



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

# README Document for TROPESS Forward Stream, Standard and Summary Products

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Kevin Bowman, John Worden, Kristal Whitten, Valentin Kantchev, Adrian Tinio, Kristen Fahy,  
Sirvard Akopyan

Jet Propulsion Laboratory, California Institute of Technology

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Goddard Earth Sciences Data and Information Services Center (GES DISC)  
<http://disc.gsfc.nasa.gov>  
NASA Goddard Space Flight Center  
Code 610.2  
Greenbelt, MD 20771 USA

**Prepared By:**

**Your Name**

**Kevin W. Bowman**

Name  
GES DISC  
GSFC Code 610.2

Name  
JPL/Caltech

Date

**Reviewed By:**

**Reviewer Name**

**Date**

Reviewer Name  
GES DISC  
GSFC Code 610.2

Date

**Goddard Space Flight Center  
Greenbelt, Maryland**

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# ● 1.0 Introduction

This document provides basic information for using the TROPES datasets listed in Table 1.

The TROPES forward processing stream generates products that include atmospheric composition measurements of ozone (O<sub>3</sub>), carbon monoxide (CO), ammonia (NH<sub>3</sub>), peroxyacetyl nitrate (PAN), methane (CH<sub>4</sub>), and deuterated water vapor (HDO) derived from radiances measured by the NASA CrIS, Aqua AIRS, and Aura OMI sounders. These products provide global coverage. The data are subsampled using a grid sampling approach where the region is divided into 0.7 degree latitude (lat) x 0.7 degree longitude (lon) grid boxes for AIRS-OMI products, and 0.8 degree lat x 0.8 degree lon grid boxes for the CrIS products. The single, center most target within each box is selected to be included in the dataset. The dataset provides both day and night time coverage.

The CrIS products described in this document are generated from 2 input sources. TROPES CrIS products from February 1, 2021 through May 21, 2021 were generated from L1B input files from the Suomi-NPP CrIS instrument. Due to the loss of the Longwave Band on the side A electronics on Suomi-NPP CrIS instrument first encountered on May 21, 2021, subsequent CrIS processing has switched to using the L1B input files from the JPSS1/NOAA20 CrIS instrument in order to mitigate impact on TROPES retrieval product accuracy.

**Table 1.** Datasets / collections described in this document.

| Long Name   | Short Name         | DOI                  |
|---|--------------------|----------------------|
| <b>Standard Products</b>  |                    |                      |
| TROPES AIRS-OMI L2 Ozone for Forward Stream, Standard Product       | TRPSDL2O3AIRSOMIFS | 10.5067/V9HA0ZB6Y3UZ |
| TROPES OMI L2 Ozone for Forward Stream, Standard Product            | TRPSDL2O3OMIFS     | 10.5067/HL2UFH62ELJO |
| TROPES AIRS L2 Ozone for Forward Stream, Standard Product           | TRPSDL2O3AIRSFS    | 10.5067/1OOD0AX232CJ |
| TROPES AIRS L2 Carbon Monoxide for Forward Stream, Standard Product | TRPSDL2COAIRSFS    | 10.5067/I1NONOEPXLHS |
| TROPES AIRS L2 Atmospheric Temperature for Forward Stream, Standard | TRPSDL2TATMAIRFS   | 10.5067/XGCPC0JSDJCN |

| Long Name  | Short Name       | DOI                  |
|--|------------------|----------------------|
| Product  |                  |                      |
| TROPESS AIRS L2 Deuterated Water Vapor for Forward Stream, Standard Product  | TRPSDL2HDOAIRSFS | 10.5067/K3OGAJGRUAB8 |
| TROPESS AIRS L2 Water Vapor for Forward Stream, Standard Product             | TRPSDL2H2OAIRSFS | 10.5067/GAAB1GIBBQKU |
| TROPESS AIRS L2 Methane for Forward Stream, Standard Product                 | TRPSDL2CH4AIRSFS | 10.5067/LP1B3RFV5WK7 |
| TROPESS AIRS L2 Ammonia for Forward Stream, Standard Product                 | TRPSDL2NH3AIRSFS | 10.5067/EYXLPVGTSWFF |
| TROPESS CrIS L2 Ozone for Forward Stream, Standard Product                   | TRPSDL2O3CRSFS   | 10.5067/8LMUGJ8X1ZXB |
| TROPESS CrIS L2 Carbon Monoxide for Forward Stream, Standard Product         | TRPSDL2COCRSFS   | 10.5067/EA7G2TTV84RV |
| TROPESS CrIS L2 Atmospheric Temperature for Forward Stream, Standard Product | TRPSDL2TATMCRSFS | 10.5067/XL382B4YZJP5 |
| TROPESS CrIS L2 Deuterated Water Vapor for Forward Stream, Standard Product  | TRPSDL2HDOCRSFS  | 10.5067/XTPEDYJ62GGN |
| TROPESS CrIS L2 Water Vapor for Forward Stream, Standard Product             | TRPSDL2H2OCSRFS  | 10.5067/YUE7KKLKA1RS |
| TROPESS CrIS L2 Methane for Forward Stream, Standard Product                 | TRPSDL2CH4CRSFS  | 10.5067/MRTPR45H95EC |
| TROPESS CrIS L2 Ammonia for Forward Stream, Standard Product                 | TRPSDL2NH3CRSFS  | 10.5067/B4TF7ND8A3O7 |

