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

Making **Ea**rth **S**cience Data Records for **U**se in **R**esearch **E**nvironment**s** (MEaSUREs)

Product Specification and README Document for MINDS NO_2, Version 1.0

Goddard Earth Sciences Data and Information Services Center (GES DISC)

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

NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA

Principal Investigators:	Lok N. Lamsal, USRA and GSFC, Code 614 Nickolay A. Krotkov, GSFC, Code 614
Algorithm Developers:	Lok N. Lamsal, USRA and GSFC, Code 614 Sergey Marchenko, SSAI and GSFC, Code 614 Wenhan Qin, SSAI and GSFC, Code 614 Bradford Fisher, SSAI and GSFC, Code 614 Eun-Su Yang, SSAI and GSFC, Code 614 Zachary Fasnacht, SSAI and GSFC, Code 614 Alexander Vasilkov, SSAI and GSFC, Code 614
Algorithm Support:	Peter J.T. Leonard, GSFC, Code 619 Phil Durbin, GSFC, Code 619

Last Revised: June 16, 2020

Prepared By:

Lok N. Lamsal	**Peter J. T. Leonard**
Name GSFC Code 614	Name GSFC Code 619
June 16, 2020	
Date	

Reviewed By:

Jane Jian Zeng	June 17, 2020
Reviewer Name GES DISC GSFC Code 610.2	Date

Goddard Space Flight Center
Greenbelt, Maryland

Revision History

Revision Date	Changes	Author

Table of Contents

1.0 Introduction

This document provides a summary of version 1.0 of the **M**ult**I**-decadal **N**itrogen dioxide and **D**erived products from **S**atellites (MINDS) products. The goal of the MINDS project is to create consistent long-term global trend-quality data records of nitrogen dioxide (NO_2) column products for 1995-present.

Table 1: Summary table of MINDS NO_2 product, version 1.0.

SPECIES	**NITROGEN DIOXIDE (NO_2)**
DATA VERSION	MINDS_NO2, v1.0
VERSION RELEASE DATE	July 2020
RETRIEVED QUANTITIES	Total slant column density Total vertical column density Tropospheric column density Stratospheric column density
DATE RANGE	1995-Present
DATA COVERAGE	Global
DATA LOCATION	`https://disc.gsfc.nasa.gov/`
POINT OF CONTACT	Lok N. Lamsal NASA Goddard Space Flight Center lok.lamsal@nasa.gov 301-614-5160

1.1 Satellite NO_2 Observations

Nitrogen oxides (NO_x = nitric oxide (NO) + NO_2) are important atmospheric trace gases that have significant impacts on human health. They play key roles in tropospheric and stratospheric ozone chemistry and atmospheric aerosol formation. Major sources of tropospheric NO_x include combustion, soil emissions, and lightning. In the lower troposphere, NO_2 is a toxic gas and a precursor to tropospheric ozone through the reaction of NO_x with volatile organic compounds. In the stratosphere, NO_x is linked to upwelling of tropospheric emissions of nitrous oxide (N_2O), and contributes to both production and loss cycles of ozone. Stratospheric NO_x is produced mainly by the reaction of N_2O with O(1D).

NO_2 has strong absorption lines in the visible (Vis) and near ultraviolet (UV). Spectroscopic ground-based measurements of NO_2 date back nearly 4 decades and have evolved to a new generation of instruments capable of providing global observations at high spatial and temporal resolutions from both the ground and space.

Most state-of-the-art satellite NO_2 retrievals use the well-known Differential Optical Absorption Spectroscopy (DOAS) technique (Platt and Stutz, 2006). These NO_2 retrieval algorithms apply a similar general methodology, composed of 1) a DOAS spectral fit of absorption spectra of NO_2 and other gases as well as Raman spectra to a measured reflectance spectrum to determine the slant column density (SCD), which represents the integrated abundance of NO_2 molecules along the average photon path through the atmosphere, 2) calculation of an air mass factor (AMF) to convert the SCD into a vertical column density (VCD), and 3) a scheme to separate stratospheric and tropospheric VCDs.

1.2 Dataset/Mission Instrument Description

The first satellite global tropospheric NO_2 observations were made in the middle 1990s with the Global Ozone Monitoring Experiment (GOME) instrument (Burrows et al., 1998). Similar measurements, but at higher spatial resolution, were continued with the Scanning Imaging Spectrometer for Atmospheric Cartography (SCIAMACHY) instrument (Bovensman et al., 1999), the Ozone Monitoring Instrument (OMI, Levelt et al., 2006), and GOME-2 (Callies et al., 2000). As an operational mission, continuity of morning time GOME-2 observations is ensured by three “copies” of instruments onboard the European Meteorological Operational satellite (MetOp) platforms: A (2006-present), B (2012-present), and C (2018-present). All instruments follow the daytime sun-synchronous ascending or descending polar orbits, measuring the sunlit part of the globe in the morning (~9:00-11:00 local time) or early afternoon (~12:30-14:30 LT). Table 2 provides basic information and a link of the past and concurrent UV-Vis satellite instruments that are capable of providing tropospheric NO_2 observations, and are part of the MINDS project.

