

Table of contents

Chapter 1: Introduction	1
Chapter 2: Satellite instruments	5
2.1 Satellite measurement techniques	5
2.1.1 Classification by observation geometry	5
2.1.2 Classification by wavelengths	7
2.1.3 Satellite orbits	8
2.2 Instrument and retrieval descriptions	9
2.2.1 LIMS on Nimbus 7	9
2.2.2 SAGE I on AEM-B, SAGE II on ERBS, and SAGE III on Meteor-3M	9
2.2.3 HALOE on UARS	11
2.2.4 MLS on UARS	12
2.2.5 POAM II on SPOT-3 and POAM III on SPOT-4	13
2.2.6 OSIRIS on Odin	15
2.2.7 SMR on Odin	17
2.2.8 GOMOS on Envisat	17
2.2.9 MIPAS on Envisat	18
2.2.10 SCIAMACHY on Envisat	20
2.2.11 ACE-FTS on SCISAT-1	21
2.2.12 ACE-MAESTRO on SCISAT-1	22
2.2.13 HIRDLS on Aura	23
2.2.14 MLS on Aura	24
2.2.15 TES on Aura	25
2.2.16 SMILES on the ISS	26
Chapter 3: Climatology framework	29
3.1 Climatology construction	29
3.1.1 Methodology	29
3.1.2 Local time scaling	31
3.1.3 Instrument-specific information	32
3.1.3.1 LIMS climatologies	32
3.1.3.2 SAGE I/II/III climatologies	32
3.1.3.3 HALOE climatologies	32
3.1.3.4 UARS-MLS climatologies	32
3.1.3.5 POAM II/III climatologies	33
3.1.3.6 OSIRIS climatologies	33
3.1.3.7 SMR climatologies	34

3.1.3.8	GOMOS climatologies	34
3.1.3.9	MIPAS climatologies	34
3.1.3.10	SCIAMACHY climatologies	35
3.1.3.11	ACE-FTS climatologies	35
3.1.3.12	ACE-MAESTRO climatologies	36
3.1.3.13	HIRDLS climatologies	36
3.1.3.14	Aura-MLS climatologies	36
3.1.3.15	TES climatologies	37
3.1.3.16	SMILES climatologies	37
3.2	Climatology uncertainties	37
3.2.1	Uncertainties due to sampling	38
3.2.2	Uncertainties due to averaging technique	40
3.2.3	Climatology error bars	42
3.3	Climatology diagnostics	43
3.3.1	The multi-instrument mean (MIM)	44
3.3.2	Annual and monthly mean cross sections and profiles	44
3.3.3	Seasonal cycles	44
3.3.4	Time series of latitude and altitude profiles	45
3.3.5	Summary plots	45
Chapter 4:	Climatology evaluations	47
4.1	Ozone – O₃	47
4.1.1	Availability of O ₃ measurements	47
4.1.2	O ₃ evaluations: Zonal annual mean cross sections, vertical and meridional profiles	48
4.1.3	O ₃ evaluations: Seasonal cycles	61
4.1.4	O ₃ evaluations: Interannual variability	65
4.1.5	O ₃ evaluations: QBO	67
4.1.6	O ₃ evaluations: Antarctic ozone hole	70
4.1.7	Summary and conclusions: O ₃	73
4.1.8	Recommendations: O ₃	77
4.2	Water vapour – H₂O	77
4.2.1	Availability of H ₂ O measurements	77
4.2.2	H ₂ O evaluations: Zonal mean cross sections, vertical and meridional profiles	79
4.2.3	H ₂ O evaluations: Seasonal cycles	90
4.2.4	H ₂ O evaluations: Tape recorder	94
4.2.5	H ₂ O evaluations: Horizontal tape recorder	94
4.2.6	H ₂ O evaluations: Polar vortex dehydration	97
4.2.7	H ₂ O evaluations: Interannual variability	98
4.2.8	Summary and conclusions: H ₂ O	101
4.2.9	Recommendations: H ₂ O	104
4.3	Methane – CH₄	106
4.3.1	Availability of CH ₄ measurements	106
4.3.2	CH ₄ evaluations: Zonal mean cross sections, vertical and meridional profiles	106
4.3.3	CH ₄ evaluations: Latitude-time evolution	109

