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AN INTERIM REFERENCE MODEL FOR THE VARIABILITY OF THE MIDDLE ATMOSPHERE H_2O VAPOR DISTRIBUTION

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ABSTRACT

Water vapor is an important minor constituent in the studies of the middle atmosphere for a variety of reasons, including its role as a source for active HO_y chemicals and its use in analysis of transport processes. A number of in situ and remote techniques have been employed in the determination of water vapor distributions. Two of the more complete data sets have been used to develop an interim reference profile. First, there are the 7 months of Nimbus 7 LIMS data obtained during November 1978 to May 1979 over the range 64S to 84N latitude and from about 100-mb to 1-mb. By averaging radiances before retrieval, LIMS random errors have been reduced, and the results have been improved and extended recently from 1.5-mb to 0.5-mb. Secondly, the ground-based microwave emission technique has provided many profiles from 0.2-mb to 0.01-mb in the mid mesosphere at several fixed Northern Hemisphere mid latitude sites. These two data sets have been combined to give a mid latitude, interim reference water vapor profile for the entire vertical range of the middle atmosphere and with accuracies of better than 25 percent. The daily variability of stratospheric water vapor profiles about the monthly mean has also been established from these data sets for selected months. Information is also provided on the longitudinal variability of LIMS water vapor profiles about the daily, weekly, and monthly zonal means. Generally, the interim reference water vapor profile and its variability are consistent with prevailing ideas about chemistry and transport.

INTRODUCTION

Water vapor (H_2O) is an important minor constituent in the middle atmosphere for several reasons. It is a major source of the active chemical radicals, OH and HO_2, which affect the ozone distribution in the mesosphere /1/ and upper stratosphere /2/. Water vapor plays a significant role in the ion cluster chemistry of the mesosphere /3, 4/. Condensed phase water in the form of nacreous or polar stratospheric clouds at high latitudes of the winter hemisphere is regulated by the water vapor mixing ratio and atmospheric temperatures needed to reach saturation /5/. Similar constraints apply for the noctilucent or polar mesospheric clouds that occur near the summer polar mesopause /6/. The infrared emission from water vapor in the upper troposphere helps determine the temperature distribution at the lower boundary of the middle atmosphere. Water vapor also contributes in a minor way to the radiative balance throughout the middle atmosphere /7/. For most of the middle atmosphere, water vapor can be used as a tracer molecule to describe a net global transport or circulation there /8, 9/. Knowledge of the peak mesospheric H_2O mixing ratio, the altitude of the peak value, and the rate of mixing ratio decrease above the altitude peak is needed to validate chemical/transport models and to gain an improved understanding of seasonal changes in the mesosphere /10/. Finally, the long-term trend in middle atmosphere water vapor can be an indicator of trends in minimum tropical tropopause temperatures, coupled with the effect in the upper stratosphere of the increase in methane, which is a source gas of water vapor there /11/.

Russell /12/ presented a comprehensive review with references for those satellite and in situ data sets that are generally available for defining the distribution of middle atmosphere water vapor. The primary data source for those distributions was derived from the 7 months of observations from the Nimbus 7 Limb Infrared Monitor of the Stratosphere (LIMS) experiment which began operations in late October 1978. Data were obtained from 64S to 84N latitude and from about 1-mb to 100-mb. Those data were supplemented with results from the Grille Spectrometer on Spacelab 1 /13/ and the host of microwave radiometer measurements of water vapor (e.g. /14/) to produce a Northern Hemisphere mid latitude reference profile for the winter/spring seasons from about 100- to 0.005-mb. Profiles of water vapor by several different techniques from rocket soundings at high latitudes of the Northern Hemisphere are also available (e.g. /15/), and they may be used to supplement LIMS results above 1-mb. The rocket data and techniques were reviewed in /7/. Because those soundings have occurred sporadically over a 10-year period, no attempt has been made to develop a reference profile of water vapor variability for the high latitude mesosphere. Information is lacking on mesospheric water vapor measurements at low latitudes or in the Southern Hemisphere. Finally, measurements of water vapor using balloon-borne and airborne techniques have provided considerable information about the water vapor profile in the mid to low stratosphere /2/. In particular, Mastenbrook and Oltmans /16/ report a 16-year time series of measurements using frost-point hygrometer soundings near Washington, D.C. A similar series is now available for 1981-1986 from measurements at Boulder, Colorado /17/.

Although a climatology of middle atmosphere water vapor has yet to be achieved, there is now sufficient information for establishing a reference model for some latitudes and seasons. This model is heavily weighted by the extensive LIMS data set (see /12/ for details). Tabulated reference profiles are given in this paper, along with their estimated uncertainties. In addition, new information is presented on the longitudinal variations about the zonal mean profiles, on the monthly variations of the zonal mean distributions, and time series of the zonal mean and wave amplitudes on a pressure surface. Variability of mesospheric water vapor on daily to seasonal timescales is also presented using data from ground-based microwave radiometers at Northern Hemisphere mid latitudes. All of these results should provide adequate information about middle atmospheric water vapor for initial scientific studies and for use in comparisons with modeled distributions of water vapor and the association of the HO_x and O_x chemical families.

MONTHLY ZONAL MEAN LIMS WATER VAPOR DISTRIBUTIONS

The quality of the individual LIMS water vapor profiles (LAIPAT tapes) archived at the National Space Sciences Data Center (NSSDC) in Greenbelt, Maryland, has been discussed in /12, 18, 19/. An extensive study was conducted to validate the LIMS data and to establish any limitations of the results. Table 1 from /12/ summarizes those results and is reproduced here. Note that the measured precision in orbit (geophysical plus instrument effects) is about 0.2 to 0.3 ppmv from 50- to 2-mb, decreasing to 0.7 ppmv at 1-mb. Single profile accuracy at mid and high latitudes varies from 30 percent near the stratopause to 20 percent in the mid stratosphere and 37 percent at 50-mb. Accuracy estimates are better for zonal mean LAIPAT profiles, becoming 27 percent, 17 percent, and 20 percent, respectively /20/.

Russell et al. /18/ noted that there is an apparent diurnal variation in water vapor (day values higher than night values) of as much as 1 to 2 ppmv near 1-mb, decreasing to 0.2 ppmv near 10-mb. Kerridge and Remsberg /21/ have found that the probable explanation for the difference is the presence during daytime of small radiance contributions from vibrationally excited water vapor and, especially, NO, at the long wavelength side of the LIMS water vapor channel. Correction for these effects in the retrieval eliminates the bias between day and night water vapor. Because corrections for these mechanisms have not been applied to the archived data and because these mechanisms are inoperative at night, we have chosen to present LIMS reference profiles and variability using only nighttime water vapor data.

