PROGRESS REPORT

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ABSTRACT

In the past year we have been investigating a new algorithm for the derivation of column sulfur dioxide, column ozone, and aerosol optical depth from the TOMS HDT archived albedos. Simulations of the measured albedos were made using a radiative transfer model, and a technique developed to separate the effects of the aerosol optical depth from the absorption optical depth. The retrieval adopted obtained values for the three parameters with high accuracy. This retrieval was then applied to the TOMS data.

SCIENCE ACTIVITIES

In the past year we have been developing a new algorithm to obtain SO_2 from the measured TOMS radiances. The SO_2 cloud that results from the eruption of volcanoes is largely confined to the altitude range above 15 km, and thus the effect of SO_2 on the measured N value should be the same as if one had added extra ozone to the altitude profile. Our first approach to the derivation of SO_2 was therefore to prepare a set of N-value look-up tables using the TOMS equatorial ozone profiles (our test case was the El Chichon eruption), plus a range of column sulfur dioxide values, for particular solar zenith angles, scan angles, and azimuthal angles, etc.. An example of such a table for the A and B pairs used in the current algorithm is given in Table 1.

An examination of Table 1 shows that, for each pair, there will be many sets of values for the ozone and sulfur dioxide column amounts that will lead to the same N-value. If we plot the column ozone amounts versus the corresponding column sulfur dioxide for a particular pair then the result is a straight line, at least under the conditions that we have studied. If we now plot the second pair on the same graph, the interaction of the two lines will give the actual column amounts for ozone and SO_2. Figure 1 shows such a plot.

One thing that is immediately clear from Figure 1 is that the two lines are almost parallel. The slope of the two lines is proportional to the ratio of the SO_2 absorption coefficient to the ozone absorption coefficient for the particular pair. Table 2 lists this ratio for the A and B pairs currently used in the TOMS algorithm. The ratio of the SO_2 coefficient to the ozone coefficient for the two pairs differs only by 3.7%, which is consistent with the results shown in Figure 1. We chose a modified set of pairs, A′ and B′, also shown in Table 2 which give a wider angle between the two lines, as shown in Figure 2, however the ratio of the cross sections still only differs by 15%.

We than applied this algorithm to the TOMS HDT data for April 15th, 1982. Figure 3 shows the results obtained for a pass over the volcanic cloud. Each point is the average across a scan, where the

scan angle has been limited to less than 30 degrees. In addition, only data for cloud free conditions (reflectivity less than 0.15) has been analyzed. A significant feature of Figure 3 is that as the column SO_2 increases across the cloud, the column ozone decreases. This could be a chemical effect, but one must remember that the volcanic plume that brings SO_2 into the stratosphere could also bring ozone-poor air from the troposphere. Our concern however was that the effect was an artifact due to the basic assumption that by using pairs of wavelengths the effect of aerosols would cancel out.

We then calculated the effect of sulfate aerosols on the radiances using the Dave code. Table 3 gives results for the retrieved column sulfur dioxide and ozone using the algorithm discussed above for various optical depths of aerosols. There is an obvious impact of the aerosols on the retrieved column amounts. We therefore decided to see if it were possible to account for the aerosols. In order to do this, we had to develop another algorithm.

The principle behind the derivation of total ozone from the TOMS radiances is that most of the measured radiance comes from the troposphere, and not from where the bulk of the ozone resides. Thus all of the radiation passes through the ozone layer twice. In other words the efficiency for the detection of added stratosphere ozone is 1.0. But in essence this is the same as saying that the measured N value depends only on the absorption optical depth T_{abs} in the stratosphere, where T_{abs} is given by :-

$$T_{abs} = L.(\Omega*\alpha + \Sigma*\gamma) \qquad \text{.....(1)}$$

where Ω and Σ are the column amounts of ozone and sulfur dioxide, and α and γ are their respective absorption coefficients. L is the path length. Figure 4 shows calculated N values versus the absorption optical depth for one particular set of solar zenith angle, scan angle, and azimuthal angle. In this and for all future calculations the profile for the tropospheric ozone has been kept constant. The ozone content and the sulfur dioxide content were varied randomly, and each point represents one of these combinations. As expected the points fall on the same line. Thus if

one has a measured N value, one can determine the absorption optical depth.

Sulfate aerosols are non-absorbing, and when added to the stratosphere only scatter radiation back to space, thus reducing the amount of solar flux that reaches lower altitudes, the net result being a decrease in the N value. The impact of the aerosols on the measured N value will depend on the aerosol optical thickness, the aerosol particle size distribution, the aerosol refractive index, and the altitude profile. In our initial analysis we have assumed that the shape of the altitude profile of the SO_2 and the aerosols is gaussian with a peak at 25 km, and a half width of 2 km. The refractive indices for the aerosols were taken from WMO TD #24.