| Long Name  | Short Name        | DOI                  |
|--|-------------------|----------------------|
| TROPESS CrIS L2 Peroxyacetyl for Forward Stream, Standard Product                  | TRPSDL2PANCRSFS   | 10.5067/MQITF51HVPNW |
| TROPESS CrIS-JPSS1 L2 Ozone for Forward Stream, Standard Product                   | TRPSDL2O3CRS1FS   | 10.5067/WUKWENW76N5P |
| TROPESS CrIS-JPSS1 L2 Carbon Monoxide for Forward Stream, Standard Product         | TRPSDL2COCRS1FS   | 10.5067/BYIIUV3PR9L6 |
| TROPESS CrIS-JPSS1 L2 Atmospheric Temperature for Forward Stream, Standard Product | TRPSDL2TATMCRS1FS | 10.5067/DBWOVPBIHL90 |
| TROPESS CrIS-JPSS1 L2 Deuterated Water Vapor for Forward Stream, Standard Product  | TRPSDL2HDOCRS1FS  | 10.5067/WS2EO2ZDOM75 |
| TROPESS CrIS-JPSS1 L2 Water Vapor for Forward Stream, Standard Product             | TRPSDL2H2OGRS1FS  | 10.5067/MRHSM2PY0DZZ |
| TROPESS CrIS-JPSS1 L2 Methane for Forward Stream, Standard Product                 | TRPSDL2CH4CRS1FS  | 10.5067/QOFZLQYMGA72 |
| TROPESS CrIS-JPSS1 L2 Ammonia for Forward Stream, Standard Product                 | TRPSDL2NH3CRS1FS  | 10.5067/7I3KMUCCJNEN |
| TROPESS CrIS-JPSS1 L2 Peroxyacetyl for Forward Stream, Standard Product            | TRPSDL2PANCRS1FS  | 10.5067/W0W6L8M6J85X |
| <b>Summary Products</b>  |                   |                      |

|   |                    |                      |
|---|--------------------|----------------------|
| TROPESS AIRS-OMI L2 Ozone for Forward Stream, Summary Product | TRPSYL2O3AIRSOMIFS | 10.5067/YOQS41ON99CE |
| TROPESS OMI L2 Ozone for                                      | TRPSYL2O3OMIFS     | 10.5067/ZFQQYOR9H4OX |

|   |                  |                      |
|---|------------------|----------------------|
| Forward Stream, Summary Product   |                  |                      |
| TROPESS AIRS L2 Ozone for Forward Stream, Summary Product                   | TRPSYL2O3AIRSFS  | 10.5067/C1MS8SM5FBDO |
| TROPESS AIRS L2 Carbon Monoxide for Forward Stream, Summary Product         | TRPSYL2COAIRSFS  | 10.5067/GRQCDD4L9P18 |
| TROPESS AIRS L2 Atmospheric Temperature for Forward Stream, Summary Product | Not Provided     | N/A                  |
| TROPESS AIRS L2 Deuterated Water Vapor for Forward Stream, Summary Product  | TRPSYL2HDOAIRSFS | 10.5067/2UILXXXCZLQN |
| TROPESS AIRS L2 Water Vapor for Forward Stream, Summary Product             | Not Provided     | N/A                  |
| TROPESS AIRS L2 Methane for Forward Stream, Summary Product                 | TRPSYL2CH4AIRSFS | 10.5067/2N3XGOWWH69U |
| TROPESS AIRS L2 Ammonia for Forward Stream, Summary Product                 | TRPSYL2NH3AIRSFS | 10.5067/NJU5C9752RD4 |
| TROPESS CrIS L2 Ozone for Forward Stream, Summary Product                   | TRPSYL2O3CRSFS   | 10.5067/LT66296ATQD7 |
| TROPESS CrIS L2 Carbon Monoxide for Forward Stream, Summary Product         | TRPSYL2COCRSFS   | 10.5067/VJPF383IL5E1 |
| TROPESS CrIS L2 Deuterated Water Vapor for Forward Stream, Summary Product  | TRPSYL2HDOCRSFS  | 10.5067/5X25TK595WAF |
| TROPESS CrIS L2 Methane for Forward Stream, Summary Product                 | TRPSYL2CH4CRSFS  | 10.5067/DBLUVSN1KWX2 |

|  |                 |                      |
|--|-----------------|----------------------|
| TROPESS CrIS L2 Ammonia for Forward Stream, Summary Product      | TRPSYL2NH3CRSFS | 10.5067/87GYER1R69D2 |
| TROPESS CrIS L2 Peroxyacetyl for Forward Stream, Summary Product | TRPSYL2PANCRSFS | 10.5067/ITM51B0FIBDV |
| <b>Mega City Products</b><br>See Appendix: Mega Cities           |                 |                      |

## o 1.1 Description of the Datasets

TROPESS L2 Standard Products are for users that are doing full analysis with averaging kernel and covariance corresponding to retrieved vertical profiles. L2 Summary products have a smaller files size and are more convenient for first-look and rapid analysis. Summary products are total and partial column product and include column averaging kernel.

These data are processed by the NASA TRopospheric Ozone and Precursors from Earth System Sounding (TROPESS) project, which uses an optimal estimation algorithm whose heritage comes from the NASA Tropospheric Emission Spectrometer (TES) satellite project (Beer et al, 2006, Bowman et al, 2006).

Consequently, the data sets include the retrieved atmospheric states (vertical profiles), and diagnostic information including observation operators, (averaging kernels), to facilitate data assimilation and intercomparison, and error covariances that characterize the accuracy and precision. The organization of the data structures and variables described in this document are similar to the TES data. More information about these data can be found at <https://tes.jpl.nasa.gov/> and [User Guides](#).

## o 1.2 TRopospheric Ozone and Precursors from Earth System Sounding (TROPESS) Description

Tropospheric sounding from satellite observations provides critical information about atmospheric composition and its impact on human health and climate. The TRopospheric Ozone and Precursors from Earth System Sounding (TROPESS) project generates Earth System Data Records (ESDRs) of ozone and other atmospheric constituents by processing data from multiple satellites through a common retrieval algorithm and ground data system. These products are rigorously validated using uncertainty analysis in conjunction with independent measurements. These steps quantify the accuracies needed to make long-term trends through multi-satellite records and chemical data assimilation.



The TROPES activity leverages innovations pioneered by the Tropospheric Emission Spectrometer (TES) team in combining data from multiple satellites to form a common retrieval framework, which is known as the MUlti-SpEctra, MUlti-SpEcies, Multi-SEnsors (MUSES) science data processing system (MUSES-SDPS). This framework has been applied to a combined suite of hyper-spectral thermal infrared, near-infrared, and ultraviolet instruments to generate ESDRs of Earth's tropospheric composition, including ozone, carbon monoxide, and water vapor deuterium. The ESDRs resulting from combinations of instruments/wavelength regions have increased sensitivity to the lower troposphere relative to composition measurements derived from any single instrument.