Over most of the stratosphere, the other principal systematic error in water vapor is due to bias errors in temperature through the retrieval. Such biases can affect either night or day data. An extreme example of this occasional problem was pointed out in /22/, Figs. 6c and 7, for a situation when large vertical and horizontal gradients in temperature existed at high northern latitudes in early February 1979. The effect on water vapor there is of the order of several ppmv. On the other hand, a much more prevalent, positive temperature bias occurs near the tropical tropopause. That bias is estimated to yield water vapor values that are too low between ±15 degrees latitude by about 0.3 ppmv at 50-mb and 0.6 ppmv at 70-mb, with only half that bias at ±25 degrees latitude /19/. However, no such corrections have been applied to the archived data.

The monthly mean profiles derived from the archived vertical profile tapes (LAIPAT) were presented for the latitude zones 32S-56S, 28S-28N, 32N-56N, and 56N-84N in /12/--his Tables 4 and 5. The average profile for 28S-28N was adjusted for the temperature bias effect at 50-mb and 70-mb. Results for each latitude zone have been interpolated linearly in log pressure to yield the reference profiles in Tables 2 and 3. The zonal mean distributions are shown in Fig. 1 (a through g). Similar figures have been produced from the LIMS Map Archive Tapes (LAMAT) at NSSDC /23/, and a detailed description of that product is given in /22/.

Tables 2 and 3 also contain information about the standard deviation of the daily nighttime zonal means about the monthly nighttime zonal mean and, in general, the changes

TABLE 1 LIMS H_2O Estimated Accuracy and Correlative Measurement Comparison Statistics

Pressure (mb)	Measured On-Orbit Precision (ppmv)	Estimated Accuracy (%)1	Comparison with Correlative Measurements*	
			Mean Difference (%)	RMS Difference (%)
5	0.2	24	-20.9	41.1
7			-18.0	47.2
10		20	- 6.5	24.8
15			7.1	28.7
20			16.3	23.5
30	0.3	23	21.4	27.6
50		37	10.1	28.4
70			- 7.7	28.8
100		39	18.6	28.9

1Based on measured instrument parameters and computer simulations based on 13 comparisons with balloon remote and in situ H_2O measurements.

*Based on 13 comparisons with balloon remote and in situ H_2O measurements.

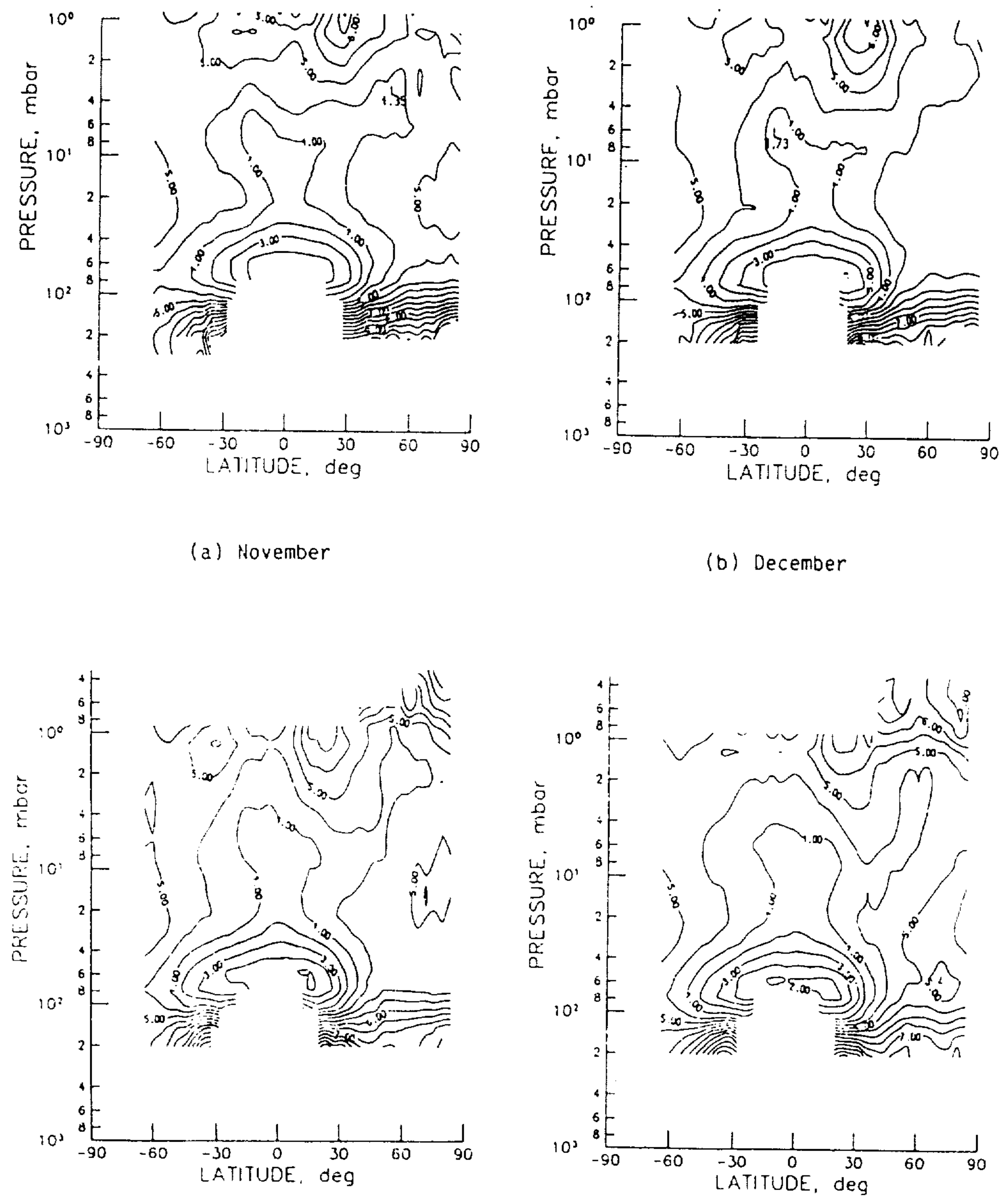
TABLE 2 LIMS Monthly Zonal Mean H_2O Mixing Ratio Profiles in the 32°S - 56°S and 28°S - 28°N Latitude Ranges For November 1978 Through May 1979

