N95- 10654

303609

RESULTS OF INTERNATIONAL DOBSON SPECTROPHOTOMETER CALIBRATIONS AT AROSA, SWITZERLAND, 1990

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ABSTRACT

An international comparison of Dobson ozone spectrophotometers, organized and partially funded by the World Meteorological Organization (WMO), was held at the Lichtklimatisches Observatorium (LKO) in Arosa, Switzerland, July-August 1990. Countries participating with a total of 18 Dobson instruments were Belgium, Czechoslovakia, Denmark, Germany, Greece, Hungary, Iceland, Norway, Poland, Portugal, Rumania, Spain, Switzerland, the United Kingdom, the United States, and the United Soviet Socialist Republics. The reference standard instrument for the comparison was U.S.A. Secondary Standard Dobson Spectrophotometer 65 maintained by the NOAA Climate and Monitoring and Diagnostics Laboratory, Boulder, Colorado. The mean difference in ozone obtained with the Dobson instruments relative to Dobson instrument 65, calculated from ADDSGQP observations in the air mass range 1.15-3.2, was -1.0 ± 1.2 (1σ) percent. The WMO Standard Brewer Spectrometer 39 also participated. In the mean, the Brewer instrument measured 0.6 ± 0.2 (1σ) percent more ozone than did Dobson instrument 65. Results are presented, also, of ozone vertical profile measurements made with the Dobson instruments, two Brewer spectrometers, a LIDAR, a balloon ozonesonde flown from Hohenpeissenberg, Germany, and balloon ozonesondes flown from Payerne, Switzerland.

1. INTRODUCTION

A program to calibrate Dobson ozone spectrophotometers of the global Dobson instrument station network, relative to United States standard Dobson instrument 83, began in the mid-1970s under auspices of the WMO. In 1980, the WMO designated Dobson instrument 83 as the Standard Dobson Spectrophotometer for the World. Long-term (1962-present) ozone measurement precision of this instrument has been maintained at better than ±1% [*Komhyr et al.*, 1989*a*]. Since the mid-1970s, virtually all global network Dobson instruments have been calibrated several times relative to instrument 83, either directly or through secondary standard instruments having calibrations traceable to instrument 83. Eight such foreign secondary standards were established in 1977 [*Komhyr et al.*, 1980]. Two United States secondary standards, instruments 65 and 86, were established in the early 1980s.

The Arosa 1990 Dobson instrument calibrations were a continuation of an ongoing program of the WMO Dobson Spectrophotometer Central Laboratory, NOAA/ERL Climate Monitoring and Diagnostics Laboratory, Boulder, Colorado, to improve the quality of total ozone measurements throughout the world. It was held mid-July to mid-August at the Lichtklimatisches Observatorium with the aid of the Swiss Meteorological Institute (SMI), Payerne, and the Eldgenossische Technische Hochschule (ETH), Zurich. Purposes of the instrument intercomparisons were to certify the calibration levels of the participating instruments relative to a standard instrument, and to identify instruments with optical or electronic problems for repair. A total of 18 Dobson instruments from 16 countries participated (Table 1). Three of the instruments (50, 104, and 107) received some optical alignment, six (12, 14, 84, 118, 120, and 121) required various electronic repairs, while optical wedge calibrations were performed on eight instruments (15, 50, 74, 84, 92, 104, 110, and 118). The wavelength settings of all instruments were verified.

While enroute to Arosa, a stop was made at the Observatoire de Haute Provence (OHP), France, for calibration checks on Dobson instruments 49 and 85. Results obtained are also presented in Table 1.

Toward the end of the intercomparison campaign, Umkehr observations were made with the Dobson instruments to compare their performance when measuring ozone vertical distribution. Participating in these comparisons were Brewer spectrometers 39 and 40, the lidar at Hohenpeissenberg, Germany, and balloon-ozonesondes at Hohenpeissenberg and Payerne, Switzerland.

