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LINEAR APPROXIMATION FOR THE INTERPRETATION OF THE "ADZB" OBSERVATIONS WITH A DOBSON SPECTROPHOTOMETER AT MEXICO CITY

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RESUMEN

Se obtiene una expresión lineal para la interpretación de las observaciones de ozono total del tipo "ADZB" efectuadas en la Ciudad de México y se hace un análisis comparativo de los nomogramas para la interpretación de estas observaciones, desarrollados en Canadá, Inglaterra y Suecia, con el método propuesto. Se encontró que la interpretación de las observaciones en la Ciudad de México, con las cartas Canadiense e Inglesa, dan resultados erróneos. La interpretación con el método propuesto, cuando la cantidad total de ozono se encuentra entre 240 y 320 UD y cuando la masa óptica se encuentra entre 1 y 2.5 da resultados similares a los obtenidos con el nomograma Sueco.

En la Ciudad de México, para cantidades elevadas de ozono (X>320UD), las observaciones tipo "ADZB" proporcionan resultados inciertos, lo que probablemente se debe a la contaminación atmosférica; en estas condiciones no se recomienda el uso de estas observaciones para la determinación de la cantidad total de ozono.

ABSTRACT

A linear analytical expression for the reduction of the "ADZB" type total ozone observations made at Mexico City is obtained. A comparative analysis among the charts developed in Canada, England, Sweden and the method proposed here is made. We find that the observations at Mexico City give erroneous results when they are interpreted using the Canadian and English charts. The reduction of the data using the method proposed here when the total ozone amount was between 240 and 320 DU and when the optical mass was between 1 and 2.5, give similar results to those obtained using the Swedish chart.

For high ozone amounts (X> 320DU) the "ADZB" total ozone observations give uncertain results at Mexico City, this is probably caused by atmospheric pollution and, under these conditions, the use of this type of observation is not recommended.

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INTRODUCTION

Total ozone amount in the atmospheric vertical column is determined, from the earth's surface, using a Dobson spectrophotometer. This instrument selects, from the direct solar radiation beam, pre-established wavelength pairs at the Huggins bands in the ultraviolet region of the spectrum. These pairs are named A(3055Å, 3254Å), B(3088Å, 3291Å), C(3114Å, 3324Å) and D(3176Å, 3398Å) and have been selected in such a way that the ozone absorption coefficient for the shorter wavelength is much larger than that corresponding to the longer wavelength. When the direct solar radiation beam penetrates the atmosphere, the ratio between the intensities corresponding to the short and long wavelength for each pair is modified with respect to the incident radiation at the top of the atmosphere. Then, the greater the amount of ozone in the atmosphere, the greater the modification of this ratio. These changes are determined with the Dobson spectrophotometer.

Using two wavelength pairs and the Bouger-Lambert law (Dobson, 1957), it is possible to eliminate the effects of air and haze and to obtain, with a simple analytical expression, the total ozone amount. The method just outlined corresponds to the direct sun (DS) observations. When the solar disc is covered with clouds, ozone can be determined using the diffuse radiation coming within a 7° cone around the clear zenith or blue zenith ("ZB" observations). This radiation is the result of multiple scattering processes through a definite optical path and through a definite amount of ozone. The ratio of intensities for each wavelength pair will then be a function of the total ozone in the atmosphere. The scattering of radiation is a complex problem, therefore it is easier to reduce "ZB" observations by using empirical charts or nomograms based on many quasi-simultaneous "DS"-"ZB" observations. These nomograms have as ordinate the value $(N\text{-}N')_{ZB}/\mu$, where N and N' are obtained from the instrument readings and the N tables of each instrument, and the ozone optical mass, μ, as abscisa. The N values represent the logarithm of the intensity ratio of the wavelength in each pair plus a constant. To each point on the plane representing a "ZB" type observation there is a corresponding total ozone amount obtained using the "DS" quasi-simultaneous observation. The nomogram is obtained by drawing curves of equal ozone amount using a suitable smoothing method (Rindert, 1973).

With this procedure nomograms for England (Dobson and Normand, 1962), Canada (Komhyr, 1961) and Sweden (Rindert, 1973) have been developed. As it was mentioned, the incident radiation, when a "ZB" observation is made, is the result of multiple scattering processes. Thus the shape and position of the curves in the nomogram will be functions of the vertical ozone distribution, local albedo, atmospheric turbidity and instrumental factors (Komhyr, 1980). Therefore, although the charts can serve as useful starting tools for preliminary reduction of the data, it is necessary to obtain a sufficient number of comparisons between direct sun and zenith sky observations at each station to correct the charts or to construct new ones so that these may yield optimum results at the location.

