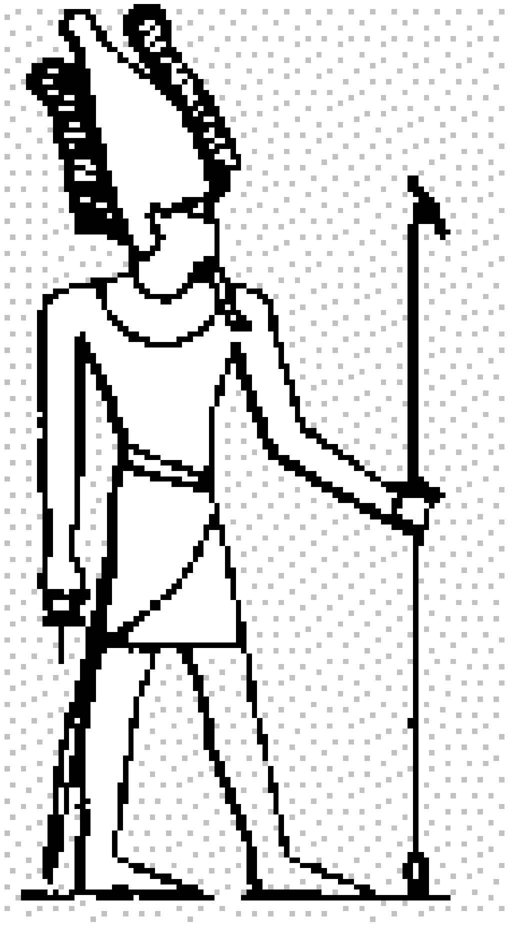

# OSIRIS Level 2 Daily Data Products: Users Guide.

April 05, 2012
Ozone V5.07
Aerosols V5.07
NO2 V3 and V5
BrO
OH

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# 1 Updates

- 2012-04-05, V5.07, O3 MART. Swath field names have been changed to more meaningful values
- 2012-05-05, V5.07, Aerosol MART. Swath field names have been changed to more meaningful values.

## 2 OSIRIS Overview

The **O**ptical **S**pectrograph and **I**nfra**R**ed **I**maging **S**ystem (OSIRIS) is an optical instrument onboard the Odin spacecraft launched on February 20, 2001 into a 600km, sun-synchronous, 97° inclination orbit with an ascending node near dusk, a descending node near dawn and a period of 96 minutes. Odin was built and operated by the Swedish Space Corporation in collaboration with Canada, France and Finland. OSIRIS is one of the first of a new set of instrumentation designed to measure atmospheric parameters from a limb-viewing geometry, a technique that attempts to generate geographic coverage comparable to nadir observations while maintaining the height resolution associated with occultation observations, [11]. Odin is a multi-purpose mission sharing observation time equally between astronomical and atmospheric goals. Time is nominally allocated in one day granules with a typical schedule alternating days between astronomical and atmospheric measurements. One orbit is required to transition the attitude control system from astronomy to atmospheric mode and vice-versa. OSIRIS does not participate in astronomical measurements.

### 2.1 Optics

The Optical Spectrograph measures spectra across the entire visible range using a diffraction grating whose output is imaged onto 32 rows of 1353 pixels of a CCD detector. The 1353 pixels sample the spectra every 0.3 nm from 274 nm to 810 nm while the 32 rows are summed into one row using both on and off chip techniques to maximize signal to noise. The point spread function of the grating and optics has a FWHM of approximately 1 nm. An interface between two pieces of glass used to sort the orders of the diffraction grating inhibits measurements between 477nm and 531nm, this region is normally blanked out by onboard software to reduce telemetry bandwidth. The grating slit has an angular width, parallel to the horizon, of 36 arc minutes and a vertical width, parallel to the vertical, of 1.1 arc minutes. As a rule of thumb, 1 arc minute of angle at the OSIRIS optics corresponds to 1 km at the associated tangent point.

### 2.2 Measurement format

Vertical profiles of the limb-scattered sunlight are generated by rotating the entire Odin spacecraft over a nominal altitude range extending from the upper troposphere ($\sim$ 7 km) to the middle/upper mesosphere (65-90 km) depending upon the selected operational mode. The scan rate is normally 0.75 km/s requiring 80 to 120 seconds to perform one vertical scan producing anywhere between 40 and 60 scans per orbit. Rotating the entire satellite has the distinct advantage that there is very little relative movement, if any, between OSIRIS and the star-trackers used for attitude determination. OSIRIS employs a data throttling algorithm that nominally generates one spectrum every 2 km in altitude although, due to a variety of real-time parameters, it does not produce images that are evenly spaced in altitude or time.

OSIRIS, by its very nature, is limited to measurements in the sunlit hemisphere and when coupled to the Odin orbit, which itself is nominally constrained to the dawn/dusk meridian, means that OSIRIS only makes useful measurements in the summer-time hemisphere. There are two periods, one in October and the other in February, when Odin flies down the terminator and produces truly global coverage while for the remainder of the year measurements are in either the Northern Hemisphere (Mar-Sep) or Southern Hemisphere (Oct-Feb). Measurements are usually limited to the orbital plane, limiting the latitudinal coverage to 82°N to $-82$°S. Occasionally, during Polar Stratospheric Cloud season for example, measurements are made out of the orbital plane so Odin can observe all the way to the North or South pole.

Normal operations scan the OSIRIS spectrograph across the altitude range of interest and produce a Level-1 height profile of limb spectra for each upward or downward scan. This height profile, which is often referred to simply as a *scan*, is the basic data granule for the various Level-2 inversion algorithms.

It is conceptually convenient to think of a scan as representing a single geographic location but in reality it represents a much larger extended region of the atmosphere. A typical species retrieval requires Odin to scan 40-60 km in altitude which, since Odin scans altitude at approximately 0.75 km/s and physically moves along the orbit at 7 km/s, represents a geographic region 350-560 km in extent ($\sim$ 4-5° of latitude as a quick guideline). This *scan* scale size is comparable in size to the area of atmosphere that contributes significant radiation to any one spectral measurement during the scan; for example, the local horizon at 25 km altitude is located approximately 5° from the tangent point. Consequently, limb viewing geometry inherently retrieves species at lower spatial resolutions than most nadir instruments.

On the other hand limb viewing geometry is considerably less sensitive to high frequency structure in the ground/tropospheric signal as it averages upwelling radiation over several degrees of latitude. This effectively eliminates the need to detect and mask regions of patchy cloud as it is sufficient in most inversions to simply model the average upwelling radiation. The instrument cannot meaningfully measure below the upper cloud deck and even under clear sky conditions starts to suffer detector saturation problems at altitudes below 7 km altitude. At the other extreme, OSIRIS completely runs out of limb-scattered signal at around 85-90km altitude.

## 2.3 Pointing

The attitude control system on Odin employs two star-trackers during astronomy mode and only one star-tracker during aeronomy mode. The Swedish Space Corporation routinely achieves pointing accuracies better than 0.1 arc minutes during astronomy mode and 0.2 to 0.3 arc minutes in aeronomy mode, corresponding to 200-300 meters altitude error at the tangent point. The relative orientation of the OSIRIS bore-sight to the star-trackers has been measured to an accuracy of 0.05 arc minutes from observations of Jupiter and the star Vega. We have never observed any significant deformation or twisting of the satellite platform when looking at astronomical objects. The attitude control system is occasionally compromised when the moon or other bright objects contaminate the star-trackers field of view.

## 2.4 Calibration

The OSIRIS spectrograph was extensively calibrated in 1998 before delivery to Swedish Space Corporation and this data set still provides the foundation for many of the OSIRIS calibration curves used in all analyses to date. The OSIRIS absolute calibration is performed using sunlight scattered off the atmosphere. We choose a special observation geometry which is essentially a single Rayleigh scatter off the atmosphere and is insensitive to atmospheric ozone, other minor constituents and surface albedo. The technique requires knowledge of the air density at 60 km altitude for which we use ECMWF: we average over several hundred measurements over the course of a couple of weeks to help eliminate any variation in the air density. We are able to get good consistency around the 1% level with the technique and we estimate that the final absolute calibration is better than $\sim 5\%$.

Most of the Level 2 Data Products are insensitive to errors in the OSIRIS absolute calibration as they ratio the spectra observed at one height with a spectrum from a reference height, canceling out any calibration errors; their is a slight dependency as we must include an albedo term in the radiative transfer which requires good absolute calibration.

Baffle scatter is a significant problem for all observations throughout the mesosphere. It is attributed to bright, out-of-field light from the Earth's surface or atmosphere scattering off dust on the first mirror into the field of view. Baffle scatter manifests itself as a tropospheric spectral signature superimposed upon the expected mesospheric signal. For example strong water absorption signals are often present in mesospheric measurements which, in reality, are attributable to water absorption in the spectra of baffle scattered light rather than the true limb scattered mesospheric radiance. Baffle scatter effects start to be seen at altitudes as low as 40 km where they are just 1 or 2% of the total signal at the red end of the spectrum. The relative importance of baffle scatter steadily increases with altitude until ~80km where it dominates over the mesospheric Rayleigh scattered light. There is currently no standard processing algorithm for baffle scatter removal and individuals must develop their own procedures to handle this effect.

