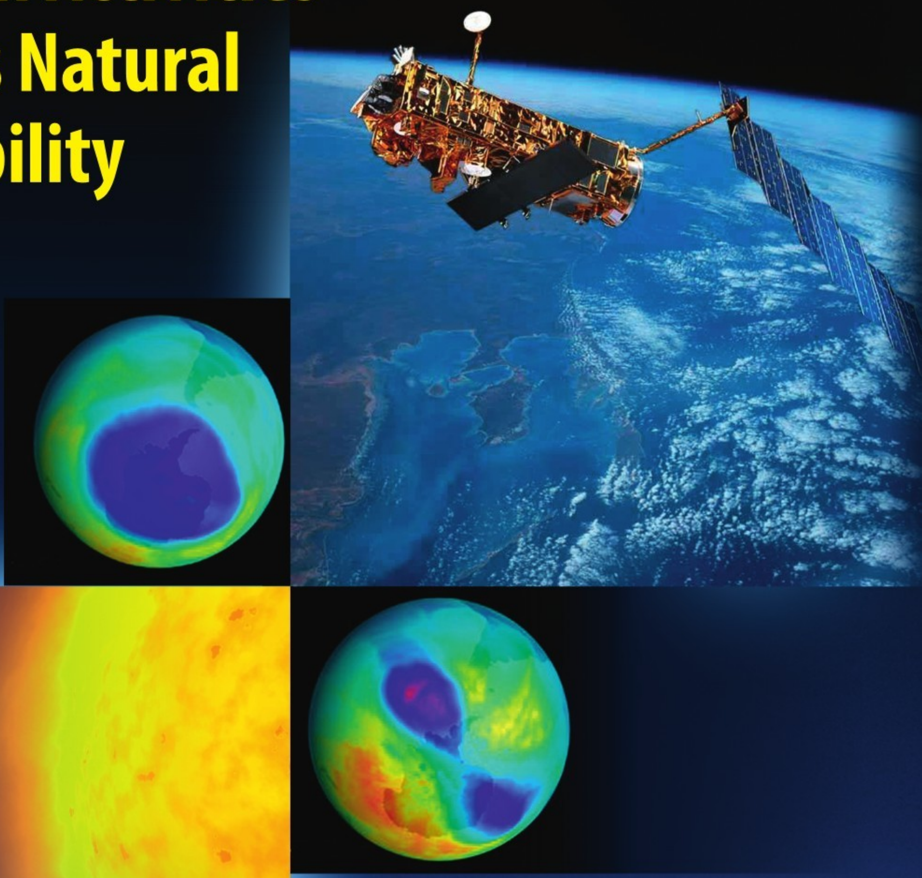
REMOTE SENSING AND ATMOSPHERIC OZONE

Human Activities versus Natural Variability



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Preface

Ozone is so rare in the atmosphere (there are only about three ozone molecules per 10 million air molecules) that if it was brought down to the Earth's surface and compressed to standard temperature and pressure, it would form a layer about as thick as a small coin. In spite of this, the importance of ozone, particularly in protecting the biosphere from the harmful effects of solar ultraviolet radiation, vastly exceeds what one might expect from this minor trace gas in the atmosphere. In the mid 1970s some scientists alerted the world to the fact that atmospheric ozone (which is mostly in the stratosphere) was being destroyed by manufactured chemicals released into the atmosphere. This led in 1987 to the Montreal Protocol to protect the ozone layer, which has been ratified by virtually every country in the world.

Remote sensing, which is mostly concerned with using Earth-orbiting satellites to study the Earth, played a vital role in the events leading up to the Montreal Protocol and since then has continued to play an important role in monitoring the implementation of the Montreal Protocol. The era of satellite remote sensing began on October 4, 1957, when the former Soviet Union launched Sputnik 1, the world's first artificial satellite (a 55 cm diameter sphere that weighed 83 kg with four antennae attached to it). It circled the Earth once every 96 minutes and transmitted radio signals that could be received on Earth. On November 3, 1957, a second satellite, Sputnik 2, was launched carrying a dog named Laika. The United States launched its first satellite, Explorer 1, on January, 31 1958, and its second, Vanguard 1, on March 17, 1958.

The launch of Sputniks 1 and 2 over 50 years ago marked the beginning of a long period of successful launches of a large number of Earth-orbiting unmanned spacecraft for environmental observation. Earth-orbiting satellites now play a crucial role in studying resources and environmental conditions in the atmosphere, biosphere, cryosphere, geosphere, and the oceans; in particular, in the present context they are involved in studying atmospheric ozone. Traditional measurements of atmospheric ozone from the ground, using ultraviolet spectrophotometers, and from ozonesonde balloons were being made for many years before remote-sensing satellites came to be developed and operated. However, these traditional methods only measured ozone concentrations at a few points on the surface of the Earth. The advantage of remote sensing is that it provides frequent coverage of the whole Earth.