Pressure (mb)	MEAN WATER VAPOR MIXING RATIO (ppmv) ± STANDARD DEVIATION (ppmv) OF THE DAILY ZONAL MEAN ABOUT THE MONTHLY MEAN													
	32°S - 56°S							28°S - 28°N*						
	Nov.	Dec.	Jan.	Feb.	March	April	May	Nov.	Dec.	Jan.	Feb.	March	April	May
1.5	4.9±.28	4.9±.27	4.9±.25	4.7±.26	4.5±.31	4.4±.38	4.4±.45	5.4±.36	5.1±.41	5.0±.33	5.0±.34	5.2±.32	5.1±.32	5.1±.33
2.0	4.9±.22	4.9±.22	4.9±.19	4.7±.20	4.4±.25	4.2±.30	4.2±.35	5.1±.27	4.9±.30	4.8±.25	4.7±.25	4.9±.24	4.9±.24	4.9±.26
3.0	4.8±.16	4.9±.16	4.9±.14	4.7±.16	4.4±.17	4.2±.23	4.1±.30	4.8±.20	4.6±.23	4.5±.20	4.4±.19	4.6±.19	4.6±.10	4.7±.21
5.0	4.7±.13	4.8±.14	4.7±.12	4.6±.12	4.4±.13	4.3±.19	4.1±.21	4.3±.16	4.2±.18	4.1±.16	4.1±.16	4.2±.15	4.3±.14	4.3±.15
7.0	4.6±.12	4.7±.12	4.6±.10	4.5±.10	4.5±.12	4.4±.16	4.3±.19	4.1±.14	4.0±.15	4.0±.15	4.0±.13	4.1±.13	4.1±.11	4.1±.12
10.0	4.7±.12	4.7±.10	4.7±.09	4.6±.09	4.7±.11	4.6±.14	4.6±.18	4.1±.12	4.1±.12	4.1±.11	4.0±.11	4.0±.11	4.0±.09	4.0±.10
16.0	4.8±.12	4.7±.11	4.7±.09	4.7±.09	4.8±.11	4.8±.13	4.8±.18	4.2±.09	4.2±.12	4.1±.11	4.0±.11	4.0±.09	3.9±.07	4.0±.10
30.0	4.7±.12	4.7±.13	4.6±.10	4.6±.11	4.8±.12	4.9±.12	5.0±.19	3.9±.09	3.9±.11	3.7±.12	3.7±.11	3.7±.11	3.8±.10	3.9±.10
50.0	4.1±.15	3.9±.15	3.8±.11	3.8±.12	4.1±.17	4.5±.17	4.8±.23	2.8±.12	2.7±.13	2.6±.14	2.5±.12	2.6±.13	2.7±.13	2.8±.11
70.0	3.9±.18	3.7±.16	3.5±.14	3.5±.14	3.8±.20	4.4±.23	4.9±.30	2.8±.23	2.6±.26	2.6±.27	2.4±.25	2.4±.30	2.5±.26	2.7±.22
100.0	4.5±.25	4.2±.30	4.1±.24	4.2±.25	4.6±.23	5.3±.38	5.8±.47	3.9±.41	3.6±.64	3.7±.51	3.5±.61	3.4±.68	3.6±.55	3.9±.46

*Mixing ratios at the 50-mb and 70-mb levels have been increased by ≈ 0.15 and 0.3 ppmv, respectively, to account for water vapor bias effects described in /18, 19/.

TABLE 3 LIMS Monthly Zonal Mean H_2O Mixing Ratio Profiles in the 32°N - 56°N and 56°N - 84°N Latitude Ranges For November 1978 Through May 1979

Pressure (mb)	MEAN WATER VAPOR MIXING RATIO (ppmv) ± STANDARD DEVIATION (ppmv) OF THE DAILY ZONAL MEAN ABOUT THE MONTHLY MEAN													
	32°N - 56°N							56°N - 84°N						
	Nov.	Dec.	Jan.	Feb.	March	April	May	Nov.	Dec.	Jan.	Feb.	March	April	May
1.5	5.2±.49	4.9±.45	4.9±.37	4.9±.34	5.2±.37	5.4±.26	5.5±.24	5.0±.64	4.4±.62	4.5±.94	4.6±.46	5.2±.41	5.2±.24	5.1±.20
2.0	4.8±.37	4.7±.41	4.7±.30	4.7±.27	5.0±.32	5.2±.22	5.3±.19	4.7±.51	4.3±.55	4.4±.95	4.5±.36	4.8±.35	5.0±.21	5.1±.16
3.0	4.5±.29	4.5±.40	4.7±.26	4.7±.23	4.9±.26	5.2±.18	5.3±.15	4.6±.46	4.5±.51	4.6±.62	4.6±.32	4.7±.28	5.0±.23	5.1±.12
5.0	4.4±.24	4.4±.31	4.6±.22	4.6±.19	4.8±.18	4.9±.15	5.0±.13	4.7±.39	4.7±.47	4.7±.40	4.7±.27	4.8±.23	5.0±.20	5.1±.11
7.0	4.5±.21	4.4±.26	4.5±.22	4.5±.17	4.7±.14	4.8±.13	4.9±.12	4.7±.33	4.8±.44	4.8±.36	4.8±.25	4.8±.20	4.9±.16	5.0±.10
10.0	4.7±.18	4.5±.25	4.6±.20	4.6±.16	4.7±.12	4.7±.12	4.7±.12	4.9±.31	4.9±.42	5.0±.32	5.0±.27	4.9±.16	5.0±.13	5.1±.09
16.0	4.8±.17	4.7±.23	4.7±.20	4.6±.15	4.6±.12	4.7±.11	4.7±.12	5.0±.29	4.8±.34	5.0±.30	5.3±.30	5.0±.15	5.0±.13	5.1±.09
30.0	4.5±.17	4.6±.23	4.7±.22	4.8±.17	4.6±.13	4.7±.11	4.7±.11	5.0±.24	4.8±.33	4.9±.35	5.5±.23	5.3±.19	5.1±.11	5.2±.13
50.0	4.1±.21	4.1±.28	4.3±.24	4.4±.22	4.3±.19	4.4±.12	4.0±.13	4.9±.23	4.8±.34	4.7±.37	5.1±.39	5.3±.19	5.0±.13	4.9±.13
70.0	4.1±.27	4.2±.34	[illegible]	[illegible]	4.1±.29	4.4±.16	3.8±.15	5.2±.28	5.1±.43	4.8±.39	5.2±.46	5.4±.22	5.1±.18	4.8±.15
100.0	5.2±.41	5.0±.55	[illegible]	5.0±.46	4.7±.52	6.0±.28	4.3±.28	6.6±.43	6.4±.64	5.7±.58	6.0±.59	6.0±.32	5.7±.26	5.2±.21