Dark current in the spectrograph CCD has been monitored throughout the mission, it is actively measured once every 2 to 4 days when the instrument is first powered on. While dark current exhibits many quirks and peculiarities it is not a cause for general concern for Level 2 inversions within the stratosphere as the observed, daytime, limb radiances are several orders of magnitude brighter than the dark current signal. However radiation hits on the CCD, which manifest themselves as bright spikes in the spectra, have not been removed from the Level 1 radiance profiles and could occasionally impact Level 2 species retrieval, especially when Odin is in auroral zones and over the South Atlantic anomaly.

# 3 OSIRIS Level 2 Data Files

The OSIRIS team routinely execute several inversion algorithms on the Level 1 radiance profiles to yield height distributions of various atmospheric species. The current list of algorithms executed are given in Table 1.

| **Technique** | **Filename** `DataType` | **Developers** |
|---|---|---|
| $O_3$ using MART. | L2-O3-Limb-MART | U. of Sask. |
| $NO_2$ from DOAS and Optimal Estimation. | L2-NO2-Limb-Chalmers-DOAS-OE | Chalmers. |
| Aerosols using MART. | L2-Aerosol-Limb-MART | U. of Sask. |
| Zonal BrO from DOAS and Optimal Estimation | L2-BRO-Limb-Zonal-DOAS-OE | Environment Canada. |
| OH 308nm Prompt and Resonance VER | L2-OH-Limb | Gattinger and Llewellyn. |

Table 1: OSIRIS Level 2 Daily Data Products

All of the algorithms, except for Zonal BrO, have a one-to-one correspondence with the satellite scans and generate one height profiles for each scan of the satellite. Not all scans can be processed by the algorithms, for example most will reject scans where the solar zenith angle is greater than $\sim 90°$. The height profiles that are successfully generated are calculated on fixed height scales suitable for storage in an HDF-EOS5 swath format, [19]. The range and resolution of the height levels is algorithm specific.

A single time and geographic location is assigned to each profile that refers to the instant when the spacecraft was staring at a specific reference altitude during the scan and the geographic location of the tangent point at that instant. The reference altitude for each species is fixed throughout the mission and is chosen so it is relatively close to the peak number density of the species of interest (e.g. 25 km for $O_3$). This assignment has the effect of unevenly distributing the height profiles around the satellite orbit as the reference altitude is not normally exactly in the middle of the scan.

All of the height profiles for a given algorithm and species are grouped together according to their date of observation and written to a single HDFEOS5, daily, data product file. Different data products are written to different HDFEOS5 files. We generally follow the guidelines of the Aura satellite, [4], for creating our HDFEOS5 data files. OSIRIS aeronomy observations occasionally stop shortly after midnight (UTC) and results in a daily data product with only one or two height profiles for that day.

Conceptually, each daily data product file contains a two-dimensional array stored as a HDFEOS5 swath where the $X$ axis is scan number, or time, and the $Y$ axis is altitude. Missing values are inserted into the array elements where inversion values are not available. Most inversion algorithms determine the number density of a given species as a function of altitude so, for convenience, we also generate the volume mixing ratio profile and store it in the same swath. We also store the atmospheric state and radiative transfer inputs used in the inversion so users can replicate the conditions used in the inversion algorithm.

The HDFEOS5 specification defines a unit of time measurement that is based upon TAI, which is based upon atomic clocks. Timing within the OSIRIS data products are based upon UTC (Coordinated Universal Time). While the two time scales are closely related conversion from UTC to TAI requires knowledge of the Earth's rotation. At the current time (2006) TAI and UTC differ by about 60 seconds. Rather than deal with the all of the nuances between TAI and UTC we approximate one to the other: all of the TAI times stored in the OSIRIS swath data products are really UTC. This approximation only affects the apparent time at which a profile is measured, it does not affect the geographic location of the measurements. We do not consider this to be a serious deficiency.

The OSIRIS Level 2, Daily, Data Products are distributed using HDF-EOS5. This is a file format that has been commonly adopted by the Earth sciences community, is available on most operating systems and has considerable resources on the web for the end user. Details and downloads of HDF-EOS5 can be found at http://hdfeos.net. Many of the OSIRIS Level 2 data products have been inspired by and loosely follow the guidelines published by the AURA team, "HDFEOS Aura file format guidelines" Craig et al. 2005.

## 3.1 FTP Download

All of the OSIRIS Level 2 Daily Data products are available for FTP download from our FTP server, ftp://odin-osiris.usask.ca/Level2. Usernames and passwords to access the data set are provided, free of charge, once a user has registered with ESA,

`http://eopi.esa.int/esa/esa`

. The Level 2 data are stored in directories sorted by year and month, e.g. directory /200512 stores all OSIRIS Level 2 Data products for December 2005.

## 3.2 Software For Reading Data

ESA provides a software package called CODA (formerly distributed as BEAT) available at

`http://www.stcorp.nl/beat`

which can be used to read OSIRIS data products. The CODA software package is available for multiple platforms and software packages, e.g. Windows, Linux, C, C++, Fortran, IDL, Matlab and python. Please note that we have experienced problems with some 64 bit versions of CODA but version 2.4 works on our Windows 7 machines.

Here is an example of how we use CODA in Matlab to read our data files.

```
>> fhd = coda_open('OSIRIS-Odin_L2-Aerosol-Limb-MART_v05-01_2001m1213.he5');
>> data = coda_fetch( fhd);
```

A generic data browsing tool, HDFView, can be downloaded free of charge from,

`http://http://www.hdfgroup.org/hdf-java-html/hdfview/`

and is a convenient way to quickly inspect the contents of a HDFEOS5 file.

The OSIRIS Level2 files were written with HDFEOS-5 version 1.11.

## 3.3 Conditions of Use

The OSIRIS Level 2 Daily Data Products are provided free of charge to all users in the spirit of scientific collaboration. The data products are governed by ESA data distribution guidelines. We request that users contact the algorithm lead developers if they intend to publish or make extensive use of these products. Our reasons are two-fold: first, we feel users should talk with the developers so they can appreciate any subtleties in the data products, avoiding unnecessary misinterpretation. Second, we need to protect our own PhD programs as many of our students have expended considerable effort in producing these data products and need time to complete their research.

## 3.4 Filenames

The filenames for the OSIRIS Level 2 Daily Data products follow the guidelines set by the Aura team. Briefly, each filename consists of a name or basis, before the period and an extension after the period. The file extension is always the string "he5". The name or basis consists of 4 sections where each section is delimited from the next by an underscore character. The filename is always in the form,

```
< InstrumentID > _ < DataType > _ < Version > _ < DataID >.he5
```

**InstrumentID** is always "OSIRIS–Odin".

**DataType** field is the string "L2" followed by a sequence of descriptive subtypes separated by dashes.

**Version** represents the version number of the processing algorithm and is in the format,

`v` $<$ `major` $>$ `-` $<$ `minor` $>$
e.g. "v02-10" should be interpreted as version 2.10.

**DataID** is the date of observation and is coded in the form,

$<$ *`yyyy`* $>$ `m` $<$ *`mm`* $><$ *`dd`* $>$

where *yyyy* is the 4 digit year, *mm* is the 2 digit month padded with leading zeroes and *dd* is the 2 digit day of the month (01-31) padded with leading zeroes. E.g. 2005m1231 corresponds to December, 31 2005.

Some filename examples for 23 July, 2004 are given below,

```
OSIRIS-Odin_L2-Aerosol-Limb-MART_v05-01_2004m0723.he5
OSIRIS-Odin_L2-NO2-Limb-Chalmers-DOAS-OE_v03-00_2004m0723.he5
OSIRIS-Odin_L2-O3-Limb-MART_v05-01_2004m0723.he5
```

## 3.5 Swaths

Swaths are an HDF-EOS5 construct that permit the storage of two-dimensional data in a file. Swaths were initially conceived for storage of horizontal, cross-track, sweeps of data generated by a satellite as it moved along its orbit. However, since swath structures are very general in nature, we have modified this definition for the Odin-OSIRIS data products so the cross-track sweep is in the vertical direction rather than the horizontal.

