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 1.1

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

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

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Revision History

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October 28, 2020	Added contents for OMI_MINDS_NO2d product	Peter Leonard/Lok Lamsal
February 17, 2021	Updated GES DISC help desk email	Jane Zeng
March 30, 2022	Updated for Version 1.1 OMI_MINDS_NO2, OMI_MINDS_NO2G and OMI_MINDS_NO2d products.	Peter Leonard/Lok Lamsal
March 31, 2022	Changed Code 610.2 to 619	Feng Ding
May 19, 2022	Added TROPOMI_MINDS_NO2	Peter Leonard/Lok Lamsal
November 18, 2022	Added GOME_MINDS_NO2	Peter Leonard/Lok Lamsal

Table of Contents

1.0 Introduction

This document provides a summary of version 1.1 of the **M**ult**I**-decadal **N**itrogen dioxide and **D**erived products from **S**atellites (MINDS) Nitrogen Dioxide (NO_2) products. The goal of the MINDS project is to create consistent long-term global trend-quality data records of NO_2 column products for 1995-present.

Table 1: Summary table of MINDS NO_2 product, version 1.1.

SPECIES	NITROGEN DIOXIDE (NO_2)
DATA VERSION	MINDS_NO2, v1.1
VERSION RELEASE DATE	March 2022
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.

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
TROPOMI (S5-P)	11/2017-present	>3.5 km x 5.5 km	13:30	https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-5p

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), GOME-2 (Callies et al., 2000), and TROPOspheric Monitoring Instrument (TROPOMI, Veefkind et al., 2012). 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 (2006-2021), 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.

1.2 NO_2 Retrieval Method

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.

Our approach consists of applying our carefully validated NO_2, cloud, and geometry-dependent surface reflectivity retrieval algorithms as described in Lamsal et al., (2021) consistently to all MINDS instruments. Specifically, the algorithm includes:

- An improved DOAS algorithm for retrieving SCDs [Marchenko et al., 2015] for NO_2. The key features of the algorithm include independent, accurate registration of wavelength scales between radiance and irradiance spectra, iterative subtraction of rotational Raman scattering effect signal, and sequential retrieval of SCD of NO_2 and interferring species (H_2O and CHOCHO);
- Improved AMF calculation as follows:
    - Use of a daily and satellite field of view (FOV) specific geometry-dependent surface Lambertian Equivalent Reflectivity (GLER) product in both NO_2 and cloud retrievals. The GLER data are derived by coupling the atmosphere with the MODIS surface bidirectional reflectance distribution function (BRDF) data for land [Vasilkov et al., 2017, Qin et al., 2019], and an observationally-constrained (VLIDORT) model of reflection and water-leaving radiance for water surfaces [Vasilkov et al., 2017, Fasnacht et al., 2019];
    - Use of improved cloud parameters (effective cloud fraction (ECF) and optical centroid pressure (OCP)) that are retrieved using the GLER product [Vasilkov et al., 2018];
    - Use of a more accurate terrain pressure calculated using satellite ground pixel-averaged terrain height and GMI terrain pressure. The terrain height information comes from the Digital Elevation Model (DEM) data at 2 arcmin resolution;
    - Improved treatment over snow/ice surfaces by using the concept of scene ler and scene pressure;
    - Use of improved higher resolution GMI model-based a priori NO_2 profile shapes with updated year-specific emissions.
- Improved de-striping approach to remove cross-track artifacts using data from unpolluted areas in tropics.
- An observation-based stratosphere-troposphere separation scheme to estimate stratospheric NO_2 field by spatial interpolation using retrieved SCD data over unpolluted or cloudy areas (Buesela et al., 2013).

While we attempt to maintain algorithm consistency between instruments, currently there are some variations in implementation. For example, in contrast to our standard approach discussed in Lamsal et al (2021), GOME and TROPOMI retrievals are based on a-priori NO_2 profiles from

high resolution GMI daily simulation at 0.25° x 0.25° and cloud products are based on FRESCO, but are adjusted for GLER. In addition, TROPOMI NO_2 SCD data are taken from the operational ESA/KNMI product, version 2.3.1. We will keep addressing these variations in future updates.

1.3 Dataset Description

The Level-2 orbital (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.

