Making **E**a**r**th **S**cience Data Records for **U**se in **R**esearch **E**nvironment**s** (MEaSUREs)

README Document for

TOMSN7SO2

Goddard Earth Sciences Data and Information Services Center (GES DISC) http://disc.gsfc.nasa.gov

NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA

Principal Investigators: Nickolay A. Krotkov, Pawan K. Bhartia, Code 614
Nickolay.A.Krotkov@nasa.gov
301-614-5553

Algorithm Developer: Brad Fisher , SSAI, Code 614
bradford.fisher@ssaihq.com
301-867-2188

Algorithm Support: Peter Leonard, ADNET, Code 619
peter.j.leonard@nasa.gov

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

Last Revised: June 23 2017

Reviewed by: ***Andrey Savtchenko***

Name	Name
GES DISC	External Organization
GSFC Code 610.2	
Date	

Goddard Space Flight Center
Greenbelt, Maryland

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

Revision History

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

TABLE OF CONTENTS

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

1. INTRODUCTION

1.1 TOMS Nimbus-7 MEaSUREs SO_2 Dataset: TOMSN7SO2

This document contains a brief description of the TOMSN7SO2 data product. TOMSN7SO2 is a Level 2, orbital track volcanic sulfur dioxide (SO_2) product for the Total Ozone Mapping Spectrometer (TOMS) onboard NASA's Nimbus 7 satellite, which was launched on October 24, 1978 into polar sun-synchronous orbit and collected data from November 1, 1978 to May 6, 1993. This was the first mission to provide daily contiguous global maps of total ozone (O_3). As part of the NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) program, the Goddard Earth Science (GES) Data and Information Data Center (DISC) has released a new SO_2 Earth System Data Record (ESDR), TOMSN7SO2, re-processed using new 4 UV wavelength bands MS_SO2 algorithm that spans the full Nimbus 7 data period. TOMSN7SO2 is a Level 2 orbital swath product, which will be used to study the fifteen-year SO_2 record from the Nimbus-7 TOMS and to expand the historical database of known volcanic eruptions.

1.2 TOMS Instrument

TOMS is a fixed-grating Ebert-Fastie monochromator with photomultiplier tube detector that measures solar backscattered ultraviolet (BUV) radiances (I) at 6

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

narrow wavelengths bands (Full Width at Half Maximum band width ~1.1nm) in the near ultraviolet (UV) spectral region as well as the incident solar irradiances (F) (Heath, *et al*., 1975). The ratio of radiance to irradiance provides the spectral reflectivity parameter used in the ozone retrieval. The wavelength band centers shown in Table 1 were selected to optimize column ozone retrievals assuming that two pairs of shorter, absorbed wavelengths would be needed to cover the full dynamic range of ozone and solar zenith angles encountered globally, similar to the Dobson Spectrophotometer design. Two additional non-absorbed longer wavelengths were provided to measure the surface or cloud reflectivity (R) and its spectral dependence.

Table 1

Channel Number	Wavelength, vacuum [nm]	Used in SO_2 retrieval	MS_SO2 Retrieved Parameter
1	312.34	Not Used	
2	317.35	x	SO_2
3	331.06	x	O_3
4	339.66	x	$dR/d\lambda$
5	359.99	Not Used	
6	379.89	x	R

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

TOMS scans in the cross-track direction in 3° steps from 51° on west side of nadir to 51° on the east, for a total of 35 cross-track samples. The instantaneous field-of-view (FOV) of 3° x 3° results in a footprint varying from a 50 km x 50 km square FOV at nadir to a 125 km by 280 km diamond-shaped FOV at the scan extremes. The total swath width is 3000 km covering Earth's surface in 14 orbits per day.

1.3 Science Background

The original design of the TOMS instrument assumed that ozone was the only significant gaseous absorber in near UV wavelengths (Dave and Mateer 1967). A second absorber was later discovered in 1982 as a high ozone anomaly observed over the El Chichon volcano in Mexico and recognized as SO_2 gas absorption in the volcanic cloud (Krueger 1983). Following the discovery, Krueger *et al*. (1995) developed a first algorithm to separate the ozone and SO_2 signals and to retrieve the column amount of SO_2. The off-line retrieval has been used on a case-by-case basis to retrieve SO_2 mass from explosive eruptions using TOMS measurements on Nimbus-7 and follow-up missions (Krueger *et al.,* 2000; Carn *et al*., 2003). The TOMSN7SO2 data product is the first public release of the complete Nimbus-7 TOMS SO_2 Level 2 data, re-processed with a new 4 UV wavelength bands algorithm that is fast enough to permit production of the entire global dataset.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