We first calculated the N value for various values of T_{abs}, and aerosol optical depths, T_{aer}. Then we derived an effective absorption optical depth, T_{eff}, from the pure absorption look-up tables similar to the curve shown in Figure 4. We then calculated a quantity ΔT, given by:-

$$\Delta T = T_{eff} - T_{abs} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Figure 5 shows the calculated ΔT for ground reflectivities of 0 and 0.4, a solar zenith angle of 30°, and zero scan and azimuthal angles for the four TOMS wavelengths. To a first approximation one can assume that ΔT is independent of wavelength, i.e. for each of the wavelengths one can write:-

$$T_{eff} = T_{abs} + A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where A is a constant.

When we plot A versus the aerosol optical depth for a particular case of solar zenith angle, scan angle, and azimuthal angle, the curve is almost linear. We found no case for any of the range of angles met with in the TOMS data analysis which did not show a single value dependence. Having determined A from the measured radiances, we can now go back to calculated tables, as

illustrated in Figure 5, to determine the exact value of ΔT for each wavelength, and hence T_{abs} for each wavelength. It is now a simple job to determine the values of Ω and Σ. Figure 6 shows some preliminary results for the same conditions as Figure 3 for SO_2, Ozone and aerosol optical depth. The results for SO_2 are lower than for Figure 3, and the corresponding dip in ozone is less. The aerosol optical depth curve follows the SO_2 curve.

We then applied the new algorithm to the data for the entire globe. The results of this analysis are shown in Figure 7. Interesting features are seen over China and the Sahara, namely negative optical depths. Both China and the Sahara have tropospheric dust clouds during April and these are composed of silicate aerosols which are absorbing. As the assumption in the algorithm was that we had non-absorbing aerosols, these dust clouds could have an apparent negative optical depth.

N VALUE FOR RANGE OF SO_2 AND OZONE COLUMN AMOUNTS

SULFUR DIOXIDE, DU

OZONE, DU

	0	5	10	15	20	25	30	
225	36.6609	39.2082	41.7418	44.2393	46.7272	49.2065	51.6417	
250	41.4089	43.9424	46.4138	48.9016	51.3441	53.7886	56.2264	
275	46.1033	48.5794	51.0503	53.4859	55.9157	58.3204	60.7094	A PAIR
300	50.7108	53.1458	55.5707	57.9703	60.3547	62.7232	65.0727	
325	55.1999	57.5983	59.9767	62.3427	64.694	67.0155	69.3144	
225	16.5265	17.9457	19.3537	20.7537	22.1528	23.5485	24.9283	
250	18.7276	20.148	21.5548	22.9273	24.3305	25.7122	27.0885	
275	20.9397	22.331	23.7418	25.109	26.4822	27.8556	29.2357	B PAIR
300	23.1294	24.5233	25.8857	27.2641	28.6344	30.003	31.3454	
325	25.2862	26.6608	28.0151	29.3818	30.7487	32.0954	33.447	

TABLE 1.

TABLE 2. ABSORPTION COEFFICIENTS FOR SO_2 AND OZONE.

o TOMS WAVELENGTHS:

WAVELENGTH		O_3 COEFF	SO_2 COEFF
3125		1.652	4.25
3175		.886	2.33
3312		.147	.046
3398		.027	.018
3125/3312	A PAIR	1.505	4.204
3175/3398	B PAIR	.859	2.312
3125/3398	A'PAIR	1.625	4.232
3175/3312	B'PAIR	.739	2.284

o RATIOS OF SO_2 COEFF TO O_3 COEFF

PAIR	RATIO
A PAIR	2.79
B PAIR	2.69
A'PAIR	2.60
B'PAIR	3.09

TABLE 3.

INPUT OZONE : 275 D.U

INPUT SO2 : 50 D.U

				AOT=0.05		AOT=0.1		AOT=0.2	
REF.	SZA.	SCN.	AZM	O3	SO2	O3	SO2	O3	SO2
0.10	0.00	12.00	30.00	268.91	53.34	260.54	56.59	244.22	64.96
0.10	0.00	16.00	30.00	268.44	53.43	260.54	56.59	244.22	64.96
0.10	0.00	20.00	30.00	268.02	53.53	260.54	56.59	244.22	64.96
0.10	0.00	24.00	30.00	267.91	53.63	260.54	56.59	244.22	64.96
0.10	0.00	28.00	30.00	268.03	53.71	261.47	56.53	244.94	64.90
0.10	0.00	32.00	30.00	268.19	53.80	261.47	56.53	244.94	64.90
0.10	0.00	36.00	30.00	268.26	53.93	261.47	56.53	244.94	64.90
0.20	0.00	12.00	30.00	268.93	53.33	262.94	56.43	246.60	64.82
0.20	0.00	16.00	30.00	268.49	53.42	263.19	56.46	248.33	64.76
0.20	0.00	20.00	30.00	268.05	53.52	263.19	56.46	248.33	64.76
0.20	0.00	24.00	30.00	267.92	53.61	263.19	56.46	248.33	64.76
0.20	0.00	28.00	30.00	268.01	53.68	263.19	56.46	248.33	64.76
0.20	0.00	32.00	30.00	268.14	53.77	263.19	56.46	248.33	64.76
0.20	0.00	36.00	30.00	268.18	53.89	263.19	56.46	248.33	64.76

