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REVISED REFERENCE MODEL FOR NITRIC ACID

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ABSTRACT

A nearly global set of data on the nitric acid distribution was obtained for seven months by the Limb Infrared Monitor of the Stratosphere (LIMS) experiment on the Nimbus 7 spacecraft. The evaluation of the accuracy, precision and resolution of these data is described, and a description of the major features of the nitric acid distributions is presented. The zonal mean for nitric acid is distributed in a stratospheric layer that peaks near 30 mb, with the largest mixing ratios occurring in polar regions, especially in winter.

INTRODUCTION

Nitric acid was first identified in the stratosphere by Murcray *et al.* /1/, who measured its infrared absorption spectrum from a balloon. It has subsequently been measured many times from balloons /2/, aircraft /3/ and more recently the shuttle /4/. In addition, it has been observed by direct collection on filters from balloons and aircraft /5/. Nitric acid is formed by the three body reaction

$$NO_2 + OH + M \rightarrow HNO_3 + M$$

although other processes may be involved during high latitude winter conditions. It is destroyed by the reactions

$$HNO_3 + h\nu \rightarrow OH + NO_2$$

and

$$HNO_3 + OH \rightarrow NO_3 + H_2O.$$

The time scales are several days /6/, indicating that the distribution will be strongly influenced by atmos...: motions.

The only near-global observations were obtained by the Limb Infrared Monitor of the Stratosphere (LIMS), which flew on the Nimbus 7 spacecraft. Because these are in good agreement with the other data, they are the b...s for the nitric acid model proposed here. The LIMS was a 6 channel infrared radiometer that scanned the earth's limb, measuring emitted radiances that could be inverted to yield profiles of nitric acid and other quantities. The experiment and the data reduction have been described by Gille and Russell /7/; other discussions are contained in Russell and Gille /8/ and Gille *et al.* /9/. The features of IR limb scanning relevant to the measurement of HNO_3 include the long viewing paths, giving maximum sensitivity to small amounts of the gas, high vertical resolution if narrow field of view detectors are used, and the ability to obtain measurements on both the day and night sides of the orbit. However, to obtain high signal to noise ratios with the narrow detectors required that they be cooled. The use of a solid cryogen limited the LIMS lifetime to about 7 months.

Over this period, from 25 October 1978 to 28 May 1979, the instrument operated extremely well. On the average, over 1000 profiles were derived each day, from 64°S to 84°N. These profiles were then objectively analyzed using the Kalman filter approach suggested by Rodgers /10/ and described in more detail by Kohri /11/. This leads to daily estimates of the zonal mean mixing ratio and the coefficients describing 6 waves in longitude. Only a model for the zonal mean distribution is presented here.

ACCURACY AND PRECISION OF THE NITRIC ACID DATA

The characteristics of the LIMS HNO_3 data were discussed by Gille *et al.* /12/. The vertical range of the data is set by the region of adequate signal to noise ratio, and, at the bottom, by the frequent occurrence of clouds. For the HNO_3 signal, the upper limit occurred at about the 2 mb pressure level, or around 45 km altitude. Clouds usually impose a lower limit at or above the 100 mb pressure level in the tropics. Retrievals to lower altitude are possible at higher latitudes, but with rather small signal to noise ratios. In this discussion the lower boundary is taken to be 100 mb.

The precision of the profiles, or scan-to-scan repeatability, is about 0.05-0.1 ppbv in undisturbed regions where atmospheric variability does not contribute to the variations. This intrinsic precision is of the order of 2% up to 7 mb, rising to only 5% at 4 mb. When natural atmospheric variability is included, which may incorporate real variations on scales smaller than the approximately 100 km inter-scan spacing, a repeatability at almost all latitudes and altitudes of 0.1 ppbv is found.

The accuracy is much more difficult to establish. Gille *et al.* /12/ estimated the errors presented in Table 1. These estimates, at least away from the top levels, are thought to be rather conservative. Again, these were checked through comparison with 15 balloon-borne measurements from 100 to 10 mb. These differences are also collected in Table 1. They are approximately the errors associated with the balloon-borne measurements. However, the LIMS results become increasingly larger than the correlative measurements with altitude, leading the authors to suggest that they were in error. In addition, chemical consistency suggests that the original values are too large /13/. Subsequently Bailey and Gille /14/ have shown that an instrumental correction should be applied that slightly reduces the radiances at all altitudes. This has the effect of significantly reducing the HNO_3 mixing ratios above 10 mb, where the signals are small. The results presented here have now been corrected for this effect. These results therefore differ at the upper levels from those presented in Gille *et al.* /15/.

<u>TABLE 1</u> LIMS Nitric Acid Errors⁺

Pressure Level (mb)	No. of Comparisons	Estimated Systematic Errors (%)	Differences from Correlative Measurements (%)
80		42	
70	4		-19 ± 24
50	14	41	4 ± 8
30	14	33	9 ± 7
10	12	29	27 ± 11
7	11		53 ± 11
5	6		90 ± 4
3		65	

⁺ From Gille *et al.* /12/.

NITRIC ACID DISTRIBUTION

<u>Vertical Distribution</u>

Vertical profiles of HNO_3 at 60°S, 32°S, the equator, 32°N and 60°N are shown in Figure 1. At the equator, there is little vertical variation. A slight maximum of between 2 and 3 ppbv is located near 20 mb, but the seasonal variation is quite small. At 32°S the maximum of about 7 ppbv is shifted down to 30 mb. There is a minimum in mid-summer with a maximum observed value in May, suggesting an annual variation with largest values in winter. Temporal variations are shown in more detail below. A similar variation (shifted by 6 months) is shown at 32°N.

The variation is similar but much larger at 60°S. The peak values, again at 30 mb, are over 10 ppbv. At 60°N the largest values are in winter, with maxima of nearly 10 ppbv, again at 30 mb.

In summary, the tropics are characterized by low mixing ratios, and have a small seasonal variation. At higher latitudes the mixing ratios are larger, and have an annual variation characterized by a fall-winter maximum. There is very little variation in the pressure of the peak values, which increases from 20 mb in the tropics to 30 mb at high latitudes.

