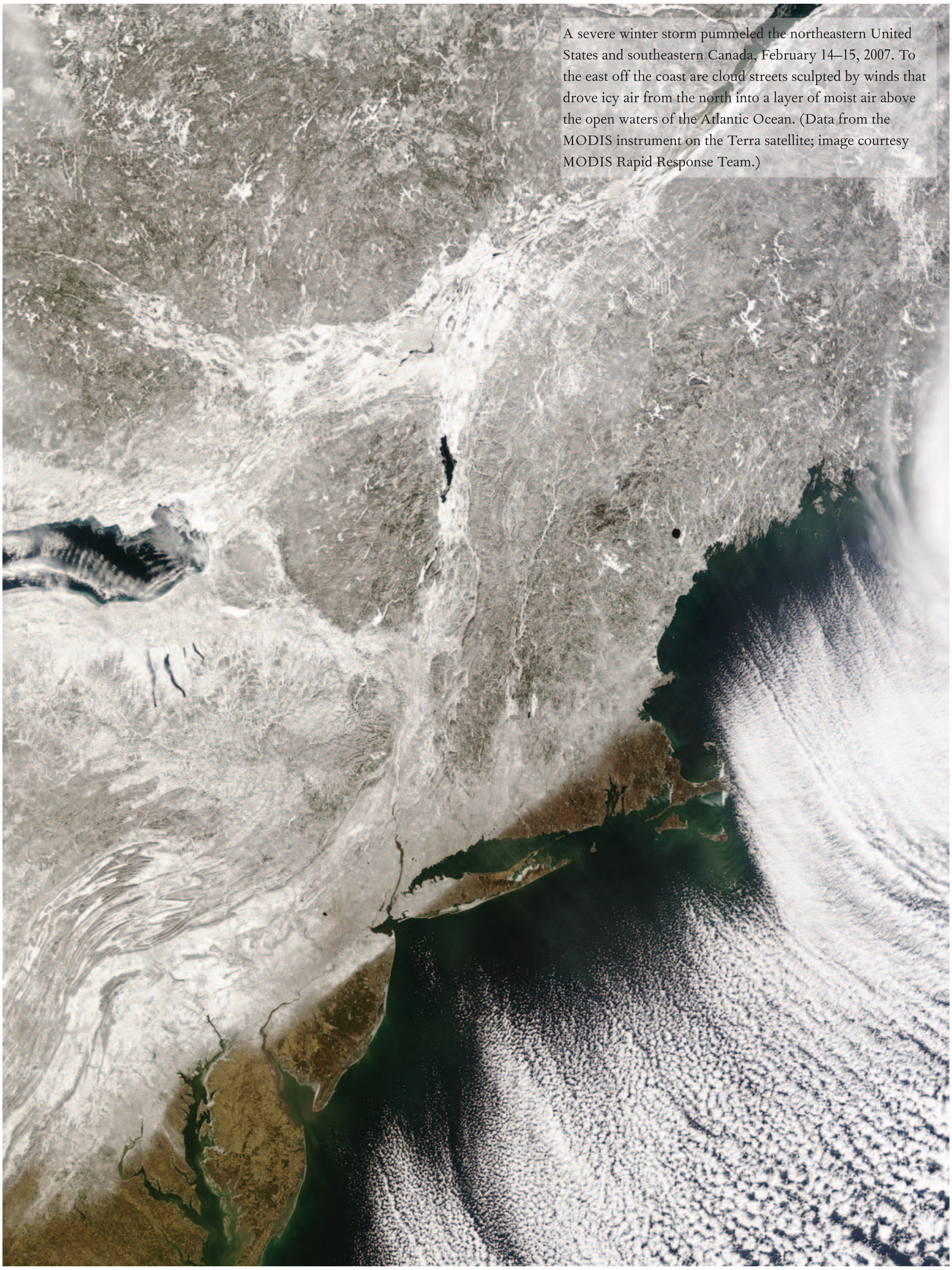
Cambridge University Press
978-0-521-82870-3 - Our Changing Planet: The View From Space
Edited by Michael D. King, Claire L. Parkinson, Kim C. Partington and Robin G. Williams
Excerpt
More information



A severe winter storm pummeled the northeastern United States and southeastern Canada, February 14–15, 2007. To the east off the coast are cloud streets sculpted by winds that drove icy air from the north into a layer of moist air above the open waters of the Atlantic Ocean. (Data from the MODIS instrument on the Terra satellite; image courtesy MODIS Rapid Response Team.)