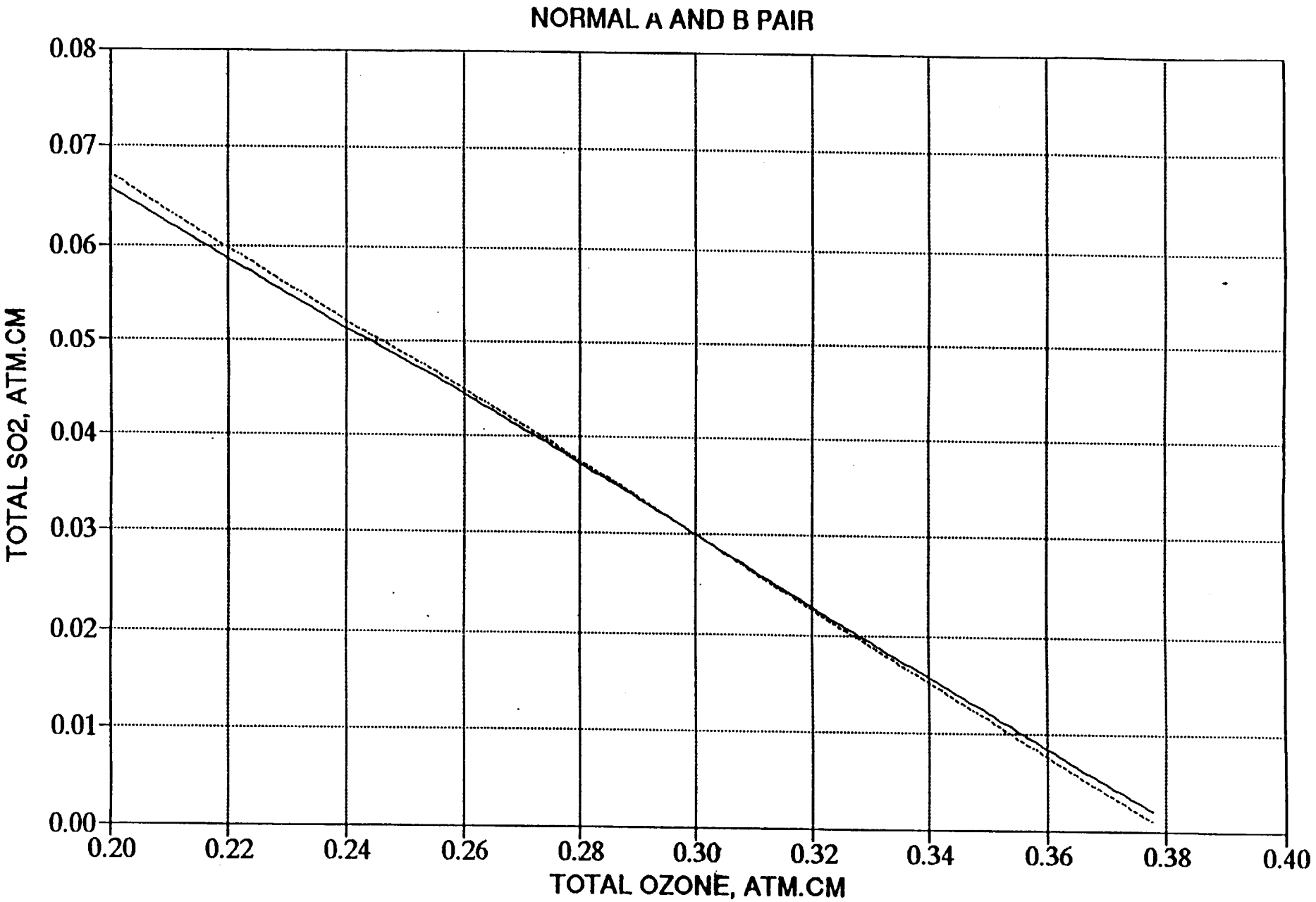

NORMAL A AND B PAIR
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
TOTAL SO2, ATM.CM
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34
0.36
0.38
0.40
TOTAL OZONE, ATM.CM
A PAIR
B PAIR

FIGURE 1.

