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Winter Measurements of Ozone Over the Organ Mountains, New Mexico

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This paper gives data on the total amount of ozone above the Organ Mountains at the White Sands Proving Ground in New Mexico from December 16 to 19, 1947, and from January 6 to 8, 1948, as determined from solar ultraviolet measurements by a phototube and filter method. The measurements indicate ozone in the stratosphere in an amount equivalent to a layer about 0.19 centimeter in thickness at normal temperature and pressure for each of the two periods.

I. Introduction

The measurements of the total amount of ozone in the stratosphere over the Organ Mountains in New Mexico recorded in this paper represent additional effort toward a check between the filter method employed at this Bureau and those employed by the Naval Research Laboratory in their V–2 rocket experiments at the White Sands Proving Ground, New Mexico. These measurements were sponsored jointly by the Naval Research Laboratory and the National Bureau of Standards. The data have been reduced in a manner similar to that employed for previous measurements [1, 2].[1]

During the period of the year in which these measurements were made the sun was near its maximum southern position, hence at no time was the mass of the column of air traversed by sunlight less than about 1.73 times that of the zenith air mass of the station. About 3 hr before (or after) solar noon, when the air mass was greater than about 3.00, the ultraviolet radiant energy within the ozone band, 3,000 to 3,400 A, was so nearly completely absorbed that precise measurements were considered unobtainable because of increased dust scattering at low solar altitudes. Hence in the present report only those values for air masses less than about 3.00 are given.

In this method for the determination of total ozone, the results are based on the relative spectral energy emitted by the sun within the spectral region of 3,000 to 3,400 A (see fig. 3). As a matter of fact, because of the high air masses encountered during the winter season, which greatly reduce the solar energy of wavelengths shorter than 3,100 A, together with the low relative spectral response of the phototubes and the low ozone absorption for wavelengths above 3,350 A, it is only between about 3,100 and 3,350 A that an accurate knowledge of the relative solar-energy emission of the sun is required.

It is a known fact that there are large fluctuations in the short ultraviolet emission from the sun [20, 21, 22], which appear to be associated with sun spots and other solar activity. However, no extensive study has been made, either of solar variation at these wavelengths or of ozone changes accompanying increases in short wavelength solar emission because of the difficulties involved in transporting precision instruments above the ozone layer of the stratosphere [17, 18, 19]. According to the records of the U. S. Naval Observatory and the Radio Division of the National Bureau of Standards, there was no unusual solar activity during either period in which the herein recorded ozone measurements were made. A few small sun spots were present in each case, but no pronounced radio or magnetic phenomena commonly associated with excessive solar activity were detected.

It is generally conceded that the photochemical

[1] Figures in brackets indicate the literature references at the end of this paper.

production of ozone occurs principally at altitudes exceeding 30 km [11, 12, 13], which level is above about 90 percent of the total ozone present at any time within the atmosphere. Hence, the major portion of the ozone at a particular time and place has been carried downward by air currents, or other means, so that any fluctuations due to ultraviolet solar variations would become second-order effects. Furthermore, the small changes in the total solar emission, as measured at the earth's surface, are indicative of the fact that changes in the longer wavelengths (3,000 to 3,400 A) transmitted by the atmosphere are relatively small. Although it is not possible, by this method or by any of those dependent upon ultraviolet measurements, to separate changes in the spectral quality of solar radiant flux from true ozone changes, it is believed that changes in solar emission have but a small effect upon the results and may therefore be neglected without making a serious error in the determination of the total amount of stratosphere ozone.

II. Instruments and Methods

In this work at San Augustine Pass in the Organ Mountains, New Mexico, the same two Westinghouse type 767 titanium phototubes (No. 2 and 6) and the same type of amplifier were employed as in the previous work at Mount Evans, Colorado [2] in the summer of 1936, and in the Organ Mountains [1] in the summer of 1947. Two new filters having transmittances intermediate between those for Ba–3 and Ba–1 and between Ba–1 and Ni were substituted for two of the previously employed filters—Cx and Ba–3—in order to keep all of the observed transmittances between about 25 and 75 percent, that is, within the transmission range most sensitive for measurement of ozone changes.