4.3.4	CH ₄ evaluations: Interannual variability	111
4.3.5	Summary and conclusions: CH ₄	112
4.3.6	Recommendations: CH ₄	114
4.4	Nitrous oxide – N₂O	114
4.4.1	Availability of N ₂ O measurements	114
4.4.2	N ₂ O evaluations: Zonal mean cross sections, vertical and meridional profiles	115
4.4.3	N ₂ O evaluations: Seasonal cycles	117
4.4.4	N ₂ O evaluations: Interannual variability	118
4.4.5	Summary and conclusions: N ₂ O	119
4.4.6	Recommendations: N ₂ O	121
4.5	Trichlorofluoromethane – CCl₃F (CFC-11)	121
4.5.1	Availability of CFC-11 measurements	122
4.5.2	CFC-11 evaluations: Zonal mean cross sections, vertical and meridional profiles ..	122
4.5.3	CFC-11 evaluations: Interannual variability	123
4.5.4	Summary and conclusions: CFC-11	126
4.6	Dichlorodifluoromethane – CCl₂F₂ (CFC-12)	127
4.6.1	Availability of CFC-12 measurements	127
4.6.2	CFC-12 evaluations: Zonal mean cross sections, vertical and meridional profiles ..	127
4.6.3	CFC-12 evaluations: Interannual variability and seasonal cycle	129
4.6.4	Summary and conclusions: CFC-12	130
4.7	Carbon monoxide – CO	132
4.7.1	Availability of CO measurements	133
4.7.2	CO evaluations: Zonal mean cross sections, vertical and meridional profiles	133
4.7.3	CO evaluations: Vertical and meridional profiles	136
4.7.4	CO evaluations: Latitude-time evolution	137
4.7.5	CO evaluations: Seasonal cycles	137
4.7.6	CO evaluations: Interannual variability	139
4.7.7	Summary and conclusions: CO	139
4.7.8	Recommendations: CO	143
4.8	Hydrogen fluoride – HF	143
4.8.1	Availability of HF measurements	143
4.8.2	HF evaluations: Zonal mean cross sections, vertical and meridional profiles	143
4.8.3	Summary and conclusions: HF	145
4.9	Sulfur hexafluoride – SF₆	147
4.9.1	Availability of SF ₆ measurements	147
4.9.2	SF ₆ evaluations: Zonal mean cross sections, vertical and meridional profiles	148
4.9.3	SF ₆ evaluations: Interannual variability and seasonal cycle	149
4.9.4	Summary and conclusions: SF ₆	149
4.10	Nitrogen monoxide – NO	151
4.10.1	Availability of NO measurements	152
4.10.2	NO evaluations: Zonal mean cross sections and vertical profiles	153
4.10.3	NO evaluations: Seasonal cycles	157
4.10.4	NO evaluations: Interannual variability	157
4.10.5	Summary and conclusions: NO	158

4.11 Nitrogen dioxide – NO₂	161
4.11.1 Availability of NO ₂ measurements	161
4.11.2 NO ₂ evaluations: Zonal monthly mean cross sections and vertical profiles of local sunrise/sunset climatologies	163
4.11.3 NO ₂ evaluations: Zonal monthly mean cross sections of 10am/pm climatologies	168
4.11.4 NO ₂ evaluations: Seasonal cycles	171
4.11.5 NO ₂ evaluations: Interannual variability	173
4.11.6 NO ₂ evaluations: Downward transport of NO ₂ during polar winter	174
4.11.7 Summary and conclusions: NO ₂	176
4.12 Nitrogen oxides – NO_x	180
4.12.1 Availability of NO _x measurements	181
4.12.2 NO _x evaluations: Zonal mean cross sections	181
4.12.3 NO _x evaluations: Seasonal cycles	183
4.12.4 NO _x evaluations: Interannual variability	185
4.12.5 NO _x evaluations: Downward transport of NO _x during polar winter	187
4.12.6 Summary and conclusions: NO _x	187
4.13 Nitric acid – HNO₃	190
4.13.1 Availability of HNO ₃ measurements	190
4.13.2 HNO ₃ evaluations: Zonal mean cross sections and vertical profiles	191
4.13.3 HNO ₃ evaluations: Seasonal cycles	194
4.13.4 HNO ₃ evaluations: Interannual variability	195
4.13.5 Summary and conclusions: HNO ₃	195
4.14 Peroxynitric acid – HNO₄	198
4.14.1 Availability of HNO ₄ measurements	198
4.14.2 HNO ₄ evaluations: Zonal mean cross sections and vertical profiles	199
4.14.3 Summary and conclusions: HNO ₄	200
4.15 Dinitrogen pentoxide – N₂O₅	201
4.15.1 Availability of N ₂ O ₅ measurements	201
4.15.2 N ₂ O ₅ evaluations: Zonal mean cross sections and vertical profiles	201
4.15.3 Summary and conclusions: N ₂ O ₅	203
4.16 Chlorine nitrate – ClONO₂	203
4.16.1 Availability of ClONO ₂ measurements	203
4.16.2 ClONO ₂ evaluations: Zonal mean cross sections and vertical profiles	204
4.16.3 Summary and conclusions: ClONO ₂	206
4.17 Total reactive nitrogen – NO_y	206
4.17.1 Availability of NO _y measurements	207
4.17.2 NO _y evaluations: Zonal mean cross sections and vertical profiles	207
4.17.3 NO _y evaluations: Seasonal cycles	208
4.17.4 NO _y evaluations: Interannual variability	210
4.17.5 Summary and conclusions: NO _y	211
4.18 Hydrogen chloride – HCl	213
4.18.1 Availability of HCl measurements	213
4.18.2 HCl evaluations: Zonal mean cross sections, vertical and meridional profiles	213
4.18.3 HCl evaluations: Latitude-time evolution	216