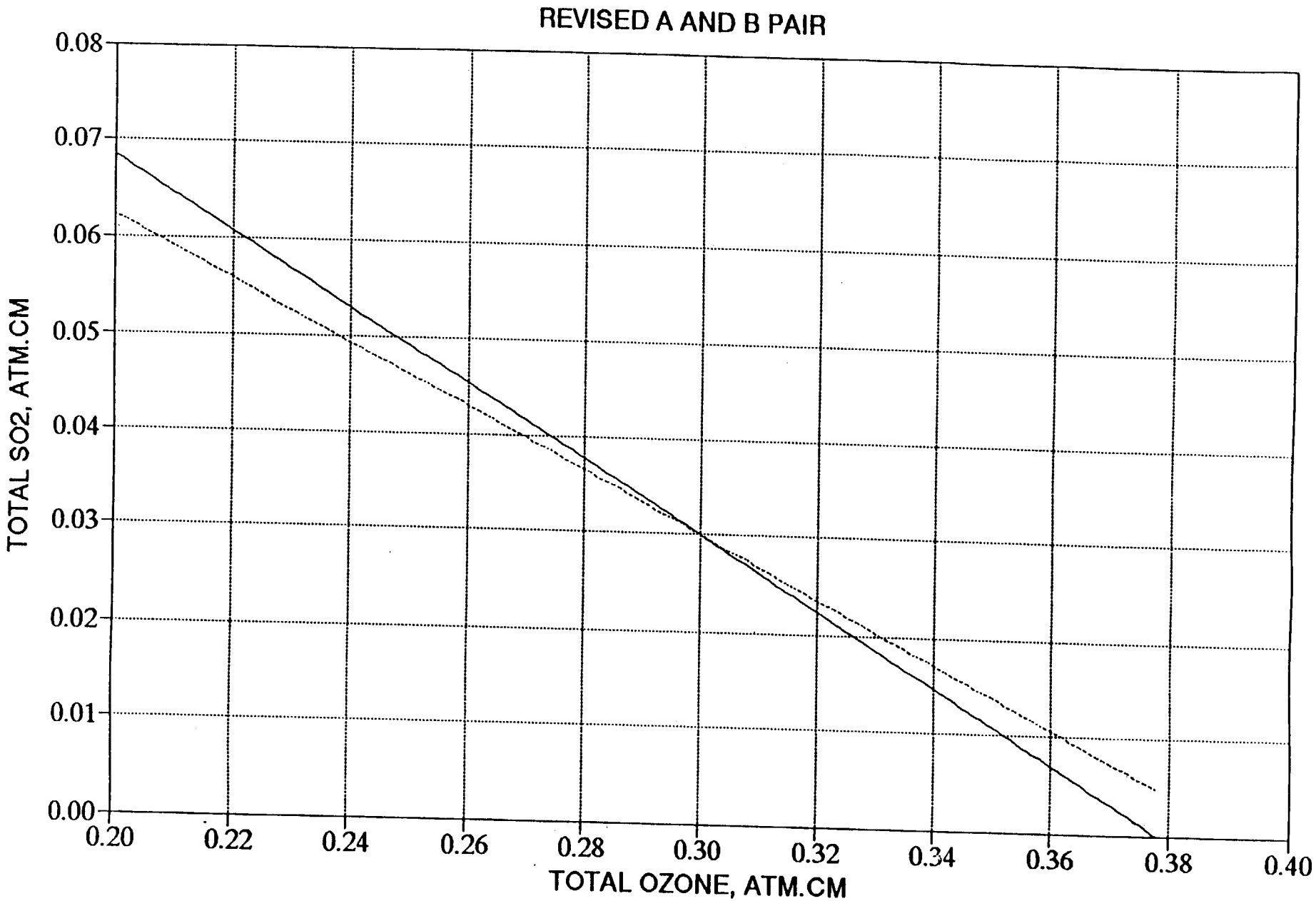

REVISED A AND B PAIR
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
TOTAL SO2, ATM.CM
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34
0.36
0.38
0.40
TOTAL OZONE, ATM.CM
A PAIR
B PAIR

FIGURE 2.

