National Aeronautics and Space Administration Goddard Earth Science Data Information and Services Center (GES DISC)

README Document for Suomi-NPP OMPS NM Nitrogen Dioxide (NO_2) L2 Product

Version 2.0

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1.0 Introduction

This document provides basic information for using the Suomi National Polar-orbiting Partnership (NPP) Ozone Mapping and Profiling Suite (OMPS) Nadir Mapper (NM) Nitrogen Dioxide (NO_2) Level 2 (L2) orbital products, or OMPS_NPP_NMNO2_L2 (NMNO2-L2) for short. The NMNO2-L2 product consists of measurements of atmospheric NO_2 abundance, namely the total, stratospheric, and tropospheric NO_2 vertical column amounts, and other geophysical parameters that characterize the measurement conditions.

1.1 OMPS Instrument Description

The Ozone Mapping and Profiling Suite (OMPS) is designed to measure the global distribution of total column ozone on a daily basis, as well as the vertical distribution of ozone in the stratosphere and lower mesosphere (~15 – 60 km).

Nadir Mapper (NM) – The NM is designed primary for mapping global total column ozone distribution from its measurements of backscattered ultraviolet (BUV) spectra between 300 – 380 nm.

Nadir Profiler (NP) – The NP is designed for monitoring stratospheric ozone profiles, retrieved from the measured backscattered UV spectra between 250 – 310 nm.

Limb Profiler (LP) – The LP measures limb scattered radiation in the UV, visible, and near-infrared (NIR) spectral regions, from which ozone density and aerosol extinction coefficient profiles are estimated in altitude range between the lower stratosphere (10 – 15 km) and the upper stratosphere (55 km).

OMPS NM observations and its nitrogen dioxide (NO_2) measurements will be described here.

1.1.1 OMPS NM

The OMPS-NM is a nadir-viewing hyperspectral instrument measures BUV radiance spectra, covering the 300–380 nm wavelength range with a spectral resolution of ~1 nm and a sampling rate of ~0.42 nm per pixel. Suomi NPP is in a Sun-synchronous orbit with a local ascending (northbound) equator crossing time at 1:30 PM. The OMPS-NM provides contiguous daily global coverage in about fourteen (14) orbits using a two-dimensional charge-coupled device (CCD) that scans a 2800 km cross-track swath (110° field of view), divided into 35 instantaneous fields of views (IFOVs) or pixels, which have a ground footprint size of 50 km × 50 km at nadir. One orbit of OMPS-NM observations contains about 400 cross-track viewing lines, each scanning ~7.5 seconds along track, from southern to northern terminator on the sunlit side of the Earth. While the OMPS-NM is designed primarily to measure global total ozone (O_3), other geophysical quantities, such as trace gas (NO_2 and SO_2) abundances and the cloud optical centroid pressure (OCP) [*Vasilkov et al*, 2014], may be derived from the hyperspectral measurements of OMPS-NM. More comprehensive descriptions of the OMPS-NM instrument and its performance are given in *Seftor et al* [2014] and *Flynn et al* [2014].

1.2 Algorithm Background

1.2.1 Direct Vertical Colum Fitting algorithm

The Direct Vertical Colum Fitting (DVCF) algorithm [*Yang et al*, 2013, 2014] is applied to the OMPS-NM spectral measurements to retrieve the atmospheric NO_2 vertical columns. The DVCF algorithm was called the Iterative Spectral Fitting (ISF) algorithm, when it was first developed [*Yang et al,* 2009a] for simultaneous O_3 and SO_2 retrieval from the observations of Ozone Monitoring Instrument (OMI) flying on the Aura spacecraft. Since then, a number of advancements have been developed to improve the accuracy of O_3/SO_2 quantification, and to measure additional geophysical parameters, including SO_2 plume height [*Yang et al*, 2009b, 2010], effective cloud pressure [*Yang et al*, 2013], and nitrogen dioxide (NO_2) vertical column [*Yang et al,* 2014].

The retrieval approach of DVCF algorithm determines trace gas vertical columns and other geophysical parameters by adjusting them iteratively until the difference between the satellite-measured Earth view radiance spectra and those simulated using an accurate radiative transfer model is minimized. Algebraically, the DVCF algorithm equation for a wavelength (λ) is expressed as

$$\ln I_m - \ln I_{TOA} = \Delta X \int_0^{\infty} \frac{\partial \ln I_{TOA}}{\partial \tau_z} \sigma_X(T_z) S_z dz - \sum_{j=1}^{n} \xi_j \sigma_j(T_j) + \left(\sum_{k=0}^{N_R} \Delta R_k (\lambda - \lambda_{ref})^k \right) \left. \frac{\partial \ln I_{TOA}}{\partial R_0} \right|_{R_0 = R_{0_i}} + \varepsilon. \quad (1)$$

