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DIRECT MEASUREMENTS OF TROPOSPHERIC OZONE USING TOMS DATA

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ABSTRACT

Fishman and Larsen (1987) have proposed a new algorithm, called "tropospheric residual method", which retrieves the climatological tropospheric ozone by using SAGE (Stratospheric Aerosol and Gas Experiment) and TOMS (Total Ozone Mapping Spectrometer) data. In this paper, we will examine the feasibility of detection for tropospheric ozone using only TOMS data. From a case study over the Atlantic Ocean off coast of west Africa, it has been found that total ozone in the archived TOMS data has been overestimated over a region of marine-stratocumulus clouds.

INTRODUCTION

The TOMS total ozone data is derived from the backscattered ultraviolet radiances measured by the TOMS instrument on Nimbus-7 using an algorithm that was developed principally for measurements of stratospheric variability. In 1986, Fishman et. al., used the TOMS total ozone data to determine tropospheric ozone fields in the tropics. They assumed that horizontal stratospheric gradients in the tropics are small, and used the TOMS relative total ozone field as a surrogate for the tropospheric ozone field. In 1987, Fishman and Larsen, extended this method, by using the SAGE profiles to determine the stratospheric ozone field, and then subtracted this quantity from the TOMS data. In this paper we examine the physics of the TOMS algorithm as it applies to the measurement of tropospheric ozone.

PRESENT ALGORITHM

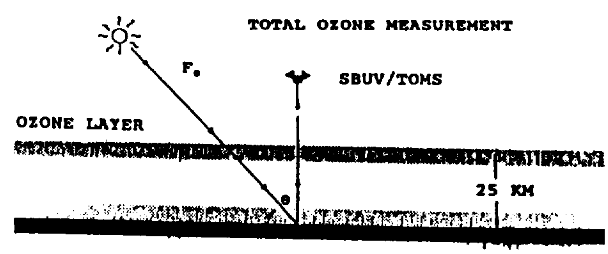
A simplified schematic of the principle of the TOMS measurement is shown in Figure 1. This simple case assumes that the atmosphere does not scatter, and that the layer of ozone is confined to a narrow strip in the stratosphere. If the reflectivity of the ground is R, then the measured albedo A is given by:

$$A = R \exp(-\alpha\Omega s - \beta\Delta s) \qquad (1)$$

where α is the ozone absorption cross section, Ω is the column content of the ozone layer, β is the Rayleigh scattering coefficient for the atmosphere, and Δ is the column content of the atmosphere. s, the path length, is given by :

$$s = 1/\cos(\theta) \qquad (2)$$

θ is given in Figure 1. If we can measure the reflectivity, R, then the only unknown in equation (1) is Ω. In the TOMS algorithm, R is measured at another wavelength where the absorption due to ozone is negligible, the assumption being that in the ultraviolet R varies only slowly with wavelength.



$$I_{ground} = F_0 . \exp-(\sec\theta . \Omega . \alpha)$$

$$I_{satellite} = I_{ground} . R . \exp(-\Omega . \alpha)$$

$$= F_0 . R . \exp-((1+\sec\theta) . \Omega . \alpha)$$

Fig. 1. Schematic diagram that shows how TOMS measures the backscattered radiation from reflecting surface. F_0 is the solar irradiance, I_{ground} is the intensity reaching to ground, I_{sat} is the measured intensity by TOMS, Ω is total ozone, and α is the ozone absorption coefficient.

Unfortunately for the simple method described above, the atmosphere does scatter, and thus the measured radiance at the instrument is the sum of the reflected sunlight plus the scattered sunlight from the atmosphere. However because the density of the atmosphere increases exponentially as the altitude decreases, almost all of the scattered radiation comes from the troposphere. Thus, if the ozone were confined to the stratosphere, as shown in the illustration, then one can derive an equation similar to (1), where R is replaced with the effective reflectivity of the ground plus the atmosphere. In reality, about 90% of the column ozone is in the stratosphere.

However it is the 10% in the troposphere which is of interest to us now. In the illustrations above, the total radiance, both reflected and scattered, passes through the entire ozone column, and thus the efficiency of detection of the ozone column is 100%. However if we now consider ozone in the troposphere, the outgoing scattered radiation from a particular altitude will not pass through any ozone below it, thus the efficiency of detection for tropospheric ozone will in general become less than 100%, and will get worse the lower the altitude of the ozone layer. Figure 2 gives the results of calculations of this efficiency as a function of the altitude of the ozone, and the reflectivity of the surface. Note that the efficiency becomes larger as the reflectivity of the surface increases, i.e. as the reflected sunlight becomes larger than the scattered sunlight. It should be noted that the efficiency can become larger than 100%. This is because multiple scattering at the lower boundary can increase the effective path length, and hence enhance the effect of the absorption due to ozone.