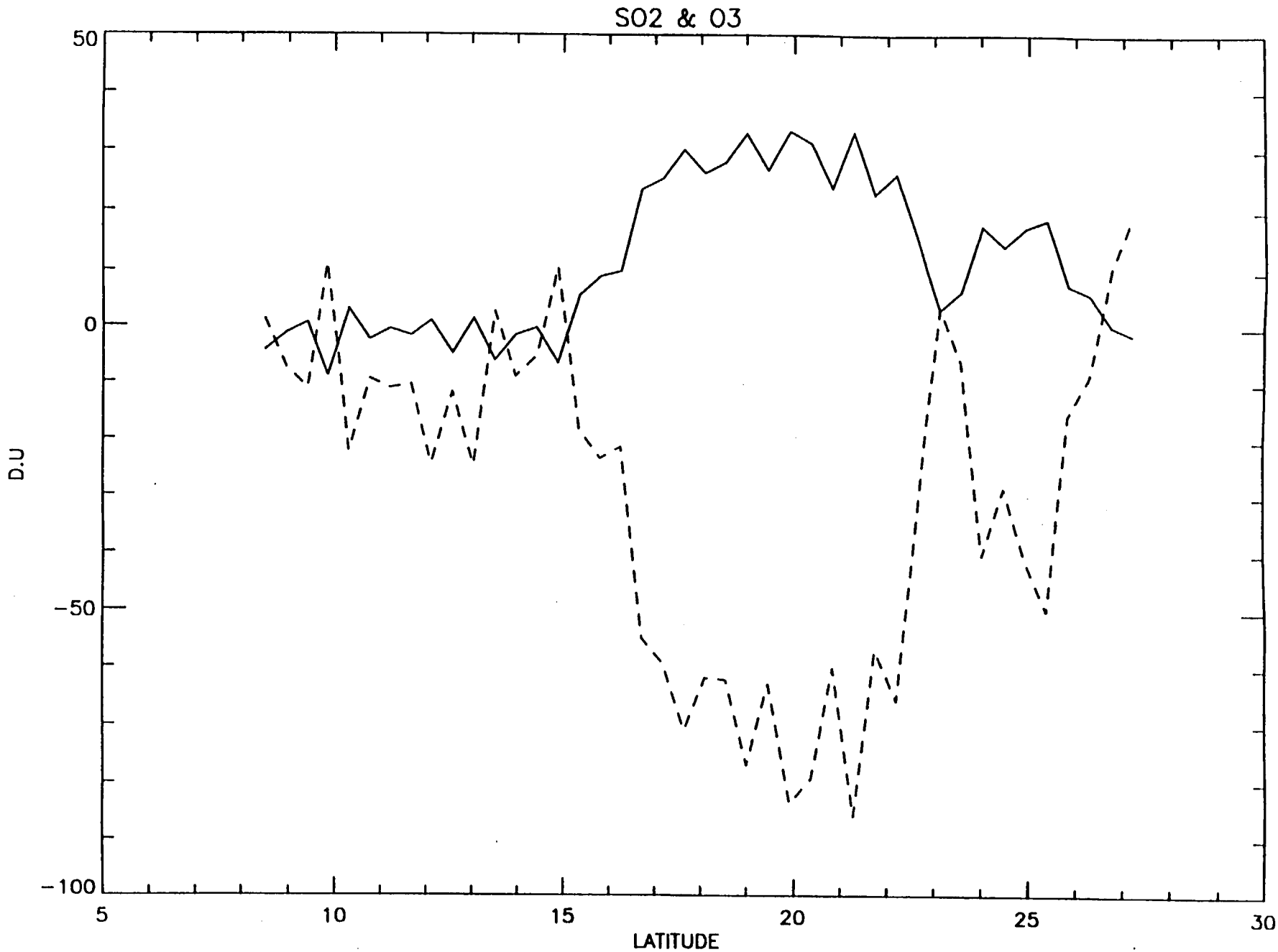