## 0 1.3 Data Disclaimer

While atmospheric profiles of these species are provided from the surface to the top-of-atmosphere, the user should primarily focus their analyses on the vertical range where the sensitivity of the measurements is greatest. That sensitivity can vary, and should be diagnosed from the averaging kernel (Bowman *et al.*, 2002). For most species, peak sensitivity is in the free troposphere. However, for some species, such as NH<sub>3</sub>, the sensitivity is in the lower troposphere.

The TROPES / MUSES retrievals of atmospheric composition in this collection have not yet been formally validated by aircraft or ground measurements. However, the following evaluations have been done:

- O<sub>3</sub>: Informal comparison of CrIS O<sub>3</sub> retrievals have been made with AIRS and TES data, which in turn have been validated (Nassar *et al.*, 2008; Boxe *et al.*, 2010; Verstraten *et al.*, 2013; Fu *et al.*, 2018) and show that CrIS retrievals are consistent with the AIRS and TES retrievals.
- CO: CrIS CO retrievals have been compared to MOPITT CO, which agree on average between 3-10% (Fu *et al.*, 2016).
- PAN: CrIS PAN retrievals have been informally compared with TES PAN (Payne *et al.*, 2014) and have shown to be broadly consistent. CrIS PAN data have also been provisionally validated using in situ aircraft profiles from the Atmospheric Tomography Mission (ATom).
- NH<sub>3</sub>: The CrIS NH<sub>3</sub> retrievals have been compared to CrIS retrievals processed with the algorithms described in Shepard *et al.*, (2011) and Shepard and Cady-Pereira (2015). Both algorithms are derived from the TES algorithm. The retrievals compare within expected uncertainties.

### ■ 1.3.1 Data Citation and Acknowledgment

The datasets may be acknowledged in publications using the Digital Object Identifiers (DOIs) listed in Table 1.

If you plan on using any of these data please cite the following for a general description of the TROPES retrieval algorithm: (Bowman *et al.*, 2006; Worden *et al.*, 2012; Fu *et al.*, 2018).

In addition, there are several specific algorithm papers related to the retrieval and validation of each species, please cite depending on which data product is used:

- For validation methods and indirect comparisons with TES ozone retrievals, please reference the following: H. Worden *et al.* (2007), Boxe *et al.* (2010), Verstraeten *et al.*, (2013).
- For validation of CO retrievals please reference the following: Luo *et al.* (2007a; 2007b), Fu *et al.*, (2016), Buchholz *et al.*, (2021).
- For validation of NH<sub>3</sub> retrievals please cite the following: Shephard and Cady-Pereira (2015).
- For discussion of the PAN retrieval please cite: Payne *et al.*, (2014).

### ■ 1.3.2 Contact Information

Please contact John Worden ([john.r.worden@jpl.nasa.gov](mailto:john.r.worden@jpl.nasa.gov)) for any additional information needed about these data.

### ■ 1.3.3 Version 1

This is the first version of this product.

### ■ 1.3.4 Algorithm Version

| Algorithm Version | Change Description   |
|-------------------|--|
| 1.20.0            | Fixed the retrieval strategy for Methanol for CrIS. Other products are not affected by this change.  |
| 1.19.0            | Modified radiative transfer approach <ul style="list-style-type: none"> <li>● Switched from using VLIDORT 2.5 to an approach using scalar LIDORT 3.8<sup>1</sup></li> <li>● Utilizing a Principal Component Analysis based approach to speed up multiple scattering computations<sup>2</sup></li> <li>● Incorporated the use of the ReFRACtor reusable software framework for atmospheric composition</li> </ul> |

| Algorithm Version | Change Description  |
|-------------------|---|
|                   | <ol style="list-style-type: none"> <li>1. Spurr, R., Christi, M. (2019). <i>The LIDORT and VLIDORT Linearized Scalar and Vector Discrete Ordinate Radiative Transfer Models: Updates in the Last 10 Years</i>. In: Kokhanovsky, A. (eds) <i>Springer Series in Light Scattering</i>. Springer Series in Light Scattering. Springer, Cham. <a href="https://doi.org/10.1007/978-3-030-03445-0_1">https://doi.org/10.1007/978-3-030-03445-0_1</a></li> <li>2. Natraj, V., Shia, R. L., &amp; Yung, Y. L. (2010). <i>On the use of principal component analysis to speed up radiative transfer calculations</i>. <i>Journal of Quantitative Spectroscopy and Radiative Transfer</i>, 111(5), 810-816.</li> </ol> |
| 1.18.0            | <p>Add `xa` prior variable to PAN summary products</p> <p>First public release for all summary products</p> <p>Use `desert_emis_qa` quality &gt; 0.925` filter for PAN</p>  |
| 1.17.0            | <p>Implement strategy for CrIS to move the methanol step processing AFTER the ammonia step.</p> <p>Correcting AveragingKernelDiagonal calculation.</p>  |
| 1.16.0            | <p>Using CAMELv2 emissivity dataset instead of UWIS for AIRS and CrIS</p> <p>Incorporated a new strategy in CrIS processing without the mid-wave channel. This will not produce HDO and CH4 products.</p> <p>Fixed a bug in prior column calculations</p> <p>Adding H2O columns to CO and PAN summary products</p>  |
| 1.15.0            | <p>Processing pipeline is fully implemented in Python.</p> <p>This introduced statistically insignificant differences in the products compared to previous version 1.14.0.</p>  |
| 1.14.0            | <p>PAN updates: Fixed the code for handling negative PAN values.</p>  |

| Algorithm Version | Change Description  |
|-------------------|---|
| 1.13.0            | Incorporated a fix to improve NLLS Solver output.   |
| 1.12.0            | Fixed HDO error calculation.<br>Updated standard product files and official summary products.                                     |
| 1.11.0            | New NH3 microwindows for AIRS.  |
| 1.10.0            | Fixed to use correct observation time in CrIS products.   |
| 1.9.0             | New NH3 microwindows for CrIS data processing, improved NH3 algorithm.  |
| 1.8.0             | Implemented the use of a new CO covariance matrix.<br>For AIRS data processing, better handling of solar irradiance coefficients. |
| 1.7.0             | OMI Retrieval algorithm updates.  |
| 1.6.0             | AIRS retrieval algorithm updates.   |
| 1.5.0             | First Release.  |

## o 1.4 Quality Flags

There are a number of internal metrics of retrieval performance, e.g., statistics of spectral residuals, that are evaluated and used to calculate quality flags. For the standard products, these quality flags have already been applied such that only data that satisfies these flags are provided. Since quality flags vary by species, not all species are available at the same geolocation. Users will need to use the geolocation fields (see § 3.3) to match the targets for comparing species. Code for matching targets can be found in links in § 5.1.1 *Code examples: Python, Matlab, IDL*. Quality flags are subject to change in light of new sources of validation. The approaches used are described in detail in algorithm documentation.

