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GENERAL COMPARISON OF OZONE VERTICAL PROFILES OBTAINED BY VARIOUS TECHNIQUES DURING THE 1983 MAP/GLOBUS CAMPAIGN*

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Abstract—As part of the 1983 MAP/GLOBUS campaign, atmospheric ozone profile measurements were made using a large variety of different techniques both from balloon platforms and the ground. It is shown that, for most techniques, the measured height distributions agree to within ±5% with the exception of the remote visible absorption method. This ±5% uncertainty is of the order of the individual inter-system accuracy. It is suggested that since the differences with the visible absorption method are in magnitude rather than in form, that the absorption cross-section data could be the possible cause for the discrepancy.

INTRODUCTION

One of the major scientific objectives of the first MAP/GLOBUS campaign was to make accurate measurements of atmospheric ozone; see Offermann (1983). The further aim was that with such measurements the accuracy of each type of ozone instrument could be determined by

(1) the comparison of *in situ* type instruments;
(2) the comparison of remote sensing instruments;
(3) the comparison of remote *in situ* data where possible;
(4) the comparison of ground based data with that from balloons launched from the same place.

A summary of the various ozone sensing devices used during MAP/GLOBUS and their principal investigators is given in Table 1.

The comparison of data from the *in situ* instruments is given in Aimedieu *et al.* (1987) while that of the remote instruments in de la Noë *et al.* (1987) and Simon *et al.* (1987). A large gondola instrumented specifically to measure atmospheric O_3, Gondola G3, was flown twice during MAP/GLOBUS and the flight on 14 September coincided with the flight of the planetary occultation instrument of Rigaud, detailed in Simon *et al.* (1987). The data from this instrument, measuring the ozone absorption in the Chappuis band during the rising of Venus, and that from a spectrometer measuring the absorption due to O_3 in the solar spectrum, in both the Chappuis and Huggins bands, see Simon *et al.* (1987), are used as data sets

*Joint publication of results from the MAP/GLOBUS campaign of 1983.

TABLE 1. SYSTEMS USED TO PRODUCE OZONE PROFILES DURING MAP/GLOBUS

Instrument	Technique	Location	Principal investigator(s)	Affiliation
Ground-based				
Lidar	u.v. absorption	Observatoire Haute Provence (OHP)	G. Megie J. Pelon	Service d'Aeronomie du CNRS, Verrieres
Dobson	u.v. absorption (Umkehr)	OHP	P. Marché	Université de Reims, Reims
Dobson	u.v. absorption (Umkehr)	Biscarosse	M. Lovisa	Station Mesostratosphérique, EERM, Biscarosse
Microwave radiometer	μ wave emission	Floriac	J. de La Noë	Observatoire de l'Université de Bordeaux I, Floriac
Lidar	u.v. absorption	Zugspitze	K. W. Rothe	Sektion Physik der Univ. München, Munich
Balloon-borne (a) *remote*				
Stellar occultation	vis. absorption	Aire sur l'Adour	P. Rigaud	Laboratoire de Physique et Chémie de l'Environnement, Orléans
Spectrometer	vis. absorption u.v. absorption	Aire sur l'Adour	P. C. Simon	Institut d'Aeronomie Spatiale de Belgique, Brussels
Microwave radiometer	μ wave emission	Aire sur l'Adour	C. J. Gibbins	Rutherford Appleton Laboratory, Chilton, U.K.
Spectrometer	i.r. emission	Aire sur l'Adour	D. Offermann	Physics Dept., University of Wuppertal, Wuppertal
Balloon-borne (b) in situ				
Chemiluminescent	gas phase reaction	Aire sur l'Adour	P. Aimedieu W. A. Matthews	Service d'Aeronomie du CNRS, Verrieres
Modified Dasibi	u.v. absorption	Aire sur l'Adour	D. Robbins	NASA Johnson Space Center, Houston
Brewer-Mast	wet chemical	Aire sur l'Adour	W. A. Matthews W. Attmannspacher	Service d'Aeronomie du CNRS, Verrieres
Brewer-Mast	wet chemical	OHP	G. Megie	Service d'Aeronomie du CNRS, Verrieres
Brewer-Mast	wet chemical	Observatorium Hohenpeissenberg	W. Attmannspacher	Observatorium Hohenpeissenberg, Hohenpeissenberg
Brewer-Mast	wet chemical	Uccle	D. De Muer	Institut Royale Metéorologique, Brussels
E.C.C.	wet chemical	Aire sur l'Adour	W. Komhyr W. A. Matthews	NOAA Environmental Resources Laboratory, Boulder
E.C.C.	wet chemical	El Arenosillo	J. M. Cisneros	Instituto Nacional de Meteorologia, Madrid
E.O.L.O.	decolouration tubes	Aire sur l'Adour	J. M. Cisneros	Instituto Nacional de Meteorologia, Madrid
E.C.C.	wet chemical	Garmisch Partenkirchen	R. Reiter	Fraunhofer Institute für Atmosphärische Umweltforschung, Garmisch-Partenkirchen