### 3.5.1 Swath Dimensions

| ***Dimension*** | ***Description*** |
|---|---|
| nTimes | Number of profiles in the swath |
| nLevels | Number of altitudes in the primary data products |
| nLevels2 | Number of altitudes in the model profiles |

Table 2: Swath Dimensions used in OSIRIS L2 Daily Data Products

Any HDF-EOS5 Swath can hold an indefinite number of fields where each field is either a scalar or a multi-dimensional array. We define 3 dimensions in the OSIRIS swath data products. The first dimension, **Time**, indexes along the satellite track, the second dimension,**nLevels**, indexes the vertical coordinate of the retrieved species and the final dimension, **nLevels2**, indexes a secondary vertical coordinate used for model profiles and radiative transfer calculations. The swath dimensions are summarized in Table 2. This information is most useful for users who are accessing the swath directly through the HDF-EOS5 Swath API and is used to allocate appropriately sized, swath field arrays. Higher level software interfaces, such as Matlab and IDL, normally make this information transparent to the end user.

### 3.5.2 Swath Level Attributes

Metadata, or attributes, specific to a swath can be stored within a swath using the HDF-EOS5 Swath API. We follow the Aura satellite guidelines and, in their spirit, store the information specified in table 3 in each OSIRIS Level 2 Swath. Most of the fields are specific to the OSIRIS instrument although we do provide *VerticalCoordinate* as per Aura guidelines. This information is of minimal interest to most data users. Several of the fields are readily available from the filename.

| ***Attribute Name*** | ***Type*** | ***Description*** |
|---|---|---|
| L2 Source Retrieval Technique | char | Algorithm Specific |
| L2 Version | char | Level 2 Version |
| L1 Version | double | TAI93 of L1 Version |
| VerticalCoordinate | char | "Altitude" |

Table 3: OSIRIS L2 Swath Level Attributes

### 3.5.3 File Level Attributes

| ***Attribute Name*** | ***Type*** | ***Description*** |
|---|---|---|
| InstrumentName | char | "OSIRIS" |
| ProcessLevel | char | "L2" |
| GranuleMonth | int | Month 1...12 |
| GranuleDay | int | Day 1...31 |
| GranuleYear | int | 4 digit year, e.g. 2004 |
| TAI93At0zOfGranule | double | TAI93 of 0z of granule |
| PGEVersion | char | Processing Version |

Table 4: File Level Attributes for OSIRIS Level 2 Daily Data Products

Metadata, or attributes, specific to a HDF-EOS5 file can be stored in a file using the HDF-EOS5 API. We follow Aura guidelines and store similar file level attributes. File level attributes are not intended for end users but for automated file searching, processing and plotting algorithms. The file level attributes shown in Table 4 are defined within the OSIRIS Level 2 Daily Data Products file.

# 4 $O_3$ using MART

This algorithm was developed by the OSIRIS team using a Multiplicative Algebraic Reconstruction Technique (MART) which has allowed them to combine the O3 absorption signatures in the UV Huggins band with those in the visible Chappuis band. This results in O3 profiles that extend from around 7 km up to 65 km. The data product is truncated at lower altitudes when the height profiles are deemed to have hit cloud tops, which can be polar stratospheric clouds in polar regions. Data below the cloud tops are flagged as missing.

The MART technique is described in [17] and the radiative transfer model, SASKTRAN V2, is described in [2]. The algorithm analyzes radiance profiles at the following wavelengths: 292.43 nm, 302.17 nm, 306.06 nm, 309.58 nm, 315.82 nm, 322.00 nm, 331.09nm, 350.31 nm, 543.84 nm, 602.39nm and 678.85 nm. Daily ECMWF analyses (T106) are used for the background, atmospheric density and temperature; MSIS is is used for altitudes above the ECMWF range and is forced to join the upper ECMWF density profile. O3 cross-sections are from Bogumil, Orphal and Burrows and have been adjusted to the OSIRIS point spread function. The MART algorithm internally retrieves $NO_2$, aerosols, albedo and $O_3$ profiles so it can properly handle spectral contamination of height profiles from overlapping species.

Further details relating to the product details and quality assurance can be found at our web site, http://odin-osiris.usask.ca.

## 4.1 Lead Person

University Of Saskatchewan is responsible for this algorithm. The appropriate contact people are D. A. Degenstein and A. E. Bourassa.

Institute of Space And Atmospheric Studies,
Physics Dept.,
University Of Saskatchewan,
Saskatoon,
Saskatchewan, Canada.
email: doug.degenstein@usask.ca, adam.bourassa@usask.ca

## 4.2 Version History

The latest version is 5.07 which version was released in March 2012. The version 5.0x series, (V5.01, V5.03, V5.06 and V5.07), is a family of products where we have intentionally used an identical algorithm at the core of the code and we have ensured that (essentially) identical results are achieved when each version was applied to identical data. Differences between the versions arise due to improvements in the pre-filtering of input data (e.g. radiation hits, bad attitude etc.) as well as the addition of an error analysis in V5.07. Version 5.07 is available for download from our site. We do have plans to develop another version of retrieval that will improve a few algorithm issues within the core of the code but this product will be released as a completely separate version independent of the 5.0x series.

## 4.3 File Format

The $O_3$ MART data products are stored in daily files which contain profiles of $O_3$ from each scan of OSIRIS that was suitable for analysis. Data files exist from November 2001 until the present day. There are gaps in the data product as OSIRIS would nominally run every other day from 2001 to May 2007. OSIRIS has run almost continuously since May 2007. Other gaps in the data occur when the spacecraft was running special modes, OSIRIS was undergoing engineering work or OSIRIS had technical problems. The filenames follow the guidelines given in section 3.4. The swath name and the filename components are given in Table 5.

| Property | Value |
|---|---|
| Swath Name | "OSIRIS\Odin O3MART" |
| InstrumentID | "OSIRIS-Odin" |
| DataType | "L2-O3-Limb-MART" |
| Versions | 2.10, April 2006 (available by special request) |
| | 5.01/5.03 series, October 2009 |
| | 5.06 series, June 2011. |
| | 5.07 series, March 2012. Includes error analysis |

Table 5: Swath and filename strings for "$O_3$ from Chappuis/Huggins and MART"

## 4.4 Description of O3 MART Geolocation fields

The swath geolocation fields stored in the NO2 swaths are summarized in Table 6 and described below.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| Time | `double` | nTimes | TAI 1993 |
| Latitude | `float` | nTimes | deg -90. . . 90 |
| Longitude | `float` | nTimes | deg -180. . . 180 |
| Altitude | `float` | nLevels | km |
| SolarZenithAngle | `float` | nTimes | deg 0. . . 180 |
| SolarAzimuthAngle | `float` | nTimes | deg -180. . . 180 |
| SolarScatteringAngle | `float` | nTimes | deg 0. . . 180 |
| LocalSolarTime | `float` | nTimes | hours |
| ScanNo | `long` | nTimes | |
| ScanUpFlag | `byte` | nTimes | 1=up, 0=down |
| ScanStartTime | `double` | nTimes | TAI 1993 |
| ScanStartLatitude | `float` | nTimes | deg -90. . . 90 |
| ScanStartLongitude | `float` | nTimes | deg -180. . . 180 |
| ScanEndTime | `double` | nTimes | TAI 1993 |
| ScanEndLatitude | `float` | nTimes | deg -90. . . 90 |
| ScanEndLongitude | `float` | nTimes | deg -180. . . 180 |
| RTModel_Altitude | `float` | nLevels2 | km |

Table 6: Geolocation Fields for "$O_3$ from Chappuis/Huggins and MART"

**Time** The nominal time of the scan in UTC expressed as TAI93 assuming no offset between UTC and TAI93. This corresponds to the instant when the tangent point of the OSIRIS look vector was at 25 k.m.

**Latitude** The nominal latitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time Time.

**Longitude** The nominal longitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time Time.

**Altitude** The geometric altitude of the primary swath data products expressed in km. The altitudes are specified with respect to the IAU 1976 reference geoid.

**SolarZenithAngle** The solar zenith angle expressed in degrees at the nominal tangent point of the scan. $0°$ is sun overhead, $90°$ is sun on the horizon.

**SolarAzimuthAngle** The solar azimuth angle expressed in degrees at the nominal tangent point of the scan. 0° is due North, 90° is due East, 180° is South and 270° is West.

**SolarScatteringAngle** The solar scattering angle expressed in degrees at the nominal tangent point of the scan. 0° corresponds to forward scatter and 180° corresponds to backscatter.

**LocalSolarTime** The local solar time at the nominal tangent point expressed in hours, 0. . . 24.

**ScanNo** The unique identification number of this scan. This number is generated from 1000∗orbit number+ (scan in orbit).

**ScanUpFlag** Indicates if the scan was going up (1) or going down (0). OSIRIS image sampling rates are known to be different between upward and downward scans.

**ScanStartTime** The UTC start time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanStartLatitude** The latitude of the tangent point in degrees at the start of the scan.

**ScanStartLongitude** The longitude of the tangent point at the start of the scan.

**ScanEndTime** The end time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanEndLatitude** The latitude of the tangent point at the end of the scan.

**ScanEndLongitude** The longitude of the tangent point at the end of the scan.

**RTModel_Altitude** The geometric altitude of the model inputs expressed in km. The altitudes are with respect to the IAU 1976 reference geoid. This secondary altitude scale is introduced as model inputs for radiative transfer and inversion are on a different altitude scale.