The Level-3 (L3) daily data products are grid type rather than swath type. A L3 product is created by mapping a day's worth of L2 data (usually 14 or 15 orbits) into a regular 0.25-deg latitude by 0.25-deg longitude grid after screening the data for cloud and data quality flags. NO_2 column data in any grid cell is an area-weighted average of all L2 data that have any overlap with that grid cell. Grid cells that did not have any overlapping L2 data are assigned a fill value ($-2.0^{100} = -1.26765\times10^{30}$). The parameters specifying the grid cell locations are available in the metadata included in each file.

The Level-2 gridded (L2G) daily data products are created by mapping a day's worth of L2 orbital data into a regular 0.25-deg latitude by 0.25-deg longitude grid without applying any screening. These daily NO2G data are found to be more convenient by some users than using the orbital files for producing daily mappings of the data, generating their own L3 products, and evaluating model output using satellite NO_2 observations. When using the NO2G data, users are encouraged to apply appropriate data filtering for cloud and data quality flags as discussed in Section 1.4.

1.4 Data Citation and Acknowledgment

OMI_MINDS_NO2: 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 (2022), 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/DATA204.

OMI_MINDS_NO2d: 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 (2022), OMI/Aura NO_2 Column Daily L3 Global

Gridded 0.25 degree x 0.25 degree, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: **[Data Access Date]**, DOI: 10.5067/MEASURES/MINDS/DATA304.

OMI_MINDS_NO2G: 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 (2022), OMI/Aura NO_2 Column Daily L3 Global Gridded 0.25 degree x 0.25 degree, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: **[Data Access Date]**, DOI: 10.5067/MEASURES/MINDS/DATA214.

TROPOMI_MINDS_NO2: 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 (2022), 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/DATA203.

GOME_MINDS_NO2: 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 (2022), Nitrogen Dioxide (NO2) 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/DATA202.

1.5 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., 2020]. They are also evaluated by comparing with independent observations [Lamsal et al., 2021]. 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 0.30 or lower for selecting the data; the ECF threshold of 0.30 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.

Our assessment of GOME NO_2 retrievals is that slant column retrievals are often severely affected by the quality of Level 1 radiance and irradiance data. We attempt to address a part of this problem by substituting the irradiance measurements that do not pass the quality control by appropriate observations taken within a 60-day interval centered on the day of observation. If the slant column data were still of inferior quality, we exclude them for the public version.

2.0 Data Organization

A single MINDS NO_2 L2 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, L3 and L2G product files are named via the following convention:

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

where

<DataID> = <ObservationDateTime>-o<Orbit#> for L2 files

or

<DataID> = <ObservationDate> for L2G or L3 files

and

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

Example of an OMI-MINDS-NO2 L2 file name:

OMI-Aura_L2-OMI_MINDS_NO2_2011m1010t2318-o38499_v01-01-2022m0208t141026.nc

where:

<InstrumentID> = OMI-Aura

<DataType> = L2-OMI_MINDS_NO2

<ObservationDateTime> = 2011m1010t2318

<Orbit#> = 38499

<Version#> = 01-01

<ProductionDateTime> = 2019m0208t141026

<Suffix> = nc

Example of an OMI-MINDS-NO2d L3 file name:

OMI-Aura_L3-OMI_MINDS_NO2d_2011m1010_v01-01-2022m0218t103821.nc

where:

<InstrumentID> = OMI-Aura

<DataType> = L3-OMI_MINDS_NO2d

<ObservationDate> = 2011m1010

<Version#> = 01-01

<ProductionDateTime> = 2022m0218t103821

<Suffix> = nc

Example of an OMI-MINDS-NO2G L2G file name:

OMI-Aura_L2G-OMI_MINDS_NO2G_2011m1010_v01-01-2022m0331t123456.nc

where:

<InstrumentID> = OMI-Aura

<DataType> = L2G-OMI_MINDS_NO2G

<ObservationDate> = 2011m1010

<Version#> = 01-01

<ProductionDateTime> = 2022m0331t123456

<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 products files are in netCDF-4 and are CF-compliant. 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. NetCDF was developed by UCAR/Unidata (http://doi.org/10.5065/D6H70CW6) https://www.unidata.ucar.edu/software/netcdf/.

