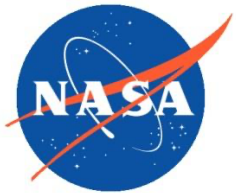

National Aeronautics and Space Administration
Goddard Earth Science Data Information and Services Center (GES DISC)

README Document for Sentinel-5P TROPOMI Nitrogen Dioxide (NO_2) Level 3 CONUS 0.01 x 0.01 Degree Data

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

http://disc.gsfc.nasa.gov

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Revision History

Revision Date	Changes	Author

Table of Contents

1.0 Introduction

This document provides basic information for using the HAQAST Sentinel-5P TROPOMI Nitrogen Dioxide (NO_2) Level 3 CONUS Monthly, Seasonal, and Annual 0.01 x 0.01 Degree Data.

The Level 3 monthly, seasonal, and annual averages of tropospheric vertical NO_2 column densities (VCDs) have been generated for understanding the spatial distribution, trends, and health impacts of NO_2 across the continental United States at a high spatial resolution.

1.1 Dataset Description

Level 2 tropospheric NO_2 vertical column densities from the Tropospheric Monitoring Instrument (TROPOMI) on the Copernicus Sentinel 5-Precursor satellite mission are provided operationally by the European Space Agency (ESA). TROPOMI acquires tropospheric NO_2 vertical column densities once per day globally at approximately 13:30 local time. As of January 2024, the operational algorithm released by ESA is Version 2.6, which is identical to Versions 2.4 and 2.5 over non snow/ice scenes. In this Level 3 product, labeled Version 2.4 for consistency, we have generated monthly, seasonal, and annual averages at a spatial resolution of 0.01˚ x 0.01˚ (~1 km^2) using a consistent algorithm that can be used for trend analysis.

The Level 3 monthly, seasonal, and annual averages have been generated by first filtering data to exclude pixel measurements when the qa_value is less than 0.75. All remaining “valid” pixel measurements are then super-imposed onto to a fixed 0.01˚ x 0.01˚ grid, and averaged together over monthly, seasonal, and annual timeframes. If a location has two valid measurements per day, which represents approximately 5% of days, these count as individual measurements and therefore some locations can have more than 31 measurements per month. For monthly averages, most locations have 12 – 25 measurements per month. For seasonal averages, most locations have 35 – 75 measurements per month. For annual averages, most locations have 150 – 300 measurements per month.

In this Level 3 dataset, between 1 May 2018 and 17 July 2022, we use re-processed (RPRO)

Version 2.4 data provided by ESA. Starting 18 July 2022, we use the offline (OFFL) Version 2.4 data provided by ESA. Pre-dating 17 July 2022, versions of the OFFL algorithm used different assumptions, and therefore the OFFL product cannot be used for trend analyses that temporally bisect 17 July 2022. All Level 2 data can be downloaded on the Copernicus Dataspace Browser (https://dataspace.copernicus.eu/). A compilation of algorithm changes can be found in the Level 2 Product README: https://sentinels.copernicus.eu/documents/247904/3541451/Sentinel-5P-Nitrogen-Dioxide-Level-2-Product-Readme-File.pdf

1.2 Data Disclaimer

Data should be used with care and proper citations. Additional details beyond those provided in this document regarding how Level 2 tropospheric vertical NO_2 column contents were generated can be found in the TROPOMI NO_2 Algorithm Theoretical Basis Document (ATBD): https://sentinel.esa.int/documents/247904/2476257/sentinel-5p-tropomi-atbd-no2-data-products and Product README: https://sentinels.copernicus.eu/documents/247904/3541451/Sentinel-5P-Nitrogen-Dioxide-Level-2-Product-Readme-File.pdf. Examples uses of this Level 3 product related to health and air quality can be found in the Goldberg et al. (2021) citation in Section 1.2.1.

