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LIDAR MEASUREMENTS OF STRATOSPHERIC OZONE AT TABLE MOUNTAIN, CALIFORNIA, SINCE 1988.

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ABSTRACT

Regular measurements of stratospheric ozone concentration profiles have been made at Table Mountain, California, since January 1988. During the period to December 1991, 435 independent profiles were measured by the differential absorption lidar technique. These long-term results, and an evaluation of their quality, is presented in this paper.

1. INTRODUCTION

The development of a differential absorption lidar (DIAL) system at JPL, for long-term measurements of stratospheric ozone concentration profiles and potentially for inclusion in the Network for the Detection of Stratospheric Change (NDSC), began in 1986. The DIAL system at the JPL Table Mountain Facility (TMF, 34.4° N, -117.7° W) was developed specifically to have the characteristics suitable for long-term measurements as proposed for the NDSC and has been making routine measurements since January 1988. The experimental arrangement, which uses high power, ultraviolet laser wavelengths at 308 and 353 nm to probe the stratosphere, has been fully described elsewhere as have the data analysis procedures [*McDermid et al*, 1990(a), 1991, 1992].

2. PERFORMANCE EVALUATIONS

For such long-term measurement programs to be successful it is necessary to ensure the quality of the results by rigorous calibration procedures and intercomparisons. To evaluate the quality of the TMF lidar results it has participated in a number of intercomparisons [*McDermid et al*, 1990(b)(c)(d)] culminating with the first formal NDSC sponsored campaign, Stratospheric Ozone Intercomparison Campaign 1989 (STOIC), which was carried out at TMF during July and August 1989 [*Margitan et al*, 1992]. The STOIC study compared the ozone profiles measured by two DIAL systems, a 110 GHz microwave radiometer, electrochemical concentration cell (ECC) balloon sondes, ROCOZ-A rocket sondes, and SAGE II solar occultation satellite measurements. Some intercomparisons were also made with Umkehr inversions from Dobson and Brewer instruments. STOIC represented a very important stage in the development of stratospheric ozone DIAL systems since it confirmed the power of the technique for making reliable, accurate measurements [*McDermid et al*, 1992]. A summary of the performance of the TMF lidar during STOIC is shown in figure 1. This figure compares the mean lidar profile from the two week period with the mean of all of the other profiles (>200) and shows agreement to better than 5% over the range from 18 to 47 km altitude. The lidar results above 45 km are subject to the greatest uncertainty and are of limited value, even though they agree well with the STOIC average. A long-term comparison of ozone results from microwave, lidar and SAGE II is discussed in these proceedings [*Parrish et al*, 1992].

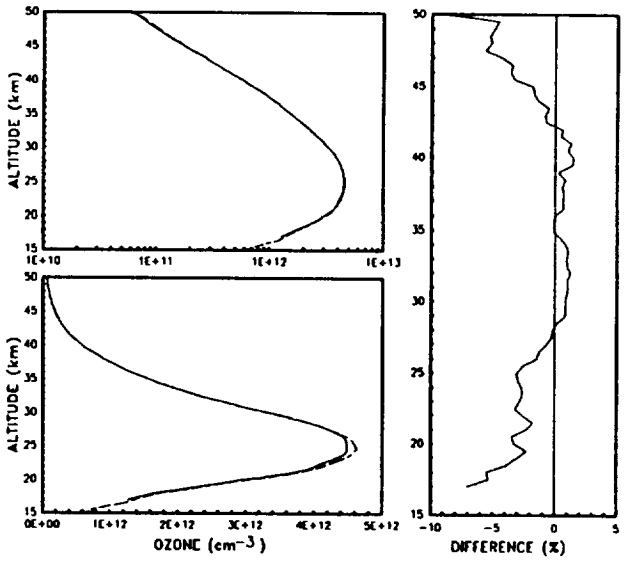

Figure 1. Comparison of the JPL lidar average to the overall average during STOIC. (Lidar results - *solid lines*, STOIC results - *dashed lines*).