Cambridge University Press
978-0-521-82870-3 - Our Changing Planet: The View From Space
Edited by Michael D. King, Claire L. Parkinson, Kim C. Partington and Robin G. Williams
Excerpt
More information

Anvil clouds over the South Pacific Ocean, December 2, 2000. (Photograph from the International Space Station, NASA image number ISS006-E-5820.)

Cambridge University Press
978-0-521-82870-3 - Our Changing Planet: The View From Space
Edited by Michael D. King, Claire L. Parkinson, Kim C. Partington and Robin G. Williams
Excerpt
More information

Cambridge University Press
978-0-521-82870-3 - Our Changing Planet: The View From Space
Edited by Michael D. King, Claire L. Parkinson, Kim C. Partington and Robin G. Williams
Excerpt
More information

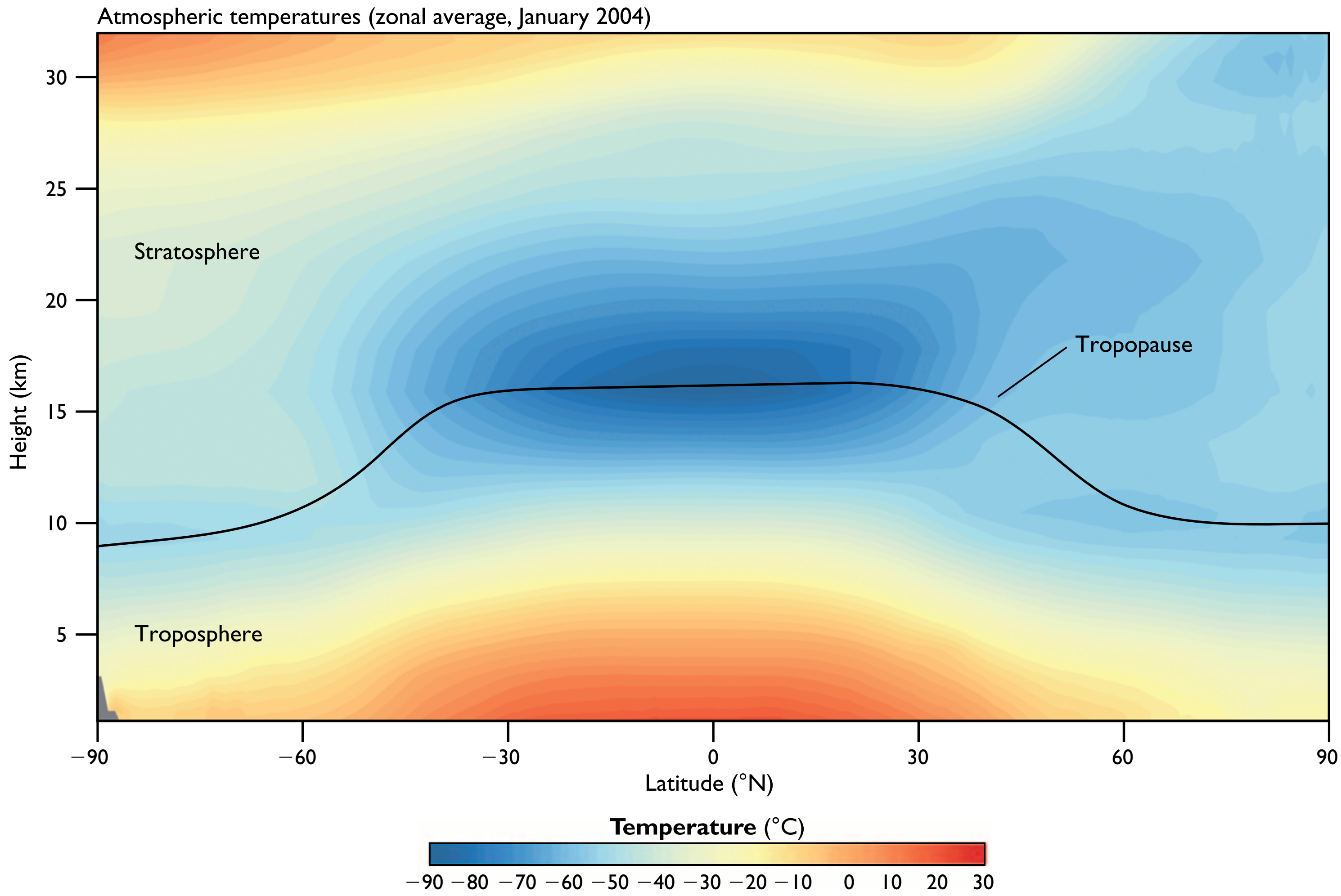
This photograph, acquired February 1984 by an astronaut aboard the Space Shuttle, shows a series of mature thunderstorms located near the Parana River in southern Brazil. (NASA Earth from Space image number STS41B-41-2347.)