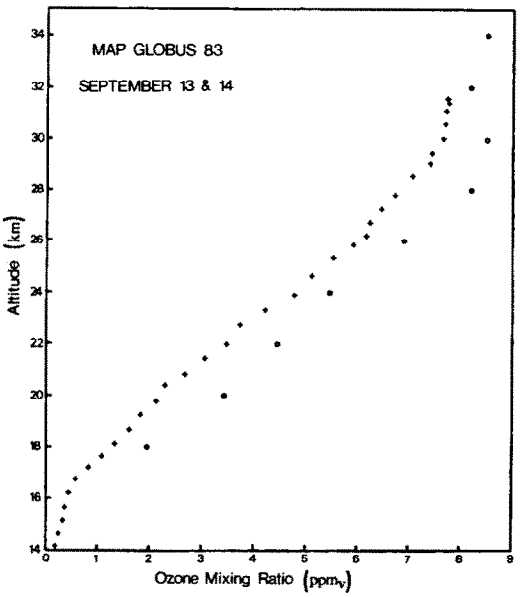

FIG. 1. OZONE MIXING RATIOS (ppmv) DERIVED FROM SELECTING AND AVERAGING *in situ* MEASUREMENTS PERFORMED WITH A VARIETY OF TECHNIQUES ON GONDOLA G3 FROM THE FLIGHT ON 14 SEPTEMBER (CROSSES) TOGETHER WITH THOSE MEASURED REMOTELY BY PLANETARY OCCULTATION ON THE NIGHT OF 13/14 SEPTEMBER (OPEN CIRCLES), ARE PLOTTED AS A FUNCTION OF ALTITUDE.
The planetary occultation experiment observed the rising of Venus and the data from this instrument are systematically larger than the *in situ* data.

to link the remotely measured ozone to that measured *in situ*.

Fortunately, there were not large variations in total ozone observed over southern France during September 1983; see de La Noë *et al.* (1987) and Muller and Krueger (1987). These latter authors also demonstrate that the balloon trajectories were essentially parallel to the ozone gradients, suggesting that there was little ozone variation during the balloon flights themselves.

In their paper, Aimedieu *et al.* (1987) conclude that in the 70–10 mb height region, the sampling techniques they studied produced coherent data. Further, they suggest that it is possible, using a combination of such instruments, to estimate the ozone mixing ratio in this height region with a 3% uncertainty.

The uncertainty in the remote measurement with the planetary occultation instrument varies from 10% at 18 km to 4% at 34 km; see Simon *et al.* (1987). These data, together with the "average" profile from the G3 gondola are plotted in Fig. 1.

As already mentioned, analysis of data from the high resolution infrared sounder on the *Tiros-N* satellite series and the total ozone mapping spectrometer on *Nimbus* 7 for the period of the MAP/GLOBUS campaign, see Muller and Kreuger (1987), showed that the total ozone contours were roughly parallel with the flight paths on 13/14 September.

Gondola G5 with the stellar occultation experiment was started some 7 h before G3 was launched and the maximum separation of the trajectories during the ascent phases of these flights differed by only some 7 km.

The planetary occultation experiment observed the rising of Venus in the East which further distances its observation points from that measured *in situ* on Gondola 3. However, from the curves shown in Fig. 1, it can be seen that while the trend in ozone mixing ratio is followed fairly closely it is the absolute values that differ. On average the ozone values retrieved by the remote method using the Chappuis bands are 25% higher than those measured *in situ*.

This same trend of consistently higher ozone values retrieved from Chappuis band absorption measurements is shown in Fig. 2, where the averaged data from the *in situ* gondola G3 are compared with those of the visible/u.v. spectrum flown on gondola G2b; see Simon *et al.* (1987).