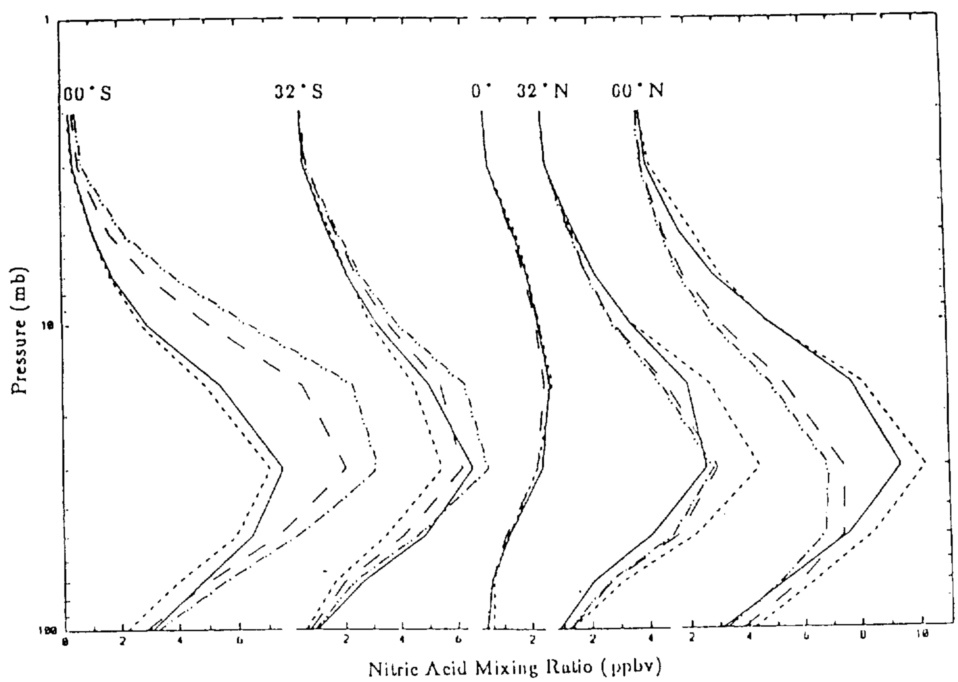

Figure 1. Vertical profiles of monthly average zonal mean HNO_3 mixing ratios at five latitudes for October (——), January (- - -), April (— —), and May (- ·· -).

Monthly Average Zonal Mean Cross-Sections

At every location there are short-term variations, associated with dynamical effects, as well as seasonal changes. Even after taking the zonal mean, there are short period temporal variations. However, over a month the standard deviation of these variations are usually small. Figure 2, for January (1979) shows that the standard deviation of the daily values is less than 5% except at upper levels in the winter hemisphere, where it can be over 30%. (The increased values at the tropical tropopause are due in part to incomplete removal of cloud contaminated profiles, and in part to the difficulty of accurately following the sharp radiance decrease above clouds, in conjunction with the low mixing ratios there.) In contrast, in April (Figure 3) the standard deviation is less than 5% almost everywhere, and never greater than 15%. The standard deviation of the monthly averaged zonal means (these values divided by $\sqrt{N}$, where N is the number of days with data in the month) are therefore less than 1%, except for the high upper polar winter stratosphere, where they are still only 6%, so the random uncertainties associated with the following mean cross-sections are rather small. These standard deviations are tabulated in Table 2.

The monthly average zonal mean nitric acid distributions for October through May are presented in Figures 4-11, and in tabular form in Table 3. The general features of the nitric acid distribution are illustrated by the October data (Figure 4). There is a broad saddle in the tropics, centered near 20 mb, and characterized by values of 2-3 ppbv. Mixing ratios decrease slowly above and below this level, indicating profiles characterized by low and relatively constant values. Maximum values increase toward both poles, with the altitude of the maximum decreasing to the 30 mb level at high latitudes. In the Northern Hemisphere (NH), the maximum of 3 ppbv at 20 mb for 10° N progresses to a maximum of 12 ppbv at 30 mb for 84°N. The latitudinal variations are similar in the Southern Hemisphere (SH) as far as they can be seen. Note also that the isolines are relatively flat on the upper side of the layer, but have fairly steep slopes on the lower side. Finally, there is an indication of slightly higher values at high northern latitudes and high altitudes.

There is a regular progression in the monthly mean values. In November (Figure 5), the northern polar maximum has increased to its maximum value, while the maximum at 64°S has decreased. By December (Figure 6), the northern maximum has dropped back to less than 11 ppbv, while the southern maximum has fallen further.

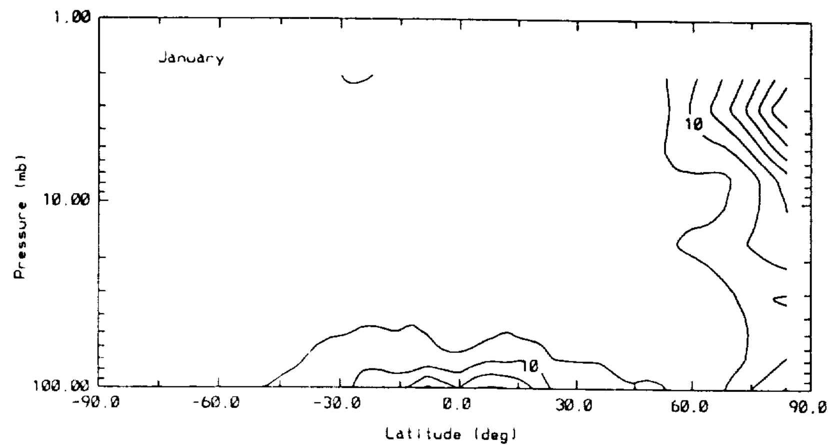

Figure 2. Cross section of the standard deviation of the daily HNO_3 mixing ratios from the monthly average, as a percent of the average value, for January. Contour interval is 5%.