Total ozone observations have been made at Mexico City, starting in August 1979 using the Dobson spectrophotometer #98 modernized and intercompared with the standard Dobson #83 at Boulder, Colorado. At Mexico City latitude (20N), during all the year, from the early hours of the morning until the late hours of the afternoon, the optical mass remains less than 3. Therefore the observations were only made with the "AD" wavelength pairs according to the times of routine measurements table (Komhyr, 1980).

Differences of 5 to 10% were found between the ozone determined with direct sun observations at Mexico City and ozone obtained from the Canadian "ADZB" chart. This disagreement was even greater when the English chart was used.

In this work, we develop a simple linear approximation for the reduction of the "ADZB" total ozone observations using the set of quasi-simultaneous observations collected at Mexico City. This approximation is useful within the range of total ozone X, and optical mass μ, characteristic of the location (240 DU$\leq$X$\leq$320 DU and $1<\mu\leq 2.5$). A comparison among the English, Canadian and Swedish charts, with the method proposed here was made.

PROPOSED APPROXIMATION

The approximation consists in fitting a linear multiple variable equation for the total ozone amount X, considering as the independent variables the values N_{AD}/μ ($N_{AD}/\mu = (N_A - N_D)/\mu$) and μ, the optical mass. The necessary and sufficient condition for validity of this approximation is that equal ozone lines in the plane be parallel and the distance between them proportional to the ozone amount.

A diurnal variation as large as 10 DU/hr has been observed at Mexico City (Bravo, 1984). Therefore 2 observations are considered quasi-simultaneous if their time difference is less than 15 min. This means that the total ozone amount varies less than 1% during this time interval.

The shape and position in the plane of the curves of equal ozone is obtained classifying the "ZB" observations in 10 different sets: 240-250, 250-260, . . . , 330-340 DU according to their associated "DS" ozone amount. The points are plotted in the N_{AD}/μ vs. μ plane.

Table 1

Parameters of the regression lines

OZONE INTERVAL D. U.	Y INTERCEPT	SLOPE	MULTIPLE CORRELATION COEFFICIENT	SAMPLE SIZE
240-250	40.52 ± 0.13	- 2.27 ± 0.33	- 0.87	64
250-260	42.25 ± 0.11	- 2.46 ± 0.20	- 0.76	121
260-270	43.17 ± 0.11	- 2.40 ± 0.23	- 0.72	106
270-280	43.89 ± 0.15	- 2.03 ± 0.20	- 0.74	87
280-290	45.40 ± 0.16	- 2.11 ± 0.19	- 0.76	89
290-300	47.86 ± 0.16	- 2.83 ± 0.25	- 0.78	81
300-310	47.18 ± 0.17	- 1.63 ± 0.35	- 0.49	70
310-320	48.55 ± 0.17	- 1.80 ± 0.35	- 0.51	75
320-330	45.56 ± 0.21	- . 66 ± 0.92	0.24	54
330-340	48.61 ± 0.37	- 0.00 ± 1.02	0.00	24

The points in each set were distributed in ribbons bounded by two parallel straight lines, then, using a least squares fitting method a straight line was adjusted to the points in each set, associating to each line the average ozone value of the corresponding intervals. The parameters of the regression lines are shown in Table 1.

To show that the slopes of these lines are not significantly different let us consider the following parameter, as a measure of the difference between slopes

$$Z = \frac{m_1 - m_2}{\sqrt{\sigma_1^2 + \sigma_2^2}} \tag{1}$$

where m_1 and m_2 are the values of the slopes of any 2 lines and σ_1 and σ_2 are their standard deviations. Table 2 shows Z parameter values of all slope combinations. According to this, the slopes of the lines associated with 295 DU, 325 DU and 335 DU show significant differences (furthermore the 325 DU line shows a null correlation coefficient). This means that the remainder slopes are not significantly different and thus the corresponding lines can be considered parallels.

