introductory science course. This volume treats the physical aspects of climate change science and is intended for a one-semester or one-quarter introductory science course.

Volume II emphasizes the historical aspects of climate change and Earth science. Each volume is a stand-alone treatment of climate change science, Volume I emphasizing the physical and chemical portions of the science while Volume II emphasizes the evolution and historical aspects of the science. Each volume presents arguments of climate change and global warming skeptics and deniers and the scientific evidence that refutes or supports each argument. The last two chapters in this text discuss denial in the face of overwhelming scientific evidence.

Neither volume assumes a prior college or preparatory course in science or mathematics but they do assume an interest in the world around us. The necessary science is introduced in the context of the evolving subject matter in the text. Mathematics is kept to a minimum in each volume and an understanding of preparatory-school algebra should be sufficient to tackle the mathematics of most climate science concepts contained herein. Additional readings for each chapter contain mathematical material where appropriate.

This volume will also serve as a basic college textbook in beginning Earth science for students who want to understand what modern climate science is all about and whether the Earth is warming to a dangerous level as some say it is. There are others that say that global warming is a "hoax" and questions have been raised about the legitimacy of climate science and those who practice it. Hopefully this

book will provide the necessary background for students who want to understand and appreciate the complexities and problems of Earth's climate and climate change science and of those scientists who try to comprehend and explain them. There will be discussions of the legitimate nature of climate science, its current status, some of the problems climate scientists have had to face, and what climate science can contribute to the future of humankind on Planet Earth.

Climate science is far from being a hoax but there are still unanswered questions, as that is the nature of science in general. Climate science would hardly be a science if all questions had already been answered. But climate change science is a legitimate branch of science dealing with an Earth that is being greatly impacted and thus greatly changed by humankind. As in all aspects of science, there is an inherent search for truth. The final two chapters of this text deal with the concepts of denial as it relates to climate science and climate scientists.

Most scientists are well educated and free thinkers who try and keep their minds uncluttered by prejudices; but by human nature this is not always possible to do. However, it is inane to think that the thousands of climate scientists throughout the world have agreed to defraud the public into believing a false claim; that is, that the Earth is warming! The truth is that the Earth *is* warming and the scientists are and have been gathering facts and reporting the truth, or as close to it as they can come. There is no collusion among climate scientists as some have claimed. Those attempting to deny global warming are mainly not climate scientists but are something else; talk-show hosts, weather reporters, right-wing politicians and personalities, anti-science zealots, etc.

This textbook gives the physical evidence for climate change and global warming and is a synthesis of current climate change knowledge. There are parts (Parts IX and X) in this volume that present the ideas of skeptics and deniers and the scientific evidence that either refutes or substantiates their claims. There is also material that concerns the debunking of myths and there are many myths related to science in general and climate change science in particular.

Most scientists are realists and their primary concern is for the best future for humanity on this planet. It is the main reason most of them became scientists. The principal driver of scientific endeavor is to advance human knowledge and to make the Earth a more pleasant place, or at least a better place; a better understood place, for future generations to live. Scientists and others may differ about their definition of "better" but most want to improve the Earth and human society.

Most scientists are excited about their science and they hope to be able to impart that excitement to the students that they teach or for whom they write. Scientists are among the best educated members of society and now is a great time to be a scientist because knowledge is expanding astronomically, in quantum leaps. New knowledge is always exciting in one's major field of interest, but what is being found out today about the Earth and its climate is truly amazing. New satellites are being sent into space and Earth orbit to monitor Earth's climate in ways never before imagined or thought possible. Scientists are learning more and more about the past climates of other planets as well as about that of the Earth. Other space vehicles are exploring other parts of the Universe and man is getting ready to explore other planets.

In the 1960s and 1970s the Earth sciences experienced a change which has been described as a paradigm shift. New information was being acquired from the ocean basins concerning their ages and characteristics and new methods of exploring, sampling, and analyzing were being developed. Scientists had begun to obtain ice cores from Antarctica, Greenland, and some of the glaciers in mountainous areas of the world. Their analysis was beginning to yield important new information about past climate changes; the most recent changes that had taken place on Earth during the past 850,000 years.

