

**Appendix A**  
**Contributors and Reviewers**

---

**Appendix B**  
**List of Figures and Tables**

## APPENDIX A

### CONTRIBUTORS AND REVIEWERS

#### STEERING COMMITTEE

##### Chairmen

R.T. Watson	NASA Headquarters	USA
D.L. Albritton	NOAA Aeronomy Laboratory	USA

##### Members

F. Arnold	Max-Planck-Institut fur Kernphysik	FRG
R.D. Bojkov	World Meteorological Organization	Switzerland
D. Ehhalt	Kernforschungsanlage Julich	FRG
P. Fraser	CSIRO	Australia
I. Isaksen	University of Oslo	Norway
V. Khattatov	State Committee for Hydrometeorology	USSR
C. Mateer	Atmospheric Environment Service (Retired)	Canada
T. Matsuno	University of Tokyo	Japan
M. Prendez	Universidad de Chile	Chile
J.A. Pyle	University of Cambridge	UK
B.H. Subbaraya	Physical Research Laboratory	India
P. Usher	United Nations Environment Programme	Kenya

#### AUTHORS

##### Chapter 1. Polar Ozone

##### Coordinator

S. Solomon	NOAA Aeronomy Laboratory	USA
------------	--------------------------	-----

##### Principal Authors

W.L. Grose	NASA Langley Research Center	USA
R.L. Jones	Meteorological Office	UK
M.P. McCormick	NASA Langley Research Center	USA
M.J. Molina*	Jet Propulsion Laboratory	USA
A. O'Neill	Meteorological Office	UK
L.R. Poole	NASA Langley Research Center	USA
K.P. Shine	University of Reading	UK
S. Solomon	NOAA Aeronomy Laboratory	USA

\*Dr. Molina has been at MIT since Fall 1989.

## CONTRIBUTORS

### Other Contributors

R.A. Plumb	Massachusetts Institute of Technology	USA
U. Schmidt	Kernforschungsanlage Julich	FRG
V. Pope	Meteorological Office	UK

## Chapter 2. Global Trends

### Coordinator

G. Megie	Service d'Aeronomie du CNRS	France
----------	-----------------------------	--------

### Principal Authors

M.-L. Chanin	Service d'Aeronomie du CNRS	France
D. Ehhalt	Kernforschungsanlage Julich	FRG
P. Fraser	CSIRO	Australia
J.F. Frederick	University of Chicago	USA
J.C. Gille	National Center for Atmospheric Research	USA
M.P. McCormick	NASA Langley Research Center	USA
G. Megie	Service d'Aeronomie du CNRS	France
M. Schoeberl	NASA Goddard Space Flight Center	USA

### Other Contributors

L. Bishop	Allied-Signal, Inc.	USA
R.D. Bojkov	World Meteorological Organization	Switzerland
W. Chu	NASA Langley Research Center	USA
J.J. DeLuisi	NOAA Air Resources Laboratory	USA
J.F. Frederick	University of Chicago	USA
M. Geller*	NASA Goddard Space Flight Center	USA
S. Godin	Service d'Aeronomie du CNRS	France
N.R.P. Harris	University of California, Irvine	USA
W.J. Hill	Allied-Signal, Inc.	USA
R.D. Hudson	NASA Goddard Space Flight Center	USA
J.B. Kerr	Atmospheric Environment Service	Canada
W.D. Komhyr	NOAA Air Resources Laboratory	USA
K. Kunzi	University of Bremen	FRG
K. Labitzke	Freie Universitat, Berlin	FRG
C. Mateer	Atmospheric Environment Service (Retired)	Canada
R.D. McPeters	NASA Goddard Space Flight Center	USA
A.J. Miller	NOAA Climate Analysis Center	USA
R.M. Nagatani	NOAA Climate Analysis Center	USA
G.C. Reinsel	University of Wisconsin, Madison	USA
G.C. Tiao	University of Chicago	USA

\*Dr. Geller is now with SUNY Stony Brook.

## Chapter 3. Theoretical Predictions

## Coordinator

G. Brasseur	National Center for Atmospheric Research	Belgium
-------------	--	---------

## Principal Authors and Contributors

B.A. Boville	National Center for Atmospheric Research	USA
G. Brasseur	National Center for Atmospheric Research	Belgium
C. Bruhl	Max-Planck-Institut für Chemie	FRG
M. Caldwell	Utah State University	USA
P. Connell	Lawrence Livermore National Laboratory	USA
A. De Rudder	Belgium Institute for Space Aeronomy	Belgium
A. Douglass	NASA Goddard Space Flight Center	USA
I. Dyominov	Novosibirsk State University	USSR
D. Fisher	E.I. DuPont de Nemours and Co., Inc.	USA
J.F. Frederick	University of Chicago	USA
R. Garcia	National Center for Atmospheric Research	USA
C. Granier	Service d'Aeronomie du CNRS	France
R. Hennig	Max-Planck-Institut für Chemie	FRG
M. Hitchman	University of Wisconsin	USA
I. Isaksen	University of Oslo	Norway
C. Jackman	NASA Goddard Space Flight Center	USA
M. Ko	Atmospheric and Environmental Research, Inc.	USA
S. Madronich	National Center for Atmospheric Research	USA
M. Prather	NASA Goddard Institute for Space Studies	USA
R. Rood	NASA Goddard Space Flight Center	USA
S. Solomon	NOAA Aeronomy Laboratory	USA
F. Stordal	University of Oslo	Norway
T. Sasaki	Meteorological Research Institute	Japan
G. Visconti	University de l'Aquila	Italy
S. Walters	National Center for Atmospheric Research	USA
D. Wuebbles	Lawrence Livermore National Laboratory	USA
A. Zadarozhny	Novosibirsk State University	USSR
E. Zhadin	Central Aerological Observatory	USSR

## Chapter 4. Halocarbon Ozone Depletion and Global Warming Potentials

## Coordinators

R.A. Cox	Harwell Laboratory	UK
D.J. Wuebbles	Lawrence Livermore National Laboratory	USA

## CONTRIBUTORS

### Principal Authors and Contributors

R. Atkinson	California Statewide Air Pollution Center	USA
P. Connell	Lawrence Livermore National Laboratory	USA
H.P. Dorn	Kernforschungsanlage Julich	FRG
A. De Rudder	Belgium Institute for Space Aeronomy	Belgium
R.G. Derwent	Harwell Laboratory	UK
F.C. Fehsenfeld	NOAA Aeronomy Laboratory	USA
D. Fisher	E. I. DuPont de Nemours and Co., Inc.	USA
I. Isaksen	University of Oslo	Norway
M. Ko	Atmospheric and Environmental Research, Inc.	USA
R. Lesclaux	Universite de Bordeaux	France
S.C. Liu	NOAA Aeronomy Laboratory	USA
S.A. Penkett	University of East Anglia	UK
V. Ramaswamy	NOAA Geophysical Fluid Dynamics Laboratory	USA
J. Rudolph	Kernforschungsanlage Julich	FRG
H.B. Singh	NASA Ames Research Center	USA
W.-C. Wang	Atmospheric and Environmental Research, Inc.	USA