Table 2

Z Parameter, measures the difference in slopes

O_3	245	255	265	275	285	295	305	315	325	335
245	0	0.491	0.324	0.618	0.406	1.355	1.314	0.980	4.027	2.127
255	0.491	0	0.192	1.521	1.247	1.159	2.030	1.637	4.383	2.377
265	0.324	0.192	0	1.210	0.952	1.266	1.812	1.433	4.288	2.306
275	0.618	1.521	1.210	0	0.299	2.475	0.977	0.579	3.927	1.963
285	0.406	1.247	0.952	0.299	0	2.248	1.190	0.787	4.021	2.046
295	1.355	1.159	1.266	2.475	2.248	0	2.742	2.380	4.712	2.705
305	1.314	2.030	1.812	0.977	1.190	2.742	0	0.327	3.342	1.517
315	0.980	1.637	1.433	0.579	0.787	2.380	0.327	0	3.513	1.671
325	4.027	4.383	4.288	3.927	4.021	4.712	3.342	3.513	0	3.214
335	2.127	2.377	2.306	1.963	2.046	2.705	1.517	1.671	1.214	0

To show that the distance between the lines in the plane is proportional to the amount of ozone, the ordinates of the eight first lines, when the optical mass was 1.5 (the region of greatest density of observations) were plotted against their total associated ozone amount (Fig. 1), the correlation coefficient obtained was 0.9994. This result means that the distance between the lines is proportional to the total ozone amount.

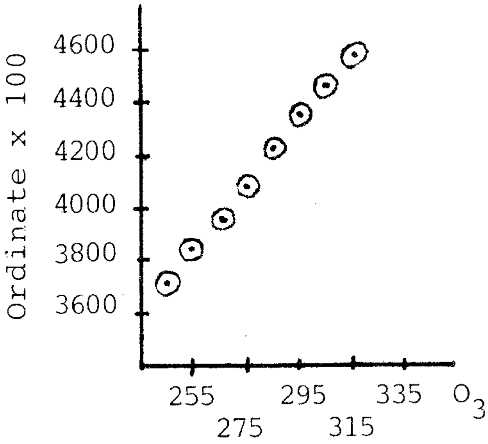

Fig. 1. Ordinate of the eight first lines when the optical mass was 1.5.

The last two results indicate that the "ADZB" type observation can be reduced, to obtain "ADDS" total ozone, using a linear regression equation of the ozone amount on N_{AD}/μ and μ.

MULTIPLE VARIABLE REGRESSION FITTING (MVR)

The fitting of the multiple variable equation was made using 639 quasi-simultaneous observations corresponding to the 8 lines between 240 and 320 DU; the two remaining lines (between 320 and 340 DU) were not included because, as it was mentioned, they have parameters significantly different from the other lines; the lines corresponding to the points with ozone values between 290 and 300 were included; this was done because its ordinate, when $\mu = 1.5$ aligned well with the other points (Fig. 1). This means that the trend of the points in the region of the greatest density of observations, for the 295 DU line, does not separate significantly from the remaining points in the plane. The regression coefficients are shown in the following formula

$$X_{ADZB} = \underset{\pm 0.12}{7.552}\,(N_{ADZB}/\mu) + \underset{\pm 1.1}{15.30}\mu - \underset{\pm 0.36}{56.28} \tag{2}$$

This formula reduces the optical mass (μ), at the time of the observation, and the N_{ADZB} ($N_{ADZB} = N_{AZB} - N_{DZB}$) observed values to the total ozone (X_{ADZB}) that would be obtained using an "ADDS" observation. The numbers under the regression coefficient represent the 95% confidence level interval. The standard error of estimate was 4.5 DU and the coefficient of multiple correlation was 0.979. The validity of this equation is restricted to the values within the range of the observations i.e. ozone values between 240 and 320 DU; at Mexico City almost all ozone observations are within this range and correspond to μ values between 1 and 2.5 and to N_{AD}/μ values between 35 and 46. Within these ranges the precision of the reduction of the observations is similar to that reported by Komhyr (1961) as shown in Table 3.

Table 3

Precision of the reduction of the observations

	Error		
Frequency	⩽1%	⩽2%	⩽3%
Komhyr	54%	78%	95%
MVR	46%	79%	94%

COMPARISON OF THE CHARTS DEVELOPED IN ENGLAND, CANADA AND SWEDEN WITH THE MVR METHOD

Table 4 shows N_{AD}/μ values as functions of the optical mass and ozone amounts. The values are given for the charts developed at England (Dobson and Normand, 1962), Canada (Komhyr, 1961) and Sweden (Rindert, 1973). The results obtained using equation (2) are also shown. Table 5 shows the percent differences of the total ozone amount with respect to the Swedish chart. The English chart gives ozone amounts 1% to 12% smaller than the Swedish chart in the high ozone and large optical mass and in the low ozone and small optical mass regions respectively.