Procedures used in calibrating Dobson spectrophotometers relative to a reference instrument have been described by *Komhyr et al.* [1980, 1989*b*]. The reference instrument used at LKO and OHP was U.S.A. secondary standard spectrophotometer 65. It was calibrated against World Standard Dobson Spectrophotometer 83, May 21,

Table 1. Instruments and Participants of the 1990 LKO, Arosa, Dobson and Brewer Instrument Intercalibrations

Instrument Number	Country	Participants
	Dobson Instruments	
13	Portugal	D. Henriques
14	Norway	K. Henriksen
		T. Svende
15, 101	Switzerland	K. Aeschbacher
		H. Schill
40	Belgium	H. DeBacker
		R. DeMuer
41	England	A. Lapworth
50	Iceland	B. Thorkelson
64	Germany	U. Feister
	(Potsdam)	P. Plessing
65	United States	W. Komhyr
		R. Grass
		R. Evans
74	Czechoslovakia	K. Vanicek
84	Poland	M. Degorska
		R. Rajewska-Wiech
92	Denmark	P. Eriksen
104	Germany	R. Hartsmannsgruber
	(Hohenpeissenberg)	U. Kohler
110	Hungary	Z. Nagy
		F. Miskolczi
		G. Koksa
118	Greece	C. Varotsos
		D. Asimakopoulos
120	Spain	J. Cacho
		A. Diaz
121	Rumania	M. Frimescu
	Brewer Instrument	
39	WMO	I. Asbridge

1990, and assigned a calibration scale dated May 21, 1990 F1. The F1 designation reflects a slight improvement in the 1962-1989 calibration level of World Standard Dobson instrument 83, amounting to an increase in measured ozone values of 0.3%. This change in the instrument 83 calibration scale stemmed from slightly improved computations of μ, the effective path length of light through the ozone layer.

Results of preliminary calibrations of the various Dobson instruments are shown in Table 2. Preliminary calibrations assess the "as is" status of the instruments, yielding information that may be used in correcting total ozone data obtained in the past. The last column in Table 2 shows mean percent differences in ozone measured by the various instruments within the air mass range 1.15-3.2, compared with ozone values measured with Dobson instrument 65. Columns 4-7 of Table 2 present similar data for narrower air mass observing ranges.

Table 2. Results of Initial Dobson Instrument Calibrations at Arosa in 1990 Relative to Secondary Standard Dobson Instrument 65*

Dobson Inst. Number	Last Calibration Date	Arosa Calibration Date	Test Instrument - Instrument 65 Total Ozone Difference in Percent				
			$\mu =$ 1.15-1.5	$\mu =$ 1.5-2.0	$\mu =$ 2.0-2.5	$\mu =$ 2.5-3.2	$\mu =$ 1.15-3.2
13	10/20/87	08/02/90	0.9	0.6	-0.5	0.0	0.3
14	09/29/77	08/02/90	-0.5	-0.6	-1.5	-1.3	-1.0
15	07/18/90†	07/25/90	-6.4	-5.0	-3.5	-4.9	-5.0
40	08/15/86	08/02/90	-1.3	-0.9	-0.6	0.4	-0.6
41	09/17/85	07/25/90	-0.4	-0.5	-0.8	-0.7	-0.6
50	08/20/77	07/19/90	-2.7	-3.1	-3.4	-3.5	-3.2
64	08/21/86	07/25/90	0.2	0.1	-	0.3	0.2
74	08/15/86	07/19/90	-1.1	-0.6	-0.8	-0.1	-0.7
84	01/01/89	07/25/90	-0.3	0.1	0.9	0.7	0.4
92	08/15/86	07/25/90	-0.1	-0.1	-0.8	-1.1	-0.5
101	08/21/86	07/25/90	0.2	0.3	0.7	0.3	0.4
104	10/01/88	07/25/90	-1.7	-2.2	-2.9	-2.8	-2.4
107	09/08/88	07/25/90	-1.2	-1.0	-	-0.6	-1.0
110	06/16/88	07/25/90	0.3	0.7	1.4	1.3	0.9
118	-	07/25/90	-2.3	-	-	-	-2.3‡
120	11/04/89	08/05/90	-2.3	-2.5	-1.9	-1.0	-1.9
121	06/15/88	07/25/90	0.4	0.4	-0.1	0.5	0.3
49*	06/21/83	07/07/90	-1.6	-1.6	-1.4	-0.7	-1.3
85*	/83	07/07/90	-0.7	-0.4	0.0	0.4	-0.2

*Calibrations performed at OHP, France
†N-tables adjusted yearly by Langley plot method
‡Applies to μ range of 1.15-1.5 only

Final calibration data are shown in Table 3. These results were obtained after optical adjustments, wedge calibrations, and repairs were made to some of the instruments as indicated above. As in Table 2, performance of the instruments relative to instrument 65, is characterized in Table 3 as a function of air mass.

