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Total Ozone Mapping Spectrometer (TOMS) Level-3 Data Products User's Guide

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The Nimbus-7 TOMS instrument was built by Beckman Industries, Inc. of Anaheim, California. Beckman Industries also built an engineering model that was eventually adapted for use aboard the Russian Meteor-3 Spacecraft by Perkin Elmer Corp., Pomona, California. The Earth Probe TOMS instrument was built and launched by Orbital Sciences Corporation of Pomona, California, which also built two additional TOMS, one of which was launched aboard the Japanese meteorological satellite, ADEOS. The other is scheduled for launch aboard QuikTOMS in August of 2000.

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1.0 INTRODUCTION

This document is a guide to the Level-3, or mapped, data products derived from measurements made by the series of Total Ozone Mapping Spectrometers (TOMS), and processed by the National Aeronautics and Space Administration (NASA). It discusses the derivation of the parameters provided in Level-3 format, uncertainties in the data, the gridding algorithm used to map individual TOMS fields of view (FOV), and the organization of the data products. The TOMS Level-3 data are archived at the Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC), and are also made available in near real-time, using a preliminary calibration, through the TOMS Web site given in Appendix B.

The TOMS experiment provides measurements of Earth's total column ozone by measuring the backscattered Earth radiance at a set of discrete 1-nm wavelength bands. Both absorbed and non-absorbed regions of the backscattered ultraviolet (buv) are sampled, and the concept of differential absorption is used to derive total column ozone from these measurements. The instruments use a single monochromator and scanning mirror to sample the buv radiation at 3-degree intervals along a line perpendicular to the orbital plane. Then the mirror quickly returns to the first position, not making measurements on the retrace, and then another scan begins. TOMS uses periodic measurements of the Sun to provide normalization of the buv radiances to solar output, and to remove some instrument dependence. As shown in Table 1.1, the TOMS scanning mechanism provides (except for Earth Probe) equatorial inter-orbit overlap (EIOO) so that the entire sunlit portion of the globe is sampled daily. The Sun's synchronous near-polar orbits (except for Meteor-3) provide these measurements at the same approximate local time, which is the local equator crossing time (LECT), over most of the globe throughout the course of the experiment.

Table 1.1. TOMS Data Set Characteristics.

Spacecraft	Useful Data Begin	Useful Data End	Nominal Altitude	Scan Steps	Nominal EIOO	Nominal LECT
Nimbus-7	10/31/78	5/6/93	955 km	35	100 km	11:50 AM
Meteor-3	8/22/91	12/28/94	1200 km	35	1000 km	Periodic
EP (500 km)	7/25/96	12/3/97	500 km	35	-1100 km	11:15 AM
ADEOS	9/11/96	6/29/97	795 km	37	100 km	10:40 AM
EP (740 km)	12/13/97	Present	740 km	35	-500 km	11:15AM

Retrieval of total ozone is based on a comparison between the measured radiances and radiances derived by radiative transfer calculations for different ozone amounts and the conditions of the measurement. It is implemented by using radiative transfer calculations to generate a table of backscattered radiance as a function of total ozone, viewing geometry, surface pressure, surface reflectivity, and latitude. Given the computed radiances for particular observing conditions, the total ozone value can be derived by interpolation in radiance as a function of ozone. In order to interpret the measured radiances, the reflective properties of the surface must first be characterized. A useful byproduct of this characterization is an effective surface reflectivity. The derived ozone is adjusted to account for inconsistency between the measured atmosphere and radiative transfer calculations based on the assumption of pure Rayleigh scattering. A useful byproduct of this calculation is the Aerosol Index (AI), which is sensitive to non-Rayleigh scattering associated with tropospheric aerosols. Finally, given the ozone and reflectivity measurements of TOMS, estimates of the erythemal exposure may be calculated using radiative transfer tables developed for that purpose.

The ozone and reflectivity derived from TOMS have been available as a Level-3 product for some time. Now the aerosol index and erythemal exposure are being made available as well. These parameters are described in more detail below in Section 2. Error budgets for the parameters are discussed in Section 3. The algorithm for mapping the orbital sequence of individual TOMS measurements onto a fixed grid is described in Section 4, and the available data formats are described in Section 5.

2.0 OVERVIEW

The Version 7 TOMS total column ozone and Lambertian effective surface reflectivity algorithms are described in detail in The EP/TOMS Data Products User's Guide (McPeters *et al.*, 1998). We provide a brief description here of the reflectivity and ozone algorithms as well as the aerosol index and erythemal ultraviolet algorithms, which have been developed as an extension of the first two. The reflectivity and ozone algorithms essentially consist of a comparison between TOMS measured radiances and theoretical radiances calculated using radiative transfer.

The calculation of normalized radiances at two standard pressure levels follows the formulation of Dave (1964). A spherical correction for the incident beam has been incorporated, and Version 7 accounts for molecular anisotropy (Ahmad and Bhartia, 1995). Consider an atmosphere bounded below by a Lambertian reflecting surface of reflectivity R. The backscattered radiance emerging from the top of the atmosphere as seen by a TOMS instrument, I, is the sum of purely atmospheric backscatter I_a, and reflection of the incident radiation from the reflecting surface I_s.

$$I(\lambda, \theta, \theta_0, \Omega, P_0, R) = I_a(\lambda, \theta, \theta_0, \phi, \Omega, P_0) + I_s(\lambda, \theta, \theta_0, \phi, \Omega, P_0, R) \quad (1)$$

where

λ = wavelength,
θ = satellite zenith angle, as seen from the ground,
θ_0 = solar zenith angle,
ϕ = azimuth angle,
Ω = column ozone amount,
P_0 = pressure at the reflecting surface, and
R = effective reflectivity at the reflecting surface.

The surface reflection term can be expressed as follows:

$$I_s(\lambda, \theta, \theta_0, \Omega, P_0, R) = \frac{RT(\lambda, \theta, \theta_0, \Omega, P_0)}{1 - RS_b(\lambda, \Omega, P_0)} \quad (2)$$

and

$$T(\lambda, \theta, \theta_0, \Omega, P_0) = I_d(\lambda, \theta, \theta_0, \Omega, P_0)\, f(\lambda, \theta, \Omega, P_0) \quad (3)$$

where

S_b = fraction of radiation reflected from surface that atmosphere reflects back to surface,
I_d = total amount of direct and diffuse radiation reaching surface at P_0,
f = fraction of radiation reflected toward satellite in direction θ that reaches satellite,

and the other symbols have the same meaning as before. The denominator of Equation 2 accounts for multiple reflections between the ground and the atmosphere.

The intensity of radiation as it passes through a region where it is absorbed and scattered can be described in general terms as having a dependence $I \propto \exp(-\tau)$. For a simplified case, where all processes can be treated as absorption, the optical depth τ depends on the number of absorbers n in a column and the absorption efficiency α of the absorbers; that is, $I \propto \exp(-n\alpha)$. The column number should scale approximately as -log I. The ozone algorithm therefore uses ratio of un-normalized radiance (I) to irradiance (F) in the form of the N-value, defined as

$$N = -100 \log_{10}\left(\frac{I}{F}\right) \quad (4)$$

The N-value provides a unit for backscattered radiance that has a scaling comparable to the column ozone; the factor of 100 may have been originally introduced to produce a convenient numerical range. (This same definition is used in the derivation of ozone from the ground-based Dobson and Brewer networks.)

The algorithm's basic approach is to use a radiative transfer model to calculate the N-values that should be measured for different ozone amounts, given the location of the measurement, viewing conditions, and surface properties, and then to find the column ozone that yields the measured N-values. In practical application, rather than calculating N-values separately for each scene, detailed calculations are performed for a discrete set of total column ozone amounts, vertical distributions of ozone, solar and satellite zenith angles, and two choices of pressure at the reflecting surface. The calculated N-value for a given scene at each wavelength needed is then obtained by interpolation in the grid of theoretical N-values.

2.1 Surface Reflection

To calculate the radiances for deriving ozone from a given measurement requires that the height and reflectivity of the reflecting surface beneath the atmosphere be known. The TOMS algorithm assumes that reflected radiation can come from two levels, ground and cloud. This conceptually simple model has been found to improve the total ozone retrieval in the presence of partially clouded scenes. It becomes somewhat complex, however, when the presence of snow is likely, because the TOMS cannot distinguish between a cloud and snow. The terrain height, the cloud height, and the presence of snow or ice in the Field-of-View (FOV) are determined in static databases. The terrain height is fixed and well known. The cloud height and snow/ice are monthly climatological maps based on information from the International Satellite Cloud Climatology Project (ISCCP) and by the Air Force Global Weather Center, respectively. The impact of the use of ISCCP on the TOMS derived ozone is discussed in Hsu et al., 1997.

Reflectivity is determined from the measurements at the longest TOMS wavelength. Because the scene is modeled in two parts, the first step is to determine separate calculated radiances for reflection off the ground and reflection from cloud, based on the tables of pre-calculated radiances. For reflection from the ground, the terrain height pressure is used, and the reflectivity is assumed to be 0.08. For cloud radiances, a pressure corresponding to the cloud height from the ISCCP-based climatology is used, and the reflectivity is assumed to be 0.80. The ground and cloud radiances, I_g and I_c, are then compared with the measured radiance, I_m. If $I_g \le I_m \le I_c$, and if snow/ice is assumed not to be present, an effective cloud fraction f is derived using

$$f = \frac{I_m - I_g}{I_c - I_g}. \tag{5}$$

If snow/ice is assumed to be present, then the value of f is divided by 2, based on the crude assumption that there is a 50-50 chance that the high reflectivity arises from cloud. The decrease in f means that there is a smaller contribution from cloud and a higher contribution from ground with a high reflectivity due to snow and ice. Then Equation 5 is solved for a revised value of I_{ground}, and an alternate ground reflectivity is re-calculated using Equation 2.