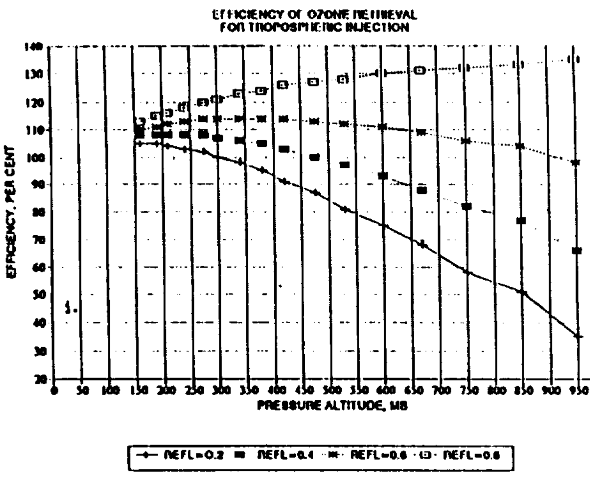


Fig. 2. The efficiency of detection for tropospheric ozone as a function of the altitude and the reflectivity of the surface (1000 mb). X-axis is the altitude in atmosphere, y-axis is the retrieval efficiency (sensitivity) of tropospheric ozone in percentage, and R is the reflectivity of the surface. The values are calculated at zero solar zenith angle, azimuthal angle, and scan angle.

There is another factor however which effects the derivation of tropospheric ozone, the height of the reflecting boundary within the TOMS footprint. The present algorithm assumes a cloud base if the derived reflectivity is 0.6 or greater (snow and ice is discriminated against by reference to other satellite data). The lower boundary is then obtained from a climatological table of mean cloud height versus latitude. If the reflectivity is less than 0.2, then the lower boundary is obtained from a table of terrain height versus latitude and longitude. If the reflectivity is between 0.2 and 0.6, then broken clouds are assumed, and the lower boundary is obtained by interpolation between the terrain height and the mean cloud height.

In general, of course, the cloud height is not at the mean. If the real cloud height is below the climatological mean, then the observed albedo will be larger than the expected albedo, and the algorithm will interpret this as additional ozone. The reverse is true for a real cloud height greater than the climatological mean.

RESULTS

Figure 3-a shows a plot of the total ozone and Figure 3-b shows a plot of lower boundary reflectivity as retrieved by TOMS (archived TOMS data) for a region off the west coast of Africa, on October 14, 1989.

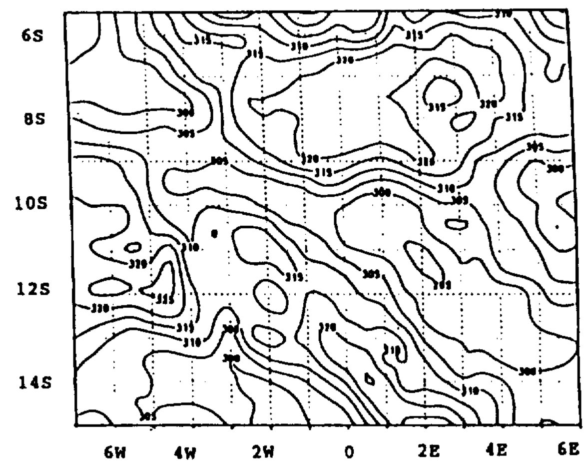


Fig. 3-a. Total ozone from the archived TOMS data on October 14, 1989. The unit is Dobson (D.U) and the interval is 5 D.U. X-axis is latitude and y-axis is longitude.

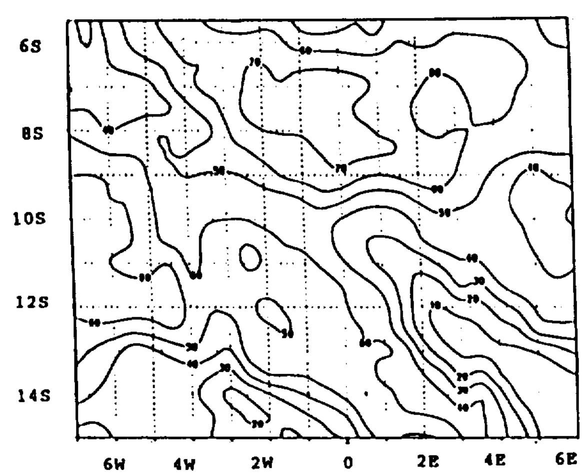


Fig. 3-b. Reflectivity from the archived TOMS data on October 14, 1989. The unit is percentage (%) and the interval is 10%. X-axis is latitude and y-axis is longitude.