2. MULTI-SATELLITE SO_2 ALGORITHM

2.1 General Description

This section describes the new Multi-Satellite SO_2 (MS_SO2). This algorithm builds on the heritage of the TOMS total ozone (TO3) algorithm (Dave and Mateer, 1967, McPeters *et al*., 1996), but adds sulfur dioxide (SO_2) as a second absorber to the pre-computed BUV look-up tables. The algorithm uses four of the six spectral bands to retrieve a state vector ($\hat{X}$) with 4 parameters: SO_2 column amount, O_3 column amount, the Lambertian equivalent reflectivity (LER) at 380 nm, R, and the spectral dependence of R, dR/dλ. The algorithm relies on spectral differences in SO_2 and O_3 cross sections to simultaneously quantify the amounts of the two trace gases (see Table 1 and Figure 1). SO_2 is more absorbing than O_3 at the shorter channels (312 and 317 nm), whereas O_3 is more absorbing at the longer absorbing channel (331 nm). Figure 1 shows the O_3 and SO_2 spectral cross sections in the near-UV spectral range and the SO_2 to O_3 cross section ratio over the same range. It is relative differences in the cross-section ratio that allows for the separation of the two gases. The three vertical bars show the centers of the absorbing spectral bands used in the retrieval.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

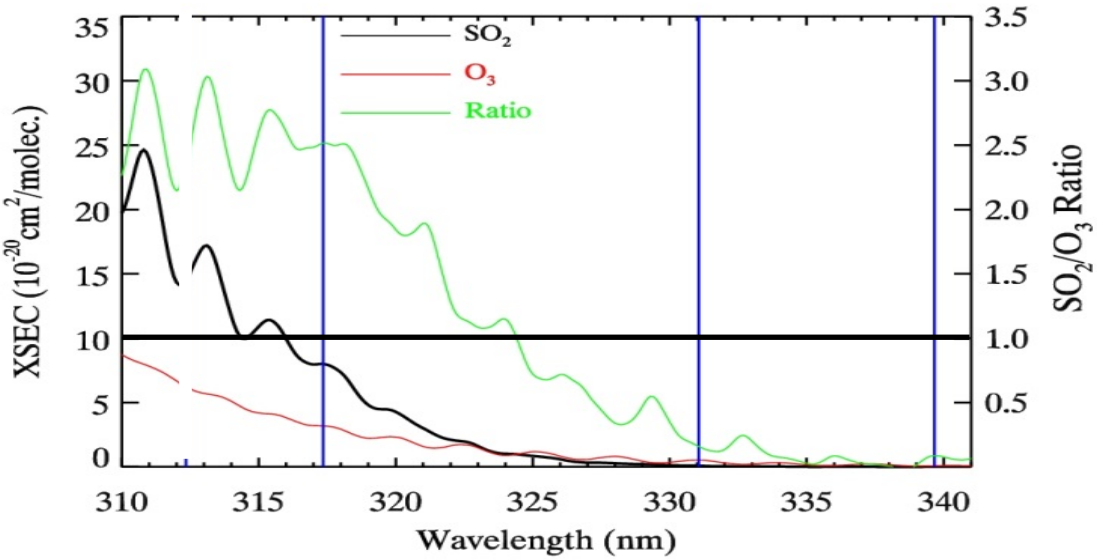

Figure 1. SO_2 (black) and O_3 (red) cross-sections and their ratio (green) at UV wavelengths. The three vertical bars show the location of the absorbing channels used in the retrieval.

2.2 Step 1 Retrieval

The SO_2 retrieval is performed in two steps and applied iteratively for each FOV. The retrieval starts with a first guess value of total column ozone based on climatology and assuming zero SO_2. The LER is then computed at 380 nm (R). Because O_3 and SO_2 absorption is very weak at this wavelength, R remains fixed during the iterations. The algorithm then uses 3 shorter spectral bands to retrieve $\Delta(\partial R/\partial\lambda)$, ΔO_3 and ΔSO_2 adjustments to the state vector: $\Delta \boldsymbol{x}$ =[ΔSO_2, ΔO_3, $\Delta(\partial R/\partial\lambda)$], assuming a linear $R(\lambda)$ spectral dependence:

$$\Delta y_i = N_{m_i} - N_{c_i} = \frac{\partial N_{c_i}}{\partial SO_2}\Delta SO_2 + \frac{\partial N_{c_i}}{\partial O_3}\Delta O_3 + \frac{\partial N_{c_i}}{\partial R}(\lambda_i - \lambda_R)\Delta\frac{\partial R}{\partial \lambda} \qquad (1)$$