Note that the ozone algorithm does not use a single surface reflectivity to characterize the whole scene. However, an effective reflectivity is derived from the cloud fraction and provided as a separate Level-3 data product. This is done in all cases using the following expression:

$$R = R_g(1 - f) + R_c f \tag{6}$$

where R_g is 0.08 when snow/ice cover is assumed absent and has the recalculated value when it is assumed present. This reflectivity is included in the TOMS data products but plays no role in the retrieval.

If the measured radiance is less than the calculated ground radiance, then the radiation is considered to be entirely from surface terrain with a reflectivity less than 0.08. Equations 1 and 2 can be combined to yield

$$R = \frac{I_m - I_a}{T + S_b(I_m - I_a)}. \tag{7}$$

The ground reflectivity can be derived using an I_a obtained assuming ground conditions. Similarly, if the measured radiance is greater than the cloud radiance, when snow/ice are absent, the reflected radiance is assumed to be entirely from cloud with reflectivity greater than 0.80, and an I_a derived using the cloud conditions is used in Equation 7 to derive the effective reflectivity. If snow/ice are present, the cloud and ground are assumed to contribute equally to I_m at the reflectivity channel. Equation 7 can then be used to calculate new values of both ground and cloud reflectivities from these radiances. Radiances at shorter wavelengths are calculated using these reflectivities and a value of 0.5 for *f*.

2.2 Total Column Ozone

The ozone derivation is a two-step process. In the first step, an initial estimate is derived using the difference between N-values at a *pair* of wavelengths; one wavelength is significantly absorbed by ozone, and the other is insensitive to ozone. Use of this difference provides a retrieval insensitive to wavelength-independent errors, such as a zero-point offset in the calibration of the instrument. In deriving the initial estimate, the same pair is always used (318 nm and 331 nm).

In the second step, N-values are calculated using the initial ozone estimate along with the measurement geometry and the surface model described in the previous section. In general, these calculated values do not equal the measured N-values. The measurement residue is defined as N_{meas} - N_{calc}. Using the residues at a properly chosen *triplet* of wavelengths, it is possible to simultaneously solve for a correction to the original ozone estimate and for an additional contribution to the radiances that is linear with wavelength (McPeters *et al.*, 1998). In this calculation, the TOMS total ozone is determined as well as an estimate of the atmosphere's departure from the model assumption of Rayleigh scattering. The triplet consists of two pair wavelengths, one strongly absorbed and one weakly absorbed by ozone, plus a reflectivity channel, which is insensitive to ozone. The separation of the reflectivity wavelength from the pair wavelengths is far larger than the separation between the pairs; thus, the measurement at the reflectivity channel provides a long baseline for deriving any residual wavelength dependence. The pair wavelengths used are those most sensitive to ozone at the optical path length of a given measurement. As the optical path, s, given by

$$s = (sec\theta_0 + sec\theta)\Omega \tag{8}$$

increases, longer more weakly absorbed channels are used. Tables 2.1 and 2.2 show the nominal wavelengths of the triplets used for the early and recent TOMS, respectively.

Table 2.1. Nominal Pair/Triplet Wavelengths for Nimbus-7 and Meteor-3 TOMS.

Pair/Triplet Designation	Ozone Sensitive Wavelength (nm)	Ozone Insensitive Wavelength (nm)	Reflectivity Wavelength (nm)	Range of Application (optical path s)
A	312.5	331.0	380.0	$1 \geq s$
B	317.5	331.0	380.0	$3 \geq s > 1$
C	331.0	340.0	380.0	$s > 3$

Table 2.2. Nominal Pair/Triplet Wavelengths for ADEOS and Earth Probe TOMS.

Pair/Triplet Designation	Ozone Sensitive Wavelength (nm)	Ozone Insensitive Wavelength (nm)	Reflectivity Wavelength (nm)	Range of Application (optical path s)
A	312.5	331.0	360.0	$1 \geq s$
B	317.5	331.0	360.0	$3 \geq s > 1$
C	322.0	331.0	360.0	$s > 3$

2.3 Aerosol Index

As mentioned above, the Version 7 TOMS algorithm simultaneously determines total column ozone and the atmosphere's departure from the model assumption of Rayleigh scattering. This departure is parameterized by the 331 nm residue, which is called the Aerosol Index (AI). It is evidence of apparent wavelength dependence in the effective surface reflectivity between 331 nm and the reflectivity channel.

For EP/TOMS for example, the AI is defined as

$$AI = -100\left(\log\left(\frac{I_{331}}{I_{360}}\right)_{meas} - \log\left(\frac{I_{331}}{I_{360}}\right)_{calc}\right) \tag{9}$$

where I_{meas} is the TOMS-measured backscattered radiance, and I_{calc} is the radiance calculated from a radiative transfer model of the atmosphere with Rayleigh scattering and ozone absorption, at wavelengths of 331 and 360 nanometers. The AI is essentially a measure of the change in spectral contrast between the 331 and 360 nanometer wavelengths introduced by tropospheric aerosols, which are not accounted for in the radiative transfer model. A positive AI generally indicates the presence of ultraviolet (UV)-absorbing aerosols such as desert dust, smoke from biomass burning, and volcanic ash. A negative AI is usually associated with non-absorbing aerosols, although an AI < 0 may result when absorbing aerosols exist near the Earth's surface (below about 1.5 km) where Mie scattering may dominate (Hsu *et al.* 1999). Clouds produce no AI signature. AI with an absolute value > 4 are excluded (error code 2) from the level 3 total ozone, reflectivity and erythemal exposure products due to increased errors in the retrieval.

The Nimbus-7 and Meteor-3 TOMS aerosol indices were obtained using radiances at 340 and 380 nanometers. For comparison with the newer ADEOS and EP TOMS data at 331 and 360 nm, the older AI need to be multiplied by a wavelength adjustment constant equivalent to (331-360)/(340-380) = 0.725 (Hsu *et al.* 1999).

2.4 Erythemal Exposure

The Erythemal Exposure data product is an estimate of the daily integrated ultraviolet irradiance, calculated using a model for the susceptibility of caucasian skin to sunburn (erythema). This can be interpreted as an index of the potential for biological damage due to solar irradiation, given the column ozone amount and cloud conditions on each day. The Erythemal Exposure is defined by the integral

$$Exp. = \frac{1}{d_{es}^{2}}\int_{280nm}^{400nm} S(\lambda)W(\lambda)d\lambda \int_{t_{sr}}^{t_{ss}} C(\lambda, \theta_0, \tau_{cl})F(\lambda, \theta_0, \Omega)dt \tag{10}$$

where

- d_{es} = Earth-Sun distance, in A.U.
- S = Solar irradiance incident on the top of the atmosphere at 1 A.U.
- W = Biological action spectrum for erythemal damage (see below)
- t_{sr}; t_{ss} = Time of sunrise, time of sunset
- C = Cloud attenuation factor
- τ_{cl} = Cloud optical thickness
- θ_0 = Solar zenith angle (function of time, t)
- F = Spectral irradiance at the surface under clear skies, normalized to unit solar spectral irradiance at the top of the atmosphere
- Ω = Total column ozone

The Earth-Sun distance and sunrise and sunset times, as well as the dependence of the solar zenith angle on time during a given day depend on the latitude and the time of year, and are calculated from standard formulae [USNO, 1992; Smart, 1977]. The extraterrestrial solar irradiance incident at the top of the atmosphere when the Earth is at a distance of 1 Astronomical Unit (A.U.) from the Sun was measured over the wavelength interval of interest by the ATLAS-3/SUSIM instrument [Woods *et al.*, 1996].

The weighting function, $W(\lambda)$, used to approximate the wavelength-dependent sensitivity of caucasian skin to erythema-causing radiation is the model proposed by McKinlay and Diffey [McKinlay and Diffey, 1987], and adopted as a standard by the *Commission Internationale de l' Eclairage* (CIE).

$$
\begin{aligned}
W(\lambda) &= 1, && \text{if} \quad \lambda \le 298 \\
W(\lambda) &= 10^{-0.094(\lambda - 298)}, && \text{if} \quad 298 \le \lambda \le 328 \\
W(\lambda) &= 10^{-0.015(\lambda - 139)}, && \text{if} \quad 328 \le \lambda
\end{aligned}
\qquad (11)
$$

The function F is the normalized global (direct plus diffuse) irradiance incident on a horizontal surface at the terrain altitude of a given location, given the total column ozone measured by TOMS, the wavelength, and solar zenith angle. The value of F is computed using the table of solutions of the radiative transfer equation, which are used in the TOMS ozone retrievals. The actual incident global spectral irradiance under cloud-free skies is the product of S and F, adjusted for variation in Sun-Earth distance.

The cloud factor C is obtained in two steps. First, the 380 nm (Nimbus-7) or 360 nm (Adeos, EarthProbe) radiances, solar and viewing angles, terrain height, and climatological surface albedos [Herman and Celarier, 1997] are used to derive a model cloud optical thickness (τ_{cl}) using tables of solutions of the radiative transfer equation at these wavelengths. In the second step, the attenuation of the global irradiance due to a model uniform cloud of that optical thickness is computed. In both these steps, the cloud is modeled as a homogeneous Mie-scattering layer, located between 500 mbar and 350 mbar. The scattering phase function is the C-1 model of Deirmendjian [Deirmendjian, 1969].

Because most locations on the Earth are viewed by the TOMS instrument only once per day, the model cloud optical thickness is presumed to be valid throughout the day. This can lead to large discrepancies between TOMS-estimated exposures and ground-based measurements. In regions where there is substantial diurnal variability in cloud cover, averaging over periods of at least a week is recommended when comparing the TOMS-based estimates and ground-based measurements of erythemal exposure.

