**MIPD document for detection of Lightning, Nitrogen dioxide, Fire and Power outage using satellite data**

***(MIPD: Mission Instrument Product Data)***

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **To detect** | **Lightning** | | **NO2** | | | **Fire** | | **Night-time artificial light** |
| **Instrument used** | Lightning Imaging Sensor (LIS) | | TROPOspheric Monitoring Instrument (TROPOMI) | | | Moderate-resolution Imaging Spectroradiometer (MODIS) | | Visible Infrared Imaging Radiometer Suite (VIIRS) |
| Platform/Satellite | TRMM (Tropical Rainfall Measuring mission) | ISS (International Space Station) | Sentinel-5 Precursor | | | Terra (EOS/AM-1) satellite |  | Suomi National Polar-orbiting Partnership (NPP) satellite |
| Launch date | 1997-11-28 | 2017-02-19 | 2017-10-13 | | | 1998-12-18 | 2002-05-02 | 2011-10-28 |
| Spatial coverage | N:35.0, S: -35.0, E: 180.0, W: -180.0 | N:5.0, S: -54.0, E: 180.0, W: -180.0 | global | | | global | | global |
| Spatial resolution | 3 kms (nadir) to  6 km (edge-of-scan) | 4kms (nadir) to 8kms (edge-of-scan) | 7kms x 3.5kms | 5.5kms x 3.5kms | | 1 km(nadir) | | 0.4km (nadir) to  0.8km(edge-of scan) |
| Swath width | 550 kms | 550 kms | 2600 kms | | | 2300 kms | | 3000 kms |
| orbit | non sun sync, circular, low inclination | | sun sync, circular, low inclination | | | sun sync, circular, low inclination | | sun sync, circular, low inclination |
| orbital period | 92.4 mins (after 2001) | 90-93 mins | 101 minutes | | | 99 minutes | 98.8 minutes | 101 minutes |
| inclination | 35º | 51.6º | 98.74º | | | 98.5º | 98.2º | 98.74º |
| altitude | 402.5+-1 kms (after 2001) | ~400 kms | 824 kms (LEO) | | | 705 kms | | 824 kms |
| repeat cycle | ~42 days | 3 - 5 days | 17 days (227 orbits) | | | 233 orbits | | 16 days (quasi-8-day) |
| equator crossing time |  |  | 13:35 LTAN | | | 10:30 AM LTDN | 13:30 LTAN | 10:30 AM LTDN |
|  |  |  |  |  |  |  |  |  |
| **Data product ID** | lislip\_v4 | isslis\_v2\_fin | SP5\_L2\_NO2\_v01.03.02 | SP5\_L2\_NO2\_v01.04.00 | SP5\_L2\_NO2\_v02.04.00 | MOD14 v061 | MYD14 v061 | VNP46A2 |
| Data source | NASA Earthdata | NASA Earthdata | NASA Earthdata | NASA Earthdata | NASA Earthdata | NASA Earthdata | NASA Earthdata | NASA Earthdata |
| File name | [Lightning Imaging Sensor (LIS) on TRMM Science Data V4](https://search.earthdata.nasa.gov/search/granules?p=C1983762329-GHRC_DAAC&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&fi=LIS&as%5binstrument%5d%5b0%5d=LIS&tl=1663152894.749!3!!) | [Quality Controlled Lightning Imaging Sensor (LIS) on International Space Station (ISS) Science Data V2](https://search.earthdata.nasa.gov/search/granules?p=C2303212754-GHRC_DAAC&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&q=Quality%20Controlled%20Lightning%20Imaging%20Sensor%20(LIS)%20on%20International%20Space%20Station%20(ISS)%20Science%20Data%20V2&fi=LIS&as%5binstrument%5d%5b0%5d=LIS&tl=1663152894!3!!) | [Sentinel-5P TROPOMI Tropospheric NO2 1-Orbit L2 7km x 3.5km V1 (S5P\_L2\_\_NO2\_\_\_) at GES DIS](https://search.earthdata.nasa.gov/search/granules?p=C1442068511-GES_DISC&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&q=Sentinel-5P%20TROPOMI%20Tropospheric%20NO2%201-Orbit%20L2%207km%20x%203.5km%20V1%20(S5P_L2__NO2___)%20at%20GES%20DIS&tl=1663153080.458!3!!) | [Sentinel-5P TROPOMI Tropospheric NO2 1-Orbit L2 5.5km x 3.5km V1 (S5P\_L2\_\_NO2\_\_\_\_HiR) at GES DISC](https://search.earthdata.nasa.gov/search/granules?p=C1627516298-GES_DISC&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&q=Sentinel-5P%20TROPOMI%20Tropospheric%20NO2%201-Orbit%20L2%205.5km%20x%203.5km%20V1%20(S5P_L2__NO2____HiR)%20at%20GES%20DISC%20&tl=1663153080!3!!) | [Sentinel-5P TROPOMI Tropospheric NO2 1-Orbit L2 5.5km x 3.5km V2 (S5P\_L2\_\_NO2\_\_\_\_HiR) at GES DISC](https://search.earthdata.nasa.gov/search/granules?p=C2089270961-GES_DISC&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&q=Sentinel-5P%20TROPOMI%20Tropospheric%20NO2%201-Orbit%20L2%205.5km%20x%203.5km%20V2%20(S5P_L2__NO2____HiR)%20at%20GES%20DISC&tl=1663153080!3!!) | [MODIS/Terra Thermal Anomalies/Fire 5-Min L2 Swath 1km V061](https://search.earthdata.nasa.gov/search/granules?p=C1621383535-LPDAAC_ECS&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&q=MOD14%20-%20MODIS/Terra%20Thermal%20Anomalies/Fire%205-Min%20L2%20Swath%201km%20V061&tl=1663153080!3!!) | [MODIS/Aqua Thermal Anomalies/Fire 5-Min L2 Swath 1km V061](https://search.earthdata.nasa.gov/search/granules?p=C1621434243-LPDAAC_ECS&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&q=MYD14%20-%20MODIS/Aqua%20Thermal%20Anomalies/Fire%205-Min%20L2%20Swath%201km%20V061&tl=1663153080!3!!) | [VIIRS/NPP Gap-Filled Lunar BRDF-Adjusted Nighttime Lights Daily L3 Global 500m Linear Lat Lon Grid](https://search.earthdata.nasa.gov/search/granules?p=C1898025206-LAADS&pg%5b0%5d%5bv%5d=f&pg%5b0%5d%5bgsk%5d=-start_date&q=VIIRS/NPP%20Gap-Filled%20Lunar%20BRDF-Adjusted%20Nighttime%20Lights%20Daily%20L3%20Global%20500m%20Linear%20Lat%20Lon%20Grid&tl=1663153080!3!!) |
| Temporal extent | 1998-01-01 to 2015-04-08 | 2017-03-01 to ongoing | 2018-04-30 to 2019-08-06 | 2019-08-06 to 2021-07-01 | 2021-07-01 to ongoing | 2000-02-24 to ongoing | 2002-07-04 to ongoing | 2012-01-19 to ongoing |
| Temporal resolution | 1 file per orbit | | daily | | | daily, 5-minutes temporal satellite increments (swaths) at 1 km spatial resolution | | daily |
| Lag period | - | ~2 days | ~8 days | | | ~10 hours | | ~8 days |
| Native format | HDF4 and netCDF-4 | | netCDF-4 | | | HDF4 | | HDF5 |