New determinations were made on the relative spectral responses of the phototubes and of the spectral transmittances of the four filters employed. No weight was given to any previous measurements. Small differences in the values employed are therefore the result of physical changes or may be credited to experimental error in either the former or present determinations. The relative spectral responses of the two phototubes and the spectral transmittances of the four filters employed are given in figure 1.

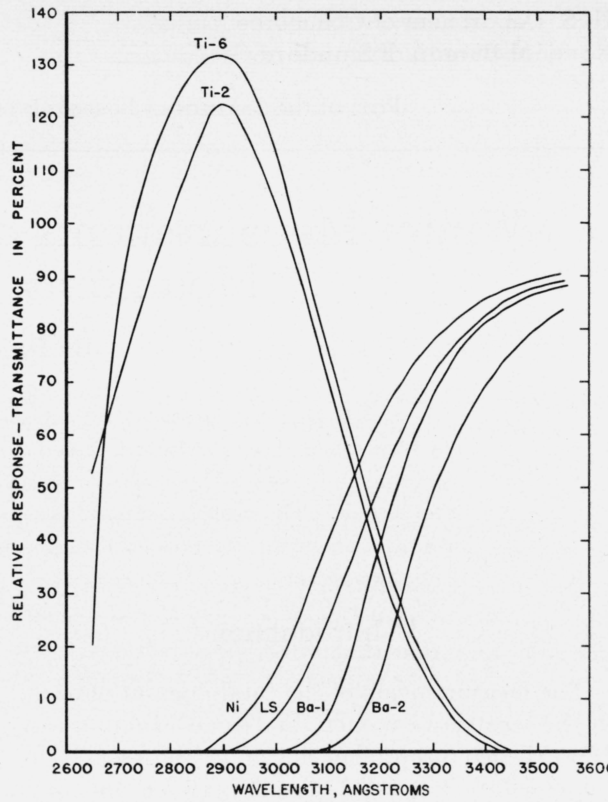

FIGURE 1. *Relative spectral response curves for the two titanium phototubes; also the spectral transmittances of the four filters employed in this work.*

These data were obtained at room temperatures, or slightly above, as affected by the radiant energy employed in the tests, and require a correction if the temperature is excessively different for the field observations. It has been found that the relative spectral response of these phototubes changes but little with temperature over reasonable ranges. However, such is not the case with the glass filters, or of the glass envelopes of the phototubes. Since the phototubes are used within a spectral region where there is no appreciable absorption in the glass (3,000 to 3,400 A), changes in the spectral transmittance of the glass envelope may be neglected. For the filters, a change in temperature of 20 deg C resulted in a change in integrated filter transmittance of about 1 percent, in the 40- to 50-percent range, when the source was simulated sunlight with the phototube used as the receiver. Approximate corrections were made in the case of the December 1947 measurements because of the low temperatures (about 0 °C) encountered. For the January 1948 measurements, no corrections were made, since the weather was warm, being little below normal room temperature at the observing station.

In this work the phototube current is amplified by means of a portable balanced-tube-direct-current amplifier and read on a 0 to 15 microampere Weston model 440 meter. Complete details covering the construction and operation of the amplifier were given in a previous publication [2]. Readings are made without and with each of the four filters in succession. A record is made in which the time of day is tabulated for each set of readings for each filter. Measurements are usually alternately made with two phototubes. The total percentage transmittances of the filters were calculated and plotted as a function of air mass for each of the days on which measurements were made. (See figs. 4, 5, 6, 7).

The determination of the solar air mass as a function of standard time of the station is a rather detailed operation that must be performed before it is possible to interpret the filter-transmittance data intelligently. Reference may be made to a previous paper for details in the determination of air mass at San Augustine Pass [1].

In order to obtain a measure of the total amount of stratosphere ozone at the time of the observations by this method, a solar energy curve outside the atmosphere is either calculated from the measurements or else assumed. For this work, the relative energy curve obtained and employed in the previous work [1] has been used without adjustment. Starting with this relative spectral energy curve, and by a process of arithmetical integration (using 20 A as a unit) a set of transmittance curves for the four filters and two phototubes, as a function of solar air mass was calculated. For these calculations, the Fabry and Buisson [3] transmittance coefficients for ozone and the Rayleigh scattering (atmospheric transmittance) coefficients as used by O'Brien [4] in the reduction of the stratosphere balloon data (*Explorer I* and *II*) have been used. Some of the ozone and scattering (transmittance) curves employed are reproduced in figure 2.