Ice cores have taken us back to about 850,000 years ago when the Earth was not so different from what it is now. The continents were approximately where they are today and climate was not too different. But something happened around 700,000 years ago and the Earth cooled to begin cycles of expanding and then retreating of continental-sized ice sheets that covered vast areas of North and South America, Asia and Europe (Eurasia). Ice sheets, including glaciers, also expanded in mountains such as the Alps, Andes, Himalayas, and Rockies. Reasons for these cycles are considered in this text as well as the evidence that allowed scientists to arrive at the conclusion that glacial ice had been much more extensive in the past than it is today. In the span of just a few hundreds of thousands of years, the Earth's climate has undergone radical changes and ice cores have allowed scientists to learn a great deal about the "Ice Age" and its causes. It will be seen that the Earth has experienced several "ice ages" and the latest one is the one about which we know the most.

The major paradigm shift in the Earth sciences has been referred to as Plate Tectonics, which is introduced in this volume but treated extensively in Volume II. It represents a legitimate paradigm shift; but the monumental changes taking place in the knowledge about the Earth involve more than lithospheric plates, their configurations, boundaries, and their motions. The Earth science paradigm shift has broadened and now also involves changes in the interpretation of Earth's climate; the interactions between the atmosphere, biosphere, lithosphere, asthenosphere, and anthrosphere; as well as the evolution of Earth's climate through time, known as paleoclimatology. Scientists' knowledge of climate change science as well as the modern concept of Plate Tectonics constitute paradigm shifts.

If humans can understand climates of the past, perhaps we can better understand what the climate of the future will be and humankind may be able to mitigate some of the problems that are sure to occur in many future scenarios of Planet Earth's climate.

Some scientists will be fortunate enough to influence a few students or colleagues in a positive way. A few will be able to reach many more by publication or performance in the classroom or on the lecture circuit. And a very few will reach the pinnacle of their profession by excelling at every level. This work will attempt to impart some of the writers' excitement about the Earth and its climate to the readers of this text and will hopefully extend their knowledge of Earth and its potential for allowing us to live, work, play, and learn about its many mysteries. Perhaps we can decipher its clues and features, and thereby arrive at solutions to many of its problems.

This book is written for students who are looking to balance their education with a basic science course. And it is also written for the instructors who teach them.

There is enough material here for both as well as for others that want to accept the challenge to gain a better understanding of Earth and its climate.

That the planet is warming is unequivocal. Climate change scientists have gone far beyond the simple concept of global warming and now are attempting to devise ways that humans can cope with ever increasing temperatures and their effects. If scientists can unravel and document the convoluted facts of our world's climate and better understand the ramifications of global warming, the better the chances are that humankind can survive in the years and centuries to come. There is an urgent call for understanding the climate and doing everything possible to mitigate its warming and it is hoped that these texts will help.

Climate change science has become a different branch of science from just climate science, that which has been practiced by climatologists over the years. Climatologists have always been aware that climate can change and can heat up or cool down, usually taking hundreds and possibly thousands of years to make a major change. Scientists and others have known about the most recent ice age for around 200 years or more. We now know about ice ages that took place even further back in time, as far back as 700 million years. Some have said that we are headed for another ice age and perhaps we would be if global warming was not happening. Humans have been adversely affecting Earth's climate for at least 8,000 years, beginning with agriculture and the demise of the hunter-gatherer stage of human history.

Climate change scientists are a relatively new breed of scientist with backgrounds in Earth history, geology, geography, biology, oceanography, astronomy, mathematics, physics, chemistry, engineering, and are able to juggle multitasks at blinding speed thanks mainly to advances in computer science and engineering. Climate science is changing rapidly now and climate change scientists must keep pace with these rapid changes.

Climate change scientists deal with massive amounts of data over relatively long time periods and are able to see significant trends revealed by analyses of these data. The most obvious are the trends in temperatures, changes in sea level, volume changes in glaciers and their waxing and waning, changes in atmospheric and oceanic circulation, configuration of continents and their locations over the Earth's surface, trends in energy amounts received and distributed by Earth processes, etc. Trends are revealed after assembling and analyzing these data with analytical methods developed over many years and agreed to by international groups of scientists. These methods and results are discussed in the pages that follow.

