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GROUND-BASED INTERCOMPARISONS OF SBUV/2 FLIGHT INSTRUMENTS THE WORLD STANDARD DOBSON SPECTROPHOTOMETER 83 AND OVERPASS OBSERVATIONS FROM NIMBUS-7 TOMS AND NOAA-11 SBUV/2

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I. INTRODUCTION

Total ozone data obtained during summers at Mauna Loa Observatory, Hawaii, with Dobson Spectrophotometer 83 are routinely compared with overpass total ozone data from the Total Ozone Mapping Spectrometer (TOMS) and the Solar Backscatter Ultraviolet (SBUV) spectrometer launched aboard the Nimbus 7 satellite in 1978. Results from the TOMS/Dobson instrument comparisons through 1990 have been presented by McPeters and Komhyr [1991]. Dobson spectrophotometer 83 was established as the standard instrument for the U.S.A. Dobson instrument station network in 1962. In 1980, the instrument was designated by the World Meteorological Organization (WMO) as the Standard Dobson Spectrophotometer for the World. Long-term ozone measurement precision of the instrument has been maintained at ± 0.5% [Komhyr et al., 1989]. On an absolute scale, the ozone measurement accuracy of the instrument is estimated to ± 3%.

In early April, 1990, comparison of total ozone and vertical distribution (Umkehr) observations were made for the first time with Dobson spectrophotometer 83.The work was conducted at the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) in Boulder, Colorado, and at the research and instrument manufacturing facility of the Ball Aerospace Systems Division located about 2 km east of Boulder. (The SBUV-2, S/N-2 instrument, built by Ball Aerospace Systems Division, is scheduled for launch aboard the NOAA-13 satellite). We present results of the comparisons, which include ozone vertical distribution data obtained with a balloon-borne electrochemical concentration cell (ECC) ozonesonde [Komhyr, 1969].

2. INSTRUMENTATION

2.1 The Dobson Spectrophotometer

A schematic of the Dobson spectrophotometer is shown in Figure 1. Observations of total ozone, using sunlight, are made by measuring the relative intensities of pairs of wavelengths (A: 305.5/325.0 nm; B: 308.9/329.1 nm; C: 311.5/332.4 nm; and D: 317.5/339.9 nm) that pass through slits S_2 and S_3 of the instrument. The wavelengths are chosen so that absorption by atmospheric ozone is considerably greater for the shorter wavelength of each pair. In practice, interference due to aerosols is removed by making observations on double pair wavelengths (e.g., the AD or CD wavelengths). Total ozone amounts can also be deduced from observations on clear or cloudy zenith sky. Ozone vertical distributions can be determined from one-half day, clear zenith sky observations using the Umkehr method of Gotz [Gotz et al., 1934; Mateer and Dutsch 1965; DeLuisi 1979].

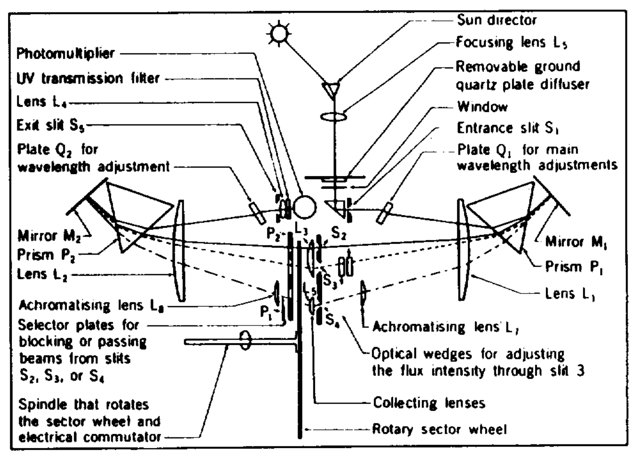

Figure 1. Schematic of Dobson Ozone Spectrophotometer

2.2 SBUV Instruments

The first Backscatter Ultraviolet (BUV) instrument, based on a proposal by Heath and Dave [1967], was launched aboard the Nimbus 4 satellite in 1970. A slightly modified version of the instrument which incorporated means of protecting the instrument's diffuser was launched aboard the Atmospheric-Explorer 5 satellite in 1975. A redesigned and improved version Solar Backscatter Ultraviolet (SBUV) instrument, incorporating a wavelength scan capability from