The Dynamic Atmosphere: Introduction

Michael D. King

The Earth's atmosphere is a thin veil that extends up to 1000 km from the Earth's surface into space, but the bulk of the atmosphere (99.9999%) by mass resides below 100 km. It is a layer of gases surrounding the planet that consists of roughly 78% nitrogen and 21% oxygen, with important trace amounts of other gases such as ozone, carbon dioxide, methane, nitrogen oxides, and water vapor. Its temperature varies significantly with altitude, and it is generally divided into 5 distinct layers, from the troposphere, derived from the Greek work 'tropos' meaning to turn or mix, where man lives and the bulk of weather occurs, to the stratosphere, extending from an altitude of about 7–17 km to about 50 km and containing the layer of important stratospheric ozone that protects man from harmful ultraviolet radiation from the sun, to three higher layers, known respectively as the mesosphere, thermosphere, and exosphere.

Many aspects of the Earth's atmosphere are undergoing significant alterations as a direct consequence of human activity. Some very familiar alterations to atmospheric composition, in particular the increase in carbon dioxide concentration since the industrial revolution and



Atmospheric temperature as a function of height and latitude for January 2004, showing the lower layers of the Earth's atmosphere and the decrease in temperature with height in the troposphere and the temperature increase in the stratosphere. (Data from the AIRS and AMSU instruments on the Aqua satellite.)