2. BREWER INSTRUMENT MEASUREMENTS

Dobson spectrophotometer 64 and Brewer spectrophotometer 39 were intercalibrated July 25, 1990. For observations on AD wavelengths the Brewer instrument measured higher ozone values than did the Dobson instrument by 0.1%, 0.3%, 0.8%, and 1.2% at effective ozone layer path lengths μ of 1.15-1.5, 1.5-2.0, 2.0-2.5, and 2.5-3.2, respectively, for a mean difference of 0.6%. Part of this difference stemmed from slightly different methods used for computing μ. Using μ values derived for the Dobson instrument observations in processing both sets of data, the discrepancy in the mean ozone difference for the two instruments decreased to 0.4%.

At higher μ, outside the range of normal AD-DSGQP observations, the Dobson instrument values fell more quickly with increasing μ than did the Brewer instrument values. In the μ range 3.2-4.0, for example, the Dobson instrument ozone values were lower by 2.9%. Considering direct sun observations on CD wavelengths within this μ range, both

Table 3. Results of Final Dobson Instrument Calibrations at Arosa in 1990 Relative to Secondary Standard Dobson Instrument 65*

Dobson Instrument Number	Date of Calibration N-Tables†	Test Instrument - Instrument 65 Total Ozone Difference in Percent μ = 1.15-1.5	μ = 1.5-2.0	μ = 2.0-2.5	μ = 2.5-3.2	μ = 1.15-3.2
13	08/02/90	0.8	0.5	-0.5	0.0	0.2
14	08/02/90	1.3	0.8	-0.5	-0.5	0.2
15	No final calibration					
40	08/02/90	-0.6	-0.3	-0.3	0.7	-0.1
41	08/02/90	0.8	0.6	-0.2	-0.3	0.2
50	08/02/90	0.2	0.2	0.0	-0.1	0.1
64	08/02/90	-0.7	0.1	0.1	0.1	-0.1
74	08/02/90	-0.4	0.4	0.0	-0.1	0.0
84	08/02/90	-0.6	0.3	-0.1	0.2	0.0
92	08/02/90	-0.6	0.2	0.1	0.0	-0.1
101	08/02/90	0.1	0.6	0.2	-0.5	0.1
104‡	08/02/90	0.6	0.6	-0.1	0.3	0.2
107	08/09/90	0.3	-0.3	0.2	0.0	0.0
110	08/02/09	-1.3	-0.4	0.0	0.6	-0.3
118	08/05/90	0.2	0.4	0.0	-0.4	0.1
120	08/09/90	1.1	0.2	-0.2	-0.2	0.2
121	06/15/88	0.1	0.9	0.1	-0.6	0.1
49*	07/10/90	0.0	-0.3	0.0	0.1	0.0
85*	07/10/90	-0.5	-0.2	-0.2	0.5	-0.1

*Calibrations performed at OHP, France
†N-tables date is the date of final calibration, except for instrument 121 for which the existing 1988 tables were found to be acceptable.
‡Using wedge calibration of 06/28/91

instruments gave results in the mean that agreed to within 0.3%.

A second intercomparison of the Dobson and Brewer instruments August 2, 1990, yielded essentially identical results.

3. OZONE VERTICAL DISTRIBUTION MEASUREMENTS

On the morning of August 3, 1990, simultaneous Umkehr observations were made in Arosa with 14 newly calibrated Dobson instruments. Included in the intercomparisons, also, were Dobson instrument 15 routinely operated at LKO, as well as automated LKO Dobson instrument 51. Brewer spectrometers 39 and 40 also participated. Also that morning, the SMI facility at Payerne, Switzerland (200 km west), flew balloon ozonesondes at 0600 an 1200 hours UTC, and the Meteorological Observatory at Hohenpeissenberg, Germany (130 km northeast), flew an ozonesonde at 0128 UTC. Lidar ozone measurements were made at Hohenpeissenberg the night before at 2111 UTC and the night after at 2053 UTC.

Dobson instrument Umkehr observations were processed using C-wavelengths data and the conventional Umkehr inversion algorithm [*Mateer and Dütsch*, 1964]. Brewer instrument data were processed using a short Umkehr inversion technique similar to that developed by *DeLuisi* [1979]. The method uses observations made on three Brewer instrument wavelength pairs similar to the Dobson instrument A, C, and D wavelength pairs.

