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RESULTS FROM TWO YEARS OF OZONE DATA TAKEN WITH A NEW, GROUND-BASED MICROWAVE INSTRUMENT: AN OVERVIEW

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ABSTRACT

An overview of two years of data obtained with a ground-based microwave instrument is given. Intercomparisons with data obtained by the co-located JPL lidar and by SAGE II during near overpasses of the site are discussed, as are comparisons with mesospheric data taken earlier by SME and LIMS. Observations of diurnal variations of mesospheric ozone are shown.

Ground-based microwave observation of emission lines from the rotational transitions of ozone in the middle atmosphere has several advantages for ozone measurement and monitoring: measurements can be made day or night with high time resolution; the technique covers a wide altitude range, from 20 to 70 km; it is calibrated using accurate and easily constructed black body thermal sources; it is unaffected by stratospheric aerosol loading; and it is readily adaptable to semi-automatic operation.

In July, 1989, a new, ground-based microwave ozone instrument developed at the Millitech Corporation was installed at the Table Mountain Observatory in southern California (34 deg. N, 118 deg. W). Except for the period between November, 1989 and May, 1990, the instrument has been in nearly continuous operation since installation, recording an observation every 20 minutes. The instrument is largely automated so that it requires a minimum of operator intervention. It can be accessed remotely by dial-up modem; its data are downloaded to the NASA-Langley Research Center for processing in this manner.

A differential absorption lidar operated by the Jet Propulsion Laboratory (McDermid, et al., 1990) is also located at the Table Mountain site, making frequent simultaneous and co-located intercomparisons possible over a two year period. Occasional overpasses of the Table Mountain site by the SAGE II satellite instrument (McCormick, et al., 1989) furnishes a third data set for intercomparison. While not simultaneous, data from SME and LIMS are available for comparison at the highest altitudes covered by the microwave instrument.

The instrument consists of a microwave receiver and a 122 channel spectrometer. It is normally tuned to observe the ozone line at 110.836 GHz ($\lambda = 2.6$ mm); it can, alternatively, be tuned to the line at 109.559 GHz as a check of internal self consistency. The instrument is calibrated using the thermal radiation from blackbody standards. The instrument, the observing technique, and calibration method are described in Parrish, et. al, 1992. A typical spectrum is also shown in that paper. The ozone altitude distribution is retrieved from the details of the pressure-broadened spectral line shape. The retrieval method is described in Connor, et al., 1991, and Parrish, et al., 1992, and is based on the work of Rodgers (1976).

Connor, et al., (1991) describes an analysis of the vertical resolution and errors of measurements made with our instrument. These errors depend on the instrument characteristics, the retrieval algorithm parameters and the integration time. For the parameters used in preparing the typical daily average, the vertical resolution is 8 to 10 km at altitudes between 20 and 40 km, degrading to 14 km at 60 km and remaining between 14 and 15 km at altitudes between 60 and 70 km. (Further calculations indicate that the resolution could be improved to 10 km at altitudes up to 70 km altitude by increasing the number of high resolution channels near the line center in the spectrometer.) The vertical resolution is defined as the full width to half maximum of the instrument averaging kernels, as discussed in Rodgers (1990). The estimated accuracy for an integration time of eight hours during the daytime (i.e. a typical "daily average") is 5 to 8% between 20 and 60 km, degrading to 23% at 70 km. The mesospheric accuracy is improved at night because of the increased mesospheric ozone concentration, so that the estimated accuracy becomes 5 to 8% from 20 to 70 km.

Comparisons of three or more independent measurements that are, to the extent possible, simultaneous and co-located, are useful in determining the source of discrepancies between any pair of measurements. Figure 1 shows differences between averages of microwave data and of lidar and SAGE data when the averages are taken over various periods of several months between July, 1989 and June, 1991. Because the lidar and SAGE measurements have much higher vertical resolution than the microwave measurement, the lidar and SAGE data have been smoothed with the microwave averaging kernels to eliminate the effect of unequal vertical resolutions from the intercomparisons. The differences are typically about 5%. With the exception of the SAGE-microwave difference above 46 km in the September-December 1990 period, they are less than 10%. There is a clear quasisinusoidal pattern to the differences, and the fact that the other two instruments agree better with each other than with the microwave instrument up to 42 km suggests that

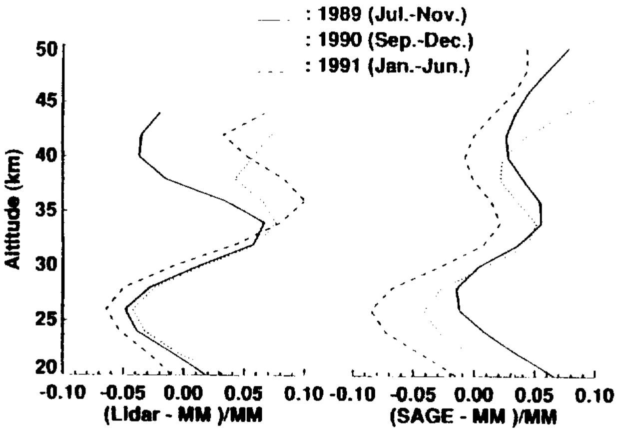

Figure 1. Each curve shows the difference between the JPL lidar and microwave data (left panel) and between the SAGE II and microwave data (right panel), when averaged over a subset of the data. Curves are shown for several periods between July, 1989 and June 1991. The lidar and SAGE data have been smoothed to the resolution of the microwave measurement using the microwave averaging kernels.