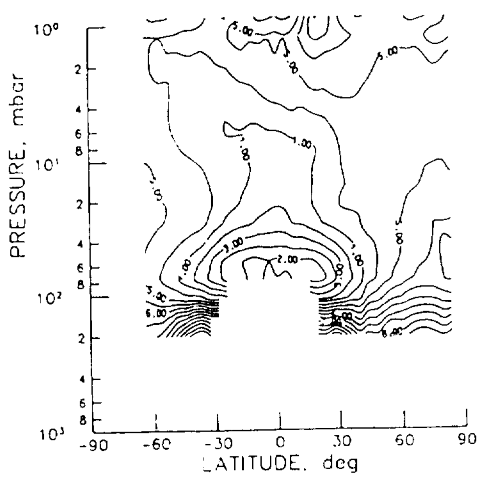
(a) November

(b) December

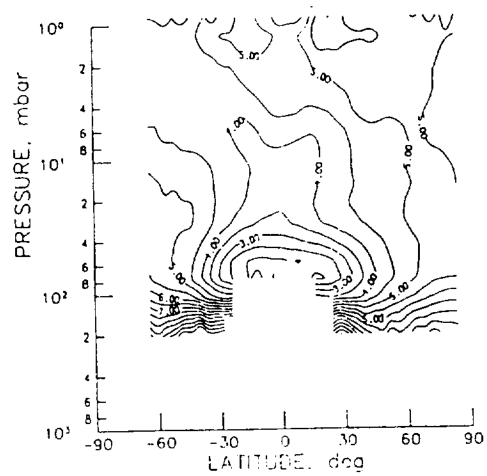
(c) January

(d) February

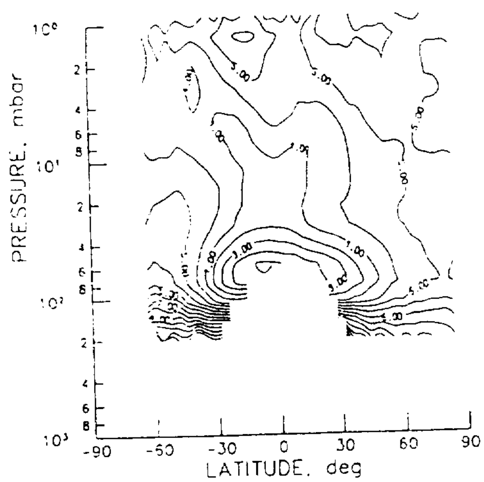
Figure 1. LIMS H_2O zonal mean pressure versus latitude cross section for descending orbital data. Countour interval 0.5 ppmv. (a) November, (b) December, (c) January, (d) February, (3) March, (f) April and (g) May.



(e) March



(f) April



(g) May

Figure 1 continued.

are very small. Figure 2 (a,b) shows those results for the months of November and May. Zonal mean deviations are minimal in the mid stratosphere, and they are a bit smaller for late autumn versus late spring, possibly due to a stronger net transport during late autumn.

Day-to-day zonal mean variability in Fig. 2 near 1-mb is about 15 percent, which is larger than expected for the real atmosphere. However, a significant fraction of that variability is due to random error in the measured radiances and from uncertainties in the retrieval at the tops-of-profiles. According to /18/, radiance signal-to-noise (S/N) for individual profiles is only about 2 to 3 at 1-mb. In fact, variations near 1-mb may be more indicative of data quality there than independent simulations of known LIMS error mechanisms. In that regard, it is also noted that variability at 1-mb decreases at 60S in November (Fig. 2a) and at 60N in May (Fig. 2b).

Seasonal mean mixing ratios are given in Table 4 from the LIMS data, along with the daily variations about the seasonal means. If one compares the northern and southern mid latitude zones (32-56 degrees latitude), it is clear that more change is occurring in winter versus summer, i.e., standard deviations are larger by a factor of 2 in winter. This difference is most likely related to the relative absence of net transport due to stratospheric wave activity in mid latitude summer /24/.

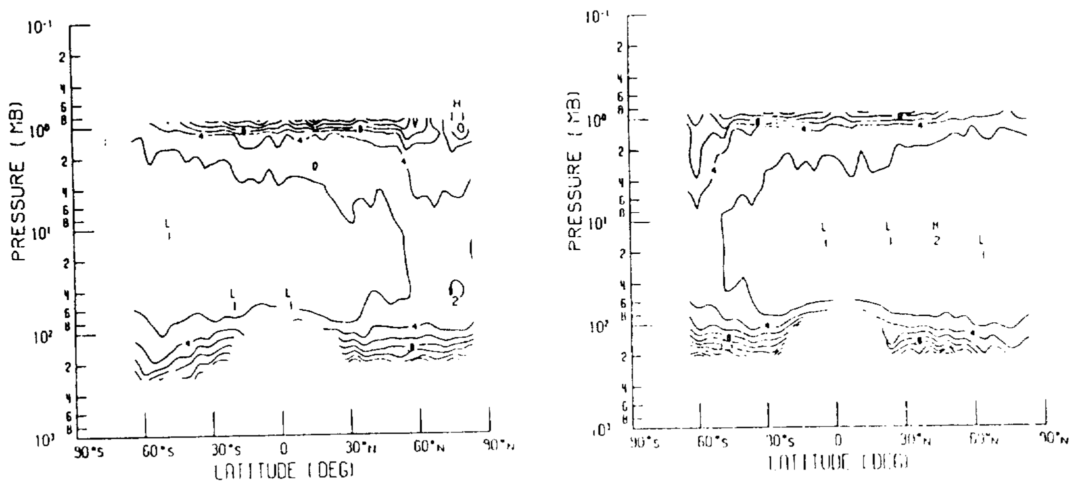
Changes in the monthly zonal mean water vapor cross sections (Fig. 1) occur smoothly with time over the 7 months. In fact, the November and May distributions are nearly mirror images. Between 10-mb and 1-mb, the largest change in the distribution occurs from January to March at a time when the diabatic circulation is undergoing a similar shift /25/. These changes in the net circulation are also being influenced by strong gradients in radiative cooling in the Northern Hemisphere in response to the poleward heat transport by enhanced planetary wave activity.