*\*(References: eoportal, IPDAAC USGS, NASA GHRC DAAC, NASA GFSC, ESA, Netherland Space Agency, University of Maryland)*

*Timeline

Description automatically generated with medium confidence*

Due to non-idealistic conditions the measurements data we would be using would not be showcasing actual reality. All possible efforts are made to recognize and minimize the error percentage by optimization and innovation, following are the parameters where the observation may .

* Measurement science assumptions
* Hardware/mechanical issues- Material properties, Manufacturing tolerances, electronic circuit, and processor limits
* External climatic parameters
* Sensor calibrations
* Data validation
* Data product /software limitations /detection errors
* Satellite running health status /lifetime
* **Lightning detection**

**LIS instrument\_TRMM V2 & QC\_ISS\_V2 products**

* **About Mission – TRMM and ISS**

TRMM is a joint NASA/JAXA (formerly NASDA) mission within NASA's ESE (Earth Science Enterprise) program with a low-inclination (equatorial) orbit. TRMM is the first mission dedicated to observing and understanding tropical and subtropical rainfall, one of the most important, but least understood parameters in global change. The TRMM satellite orbit gradually declined in the last year of operation from 2014 - 2015. In 2015, TRMM was removed from orbit. Field-of-view and measurement spatial resolution varied slightly for each of the two orbital altitudes. (Kramer)

After more than 17 years on orbit, the LIS instrument, flown on the TRMM has successfully demonstrated space-based lightning observations as an effective remote sensing tool for Earth science research and applications. In April 2013, a space-qualified LIS built as the flight spare for TRMM, was selected for flight as a science mission on the International Space Station. The ISS-LIS will be flown as a hosted payload on the DoD STP-H5’s investigations mission, which is scheduled for launch in 2017 aboard a SpaceX launch vehicle for a 2-4 year or longer mission. (Kramer, ISS:LIS)

* **About Instrument - LIS:** (H. Christian, 2000)

The LIS instrument records the time of occurrence of a lightning flash, measures the radiant energy, and determines the location of flashes within its field-of-view.

The LIS sensor contains a staring imager which is optimized to locate and detect lightning with storm-scale resolution of 3 km at NADIR, 6km at limb in case for LIS on TRMM (4-8kms spatial resolution in case of LIS on ISS) over a large region (FOV 550-550 km) of the Earth's surface. The field of view (FOV) is sufficient to observe a point on the Earth or a cloud for 90 seconds, adequate to estimate the flashing rate of many storms. It can estimate lightning frequency for storms with flash rates as low as 1-2 discharges per minute. Sampling frequency of every 2ms over 90 seconds.

The LIS algorithm accumulates the individual LIS events into groups, flashes, and areas. Flash events from adjacent pixels occurring at a certain time are grouped together, Flashes within 330ms time interval are grouped together and finally if flashes occur within 5kms of area they are grouped.

A real-time event processor (RTEP) removes the background signal, thus enabling the system to detect weak lightning and achieve a 90% detection efficiency (ranges from 69% near noon to 88% at night.)