3. LONG-TERM RESULTS

This paper considers the results obtained over the four year period from January 1988 through December 1991. During this period, some 435 independent ozone concentration profiles were measured. Initially the ozone profile was measured between 30 and 50 km altitude. These measurements were extended down to 20 km in July 1988 and then to approximately 16 km in January 1990.

The long term ozone lidar results are considered in terms of the monthly mean profiles. The distribution of these measurements is given in table 1 where the numbers of measurements that were made in each month, throughout the four year period, are listed. A mean climatology has also been developed from this data set and the total number of profiles contributing to each monthly profile is also given in table 1.

	1988	1989	1990	1991	Total
January		13	2	7	22
February	7	10	4	5	26
March	3	9	2	5	19
April	4	11	4	8	27
May	12	11	1	7	31
June	8	18	6	16	48
July	5	23	13	11	52
August	8	17	13	3	41
September	1	15	9	12	37
October	19	12	16	15	62
November	13	16	7	10	46
December	13	2	6	3	24
Total	93	157	83	102	435

Table 1. Distribution of ozone measurements by month.

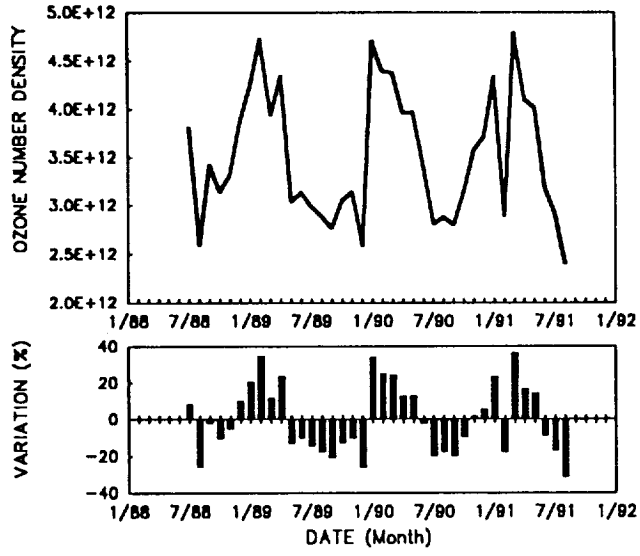

Figure 2. 20 km: monthly mean ozone variations.

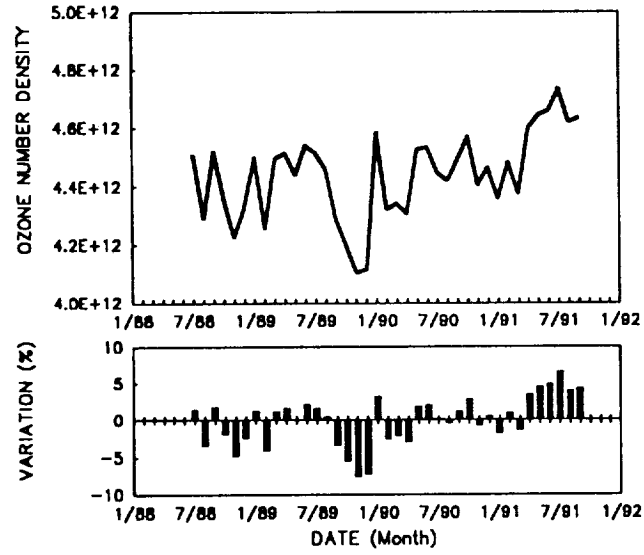

Figure 3. 25 km: monthly mean ozone variations.

