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OZONE REFERENCE MODELS FOR THE MIDDLE ATMOSPHERE (NEW CIRA)

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1 INTRODUCTION

Over the last 50 years, a number of measurements of ozone in the middle atmosphere have been obtained from the ground and from balloons, rockets, and satellites. Numerous models have been developed to summarize various portions of these measurements since detailed knowledge of the global distribution of ozone is important for studies of atmospheric circulation, dynamic processes, and the radiation balance and the photochemistry of the atmosphere. From the ground-based ozone network, the latitudinal-seasonal variations of total column ozone were summarized by Dutsch [1] and the longitudinal variations were included in a series of monthly atlases for the period 1957 to 1967 by London *et al.* [2]. Measurements of vertical structure obtained from balloonsondes and rocket data at midlatitudes in the Northern Hemisphere were summarized in a 45° annual model generated by A. Krueger and R. Minzner contained in the United States Standard Atmosphere Supplements, 1976 [3]. Bojkov [4] generated models of ozone vertical structure related to total column ozone amount based on Dobson data and early Umkehr measurements. Models relating the vertical structure of ozone to total ozone based on approximately 7000 balloonsondes and a number of rocketsondes were generated by Hilsenrath *et al.* [5] as a "first guess" for the Nimbus 4 Backscattered Ultraviolet (BUV) ozone experiment retrievals of total ozone and vertical structure and for the early Nimbus 7 SBUV/TOMS total ozone retrievals. Similar models based on essentially the same data base were generated by Mateer *et al.* [6] as a "first guess" for inversion of "short" Umkehr obser-vations to determine vertical structure of ozone from the ground. The 22 vertical profiles in [6] were given as a function of latitude (low, mid and high) and total column ozone, but not season. Inconsistencies between rocket and balloon data were handled differently by Mateer *et al.* [6] than by Hilsenrath *et al.* [5]. Bhartia *et al.* [7] have developed similar models using both ozonesonde and satellite data. Klenk *et al.* [8] developed a model of ozone vertical structure based on Nimbus 4 BUV data at pressures less than 15.6 mb and on balloon data at lower altitudes. This model was used as a "first guess" for vertical structure retrievals from the Nimbus 7 Solar Backscattered Ultraviolet (SBUV) ozone experiment. The model consisted of a simple parametric representation of the annual and latitudinal variations of ozone as a function of pressure and assumed symmetry between the Northern and Southern Hemispheres. Also included in this model is the ozone covariance matrix which describes the variance of ozone in individual atmospheric layers and the covariances between adjacent layers. An ozone covariance matrix is also included in the models of Mateer *et al.* [6]. Dutsch [9] compiled data on the vertical ozone distribution using chemical-type balloon soundings and early BUV results. A tabulation of monthly Nimbus 7 SBUV ozone profiles for the period November 1978 through October 1979 is provided by McPeters *et al.* [10] in 10° latitude increments from 0.17 mb to the surface. Results are given in terms of column density and its standard deviation, volume mixing ratio and number density. Heath *et al.* [11] have generated a set of atlases of total ozone for the period April 1970 - December 1976 based on Nimbus 4 BUV data. Bowman and Krueger [12] have provided a climatology of total ozone from Nimbus 7 TOMS measurements. Tolson [13] has generated a ninth-order, ninth-degree spherical harmonic model to represent the monthly mean total colum-nar ozone field over the 7-year period of the Nimbus 4 BUV data set. Annual and semiannual components are determined for both latitudinal and longitudinal variations, and the biennial and longer term variations are determined as a function of latitude. Hasebe [14] has modeled the latitudinal and longitudinal variations in the total columnar ozone field over the 7-year period of the Nimbus 4 BUV data set using filtering techniques. Global mean total column ozone and its annual, semiannual, quasibiennial and longer term components have been determined through spherical harmonic analysis [13,15].

Data on total ozone and its vertical structure have been obtained from a number of satellite experiments. Shown in Table 1 (Krueger *et al.* [16]) is a tabulation of most satellite ozone experiments through 1978. Included are solar and stellar occultation, solar backscatter ultraviolet, and infrared types. Since then, other satellites have been launched with ozone measurement capability including Applications Explorer 2 [17], Dynamics Explorer 1 [18,19], Solar Mesosphere Explorer [20], EXOS-C [21] and instruments aboard the NOAA series of satellites (TOVS and SBUV 2) [22,23] and ERBS (SAGE II) [24].

With the wealth of recent satellite data allowing high precision determination of ozone variations with pressure, latitude, and time, it was decided to generate models of ozone vertical structure based not just on one satellite experiment, but on multiple data sets from satellites. This is the first time such models have been generated [25- 28]. The very good absolute accuracy of the individual data sets allowed the data to be directly combined to generate these models. The data used for generation of these models are from some of the most recent satellite measurements over the period 1978-1983. A discussion is provided of validation and error analyses of these data sets. Also, inconsistencies in data sets brought about by temporal variations or other factors are indicated. The models cover the pressure range from 20 to 0.003 mb (25 to 90 km). The models for pressures less than 0.5 mb represent only the day side and are only provisional since there was limited longitudinal coverage at these levels. The models start near 25 km in accord with previous CIRA models. Models are also provided of ozone mixing ratio as a function of height using the conversion from pressure to height given by Barnett and Corney [29]. The monthly standard deviation and interannual variations relative to zonal means are also provided.

In addition to the models of monthly latitudinal variations in vertical structure based on satellite measurements, monthly models of total column ozone and its characteristic variability as a function of latitude based on 4 years of Nimbus 7 measurements, models of the relation between vertical structure and total column ozone [6], and a midlatitude annual mean model similar to [3] are incorporated in this set of ozone reference atmospheres. Various systematic variations are discussed including the annual, semiannual, quasibiennial oscillations, diurnal variations, longitudinal variations, and response to solar activity variations.

Considering the good agreement among satellite data sets from 1978-1982 (generally within 10% of the interim reference models below 0.5 mb) it is expected that the present tables will be useful for many applications.

2. SATELLITE DATA FOR REFERENCE MODELS

The reference models provided here of monthly latitudinal variations of vertical structure are based on ozone data from five satellite experiments (see Table 2): Nimbus 7 Solar Backscatter Ultraviolet (SBUV), Nimbus 7 Limb Infrared Monitor of the Stratosphere (LIMS), Applications Explorer Mission-2 Stratospheric Aerosol and Gas Experiment (SAGE), Solar Mesosphere Explorer UV Spectrometer (SME-UVS), and Solar Mesosphere Explorer 1.27 μm Airglow (SME-IR). Other ozone data sets are included to define the nature of systematic variations other than the latitudinal-seasonal variation.

The nadir-viewing SBUV experiment determines the vertical structure of ozone from absorption of solar ultraviolet backscattered radiation between 250 and 340 nm. The resolution of the ozone measurements is about 8 km in the vertical. For these studies, the first 4 years of SBUV data were employed (November 1978 - September 1982) using daily zonal averages every 10° in latitude over the illuminated portion of the earth from 20 mb to 0.5 mb. Data contaminated by volcanic emissions after October 1980 (including El Chichon) have been removed [30].

Validation studies have been performed on the SBUV data employing balloon, rocket, and ground-based Umkehr measurements [31]. The precision of the SBUV measurements was found to be better than 8% for pressures between 1 and 64 mb. Constant biases of generally less than 10% between the SBUV results and the balloon and Umkehr results may be largely due to errors in ozone absorption cross-sections assumed earlier. Ozone absorption cross sections

TABLE 1 Satellite experiments to measure ozone [16]

Type	Satellite	Wavelengths	Latitude Coverage	Comments	References
		nm			
Occultation Solar	Echo 1	590, 529.5	17°N	Dec. 1960	Venkateswaran *et al.* [106]
	USAF 1962	260	33°S-13°S	July 1962	Rawcliffe *et al.* [107]
	Ariel 2	200-400	50°S-50°N	Apr., May, Aug. 1964	Miller and Stewart [108]
	AE-5	255.5	5°N	Dec. 1976	Guenther *et al.* [109]
Stellar	OAO-2	250	16°S-43°N	Jan. 1970 Aug. 1971	Hays and Roble [110]
	OAO-3	258-343	12°S-3°N	July 1975	Riegler *et al.* [111]
Back-scatter uv Profile	USAF 1965	284	60°S-60°N	Feb., Mar. 1965	Rawcliffe and Elliott [112]
	USSR	225-307	60°S-60°N	Apr. 1965	Iozenas *et al.* [113]
		250-330	60°S-60°N	June 1966	Iozenas *et al.* [113]
	1966-111B	175-310	80°S-80°N	1966	Elliott *et al.* [114]
	OGO-4	110-340	80°S-80°N	Sep. 1967- Jan. 1969	Anderson *et al.* [115]
	Nimbus 4 b.u.v.	255.5-305.8	80°S-80°N	Apr. 1970- Jul. 1977	Heath *et al.* [54]
	AE-5 b.u.v.	255.5-305.8	20°S-20°N	Nov. 1975- Apr. 1977	Frederick *et al.* [116]
	Nimbus 7 s.b.u.v.	255.5-305.8	80°S-80°N	Nov. 1978	Heath *et al.* [117]
Total	Nimbus 4 b.u.v.	312.5-339.8	80°S-80°N	Apr. 1970-	Mateer *et al.* [118]
	AE-5 b.u.v.	312.5-339.8	20°S-20°N	Nov. 1974- Jul. 1977	
	Nimbus 7 t.o.m.s.	312.5-339.8	global	Nov. 1978	Heath *et al.* [117]
		μm			
Infrared Emission Profile	Nimbus 6 l.r.i.r.	9.6	65°S-90°N	Jun. 1975- Jan. 1976	Gille *et al.* [55]
	Nimbus 7 l.i.m.s	9.6	65°S-90°N	Oct. 1978- May 1979	Nimbus Project [119, 120]
Total	Nimbus 3 i.r.i.s.	9-10 spectral scan	80°S-80°N		Hanel *et al.* [121]
	Nimbus 4 i.r.i.s.	9-10 spectral scan	80°S-80°N	Apr. 1970 Jan. 1971	Prabhakara *et al.* [58]
	Block 5 m.f.r. (4 flights)		global	Mar. 1977	Lovill *et al.* [122]
	Tiros N h.i.r.s	9.71	global	Nov. 1978	

TABLE 2 Satellite data used for interim reference ozone models

Instrument	Incorporated Pressure Range	Incorporated Time Interval
Nimbus 7 LIMS	0.4 - 20 mb	11/78 - 05/79
Nimbus 7 SBUV	0.4 - 20 mb	11/78 - 09/82
AE-2 SAGE	4 - 20 mb	02/79 - 12/79
SME UVS	0.07 - 0.5 mb	01/82 - 12/83
SME IR	0.003 - 0.5 mb	01/82 - 12/83
Nimbus 7 TOMS	Total	11/78 - 09/82

incorporated recently by the International Ozone Commission of IAMAP are employed in the inversion of the data employed in the present models (Version 5) [32-34].

The LIMS instrument, a six-channel cryogenically cooled radiometer measured O_3 and temperature in the stratosphere and mesosphere and H_2O, HNO_3, and NO_2 distributions in the stratosphere from 84°N to 64°S latitude from October 25, 1978 to May 28, 1979 [35,36]. The LIMS ozone channel measures emission near 9.6 µm with a field of view at the limb of less than 3 km in the vertical and 18 km in the horizontal (perpendicular to the line of sight).

Monthly zonal means of Kalman-filtered LIMS ozone values are incorporated in the model for the period November 1978 through May 1979 from 60°S to 80°N and from 20 mb to 0.5 mb. Non LTE effects become important above these altitudes [37]. Validation studies have been performed using balloon and rocket underflights, Umkehr soundings, and Dobson measurements [38]. Comparison with the correlative measurements shows mean differences of less than 10% at mid latitudes for balloon-borne sensors and less than 16% up to 0.3 mb for rocket data. The comparison with balloon measurements near 20 mb indicate LIMS data may be high by about 8% at low latitudes. At greater pressures there is evidence of a significant bias relative to balloon data in this region.

The SAGE instrument is a four-channel sun photometer which measured solar intensity at sunrise and sunset to derive ozone, aerosol, and NO_2 concentrations. Absorption of 0.6 µm solar radiation by ozone allowed determination of the vertical structure of ozone to be obtained up to 30 times per day from February 1979 until September 1981. After data processing, the vertical resolution of the data was estimated to be 1 km up to approximately 40 km altitude and 5 km above 40 km. The horizontal resolution was estimated to be 200 to 300 km in the viewing direction and 200 km perpendicular to the field of view [39]. Monthly latitudinal coverage depends on the time of year and solar geometry, but can extend from 78°S to 78°N. However, on any particular day, the vertical structure is obtained at a discrete latitude for sunrises or sunsets. Comparisons were made between balloon measurements and SAGE profiles from 18 to 28 km, and average differences were found to be less than 10% [17,40]. Comparisons by McCormick *et al.* [17] with rocketsondes up to 60 km yielded average differences of less than 14% . An initial comparison between SAGE and SBUV in March-April 1979 indicated agreement to generally better than 15% between 5 and 30 mb [39]. A comparative study between the three data sets SBUV, SAGE, and LIMS for March 1979 has been performed by Fleig *et al.* [41,42]. The LIMS/SBUV comparisons are shown to be very good in the upper stratosphere, while the SBUV/SAGE comparisons are shown to be very good in the lower stratosphere.

Mesospheric ozone mixing ratios are available from two limb- scanning experiments aboard the Solar Mesosphere Explorer (SME) spacecraft (which was launched 6 October 1981). The first of these, the SME-UVS, is a two-channel Ebert-Fastie spectrometer. The instrument measures the Rayleigh scattering of solar photons at the earth's limb at wavelengths of 265 nm and 296.4 nm from which the ozone profile is determined between 1.0 mb and 0.07 mb [43]. The field of view of the instrument is 3.5 km in the vertical by 35 km in the horizontal at the limb. Generally zonal means are not obtained. The primary orbits were over the longitude range from 40°W to 100°W, and the local solar time of measurement at the equator is 15 hours. An error analysis indicates total errors should range from 6% at 48 km to 15% at 68 km (1.0 to 0.1 mb) [43,44]. The data chosen for the model are over the range 0.5 mb to 0.1 mb over the period January 1982 through December 1983.

The second SME experiment, SME-IR, is a near-infrared experiment that measures 1.27 µm airglow from which ozone densities from 50 to 90 km are deduced. The dayglow is principally associated with photodissociation of ozone [45]. Monthly means from this experiment agree fairly well with the SME-UVS experiment and with Krueger and Minzner [3]. Thomas *et al.* [46] describe the error analysis of this experiment in some detail. Random errors are estimated to be less than 10% from 50 to 82 km, and increase to 20% at 90 km. Systematic errors are estimated to be 15% but could be as high as 50%. The data used for the model are monthly means over the range 0.5 mb to 0.003 mb and over the period January 1982 through December 1983. The local solar time of the measurements is again about 15 hours. Latitudinal coverage is consistent with the illuminated earth, and longitudinal coverage is principally from 40°W to 100°W.

Reviews on mesospheric ozone are found in [47-51]. Ozone measurements made in the Aladdin program [52] by several techniques on June 29-30, 1974, are in good agreement with SME measurements below 70 km. Above 75 km, Aladdin ozone is a factor of 2-3 lower than SME-IR. It is very possible that this is a real ozone variation [53].

Other satellite instruments which have obtained measurements of the vertical structure of ozone include the Nimbus 4 BUV experiment [54] and the Nimbus 6 Limb Radiance Inversion Radiometer (LRIR) [55]. Since the Nimbus 4 BUV experiment had problems with a serious drift in bias, the Nimbus 7 SBUV data from 1978-82 was considered to be a better choice for the model. The Nimbus 7 LIMS is generally considered an improvement over the Nimbus 6 LRIR experiment and was therefore chosen for the model. More recent experiments such as SBUV 2, SAGE II, and EXOS-C are still in the validation phase.

The models of total column ozone given here are based on 4 years of Nimbus 7 TOMS measurements. The TOMS instrument is used to determine total column ozone by measuring backscattered solar ultraviolet radiation attenuated by ozone employing a simple monochrometer whose instantaneous field of view scans through the subsatellite point and perpendicular to the orbital plane. Backscattered and direct solar radiation are sampled at six wavelengths from 312.5 nm to 380 nm. The resolution of ozone measurements is about 50 km in the horizontal. For these studies the first 4 years of TOMS data were employed (November 1978 - September 1982) using daily zonal averages every 5° in latitude over the illuminated portion of the earth. Comparisons of TOMS data with ground-based Dobson and M-83 data have shown a retrieved precision of better than 2% and biases of 6% where the TOMS measurements have lower values than the Dobson measurements [56].