* **Measurement science:** (H. Christian, 2000)

The optical pulse sensors are designed to detect the prominent emission optical spectra produced by oxygen emission triplet in the lightning spectrum from cloud-topline to image at 777.4 nm (OI line) onto a 128 x 128 high-speed CCD array detector

1. *Measurement threshold:* 4.7 mJ m-2 sr -1

*(Based on peak radiant energy density produced from 90% of lightning studied in extensive measurements from an instrumented NASA U-2)*

1. *Maximal:* 181 mJ m-2 sr -1

*(as reported by Goodman et al. (1988), any event more energetic than the optical energy associated with the maximum 0x7f reading will be tagged 0x7f, i.e., saturation will occur.)*

1. *Telemetry link data transfer rate:* 6kb/s

*(If the on-board buffers are not sufficiently large to handle some high pulse data rate incidents, the buffers will overflow. This will result in unrecoverable loss of data. Data correction in such overflow condition is automated)*

* **Quality Control of the LIS Data:** (H. Christian, 2000)(Bugbee, Data User Guide - Lightning Imaging Sensor (LIS) on TRMM, 2020)(Bugbee, Data User Guide - International Space Station (ISS) Lightning Imaging Sensor (LIS) datasets, 2020)

LIS responds to several optical signals, not all of which are necessarily lightning-related. A significant amount of software filtering maximizes both detection efficiency and confidence level so that each datum is a lightning signal and not noise.

Each LIS lightning event in a LIS file is tagged with four low-level quality indicators, as follows:

1. Non-noise Probability (the probability that the event is not caused by random noise or energetic particles).
2. Solar Glint Factor (a number that indicates the likelihood that the event was caused by direct reflected solar radiation).
3. Event Rate Ratio (a number that represents the ratio of "accepted" events to the raw detected events during a one-second period at the time of the event).
4. Probability Density (a number that indicates whether the event is geolocated in the vicinity of other events that are likely to be lightning).

The LIS data file is manually inspected for irregularities in the data set. The data files that fail specific quality assurance are flagged. The high-level quality flags assigned to each LIS HDF data file (included as part of the HDF file) are as follows:

1. Instrument Alert Flag
2. Platform Alert Flag
3. External Alert Flag
4. Processing and Algorithm Alert Flag

* **Orbit file Varieties:**

The orbit files from LIS can come in 5 varieties, or classes:

Class 1- Good files - these files contain good data - be forewarned that occasionally the instrument/platform fatal flags may be intermittently set in some of these orbits. In these orbits, about 50 of the one second data flags are set to fatal or warning. Unless these flags are contiguous, the data is considered good. The vast majority of the LIS files are in this category.

Class 2- Good files containing 0 events - These are a subset of the good files, except that no events were observed. There are only about 10 of these files a year.

Class 3- Files unreadable with the idl code

Class 4- Files with known anomalies - These files have been observed to have some sort of anomaly, such that lightning data are available for only part of the orbit. The one second data flags are set correctly in these files. **(*NOTE: However, that not all the files anomalies may be listed on the web site. It is up to the user to check the one second data to verify that the data are good. In particular, LIS buffer overflows may not be listed due to the short duration of the data outage.In addition, files that occur immediately before and after files of type Class 3 will probably be in this category and will not be listed on the anomalies page.)***

Class 5- Missing files

*NOTE: Because they contain no useful science data, files of type Class 3 and Class 5 will not be distributed.*

* The **pre-launch calibration** primarily addresses LIS radiometric calibration, and the **post-launch calibration** is carried out once the LIS is launched and becomes operational the performance of the LIS will be characterized and key performance parameters are calibrated. The coincident databases that are assembled from regional ground-based lightning networks, long range sferics networks, interferometry, VHF time-of-arrival, optical and electric field sensors and LIS prototype Optical Transient Detector (OTD), the high altitude ER-2 aircraft for the calibration/validation efforts. (H. Christian, 2000)
* **Validation** is the process of verifying and tuning the performance of both the data processing

algorithms described in this document and the LIS hardware. This process will include- remotely adjusting threshold settings to maximize detection and minimize false alarm rate,

verifying the true amplitude, time of occurrence, and location of lightning events detected, and verifying background image brightness and alignment**-launch validation:** Use data from OTD and process using LIS algorithm, check with other ground truth observations.

**Post-launch validation:** Use data from OTD as well as LIS sensor and process both using LIS algorithm check with other ground truth observations. (H. Christian, 2000)

* **The LIS data for a single orbit is stored in two HDF files: one containing the major science**

**data and the other the background images.** *(This is done so users who are not interested in the background images do not have to download the large background files to get to the lightning data.)* (H. Christian, 2000)

*For more information:*

* Lightening research by GHRC: [Lightning Research - Micro Articles - Data Recipes | GHRC Lightning (nasa.gov)](https://ghrc.nsstc.nasa.gov/lightning/lightning-research.html)
* Lightning measurement science using LIS instrument? Refer following paper:

Christian and S. J. Goodman, 1987. Optical observations of lightning from a high-altitude airplane

Goodman, H. J. Christian, and W. D. Rust, 1988a. Optical pulse characteristics of intracloud and

cloud-to-ground lightning observed from above clouds.