## Reviewers

Attendees: Review Meeting, 10-14 July 1989,  
Les Diablerets, Switzerland

D.L. Albritton	NOAA Aeronomy Laboratory	USA
R.D. Bojkov	World Meteorological Organization	Switzerland
G. Brasseur	National Center for Atmospheric Research	Belgium
D. Cariolle	Meteorologie Nationale EERM/CNRM	France
G.D. Cartwright	NOAA National Weather Service/WMO	USA
M.-L. Chanin	Service d'Aeronomie du CNRS	France
A. Charnikov	Central Aerological Observatory	USSR
R.A. Cox	Harwell Laboratory	UK
D.H. Ehhalt	Kernforschungsanlage Julich	FRG
J.C. Farman	British Antarctic Survey	UK
D. Fisher	E.I. DuPont de Nemours and Co., Inc.	USA
P.J. Fraser	CSIRO	Australia
J.F. Frederick	University of Chicago	USA
J.C. Gille	National Center for Atmospheric Research	USA
W.J. Hill	Allied-Signal, Inc.	USA
M. Hitchman	University of Wisconsin	USA
A.M.A. Ibrahim	Egyptian Meteorological Authority	Egypt
M. Ilyas	University of Science of Malaysia	Malaysia
J.B. Kerr	Atmospheric Environment Service	Canada
M.J. Kurylo	NASA Headquarters	USA
C. Mateer	Atmospheric Environment Service (Retired)	Canada
T. Matsuno	University of Tokyo	Japan

## CONTRIBUTORS

M.P. McCormick	NASA Langley Research Center	USA
M. McFarland	E. I. DuPont de Nemours and Co., Inc.	USA
G. Megie	Service d'Aeronomie du CNRS	France
M.J. Molina	Jet Propulsion Laboratory	USA
A. O'Neill	Meteorological Office	UK
A. Owino	Kenya Meteorological Department	Kenya
S.A. Penkett	University of East Anglia	UK
M. Prather	NASA Goddard Institute for Space Studies	USA
M. Prendez	Universidad de Chile	Chile
J.A. Pyle	University of Cambridge	UK
V. Ramaswamy	NOAA Geophysical Fluid Dynamics Laboratory	USA
J.M. Rodriguez	Atmospheric and Environment Research, Inc.	USA
J.M. Russell	NASA Langley Research Center	USA
S. Solomon	NOAA Aeronomy Laboratory	USA
R. Stolarski	NASA Goddard Space Flight Center	USA
B.H. Subbaraya	Physical Research Laboratory	India
A.F. Tuck	NOAA Aeronomy Laboratory	USA
P. Usher	United Nations Environment Programme	Kenya
R.T. Watson	NASA Headquarters	USA
D.J. Wuebbles	Lawrence Livermore National Laboratory	USA

### Mail Reviewers

J.G. Anderson	Harvard University	USA
J.K. Angell	NOAA Air Resources Laboratory	USA
R. Atkinson	Bureau of Meteorology	Australia
G. Betteridge	Physics and Engineering Laboratory, DSIR	New Zealand
J.P. Burrows	Max-Planck-Institut fur Chemie	FRG
B. Carli	IROF-CNR	Italy
S. Chubachi	Meteorological Research Laboratory	Japan
T.S. Clarkson	Meteorological Service	New Zealand
P. Crutzen	Max-Planck-Institut fur Chemie	FRG
D.W. Fahey	NOAA Aeronomy Laboratory	USA
G. Fiocco	University la Sapieuza	Italy
A. Ghazi	Commission of the European Communities	Belgium
L. Gray	Rutherford - Appleton Laboratories	UK
J.S. Hoffman	Environmental Protection Agency	USA
Y. Iwasaka	Nagoya University	Japan
P. Johnson	Physics and Engineering Laboratory, DSIR	New Zealand
P. S. Jovanovic	Association of Scientific Unions	Yugoslavia
J.G. Keys	Physics and Engineering Laboratory, DSIR	New Zealand
V. Kirchoff	INPE	Brazil
D. Kley	Kernforschungsanlage Julich	FRG
Y.-P. Lee	National Tsing Hua University	Taiwan
W.A. Matthews	Physics and Engineering Laboratory, DSIR	New Zealand
R. McKenzie	Physics and Engineering Laboratory, DSIR	New Zealand
A.P. Mitra	Department of Science and Industrial Research	India

## CONTRIBUTORS

J. L. Moyers	National Science Foundation	USA
L.P. Prahm	Danish Meteorological Institute	Denmark
M. H. Proffitt	NOAA Aeronomy Laboratory	USA
L. X. Qui	Academia Sinica	PRC
F. S. Rowland	University of California, Irvine	USA
P. C. Simon	Institut d'Aeronomie Spatiale	Belgium
Y. Sasano	National Institute for Environmental Studies	Japan
J. Swager	Air Directorate	Netherlands
D.W. Wei	Institute of Atmospheric Physics, NEPA	PRC
R. Zellner	University of Gottingen	FRG
C.S. Zerefos	University of Thessaloniki	Greece

## Logistical Support

R. D. Bojkov	World Meteorological Organization	Switzerland
M. -C. Charrierts	World Meteorological Organization	Switzerland
F. M. Ormond	ARC Professional Services Group	USA
J. Waters	NOAA Aeronomy Laboratory	USA

## APPENDIX B

### LIST OF FIGURES and TABLES\*

#### FIGURES

		Page
<b>Introduction</b>		
Figure 1.1	Calculated time-dependent change in relative ozone depletion following a step change in emission of halocarbons .....	xxx
Figure 1.2	Calculated column ozone change following a pulsed input of $5 \times 10^9$ .....	xxxix
<b>Chapter 1—Polar Ozone</b>		
Figure 1.1.2-1	Logarithm of the computed lifetime of the odd oxygen family in Northern Hemisphere winter versus latitude and height .....	3
Figure 1.1.2-2	The first three years of ozone data from the Dobson instrument at Halley Bay, Antarctica compared to Spitzbergen .....	4
Figure 1.1.2-3	Observed global variation of total ozone with latitude and season .....	5
Figure 1.1.2-4	Seasonal cycles of total ozone and 50 mb temperatures at 60°N (Jan.-Dec.) and 60°S (July-June) .....	6
Figure 1.1.2-5	As in Figure 1.1.2-4, but for 80°N (Jan.-Dec.) and 80°S (July-June) .....	6
Figure 1.1.3-1	Observed long-term trends in total ozone from the ground-based Antarctic stations at Syowa, Halley Bay, and the South Pole .....	8
Figure 1.1.3-2	TOMS October monthly mean minimum total ozone measurements along with equatorial zonal wind speed .....	9
Figure 1.1.3-3	Seasonal decline in total ozone above McMurdo Station in 1986 as deduced by visible, UV, and IR spectroscopy, as well as from ozonesonde observations ....	10
Figure 1.1.3-4	(A) Same as Figure 1.1.3-3, but for 1987; (B) Seasonal decline in the daily TOMS ozone minimum during 1987 .....	11
Figure 1.1.3-5	Contour plot of the ozone decrease obtained from 1978-1988; derived from a TOMS linear trend analysis .....	12
Figure 1.1.3-6	SAGE II total column ozone above 100 mb for all measurement events from day 270 through 293 (Sept. 27- Oct., 20 1985, 1986, and 1987; September 26-October 19, 1988) .....	13
Figure 1.1.3-7	False color images of SAGE II total column ozone above 100 mb for 1985 through 1988 .....	14
Figure 1.1.5-1	Observations of the change in the vertical profile of ozone as measured by ozonesondes. At Syowa, the South Pole, Halley Bay, McMurdo, Molodezhnaya, and Dakshin Gangotri .....	18
Figure 1.1.5-2	(A) Average vertical profiles of summertime ozone from February 1-10 (SAGE II). (B) The most severely depleted profiles observed (SAGE I [1981] and SAGE II [1985-1988]) .....	19

\*Titles have been shortened to economize on space.