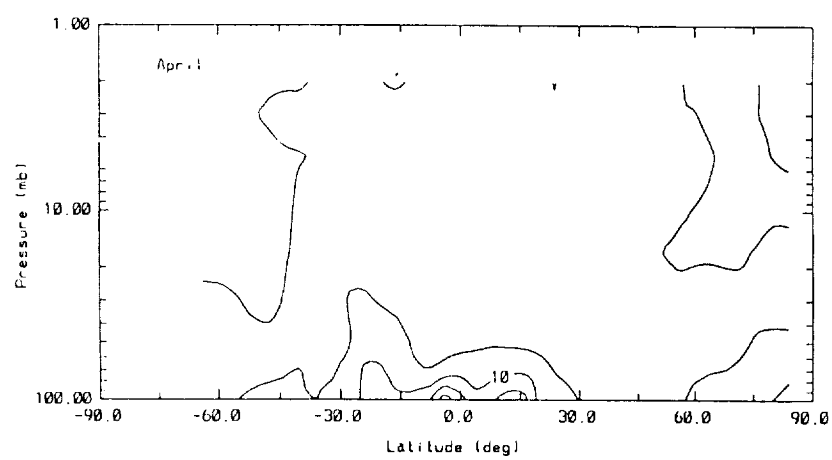

Figure 3. Same as Figure 2, but for April.

Table 2. Standard deviation of monthly average zonal mean mixing ratios (as a percent of the zonal mean)

January

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.37	0.44	0.56	0.76	0.89	0.81	0.54	0.58	0.71	0.41	0.54	0.39	0.64	1.60	3.08	5.16
3.00	0.38	0.29	0.44	0.67	0.35	0.60	0.50	0.60	0.62	0.58	0.61	0.58	0.68	1.95	3.70	6.31
5.00	0.20	0.30	0.49	0.63	0.45	0.53	0.50	0.53	0.38	0.42	0.84	0.61	0.78	1.33	1.83	4.15
7.00	0.43	0.45	0.35	0.61	0.43	0.40	0.38	0.26	0.25	0.52	0.65	0.41	0.52	0.80	0.87	2.42
10.00	0.43	0.43	0.42	0.40	0.20	0.24	0.24	0.31	0.25	0.43	0.50	0.30	0.71	0.66	1.05	2.12
16.00	0.43	0.41	0.34	0.21	0.18	0.33	0.33	0.61	0.57	0.89	0.76	0.63	0.87	1.05	1.54	2.29
30.00	0.41	0.33	0.12	0.14	0.50	0.77	0.67	0.65	0.34	0.54	0.33	0.42	0.30	0.39	0.82	0.89
50.00	0.30	0.19	0.22	0.55	0.83	0.92	0.92	0.42	0.84	0.58	0.42	0.40	0.50	0.64	0.65	1.13
70.00	0.26	0.14	0.42	0.83	1.38	1.51	1.11	1.10	1.63	1.69	0.88	0.73	0.60	0.57	0.65	1.52
100.00	0.23	0.32	0.89	1.23	1.59	2.32	3.30	2.69	3.71	2.54	1.61	1.11	1.04	0.52	1.13	2.34

April

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	1.32	1.33	1.12	1.04	0.60	0.90	0.84	0.74	0.72	0.80	0.76	0.75	0.74	1.08	1.61	2.19
3.00	1.22	1.57	0.90	0.58	0.75	0.45	0.70	0.48	0.53	0.74	0.48	0.58	0.69	0.87	1.48	1.97
5.00	1.65	1.56	1.10	0.95	0.59	-0.56	0.62	0.38	0.54	0.61	0.62	0.44	0.50	0.62	1.23	1.86
7.00	1.80	1.60	1.43	0.85	0.46	0.42	0.36	0.35	0.29	0.31	0.40	0.23	0.33	0.70	1.32	1.46
10.00	1.55	1.61	1.52	0.80	0.58	0.35	0.27	0.24	0.25	0.22	0.14	0.25	0.42	0.97	1.24	1.04
16.00	1.22	1.23	1.38	0.75	0.70	0.69	0.32	0.30	0.44	0.41	0.30	0.38	0.80	1.03	1.01	0.66
30.00	0.72	0.74	1.07	0.49	0.63	0.86	0.25	0.52	0.29	0.17	0.31	0.42	0.59	0.62	0.71	0.58
50.00	0.49	0.48	0.72	0.75	0.63	1.51	0.78	0.59	0.81	0.46	0.36	0.59	0.37	0.56	0.73	1.11
70.00	0.57	0.53	0.72	0.93	1.01	1.93	0.95	1.50	1.51	1.59	0.64	0.64	0.38	0.76	0.98	1.54
100.00	0.87	0.83	1.11	0.93	1.21	2.55	2.38	3.13	2.95	1.52	0.00	0.83	0.49	1.15	1.43	1.83

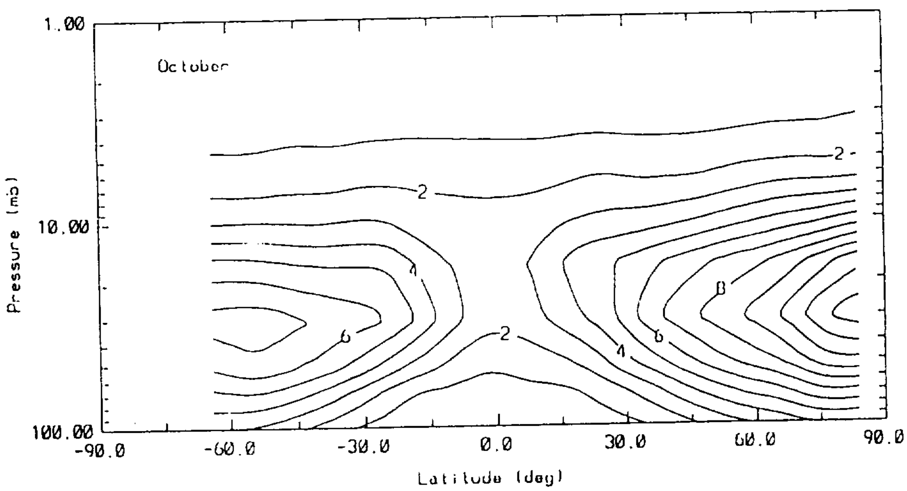

Figure 4. Monthly averaged zonal mean cross section of HNO_3 mixing ratio (ppbv) for October (last 7 days).