Here I_m is the measured reflecance spectrum (i.e., the ratio of the NM measured radiance to the NM measured irradiance), and I_{TOA} is the calculated reflectance at the i^{th} iteration based on a forward model, at the top of the atmosphere (TOA). Equation (1) includes one absorbing gas, which is NO_2 in this case, for its vertical column (X) retrieval by fitting of the vertical column weighting function, $\int_0^{\infty} \frac{\partial lnI_{TOA}}{\partial \tau_z} \sigma_X(T_Z)\, S_z\, dz$, while for additional trace gases (including O_3, HCHO, BrO, and OCLO), only their slant columns $\{\xi_j, j = 1 \dots n\}$ are determined in the fitting of their molecular absorption cross sections $\{\sigma_j(T_j), j = 1 \dots n\}$ at their respective temperature sections $\{T_j, j = 1 \dots n\}$. S_z is the shape factor, which is the normalized vertical profile; T_z is the atmospheric temperature, a function of altitude (z); ε is the total error, including both satellite measurement error and the forward modeling uncertainty.

Starting with an initial guess of state vector {X, and $\xi_j, j = 1 \dots n$}, the OCP and the reflectivity parameters {R_k, k = 0…N_R}, which specify the Mixed Lambert-Equivalent Reflectivity (MLER) model, are determined using reflectance measurements in the wavelength region (350 – 365 nm). Next the set of linear equations (1) for each wavelength in the fitting window (345 – 378 nm) can be solved by least squares fitting of residuals ($\ln I_m - \ln I_{TOA}$) to the vertical column weighting function and molecular absorption cross sections to obtain state vector adjustments {ΔX, and $\Delta\xi_j, j = 1 \dots n$}.

The total absorption optical thickness due to the trace gas (X) may be expressed as $\tau = \int_0^\infty \tau_z \, dz = X \int_0^\infty \sigma_X(T_z) \, S_z \, dz$. In the weak absorption regime, which characterized by small total absorption optical thickness (τ), the nonlinear-absorption effect may be ignored, as in the case of NO_2 retrieval from the spectral range 345 – 378 nm. In this regime, the initial state vector is set to zero for the vertical column X and for all the slant columns {$\xi_j, j = 1 \dots n$}. In other words, I_{TOA} is calculated without including the absorptions of trace gases, and the derived state vector adjustments are then equal to the total vertical column and the total slant columns, completing the estimation of the total vertical column (X) in one step without additional iteration.

The forward model used in DVCF algorithm is the TOMRAD model [*Dave*, 1965] with added contributions from rotational Raman scattering (RRS) calculated using the LIDORT-RRS code [*Spurr et al.*, 2008], to provide highly accurate modeling of radiative transfer in Rayleigh atmosphere. The shape factor S_z, needed in computing the vertical column weighting function, $\int_0^\infty \frac{\partial ln I_{TOA}}{\partial \tau_z} \sigma_X(T_z) \, S_z \, dz$, is selected based on time and location from the NO_2 monthly mean profiles constructed from a full year GEOS-Chem run with 2012 meteorology and emission [*Yang et al*, 2014].

Clouds and aerosols are frequently co-located with NO_2 in the tropsphere, especially in satellite observations of air pollutions. The presence of aerosols/clouds changes the photon contributions to the satellite measured UV radiation compared to the Rayleigh atmosphere. To account for the combined effects of surface reflection and atmospheric scattering without explicitly including clouds/aerosols in the forward model computation, the DVCF approach derives the albedo and the pressure of the underlying boundary in cloud-free and fully cloud-covered IFOVs, or the cloud fraction and effective cloud pressure for the partially cloudy IFOV, including the spectral variation of the albedo or cloud fraction in a sub window of the full NO_2 fitting range. They are then extrapolated to the full range the based on the N_R order polynomial of λ-λ_{ref} (see equation 1). The DVCF algorithm derives the MLER parameters self consistently with the reflectance measurements, i.e., forward modeling with the derived MLER parameters closely reproduces the measured reflectance spectrum in the full fitting spectral range. Doing so simulates the light path distributions closely to provide a proper treatment of measurement sensitivity effects. For instance, they are incorporated in the DVCF weighting functions calculation to account for the sensitivity reduction due to the partial shielding of trace gases located below the scattering particles, as well as sensitivity enhancement for trace gases located at higher altitudes.

Note that the first order coefficient (R_1, left hand side, third term of equation 1) of the derived MLER parameters is a useful quantity to characterize the observing condition, because R_1 may be used as an Aerosol Index (AI): a positive AI indicates the presence of UV absorbing aerosols, even with underlying clouds, while a negative AI signifies the absence of absorbing aerosols and the likely presence of non-absorbing aerosols (like sulfate) and/or clouds.