In the last two centuries, humankind has dumped an amazing amount of carbon and carbon dioxide (CO₂) into the atmosphere by the burning fossil fuels. Humans added another 110 billion tons via deforestation and land-use changes. The activities of humankind since the start of the Industrial Revolution in the mid-eighteenth century have had and are still having a tremendous and negative impact on Earth's land, ocean, atmosphere, biota, and human health.

The atmosphere weighs about 5 quadrillion tons, and carbon dioxide, despite human emissions, remains a small component of that. But it grows larger every day. The International Energy Agency (IEA) expects annual global CO₂ emissions from

fossil fuels alone to top 40 billion tons added to the atmosphere each year by 2030. It is not that humans will suffocate from the additional CO₂ directly, but that it will cause an increase in Earth's temperature to a degree that will make the planet too hot for humans to live on it or in it. CO₂ is not toxic at levels in the foreseeable future for the atmosphere but its role as a greenhouse gas is a concern at levels seen over the past several decades. This concern is treated in the following pages.

Climate change is real, is being reflected today in major changes in weather patterns throughout the globe, and climate change scientists are working with these changes to find causes and ways to deal with them. Modern citizens of the world need to become better acquainted with the climate changes that are occurring and it is hoped that the words that follow will help.

The Internet has been extensively used in the writing of this work. Websites are listed throughout these texts and contain additional information on the topic under consideration. The authors strongly recommend that these or similar sites be visited for additional information whenever desired or needed. The Internet is an amazing resource for information but it must be used with care and discrimination. There is much misinformation (and disinformation) on the web and one needs to be able to recognize it when found and be able to separate the bad from the good. It is hoped that these texts will aid in this discrimination.

A timeline for some of the major events in the recent development of modern climate change science is given below beginning around 1965 with work by Manabe and Wetherald who built the first comprehensive model of Earth's climate system.

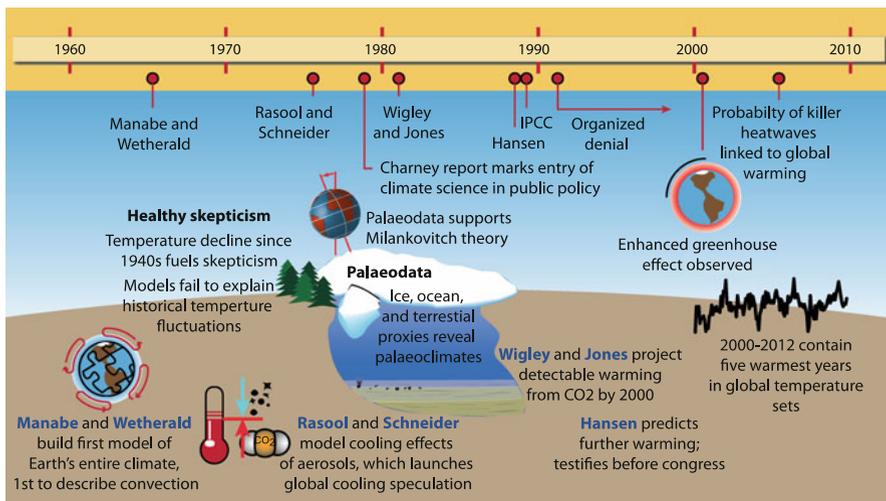


Fig. 1 Timeline for the development of modern climate change science from around 1965 to 2010 (From SkepticalScience.com, viewed 5/11/2012)

The following text is intended to be used in introductory science courses. It introduces concepts common to all the sciences and includes an introduction to the scientific method, some geology, chemistry, physics, and astronomy and other subjects such as statistics, philosophy, and meteorology necessary to understand climate change science.