The method is illustrated by an example in table 1, which gives all the steps in the determination of one point (air mass=1.75) on each of the calculated (0.20 cm) ozone curves for phototube Ti-2. This table incidentally gives the relative spectral energy distribution for air mass, $M=0$,

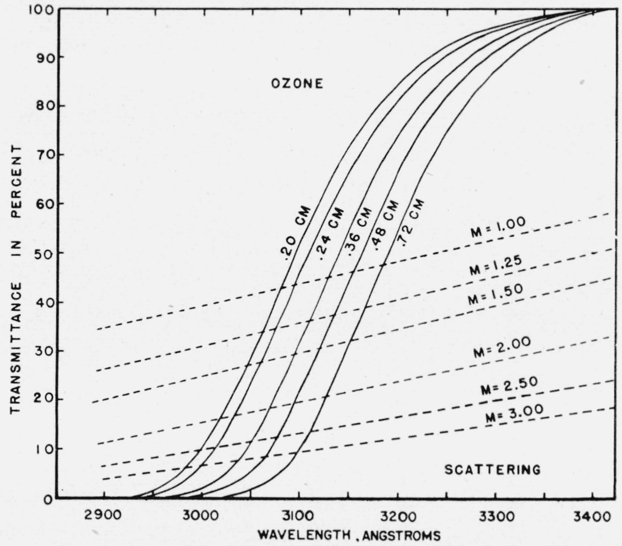

FIGURE 2. *Spectral transmittance of the atmosphere in terms of molecular (Rayleigh) scattering and ozone absorption.*

that is, outside the earth's atmosphere; also the transmittances of the four filters and the relative spectral response of one of the phototubes. For further details regarding this table, reference should be made to previous papers [1, 2].

In figure 8 some of the measurements made during the summer of 1947 [1] are reproduced, together with new calculations of ozone based on the recently determined phototube responses and filter transmittances. The curves shown by the long dashes (in fig. 8) are based on the relative solar spectral energy data of table 1 for $M=0$. The curves shown by the short dashes are based on relative solar energy data (see fig. 3) obtained from V–2 rocket experiments by the Naval Research Laboratory [5]. Similar calculations with the NRL curve are shown in figures 4, 5, 6, and 7 for the winter measurements.

Several things should be noted relative to the choice of the solar energy curve outside the earth's atmosphere. The NBS curve [1] was obtained by a phototube and filter integration method and may not be precise with regard to specific features, since the curve obtained is simply a smooth curve, which appears to best represent the experimental data. On the other hand, the NRL curve is an envelope of the observed spectral emission curve of the sun wherein the Fraunhaufer absorption lines and bands are neglected. If the absorption bands were uniformly distributed, no error would result. The author prefers to use the NBS curve

TABLE 1.—*Method employed in the calculation of ozone values*

This example includes a single set of data for phototube Ti-2 for air mass M=1.75 and an ozone value of 0.20 cm ntp