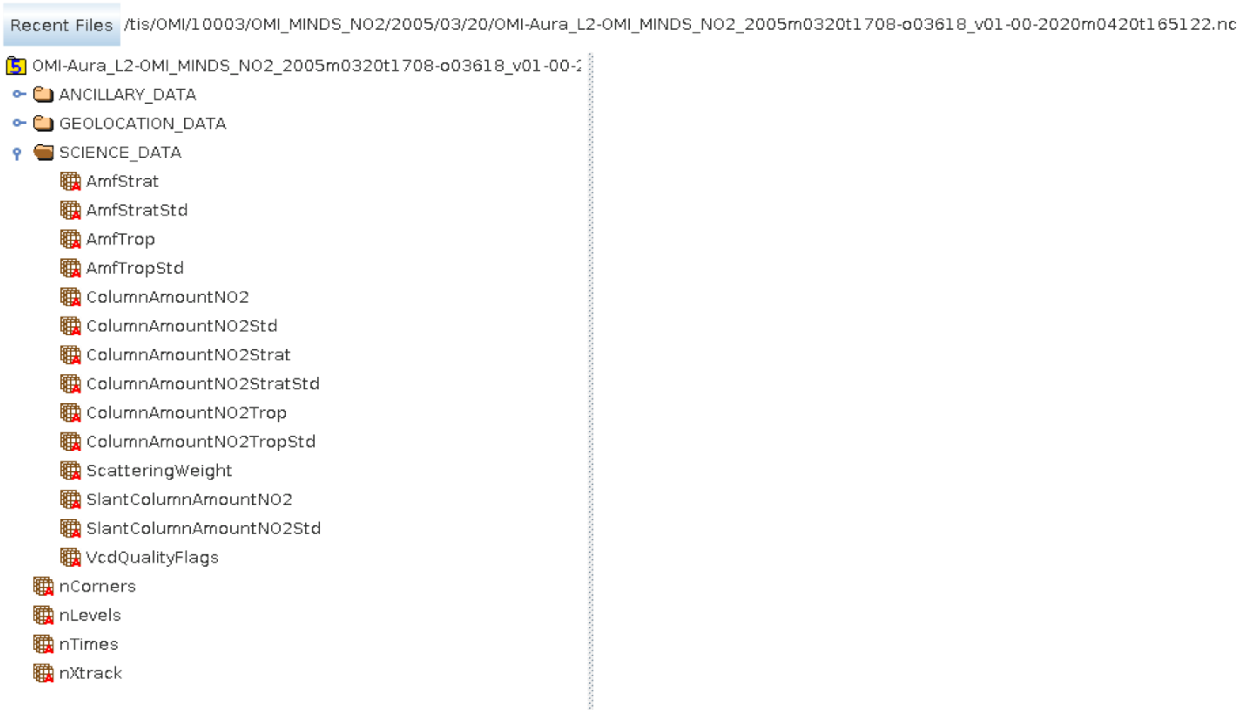

Figure 1: OMI_MINDS_NO2 netCDF data file structure.

The netCDF-4 file structure is shown in Figure 1. MINDS L2 files contain three data groups: ANCILLARY_DATA, GEOLOCATION_DATA, and SIENCE_DATA. The details on attributes, dimensions, and variables are provided in Appendix A for L2 files and Appendix B for L3 files.

2.3 Key Science and Ancillary Data Fields

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

2.3.1 L2 and L2G 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 (Marchenko et al., 2015; Lamsal et al., 2022). For TROPOMI, the SCD data are taken from the operational NO_2 product from ESA/KNMI. 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 in the GEOLOCATION_DATA field.

VcdQualityFlag: This variable contains quality assurance information for the tropospheric vertical column. The least significant bit is the summary quality flag. We recommend that users only use data for which this bit is zero (*i.e.,* VcdQualityFlag 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., 2021]. 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: Effective cloud fraction describes the relative partitioning of a satellite ground pixel into cloudy and cloud free parts. ECF 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 cloud algorithm that employs consistent retrieval approach and inputs used in NO_2 algorithm (Vasilkov et al., 2018). Its unit is hPa.