The Level-2 (L2) NO_2 product includes stratospheric, tropospheric, and total VCDs, their uncertainties, geolocation information, several auxiliary data, and data quality flags. Two kinds of data fields are found in the file: product data, and flags. While most product data fields are of a floating-point (“real”) type, some have been stored as integers. The fields have field-level metadata, which characterize the values contained in the data fields. These include the fill-values that are used when no meaningful data are available, and a scale factor and offset. These are usually 1.0 and 0.0, respectively, indicating that the values have not been modified. Flag fields may have 8, 16, 32, or 64 bits per word, stored as unsigned integer values, containing a collection of bits that each indicate processing conditions that should be taken as warnings or errors, or may indicate which path was taken through one of the algorithms, or may indicate why some data field(s) have been assigned fill values.

Table 2: Satellite instruments included in MINDS.

Instrument (Satellite)	Year	Spatial resolution	Equator crossing time	Instrument link
GOME (ERS-2)	04/1996-06/2003	40 km × 320 km	10:30	https://wdc.dlr.de/sensors/gome/
SCIAMACHY (ENVISAT)	08/2002-04/2012	30 km × 60 km	10:00	https://atmos.eoc.dlr.de/sciamachy/
OMI (Aura)	10/2004-present	>13 km × 24 km	13:45	https://aura.gsfc.nasa.gov/omi.html
GOME-2 (MetOp-A,B)	01/2007-present	40 km × 80 km	9:30	https://atmos.eoc.dlr.de/app/missions/gome2

In addition to L2 files, we also create Level-3 (L3) daily data products. These are grid type, rather than swath type files. To create L3 product, a day's worth of L2 data (usually 14 or 15 orbits) are mapped into a regular 0.25 deg latitude by 0.25 deg longitude grid. The parameters specifying the grid cell locations are available in the metadata included in each file.

1.3 Data Citation and Acknowledgment

Lok N. Lamsal, Nickolay A. Krotkov, Sergey V. Marchenko, Joanna Joiner, Luke Oman, Alexander Vasilkov, Bradford Fisher, Wenhan Qin, Eun-Su Yang, Zachary Fasnacht, Sungyeon Choi, Peter Leonard, and David Haffner (2020), Nitrogen Dioxide (NO_2) Column 1-orbit L2 Swath Product, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: **[Data Access Date]**, DOI: 10.5067/MEASURES/MINDS/DATA201.

1.4 Data Quality Issues

The quality of the data in this release has been established by consistency checks with previous versions, which were extensively evaluated [Celarier et al., 2008, Lamsal et al., 2014, Krotkov et al., 2017, Choi et al., 2019]. They are also evaluated by comparing with independent observations [Lamsal et al., 2020]. Our validation effort using other independent measurements and campaign data from ground-, aircraft-, and satellite-based instruments is ongoing.
We provide a summary quality flag, a single bit, that may be interrogated to select data. For most users, the Summary Quality Flag (least significant bit of the VcdQualityFlags data field) should suffice. Errors in tropospheric NO_2 retrievals are large for observations under cloudy conditions and over snow/ice surfaces. The product development team recommends to use a cloud screening criterion of the effective cloud fraction (ECF) of 0.2 to 0.3 for selecting the data; the ECF threshold of 0.3 used in our L3 processing reflects a compromise between data quality and quantity.

In case of OMI, an anomaly began to appear in the Level 1B radiances in certain cross-track rows (53 and 54; numbered from 0) starting June 25, 2007 or even earlier. On May 11, 2008 cross-track rows 37–42 started to be affected toward the northern end of the OMI orbit. The anomaly has developed and changed affecting more rows with time; additional rows are found to have anomaly as identified by the NO_2 algorithm. This phenomenon has been named the "row anomaly" (RA) referring to affected rows of the CCD detector. Row anomaly information is available in the XTrackAnomalyFlags data field. In RA-affected pixels, the column amount fields have been set to their respective fill values, so XTrackQualityFlags does not need to be explicitly checked. In certain periods of time, this row-anomaly problem will result in up to 50% data rejection rate.

2.0 Data Organization

A single MINDS NO_2 product file represents one orbit of data and contains all satellite measurements for the sunlit portion of the Earth. File size and dimensions of the data vary according to ground resolution and swath coverage of the instrument. For instance, OMI/Aura performs approximately 1650 measurements per orbit with one measurement every 2 seconds. In the global observation mode, 60 across track ground pixels (FOVs) are measured simultaneously covering a swath of approximately 2600 km wide and allow daily global coverage. For each day there are 14-15 files, identified by an orbit number.