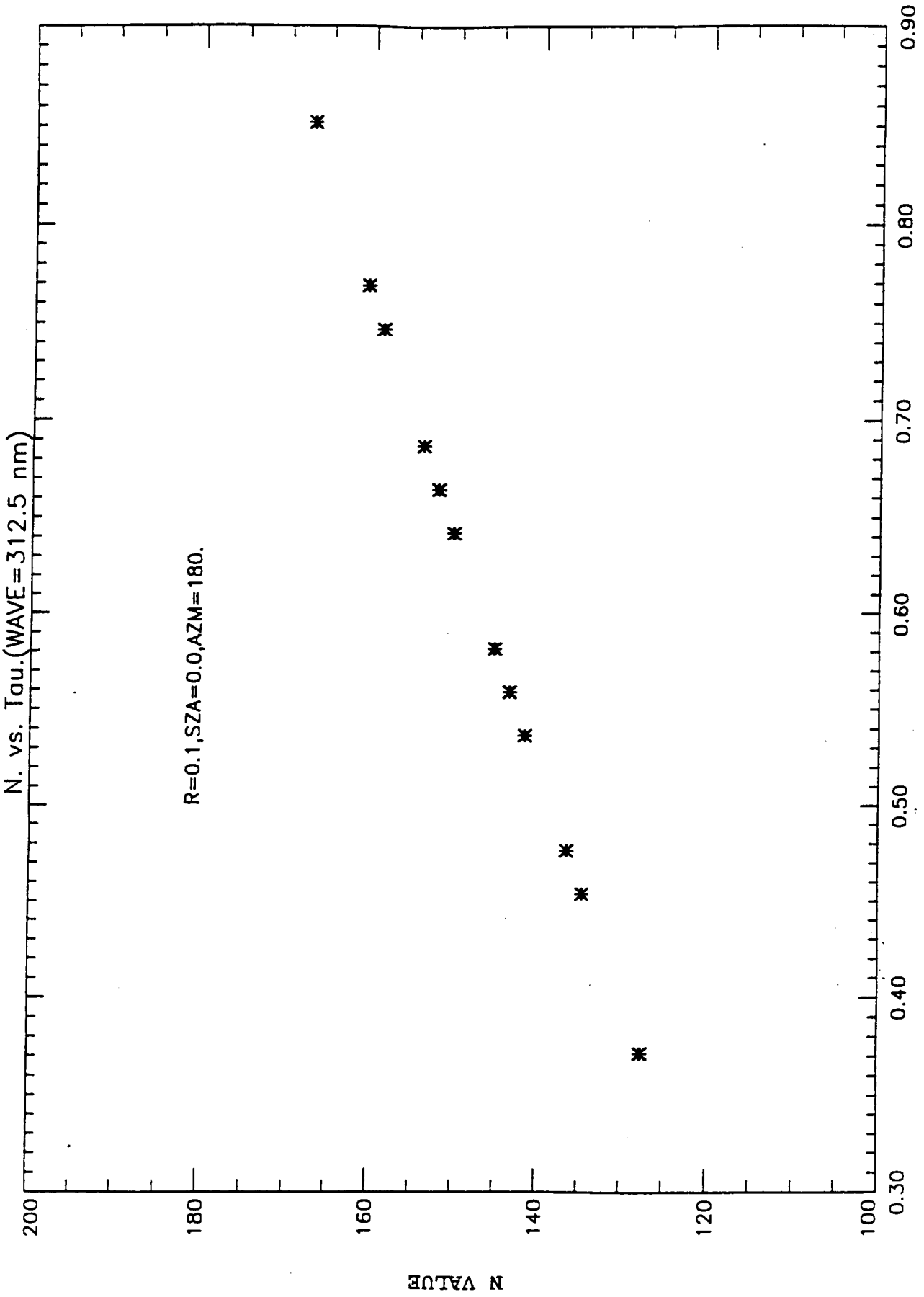