SnowIceFlags: The snow-ice flag values are determined from the Near-real-time Ice and Snow Extent (NISE) and the Interactive Multisensor Snow and Ice Mapping System (IMS) database, and are used consistently in the GLER, cloud, and NO_2 algorithms.

qa_value: The quality assurance value taken from the operational ESA/KNMI NO_2 product and is relevant for TROPOMI only. it is unitless and the values range from 0 to 1. Users are advised to use this data quality indicator with qa_value > 0.75, which removes cloud-covered scenes, scenes covered by snow/ice, and problematic retrievals.

2.3.2 L3 Data Fields

ColumnAmountNO2: The grid-average total vertical column density derived using data with solar zenith angle < 85 deg and VcdQualityFlags = 0. The units are molecules cm^{-2}.

ColumnAmountNO2CloudScreened: The grid-average total vertical column density derived using data with ECF < 0.3, solar zenith angle (SZA) < 85 deg and VcdQualityFlags = 0. The units are molecules cm^{-2}.

ColumnAmountNO2TropCloudScreened: The grid-average tropospheric vertical column density derived using data with ECF < 0.3, SZA < 85 deg and VcdQualityFlags = 0. The units are molecules cm^{-2}.

Weight: The grid-specific weight applied in creating L3 data. This can be used to combine gridded data from multiple L3 files and geographical regions in order to compute spatial or temporal averages.

3.0 GES DISC Data Services

If you need assistance or wish to report a problem:
Email: gsfc-dl-help-disc@mail.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 619 Greenbelt, MD 20771 USA

4.0 Acknowledgements

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Appendix A - OMI_MINDS_NO2 File Format

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

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

A.1 File-Level Attributes

The following table describes the 52 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) (same as institution).	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 in the product.	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 equator crossing of the orbit.	32-bit floating-point
EquatorCrossingTime	The time of the ascending equator crossing of the orbit.	String
FOVResolution	The highest resolution on the ground of the observations.	String
Format	The data format used for the product (e.g., netCDF-4).	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
GranuleID	The full name of the granule (same as	String

	LocalGranuleID).	
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
IdentifierProductDOI	The Digital Object Identifier (DOI) of the product.	String
IdentifierProductDOIAuthority	The URL of the relevant DOI authority.	String
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 (same as GranuleID).	String
LocalityValue	The flag indicating the locality of the granule.	String
LongName	The long name of the product (same as title).	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 (same as orbit).	32-bit integer
PGEName	The name of the software that produced the granule.	String
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
ProcessingCenter	The data processing facility that produced the granule.	String
ProcessingLevel	The processing level of the granule.	String
ProductType	The type of product.	String
ProductionDateTime	The production date-time of the granule.	String
RangeBeginningDate	The date at the beginning of the granule.	String
RangeBeginningTime	The time at the beginning of the	String

	granule.	
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
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 granule.	String
institution	The institutional affiliation of the author(s) (same as AuthorAffiliation).	String
orbit	The orbit number of the granule (same as OrbitNumber).	String
references	A list of references for the product.	String
source	The instrument and platform that gathered the observations for the product.	String
title	The title of the product (same as LongName).	String

A.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

A.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.

A.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

A.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

A.6 Geolocation Variables

The following table describes the 18 geolocation variables in the OMI_MINDS_NO2 product.

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 - 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-	32-bit integer

	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 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	The 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

A.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.

Variable Name	**Description**	**Data Type**
CloudFraction	The effective cloud fraction associated with the ground pixel (from OMCDO2N, an internal product).	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 optical centroid 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 optical centroid 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 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).	32-bit integer

A.8 Science Variables

The following table describes the 14 science variables in the OMI_MINDS_NO2 product.

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 pixel.	32-bit floating-point
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

A.9 Differences Between OMI_MINDS_NO2 and TROPOMI_MINDS_NO2 Products

We have attempted to maintain consistency of the file format for different satellite instruments. This appendix lists the parameters that differ between the OMI_MINDS_NO2 and TROPOMI_MINDS_NO2 products.