Seasonal changes are also apparent at mid latitudes of the lower stratosphere, but water vapor variations at the tropical hygropause are less apparent from the zonal mean data. Tropical forcing due to the semiannual oscillation (SAO) is most pronounced in late winter to early spring, which must contribute to the appearance of a double minimum in water vapor near 7-mb on either side of the Equator during April and May /26/.

The relative water vapor maxima near 1-mb and above and between 60N and 84N in January and February 1979 (Fig. 1 c,d) are not believed to be real for the following reasons. The production of nitric oxide (NO) by auroral particle precipitation followed by partitioning between NO and NO_2 and downward transport by the mean meridional circulation in the polar winter mesosphere has been analyzed /27/. Kerridge and Remsberg /21/ have shown that the vibrationally excited emission from this relatively large amount of mesospheric NO_2 in polar night must be accounted for during the H_2O retrieval in order to give accurate water vapor levels. After correcting for these effects, the water vapor values are not elevated there, and they appear to be more in line with the idea that there is a net downward transport of relatively dry air from mesosphere to stratosphere at high latitudes of the winter hemisphere /28/.

Global-average estimates of the LIMS water vapor have been prepared for December-January-February and March-April-May, along with estimates of accuracy in the zonal mean (Fig. 3). Water vapor values for each 4 degree latitude zone are multiplied by the fractional global area due to that zone, followed by a sum over all zones, to yield an area-weighted profile for comparison with one-dimensional models. Mixing ratios at 64S were extended to 90S and values at 84N were extended to 90N, but because those areas represent only 5 percent of the globe, the uncertainty due to the extrapolation is small. The average mixing ratio is nearly constant at 4.4 ppmv from 30- to 5-mb, decreasing to 3.5 ppmv at 50-mb. Mixing ratios increase from 4.4 ppmv at 5-mb to 5.0 ppmv at 1.5-mb, consistent with the idea of methane oxidation as a source of water vapor in the upper stratosphere (see also /19, 29/). The estimated accuracy at 1-mb is poorer than the difference between the mean values at 1-mb and 1.5-mb, so interpretations of the increase from 1.5- to 1-mb are not meaningful; this is not the case at 50-mb.

Prior to the existence of the LIMS data set, there was still some uncertainty about the magnitude and even the sign of the meridional gradient of water vapor. Given the precision, accuracy, and general physical consistency of the LIMS water vapor, there is no reason to doubt results such as those displayed for 2 January 1979, in Fig. 4, where meridional gradients are shown at 50-mb, 10-mb, and 3-mb. Based on current understanding of the measurements, the only caveat to these gradients would be a probable H_2O underestimate of 0.3 ppmv between ±15 degrees latitude at 50-mb.



2(a) November

2(b) May

Figure 2. LIMS H_2O standard deviation (ppmv) of daily zonal mean profiles about the monthly zonal mean. (a) November and (b) May.

TABLE 4 LIMS Zonal Mean H_2O Profiles (ppmv) ± Standard Deviation of the Daily Zonal Mean about the Seasonal Mean for Various Latitude Bands for Northern Hemisphere winter (November, December, January) and Spring (March, April, May).

Pressure	32°N - 56°N**		28°S - 28°N*		32°N - 56°N		56°N - 84°N	
(mb)	Summer	Autumn	Winter	Spring	Winter	Spring	Winter	Spring
1.5	4.9±.29	4.5±.42	5.2±.41	5.1±.37	5.0±.49	5.4±.27	4.6±.61	5.2±.38
2.0	4.9±.23	4.3±.35	4.9±.32	4.9±.29	4.8±.38	5.2±.27	4.4±.51	5.0±.38
3.0	4.8±.16	4.2±.30	4.6±.26	4.6±.22	4.6±.33	5.1±.27	4.6±.46	5.0±.35
5.0	4.7±.13	4.2±.24	4.2±.20	4.3±.17	4.5±.28	4.9±.21	4.7±.42	4.9±.26
7.0	4.6±.12	4.3±.20	4.0±.17	4.1±.14	4.4±.26	4.8±.17	4.7±.39	4.9±.20
10.0	4.7±.11	4.6±.17	4.1±.14	4.0±.12	4.6±.26	4.7±.16	4.9±.39	5.0±.16
16.0	4.7±.12	4.8±.16	4.2±.12	4.0±.10	4.7±.23	4.7±.14	4.9±.36	5.0±.14
30.0	4.7±.13	4.9±.16	3.8±.14	3.8±.13	4.6±.22	4.7±.12	4.9±.36	5.2±.18
50.0	3.9±.17	4.5±.32	2.8±.16	2.7±.17	4.2±.27	4.1±.18	4.8±.35	5.1±.24
70.0	3.7±.24	4.3±.47	2.7±.29	2.5±.31	4.2±.32	3.9±.27	5.1±.41	5.1±.30
100.0	4.3±.33	5.2±.62	3.7±.54	3.7±.57	5.1±.53	4.5±.39	6.2±.64	5.7±.44

*Mixing ratios at the 50-mb and 70-mb levels have been increased by 0.15 and 0.3 ppmv, respectively, to account for water vapor bias effects described in /18, 19/.

**The November, December, and January average is summer in the Southern Hemisphere and March, April, and May is autumn.

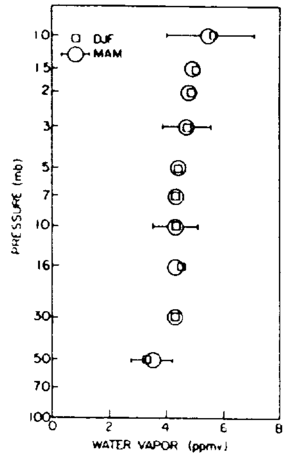


Figure 3. Global area-weighted average LIMS H_2O nighttime profiles for December, January, and February (□) and March, April, and May (O). Horizontal bars represent accuracy of zonal mean.