160–400 nm in 0.2 nm steps and a reference diode to detect photomultiplier tube gain changes, was launched aboard the Nimbus 7 satellite in 1978. These early instruments were built by Beckman Instruments, Fullerton, California. Subsequently, a series of redesigned SBUV-2 instruments have been built by Ball Aerospace Corporation, Boulder, Colorado. Improvements include a programmable direct-drive grating and onboard measurements of the spectral changes in diffuser plate reflectivity from 180–400 nm. The SBUV-2 instruments are being flown on the TIROS-N series of NOAA satellites. Two satellites of the series, NOAA-9 carrying SBUV-2 instrument S/N-1 and NOAA-11 carrying SBUV instrument S/N-4, were launched in October, 1984, and October, 1989, respectively. The prototype SBUV-2 instrument, named the SSBUV, is being flown periodically on the Space Shuttle.

The SBUV-2 instrument is comprised of two modules: a Sensor Module (Figure 2), and an Electronics and Logic Module. The Sensor Module consists of a spectral scanning tandem Ebert-Fastie double monochrometer (F/5), and a surface reflectance radiometer operating at 379 nm. Scanning with a spectral band pass of 1.1 nm, in steps of 0.14 nm, can be performed in the 160–400 nm spectral range in 192 seconds. Scanning can also be performed in the 32 seconds at twelve wavelengths that can be selected by command from the ground. The instrument views the solar-illuminated Earth in nadir, or a solar illuminated ground aluminum diffuser plate located in the vicinity of the northern terminator, with a field of view of 11.3 x 11.3 degrees.

3. TOTAL OZONE OBSERVATIONS COMPARED

Comparison total ozone observations were made with Dobson spectrophotometer 83 and with the ground-based SBUV-2, S/N-2 satellite ozone instrument on April 7 between 8:22 and 11:40 hr M.S.T. During early morning the sky was clear but became more and more hazy as the day progressed due to build up of light cirrus clouds and aircraft contrails. Observation with the SBUV-2 instruments were made on the standard Dobson instrument A and D wavelengths. Effective ozone absorption coefficients for the SBUV-2 instrument at the Dobson instrument A, C, and D wavelengths, based on the laboratory measurements of Bass and Paur [1985], were computed. They are 1.7572, 0.8356, and 0.3666 atmo-cm^{-1}, respectively. Ozone absorption coefficients used in processing the Dobson instrument data were also those of Bass and Paur [1985], adapted for use with the Dobson instruments by Mateer [1990] and slightly modified by Komhyr [1991] to yièld consistent total ozone values from observations made on different combination of wavelengths. They were for the A, C, and D wavelength pairs, 1.806, 0.833, 0.374 atm-cm^{-1}, respectively. The absorption coefficients for both instruments include an adjustment for an effective atmospheric temperature of -48.5 °C, which was the measured effective atmospheric temperature over Boulder on April 7, 1990. Particle scattering coefficients used in processing the total ozone observations data for both instruments were 0.114, 0.109, and 0.104 atm^{-1} for the A, C, and D wavelengths, respectively.

Comparison of total ozone amounts from direct sun observations obtained in Boulder on April 7, 1990, with Dobson spectrophotometer 83 and the SBUV-2 flight model 2 (Table 1) yielded mean values of 316.0 ± 1.7 DU and 317.8 ±1.8 DU respectively. A comparison of the individual soundings is shown in Figure 3 for a range of air mass from 1.2–2.0 which is defined as secant Q, where Q is the solar zenith angle. The differences in total ozone determined from the observation are shown in Figure 4. There is very little solar zenith angle or air mass dependence. Two nearby TOMS soundings gave 315 and 319 DU and a nearby SBUV-2 sounding from NOAA-11 yielded 322 DU (Table 2). This close agreement is very encouraging. This agreement is better than that which has been observed during similar comparison observations made in the past at Mauna Loa Observatory (MLO) in Hawaii which were within the variability of the MLO comparison data. The NOAA-11 SBUV-2 satellite instrument measured 2.0% more ozone over Boulder on April 7 than did Dobson instrument 83.