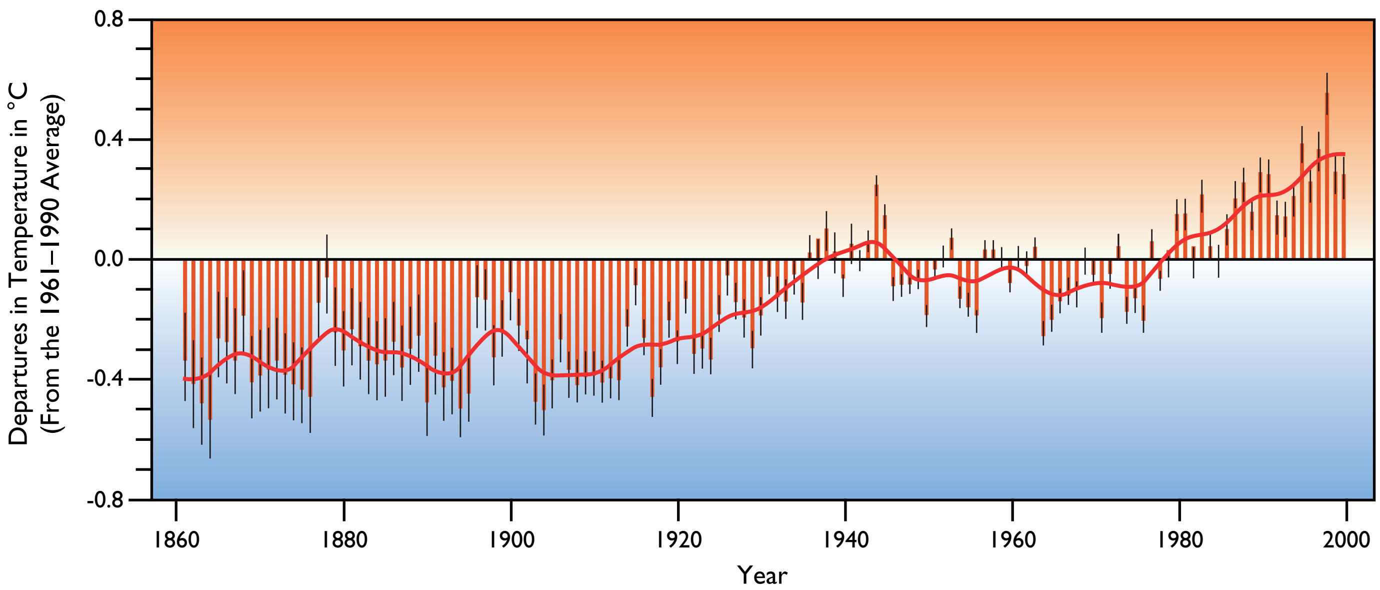
Our Changing Planet, ed. King, Parkinson, Partington and Williams
Published by Cambridge University Press © Cambridge University Press 2007

the decrease in stratospheric ozone over Antarctica in the Austral spring (the so-called ozone hole), were first observed and long-term trends established from ground-based observations. Satellite and aircraft data, however, have also significantly increased our understanding. For instance, satellites have played a key role in establishing the size and transformation of the ozone hole in the Antarctic, as well as ozone changes in the Arctic and mid-latitudes, and the connection between human produced chlorofluorocarbons (CFCs) and ozone loss was first established from NASA aircraft observations in the late 1980s. Other atmospheric characteristics, though perhaps changing with time, have not been observed globally prior to the advent of the satellite era or were not possible to observe prior to the development of sophisticated instrumentation available for the first time in just the past 5–10 years or so. Regarding other aspects of the Earth's atmosphere, though observed for perhaps 20 years from space, further technology improvements permitted increasing quality and quantification of atmospheric characteristics as we approached and entered the 21st century.

Humans as well as Nature have had impacts on the environment through the long-range transport of dust, smoke, and other aerosol particles in the Earth's atmosphere, and many of these impacts are observable from satellite observations. Several categories of dust impacts on the ocean are illustrated under "The Restless Ocean" in chapters on the ocean biosphere and red tides, both of which are directly impacted by the iron content in dust. In this section, 15 chapters illustrate the many ways that satellite data are being used to reveal characteristics of the Earth's atmosphere, including clouds, air pollution, severe storms, and atmospheric composition.

Illustrating the application of satellite imagery to the study of Earth's dominant atmospheric phenomenon, as viewed from space, the chapter on "Clouds: Are the Shutters of the Universe Changing?" describes satellite observations of global cloud cover as well as high clouds from the late 1990s to the first several years of the 21st century. This chapter shows that the total cloud cover of the Earth is around 75%, and has undergone no appreciable change over this period, though high clouds do show a noticeable increase in occurrence. There is no effect of El Niño or La Niña events on total cloud cover worldwide, though the distribution of clouds changes spatially between these two states of the climate system, especially in the tropical Pacific.