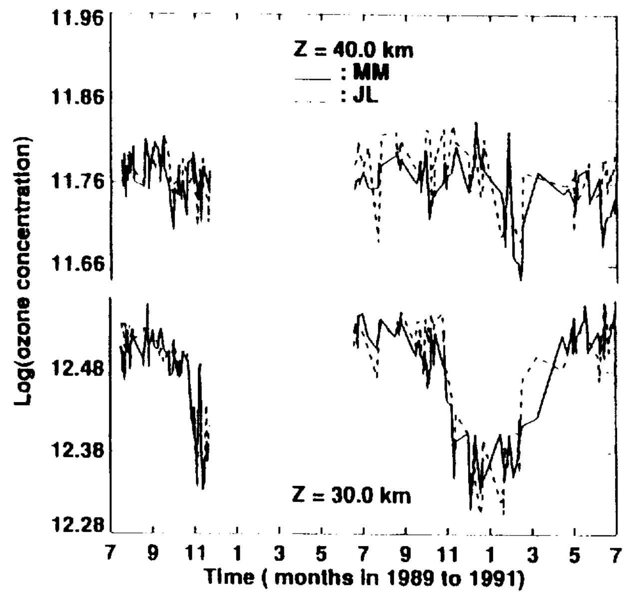

Figure 2. Time series of microwave and JPL lidar data at 30 and 40 km. The log of the ozone concentration is plotted against time. The two instruments track each other closely during seasonal ozone variations, and both see sharp short term variations on November 5, 1989 and November 8, 1990. (Adapted from Tsou, Connor, Parrish, McDermid, and Chu "Ground-based Microwave Observations of Ozone: Comparison to lidar and satellite observations", presented at the 24th General Assembly of the IUGG, August 11-24, 1991.)

this pattern is due to a systematic effect of the microwave measurement. We do not presently know whether it is an effect of this particular instrument or one of the measurement technique. There is an approximation in the present data processing algorithm that causes the ozone to be slightly underestimated at higher altitudes; qualitatively, it appears that eliminating this approximation should bring the microwave data into better agreement with the other two instruments. This approximation is being eliminated in a reprocessing of the data that is now underway.

There is no evidence for relative calibration drift between the microwave and the other two instruments. The microwave-lidar difference patterns shown in Figure 1 are very consistent over time up to 34 km, varying 3% or less over the two year period. The microwave-SAGE II patterns change more from period to period below 35 km than do the microwave-lidar differences; this is probably due to the smaller number of microwave-SAGE II intercomparisons, and the fact that the SAGE overpasses may be as far as 1000 km from the Table Mountain site in the set selected for intercomparison. However, the microwave-SAGE patterns have the same shape over a wide range of altitude, changing less than 7% over time up as far as 45 km, and less than 4% in the 35 to 40 km range.

Individual ozone measurements made by both the lidar and the microwave instrument are shown in Figure 2 as a function of time between July, 1989 and June, 1991 for altitudes of 30 and 40 km. The figure shows that both instruments see a seasonal ozone decrease in November at 30 km and natural short term ozone variations during this period.

To look for interannual variations, we have compared the lidar and microwave data taken during corresponding periods in 1989 and 1990. Figure 3 shows data from two periods when numerous good measurements were made by both instruments in both years. The instruments agree to within 5% in both cases; in the November period there is a clear interannual variation of up to 10% that is seen by both instruments.

Mesospheric data sets available for intercomparison with the microwave data include those produced by the infrared and ultraviolet instruments on the SME satellite, and that from the LIMS instrument. The SME near infrared measurements were made in emission in daytime (Thomas, et al. 1984) and covered 0.75 mb to .002 mb (51 to 90 km). The SME ultraviolet absorption measurements (Rusch et al., 1984) only covered the range between 1.0 to 0.1 mb (48 to 66 km); this range is too narrow for direct intercomparison with the microwave data, given the low vertical resolution of the microwave measurement. LIMS zonal mean data are available up to 0.1 mb (Remsburg, et al. 1984). It is now known that the LIMS daytime data are subject to non-LTE effects which preclude the retrieval of an accurate profile above 0.5 mb (Solomon, et al. 1986), but the nighttime data should be nearly free of these effects. Of course, the SME and LIMS measurements were not made simultaneously with the microwave measurements. To obtain comparable data, we have chosen LIMS and SME data that were taken at the latitude of the microwave instrument site, on dates that correspond seasonally to the dates when the microwave measurements were made, and as nearly at the same phase of the solar cycle as possible. The microwave data used for the intercomparisons were taken between October, 1990 and June, 1991; the SME data are from 1982, and the LIMS data are from 1978 and 1979. The data are from the NSSDC archives; the LIMS data are described in Remsburg, et al., (1990), and the SME data have been reprocessed as described in WMO (1988).