1.2.1 Data Citation and Acknowledgment

Cite the following references when using this dataset:

Copernicus Sentinel-5P (processed by ESA), 2021, TROPOMI Level 2 Nitrogen Dioxide total column products. Version 02. European Space Agency. https://doi.org/10.5270/S5P-9bnp8q8

Goldberg, D. L., Anenberg, S. C., Mohegh, A., Lu, Z. and Streets, D. G.: TROPOMI NO_2 in the United States: A detailed look at the annual averages, weekly cycles, effects of temperature, and correlation with surface NO_2 concentrations, 2021, *Earth's Future,* https://doi.org/10.1029/2020EF001665

1.2.2 Contact Information

For more information on the dataset, contact Dan Goldberg, Assistant Research Professor,

George Washington University (dgoldberg@gwu.edu).

2.0 Data Organization

The data consist of monthly, seasonal, and annual averages of the tropospheric vertical NO_2 column contents as measured by TROPOMI.

2.1 Product list

The products and data DOIs are listed in Table 1 below.

Table 1: List of Collections in HAQ TROPOMI NO2 CONUS version 2.4

Short Name	Format	Description	Data DOI (Linked to the dataset landing page)
HAQ_TROPOMI_NO2_CONUS_M_L3	netCDF4	Sentinel-5P TROPOMI Nitrogen Dioxide (NO2) CONUS **Monthly** Level 3 0.01 x 0.01 Degree Gridded Data	10.5067/MKJG22GUOD34
HAQ_TROPOMI_NO2_CONUS_S_L3	netCDF4	Sentinel-5P TROPOMI Nitrogen Dioxide (NO2) CONUS **Seasonal** Level 3 0.01 x 0.01 Degree Gridded Data	10.5067/QVH8JOFDSU2J
HAQ_TROPOMI_NO2_CONUS_A_L3	netCDF4	Sentinel-5P TROPOMI Nitrogen Dioxide (NO2) CONUS **Annual** Level 3 0.01 x 0.01 Degree Gridded Data	10.5067/ACADNS5UBWPQ

2.2 File Naming Convention

2.2.1 Monthly files

Monthly tropospheric vertical NO_2 column contents data files are named in accordance with the following convention:

HAQ_TROPOMI_NO2_CONUS_QA75_L3_Monthly_ MMYYYY_V2.4_DDDDDDDD.nc4

where “MM” is the two-digit month [01, 02, etc.], “YYYY” is the four-digit year [2018, 2019, etc.], and “DDDDDDDD” is the date the file was created.

Filename example:
HAQ_TROPOMI_NO2_CONUS_QA75_L3_Monthly_052018_V2.4_20231221.nc4

2.2.2 Seasonal files

Seasonal tropospheric vertical NO_2 column contents data files are named in accordance with the following convention:

HAQ_TROPOMI_NO2_CONUS_QA75_L3_Seasonal_ SSS_YYYY_V2.4_DDDDDDDD.nc4

where “SSS” is the three-letter climatological season [MAM, JJA, SON, and DJF] and “YYYY” is the four-digit year [2018, 2019, etc.], and “DDDDDDDD” is the date the file was created.

Filename example:
HAQ_TROPOMI_NO2_CONUS_QA75_L3_Seasonal_JJA_2018_V2.4_20231221.nc4

For DJF, the year listed in the filename corresponds to the December year.

2.2.3 Annual files

Annual tropospheric vertical NO_2 column contents data files are named in accordance with the following convention:

HAQ_TROPOMI_NO2_CONUS_QA75_L3_Annual _YYYY_V2.4_DDDDDDDD.nc4

where “YYYY” is the four-digit year [2019, 2020, etc.]

Filename example:
HAQ_TROPOMI_NO2_CONUS_QA75_L3_Annual _2019_V2.4_20231221.nc4

2.3 File Format and Structure

The data 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/. These files follow the CF 1.10 conventions.

2.4 Key Science Data Fields

The key science data field is “*Tropospheric_NO2*” which provides tropospheric vertical NO_2 column contents at 0.01˚ x 0.01˚ (~1 km^2) resolution.