## FIGURES

Page

Figure 1.1.5-3	Trend in total ozone at 18 km observed from ozonesondes at McMurdo Station in 1986 and 1987 .....	20
Figure 1.2.1-1	(Left) Vertical profiles of cloud particles observed during balloon soundings at McMurdo Station in September, 1988. (Right) Particle size distributions at various altitudes .....	25
Figure 1.2.2-1	Observations of PSC sightings (per week) from SAM II during 1979, 1980, 1981, 1982, and 1984 for May through October in the Southern Hemisphere vortex ...	28
Figure 1.2.2-2	As in Figure 1.2.2-1, but for 20, 22, and 24 km .....	29
Figure 1.2.2-3	As in Figure 1.2.2-1, but for 1985 through 1988 .....	29
Figure 1.2.2-4	As in Figure 1.2.2-3, but for 20, 22, and 24 km .....	30
Figure 1.2.2-5	As in Figure 1.2.2-1, but for November through April in the Northern Hemisphere vortex for the 1978-1979 through 1983-1984 winter seasons .....	31
Figure 1.2.2-6	As in Figure 1.2.2-5, but for 20, 22, and 24 km .....	31
Figure 1.2.2-7	As in Figure 1.2.2-5, but for 1984-1985 through 1988-1989 .....	32
Figure 1.2.2-8	As in Figure 1.2.2-7, but for 20, 22, and 24 km .....	32
Figure 1.2.3-1	SAM II optical depth integrated from 2 km above the tropopause to 30 km, for the Northern and Southern Hemispheres .....	33
Figure 1.2.3-2	Observations of SAM II PSC sightings for Antarctica from 1979 through 1988 at 14, 16, and 18 km, during the month of October .....	34
Figure 1.2.3-3	As in Figure 1.2.3-2, but for September .....	35
Figure 1.2.4-1	Changes in net heating caused by mountain PSCs with and without cirrus .....	38
Figure 1.3.2-1	Plot of the flight track data for the encounter with a PSC event on August 17, 1987 .....	41
Figure 1.3.2-2	Observations of the percent of total observed nitrate in the particulate phase as a function of time for September 4, 1987 .....	42
Figure 1.5.1-1	ClO dimer thermal decomposition and photolysis rates .....	47
Figure 1.5.1-2	Calculated time behavior of ClO and ClONO <sub>2</sub> during Arctic spring for three different cases .....	50
Figure 1.5.2-1	Absorption cross sections of ClOOCl .....	51
Figure 1.5.2-2	Rate constants for the ClO + ClO + M → Cl <sub>2</sub> O <sub>2</sub> + M reaction, with N <sub>2</sub> as the third body M .....	52
Figure 1.5.2-3	Photolysis rates for Cl <sub>2</sub> O <sub>2</sub> , HOCl, Cl <sub>2</sub> , HNO <sub>3</sub> , and O <sub>2</sub> at 70°S at noon as a function of day, at the 50 mb level .....	53
Figure 1.6.1-1	Observed ClO mixing ratio latitude gradients on the 425 and 450 K potential temperature surfaces averaged over the AAOE mission period .....	56
Figure 1.6.1-2	The vertical profile of ClO mixing ratio within the southern polar vortex, from ground-based microwave measurements and in situ measurements .....	56
Figure 1.6.1-3	Diurnal variation of the column abundance of ClO below about 25 km at McMurdo Station, Antarctica .....	57
Figure 1.6.1-4	Diurnal variation of the column abundance of OClO above McMurdo Station September 18-19, 1986 .....	58
Figure 1.6.1-5	Daily measurements of the sunset OClO column abundances above McMurdo Station in 1986 and 1987 .....	59
Figure 1.6.1-6	Observed distribution of the ClONO <sub>2</sub> column abundance, a function of latitude relative to the edge of the vortex in August and September, 1987 .....	60
Figure 1.6.1-7	Observed latitude gradients of HCl and HF on the 24th of September and 2nd of October, 1987 .....	61

	Page
Figure 1.6.2-1	Observations of the latitude gradient of column NO <sub>2</sub> in the Southern Hemisphere ..... 63
Figure 1.6.2-2	Observations of the seasonal trend in morning and evening twilight slant column NO <sub>2</sub> abundances from three Antarctic sites ..... 64
Figure 1.6.2-3	Total NO <sub>2</sub> (a), total O <sub>3</sub> (b), and 50 mb temperature (c) at Molodezhnaya in 1987 and Mirny in 1988 ..... 65
Figure 1.6.2-4	Cross section of NO <sub>2</sub> vs. latitude and pressure for the period September 27 to October 7, 1987, from SAGE II observations ..... 66
Figure 1.6.2-5	Observed column of HNO <sub>3</sub> plotted as a function of latitude relative to the edge of the polar vortex in August and September, 1987 ..... 66
Figure 1.6.2-6	Measurements of total reactive nitrogen (NO <sub>y</sub> ) versus N <sub>2</sub> O obtained from aircraft observations ..... 67
Figure 1.6.2-7	Observed total reactive nitrogen profile as a function of potential temperature .. 69
Figure 1.6.2-8	Observed NO mixing ratios versus latitude relative to the chemically perturbed region ..... 70
Figure 1.6.3-1	Observed latitude gradient of H <sub>2</sub> O on September 22, 1987 near 450 K surface ... 70
Figure 1.6.3-2	Cross section of H <sub>2</sub> O vs. latitude and pressure for the period September 27 to October 7, 1987, measured by SAGE II ..... 71
Figure 1.6.3-3	BrO mixing ratios versus latitude for nine flights from about 54° and 72°S, taken between August 28 and September 22, 1987 ..... 72
Figure 1.6.3-4	Variation of the BrO mixing ratio with potential temperature ..... 73
Figure 1.6.3-5	Diurnal variation of the BrO slant column at McMurdo Station ..... 74
Figure 1.6.4-1	Calculated and observed ClO mixing ratios on the 428 K surface, 4-12 September, 1987 ..... 76
Figure 1.6.4-2	Calculated and observed ClO mixing ratio profiles at 72°S, 4th/9th September, 1987 ..... 77
Figure 1.6.4-3	Observed NO and ClO mixing ratios from an aircraft flight on August 28, 1987
Figure 1.6.4-4	Observed and calculated rates of ozone decline for different ClO dimer formation rates as a function of potential temperature ..... 79
Figure 1.6.4-5	Observed October mean total ozone abundance over Halley Bay, Antarctica ... 81
Figure 1.7.1-1	The range, near 90 mb, of minimum brightness temperatures poleward of latitude 20, computed daily for winter and spring from 1980 to 1988 ..... 83
Figure 1.7.1-2	Comparison of N <sub>2</sub> O vertical profiles during austral winter-spring, austral summer, and austral winter ..... 84
Figure 1.7.1-3	Vertical distributions of the total amount of chlorine bonded in the five most abundant anthropogenic halocarbons ..... 85
Figure 1.7.1-4	(i) Monthly mean perspectives during June 1982 of the three-dimensional structure of the westerly vortex in the Southern Hemisphere ..... 86
Figure 1.7.1-4	(ii) As for Figure 1.7.1(i), but for September ..... 87
Figure 1.7.1-4	(iii) As for Figure 1.7.1(i), but for October ..... 87
Figure 1.7.1-5	Time of the reversal of the zonal wind at latitude 60°, and of the temperature difference between 60° and 85° for the Northern and Southern Hemispheres .... 88
Figure 1.7.1-6	Evolution of zonal-mean total ozone (Dobson units) derived from the TOMS instruments, 1987 and 1988 ..... 90
Figure 1.7.1-7	Minimum brightness temperature near 90 mb (Channel 24 of the MSU) in the Southern Hemisphere during 1987 ..... 91