Goodman, D. E. Buechler, P. D. Wright, and W. D. Rust, 1988b. Lightning and precipitation history of a microburst producing storm

Goodman, and P. J. Meyer, 1988c. Convective tendency images derived from a combination

of lightning and satellite data]

* [LIS Algorithm Theoretical Basis Document](http://lightning.nsstc.nasa.gov/bookshelf/pubs/atbd-lis-2000.pdf)
* Information related to TRMM satellite and mission:

<https://www.eoportal.org/satellite-missions/trmm#lis-lightning-imaging-sensor>

* Information related to ISS satellite and mission:

https://www.eoportal.org/satellite-missions/iss-lis

<https://www.nasa.gov/mission_pages/station/main/index.html>

* Differences in LIS placed on TRMM and ISS:

<https://ghrc.nsstc.nasa.gov/home/micro-articles/earth-observations-lightning-imaging-sensor>

* LIS on TRMM information by GHRA: <https://ghrc.nsstc.nasa.gov/uso/ds_docs/lis/lis_dataset.html>
* Data user guide of LIS on TRMM: <https://ghrc.nsstc.nasa.gov/pub/lis/trmm/doc/lislip_dataset.pdf>
* Data user guide of LIS on ISS, September 2021 Version 2 updates: <https://ghrc.nsstc.nasa.gov/pub/lis/iss/doc/isslis_dataset.pdf>
* Orbit files with known anomalies (Class 4 error) for TRMM-LIS are listed in: <https://ghrc.nsstc.nasa.gov/lightning/data/data_lis_trmm_anomalies.html>
* Orbit files with known anomalies (Class 4 error) for ISS-LIS are listed in: <https://ghrc.nsstc.nasa.gov/lightning/data/ISSLIS-Anomalies.pdf>]

**Nitrogen Dioxide detection**

**TROPOMI instrument\_\_L2\_NO2\_product**

* **About Mission – S5P:**

The Copernicus Sentinel-5 Precursor (Sentinel-5P or S5P) satellite mission is one of the European Space Agency's (ESA) new mission family - Sentinels, and it is a joint initiative between the Kingdom of the Netherlands and the ESA. *[Copernicus is the new name of the European Commission's Earth Observation Programme, previously known as GMES (Global Monitoring for Environment and Security).]* (Kramer)

A unique feature of the Sentinel-5P mission lies in the synergistic exploitation of simultaneous measurements of imager data from the VIIRS (Visible/Infrared Imager and Radiometer Suite), embarked on the Suomi NPP (NPOESS Preparatory Project) satellite of NASA/NOAA. The Sentinel-5P orbit is selected such that it trails behind Suomi NPP by 5 min in LTAN, allowing the Sentinel-5P observation swath to remain within the scene observed by Suomi NPP.

* **About Instrument – TROPOMI:** (Kramer)

The sole payload on Sentinel-5P is the TROPOspheric Monitoring Instrument (TROPOMI), which is a nadir-viewing 108-degree Field-of-View push-broom grating hyperspectral spectrometer a DOAS (Differential Optical Absorption Spectrometer) instrument, covering the wavelength of ultraviolet-visible (UV-VIS, 270nm to 495nm), near infrared (NIR, 675nm to 775nm), and shortwave infrared (SWIR, 2305nm-2385nm). Sentinel-5P is the first of the Atmospheric Composition Sentinels, to provide data on atmospheric trace gases (ozone, NO2, SO2, CH4, CO, formaldehyde, aerosols, and cloud) impacting air quality and climate. Information would be further used for air-quality forecasts, improve our understanding of chemical and physical atmospheric processes and for decision-making.

**Measurement science for NO2 detection:**

TROPOMI works by comparing reflected light from Earth's atmosphere with direct sunlight at various wavelengths *(reflectance spectra, the ratio of Earth radiance and sun irradiance measurements)*, from infrared to ultraviolet. It uses diffraction gratings to split this light, allowing it to sift out the spectral fingerprints of its target trace gases. (Kramer)

The TROPOMI retrieval of total and tropospheric NO2, is based on the DOMINO approach, a DOAS retrieval, a pre-calculated air-mass factor (AMF) look-up table, and a data assimilation/chemistry transport model for the separation of the stratospheric and tropospheric contributions to the NO2 column. (J.H.G.M. van Geffen, 2022)

* **NO2 detection spectrometer module details**(Kramer)

*NO2 Spectral fingerprint of NO2:* 405 - 500 nm (VIS spectral band)

NO2 detection by UVN(UV-VIS-NIR) spectrometer module, Band number: 4, spatial resolution-0.55°, spatial sampling – 7km x 7km, Signal-to-Noise ratio (SNP): 1500

Telescope FOV of 108°, 25 detectors, detector binning factor: 4 detector pixels are binned to have a 7 km resolution at nadir *(Since the sampling measured on ground increases with the swath angle, it is possible to have lower binning factors towards the extreme swath angles.)*

{ The exposure time settings are to be used to optimize the SNRs (Signal-to-Noise Ratios) for different latitudes and for special cases such as ozone hole conditions. Since the exposure times for all bands have to fit into the same satellite travel distance, TROPOMI allows to set exposure time with step size 1ms and to adjust the exposure co-addition time and thereby the spatial sampling in the flight direction.

Error elimination at instrument level:

Co-registration: Co-registration means that all wavelengths of a given detector row have the same viewing directions, both in the across-flight and in the flight direction. Co-registration is important because level 1-2 product retrieval algorithms assume all wavelengths in the Level 1 product observe the same air mass.