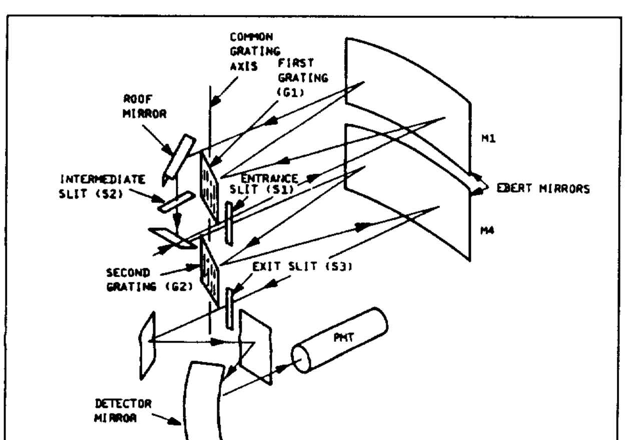

Figure 2. Schematic of the SBUV-2 Double Monochrometer

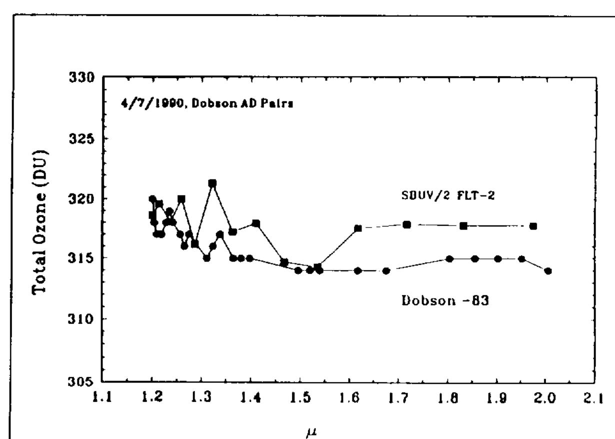

Figure 3. Total Ozone vs. mu SBUV/2 FLT-2 and Dobson Instrument-83

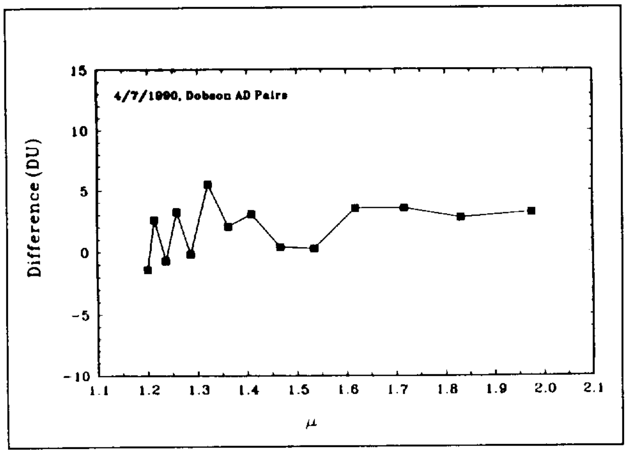

Figure 4. Difference of Total Ozone between SBUV/2 FLT-2 and Dobson Instrument-83.

Table 1 Total Ozone Comparison Data, Boulder Colorado (40.0°N, 105.3°W)

Dobson 83 (DU)	Ground-Based SBUV-2, FM-2 (DU)	TOMS (DU)	NOAA-11 SBUV-2 (DU)
	April 4, 1990		
324.5±1.3, N=4 9:54-10:26 M.S.T.	No data	330 % Difference from D-83:+1.7	327.0 % Difference from D-83: +0.8
	April 7, 1990		
316.0±1.7, N=27 8:22-11:39 M.S.T.	317.8±1.8, N=14 8:22-11:39 M.S.T. % Difference from D-83: 0.6	315 (39.9°N, 105.1°W) 319 (40.4°N, 105.3°W) % Difference from D-83: -0.3, +0.9	322.2 (39.9°N, 107.0°W) % Difference from D-83:+2.0

Table 2 Comparison of Ozone Vertical Distribution Data Boulder, Colorado (40.0°N, 105.°W)