Center of wave-length interval	Relative spectral energy M=0	Scattering transmittance M=1.75	Transmittance 0.35 cm O_3	Column 2×3×4 relative energy M=1.75	Relative response phototube Ti=2	Column 5×6 integrated response	Transmittance of Ni filter	Column 7×8 integrated response	Transmittance of LS filter	Column 7×10 integrated response	Transmittance of Ba-1 filter	Column 7×12 integrated response	Transmittance of Ba-2 filter	Column 7×14 integrated response
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A														
2,940	47	0.157	--------	--------	1.18	--------	0.066	--------	0.02	--------	--------	--------	--------	--------
60	56.5	.182	0.001	0.01	1.14	0.01	.094	--------	0.03	--------	--------	--------	--------	--------
80	58	.191	.004	.04	1.10	.04	.129	--------	.04	--------	--------	--------	--------	--------
3,000	58.5	.198	.020	.23	1.04	.24	.167	0.04	.07	0.02	0.001	--------	--------	--------
20	55.5	.207	.046	.53	0.985	.52	.210	.11	.09	.05	.003	--------	--------	--------
40	52	.216	.087	.98	.92	.90	.257	.23	.13	.11	.007	0.01	--------	--------
60	50	.224	.151	1.69	.85	1.44	.304	.44	.17	.24	.018	.03	0.001	--------
80	49.5	.232	.238	2.73	.78	2.13	.355	.76	.21	.44	.039	.08	.003	--------
3,100	49	.241	.331	3.91	.70	2.74	.407	1.12	.26	.70	.076	.21	.008	0.02
20	49.5	.249	.423	5.21	.63	3.28	.458	1.50	.31	1.01	.130	.43	.018	.06
40	52	.258	.509	6.83	.55	3.76	.507	1.91	.36	1.36	.192	.72	.037	.14
60	56	.267	.597	8.93	.475	4.24	.552	2.34	.41	1.75	.263	1.12	.069	.29
80	59	.275	.682	11.07	.41	4.54	.597	2.71	.47	2.11	.336	1.53	.114	.52
3,200	64	.283	.753	13.64	.35	4.77	.634	3.02	.51	2.45	.405	1.93	.168	.80
20	74	.292	.808	17.46	.29	5.06	.670	3.39	.56	2.83	.473	2.39	.232	1.17
40	88	.300	.850	22.44	.24	5.39	.701	3.78	.60	3.25	.534	2.88	.297	1.60
60	94	.309	.885	25.71	.195	5.01	.731	3.66	.65	3.23	.591	2.96	.364	1.82
80	96	.317	.913	27.78	.15	4.17	.756	3.15	.68	2.84	.638	2.66	.426	1.78
3,300	98	.325	.936	29.81	.115	3.43	.776	2.66	.71	2.45	.681	2.34	.483	1.66
20	99	.334	.952	31.48	.085	2.68	.800	2.14	.74	1.99	.718	1.92	.539	1.45
40	99	.343	.965	32.77	.060	1.97	.817	1.61	.77	1.51	.748	1.47	.586	1.15
60	99	.352	.978	34.08	.037	1.26	.832	1.05	.79	0.98	.774	0.98	.629	0.79
80	99	.360	.992	35.35	.021	0.74	.844	0.62	.81	.60	.795	.59	.666	.49
3,400	99	.368	.997	36.32	.010	.36	.856	.31	.83	.30	.813	.29	.697	.25
20	99	.376	.998	37.15	.002	.07	.866	.06	.84	.06	.829	.06	.725	.05
Total	--------	--------	--------	--------	--------	58.75	--------	36.61	--------	30.28	--------	24.60	--------	14.04
Percentage transmittance	--------	--------	--------	--------	--------	--------	--------	62.3	--------	51.5	--------	41.9	--------	23.9

as its use results in closer agreement with the experimental data for high air masses relatively to low air masses. This characteristic is more pronounced in the case of air masses between 1.0 and 1.7 (see fig. 8). For the measurements recorded herein, calculations based on the NRL solar curve indicate ozone in the amount of about 0.04 cm greater than when calculated on the basis of the NBS curve. Between air masses 1.0 and 1.7, the difference is less and ranges between about 0.02 and 0.04 cm (see fig. 8).

III. Amount of Stratosphere Ozone

In figures 4, 5, 6, and 7 are represented the observed data and the calculated effects of assumed amounts of ozone above the San Augustine Pass in the Organ Mountains for the period of December 16 to 19, 1947, and January 6 to 8, 1948. The scattering of the data, which is of the order of about 1 percent and corresponds to about 0.03 cm of ozone, is probably for the greater part random deviation of observations. Although there are some indications of real ozone changes, they are small. According to the Weather Bureau reports, immediately preceding the measurements on December 16 to 19, 1947, polar continental and possibly polar maritime air had moved into the New Mexico area from the northwest. This cold air extended up to 13,000 ft on the 15th, and then became warm again up to 23,000 ft by the 17th. On the morning of the 17th, the tropopause was colder and higher than it had been on