Total ozone amount used in processing the Umkehr data was 319 DU, a value measured to within ±1% by 12 of the participating instruments. (Dobson instruments 50, 64, 74, and 110 measured 2% less ozone.) For data comparisons, ozonesonde ozone partial pressures were converted to Umkehr layer partial pressures. Lidar ozone data, normally expressed in molecules cm^{-3} as a function of altitude, were also converted to Umkehr layer ozone partial pressures using auxiliary Hohenpeissenberg rawinsonde data.

Table 4 presents mean ozone partial pressures in Umkehr layers 1-9 derived from measurements with the 16 Dobson instruments (see also Figure 1). Ozone partial pressure percent deviations from these means, for the individual Dobson instruments as well as for three ozonesonde soundings and two lidar soundings, are shown in Table 5. Salient features of the comparison data are described in section 4.

4. CONCLUSIONS

Results of the 1990 Arosa Dobson instrument calibrations were highly satisfactory. Of 17 Dobson instruments calibrated in Arosa, the calibration of 12 instruments agreed with that of WMO/U.S.A. secondary standard instrument 65 to within ±1%. Of the instruments exhibiting more discrepant calibration values, instrument 15 (Switzerland) is operated on its own calibration scale for consistency in its long-term ozone record; instrument 50 (Iceland) had not been calibrated in 13 years; instrument 104 (Germany) required some optical adjustments; instrument 118 (Greece) had not been previously calibrated relative to

TABLE 4. Mean Ozone Partial Pressures in Umkehr Layers 1-9 Derived August 2, 1990, at Arosa,Switzerland From Simultaneous Measurements With 16 Dobson Spectrophotometers*

Umkehr Layer Number	Pressure Range (mb)	Approx. Height (km)	O_3 Partial Pressure (mb)
1	1000.0 - 250.0	5.1	28.8
2	250.0 - 125.0	12.5	45.8
3	125.0 - 62.5	16.9	74.4
4	62.5 - 31.2	21.4	124.4
5	31.2 - 15.6	25.9	125.9
6	15.6 - 7.8	30.4	90.1
7	7.8 - 3.9	35.0	46.9
8	3.9 - 1.96	40.0	17.2
9	1.96 - 0.98	45.2	5.4

*Dobson instruments used are identified in Table 5.

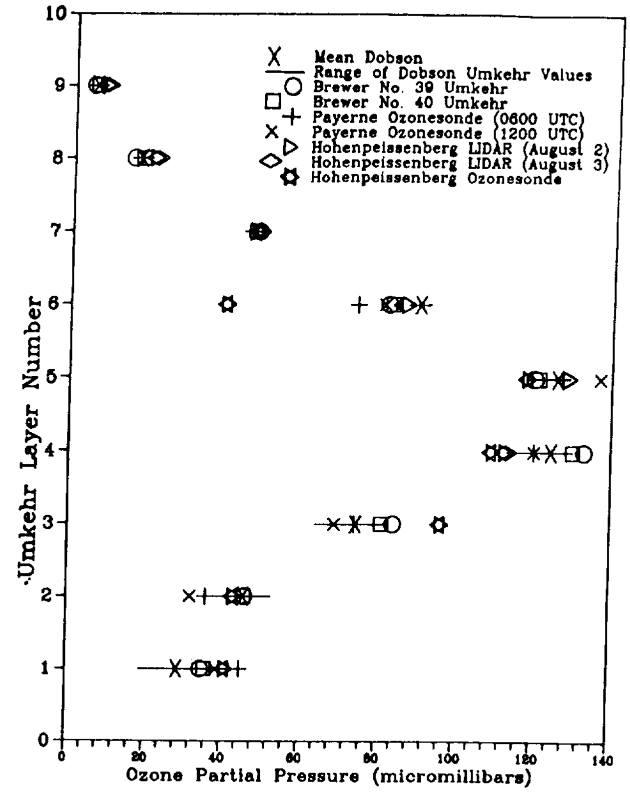

Figure 1. Ozone partial pressures in Umkehr layers 1-9 measured at Arosa, Switzerland, and vicinity August 3, 1990, with 16 Dobson instruments, 3 balloonborne ozonesondes, and an ozone lidar.