## 4.5 Description of O3 MART Data fields

The swath data fields stored in the O3 swaths are summarized in Table 7 and described below. Most users will only need access to the fields O3, O3NumberDensity and O3Precision. The fields beginning with the prefix "RTModel" are stored for by the OSIRIS Processing Center for diagnostic purposes and will not be of interest to most users although they are free to use them if they wish.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| O3 | `float` | nLevels × nTimes | vmr |
| O3Precision | `float` | nLevels × nTimes | vmr |
| O3NumberDensity | `float` | nLevels × nTimes | $cm^{-3}$ |
| RTModel_Albedo | `float` | nTimes | |
| RTModel_AirDensity | `float` | nLevels2 × nTimes | $cm^{-3}$ |
| RTModel_Temperature | `float` | nLevels2 × nTimes | K |
| RTModel_O3InitialGuess | `float` | nLevels2 × nTimes | $cm^{-3}$ |
| RTModel_O3Density | `float` | nLevels2 × nTimes | $cm^{-3}$ |

Table 7: Data Fields for "$O_3$ MART"

**O3** Measured ozone profiles expressed as volume mixing ratio. The profiles are bounded at upper and lower limits by "Missing Value". OSIRIS does not measure the volume mixing ratio directly but calculates this parameter from the ratio of O3NumberDensity to RTModel_AirDensity at each altitude. The field is provided for users convenience and uses the same field name as the AURA-MLS instrument. The field O3NumberDensity is the fundamental product derived from the OSIRIS ozone inversion algorithms.

**O3Precision** The error in the ozone volume mixing ratio. File versions earlier then V5.07 are empty and only contains "Missing Value". The error in V5.07 and later is derived from interpolation of the covariance matrix on the irregular measurement grid to the regular spaced retrieval grid. The error can be converted to an equivalent number density error by multiplication with field RTModel_AirDensity.

**O3NumberDensity** The measured ozone profiles expressed as number density. The O3 number density is derived directly from the inversion algorithm. The profiles are bounded at upper and lower altitudes by "Missing Value". Molecules/cm$^3$.

**RTModel_Albedo** The ground albedo value used in the radiative transfer code. The ground albedo is assumed to have no wavelength dependence.

**RTModel_AirDensity** The atmospheric air density profile used in the radiative transfer model. The field is also used to convert O3NumberDensity number density to O3 volume mixing ratio. The RTModel_AirDensity is derived from interpolation of an ECMWF T106 data product. The ECMWF analysis has been extended to the (virtual) ground when required using logarithmic extrapolation. The upper end of the profile, typically above approx. 60 km, has been extended using a simple MSIS model which is scaled to join the ECWMF model at its highest pressure level. This field was formerly known as RTModel_NeutralDensity. Molecules/cm$^3$.

**RTModel_Temperature** The atmospheric temperature profile used in the radiative transfer model in the inversion algorithms. The inversion scheme tracks changes of the $O_3$ cross-section with temperature. This field was formerly known as RTModel_NeutralTemperature. Kelvins

**RTModel_O3InitialGuess** The initial guess of $O_3$ used in the MART retrieval, expressed as a number density. Note that the field is not an a-priori in the sense used by statistical matrix inversion schemes (e.g. optimal estimation). This field was formerly known as RTModel_O3Apriori. Molecules/cm$^3$.

**RTModel_O3Density** The $O_3$ profile expressed as a number density used in the last iteration of the radiative transfer model. This is identical to the primary data product, O3NumberDensity, except it is not bounded at lower and upper altitudes by "Missing Value" according to the vertical extent of the retrieval, i.e. it extends from 0.5 km to 99.5 km. Molecules/cm$^3$.

# 5 $NO_2$ from DOAS and Optimal Estimation

The Odin-OSIRIS $NO_2$ from DOAS and Optimal Estimation data product is derived from inversion of OSIRIS height profiles of OSIRIS radiance. The retrieval technique is developed in [18] and fully described in [10]. A detailed validation study is available in [3].

## 5.1 Lead Person

The appropriate contact people are Chris McLinden at Environment Canada, Ian McDade at York University and Donal Murtagh and Samuel Broehde at Chalmers University Of Technology

Chris Mclinden
Air Quality Research Division,
Environment Canada, Toronto,
Ontario, Canada .
email: Chris.McLinden@ec.gc.ca
I. C. McDade, Centre for Research in Earth And Space Science,
York University,
Toronto,
Ontario, Canada.
email: mcdade@yorku.ca

Donal Murtagh or Samuel Broehde
Global Environmental Measurements
Chalmers University Of Technology, SE-412 96
Göteborg,
Sweden.
email: donal@chalmers.se, email: brohede@rss.chalmers.se

## 5.2 Version History

Two versions are produced: version 3 and version 5. Version 3.00 was started in 2006 while version 5.00 started in December 2010. Version 3 is available for the entire mission and continues to be produced. Version 5 will be eventually available for the entire mission but may require substantial time (months) to reprocess the mission. The two data versions use the same processing code but differ in the incoming Level 1 radiance data. Briefly the OSIRIS level 1 radiance data had a major upgrade in September 2008 when new dark current and absolute calibration algorithms were applied to the OSIRIS Level 1 radiance data in September 2008. The improved dark current removal slightly improves the NO2 retrieval. The version 3.0 data files are a mixture of pre-September 2008 and post-September 2008 level 1 calibrations. The version 5 files are exclusively based upon the post-September 2008 Level 1 data files.

## 5.3 File Format

The $NO_2$ DOAS data products are stored in daily files which contain profiles of $NO_2$ from each scan of OSIRIS that was suitable for analysis. Data files exist from November 2001 until the present day. There are gaps in the data product as OSIRIS would nominally run every other day from 2001 to May 2007. OSIRIS has run almost continuously since May 2007. Other gaps in the data occur when the spacecraft was running special modes, OSIRIS was undergoing engineering work or OSIRIS or Odin had technical problems. The

| Property | Value |
|---|---|
| Swath Name | "OSIRIS\Odin NO2 DOAS OE" |
| InstrumentID | "OSIRIS-Odin" |
| DataType | "L2-NO2-Limb-DOAS-OE" |
| Versions | 3.00, July 2006. 5.00 Dec 2010 |

Table 8: Swath and filename strings for "$NO_2$ from DOAS and Optimal Estimation"

filenames follow the guidelines given in section 3.4. The swath name and the filename components are given in Table 8.

## 5.4 Description of NO2 DOAS Geolocation fields

The swath geolocation fields stored in the NO2 swaths are summarized in Table 9 and described below.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| Time | `double` | nTimes | TAI 1993 |
| Latitude | `float` | nTimes | deg -90...90 |
| Longitude | `float` | nTimes | deg -180...180 |
| Altitude | `float` | nLevels | km |
| SolarZenithAngle | `float` | nTimes | deg 0...180 |
| SolarAzimuthAngle | `float` | nTimes | deg -180...180 |
| SolarScatteringAngle | `float` | nTimes | deg 0...180 |
| LocalSolarTime | `float` | nTimes | hours |
| ScanNo | `long` | nTimes | |
| ScanUpFlag | `byte` | nTimes | 1=up, 0=down |
| ScanStartTime | `double` | nTimes | TAI 1993 |
| ScanStartLatitude | `float` | nTimes | deg -90...90 |
| ScanStartLongitude | `float` | nTimes | deg -180...180 |
| ScanEndTime | `double` | nTimes | TAI 1993 |
| ScanEndLatitude | `float` | nTimes | deg -90...90 |
| ScanEndLongitude | `float` | nTimes | deg -180...180 |

Table 9: Geolocation fields for "$NO_2$ from DOAS and Optimal Estimation"

**Time** The nominal time of the scan in UTC expressed as TAI93 assuming no offset between UTC and TAI93. This time normally corresponds to the instant when the tangent point of the OSIRIS look vector was at a specific reference altitude, e.g. 25 k.m.

**Latitude** The nominal latitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time **Time**.

**Longitude** The nominal longitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time **Time**.

**Altitude** The geometric altitude of the primary swath data products expressed in km. The altitudes are specified with respect to the IAU 1976 reference geoid.

**RTModel_Altitude** The geometric altitude of the model inputs expressed in km. The altitudes are with respect to the IAU 1976 reference geoid. This secondary altitude scale is introduced as model inputs for radiative transfer and inversion are on a different altitude scale.

**SolarZenithAngle** The solar zenith angle expressed in degrees at the nominal tangent point of the scan. 0° is sun overhead, 90° is sun on the horizon.

**SolarAzimuthAngle** The solar azimuth angle expressed in degrees at the nominal tangent point of the scan. 0° is due North, 90° is due East, 180° is South and 270° is West.

**SolarScatteringAngle** The solar scattering angle expressed in degrees at the nominal tangent point of the scan. 0° corresponds to forward scatter and 180° corresponds to backscatter.