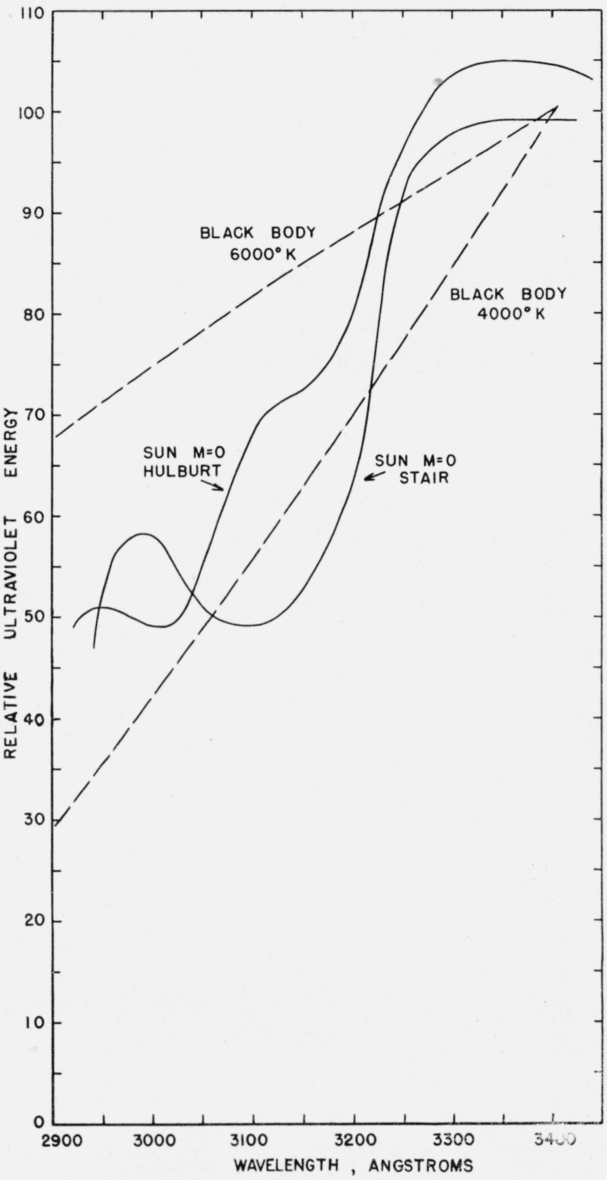

FIGURE 3. *Distribution of energy in the extreme ultraviolet of the solar spectrum.*

The Stair curve is based on previous measurements at Mount Evans, Colo., and at the Organ Mountains, New Mex., and is plotted in terms of microwatts per square centimeter per 10 A. The Hulburt curve is in relative units and is based on V-2 rocket experiments made by the Naval Research Laboratory at White Sands Proving Ground. The curves for black bodies are plotted on relative scales, being arbitrarily set at 100 for 3,400 A.

the 16th (all observations at Albuquerque, New Mex.). This condition continued through the night of the 18th, at which time a second upper cold front has passed the Organ Mountain area. Usually there was a west wind of variable intensity, being somewhat erratic on the 16th in that it shifted to the north and northeast during a part of the day. During the remainder of the 4-day period, there was less wind—at times none. There was an increase in barometric pressure on the 16th, followed by a gradual reduction during the remainder of the period. There is some indication of a decrease in the total amount of ozone during the period (see figs. 4 and 5). This is in agreement with other measurements, in that a decrease in ozone value is to be expected as an anticyclonic mass of air moves into a region [14]. The sky was almost cloudless throughout the day during the 16th and 17th. Much of the sky was covered by thin clouds on the 18th, so that measurements could be made during only part of the afternoon. There was some cloudiness on the 19th, but most of the time the area surrounding the sun was clear.

For several days preceding the ozone measurements on January 6 to 8, 1948, a mass of modified polar continental air had been moving into the Organ Mountain area. There was a continuation of this situation throughout most of the time of the observations, except that on the morning of January 6th the southwestern edge of a high pressure area moved into New Mexico. A light southwest wind was blowing most of the time, and the temperature was high for this season of the year. Haze, local smoke, and clouds produced some interference with the measurements during most of the day of the 6th. Clouds interrupted the work at about 2:15 pm. On the 7th and 8th, there was but little smoke or haze and no clouds throughout the day. The slightly higher ozone values observed on January 6th may be real or may be the result of uncorrected amounts of smoke and haze.

The mean values of ozone, when all of these measurements are considered, appear to be about 0.19 cm for each of the two periods. The data obtained with phototube Ti–6 are higher than those obtained with Ti–2. Any difference must be experimental error, since for the previous calibration of the phototubes as employed for the June and July measurements [1] the data were the reverse in relative amount. Furthermore, the lack of complete agreement for the calculated amount of stratosphere ozone between the measurements with the four filters may also be considered experimental error and indicates the degree of precision that may be expected in this work.