TABLE 5. Individual Dobson, Brewer, Ozonesonde, and Lidar Instrument Ozone Partial Pressure Percent Differences from Mean Ozone Partial Pressures in Umkehr Layers 1-9 Derived From Measurements With 16 Dobson Spectrophotometers August 3, 1990, at Arosa, Switzerland

Layer No.:	1	2	3	4	5	6	7	8	9	r*
					Dobson Instruments					
13	-10	0	+1	0	+1	+2	+4	+1	+2	0.38
14	+4	-4	-1	0	0	0	0	-2	-6	0.26
15	+11	+14	-2	-4	-3	-2	-2	+1	+6	0.42
40	-27	-4	+9	+5	+2	0	+2	+6	+13	0.23
41	-6	+5	+3	+1	-1	-1	-2	-2	-2	0.23
50	+1	0	+1	0	+1	0	-4	-6	-9	0.21
51	+4	0	-1	0	+1	0	0	+2	+6	0.23
64	+15	-21	-6	0	+2	+2	+2	+3	+6	0.34
65 (standard)	+4	+3	+1	0	0	-1	-4	0	-7	0.20
74	+1	+7	-1	-2	-2	0	+2	+1	+2	0.33
84	-3	0	+1	0	0	0	0	+1	+4	0.28
92	-6	0	+1	0	0	+1	+2	0	-2	0.24
101	+15	-10	-7	-1	+2	+1	-2	-2	0	0.39
104	-34	-2	+10	±5	+2	+1	+2	+5	+9	0.35
110	-20	-4	+5	+3	+2	+1	+2	+2	+6	0.35
121	+5	+16	-14	-10	-6	-3	-6	-9	-15	0.33
					Brewer Instruments					
39	+25	+3	+16	+10	-2	-7	+4	-8	-9	0.51
40	+28	+3	+12	+8	-2	-6	+2	-5	+6	0.39
					Payerne Ozonesondes					
0600 UTC	+56	-21	-1	-4	+1	-18	-	-	-	-
1200 UTC	+35	-30	-7	-4	+9	-10	-	-	-	-
					Hohenpeissenberg Ozonesonde					
0728 UTC	+42	-6	+29	-12	-6	-9	-	-	-	
Lidar 1 2111 UTC†	-	-	-	-5	+1	-9	-	-	-	
Lidar 2 2053 UTC	-	-	-	-3	-2	-9				

*The factor "r" is a data quality control indicator. An ozone profile with "r" greater than 0.7 is considered unreliable.
†This lidar sounding made August 2, 1990.

World Primary Standard Dobson Instrument 83; and instrument 120 (Spain) had an electrical problem that affected initial results.

Final instrument calibrations (Table 3) yielded calibration discrepancies, relative to the calibration scale of instrument 65, of only ±0.2%. Note that instruments 14, 110, and 120 exhibit larger μ-dependent data than do the other instruments and may require further work to improve their performance.

Intercalibration of Dobson instrument 65 and Brewer instrument 30, gave results which agreed on average to within 0.6% for observations made on AD wavelengths in the μ range 1.15-3.2. Using the same method of computing μ for both instruments reduced the discrepancy to 0.4%. The Dobson instrument exhibited a slight μ dependency in measured ozone at $2.5 < \mu < 3.2$. No such μ dependency was observed for observations on CD wavelengths.

With regard to ozone vertical distribution comparison observations, note (Table 5) the highly satisfactory agreement in results obtained with 15 of the 16 Dobson instruments when measuring ozone in Umkehr layers 4-8, namely, ±5%, ±3%, ±2%, ±4%, and ±6%, respectively. Discrepancies in results in Umkehr layers 1-3 and 9 are larger. The sonde and Brewer instrument ozone vertical distribution data indicate, furthermore, that ozone amounts were underestimated in Umkehr layer 1 but overestimated in layer 6 by the conventional Umkehr technique. This shortcoming of the conventional Umkehr inversion algorithm is likely to be remedied by the new-conventional method [*Mateer and DeLuisi*, 1992] that uses improved à priori ozone profile statistics and takes into account the temperature dependence of ozone absorption coefficients.

ACKNOWLEDGMENTS

The 1990 Arosa international Dobson spectrophotometer calibrations were conducted under the auspices and partial financial support of the WMO Global Ozone Research and Monitoring Project. Appreciation is expressed to Dr. B. Hoegger of the SMI for providing the LKO Arosa site for the calibrations, and to Dr. J. Staehelin of the Laboratory for Atmospheric Physics, ETH, for hosting the calibrations. Special thanks are given to I. A. Asbridge of Canada for assistance provided in calibrating the instruments.

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