The algorithm uses the same database as the TOMS ozone retrieval algorithm to determine the probability of presence of snow/ice in the instrument's field of view. In the presence of snow/ice, the algorithm assumes a surface albedo of 40 percent. While this albedo is typical of snow cover over midlatitude and subpolar regions, it may give rise to an overestimate of the erythemal exposure in urban or rugged areas, where the actual albedo is generally less than 40 percent. In conditions of freshly fallen snow, or snow on a flat terrain, the actual albedo is generally greater than 40 percent, and the algorithm will tend to underestimate the erythemal exposures. The algorithm assumes that any excess upward radiance, above what would be due to the 40 percent reflective surface, is due to clouds, and the appropriate correction is made.

In high-altitude regions having high surface reflectivity, the algorithm tends to overestimate the UV exposure. In the high Andes region of Peru, and in the Himalayas TOMS-based exposures may be overestimated by up to 20 percent.

The algorithm does not take account of the effects of absorbing aerosols, e.g., under smoke plumes from biomass burning, and in the great deserts during seasons when the desert dust is lofted by winds. Under these conditions, the UV attenuation can exceed 80 percent.

In the above expression for the exposure, the quantity S/d^2_{se} has units of [nW m^{-2} nm^{-1}]. The functions F and C are dimensionless. It is common in the literature to also regard W as being dimensionless, and hence the exposure as having units of [J m^{-2}]. However, the biological response to radiation should be expressed in units that relate the biological damage to the incident energy, thus giving the exposure units of [B.D./ m^{-2}], where B.D.= Biological Damage, expressed in biologically meaningful units. The normalization of the McKinlay and Diffey (CIE) action spectrum for erythema is chosen to be such that the function is equal to unity at 298 nm. Because the normalization of W is arbitrary, the units of exposure should also be considered to be arbitrary.

Calculated exposure values will be found generally in the range [0 to 104], though values upward of about 8,000 can occur at very high altitudes in the tropics and subtropics. The median exposure value at the subsolar latitude usually falls in the range [6,000 to 8,000].

The file descriptions of the Level-3 Products are given in Section 5, Data Formats. It should be noted that in the native Level-3 format (the character format available at the TOMS web site given in Appendix B), the erythemal exposure is stored in a different form from the other Level-3 parameters. This is done to preserve the native Level-3 format convention that the data be represented by 3 ASCII characters. So, each value code consists of three digits: a 1 digit exponent (E), and a 2 digit mantissa (M). A decimal point is implied between the two digits of the mantissa. Together, E and M encode a value of M X 10^E. For example, the value code 342 represents the value 4.2 X 10^3. (Note that a value code of 999 is a fill-value to indicate TOMS data were unavailable.) The Level-3 Hierarchical Data Format (HDF) files archived at the GSFC DAAC are produced from the native Level-3, and at this stage of our processing, the storage format is converted to normal 2-byte integer (e.g., 4200) and the fill value is changed to -999 to avoid ambiguity.

2.5 Ultraviolet Surface Irradiance

We plan to provide three additional surface UV parameters in the near future. These will be the estimated normal UV irradiance at the surface for 305 and 324 nm wavelengths and the instantaneous erythemal irradiance at the time of the TOMS overpass (LECT). The erythemal UV parameter described in the previous section provides an estimate of exposure to harmful UV radiation at the surface integrated over wavelength and over the day (Equation 10). The local estimates we plan to provide of UV irradiance at specific wavelengths, F(λ), may be more useful for comparisons with other measurements of UV irradiance at the Earth's surface.

$$F(\lambda) = \frac{1}{D_{es}^{2}} S(\lambda) C(\lambda, \theta_0, \tau_{cloud}) F_{clear}(\lambda, \theta_0, \Omega)$$

where the variables are defined in the same way as in Equation 10. The instantaneous erytheural irradiance will be a weighted average of F(λ) computed using the weights in Equation 11.

We plan to provide these parameters in a format similar to that described in Section 5, both native ASCII and HDF.

3.0 UNCERTAINTY

The uncertainty in Version 7 TOMS total column ozone is similar for all of the TOMS instruments (Table 3.1). The error budget for each is detailed in the TOMS Data User's Guides [McPeters *et al.*, 1996, Herman et al., 1996, McPeters *et al.*, 1998, and Krueger *et al.*, 1998]. The uncertainty in the absolute scale, or mean bias relative to truth, is largely driven by uncertainty in the laboratory measurements of ozone absorption cross-section. The uncertainty in the precision of the measurements is driven by two effects. One is the small, but highly variable amount of tropospheric ozone to which TOMS is only partially sensitive. The second results from uncertainty in the actual cloud height and the associated problem of estimating the amount of ozone obscured by the cloud [Klenk *et al.*, 1982]. This first effect is of particular concern for researchers estimating tropospheric ozone based on the difference between the TOMS total ozone and some estimate of stratospheric column ozone. Because the TOMS measures less than half of any variations in the lowest 5 km of the atmosphere, such methods tend to be insensitive as well. Also, because the tropospheric residual is the difference of two larger numbers, it is sensitive to other small errors in the TOMS measurement or in the estimate of the stratospheric column. Post-flight analysis of earth radiance measurements was used in the calibration of Nimbus-7 TOMS to achieve a long-term accuracy of 1 percent per decade [Wellemeyer, *et al.*, 1996]. An improved in-flight calibration technique was developed and deployed on subsequent TOMS, and each of them is accurate to better than 1 percent over each instrument lifetime. The relative bias between the four TOMS datasets is discussed below.

Table 3.1. Uncertainty in TOMS Derived Ozone.

Uncertainty in:	Nominal	Solar Zenith Angle > 80
Absolute Value	3%	4%
Precision	2%	5%
Long-term Mean	1%	1%

The effective Lambertian equivalent surface reflectivity and the AI are not physical quantities. Because of this, no algorithmic error sources have been included in Table 3.2. Nominal instrument calibration errors of 1.5 percent at the reflectivity channel and 0.75 percent at the aerosol channel relative to the reflectivity channel have been assumed. As in the case of the ozone uncertainties above, the uncertainties in reflectivity and AI are fairly similar for all the TOMS instruments.

Table 3.2. Uncertainty in TOMS Reflectivity and Aerosol Index.

Uncertainty in:	Reflectivity at Low Reflectivity	Reflectivity at High Reflectivity	Aerosol Index (N-value)
Absolute Value	0.01	0.02	0.30
Precision	0.002	0.003	0.15
Long-term Mean	0.005	0.01	0.1

Estimates of the uncertainty in TOMS erythemal exposure have been developed through comparison with ground based Brewer Instruments [Herman *et al.*, 1999]. Under clear sky conditions, discrepancies between TOMS and erythemal exposures measured by ground-based instruments are relatively small. They result mainly from a combination of uncertainties in the solar spectral irradiance measured by ATLAS-3/SUSIM [Cebula, et al., 1996] and the ozone and reflectivity measured by TOMS. Systematic error occurs however, if aerosols or to a lesser extent, urban haze are present. These effects are unaccounted for in the current algorithm. Even larger systematic errors occur when snow or ice is present in a scene where it is unexpected from the climatology. Care should be taken not to use this data set to characterize regions where this is likely to occur (e.g., where there is considerable interannual variability in snow-cover on the ground).

Table 3.3. Uncertainty in TOMS Erythemal Exposure.

Uncertainty in:	Under Clear Conditions	Absorbing Aerosols in FOV
Systematic Error	0.0	+10%
Random Error	4.5%	5.0%
Long-term Mean	1%	1%

3.1 Trend Considerations

The uncertainties in the long term means presented above in Tables 3.1–3.3 pertain to the individual data sets of individual TOMS instruments. Upon combining data from the various TOMS, additional uncertainties associated with the relative instrument calibrations come into play. Figure 3.1, which is reproduced from the Meteor-3 TOMS Data User's Guide [Herman *et al.*, 1996], shows the difference of zonal means of ozone for Meteor-3 minus Nimbus-7 computed using the Level-3 products from the two instruments. The Meteor-3 TOMS calibration was actually adjusted to be consistent with Nimbus-7, but the trends were not. Because of the overlap in time between these two data sets, the relative bias and trend can be established quite well [McPeters *et al.*, 1996].

After Nimbus-7 and Meteor-3, however, the next TOMS did not begin taking data until late July, 1996. Therefore, the uncertainty in ozone trend studies that span this gap must include a component resulting from the relative calibration uncertainty of two TOMS. Recent studies indicate that this component is 2%–3% in ozone [Jaross *et al.*, 2000].

The spectral discrimination technique used in the long-term calibration of the Nimbus-7 TOMS also provides an estimate of the absolute calibration at the reflectivity wavelength [Wellemeyer *et al.*, 1999]. This estimate relies upon an assumption about the true relationship of the ultraviolet backscatter at a pair of reflectivity channels, but the importance of this assumption is reduced when comparing the absolute calibration of one buv instrument with another. Application of the spectral discrimination technique to Nimbus-7 and Earth Probe TOMS indicates that the Nimbus-7 TOMS reflectivity channel is biased high relative to Earth Probe by about 0.005 at low reflectivity and about 0.015 at high reflectivity. Comparisons of reflectivities of similar surfaces from the two TOMS indicate that the offset may be larger by a factor of two.

The AI from Nimbus-7 and Earth Probe TOMS both have downward drifts of about 0.3 N-value over the length of the respective data records. These drifts are within the calibration uncertainties, as is the offset of approximately 0.1 N-value.