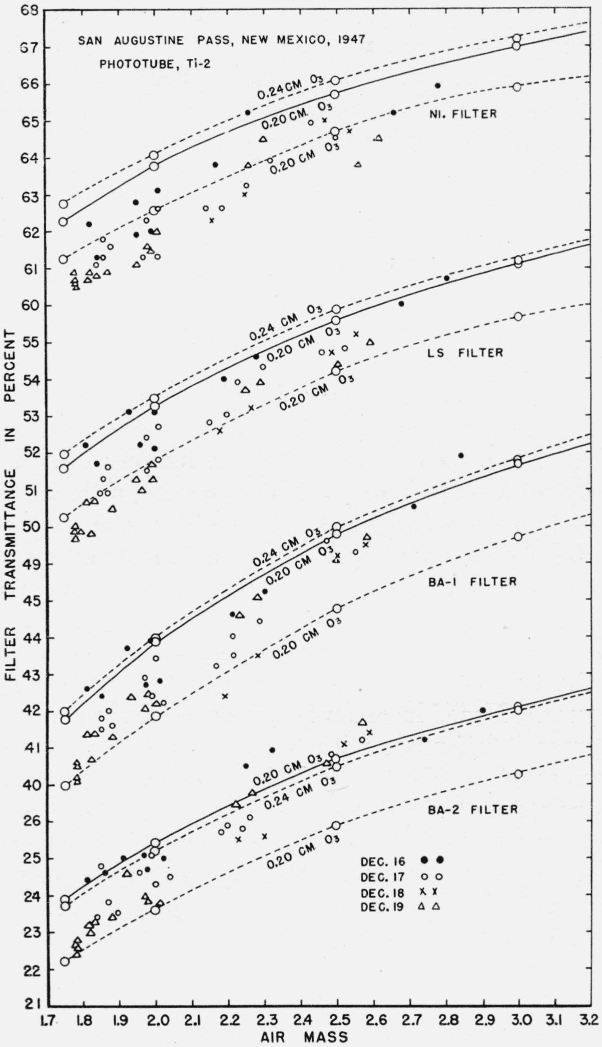

FIGURE 4. *Amount of ozone in the stratosphere, based on observations with titanium phototube 2.*

[Calculations based on the Stair solar energy curve (solid lines) and the Hulburt solar energy curve (dotted lines) for air mass, $M=0$.

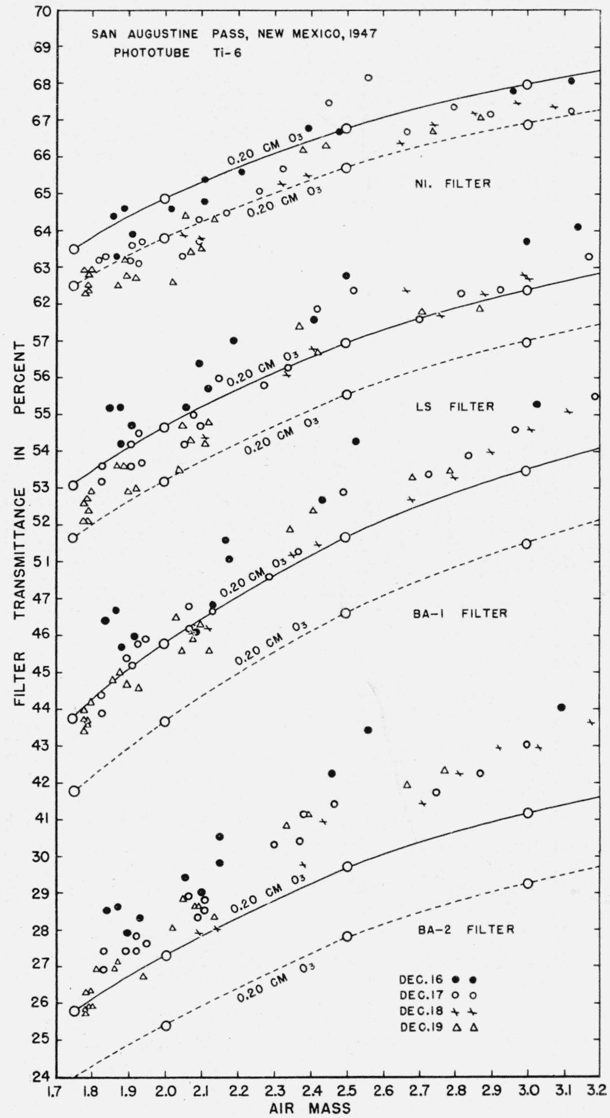

FIGURE 5. *Amount of ozone in the stratosphere, based on observations with titanium phototube 6.*

Calculations based on the Stair solar energy curve (solid lines) and the Hulburt solar energy curve (dotted lines) for air mass, $M=0$.