The chapter entitled "Cloud Optical and Microphysical Properties" provides an overview of liquid water and ice clouds, illustrating both the spatial distribution of these clouds in the Earth's atmosphere and the size of the liquid water drops and ice crystals found within these two types of clouds. This chapter is followed by a chapter on "Clouds and the Earth's Radiation Budget," describing the balance between the incoming solar radiation from the sun that is absorbed by the Earth-atmosphere system and the outgoing longwave radiation emitted by the Earth. Though close to balance over the globe when averaged over the year, there were periods of excessive loss of energy following the eruption of the Mt. Pinatubo volcano in 1991. The "Water Vapor" chapter highlights the global distribution of water vapor in the Earth's atmosphere in January, April, July, and October and indicates both the fluid nature of water vapor in the atmosphere and how it varies over the world's oceans from 1987 to 2005. This chapter demonstrates that water vapor over the world's oceans has responded to an overall warming of the Earth-atmosphere system that has led to an increase of water vapor with time, with additional fluctuations in response to global climatic events such as El Niños and La Niñas.



Combined annual land-surface air and sea surface temperature anomalies (°C) from 1861–2000, relative to 1961 to 1990. The Earth's surface temperature is shown year by year (red bars) and approximately decade by decade (solid red line). There are uncertainties in the annual data (thin black whisker bars represent the 95% confidence range) due to data gaps, random instrumental errors and uncertainties, uncertainties in bias corrections in the ocean surface temperature data and also in adjustments for urbanization over the land. Over both the last 140 years and 100 years, the best estimate is that the global average surface temperature has increased by 0.6 ± 0.2°C. (Adapted from *Climate Change 2001: The Scientific Basis*, Intergovernmental Panel on Climate Change, Cambridge University Press.)

Several chapters center on precipitation, which is essential to human sustenance. This group of chapters begins with an overview of "A World of Rain," which shows the global distribution of precipitation from 28 years of satellite observations. During this period there have been several El Niños and La Niñas, and the differences in precipitation patterns between these events are dramatically illustrated, with areas of excessive precipitation and excessive droughts during El Niño years clearly identified. This chapter also illustrates the seasonal and spatial distribution of precipitation during the Asian monsoon in the Indian Ocean and western tropical Pacific, the planet's greatest seasonal shift in rainfall. The chapter "Hurricanes: Connections with Climate Change" discusses Nature's extreme rainfall process of the tropics and subtropics, known in various regions of the world as hurricane, typhoon, or cyclone. The capability of space-based radar on the Tropical Rainfall Measuring Mission (TRMM) to monitor the three-dimensional distribution of rainfall within hurricanes, has only been available since 1997 and is used in the production of some of the rain rate analysis illustrated in this chapter. Since many North Atlantic hurricanes are 'born' off the west coast of Africa and transported across the Atlantic, this chapter is illustrated with both dust storms off the Cape Verde Islands during hurricane formation and subsequent transport, and tracking, from the TRMM satellite, as Hurricane Isabel approaches the mainland in the United States in 2003. Due to the large tropical ocean extent of hurricane and typhoon formation and development, satellites are an essential component in formulating warnings and improving landfall predictions of numerical weather prediction centers worldwide.

Another natural phenomenon that contributes to injuries and loss of life worldwide is lightning, which is summarized in a "Lightning" chapter. Lightning has been viewed as a curious phenomenon of nature for millennia; and Benjamin Franklin in the 1700s invented the lightning rod and designed an experiment to use a kite to see if lightning was an electrical discharge. Detecting lightning from space, and hence globally, did not occur until 1995, and subsequent analysis, presented in this chapter, shows the global and seasonal distribution of lightning worldwide. The space-based observations have revealed that about 90% of all lightning occurs over land, with the ocean lightning occurring primarily along warm ocean currents with convective activity, such as the Gulf Stream of the North Atlantic and the Agullas Current off South Africa.