1.2.2 Stratosphere-Troposphere Separation (STS)

An initial STS is performed with the estimated total vertical column (X), which is partitioned into stratospheric (V_i^s) and tropospheric components using tropopause inputs and the prescribed shape factor (S_z). These initial stratospheric and tropospheric columns usually contain errors due to the mismatch between the actual NO_2 vertical distribution in an IFOV and the prescribed shape factor. By analyzing the spatial distribution of the initial stratospheric columns, the shape factor prescription mismatches can be identified and then corrected. Specifically, the high frequency structures (excluding measurement noise) detected in the retrieved stratospheric NO_2 field are attributed to signals from the troposphere due to imperfections in shape factor prescription, and smoothing them out yields more accurate stratospheric and tropospheric NO_2 vertical columns. To accomplish this, two smooth stratospheric fields are constructed from the initial field for each cross-track position of an orbit of satellite data using the sliding median correction technique [*Yang et al*, 2007] (first developed for SO_2 retrieval). The values of these two smoothed fields at each pixel are taken to be the median values of two sliding group pixels centered on the selected pixel, covering two latitude bands, about 2° and 20°, respectively, along the orbital track. The spatial extent of the larger latitude band is reduced when the selected pixel is near the terminator to ensure that a roughly equal number of pixels on either side of the selected pixel are included. The smaller latitude band is used to generate a smoothed field (m_h) that retains possible tropospheric signals but without the intrinsic noise in the measurements, while the larger one is used to construct a smoothed field (m_l) with minimal tropospheric contributions, by obtaining the median value from a group of predominantly background pixels, i.e., pixels with little or no elevated tropospheric NO_2. To ensure this condition is satisfied even for large regions (e.g., China and Europe) with elevated tropospheric NO_2, the size of latitude band may be increased (up to 30°), and/or the pixels with elevated NO_2 based on initial retrievals maybe be excluded in the median calculations. Thus, the excesses (+) and deficits (−) of stratospheric NO_2 are obtained from the difference between the two smoothed fields (m_l−m_h). The tropospheric columns are then adjusted: stratospheric excesses are added to and deficits are subtracted from the tropospheric fields, while accounting for their different measurement sensitivities. Algebraically, the corrected stratospheric NO_2 column is equal to $V_s = V_i^S + (m_l - m_h)$, and the corresponding tropospheric NO_2 columns (V_t) are retrieved by solving a new set of linear equations:

$$\ln I_m - \ln I_{TOA} + V_s \int_{z_{tp}}^{\infty} m_z S_z \sigma(T_z) dz + \sum_{j=1}^{n} \xi_j \sigma_j(T_j) - \left(\sum_{k=0}^{N_R} \Delta R_k (\lambda - \lambda_{ref})^k \right) \left. \frac{\partial \ln I_{TOA}}{\partial R_0} \right|_{R_0 = R_{0_i}}$$

$$= -V_t \int_0^{z_{tp}} m_z S_z \sigma(T_z) dz + \varepsilon, \qquad (2)$$

where $m_z = -\partial \ln I_{TOA} / \partial \tau_z$ is the altitude-resolved air mass factor (AMF), and z_{tp} is the tropopause altitude.

1.3 Data Disclaimer

NMNO2-L2 product contains a data field PixelQuality, which is equal to 0 or -1 for each IFOV to indicate valid retrieval or bad data. We recommend discarding IFOVs with PixelQuality equal to -1.

Processing is skipped when solar zenith angle is greater than or equal to 88° or viewing zenith angle greater than 70°. For these IFOVs, the PixelQuality set to -1 and the corresponding retrieved data fields: NO_2, OCP, and reflectivity parameters, are set to fill values.

Successful retrievals are usually achieved for nearly all the IFOVs within the angular ranges specified above. However the DVCF retrievals may fail for a very tiny fraction of the IFOVs, mostly due to artifacts contained in the measured reflectance spectra, such as negative radiances or inconsistent values among different spectral regions. The PixelQuality is set to -1 for a failed retrieval.

Like other hyper-spectral UV instruments, OMPS-NM spectral measurements often contain ‘spectral spikes’, i.e., unusually high or low radiance values that far exceed the radiance measurement noise levels of the instrument. NMNO2-L2 processing includes spike detection and excludes detected spike pixels in the fitting of measured spectra. This detection works nearly perfectly for isolated spikes, but is less effective when multiple adjacent spectral pixels are spiked simultaneously, as in the case when the CCDs are bombarded by energetic charged particles in the South Atlantic Anomaly (SAA) region, which is roughly bounded by the lat-lon box: -50° < latitude < 0° and -20° < longitude < -90°. Inside the SAA region, the retrieved NO_2 columns tend to have much higher noise level than those outside the region.