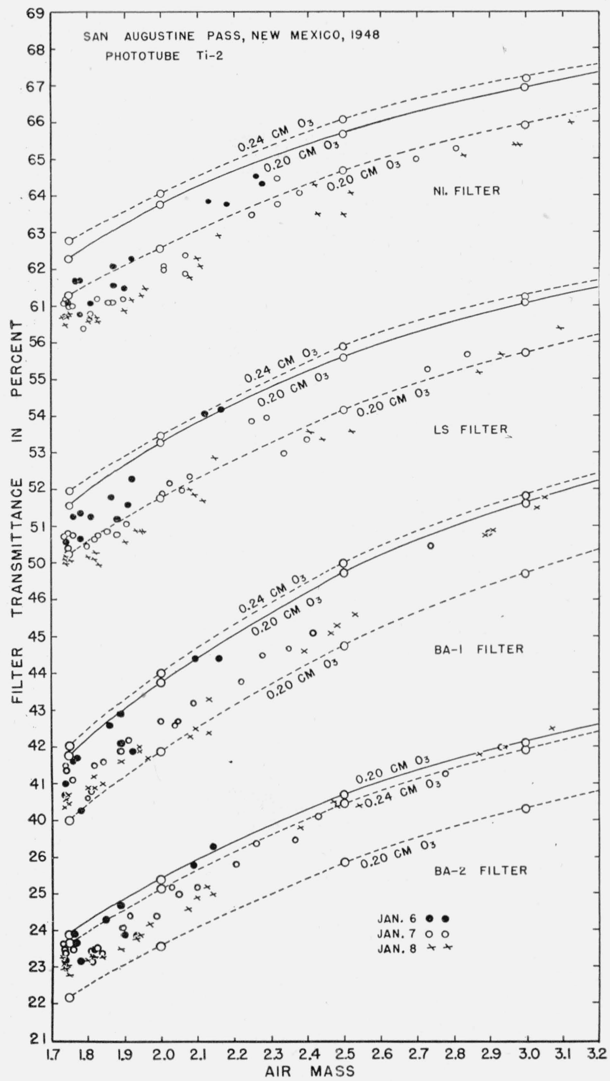

FIGURE 6. *Amount of ozone in the stratosphere, based on observations with titanium phototube 2.*

Calculations based on the Stair solar energy curve (solid lines) and the Hulburt solar energy curve (dotted lines) for air mass, $M=0$.