In the swath direction, this is possible by reducing the detector pixel binning from 4 to 2 and thereby have a spatial sampling of 3.5 km. In the flight direction, the co-addition time is reduced by a factor 3 and thereby the spatial sampling is about 2.3 km. The stability of the co-registration during flight is estimated to be within 10% of a ground pixel which is sufficiently small.

Heterogeneous scenes: In the case of minor absorbing gases reflectance spectra need to be free from any distortion on the 10-3 to 10-4 level and with a very accurate wavelength definition in the order of 1/100 of a spectral sampling distance. The slit functions are used to compute from high resolution scene spectra the pixel content for each detector pixel and this allows to compute an error by comparing the result with that of an averaged constant scene. The heterogeneous scene has errors of about 0.015 nm.}

The ground segment main elements are the FOS (Flight Operations Segment) located at ESOC in Darmstadt, their tasks if of commanding, tracking and monitoring of the spacecraft as well as the acquisition, processing, archiving and dissemination of science data, respectively.

* **About data:**

The PDGS (Payload Data-processing Ground Segment) and Mission Planning Facility located in DLR German Remote Sensing Data Center (DFD) in Oberpfaffenhofen, process the data with the Level 0/1b & Level 2 data products. The data processors that convert the measurement data into geophysical data products were developed by the DLR Remote Sensing Technology Institute, the University of Bremen and the Max Planck Institute for Chemistry in Mainz as part of a European consortium. (Kramer)

* ***NOTE:***(Henk Eskes, 2022)

On August 6th, 2019, the instrument settings of TROPOMI were changed. The nominal integration time

was reduced from 1080 ms to 840 ms.

Before the change the pixel size is 7*.*2×3*.*6km2 for band 4, after co-addition in the flight direction.

After the change in the settings, the pixel dimension in the flight direction is reduced to 5*.*6×3*.*6km2 for band 4.

* **Data Quality Flags at product level:** (H. J. Eskes, 2022)

The output for each ground pixel is accompanied by a quality indicator, the qa\_value, indicating the status and quality of the retrieval result. The "quality assurance value" (qa\_value or fQA) is a continuous variable ranging from 0 (error, therefore no output) to 1 (no errors and no warnings).

{The qa\_value indicates whether the footprint is cloud covered or not, and whether there is snow or ice on the surface. It is set to 0 if anywhere in the processing an error occurred, as indicated by the processing\_- quality\_flags.

Warnings related to the South Atlantic Anomaly, sun glint, or missing non-critical input data lower the qa\_value. Apart from warnings and errors, the qa\_value depends on the solar zenith angle, tropospheric air-mass factor, quality of the DOAS fit, and filters unrealistic albedo values.

Since the processor version 1.2 data product additional retrievals over snow-ice get a qa\_value > 0.75, namely when the cloud pressure is close to the surface pressure, indicating that there is no cloud. This significantly improves the coverage for high latitudes.}

For variables nitrogendioxide\_tropospheric\_column, nitrogendioxide\_total\_column, nitrogendioxide\_summed\_total\_column:

qa\_value > 0.75, is the recommended pixel filter. It removes cloud-covered scenes (cloud radiance fraction > 0.5), partially snow/ice covered scenes, errors, and problematic retrievals.

qa\_value > 0.50 adds the good quality retrievals over clouds and over scenes covered by snow/ice. Errors and problematic retrievals are still filtered out. In particular, this filter may be useful for assimilation and model comparison studies.

For variable nitrogendioxide\_stratospheric\_column: qa\_value > 0.50 is recommended

* **Known Data Quality Issues *(in version 02.03.01):*** (H. J. Eskes, 2022)

Currently, the following data quality issues are known, not covered by the quality flags, and should be kept in mind when using the NO2 product.

1. Bands 4 and 6 spatial misalignments can be in the order of half a ground pixel. These parameters are used in the NO2 air-mass factor calculations. Note that the cloud fraction is determined in the NO2 fitting window, avoiding the uncertainty by misalignment for this parameter.
2. Surface albedo grid affects the NO2 column products quality especially at coastal areas.
3. Conservative filtering

The pixel flagging, reflected in the qa\_value, is defined in a conservative way. When the FRESCO cloud retrieval reports an error, in combination with the misalignment issue, one consequence is the loss of the first row (west side of the orbit), even though good NO2 slant column retrievals are possible. Another example is the removal of observations when the albedo database shows suspiciously high values.

1. Data in snow\_ice\_flag variable for pixels with SZA > 88°

Since ground pixels with SZA > 88° are not processed, these pixels do not have NO2 column data, hence the NO2 data quality is not affected. The issue will be solved in the next processor update.

1. Variables in the NO2 DOAS fit with an across-track low-order “wave” (since version 02.02.00)

, causing unexpected values mainly in the western part of the swath. The variables concerned are the slant columns of ozone, liquid water and O2-O2 in the NO2 fit. The NO2 slant columns are *not* significantly affected. The issue may change once the radiance degradation correction is also in place.

* **Data Calibration/Validation:** (H. J. Eskes, 2022)

Independent preliminary validation by S5p MPC Cal/Val experts and the S5PVT concludes that NRTI / OFFL NO2 data is in overall agreement with (i) reference measurements collected from global ground-based networks, (ii) the corresponding satellite data products from OMI, and (iii) is compliant with the requirements as defined in S5p Calibration and Validation Plan [RD01].