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

where i = 1, 2, 3 corresponds to the 317, 331, and 340nm bands and λ_R=380m. The left-hand side of Eq. 1 represents the difference (residual) between the measured and calculated sun normalized BUV radiances expressed in N-value units, defined in Equation 2 as:

$$\text{N-value} = -100\log_{10}(I/F) \qquad (2)$$

where I is the measured radiance and F is the TOA incoming solar flux.

The partial derivatives (Jacobians) on the right-hand side form a Jacobian K-matrix. The matrix consists of the N value sensitivities associated with linear perturbations in state vector parameters: SO_2, O_3 and dR/dλ (*i.e.*, reflectivity spectral slope)

$$K = \begin{pmatrix} \frac{\partial N_{317}}{\partial SO2} & \frac{\partial N_{317}}{\partial O3} & \frac{\partial N_{317}}{\partial x}(\lambda_i - \lambda_R) \\ \frac{\partial N_{331}}{\partial SO2} & \frac{\partial N_{331}}{\partial O3} & \frac{\partial N_{331}}{\partial R}(\lambda_i - \lambda_R) \\ \frac{\partial N_{340}}{\partial SO2} & \frac{\partial N_{340}}{\partial O3} & \frac{\partial N_{340}}{\partial R}(\lambda_i - \lambda_R) \end{pmatrix} \qquad (3)$$

The K matrix elements are computed for each spectral band from the BUV radiance look-up tables (LUT). The LUT's nodal points correspond to surface pressure, satellite-viewing geometry (solar zenith, satellite nadir, and relative azimuthal angles), total ozone and column SO_2, assuming TOMS standard Ozone profiles. For SO_2 the algorithm assumes three Gaussian shape profiles (2-km half-width), with different peak SO_2 altitudes: 8 km (middle troposphere, TRM data),

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

13 km (Upper Tropospheric/Lower Stratospheric, TRU data), and 18 km (lower stratospheric, STL data). The RT calculations were compiled off-line using TOMRAD radiative transfer code (Dave 1965).

The state vector increment, **Δx**, is defined in (4). The adjustment to **Δx** after each iteration is subsequently determined by inverting the 3 x 3 Jacobian matrix **K**:

$$\Delta x = K^{-1}\Delta y = \begin{pmatrix} \Delta SO_2 \\ \Delta O_3 \\ \Delta \frac{\partial R}{\partial \lambda} \end{pmatrix} \qquad (4)$$

The differentials **Δx** are added to the previous iteration state **x** values, beginning with a first guess to obtain the column amounts of SO_2 and O_3 in Dobson units (1 DU= $2.69*10^{16}$ molec. cm^{-2}) and $\partial R/\partial\lambda$ [nm^{-1}]. The largest change in SO_2 column amount occurs in the first iteration and the process typically converges in 2-3 iterations depending on the actual SO_2 amount.

2.3 Step 2 Retrieval

Volcanic ash and large SO_2 amounts in volcanic clouds bias high the Step 1 O_3 retrieval, leading to an underestimation of SO_2. In such cases the algorithm applies a "Step 2" correction. The correction is initiated when either of the following two criteria is met in Step 1:

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

1) SO_2 amount exceeds 20 DU, or

2) O_3 exceeds 2 standard deviations of the background regional mean O_3 (where the regional O_3 statistics do not include FOVs with $SO_2 > 20$ and UV aerosol index (AI) > 2).

The AI is calculated using the following equation:

$$AI = (340 - 380)\frac{\partial N_{340}}{\partial R}\frac{\partial R}{\partial \lambda} \qquad (5)$$

where the Jacobian $\partial N/\partial R$ is computed at 340 nm. The scale factor accounts for wavelength difference between the TOMS longer (reflectivity) spectral bands.