3.2 Errors Due to Tropospheric Aerosols and Glint

The ozone correction described in Section 2.2 is based on the assumption that departures in measured radiance from the Rayleigh scattering atmosphere assumed in the model will be linear with wavelength in N-value (or percent radiance). This assumption works well for non-absorbing channels, but at shorter wavelengths where ozone absorption occurs and Rayleigh scattering increases, the backscatter becomes less dependent on the scattering characteristics of the troposphere. A better assumption, called the Dave assumption, is that the effective surface reflectivity is linear with wavelength [Dave, 1978], because the backscatter sensitivity to surface reflectivity falls off at shorter wavelengths for similar reasons. The cases in which this assumption becomes important are the cases where significant non-Rayleigh dependence is identified by the 331 nm residue, or AI. Clearly, the presence of tropospheric aerosol is such a case, but a less obvious case results from sun glint.

Sun glint is associated with non-Lambertian surface reflectivity rather than non-Rayleigh scattering, but the effect on the buv is similar. If TOMS scans through the image of the sun reflected off the ocean surface, the 331 nm residue is elevated and the TOMS underestimates ozone. This effect is illustrated in Figure 3.2, which shows a sample EP/TOMS scan affected by sun glint and corrected ozone obtained using the Dave assumption. This assumption may be formulated using information from the Level-2 product by assuming that the residues of the triplet ozone retrieval are

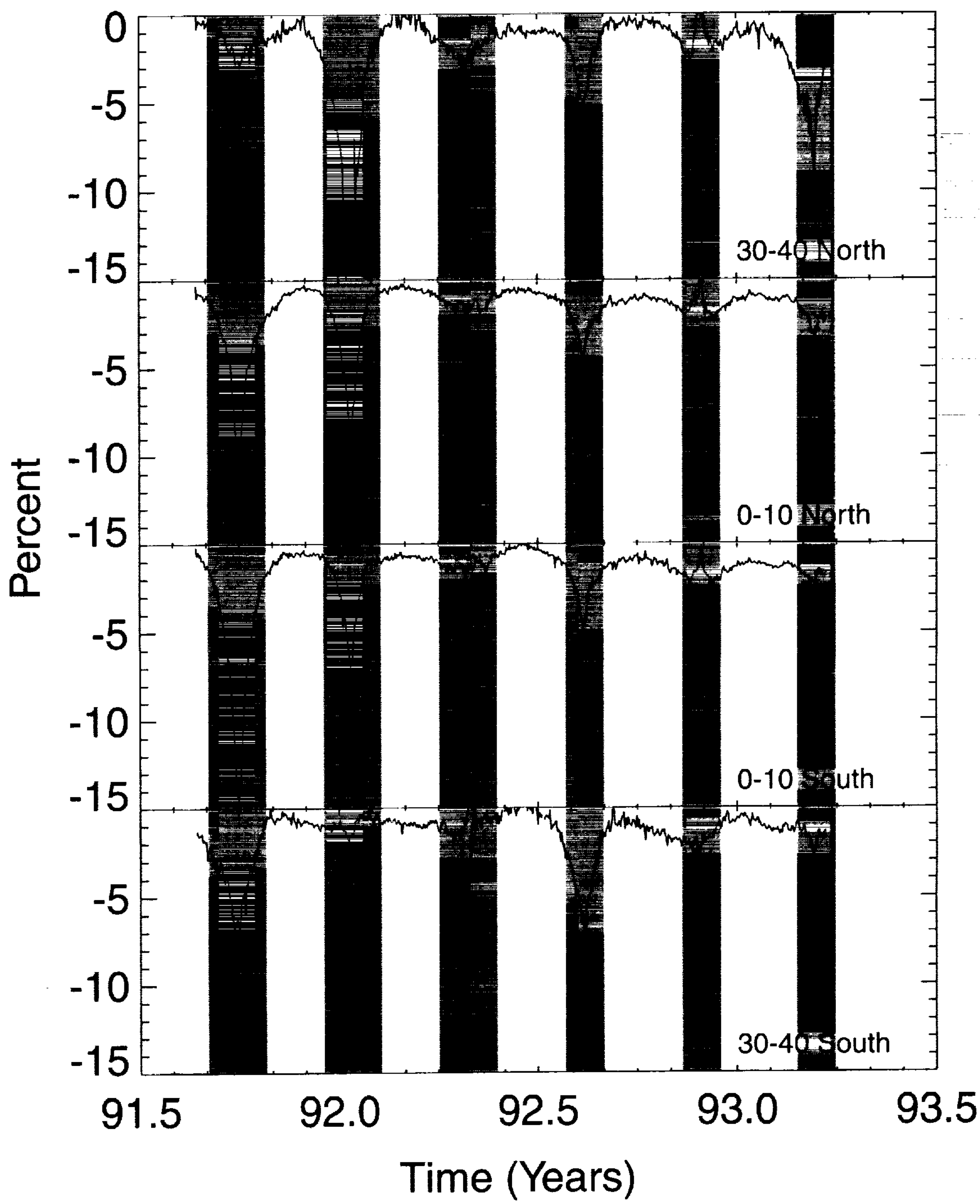

Figure 3.1. Meteor-3 - Nimbus-7 Level-3 Zonal Mean Ozone Differences. Shaded areas indicate periods when Meteor-3 Level-3 data are not reported due to extreme viewing geometry.

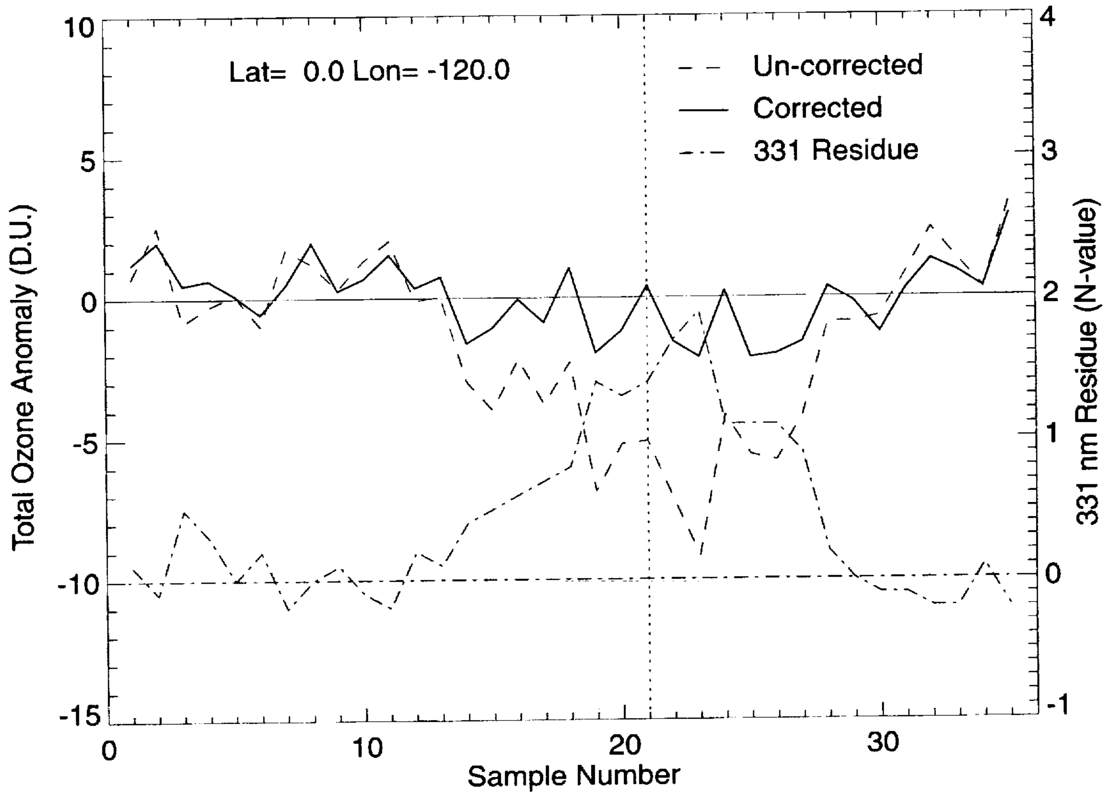

Figure 3.2. Impact of Sun Glint on TOMS Derived Ozone. Elevated values of AI (331 nm residue) are associated with under-estimation of ozone in sun glint geometry.

due to an error in ozone associated with such a linear dependence in reflectivity. Expressions for the residues at two channels (e.g. 313 nm and 331 nm) can be written as

$$r_{331} = \Delta\Omega s_{331} + \Delta R_{331} sr_{331} \tag{12}$$

and

$$r_{313} = \Delta\Omega s_{313} + \Delta R_{331}\frac{(313-360)}{(331-360)} sr_{313} \tag{13}$$

These two equations can be solved for the "true" ozone amount that is consistent with the R(lambda) assumption.

$$\Omega = \Omega_0 + \frac{(\Delta\lambda_{313} r_{331} sr_{313} - \Delta\lambda_{331} r_{313} sr_{331})}{(\Delta\lambda_{313} s_{331} sr_{313} - \Delta\lambda_{331} s_{313} sr_{331})} \tag{14}$$

Where—

r_λ - Residue reported on current level-2 for channel λ
Ω_0 - Total ozone reported on current level-2
s_λ - Sensitivity of channel λ radiance to changes in ozone
R_λ - Lambertian equivalent surface reflectivity (or reflectivity) for channel λ
sr_λ - Sensitivity of channel λ radiance to changes in reflectivity
ΔR_λ - Difference of R_λ from reflectivity reported on level-2
$\Delta\lambda_\lambda$ - Difference of channel λ wavelength from 360 nm

This expression provides a good correction for cases of sun-glint present in the V7 TOMS ozone data as shown in the figure. This example is near the equator at equinox and the Earth Probe has a local equator crossing time of about 10:30, so when EP/TOMS scans to the east, it observes the image of the sun reflected in the ocean, centered near scan position 21. The 331 nm residue shows a fairly broad region (scan positions 14 - 27) to be affected by the glint. The correction equation presented above applies to A-triplet retrievals from EP/TOMS. A similar correction can be written for EP/TOMS B-triplet retrievals by substituting 318 nm everywhere for 313 nm, and for N7/TOMS A-triplet by substituting 380 nm everywhere for 360 nm, and so on.