	April 4, 1990			April 7, 1990		
Umkehr Layer	Dobson 83	Dobson 61	Grnd-Based SBUV-2, FM-2	NOAA-11 SBUV-2, FM-4 (38.7°N, 114.9°W)	ECC Ozonesonde	NOAA-11 SBUV-2, FM-4 (39.9°N, 107.0°W)
9	5.3	5.4	5.7	5.2	-	4.9
(1.96-0.98mb)		(+1.9)	(+7.5)	(-1.9)		(-)
8	17.2	17.1	18.3	19.3	-	18.4
(3.9-1.96mb)		(-0.6)	(+6.4)	(+12.2)		(-)
7	42.8	41.5	44.8	47.4	-	46.3
(7.8-3.9mb)		(+3.0)	(+4.7)	(+10.7)		(-)
6	72.4	67.8	75.5	81.1	77.2	80.1
(15.6-7.8mb)		(-6.4)	(+8.7)			(+3.8)
5	115.3	109.4	118.6	125.1	118.7	125.1
(31.2-15.6mb)		(-5.4)	(+2.9)	(+8.4)		(+5.4)
4	132.4	126.0	133.8	145.1	135.1	148.8
(62.5-31.2mb)		(-4.8)	+1.1	(+9.6)		(+10.1)
3	90.1	89.9	84.2	83.2	84.7	92.4
(125-62.5mb)	(-0.2)	(-6.5)	(-7.7)	(-7.7)	(+9.1)	(+2.6)
2	56.8	62.5	48.2	38.6	34.0	44.7
(250-125mb)		(+10.0)	(-15.4)	(-14.4)		(+31.5)
1	27.8	33.3	23.9	25.0	28.8	25.6
(1000-250mb)		(+19.8)	(-14.0)	(-10.1)		(-11.1)
Total O_3(DU)	**327**	**325**	**323**	**327**	**318**	**322**

Layer ozone amounts are ozone partial pressures (nb). For April 4, values in parenthesis are percent difference in ozone from Dobson instrument 83 values. For April 7, values in parenthesis are present differences in ozone for NOAA SBUV-2 compared to ECC ozonesonde values.

Total ozone direct sun observations with ground-based SBUV-2, FM-2 were not made in Boulder on April 4—a time of Umkehr observation comparisons. Dobson instrument 83 and TOMS overpass data on the day (Table 1) agreed to 1.7%, with TOMS giving the higher value. Compared to Dobson instrument 83 data, NOAA-11 SBUV-2 overpass ozone values were 0.8% high. The two instruments were, however, not viewing the same air mass since at the time of observations the satellite was displaced from Boulder by 1.3°N and 9.5°W. Additional SBUV-2 data (not presented) showed that a strong north-south ozone gradient was present over the western U.S.A. on April 4.

4. OZONE VERTICAL DISTRIBUTION DATA COMPARED

Umkehr observations were made April 4, 1990, in Boulder with Dobson spectrophotometers 83 and 61, and with the ground-based SBUV-2, FM-2 operated at the Dobson instrument wavelengths A, C, and D. Plots of N-values versus solar zenith angle for the two instruments are shown in Figure 5. Results are not identical, partly because the slit functions of the two instruments are not equivalent. (Slit one-half widths for the short and long Dobson instrument wavelengths are 1 and 3 nm, respectively, whereas for the SBUV-2 instrument they are all 1.1 nm). Differences in N-values for the two instruments are shown in this figure. The reason for the abrupt change in N-values for A and C pair wavelengths for solar zenith angles greater than 75° is being investigated. Note the lack of solar zenith angle dependence in the D-wavelength pair.

Inversions of C-wavelength observational Umkehr data for Dobson instruments 83 and 61, and for the ground-based SBUV-2, FM-2 instrument, to obtain ozone vertical distributions in Umkehr layers 1–9, were performed by C.L. Mateer (Scarborough, Ontario, Canada), who recently devised an improved data reduction algorithm. The newer algorithm incorporates better ozone absorption and primary scattering coefficients (but does not account for secondary scattering) than does the conventional algorithm (Mateer and Dutsch, 1964) used in the past. The observational Umkehr data were not processed by the "short" Umkehr method which utilizes A, C, and D wavelengths (DeLuisi, 1979), owing to improvements needed to the "short" Umkehr inversion algorithm

Umkehr ozone profiles for Dobson instrument 83 and the ground-based SBUV-2, FM-2 satellite ozone spectrometer are shown in Figure 6. Results in Umkehr layers 3–9 agree to within ± 7% with an agreement of 1.1% in the region of ozone maximum (Umkehr layer 4). A skewness in the comparison data is evident, with the SBUV-2 ozone values somewhat larger at the higher altitudes and smaller at the lower altitudes than are the Dobson instrument 83 data. Agreement is poor in Umkehr layers 1 and 2 where the sensitivity of the Umkehr method to ozone is poor.