Parameter	**OMI_MINDS_NO2**	**TROPOMI_MINDS_NO2**	**Notes**
nTimes	1644 (Typical size)	4172 (Typical size)	See A.2
nXtrack	60	450	See A.2
Corner Latitude	Named FoV75CornerLatitude	Named CornerLatitude	See A.6 for OMI FoV75. TROPOMI is tiled.
Corner Longitude	Named FoV75CornerLongitude	Named CornerLongitude	See A.6 for OMI FoV75. TROPOMI is tiled.
Ground Pixel Area	Named FoV75Area	Named GroundPixelArea	See A.6 for OMI FoV75. TROPOMI is tiled.
GroundPixelQuality Flags	Included	Not Included	See A.6
CloudFractionStd	Included	Not Included	See A.7
CloudPressureStd	Included	Not Included	See A.7
qa_value	Not Included	Included	The quality assurance (QA) value associated with the ground pixel as provided in the

			operational TROPOMI NO2 product by ESA.
XTrackQualityFlags	Included	Included	See A.7 for OMI. For TROPOMI, a value of 0 indicates no problems, while a value of 1 indicates no cloud data available.

A.10 Differences Between OMI_MINDS_NO_2 and GOME_MINDS_NO_2 Products

We have attempted to maintain consistency of the file format for different satellite instruments. This appendix lists the parameters that differ between the OMI_MINDS_NO_2 and GOME_MINDS_NO_2 products.

Parameter	**OMI_MINDS_NO2**	**GOME_MINDS_NO2**	**Notes**
nTimes	1644 (Typical size)	550 (Typical size)	See A.2
nXtrack	60	3	See A.2
Corner Latitude	Named FoV75CornerLatitude	Named CornerLatitude	See A.6 for OMI FoV75. GOME is tiled.
Corner Longitude	Named FoV75CornerLongitude	Named CornerLongitude	See A.6 for OMI FoV75. GOME is tiled.
Ground Pixel Area	Named FoV75Area	Named GroundPixelArea	See A.6 for OMI FoV75. GOME is tiled.
GroundPixelQuality Flags	Included	Not Included	See A.6
SceneLER	Included	Not Included	See A.7
ScenePressure	Included	Not Included	See A.7
SnowIceFlags	Not Included	Included	The snow-ice flags associated with the ground pixel (from GOMGLER): 0 = land, 1-100 sea ice (percent), 101 = permanent ice, 103 = snow, 104 = water, 201-300 land snow (percent plus 200).

VcdQualityFlags	Included	Included	See A.8 for OMI. For GOME: Bits 0 to 3 – currently unused, Bit 4 – ascending data flag (0 for descending data), Bits 5 to 11 – currently unused, Bit 12 – AMF/SCD flag (0 for good AMF/SCD data, 1 for bad AMF/SCD data).
XTrackQualityFlags	Included	Not Included	See A.7

Appendix B - OMI_MINDS_NO2d File Format

This appendix describes the file format of the OMI_MINDS_NO2d product, including the file-level attributes, dimensions, groups, variable-level attributes, fill values, geolocation variables, bounds variables, and science variables.

B.1 File-Level Attributes

The following table describes the 51 file-level attributes that appear at root level in the OMI_MINDS_NO2d product.

Attribute Name	Description	Data Type
AuthorAffiliation	The institutional affiliation of the author(s) (same as institution).	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 in the product.	String
DayNightFlag	The flag indicating whether the observations were made on the day or night side of Earth.	String
EasternmostLongitude	The longitude of the easternmost data in the granule.	32-bit floating-point
EndOrbit	The orbit number of the final orbit used to construct the granule.	32-bit integer
EndUTC	The UTC at the end of the granule.	String
Format	The data format used for the product (e.g., netCDF-4).	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
GranuleID	The full name of the granule (same as LocalGranuleID).	String
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
IdentifierProductDOI	The Digital Object Identifier (DOI) of the product.	String
IdentifierProductDOIAuthority	The URL of the relevant DOI authority.	String
InputPointer	A list of the input file(s) used to produce the granule.	String
InstrumentShortName	The short name of the instrument.	String
LatitudeResolution	The resolution in latitude of the grid in the granule.	32-bit floating-point
LocalGranuleID	The full name of the granule (same as GranuleID).	String
LocalityValue	The flag indicating the locality of the granule.	String
LongName	The long name of the product (same as title).	String
LongitudeResolution	The resolution in longitude of the grid in the granule.	32-bit floating-point
NorthernmostLatitude	The latitude of the northernmost data in the granule.	32-bit floating-point
PGEName	The name of the software that produced the granule.	String
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
ProcessingCenter	The data processing facility that produced the granule.	String
ProcessingLevel	The processing level of the granule.	String