2.0 Data Organization

These data contain NO_2 and the associated information retrieved from OMPS-NM spectral measurements using the DVCF algorithm. The NMNO2-L2 app processes the OMPS-NM Level 1B (L1B) data and generates the Level 2 (L2) product file: one orbit of L1B data yields one L2 data granule, which covers the sunlit portion of the orbit with an approximately 2800 km wide swath. During the normal mode of operation, each swath contains approximately 400 viewing or scan lines along the ground track of the satellite, with each scan line containing 36 pixels or IFOVs across the satellite track. Note that instead of the 35 (typically described for the OMPS-NM) cross-track pixels, 36 cross-track pixels are contained in the OMPS-NM L1B data, due to the L1B processing in the NASA Ozone SIPS retains the two central (near-nadir) IFOVs (30 km × 50 km and 20 km × 50 km), without aggregating them into the nominal 50 km x 50 km pixel. Suomi NPP's orbit period is ~101 minutes, yields 14 or 15 granules per day, providing fully contiguous coverage of the globe during normal mode operation. The data stored in a L2 granule file are ordered in time sequence.

2.1 File Naming Convention

The OMPS-NM data products uses the following file name convention:
OMPS-satellite_shortname-**L**level _observationTime_**o**oribtnumber_productionTime.**h5**

Where:

- satellite = NPP
- shortname = NMNO2
- level = 2
- observationTime = start date and time of measurements in *yyyy***m***mmdd***t***hhmmss* format
  - *yyyy* = 4-digit year number[2012-current]
  - *mm* = 2-digit month number [01-12]
  - *dd* = 2-digit day number [01-31]
  - *hhmmss* = observation time [UTC time]
- orbitnumber = 5-digit orbit number
- productionTime = file creation stamp in *yyyy***m***mmdd***t***hhmmss* format
  - *yyyy* = 4-digit year number[2012-current]
  - *mm* = 2-digit month number [01-12]
  - *dd* = 2-digit day number [01-31]
  - *hhmmss* = production time [local time]

Filename example:

OMPS-NPP_NMNO2-L2_2013m0321t034645_o07233_2017m0504t005649.h5

2.2 File Format and Structure

NMNO2-L2 data files are provided in the HDF5 format (Hierarchical Data Format Version 5), developed at the National Center for Supercomputing Applications http://www.hdfgroup.org/. These files use the Swath data structure format, with two primary groups: GeolocationData and ScienceData. Section 3.0 describes the dimensions, global attributes, and data fields in more detail.

2.3 Key Science Data Fields

The data fields most likely to be used by typical users of the NMNO2-L2 product are listed in this section. Important information about data temporal coverage and data quality is also provided.

Parameter	Group
Latitude	GeolocationData
Longitude	GeolocationData
ColumnAmountNO2	ScienceData
ColumnAmountNO2strat	ScienceData
ColumnAmountNO2tropo	ScienceData
RadiativeCloudFraction	ScienceData
PixelQualityFlags	ScienceData

2.3.1 Data Temporal Coverage

The first OMPS-NM measurements used to create the NMNO2-L2 product were taken on January 28, 2012. OMPS-NM data for February-March 2012 have numerous gaps due to variations in instrument operations and changes in sample tables. Regular operations began on April 2, 2012. OMPS-NM performed high spatial resolution observations about one day per week from April 2012 to June 2016. These high-resolution data have reduced spectral coverage, and they are not processed with the current version of NMNO2-L2 app.

2.3.2 Data Quality

Fill values are inserted into data fields in ScienceData group for the IFOVs with solar zenith angle (SZA) >= 88° or with viewing zenith angle (VZA) > 70°. Fill values are also set for these data fields of IFOVs with processing error, which is rarely encountered for OMPS-NM data. In short, successful retrieval is usually achieved for nearly all the OMPS-NM observations that fall within the valid angular range.

The uncertainty of ColumnAmountNO2tropo increases significantly for SZA > ~86°, due to the orbital STS scheme becomes less effective when approaching the terminator.

ColumnAmountNO2, ColumnAmountNO2strat, and ColumnAmountNO2tropo data may contain negative values due to random noise in the measured radiance spectra. Negative NO_2 columns are valid data, and excluding them in spatial or temporal averages would introduce positive biases in the means.

3.0 Data Contents

3.1 Dimensions

The NMNO2-L2 product includes the following dimension terms:

Name	long_name	Value
DimAlongTrack	Along-track dimension	400
DimCrossTrack	Cross-track dimension	36
DimCorners	IFOV corner dimension	4

3.2 Global Attributes

Metadata in the NMNO2-L2 product data files includes attributes whose value is constant for all files and attributes whose value is unique to each individual file. Table 3.2.1 summarizes these global attributes.