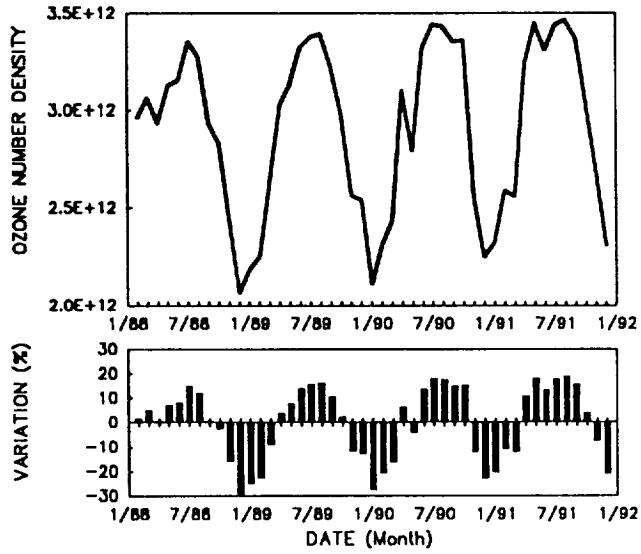

Figure 4. 30 km: monthly mean ozone variations.

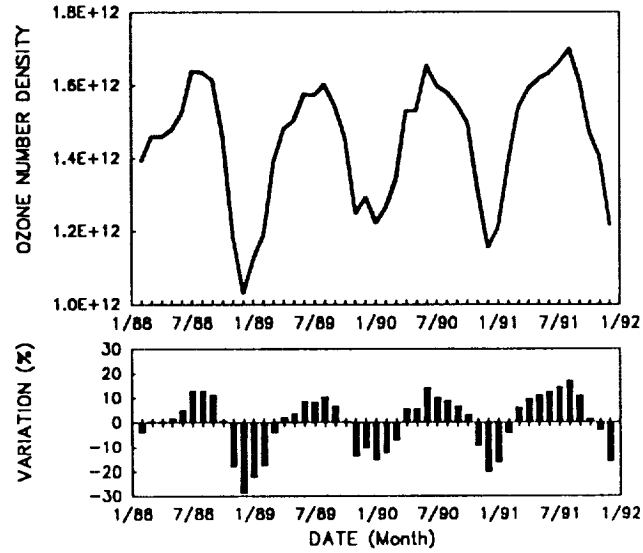

Figure 5. 35 km: monthly mean ozone variations.

The lidar data analysis provides ozone concentrations at 0.6 km intervals. The actual vertical range resolution varies from 1 km at 20 km, 2 km at 30 km, 4 km at 40 km, to 8 km at 50 km altitude. In figures 2-7 the monthly mean ozone concentration at fixed 5 km intervals from 20 to 45 km is plotted as a function of time. As an interpretive aid, the percentage variation of these concentrations about the overall mean for the specific altitude is shown in the associated bar graph.

There are a number of interesting features of these plots that should be noted. The first point relates to the very large magnitude of the percentage changes of the ozone concentration at most altitudes up to 40 km. At 20, 30, and 35 km (figs. 2,4,5) these variations are on the order of ±30%. A second point relates to the differences in the seasonal oscillations observed at different altitudes. Time-periodic variations in the ozone profile, as observed by SAGE II, have been described in detail by *Wang et all* 1988]. The lidar

results show similar behavior to the SAGE II data with an annual oscillation (AO) observed below 40 km (figs. 2,4,5), but with indications of a double, semi-annual oscillation (SAO) at 40 km and above (figs. 6,7). It is also interesting to note that the oscillations at 20 km are anti-correlated with those at 30 and 35 km, and at 25 km there is essentially a node point where the seasonal variations are <10% (fig. 3).