Volume I of the textbook is divided into Parts I–XI. Each part is listed as follows:

Part I – Scientific Principles and the Scientific Method

Part II – Overview of Climate Change Science

Part III – Earth’s Atmosphere

Part IV – The World Ocean and Climate

Part V – Earth’s Cryosphere and Recent Climate History

Part VI – Land and Its Climates

Part VII – Climate Models

Part VIII – Climates of the Past (Paleoclimatology)

Part IX – Future Climates and Mitigation

Part X – Understanding Climate Change Denial

Part XI – Specific Declarations Against Climate Science and Climate Scientists

There are also appendices that will serve as reference for parts of the text, a list of abbreviations used in the text, and a glossary of climate change terms.

The book may serve as an introduction to Earth science, climate science, environmental science, geology, and general science students. It may also be used in Advanced Placement courses in the Earth sciences for college preparatory schools. It is a textbook for introductory science students at any level.

The text is written with the basic premise of allowing the instructor maximum flexibility in teaching the introductory science course. It allows the instructor and introductory science student to build on a solid foundation of scientific and introductory information. Some chapters begin with an appropriate quotation relating to that chapter’s material. A list of terms and topics (“Things to Know”) that the student should keep in mind as the chapter is read follows the quotation or begins the chapter. Some chapters have sections that contain advanced material pertinent to the subject matter of that chapter and the instructor may elect to assign the material or not. The instructor may choose which materials to emphasize in each chapter, change the sequence of material covered in the text, or add additional material. An attempt has been made to have each chapter stand alone and not be dependent on the previous chapter.

The text begins with an introduction to basic scientific principles used in all the sciences, such as the scientific method(s), laws of thermodynamics, the gathering and interpretation of data, a few of the giants of science and their contributions, a few selected climate change scientists and their contributions, Newton’s laws of motion, etc.

The introduction is followed by a series of chapters on the major aspects of climate change and its effects and interactions with the atmosphere, the World Ocean, glaciers, and land. Modeling the climate (PART VII, Chap. 18) is a separate chapter

as is a section on past climates, and specific arguments of climate change skeptics and deniers.

Terms found in the Glossary or given for emphasis are defined when first introduced.

This volume, *The Physical Climate*, is written with the student's best interest in mind. It is hoped that it has condensed a difficult and multifaceted subject (climate change) and made it a bit easier to understand. The attempt is a synthesis of modern climate change science and the principles used to understand it and it is hoped that the reader will gain a better understanding of the world around us and the need for conservation of its resources.

G. Thomas Farmer
John Cook

Acknowledgements

The current textbook (Volume I) authors have relied heavily on the following individuals, works, and web sites:

- The American Physics Institute web pages by Spencer Weart
- The Intergovernmental Panel on Climate Change (IPCC)
- The United States National Academies of Science (NAS)
- The United States National Research Council (NRC)
- White House Council of Environmental Quality (CEQ)
- SkepticalScience.com
- Science-Skeptic.com
- RealClimate.org
- WhatsUp.com
- U.S. National Aeronautics and Space Administration/Goddard Institute of Space Studies (NASA/GISS)
- U.S. National Aeronautics and Space Administration (NASA) Earth Observations
- U.S. National Oceanic and Atmospheric Administration (NOAA)
- U.S. Environmental Protection Agency (EPA)
- United States Geological Survey (USGS)
- Google.com
- U.S. National Climate Data Center (NCDC)
- U.S. National Weather Service
- U.S. National Environmental Satellite, Data, and Information Service
- U.S. National Oceanic Data Center
- NOAA Office of Atmospheric Research
- U.S. Department of Energy
- U.S. National Regional Center for Atmospheric Research (NCAR)
- Australian Bureau of Meteorology
- U.S. Group for High Resolution Sea Surface Temperatures (GHRSSST)
- Henry Pollack, “A World Without Ice”
- Richard Alley, “Earth: The Operator’s Manual”

- Oreskes and Conway, “Merchants of Doubt”
- The American Meteorological Society
- Wikipedia, The Free Encyclopedia
- HotTopic.com
- TheClimateShow.com
- Thomas L. Friedman’s “Hot, Flat, and Crowded”
- Wendy Cook
- Donna Farmer
- Steven Farmer
- William Patrick Roberts

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