Cambridge University Press
978-0-521-82870-3 - Our Changing Planet: The View From Space
Edited by Michael D. King, Claire L. Parkinson, Kim C. Partington and Robin G. Williams
Excerpt
More information

The tracking of atmospheric temperature from space is highlighted in the chapter entitled "Warming and Cooling of the Atmosphere." This chapter demonstrates how the lower stratosphere has been cooling and the troposphere has been warming in the past 25 years. These trends were interrupted by two large volcanic eruption events that injected sulfate particles (sulfuric acid) into the stratosphere, causing a veil around the planet that reflected sunlight back to space, cooling the lower atmosphere (the troposphere) while warming the lower stratosphere. This chapter also shows the spatial distribution of tropospheric warming and stratospheric cooling in °C/decade.

This section continues with 2 chapters highlighting natural and manmade 'pollution,' one entitled "Dust in the Wind" that illustrates the long-range transport of dust from the Taklimakan Desert in China as it crosses the Pacific and arrives in the United States. Though dust storms in China (Taklimakan and Gobi deserts in particular) are 'natural,' they have been increasing in the last two decades in large part due to land use practices and the desertification of Inner Mongolia. Dust storms in north Africa and the middle East are also widespread and seasonal, and these are illustrated and discussed in this chapter. In addition to dust from natural and transformed land practices, the chapter on "Atmospheric Pollution: A Global Problem" turns attention to the global distribution of carbon monoxide (CO), a trace gas that results from incomplete combustion, either from fires or fossil fuel burning by industry, domestic heating, and motor vehicles. It is also a precursor gas to the formation of tropospheric ozone that is an oxidant and bad for plants and human lungs. This chapter uses space-based observations, not available prior to 2000, to map the global distribution of CO, which shows the expected high concentration in the Northern Hemisphere due to industrial activity but also the very sizeable CO maximum that occurs in southern Africa and in Brazil due to biomass burning in the Austral spring (September–November).

This section then turns to 2 chapters on additional human impacts on the Earth's atmosphere. The first, "Ship Tracks," concerns ships at sea emitting sulfate particles from their smoke stacks that serve as cloud condensation nuclei. The resulting ship-modified clouds are brighter and, especially, consist of larger numbers of smaller cloud drops that reflect more solar radiation back to space. Using satellite observations with the right optical sensitivity, it is possible to detect the presence of ships at sea beneath clouds due to the residual effect they leave in the cloud's reflectance as seen from satellites. Another phenomenon readily observable from space and due entirely to man's modern activities are "Airplane Contrails," in which 'condensation trails' are produced in the exhaust of commercial aircraft at altitudes in the upper troposphere where aircraft operate.

The section concludes with 3 chapters highlighting atmospheric chemistry and the effects that mankind has on atmospheric composition. "Weekly Cycle of Nitrogen Dioxide Pollution from Space" shows the amazing characteristic that nitrogen dioxide (NO_2), a short-lived, manmade chemical of the lower atmosphere, leaves a daily signal that reflects human activity. All major cities of the world, industrial coal-fired power plants, and regions of high lightning activity, are clearly evident from space-based observations. Furthermore, in the eastern United States and Europe (especially the Poe Valley of Italy), the NO_2 signal is much reduced on Sunday versus mid-week, whereas in the Islamic countries of the Middle East the NO_2 level is lowest on Friday and in Jewish Jerusalem it is lowest on Saturday.