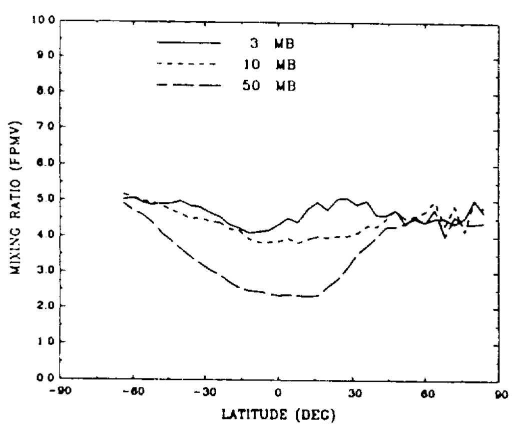


Figure 4. LIMS zonal mean H_2O mixing ratio versus latitude at 3-, 10-, and 50-mb on January 2, 1979.

ZONAL VARIATIONS IN LIMS WATER VAPOR

Estimates of variations about the zonal mean have been determined from the archived LAIPAT by calculating a 5-day zonal mean cross section and determining the standard deviation in ppmv of the individual profiles about the mean result. Figure 5a is an example for 5 days of data between 20-26 May 1979. These variations include both "noise" and real wave activity. Minimum May standard deviations of 0.4 ppmv occur near 20-mb at low latitudes and in the Northern Hemisphere when wave activity is expected to be weak. Variations in the upper stratosphere are related more to the noise associated with the low signal-to-noise at tops of profiles, while increases in the absolute variations at 100-mb and below are due, in part, to the fact that water vapor mixing ratios increase sharply at these levels such that small variations in the pressure registration of the water vapor radiance profiles have become significant. The larger standard deviations in the mid stratosphere at 40S to 64S are most likely due to enhanced wave amplitudes there during late autumn (see also /30/). Figure 5b is similar to 5a, but for 27-31 October 1978. Again, the hemispheric mirror image is apparent between the two periods.

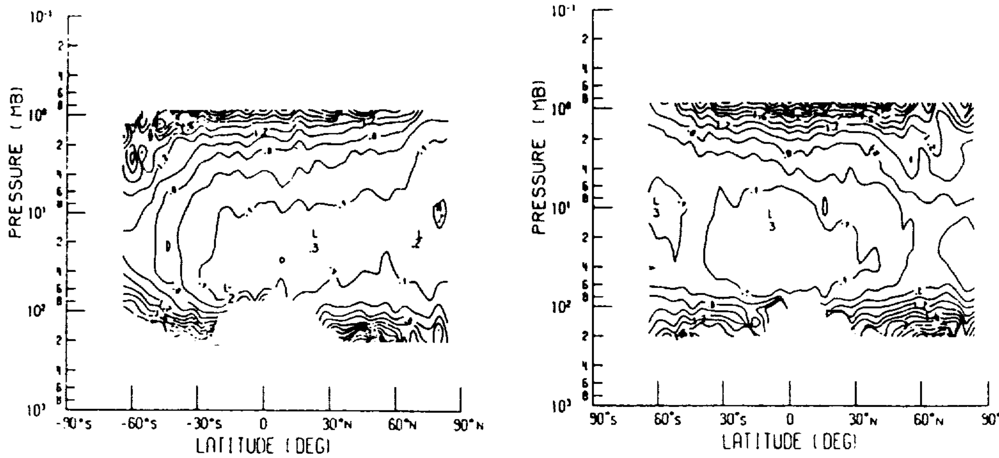
Water vapor variability is presented for another period, 1-5 February 1979, that was dynamically active in the Northern Hemisphere. Figures 6a and 6b show results for ascending (or day) and descending (or night) data at 5-mb and 50-mb. Note that regardless of the day/night difference of about 0.5 ppmv (not shown) that exists in the zonal mean result at 5-mb and Equator, the standard deviations about the respective ascending and descending zonal means are very similar in Fig. 6a. At 5-mb, there appears to be a gradual increase in variability from 60S to North Pole. However, if the water vapor field near 5-mb possesses weak meridional and vertical gradients (Fig. 1d), the effect of atmospheric waves on the field will be unnoticed. Conversely, variations at 50-mb (Fig. 6b) are nearly constant at 0.4 ppmv from 64S to 30N, but by 60N, they have increased by a factor of 3 to 1.2 ppmv. From Fig. 1d, one can see that there are strong meridional gradients at 50-mb at mid latitudes of both hemispheres, so low standard deviations in the Southern Hemisphere are indicative of little wave activity, while such activity is more apparent in the Northern Hemisphere. For example, the north polar vortex is shifted off the Pole in early February 1979, so a strong wave 1 amplitude should be evident. A time series of the wave 1 amplitude in ppmv at 5-mb and 50-mb was determined from the zonal, Fourier coefficient form of the LIMS data set /22/. The Fourier analysis yields wave 1 amplitudes of 0.2 to 0.4 ppmv at 5-mb for day 100 (1 February) or about one-half the variability in Fig. 6a. Figure 7 for 50-mb shows that the wave 1 amplitudes for day 100 are 0.6 to 1.0 ppmv from 60N to 80N, accounting for most of the variation in Fig. 6b. Previous analyses have also shown good correspondence in the patterns of the large-scale water vapor fields and coincident maps of geopotential height or potential vorticity, in line with ideas about water vapor being an appropriate tracer of transport processes throughout the middle atmosphere /22, 31/.

VARIABILITY OF MESOSPHERIC WATER VAPOR

Information about mesospheric water vapor and its variations is available from two extensive data sets. First, because of the analyses conducted in /21/, more confidence can be placed in the lower mesospheric nighttime water vapor values reported by /32/ from LIMS results (winter/spring 1978-1979) between 0.5-mb and 1.5-mb as retrieved from specially processed, averaged radiance profiles. Secondly, sets of water vapor profiles derived from ground-based measurements of microwave emission were reported for spring 1984 at Jet Propulsion Laboratory (JPL), California (34N, 50- to 85-km) /33/, for winter/spring 1985 from JPL at 60- to 80-km by /34/, and for spring 1984 at Pennsylvania State University (PSU) (41N, 65- to 80-km) by /35/. The microwave measurement technique and earlier H_2O results are summarized briefly in /12/.