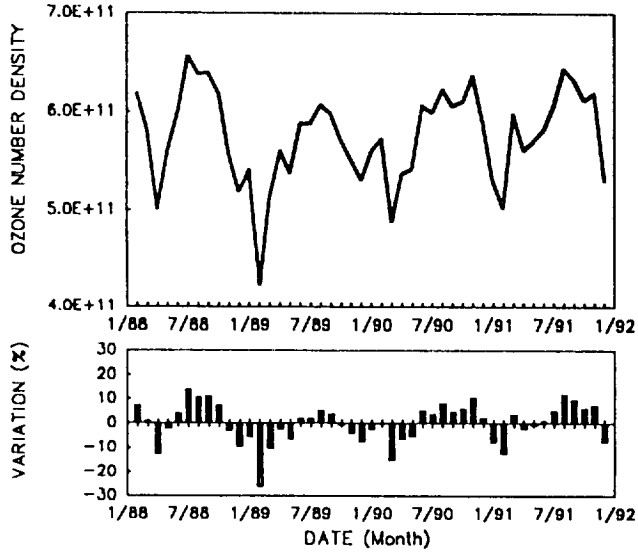

Figure 6. 40 km: monthly mean ozone variations.

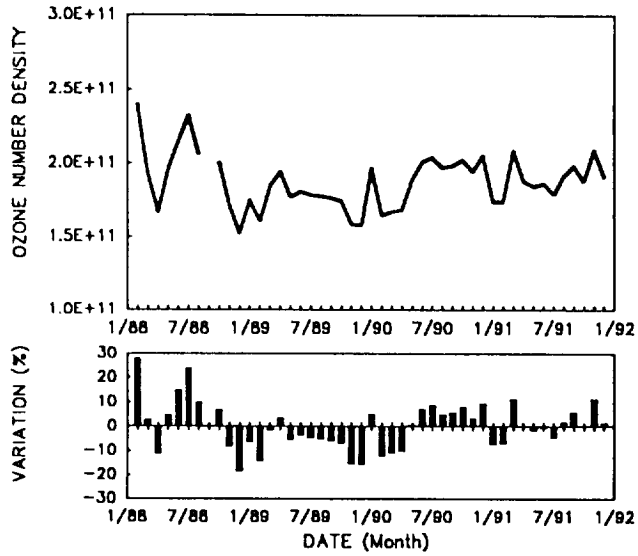

Figure 7. 45 km: monthly mean ozone variations.

All of the measurements made for each month over the four-year period have also been averaged to give a mean climatology for this location. The final column of table 1 gives the numbers of measurements averaged for each month. Example of these profiles for January, April, July and September are shown in figure 8. It is not possible to show all of the months on a single plot and still be able to discern the profiles for the individual months, however; the selected profiles shown examples of all seasons. It can be seen from figure 8 that in the winter, January, the peak of the ozone layer is at approximately 22 km and the maximum concentration is about 5.5 x 10^{12} molecule.cm^{-3}. The thickness of the layer, at the half-maximum-concentration points, is about 10 km. In the summertime, the peak of the ozone layer is at higher altitude, 25 km, and the maximum concentration is lower, approximately 4.5 x 10^{12} molecule.cm^{-3}. However, the thickness of the layer is greater at about 15 km. Figure 8 also clearly shows the node in the seasonal variations at 25 km.

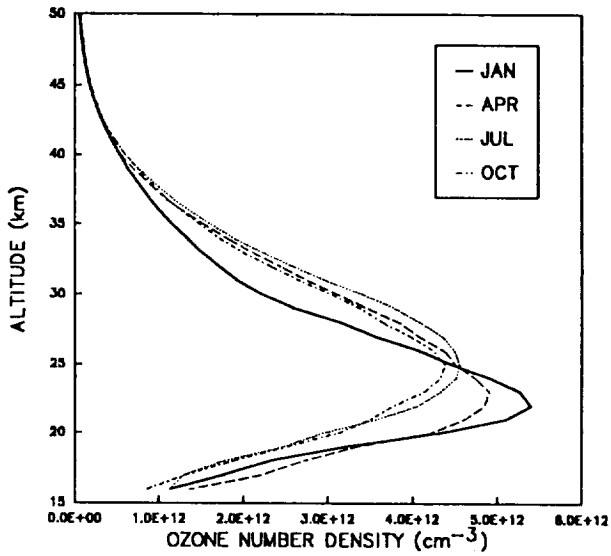

Figure 8. Four-year monthly averages for January, April, July, and September. Other months are omitted for clarity.