2.1 File Naming Convention

The MINDS L2 files are in the netCDF version 4 (netCDF-4) and CF-complaint format:

<InstrumentID>_<DataType>_<DataID>_<Version>.<Suffix>,

where

<DataID> = <ObservationDateTime>-o<Orbit#>

and

<Version> = v<Version#>-<ProductionDateTime>

Below is an example of an OMI-MINDS-NO2 L2 file name:

OMI-Aura_L2-OMI_MINDS_NO2_2011m1010t2318-o38499_v01-00-2019m0816t193742.nc

where:

<InstrumentID> = OMI-Aura

<DataType> = L2-OMI_MINDS_NO2

<ObservationDateTime> = 2011m1010t2318

<Orbit#> = 38499

<Version#> = 01-00

<ProductionDateTime> = 2019m0816t193742

<Suffix> = nc

The observation and production date/time is given as yyyy+”m”+mmdd+”t”+hhmmss with yyyy representing year, mmdd representing month and day, and hhmmss representing hour, minute, and seconds in UTC.

2.2 File Format and Structure

The MINDS files are in netCDF-4 format. NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data that was developed by UCAR/Unidata (http://doi.org/10.5065/D6H70CW6) https://www.unidata.ucar.edu/software/netcdf/.

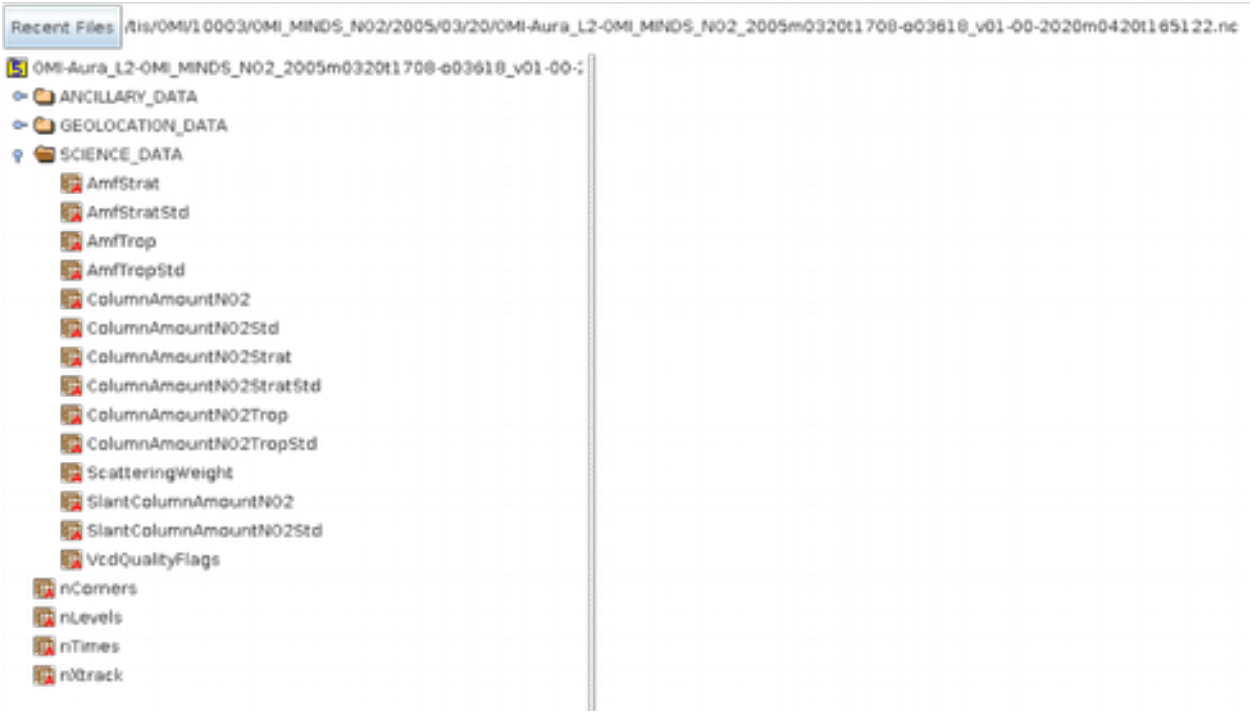

Figure 1: OMI_MINDS_NO2 netCDF data file structure.

The netCDF-4 file structure is shown in Figure 1. MINDS L2 files contain three data groups: ANCILLARY_DATA, GEOLOCATION_DATA, and SCIENCE_DATA. The details on attributes, dimensions, and variables are provided in Section 3.

2.3 Key Science and Ancillary Data Fields

This section provides a brief introduction of key science and ancillary data fields.