3.2.1 Global Attributes Table

Global Attribute	Type	Description
DATA_QUALITY	Integer16	Granule level flag: 0=some good data, 1= no good data
DOI	String	DOI value
DayNightFlag	String	Identify day or night measurements
EquatorCrossingDate	String	Equator crossing date
EquatorCrossingLongitude	Float32	Equator crossing longitude
EquatorCrossingTime	String	Equator crossing time
Format	String	Data file format

LocalGranuleID	String	File name
LongName	String	Full product name
OrbitNumber	Integer32	Orbit number
PGEVersion	String	Software version
ProductDateTime	String	Time of file creation
RangeBeginningDateTime	String	Starting date and time of data
RangeEndingDateTime	String	Ending date and time of data
ShortName	String	Short product name
TAI93At0zOfGranule	Real64	TAI time at 00:00 UTC at date of start of granule
VersionID	String	Version ID for this product
VersionNumber	String	Version number for this product
acknowledgement	String	Acknowledgement of data producer
comment	String	Any additional comments
contributor_name	String	Name of data creator
contributor_role	String	Role of data creator
creator_email	String	e-mail address of data creator
creator_institution	String	Organization of data creator
creator_name	String	Name of data creator
creator_type	String	Type of data creator (e.g. person, organization)
date_created	String	Date of file creation
history	String	History of file
id	String	Short product name
institution	String	Producer of data
keywords	String	Identifying keywords
keywords_vocabulary	String	Source of keywords used in metadata
license	String	Source of data information regulations

metadata link	String	Web address for metadata DOI
processing_level	String	Level of data product (e.g. L1B, L2)
publisher_email	String	e-mail address of data publisher
publisher_institution	String	Organization of data publisher
publisher_name	String	Name of data publisher
publisher_type	String	Organization type of data publisher
publisher_url	String	URL of data publisher
references	String	Reference material for data product
source	String	Source of measurement data
summary	String	Any additional summary
time_coverage_end	String	Ending data and time of data
time_coverage_start	String	Starting date and time of data
title	String	Title of data product

3.3 Products/Parameters

3.3.1 Level 2 Data Fields in GeolocationData Group

Data Field Name	Description	Units	Dimension
GroundPixelQualityFlags	Ground Pixel Quality Flag	No Units	DimAlongTrack, DimCrossTrack
ImageMidpoint_TAI93	TAI93 Image Midpoint Time	seconds	DimAlongTrack
InstrumentQualityFlags	Swath Level Geolocation Quality Flags	No Units	DimAlongTrack
Latitude	Geodetic Latitude of IFOV center	degrees_North	DimAlongTrack, DimCrossTrack
LatitudeCorner	Geodetic Latitude of IFOV Corner Points	degrees_North	DimAlongTrack, DimCrossTrack, DimConers
Longitude	Geodetic Longitude of IFOV center	degrees_East	DimAlongTrack, DimCrossTrack
LongitudeCorner	Geodetic Longitude of IFOV Corner Points	degrees_East	DimAlongTrack, DimCrossTrack, DimConers
RelativeAzimuthAngle	Relative Azimuth Angle	degrees	DimAlongTrack, DimCrossTrack
SolarAzimuthAngle	Solar Azimuth Angle	degrees	DimAlongTrack, DimCrossTrack

SolarZenithAngle	Solar Zenith Angle	degrees	DimAlongTrack, DimCrossTrack
SpacecraftAltitude	Spacecraft Altitude	m	DimAlongTrack
SpacecraftLatitude	Spacecraft Latitude	degrees_North	DimAlongTrack
SpacecraftLongitude	Spacecraft Longitude	degrees_East	DimAlongTrack
SpacecraftSolarZenith	Sub Satellite Solar Zenith Angle	degrees	DimAlongTrack
UTC_CCSDA_A	UTC Image Midpoint Time, a twenty-seven character UTC date-and-time string	No Units	(DimAlongTrack)
ViewingAzimuthAngle	Viewing Azimuth Angle	degrees	DimAlongTrack, DimCrossTrack
ViewingZenithAngle	Viewing Zenith Angle	degrees	DimAlongTrack, DimCrossTrack

NOTE: ***Data fields in the GeolocationData Group are copied from the input L1B file.***

GroundPixelQualityFlag. Bit-packed definition table:

0-7	Unused		
8	Eclipse Flag	WARNING	Indicates ground pixel is within umbra or penumbra of the moon
9-15	Unused		

InstrumentQualityFlags. Bit-packed definition table:

0-3	Unused		
4-5	SAA Flag	WARNING	Indicates location of spacecraft w.r.t. SAA 0 = outside SAA boundaries 1 = <5% of nominal maximum SAA effect 2= between 5% and 40% of nominal maximum SAA effect 3 = >40% of nominal maximum SAA effect
6-19	Unused		
20	Maneuver Flag	WARNING	Indicates a spacecraft attitude maneuver was in progress during the measurement
21	Attitude Threshold Flag	WARNING	Indicates any of the 3 geodetic spacecraft attitude Euler angles exceeds a defined threshold
22-31	Unused		

ImageMidpoint_TAI93. The time in seconds since 1993-01-01 00:00:00 at the mid-point of a scan line

Latitude. Geodetic Latitude of the IFOV center

LatitudeCorner. Geodetic Latitude of the IFOV corners, CCW relative to flight direction: LL,LR,UR,UL

Longitude. Geodetic Longitude of the IFOV center

LongitudeCorner. Geodetic Longitude of the IFOV corners, CCW relative to flight direction: LL,LR,UR,UL

RelativeAzimuthAngle. The relative azimuth angle at the center of the IFOV, it is equal to (SolarAzimuthAngle+180°−ViewingAzimuthAngle)

SolarAzimuthAngle. The solar azimuth angle at the center of the IFOV

SolarZenithAngle. The solar zenith angle at the center of the IFOV

SpacecraftAltitude. Spacecraft altitude above the Earth surface

SpacecraftLatitude. Geodetic latitude at the sub-point of spacecraft

SpacecraftLongitude. Geodetic longitude at the sub-point of spacecraft

SpacecraftSolarZenith. The solar zenith angle at the sub-point of spacecraft

UTC_CCSDA_A. A twenty-seven character UTC date-and-time string, representing the UTC time at the mid-point of a scan line

ViewingAzimuthAngle. The viewing azimuth angle at the center of the IFOV

ViewingZenithAngle. The viewing zenith angle at the center of the IFOV

3.3.2 Level 2 Data Fields in ScienceData Group

Data Field Name	Description	Units	Dimension
AerosolIndex	UV Aerosol Index	1	DimAlongTrack, DimCrossTrack
CloudFraction	Cloud Fraction	1	DimAlongTrack, DimCrossTrack
CloudPressure	Effective Cloud Pressure	hPa	DimAlongTrack, DimCrossTrack
CloudRefletivity	Cloud Reflectivity	1	DimAlongTrack, DimCrossTrack
ColumnAmountNO2	Total NO_2 Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountNO2strat	Stratospheric NO_2 Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
ColumnAmountNO2tropo	Tropospheric NO_2 Vertical Column Amount	DU	DimAlongTrack, DimCrossTrack
GroundRefletivity	Ground Reflectivity	1	DimAlongTrack, DimCrossTrack

PixelQualityFlags	Pixel Quality Flags	No Units	DimAlongTrack, DimCrossTrack
RadiativeCloudFraction	Radiative Cloud Fraction	1	DimAlongTrack, DimCrossTrack
ScenePressure	Effective Scene Pressure	hPa	DimAlongTrack, DimCrossTrack
SceneRefletivity	Lambertian Equivalent Reflectivity	1	DimAlongTrack, DimCrossTrack
SlantColumnAmountNO2	NO_2 Slant Column Amount	DU	DimAlongTrack, DimCrossTrack
TerrainPressure	Terrain Pressure	hPa	DimAlongTrack, DimCrossTrack

AerosolIndex. UV Aerosol Index determined from spectral slope of the reflectivity based on the retrieved MLER parameters

CloudFraction. MLER cloud fraction

CloudPressure. Pressure for the MLER cloud surface

CloudRefletivity. Albedo for the MLER cloud surface

ColumnAmountNO2. Total vertical column amount NO_2 retrieved using the DVCF algorithm

ColumnAmountNO2strat. Stratospheric vertical column amount NO_2

ColumnAmountNO2tropo. Tropospheric vertical column amount NO_2

GroundRefletivity. Albedo of the MLER terrain or sea surface.

PixelQualityFlags. Pixel Quality Flags contains 2 values with the following definition:

0 = Good_Pixel

-1 = Bad_Pixel

RadiativeCloudFraction. Radiative cloud fraction - the fraction of measured radiance contributed from clouds/aerosols within the IFOV.

ScenePressure. Effective Scene Pressure of the IFOV

SceneRefletivity. Lambertian Equivalent Reflectivity of the IFOV

SlantColumnAmountNO2. NO_2 Slant Column Amount

TerrainPressure. Pressure for the MLER terrain or sea surface

4.0 Options for Reading the Data

There are many tools and visualization packages (free and commercial) for viewing and dumping the contents of HDF5 files. Libraries are available in several programming languages for writing software to read HDF5 files. A few simple to use command-line and visualization tools, as well as programming languages for reading the L2 HDF5 data files are listed in the sections below. For a comprehensive list of HDF5 tools and software, please see the HDF Group's web page at http://www.hdfgroup.org/products/hdf5_tools/.