The upgrade to version 01.04.00 involved a change of the FRESCO-S auxiliary cloud product which resulted in an expected substantial increase of the tropospheric NO2 column with respect to the previous version 01.03.02.

Exhaustive validation of version 01.04.00 was performed by the S5P MPC Cal/Val team since the operational switch at the beginning of December 2020 up to July 2021 (time of operational switch to version 02.02.00). The upgrade to version 02.02.00 leads to a further increase of the tropospheric NO2 columns for polluted cloud-free scenes (see section 5).

Up to date validation results are available in the Routine Operations Consolidated Validation Reports (ROCVR) that are accessible through the MPC Validation Data Analysis Facility (VDAF) website at http://mpc-vdaf.tropomi.eu. The ROCVR reports are issued quarterly and reports released after September 2021 include validation results based on processor version 02.xx.xx, while previous ROCVR reports cover validation results for versions 01.02.xx up to 01.04.00.

*For more information:*

* Sentinel 5P TROPOMI user guide:

<https://sentinel.esa.int/web/sentinel/user-guides/sentinel-5p-tropomi>

* Sentinel 5P website:

[1] <https://sentinel.esa.int/web/sentinel/missions/sentinel-5>

* Products and Algorithms:

<https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms>

* Information about Sentinial-5P satellite, mission and unique observations:

[2] <https://www.eoportal.org/satellite-missions/copernicus-sentinel-5p>

<https://www.esa.int/Enabling_Support/Operations/Sentinel-5P_operations>

* Level 1B and level 2(L2\_NO2\_) products – User technical documentation information
  + ATBD (Algorithm Theoretical Basis Document)
  + IODD (Input Output Data definition)
  + PRF (Product Readme File)
  + PUM (Product Readme File)

<https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-5p/products-algorithms>

**Fire detection**

**MODIS instrument\_MOD14/MYD14 (level 2,collection 6.1) product**

* **About Mission: Terra (EOS/AM-1) and Aqua (EOS/PM-1):**

The objective of the mission is to obtain information about the physical and radiative properties of clouds (ASTER, CERES, MISR, MODIS); air-land and air-sea exchanges of energy, carbon, and water (ASTER, MISR, MODIS); measurements of trace gases (MOPITT); and volcanology (ASTER, MISR, MODIS). Complemented by aircraft and ground-based measurements, Terra data will enable scientists to distinguish between natural and human-induced changes. (Kramer H. J.)

The focus of the Aqua mission is the multi-disciplinary study of the Earth's water cycle, including the interrelated processes (atmosphere, oceans, and land surface) and their relationship to Earth system changes. The data sets of Aqua provide information on cloud formation, precipitation, and radiative properties, air-sea fluxes of energy, carbon, and moisture (AIRS, AMSU, AMSR-E, HSB, CERES, MODIS); and sea ice concentrations and extents (AMSR-E). (Kramer H. J., Aqua)

* **About Instrument: Moderate-resolution Imaging Spectroradiometer (MODIS):**

MODIS is an optomechanical imaging spectroradiometer (whiskbroom type), consisting of a cross-track scan mirror (continuously rotating double-sided scan mirror assembly) and collecting optics, and a set of linear detector arrays with spectral interference filters located in four focal planes.

* **Measurement Science:**

MODIS Instrument IFOV (spatial resolution) = 1000 m (bands 8-36) with 10 detectors per band are used to detect cloud/surface temperature at an absolute temperature accuracy of 0.2 K for oceans and 1 K for land. The fire detection strategy is based on absolute detection of a fire (when the fire strength is sufficient to detect), and on detection relative to its background (to account for variability of the surface temperature and reflection by sunlight). (Kramer H. J., Terra)

**Onboard Calibration**

MODIS onboard calibration employs various techniques for comprehensive verification of spectral, radiometric, and spatial measurements.

They include: Spectro radiometric Calibration Assembly (SRCA), Blackbody (BB) calibration of thermal bands on every scan (a v-groove blackbody), Solar Diffuser (SD) reference, Solar Diffuser Stability Monitor (SDSM). (Kramer H. J., Terra)

* **About MODIS Thermal Anomalies/Fire product (MOD14/MYD14):**

MODIS Thermal Anomalies/Fire products are primarily derived from MODIS 4- and 11-micrometer radiances. The product includes fire occurrence (day/night), fire location, the logical criteria used for the fire selection, detection confidence, Fire Radiative Power and numerous other layers describing fire pixel attributes. The product distinguishes between fire, no fire and no observation. (Frazier, MODIS Thermal Anomalies/Fire, n.d.)