For each FOV meeting Step 2 criteria, the ozone is first corrected by masking the volcanic plume region and then linearly interpolating O_3 from outside the plume along the orbital track for each affected swath position. The interpolated O_3 is more uncertain for large regional plumes like Pinatubo and in mid- and high-latitudes with large O_3 variability. Step 2 uses only 317 nm and 340 nm spectral bands and one iteration to calculate the correction $\mathbf{\Delta x} = [\Delta SO_2, \Delta\partial R/\partial\lambda]$ and apply it to Step 1 retrievals: $SO_2 = SO_2$ (Step 1) + ΔSO_2 and $\Delta\partial R/\partial\lambda = \Delta\partial R/\partial\lambda$ (Step 1) + $\Delta\partial R/\partial\lambda$. Note that even though the corrected O_3 is not explicitly used in the construction of the K-matrix, it is used to select the SO_2, R and O_3 nodes in the LUTs. A Step 2 algorithm flag is provided in the product. The flag informs users whether Step 2 was applied and which of the above criteria was used in the selection process.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

2.4 Soft Calibration of the 340 Channel

The mean SO_2 background far away from any SO_2 sources is assumed to be zero, but due to noise in the retrieval system (*e.g.*, instrument, forward model), the retrieved SO_2 values fluctuate around zero (positive and negative). To correct for any residual SO_2 bias in the mean background, the algorithm inverts the K-matrix – what Rogers (2000) refers to as the gain matrix (or G-matrix) – and uses the matrix element associated with the SO_2 sensitivity at 340 nm to calibrate the 340 radiance.

An SO_2 and aerosol–free TOMS orbit over the central Pacific was selected for this procedure. A Step 1 retrieval is then performed for this orbit with no soft calibration applied. Using the SO_2 field generated for this orbit, a correction to the 340 radiance is then computed as shown in (6)

$$dN_{340} = Mean\left(\frac{SO2}{\frac{\partial SO2}{\partial N_{340}}}\right) \qquad (6)$$

where, $\partial SO_2/\partial N_{340}$ is the (2,2) G-matrix element corresponding to the SO_2 sensitivity in the 340 spectral band. This calculation is applied at two latitude bands: 1) abs(lat) ≤ 30° and 2) abs(lat) > 30°. Figure 2 shows a plot of the N-value correction applied at both latitude bands.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

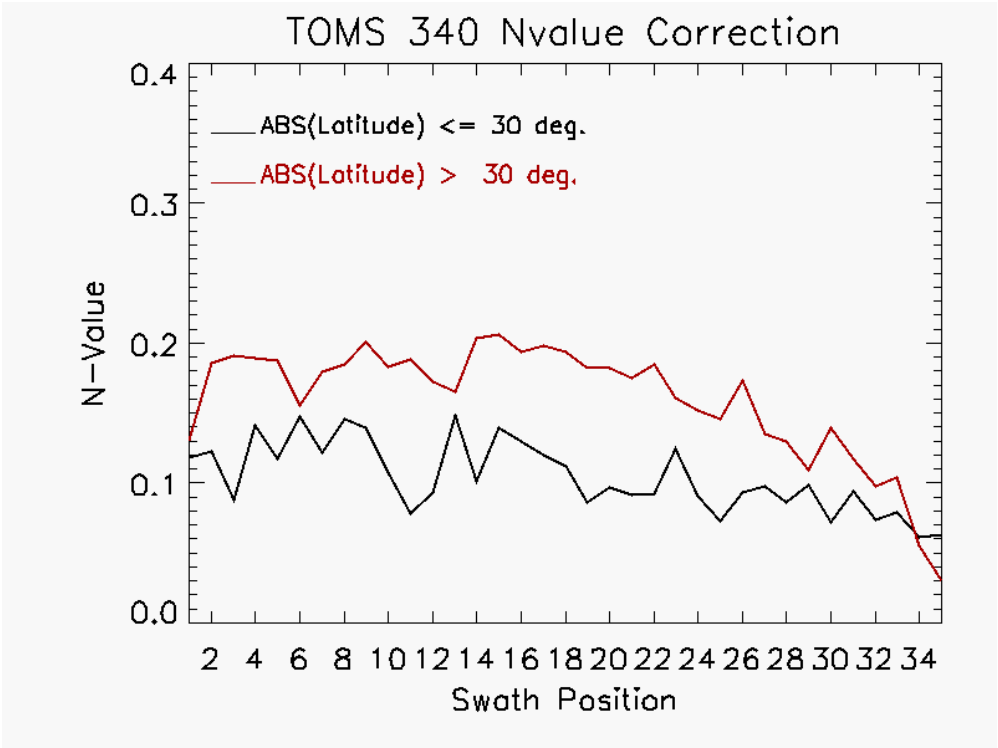

Figure 2. N-Value correction of the 340 nm channel at two latitude bands: 1) 30S ≤ Latitude < 30N and 2) Latitude < 30S and Latitude > 30N.