The residues resulting from a single retrieval affected by glint are shown in Figure 3.3 for the case of the Version 7 retrieval and for the Dave assumption. The triplet assumption used in the Version 7 algorithm is shown by the solid line, which connects the V7 residues for the triplet wavelengths used in the retrieval (313 nm, 331 nm, and 360 nm). Because the sensitivity of the upwelling radiance to surface reflectivity ($\partial N/\partial R$) is a function of wavelength, the Dave assumption is non-linear in units of n-value (or percent radiance), as illustrated by the dashed line in the figure.

Because of the elevation of the aerosol index, the measurements made in the sun glint geometry over oceans have been excluded from the Level-3 aerosol index product. However, the Level-3 ozone product does not have any correction or exclusion for moderate glint or low levels of aerosol contamination.

Careful simulations of the effects of tropospheric aerosol contamination on TOMS retrievals have been carried out [Torres *et al.*, 1999], and reported in the EP/TOMS Data User's Guide [McPeters *et al.*, 1998]. These results indicate that the relationship between the aerosol index and percent error in the V7 TOMS derived ozone is linear with a slope of about -1.1 percent ozone/n-value for N7 and M3 TOMS and about 1.2 percent ozone/n-value for EP and ADEOS TOMS. A Level-3 ozone correction based on these results is provided in Appendix C. Our analysis indicates that the Dave correction provides a very similar result. A slight under-correction is probably due to additional absorption due to the aerosols. The aerosol correction due to Torres et al. is recommended.

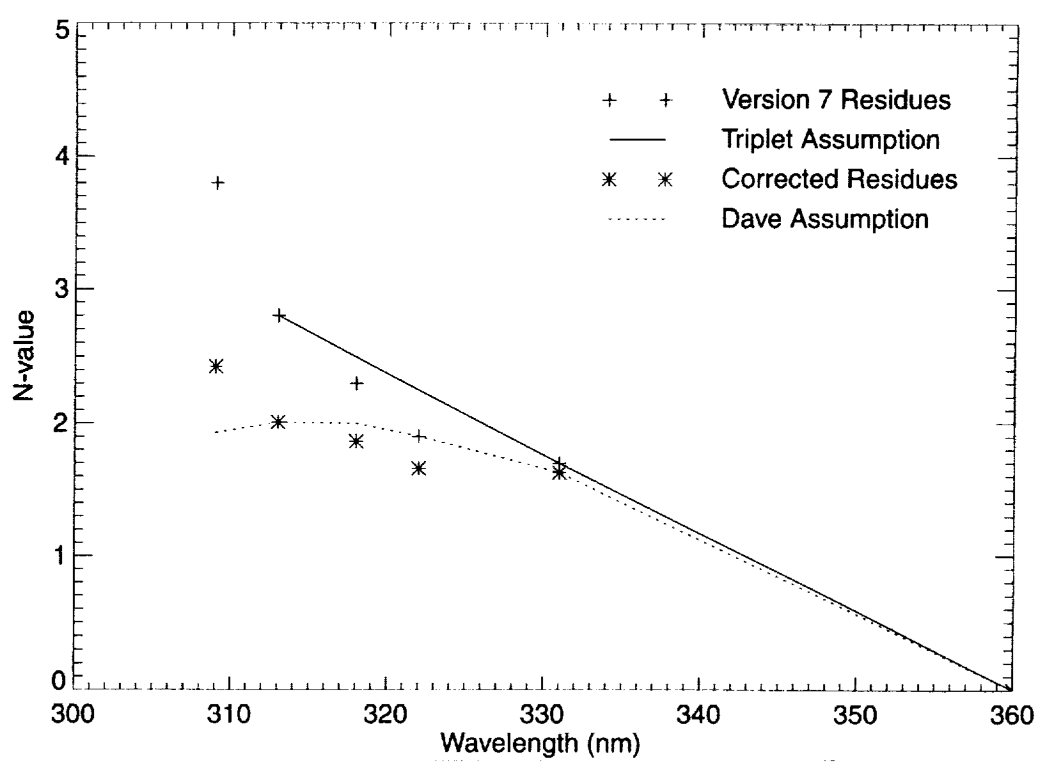

Figure 3.3. Impact of Alternate Assumptions about Un-modeled Effects

Both the glint and aerosol errors are of significant magnitude, but are restricted to a limited spatial and temporal domain and have little or no effect on global studies of long-term trend for example. However, in regional or short term studies a correction may be required. The linear relationship between ozone error and aerosol index implies that the Level-3 aerosol index map could be used to correct the Level-3 ozone map. This would be true except that the populations are different in the two products. In the ozone product, retrievals with aerosol index greater than 4 are excluded from the averaging process as poor quality retrievals. (This limits ozone errors at about -4 percent.) In the aerosol product, they are included to provide all available aerosol information. Still, Level-3 aerosol index values that are not close to the screening threshold can be safely used to correct ozone, and higher values can identify areas where Level-3 ozone values should be ignored if they have not already been excluded by the Level-3 algorithm. A correction procedure is provided in Appendix C.

The glint correction provided above in Equation 14 can only be applied to the Level-2 product, and the Level-3 data contain no information about viewing geometry. However, the Level-3 map of aerosol index from which the glint affected regions have been excluded can be used to identify glint affected regions in the ozone map. Such regions can be omitted or filled by interpolation. We plan to provide corrected Level-3 ozone maps in the future. In the meantime, we hope these Level-3 based corrections for tropospheric aerosol and glint contamination of the Level-3 ozone product (Appendix C) prove useful in ongoing studies that require improved accuracy.

4.0 GRIDDING ALGORITHM

The level-3 gridding algorithm is used to combine the orbital TOMS measurements into a daily map product with a fixed global grid. The reported grid is 1 degree in latitude by 1.25 degrees longitude over the entire globe. Only high quality level-2 data are included in the cell averages, except as discussed above in Section 3.2. Data that have been flagged for extreme residues are included in the averages of aerosol index, so that extreme aerosol events will be represented.

At higher latitudes where orbital overlap occurs, only the average from the orbit that provides the best view of a given cell is reported. In practice, cell averages are computed separately for each TOMS orbit, and the one with the shortest average path index is selected. The path index is calculated as $\sec(\theta_0) + 2\sec(\theta)$, where θ_0 and θ are the solar zenith and spacecraft zenith angles respectively, defined as the Instantaneous Field-of-View (IFOV). This index is designed to place more importance on the spacecraft zenith angle than on solar zenith angle relative to the proper calculation of geometric path $(\sec(\theta_0) + \sec(\theta))$.

The cell averages are computed as weighted averages of TOMS parameters derived for IFOVs that overlay the given cell. For this purpose, a simple rectangular model is used for the actual TOMS IFOV. Figures 4.1 and 4.2 show the actual TOMS FOVs as determined using a ray trace model of the instrument for an equatorial case and a high latitude case, respectively. Figures 4.3 and 4.4 show the actual FOVs as well as the modeled FOVs that are used in the average for the sample grid cells highlighted in Figures 4.1 and 4.2, respectively. EP/TOMS data from the high orbit period are shown. The fractional area of overlap of the rectangular IFOV with a given cell is used to weight its contribution to the given grid cell average. A single TOMS IFOV can contribute weight to more than one cell average within a single 1 degree latitude band. Any IFOV with its center outside the latitude band is ignored as a simplification to the calculation. At high latitudes, the averaging cells are extended in longitude. Between 50 and 70 degrees latitude, the cells are 2.5 degrees in longitude, as in the high latitude case shown in Figures 4.2 and 4.4. Above 70 degrees latitude, the cells are 5.0 degrees in longitude. Once an average is computed for these cells, the same average value is reported in each of the 1.25 degree longitude cells that are contained within the averaging cell.

At extremely high latitudes, the model remains the same. Figure 4.5 is similar to Figures 4.3 and 4.4 except that it illustrates the modeling of a sample cell at 84.5 degrees latitude. In this case, the Earth Probe spacecraft has reached its highest latitude and is scanning toward the North Pole. The magnification of the longitudinal dimension apparent in this graphic becomes even more extreme closer to the pole. When the center of the FOV is at about 89.85 degrees or higher, the modeled FOV covers 360 degrees of longitude, representing an area of about 7500 km^2, which is comparable to the actual polar FOV size of EP/TOMS of 7000 km^2.

The TOMS level-3 product is non-synoptic. Because the TOMS fly on polar orbiting satellites, all measurements are made at a local time roughly equal to the LECT. The Western Pacific is measured near the beginning of the Greenwich Mean Time (GMT) day, and the Eastern Pacific is measured near the end of the GMT day. There is a 24-hour discontinuity in the data at 180th meridian. Individual TOMS IFOVs are sorted into different days across the 180th meridian to ensure that this is the only place where such a time discontinuity occurs. In order to accomplish this while providing a complete global map, some data from the previous GMT day are used at the beginning of our Level-3 day and some data from the next GMT day are used at the end. The nominal LECT for each TOMS instrument is presented in Table 1.1. The LECT for each daily global file is provided in the output data format as described below in Section 5.