3.0 Data Contents

3.1 Data Set Attributes (File Metadata)

In addition to SDS arrays containing variables and dimension scales, global metadata is also stored in the files. Some metadata are required by standard conventions, some are present to meet data provenance requirements and others as a convenience to users of Nitrogen Dioxide Surface-Level Annual Average Concentrations products. A summary of global attributes present in all files is shown in Table 2.

Table 2. Global metadata attributes associated with each SDS.

Global Attribute	Description	Type
history	audit trail for modifications to the original data	string
institution	specifies where the Level 3 data were produced	string
source	the method of production of the original data including the model used to generate the data	string
Conventions	Climate and Forecast (CF) metadata conventions	string
LongName	long name of the collection	string
ShortName	short name of the data type (collection)	string
title	description of dataset	string
VersionID	version of the dataset	string
Format	format of the data file	string
DataSetQuality	information on QA/QC underlying dataset	string

IdentifierProductDOI	Digital Object Identifier	string
IdentifierProductDOIAuthority	Digital Object Identifier domain	string
ProcessingLevel	degree of data processing applied to Earth Observations data	string
GranuleID	short name of the data type with the specific time frame appended	string
ProductionDateTime	Date the file was written	string
SouthBoundingCoordinate	southbound latitude	string
NorthBoundingCoordinate	northbound latitude	string
WestBoundingCoordinate	westbound longitude	string
EastBoundingCoordinate	eastbound longitude	string
RangeBeginningDate	begin date of data	string
RangeBeginningTime	begin time of data	string
RangeEndingDate	end date of data	string
RangeEndingTime	end time of data	string
comment	Generator and email address	string
references	Published references that describe the data or methods used to produce the data	string

3.2 Dimensions

Global Attribute	Description	Dimensions
Latitude	latitude of the center of the cell, starting at 24.50, by 0.01 degree increments	2500
Longitude	longitude of the center of the cell, latitude starting at -124.75, by 0.01 degree increments	5800

3.3 Data Fields

Data Field Name	Long_Name/Description	Type	Dimensions	Undefined Value	Units
Tropospheric_ NO2	Tropospheric vertical column NO2 density	32-bit floating-point	(lon, lat)	-999.0	Molecules cm^{-2}
Number_obs	Number of valid pixels used for the average	32-bit floating-point	(lon, lat)	-999.0	count