4.1 Command Line Utilities

4.1.1 h5dump (free)

The h5dump tool, developed by the HDFGroup, enables users to examine the contents of an HDF5 file and dump those contents, in human readable form, to an ASCII file, or alternatively to an XML file or binary output. It can display the contents of the entire HDF5 file or selected objects, which can be groups, datasets, a subset of a dataset, links, attributes, or datatypes. The h5dump tool is included as part of the HDF5 library, or separately as a stand-alone binary tool:

http://www.hdfgroup.org/HDF5/release/obtain5.html

4.1.2 ncdump (free)

The ncdump tool, developed by Unidata, will print the contents of a netCDF or compatible file to standard out as CDL text (ASCII) format. The tool may also be used as a simple browser, to display the dimension names and lengths; variable names, types, and shapes; attribute names and values; and optionally, the values of data for all variables or selected variables. To view HDF5 data files, version 4.1 or higher is required. The ncdump tool is included with the netCDF library. **NOTE: you must include HDF5 support during build.**

http://www.unidata.ucar.edu/downloads/netcdf/

4.1.3 H5_PARSE (IDL/commercial)

The H5_PARSE function recursively descends through an HDF5 file or group and creates an IDL structure containing object information and data values. You must purchase an IDL package, version 8 or higher, to read the L2 HDF5 data files.

http://www.harrisgeospatial.com/ProductsandSolutions/GeospatialProducts/IDL.aspx

4.2 Visualization Tools

4.2.1 HDFView (free)

HDFView, developed by the HDFGroup, is a Java-based graphic utility designed for viewing and editing the contents of HDF4 and HDF5 files. It allows users to browse through any HDF file, starting with a tree view of all top-level objects in an HDF file's hierarchy. HDFView allows a user to descend through the hierarchy and navigate among the file's data objects. Editing features allow a user to create, delete, and modify the value of HDF objects and attributes. For more info see:

http://www.hdfgroup.org/hdf-java-html/hdfview/

4.2.2 Panoply (free)

Panoply, developed at the Goddard Institute for Space Studies (GISS), is a cross-platform application which plots geo-gridded arrays from netCDF, HDF and GRIB dataset required. The tool allows one to slice and plot latitude-longitude, latitude-vertical, longitude-vertical, or time-latitude arrays from larger multidimensional variables, combine two arrays in one plot by differencing, summing or averaging, and change map projections. One may also access files remotely into the Panoply application.

http://www.giss.nasa.gov/tools/panoply/

4.2.3 H5_BROWSER (IDL/commercial)

The H5_BROWSER function presents a graphical user interface for viewing and reading HDF5 files. The browser provides a tree view of the HDF5 file or files, a data preview window, and an information window for the selected objects. The browser may be created as either a selection dialog with Open/Cancel buttons, or as a standalone browser that can import data to the IDL main program. You must purchase an IDL package, version 8 or higher to view the L2 HDF5 data files.

http://www.harrisgeospatial.com/ProductsandSolutions/GeospatialProducts/IDL.aspx

4.3 Programming Languages

Advanced users may wish to write their own software to read HDF5 data files. The following is a list of available HDF5 programming languages:

Free:

C/C++ (http://www.hdfgroup.org/HDF5/release/obtain5.html)

Fortran (http://www.hdfgroup.org/HDF5/release/obtain5.html)

Java (http://www.hdfgroup.org/hdf-java-html/)

Python (http://alfven.org/wp/hdf5-for-python/)

GrADS (http://www.iges.org/grads/)

Commercial:

IDL (http://www.harrisgeospatial.com/ProductsandSolutions/GeospatialProducts/IDL.aspx)

Matlab (http://www.mathworks.com/products/matlab/

5.0 Data Services

Access of GES DISC data now requires users to register with the NASA Earthdata Login system and to request authorization to "NASA GESDISC DATA ARCHIVE Data Access". Please note that the data are still free of charge to the public.

5.1 GES DISC Search

The GES DISC provides a keyword, spatial, temporal and advanced (event) searches through its unified search and download interface:

https://disc.gsfc.nasa.gov/

The interface offers various download and subsetting options that suit the user's needs with different preferences and different levels of technical skills. Users can start from any point where they may know little about a particular set of data, its location, size, format, etc., and quickly find what they need by just providing relevant keywords, such as a data product (e.g. "OMPS"), or a parameter such as "ozone".