The same arguments pertaining to the non-simultaneity of measurements and the spatial separation of the sampling volumes as discussed in relation to Fig. 1 also apply here. Even though the ground-based and satellite total ozone data indicate a slight increase in the amount of O_3 in the atmosphere between 24 and 28 September, the differences are still outside the error bars of each data set.

The data obtained with the same spectrometer, but utilizing the absorption by ozone in the Huggins band exemplify the discrepancy. These data, measured on 28 September, agree more closely in absolute value with the average profile from the *in situ* measurements. However, the data appear to exhibit a different form. These data show a rapid decrease in O_3 mixing ratio above 28 km and this is not seen by *in situ* data. This is possibly a consequence of viewing the sun at angles close to the balloon's horizon and hence errors in the pressure altitude propagate into the geometrical altitude and significantly affect the data inversion technique.

Ozone profiles were measured remotely from the ground during MAP/GLOBUS by three independent techniques. A u.v. lidar system using the DIAL technique was operated during the night from the Observatoire de Haute Provence, several Dobson spectrophotometers made Umkehr observations at twilight and a microwave spectrometer was operated at the Observatoire de Bordeaux in the 110 GHz region to measure the theremal emission by ozone of

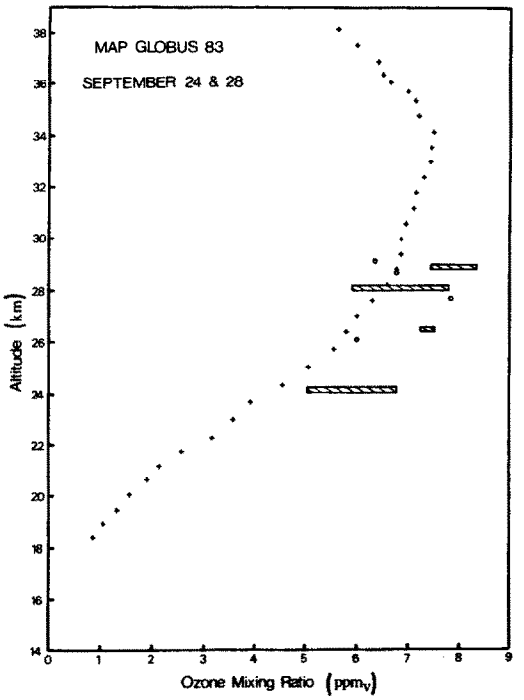

FIG. 2. OZONE MIXING RATIO DATA FROM GONDOLA G3 FROM ITS FLIGHT ON 24 SEPTEMBER TOGETHER WITH DATA MEASURED WITH THE VISIBLE AND ULTRAVIOLET SPECTROMETER FLOWN ON GONDOLA G2b ON 28 SEPTEMBER ARE SHOWN AS A FUNCTION OF ALTITUDE.
Again the Chappuis band measurements (shaded band) are consistently larger than the *in situ* data (crosses), while those retrieved from the ultraviolet absorption measurement (open circles), although matching more closely in absolute value, differ in the form of their profile.

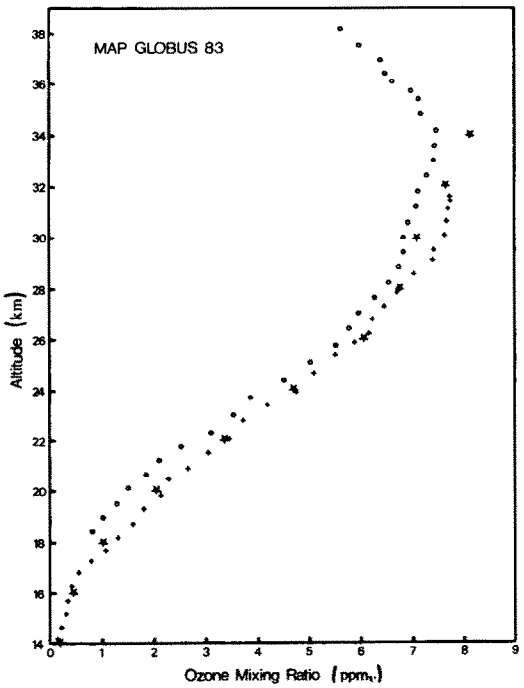

FIG. 3. OZONE MIXING RATIOS MEASURED *in situ* ON GONDOLA G3 FROM ITS FLIGHTS ON 14 SEPTEMBER (CROSSES) AND 24 SEPTEMBER (OPEN CIRCLES) COMPARED WITH THE "OZONE REPRESENTATIVE ATMOSPHERE" (STARS), SEE SIMON *et al.* (1987), WHICH IS THE AVERAGE PROFILE COMPILED FROM DATA RECORDED AT THE OBSERVATOIRE DE HAUTE PROVENCE BETWEEN 9 AND 28 SEPTEMBER 1983.