**LocalSolarTime** The local solar time at the nominal tangent point expressed in hours, 0. . . 24.

**ScanNo** The unique identification number of this scan. This number is generated from 1000∗orbit number+ (scan in orbit).

**ScanUpFlag** Indicates if the scan was going up (1) or going down (0). OSIRIS image sampling rates are known to be different between upward and downward scans.

**ScanStartTime** The UTC start time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanStartLatitude** The latitude of the tangent point in degrees at the start of the scan.

**ScanStartLongitude** The longitude of the tangent point at the start of the scan.

**ScanEndTime** The end time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanEndLatitude** The latitude of the tangent point at the end of the scan.

**ScanEndLongitude** The longitude of the tangent point at the end of the scan.

## 5.5 Description of NO2 DOAS Data fields

The swath data fields stored in the NO2 swaths are summarized in Table 10 and described below.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| NO2 | `float` | nLevels × nTimes | vmr |
| NO2Precision | `float` | nLevels × nTimes | vmr |
| NO2NumberDensity | `float` | nLevels × nTimes | $cm^{-3}$ |
| MeasResolution | `float` | nLevels × nTimes | |
| MeasResponse | `float` | nLevels × nTimes | |
| RTModel_NeutralDensity | `float` | nLevels × nTimes | $cm^{-3}$ |
| RTModel_NeutralTemperature | `float` | nLevels × nTimes | K |
| RTModel_NO2Apriori | `float` | nLevels × nTimes | $cm^{-3}$ |

Table 10: Data fields for "$NO_2$ from DOAS and Optimal Estimation"

**NO2** The set of $NO_2$ profiles expressed as a volume mixing ratio. Each profile is derived from the ratio of NO2NumberDensity to RTModel_NeutralDensity at each altitude. Note that NO2NumberDensity is the fundamental product.

**NO2Precision** The error in the set of $NO_2$ profiles expressed as a volume mixing ratio.

**NO2NumberDensity** The set of $NO_2$ profiles expressed as number density. These are the profiles derived directly from the inversion algorithm. Molecules/cm3.

**MeasResolution** The vertical resolution is inferred from the approximate width of the averaging kernels, i.e. the rows of the averaging kernel matrix. The width is determined using the Backus-Gilbert spread method, as outlined in [16]. Note that the given resolution does not take into account the finite effective instrument resolution (instantaneous resolution + spatial smearing) since the forward model does not include these effects.

**MeasResponse** The response of the retrieval, or the contribution of the a priori to the result, is determined from the area of the averaging kernels.

$$resp(i) = \sum_j K(i,j) \frac{x_a(j)}{x_a(i)}$$

**RTModel_NeutralDensity** The neutral density profile used in the radiative transfer model and for conversion from number density to volume mixing ratio. Molecules /cm$^3$.

**RTModel_NeutralTemperature** The neutral density temperature profile used in the radiative transfer model in the inversion algorithms. Most inversions change the cross-section of $O_3$ and $NO_2$ with temperature. Kelvin

**RTModel_NO2Apriori** The a-priori $NO_2$ model, expressed as a number density. Molecules/cm$^3$.

# 6 Aerosols from Wavelength Pairs and MART

## 6.1 Lead Person

University Of Saskatchewan has been responsible for developing the aerosol retrieval algorithm based upon MART. The appropriate contact people are A. E. Bourassa and D. A. Degenstein.

Institute of Space And Atmospheric Studies,
Physics Dept.,
University Of Saskatchewan,
Saskatoon,
Saskatchewan, Canada.
email: doug.degenstein@usask.ca, adam.bourassa@usask.ca

## 6.2 Version History

## 6.3 File Format

| Property | Value |
|---|---|
| Swath Name | "OSIRIS\Odin Aerosol MART" |
| InstrumentID | "OSIRIS-Odin" |
| DataType | "L2-Aerosol-Limb-MART" |
| Versions | 5.01/5.03 series, October 2009 |
| | 5.06 series, June 2011. |
| | 5.07 series, March 2012. Includes error analysis |

Table 11: Swath and filename strings for "Aerosols from Wavelength Pairs and MART"

## 6.4 Description of Aerosol Swath Geolocation Fields

The aerosol geolocation fields are given in table 12 and descriptions are given below

**Time** The nominal time of the scan in UTC expressed as TAI93 assuming no offset between UTC and TAI93. This time normally corresponds to the instant when the tangent point of the OSIRIS look vector was at a specific reference altitude, e.g. 25 k.m.

**Latitude** The nominal latitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time **Time**.

**Longitude** The nominal longitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time **Time**.

**Altitude** The geometric altitude of the primary swath data products expressed in km. The altitudes are specified with respect to the IAU 1976 reference geoid.

**RTModel_Altitude** The geometric altitude of the model inputs expressed in km. The altitudes are with respect to the IAU 1976 reference geoid. This secondary altitude scale is introduced as model inputs for radiative transfer and inversion are on a different altitude scale.

**SolarZenithAngle** The solar zenith angle expressed in degrees at the nominal tangent point of the scan. 0° is sun overhead, 90° is sun on the horizon.

**SolarAzimuthAngle** The solar azimuth angle expressed in degrees at the nominal tangent point of the scan. 0° is due North, 90° is due East, 180° is South and 270° is West.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| Time | `double` | nTimes | TAI 1993 |
| Latitude | `float` | nTimes | deg -90...90 |
| Longitude | `float` | nTimes | deg -180...180 |
| Altitude | `float` | nLevels | km |
| SolarZenithAngle | `float` | nTimes | deg 0...180 |
| SolarAzimuthAngle | `float` | nTimes | deg -180...180 |
| SolarScatteringAngle | `float` | nTimes | deg 0...180 |
| LocalSolarTime | `float` | nTimes | hours |
| ScanNo | `long` | nTimes | |
| ScanUpFlag | `byte` | nTimes | 1=up, 0=down |
| ScanStartTime | `double` | nTimes | TAI 1993 |
| ScanStartLatitude | `float` | nTimes | deg -90...90 |
| ScanStartLongitude | `float` | nTimes | deg -180...180 |
| ScanEndTime | `double` | nTimes | TAI 1993 |
| ScanEndLatitude | `float` | nTimes | deg -90...90 |
| ScanEndLongitude | `float` | nTimes | deg -180...180 |
| RTModel_Altitude | `float` | nLevels2 | km |

Table 12: Geolocation Fields for "Aerosols from Wavelength Pairs and MART"

**SolarScatteringAngle** The solar scattering angle expressed in degrees at the nominal tangent point of the scan. 0° corresponds to forward scatter and 180° corresponds to backscatter.

**LocalSolarTime** The local solar time at the nominal tangent point expressed in hours, 0...24.

**ScanNo** The unique identification number of this scan. This number is generated from 1000∗orbit number+ (scan in orbit).

**ScanUpFlag** Indicates if the scan was going up (1) or going down (0). OSIRIS image sampling rates are known to be different between upward and downward scans.

**ScanStartTime** The UTC start time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanStartLatitude** The latitude of the tangent point in degrees at the start of the scan.

**ScanStartLongitude** The longitude of the tangent point at the start of the scan.

**ScanEndTime** The end time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanEndLatitude** The latitude of the tangent point at the end of the scan.

**ScanEndLongitude** The longitude of the tangent point at the end of the scan.

## 6.5 Description of Aerosol Swath Data Fields

The swath data fields are summarized in Table 13.and descriptions are given below.

**AerosolExtinction** Height profiles of Aerosol extinction coefficient per kilometer at 750 nm. The profiles are bounded at upper and lower altitudes by "Missing Value". This field was formerly known as Aerosol. Extinction per kilometer.

**AerosolPrecision** The random error in the aerosol extinction per kilometer at 750 nm. The profiles are bounded at upper and lower altitudes by "Missing Value". Not available before version 5.07. Extinction per kilometer.

| *Field* | *Type* | *Dimension* | *Description* |
|---|---|---|---|
| AerosolExtinction | `float` | nLevels × nTimes | $km^{-1}$ |
| AerosolPrecision | `float` | nLevels × nTimes | $km^{-1}$ |
| RTModel_Albedo | `float` | nTimes | |
| RTModel_AirDensity | `float` | nLevels2 × nTimes | $cm^{-3}$ |
| RTModel_Temperature | `float` | nLevels2 × nTimes | K |
| RTModel_AerosolInitialGuess | `float` | nLevels2 × nTimes | $km^{-1}$ |
| RTModel_AerosolExtinction | `float` | nLevels2 × nTimes | $km^{-1}$ |

Table 13: Data Fields for "Aerosols from Wavelength Pairs and MART"

**RTModel_Albedo** The ground albedo value used in the radiative transfer code. The ground albedo is assumed to have no wavelength dependence. No units.