**About MOD14 v061 product**

The Moderate Resolution Imaging Spectroradiometer (MODIS) Thermal Anomalies and Fire MOD14 Version 6.1 product (MOD14 v061) is used to generate all of the higher-level fire products, but can also be used to identify fires and other thermal anomalies, such as volcanoes. (Berrick)

In the MOD14 product the second alphabet ‘O’ denotes data from Terra satellite

**About MYD14 v061 product** (Kramer H. J., Aqua)

The Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) Thermal Anomalies and Fire MYD14 Version 6.1 product (MYD v061) is used to generate all of the higher-level fire products but can also be used to identify fires and other thermal anomalies, such as volcanoes. (Berrick, MYD14)

In the MYD14 product the second alphabet ‘Y’ denotes data from Aqua satellite (EOS/PM-1) satellite (signifying its afternoon equatorial crossing time)

* **MOD14/MYD14 level2 collection 6.1 product- Validation and version improvements**:

Validation at stage 3 (<https://modis-land.gsfc.nasa.gov/MODLAND_val.html> ) has been achieved for all MODIS Thermal Anomalies and Fire products. Further details regarding MODIS land product validation for the MOD14 data product is available from the MODIS land team validation site (<https://modis-land.gsfc.nasa.gov/ValStatus.php?ProductID=MOD14>). (Berrick)

Improvements/Changes from Previous Versions: (Berrick) : The Version 6.1 Level-1B (L1B) products have been improved by undergoing various calibration changes that include: changes to the response-versus-scan angle (RVS) approach that affects reflectance bands for Aqua and Terra MODIS, corrections to adjust for the optical crosstalk in Terra MODIS infrared (IR) bands, and corrections to the Terra MODIS forward look-up table (LUT) update for the period 2012 - 2017.A polarization correction has been applied to the L1B Reflective Solar Bands (RSB).

* **Data Quality Control:** (Louis Giglio, 2021)

*FP confidence:* Fire-pixel confidence classes associated with the confidence level (C) computed for each fire pixel.

Range Confidence Class

0% ≤ C < 30% low

30% ≤ C < 80% nominal

80% ≤ C ≤ 100% high

Three classes of fire pixels (low confidence, nominal confidence, high confidence) are provided in the fire masks of the MODIS Level 2 and Level 3 fire products. Users requiring fewer false alarms may wish to consider only nominal- and high-confidence fire pixels, and treat low-confidence fire pixels as clear, non-fire, land pixels. Users requiring maximum fire detectability, who can tolerate a higher incidence of false alarms, should consider all three classes of fire pixels.

The algorithm examines each pixel of the MODIS swath, and ultimately assigns to

each one of the following classes: *missing data*, *cloud*, *water*, *non-fire*, *fire*, or *unknown*. Processing continues the remaining clear land pixels. Additional specialized tests are used to eliminate false detections caused by sun glint, desert boundaries, errors in the water mask, and small forest clearings. Candidate fire pixels that are not rejected while applying these tests are assigned a class of *fire*. Pixels for which the background characterization could not be performed, i.e., those having an insufficient number of valid pixels, are assigned a class of *unknown*.

* **Collection 6 Known Problems:** (Louis Giglio, 2021)

1. Pre-November 2000 Data Quality Prior to November 2000, the Terra MODIS instrument suffered from several hardware problems that adversely affected all of the MODIS fire products
2. Detection Confidence in the Collection 4 fire product did not adequately identify highly questionable, low confidence fire pixels. Such pixels,

which by design should have a confidence close to 0%, were too often assigned much higher confidence estimates of 50% or higher. While an adjustment implemented in the Collection 5 code partially mitigated this problem, some highly questionable fire pixels are still classified as nominal confidence fires. A second minor adjustment was implemented for Collection 6 to help correct this problem.

1. Some non-fire static hot-spot sources are unflagged as such in the *type* field of theMCD14ML product.
2. August 2020 Aqua Outage for 2 weeks: A failure of the Aqua formatter-multiplexer unit (FMU) on 16 August 2020 led to the loss of regular science data telemetry for a period of about two weeks. During this time the MODIS instrument remained otherwise functional, and an effort was made to generate the standard Aqua science products from Direct Broadcast Aqua MODIS data collected by Direct Readout ground stations around the world.

* **Product Validation:**

Validation of the Terra MODIS active fire product has primarily been performed using coincident,high resolution fire masks derived from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery. See Morisette et al. (2005a,b), Csiszar et al. (2006), and Schroeder et al. (2008) for details. A very brief (though now somewhat obsolete) discussion of the general validation procedure, with some early results, can be found in Justice et al. (2002). For information about the methodology for producing the ASTER fire masks, see Giglio et al. (2008).

More recent work described has achieved Stage 3 validation of the Level 2 Terra MODIS fire product using 2500 ASTER scenes distributed globally and acquired from 2001 through 2006 (Figure 10). See Giglio et al. (2016) for details.

* **Why didn’t MODIS detect a particular fire?**

This can happen for any number of reasons. The fire may have started and ended in between satellite overpasses. The fire may be too small or too cool to be detected in the 1 km2 MODIS footprint.

Cloud cover, heavy smoke, or tree canopy may completely obscure a fire. Occasionally the MODIS instruments are inoperable for extended periods of time (e.g. the Terra MODIS in September 2000) and can of course observe nothing during these times.

* **The Level 3 MOD14A1/MYD14A1, tile based, fire pixel detected in each grid with daily maximum value composite for 8-days packed into single file.**
* **The Level 3 MOD14A2/MYD14A2, tile based, fire pixel detected in each grid with maximum value composite for all 8-days**
* **Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning (10:30AM), while Aqua passes south to north over the equator in the afternoon(01:30PM). Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days.** (Frazier, n.d.)