This book is concerned with showing how remote sensing contributes to the study of atmospheric ozone and the consequences of human activities on atmospheric ozone. We cover the traditional measurement of ozone concentration in the atmosphere and give a comprehensive description of the large number of different satellite systems for the study of atmospheric ozone. This is followed by a consideration of the consistency of the ozone observations obtained with different methodologies and techniques and the importance of intercomparisons between various atmospheric ozone datasets and between various ozone-monitoring systems. We give a summary of the state of knowledge of the dynamics of atmospheric ozone and then consider the Montreal Protocol, how it came about and how its implementation is being monitored.

Remote sensing played a key role in the scientific research that led to the Montreal Protocol on ozone-depleting substances and it continues to play an important role in the monitoring of the success of the Protocol (we edited a special issue of the *International Journal of Remote Sensing* on Remote Sensing and the Implementation of the Montreal Protocol, Volume 30, Numbers 15–16, August 2009). Our introductory paper in that special issue (pp. 3853–3873) forms the basis of Chapter 5 of this book. In this context, the topic on the evolution of the Antarctic ozone hole is discussed based on the proposition by Mario Molina and Sherwood Rowland that human manufacture and release of CFCs (chlorofluorocarbons) into the atmosphere causes ozone depletion.

In view of various criticisms of the Intergovernmental Panel on Climate Change (IPCC) and a general feeling of depression induced by the apparent slowness of the international community in addressing the problems of global warming and climate change, it is perhaps instructive to consider the relation between the Montreal Protocol and the Kyoto Protocol and we do discuss this question.

We end with a summary of the results of research work since 1987 (i.e., since the Montreal Protocol was formulated). This involves the study of ozone depletion, both the steady decline in concentration amounting to a few percent per decade, depending on location, and the catastrophic temporary development of the ozone hole for a few months each year in the Antarctic and, more recently, in the Arctic. It also involves the relation between changes in ozone and climatic conditions.

In some ways this book is a sequel to *Atmospheric Ozone Variability: Implications for Climate Change, Human Health and Ecosystems*, by K.Ya. Kondratyev and C.A. Varotsos (Springer/Praxis, 2000). However, a great deal has happened since that book was written, both in terms of new remote-sensing systems and results and in connection with long-term datasets and ozone depletion. We now concentrate here on the science of studying atmospheric ozone itself, principally using remote-sensing techniques. In writing the present book, we have relied on many sources of information, including of course papers from research journals, the proceedings of the various Quadrennial Ozone Symposia and the Reports on the Scientific

Assessment of Ozone Depletion by WMO/UNEP (the World Meteorological Organization and the United Nations Environment Program), which we have listed in our Table 6.1. However, when it came to the 2008 Quadrennial Ozone Symposium held in Tromsø, Norway, no proceedings volume was published; only a set of abstracts was produced and it was left to participants to publish their work in refereed journals. We have made extensive use of these abstracts and they enabled us to find many recently published papers that we have cited, but we have not cited any of the Tromsø abstracts themselves.

We are grateful to many present and former students and colleagues who have contributed to our understanding of remote sensing and atmospheric ozone.

Inevitably, we have reproduced a large amount of copyright material and we are grateful to the various copyright holders who have given their permission and who are acknowledged *in situ* in the text, figures, or tables. Every effort has been made to trace original copyright holders of previously published material but with mergers in the publishing industry it is not always possible to track them down, so we offer our apologies where any have been overlooked. We are very grateful to Clive Horwood, of Praxis Publishing, for his help and encouragement during the writing of this book and to the staff of OPS for their production work.