**RTModel_AirDensity** The atmospheric air density profile used in the radiative transfer model. The RTModel_AirDensity is derived from interpolation of an ECMWF T106 data product. The ECMWF analysis has been extended to the (virtual) ground when required using logarithmic extrapolation. The upper end of the profile, typically above approx. 60 km, has been extended using a simple MSIS model which is scaled to join the ECWMF model at its highest pressure level. This field was formerly known as RTModel_NeutralDensity. Molecules/$cm^3$.

**RTModel_Temperature** The atmospheric temperature profile used in the radiative transfer model in the inversion algorithms. The profile is derived from linear interpolation of an ECMWF T106 data product. The ECMWF analysis has been extended to the (virtual) ground when required using linear extrapolation and extended above the top of ECMWF using MSIS. This field was formerly known as RTModel_NeutralTemperature

**RTModel_AerosolInitialGuess** The initial guess aerosol model, expressed as extinction per kilometer at 750 nm. Note that the field is not an a-priori in the sense used by statistical matrix inversion schemes (e.g. optimal estimation). This field was formerly known as RTModel_AerosolAPriori.

**RTModel_AerosolExtinction** The aerosol profile expressed as extinction per kilometer at 750 nm used in the last iteration of the radiative transfer model. This is identical to the primary data product, AerosolExtinction, except it is not bounded at lower and upper altitudes by "Missing Value" according to the vertical extent of the retrieval, i.e. it extends from 0.5 km to 99.5 km. This field was formerly known as RTModel_AerosolDensity.

# 7 Zonal BrO from DOAS and Optimal Estimation

The Odin-Osiris zonal BrO data product is derived from OSIRIS height profiles of radiance. Measurement of BrO using the OSIRIS instrument is challenging as individual height profiles generally lack sufficient signal to noise by a factor of approximately 3. The OSIRIS team has zonally averaged radiance profiles before inversion to increase signal to noise into latitude bins 10° degrees wide centered from $85°N$ to $85°S$. The number of scans in any bin is typically between 10 and 25. The Odin-OSIRIS BrO product is divided into two groups: the morning sector measurements (AM) and the afternoon sector (PM). The sun-synchronous nature of the Odin orbit ensures that observations at different longitudes in the same latitude bin occur with the same basic solar geometry as long as we differentiate between the up-leg and down-leg of the orbit. The northbound, up-leg of the orbit occurs in the evening sector and measurements from this sector are averaged into the PM measurements. The down-leg measurements occur in the dawn sector and are averaged into the AM measurements.

The data product at the time of production (February 2009) has limited validation against other measurements. The interested reader is referred to [14] for more details on analysis and validation work.

## 7.1 Lead Person

Chris Mclinden at the Air Quality Research Division, Environment Canada, Toronto, Canada is the contact person for the zonal BrO data product.
email: Chris.McLinden@ec.gc.ca

## 7.2 Version History

## 7.3 BrO File format

The BrO measurements are stored in daily files which contain the average zonal profiles for each day of OSIRIS operation. The files are named according to the file-naming convention outlined in section 3.4. The *DataType* section of the filename as well as the names of the AM and PM swaths stored in the files are given in Table 14.

OSIRIS was nominally operational every other day from 2001 to June 2007 and continuously from June 2007 to the present day (date of writing March 2009). Occasional gaps in the data record are due to special operational modes, engineering periods or instrument malfunction. Each day is defined as 00:00:00 UTC to 23:59:59.999 UTC and this can create a peculiar data file if OSIRIS was turned on a few minutes before midnight or turned off a few minutes after midnight. The data field, "NumScansAveraged" can be used to diagnose this condition.

| Property | Value |
|---|---|
| Swath Name | "`OSIRIS\Odin BrO Zonal Doas AM`" |
| | "`OSIRIS\Odin BrO Zonal Doas PM`" |
| InstrumentID | "`OSIRIS-Odin`" |
| DataType | "`L2-BRO-Limb-Zonal-DOAS-OE`" |
| Version | 4.00, Jan 2009 |
| Version | 5.00, Jan 2011 |

Table 14: Swath and filename strings for "Zonal BrO from DOAS and Optimal Estimation"

## 7.4 Description of swath geolocation fields

The swath geolocation fields are summarized in Table 15. with descriptions given below. The number of times, nTimes, is always 18 and the number of height levels, NLevels, is always 11.

| ***Field*** | ***Type*** | ***Dimension*** | ***Comment*** | ***Description*** |
|---|---|---|---|---|
| Time | `double` | nTimes | Average time in latitude bin | TAI 1993 |
| Latitude | `float` | nTimes | Central Latitude of latitude bin | deg -90. . . 90 |
| Longitude | `float` | nTimes | Always 0.0 | deg -180. . . 180 |
| Altitude | `float` | nLevels | Interpolated Heights | km |
| TangentHeight | `float` | nLevels | Slant column tangent heights | km |
| AvgLat | `float` | nTimes | Average Latitude in latitude bin | deg -90. . . 90 |
| AvgLong | `float` | nTimes | Average Longitude in latitude bin | deg -180. . . 180 |
| AvgSZA | `float` | nTimes | Average solar zenith angle | deg 0. . . 180 |
| AvgSAA | `float` | nTimes | Average solar azimuth angle | deg -180. . . 180 |
| AvgSSA | `float` | nTimes | Average solar scattering angle | deg 0. . . 180 |
| AvgLST | `float` | nTimes | Average local solar time | hours 0. . . 24 |
| NumScansAveraged | `long` | nTimes | Number of scans in each latitude bin | |
| NumUniqueOrbits | `long` | nTimes | Number of unique orbits in each latitude bin | |

Table 15: Geolocation fields for “Zonal BrO from DOAS and Optimal Estimation”

**Time** The time of 00:00 UTC on the day of the data. The UTC is expressed as TAI93 assuming no offset between UTC and TAI93.

**Latitude** The central latitude of a 10° latitude bin. This is always an 18 element array.

**Longitude** The longitude of the zonally averaged data is meaningless. This value, which is provided for HDFEOS compatibility, is always 0.0.

**Altitude** The geometric altitude of each data bin expressed in km. This is always an 11 element array going from 16 km to 36 km in steps of 2 km.

**TangentHeight** The geometric tangent altitude of the slant column BrO data expressed in km. This is always an 11 element array going from 16 km to 36 km in steps of 2 km.

**AvgLat** The average latitude expressed in degrees of all of the scan measurements that contributed to this data bin.

**AvgLong** The average longitude expressed in degrees of all of the scan measurements that contributed to this data bin.

**AvgSZA** The average solar zenith angle expressed in degrees of all of the scan measurements that contributed to this data bin.

**AvgSAA** The average solar azimuth angle expressed in degrees of all of the scan measurements that contributed to this data bin.

**AvgSAA** The average solar scattering angle expressed in degrees of all of the scan measurements that contributed to this data bin.

**AvgLST** The average local solar time expressed in hours, 0. . . 24, of all of the scan measurements that contributed to this data bin.

**NumScansAveraged** The number of scan measurements that contributed to this data bin.

**NumUniqueOrbits** The number of unique orbits that contributed to this data bin. In theory, the satellite makes between 14 and 15 unique orbits each day. This value indicates how many of those orbits contributed to the data bins

| *Field* | *Type* | *Dimension* | *Description* |
|---|---|---|---|
| AprioriBrO | `float` | nLevels × nTimes | molecules/cm$^3$ |
| AprioriBrOError | `float` | nLevels × nTimes | molecules/cm$^3$ |
| BrO | `float` | nLevels × nTimes | molecules/cm$^3$ |
| BrOMeasError | `float` | nLevels × nTimes | molecules/cm$^3$ |
| BrOMeasResolution | `float` | nLevels × nTimes | km |
| BrOMeasResponse | `float` | nLevels × nTimes | |
| BrOPrecision | `float` | nLevels × nTimes | molecules/cm$^3$ |
| BrOSmoothingError | `float` | nLevels × nTimes | molecules/cm$^3$ |
| BrOVMR | `float` | nLevels × nTimes | vmr |
| NeutralDensity | `float` | nLevels × nTimes | molecules/cm$^3$ |
| Temperature | `float` | nLevels × nTimes | K |
| Pressure | `float` | nLevels × nTimes | hPa |
| EquivLatitude | `float` | nLevels × nTimes | degrees |
| SlantColumnBrO | `float` | nLevels × nTimes | molecules/cm$^2$ |
| SlantColumnBrORMSFitResidual | `float` | nLevels × nTimes | |
| SlantColumnBrOPrecision | `float` | nLevels × nTimes | molecules/cm$^2$ |

Table 16: Data fields for "Zonal BrO from DOAS and Optimal Estimation"

## 7.5 Description of swath data fields

The swath data fields are summarized in Table 16. All of the data fields are given as 2-D arrays with 11 heights and 18 latitudes. The height dimension extends from 16 km to 36 km in 2 km increments. The latitude dimension extends from -85N to 85N in 10° increments. Missing values will be present in nearly all files as OSIRIS can only retrieve BrO from the sunlit sections of the atmosphere which, due to the nature of the Odin orbit, excludes the winter hemisphere. Missing values in all fields are represented by -9999.0.