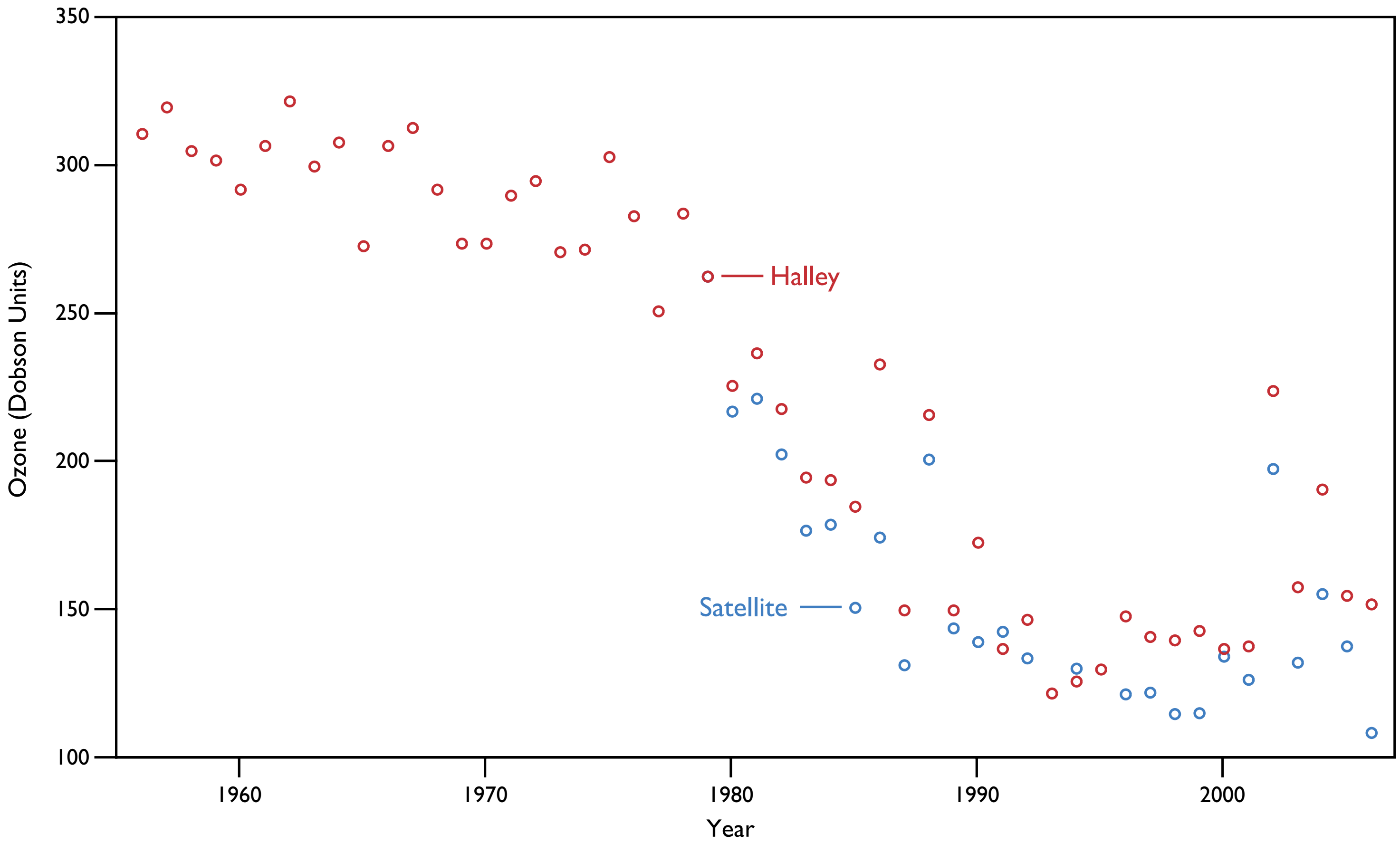
A subsequent chapter on the "The Ozone Hole" highlights this well-documented and satellite-observed phenomenon of significant stratospheric ozone loss over Antarctica every

Austral spring (especially late September and early October). The spatial and interannual variation of the ozone hole is illustrated, coupled with a time series showing the size of the ozone hole in comparison to the area of Antarctica and North America.

This section concludes with a chapter on "The Chlorine Threat to Earth's Ozone Shield" that centers on the deleterious effect that chlorine monoxide (ClO), a biproduct of manmade chlorofluorocarbons, has on stratospheric ozone both in the Arctic and the Antarctic. This gas is released only during daylight and in the presence of polar stratospheric clouds that form at high altitudes in polar regions due to the very cold temperatures and atmospheric composition. As a direct consequence of the Montréal Protocol and its various amendments and adjustments, production of CFCs was stopped worldwide in the 1990s and the ClO and hence ozone concentrations are expected to return to 1980 levels by 2070 or so, thereby reducing skin cancer cases, as shown in this chapter.