## ● 2.0 Data Organization

These data represent a compilation of observations of different species (O<sub>3</sub>, CO, NH<sub>3</sub>, CH<sub>4</sub>, PAN, HDO, H<sub>2</sub>O, and TATM) derived from the CrIS-SNPP, and AIRS-Aqua, OMI-Aura L1B retrievals.

There is 1 file per species, and the data are divided into a series of daily segments with one segment per file.

Each file contains all observations of a given species made during a period of exactly 1 day, identified by the date in the filename.

### ○ 2.1 File Format and Structure

The files in these collections 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:

<https://www.unidata.ucar.edu/software/netcdf/>.

### ○ 2.2 File Naming Convention

The filenames for these data products are described in Table 2, where YYYYMMDD should be replaced by the observation date.

Below is an example of the general TROPES file naming convention used to identify each granule:

**[ProjectID]**\_**[Instrument-Platform]**\_**[ProductLevel]**\_**[ProductType]**\_**[ProductName]**\_**[DateStamp]**\_**[AlgorithmName]**\_**[AlgorithmVersion]**\_**[ProcessingStrategy]**\_**[FormatVersion].nc**

where:

- **[ProjectID]**: corresponds to the project identifier for the collection (i.e., TROPES).
- **[Instrument-Platform]**: corresponds to the instrument/sensor and corresponding platform used as L1B input dataset(s) used in the generation of the L2 data products. For Collections where more than one **[INSTRUMENT-PLATFORM]** combination is used as throughout the

record, the original heritage of the L1B input datasets will be traceable in the filename. For sensor-platform sets we use a '-' (dash) for the platform specification. For multi-sensor and platform combinations, we use an '\_' (underscore) to delineate the different instruments.

Examples:

- *Single sensor: [INSTRUMENT-PLATFORM]*
    - [AIRS-Aqua]
    - [OMI-Aura]
    - [CrIS-SNPP]
    - [CrIS-JPSS1]
    - [CrIS-JPSS2]
    - [TROPOMI-S5P]
  - *Multi-sensor: [INSTRUMENT-PLATFORM\_INSTRUMENT-PLATFORM]*
    - [AIRS-Aqua\_OMI-Aura]
    - [CrIS-SNPP\_TROPOMI-S5P]
    - [CrIS-JPSS1\_TROPOMI-S5P]
    - [CrIS-JPSS2\_TROPOMI-S5P]
- 
- **[ProductLevel]:** The data processing level of the file. All TROPES collections are Level 2 (L2) products, following the [NASA Data Processing Levels](#).
  - **[ProductName]:** Short name to describe the data product name. Allowable values: Full, Standard and Summary. Standard products contain a subset of the parameters in the Full archival product.
  - **[ProductType]:** A short name to describe the primary atmospheric species or parameter included in the data file. Gas phase species names follow the chemical compound name and contain the symbols of the atoms of the elements present in the compound, as well as how many there are for each element in the form of subscripts. Acceptable values are:
    - O3 = Ozone
    - CO = Carbon monoxide
    - NH3 = Ammonia
    - PAN = Peroxyacetyl nitrate
    - CH4 = Methane
    - HDO = Deuterated water vapor
    - H2O = Water vapor
    - TATM = Atmospheric temperature
  - **[DateStamp]:** Date stamp is the observation period of the data contained in the product. Products are aggregated daily and will use the [DateStamp] notation YYYYMMDD, where:
    - YYYY: is the full calendar year.
    - MM: is the 2-digit month of the year. Single-digit months employ a leading zero.
    - DD: is the 2-digit day of the month. Single-digit days employ a leading zero.
  - **[AlgorithmName]:** The algorithm used to produce the data products (MUSES). Information indicating where the data were processed is covered in the global attributes.
  - **[AlgorithmVersion]:** 2-digit (zero-padded) version number following capital "R". The initial version will be R0.0, with the first release being R1.0. This will reset only with Major version updates. Example: "Rxp"
  - **[ProcessingStrategy]:** a two-letter code for the processing strategy used in generating the L2 science data products. Allowable values are:

- FS: Forward Stream. Low-latency data products generated from the MUSES-SDPS forward processing streams.
- RS: Reanalysis Stream. Products are generated from the MUSES-SDPS reanalysis processing streams.
- SC: Special Collections. Provided on an as-needed and as-available basis to support NASA field missions and individual-investigator requests over specific regions.
- **FormatVersion:** 2-digit number, prefixed by a capital F. A change in the format version signals a change in the netcdf file layout, which would likely require a change in the users' data readers. Example: "Fxp".