**BrO** The retrieved BrO number density (molecules/cm$^3$).

**BrOVMR** The retrieved BrO expressed as a volume mixing ratio.

**BrOPrecision** The total retrieved error on the BrO number density. The Precision is also the Measurement error and the Smoothing error, added in quadrature (molecules/cm$^3$).

**BrOMeasError** The error component due to noise in the retrieval (molecules/cm$^3$)

**BrOMeasResolution** The vertical resolution is inferred from the approximate width of the averaging kernels, i.e. the rows of the averaging kernel matrix. The width is determined using the Backus-Gilbert spread method, as outlined in [16]. Note that the given resolution does not take into account the finite effective instrument resolution (instantaneous resolution + spatial smearing) since the forward model does not include these effects.

**BrOMeasResponse** The response of the retrieval, or the contribution of the a-priori to the result, is determined from the area of the averaging kernels.

$$resp(i) = \sum_j K(i,j) \frac{x_a(j)}{x_a(i)}$$

**BrOSmoothingError** The error component arising from the limited vertical resolution of the measurements (molecules/cm$^3$)

**SlantColumnBrO** The fitted BrO Slant Column Density from DOAS as a function of tangent height on the same vertical grid as BrO number density. (molecules/cm$^2$)

**SlantColumnBrORMSFitResidual** The root-mean-square (RMS), over wavelength, of the DOAS fit residual as a function of tangent height (dimensionless)

**SlantColumnBrOPrecision** The uncertainty in the BrO Slant Column Density as a function of tangent height (molecules/cm$^2$).

**AprioriBrO** The a priori BrO profile in number density as calculated in a photochemical box model (molecules/cm$^3$)

**AprioriBrOError** The uncertainty assigned to the a prioiri BrO, used in the optimal estimation (v4.0 uses 100%) (molecules/cm$^3$)

**NeutralDensity** The background neutral atmosphere number density profile used in the retrieval. The number density data are derived from ECMWF data. The units are molecules/cm$^3$.

**Temperature** The background neutral atmosphere temperature profile used in the retrieval expressed in Kelvins. The temperature data are derived from ECMWF data.

**Pressure** The background neutral atmosphere profile profile used in the retrieval expressed in hPascals. The pressure data are derived from ECMWF data.

**EquivLatitude** The equivalent latitude as a function of altitude (degrees)

# 8 OH 308nm Prompt and Resonance Volume Emission Rates

The Odin-OSIRIS OH data product is derived from inversion of OSIRIS height profiles of radiance in the wavelength range centered around the OH $A^2\Sigma^+ - X^2\Pi$ $0-0$ band emission at 308nm. This work is considered to be a new technique that has yet to be validated. A full description of the inversion technique can be found in [7] and [6]. The emission consists of two separate terms. The first is the solar resonance volume emission rate and the second is the prompt OH volume emission rate.

## 8.1 Lead Person

Dick Gattinger (retired) is the lead person for the OH emissions data product. He can be contacted via Ted Llewellyn (email: edward.llewellyn@usask.ca) or Doug Degenstein (email: doug.degenstein@usask.ca).

## 8.2 Version History

## 8.3 OH File Format

The OH volume emission rate products are stored in daily files which contain profiles of OH volume emission rates from each scan of OSIRIS that was suitable for analysis. Data files exist from the November 2001 until the present day although there can be substantial gaps in the data product as OSIRIS scans are frequently not suitable for inversion of the OH emission rates.

| Property | Value |
|---|---|
| Swath Name | "`OSIRIS\Odin OH `" |
| InstrumentID | "`OSIRIS-Odin`" |
| DataType | "`L2-OH-Limb`" |
| Version | 4.00, Jan 2009 |

Table 17: Swath and filename strings for "OH Prompt and Resonance"

## 8.4 Description of OH swath geolocation fields

The geolocation fields stored in OH swaths are summarized in Table 18 and described below.

| ***Field*** | ***Type*** | ***Dimension*** | ***Comment*** | ***Description*** |
|---|---|---|---|---|
| Time | `double` | nTimes | Average time of measurement | TAI 1993 |
| Latitude | `float` | nTimes | Latitude of measurement | deg -90...90 |
| Longitude | `float` | nTimes | Longitude of measurement | deg -180...180 |
| Altitude | `float` | nLevels | Heights of retrieved profile | km |
| SZA | `float` | nTimes | Solar zenith angle | deg 0...180 |
| SSA | `float` | nTimes | Solar scattering angle | deg 0...180 |
| LST | `float` | nTimes | Local Solar Time | deg 0...24 |
| PMCIndicator | `float` | nTimes | PMC Indicator | |

Table 18: Geolocation fields for "OH Prompt and Resonance"

**Time** The nominal time of the OSIRIS scan from which the emission rates were retrieved.. The time is expressed as TAI93 assuming no offset between UTC and TAI93.

**Latitude** The nominal latitude of the scan.

**Longitude** The nominal longitude of the scan.

**Altitude** The geometric altitude of each data bin expressed in km. This is always a 41 element array going from 60 km to 100 km in steps of 1 km.

**SZA** The nominal solar zenith angle of each OSIRIS scan in the file expressed in degrees.

**SSA** The nominal solar scattering angle of each OSIRIS scan in the file expressed in degrees.

**LST** The nominal local solar time of each OSIRIS scan in the file expressed in hours.

**PMCIndicator** A number output from the analysis to help identify interference from polar mesospheric clouds. Values close to 1 are probably free from PMC interference while significantly higher values suggest the data may not be trustworthy.

## 8.5 Description of OH data fields

The OH data fields are summarized in table 19 and described below.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| OHPrompt | `float` | nLevels × nTimes | molecules/cm$^3$ |
| OHPromptError | `float` | nLevels × nTimes | molecules/cm$^3$ |
| OHResonance | `float` | nLevels × nTimes | molecules/cm$^3$ |
| OHResonanceError | `float` | nLevels × nTimes | molecules/cm$^3$ |

Table 19: Data fields for "OH Prompt and Resonance"

**OHPrompt** The altitude profile of the OH prompt volume emission rate for the given OSIRIS scan. Photons/cm$^3$.

**OHPromptError** The error in the OH prompt volume emission rate. Photons/cm$^3$.

**OHResonance** The altitude profile of the OH solar resonance volume emission rate for the given OSIRIS scan. Photons/cm$^3$.

**OHResonanceError** The error in the OH solar resonance volume emission rate. Photons/cm$^3$.

# 9 $O_3$ from Chappuis Triplet and Optimal Estimation. Deprecated

This was the first algorithm implemented by the OSIRIS team to retrieve $O_3$ from the OSIRIS radiance data. The algorithm has since been superseded by the $O_3$ MART algorithm. The algorithm retrieves vertical profiles of $O_3$ from analysis of the Chappuis absorption band: a height dependent retrieval vector is derived from the ratio of limb radiances at three wavelengths, one near the center of the absorption band and two to either side. The wavelengths used are 601.9 nm for the center of the band and 532.2 nm and 671.3 nm for the side regions, corresponding to pixels 826, 652 and 998 on the CCD, respectively. Each retrieval vector is normalized to a retrieval vector measured at the reference altitude of 50 km. The retrieval vectors are inverted using the optimal estimation technique developed by [16]. The method is described in more detail together with sensitivity studies and validation studies in [21], [5], [10] and [22]. For more information contact Craig Haley (cshaley@yorku.ca) or Christian von Savigny (csavigny@iup.physik.uni-bremen.de).

## 9.1 Level 1 Data

In any given orbit, all scans defined in the OSIRIS Spectrograph Level 1 data product are processed, provided that,

1. there is associated attitude data.
2. Odin was scanning (ACSState == ACS LIMBSCAN)
3. the maximum SZA in the scan is less than 92°
4. the range of the scan is within 10 km of the desired range, both top and bottom.

Processing flags, spectral outliers and astronomical objects in the field of view are not dealt with at the current time. Attitude information for each suitable observation is determined at a representative time for each spectra to account for spatial smearing by assuming an exponential atmosphere. Data over the range 10km to 50km are selected and minimum and maximum values of latitude, longitude, solar zenith angle (sza), solar scattering angle (ssa) etc. are determined at the minimum and maximum tangent heights. Radiances and uncertainties are interpolated to a 2km altitude grid over the desired altitude range using a piecewise cubic Hermite interpolation.

## 9.2 RT Model

The radiative transfer model, LIMBTRAN ([9] and [15]), is used for modelling both the retrievals vectors and the weighting functions. The model is operated in full multiple scattering mode with 3 solar zenith angle calculations. Refraction is not included in LIMBTRAN. Absorption cross sections for $O_3$, $NO_2$, BrO, OClO, and $O_4$ are from [1], [20], [24], [23] and [8], respectively. The temperature dependencies of $O_3$ and $NO_2$ are accounted for by linear interpolation between the available temperatures.