Global measurements of total ozone from backscattered ultraviolet measurements have also been obtained from the Nimbus 4 Backscattered Ultraviolet (BUV) and the Nimbus 7 SBUV experiments. The TOMS experiment, however, obtains more measurements per day than the other two and does not appear to have the serious drift problems which occurred on the Nimbus 4 BUV experiment. Infrared experiments which measure total column ozone from absorption of 9.6 μm radiation have included the Nimbus 4 Infrared Interferometer Spectrometer (IRIS), the DMSP Multifilter Radiometers (MFR), and the ongoing Tiros Operational Vertical Sounders (TOVS). A study of the relative biases between a limited amount of the TOMS, MFR, TOVS and SBUV total column ozone results was performed [57] showing excellent global average agreement between the TOMS and MFR (3%) but not as good agreement between SBUV and MFR (5%) or between TOVS and MFR (7%), where in each case MFR gave a lower value for total ozone. Significant latitudinal biases relative to BUV data have been noted in the Nimbus 4 IRIS data [58,59].

3. MODELS OF TOTAL COLUMN OZONE

The monthly latitudinal models of total column ozone are based on the archived first 4 years of data from the Nimbus 7 TOMS experiment. The total column ozone values tabulated here are 5.5% higher than the TOMS archived data to be more in accord with the improved ozone cross sections of Bass and Paur [33] and with Dobson measurements [56]. A more detailed correction for the future TOMS algorithm improvements is given by Fleig *et al.* [60]. Shown in Figure 1 is total column ozone in Dobson units (the Dobson unit is defined as 10^{-5} meters of ozone at 0°C and at standard sea level pressure) as a function of latitude and month. Note the high values in mid and high latitudes in spring in the Northern Hemisphere and at mid latitudes in local spring in the Southern Hemisphere. Also note the low values in September-October near 80°S. These low values reflect the recently discovered "ozone hole" in the Antarctic [61]. Much higher values of ozone were detected in the springtime Antarctic before the 1980s [61,62]. Shown in Figure 2 is the standard deviation in percent of individual ozone measurements relative to the zonal mean obtained each month for a 1-year period (November 1978 - October 1979). Minimum standard deviations occur at low latitudes while the maximum values occur near the "ozone hole." A comparison of monthly ozone values from year to year over the 4-year period (November 1978 - September 1982) gives an approximate idea of patterns of interannual variability in total ozone. Shown in Figure 3 is the interannual variability expressed as standard deviation (in percent) relative to 4-year means as a function of latitude and month. The variations are generally less than 4% (except near October, 80°S) and are strongly related to quasibiennial variations discussed briefly in the section "Other Ozone Variations." The large variations in October, 80°S again reflect the recently discovered antarctic ozone hole.

Shown in Table 3 is a tabulation of the latitudinal variation of total column ozone in Dobson units for each month based on the dayside observations of ozone over the 4-year period. The spaces indicate times when no TOMS measurements were available.

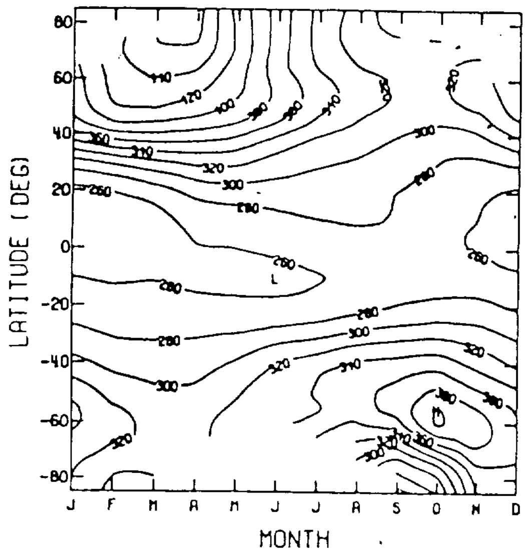

Figure 1. Zonal mean of total column ozone (Dobson units) as a function of latitude and month.

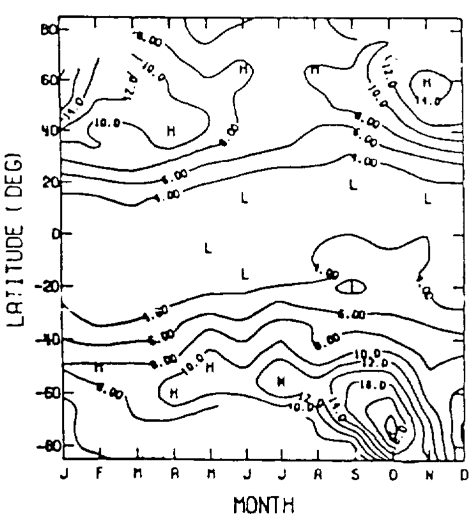

Figure. 2. Standard deviation (percent) from zonal mean of total column ozone for period January 1979 through December 1979 (Nimbus 7 TOMS data).

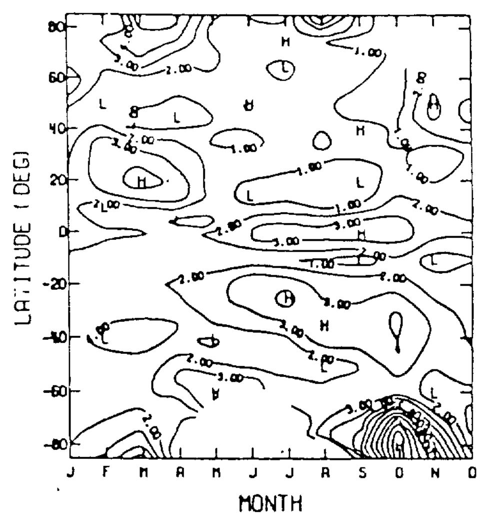

Figure 3. Interannual variability of total column ozone expressed as yearly standard deviation (percent) from 4-year zonal means (Nimbus 7 TOMS data).

TABLE 3. Zonal Mean Total Column Ozone (Dobson units)

φ	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
85°	-	-	467	467	411	371	333	311	283	-	-	-
80°	-	-	470	465	414	371	332	308	291	-	-	-
75°	-	433	460	462	416	370	332	308	302	299	-	-
70°	-	436	459	455	415	368	334	313	308	309	314	-
65°	395	432	451	444	410	367	338	320	312	315	332	-
60°	392	428	441	431	406	372	346	327	317	317	332	358
55°	390	426	433	421	402	375	350	330	318	317	327	353
50°	387	418	420	410	394	372	346	326	313	312	322	349
45°	376	402	401	395	382	360	335	319	307	302	311	338
40°	354	374	377	373	363	341	321	310	300	291	297	320
35°	322	338	347	348	342	323	310	303	295	283	284	299
30°	292	303	316	325	324	311	302	298	290	280	276	281
25°	269	278	291	304	307	301	296	291	284	275	270	267
20°	254	261	271	287	291	290	289	286	279	270	263	256
15°	248	251	260	275	279	282	284	283	279	268	261	252
10°	246	246	254	267	271	275	280	281	279	267	260	251
5°	247	248	254	261	264	268	274	277	278	263	258	251
0°	251	250	255	259	260	263	268	273	276	263	259	253
-5°	255	254	257	258	258	259	262	268	272	265	264	257
-10°	260	258	259	259	257	256	259	264	270	269	270	264
-15°	266	262	261	260	258	258	261	266	273	277	278	272
-20°	271	265	264	263	264	264	268	274	282	287	286	279
-25°	277	270	269	271	271	273	279	288	295	301	298	287
-30°	286	278	277	278	281	289	295	306	313	317	311	297
-35°	295	286	284	284	291	306	315	327	333	336	323	307
-40°	306	294	289	289	303	319	331	343	348	354	335	318
-45°	319	303	296	297	312	327	340	353	360	371	350	332
-50°	334	313	305	306	318	328	342	355	367	387	366	347
-55°	344	322	312	314	322	328	338	351	368	402	381	358
-60°	344	325	315	318	323	337	344	339	353	402	390	365
-65°	338	324	317	319	322	-	340	325	324	374	388	366
-70°	331	317	312	313	-	-	-	307	291	333	376	364
-75°	324	306	305	302	-	-	-	294	267	297	357	358
-80°	320	299	299	-	-	-	-	-	253	274	346	356
-85°	316	294	295	-	-	-	-	-	230	259	341	353

4. MODELS OF VERTICAL STRUCTURE OF OZONE

As described in section 2 the vertical structure models of monthly latitudinal variations are based on the SBUV, LIMS, SAGE, SME-UVS, and SME-IR data tabulated in Table 2. The 4-year mean of the SBUV data was given a weight of 2 due to the combination of extensive temporal and spatial coverage, while the other shorter data sets were each given a weight of 1.

Although there is interannual variability, comparison of the SBUV data over the 4-year period of measurements shows a remarkable similarity of structure from year to year. For example, shown in Figure 4 is the vertical structure at 0°, 20°N, 40°N and 60°N for November of 1978, 1979, 1980 and 1981. Note how the 0° and 20°N profiles come together near 4 mb. The 60°N profile changes in each case from the lowest profile at 4 mb to the highest at 1.5 mb.

Shown in Figure 5 is the interannual variability of zonal mean ozone expressed as standard deviation (in percent) relative to the mean of 4 years of SBUV data as a function of pressure and latitude for the months of November and July. As indicated in the previous figure, the interannual variability of zonal means in November is very low, generally less than 4%. In contrast, the month of July gave the largest variability over this 4-year period with the maximum variability occurring at high winter latitudes. The interannual variability appears to be strongly related to quasibiennial oscillations.

Figure 6 shows the average standard deviation (in percent) of the individual data points making up the monthly zonal means based on the 4 years of SBUV data. The standard deviations are shown as a function of latitude and pressure and appear considerably different from the interannual variability displayed in Figure 5. Minimum standard deviations occur near the equator and in the summer hemisphere. Standard deviations can exceed 15% at high latitudes and result from substantial longitudinal variations in ozone as well as changes in the zonal means during the month. The patterns for individual years look very similar to these 4-year mean patterns.

In Figure 7 is shown an example of the agreement between the five data sets used to generate models of the ozone vertical structure from 20 mb to 0.003 mb (25 to 90 km). Note that the mixing ratio is displayed on a log scale to allow accurate representation of the two orders of magnitude variation over this altitude range. It should be recognized that each data set represents entirely different techniques of measuring the vertical structure of ozone. The agreement shown here is fairly representative. Generally the SBUV ozone values redetermined with the improved ozone cross section (Version 5) give better agreement with the LIMS and SAGE data sets than the earlier versions.

Table 4 gives the monthly zonal mean ozone volume mixing ratios (ppmv) as a function of pressure and latitude. The standard type face indicates only one data type was used to determine the average. Italicsindicate that the percent standard deviation from the model of weighted data types exceeded 10 percent. An underlined entry indicates standard deviations from the model of less than 10 percent. The dashed entry indicates zonal means were not available at that latitude and pressure. As may be noted, in most cases at altitudes below 0.5 mb the standard deviation from the model of weighted data types was less than 10 percent. Considering the difference in techniques, this is noteworthy. Owing to the lack of longitudinal coverage for the data types used above 0.5 mb and the somewhat larger differences between data types, the (dayside) model above 0.5 mb should be considered only provisional. Nightside mesospheric ozone concentrations are generally much higher than dayside values [51]. Shown in Figure 8 are the ozone distributions given in Table 4 for the equinox and solstice months.

Comparison of entries in Table 4 shows the nature of the annual and semiannual variations of ozone in the middle atmosphere. The amplitudes of annual variations are generally highest at high latitudes, and amplitudes are especially high near 15-5 mb, 2.0-0.5 mb, and above 0.03 mb. Amplitudes are high at low and mid latitudes near 0.1 mb. There is a sharp change of phase near 4 mb with maximum ozone values in summer below this altitude and maximum values in winter in the upper stratosphere. Figure 9 shows the ozone annual variation in percent of annual mean at 50°S and 50°N over the entire range of altitudes. Notice the asymmetry between the two hemispheres. A substantial semiannual variation occurs near the equator from 15 - 3 mb, but the largest semiannual variation occurs at mid and high latitudes above 0.03 mb [63], and at high latitudes near 1 mb. Figure 10 shows the ozone semiannual variation in percent of the annual mean at 30°S and 30°N for the entire range of altitudes. The annual and semiannual components were solved for simultaneously . Note the symmetry in the low

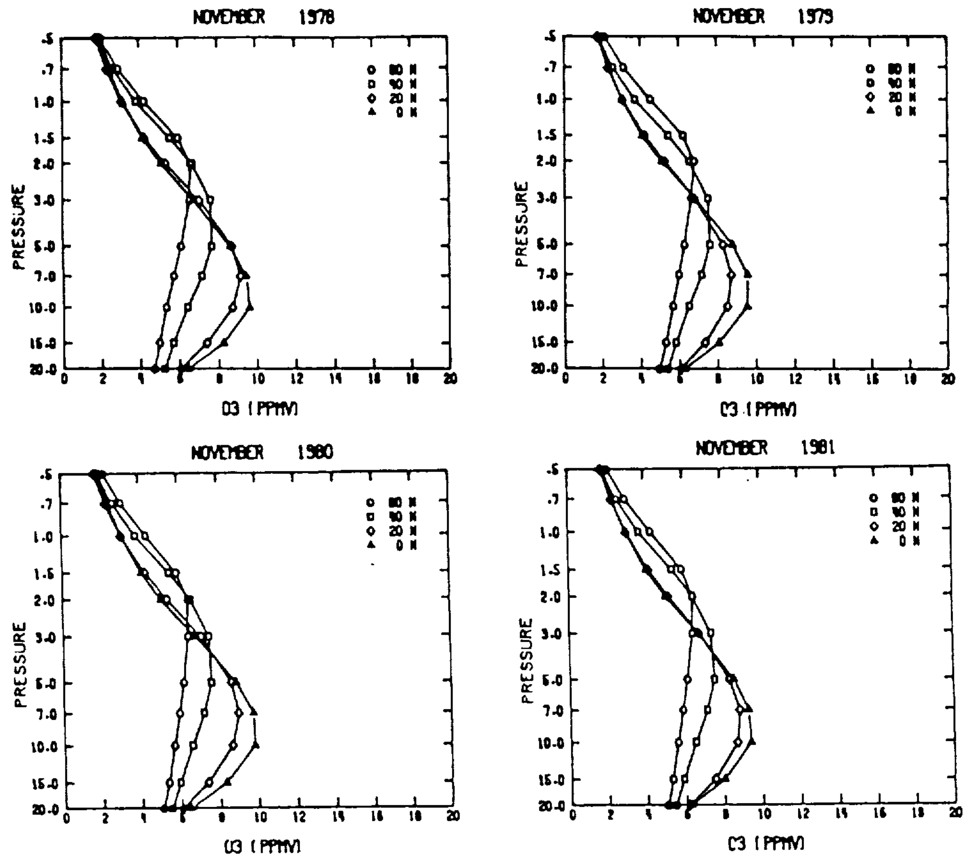

Figure 4. Similarity of ozone vertical structure in November from year to year (Nimbus 7 SBUV data).

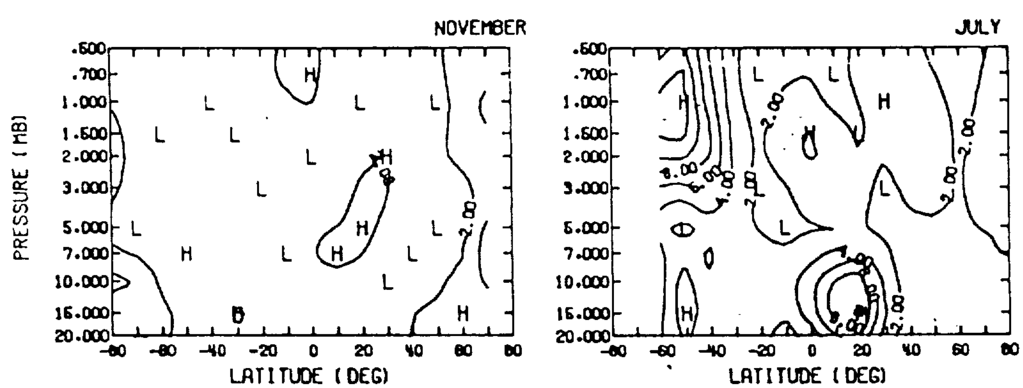

Figure 5. Interannual variability of ozone vertical structure expressed as yearly standard deviation (percent) from 4-year zonal means for the months of November and July (Nimbus 7 SBUV data).