**Table 2. TROPES file naming conventions**

| Short Name         | Filename Pattern   |
|--------------------|--|
| TRPSDL2O3AIRSOMIFS | TROPES_AIRS-Aqua_OMI-Aura_L2_Standard_O3_20200912_MUSES_R1p11_FS_F0p1.nc |
| TRPSDL2O3OMIFS     | TROPES_OMI-Aura_L2_Standard_O3_20200912_MUSES_R1p11_FS_F0p1.nc           |
| TRPSDL2O3AIRSFS    | TROPES_AIRS-Aqua_L2_Standard_O3_20200912_MUSES_R1p11_FS_F0p1.nc          |
| TRPSDL2COAIRSFS    | TROPES_AIRS-Aqua_L2_Standard_CO_20200912_MUSES_R1p11_FS_F0p1.nc          |
| TRPSDL2TATMAIRSFS  | TROPES_AIRS-Aqua_L2_Standard_TATM_20200912_MUSES_R1p11_FS_F0p1.nc        |
| TRPSDL2HDOAIRSFS   | TROPES_AIRS-Aqua_L2_Standard_HDO_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSDL2H2OAIRSFS   | TROPES_AIRS-Aqua_L2_Standard_H2O_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSDL2CH4AIRSFS   | TROPES_AIRS-Aqua_L2_Standard_CH4_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSDL2NH3AIRSFS   | TROPES_AIRS-Aqua_L2_Standard_NH3_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSDL2O3CRSFS     | TROPES_CrIS-SNPP_L2_Standard_O3_20200912_MUSES_R1p11_FS_F0p1.nc          |
| TRPSDL2COCRSFS     | TROPES_CrIS-SNPP_L2_Standard_CO_20200912_MUSES_R1p11_FS_F0p1.nc          |
| TRPSDL2TATMCRSFS   | TROPES_CrIS-SNPP_L2_Standard_TATM_20200912_MUSES_R1p11_FS_F0p1.nc        |
| TRPSDL2HDOCRSFS    | TROPES_CrIS-SNPP_L2_Standard_HDO_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSDL2H2OCSRFS    | TROPES_CrIS-SNPP_L2_Standard_H2O_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSDL2NH3CRSFS    | TROPES_CrIS-SNPP_L2_Standard_NH3_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSDL2PANCRSFS    | TROPES_CrIS-SNPP_L2_Standard_PAN_20200912_MUSES_R1p11_FS_F0p1.nc         |
| TRPSYL2O3AIRSOMIFS | TROPES_AIRS-Aqua_OMI-Aura_L2_Summary_O3_20200912_MUSES_R1p11_FS_F0p1.nc  |

|                  |  |
|------------------|--|
| TRPSYL2O3OMIFS   | TROPESS_OMI-Aura_L2_Summary_O3_20200912_MUSES_R1p11_FS_F0p1.nc   |
| TRPSYL2O3AIRSFS  | TROPESS_AIRS-Aqua_L2_Summary_O3_20200912_MUSES_R1p11_FS_F0p1.nc  |
| TRPSYL2COAIRSFS  | TROPESS_AIRS-Aqua_L2_Summary_CO_20200912_MUSES_R1p11_FS_F0p1.nc  |
| TRPSYL2HDOAIRSFS | TROPESS_AIRS-Aqua_L2_Summary_HDO_20200912_MUSES_R1p11_FS_F0p1.nc |
| TRPSYL2CH4AIRSFS | TROPESS_AIRS-Aqua_L2_Summary_CH4_20200912_MUSES_R1p11_FS_F0p1.nc |
| TRPSYL2NH3AIRSFS | TROPESS_AIRS-Aqua_L2_Summary_NH3_20200912_MUSES_R1p11_FS_F0p1.nc |
| TRPSYL2O3CRSFS   | TROPESS_CrIS-SNPP_L2_Summary_O3_20200912_MUSES_R1p11_FS_F0p1.nc  |
| TRPSYL2COCRSFS   | TROPESS_CrIS-SNPP_L2_Summary_CO_20200912_MUSES_R1p11_FS_F0p1.nc  |
| TRPSYL2HDOCRSFS  | TROPESS_CrIS-SNPP_L2_Summary_HDO_20200912_MUSES_R1p11_FS_F0p1.nc |
| TRPSYL2NH3CRSFS  | TROPESS_CrIS-SNPP_L2_Summary_NH3_20200912_MUSES_R1p11_FS_F0p1.nc |
| TRPSYL2PANCRSFS  | TROPESS_CrIS-SNPP_L2_Summary_PAN_20200912_MUSES_R1p11_FS_F0p1.nc |

## 0 2.3 Key Science Data Fields

The TROPESS L2 Standard Products have been designed with users in mind. The Key Science Data Fields expected to be of interest for most users are:

**Table 3.** Key science data fields.

| Data Field Name  | Long_Name/Description   | Type  | Dimensions           | Undefined Value | Units |
|------------------|---|-------|----------------------|-----------------|-------|
| x                | Retrieved state, as volume mixing ratio (VMR) relative to dry air.  | float | target, level        | -999.0          | 1     |
| xa               | A priori state, as volume mixing ratio relative to dry air  | float | target, level        | -999.0          | 1     |
| averaging_kernel | Sensitivity of the retrieved state to the true state. For CO, O3, and NH3 retrieved states are in ln(VMR). For PAN, | float | target, level, level | -999.0          | 1     |



|                   |   |       |                      |        |   |
|-------------------|---|-------|----------------------|--------|---|
|                   | retrieved states are linear.  |       |                      |        |   |
| observation_error | Measurement + systematic + cross-state error. Use for comparisons with other measurements and for assimilations | float | target, level, level | -999.0 | 1 |

## ● 3.0 Data Contents

### o 3.1 Data Set Attributes (File Metadata)

A summary of global attributes present in all files is shown in Table 4 below.

**Table 4.** Global data attributes.

| Global Attribute              | Description                            | Type   |
|-------------------------------|--|--------|
| ShortName                     | ESDT short product name                | string |
| LongName                      | Full product name                      | string |
| VersionID                     | Version ID for this product            | int    |
| IdentifierProductDOIAuthority | Organization providing DOI information | string |
| IdentifierProductDOI          | DOI value                              | string |
| Format                        | Data file format                       | string |
| ProcessingLevel               | Level of data product                  | string |
| SouthBoundingCoordinate       | South bounding latitude                | double |
| NorthBoundingCoordinate       | North bounding latitude                | double |
| WestBoundingCoordinate        | West bounding longitude                | double |
| EastBoundingCoordinate        | East bounding longitude                | double |
| Conventions                   | Name of convention(s) for metadata     | string |
| MeasuredParameter             | Species measured for this product      | string |

|            |                                   |        |
|------------|-----------------------------------|--------|
| Platform   | Platform for measuring instrument | string |
| Instrument | The measuring instrument          | string |

## 0 3.2 Variable Data Attributes

Each variable has its own associated attributes. Variable attributes are a CF standard and are used to describe the variable in more detail to properly interpret its value (see Table 5).