ProductType	The type of product.	String
ProductionDateTime	The production date-time of the 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
SouthernmostLatitude	The latitude of the southernmost data in the granule.	32-bit floating-point
StartOrbit	The orbit number of the first orbit used to construct the granule.	32-bit integer
StartUTC	The UTC at the start of the granule.	String
TAI93At0zOfGranule	The TAI93 time at UTC midnight for the day of the granule.	64-bit floating-point
VersionID	The product version.	String
WesternmostLongitude	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 granule.	String
institution	The institutional affiliation of the authors (same as AuthorAffiliation).	String
references	A list of references for the product.	String
source	The instrument and platform that gathered the observations for the product.	String
title	The title of the product (same as LongName).	String

B.2 Dimensions

The following table describes the four dimensions in the OMI_MINDS_NO2d product.

Dimension Name	Description	Dimension Size
BoundsIndex	The dimension representing the index for the bounds variables.	2
Latitude	The dimension representing latitude in the grid.	720
Longitude	The dimension representing longitude in the grid.	1440
Time	The dimension representing time for the grid file. This dimension of size one facilitates the concatenation of data from several consecutive grid files.	1

B.3 Groups

There are no groups in the OMI_MINDS_NO2d product - all variables appear at root level.

B.4 Variable-Level Attributes

The following table describes the attributes attached to the variables in the OMI_MINDS_NO2d 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
bounds	The path to the relevant bounds variable (applies to the Latitude, Longitude and Time variables only).	String
cell_methods	The method by which the science data values in each grid cell are calculated.	String
coordinates	The paths to the relevant coordinate variables (if applicable).	String
description	A detailed description of the variable.	String
grid_mapping	The mapping used in the grid.	String
grid_mapping_name	An attribute for the crs dummy variable.	String
inverse_flattening	An attribute for the crs dummy variable.	32-bit floating-point
long_name	The name for the variable that can be used in plots.	String
longitude_of_prime_meridian	An attribute for the crs dummy variable.	32-bit floating-point
semi_major_axis	An attribute for the crs dummy variable.	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

B.5 Fill Values

The following table summarizes the fill values used in the OMI_MINDS_NO2d product.

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

B.6 Geolocation Variables

The following table describes the four geolocation variables in the OMI_MINDS_NO2d product. The dimensions of these variables are either Latitude or Longitude or Time, with the execption of the crs dummy variable, which has no dimensions.

Variable Name	Description	Data Type
Latitude	The terrestrial latitude (in degrees) at the center of the grid cell.	32-bit floating-point
Longitude	The terrestrial longitude (in degrees) at the center of the grid cell.	32-bit floating-point
Time	The time (in continuous days since 1972-01-01 00:00:00 UTC) for the observations in the grid file.	32-bit floating-point
crs	A dummy variable with attributes that specify the Coordinate Reference System used for the grid.	32-bit integer

B.7 Bounds Variables

The following table describes the three bounds variables in the OMI_MINDS_NO2d product. The dimensions of these variables are either Latitude or Longitude or Time x BoundsIndex.

Variable Name	Description	Data Type
LatitudeBounds	The terrestrial latitude bounds (in degrees) for each grid cell.	32-bit floating-point
LongitudeBounds	The terrestrial longitude bounds (in degrees) for each grid cell.	32-bit floating-point
TimeBounds	The time bounds (in continuous days since 1972-01-	32-bit floating-point

	01 00:00:00 UTC) for the observations in the grid file.	

B.8 Science Variables

The following table describes the four science variables in the OMI_MINDS_NO2d product. The dimensions of these variables are Time x Latitude x Longitude.

Variable Name	Description	Data Type
ColumnAmountNO2	The average total NO_2 vertical column density (in molec/cm^2) for high quality observations with solar zenith angles less than 85 degrees.	32-bit floating-point
ColumnAmountNO2CloudScreened	The average total NO_2 vertical column density (in molec/cm^2) for high quality observations with effective cloud fractions less than 0.3 and solar zenith angles less than 85 degrees.	32-bit floating-point
ColumnAmountNO2TropCloudScreened	The average tropospheric NO_2 vertical column density (in molec/cm^2) for high quality observations with effective cloud fractions less than 0.3 and solar zenith angles less than 85 degrees.	32-bit floating-point
Weight	The recommended weight to be used when comparing the NO_2 column amounts for two or more grid cells.	32-bit floating-point

Appendix C - OMI_MINDS_NO2G File Format

This appendix describes the file format of the OMI_MINDS_NO2G product, including the file-level attributes, dimensions, groups, variable-level attributes, fill values, geolocation variables, ancillary variables, and science variables.