## FIGURES

	Page
Figure 1.7.1-8	The fractional area of the Southern Hemisphere over which minimum temperatures near 90 mb in 1987 fell below 193 K ..... 91
Figure 1.7.1-9	As for Figure 1.7.1-7 but for 1988 ..... 92
Figure 1.7.1-10	As for Figure 1.7.1-8 but for 1988 ..... 92
Figure 1.7.1-11	Isentropic maps of Ertel's potential vorticity and winds on the 500 K isentropic surface in the Southern Hemisphere on 1 August 1987 ..... 93
Figure 1.7.1-12	As for Figure 1.7.1-11, but for 31 October 1987 ..... 94
Figure 1.7.1-13	As for Figure 1.7.1-11, but on 1 August 1988 ..... 94
Figure 1.7.1-14	As for Figure 1.7.1-11, but on 20 October 1988 ..... 95
Figure 1.7.1-15	As for Figure 1.7.1-11, but for the Northern Hemisphere on 18 January 1989 .... 96
Figure 1.7.1-16	As for Figure 1.7.1-11, but for the Northern Hemisphere on 20 February 1989 .. 97
Figure 1.7.1-17	Minimum brightness temperature derived from channel 24 of the MSU in the Northern Hemisphere for December through May ..... 98
Figure 1.7.1-18	The total ozone fields (in Dobson units) from November 1978 to October 1987 with annual cycle removed ..... 99
Figure 1.7.1-19	As for Figure 1.7.1-18, but after application of a broad-band filter ..... 100
Figure 1.7.1-20	Variation in October mean total ozone and 70 mb temperature over the South Pole ..... 101
Figure 1.7.1-21	As for Figure 1.7.1-20, but for the April mean in the Northern Hemisphere ..... 101
Figure 1.7.1-22	Correlation of August-September winds over Singapore at 30 mb with the total ozone decline rate in September ..... 102
Figure 1.7.1-23	Ozone mixing ratio variation at the maximum of the 11-year solar cycle ..... 103
Figure 1.7.2-1	An example of a mini-hole over the Antarctic Peninsula on 5 September 1987 ... 105
Figure 1.7.2-2	(i) Longitude/pressure cross sections on 5 September 1987 at latitude 65°S from 90°W to 30°W, and from 250 to 30 mb ..... 106
Figure 1.7.2-2	(ii) As for Figure 1.7.2-2 (i) ..... 107
Figure 1.7.2-3	A sequence of potential vorticity distributions on the 428 K surface of potential temperature ..... 108
Figure 1.7.4-1	Ertel's potential vorticity on the 600 K isentropic surface ..... 111
Figure 1.7.4-2	TOMS total ozone. Monthly variation of difference between 1987-1988 average and 1979-1980 average as a function of latitude ..... 112
Figure 1.7.4-3	Percent change in the simulated steady-state seasonal and latitudinal distribution of zonal-mean column ozone ..... 113
Figure 1.7.4-4	Percent difference in zonal-mean column ozone for Antarctic ozone hole ..... 114
Figure 1.7.4-5	Percent difference in the integrated global and hemispheric column ozone for Antarctic ozone hole ..... 116
Figure 1.7.4-6	TOMS total ozone for the Southern Hemisphere ..... 117
Figure 1.7.4-7	Difference between Ertel's potential vorticity (500 K isentropic surface) for 8 December and 14 December 1987 ..... 118
Figure 1.8.1-1	Linear trends calculated from NMC data for the period 1979-1986, for August, September, November, and December ..... 119
Figure 1.8.2-1	Deviations of temperatures 1958-1988 (°C) for Angell's (1988b) six south polar stations ..... 120
Figure 1.8.2-2	Monthly mean temperatures at 100 mbar for Halley Bay, 1958-1988 ..... 121
Figure 1.8.2-3	Temperatures at 100 mbar as a function of month from Halley Bay ..... 122
Figure 1.8.2-4	Deviation of NMC zonal mean temperatures for 1987 from the 1979-1986 mean for September to December ..... 123

	Page
Figure 1.8.3-1	2-D model temperatures at 39 mb and 76°S with and without an imposed ozone hole ..... 125
Figure 1.8.3-2	Deviation of zonal mean temperature for a calculation with an imposed ozone hole from a control run without the hole, using the NCAR Community Climate Model ..... 126
Figure 1.9-1	Ratio of biologically effective downward radiation computed for a range of ozone values at McMurdo ..... 127
Figure 1.9-2	Computed time history of erythemal irradiance for local noon and clear skies over Palmer Station ..... 129
Figure 1.9-3	Spectra of UV solar irradiance measured from Palmer Station at local noon ..... 130
Figure 1.9-4	Ratio of noontime irradiance for 295-305 nm to that for 335-345 nm, for the period 19 September and 21 December 1988 ..... 131
Figure 1.10.1-1	Observation of the Noxon cliff ..... 131
Figure 1.10.1-2	The mean annual cycle of NO <sub>2</sub> at 71°N (Point Barrow, Alaska) ..... 132
Figure 1.10.1-3	Variation of total NO <sub>2</sub> column abundance over Point Barrow, Alaska (71°N) in three different winter-spring seasons ..... 133
Figure 1.10.1-4	NO <sub>x</sub> (NO + NO <sub>2</sub> ) mixing ratio profiles observed on balloon flights using a chemiluminescent detector ..... 134
Figure 1.10.1-5	Zonally and monthly averaged HNO <sub>3</sub> mixing ratio distributions for November, December, and January from LIMS observations ..... 136
Figure 1.10.1-6	Latitude gradients of HCl and HF in the Northern Hemisphere ..... 137
Figure 1.10.1-7	Observations of the nighttime abundance of OClO versus lunar zenith angle at various locations ..... 138
Figure 1.10.2-1	Ozone partial pressure and mixing ratio profiles measured at Kiruna, Sweden, on 23 January, 1989 ..... 140
Figure 1.10.2-2	NMC temperatures at 30 mb for the 1988-1989 Northern Hemisphere winter-spring season ..... 141
Figure 1.10.2-3	NMC temperatures at 30 mb for the 1975-1976 Northern Hemisphere winter-spring season ..... 142
 <b>Chapter 2—Global Trends</b>	
Figure 2.1-1	Time-lines of measurements available for use in ozone trend analyses at the present time ..... 164
Figure 2.1-2	Location of Dobson and M-83 stations ..... 166
Figure 2.1-3	Time-lines for ozone-measuring systems that are projected to be operating over the next decade ..... 175
Figure 2.1-4a	Comparison between archived TOMS total ozone data and Dobson data ..... 182
Figure 2.1-4b	Comparison between TOMS total ozone data where diffuser plate degradation was corrected by the “pair justification” method and Dobson data ..... 183
Figure 2.1-5	Samples of profile pairs measured by ozonesondes and the SAGE I instrument and the mean percentage difference between the ozonesondes and the SAGE I ozone ..... 186
Figure 2.1-6	Samples of profile pairs measured by ozonesondes and the SAGE II instrument and the mean percentage difference between the ozonesondes and the SAGE II ozone ..... 187
Figure 2.1-7	Mean differences between SAGE I and ozonesondes and SAGE II and ozonesondes ..... 188