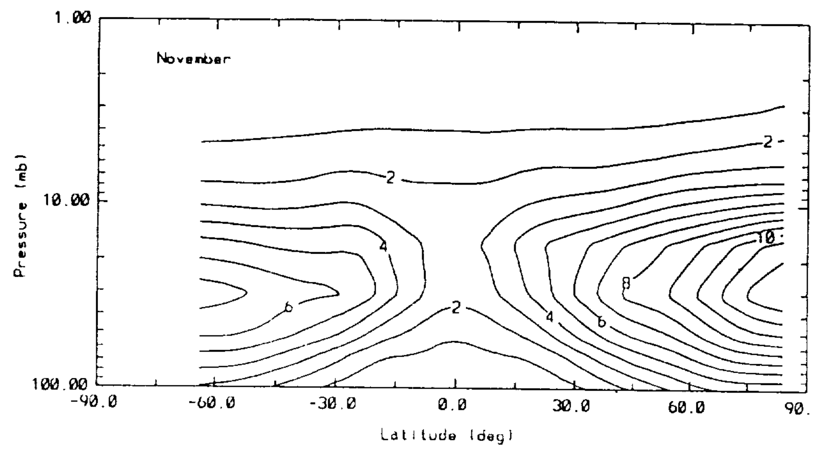

Figure 5. Same as Figure 4, but for November.

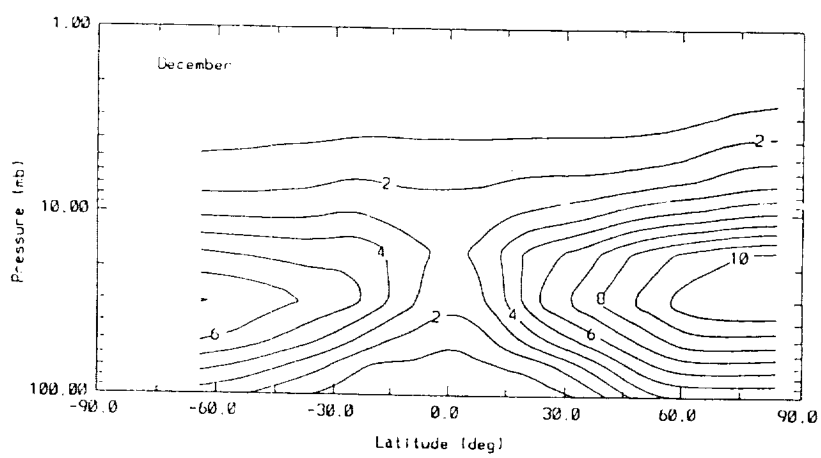

Figure 6. As Figure 4, but for December.

January's distribution (Figure 7) is much like December's, but with some increase in the winter polar upper stratosphere. This latter feature is largely gone in February (Figure 8), and the NH high latitude maximum has decreased below 10 ppbv, while that in the SH has increased. These seasonal changes continue in March (Figure 9) and April (Figure 10), until by May (Figure 11) the NH maximum is only slightly above 7 ppbv, while the SH max at 64°S is over 11 ppbv. In addition, there has been an increase in the SH (winter) polar upper stratosphere.

A comparison of November and May, the two nearly complete months that are 6 months apart, indicates little change in the tropics. However, they show a 7 ppbv contour in the SH in November that is not present at 64°N in May. Similarly, in May the mixing ratios near 60°S are larger than those near 60°N in November. It is clear that the SH maxima and minima have larger mixing ratios than those in the NH, indicating an asymmetry between the hemispheres in nitrogen compounds. This has also been seen in NO_3, and estimates of the total odd nitrogen.

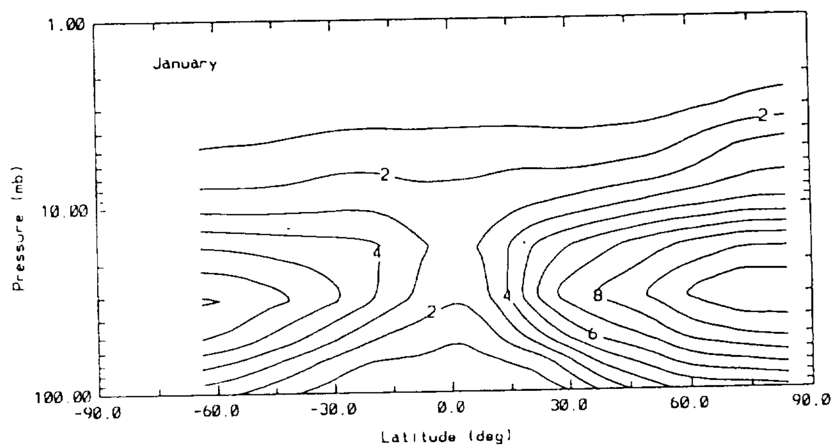

Figure 7. As Figure 4, but for January.

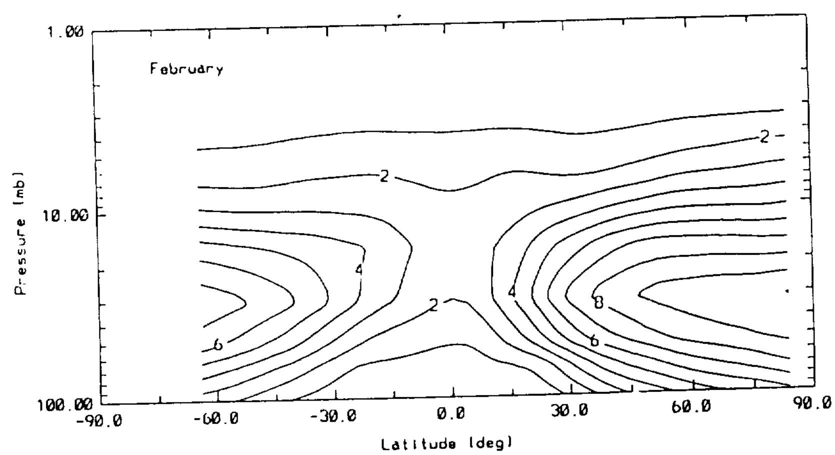

Figure 8. As Figure 4, but for February.