4.18.4	HCl evaluations: Interannual variability.....	217
4.18.5	Summary and conclusions: HCl	218
4.18.6	Recommendations: HCl.....	220
4.19	Chlorine monoxide – ClO	220
4.19.1	Availability of ClO measurements	220
4.19.2	ClO evaluations: Zonal mean cross sections	221
4.19.3	ClO evaluations: Vertical and meridional profiles	224
4.19.4	Summary and conclusions: ClO	225
4.20	Hypochlorous acid – HOCl	226
4.20.1	Availability of HOCl measurements	227
4.20.2	HOCl evaluations: Zonal mean cross sections	228
4.20.3	HOCl evaluations: Vertical and meridional profiles	229
4.20.4	Summary and conclusions: HOCl	231
4.21	Bromine oxide – BrO	231
4.21.1	Availability of BrO measurements	231
4.21.2	BrO evaluations: Monthly zonal mean cross sections	232
4.21.3	BrO evaluations: Vertical and meridional profiles	234
4.21.4	Summary and conclusions: BrO	235
4.22	Hydroxyl radical – OH	236
4.22.1	Availability of OH measurements	236
4.22.2	OH zonal mean cross sections	237
4.22.3	OH vertical profiles from Aura-MLS	238
4.22.4	Summary and conclusions: OH	238
4.23	Hydroperoxy radical – HO₂	239
4.23.1	Availability of HO ₂ measurements	239
4.23.2	HO ₂ evaluations: Zonal mean cross sections	239
4.23.3	HO ₂ evaluations: Vertical profiles	240
4.23.4	Summary and conclusions: HO ₂	240
4.24	Formaldehyde – CH₂O	242
4.24.1	Availability of CH ₂ O measurements	243
4.24.2	CH ₂ O evaluations: Annual zonal mean cross sections	243
4.24.3	CH ₂ O evaluations: Meridional profiles	243
4.24.4	Seasonality in CH ₂ O	244
4.24.5	Summary and conclusions: CH ₂ O	245
4.25	Acetonitrile - CH₃CN	246
4.25.1	Availability of CH ₃ CN measurements	246
4.25.2	CH ₃ CN evaluations: Zonal mean cross sections	246
4.25.3	Summary and conclusions: CH ₃ CN	246
4.26	Aerosol	247
4.26.1	Availability of aerosol measurements	247
4.26.2	Aerosol evaluations: Vertical and meridional profiles at similar wavelengths	248
4.26.3	Aerosol evaluations: Altitude profiles	253
4.26.4	Aerosol evaluations: Interannual variability.....	255
4.26.5	Summary and conclusions: Aerosol	263

4.27 Upper troposphere / lower stratosphere (UTLS) ozone evaluations based on TES averaging kernels	270
4.27.1 Availability of UTLS ozone satellite datasets	271
4.27.2 TES ozone and operational operator	271
4.27.3 UTLS ozone evaluations: Zonal mean cross sections, vertical and meridional profiles	273
4.27.4 UTLS ozone evaluations: Seasonal cycles	281
4.27.5 UTLS ozone evaluations: Interannual variability	283
4.27.6 Summary and conclusions: UTLS ozone	283
4.27.7 Recommendations: UTLS ozone	287
 Chapter 5: Implications of results	289
5.1 Implications for model-measurement intercomparison	289
5.1.1 Seasonal cycles	290
5.1.2 Vertical and meridional profiles	295
5.1.3 Recommendations for short-lived species	298
5.1.4 Suggestions for new diagnostics	299
5.2 Implications for merging activities	301
5.2.1 Error characterisation of instruments	301
5.2.2 Drifts and jumps between datasets	302
5.2.3 Altitude resolution and a priori information	303
5.3 Implications for future planning of satellite limb-sounders	304
 References	305