The chapters in this section illustrate a representative, though not exhaustive, sample of the many characteristics of the Earth's atmosphere that are readily observable from space. Other phenomena not illustrated in this section include (i) stratospheric sulfur dioxide (SO_2) arising from volcanic eruptions, (ii) tropospheric SO_2 arising from coal-fired power plants and copper smelters, (iii) the spatial distribution of manmade and natural aerosol particles, and (iv) the vertical distribution of many atmospheric constituents. As this section demonstrates, satellite imagery can show more readily than any other means the large-scale state of the atmosphere, its many dynamical processes, and the evolution of atmospheric conditions worldwide.

Measurements of the total ozone content of the atmosphere at Halley, Antarctica, have been made from ground-based instruments since 1956 and satellites since 1980. These observations of the minimum total ozone during September and October show an acute drop in total atmospheric ozone in the early- and mid-1980s, commonly referred to as the ozone hole. (Ground-based measurements from the Dobson ozone spectrophotometer and satellite measurements from the TOMS instrument on the Nimbus 7, Meteor 3, and Earth Probe satellites and the OMI instrument on Aura.)



Donald P. Wylie
W. Paul Menzel

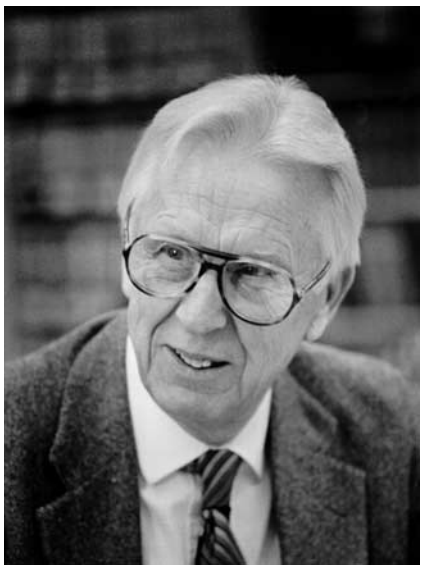
Clouds: Are the Shutters of the Earth Changing?

Photograph by Nasir Khan.

Clouds are a strong modulator of the amount of solar heating and thermal cooling of the Earth system. This is why Vern Suomi called them "the shutters of the Earth." We are currently in a warming trend that is often attributed to the increase in carbon dioxide (CO_2) in the atmosphere. But clouds cover approximately three-fourths of the Earth and a small increase in cloud cover could offset the warming from increased CO_2 in the atmosphere.

Global cloud observations using satellites were first advocated by Vern Suomi, often called the "father of satellite meteorology." It has been found that clouds vary greatly over the Earth, just as our weather does, and their effect on warming and cooling has to be inferred from the combined effect of all clouds in all places. Thick liquid water clouds are cooling the Earth through their reflection of sunlight. Thin ice clouds, called cirrus, allow sunlight to enter the Earth system but trap thermal radiation attempting to leave. Cirrus clouds are warming the Earth.

The International Satellite Cloud Climatology Project (ISCCP) has collected the largest global cloud data set using visible and infrared measurements from the international suite of weather satellites. As a supplement, multi-spectral infrared measurements from the National Oceanic and Atmospheric Administration polar orbiting High Resolution Infrared Radiation Sounders (HIRS) have been used for enhanced cirrus detection. Using regions of the infrared spectrum with differing sensitivity to atmospheric carbon dioxide, the HIRS measurements probe the atmosphere to different depths and reveal thin ice clouds high in the atmosphere.



The father of satellite meteorology—Verner Suomi (1915–1995). (Photograph from University of Wisconsin archives.)

Our Changing Planet, ed. King, Parkinson, Partington and Williams
Published by Cambridge University Press © Cambridge University Press 2007