SlantColumnAmountNO2 and SlantColumnAmountNO2Std: Retrieved slant column density (SCD) S and its uncertainty. S is the retrieved total areal density of NO_2 molecules along the effective optical path from the sun into the atmosphere, and then toward the satellite. This is calculated from the measured Earthshine radiance and solar irradiance using a variant of the DOAS algorithm, with an NO_2 cross section measured at 220 K. The units are molecules cm^{-2}.

ColumnAmountNO2Strat and ColumnAmountNO2StratStd: Estimates of the stratospheric vertical column density (VCD), derived from S, and its uncertainty. The units are molecules cm^{-2}.

ColumnAmountNO2Trop and ColumnAmountNO2TropStd: Estimates of the tropospheric vertical column density, derived from S, and its uncertainty. The units are molecules cm^{-2}.

ColumnAmountNO2 and ColumnAmountNO2Std: Estimates of the total (ColumnAmountNO2Trop + ColumnAmountNO2Strat) vertical column density and its uncertainty. The units are molecules cm^{-2}.

ScatteringWeight: Vector ***A*** [no units] that describes the relationship between slant column density, S_i, and the vertical column density, V_i, for each atmospheric layer *i*. Combining scattering weight with a priori NO_2 profile shape yields AMF. ***A*** is a function of the observational geometry (solar and viewing azimuth and zenith angles), surface reflectivity, and cloud pressure and cloud fraction, and contains a correction for the temperature dependence of the NO_2 cross section. The scattering weights are stored as a 3-dimensional array with dimensions (pressure levels, across track, along track, *e.g.*, [35,60,1644] for OMI). The grid of pressure levels is available as the data field ScatteringWeightPressure.

VcdQualityFlags: This variable contains quality assurance information for vertical columns. The least significant bit is the summary quality flag. We recommend that users only use data for which this bit is zero (*i.e.*, VcdQualityFlags is an even integer).

TerrainReflectivity: Geometry-dependent dynamic surface Lambertian-Equivalent Reflectivity (GLER) at 440 nm for each instrument field of view (or ground pixel) [Qin et al., 2019; Fasnacht, 2019; Lamsal et al., 2020]. GLER captures both true surface reflectance changes (seasonal and interannual) and changes of solar and viewing geometries. It is calculated using MODIS surface bidirectional reflectance distribution function (BRDF) product over land, and a model of reflection from rough ocean surface and water-leaving radiance.

CloudFraction: Cloud fraction describes the relative partitioning of a satellite ground pixel into cloudy and cloud free parts. Effective cloud fraction (ECF) used here is the cloud fraction derived from satellite measurements, assuming constant cloud albedo of 0.8 which is a common assumption in satellite trace gas retrievals (Stammes et al., 2008). It is derived from the

measured reflectivity at 466 nm (a wavelength little affected by gaseous absorption or rotational-Raman scattering) and assumed spectrally independent. Its value ranges from 0 to 1, representing fully clear and cloudy conditions, respectively.

CloudRadianceFraction: Cloud radiance fraction (CRF_{440}) is an estimate of the fraction of photons reaching the satellite instrument that come from cloud-covered parts of the scene. It is calculated at 440 nm by combining ECF with calculations of top-of-the-atmosphere solar normalized radiance at 440 nm (I_{440}) from a radiative transfer model.

CloudPressure: The cloud optical centroid pressure (or cloud pressure) represents an effective cloud pressure derived from the O_2-O_2 cloud algorithm that employs consistent retrieval approach and inputs used in NO_2 algorithm (Vasilkov et al., 2018). Its unit is hPa.

3.0 File Format

This section describes the file format of the OMI_MINDS_NO2 product, including the file-level attributes, dimensions, groups, variable-level attributes, fill values, geolocation data variables, ancillary data variables, and science data variables.

This section will be expanded as the other MINDS NO_2 products become available.

3.1 File-Level Attributes

The following table describes the 47 file-level attributes that appear at root level in the OMI_MINDS_NO2 product.

Attribute Name	Description	Data Type
AuthorAffiliation	The institutional affiliation of the author(s).	String
AuthorName	The names of the author(s).	String
Conventions	The conventions plus version numbers used in the product.	String
DataSetQuality	An assessment of the quality of the data.	String
DayNightFlag	The flag indicating whether the observations were made on the day or night side of Earth.	String
EastBoundingCoordinate	The longitude of the easternmost data in the granule.	32-bit floating-point
EquatorCrossingDate	The date of the ascending equator crossing of the orbit.	String
EquatorCrossingLongitude	The longitude of the ascending	32-bit floating-point