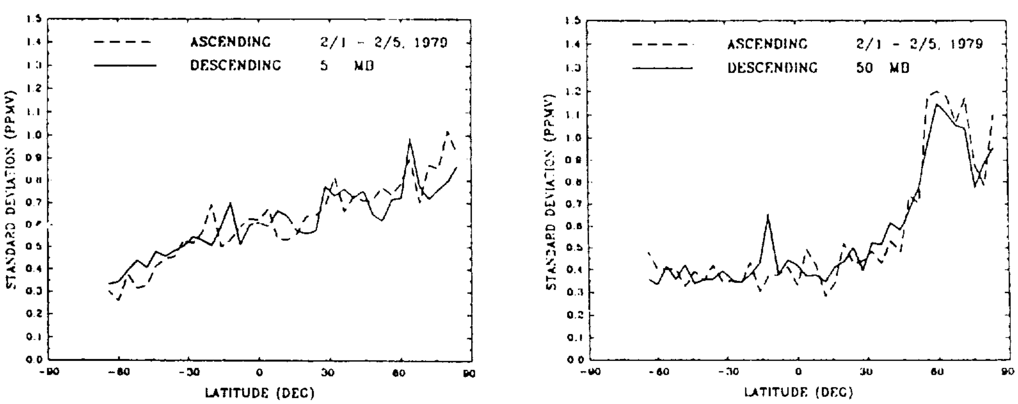
Bevilacqua et al. /33/ reported a monthly increase in water vapor of a factor of 2 at 75-km from April to June 1984, and they concluded that the change was due to a seasonal variation in mixing due to gravity wave breaking. Comparisons of the 1984 and 1985 profiles at 34N indicate general agreement in shape and magnitude from 60- to 80-km. Comparisons with data obtained in the early 1980's at Haystack Observatory (43N) reported by /36, 14/, indicate slightly lower mixing ratios for spring than at JPL. Tsou et al. /35/ find a similar difference between the 1984 results at JPL and PSU, which they attribute to latitudinal and/or longitudinal variations in the occurrence of breaking gravity waves. Gordley et al. /32/ also found a definite latitudinal variation in LIMS zonal mean water vapor in the lower mesosphere with values at 34N being greater than those at 41N and 43N by about 1 ppmv. Thus, LIMS provides supporting evidence that there are latitudinal variations in mesospheric water vapor.

An estimate of a mean water vapor profile in the mesosphere at Northern Hemisphere mid latitudes has been derived for spring (April and May) from 1.5-mb to 0.01-mb by using the radiance-averaged LIMS data from 1.5- to 0.5-mb, plus the microwave results above that.



(a) May 20-26 (b) October 27-31

Figure 5. LIMS H_2O standard deviation (ppmv) of individual profiles about the zonal mean for (a) May 20-26 and (b) October 27-31.



(a) 5-mb (b) 50-mb

Figure 6. LIMS H_2O standard deviation (ppmv) versus latitude for individual profiles about the 5-day zonal mean for February 1-5, 1979, at (a) 5-mb and (b) 50-mb.

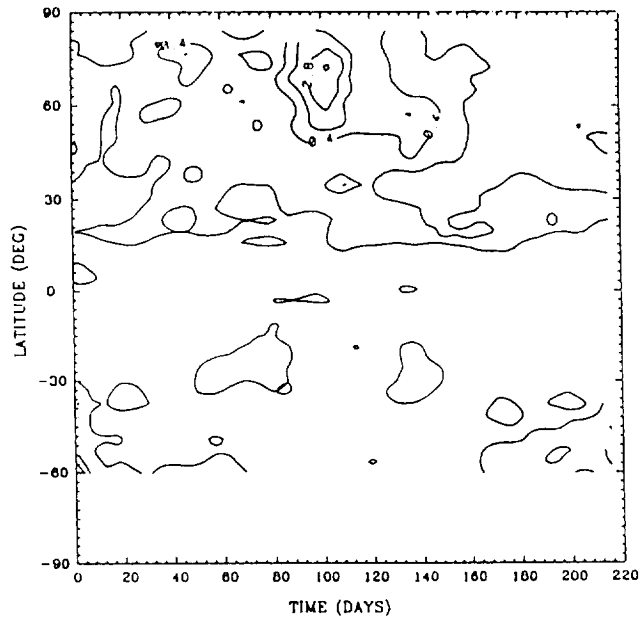


Figure 7. LIMS descending mode H_2O wave 1 amplitude (ppmv) for October 25, 1978 to May 28, 1979 at 50-mb.

Table 5 contains the 2-month average, plus the monthly difference profiles from the combined data sets. Data from Fig. 8 of /35/ were used from 0.1- to 0.01-mb, and LIMS data prepared in the manner described in /32/ were used for 1.5- to 0.5-mb. The average values at 0.2-mb (near 60-km) in Table 5 were obtained from the Haystack results (43N) of /36/, their Fig. 2, plus the JPL results (Fig. 4 of /33/).

A REFERENCE WATER VAPOR PROFILE AND ITS VARIABILITY

A springtime, Northern Hemisphere, mid latitude water vapor profile and its variability were constructed from the data in Table 5 and from the mean spring results at 32N to 56N in Table 4 from 2.0-mb to 100-mb. Variability from 2.0-mb to 100-mb for mid latitude spring was derived by combining data on variations of single LIMS profiles about the 5-day zonal mean as in Fig. 5, plus the variation of the daily zonal mean profiles about the seasonal mean in Table 4. Variations from 0.5- to 1.5-mb were set to those at 2.0-mb, since information on variability about the zonal mean is lacking for that region. Variations from 0.2- to 0.01-mb were derived by averaging the differences between the April and May profiles at 34N, 41N, and 43N from /35/ and /36/. Figure 9 in /35/ contains information about the larger water vapor variations for the daily time series for each month, but because these variations were not tabulated, they were not included in the variability for the reference profile. This means that the real atmospheric variability at those levels is being underestimated here. The final combined profile is given in Table 6 and Fig. 8. It is also noted that this profile is somewhat different from the combined profile in Table 7 of /12/ because that earlier profile contained an average of several different kinds of mid latitude mesospheric measurements, it was derived as a winter/spring average, and for the LIMS data, it only contained variations of the daily zonal means about the seasonal means.