It is obvious from figure 8 that most of the seasonal variations observed in the ozone concentration profile are due to redistribution of ozone. As part of the routine lidar data analysis the ozone concentration profile is integrated between 20 and 40 km and converted to Dobson units (DU). The seasonal variations in this ozone column are shown in figure 9.

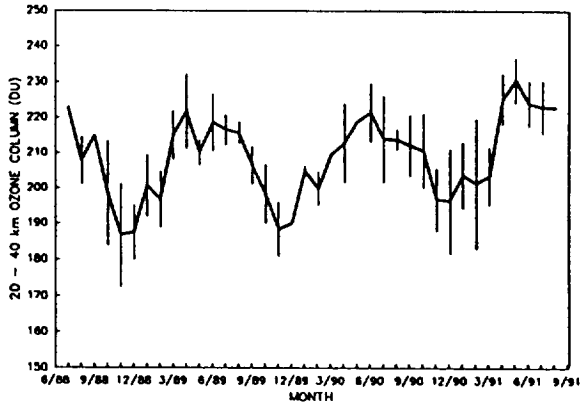

Figure 9. Seasonal variation of the monthly mean integrated ozone column from 20 - 40 km altitude in Dobson units. Error bars indicate the standard deviation of the mean.

The mean ozone column content from 20 - 40 km is on the order of 200 DU for the period under study. The seasonal variations observed in this column are <10%.

4. VOLCANIC AEROSOLS

Mount Pinatubo (15.1° N, 120.4° W) erupted in June 1991, injecting large quantities of material into the stratosphere. Enhanced atmospheric backscattering was first observed at TMF, in the region between 15 and 20 km, on July 4, 1991. At the beginning of August, 1991, sporadic enhancement of the aerosol scattering above 20 km was observed. By the end of 1991 substantial aerosol scattering up to 30 km altitude was observed in all lidar measurements. On some occasions there were aerosol layers up to 35 km. Figure 10 shows an example of a recent stratospheric aerosol backscattering profile at 353 nm.

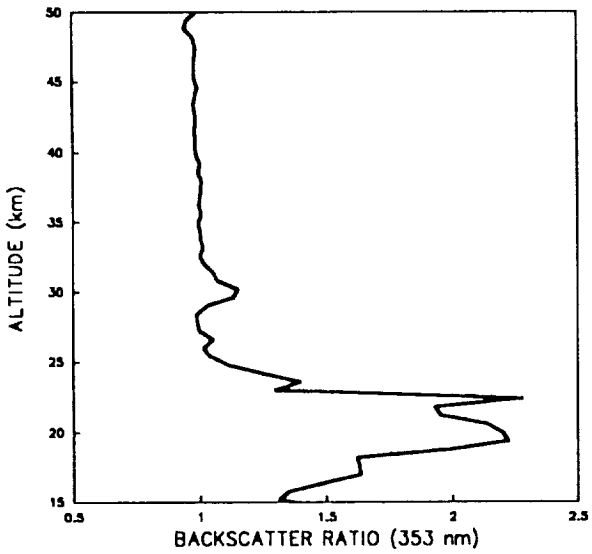

Figure 10. Aerosol backscattering profile for May 1, 1992.

The presence of these aerosols has a major impact on the measurements of stratospheric ozone concentration profiles using the differential absorption lidar technique. In the altitude regions of the aerosol layers, the wavelength differential of the aerosol backscatter and extinction coefficients is not sufficiently well established to make corrections and accurate ozone values cannot be retrieved at the present time in these regions. However, even though the ozone measurements are compromised in the regions of the aerosol layers, they appear to be unaffected in clear regions and ozone measurements up to approximately 50 km are still possible.

A modification to the DIAL technique using the atmospheric nitrogen Raman signal has been suggested and demonstrated by the NASA-GSFC Lidar Group [*McGee*, 1992, *Singh et al*, 1992]. This new method allows the determination of ozone values within the aerosol layers and system modifications are presently underway to implement this method with the TMF lidar.

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