C.1 File-Level Attributes

The following table describes the 68 file-level attributes that appear at root level in the OMI_MINDS_NO2G product.

Attribute Name	Description	Data Type
AuthorAffiliation	The institutional affiliation of the author(s) (same as institution).	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 in the product.	String
DayNightFlag	The flag indicating whether the observations were made on the day or night side of Earth.	String
EasternmostLongitude	The longitude of the easternmost data in the granule.	32-bit floating-point
EndUTC	The UTC at the end of the granule.	String
EquatorCrossingDate	The dates of the ascending equator crossings of each orbit used to create the granule.	String
EquatorCrossingLongitude	The longitudes of the ascending equator crossings of each orbit used to create the granule.	32-bit floating point
EquatorCrossingTime	The times of the ascending equator crossings of each orbit used to create the granule.	String
FirstLineInOrbit	The first line number from each orbit used to create the granule.	32-bit integer
Format	The data format used for the product (e.g., netCDF-4).	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
GranuleID	The full name of the granule (same as LocalGranuleID).	String
GranuleMonth	The month of the year at the	32-bit integer

	beginning of the granule.	
GranuleYear	The year at the beginning of the granule.	32-bit integer
IdentifierProductDOI	The Digital Object Identifier (DOI) of the product.	String
IdentifierProductDOIAuthority	The URL of the relevant DOI authority.	String
InputPointer	A list of the input file(s) used to produce the granule.	String
InstrumentShortName	The short name of the instrument.	String
LastLineInOrbit	The last line number from each orbit used to create the granule.	32-bit integer
LatitudeResolution	The resolution in latitude of the grid in the granule.	32-bit floating-point
LocalGranuleID	The full name of the granule (same as GranuleID).	String
LocalityValue	The flag indicating the locality of the granule.	String
LongName	The long name of the product (same as title).	String
LongitudeResolution	The resolution in longitude of the grid in the granule.	32-bit floating-point
MaximumNumberOfObservationsPerGridCell	The maximum number of observations per grid cell in the granule.	32-bit integer
MinimumNumberOfObservationsPerGridCell	The minimum number of observations per grid cell in the granule.	32-bit integer
NorthernmostLatitude	The latitude of the northernmost data in the granule.	32-bit floating-point
NumberOfEmptyGridCells	The number of empty grid cells in the granule.	32-bit integer
NumberOfExcessObservationsAcceptedIntoGrid	The total number of observations in the granule in excess of the first observation per grid cell.	32-bit integer
NumberOfGridCells	The number of grid cells in the granule.	32-bit integer
NumberOfLinesMissingGeolocationInOrbit	The number of lines with missing geolocation for each orbit used to create the granule.	32-bit integer
NumberOfMultiplyPopulatedGridCells	The total number of grid cells in the	32-bit integer

	granule that contain more than one observation (the word multiply is used as an adverb in this case).	
NumberOfObservationsAcceptedIntoGrid	The number of observations accepted into the grid in the granule.	32-bit integer
NumberOfObservationsConsideredForGird	The number of observations considered for the grid in the granule.	32-bit integer
NumberOfObservationsRejectedFromGrid	The number of observations rejected from the grid in the granule.	32-bit integer
NumberOfOrbits	The number of orbits used to create the granule.	32-bit integer
NumberOfPopulatedGridCells	The number of grid cells in the granule that contain observations.	32-bit integer
OrbitNumber	The orbit numbers of the orbits used to create the granule.	32-bit integer
OrbitalPeriod	The orbital periods of the orbits used to create the granule.	32-bit integer
PGEName	The name of the software that produced the granule.	String
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
ProcessingCenter	The data processing facility that produced the granule.	String
ProcessingLevel	The processing level of the granule.	String
ProductType	The type of product.	String
ProductionDateTime	The production date-time of the 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

SouthernmostLatitude	The latitude of the southernmost data in the granule.	32-bit floating-point
StartUTC	The UTC at the start of the granule.	String
TAI93At0zOfGranule	The TAI93 time at UTC midnight for the day of the granule.	64-bit floating-point
VersionID	The product version.	String
WesternmostLongitude	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 granule.	String
institution	The institutional affiliation of the authors (same as AuthorAffiliation).	String
references	A list of references for the product.	String
source	The instrument and platform that gathered the observations for the product.	String
title	The title of the product (same as LongName).	String

C.2 Dimensions

The following table describes the three dimensions in the OMI_MINDS_NO2G product.