The SME and LIMS data also have been convolved with the averaging kernels of the microwave measurement to make them comparable to the microwave data. The averaging kernels were calculated using the technique described in Connor, et al., 1991. Although 70 km is

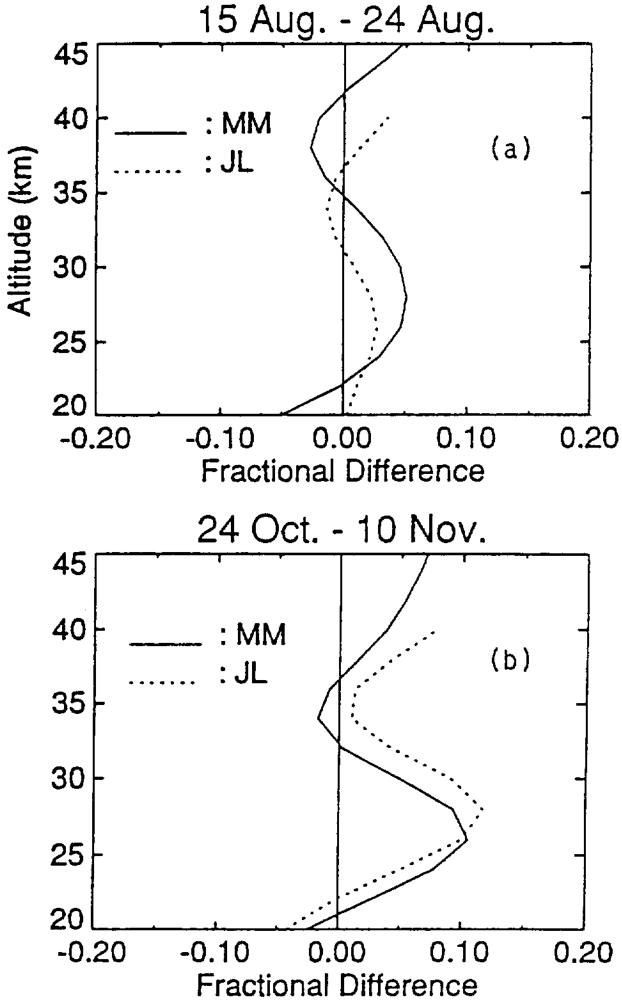

Figure 3. Interannual ozone changes: the fractional difference in ozone between two periods in 1990 and corresponding periods in 1989 as measured by the JPL lidar and by the microwave instrument. The lidar data have been smoothed to the resolution of the microwave measurement using the microwave averaging kernels.

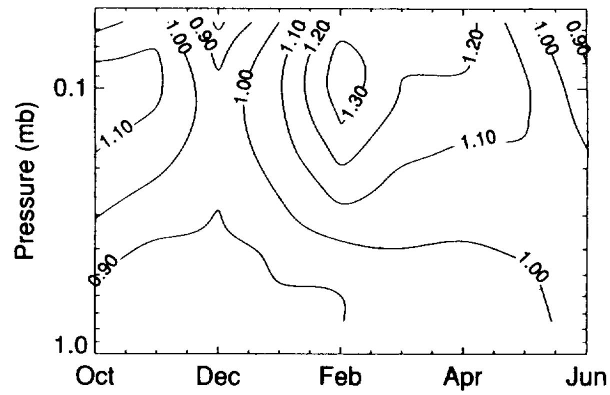

Figure 4. Comparison of the microwave data to SME infrared data for midafternoon daylight hours. The SME data has been convolved with the microwave averaging kernels, and the microwave-measured mixing ratios divided by the convolved SME mixing ratios are plotted versus altitude (pressure) and month.

the upper limit at which the microwave instrument can make altitude-resolved measurements, the averaging kernels were calculated for altitudes up to 90 km to include the contribution from ozone above 70 km to the microwave data.

Figure 4 shows the ratio of the microwave data to the convolved SME infrared data, in a contour plot against pressure and month. Data taken near 1530 hours, local solar time was selected for this plot. Because the SME data extends up to 90 km, it completely covers the altitude range over which there may be a significant contribution to the microwave retrieval. The agreement over the 8 month time span is typically within 10%, except for one discrepancy of up to 30%. Because the microwave measurement errors are of the order of 20% at those altitudes during daylight hours, and because the measurements were not made simultaneously, we do not consider this discrepancy significant.