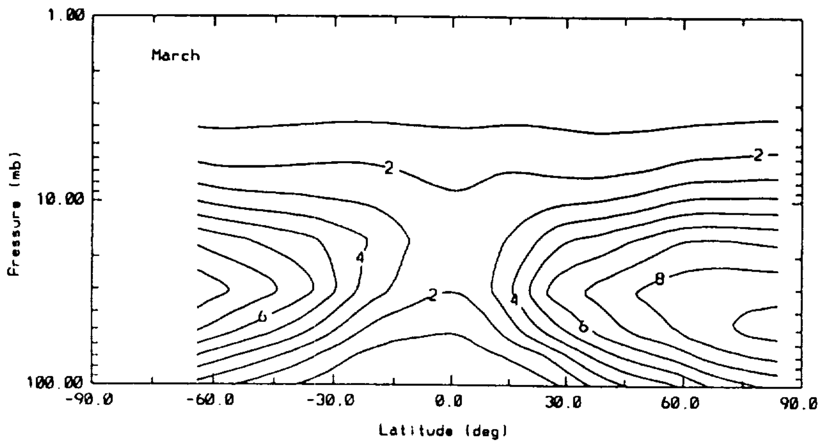

Figure 9. As Figure 4, but for March.

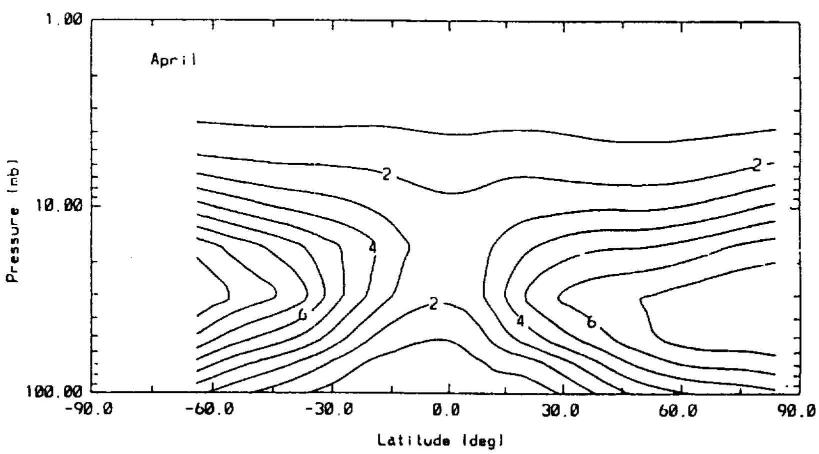

Figure 10. As Figure 4, but for April.

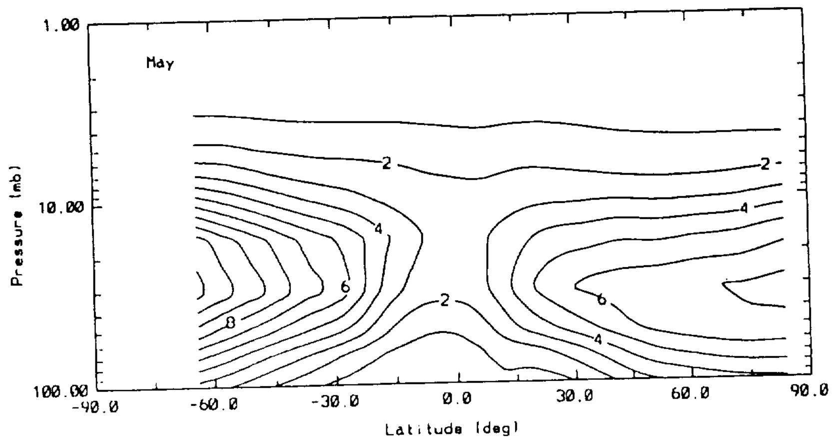

Figure 11. As Figure 4, but for May (first 28 days).

Temporal Variations

The temporal variation of the zonal mean is conveniently displayed by time-height cross sections. At the equator (Figure 12) there is a semi-annual oscillation, where the HNO_3 maxima occur at the beginning of January and (probably) July at 16 and 10 mb. The minimum at each level is close to the mid-point between the maxima. This is consistent with semi-annual vertical motions, having maximum strength in March, with minimum motions in December and June as found by Gille *et al.* /16/.

At 32°N and S (not shown), the patterns are similar to those at 60°, but the variations are weaker. The NH maxima and SH minima occur in February at 50 and 30 mb, which also shows the higher SH values in late autumn than in the NH. Again, there is a suggestion that the NH maximum occurs earlier than the SH minimum.

At 60°N and S (Figures 13 and 14) there is an annual variation, which is out of phase between the two hemispheres, with the NH maximum and SH minimum occurring in late December at 30 mb. The patterns are similar above 30 mb, but the May values in the SH are larger than the NH maxima in December, as noted earlier.

These plots (and that for 80°N, presented in Gille /17/) show long term (seasonal) changes, probably due to photochemical effects, and short period variations, especially during the winter, that are related to dynamical effects. There are marked decreases during the times of major disturbances in the stratosphere, which are to be expected when the downward motions which lead to stratospheric warmings through adiabatic compression bring down air that is poorer in HNO_3.