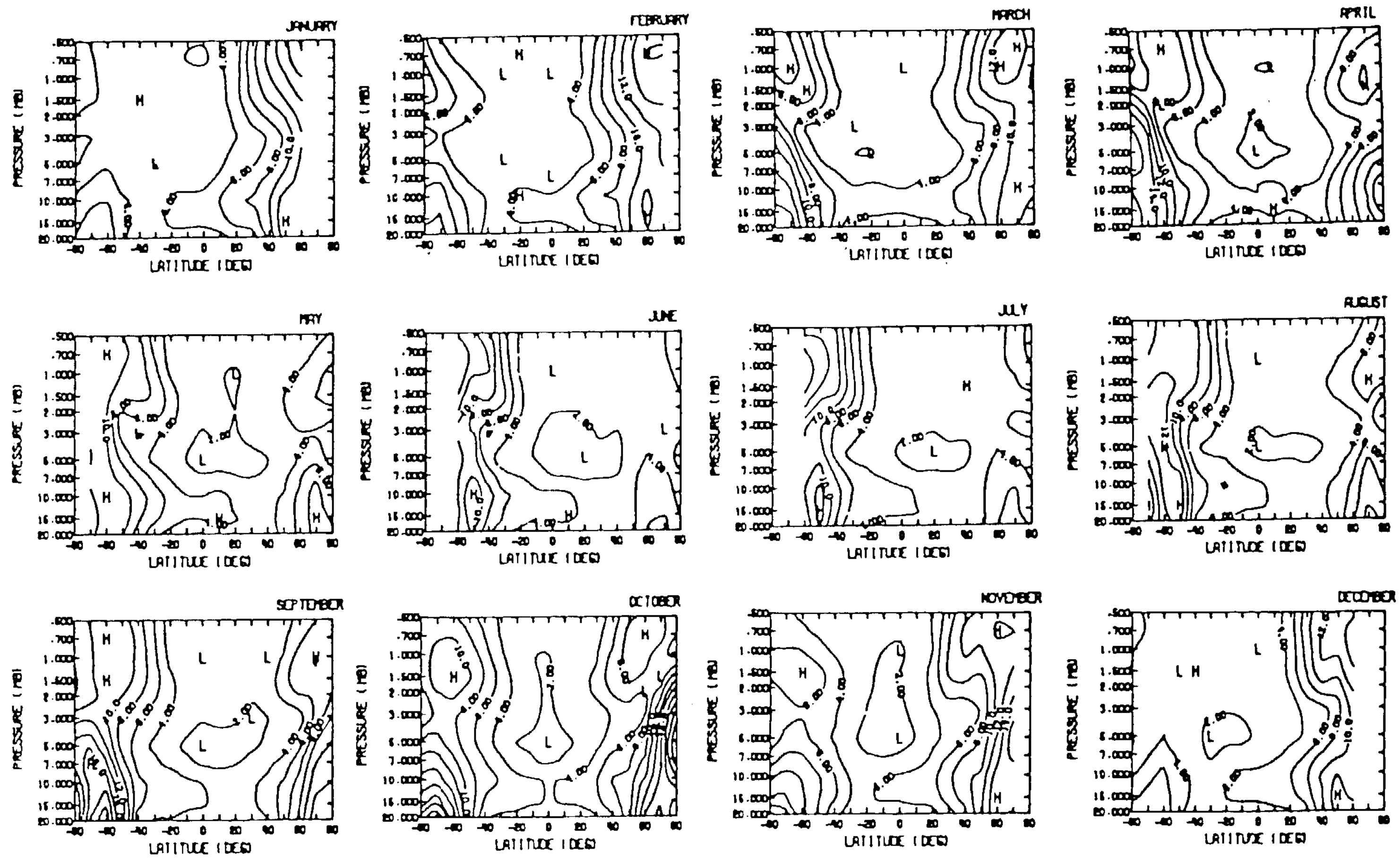

Figure 6. Average monthly standard deviation (percent) from zonal mean ozone (Nimbus 7 SBUV data)

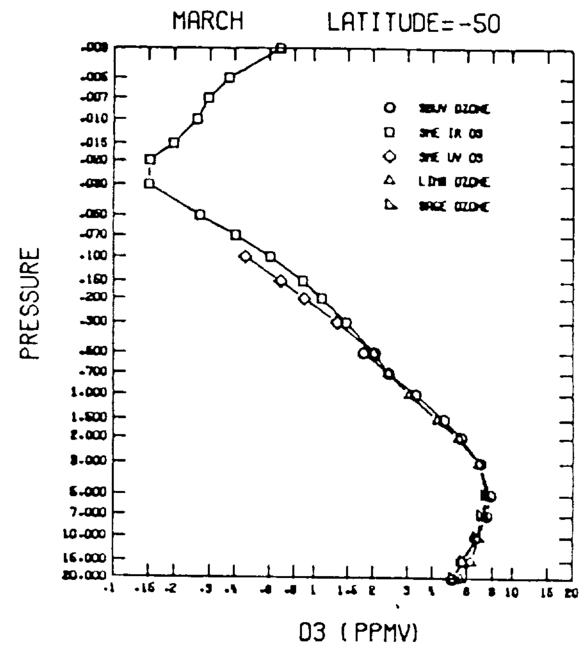

Figure 7. Comparison of measurements from five satellite experiments of zonal mean ozone volume mixing ratios for March, 50°S.

TABLE 4. Zonal Mean Ozone Mixing Ratios (ppmv) as Function of Pressure (standard typeface: only 1 data set used in average, italics: standard deviation of data types > 10% , underlined: standard deviation ≤ 10%)

average ozone (ppmv) for January

p (mb)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.55	.72	.80	.78	.70	.63	.57	.53	.53	.52	.52	.66	.81	.84	.83	-	-
.005	.26	.35	.45	.51	.49	.46	.43	.42	.41	.38	.35	.42	.50	.52	.50	-	-
.007	.18	.21	.28	.35	.36	.36	.37	.38	.39	.37	.32	.30	.31	.30	.27	-	-
.010	.15	.15	.18	.22	.24	.26	.29	.31	.33	.34	.32	.28	.23	.19	.14	-	-
.015	.16	.15	.15	.16	.15	.16	.19	.20	.21	.23	.27	.28	.26	.23	.17	-	-
.020	.17	.16	.15	.14	.14	.13	.14	.16	.16	.17	.21	.25	.27	.28	.24	-	-
.030	.21	.19	.18	.17	.15	.14	.15	.15	.15	.16	.17	.19	.24	.32	.37	-	-
.050	.31	.28	.26	.25	.24	.22	.22	.22	.23	.23	.24	.27	.30	.37	.47	-	-
.070	.41	.38	.37	.36	.34	.32	.31	.32	.32	.32	.34	.41	.46	.49	.53	-	-
.100	.54	.53	.52	.49	.48	.48	.49	.49	.47	.46	.49	.53	.69	.69	.67	-	-
.150	.76	.74	.73	.73	.74	.76	.74	.71	.68	.68	.69	.75	.79	1.01	.93	-	-
.200	.89	.90	.92	.92	.96	.98	.96	.92	.89	.89	.92	.99	1.04	1.28	1.19	-	-
.300	1.13	1.17	1.21	1.25	1.32	1.37	1.35	1.30	1.27	1.27	1.33	1.42	1.48	1.77	-	-	-
.500	1.41	1.50	1.62	1.75	1.86	1.93	1.91	1.85	1.83	1.84	1.88	1.99	2.16	2.26	2.07	1.91	1.79
.700	1.66	1.80	1.97	2.14	2.28	2.36	2.35	2.30	2.29	2.29	2.31	2.45	2.71	2.80	2.70	2.36	2.22
1.000	2.15	2.28	2.46	2.63	2.82	2.97	3.03	3.03	3.04	3.05	3.10	3.33	3.67	3.75	3.55	3.04	2.89
1.500	2.99	3.07	3.26	3.43	3.67	3.92	4.10	4.19	4.23	4.28	4.42	4.74	5.05	5.04	4.65	3.98	3.75
2.000	3.92	3.97	4.17	4.38	4.66	4.95	5.20	5.35	5.40	5.46	5.60	5.87	6.03	5.88	5.33	4.65	4.34
3.000	5.45	5.48	5.77	6.13	6.48	6.82	7.13	7.34	7.35	7.31	7.27	7.21	7.04	6.65	5.96	5.34	5.06
5.000	5.99	6.26	6.96	7.63	8.20	8.66	9.07	9.36	9.14	8.79	8.33	7.79	7.29	6.67	6.14	5.55	5.39
7.000	5.49	5.94	6.94	7.82	8.54	9.08	9.56	9.96	9.68	9.16	8.35	7.60	6.99	6.34	6.02	5.37	5.27
10.000	4.62	5.14	6.32	7.30	8.10	8.66	9.15	9.71	9.62	9.03	7.96	7.11	6.52	5.98	5.83	5.01	4.91
15.000	3.86	4.36	5.52	6.41	7.08	7.45	7.78	8.15	8.09	7.66	6.92	6.41	6.10	5.78	5.52	4.62	4.45
20.000	3.52	3.96	4.99	5.68	6.10	6.25	6.36	6.42	6.27	6.12	5.91	5.84	5.82	5.67	5.19	4.34	4.14

average ozone (ppmv) for February

p (mb)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.43	.56	.64	.64	.60	.57	.60	.69	.73	.70	.65	.63	.66	.73	.75	.77	-
.0Q5	.21	.29	.37	.39	.38	.39	.44	.47	.47	.47	.44	.42	.42	.43	.41	.37	-
.007	.14	.18	.24	.28	.30	.35	.41	.42	.42	.42	.39	.33	.30	.27	.23	.18	-
.010	.13	.14	.16	.20	.23	.29	.35	.35	.36	.38	.38	.33	.27	.22	.17	.12	-
.015	.14	.13	.14	.14	.16	.18	.21	.22	.24	26	30	.32	.31	.28	.24	.20	-
.020	.15	.15	.14	.14	.13	.14	.15	.16	.17	.18	.21	.26	.30	.31	.30	.27	-
.030	.20	.19	.18	.17	.15	.15	.15	.16	.16	.16	.17	.19	.23	.29	.35	.38	-
.050	.30	.29	.28	.26	.24	.24	.23	.23	.23	.24	.25	.27	.29	.32	.39	.46	-
.070	.40	.40	.40	.38	.36	.34	.33	.32	.32	.32	.36	.40	.43	.45	.48	.52	-
.100	.56	.54	.53	.52	.50	.50	.50	.50	.48	.46	.48	.52	.53	.64	.63	.64	-
.150	.76	.75	.75	.77	.78	.77	.75	.73	.71	.70	.70	.71	.72	.75	.74	.85	-
.200	.92	.92	.94	.97	1.01	1.01	.98	.94	.92	.91	.93	.94	.95	.95	.93	1.04	-
.300	1.20	1.22	1.26	1.31	1.39	1.41	1.36	1.30	1.29	1.30	1.34	1.37	1.37	1.35	1.32	1.50	-
.500	1.59	1.63	1.73	1.83	1.93	1.96	1.91	1.83	1.82	1.85	1.88	1.94	2.02	2.14	2.22	2.25	2.16
.700	2.00	2.01	2.12	2.25	2.37	2.42	2.34	2.24	2.22	2.25	2.29	2.40	2.60	2.86	2.98	2.95	2.60
1.000	2.73	2.68	2.73	2.86	3.00	3.09	3.03	2.90	2.86	2.91	3.02	3.24	3.58	3.93	4.00	3.80	3.22
1.500	3.81	3.71	3.71	3.81	3.98	4.11	4.10	3.95	3.87	3.98	4.20	4.58	5.10	5.38	5.22	4.79	4.11
2.000	4.65	4.61	4.68	4.80	4.98	5.15	5.17	5.06	4.99	5.09	5.30	5.73	6.24	6.29	5.92	5.41	4.82
3.000	5.60	5.84	6.16	6.42	6.68	6.91	7.03	7.08	7.05	7.04	7.09	7.37	7.45	7.04	6.47	6.07	5.69
5.000	5.52	6.28	7.10	7.58	8.05	8.60	9.02	9.37	9.23	8.99	8.76	8.39	7.73	7.00	6.49	6.42	6.30
7.000	4.84	5.78	6.90	7.56	8.21	9.00	9.60	10.20	10.10	9.68	9.09	8.20	7.32	6.72	6.31	6.46	6.31
10.000	3.98	4.84	6.12	7.02	7.85	8.63	9.33	10.03	10.10	9.59	8.73	7.52	6.68	6.37	6.15	6.42	6.07
15.000	3.39	4.08	5.27	6.07	6.82	7.46	7.95	8.37	8.38	7.97	7.37	6.63	6.15	6.03	6.01	6.06	5.72
20.000	3.22	3.78	4.76	5.34	5.89	6.21	6.40	6.50	6.39	6.22	6.12	5.94	5.82	5.82	5.80	5.54	5.30

TABLE 4 - continued

average ozone (ppmv) for March

p (mb)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.37	.58	.66	.68	.74	.82	.81	.74	.69	.71	.76	.77	.68	.58	.57	.60	.61
.005	.21	.28	.31	.38	.48	.53	.52	.47	.44	.46	.49	.48	.42	.35	.33	.31	.27
.007	.15	.21	.24	.30	.38	.43	.43	.41	.40	.41	.42	.41	.36	.30	.26	.22	.16
.010	.12	.19	.22	.26	.33	.38	.37	.34	.33	.34	.37	.39	.38	.34	.28	.22	.15
.015	.12	.15	.16	.20	.24	.25	.23	.21	.20	.22	.26	.32	.38	.39	.36	.31	.23
.020	.15	.15	.14	.15	.17	.18	.16	.15	.16	.16	.19	.24	.33	.38	.39	.37	.31
.030	.20	.18	.17	.15	.14	.15	.17	.17	.17	.17	.17	.18	.23	.29	.37	.43	.41
.050	.30	.30	.29	.27	.25	.25	.25	.24	.23	.24	.25	.27	.28	.30	.37	.46	.48
.070	.40	.40	.41	.40	.38	.35	.34	.33	.31	.32	.36	.39	.41	.43	.46	.50	.52
.100	.55	.54	.53	.53	.51	.50	.51	.50	.48	.47	.48	.49	.52	.54	.55	.58	.61
.150	.79	.77	.77	.78	.77	.75	.75	.74	.73	.72	.71	.72	.74	.74	.73	.74	.75
.200	.99	.97	.98	1.00	.99	.97	.96	.96	.95	.94	.93	.92	.95	.94	.91	.91	.93
.300	1.33	1.35	1.36	1.38	1.39	1.37	1.34	1.33	1.34	1.33	1.32	1.32	1.33	1.32	1.28	1.29	1.35
.500	1.97	1.96	1.92	1.93	1.95	1.93	1.89	1.88	1.89	1.90	1.92	1.94	1.94	1.96	2.02	2.12	2.27
.700	2.82	2.58	2.42	2.40	2.40	2.37	2.32	2.30	2.30	2.31	2.35	2.41	2.42	2.50	2.69	2.89	3.00
1.000	3.86	3.62	3.30	3.20	3.17	3.11	2.99	2.90	2.88	2.92	3.03	3.17	3.27	3.45	3.75	3.96	3.93
1.500	5.01	5.04	4.66	4.46	4.36	4.28	4.06	3.83	3.77	3.86	4.10	4.39	4.67	5.02	5.33	5.33	5.00
2.000	5.41	5.80	5.69	5.53	5.45	5.37	5.12	4.80	4.71	4.85	5.15	5.51	5.92	6.29	6.42	6.18	5.74
3.000	5.39	6.26	6.76	6.93	7.00	7.06	6.93	6.60	6.48	6.63	6.91	7.21	7.61	7.73	7.41	6.88	6.49
5.000	5.08	6.05	7.00	7.58	8.03	8.43	8.77	8.95	8.91	8.90	8.84	8.65	8.48	7.99	7.31	6.65	6.50
7.000	4.65	5.40	6.51	7.32	8.00	8.68	9.34	9.94	10.05	9.80	9.31	8.71	8.13	7.45	6.78	6.28	6.30
10.000	4.09	4.52	5.64	6.67	7.55	8.45	9.36	10.28	10.59	10.12	9.27	8.26	7.38	6.72	6.24	6.03	6.18
15.000	3.73	3.98	4.87	5.81	6.55	7.26	7.93	8.54	8.70	8.37	7.83	7.14	6.48	6.08	5.86	5.86	5.95
20.000	3.61	3.85	4.49	5.19	5.70	6.10	6.42	6.66	6.67	6.57	6.47	6.23	5.91	5.73	5.65	5.68	5.58