Figure 5 is a contour plot of the ratio of the microwave data to the convolved LIMS data for times near local midnight. Because the LIMS data only covers up to 0.1 mb (66 km), it is necessary to extrapolate the LIMS data above this limit in order to convolve it with the microwave averaging kernels. Above 0.1 mb, we have assumed that the mixing ratio is equal to its value at 0.1 mb in performing the convolution. The results shown in the figure begin to be affected by this assumption above about .3 mb, increasingly so with increasing altitude. The figure shows that the microwave and convolved LIMS data agree to 5% over most of the 10 - 0.1 mb altitude range throughout the seven month period.

The microwave instrument's altitude coverage to 70 km and high time resolution give it the capability needed for measuring the diurnal variation of mesospheric ozone. Figure 6 shows, as an example, the average ozone mixing ratio as a function of local solar time for the month of December, 1990. In forming the average, the retrieved profiles are binned by solar elevation angle, with the bins defined so that each represents approximately 30 minutes of elapsed time except within about an hour of sunrise and sunset, when each bin corresponds to approximately 20 minutes. The principal features of the data are as follows: The midnight to midafternoon ratio increases from about 14% at 50 km to a factor of 6 at 70 km. There is an early morning minimum at 60 and 70 km, and a clear morning-afternoon asymmetry at all three altitudes. Similar features have been reported by Zommerfelds, et al., (1989). The relatively low resolution of the microwave measurements must be taken into account in comparing these data with models; this may be done by convolving the model output with the measurement averaging kernels, for example. This work is in progress.

CONCLUSIONS

From these intercomparisons, we conclude that the precision of the microwave measurement in the stratosphere is 4 to 8%, as calculated in the error analysis of Connor et al., 1991. The long term comparisons with the lidar and SAGE indicate that the absolute accuracy of the microwave measurement is 7% or better up to 45 km; and that the stability of the measurements is such that interannual variations can be measured with an accuracy of 5% up to at least 40 km. In the mesosphere, the microwave data are consistent with SME and LIMS data taken at the same latitude and season, thereby strengthening the

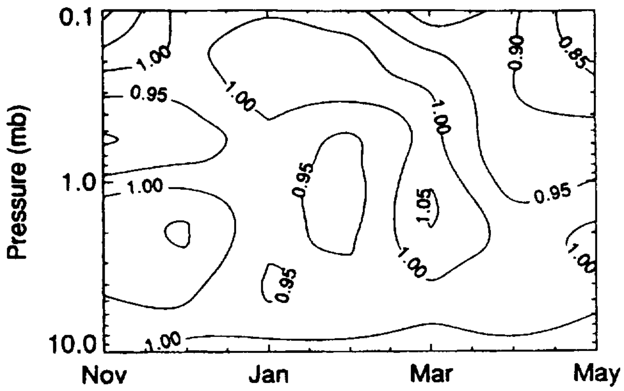

Figure 5. Comparison of the microwave data to LIMS data for times near midnight. The LIMS data has been convolved with the microwave averaging kernels and the microwave mixing ratios divided by the convolved LIMS mixing ratios are plotted versus altitude (pressure) and month. See discussion in the text.

climatological data base for comparison with mesospheric models.

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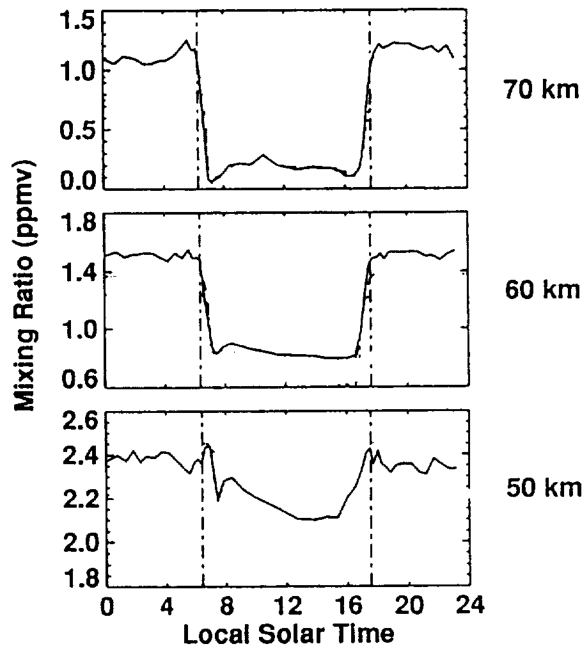

Figure 6.The ozone mixing ratio as a function of local solar time for December, 1990. The data are binned as described in the text.

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