Table 3. Monthly average zonal mean mixing ratios (parts per billion by volume)

October

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.29	0.30	0.32	0.32	0.32	0.33	0.33	0.34	0.35	0.34	0.34	0.34	0.39	0.40	0.45	0.55
3.00	0.44	0.44	0.46	0.46	0.47	0.48	0.47	0.49	0.51	0.49	0.51	0.53	0.58	0.63	0.72	0.84
5.00	1.15	1.14	1.22	1.29	1.39	1.52	1.40	1.42	1.41	1.61	1.56	1.48	1.53	1.78	1.90	1.92
7.00	1.82	1.80	1.85	1.92	2.05	2.02	1.94	1.90	1.93	2.18	2.25	2.20	2.48	2.92	3.21	3.30
10.00	2.95	2.98	3.00	2.94	3.09	2.83	2.27	2.26	2.60	3.09	3.30	3.60	4.16	4.77	5.34	5.99
16.00	5.40	5.45	5.23	4.95	4.94	4.25	2.97	2.71	3.29	4.55	5.17	6.10	6.94	7.69	8.69	10.09
30.00	7.45	7.53	7.45	6.94	6.40	5.31	3.42	2.41	2.91	4.00	5.52	7.30	8.40	9.38	10.84	12.39
50.00	6.21	6.40	6.52	5.71	4.52	2.98	1.78	1.21	1.53	2.22	3.74	5.17	6.60	7.56	8.77	9.90
70.00	4.71	4.80	4.63	3.66	2.33	1.02	0.67	0.56	0.73	0.90	1.85	3.11	4.41	5.30	6.32	6.97
100.00	3.18	3.07	2.55	1.70	0.84	0.43	0.39	0.41	0.60	0.69	0.76	1.38	2.30	3.08	3.71	4.01

November

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.27	0.27	0.28	0.30	0.31	0.32	0.34	0.33	0.34	0.33	0.33	0.36	0.41	0.45	0.52	0.59
3.00	0.39	0.40	0.43	0.44	0.46	0.48	0.50	0.49	0.50	0.49	0.54	0.57	0.62	0.71	0.80	1.05
5.00	1.09	1.10	1.15	1.23	1.39	1.49	1.40	1.44	1.42	1.58	1.55	1.56	1.68	1.97	2.17	2.36
7.00	1.72	1.72	1.71	1.82	2.06	2.00	1.92	1.90	1.93	2.19	2.27	2.40	2.80	3.23	3.43	3.58
10.00	2.85	2.81	2.70	2.75	3.00	2.69	2.31	2.28	2.58	3.11	3.40	3.92	4.66	5.30	5.85	6.40
16.00	5.24	5.15	4.86	4.67	4.69	4.34	3.10	2.78	3.38	4.76	5.64	6.67	7.64	8.58	9.78	11.10
30.00	7.54	7.42	6.97	6.40	6.15	5.08	3.35	2.44	2.97	4.30	6.10	7.86	8.68	9.82	11.39	12.74
50.00	6.30	6.27	5.95	5.17	4.23	2.76	1.76	1.17	1.60	2.44	4.09	5.64	6.61	7.70	9.08	9.93
70.00	4.63	4.52	4.14	3.25	2.10	0.98	0.76	0.60	0.74	0.98	2.01	3.43	4.56	5.59	6.04	7.04
100.00	2.87	2.77	2.26	1.51	0.77	0.44	0.63	0.52	0.61	0.53	0.78	1.69	2.48	3.44	4.03	4.11

December

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.25	0.25	0.27	0.30	0.32	0.34	0.35	0.34	0.34	0.33	0.35	0.37	0.39	0.45	0.56	0.64
3.00	0.38	0.39	0.42	0.44	0.48	0.52	0.51	0.51	0.51	0.49	0.53	0.57	0.61	0.76	1.04	1.20
5.00	1.05	1.08	1.15	1.25	1.38	1.52	1.46	1.46	1.47	1.60	1.60	1.57	1.71	2.00	2.51	2.85
7.00	1.66	1.66	1.71	1.82	2.02	2.07	1.95	1.95	2.01	2.22	2.31	2.48	2.81	3.14	3.54	3.90
10.00	2.71	2.69	2.68	2.72	2.93	2.82	2.48	2.35	2.61	3.10	3.50	4.07	4.80	5.28	5.68	6.10
16.00	4.90	4.84	4.67	4.51	4.53	4.34	3.39	2.88	3.48	5.09	6.02	7.08	8.24	9.09	9.70	10.05
30.00	7.10	7.01	6.65	6.15	5.68	4.71	3.20	2.42	3.09	5.28	6.97	8.21	9.28	10.41	10.91	11.02
50.00	6.18	6.02	5.43	4.64	3.68	2.47	1.68	1.18	1.77	3.14	4.59	5.88	7.10	8.30	8.65	8.46
70.00	4.34	4.17	3.57	2.78	1.80	0.86	0.78	0.63	0.82	1.12	2.10	3.74	5.34	6.26	6.40	6.30
100.00	2.55	2.40	1.87	1.24	0.67	0.41	0.72	0.58	0.63	0.47	0.81	1.88	3.34	3.09	4.09	4.10

January

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.24	0.25	0.28	0.30	0.33	0.34	0.34	0.35	0.34	0.32	0.34	0.36	0.38	0.41	0.51	0.60
3.00	0.38	0.39	0.42	0.46	0.50	0.53	0.53	0.53	0.53	0.49	0.51	0.53	0.67	0.76	1.07	1.32
5.00	1.07	1.10	1.14	1.28	1.48	1.55	1.49	1.52	1.57	1.58	1.45	1.60	1.68	2.23	2.90	3.40
7.00	1.70	1.71	1.73	1.88	2.09	2.13	1.96	1.97	2.05	2.18	2.20	2.38	2.66	3.16	3.72	4.04
10.00	2.79	2.76	2.74	2.80	2.88	2.88	2.61	2.34	2.50	2.94	3.35	3.82	4.32	4.72	5.07	5.25
16.00	4.98	4.94	4.75	4.54	4.30	4.17	3.34	2.79	3.31	4.83	5.90	6.72	7.43	8.07	8.61	8.77
30.00	7.15	7.09	6.63	6.03	5.24	4.13	3.00	2.23	3.08	5.63	7.61	8.37	9.17	10.20	10.88	10.95
50.00	6.12	5.92	5.19	4.24	3.20	2.14	1.56	1.15	1.76	3.36	5.23	6.47	7.20	8.39	8.91	9.22
70.00	4.18	3.98	3.29	2.39	1.45	0.87	0.78	0.64	0.80	1.17	2.69	4.41	5.40	6.43	6.84	7.17
100.00	2.35	2.19	1.66	1.00	0.55	0.51	0.70	0.62	0.67	0.52	1.06	2.41	3.47	4.19	4.41	4.58