4.0 Data Access

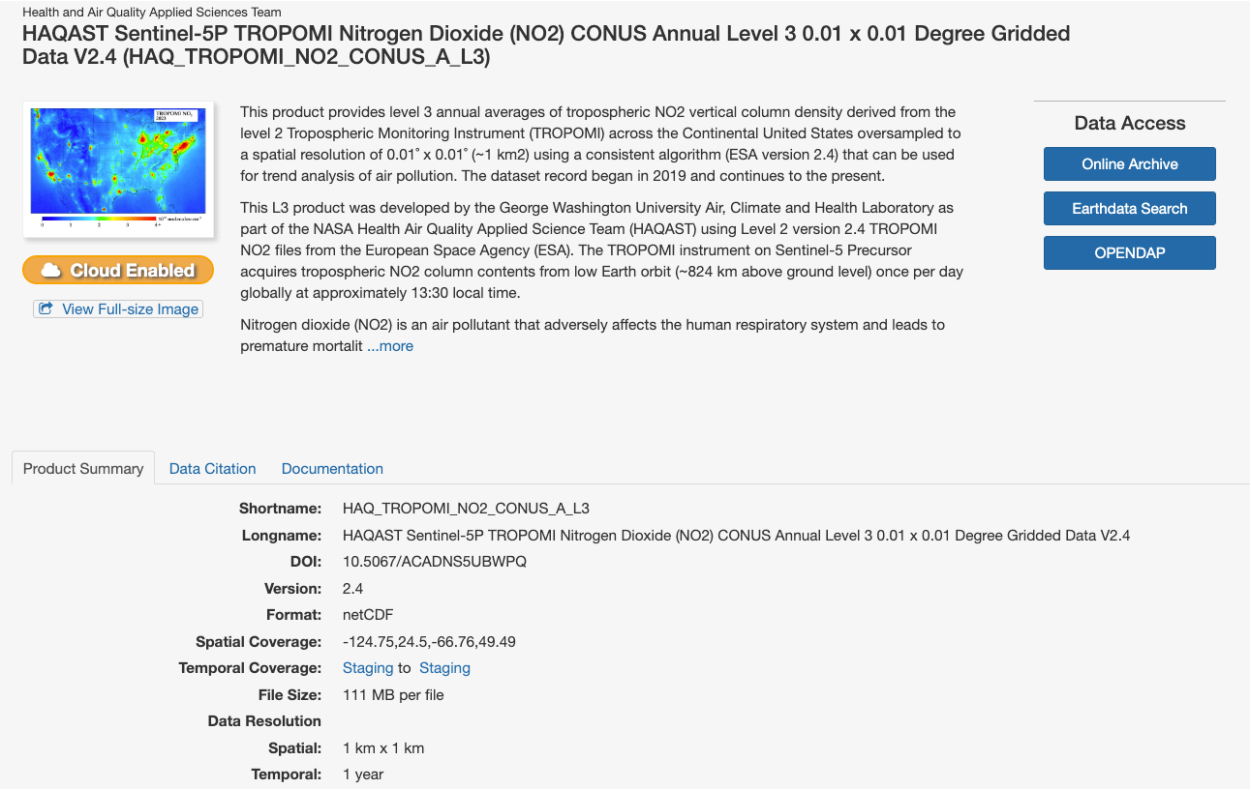
4.1 Search products

The products of this project can be found by searching ‘HAQ’ in the search box after selecting ‘Data Collection’ on the GES DISC website: https://disc.gsfc.nasa.gov/, or on the NASA Earthdata Search interface: https://search.earthdata.nasa.gov/search.

4.2 Dataset landing page

The dataset landing page consists of the links of data access, product summary, documentation, and references, which can be found by clicking the product title from the product search result of section 4.1, for example:

https://disc.gsfc.nasa.gov/datacollection/HAQ_TROPOMI_NO2_CONUS_A_L3_2.4.html, which looks like below.



4.3 Direct access

The data may be downloaded directly from the HTTPS service at:
https://acdisc.gesdisc.eosdis.nasa.gov/data/HAQAST/.

5.0 Options for Reading the Data

5.1 Command Line Utilities

5.1.1 ncdump

The ncdump tool can be used as a simple browser for HDF data files, to display the dimension names and sizes; variable names, types, and shapes; attribute names and values; and optionally, the values of data for all variables or selected variables in a netCDF file. The most common use of ncdump is with the –h option, in which only the header information is displayed.

ncdump [-c|-h] [-v ...] [[-b|-f] [c|f]] [-l len] [-n name] [-d n[,n]] filename
Options/Arguments:
[-c] Coordinate variable data and header information
[-h] Header information only, no data
[-v var1[,...]] Data for variable(s) <var1>,... only data
[-f [c|f]] Full annotations for C or Fortran indices in data
[-l len] Line length maximum in data section (default 80)
[-n name] Name for netCDF (default derived from file name)
[-d n[,n]] Approximate floating-point values with less precision filename File name of input netCDF file
(https://www.unidata.ucar.edu/software/netcdf/workshops/2011/utilities/Ncdump.html)

5.1.2 HDFView

HDFView is a Java based graphical user interface created by the HDF Group which can be used to browse HDF files. The utility allows users to view all objects in an HDF file hierarchy which is represented as a tree structure. Additional information about HDFView can be found at https://support.hdfgroup.org/products/java/hdfview/ and for HDF at https://portal.hdfgroup.org/display/support

5.2 Tools/Programming

The product files can be read and queried using the NetCDF4 library and tools maintained by Unidata (http://www.unidata.ucar.edu/software/netcdf/). Support for reading NetCDF is offered in many programming languages, including Python, Matlab, IDL, C/C++ and Fortran. NetCDF4 files are legal HDF5 files with additional bookkeeping information managed by the NetCDF4 library. It is therefore possible to inspect and copy data out of the NetCDF4 files by using the HDF5 utilities and libraries maintained by the HDF Group (https://www.hdfgroup.org/products/hdf5_tools/index.html) or by using the HDF5 interface in your favorite programming language. However, the two libraries should not be considered fully interchangeable.