FIGURE 3. OZONE AND SULFUR DIOXIDE FOR APRIL 15, 1982

FIGURE 4. N VALUE VERSUS ABSORPTION OPTICAL DEPTH



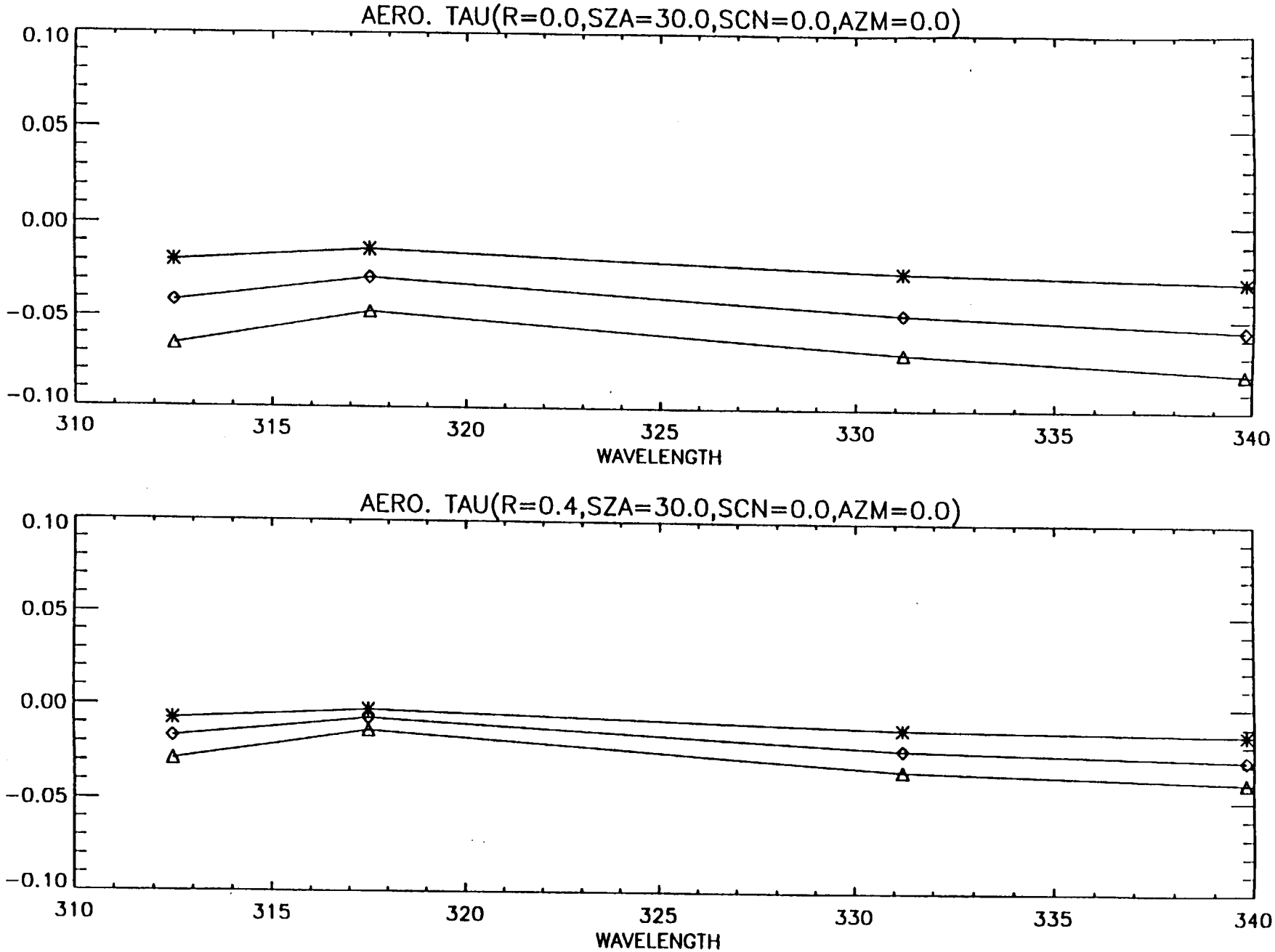


FIGURE 5. CALCULATED ΔT FOR TOMS WAVELENGTHS

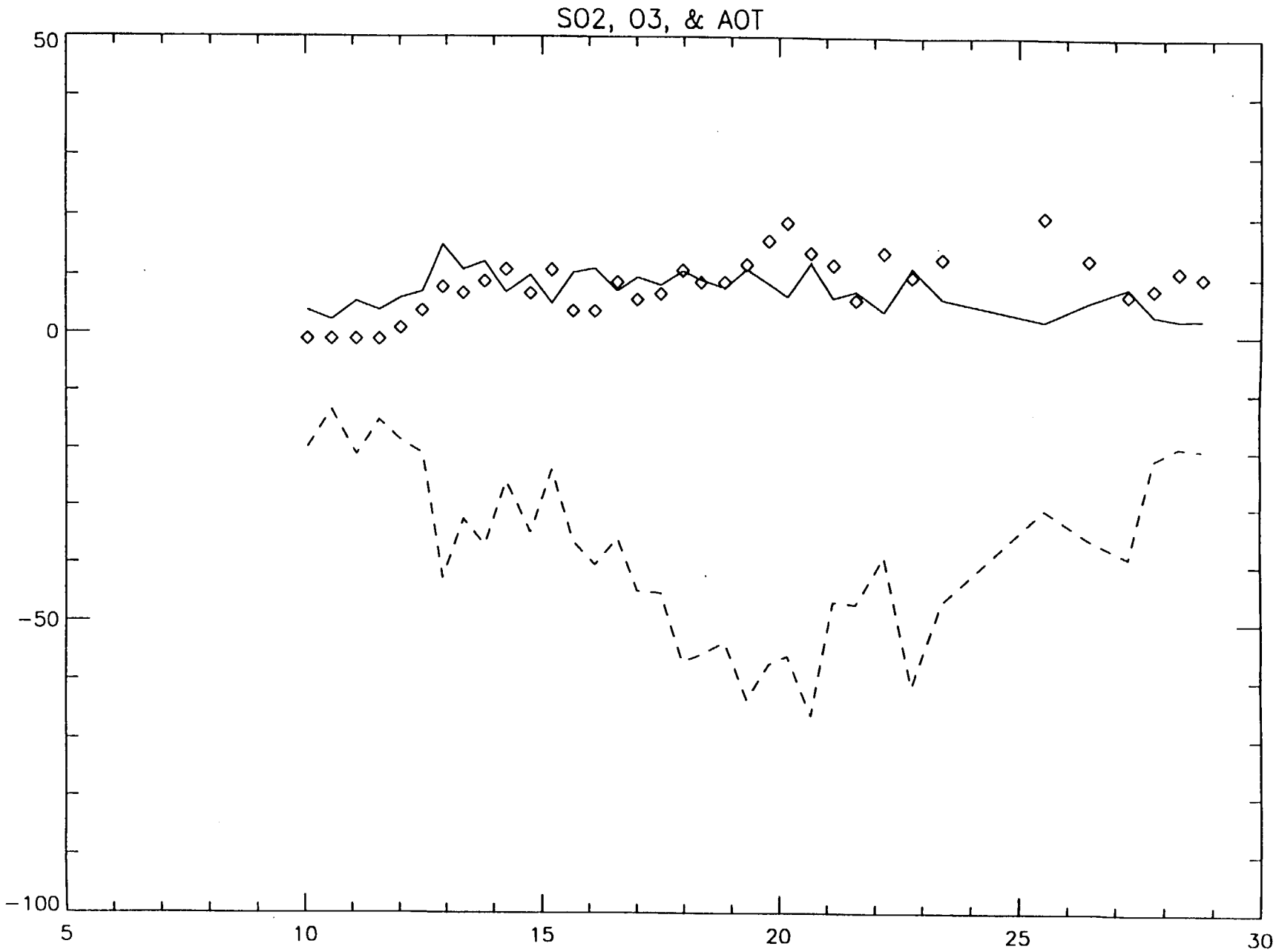