*For more information:*

* MODIS thermal anomalies/Fire product

<https://modis.gsfc.nasa.gov/data/dataprod/mod14.php>

* For complete information about known issues please refer to: <https://landweb.modaps.eosdis.nasa.gov/cgi-bin/QS/new/pages.cgi?name=known_issues&_ga=2.28489589.87312636.1662651805-268323699.1660396747>
* MODIS Collection 6 Active Fire Product User’s Guide Revision C:

<https://modis-fire.umd.edu/files/MODIS_C6_Fire_User_Guide_C.pdf>

* Details EOS instruments performance, quality analysis, validation:

<https://gis-lab.info/docs/justice02_the_modis_fire_products.pdf>

<https://ntrs.nasa.gov/api/citations/20020038850/downloads/20020038850.pdf>

**Nighttime artificial light detection**

**VIIRS satellite instrument\_ VNP46A2 product**

* **About Mission - Suomi National Polar-orbiting Partnership (NPP):** (Kramer)

NPP is a joint NASA/IPO (Integrated Program Office)/NOAA LEO weather satellite mission initiated in 1998. In honor of the late Verner E. Suomi, a meteorologist at the University of Wisconsin, who is recognized widely as "the father of satellite meteorology." NASA renamed its newest Earth-observing satellite (launched on October 2011), to Suomi NPP (National Polar-orbiting Partnership) in January 2012.

The primary mission objectives are:

1) To demonstrate the performance of four advanced sensors VIIRS, CrIS, OMPS and ATMS (risk reduction mission for key parts of the NPOESS mission) and their associated Environmental Data Records (EDR), such as sea surface temperature retrieval.

2) To provide data continuity for key data series observations initiated by NASA's EOS series missions (Terra, Aqua and Aura) - and prior to the launch of the first NPOESS series spacecraft. Because of this second role, NPP is sometimes referred to as the EOS-NPOESS bridging mission.

This suite of sensors is able to provide cloud, land and ocean imagery, covering the spectral range from the visible to the thermal infrared, as well as temperature and humidity profiles of the atmosphere, including ozone distributions

* **About Instrument - Visible Infrared Imaging Radiometer Suite (VIIRS):**

The VIIRS instrument observes and collects global satellite observations that span the visible and infrared wavelengths across land, ocean, and atmosphere.

VIIRS-derived data products are used to measure cloud and aerosol properties, ocean color, fires, ocean and land surface temperature, ice movement and temperature, and Earth's albedo. Climate scientists are using this data to improve understanding of global climate change.

* **Measurement science**

VIIRS consists of 22 spectral bands from the ultra-violet to the mid-infrared, one of which is able to observe nighttime lights, the day night band (DNB). DNB is a panchromatic band which is ultra-sensitive in low-light conditions that allows us to observe nighttime lights with better spatial and temporal resolutions.

The VIIRS sensor was designed to extend and improve upon the series of measurements initiated by its predecessors, the Advanced Very High Resolution Radiometer (AVHRR), the Moderate Resolution Imaging Spectroradiometer (MODIS), and the Sea-viewing Wide Field-of-view Sensor (SeaWIFS).  (Wolfe)

* **VIIRS Instrument Performance and Monitoring:**

Results from the on-orbit verification in the postlaunch check-out and intensive calibration and validation have shown that VIIRS is performing very well. (Suomi NPP VIIRS , n.d.)

For more up-to-date detailed information on VIIRS Calibration and Validation check this link:

<https://ncc.nesdis.noaa.gov/VIIRS/>

* **Quality Control:**

The black marble product VNP46A2 (level 3) is a daily moonlight- and atmosphere-corrected Nighttime Lights (NTL) product called VIIRS/NPP Gap-Filled Lunar BRDF-Adjusted Nighttime Lights Daily L3 Global 500m Linear Lat Lon Grid.

Key algorithm enhancements include: (1) lunar irradiance modeling to resolve non-linear changes in phase and libration; (2) vector radiative transfer and lunar bidirectional surface anisotropic reflectance modeling to correct for atmospheric and bidirectional reflectance distribution function (BRDF) effects; (3) geometric-optical and canopy radiative transfer modeling to account for seasonal variations in NTL; and (4) temporal gap-filling to reduce persistent data gaps.

It contains seven Science Data Sets (SDS) that include- DNB BRDF-Corrected NTL, Gap-Filled DNB BRDF-Corrected NTL, DNB Lunar Irradiance, Latest High-Quality Retrieval, Mandatory Quality Flag, Cloud Mask Quality Flag, and Snow Flag.

* **Mandatory\_Quality\_Flag in VPN46A2 product:**



Lightening detection using VIIRS: <https://journals.ametsoc.org/view/journals/wefo/26/3/waf-d-10-05002_1.xml>

*For more information:*

* Black marble website:

<https://blackmarble.gsfc.nasa.gov/>

* NASA's Black Marble nighttime lights product suite paper:

<https://doi.org/10.1016/j.rse.2018.03.017>

* NASA Black Marble product User guide:

<https://viirsland.gsfc.nasa.gov/PDF/BlackMarbleUserGuide_v1.2_20210421.pdf>

* NASA Black Marble ATBD

<https://viirsland.gsfc.nasa.gov/PDF/VIIRS_BlackMarble_ATBD_V1.1.pdf>

* Sumi NPP satellite, mission and unique observations:

<https://www.eoportal.org/satellite-missions/suomi-npp>