Matlab users should note that the Matlab NetCDF4 interface is currently (as of version R2017a) not able to read attributes that are string arrays, and will throw an exception if that is attempted.

5.2.1 Python

The following code snippet shows how to read the variable lat, lon, and no2 from the dataset with the name “filename”. Also shown are some basic information about the size of the variables arrays.

```
import netCDF4 as nc
```

```
nc_fid = nc.Dataset(filename ,mode='r',format='NETCDF4')

# Read in the variables
lat = nc_fid.variables['Latitude'][:]
lon = nc_fid.variables['Longitude'][:]
no2 = nc_fid.variables['Tropospheric_NO2'][:]

# Print out the minimum, maximum, and dimensions for the three variables
print("-- lat  Min/Max values", lat[:].min(), lat[:].max())
print("lat.shape:", lat.shape)
print("-- lon Min/Max values:", lon[:].min(), lon[:].max())
print("lon.shape:", lon.shape)
print("—no2 Min/Max values:", no2 [:].min(), no2 [:].max())
print("no2.shape:", no2.shape)
```

5.2.2 IDL

The following code snippet shows how to read the variable lat, lon, and no2 from the dataset with the name “filename”.

```
;Open file
fid = ncdf_open(filename)
print, 'filename=', filename

;Read-in variables
varname = 'Tropospheric_NO2'
varid = ncdf_varid(fid, varname)
ncdf_varget,fid,varid, no2

varname = 'Latitude'
varid = ncdf_varid(fid, varname)
ncdf_varget,fid,varid, Latitude

varname = 'Longitude'
varid = ncdf_varid(fid, varname)
ncdf_varget,fid,varid, Longitude

;Close file
ncdf_close, fid
```

5.2.3 Panoply

The netCDF-4 files could be visualized with the NASA free data tool Panoply. Example is available as below:

Quick View Data with Panoply

6.0 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

6.1 How To Articles

The GESDISC web site contains many informative articles under the "How To Section", "FAQ" (frequently asked questions), "News", "Glossary", and "Help" . A sample of these articles includes:

Earthdata Login for Data Access

How to Download Data Files from HTTPS Service with wget

How to Obtain Data in NetCDF Format via OpeNDAP

Quick View Data with Panoply

How to Read Data in NetCDF Format with R

How to Read Data in HDF-5 or netCDF Format with GrADS

How to read and plot NetCDF MERRA-2 data in Python

How to Subset Level-2 Data

How to use the Level 3 and 4 Subsetter and Regridder

7.0 Acknowledgments

The creation of this dataset was funded by NASA Health and Air Quality Applied Science's Team (HAQAST).

8.0 References

Copernicus Sentinel-5P (processed by ESA), 2021, TROPOMI Level 2 Nitrogen Dioxide total column products. Version 02. European Space Agency. https://doi.org/10.5270/S5P-9bnp8q8

Eskes, H. J., Eichmann, K.-U., Lambert, J.-C., Loyola, D., Stein-Zweers, D., Dehn, A., & Zehner, C. (2023). *S5P MPC Product Readme Nitrogen Dioxide*. https://sentinels.copernicus.eu/documents/247904/3541451/Sentinel-5P-Nitrogen-Dioxide-Level-2-Product-Readme-File.pdf.

Goldberg, D. L., Anenberg, S. C., Mohegh, A., Lu, Z. and Streets, D. G.: TROPOMI NO_2 in the United States: A detailed look at the annual averages, weekly cycles, effects of temperature, and correlation with surface NO_2 concentrations, 2021, *Earth's Future,* https://doi.org/10.1029/2020EF001665

Van Geffen, J. TROPOMI ATBD of the total and tropospheric NO2 data products, 2016, https://sentinel.esa.int/documents/247904/2476257/sentinel-5p-tropomi-atbd-no2-data-products