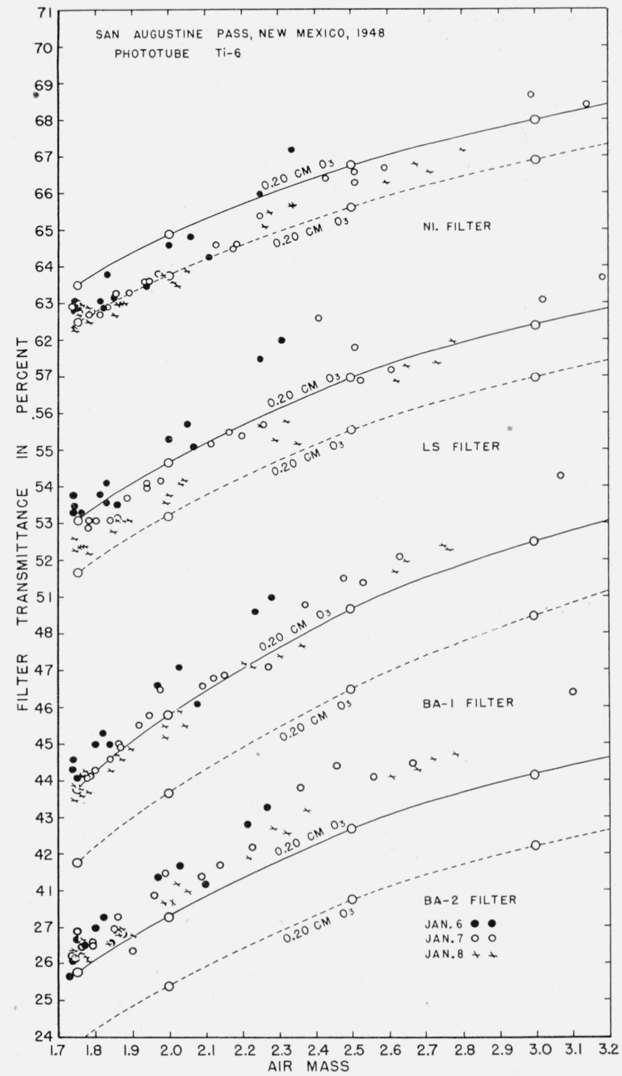

FIGURE 7. *Amount of ozone in the stratosphere, based on observations with titanium phototube 6.*

Calculations based on the Stair solar energy curve (solid lines) and the Hulburt solar energy curve (dotted lines) for air mass, $M=0$.

IV. Conclusion

Although, as previously noted in connection with ozone measurements by this method, the preliminary calibrations and calculations for a particular phototube and filters for a particular station are somewhat involved, when these are once made, it is possible, from a set of curves, to determine precisely the total ozone value from measurements with a single phototube and filter within a few minutes. The simplicity and low cost of the equipment, together with the fact that it is readily portable, makes its use practical in connection with outlying weather stations, should ozone measurements be found useful in connection with weather forecasting. Certain measurements and theoretical considerations indicate [13, 15] that total ozone concentrations, and variations from month-to-month or day-to-day are definitely associated with weather changes but are probably the effect of weather and associated air currents rather than the cause. If such is the case, measurement of total ozone

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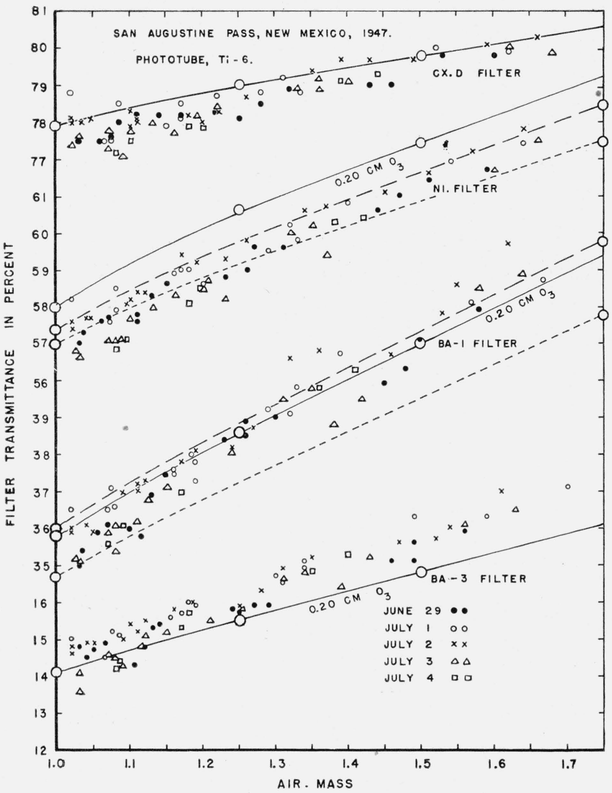

FIGURE 8. *Amount of ozone in the stratosphere, based on observations with titanium phototube 6 in June and July 1947.*

Calculations based on Stair solar energy curve (solid lines, using previously determined constants for phototube and filters; long dashes, using new calibration data for phototube and filters) and on Hulburt solar energy curve (short dashes) for air mass, $M=0$; all curves for 0.20-cm ozone ntp.

may have an indirect usefulness in forecasting and a very important application in fundamental studies of air movements at high altitudes.

The total amounts of ozone determined for the San Augustine Pass in the Organ Mountains (in Dec. 1947 and Jan. 1948) are in general agreement with other determinations for the same latitude and season of the year [6, 9, 10, 11, 16], when it is taken into consideration that the observed values reported herein were made during anticyclone periods when the ozone value should be lower than normal [14].

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