The profile in Fig. 8 contains only LIMS data, plus monthly averages of microwave emission results, some of which were published in the past year. The profile is also only appropriate for Northern Hemisphere spring. Nevertheless, this reference model has a constant mixing ratio of 4.7 ppmv from 30- to 7-mb, gradually increasing to 6.0 ppmv at 0.2-mb, then decreasing rapidly to 1.3 ppmv at 0.01-mb. The determination of the vertical position and magnitude of the peak mixing ratio at 0.2-mb must be considered uncertain because the one sigma error for that measurement is about 1.5 ppmv /33/. Obviously, more mesospheric data are needed at other seasons and latitudes and longitudes before additional reference profiles can be prepared for the middle atmosphere. Mean mixing ratios decrease to 4.0 ppmv at 50- to 70-mb, reflecting the net poleward transport of relatively dryer air from tropical latitudes.

DISCUSSION AND CONCLUSIONS

This analysis is an update of the review by /12/ on interim reference profiles for middle atmospheric water vapor. New emphasis is given to estimates of the observed variability of stratospheric water vapor using the winter/spring data from the Nimbus 7 LIMS experiment from 64S to 84N. Some initial results obtained by averaging the LIMS radiance data before retrieval are used to decrease the uncertainty in archived LIMS results from 1- to 2-mb, as well as to extend results upward to 0.5-mb. Monthly zonal mean LIMS cross sections are shown to vary smoothly over the 7 months of the data set, and these results plus global average estimates of the seasonal mean water vapor profile are physically consistent with prevailing ideas about the sources, sinks, and mechanisms affecting the water vapor distributions. Longitudinal variations about the zonal mean distribution are generally small, except in the lower stratosphere where the meridional gradient in water vapor is also large enough to reflect the effects of transport and mixing due to waves during dynamically active periods of the winter hemisphere. An extensive set of microwave emission measurements of mesospheric water vapor is included, along with LIMS data, to determine a mesospheric reference profile from 0.2- to 0.01-mb for Northern Hemisphere mid latitudes in spring. The observed variability for spring appears to be real and probably is related to variations in mean vertical advection.

Several additional water vapor data sets are expected shortly. The most extensive will be the multiyear, near-global data set from the Stratospheric Aerosol and Gas Experiment (SAGE II) underway since late 1984 /37/. This experiment is providing water vapor profiles by solar occultation for the entire stratospheric altitude range. Data from the Spacelab 3 ATMOS experiment in May 1985 should also be available soon, and they are expected to extend from 20- to 80-km. Peter et al. /38/ will report H_2O results from 20 to 70 km and 45N to 75N for December 1986 using an airborne millimeter-wave instrument. The stratospheric results are consistent with those from LIMS. In the near future, it is also anticipated that permanent millimeter-wave emission instruments will be installed at sites to be designated as part of a proposed Network for the Detection of Stratospheric Change (NDSC). Based on the LIMS results in the lower mesosphere, it appears that the profile at low latitudes is somewhat different from that at mid latitudes, so a continuous measurement is needed there.

TABLE 5 Mesospheric Mean Water Vapor Profile for Northern Hemisphere Spring at Mid Latitudes

Pressure (mb)	H_2O Mixing Ratios (ppmv)*
0.01	1.4 ± 0.6
0.025	2.0 ± 0.6
0.05	3.3 ± 0.9
0.1	5.0 ± 0.7
0.2	6.0 ± 1.0
0.5	5.5 ± 0.6
0.7	5.5 ± 0.5
1.0	5.1 ± 0.3
1.5	5.0 ± 0.2

*Specially averaged LIMS data are from 1.5-mb to 0.5-mb. Microwave data are from 0.2-mb to 0.01-mb. Variability is defined in the text.

TABLE 6 Mid Latitude Interim Reference Profile for 32°N - 56°N Spring Obtained Using LIMS Data from 100-mb to 0.5-mb and Microwave Data from 0.2-mb to 0.01-mb. Variability is defined in the text.

Pressure (mb)	H_2O Mixing Ratios (ppmv)
0.01	1.4 ± 0.6
0.025	2.0 ± 0.6
0.05	3.3 ± 0.9
0.1	5.0 ± 0.7
0.2	6.0 ± 1.0
0.5	5.5 ± 1.2
0.7	5.5 ± 1.2
1.0	5.1 ± 1.2
1.5	5.0 ± 1.2
2.0	5.2 ± 0.9
3.0	5.1 ± 0.8
5.0	4.9 ± 0.5
7.0	4.8 ± 0.4
10.0	4.7 ± 0.4
16.0	4.7 ± 0.4
30.0	4.7 ± 0.4
50.0	4.1 ± 0.4
70.0	3.9 ± 0.5
100.0	4.5 ± 0.7

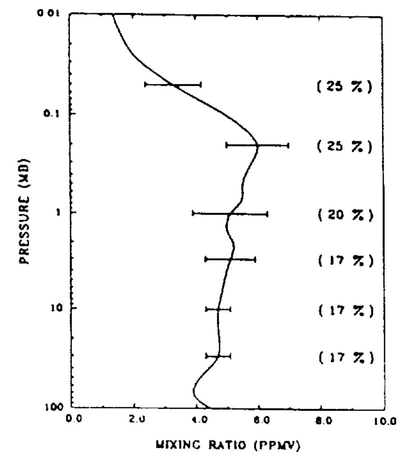


Figure 8. H_2O interim reference profile for Northern Hemisphere midlatitude springtime. Bars represent variability of the data. Numbers in parentheses represent estimated accuracies.

In the lower stratosphere, the time series of frost-point hygrometer measurements at Boulder is continuing /17/. Results will soon be available from the comprehensive tropical Stratospheric/Tropospheric Exchange Project (STEP) experiment conducted out of Darwin, Australia, in early 1987. These data should be useful in defining the water vapor fluxes, which contribute to the overall H_2O distribution in the hygropause region. Finally, preliminary results were reported from the 1987 Airborne Antarctic Ozone Expedition (AAOE), along with some balloon-borne measurements of water vapor from McMurdo Base during the National Ozone Expedition (NOZE2) and the measurements from SAGE II (see /39/). According to the measurements, it appears that a separate water vapor reference profile may be required for the special conditions associated with cold lower stratospheric temperatures over the Antarctic region, at least during winter and spring. Air for those periods is dehydrated with mixing ratios equivalent to those at the tropical hygropause (2 to 3 ppmv). With the addition of these new data sets, it should be possible to know the seasonal distribution of water vapor for the entire stratosphere and for limited, but representative, locations for the mesosphere.

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