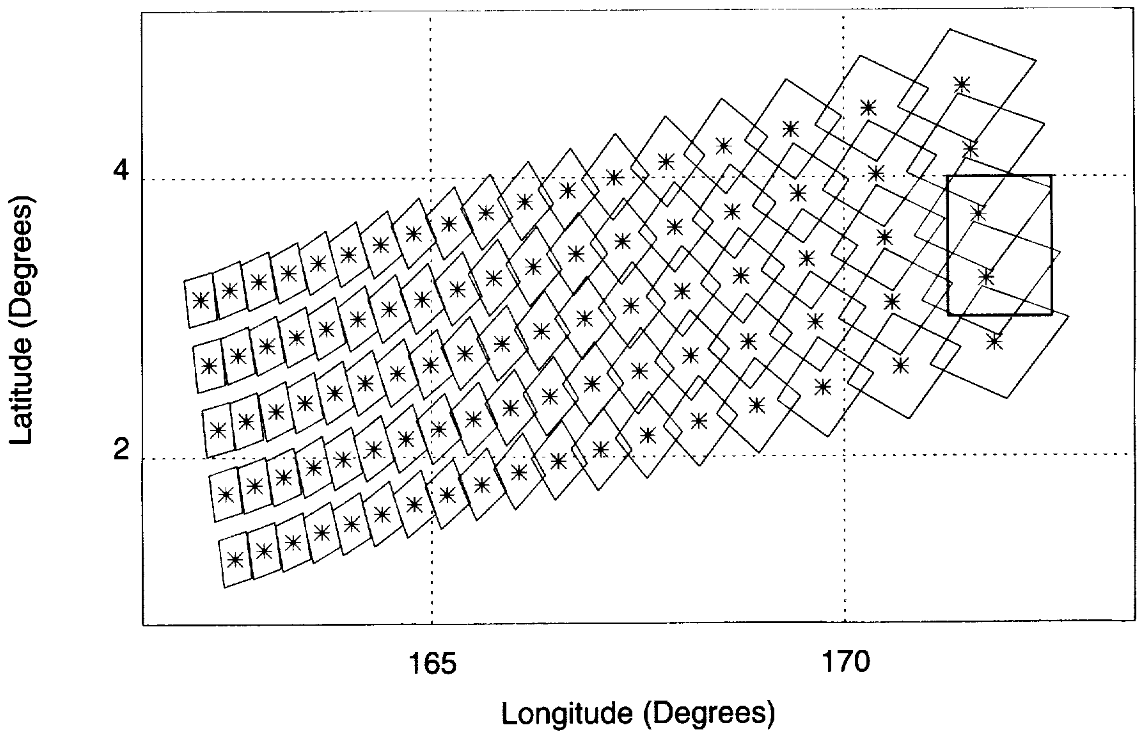

Figure 4.1. Actual EP/TOMS FOVs from Instrument Ray Tracing for Equatorial Case.

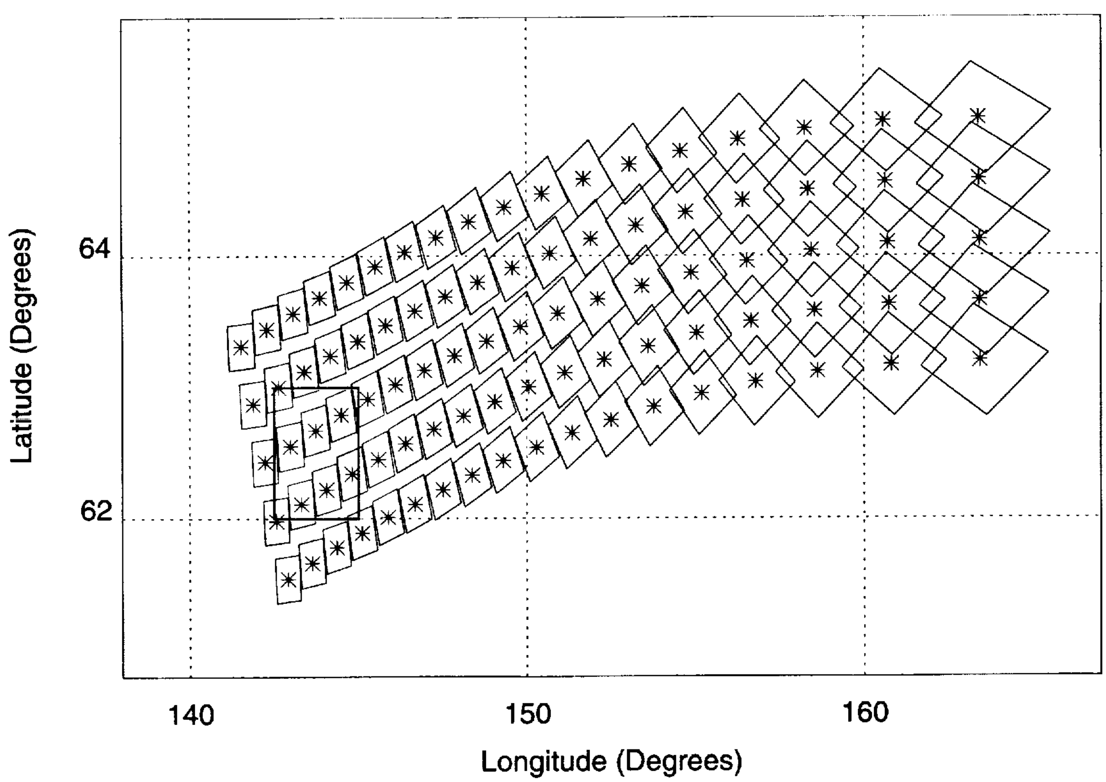

Figure 4.2. Actual EP/TOMS FOVs from Instrument Ray Tracing for High Latitude Case.

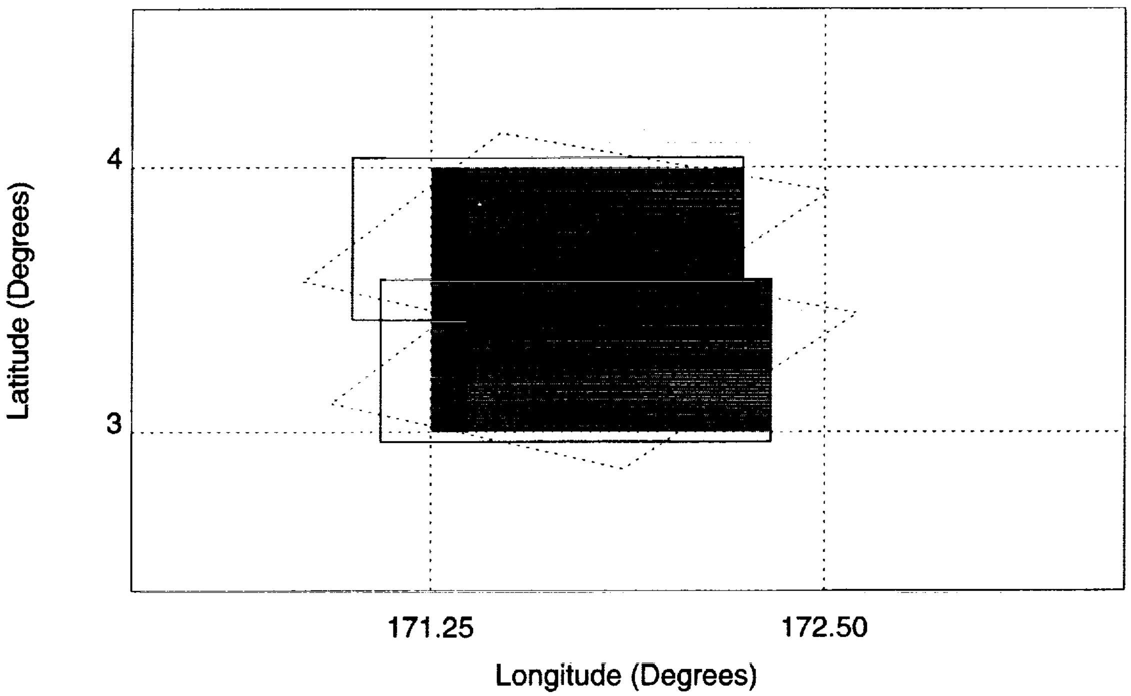

Figure 4.3. Modeled EP/TOMS FOVs for Equatorial Sample Grid Cell at Extreme Off-nadir.

