Version 8 Total Ozone Mapping Spectrometer (TOMS) Algorithm

Charles G. Wellemeyer[1], Pawan K. Bhartia[2], Steven L. Taylor[1], Wenhan Qin[1], Changwoo Ahn[1]
[1]Science Systems and Applications Inc., 10210 Greenbelt Road, Lanham, Maryland, USA
[2]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA

Abstract. The Total Ozone Mapping Spectrometer (TOMS) has made measurements of the sunlit portions of the Earth from November 1978 through the present with a 1.5 year gap between the Meteor 3 and Earth Probe. A new Version 8 Algorithm has been developed and applied to the Nimbus 7, Meteor 3, and Earth Probe Data Series. The algorithm is based on differential ozone absorption across a pair of wavelengths that are close enough to minimize the impact of wavelength dependent forward modeling errors. Version 8 enhancements include: Correction for tropospheric aerosols and sun-glint from water surfaces, better ozone and temperature climatology, and an improved forward model, particularly in regions of persistent snow and ice. Among other things, the Version 8 enhancements have reduced latitudinal dependence seen previously in the TOMS Dobson comparisons. The improvements are most noticeable in the Southern Hemisphere summer, where the effects of new climatology, and snow/ice corrections are additive.

Introduction. Data processed with the TOMS Version 7 algorithm were released in 1996 [McPeters et al., 1996]. The Version 8 algorithm addresses a number of issues that have accumulated since then. Broadly speaking, the new algorithm targets errors that occur under extreme conditions that include: scenes with heavy smoke and dust, sea-glint, bright snow/ice-covered surfaces, and measurements at large solar zenith angles. In addition, because of new climatology, the new algorithm has some effect on seasonal cycle and latitude dependence of the derived total ozone. However, inter-annual variability and long-term trends are minimally influenced by the algorithm, thus any changes in these between the new and old datasets are largely due to adjustments in the instrument calibration since the data were last released.

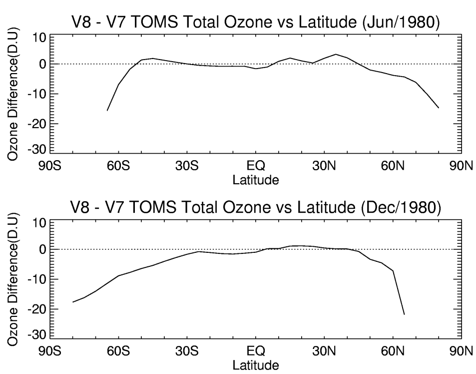
Algorithmic Enhancements. The Version 8 TOMS algorithm obtains the solution in a three-step process. An initial estimate of Lambert-Equivalent Reflectivity (LER) (or cloud fraction) and total ozone is made using the 331 nm and 318 nm TOMS bands (331 and 360 nm at very large solar zenith angles) using standard tables created using the TOMRAD radiative transfer program [Dave, 1964], with adjustments for Rotational Raman Scattering, calculated using a separate code [Spurr, 2003]. The tables are also used to compute residuals and altitude-dependent sensitivities to changes in ozone and temperature profile at each of the 6 TOMS wavelength bands. The Step 1 solution becomes a linearization point from which the solution is adjusted using ozone and temperature climatology to obtain the Step 2 solution. The process is similar to maximum likelihood estimation in which a solution is constrained using *a priori* profiles. The climatology consists of 1512 O_3 profiles that vary with latitude, month and total ozone amount, and 216 temperature profiles that vary only with latitude and month. In Step 3, the Step 2 results are corrected for the effects of aerosols, sea-glint, and variations in ozone profile from the assumed climatology. These corrections were estimated by developing a database of synthetic radiances using accurate forward models that account for Mie scattering from variety of aerosol types and sun-glint; errors due to profile shape are estimated using a dataset constructed using ozonesonde and SAGE profiles. The model calculations show that even in conditions of heavy aerosol loading the aerosol and sea-glint errors can be estimated with rms error of less than 1% using a regression model that is based on 360 nm residuals (which are also called TOMS aerosol index). The ozone profile corrections, which only become important at very large solar zenith angles, are estimated using 312.5 nm residuals.