**Table 5.** Per variable data attributes.

| Variable Attribute | Description  | Type   |
|--------------------|--|--------|
| _FillValue         | single value indicating the data point contains fill instead of valid data   | float  |
| long_name          | longer name describing the quantity being represented; typically used for plot titles  | string |
| standard_name      | standard name from CF standard name table, if one exists for the quantity being represented  | string |
| comment            | description or comment for the quantity being represented  | string |
| units              | units for variables that represent physical quantities   | string |
| coordinates        | space-separated list of the names of other variables that are coordinates for this variable  | string |
| missing_value      | same as _FillValue   | float  |
| source             | identifies variable from the input product from which this quantity is derived from; used internally by TROPES team to trace back to source. | string |

## 0 3.3 Geolocation Fields

Geolocation fields appear for every data observation and are shown in Table 6. Note that the geolocation for AIRS and CrIS is specified differently in the TROPES products, following the

geolocation information in the respective L1B files. CrIS geolocation is specified by along-track and cross-track field of regard (FOR) indices within a granule, and by field of view (FOV) within each FOR. AIRS geolocation is specified according to individual FOVs along-track and cross-track within each granule.

**Table 6.** *Geolocation fields.*

| Global Attribute        | Description                              | Type  |
|-------------------------|--|-------|
| CrIS Geolocation Fields |  |       |
| cris_atrack             | CrIS Suomi-NPP along-track index (1-45)  | int   |
| cris_xtrack             | CrIS Suomi-NPP cross-track index (1-30)  | int   |
| cris_fov                | CrIS Suomi-NPP field-of-view index (1-9) | int   |
| cris_view_ang           | CrIS Suomi-NPP view angle                | float |
| cris_granule            | CrIS Suomi-NPP granule number (1-240)    | int   |
| AIRS Geolocation Fields |  |       |
| airs_atrack             | AIRS along-track index (1-135)           | int   |
| airs_xtrack             | AIRS cross-track index (1-90)            | int   |
| airs_view_ang           | AIRS scan angle                          | float |
| airs_granule            | AIRS granule number (1-240)              |       |
| OMI Geolocation Fields  |  |       |
| omi_atrack_index        | OMI along-track index (1-1643)           | int   |
| omi_xtrack_uv1          | OMI cross-track UV1 index (1-30)         | int   |
| omi_xtrack_uv2          | OMI cross-track UV2 index (1-60)         | int   |
| omi_view_ang            | OMI UV2 solar zenith angle               | float |

Since quality flags vary by species, some species may not be available at the same geolocation. Consequently, users are recommended to employ these geolocation fields to match the targets for comparing species (for more information, see §5.1.1 *Code examples: Python, Matlab, IDL*).

## 0 3.4 Dimensions

The variable dimensions associated with the data products are shown in Table 7.

**Table 7.** Data dimensions.

| Global Attribute | Description  | Dimension Size  |
|------------------|--|---|
| target           | target/observation identifier  | Varies*   |
| level            | atmospheric pressure in hPa  | CO: 14<br>NH <sub>3</sub> : 15<br>PAN: 16<br>O <sub>3</sub> : 26<br>CH <sub>4</sub> : 26<br>HDO: 17<br>H <sub>2</sub> O: 17<br>TATM: 31 |
| datetime_utc_dim | UTC expressed as an array of integers year, month, day, hour, minute, second | 6   |

\*Note: Dimensions of “target” vary by file and date. Number of targets range from (7000-10000).

## ● 4.0 Products/Parameters

The science data variables are described in the table below

### ○ 4.1 L2 Standard Product Data Fields

The science data fields are shown in Table 8.

**Table 8.** Data fields.

| Data Field Name | Long_Name/Description                       | Type   | Dimensions | Undefined Value | Units                    |
|-----------------|---|--------|------------|-----------------|--------------------------|
| longitude       | longitude of earth view target center       | float  | target     | -999.0          | degrees_east             |
| latitude        | latitude of earth view target center        | float  | target     | -999.0          | degrees_north            |
| time            | Earth view target mid time as International | double | target     | -999.0          | seconds since 1993-01-01 |

|               |   |        |                                 |        |          |
|---------------|---|--------|---------------------------------|--------|----------|
|               | Atomic Time (TAI)<br>seconds since 1993-01-01<br>00:00:00                             |        |                                 |        | 00:00:00 |
| datetime_utc  | UTC expressed as an<br>array of integers year,<br>month, day, hour, minute,<br>second | int    | target,<br>datetime_utc<br>_dim | -999   | 1        |
| year_fraction | Year plus fraction of the<br>year   | double | target                          | -999.0 | year     |
| altitude      | Altitude at each target   | float  | target, level                   | -999.0 | m        |
| pressure      | Atmospheric pressure<br>used for retrieval at each<br>target.                         | float  | target, level                   | -999.0 | hpa      |
| target_id     | Unique id that identifies<br>observations across all<br>product files.                | long   | target                          | -999   | 1        |

|                   |  |       |                         |        |   |
|-------------------|--|-------|-------------------------|--------|---|
| x                 | Retrieved state, as<br>volume mixing ratio<br>(VMR) relative to dry air.   | float | target, level           | -999.0 | 1 |
| averaging_kernel  | Sensitivity of the<br>retrieved state to the<br>true state. For CO, O3,<br>and NH3 retrieved states<br>are in ln(VMR). For PAN,<br>retrieved states are<br>linear. | float | target, level,<br>level | -999.0 | 1 |
| observation_error | Measurement +<br>systematic + cross-state<br>error. Use for<br>comparisons with other<br>measurements and for<br>assimilations                                     | float | target, level,<br>level | -999.0 | 1 |
| signal_dof        | Degrees of Freedom for<br>Signal; trace of averaging<br>kernel   | float | target                  | -999.0 | 1 |

|                |   |       |               |        |     |
|----------------|---|-------|---------------|--------|-----|
| x_test         | The estimated state for target 0 based on x[0], xa[0], and avg_kernel[0], as volume mixing ratio (VMR) relative to dry air. | float | level         | -999.0 | 1   |
| xa             | A priori state, as volume mixing ratio relative to dry air  | float | target, level | -999.0 | 1   |
| land_flag      | If target is over land == 1, otherwise == 0   | Int   | target        | -999   | N/A |
| day_night_flag | If target is during the day == 1, otherwise == 0  | Int   | target        | -999   | N/A |

## o 4.2 L2 Summary Product Data Fields

See L2 Summary Product User's Guide.