## FIGURES

	<b>Page</b>
Figure 2.2-1	Monthly and zonally averaged Dobson total ozone values versus time after removal of seasonal, QBO, solar cycle, and nuclear test effects ..... 197
Figure 2.2-2a	Regional plots of Dobson total ozone after removal of seasonal, solar, QBO, and nuclear test effects for North America, Europe, and Japan ..... 198
Figure 2.2-2b	Same as 2.2-2a for winter months (December-March) ..... 199
Figure 2.2-2c	Same as 2.2-2a for summer months (May-August) ..... 200
Figure 2.2-3	Plots of Dobson total ozone monthly averages combined into time series for each latitudinal zone ..... 201
Figure 2.2-4	Individual trend estimates for the period 1970-1986 using the AS2 model ..... 203
Figure 2.2-5	Same as Figure 2.2-4 except trends are fitted only through October 1982 ..... 205
Figure 2.2-6	Same as Figure 2.2-4 except trends are fitted using updated data into 1988 ..... 208
Figure 2.2-7	Differences between estimated trends into 1988 versus trends through 1986 ..... 210
Figure 2.2-8	Solar coefficient computed for 25 Northern Hemisphere stations from the AS2 model ..... 211
Figure 2.2-9a	Geographic structure in total ozone changes based on TOMS ..... 212
Figure 2.2-9b	Same as Figure 2.2-9a for Southern Hemisphere ..... 213
Figure 2.2-10	Geographic pattern of change in total ozone derived from SBUV for the Northern Hemisphere winter and summer ..... 215
Figure 2.2-11	Geographic pattern of change in total ozone derived from SBUV for the Southern Hemisphere winter and summer ..... 215
Figure 2.2-12	Changes in total ozone based on eight-year data sets from the SBUV and TOMS instruments ..... 217
Figure 2.2-13	Changes in total ozone derived from Dobson data for the eight-year period over which SBUV measurements are available ..... 218
Figure 2.3-1	Latitudes of the SAGE I and SAGE II sampling locations for sunset ..... 222
Figure 2.3-2	Zonal mean ozone number density at 30 km for SAGE I during the period 2/79-11/81 and SAGE II during the period 10/84-11/87 for five latitude bands ..... 223
Figure 2.3-3	Daily mean ozone number density at 35 km for SAGE II for twelve latitude bands ..... 224
Figure 2.3-4	Mean percentage difference between SAGE II and SAGE I versus altitude computed from the intersection of SAGE I with SAGE II ..... 225
Figure 2.3-5	Deseasonalized Umkehr data at Arosa for layers 4-9, unadjusted for aerosols, for the period January 1977 through December 1987 ..... 227
Figure 2.3-6	Stratospheric aerosol optical thickness derived from lidar data for the period 1977-1987 ..... 228
Figure 2.3-7	Umkehr data trend estimates from 10 individual Umkehr stations for layers 4-9, for the period January 1977 through December 1987 ..... 229
Figure 2.3-8	Trend estimates derived from ozonesondes measurements at 9 stations for 15 fractional Umkehr layers ..... 233
Figure 2.4-1a	Seasonal temperatures with the long-term seasonal averages removed and smoothed 1-2-1 in time for Angell, Berlin, NMC, MSU, SSU ..... 238
Figure 2.4-1b	Seasonal temperatures with the long-term seasonal averages removed and smoothed 1-2-1 in time: NMC; SSU Channels 25 and 26 × ..... 239
Figure 2.4-1c	Seasonal temperatures with the long-term seasonal averages removed and smoothed 1-2-1 in time: NMC; SSU Channel 26 ..... 240
Figure 2.4-1d	Seasonal temperatures with the long-term seasonal averages removed and smoothed 1-2-1 in time: NMC 5-1 mb; SSU Channels 27 and 36 X ..... 241

	Page
Figure 2.4-2	Lidar temperature and SSU channel 27 brightness temperature from 1981 to 1987 ..... 242
Figure 2.4-3	Lidar and NMC temperature at 42 km ..... 242
Figure 2.4-4	Comparison of the 10.7 cm solar flux, in $10^{22}$ W/(m <sup>2</sup> Hz), and the 30-mb temperature, in °C, at the North Pole ..... 243
Figure 2.4-5	Summary of global stratospheric temperature differences (1985 and 1986 minus the average of 1979 and 1980) ..... 244
Figure 2.4-6	As in Figure 2.4-4, except for Tropics and including rocket stations ..... 245
Figure 2.5-1	Halocarbon (pptv) and nitrous oxide (ppbv) observations at Cape Grim, Tasmania, as part of the GAGE program ..... 248
Figure 2.5-2	CHClF <sub>2</sub> (pptv) observations at Cape Grim, Tasmania, from the Oregon Graduate Center flask sampling program ..... 249
Figure 2.5-3	CH <sub>3</sub> Cl (pptv) observations at Cape Grim, Tasmania, from the Oregon Graduate Center flask sampling program ..... 249
Figure 2.5-4	CHCl <sub>3</sub> (pptv) observations at Cape Grim, Tasmania, from the Oregon Graduate Center flask sampling program ..... 250
Figure 2.5-5	Long-term trends of N <sub>2</sub> O from the GMCC program, the SIO program, the OGC-ALE program, the FIAER-CSIR program, and CSIRO-GAGE data ..... 252
Figure 2.5-6	Long-term trends of CH <sub>4</sub> from the CSIRO global program and the FIAER-CSIR program at Cape Point, South Africa ..... 254
Figure 2.5-7	The global distribution, seasonality, and trend of CH <sub>4</sub> from the GMCC network ..... 255
Figure 2.5-8	Long-term trends of CO from the CSIRO network and from Cape Point, South Africa ..... 257
Figure 2.5-9	The temporal behavior of the CO <sub>2</sub> trends observed at the GMCC stations ..... 258
Figure 2.5-10	Surface ozone measurements at the GMCC stations, at Cape Point, South Africa, and at Cape Grim, Tasmania ..... 260
Figure 2.6-1	Aerosol integrated backscatter coefficient over the period 1974-88 ..... 262
Figure 2.7-1	Solar spectral irradiance incident on the Earth's surface computer for January and July at latitudes 34.5°, 46.0°, and 58.5°N ..... 264
Figure 2.7-2	Percent changes in solar spectral irradiance between 1970 and 1986 computed for January, March, and July at latitudes 34.5°, 46.0°, and 58.5°N ..... 266