average ozone (ppmv) for April

p (mb)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	-	-	.77	.83	.92	.93	.84	.77	.76	.79	.93	1.01	.83	.59	.52	.56	.63
.005	-	-	.35	.43	.54	.57	.50	.44	.43	.48	.62	.72	.61	.43	.36	.38	.42
.007	-	-	.24	.32	.41	.44	.41	.39	.39	.41	.49	.56	.51	.41	.34	.32	.30
.010	-	-	.25	.30	.35	.35	.34	.36	.36	.36	.39	.46	.48	.45	.41	.35	.26
.015	-	-	.28	.27	.26	.22	.20	.22	.23	.22	.24	.33	.41	.44	.43	.39	.29
.020	-	-	.28	.22	.19	.16	.15	.15	.16	.16	.17	.23	.31	.35	.37	.37	.31
.030	-	-	.26	.18	.15	.16	.17	.16	.17	.17	.17	.19	.21	.23	.26	.30	.33
.050	-	-	.32	.28	.27	.26	.26	.25	.25	.26	.27	.27	.28	.29	.31	.35	.39
.070	-	-	.42	.41	.40	.38	.37	.35	.34	.34	.37	.38	.39	.41	.43	.46	.49
.100	-	-	.56	.57	.55	.54	.54	.53	.50	.49	.50	.49	.49	.50	.53	.55	.56
.150	-	-	.80	.81	.79	.79	.80	.78	.76	.75	.75	.74	.73	.73	.73	.73	.73
.200	-	-	1.06	1.05	1.02	1.01	1.01	1.00	.98	.97	.96	.95	.95	.93	.91	.90	.89
.300	-	-	1.54	1.50	1.43	1.40	1.39	1.38	1.36	1.35	1.35	1.33	1.32	1.29	1.26	1.24	1.24
.500	2.50	2.38	2.27	2.17	2.04	1.96	1.93	1.94	1.94	1.94	1.94	1.94	1.89	1.84	1.83	1.86	1.90
.700	3.50	3.34	2.96	2.77	2.56	2.42	2.36	2.37	2.37	2.37	2.40	2.41	2.33	2.26	2.28	2.37	2.48
1.000	4.64	4.64	4.19	3.87	3.52	3.25	3.07	2.99	2.98	3.00	3.06	3.11	3.03	2.96	3.03	3.18	3.35
1.500	5.59	6.06	5.84	5.48	5.01	4.57	4.16	3.94	3.89	3.94	4.08	4.21	4.18	4.16	4.31	4.48	4.57
2.000	5.65	6.39	6.65	6.51	6.14	5.71	5.23	4.90	4.83	4.93	5.13	5.31	5.35	5.39	5.55	5.63	5.49
3.000	5.18	5.98	6.93	7.34	7.40	7.30	6.99	6.58	6.49	6.66	6.95	7.12	7.25	7.31	7.30	7.02	6.42
5.000	4.94	5.54	6.48	7.22	7.84	8.44	8.82	8.63	8.42	8.65	8.77	8.66	8.69	8.50	7.82	6.99	6.14
7.000	4.66	5.09	5.90	6.73	7.53	8.46	9.27	9.63	9.62	9.55	9.27	8.91	8.61	8.10	7.29	6.37	5.68
10.000	4.18	4.50	5.23	6.08	6.95	8.07	9.21	10.16	10.45	10.00	9.25	8.64	7.95	7.22	6.47	5.78	5.40
15.000	3.73	4.15	4.82	5.45	6.12	7.02	7.89	8.62	8.80	8.48	7.95	7.49	6.86	6.29	5.77	5.40	5.30
20.000	3.46	4.03	4.63	5.02	5.45	6.01	6.46	6.79	6.85	6.79	6.66	6.49	6.11	5.74	5.41	5.24	5.26

TABLE 4 - continued

average ozone (ppmv) for May

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	-	-	-	.99	1.02	.92	.75	.65	.63	.67	.75	.85	.84	.74	.64	.56	.48
.005	-	-	-	.51	.57	.53	.46	.42	.41	.43	.52	.62	.63	.56	.49	.41	.33
.007	-	-	-	.33	.39	.39	.40	.42	.43	.43	.45	.50	.51	.46	.41	.33	.25
.010	-	-	-	.27	.30	.32	.37	.41	.42	.40	.39	.39	.38	.36	.33	.28	.21
.015	-	-	-	.24	.22	.23	.24	.27	.26	.25	.24	.25	.25	.25	.24	.21	.19
.020	-	-	-	.22	.18	.17	.17	.18	.17	.17	.17	.19	.19	.20	.19	.19	.18
.030	-	-	-	.22	.17	.16	.16	.16	.16	.17	.18	.19	.20	.20	.19	.19	.21
.050	-	-	-	.30	.28	.28	.27	.26	.27	.27	.27	.27	.28	.29	.28	.29	.31
.070	-	-	-	.41	.41	.40	.39	.38	.38	.38	.38	.37	.38	.39	.39	.40	.43
.100	-	-	-	.59	.57	.56	.57	.55	.53	.53	.53	*.51*	*.49*	*.51*	.53	.54	.54
.150	-	-	-	.85	*.81*	*.81*	.83	.81	.79	.79	.80	*.78*	*.76*	*.76*	.76	.75	.73
.200	-	-	-	1.12	*1.05*	*1.03*	1.05	1.03	1.01	1.02	1.02	*1.00*	.97	.95	.94	.91	.88
.300	-	-	-	1.67	1.52	1.43	1.43	1.41	1.39	1.40	1.39	1.36	1.33	1.29	1.25	1.20	1.16
.500	-	2.64	*2.47*	2.46	2.24	2.02	1.96	1.97	1.97	1.97	1.96	1.95	1.89	1.82	1.74	1.66	1.59
.700	-	3.66	*3.50*	3.35	2.89	2.54	2.43	2.42	2.42	2.42	2.42	2.40	2.33	2.23	2.12	2.04	1.97
1.000	-	4.97	*4.91*	4.79	4.09	3.49	3.18	3.09	3.07	3.06	3.07	3.03	2.92	2.79	2.67	2.59	2.59
1.500	-	6.30	*6.39*	6.61	5.85	4.98	4.33	4.10	4.05	4.04	4.06	4.02	3.88	3.74	3.62	3.54	3.64
2.000	-	6.52	6.77	7.38	6.94	6.15	5.41	5.10	5.03	5.05	5.11	5.08	4.94	4.81	4.72	4.62	4.75
3.000	-	6.07	6.39	7.46	7.76	7.54	7.06	6.74	6.68	6.77	6.93	6.92	6.82	6.73	6.60	6.31	6.30
5.000	-	5.79	5.73	6.78	7.57	8.15	8.39	8.31	8.27	8.57	8.71	8.64	8.50	8.20	7.59	6.75	6.19
7.000	-	5.46	5.31	6.21	7.12	8.03	8.77	9.12	9.18	9.27	9.20	8.98	8.70	8.16	7.35	6.26	5.47
10.000	-	4.93	4.93	5.69	6.57	7.61	8.74	9.64	9.95	9.44	8.94	8.57	8.09	7.57	6.75	5.63	4.84
15.000	-	4.43	4.74	5.33	5.95	6.72	7.60	8.28	8.55	8.39	7.91	7.59	7.10	6.57	5.92	5.06	4.43
20.000	-	4.13	4.61	5.09	5.47	5.92	6.36	*6.63*	6.77	*6.86*	*6.71*	6.59	6.30	5.88	5.38	4.76	4.32

average ozone (ppmv) for June

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	-	-	-	-	.80	.78	.59	.47	.47	.54	.62	.73	.87	.94	.88	.72	.57
.005	-	-	-	-	.50	.50	.38	.34	.38	.41	.43	.51	.63	.63	.50	.39	.32
.007	-	-	-	-	.35	.37	.34	.35	.38	.39	.36	.39	.46	.42	.30	.25	.22
.010	-	-	-	-	.27	.30	.30	.31	.31	.30	.28	.27	.29	.26	.19	.18	.17
.015	-	-	.	-	.21	.22	.21	.20	.19	.19	.18	.17	.18	.18	.17	.16	.16
.020	-	-	-	-	.18	.17	.16	.15	.14	.15	.15	.15	.16	.17	.17	.17	.17
.030	-	-	-	-	.18	.17	.17	.16	.16	.17	.17	.17	.19	.20	.20	.20	.21
.050	-	-	-	-	.31	.30	.28	.26	.26	.26	.26	.27	.27	.28	.27	.28	.30
.070	-	-	-	-	.45	.45	.41	.38	.37	.37	.38	.39	.38	.38	.38	.39	.40
.100	-	-	-	-	*.58*	*.57*	*.56*	.57	.57	.58	.58	*.55*	*.52*	.53	.57	.55	.56
.150	-	-	-	-	*.82*	*.82*	*.83*	.83	.83	.85	.88	.84	.80	.80	.80	.80	.78
.200	-	-	-	-	*1.06*	*1.04*	*1.05*	1.06	1.06	1.08	1.11	1.08	1.03	1.01	.99	.96	.93
.300	-	-	-	-	1.53	1.44	1.44	1.47	1.47	1.48	1.49	1.45	1.39	1.35	1.30	1.24	1.18
.500	-	-	2.46	2.42	2.26	2.02	1.98	2.00	2.00	1.99	1.98	1.95	1.87	1.78	1.67	1.56	1.46
.700	-	-	3.56	3.54	2.96	2.56	2.46	2.46	2.46	2.45	2.44	2.41	2.30	2.16	1.99	1.83	1.71
1.000	-	-	5.01	5.16	4.29	3.56	3.30	3.22	3.19	3.16	3.13	3.05	2.88	2.68	2.47	2.28	2.16
1.500	-	-	6.50	7.11	6.19	5.06	4.51	4.30	4.24	4.19	4.15	3.98	3.73	3.49	3.24	3.05	2.97
2.000	-	-	6.77	7.74	7.27	6.16	5.55	5.30	5.23	5.21	5.20	5.01	4.73	4.49	4.24	4.05	4.03
3.000	-	-	6.20	7.36	7.96	7.43	7.05	6.91	6.88	6.94	7.02	6.84	6.59	6.38	6.07	5.83	5.87
5.000	-	-	5.64	6.37	7.53	7.93	8.27	8.43	8.55	8.72	8.78	8.63	8.36	7.84	7.14	6.38	6.08
7.000	-	-	5.32	5.74	7.04	7.82	8.47	8.94	9.19	9.28	9.17	8.99	8.63	7.91	7.01	5.91	5.37
10.000	-	-	5.02	5.29	6.53	7.45	8.11	8.88	9.23	9.11	8.67	8.45	7.95	7.42	6.52	5.29	4.71
15.000	-	-	4.82	5.19	5.93	6.48	7.04	7.67	7.97	7.84	7.38	7.22	6.83	6.36	5.66	4.68	4.18
20.000	-	-	4.68	5.25	5.57	5.76	5.97	6.20	6.36	6.40	6.20	6.15	6.00	5.64	5.09	4.33	3.94

TABLE 4 - continued

average ozone (ppmv) for July

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
								latitude									
.003	-	-	-	.58	.66	.63	.53	.48	.47	.51	.60	.66	.71	.85	.93	.80	.58
.005	-	-	-	.34	.41	.41	.37	.34	.37	.40	.42	.44	.49	.55	.52	.40	.31
.007	-	-	-	.24	.29	.32	.32	.33	.35	.36	.35	.34	.36	.37	.30	.23	.21
.010	-	-	-	.20	.24	.27	.29	.28	.28	.27	.25	.24	.24	.23	.19	.16	.17
.015	-	-	-	.21	.20	.20	.19	.17	.16	.16	.16	.16	.16	.16	.16	.16	.16
.020	-	-	-	.21	.17	.16	.15	.14	.14	.14	.14	.14	.15	.16	.17	.17	.17
.030	-	-	-	.22	.17	.16	.16	.16	.17	.17	.16	.16	.18	.20	.20	.20	.21
.050	-	-	-	.31	.31	.29	.26	.25	.25	.25	.24	.24	.27	.28	.28	.28	.31
.070	-	-	-	.43	.46	.45	.39	.36	.36	.36	.35	.36	.39	.39	.38	.39	.42
.100	-	-	-	.61	.60	.60	.57	.55	.55	.56	.58	.57	.55	.55	.57	.55	.56
.150	-	-	-	.89	.85	.86	.83	.82	.81	.84	.87	.88	.85	.82	.81	.81	.79
.200	-	-	-	-	1.09	1.08	1.06	1.04	1.04	1.06	1.11	1.12	1.09	1.04	1.00	.98	.95
.300	-	-	-	-	1.53	1.49	1.45	1.44	1.44	1.46	1.50	1.51	1.46	1.39	1.32	1.26	1.19
.500	-	-	2.05	2.14	2.22	2.07	2.00	1.99	1.99	1.99	2.00	2.00	1.93	1.81	1.68	1.55	1.44
.700	-	-	2.85	3.03	2.86	2.60	2.48	2.44	2.44	2.44	2.48	2.49	2.39	2.20	2.00	1.82	1.66
1.000	-	-	4.06	4.40	4.05	3.58	3.34	3.23	3.19	3.18	3.22	3.19	3.01	2.76	2.52	2.30	2.14
1.500	-	-	5.62	6.28	5.76	5.04	4.61	4.39	4.31	4.29	4.31	4.18	3.91	3.61	3.32	3.08	2.97
2.000	-	-	6.24	7.17	6.86	6.13	5.69	5.47	5.38	5.37	5.38	5.21	4.90	4.59	4.28	4.03	3.97
3.000	-	-	6.22	7.39	7.79	7.43	7.23	7.16	7.12	7.15	7.18	6.98	6.68	6.37	6.00	5.66	5.64
5.000	-	-	5.79	6.63	7.47	8.04	8.35	8.62	8.76	8.87	8.85	8.67	8.34	7.88	7.11	6.21	5.84
7.000	-	-	5.39	5.91	6.98	7.81	8.42	8.98	9.26	9.34	9.17	8.99	8.59	7.97	6.98	5.79	5.18
10.000	-	-	4.98	5.29	6.41	7.19	7.95	8.77	9.11	9.08	8.65	8.45	7.95	7.23	6.28	5.14	4.50
15.000	-	-	4.74	5.08	5.83	6.35	6.90	7.53	7.81	7.79	7.35	7.19	6.80	6.22	5.45	4.51	3.95
20.000	-	-	4.65	5.14	5.52	5.73	5.92	6.14	6.31	6.41	6.17	6.08	5.91	5.55	4.94	4.14	3.68

average ozone (ppmv) for August

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
								latitude									
.003	-	-	.62	.66	.69	.67	.61	.60	.61	.62	.65	.68	.67	.65	.67	.60	.44
.005	-	-	.37	.40	.43	.43	.41	.40	.40	.41	.44	.46	.43	.41	.41	.35	.24
.007	-	-	.26	.29	.32	.34	.35	.36	.36	.36	.38	.36	.32	.29	.28	.22	.18
.010	-	-	.23	.25	.28	.30	.32	.31	.30	.30	.31	.27	.23	.20	.18	.15	.15
.015	-	-	.25	.23	.24	.24	.22	.19	.18	.18	.19	.17	.16	.15	.14	.14	.13
.020	-	-	.24	.20	.19	.18	.16	.14	.14	.14	.15	.14	.14	.14	.14	.15	.15
.030	-	-	.24	.19	.17	.17	.17	.16	.16	16	.17	16	.16	.17	.18	.18	.19
.050	-	-	.33	.32	.31	.30	.26	.25	.25	.25	.25	.24	.25	.26	.27	.27	.29
.070	-	-	.44	.47	.48	.44	.38	.36	.36	.35	.34	.35	.36	.38	.38	.38	.39
.100	-	-	.60	.61	.62	.59	.54	.52	.53	.53	.52	.52	.53	.53	.52	.53	.54
.150	-	-	.84	.85	.88	.87	.82	.79	.79	.79	.79	.80	.81	.80	.77	.75	.73
.200	-	-	1.01	1.09	1.12	1.11	1.05	1.02	1.01	1.01	1.03	1.04	1.05	1.02	.96	.92	.90
.300	-	-	1.18	1.56	1.58	1.54	1.47	1.43	1.40	1.39	1.43	1.46	1.45	1.38	1.30	1.23	1.18
.500	-	1.90	1.90	2.19	2.22	2.11	2.00	1.97	1.95	1.94	1.97	2.02	1.98	1.85	1.74	1.64	1.56
.700	-	2.50	2.55	2.76	2.79	2.60	2.45	2.41	2.39	2.40	2.45	2.50	2.44	2.26	2.11	2.01	1.92
1.000	-	3.35	3.54	3.87	3.87	3.55	3.29	3.17	3.13	3.14	3.22	3.28	3.18	2.95	2.77	2.65	2.55
1.500	-	4.41	4.97	5.51	5.43	4.97	4.55	4.31	4.24	4.27	4.39	4.42	4.25	3.98	3.78	3.61	3.48
2.000	-	4.92	5.79	6.60	6.55	6.09	5.68	5.42	5.33	5.37	5.51	5.49	5.27	4.99	4.77	4.53	4.32
3.000	-	5.21	6.35	7.57	7.78	7.54	7.37	7.23	7.16	7.20	7.32	7.23	6.94	6.64	6.34	5.86	5.43
5.000	-	5.34	6.14	7.42	8.06	8.32	8.65	9.04	9.07	9.15	9.07	8.69	8.31	7.81	7.06	6.18	5.30
7.000	-	5.29	5.59	6.73	7.56	8.10	8.72	9.46	9.54	9.60	9.39	8.93	8.45	7.73	6.78	5.69	4.68
10.000	-	5.11	4.94	5.88	6.74	7.36	8.14	9.43	9.51	9.53	9.16	8.60	8.01	7.13	6.11	4.94	4.06
15.000	-	4.63	4.59	5.33	5.99	6.43	6.98	7.74	7.84	7.89	7.58	7.19	6.78	6.06	5.21	4.28	3.62
20.000	-	4.14	4.53	5.16	5.59	5.78	5.96	6.22	6.31	6.43	6.26	6.05	5.84	5.35	4.66	3.95	3.45