February

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.20	0.27	0.29	0.32	0.33	0.35	0.34	0.33	0.32	0.32	0.34	0.36	0.37	0.38	0.38	0.38
3.00	0.40	0.41	0.44	0.47	0.51	0.54	0.52	0.54	0.52	0.47	0.40	0.52	0.56	0.61	0.64	0.67
5.00	1.10	1.18	1.21	1.36	1.60	1.60	1.53	1.40	1.57	1.61	1.35	1.36	1.57	1.90	2.10	2.30
7.00	1.90	1.88	1.86	2.00	2.11	2.15	2.00	1.87	2.00	2.13	2.03	2.19	2.62	3.04	3.20	3.42
10.00	3.17	3.11	2.99	2.97	2.92	2.81	2.46	2.20	2.36	2.72	3.21	3.82	4.38	4.70	4.75	4.78
16.00	5.62	5.60	5.16	4.79	4.40	3.92	3.04	2.51	2.90	3.97	5.32	6.50	7.14	7.26	7.22	7.09
30.00	7.77	7.57	6.97	6.13	4.90	3.61	2.67	2.03	2.95	5.00	7.29	8.58	9.27	9.58	9.74	9.94
50.00	6.47	6.18	5.31	4.23	2.90	1.79	1.31	1.09	1.66	3.30	5.36	6.88	7.84	8.55	8.90	9.25
70.00	4.37	4.11	3.27	2.33	1.28	0.72	0.67	0.57	0.73	1.02	2.76	4.57	5.68	6.63	7.23	7.82
100.00	2.40	2.21	1.58	0.91	0.47	0.41	0.53	0.38	0.55	0.60	1.13	2.45	3.48	4.42	5.05	5.55

March

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.32	0.32	0.32	0.33	0.35	0.35	0.33	0.33	0.34	0.33	0.34	0.35	0.35	0.37	0.40	0.44
3.00	0.50	0.40	0.49	0.51	0.53	-0.53	0.51	0.50	0.49	0.50	0.51	0.60	0.64	0.57	0.61	0.64
5.00	1.37	1.33	1.37	1.46	1.50	1.59	1.48	1.40	1.48	1.54	1.35	1.26	1.31	1.40	1.59	1.70
7.00	2.32	2.20	2.12	2.18	2.20	2.15	1.94	1.78	1.04	1.99	1.87	1.85	2.06	2.46	2.01	2.71
10.00	3.97	3.76	3.44	3.28	3.07	2.84	2.41	2.14	2.34	2.57	2.87	3.12	3.56	4.21	4.32	4.32
10.00	6.74	6.47	5.90	5.38	4.64	3.89	2.93	2.43	2.72	3.59	4.00	5.46	6.24	6.97	7.04	6.86
30.00	8.76	8.42	7.65	6.76	5.19	3.46	2.51	2.05	2.96	5.00	6.73	7.49	8.18	8.65	8.84	8.81
50.00	7.10	6.73	5.60	4.60	3.11	1.68	1.17	1.05	1.70	3.35	5.02	6.46	7.35	8.17	8.91	9.27
70.00	4.90	4.49	3.52	2.54	1.40	0.66	0.58	0.57	0.79	1.25	2.70	4.39	5.45	6.38	7.47	8.01
100.00	2.65	2.37	1.66	1.01	0.51	0.34	0.43	0.41	0.61	0.61	1.12	2.39	3.26	4.03	5.20	5.03

April

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.42	0.41	0.39	0.37	0.36	0.35	0.33	0.34	0.33	0.33	0.33	0.33	0.31	0.32	0.33	0.35
3.00	0.64	0.63	0.58	0.55	0.56	0.56	0.61	0.60	0.50	0.50	0.50	0.47	0.46	0.48	0.51	0.52
5.00	1.78	1.72	1.62	1.58	1.61	1.66	1.52	1.34	1.43	1.54	1.30	1.21	1.17	1.20	1.31	1.49
7.00	3.22	3.02	2.65	2.43	2.32	2.14	1.93	1.79	1.90	2.04	1.05	1.81	1.77	1.86	2.12	2.55
10.00	5.40	5.06	4.33	3.78	3.39	2.91	2.41	2.10	2.35	2.63	2.78	2.02	2.88	3.08	3.50	4.10
16.00	8.62	8.17	7.19	6.27	5.17	4.21	2.99	2.50	2.86	3.76	4.47	4.87	4.05	5.30	5.86	6.40
30.00	10.16	9.64	8.63	7.79	6.67	3.79	2.57	2.23	3.16	5.09	6.20	6.72	7.04	7.42	7.84	7.98
50.00	7.93	7.32	6.14	5.18	3.70	2.00	1.19	1.06	1.97	3.41	4.72	5.82	6.78	7.40	7.60	7.09
70.00	5.60	5.01	3.84	2.89	1.73	0.74	0.56	0.55	0.92	1.26	2:42	3.88	5.14	5.92	6.20	6.36
100.00	3.21	2.83	1.95	1.27	0.65	0.35	0.41	0.41	0.65	0.55	1.04	2.15	3.18	3.81	4.19	4.62