the 6_{06}–6_{15} rotational transition. The pressure broadening of this line allows an ozone profile to be retrieved.

The data from these techniques are intercompared in de La Noë *et al.* (1987). These authors draw several conclusions from the month of data they obtained while operating their instruments in parallel during the MAP/GLOBUS campaign. They compared the lidar results with the Umkehr observations from levels 4, 5 and 6 and Brewer-Mast *in situ* profiles from Brewer-Mast sondes released from the Observatoire de Haute Provence. In level 4, the agreement is within the individual error bars of 5%. For level 5, while the lidar and Brewer-Mast values agree within their 5% uncertainty, the Umkehr values are some 10% lower. It is suggested that these lower Umkehr values are the result of aerosol interference in the retrievals; see de La Noë *et al.* (1987).

The averaged lidar and Umkehr values compare quite well in level 6 but there is a larger scatter in the data. In this region centred on 32 km, the lidar measurements are less accurate and the Brewer-Mast sondes less efficient, as has been shown in other studies, e.g. Mégie and Pelon (1983), Aimedieu *et al.* (1983) and Hilsenrath (1984).

Ozone profiles measured with microwave radiometers during MAP/GLOBUS are also available for comparison; see de La Noë *et al.* (1987). The profiles cover the altitude range from 30 to 85 km. At their lower altitude limit, the lidar and Umkehr observations are intercompared with those from the ground-based microwave radiometer, and the microwave data appear to produce systematically larger ozone values than either the lidar or the Umkehr systems but just within the error bars of the Umkehr observations. As a means of linking the *in situ* data measured on gondola G3 with ozone profiles retrieved from remote measurements made at the ground, an average profile for September 1983 has been obtained, calculated from data recorded at the Observatoire de Haute Provence. These data are plotted in Fig. 3 together with averaged profiles for the two flights of gondola G3.

As can be seen in this figure, the so called "MAP/GLOBUS representative atmosphere", Simon *et al.* (1987), fits the *in situ* data well, with the possible exception of the region around 34 km. However, here the differences are still well within the error bars. It should be noted that the two higher altitude data points for the representative atmosphere were obtained from model calculations given in Kreuger and Minzer (1976).

CONCLUSION

The ozone profiles recorded by a wide variety of techniques during the MAP/GLOBUS campaign have been summarized. After several years of cross calibration experiments and the critical examination of the experimental techniques, the agreement between the various *in situ* techniques now appears to be very good, that is, to within $\pm 5\%$. The remote balloon-borne instruments using visible and ultraviolet absorption techniques and the ground-based microwave radiometer differ from the *in situ* values by between 10 and 25%.

From the form of the profiles retrieved from the Chappuis band absorption method, we conclude that the problem could lie with the absorption cross-sections since the forms of the profiles are similar to those observed by other techniques but the absolute values are systematically larger.

The balloon-borne remote u.v. absorption method does not appear to suffer from this same problem since the magnitudes obtained are very similar to those recorded by other techniques and indeed the u.v. DIAL lidar and *in situ* u.v. absorption instruments use the same absorption cross-section data. Here we would suggest an instrumental/inversion problem. It is indeed unfortunate that there is no data available from the IASB instrument which was flown twice on the G3 gondola in tandem with the *in situ* instruments. This would have allowed a more direct comparison and helped eliminate the possibility that there were changes in the form of the ozone field around 28 km as seen from gondola G2b on 28 September, compared to that seen by other instruments during the rest of the month.

The systematically larger ozone values obtained from the microwave radiometers indicate that some inversion/cross-section bias may still exist, but there is certainly little other high-altitude ozone data recorded by other techniques with sufficient accuracy to allow a comprehensive intercomparison.

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