Dimension Name	Description	Dimension Size
LatDim	The dimension representing latitude in the grid.	720
LonDim	The dimension representing longitude in the grid.	1440
ObsDim	The dimension representing the observation number in the grid.	15

C.3 Groups

There are no groups in the OMI_MINDS_NO2G product - all variables appear at root level.

C.4 Variable-Level Attributes

The following table describes the attributes attached to the variables in the OMI_MINDS_NO2G 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
axis	The axis for the coordinate variables (axis = X for LonDim, and axis = Y for LatDim).	String
coordinates	The paths to the relevant coordinate variables (if applicable).	String
description	A detailed description of the variable.	String
grid_mapping	The mapping used in the grid.	String
grid_mapping_name	An attribute for the crs dummy variable.	String
inverse_flattening	An attribute for the crs dummy variable.	32-bit floating-point
long_name	The name for the variable that can be used in plots.	String
longitude_of_prime_meridian	An attribute for the crs dummy variable.	32-bit floating-point
semi_major_axis	An attribute for the crs dummy variable.	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

C.5 Fill Values

The following table summarizes the fill values used in the OMI_MINDS_NO2G product.

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

C.6 Geolocation Variables

The following table describes the 17 geolocation variables in the OMI_MINDS_NO2G product. The dimensions of these variables are LatDim, LonDim and ObsDim, with the following

exceptions: the LatDim variable has dimension LatDim, the LonDim variable has dimension LonDim, the NumberOfObservations variable has dimensions LatDim and LonDim, the ObsDim variable has dimension ObsDim, and the crs dummy variable has no dimensions.

Variable Name	Description	Data Type
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 - 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.	32-bit integer
LatDim	The terrestrial latitude (in degrees) at the center of the grid cell.	32-bit floating-point
Latitude	The terrestrial latitude (in degrees) at the center of the ground pixel.	32-bit floating-point
LineNumber	The line number of the observation.	32-bit integer
LonDim	The terrestrial longitude (in degrees) at the center of the grid cell.	32-bit floating-point
Longitude	The terrestrial longitude (in degrees) at the center of the ground pixel.	32-bit floating-point
NumberOfObservations	The total number of observations in the grid cell.	32-bit integer
ObsDim	The observation number in the grid cell.	32-bit integer
OrbitNumber	The orbit number of the observation.	32-bit integer
PathLength	The path length [= sec(solar zenith angle) +	32-bit floating-point

	sec(viewing zenith angle)] at the center of the ground pixel.	
SceneNumber	The scene number of the observation.	32-bit integer
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
Time	TAI93 (in continuous seconds since 12 a.m. UTC on January 1, 1993) of the observation.	32-bit floating-point
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 floaring-point
crs	A dummy variable with attributes that specify the Coordinate Reference System used for the grid.	32-bit integer

C.7 Ancillary Variables

The following table describes the 7 ancillary variables in the OMI_MINDS_NO2G product. Some of the 32-bit integer variables need to be multiplied by a scale factor to yield physical values.

Variable Name	**Description**	**Data Type**
CloudFraction	The effective cloud fraction associated with the ground pixel (from OMCDO2N, an internal product).	32-bit integer
CloudPressure	The cloud optical centroid 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
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	32-bit integer

	anomaly on the measured radiances. The first three bits (bits 0 to 2) combined can have the 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).	

C.8 Science Variables

The following table describes the 7 science variables in the OMI_MINDS_NO2G product.

Variable Name	Description	Data Type
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 pixel.	32-bit floating-point
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
VcdQualityFlags	The vertical column density quality flags for the retrieval. Each bit is set as follows:	32-bit integer

	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).	