TABLE 4 - continued

average ozone (ppmv) for September

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.42	.58	.59	.64	.74	.79	.77	.77	.77	.75	.76	.76	.69	.61	.60	.56	.46
.005	.27	.33	.36	.39	.46	.52	.51	.48	.48	.48	.49	.53	.47	.37	.31	.28	.21
.007	.24	.26	.29	.33	.38	.43	.43	.40	.38	.38	.40	.42	.38	.29	.24	.21	.16
.010	.24	.28	.31	.35	.37	.37	.35	.32	.30	.29	.32	.34	.31	.25	.21	.19	.16
.015	.27	.32	.31	.32	.30	.27	.23	.21	.20	.19	.21	.22	.22	.19	.17	.16	.17
.020	.28	.30	.27	.25	.23	.19	.17	.16	.16	.15	.16	.17	.17	.16	.15	.15	.18
.030	.28	.28	.22	.19	.17	.16	.17	.17	.16	.16	.16	.15	.15	.16	.16	.17	.21
.050	.33	.33	.31	.31	.29	.28	.26	.24	.23	.24	.24	.23	.23	.26	.26	.27	.29
.070	.41	.43	.45	.45	.45	.42	.37	.34	.33	.34	.34	.34	.35	.38	.39	.38	.38
.100	.52	.57	.58	.59	.58	.54	.50	.49	.50	.49	.47	.46	.48	.49	.48	.49	.50
.150	.70	.80	.80	.83	.84	.80	.77	.76	.76	.74	.72	.70	.72	.73	.70	.67	.67
.200	-	.99	1.01	1.05	1.06	1.03	1.00	.99	.98	.97	.96	.96	.97	.97	.94	.89	.86
.300	-	1.35	1.40	1.47	1.48	1.43	1.41	1.41	1.38	1.36	1.38	1.40	1.40	1.40	1.36	1.28	1.25
.500	1.78	1.88	1.98	2.10	2.10	2.02	1.96	1.95	1.93	1.92	1.94	1.96	1.95	1.92	1.89	1.87	1.93
.700	2.38	2.34	2.48	2.67	2.64	2.47	2.38	2.36	2.35	2.36	2.38	2.40	2.38	2.36	2.37	2.41	2.48
1.000	3.19	3.18	3.38	3.66	3.62	3.36	3.16	3.06	3.04	3.07	3.15	3.23	3.23	3.23	3.30	3.37	3.34
1.500	4.26	4.38	4.72	5.10	5.07	4.71	4.35	4.13	4.08	4.15	4.34	4.48	4.51	4.54	4.66	4.69	4.33
2.000	4.86	5.16	5.72	6.23	6.26	5.90	5.50	5.21	5.13	5.21	5.45	5.60	5.59	5.60	5.67	5.52	4.87
3.000	5.34	5.89	6.86	7.58	7.80	7.63	7.36	7.08	6.97	7.04	7.25	7.31	7.17	7.03	6.82	6.23	5.22
5.000	5.36	5.94	6.86	7.76	8.45	8.81	9.04	8.99	8.96	8.98	8.98	8.80	8.41	7.89	7.17	6.07	4.97
7.000	5.28	5.62	6.45	7.31	8.06	8.64	9.20	9.54	9.61	9.57	9.34	8.98	8.43	7.63	6.67	5.47	4.58
10.000	5.15	5.18	5.81	6.61	7.34	8.02	8.80	9.25	9.39	9.31	8.84	8.35	7.71	6.74	5.75	4.71	4.14
15.000	4.38	4.51	5.12	5.85	6.38	6.83	7.31	7.81	7.94	7.91	7.45	7.04	6.58	5.76	4.94	4.13	3.75
20.000	3.50	3.97	4.75	5.42	5.79	6.00	6.14	6.30	6.38	6.42	6.15	5.92	5.71	5.18	4.54	3.89	3.53

average ozone (ppmv) for October

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.57	.56	.54	.61	.80	.93	.87	.80	.84	.81	.76	.84	.87	.75	.66	.65	.63
.005	.38	.41	.41	.45	.58	.66	.60	.53	.55	.54	.51	.55	.55	.44	.34	.30	.23
.007	.31	.38	.41	.44	.50	.52	.47	.42	.43	.42	.39	.42	.41	.33	.25	.19	.12
.010	.29	.38	.43	.45	.44	.39	.34	.33	.33	.32	.30	.30	.31	.28	.23	.19	.12
.015	.26	.32	.35	.35	.31	.26	.24	.24	.24	.23	.22	.22	.22	.23	.25	.25	.20
.020	.23	.24	.25	.25	.23	.19	.19	.19	.20	.18	.18	.18	.18	.20	.25	.29	.25
.030	.24	.21	.20	.19	.18	.17	.17	.18	.18	.17	.16	.16	.16	.18	.24	.33	.31
.050	.35	.33	.32	.31	.29	.26	.26	.26	.25	.24	.24	.25	.26	.26	.28	.36	.37
.070	.45	.45	.44	.43	.41	.39	.38	.37	.36	.35	.35	.36	.37	.38	.38	.40	.41
.100	.56	.55	.54	.53	.50	.48	.48	.46	.46	.45	.52	.53	.55	.56	.54	.51	-
.150	.78	.75	.75	.76	.74	.74	.73	.71	.69	.69	.79	.66	.68	.70	.69	.72	-
.200	.97	.93	.94	.96	.96	.97	.96	.94	.92	.92	.93	.92	.93	.93	.91	.94	-
.300	1.31	1.28	1.30	1.33	1.37	1.39	1.40	1.39	1.37	1.38	1.41	1.40	1.37	1.36	1.36	1.37	-
.500	1.76	1.79	1.86	1.92	1.93	1.94	1.96	1.97	1.97	1.97	1.96	1.94	1.97	2.07	2.16	2.16	2.09
.700	2.16	2.18	2.33	2.40	2.36	2.31	2.33	2.35	2.37	2.37	2.34	2.32	2.44	2.68	2.84	2.88	2.94
1.000	2.83	2.87	3.10	3.22	3.17	3.07	3.04	3.03	3.04	3.06	3.10	3.18	3.44	3.80	4.05	4.06	3.97
1.500	3.86	3.93	4.26	4.47	4.43	4.27	4.14	4.05	4.03	4.09	4.27	4.53	4.96	5.41	5.66	5.49	4.96
2.000	4.75	4.91	5.34	5.64	5.66	5.47	5.27	5.11	5.03	5.11	5.35	5.67	6.09	6.42	6.49	6.07	5.26
3.000	5.92	6.33	6.93	7.39	7.58	7.47	7.24	6.98	6.82	6.86	7.10	7.32	7.41	7.30	6.92	6.18	5.18
5.000	6.19	6.87	7.70	8.30	8.74	9.04	9.17	9.06	8.90	8.87	8.89	8.66	8.01	7.33	6.75	5.92	5.03
7.000	6.00	6.61	7.39	7.99	8.47	9.06	9.53	9.76	9.75	9.68	9.45	8.83	7.79	6.91	6.24	5.52	4.81
10.000	5.76	6.08	6.66	7.14	7.50	8.18	8.90	9.52	9.77	9.89	9.48	8.53	7.26	6.27	5.54	4.99	4.45
15.000	4.86	5.27	5.96	6.30	6.44	6.92	7.47	7.99	8.05	8.16	7.79	7.09	6.21	5.52	4.97	4.49	3.98
20.000	3.92	4.64	5.60	5.84	5.82	6.03	6.24	6.36	6.33	6.44	6.26	5.90	5.45	5.05	4.70	4.19	3.62

TABLE 4 - continued

average ozone (ppmv) for November

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.50	.60	.67	.74	.82	.84	.77	.76	.79	.80	.78	.84	.98	.97	.88	-	-
.005	.33	.41	.48	.54	.59	.59	.55	.53	.55	.57	.54	.54	.59	.52	.45	-	-
.007	.24	.30	.37	.42	.45	.45	.43	.43	.45	.47	.43	.41	.41	.32	.24	-	-
.010	.18	.22	.27	.31	.32	.33	.32	.33	.35	.37	.35	.33	.30	.24	.18	-	-
.015	.15	.17	.19	.21	.22	.23	.23	.24	.25	.25	.26	.25	.24	.25	.22	-	-
.020	.17	.17	.18	.18	.18	.18	.18	.20	.20	.20	.20	.20	.20	.24	.26	-	-
.030	.21	.20	.21	.20	.19	.18	.17	.18	.17	.16	.18	.18	.19	.24	.31	-	-
.050	.31	.30	.30	.30	.28	.27	.26	.25	.25	.24	.26	.27	.28	.31	.38	-	-
.070	.43	.42	.41	.41	.40	.39	.38	.37	.36	.37	.38	.39	.41	.43	.44	-	-
.100	.54	.52	.52	.49	.46	.46	.46	.46	.47	.48	.57	.58	.58	.59	.58	-	-
.150	.74	.73	.74	.73	.72	.72	.72	.70	.70	.71	.73	.70	.70	.71	.79	-	-
.200	.91	.91	.91	.93	.93	.94	.94	.94	.93	.94	.95	.96	.95	.92	-	-	-
.300	1.20	1.21	1.24	1.28	1.32	1.35	1.38	1.40	1.38	1.38	1.41	1.45	1.43	1.37	-	-	-
.500	1.59	1.64	1.72	1.80	1.85	1.90	1.94	1.98	1.98	1.98	1.96	1.99	2.08	2.19	2.09	2.09	1.84
.700	1.86	1.93	2.07	2.15	2.21	2.26	2.30	2.36	2.40	2.37	2.31	2.37	2.60	2.87	2.98	2.89	2.42
1.000	2.42	2.47	2.63	2.72	2.78	2.86	2.94	3.02	3.07	3.06	3.04	3.22	3.68	4.14	4.24	3.98	3.24
1.500	3.37	3.38	3.55	3.64	3.71	3.82	3.94	4.02	4.06	4.09	4.19	4.60	5.34	5.87	5.76	5.26	4.14
2.000	4.38	4.39	4.59	4.71	4.79	4.90	5.01	5.04	5.05	5.09	5.26	5.76	6.46	6.77	6.38	5.78	4.55
3.000	5.96	6.06	6.32	6.61	6.76	6.85	6.90	6.81	6.70	6.72	6.92	7.25	7.43	7.18	6.45	5.88	4.74
5.000	6.39	6.76	7.29	7.93	8.40	8.67	8.82	8.69	8.36	8.35	8.27	8.03	7.46	6.78	6.04	5.67	4.29
7.000	6.03	6.45	7.09	7.84	8.49	8.97	9.34	9.41	9.11	9.01	8.70	8.08	7.01	6.26	5.67	5.39	3.82
10.000	5.58	5.87	6.46	7.11	7.76	8.41	9.00	9.45	9.43	9.32	8.73	7.83	6.39	5.72	5.31	5.00	3.42
15.000	5.05	5.26	5.81	6.22	6.67	7.23	7.74	8.17	8.23	7.93	7.46	6.78	5.78	5.33	4.98	4.52	3.18
20.000	4.67	4.90	5.40	5.64	5.89	6.22	6.46	6.61	6.53	6.37	6.18	5.82	5.30	5.05	4.68	4.11	3.01

average ozone (ppmv) for December

p (mb)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
.003	.54	.70	.79	.80	.75	.66	.58	.57	.55	.52	.60	.79	.94	.96	-	-	-
.005	.28	.35	.44	.52	.53	.47	.44	.45	.45	.42	.41	.49	.58	.57	-	-	-
.007	.20	.22	.27	.35	.38	.36	.37	.40	.41	.39	.36	.36	.37	.33	-	-	-
.010	.17	.17	.19	.23	.26	.26	.28	.33	.33	.33	.34	.31	.27	.21	-	-	-
.015	.17	.17	.17	.17	.17	.18	.20	.22	.22	.23	.26	.27	.26	.24	-	-	-
.020	.18	.18	.17	.16	.16	.15	.16	.17	.17	.18	.20	.23	.25	.27	-	-	-
.030	.22	.21	.20	.19	.18	.16	.16	.17	.17	.17	.17	.19	.23	.31	-	-	-
.050	.33	.30	.29	.28	.27	.25	.24	.25	.25	.24	.26	.30	.34	.39	-	-	-
.070	.43	.41	.40	.39	.39	.38	.36	.35	.35	.35	.38	.45	.49	.51	-	-	-
.100	.58	.57	.52	.50	.48	.49	.51	.50	.49	.48	.49	.65	.71	.70	-	-	-
.150	.78	.77	.76	.75	.75	.77	.77	.74	.71	.72	.72	.76	.80	.99	-	-	-
.200	.94	.93	.95	.95	.96	1.00	1.01	.97	.94	.94	.97	1.02	1.04	1.25	-	-	-
.300	1.20	1.22	1.26	1.29	1.33	1.40	1.42	1.39	1.36	1.37	1.42	1.48	1.50	1.78	-	-	-
.500	1.47	1.55	1.65	1.77	1.86	1.93	1.97	1.98	1.98	1.98	1.97	1.99	2.09	1.94	1.94	1.71	1.66
.700	1.65	1.77	1.94	2.10	2.21	2.29	2.34	2.40	2.44	2.41	2.35	2.38	2.57	2.72	2.68	2.21	2.15
1.000	2.11	2.23	2.42	2.57	2.72	2.86	2.99	3.11	3.18	3.15	3.13	3.25	3.63	3.92	3.74	3.00	2.93
1.500	2.92	3.00	3.19	3.34	3.53	3.77	4.01	4.18	4.27	4.29	4.35	4.66	5.27	5.59	5.10	4.14	4.03
2.000	3.90	3.95	4.13	4.31	4.54	4.81	5.08	5.25	5.32	5.35	5.45	5.80	6.37	6.49	5.79	4.86	4.72
3.000	5.61	5.64	5.83	6.16	6.45	6.71	6.96	7.04	6.99	6.97	7.02	7.18	7.31	6.92	6.10	5.39	5.21
5.000	6.27	6.46	7.03	7.71	8.18	8.57	8.90	8.89	8.55	8.26	7.97	7.74	7.28	6.54	5.94	5.19	4.98
7.000	5.79	6.13	6.99	7.82	8.47	8.97	9.38	9.49	9.08	8.66	8.10	7.62	6.89	6.07	5.69	4.81	4.62
10.000	4.99	5.40	6.40	7.41	8.16	8.75	9.24	9.60	9.36	8.79	7.90	7.25	6.38	5.65	5.42	4.37	4.25
15.000	4.35	4.72	5.62	6.41	7.01	7.44	7.77	8.04	7.93	7.53	6.87	6.44	5.85	5.42	5.10	4.08	4.00
20.000	4.10	4.38	5.13	5.66	6.05	6.29	6.40	6.44	6.27	6.11	5.85	5.73	5.48	5.30	4.77	3.86	3.77