To improve forward model accuracy we have also developed a cloud height climatology that is more appropriate for ozone retrieval using UV bands; adopted a terrain height data base with a higher spatial resolution; and switched to National Snow/Ice Center climatology for snow cover in the Northern Hemisphere. Clouds over bright snow/ice are treated differently in V8; they are essentially ignored. Based on Mie scattering calculations, thin clouds over a bright surface have negligible impact on derived ozone [Ahmad et al., 2004]. However, thick clouds over snow/ice would cause O_3 to be underestimated by the V8 algorithm by few DU.

In addition to these improvements, we are providing the data users with more error information than in previous releases. In Step 2, we calculate an altitude-dependent efficiency factor (EF); conceptually similar to Rodgers' Averaging Kernel concept [Rodgers, 2000] applied to total ozone. The EF shows how efficiently the algorithm reflects a change in the ozone amount in a layer in the derived total ozone. An ideal total ozone algorithm should have EF of one at all altitudes. For TOMS V8, the EF is nearly 1 in the stratosphere, but is ~0.5 in the lowest 5 km layer of the atmosphere, indicating that TOMS total ozone under-represents changes in ozone near the surface. This information should be particularly useful in interpreting the tropospheric ozone residuals [Fishman and Balok, 1999] from TOMS. In the upper troposphere, the EF can be both smaller and larger than 1 depending upon the cloud height.

Impact and Validation of Algorithm Changes

The following figure gives a summary of the impact of V8 algorithm on the TOMS datasets. It shows how the TOMS-derived zonal mean ozone amounts have changed with respect to the V7 algorithm for two months in 1980. The changes at high latitudes are due to a combination of effects: New ozone and temperature climatology, improved cloud model for snow-covered scenes, and the corrections for profile shape errors. The V8 results agree better with Dobson data when the slant ozone column (SOC) is less than ~1000 DU. Since the quality of Dobson measurements degrade rapidly at larger SOC, we have validated these data by comparing with integrated ozone profiles derived using the V8 SBUV algorithm [Bhartia et al., 2004]. However, there still remains the need for better validation when the SOC exceeds 1000 DU.



The major change in the tropical region is the correction for the effects of tropospheric aerosol and sun-glint. This effect is not apparent in the figure, because the impact of this correction on the zonal mean is small. During extreme events of dust, smoke from biomass burning, or sun-glint, this correction may be as large as 20 DU or more. We should point out that in the event of stratospheric injections of aerosol by major volcanic events, the V8 TOMS is still subject to errors similar to the previous Version 7 [Bhartia et al., 1993]. Also, a small dependence in TOMS ozone with satellite zenith angle persists even after the aerosol/glint correction in Version 8, with the nadir measurements being several DU smaller than the extreme off-nadir measurements, which are made at about 60° satellite zenith angle. The cause of this dependence is not known.

The V8 Aerosol Index (AI) is larger than the V7 AI. This is partly the result of using 331 nm as the reflectivity channel instead of 360 nm, and partly the result of small wavelength dependent calibration adjustments. Note that AI provides a relative, un-calibrated measure of the amount of highly absorbing aerosols in the troposphere, so its exact value is arbitrary. However, the difference between the V7 and V8 AIs may be important for those users who are deriving quantitative estimates of aerosol amounts from the AI.

References.

Ahmad, Z., P. K. Bhartia, N. Krotkov (2004), Spectral properties of backscattered UV radiation in cloudy atmospheres, *J. Geophys. Res.,* 109, D01201, doi:10.1029/2003JD003395.

Bhartia, P. K., J. R. Herman, R. D. McPeters and O. Torres (1993), Effect of Mount Pinatubo aerosols on total ozone measurements from backscatter ultraviolet (BUV) experiments, *J. Geophys. Res*., 98, 18547-18554.

Bhartia, P. K., et al. (2004), The Version 8 SBUV Ozone Profile Algorithm, paper presented at the Quadrennial Ozone Symposium, Kos, Greece, 2004.

Dave, J. V. (1964), Meaning of Successive Iteration of the Auxiliary Equation of Radiative Transfer, *Astrophys. J., 140*, 1292– 1303.

McPeters, R. D., et al. (1996), Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) Data Product's User's Guide, *NASA Reference Publication 1384,* National Aeronautics and Space Administration, Washington, DC.

Rodgers, C. D. (2000), Inverse Methods for Atmospheric Sounding, World Scientific Publishing, New York.

Spurr R. J. D. (2003), Discrete Ordinate Radiative Transfer with Rotational Raman Scattering: Theory and Applications, *Geophysical Res. Abstract*, Vol 5, 01487.