	equator crossing of the orbit.	
EquatorCrossingTime	The time of the ascending equator crossing of the orbit.	String
FOVResolution	The highest resolution on the ground of the observations.	String
GranuleDay	The day of the month at the beginning of the granule.	32-bit integer
GranuleDayOfYear	The day of the year at the beginning of the granule.	32-bit integer
GranuleMonth	The month of the year at the beginning of the granule.	32-bit integer
GranuleYear	The year at the beginning of the granule.	32-bit integer
InputPointer	A list of the input file(s) used to produce the granule.	String
InstrumentShortName	The short name of the instrument.	String
LocalGranuleID	The full name of the granule.	String
LocalityValue	The flag indicating the locality of the granule.	String
LongName	The long name of the product.	String
NorthBoundingCoordinate	The latitude of the northernmost data in the granule.	32-bit floating-point
NumTimes	The number of lines of observations in the granule.	32-bit integer
OrbitNumber	The orbit number of the granule.	32-bit integer
PGEVersion	The version of the software that produced the granule.	String
ParameterName	The name of the geophysical parameter contained in the product.	String
PlatformShortName	The short name of the platform carrying the instrument.	String
ProcessLevel	The processing level of the granule.	String
ProcessingCenter	The data processing facility that produced the granule.	String
ProductType	The type of product.	String
ProductionDateTime	The production date-time of the granule.	String
ProductionDateTimeHE5	The production date-time of the input HDF-EOS5 granule.	String

RangeBeginningDate	The date at the beginning of the granule.	String
RangeBeginningTime	The time at the beginning of the granule.	String
RangeEndingDate	The date at the end of the granule.	String
RangeEndingTime	The time at the end of the granule.	String
SensorShortName	The short name of the sensor.	String
ShortName	The short name of the product.	String
Source	The platform and instrument that gathered the observations for the product.	String
SouthBoundingCoordinate	The longitude of the southernmost data in the granule.	32-bit floating-point
TAI93At0zOfGranule	The TAI93 time at UTC midnight for the day of the granule.	64-bit floating-point
VersionID	The product version.	String
WestBoundingCoordinate	The longitude of the westernmost data in the granule.	32-bit floating-point
_NCProperties	A netCDF-4 attribute that lists the versions of netCDF-4 and HDF5 used.	String
Comment	An overall comment regarding the product.	String
History	The history of the product.	String
identifier_product_doi	The Digital Object Identifier (DOI) of the product.	String
identifier_product_doi_authority	The URL of the relevant DOI authority.	String
References	A list of references for the product.	String

3.2 Dimensions

The following table describes the four dimensions in the OMI_MINDS_NO2 product.

Dimension Name	Description	Dimension Size
nTimes	The dimension representing the along-track line number.	varies from granule to granule
nXtrack	The dimension representing the cross-track position number of an observation in a line.	60
nCorners	The dimension representing the ground-pixel-corner number.	4

nLevels	The dimension representing the pressure-level number.	35

3.3 Groups

The following table describes the three groups attached at root level in the OMI_MINDS_NO2 product.

Group Name	Description
GEOLOCATION_DATA	Contains the 18 geolocation data variables.
ANCILLARY_DATA	Contains the 12 ancillary data variables.
SCIENCE_DATA	Contains the 14 science data variables.

3.4 Variable-Level Attributes

The following table describes the attributes attached to the variables in the OMI_MINDS_NO2 product. Not all attributes are applicable to every variable.

Attribute Name	Description	Data Type
_FillValue	The fill value used for the variable.	same as for variable
add_offset	The offset that is to be added after the scale factor has been applied to an integer variable (if applicable).	32-bit floating-point
Bounds	The path to the relevant ground-pixel-corner coordinates variable (applies to the Latitude and Longitude variables only).	String
coordinates	The paths to the relevant coordinate variables (if applicable).	String
Description	A detailed description of the variable.	String
long_name	The name for the variable that can be used in plots.	String
scale_factor	The scale factor that is to be applied to an integer variable (if applicable).	32-bit floating-point
standard_name	The standard name for the variable (if applicable).	String
Units	The units for the variable.	String
valid_max	The maximum valid value for the variable.	same as for variable
valid_min	The minimum valid value for the variable.	same as for variable

3.5 Fill Values

The following table summarizes the fill values used in the OMI_MINDS_NO2 product.

Variable Data Type	Fill Value
32-bit integer	-2147483648
32-bit floating-point	-1.2676506E30
64-bit floating-point	-1.2676506002282294E30

3.6 Geolocation Variables

The following table describes the 18 geolocation variables in the OMI_MINDS_NO2 product. The dimensions of these variables are nTimes x nXtrack. Exceptions are FoV75CornerLatitude and FoVCornerLongitude with dimensions nTimes x nTrack x nCorners, time variables (SecondsInDay, Time, and UTC) with dimension nTimes, and ScatteringWeightPressure with dimension nLevels.