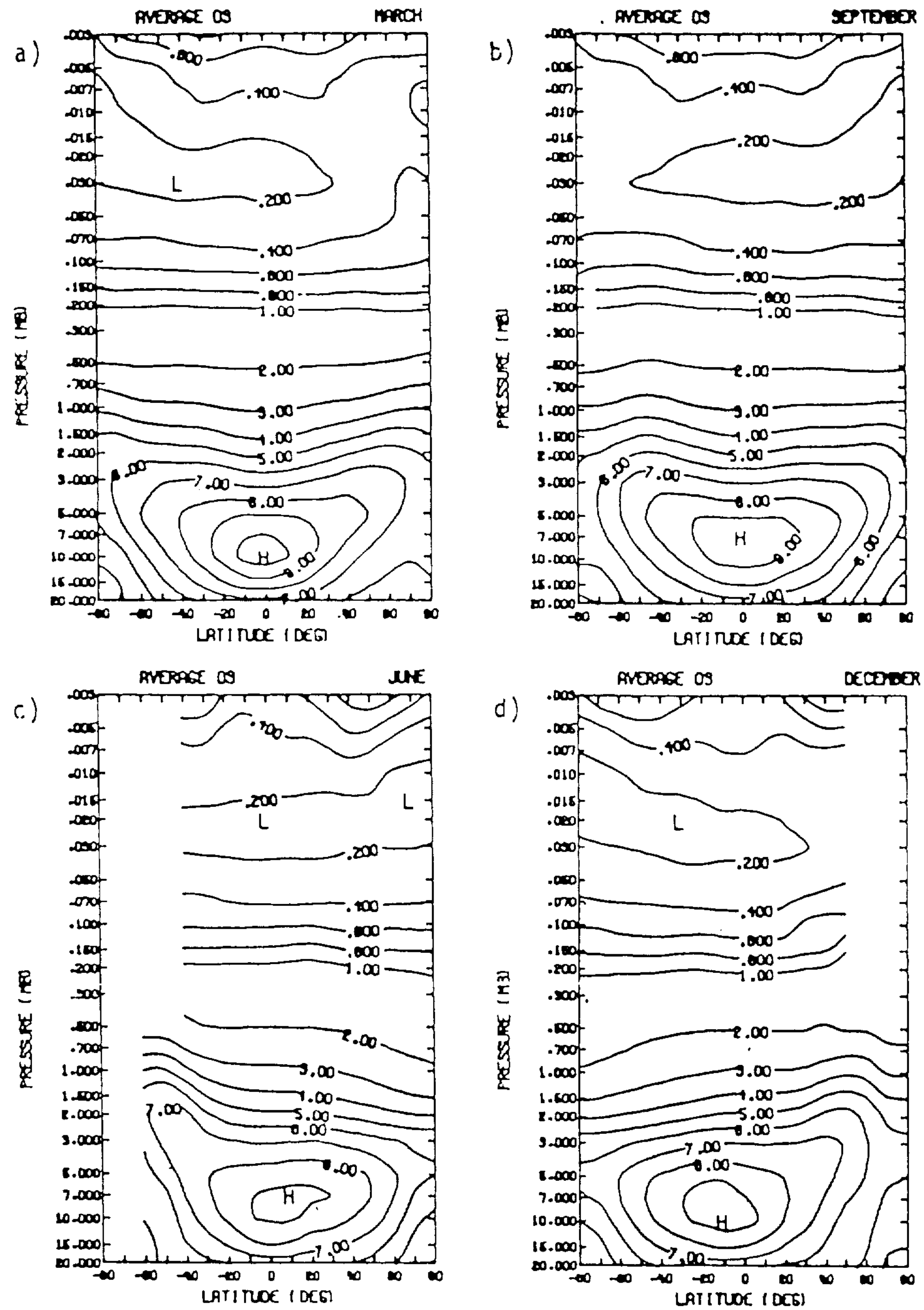

Figure 8. Monthly zonal mean ozone volume mixing ratios (ppmv) as function of latitude (deg) and pressure (mb) for (a) March, (b) September, (c) June, and (d) December.

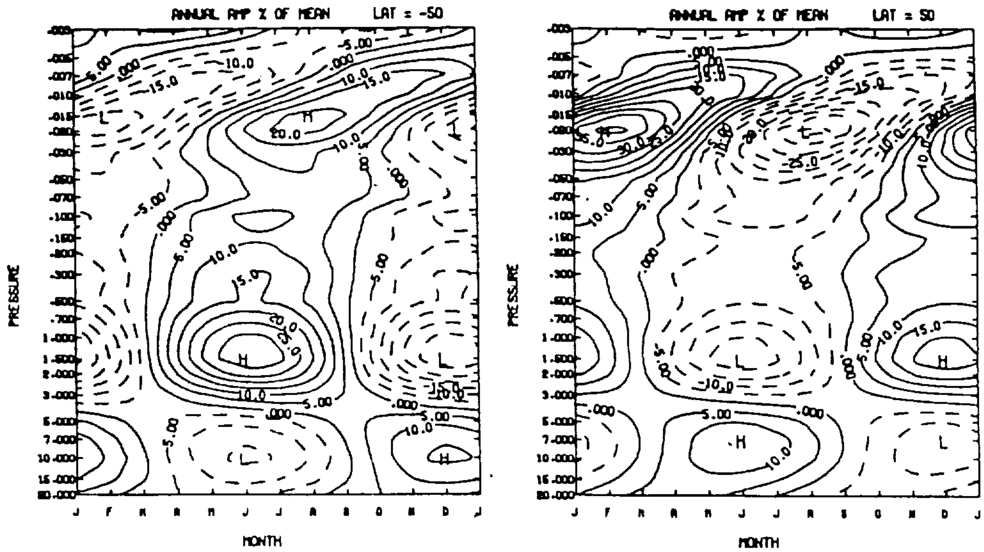

Figure 9. Annual variation of ozone volume mixing ratio in percent of annual mean at 50°S and 50°N latitude.

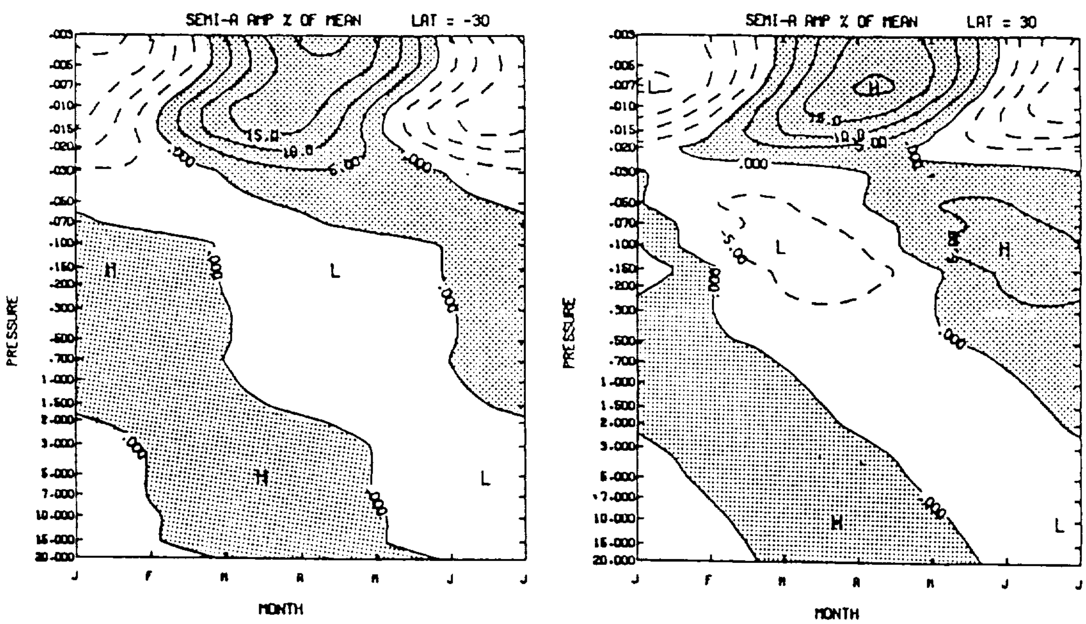

Figure 10. Semiannual variation of ozone volume mixing ratio in percent of the annual mean at 30°S and 30°N latitude.

latitude semiannual variations in the two hemispheres and evidence of propagation from the mesosphere into the stratosphere.

Shown in Figure 11 is the vertical structure of global mean ozone (weighted by cosine of latitude) and the maximum and minimum extremes of the tabulated values.

For convenience, Table 5 lists conversion factors for deriving common units for ozone measurements from volume mixing ratio.

Tabulated in Table 6 are the zonal mean ozone volume mixing ratios (ppmv) as a function of height and latitude using the conversion from pressure to height given by Barnett and Corney [29].

5. ANNUAL MEAN MIDLATITUDE MODEL

The Krueger and Minzner annual mean ozone reference model [3]of 45°N based on balloon and rocket data is compared here with this set of reference models. The Krueger and Minzner model has proven to be very useful and was included in the U. S. Standard Atmosphere, 1976. Data from rocket soundings in the latitude range of 45°N ± 15°, results of balloon soundings at latitudes from 41°N to 47°N, and latitude gradients from Nimbus 4 BUV observations were combined to give this earlier estimate of the annual mean ozone concentration and its variability at heights up to 74 km for an effective latitude of 45°N.

Shown in Figure 12a is a comparison of the vertical structure of the annual mean volume mixing ratio given by Krueger and Minzner [3] with that of the annual mean determined by averaging the monthly values at 40° and 50°N based on satellite data given in Table 4. As may be detected, there is good agreement between the balloon and rocket measurement model and the satellite measurement model. This agreement is even more noteworthy considering the lack of longitudinal coverage in the balloon and rocket measurement model. Shown in Figure 12b are the percent differences of the Krueger and Minzner model [3] from the annual mean model based on Table 4 values. Below altitudes of 0.2 mb, the agreement is generally within 10%. Above 0.2 mb, differences as large as 45% occur, but differences at all levels are within the error bars indicated by the Krueger and Minzner model. Both models give maximum mixing ratios near 5 mb.

Shown in Figure 13 is a comparison of the annual mean vertical ozone distribution from ozonesonde data from Hohenpeissenberg (FRG) (48°N, 11°E) over the period 1967-1985 and from Thalwil-Payerne (Switzerland) (47°N,7°E) over the period 1967-1982 with the 47.3°N zonal average annual mean based on the satellite data. Also the annual mean vertical structure of Umkehr data from Arosa (Switzerland) 1955-1983 is compared. These threedata sets were generously provided by R. Bojkov [64]. Considering that the ozonesonde and Umkehr data do not represent a zonal average but do represent conditions over a period of many years, the agreement is very good. Comparisons month by month of the ozonesonde data show better than 10% agreement with the zonal mean mixing ratios but show evidence of local phase shifts relative to the zonal mean variations. A number of other comparisons have been made with these satellite ozone reference models [65-68]

6. MODELS OF TOTAL OZONE-VERTICAL STRUCTURE RELATION

Mateer *et al.* [6] developed models of the vertical structure of ozone as a function of total column ozone and latitude. The models were based on balloon and rocket data. These models of the relation of total ozone to vertical structure are incorporated here. Shown in Figure 14a are low-latitude (about ±25°) profiles for ozone mixing ratios for total column ozone of 200, 230, 250 and 300 Dobson units (left to right). Shown in Figure 14b are similar mid-latitude (≈25 to 58°) profiles for total column ozone in increments of 50 Dobson units from 200 to 550 Dobson units (left to right). Finally, shown in Figure 14c are similar high-latitude (≈58 to 80°) profiles for total column ozone in increments of 50 Dobson units from 200 to 650 Dobson units (left to right). Note that the substantial variability in mixing ratio extends to lower pressures (higher altitudes) at the higher latitudes. Tabulations of the models are found in [6].

7. OTHER SYSTEMATIC VARIATIONS

A number of systematic variations of ozone in addition to latitudinal-seasonal variations have been analyzed. For brevity only a few references are included here. Empirical analyses have been performed on the quasibiennial oscillation [69], solar cycle variations [70,71] ,

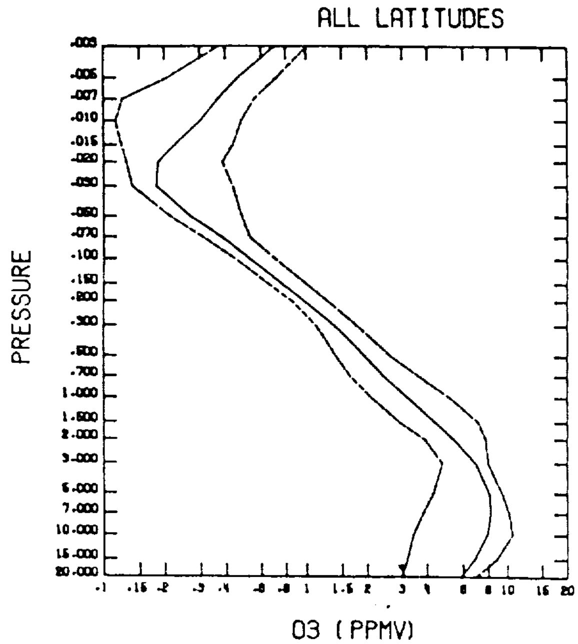

Figure 11. Global mean vertical structure of ozone volume mixing ratio (ppmv) (weighted by cosine of latitude) and the maxima and minima of Table 4 monthly latitudinal profiles.

TABLE 5. Unit Conversion

To convert from volume mixing ratio (ppmv) to the units below, multiply by:

MASS MIXING RATIO (ppmm)	1.657
MASS DENSITY ($kg\cdot m^{-2}$)	$1.657\cdot10^{-6}\cdot\rho_t$
NUMBER DENSITY (m^{-3})	$2.079\cdot10^{19}\cdot\rho_t$
PARTIAL PRESSURE (nb)	p_t

where p_t is the total atmospheric pressure in mb (1 mb = 100 pascal) and ρ_t is the total atmospheric density in $kg\cdot m^{-3}$ at a given altitude.

Total column burden (Ω) in atm·cm (1 atm·cm = 1000 Dobson units) above a given pressure (p_0) can be calculated by integrating partial pressure $p(O_3)$ with respect to $ln(p_t)$:

$$\Omega = 7.896\cdot10^{-4}\cdot\int_0^{p_0} p(O_3)\cdot d\,ln(p_t)$$

TABLE 6. Zonal Mean Ozone Mixing Ratios (ppmv) as function of altitude

average ozone (ppmv) for January

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	.16	.15	.15	.18	.20	.23	.26	.28	.29	.31	.31	.28	.24	.23	.19	-	-
75	.26	.22	.19	.17	.15	.14	.15	.15	.15	.16	.19	.23	.27	.27	.22	-	-
70	.48	.44	.40	.35	.30	.25	.24	.25	.26	.25	.25	.26	.27	.34	.42	-	-
65	.82	.79	.76	.69	.64	.60	.57	.56	.54	.53	.53	.54	.64	.58	.57	-	-
60	1.16	1.19	1.22	1.20	1.19	1.17	1.11	1.04	1.01	1.01	1.03	1.04	1.00	1.14	1.00	-	-
55	1.56	1.65	1.76	1.83	1.87	1.86	1.78	1.68	1.65	1.67	1.70	1.74	1.78	1.85	-	-	-
50	2.36	2.43	2.55	2.63	2.73	2.77	2.71	2.62	2.60	2.62	2.65	2.77	2.92	2.78	2.53	2.11	1.86
45	3.90	3.90	4.03	4.10	4.19	4.28	4.31	4.29	4.30	4.36	4.50	4.75	4.92	4.69	4.14	3.32	2.96
40	5.82	5.89	6.22	6.56	6.80	6.98	7.14	7.23	7.21	7.19	7.15	7.07	6.86	6.40	5.64	4.83	4.38
35	5.53	5.97	6.94	7.78	8.43	8.91	9.31	9.62	9.36	8.95	8.34	7.72	7.20	6.61	6.14	5.51	5.26
30	4.09	4.61	5.79	6.74	7.51	8.04	8.52	9.06	9.01	8.47	7.54	6.83	6.37	5.93	5.81	5.07	5.06
25	3.13	3.47	4.35	4.83	5.04	5.07	5.10	5.05	4.88	4.88	5.03	5.27	5.48	5.46	5.01	4.30	4.18

average ozone (ppmv) for February

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	.13	.13	.15	.17	.21	.26	.31	.31	.32	.34	.36	.33	.27	.23	.19	.14	-
75	.21	.19	.18	.16	.14	.15	.15	.16	.17	.17	.19	.23	.29	.31	.29	.25	-
70	.40	.38	.37	.33	.29	.26	.26	.26	.26	.26	.27	.27	.26	.28	.36	.42	-
65	.74	.71	.69	.67	.63	.60	.59	.58	.57	.55	.54	.54	.51	.55	.53	.56	-
60	1.15	1.15	1.17	1.19	1.21	1.18	1.12	1.08	1.06	1.07	1.07	1.02	.93	.85	.79	.87	-
55	1.65	1.67	1.76	1.83	1.89	1.87	1.78	1.71	1.70	1.73	1.75	1.73	1.67	1.57	1.45	1.51	-
50	2.67	2.61	2.65	2.75	2.85	2.86	2.74	2.59	2.55	2.61	2.67	2.75	2.83	2.82	2.75	2.58	2.26
45	4.30	4.22	4.26	4.34	4.43	4.46	4.35	4.13	4.04	4.17	4.38	4.66	4.95	4.93	4.63	4.13	3.34
40	5.65	5.99	6.39	6.64	6.87	7.06	7.08	7.03	6.97	6.98	7.03	7.23	7.21	6.77	6.19	5.64	4.95
35	5.05	5.93	6.95	7.56	8.16	8.84	9.31	9.73	9.59	9.29	8.90	8.31	7.61	6.96	6.49	6.39	6.15
30	3.65	4.41	5.62	6.46	7.26	8.02	8.69	9.34	9.42	8.93	8.18	7.17	6.50	6.29	6.13	6.42	6.12
25	3.02	3.43	4.19	4.54	4.90	4.98	5.06	5.08	4.95	4.90	5.10	5.30	5.46	5.59	5.59	5.39	5.28