**Chapter 3—Theoretical Predictions**

Figure 3.1-1	Schematic diagram showing an algorithm for determining the coupled set of transport parameters with prescribed T as input ..... 287
Figure 3.1-2	Total ozone field on 28 February 1989 as measured by TOMS and as modeled from a January 1 initial condition ..... 291
Figure 3.1-3	Two-dimensional distribution of tropospheric source gas X from nine models for the month of December ..... 295
Figure 3.1-4	Two-dimensional distribution of the ClO/HCl ratio from nine models ..... 298
Figure 3.1-5	Zonally and monthly averaged distribution of nitrous oxide observed in January 1979 by SAMS and calculated by GSFC model ..... 301
Figure 3.1-6	Same as in Figure 3.1-5 but for methane ..... 302
Figure 3.1-7	Zonally and monthly averaged distribution of nighttime NO <sub>2</sub> observed in January 1979 by LLMS ..... 303

## FIGURES

	<b>Page</b>
Figure 3.1-8	Same as in Figure 3.1-7 but for nitric acid ..... 304
Figure 3.1-9	Zonally and monthly averaged distribution of ozone for January based on data obtained by SBUV and distribution by different two-dimensional models ..... 307
Figure 3.1-10	Latitudinal and seasonal variation of the ozone column abundance based on satellite observations (TOMS) and different model calculations ..... 312
Figure 3.1-11	Comparison between one-dimensional mixing ratio profiles of chemically active trace gases measured by ATMOS ..... 316
Figure 3.2-1	Time history, 1960-2060, of mean tropospheric concentrations of the trace gases assumed for the different scenarios ..... 319
Figure 3.2-2	Time history, 1980-2060, of total atmospheric chlorine and total atmospheric bromine from the different scenarios ..... 321
Figure 3.2-3	Dobson map of percent change in column ozone from 1960 to 1980 using the specified trace-gas scenario ..... 329
Figure 3.2-4	Latitude-by-altitude contour map of the percent change in local ozone concentration from 1960 to 1980 for the specified trace-gas scenario ..... 333
Figure 3.2-5	Time-line of the percent change in column ozone as a function of latitude for the months of March from 1980 through 2060 for scenario A1 ..... 338
Figure 3.2-6	Dobson map of percent change in column ozone from 1980 to 2020 using scenario A1 ..... 340
Figure 3.2-7	Dobson map of percent change in column ozone from 1980 to 2060 using scenario A1 ..... 342
Figure 3.2-8	Latitude-by-altitude contour map of the percent change in local ozone concentration from 1980 to 2060 for scenario A1 ..... 347
Figure 3.2-9	Time-line vs. latitude of the percent change in column ozone during March from 1980 to 2060 for scenario A2 ..... 351
Figure 3.2-10	Dobson map of percent change in column ozone from 1980 to 2060 using scenario A2 ..... 352
Figure 3.2-11	Latitude-by-altitude map of the percent change in local ozone concentration from 1980 to 2060 for scenario A2 ..... 353
Figure 3.2-12	Temperature change (K) for December (scenario A1: 1980-2060) from the AER and WisCAR models ..... 354
Figure 3.2-13	Zonal wind and zonal wind change from December 1980 to December 2060 for the WisCAR model (scenario A1) ..... 355
Figure 3.2-14	Net radiative heating (K/day) for December 1980 in the AER and WisCAR models ..... 356
Figure 3.2-15	Change in net radiative heating (K/day) from December 1980 to December 2060 (scenario A1) in the AER and WisCAR models ..... 357
Figure 3.2-16	Time-line vs. latitude of the percent change in column ozone during March from 1980 to 2060 for scenario A1 ..... 359
Figure 3.2-17	Dobson map of percent change in column ozone from 1980 to 2060 using scenario B1 ..... 360
Figure 3.2-18	Latitude-by-altitude map of the percent change in local ozone concentration from 1980 to 2060 for scenario B1 ..... 361
Figure 3.2-19	Time-line vs. latitude of the percent change in column ozone during March from 1980 to 2060 for scenario C1 ..... 363
Figure 3.2-20	Dobson map of percent change in column ozone from 1980 to 2060 using scenario C1 ..... 364

	Page
Figure 3.2-21	Latitude-by-altitude map of the percent change in local ozone concentration from 1980 to 2060 for scenario C1 ..... 364
Figure 3.2-22	Time-line vs. latitude of the percent change in column ozone during March from 1980 to 2060 for scenario D1 ..... 365
Figure 3.2-23	Dobson map of percent change in column ozone from 1980 to 2060 using scenario D1 ..... 366
Figure 3.2-24	Latitude-by-altitude map of the percent change in local ozone concentration from 1980 to 2060 for scenario D1 ..... 368
Figure 3.2-25	Time-line vs. latitude of the percent change in column ozone during March from 1980 to 2060 for scenario D2 ..... 371
Figure 3.2-26	Dobson map of percent change in column ozone from 1980 to 2060 using scenario D2 ..... 371
Figure 3.2-27	Latitude-by-altitude map of the percent change in local ozone concentration from 1980 to 2060 for scenario D2 ..... 372
Figure 3.2-28	Time-line vs. latitude of the percent change in column ozone during March from 1980 to 2060 for scenario D3 ..... 372
Figure 3.2-29	Dobson map of percent change in column ozone from 1980 to 2060 using scenario D3 ..... 373
Figure 3.2-30	Latitude-by-altitude map of the percent change in local ozone concentration from 1980 to 2060 for scenario D3 ..... 373
Figure 3.2-31	Time-line vs. latitude of the percent change in column ozone during March from 1980 to 2060 for scenario D4 ..... 374
Figure 3.2-32	Dobson map of percent change in column ozone from 1980 to 2060 using scenario D4 ..... 375
Figure 3.2-33	Latitude-by-altitude map of the percent change in local ozone concentration from 1980 to 2060 for scenario D4 ..... 375
Figure 3.2-34	Two-year sequence of percent change in column ozone from the Cambridge model with PSC chemistry in the Northern Hemisphere ..... 376
Figure 3.2-35	Dobson maps of percent change in column ozone from 1960 to 2060 from the WisCAR model with and without heterogeneous chemistry on PSCs for scenario A1 ..... 377
Figure 3.2-36	Dobson maps of percent change in column ozone from 1960 to 1985 and from 1985 to 2060 from the AER model using scenario B1 ..... 378
Figure 3.2-37	Dobson maps of percent change in column ozone from 1985 to 2050 from the Oslo model with and without heterogeneous chemistry on the natural sulfate layer ..... 380
Figure 3.2-38	Dobson maps of percent change in column ozone from 1985 to 2060 from the AER model using scenario B1 ..... 381
Figure 3.2-39	Action spectra used as weighting functions to calculate biologically effective radiation ..... 381
Figure 3.2-40	Daily doses for 1979/80 based on ozone column from TOMS measurements normalized to Dobson ..... 386
Figure 3.2-41	Daily dose changes from 1960 to 1980, GSFC2 model ..... 388
Figure 3.2-42	Daily dose changes from 1960 to 2060, GSFC2 model, scenario A1 ..... 389
Figure 3.2-43	Daily dose changes from 1960 to 2060, GSFC2 model, scenario D1 ..... 390
Figure 3.2-44	Daily DNA damage dose changes from 1980 to 2060, WisCAR model, scenarios A1, A2, and D1 ..... 391