2.5 Uncertainty

The retrieval of volcanic SO_2 is subject to limitations related to the sensitivity of the instrument and the skill of the forward model in simulating the BUV radiances. Noise in the system produces a random distribution in the SO_2 background around zero. We characterize the low-end sensitivity of the instrument by estimating the random error in the distribution of retrieved SO_2, in background regions where SO_2 concentrations are considered well below the detection limit of the TOMS instrument.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

The spatial area of the individual FOVs vary, resulting in sampling differences as a function of the cross track position, which in turn affects the random error. We characterize the low-end sensitivity of the retrieval with respect to the standard deviation in the distribution of the SO_2 noise, as a function of the swath position, as shown in Figure 3. The maximum noise value of about 6 DU is attained at nadir. We set the sensitivity threshold for detecting volcanic SO_2 at 15 DU, just below the 99% confidence interval.

The uncertainty associated with the SO_2 retrieved from actual volcanic events was characterized by comparing two independent UV algorithms applied to the same BUV data set (Figure 4). In this case, MS_SO2 retrievals were compared against estimates from the independent Principal Components Algorithm (PCA). For this analysis, the PCA algorithm has been modified to use 6 TOMS channels (normally it is applied in a hyper spectral instruments). We subsequently estimated the uncertainty by computing the mean deviation and co-variance between these two sensors for several major volcanic events. Based on this analysis we estimate the uncertainty for the large SO_2 events to be about 10-15 DU.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

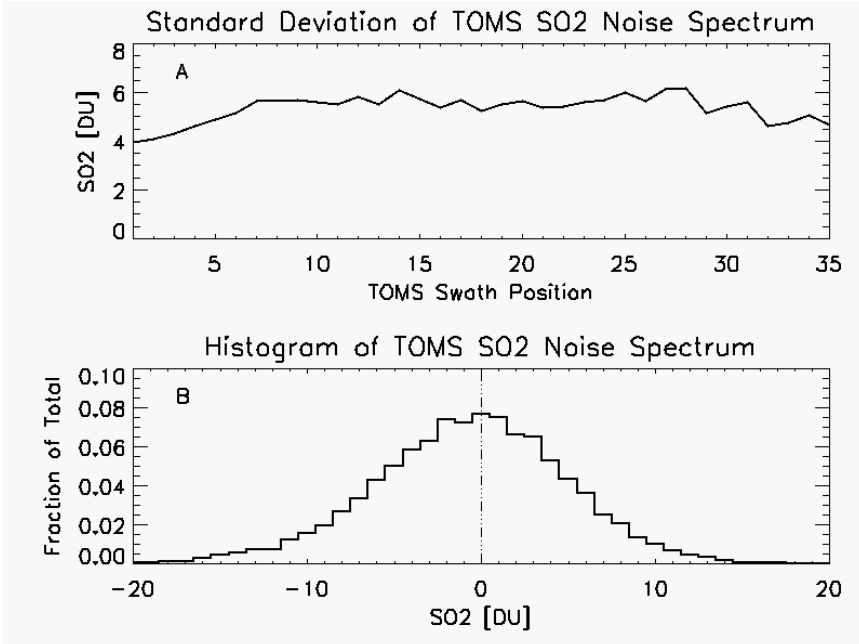

Figure 3. a) Standard Deviation of SO_2 noise as function of cross-track swath position and b) background SO_2 noise histogram for all cross-track positions.