Variable Name	Description	Data Type
FoV75Area	The mean area (in square km) of the 75% Field of View (i.e., overlapping) ground pixels (from OMPIXCOR).	32-bit floating-point
FoV75CornerLatitude	The geodetic latitudes (in degrees) of the corner coordinates of the 75% Field of View (i.e., overlapping) ground pixels (from OMPIXCOR).	32-bit floating-point
FoV75CornerLongitude	The geodetic longitudes (in degrees) of the corner coordinates of the 75% Field of View (i.e., overlapping) ground pixels (from OMPIXCOR).	32-bit floating-point
GroundPixelQualityFlags	The ground pixel quality flags (for the ground pixel): Bits 0 to 3 together contain the land/water flags: 0 - shallow ocean, 1 - land, 2 - shallow inland water, 3 - ocean coastline/lake shoreline, 4 - ephemeral (intermittent) water, 5 - deep inland water, 6 - continental shelf ocean, 7 - deep ocean, 8 to 14 - not used, 15 - error flag for land/water, Bits 4 to 7 are flags that are set to 0 for FALSE or 1 for TRUE: Bit 4 - sun glint possibility flag, Bit 5 - solar eclipse possibility flag, Bit 6 -	32-bit integer

	geolocation error flag, Bit 7 - geolocation warning flag, Bits 8 to 14 together contain the snow/ice flags (based on NISE): 0 - snow-free land, 1 to 100 - sea ice concentration (percent), 101 - permanent ice (Greenland, Antarctica), 102 - not used, 103 - dry snow, 104 - ocean (NISE-255), 105 to 123 - reserved for future use, 124 - mixed pixels at coastline (NISE-252), 125 - suspect ice value (NISE-253), 126 - corners undefined (NISE-254), 127 - error, Bit 15 - NISE nearest neighbor filling flag.	
Latitude	The terrestrial latitude (in degrees) at the center of the ground pixel.	32-bit floating-point
Longitude	The terrestrial longitude (in degrees) at the center of the ground pixel.	32-bit floating-point
RelativeAzimuthAngle	The relative (sun + 180 – view) azimuth angle (in degrees) at the center of the ground pixel.	32-bit floating-point
ScatteringWeightPressure	The pressure levels for the scattering weight profile.	32-bit floating-point
SecondsInDay	The time (in s) after UTC midnight at the start of the observation.	32-bit floating-point
SolarAzimuthAngle	The solar azimuth angle (in degrees) at the center of the ground pixel.	32-bit floating-point
SolarZenithAngle	The solar zenith angle (in degrees) at the center of the ground pixel.	32-bit floating-point
SpacecraftAltitude	The altitude of the spacecraft (in m).	32-bit floating-point
SpacecraftLatitude	The latitude of the spacecraft (in degrees).	32-bit floating-point
SpacecraftLongitude	The longitude of the spacecraft (in degrees).	32-bit floating-point
Time	TAI93 (in continuous seconds since 12 a.m. UTC on January 1, 1993) of the observation.	64-bit floating-point
UTC	UTC of the observation.	27-character string
ViewingAzimuthAngle	The viewing azimuth angle (in degrees) at the center of the ground pixel.	32-bit floating-point
ViewingZenithAngle	The viewing zenith angle (in degrees) at the center of the ground pixel.	32-bit floating-point

3.7 Ancillary Variables

The following table describes the 12 ancillary variables in the OMI_MINDS_NO2 product. Some of the 32-bit integer variables need to be multiplied by a scale factor to yield physical values. The dimensions of these variables are nTimes x nXtrack.

Variable Name	Description	Data Type
CloudFraction	The effective cloud fraction associated with the ground pixel (from OMCDO2N).	32-bit integer
CloudFractionStd	The estimated precision of the effective cloud fraction associated with the ground pixel (from OMCDO2N).	32-bit integer
CloudPressure	The cloud pressure (in hPa) retrieved using the O_2-O_2 method associated with the ground pixel (from OMCDO2N).	32-bit integer
CloudPressureStd	The estimated precision of the cloud pressure (in hPa) retrieved using the O_2-O_2 method associated with the ground pixel (from OMCDO2N).	32-bit integer
CloudRadianceFraction	The cloud radiance fraction at 440 nm associated with the ground pixel (from OMCDO2N).	32-bit integer
SceneLER	The scene Lambertian Equivalent Reflectivity (at 440 nm) associated with the ground pixel (from OMCDO2N).	32-bit floating-point
ScenePressure	The retrieved scene pressure (in hPa) associated with the ground pixel (from OMCDO2N).	32-bit floating-point
TerrainHeight	The pixel-averaged terrain height (in m) for the ground pixel (from OMGLER).	32-bit integer
TerrainPressure	The pixel-averaged terrain pressure (in hPa) for the ground pixel (from OMGLER).	32-bit integer
TerrainReflectivity	The pixel-averaged terrain or water reflectivity at 440 nm for the ground pixel (from OMGLER).	32-bit integer
TropopausePressure	The GMI tropopause pressure (in hPa) associated with the ground pixel (from MERRA-2).	32-bit floating-point
XTrackQualityFlags	The cross-track quality flags indicate the possible or probable effect of the OMI row anomaly on the measured radiances. The first three bits (bits 0 to 2) combined can have the	32-bit integer