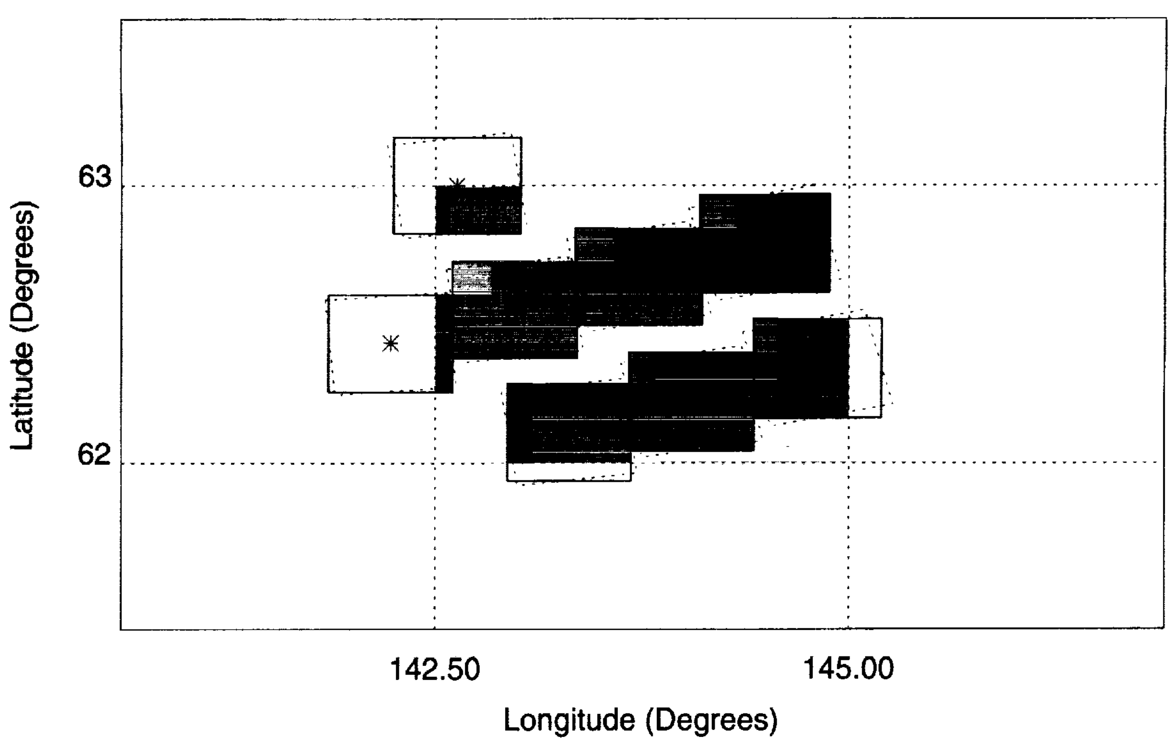

Figure 4.4. Modeled EP/TOMS FOVs for High Latitude Sample Grid Cell at Near-nadir.

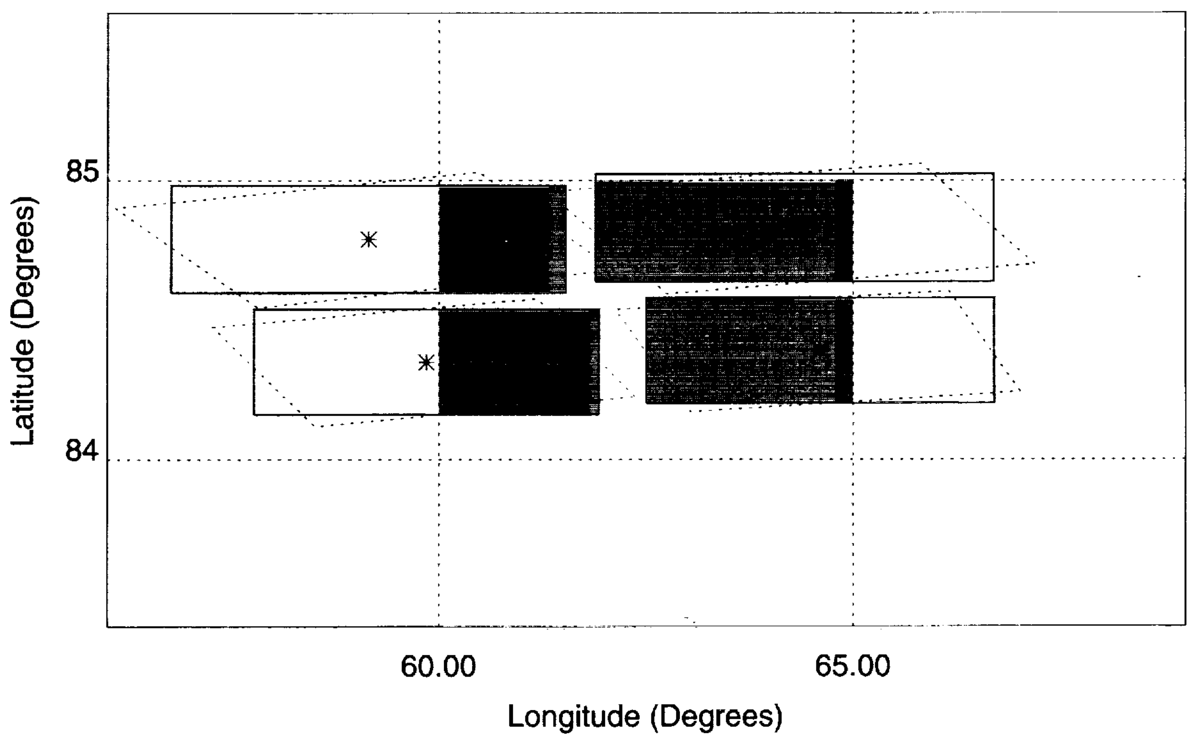

Figure 4.5. Modeled EP/TOMS FOVs for Sample Grid Cell at Extremely High Latitude.

5.0 DATA FORMATS

The TOMS Level-3 data products are available at the GSFC Distributed Active Archive (DAAC) in Hierarchical Data Format (HDF), which is described below in Section 5.1. The Level-3 data products are also made available at the TOMS Web Site in an ASCII "Native Format," which is described in Section 5.2.

5.1 Level-3 Hierarchical Data Format Product

The standard archival Level-3 products contain global arrays of total ozone, effective surface reflectivity, aerosol index, and erythemal exposure stored as daily HDF files. A Level-3 file is generated from each complete daily set of Level-2 files as described in Section 4. Currently, the ozone and effective surface reflectivity are combined in one HDF file, and the aerosol index and erythemal exposure are combined in another. In subsequent releases of the data, we may combine all four parameters in a single daily HDF file.

Each Level-3 HDF file is comprised of the following elements:

1. a File Label
2. a File Description
3. Metadata (stored as a second file description)
4. 2 Data Scientific Data Sets (SDS)
5. 2 Coordinate SDSs
6. The File Label is "TOMS_ss_DAILY_GRIDDED_DATA_mm_dd_yy" where ‘ss’ is the satellite (NIMBUS-7, METEOR-3, ADEOS, or TOMS-EP), 'mm' is month of year (1-12), 'dd' is day of month, and 'yy' is 2-digit year. Leading zeroes are used in these substitutions.

The Level-3 file names have the following form—

algYYDDD.hdf

where YY is a 2-digit year and DDD is day of year. The first two characters of the file name indicate the spacecraft (e.g., N7, M3, A1, or EP).

The File Description provides background on the TOMS instrument, processing algorithms and data products, in free format. The following metadata, for example, are included in the ozone and reflectivity HDF file—

1. Data set name ("data_set=TOMS")
2. Data product name ("data_product=Level 3 daily gridded data")
3. Granule size ("granule_size=XXXXXXX" where 'XXXXXXX' is in bytes)
4. Begin date and time ("begin_date=YYYY-MM-DD HH:MM:SS" where 'YYYY' is year, 'MM' is month of year (1-12), 'DD' is day of month, 'HH' is hour of day, 'MM' is minute of hour, and 'SS' is second of minute in UT)
5. End date and time ("end_date=YYYY-MM-DD HH:MM:SS" where 'YYYY' is year, 'MM' is month of year (1-12), 'DD' is day of month, 'HH' is hour of day, 'MM' is minute of hour, and 'SS' is second of minute in UT)
6. Geographical flag ("geog_flag=G" indicating global data)
7. Northern latitude ("north_lat=+90.00")
8. Southern latitude ("south_lat=-90.00")
9. East longitude ("east_lon=+180.00")
10. West longitude ("west_lon=-180.00")
11. Day/night flag ("day_night_flag=D" indicating daytime data)
12. Granule version ("granule_version=01" indicating first archive version)
13. Producer granule ID ("producer_granule_id=algYYDDD.hdf" where 'YY' is 2-digit year and 'DDD' is day of year both with leading zeroes as necessary)
14. Fill value for ozone ("miss_val_ozone=0")
15. Fill value for reflectivity ("miss_val_ref=999")

16. Local time of ascending node equator crossing ("lect=YYYY-MM-DD HH:MM:SS where 'YYYY' is year, 'MM' is month of year (1-12), 'DD' is day of month, 'HH' is hour of day, 'MM' is minute of hour, and 'SS' is second of minute)

The data stored in the SDSs are on a fixed 1-degree latitude by 1.25-degree longitude grid. All the gridded values are stored as 2-byte integers. The total column ozone is in units of matm-cm, reflectivity is in percent, aerosol index is in n-value units, and erythemal exposure is in relative units of biological damage as discussed in Section 2.4.

The two Coordinate SDSs stored in the Level-3 product are listed in Table 5.1.

Table 5.1. TOMS Level-3 HDF Coordinate SDSs.

Name	Type	Scaletype	Scalemin	Scalemax
Latitude	4 byte real	regular	-89.5	89.5
Longitude	4 byte real	regular	-179.375	179.375

5.2 Native Level-3 Data Product

The Native Level-3 products are also available on the same fixed 1-degree latitude by 1.25-degree longitude grid at the TOMS URL ftp://toms.gsfc.nasa.gov/pub under the sub-directories nimbus7, meteor3, adeos, and eptoms. The averaging technique for producing this grid from the Level-2 product is described above in Section 4.

Table 5.2 provides a detailed description of the first line of a daily ozone grid file. Figure 5.1 shows an example of the header and the first two latitude zones in a native Level-3 daily ozone file from the EP/TOMS. The gridded ozone values are stored as 3-digit integers in units of matm-cm. Each of the 180 latitude zones requires 10 lines. They are ordered from south to north with the first zone centered at -89.5 degrees. Within each latitude zone, values are given for each of 288 longitude zones from 180^{o} W through 0^{o} (Greenwich) to 180^{o} E. The first longitude zone is centered at -179.375 degrees. As shown in Figure 5.1, annotation is present after all values are given for a latitude zone. Zeroes denote missing ozone data; that is data that could not be collected due to lack of sunlight or other problems. A fill value of 999 is used to denote missing data for reflectivity, aerosol index, and erythemal exposure.