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Figures

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Abbreviations and acronyms

AAO	Antarctic Oscillation
AAOE	Airborne Antarctic Ozone Experiment
AASE 1	Airborne Arctic Stratosphere Expedition
ABL	Atmospheric Boundary Layer
AC&C	Atmospheric Chemistry & Climate
ACCENT	Atmospheric Composition Change: the European Network of Excellence
ACD	Apparent Column Density
ACE	Aerosol Characterization Experiment
ACE-FTS	ACE Fourier Transform Spectrometer
ACVT	Atmospheric Chemistry Validation Team
AD	A and D wavelengths
ADEOS	ADvanced Earth Observing Satellite
AEM-2	Applications Explorer Mission-2
AEMET	Agencia Estatal de METeorología
AES	Atmospheric Environment Service
AF	Adjusted Forcing
AGCM	Atmospheric General Circulation Model
AIRS	Atmospheric InfraRed Sounder
ALA	Aerosol Limb Absorption
ALOMAR	Arctic Lidar Observatory for Middle Atmosphere Research
AM2	Atmosphere Model-2
AMAS	Advanced Millimeter-wave Atmosphere Sounder
AMF	AirMass Factor
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit

AO	Arctic Oscillation
AOS	Acousto-Optical Spectrometer
APE	Airborne Polar Experiment
API	Advanced Pollution Instruments
AR	Assessment Report
ARC	ARCtic
ARCAS	All-purpose Rocket for Collecting Atmospheric Soundings
ARGOS	Advanced Remote Gaseous Oxides Sensor
amsl	Above mean sea level
ASOPOS	ASsessment of Operating Procedures for Ozone Sondes
ASSET	ASSimilation of EnvisaT data
ASUR	Airborne SUbmillimeter Receiver
ATLAS	ATmospheric Laboratory for Applications and Science
ATMOS	Atmospheric Trace MOlecule Spectroscopy
ATMS	Advanced Technology Microwave Sounder
ATOVS	Advanced TOVS
AURAMS	A Unified Regional Air quality Modeling System
AVE	Aura Validation Experiment
AWI	Alfred Wegener Institut
BADC	British Atmospheric Data Centre
BAPoMON	Background Air Pollution MOnitoring Network
BAS	British Antarctic Survey
BASCOE	Belgian Assimilation System for Chemical ObsErvations
BD	Brewer–Dobson circulation
BESOS	Balloon Experiment on Standards for Ozone Sondes
BIC	Balloon Intercomparison Campaign
BIRA	Belgisch Instituut voor Ruimte-Aëronomie
BLISS	Balloonborne Laser In-Situ Sensor
BM	Brewer–Mast (ozonesonde)
BMLS	Balloon Microwave Limb Sounder
BOMEM	BOMEM model FTIR
BP	Band Pass
BSMILES	Balloon-borne Superconducting subMIllimeter-wave Limb Emission Sondes
BUV	Backscattered UltraViolet
CALIPSO	Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations
Caltech	California Institute of Technology
CAM	Community Atmosphere Model
CANDAC	CAnadian Network for the Detection of Atmospheric Change
CAO	Central Aerological Observatory

CARIBIC	Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container
CC	Cross Correlation
CCD	Convective Cloud Differential; Charge Coupled Device
CCM	Chemistry–Climate Model
CCMVal	Chemistry–Climate Model Validation activity
CCO3L	Coordination Committee on Ozone Layer
CCOL	Coordinating Committee on the Ozone Layer
CCSM	Community Climate System Model
CCSR/NIES	Center for Climate System Research/National Institute for Environmental Studies
CDOM	Colored Dissolved Organic Matter
CEOS	Committee on Earth Observation Satellites
CERES	Clouds and the Earth Radiant Energy System
CF	Cloud cover Fraction
CFC	Chlorofluorocarbon
CFL	Courant–Friedrichs–Levy
CGE	Centro de Geofísica de Évora
CHEM	CHEMistry model
CHEOPS	CHEmistry of Ozone in the Polar Stratosphere
CHRONOS	Canadian Hemispheric and Regional Ozone and Nitrous Oxide System
CHMI	Czech HydroMeteorological Institute
CIRRIS	Cryogenic InfraRed Radiance Instrument for Shuttle
CLAES	Cryogenic Limb Array Etalon Spectrometer
CMAM	Canadian Middle Atmosphere Model
CMDL	Climate Monitoring and Diagnostics Laboratory
CMIP5	Coupled Model Intercomparison Project Phase 5
CNR	Italian National Research Council
CNRS	Centre National de la Recherche Scientifique
CONTRAIL	Comprehensive Observation Network for TRace Gases by AIrLiner
COP-7	Conference of Parties to the Vienna Convention
COPES	Core Project
CPV	CircumPolar Vortex
CrIS	Cross-track Infrared Sounder
CRISTA	CRyogenic Infrared Spectrometers and Telescopes for the Atmosphere
CTM	Chemistry–Transport Model; Chemical Tracer Model
CTMK	Continuous Time MarKov chain model
CUE	Critical Use Exemption
CUSUM	CUmulative SUM
CWT	Continuous Wavelet Transform
DAAC	Distributed Active Archive Center
DAO	Data Assimilation Office