## FIGURES

	<b>Page</b>
Figure 3.2-45	Transformed Eulerian mean vertical velocity for a 240-day average simulation performed with the NCAR Community Climate Model ..... 394
Figure 3.2-46	As in Figure 3.3-40 but for the ozone reduction scenario shown in Figure 3.3.41b; percentage change in ozone from the two-dimensional model of Ko et al., 1985 ..... 394
 <b>Chapter 4—Halocarbon Ozone Depletion Potentials and Global Warming Potentials</b>	
Figure 4.2-1	Reactions governing concentrations of OH and HO <sub>2</sub> ..... 411
Figure 4.2-2	Schematic presentation of the measured vertical distribution of NO and NO <sub>y</sub> over midlatitude oceanic and coastal regions ..... 419
Figure 4.3-1	Calculated column ozone change in the DuPont 1-D model following a pulsed input of $5.0 \times 10^9$ kg of specified gas ..... 425
Figure 4.3-2	Atmospheric concentrations of halocarbons with 5- and 100-year lifetimes following onset of a constant emission of each compound ..... 426
Figure 4.3-3	Calculated latitudinal and seasonal steady-state ozone change from emission of CFC-11 necessary for global 1% change in total ozone (LLNL 2-D model) ..... 435
Figure 4.3-4a	Calculated latitudinal and seasonal steady-state ozone change from emission of CFC-12 necessary to give 1% change in total ozone (LLNL 2-D model) ..... 436
Figure 4.3-4b	Calculated latitudinal and seasonal relative ozone depletion of CFC-12 (LLNL 2-D model) ..... 437
Figure 4.3-4c	Calculated latitudinal and seasonal relative ozone depletion of CFC-12 (AER 2-D model) ..... 437
Figure 4.3-4d	Calculated latitudinal and seasonal relative ozone depletion of CFC-12 (Oslo 2-D model) ..... 438
Figure 4.3-4e	Calculated latitudinal and seasonal relative ozone depletion of CFC-12 (DuPont 2-D model) ..... 438
Figure 4.3-5a	Calculated latitudinal and seasonal steady-state ozone change necessary to give 1% change in total ozone from emission of HCFC-22 (LLNL 2-D model) ..... 439
Figure 4.3-5b	Calculated latitudinal and seasonal relative ozone depletion of CFC-22 (LLNL 2-D model) ..... 439
Figure 4.3-5c	Calculated latitudinal and seasonal relative ozone depletion from emission of HCFC-22 (AER 2-D model) ..... 440
Figure 4.3-5d	Calculated latitudinal and seasonal relative ozone depletion from emission of HCFC-22 (Oslo 2-D model) ..... 440
Figure 4.3-5e	Calculated latitudinal and seasonal relative ozone depletion from emission of HCFC-22 (DuPont 2-D model) ..... 441
Figure 4.3-6	Calculated CFC-11 profiles from transport sensitivity study at 75°S at equinox (AER 2-D model) ..... 443
Figure 4.3-7	Calculated CFC-11 profiles from transport sensitivity study at Equator at equinox (AER 2-D model) ..... 443
Figure 4.3-8a	Calculated HCFC-22 profiles from transport sensitivity study at 75°S at equinox (AER 2-D model) ..... 444
Figure 4.3-8b	Calculated HCFC-22 profiles from transport sensitivity study at Equator at equinox (AER 2-D model) ..... 444
Figure 4.3-9a	Calculated total ozone abundance (Dobson units) from transport sensitivity studies (case 1 and case 2) ..... 445

**FIGURES**

	<b>Page</b>
Figure 4.3-9b	Calculated total ozone abundance (Dobson units) from transport sensitivity studies (case 3 and case 4) ..... 445
Figure 4.3-10a	Calculated latitudinal and seasonal relative ozone depletion from emission of HCFC-22 (case 2) ..... 446
Figure 4.3-10b	Calculated latitudinal and seasonal relative ozone depletion from emission of HCFC-22 (case 3) ..... 447
Figure 4.3-10c	Calculated latitudinal and seasonal relative ozone depletion from emission of HCFC-22 (case 4) ..... 447
Figure 4.3-11	Calculated time-dependent change in relative ozone column depletion following a step change in emission of the tested halocarbons (LLNL 1-D model) ..... 448
Figure 4.3-12	Calculated time-dependent change in relative ozone column depletion following a step change in emission of the tested halocarbons (DuPont 1-D model) ..... 449
Figure 4.3-13	Calculated time-dependent relative chlorine loading following a step change in emission of the tested halocarbons (LLNL 1-D model) ..... 450
Figure 4.4-1	Calculated change in surface temperature following a pulsed emission of $5 \times 10^9$ kg of specified gas ..... 454
Figure 4.4-2	Change of calculated warming following a step change of emission of specified gas at $5 \times 10^8$ kg/yr ..... 460
Figure 4.4-3	Column of chlorofluorocarbons following step change of emission of specified gas at $5 \times 10^8$ kg/yr ..... 460
Figure 4.4-4	Calculated relative warmings following a step change of emission of specified gas (CFC-11 reference) ..... 461