	following values: 0 - not affected by the row anomaly (pixel can be used), 1 - affected by the row anomaly (do not use pixel), 2 - somewhat affected by the row anomaly and uncorrected (use pixel with caution), 3 - affected by the row anomaly, but not optimally corrected (use pixel with caution), 4 - affected by the row anomaly and optimally corrected (pixel can be used, but is less accurate than unaffected pixel), 7 - affected by the row anomaly, but an error occurred during the attempted correction (do not use pixel).	

3.8 Science Variables

The following table describes the 14 science variables in the OMI_MINDS_NO2 product. The dimensions of these variables are nTimes x nXtrack with the exception of ScatteringWeight, which has dimensions nTimes x nTrack x nLevels.

Variable Name	Description	Data Type
AmfStrat	The calculated stratospheric Air Mass Factor associated with the ground pixel.	32-bit floating-point
AmfStratStd	The estimated precision of the calculated stratospheric Air Mass Factor associated with the ground pixel.	32-bit floating-point
AmfTrop	The calculated tropospheric Air Mass Factor associated with the ground pixel.	32-bit floating-point
AmfTropStd	The estimated precision of the calculated tropospheric Air Mass Factor associated with the ground pixel.	32-bit floating-point
ColumnAmountNO2	The estimated NO_2 vertical column density (in molec/cm^2) associated with the ground pixel.	32-bit floating-point
ColumnAmountNO2Std	The estimated precision of the NO_2 vertical column amount (in molec/cm^2) associated with the ground pixel.	32-bit floating-point
ColumnAmountNO2Strat	The estimated NO_2 stratospheric column density (in molec/cm^2) associated with the ground pixel.	32-bit floating-point
ColumnAmountNO2StratStd	The estimated precision of the NO_2 stratospheric column density (in molec/cm^2) associated with the ground	32-bit floating-point

	pixel.	
ColumnAmountNO2Trop	The estimated NO_2 tropospheric column density (in molec/cm^2) associated with the ground pixel.	32-bit floating-point
ColumnAmountNO2TropStd	The estimated precision of the NO_2 tropospheric column density (in molec/cm^2) associated with the ground pixel.	32-bit floating-point
ScatteringWeight	The calculated scattering weight profile associated with the ground pixel.	32-bit floating-point
SlantColumnAmountNO2	The estimated NO_2 slant column density (de-striped, in molec/cm^2) associated with the ground pixel.	32-bit floating-point
SlantColumnAmountNO2Std	The estimated precision of the NO_2 slant column density (in molec/cm^2) associated with the ground pixel.	32-bit floating-point
VcdQualityFlags	The vertical column density quality flags for the retrieval. Each bit is set as follows: Bit 0 - primary summary quality flag (0 for good data, 1 for a problem), Bit 1 - secondary summary quality flag (0 for no significant warnings, 1 for significant warnings), Bit 2 - reserved as possible additional summary quality flag, Bit 3 - algorithm detected pollution in field of view (0 for no significant pollution detected, 1 for significant pollution detected), Bit 4 - descending data flag (0 for ascending data, 1 for descending data).	32-bit integer

4.0 GES DISC Data Services

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

5.0 Acknowledgements

This project is funded by NASA's Earth Science Division for the 'Making Earth System Data Records for Use in Research Environments' (MEASURES) Program.

6.0 References

Bovensmann, H., Burrows, J. P., Buchwitz, M., Frerick, J., Noel, S.,Rozanov, V. V., Chance, K. V., and Goede, A.: SCIAMACHY – Mission objectives and measurement modes, J. Atmos. Sci., 56, 127–150, 1999.

Bucsela, E. J., Krotkov, N. A., Celarier, E. A., Lamsal, L. N., Swartz, W. H., Bhartia, P. K., Boersma, K. F., Veefkind, J. P., Gleason, J. F., and Pickering, K. E.: A new stratospheric and tropospheric NO_2 retrieval algorithm for nadir-viewing satellite instruments: applications to OMI, Atmos. Meas. Tech., 6, 2607–2626, https://doi.org/10.5194/amt-6-2607-2013, 2013.