5.2 Direct Download

The OMPS data products may be downloaded in their native file format directly from the archive using https access at:

https://snpp-omps.gesdisc.eosdis.nasa.gov/data/

5.3 OPeNDAP

The Open Source Project for a Network Data Access Protocol (OPeNDAP) provides remote access to individual variables within datasets in a form usable by many OPeNDAP enabled tools, such as Panoply, IDL, Matlab, GrADS, IDV, McIDAS-V, and Ferret. Data may be subsetted dimensionally and downloaded in a netCDF4, ASCII or binary (DAP) format. The GES DISC offers the OMPS data products through OPeNDAP:

https://snpp-omps.gesdisc.eosdis.nasa.gov/opendap/

If you need assistance or wish to report a problem:
Email: gsfc-help-disc@lists.nasa.gov
Voice: 301-614-5224
Fax: 301-614-5268
Address:

Goddard Earth Sciences Data and Information Services Center NASA Goddard Space Flight Center Code 610.2 Greenbelt, MD 20771 USA

6.0 More Information

Contact Information

Name: GES DISC Help Desk
URL: http://disc.gsfc.nasa.gov
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Phone: 301-614-5224
Fax: 301-614-5228
Address: Goddard Earth Sciences Data and Information Services Center
Attn: Help Desk
Code 610.2
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA

Additional OMPS and ozone data products

http://ozoneaq.gsfc.nasa.gov

Suomi-NPP mission web page

http://jointmission.gsfc.nasa.gov/suomi.html

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> Kai Yang (2017), OMPS-NPP L2 NM nitrogen dioxide (NO_2) total and tropospheric column swath orbital V2.0, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), accessed ***[data access date]***, doi: 10.5067/N0XVLE2QAVR3.

References

Dave, J. V. (1964), Meaning of successive iteration of the auxiliary equation of radiative transfer, Astrophys. J., 140, 1292–1303

Flynn, L., et al. (2014), Performance of the Ozone Mapping and Profiler Suite (OMPS) products, J. Geophys. Res. Atmos., 119, 6181–6195, doi:10.1002/ 2013JD020467.

Seftor, C. J., G. Jaross, M. Kowitt, M. Haken, J. Li, and L. E. Flynn (2014), Postlaunch performance of the Suomi National Polar-orbiting Part- nership Ozone Mapping and Profiler Suite (OMPS) nadir sensors, J. Geophys. Res. Atmos., 119, 4413–4428, doi:10.1002/2013JD020472.

McPeters, R. D., and G. J. Labow (2012), Climatology 2011: An MLS and sonde derived ozone climatology for satellite retrieval algorithms, J. Geophys. Res., 117, D10303, doi:10.1029/2011JD017006.

Spurr, R. J. D., J. de Haan, R. van Oss, and A. P. Vasilkov (2008), Discrete ordinate radiative transfer in a stratified medium with first order rotational Raman scattering, J. Quant. Spectrosc. Radiat. Transfer, 109(3), 404–425.

Vasilkov, A., J. Joiner, and C. Seftor (2014), First results from a rotational Raman scattering cloud algorithm applied to the Suomi National Polar-orbiting Partnership (NPP) Ozone Mapping and Profiler Suite (OMPS) Nadir Mapper, Atmos. Meas. Tech., 7, 2897–2906, doi:10.5194/amt-7-2897-2014.

Yang, K., N. A. Krotkov, A. J. Krueger, S. A. Carn, P. K. Bhartia, and P. F. Levelt (2007), Retrieval of large volcanic SO2 columns from the Aura Ozone Monitoring Instrument: Comparison and limitations, J. Geophys. Res., 112, D24S43, doi:10.1029/2007JD008825.

Yang, K., N. Krotkov, A. J. Krueger, S.A. Carn, P. K. Bhartia, and P. F. Levelt (2009a), Improving retrieval of volcanic sulfur dioxide from backscattered UV satellite observations, GRL, doi:10.1029/2008GL036036.

Yang, K., X. Liu, N. A. Krotkov, A. J. Krueger, and S. A. Carn (2009b), Estimating the Altitude of Volcanic Sulfur Dioxide Plumes from Space Borne Hyper-spectral UV Measurements, Geophys. Res. Lett., doi:10.1029/2009GL038025.

Yang, K. et al. (2010), Direct retrieval of sulfur dioxide amount and altitude from spaceborne hyper-spectral UV measurements: theory and application. JGR, doi:10.1029/2010JD013982.

Yang, K., R.R. Dickerson, S.A. Carn, C. Ge, and J. Wang (2013), First observations of SO2 from the satellite Suomi NPP OMPS: Widespread air pollution events over China, GRL., doi:10.1002/grl.50952.

Yang, K. et al (2014), Advancing measurements of tropospheric NO2 from space: New algorithm and first global results from OMPS, GRL., doi:10.1002/2014GL060136