# ● 5.0 Options for Reading the Data

## o 5.1 Tools/Programming Languages

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.

The following link provides a list of software and tools for manipulating and displaying NetCDF (\*.nc) data files: <https://www.unidata.ucar.edu/software/netcdf/software.html>.

### ■ 5.1.1 Code examples: Python, Matlab, IDL

Code examples for product usage from different programming languages are available at: <https://github.com/NASA-TROPESS>. In addition, code for matching targets is included at the link above.

## 0 5.2 Command Line Utilities

### ■ 5.2.1 ncdump

Outputs contents of a netCDF file as ascii. From Unidata, part of the NetCDF libraries. ncdump documentation:

[https://www.unidata.ucar.edu/software/netcdf/docs/netcdf\\_utilities\\_guide.html#ncdump\\_guide](https://www.unidata.ucar.edu/software/netcdf/docs/netcdf_utilities_guide.html#ncdump_guide)

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.

### ■ 5.2.2 NCO

NCO is a package of command-line utilities for manipulating netCDF files. Each NCO command does one very specific kind of manipulation, but you can combine them to powerful effect.

NCO Documentation: <http://nco.sourceforge.net/nco.html>

- [ncap](#) and [ncap2](#): netCDF Arithmetic Processors ([examples](#)) -- algebraic manipulation of data
- [ncatted](#): netCDF Attribute Editor ([examples](#)) -- modify metadata
- [ncbo](#): netCDF Binary Operator (includes `ncadd`, `ncsubtract`, `ncmultiply`, `ncdivide`) -- ([examples](#)) -- math involving two files
- [ncea](#): netCDF Ensemble Averager ([examples](#)) -- average across multiple input files
- [ncecat](#): netCDF Ensemble Concatenator ([examples](#)) -- combine files into a single record
- [ncflint](#): netCDF File Interpolator ([examples](#)) -- combine inputs via weighted interpolation
- [ncks](#): netCDF Kitchen Sink ([examples](#)) -- copies data to ascii or output file
- [ncpdq](#): netCDF Permute Dimensions Quickly, Pack Data Quietly ([examples](#)) -- rearrange dimensions or pack data
- [ncra](#): netCDF Record Averager ([examples](#)) -- average across time (record dimension)
- [ncrcat](#): netCDF Record Concatenator ([examples](#)) -- combine sequential files
- [ncrename](#): netCDF Renamer ([examples](#)) -- rename dimensions, variables, or attributes
- [ncwa](#): netCDF Weighted Averager ([examples](#)) -- weighted average over one file

## 0 5.3 GUI Tools

### ■ 5.3.1 Panoply

Panoply is a good generic and free visualization tool for any netCDF file. A strength

of the tool is that data can be previewed “remotely” over the network – i.e., a user can preview file content of HDF files stored on a remote site, without downloading them.

Panoply is available from Goddard Institute for Space Studies (GISS) here:

<https://www.giss.nasa.gov/tools/panoply/>

### ■ 5.3.2 HDFView

HDFView is a visual tool for browsing and editing HDF (HDF5 and HDF4) and NetCDF files. It can be downloaded from here: <https://www.hdfgroup.org/downloads/hdfview/>.

## ● 6.0 GES DISC Data Services Help Desk

If you need assistance or wish to report a problem:

**Email:** [gsfc-dl-help-disc@mail.nasa.gov](mailto: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 610.2 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 Obtain Data in NetCDF Format via SSW](#)

[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](#)



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## ● 8.0 References

Beer, R.: TES on the Aura mission: Scientific objectives, measurements, and analysis overview. *IEEE Trans. on Geosci. Remote Sensing*, 44(5):1102–1105, 2006.

Bowman, K. W., Steck, T., Worden, H. M., Worden, J., Clough, S., and Rodgers, C.: Capturing time and vertical variability of tropospheric ozone: A study using TES nadir retrievals. *J. Geophys. Res.: Atmos.*, 107(D23):ACH 21–1–ACH 21–11, 2002.

Bowman, K. W., Rodgers, C. D., Kulawik, S. S., Worden, J., Sarkissian, E., Osterman, G., Steck, T., Lou, M., Eldering, A., Shephard, M., Worden, H., Lampel, M., Clough, S., Brown, P., Rinsland, C., Gunson, M., and Beer, R.: Tropospheric Emission Spectrometer: Retrieval method and error analysis. *IEEE Trans. on Geosci. Remote Sensing*, 44(5), 2006.

Boxe, C. S., Worden, J. R., Bowman, K. W., Kulawik, S. S., Neu, J. L., Ford, W. C., Osterman, G. B., Herman, R. L., Eldering, A., Tarasick, D. W., Thompson, A. M., Doughty, D. C., Hoffmann, M. R. and Oltmans, S. J.: Validation of northern latitude Tropospheric Emission Spectrometer stare ozone profiles with ARC-IONS sondes during ARCTAS: sensitivity, bias and error analysis, *Atmos. Chem. and Phys.*, 10(20), 9901–9914, doi:10.5194/acp-10-9901-2010, 2010.

Buchholz, R., et al., Air pollution trends measured from Terra: CO and AOD over industrial, fire-prone, and background regions, *Remote Sensing of Environment*, in press, 2021.

Fu, D., Bowman, K. W., Worden, H. M., Natraj, V., Worden, J. R., Yu, S., Veefkind, P., Aben, I., Landgraf, J., Strow, L., and Han, Y.: High-resolution tropospheric carbon monoxide profiles retrieved from CrIS and TROPOMI. *Atmos. Meas. Tech.*, 9(6), 2567–2579, 2016.

Fu, D., Kulawik, S. S., Miyazaki, K., Bowman, K. W., Worden, J. R., Eldering, A., Livesey, N. J., Teixeira, J., Irion, F. W., Herman, R. L., Osterman, G. B., Liu, X., Levelt, P. F., Thompson, A. M. and Luo, M.: Retrievals of tropospheric ozone profiles from the synergism of AIRS and

OMI: methodology and validation, *Atmos. Meas. Tech.*, 11(10), 5587–5605, doi:10.5194/amt-11-5587-2018-supplement, 2018.