average ozone (ppmv) for March

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	.12	.19	.21	.25	.31	.34	.33	.29	.28	.30	.33	.37	.38	.34	.28	.22	.16
75	.16	.15	.15	.15	.16	.16	.16	.16	.16	.17	.18	.21	.29	.36	.39	.36	.28
70	.28	.28	.28	.27	.27	.27	.27	.27	.26	.26	.27	.28	.27	.29	.35	.45	.45
65	.53	.53	.55	.57	.58	.58	.59	.60	.58	.57	.55	.53	.53	.52	.52	.54	.56
60	.95	.96	1.02	1.09	1.12	1.11	1.10	1.12	1.12	1.11	1.06	1.02	.98	.92	.84	.82	.82
55	1.55	1.59	1.67	1.76	1.82	1.79	1.78	1.79	1.80	1.80	1.79	1.75	1.68	1.59	1.52	1.48	1.51
50	2.87	2.76	2.73	2.80	2.84	2.79	2.71	2.66	2.65	2.67	2.73	2.76	2.71	2.64	2.67	2.74	2.77
45	4.71	4.83	4.65	4.63	4.63	4.54	4.32	4.06	3.99	4.09	4.31	4.51	4.64	4.75	4.83	4.72	4.43
40	5.40	6.16	6.66	6.93	7.05	7.11	6.99	6.63	6.50	6.65	6.90	7.11	7.37	7.34	7.02	6.54	6.08
35	5.01	5.86	6.79	7.45	8.02	8.56	9.07	9.43	9.43	9.31	9.05	8.68	8.37	7.88	7.25	6.64	6.50
30	4.00	4.34	5.32	6.25	7.03	7.85	8.68	9.51	9.79	9.38	8.67	7.81	7.06	6.54	6.16	6.01	6.16
25	3.44	3.66	4.12	4.57	4.82	4.97	5.08	5.15	5.10	5.14	5.32	5.44	5.40	5.42	5.45	5.50	5.40

TABLE 6 - continued

average ozone (ppmv) for April

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	-	-	.25	.30	.34	.33	.31	.32	.32	.32	.34	.41	.45	.44	.41	.36	.26
75	-	-	.28	.23	.18	.16	.16	.16	.16	.16	.17	.20	.25	.28	.31	.34	.32
70	-	-	.27	.23	.25	.27	.28	.28	.27	.28	.29	.30	.31	.32	.32	.35	.39
65	-	-	.46	.51	.55	.59	.62	.62	.60	.58	.57	.56	.56	.56	.57	.57	.57
60	-	-	.86	.97	1.04	1.10	1.15	1.16	1.15	1.13	1.10	1.08	1.07	1.03	.98	.95	.94
55	-	-	1.60	1.70	1.73	1.76	1.80	1.85	1.85	1.84	1.83	1.80	1.75	1.68	1.63	1.61	1.60
50	2.59	2.67	2.70	2.78	2.85	2.79	2.76	2.76	2.75	2.75	2.79	2.80	2.70	2.58	2.57	2.63	2.73
45	4.61	4.87	4.92	5.06	4.95	4.69	4.40	4.21	4.15	4.21	4.34	4.44	4.36	4.26	4.30	4.41	4.49
40	5.65	6.32	6.77	7.08	7.25	7.26	7.04	6.67	6.57	6.73	7.00	7.13	7.18	7.14	7.07	6.81	6.28
35	5.00	5.63	6.49	7.11	7.71	8.45	9.05	9.15	9.02	9.10	9.02	8.78	8.66	8.35	7.63	6.77	5.96
30	4.29	4.52	5.15	5.86	6.58	7.57	8.57	9.44	9.71	9.32	8.66	8.14	7.51	6.87	6.20	5.62	5.36
25	3.40	3.91	4.42	4.62	4.78	5.04	5.17	5.26	5.25	5.35	5.51	5.58	5.45	5.27	5.07	5.02	5.08

average ozone (ppmv) for May

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	-	-	-	.30	.31	.32	.36	.40	.40	.38	.35	.35	.34	.32	.28	.24	.19
75	-	-	-	.23	.18	.17	.17	.17	.17	.17	.17	.19	.19	.20	.19	.19	.21
70	-	-	-	.24	.23	.27	.28	.28	.29	.29	.30	.30	.32	.34	.35	.38	.42
65	-	-	-	.45	.52	.57	.63	.64	.62	.62	.62	.61	.61	.64	.67	.69	.70
60	-	-	-	.87	.97	1.06	1.16	1.18	1.16	1.16	1.16	1.15	1.14	1.14	1.13	1.11	1.10
55	-	-	-	1.68	1.73	1.73	1.81	1.86	1.86	1.85	1.86	1.86	1.83	1.78	1.72	1.67	1.63
50	-	2.45	2.54	2.90	2.91	2.85	2.82	2.81	2.80	2.80	2.82	2.81	2.73	2.63	2.54	2.49	2.50
45	-	4.55	4.90	5.45	5.41	4.96	4.54	4.36	4.31	4.31	4.36	4.35	4.24	4.12	4.07	4.05	4.21
40	-	6.44	6.76	7.41	7.52	7.41	7.07	6.81	6.75	6.86	7.04	7.04	6.94	6.84	6.70	6.42	6.34
35	-	5.92	5.90	6.79	7.45	8.10	8.58	8.74	8.75	8.94	8.98	8.83	8.61	8.18	7.45	6.44	5.70
30	-	5.18	4.97	5.62	6.34	7.21	8.20	9.00	9.29	8.95	8.43	8.08	7.60	7.07	6.32	5.31	4.60
25	-	4.13	4.49	4.83	4.98	5.15	5.22	5.17	5.22	5.45	5.53	5.58	5.47	5.17	4.82	4.41	4.15

average ozone (ppmv) for June

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	-	-	-	-	.30	.31	.30	.31	.31	.30	.27	.26	.26	.23	.18	.16	.16
75	-	-	-	-	.18	.17	.16	.15	.15	.15	.15	.16	.18	.20	.20	.21	.24
70	-	-	-	-	.24	.28	.28	.27	.27	.27	.27	.30	.32	.35	.38	.43	.47
65	-	-	-	-	.52	.56	.61	.64	.64	.65	.67	.66	.67	.73	.79	.83	.84
60	-	-	-	-	.93	1.05	1.15	1.19	1.19	1.21	1.24	1.24	1.23	1.26	1.27	1.24	1.20
55	-	-	-	-	1.66	1.68	1.78	1.84	1.84	1.84	1.86	1.86	1.85	1.82	1.75	1.67	1.59
50	-	-	2.35	2.71	2.84	2.81	2.86	2.86	2.84	2.82	2.84	2.84	2.75	2.62	2.48	2.38	2.33
45	-	-	4.69	5.46	5.43	4.95	4.67	4.51	4.44	4.40	4.42	4.34	4.19	4.07	3.96	3.90	3.96
40	-	-	6.70	7.67	7.67	7.25	7.04	6.96	6.93	7.00	7.12	7.03	6.88	6.68	6.38	6.19	6.19
35	-	-	5.86	6.53	7.44	7.89	8.37	8.70	8.89	9.02	9.00	8.85	8.54	7.89	7.03	5.97	5.42
30	-	-	5.12	5.28	6.32	7.02	7.59	8.29	8.63	8.49	8.00	7.78	7.30	6.77	5.95	4.85	4.31
25	-	-	4.63	5.07	5.15	5.03	4.89	4.85	4.94	5.07	5.02	5.01	5.00	4.78	4.38	3.80	3.52

TABLE 6 - continued

average ozone (ppmv) for July

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	-	-	-	.22	.25	.28	.29	.28	.27	.27	.24	.24	.23	.21	.17	.16	.16
75	-	-	-	.21	.18	.16	.15	.14	.15	.15	.15	.15	.16	.19	.20	.21	.25
70	-	-	-	.25	.24	.27	.26	.26	.26	.25	.24	.26	.31	.35	.38	.43	.48
65	-	-	-	.48	.55	.59	.61	.61	.61	.62	.64	.66	.69	.73	.79	.84	.85
60	-	-	-	-	1.00	1.10	1.15	1.15	1.15	1.17	1.22	1.26	1.27	1.28	1.29	1.27	1.21
55	-	-	-	-	1.72	1.75	1.79	1.80	1.79	1.79	1.83	1.88	1.88	1.84	1.77	1.67	1.56
50	-	-	2.09	2.59	2.86	2.90	2.87	2.82	2.78	2.77	2.85	2.91	2.85	2.70	2.54	2.42	2.33
45	-	-	3.94	5.00	5.29	5.00	4.74	4.55	4.45	4.42	4.50	4.48	4.35	4.20	4.05	3.92	3.94
40	-	-	6.11	7.23	7.49	7.29	7.21	7.17	7.11	7.14	7.23	7.14	6.96	6.78	6.44	6.03	5.95
35	-	-	6.04	6.77	7.36	7.94	8.38	8.81	9.01	9.11	9.03	8.87	8.52	7.95	6.99	5.82	5.18
30	-	-	5.18	5.28	6.20	6.80	7.43	8.16	8.49	8.45	7.98	7.73	7.24	6.55	5.69	4.66	4.06
25	-	-	4.66	5.03	5.15	5.02	4.89	4.83	4.95	5.10	4.97	4.87	4.80	4.63	4.18	3.57	3.24

average ozone (ppmv) for August

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	-	-	.24	.26	.29	.30	.31	.29	.28	.28	.29	.26	.22	.19	.16	.14	.14
75	-	-	.24	.21	.19	.18	.16	.15	.15	.15	.16	.15	.14	.16	.17	.18	.20
70	-	-	.27	.24	.26	.28	.27	.26	.26	.26	.26	.25	.27	.31	.34	.36	.39
65	-	-	.49	.53	.58	.59	.60	.60	.60	.60	.58	.59	.62	.65	.67	.70	.71
60	-	-	.88	.96	1.07	1.15	1.17	1.16	1.13	1.12	1.13	1.16	1.20	1.20	1.17	1.15	1.12
55	-	-	1.25	1.69	1.80	1.82	1.82	1.81	1.78	1.76	1.78	1.84	1.86	1.80	1.73	1.67	1.61
50	-	1.96	2.26	2.69	2.98	2.95	2.87	2.80	2.75	2.75	2.83	2.92	2.91	2.77	2.66	2.58	2.50
45	-	3.26	4.01	4.92	5.25	5.01	4.73	4.51	4.40	4.42	4.58	4.67	4.60	4.44	4.31	4.16	4.01
40	-	4.76	5.92	7.15	7.57	7.46	7.37	7.24	7.13	7.17	7.34	7.30	7.09	6.84	6.49	6.02	5.49
35	-	5.27	6.28	7.39	7.87	8.21	8.69	9.26	9.30	9.38	9.24	8.83	8.40	7.75	6.85	5.79	4.81
30	-	5.26	5.13	5.78	6.42	6.91	7.56	8.61	8.74	8.75	8.36	7.81	7.28	6.45	5.52	4.49	3.76
25	-	4.43	4.53	4.96	5.11	5.04	4.92	4.84	4.96	5.10	4.99	4.87	4.77	4.49	3.98	3.49	3.18

average ozone (ppmv) for September

alt. z(km)	latitude -80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	.24	.27	.31	.34	.36	.36	.33	.30	.28	.27	.30	.31	.30	.25	.21	.19	.16
75	.28	.30	.27	.24	.21	.18	.17	.16	.16	.16	.16	.16	.16	.16	.15	.16	.19
70	.30	.30	.26	.26	.27	.28	.28	.26	.25	.26	.25	.24	.24	.25	.26	.26	.28
65	.47	.51	.52	.55	.57	.57	.57	.58	.59	.57	.54	.52	.52	.52	.50	.49	.50
60	-	.89	.92	.99	1.06	1.11	1.14	1.16	1.13	1.10	1.09	1.08	1.07	1.06	1.00	.90	.85
55	-	1.44	1.54	1.67	1.74	1.79	1.82	1.83	1.80	1.78	1.78	1.78	1.75	1.71	1.63	1.53	1.51
50	2.06	2.19	2.43	2.76	2.92	2.87	2.82	2.78	2.74	2.75	2.79	2.82	2.81	2.76	2.72	2.64	2.60
45	3.38	3.65	4.20	4.82	5.03	4.85	4.62	4.41	4.31	4.37	4.56	4.69	4.70	4.69	4.71	4.59	4.18
40	4.84	5.32	6.28	7.21	7.64	7.61	7.43	7.16	7.00	7.06	7.28	7.34	7.20	7.03	6.77	6.14	5.15
35	5.39	6.02	6.85	7.66	8.28	8.73	9.12	9.28	9.28	9.27	9.17	8.90	8.42	7.75	6.92	5.82	4.83
30	5.26	5.41	5.86	6.39	6.89	7.42	8.06	8.55	8.72	8.65	8.16	7.68	7.11	6.24	5.35	4.45	3.98
25	4.21	4.18	4.68	5.06	5.17	5.16	5.00	4.95	5.04	5.11	4.92	4.79	4.74	4.49	4.07	3.60	3.28

TABLE 6 - continued

average ozone (ppmv) for October

alt. z(km)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	.28	.36	.40	.42	.40	.35	.31	.31	.31	.29	.28	.29	.31	.29	.24	.19	.12
75	.24	.23	.22	.22	.20	.18	.18	.19	.19	.17	.17	.17	.17	.20	.25	.27	.22
70	.37	.35	.34	.32	.31	.29	.29	.28	.27	.26	.26	.25	.24	.22	.25	.34	.33
65	.61	.59	.58	.56	.56	.56	.56	.55	.54	.53	.60	.55	.55	.51	.46	.43	-
60	1.04	1.01	1.01	1.02	1.06	1.10	1.13	1.13	1.11	1.11	1.09	1.03	.96	.87	.78	.74	-
55	1.56	1.58	1.64	1.67	1.73	1.79	1.84	1.86	1.86	1.85	1.81	1.73	1.65	1.60	1.51	1.38	-
50	2.34	2.42	2.63	2.73	2.75	2.73	2.76	2.78	2.78	2.78	2.75	2.70	2.74	2.78	2.71	2.51	2.26
45	3.69	3.86	4.26	4.51	4.59	4.52	4.45	4.36	4.31	4.36	4.50	4.64	4.90	5.09	5.00	4.53	4.07
40	5.44	5.94	6.70	7.23	7.53	7.51	7.35	7.09	6.91	6.94	7.14	7.26	7.25	7.07	6.74	6.11	5.25
35	6.20	6.86	7.61	8.17	8.61	9.05	9.37	9.43	9.33	9.29	9.18	8.74	7.92	7.21	6.68	5.93	5.06
30	5.82	6.09	6.47	6.79	6.98	7.55	8.20	8.80	8.99	9.09	8.67	7.85	6.80	6.00	5.39	4.91	4.43
25	4.07	4.53	5.27	5.29	5.10	5.09	5.07	4.97	4.93	5.02	4.94	4.82	4.71	4.59	4.38	3.93	3.42

average ozone (ppmv) for November

alt. z(km)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	.16	.18	.22	.25	.28	.29	.29	.31	.33	.34	.34	.32	.32	.27	.21	-	-
75	.23	.21	.21	.19	.19	.18	.18	.19	.19	.18	.19	.20	.20	.24	.24	-	-
70	.43	.41	.39	.37	.34	.32	.30	.28	.27	.26	.27	.26	.25	.26	.34	-	-
65	.73	.71	.68	.64	.60	.58	.56	.54	.54	.55	.61	.58	.54	.49	.46	-	-
60	1.17	1.17	1.16	1.15	1.15	1.14	1.13	1.12	1.10	1.10	1.09	1.02	.89	.78	.79	-	-
55	1.65	1.70	1.76	1.79	1.82	1.84	1.85	1.85	1.85	1.84	1.80	1.72	1.63	1.48	-	-	-
50	2.40	2.45	2.57	2.61	2.63	2.66	2.71	2.75	2.78	2.76	2.68	2.65	2.67	2.66	2.43	2.17	1.77
45	3.98	4.00	4.13	4.14	4.13	4.17	4.26	4.27	4.29	4.32	4.37	4.58	4.96	5.00	4.60	3.97	3.03
40	6.10	6.27	6.53	6.80	6.91	6.97	7.00	6.87	6.74	6.75	6.89	7.07	7.14	6.96	6.40	5.78	4.42
35	6.18	6.57	7.16	7.87	8.45	8.83	9.10	9.04	8.72	8.67	8.47	8.05	7.36	6.77	6.10	5.74	4.50
30	5.37	5.58	6.13	6.65	7.21	7.84	8.40	8.88	8.91	8.71	8.18	7.41	6.19	5.64	5.29	5.04	3.53
25	4.35	4.52	4.94	5.01	5.08	5.22	5.26	5.26	5.12	5.05	5.05	4.97	4.81	4.75	4.45	3.96	2.98