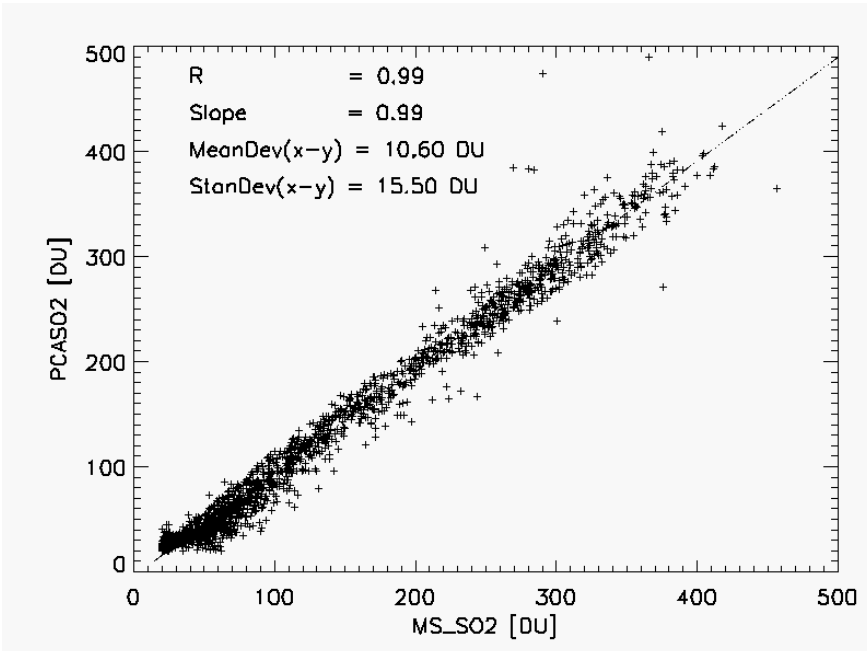

Figure 4. Scatterplot comparing retrievals from independent MS_SO2 and the PCA algorithms for several major eruptions spanning the full dynamic range of estimates. The statistical parameters are used to estimate the uncertainties for MS_SO2 retrievals in different volcanic clouds (sample of 1840 FOVs).

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

3. DATASET ORGANIZATION

The TOMSN7SO2 product provides a set of Level 2 orbital swath files produced by applying the MS_SO2 algorithm to the N7-TOMS data record.

3.1 File Naming Convention

The TOMSN7SO2 data granules (files) are named as in this example:

TOMS-N7_L2-TOMSN7SO2_1991m0817t090821-o64696_v02-00-2017m0502t064217.h5,

where the components of filename are as follows:

1. Instrument (TOMS)
2. Spacecraft (N7)
3. Process Level (L2)
4. ESDT Short Name (TOMSN7SO2)
5. Date and Time at Start of Orbit (1991-08-17 09:08:21 UTC)
6. Orbit Number (64696)
7. Product Version (02-00)
8. Production Date and Time (2017-05-02 06:42:17 UTC)
9. File Type (h5)

3.2 File Format and Structure

The TOMSN7SO2 data granules are in plain HDF5 that is netCDF4-compatible and CF-compliant. Each TOMSN7SO2 data granule contains global attributes, dimensions, an ancillary data group, a geolocation data group, a science data group, and a sensor data group.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

3.3 Key Science Data Fields

The TOMSN7SO2 science product provides four key science data fields associated with the retrieval: SO_2 column amount, O_3 column amount, the Lambertian Equivalent Reflectivity at 380 nm (R), and the reflectivity spectral slope ($\partial R/\partial \lambda$). The other retrieved parameters provide important diagnostic information.

3.3.1 SO_2 Column Amount

ColumnAmountSO2_TRM, ColumnAmountSO2_TRU and ColumnAmountSO2_STL are, respectively, the column amounts for SO_2 in assumed Gaussian distributions with 2-km standard deviations centered in the middle troposphere (8 km), the upper tropical troposphere (13 km) and the lower stratosphere (18 km).

3.3.2 O_3 Column Amount

ColumnAmountO3_TRM, ColumnAmountO3_TRU and ColumnAmountO3_STL are, respectively, the O_3 total column amounts that correspond to the SO_2 retrievals for the middle troposphere (8 km), the upper troposphere (13 km) and the lower stratosphere (18 km).

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

3.3.3 Lambertian Equivalent Reflectivity at 380 nm

The Lambertian Equivalent Reflectivity at 380 nm (LER380) is independent of the height of the assumed SO_2 layer.

3.3.3 Reflectivity Spectral Dependence ($\partial R/\partial \lambda$)

dRdlambda_TRM, dRdlambda_TRU and dRdlambda_STL are, respectively, the reflectivity spectral slopes ($\partial R/\partial \lambda$) that correspond to the SO_2 retrievals for the middle troposphere (8 km), the upper troposphere (13 km) and the lower stratosphere (18 km).

4. DATA CONTENTS

Each TOMSN7SO2 data granule contains global attributes, dimensions, an ancillary data group, a geolocation data group, a science data group, and a sensor data group. This section provides specific details regarding these components, as shown in Figure 5.