FIGURE 6 OZONE, SO_2, AEROSOL OPTICAL DEPTH, APR. 15, 1982
(COLUMN AMOUNT DU, OPTICAL DEPTH TIMES 100)

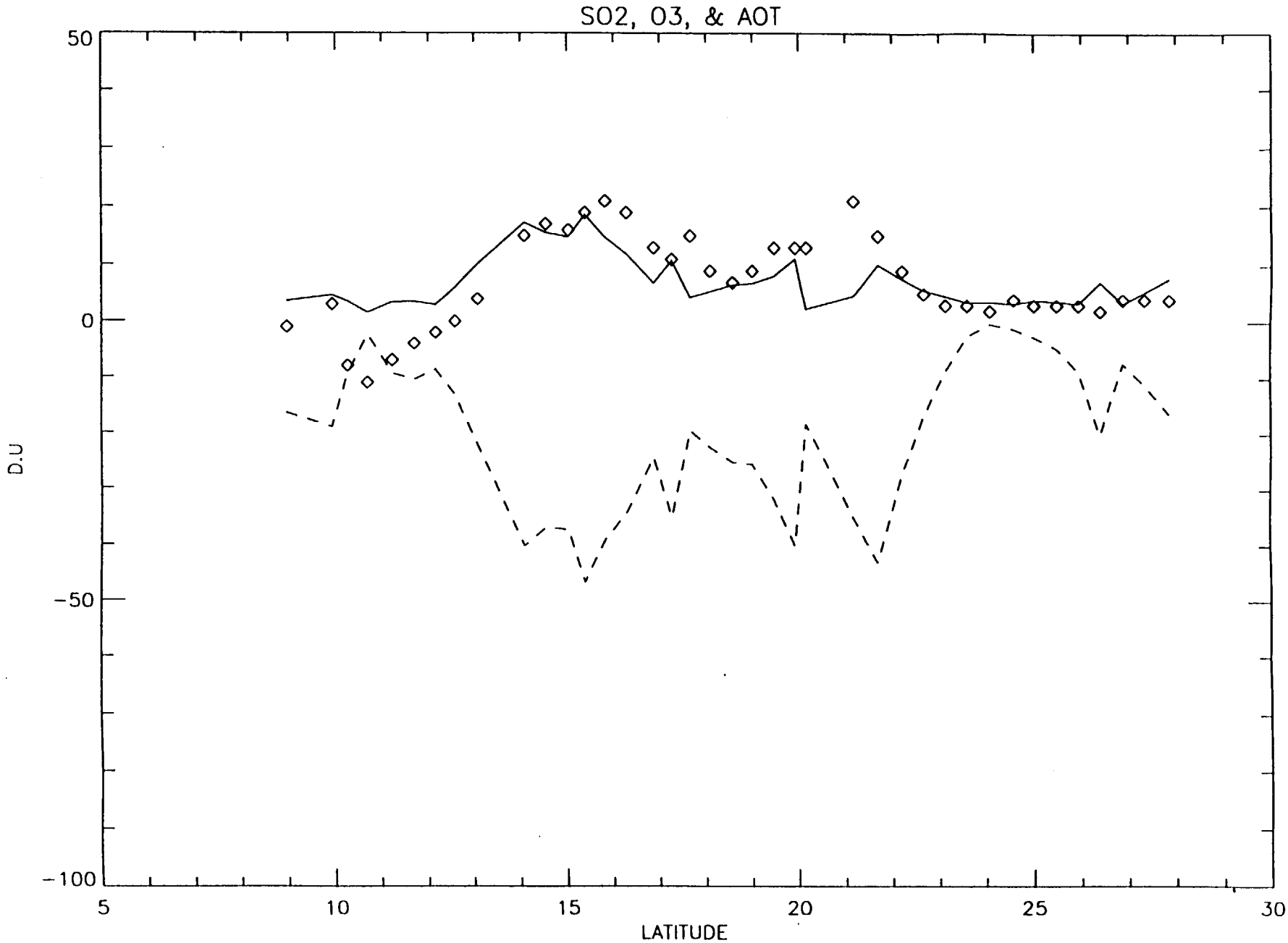


FIGURE 7. AEROSOL OPTICAL DEPTH FOR APRIL 15, 1982

REFERENCES

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