average ozone (ppmv) for December

alt. z(km)	-80°	-70°	-60°	-50°	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°
80	.17	.17	.17	.19	.22	.23	.26	.30	.30	.31	.32	.30	.29	.27	-	-	-
75	.26	.23	.22	.19	.17	.15	.16	.17	.17	.17	.19	.22	.25	.26	-	-	-
70	.51	.47	.42	.38	.35	.31	.28	.28	.27	.26	.27	.29	.29	.33	-	-	-
65	.85	.82	.77	.71	.66	.64	.62	.58	.56	.56	.55	.60	.64	.55	-	-	-
60	1.23	1.25	1.26	1.23	1.22	1.22	1.19	1.12	1.08	1.08	1.10	1.08	.97	1.03	-	-	-
55	1.58	1.66	1.76	1.83	1.88	1.89	1.86	1.82	1.80	1.80	1.79	1.74	1.68	1.78	-	-	-
50	2.31	2.38	2.49	2.55	2.64	2.71	2.74	2.76	2.79	2.76	2.73	2.70	2.66	2.42	2.11	1.67	1.54
45	3.87	3.88	3.95	3.98	4.07	4.18	4.29	4.36	4.42	4.44	4.51	4.67	4.93	4.66	3.93	2.84	2.58
40	6.04	6.08	6.26	6.53	6.74	6.90	7.04	7.04	6.95	6.94	6.97	7.03	7.04	6.68	5.84	4.69	4.33
35	5.84	6.18	7.00	7.79	8.37	8.80	9.14	9.17	8.78	8.43	8.03	7.69	7.19	6.54	5.98	5.28	5.13
30	4.57	4.95	5.91	6.83	7.54	8.09	8.55	8.92	8.76	8.27	7.48	6.93	6.21	5.60	5.42	4.52	4.48
25	3.75	3.94	4.56	4.86	5.07	5.18	5.16	5.08	4.90	4.92	4.96	5.10	5.11	5.08	4.59	3.83	3.81

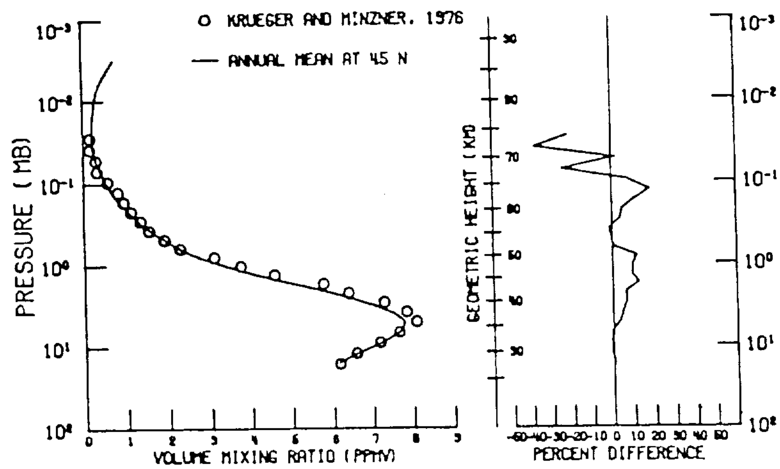

Figure 12. Comparison of annual mean ozone volume mixing ratio (ppmv) at 45°N based on the satellite data model of Table 4 and based on the balloon and rocket data model of Krueger and Minzner [3]. On the left (a) is shown the vertical structure in the two models and on the right (b) the percent difference from the satellite data model of the Krueger and Minzner model.

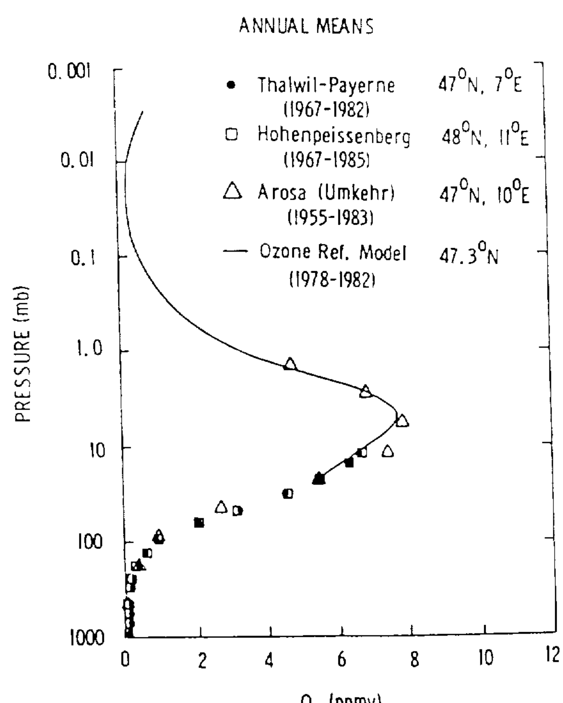

Figure 13. Comparison of annual mean ozone reference model with annual means of long-term balloon and Umkehr measurements.

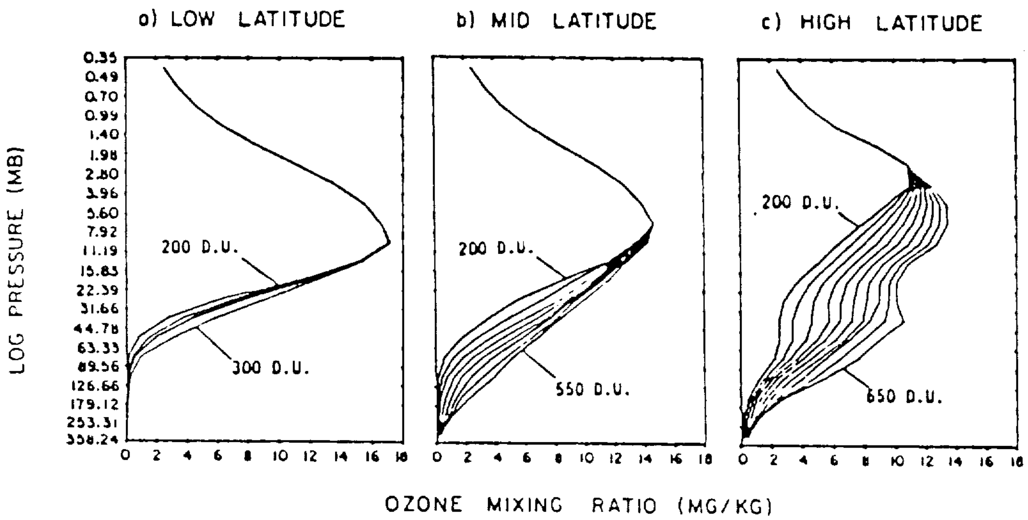

Figure 14. Variation of ozone mass mixing ratio with total ozone (from Mateer et al. [6]).
(a) low-latitude ozone profiles for total ozone of 200, 230, 250, and 300 Dobson units
(b) midlatitude ozone profiles for total ozone of 200, 250, ... 550 Dobson units
(c) high-latitude ozone profiles for total ozone of 200, 250, ..., 650 Dobson units.

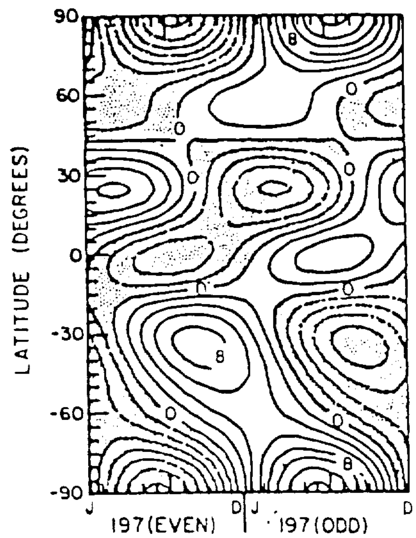

Figure 15. Biennial component of zonal mean ozone variation based on 7 years of Nimbus 4 BUV measurements. Contour interval is 2 Dobson units; solid lines are positive and the shaded area with dashed lines negative (Tolson, [13]).

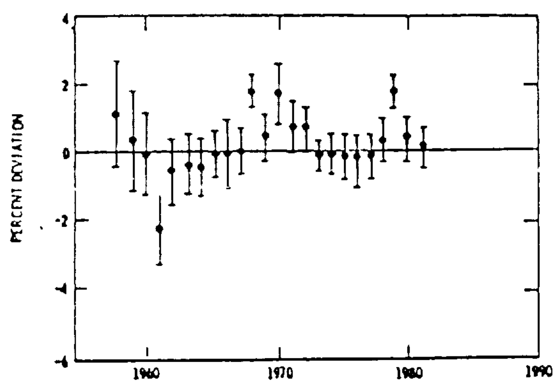

Figure 16. Variation of global yearly average total column ozone expressed as percent deviation from the mean based on ground-based Dobson spectrophotometers as well as M-83 ozonometers (Angell and Korshover, [83]).

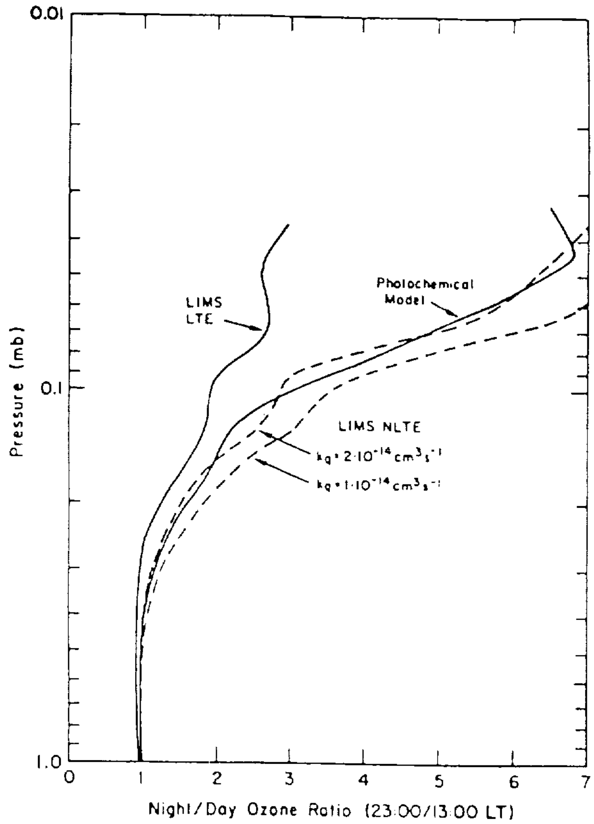

Figure 17. Vertical profile of the ozone diurnal variation calculated in a one-dimensional model and the corresponding values obtained from LIMS data after correction for non-LTE effects, assuming quenching rates of 1 and 2 x 10^{-14} cm^3 s^{-1} (from Solomon et al.[37]).

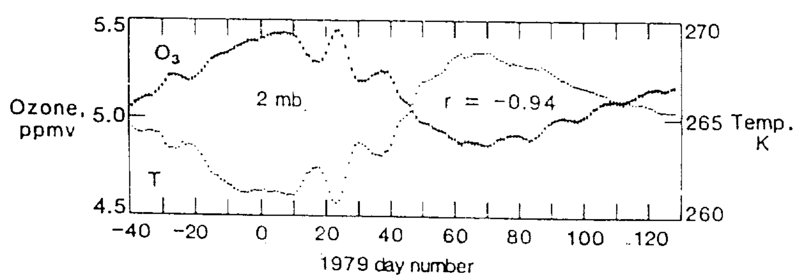

Figure 18. Comparison of Nimbus 7 LIMS measurements of zonal mean ozone and temperature obtained within 20° of the equator (Keating et al.[73]).

solar rotation variations [72-75,123] , diurnal variations [37,38,76,77] , longitudinal variations [2,11,78,79], volcanic eruptions [69,80], possible response to nuclear explosions [81], long-term trends [71,82,83], 4-year oscillations [14], response to stratospheric temperature [84-86], response to sudden winter warmings [87], and response to solar proton events [88,89].

The quasibiennial variation in ozone is thought to be related to the quasibiennial variation in equatorial zonal winds [90]. Shown in Figure 15 [13] is the biennial component of the zonal mean total ozone variation based on 7 years of Nimbus 4 BUV data. The contour interval is 2 Dobson units with the solid lines positive and the shaded area with dashed lines negative. Referring back to Figure 3, it may be seen that in the low and midlatitude regions the large interannual variations correspond to regions of large quasibiennial variation. However, since the variation is quasibiennial as opposed to biennial, the phase indicated in Figure 15 will change with time. There is also evidence that the period of the quasibiennial variation may vary somewhat with latitude [91] and that the latitude of maximum quasibiennial variation may vary somewhat with time [14].

Evidence has accumulated that variations in ozone with a period of the order of 11 years occur at various locations. On the other hand, there has been a lack of consensus as to whether these variations are related to the 11-year solar activity cycle. The early studies which were performed were reviewed by Keating [70]. Recent empirical studies on the possible response of ozone to 11-year solar variations include the works of Reinsel *et al.* [92] , Oehlert [93], Chandra [94], and Keating *et al.* [15]. From a study of Umkehr data, Reinsel *et al.* [92] estimate a 3% variation in ozone over the solar cycle near 36 km superimposed on a 3% per decade linear decline which may be associated with anthropogenic effects. Long term variations in total column ozone have been detected using the global Dobson network. Shown in Figure 16 are estimates of percent variation in global mean ozone based on those measurements as determined by Angell and Korshover [83]. Maximum values appear to occur near the times of solar maxima. It has now been established that there are solar UV variations of the order of 5% at wavelengths between 180 and 208 nm associated with the 27-day rotation period of the sun [95,96]. Analyses of satellite data are indicating a clearly detectable ozone response in both the stratosphere and mesosphere to these short-term solar variations [72-75,97,98,123]. Peak positive responses are detected near 40 km and peak negative responses (associated with solar Lyman-α radiation) are detected near 70 km [123].

The SME mesospheric measurements from which the mesospheric ozone models are based are dayside measurements. Observations and theoretical models show that mesospheric ozone is higher on the night side [37,38,51,76,77,99-103]. Shown in figure 17 is the night/day ozone ratio at the equator (January 13, 1979) based on Nimbus 7 LIMS data after correcting for non-LTE effects, assuming quenching rates of 1 and $2 \cdot 10^{-14}$ $cm^3 s^{-1}$ [37]. The photochemical model results shown in the figure employ the photochemistry in the two-dimensional model of Garcia and Solomon [104]. The night/day ratios given in Figure 17 are also in good agreement with the model of Allen *et al.* [51]. This model [51] appears to be fairly consistent with most of the measurements obtained at different latitudes, seasons, and altitudes of mesospheric diurnal variations.

Due to the temperature dependence of rate constants in the middle atmosphere, temperature decreases can result in increases of upper atmospheric ozone in regions approaching photochemical equilibrium [84]. Other processes can also lead to negative correlations between ozone and temperature [105]. The sensitivity of ozone to temperature variations reaches a maximum value near the stratopause of about 2% increase in ozone per Kelvin decrease in temperature. Shown in Figure 18 is an example of the negative response of upper stratospheric ozone to temperature variations [73]. Shown is the negative correlation between zonal mean temperature and ozone from 2 mb Nimbus 7 LIMS measurements within 20° of the equator. In addition to the stratospheric ozone response, the mesospheric ozone is found to be strongly affected by temperature variations [20].

8. RECENT RESULTS

The inversion algorithm for the SAGE ozone data has been refined and the resulting SAGE data was combined with the other satellite data sets and used to generate improved reference models [124]. However, the improved models are within 5% of the tabulations provided here. Also included in [124] are latitudinal seasonal models of nightside mesospheric ozone based on the Nimbus 7 LIMS data. Results concerning recent trends in column ozone and ozone profiles are summarized in the most recent Ozone Trends Panel report [125]. This report also identifies biases between measuring instruments.

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