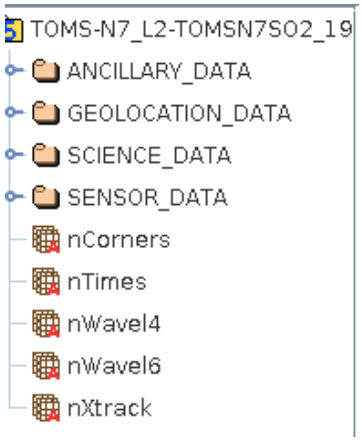

Figure 5. Shows 4 main data groups and dimensions.

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

4.1 Global Attributes

There are 43 global attributes in each TOMSN7SO2 data granule as shown in Figure 6.

```
Number of attributes = 43
   AuthorAffiliation = NASA/GSFC
   AuthorName = N. Krotkov, et al.
   Conventions = CF-1.0
   DataSetQuality = Under investigation.
   DayNightFlag = Day
   EastBoundingCoordinate = 180.0
   EquatorCrossingDate = 1985-02-09
   EquatorCrossingLongitude = 178.45999
   EquatorCrossingTime = 23:52:27
   FOVResolution = 50x50km
   GranuleDayOfMonth = 9
   GranuleDayOfYear = 40
   GranuleMonth = 2
   GranuleYear = 1985
   HDFVersion = 5-1.8.12
   InputPointer = TOMS-N7_L2-N7TO3_1985m0209t2322-o31800_v001-2015m0909t185528.he5
   InstrumentShortName = TOMS
   LocalGranuleID = TOMS-N7_L2-TOMSN7SO2_1985m0209t230022-o31800_v02-00-2017m0522t105240.h5
   LocalityValue = Global
   LongName = TOMS/N7 MS SO2 Vertical Column 1-Orbit L2 Swath 50x50 km
   NorthBoundingCoordinate = 76.2263
   NumTimes = 392
   OrbitNumber = 31800
   PGEVersion = 1.0.6
   ParameterName = Vertical Column Sulfur Dioxide
   PlatformShortName = Nimbus 7
   ProcessLevel = 2
   ProcessingCenter = ACPS
   ProductType = L2 Swath
   ProductionDateTime = 2017-05-22T10:52:40.0Z
   RangeBeginningDate = 1985-02-09
   RangeBeginningTime = 23:00:22
   RangeEndingDate = 1985-02-10
   RangeEndingTime = 00:44:31
   SensorShortName = Single Monochromator
   ShortName = TOMSN7SO2
   Source = N7/TOMS
   SouthBoundingCoordinate = -89.811134
   TAI93At0zOfGranule = -2.49091205E8
   VersionID = 2.00
   WestBoundingCoordinate = -180.0
   identifier_product_doi = 10.5067/MEASURES/SO2/DATA202
   identifier_product_doi_authority = http://dx.doi.org/
Log Info   Metadata
```

Figure 6. TOMSN7SO2 Global attributes

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

4.2 Dimensions

There are six dimensions in each TOMSN7SO2 data granule (Figure 5):

nCorners - The dimension representing the four ground-pixel corners.
nTimes - The dimension representing the time of observation.
nWavel4 - The dimension representing the subset of four TOMS wavelengths used in the retrievals.
nWavel6 - The dimension representing all six TOMS wavelengths.
nXtrack - The dimension representing the 35 cross-track scan positions.

4.3 Data Fields

4.3.1 Ancillary Data

There are only two fields, CloudPressure and TerrainPressure, in the ancillary data group in each TOMSN7SO2 data.

4.3.2 Geolocation Data

There are ten fields in the geolocation data group in each TOMSN7SO2 data granule as shown in Figure 7.

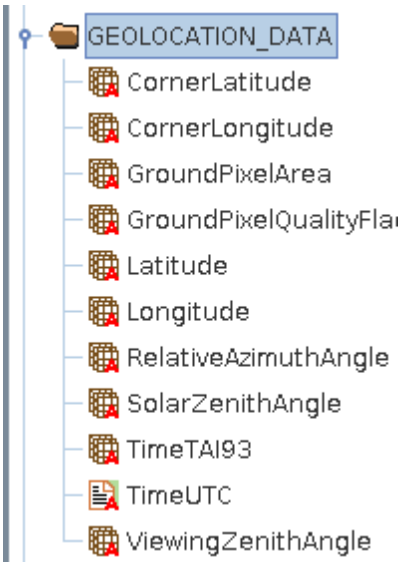

Figure 7. Geolocation Data Group

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

4.3.3 Science Data

There are 27 fields in the science data group in each TOMSN7SO2 data granule as shown in Figure 8.