Burrows, J. P., Weber, M., Buchwitz, M., Rozanov, V., Ladstaetter Weißenmayer, A., Richter, A., DeBeek, R., Hoogen, R., Bramstedt, K., Eichmann, K.-U., Eisinger, M., and Perner, D: The Global Ozone Monitoring Experiment (GOME): Mission Concept and First Scientific Results, J. Atmos. Sci., 56, 151–175, 1999.

Callies, J., Corpaccioli, E., Eisinger, M., Hahne, A., and Lefebvre, A.: GOME-2- MetOp's second-generation sensor for operational ozone monitoring, European Space Agency Bulletin, 102, 28–36, 2000.

Celarier, E.A., E. J. Brinksma, J. F. Gleason, J. P. Veerkind, A. Cede, J. R. Herman, D. Ionov, F. Goutail, J. P. P. Pommereau, J. C. C. Lambert, M. Van Roozendael, G. Pinardi, F. Wittrock, A. Sch¨onhardt, A. Richter, O. W. Ibrahim, T. Wagner, B. Bojkov, G. Mount, E. Spinei, C. M. Chen, T. J. Pongetti, S. P. Sander, E. J. Bucsela, M. O. Wenig, D. P. J. Swart, H. Volten, M. Kroon, and P. F. Levelt. Validation of ozone monitoring instrument nitrogen dioxide columns. J. Geophys. Res. Atmos., 113(6):3357–3365, mar 2008. ISSN 0021-9606. doi: 10.1029/2007JD008908.

Choi, S., Lamsal, L. N., Follette-Cook, M., Joiner, J., Krotkov, N. A., Swartz, W. H., Pickering, K. E., Loughner, C. P., Appel, W., Pfister, G., Saide, P. E., Cohen, R. C., Weinheimer, A. J., and Herman, J. R.: Assessment of NO_2 observations during DISCOVER-AQ and KORUS-AQ field campaigns, Atmos. Meas. Tech., 13, 2523–2546, https://doi.org/10.5194/amt-13-2523-2020, 2020.

Fasnacht, Z., Vasilkov, A., Haffner, D., Qin, W., Joiner, J., Krotkov, N., Sayer, A. M., and Spurr, R.: A geometry-dependent surface Lambertian-equivalent reflectivity product for UV–Vis retrievals – Part 2: Evaluation over open ocean, Atmos. Meas. Tech., 12, 6749–6769, https://doi.org/10.5194/amt-12-6749-2019, 2019.

Krotkov, N. A., Lamsal, L. N., Celarier, E. A., Swartz, W. H., Marchenko, S. V., Bucsela, E. J., Chan, K. L., Wenig, M., and Zara, M.: The version 3 OMI NO_2 standard product, Atmos. Meas. Tech., 10, 3133–3149, https://doi.org/10.5194/amt-10-3133-2017, 2017.

Lamsal, L. N., Krotkov, N. A., Celarier, E. A., Swartz, W. H., Pickering, K. E., Bucsela, E. J., Gleason, J. F., Martin, R. V., Philip, S., Irie, H., Cede, A., Herman, J., Weinheimer, A., Szykman, J. J., and Knepp, T. N.: Evaluation of OMI operational standard NO_2 column retrievals using in situ and surface-based NO_2 observations, Atmos. Chem. Phys., 14, 11587–11609, https://doi.org/10.5194/acp-14-11587-2014, 2014.

Lamsal, L.N., Krotkov, N.A., Vasilkov, A., Marchenko, S., Qin, W., Yang, E.-S., Fasnacht, Z., Joiner, J., Choi, S., Haffner, D., Swartz, W.H., Fisher, B., and Bucsela, E., OMI/Aura Nitrogen Dioxide Standard Product with Improved Surface and Cloud Treatments, Atmos. Meas. Tech., 2020 (submitted).

Levelt, P. F., G. H. J. van den Oord, M. R. Dobber, A. Malkki, H. Visser, J. de Vries, P. Stammes, J. Lundell and H. Saari, The Ozone Monitoring Instrument, IEEE Trans. Geo. Rem. Sens., 44(5), 1093–1101, doi:10.1109/TGRS.2006.872333, 2006.

Stammes, P., Sneep, M., de Haan, J. F., Veefkind, J. P., Wang, P., and Levelt, P. F.: Effective cloud fractions from the Ozone Monitoring Instrument: Theoretical framework and validation, J. Geophys. Res. - Atmos., 113, https://doi.org/10.1029/2007JD008820, 2008.

Qin, W., Fasnacht, Z., Haffner, D., Vasilkov, A., Joiner, J., Krotkov, N., Fisher, B., and Spurr, R.: A geometry-dependent surface Lambertian-equivalent reflectivity product for UV–Vis retrievals – Part 1: Evaluation over land surfaces using measurements from OMI at 466 nm, Atmos. Meas. Tech., 12, 3997–4017, https://doi.org/10.5194/amt-12-3997-2019, 2019.