In the region near 8S and between 0 to 6E, and near between 9S and 14S and 3W and 7W the total ozone contours follow closely those of the reflectivity. This is a region of marine-stratocumulus clouds. The climatological cloud height is set at about 300 mb if reflectivity is greater than 0.6, whereas the measured height is about 810 mb. The algorithm is expected to retrieve higher ozone values over this region, and, for the reasons discussed above, it is also expected that the higher the reflectivity the greater the retrieved value because of the effect of multi-scattering at the reflecting boundary. If the cloud is at or near the climatological height, and the contribution from scattered radiation is small, hence little correlation is seen between the measured total ozone and the reflectivity. In general the regions over low reflectivity show lower total ozone values.

The data for the area near 8S and 0 to 6E has been reanalysed using the measured radiances, assuming the following:

(a) The real cloud height

(b) That the measured reflectivities represent a real change in cloud reflectivities (Satellite pictures do not indicate broken clouds over this region)

(c) The standard altitude profiles used in the TOMS retrievals.

The results of this analysis are shown in Figure 4. As can be seen, the correlation between the reflectivity and the total ozone field has been removed. From a comparision between Fig 3-a and Fig 4, we can see that total ozone in the archived TOMS data has been overestimated over marine-stratocumulus cloud.

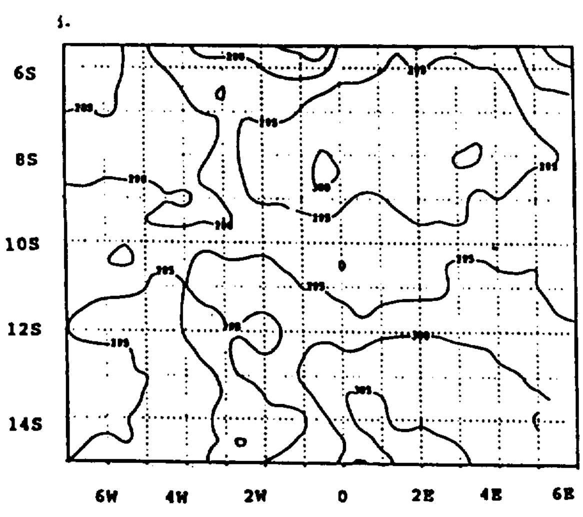


Fig. 4. Corrected total ozone over cloud whose reflectivity is greater than 45% on October 14, 1989. The unit is D.U and the interval is 5 D.U. X-axis is latitude and y-axis is longitude.

Perhaps what is more important, is that the apparent high ozone levels shown in Figure 3-a, which would be interpreted as high tropospheric levels if one subtracts a uniform stratospheric level, are removed.

CONCLUSIONS

This preliminary analysis has shown that there is indeed information in the TOMS data on levels of tropospheric ozone. However, in the region of clouds, great caution should be exercised in the use of the archived total ozone data from TOMS.

ACKNOWLEDGEMENTS

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REFERENCES

Dave, J.V., Meaning of successive iteration of the auxiliary equation in the theory of radiative transfer, *Astrophys. J., 140*, 1292-1303, 1964.

Dave, J.V., Effect of aerosols on the estimation of total ozone in an atmospheric column from the measurement of its ultraviolet radiance, *J. Atmos. Sci., 35*, 899-911, 1978.

Dave, J.V., and C.L. Mateer, A preliminary study on the possibility of estimating total atmospheric ozone from satellite measurements, *J. Atmos. Sci., 24*, 414-427, 1967.

Fishman, J., K. Fakhruzzaman, B. Cros, and D. Nganga, Identification of widespread pollution in the Southern Hemisphere deduced from satellite analyses, *Science, 252*, 1693-1696, 1991.

Fishman, J., P. Minis, and H.G. Reichle, Jr., The use of satellite data to study tropospheric ozone in the tropics,*J. Geophys. Res., 91* 14451-14465, 1986

Fishman, J., and J.C. Larsen, Distribution of total ozone and stratospheric ozone in the tropics: implication for the distribution of tropospheric ozone, *J. Geophys. Res., 91*, 14451-14465, 1987.

Fishman, J., C.E. Watson, J.C. Larsen, and J.A. Logan, The distribution of tropospheric ozone determined from satellite data, *J. Geophys. Res., 95*, 3599-3618, 1990.

Mateer, C.L., D.F. Heath, and A.J. Krueger, Estimation of total ozone from satellite measurements of backscattered ultraviolet earth radiance, *J. Atmos. Sci., 28*, 1307-1311, 1971.