- SCIENCE_DATA
  - AlgorithmFlag_STL
  - AlgorithmFlag_Step2
  - AlgorithmFlag_TRM
  - AlgorithmFlag_TRU
  - ColumnAmountO3_STL
  - ColumnAmountO3_TRM
  - ColumnAmountO3_TRU
  - ColumnAmountSO2_STL
  - ColumnAmountSO2_TRM
  - ColumnAmountSO2_TRU
  - LER380
  - NValue
  - Residual_STL
  - Residual_TRM
  - Residual_TRU
  - dNdR_STL
  - dNdR_TRM
  - dNdR_TRU
  - dNdSO2_STL
  - dNdSO2_TRM
  - dNdSO2_TRU
  - dNdTO3_STL
  - dNdTO3_TRM
  - dNdTO3_TRU
  - dRdlambda_STL
  - dRdlambda_TRM
  - dRdlambda_TRU

Figure 8. Science Data Group

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

4.3.4 Sensor Data

There is only one field, Wavelength, in the sensor data group in each TOMSN7SO2 data granule.

5. CONTACTS

Principal Investigator:	Nickolay Krotkov Nickolay.A.Krotkov@nasa.gov 301-6114-5553
Algorithm Developer:	Brad Fisher bradford.fisher@ssaihq.com 301-867-2188
Algorithm Support:	Peter Leonard peter.j.leonard@nasa.gov

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time

6. REFERENCES

Carn, S.A., Krueger, A.J., Bluth, G.J.S., Schaefer, S.J., Krotkov, N.A., Watson, I.M. and Datta, S. (2003), Volcanic eruption detection by the Total Ozone Mapping Spectrometer (TOMS) instruments: a 22-year record of sulfur dioxide and ash emissions, In: Volcanic Degassing (eds. C. Oppenheimer, D.M. Pyle and J. Barclay), *Geological Society, London, Special Publications*, **213**, pp.177-202.

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

Heath, D.F., A.J. Krueger, H.A. Roeder, and B.D. Henderson, The Solar Backscatter Ultraviolet and Total Ozone Mapping Spectrometer (SBUV/TOMS) for Nimbus G, *Optical Engineering*, 14, 323, 1975

Krotkov, N. A., A. J. Krueger, P. K. Bhartia, Ultraviolet optical model of volcanic clouds for remote sensing of ash and sulfur dioxide, *J. Geophys. Res*., 102(D18), 21891-21904, 10.1029/97JD01690, 1997

Krueger, A.J. , Sighting of El Chichón sulfur dioxide clouds with the Nimbus 7 Total Ozone Mapping Spectrometer, Science, 220, p. 1377-1378, 1983.

Krueger, A.J., L.S. Walter, P.K. Bhartia, C.C. Schnetzler, N.A. Krotkov, I. Sprod, and G.J.S. Bluth, Volcanic sulfur dioxide measurements from the Total Ozone Mapping Spectrometer (TOMS) Instruments, Journal of Geophysical Research, 100, D7, 14,057 - 14,076, 1995.

Krueger, A. J., S. J. Schaefer, N. Krotkov, G. Bluth, and S. Barker, Ultraviolet remote sensing of volcanic emissions, in Remote Sensing of Active Volcanism, Geophys. Monogr. Ser., vol. 116, edited by P. J. Mouginis-Mark, J. A. Crisp, and J. H. Fink, pp. 25-43, AGU, Washington, D. C., 2000.

Li, C., Krotkov, N. A., Carn, S., Zhang, Y., Spurr, R. J. D., and Joiner, J.: New-generation NASA Aura Ozone Monitoring Instrument (OMI) volcanic SO_2 dataset: Algorithm description, initial results, and continuation with the Suomi-NPP Ozone Mapping and Profiler Suite (OMPS), Atmos. Meas. Tech., 10, 445-458, doi:10.5194/amt-10-445-2017, 2017.

McPeters, et al., Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) data products user's guide, NASA Reference Publication 1384, pp1-67, 1996

Savtchenko, Andrey K. (GSFC-610.2)[ADNET SYSTEMS INC] Friday, June 23, 2017 at 3:16:28 PM Eastern Daylight Time