## TABLES

	<b>Page</b>
<b>Introduction</b>	
Table 1	Range of Ozone Depletion Potentials (ODPs) and halocarbon Global Warming Potentials (GWPs) determined by one-dimensional and two-dimensional models ..... xi
Table 2	Scenarios for halocarbon abundances ..... xxiv
Table 3	Range of Ozone Depletion Potentials (ODPs) determined by one-dimensional and two-dimensional models ..... xxviii
Table 4	Ozone Depletion Potentials for brominated compounds as calculated in the LLNL one-dimensional model and the University of Oslo two-dimensional model ..... xxix
Table 5	Maximum relative Chlorine Loading Potential (CLP) for examined CFCs, HCFCs, HFCs ..... xxix
Table 6	Halocarbon Global Warming Potentials (Halocarbon GWPs) scaled relative to reference set of halocarbon lifetimes ..... xxxii
 <b>Chapter 1—Polar Ozone</b>	
Table 1.1.6-1	Changes in average total ozone abundances, as measured at individual Dobson stations over the 22-year period, 1965-1986 ..... 21
Table 1.1.6-2	Coefficients of multiple regression statistical analysis of re-analyzed Dobson measurements of total ozone concentrations collected into latitudinal band averages ..... 22
Table 1.1.6-3	Percentage changes in total column ozone ..... 23
Table 1.4-1	Reaction probabilities on water-ice ..... 44
Table 1.6-1	Potential temperatures and approximate geometric altitude and pressure equivalents for late winter and early spring for the Antarctic region ..... 55
Table 1.6.4-1	Assumed chlorine tracer concentrations and inorganic chlorine content as a function of potential temperature at 72°S ..... 75
Table 1.9-1	Comparison of noontime irradiances computed for McMurdo during October with values for the summer solstice ..... 128
 <b>Chapter 2—Global Trends</b>	
Table 2.1-1	Estimated overall percentage differences of the calculated zonal mean ozone layer amount of SBUV, SAGE, and LIMS with respect to the average of these three instruments ..... 184
Table 2.1-2	Summary of Ozone Trend Estimates (in % per year) in total ozone and associated standard error ..... 191
Table 2.2-1	Comparison of trend results by season and latitude ..... 195
Table 2.2-2	List of Dobson total ozone stations at latitudes between 26°N and 64°N ..... 202
Table 2.2-3	Summary of sensitivity analysis (% per decade effect on trends) ..... 204
Table 2.2-4	Regional sensitivity analysis comparing trends from the “provisionally revised” Dobson data set with the original published data ..... 206
Table 2.2-5	Trends in total ozone derived from Dobson data updated into 1988 compared with trends derived through 1986 ..... 209

**TABLES**

	<b>Page</b>
Table 2.2-6	Trends in total ozone derived by region based on data through 1986 and data updated through October 1988 ..... 211
Table 2.2-7	Latitudes and longitudes of the 14 grid points selected for comparison of changes in ozone derived from SBUV and TOMS ..... 216
Table 2.2-8	Changes in total ozone derived from the Dobson network for periods coincident with the SBUV and TOMS data sets ..... 219
Table 2.3-1	Overall trend estimates (in % per year) from 10 Umkehr stations for the period 1977-1987 with associated standard errors ( $\pm 2\sigma$ ) ..... 230
Table 2.3-2	Ozonesonde stations, data spans, and measurement methods ..... 231
Table 2.3-3	Fractional Umkehr layers ..... 231
Table 2.3-4	Trend estimates for nine stations (in % per year; data through December 1986 when available) ..... 232
Table 2.3-5	Summary of averages of trend estimates (% per year) and standard errors (S.E. $\pm 2\sigma$ ) ..... 234
Table 2.5-1	Concentrations and global trends of tropospheric gases for 1987 ..... 246
Table 2.5-2	N <sub>2</sub> O mixing ratios and rates of increase observed in the troposphere ..... 251
Table 2.5-3	Global average methane mixing ratios and rates of increase observed in the troposphere by various laboratories ..... 253
Table 2.5-4	Surface carbon monoxide concentrations and trends ..... 256
Table 2.5-5	Surface ozone concentrations and trends deduced from ground-based and balloon-borne instruments ..... 259
Table 2.7-1	Percent changes in total column ozone, 1970-1986, used in the radiative transfer calculations ..... 265
 <b>Chapter 3—Theoretical Predictions</b>	
Table 3.1-1	Capabilities of an international group of 2-D assessment models ..... 285
Table 3.1-2	Comparison of ten rates and species at 3 mb, Equator, in March from five modeling groups ..... 300
Table 3.2-1	UNEP Scenarios: 1960 through 2060 ..... 318
Table 3.2-2a	Assumed history of trace gas concentrations: Halocarbons and other gases ..... 322
Table 3.2-2b	Assumed history of trace gas concentrations: Montreal products and replacements ..... 322
Table 3.2-3a	Projected surface mixing ratios for Scenario A: Montreal products and replacements ..... 323
Table 3.2-3b	Projected surface mixing ratios for Scenario B: Montreal products and replacements ..... 323
Table 3.2-3c	Projected surface mixing ratios for Scenario C: Montreal products and replacements ..... 324
Table 3.2-3d	Projected surface mixing ratios for Scenario D: Montreal products and replacements ..... 324
Table 3.2-4	Chlorine and bromine loading of the atmosphere for the UNEP scenarios ..... 327
Table 3.2-5	Participating assessment models ..... 332
Table 3.2-6	Global mean lifetimes (yr.) of the trace gases ..... 332
Table 3.2-7	Extended scenarios for halocarbon abundances ..... 337
Table 3.2-8	Stratopause changes from 1980 to 2060 ..... 382
Table 3.2-9	Surface UV irradiance <sup>a</sup> : Comparison of model predictions ..... 385
Table 3.2-10	Environmental effects on DNA radiation amplification factor (RAF) ..... 392

**TABLES**

**Page**

**Chapter 4—Halocarbon Ozone Depletion Potentials and Global Warming Potentials**

Table 4.2-1	Recommended rate constants and uncertainties for reactions of OH with selected HFCs and HCFCs .....	404
Table 4.2-2	Fluorine-containing products in the atmospheric degradation of selected fluorocarbons .....	408
Table 4.2-3	Atmospheric lifetime of methyl chloroform and estimates of equivalent OH concentrations .....	414
Table 4.2-4	Atmospheric lifetimes for HCFCs and HFCs .....	416
Table 4.2-5	Estimates of global hydrocarbon emissions into the atmosphere .....	420
Table 4.3-1	Chemical rate data used in ODP calculations .....	428
Table 4.3-2	Atmospheric lifetimes (in years) calculated with one-dimensional and two-dimensional models .....	429
Table 4.3-3	Ozone Depletion Potentials (ODPs) calculated with one-dimensional and two-dimensional models, assuming scaling for HCFC ODPs by methyl chloroform inferred lifetime .....	429
Table 4.3-4	Ozone Depletion Potentials (ODPs) for brominated compounds as calculated in the AER and LLNL 1-D models and the U. Oslo 2-D model .....	430
Table 4.3-5	Chlorine Loading Potentials (CLPs) from 2-D models for CFCs, HCFCs, and HFCs, scaled by lifetime of CH <sub>3</sub> CCl <sub>3</sub> (=6.3 yr.) .....	432
Table 4.3-6	Maximum relative Chlorine Loading Potential (CLP) for examined CFCs, HCFCs, HFCs and other chlorinated halocarbons .....	432
Table 4.3-7	Change in ground level trace gas concentrations assumed in sensitivity studies ...	433
Table 4.3-8	Sensitivity of calculated lifetimes to changes in trace gas values, based on AER 1-D results .....	434
Table 4.3-9	Sensitivity of ozone potentials to changes in trace gas values .....	434
Table 4.3-10	Results of transport sensitivity study (AER 2-D Model) on ODP and CLP for HCFC-22 .....	446
Table 4.4-1	Net IR radiative flux at the tropopause (@ 12 km) [Wm <sup>-2</sup> ] for 1 ppbv tropospheric mixing ratio of each gas .....	456
Table 4.4-2	Specific surface temperature (dT <sub>s</sub> ) increases and lambda (λ) values resulting from 1 ppbv of each gas .....	457
Table 4.4-3	Halocarbon Global Warming Potentials (GWPs) .....	458
Table 4.4-4	Sensitivity study—variation in trace gas levels and impact on halocarbon GWP values (AER D-1 model) .....	459