Table 4

N_{AD}/μ values as function of the optical mass and ozone amount

OZONE D.U.		OPTICAL MASS 1	1.4	1.8	2.2	2.6	3.0
250	England	43.8	41.2	39.0	37.1	35.8	35.3
	Canada	41.8	38.2	36.2	34.7	33.5	32.3
	Sweden	38.4	37.4	36.4	35.3	34.1	32.9
	Mexico	38.5	37.7	36.9	36.1	35.3	34.5
300	England	50.9	48.2	45.6	43.3	41.3	39.9
	Canada	48.7	45.4	43.2	41.5	40.0	38.3
	Sweden	46.0	44.6	43.2	41.7	40.0	38.3
	Mexico	45.2	44.3	43.5	42.7	41.9	41.1
350	England	57.9	55.2	52.5	49.8	47.2	44.4
	Canada	55.9	52.1	50.2	48.6	46.3	43.7
	Sweden	54.0	52.2	50.3	48.3	46.0	43.7
400	England	64.8	62.2	59.4	56.2	52.8	49.0
	Canda	62.7	59.5	57.3	54.6	51.5	48.2
	Sweden	61.1	59.3	57.2	54.8	52.0	48.6
450	England	71.1	68.6	65.7	62.4	58.3	53.3
	Canada	69.8	66.6	63.9	60.7	57.0	53.1
	Sweden	68.3	66.3	63.9	61.0	57.4	53.2

Table 5

Percent differences of total ozone amount with respect to Swedish chart

OZONE D.U.		1	1.4	1.8	2.2	2.6	3.0
250	England	− 12	− 10	− 7	− 5	− 5	− 8
	Canada	− 8	− 2	1	2	2	2
	Mexico	0	− 1	− 1	− 2	− 4	
300	England	− 9	− 7	− 5	− 4	− 3	− 5
	Canada	− 5	− 2	0	1	0	0
	Mexico	2	1	− 1	2	5	
350	England	− 7	− 6	− 4	− 3	− 3	− 2
	Canada	− 4	0	0	− 1	− 1	0
400	England	− 6	− 5	− 4	− 3	− 2	− 1
	Canada	− 3	0	0	0	1	1

The Canadian nomogram shows significant differences with respect to the Swedish one in the range of low optical masses. This difference increases up to -8% in the low ozone range. The English and Canadian charts differ from the Swedish one in approximately the same region.

The ozone values obtained using equation (2) differ from the values obtained with the Swedish chart in the region of large optical mass ($\mu \sim 2.6$); when the optical mass is smaller ($\mu < 2.2$) the ozone values are practically equal.

The ozone values obtained using equation (2), when the variables are within the validity range, has the advantage of reducing "ADZB" observations using an analytical expression with a precision comparable to the nomogram method.

Mexico City is located at a low latitude (20N) and the bulk of the observations have low optical masses and small ozone amounts (London and Oltmans, 1978/79); this implies that the fitting of equation (2) is skewed to the low optical masses region. On the other hand, all points in the intervals (320-330 DU) and (330-340 DU) have small optical masses ($1 \leq \mu \leq 1.5$); there are no observations with great optical masses and high ozone amounts, the dispersion of the points in these two intervals is large. This could be explained by the inhomogeneity of atmospheric pollution that produces variations in the dial readings during an ozone observation. When the ozone amount is large and the optical mass is small ($X > 320$ and $\mu < 1.5$), the inhomogeneities of the atmospheric pollution could affect the basic hypothesis of the reduction of "ZB" observations, because although the observations are made during a short interval of time, the same sky region is not observed and thus it is possible to obtain different ozone amounts. This fact has been suggested by Kerr (1973).

CONCLUSIONS

The nomograms developed for England and Canada are not applicable to Mexico City's "ADZB" observations. A linear multiple variable regression was developed, this equation reduces the data with an acceptable accuracy when it is used within the observed ranges ($1 < \mu \leq 2.5$ and $35 < N_{AD}/\mu \leq 46$). The reduction of the data made at Mexico City with this method coincides with that obtained using the nomogram developed in Sweden.

Due to the optical inhomogeneities of pollution at Mexico City, the confidence of the ADZB observations and of the proposed reduction method decrease significantly for ozone amounts greater than 320 DU. These ozone values, relatively high for Mexico City, are present only for a few days near noon ($\mu < 1.5$).

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