Luo, M. et al.: Comparison of carbon monoxide measurements by TES and MOPITT: Influence of a priori data and instrument characteristics on nadir atmospheric species retrievals, *J. Geophys. Res.*, 112(D9), D09303, doi:10.1029/2006JD007663, 2007a.

Luo, M. et al.: TES carbon monoxide validation with DACOM aircraft measurements during INTEX-B 2006, *J. Geophys. Res.*, 112(D24), D24S48, doi:10.1029/2007JD008803, 2007b.

Nassar, R., Logan, J., Worden, H., Megretskaia, I. A., Bowman, K., Osterman, G., Thompson, A. M., Tarasick, D. W., Austin, S., Claude, H., Dubey, M. K., Hocking, W. K., Johnson, B. J., Joseph, E., Merrill, J., Morris, G. A., Newchurch, M., Oltmans, S. J., Posny, F., and Schmidlin, F.: Validation of Tropospheric Emission Spectrometer (TES) Nadir Ozone Profiles Using Ozonesonde Measurements. *J. Geophys. Res.*, 113, 2008.

Payne, V. H., Alvarado, M. J., Cady-Pereira, K. E., Worden, J. R., Kulawik, S. S. and Fischer, E. V.: Satellite observations of peroxyacetyl nitrate from the Aura Tropospheric Emission Spectrometer, *Atmos. Meas. Tech.*, 7(11), 3737–3749, doi:10.5194/amt-7-3737-2014, 2014.

Shephard, M. W., Cady-Pereira, K. E., Luo, M., Henze, D. K., Pinder, R. W., Walker, J. T., Rinsland, C. P., Bash, J. O., Zhu, L., Payne, V. H., and Clarisse, L.: TES ammonia retrieval strategy and global observations of the spatial and seasonal variability of ammonia, *Atmos. Chem. Phys.*, 11, 10743–10763, <https://doi.org/10.5194/acp-11-10743-2011>, 2011.

Shephard, M. W., and Cady-Pereira, K. E.: Cross-track Infrared Sounder (CrIS) satellite observations of tropospheric ammonia, *Atmos. Meas. Tech.*, 8(3), 1323–1336, doi:10.5194/acpd-15-4823-2015, 2015.

Verstraeten, W. W., Boersma, K. F., Zörner, J., Allaart, M. A. F., Bowman, K. W. and Worden, J. R.: Validation of six years of TES tropospheric ozone retrievals with ozonesonde measurements: implications for spatial patterns and temporal stability in the bias, *Atmos. Meas. Tech.*, 6(5), 1413–1423, doi:10.5194/amt-6-1413-2013, 2013.

Worden, H. M., Logan, J. A., Worden, J. R., Beer, R., Bowman, K., Clough, S. A., Eldering, A., Fisher, B. M., Gunson, M. R., Herman, R. L., Kulawik, S. S., Lampel, M. C., Luo, M., Megretskaia, I. A., Osterman, G. B. and Shephard, M. W.: Comparisons of Tropospheric Emission Spectrometer (TES) ozone profiles to ozonesondes: Methods and initial results, *J. Geophys. Res.*, 112(D3), doi:10.1029/2006JD007258, 2007.

Worden, J., Kulawik, S., Frankenberg, C., Payne, V., Bowman, K., Cady-Pereira, K., Wecht, K., Lee, J.-E. and Noone, D.: Profiles of CH<sub>4</sub>, HDO, H<sub>2</sub>O, and N<sub>2</sub>O with improved lower tropospheric vertical resolution from Aura TES radiances, *Atmos. Meas. Tech.*, 5(2), 397–411, doi:10.5194/amt-5-397-2012, 2012.

## ● Appendix: Mega Cities

The table below describes the Mega City collection with a Latitude and Longitude boundary.

| Long Name                          | Short Name         | DOI                  | Lat    | Lon     |
|------------------------------------|--------------------|----------------------|--------|---------|
| <b>Mega City Standard Products</b> |                    |                      |        |         |
| Tokyo, Japan                       | TRPSDL2ALLCRSMGTOK | 10.5067/65ZEOTLVV7EZ | 35.68N | 139.77E |
| Mexico City                        | TRPSDL2ALLCRSMGMEX | 10.5067/PECEC1AZ5R1J | 19.13N | 99.40W  |
| Delhi, India                       | TRPSDL2ALLCRSMGDEL | 10.5067/NILL9KD1K78G | 29.02N | 77.38E  |
| São Paulo, Brazil                  | TRPSDL2ALLCRSMGSAO | 10.5067/SQVOPBQTHU10 | 23.50S | 46.62W  |
| Lagos, Nigeria                     | TRPSDL2ALLCRSMGLAG | 10.5067/4UH0WF2HOHBB | 6.60N  | 3.30E   |
| Los Angeles, USA                   | TRPSDL2ALLCRSMGLOS | 10.5067/0QPQFIXDET1X | 34.05N | 118.24W |
| Beijing, China                     | TRPSDL2ALLCRSMGBEI | 10.5067/IUJHNI1MM1QA | 39.91N | 116.40E |
| <b>Mega City Summary Products</b>  |                    |                      |        |         |
| Tokyo, Japan                       | TRPSYL2ALLCRSMGTOK | 10.5067/RAD13QSZ61JY | 35.68N | 139.77E |
| Mexico City                        | TRPSYL2ALLCRSMGMEX | 10.5067/YTO4AV07QQOW | 19.13N | 99.40W  |
| Delhi, India                       | TRPSYL2ALLCRSMGDEL | 10.5067/IHXG5JVO98VC | 29.02N | 77.38E  |
| São Paulo, Brazil                  | TRPSYL2ALLCRSMGSAO | 10.5067/AA26EWZUNMDK | 23.50S | 46.62W  |
| Lagos, Nigeria                     | TRPSYL2ALLCRSMGLAG | 10.5067/G2FKY92PRSF5 | 6.60N  | 3.30E   |
| Los Angeles, USA                   | TRPSYL2ALLCRSMGLOS | 10.5067/H66DGC3ICJMQ | 34.05N | 118.24W |
| Beijing, China                     | TRPSYL2ALLCRSMGBEI | 10.5067/GBMBES47TUOI | 39.91N | 116.40E |