The erythemal exposure is stored in a different form from the other parameters in the native Level-3 file. Each value code consists of three digits: a 1-digit exponent (E), and a 2-digit mantissa (M). A decimal point is implied between the two digits of the mantissa. Together, E and M encode a value of $M \times 10^{E}$. For example, the value code 342 represents the value 4.2×10^{3}.

Table 5.2. Format of Header Line of the Native Level-3 Daily Ozone Grid.

Character	Contents
1	American Standard Code for Information Interchange (ASCII) blank (HEX 20)
2-5	"Day:" (quotes indicate fixed content)
6	ASCII blank
7-9	day of year
10	ASCII blank
11-13	month ("Jan," "Feb," "Mar"...)
14	ASCII blank
15-16	day of month
17	","
18	ASCII blank
19-22	year
23-26	ASCII blanks
27-33	"EP/TOMS"
34-37	ASCII blanks
38-40	"STD"
41	ASCII blank
42-46	"OZONE"
47-50	ASCII blanks
51-60	"GEN:yy.ddd"
61	ASCII blank
62-70	"Asc LECT:"
71	ASCII blank
72-73	hour (local) of ascending node equator crossing
74	ASCII ":"
75-76	minute (local) of ascending node equator crossing
77	ASCII blank
78-79	"AM" or "PM" indicating morning or afternoon/evening ascending node equator crossing
80	ASCII blank
81<	lf > (line feed character; i.e., HEX 0A)

Day: 269 Sep 25, 1997 EP/TOMS STD OZONE GEN:97.269 Asc LECT: 11:19 AM
Longitudes: 288 bins centered on 179.375 W to 179.375 E (1.25 degree steps)
Latitudes: 180 bins centered on 89.5 S to 89.5 N (1.00 degree steps)

```
211211211211207207207207205205205205205205205205205205205205205205205205205205205205200200200
200199199199199197197197197195195195195194194194194194194194194194194194194194194194194194194
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201201201201201201201201201201201201201201201201197197197197199199199199198198198198196196196
196196196196196192192192192 lat = -89.5
217217217217217217217217209209209209203203203203202202202202202202202202202202202202199199199
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192192192192192192192192192192192192193193193193193193193193200200200200200200200200200200200
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211211213213213213217217217217217217217217217220220220220216216216216219219219219219219219211
211211211211211211211209209209209221221221221220220220220218218218218218218218218217217217217
216216216216214214214214208208208208206206206206206206206206206206206206203203203203198198198
198196196196196196196196196 lat = -88.5
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Figure 5.1. Sample Native Level-3 Daily Ozone File Excerpt.

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LIST OF ACRONYMS, INITIALS, AND ABBREVIATIONS

AD	Abbreviation for ADEOS
ADEOS	Advanced Earth Observing Satellite
A1	Abbreviation for ADEOS-1
AI	Aerosol Index
ASCII	American Standard Code for Information Interchange
A.U.	Astronomical Unit
BUV	Backscatter Ultraviolet
CD-ROM	Compact Disk-Read Only Memory
CIE	Commission Internationale de l' Eclairage
DAAC	Distributed Active Archive Center
D. U.	Dobson Units (= milliatmosphere-centimeters)
EIOO	Equatorial Inter-Orbit Overlap
FOV	Field-of-View
ftp	file transfer protocol
GMT	Greenwich Mean Time
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
IFOV	Instantaneous Field-of-View
ISCCP	International Satellite Cloud Climatology Project
LECT	Local Equator Crossing Time
M3	Meteor-3 spacecraft
N7	Nimbus-7 spacecraft
NASA	National Aeronautics and Space Administration
NCSA	National Center for Supercomputing Applications
netCDF	Network Common Data Format
NOAA	National Oceanic and Atmospheric Administration
OPT	Ozone Processing Team
SDS	Scientific Data Set
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
TOMS	Total Ozone Mapping Spectrometer
UARS	Upper Atmospheric Research Satellite
URL	Uniform Resource Locator
UV	Ultraviolet
V7	Version 7

APPENDIX A. SOFTWARE TO READ HDF OZONE DATA

This appendix describes software that can be used to read the TOMS HDF Level-3 data files. The software is written in C and requires the HDF version 3.3 or 4 (or higher) libraries to compile. The read software is available at the GSFC DAAC (see Appendix B). The HDF libraries can be downloaded via anonymous ftp at ftp.ncsa.uiuc.edu in directory / HDF. Copies of the most recent HDF version libraries can be downloaded from the DAAC anonymous ftp server at daac.gsfc.nasa.gov in directory /pub/hdf.

The program read_tomsl3.c can be used to read the TOMS Level-3 HDF files. Issuing the command read_tomsl3 will display a list of the HDF files in the current directory. Next, the program will display the following information—

- File label,
- Text: "File description stored in the file" (optional), and
- Metadata.

The next keystroke will display a numbered list of all the SDSs providing the name and dimensions of the SDS corresponding to each number: 1 is ozone, 4 is reflectivity. (Numbers 2 and 3 are coordinate data sets and will not be displayed by this software). The user can display either SDS by entering its number or can exit the program by entering q. The user will be prompted to output the file to the screen, an ASCII file, or to a binary file. The output will be displayed in physical values. For screen and ASCII dumps, latitude and longitude values will be included with the data values.

APPENDIX B. DATA AVAILABILITY

Data Archive

The derivative data products defined in this User's Guide are archived at and available from the NASA Goddard Space Flight Center Distributed Active Archive Center (NASA/GSFC/DAAC). All data and services offered by the Goddard DAAC are free.

The DAAC may be accessed on World Wide Web at http://daac.gsfc.nasa.gov/. Options for locating and accessing data are listed on the DAAC home page. Information about TOMS and other ozone data archived at the Goddard DAAC can be found at http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ATM_CHEM/ac_main.html. In addition to data, the DAAC Web pages contain information about HDF, the format in which it provides the Level-2 and Level-3 TOMS products, available from http://daac.gsfc.nasa.gov/REFERENCE_DOCS/HDF/gdaac-hdf.html.

The DAAC maintains a help desk, which provides assistance with its on-line ordering services. The Help Desk can be reached by—

Electronic Mail: daacuso@daac.gsfc.nasa.gov
Telephone: +1-301-614-5224 or 1-877-794-3147
FAX: +1-301-614-5268

The postal address of the DAAC is:

NASA/Goddard Space Flight Center
Distributed Active Archive Center
Code 902
Greenbelt, MD 20771

Near Real-Time Data

The TOMS Level-3 data (native format, Section 5.2) and images as well as electronic versions of the data products user's guides are available on the World Wide Web TOMS Home Page at http://toms.gsfc.nasa.gov/index.html.

APPENDIX C. OZONE CORRECTION PROCEDURES

Use of the Aerosol Index for Ozone Correction

As described in Section 3.2, errors can occur in the Version 7 TOMS ozone when the aerosol index is elevated. These errors, associated with the presence of absorbing aerosols in the troposphere [Torres *et al.*, 1999] and with the reflection of the solar image on water surfaces, are not an issue in trend determination or in studies where large amounts of data are averaged. But they may be important in the analysis of local phenomena. If a correction is needed, the value of the aerosol index for a given map cell on a given day can be used to correct the corresponding Level-3 ozone value for the effects of absorbing aerosols in the troposphere. Further, the Level-3 aerosol product is screened for the effects of sun glint. So, the screening that has been applied to the aerosol product may be used to screen the ozone product as well.

Level-3 Ozone Correction Procedure for Aerosol Contamination

For each non-fill value of Level-3 aerosol index (AI) between the latitudes of 50 North and 50 South, the corresponding Level-3 ozone value (Ω) may be corrected using the following expression:

$$\Omega_{COR} = \Omega x\left(1 + \frac{AI}{F_{ac}}\right)$$

where $F_{ac} = 90$ for N7 and M3 TOMS and
$F_{ac} = 83$ for EP and ADEOS TOMS

If the aerosol index is larger than 3.5, the Level-3 ozone value should be discarded.

Level-3 Ozone Screening Procedure for Sun Glint Contamination

A sun glint screen has been applied to the Level-3 aerosol product, because the AI is elevated in the presence of sun glint. So, a fill value has been reported for contaminated cells. These occur over water near the nadir sample of the TOMS scan when the viewing geometry is such that the solar image might be visible. If the scene is cloud covered, no sun glint contamination can occur. However, the screening algorithm makes no attempt to identify cloud, and introduces fill values for AI even in the presence of cloud.

As described in Section 3.2, sun glint also affects derived ozone. The derived ozone may be underestimated by 2 percent or as much as 4 percent in extreme cases of sun glint. If better accuracy is required, the possibly contaminated ozone values may be screened from the Level-3 data using the following procedure:

For each filled Level-3 aerosol value between the latitudes of 35 North and 35 South, any corresponding non-fill Level-3 ozone value should be discarded.

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Data from the TOMS series of instruments span the time period from November 1978, through the present with about a one and a-half year gap from January 1994 through July 1996. A set of four parameters derived from the TOMS measurements have been archived in the form of daily global maps or Level-3 data products. These products are total column ozone, effective surface reflectivity, aerosol index, and erythermal ultraviolet estimated at the Earth surface. A common fixed grid of 1 degree latitude by 1.25 degree longitude cells over the entire globe is provided daily for each parameter. These data are archived at the Goddard Space Flight Center Distributed Active Archive Center (DAAC) in Hierarchical Data Format (HDF). They are also available in a character format through the TOMS web site at http://toms.gsfc.nasa.gov. The derivations of the parameters, the mapping algorithm, and the data formats are described. The trend uncertainty for individual TOMS instruments is about 1% decade, but additional uncertainty exists in the combined data record due to uncertaininty in the relative calibrations of the various TOMS.

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