May

Pressure (mb)	-64	-60	-50	-40	-30	-20	-10	0	10	20	30	40	50	60	70	80
2.00	0.52	0.51	0.47	0.42	0.38	0.34	0.35	0.36	0.34	0.33	0.33	0.32	0.30	0.29	0.27	0.27
3.00	0.80	0.79	0.72	0.63	0.60	0.55	0.53	0.52	0.51	0.52	0.51	0.48	0.45	0.44	0.42	0.39
5.00	2.22	2.23	2.02	1.80	1.72	1.73	1.60	1.42	1.41	1.56	1.42	1.24	1.17	1.13	1.14	1.16
7.00	4.06	3.92	3.34	2.79	2.48	2.26	2.07	1.92	1.93	2.06	1.97	1.84	1.74	1.73	1.83	1.97
10.00	6.79	6.39	5.33	4.37	3.69	3.02	2.52	2.34	2.44	2.71	2.78	2.87	2.78	2.81	2.93	3.24
18.00	10.50	9.80	8.45	7.08	6.00	4.66	3.26	2.65	3.14	3.98	4.39	4.60	4.68	4.83	4.98	5.44
30.00	11.30	10.79	9.47	7.94	6.79	4.32	2.71	2.45	3.37	5.17	6.11	6.45	6.64	6.89	7.02	7.21
50.00	8.53	7.96	6.61	5.35	4.32	2.66	1.30	1.14	2.23	3.54	4.59	5.58	6.32	6.76	6.93	6.87
70.00	6.01	5.54	4.20	3.14	2.05	1.01	0.57	0.56	1.11	1.49	2.41'	3.01	4.65	5.21	5.56	5.62
100.00	3.51	3.25	2.35	1.51	0.70	0.45	0.30	0.35	0.83	0.59	1.02	1.94	2.83	3.27	3.65	3.81

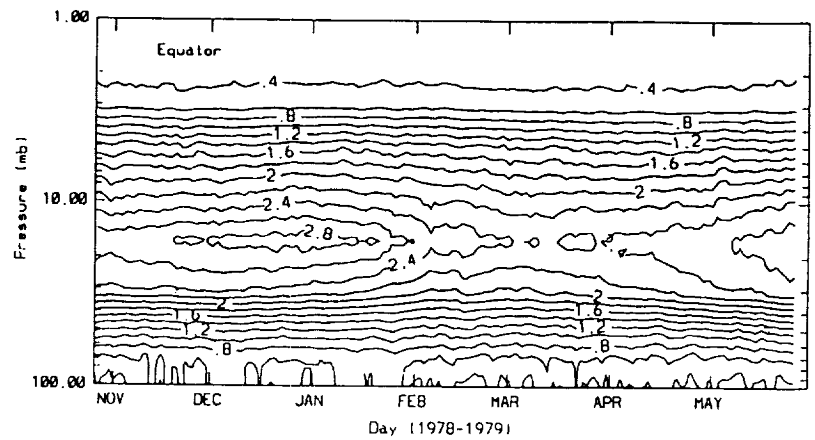

Figure 12. Time-height cross section of HNO_3 at the equator. Contour interval is 0.2 ppbv.

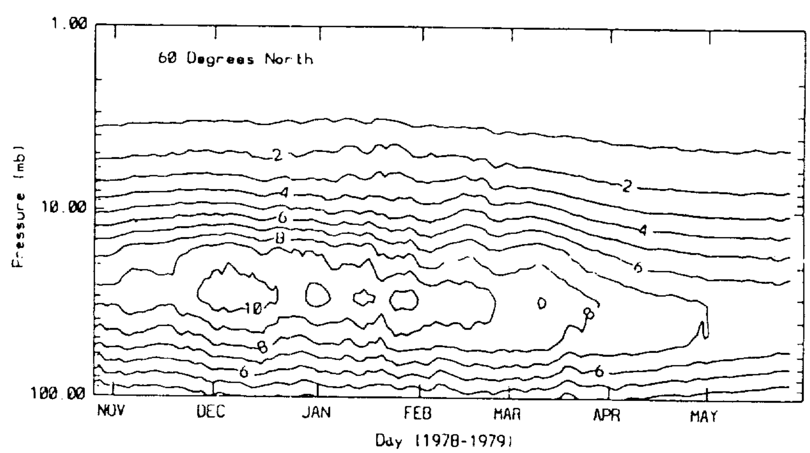

Figure 13. Time-height cross section of HNO_3 at 60°N. Contour interval is 1 ppbv.

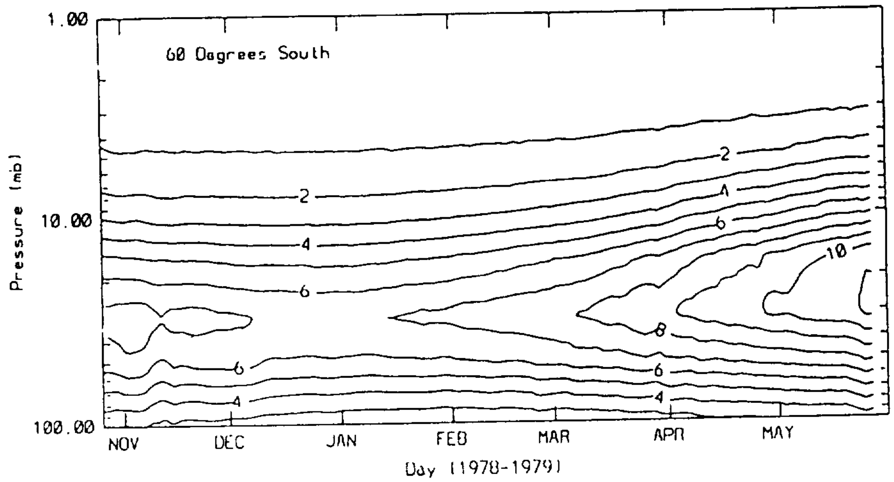

Figure 14. Time-height cross section of HNO_3 at 60°S. Contour interval is 1 ppbv.

CONCLUSIONS

The values of HNO_3 mixing ratio above 10 mb presented here have been corrected for an instrumental effect. The vertical mixing ratio profiles show a layered distribution, with the peak near 20 mb and low values in the tropics, where there is a small semi-annual variation. Poleward of 30° latitude the peak is at 30 mb and there is an annual variation, with maxima during late fall or winter and minima during summer. Cross-sections of monthly averaged zonal means emphasize the strong poleward gradients, and indicate a hemispheric asymmetry. In addition, there are slightly higher values at the upper levels near the winter pole.

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