The Dobson instrument 83 Umkehr layer ozone data are additionally compared (Table 2) with similar Dobson

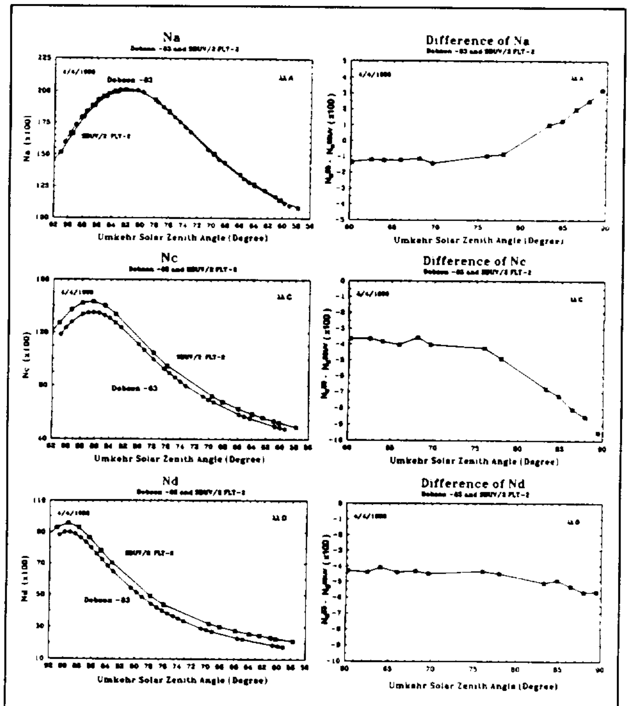

Figure 5. Umkehr observation data obtained April 4, 1990, in Boulder, Colorado, with Dobson spectrophotometer 83 and with ground-based SBUV-2, FM-2.

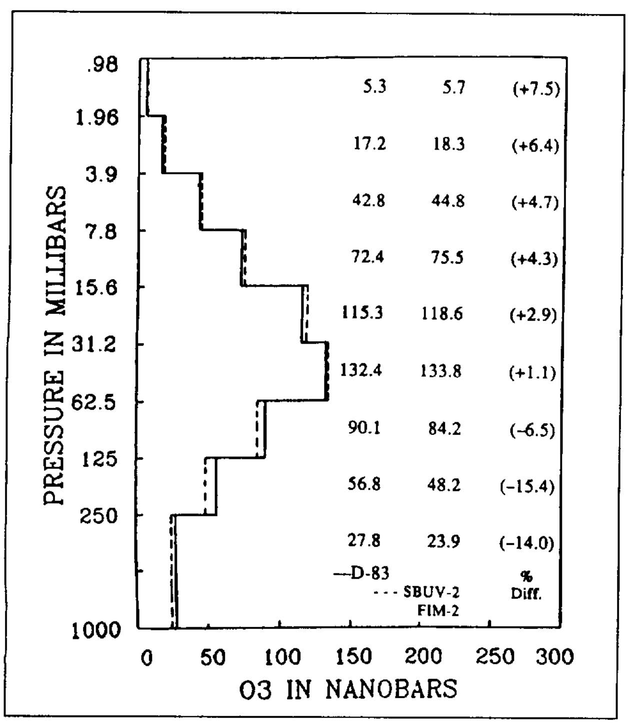

Figure 6. C-wavelength Umkehr ozone profiles determined for Boulder April 4, 1990, with Dobson instrument 83 and ground-based SBUV-2, S/N-2.

instrument 61 data and with NOAA-11 SBUV-2 instrument ozone vertical distribution data obtained April 4, 1990. Included in Table 2 are comparisons of NOAA-11 SBUV-2 and balloon-borne ECC sonde data obtained in Boulder April 7, 1990.

It is planned to continue these series of direct sun and zenith sky Umkehr comparisons of SBUV-2 flight instruments before launch and subsequently after launch against the Dobson instrument 83 and to use the satellite ozone profile and total column soundings to calculate the N-values and to compare them with the observed from the ground at Dobson, SBUV-2, and Brewer wavelengths using the Dave-Mateer code.

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