## 9.3 A-priori

Atmospheric a-priori information is from a set of reference atmospheres compiled by [13]. An individual atmosphere in the database consists of height profiles of air, $O_3$, $NO_2$, BrO, OClO and stratospheric sulphate-aerosol number-density as well as a temperature profile. Each input profile is specified on a 1.0 km grid from 0 to 100km altitude. The atmospheric climatologies are specified for each month of the year at 10° latitude intervals, 85°S, 75°S, . . . 85°N. The aerosol phase function is specified as a Henyey-Greenstein phase function with an asymmetry parameter, $g$, of 0.75. The surface albedo is approximated from the seasonal surface albedo database of [12]. Seasonal snow and ice cover are not included in the database and clouds are not accounted for.

## 9.4 Lead Person

York University has been responsible for developing an $O_3$ retrieval algorithms based upon triplet ratios and optimal estimation. The appropriate contact person is I. C. McDade. Chris McLinden from Environment Canada is also involved with the generation of this data product.

Centre for Research in Earth And Space Science,
York University,
Toronto,
Ontario, Canada.
email: mcdade@yorku.ca

## 9.5 Version History

Version 3.00 was created in 2006 and supersedes all previous versions

## 9.6 File Format

The $O_3$ triplet OE data products are stored in daily files which contain profiles of O3 from each scan of OSIRIS that was suitable for analysis. Data files exist from the November 2001 until the present day. There are gaps in the data product as OSIRIS would nominally run only every other day from 2001 to May 2007. OSIRIS has run almost continuously since May 2007. Other gaps in the data occur when the spacecraft was running special modes, OSIRIS was undergoing engineering work or OSIRIS had technical problems. The filenames follow the guidelines given in section 3.4. The swath name and the filename components are given in Table 20.

| Property | Value |
|---|---|
| Swath Name | "`OSIRIS\Odin O3 Chappuis triplet OE`" |
| InstrumentID | "`OSIRIS-Odin`" |
| DataType | "`L2-O3-Limb-York-Triplet-OE`" |
| Versions | 3.00, July 2006 |

Table 20: Swath and filename strings for "$O_3$ Chappuis Triplet and Optimal Estimation"

## 9.7 Description of O3 triplet OE geolocation fields

The swath geolocation fields stored in the O3 swaths are summarized in Table 21 and described below.

**Time** The nominal time of the scan in UTC expressed as TAI93 assuming no offset between UTC and TAI93. This time normally corresponds to the instant when the tangent point of the OSIRIS look vector was at a specific reference altitude, e.g. 25 k.m.

**Latitude** The nominal latitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time **Time**.

**Longitude** The nominal longitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time **Time**.

**Altitude** The geometric altitude of the primary swath data products expressed in km. The altitudes are specified with respect to the IAU 1976 reference geoid.

**RTModel_Altitude** The geometric altitude of the model inputs expressed in km. The altitudes are with respect to the IAU 1976 reference geoid. This secondary altitude scale is introduced as model inputs for radiative transfer and inversion are on a different altitude scale.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| Time | `double` | nTimes | TAI 1993 |
| Latitude | `float` | nTimes | deg -90. . . 90 |
| Longitude | `float` | nTimes | deg -180. . . 180 |
| Altitude | `float` | nLevels | km |
| SolarZenithAngle | `float` | nTimes | deg 0. . . 180 |
| SolarAzimuthAngle | `float` | nTimes | deg -180. . . 180 |
| SolarScatteringAngle | `float` | nTimes | deg 0. . . 180 |
| LocalSolarTime | `float` | nTimes | hours |
| ScanNo | `long` | nTimes | |
| ScanUpFlag | `byte` | nTimes | 1=up, 0=down |
| ScanStartTime | `double` | nTimes | TAI 1993 |
| ScanStartLatitude | `float` | nTimes | deg -90. . . 90 |
| ScanStartLongitude | `float` | nTimes | deg -180. . . 180 |
| ScanEndTime | `double` | nTimes | TAI 1993 |
| ScanEndLatitude | `float` | nTimes | deg -90. . . 90 |
| ScanEndLongitude | `float` | nTimes | deg -180. . . 180 |

Table 21: Geolocation fields for "$O_3$ Chappuis Triplet and Optimal Estimation"

**SolarZenithAngle** The solar zenith angle expressed in degrees at the nominal tangent point of the scan. 0° is sun overhead, 90° is sun on the horizon.

**SolarAzimuthAngle** The solar azimuth angle expressed in degrees at the nominal tangent point of the scan. 0° is due North, 90° is due East, 180° is South and 270° is West.

**SolarScatteringAngle** The solar scattering angle expressed in degrees at the nominal tangent point of the scan. 0° corresponds to forward scatter and 180° corresponds to backscatter.

**LocalSolarTime** The local solar time at the nominal tangent point expressed in hours, 0. . . 24.

**ScanNo** The unique identification number of this scan. This number is generated from 1000∗orbit number+ (scan in orbit).

**ScanUpFlag** Indicates if the scan was going up (1) or going down (0). OSIRIS image sampling rates are known to be different between upward and downward scans.

**ScanStartTime** The UTC start time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanStartLatitude** The latitude of the tangent point in degrees at the start of the scan.

**ScanStartLongitude** The longitude of the tangent point at the start of the scan.

**ScanEndTime** The end time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanEndLatitude** The latitude of the tangent point at the end of the scan.

**ScanEndLongitude** The longitude of the tangent point at the end of the scan.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| O3 | `float` | nLevels × nTimes | vmr |
| O3Precision | `float` | nLevels × nTimes | vmr |
| O3NumberDensity | `float` | nLevels × nTimes | $cm^{-3}$ |
| MeasResolution | `float` | nLevels × nTimes | |
| MeasResponse | `float` | nLevels × nTimes | |
| RTModel_NeutralDensity | `float` | nLevels × nTimes | $cm^{-3}$ |
| RTModel_NeutralTemperature | `float` | nLevels × nTimes | K |
| RTModel_O3Apriori | `float` | nLevels × nTimes | $cm^{-3}$ |

Table 22: Geolocation fields for "$O_3$ Chappuis Triplet and Optimal Estimation"

## 9.8 Description of O3 triplet OE Data fields

The swath data fields stored in the O3 swaths are summarized in Table 22 and described below.

**O3** The set of ozone profiles expressed as volume mixing ratio. Each profile is derived from the ratio of **O3NumberDensity** to **RTModel_NeutralDensity** at each altitude. Note that **O3NumberDensity** is the fundamental product derived from the OSIRIS ozone inversion algorithms.

**O3Precision** The error in the set of ozone profiles expressed as a volume mixing ratio.

**O3NumberDensity** The set of ozone profiles expressed as number density. These are the profiles derived directly from the inversion algorithm.

**MeasResolution** The vertical resolution is inferred from the approximate width of the averaging kernels, i.e. the rows of the averaging kernel matrix. The width is determined using the Backus-Gilbert spread method, as outlined in [16]. Note that the given resolution does not take into account the finite effective instrument resolution (instantaneous resolution + spatial smearing) since the forward model does not include these effects.

**MeasResponse** The response of the retrieval, or the contribution of the a priori to the result, is determined from the area of the averaging kernels.

$$resp(i) = \sum_j K(i,j)\frac{x_a(j)}{x_a(i)}$$

**RTModel_NeutralDensity** The neutral density profile used in the radiative transfer model and for conversion from number density to volume mixing ratio.

**RTModel_NeutralTemperature** The neutral density temperature profile used in the radiative transfer model in the inversion algorithms. Most inversions change the cross-section of $O_3$ and $NO_2$ with temperature.

**RTModel_O3Apriori** The a-priori $O_3$ model, expressed as a number density, used in the relevant inversion models.

## 9.9 Issues.

A number of issues have arisen in the preliminary validation of this product, including:

1. $O_3$ densities are low relative to POAM (high latitudes) above $\sim$ 30km.
2. Dip in profiles at $\sim$ 30km in tropics.

3. There appear to be significant offsets, $\sim 1.5km$, in location of peak in tropics.
4. Retrievals in regions of strong horizontal gradients in ozone are suspect.
5. Retrievals for SZA$> 85^\circ$ may have problems due to multiple scattering approximation in LIMBTRAN
6. Possible aerosol effects.

The following is a list of issues that should be addressed in the next version of processing:

1. Add check for South Atlantic Anomaly and flag retrievals.
2. Create diagnostic HDF-EOS product.
3. Add ozone hole conditions to a priori database.
4. Implement a more detailed Quality flag

And some things that would be nice to have, but require more work:

1. Add analytic weighting functions to LIMBTRAN
2. Add refraction to LIMBTRAN
3. Add vertical resolution to LIMBTRAN
4. How to deal with clouds/PSCs?
5. Check for objects in the FOV - requires access to L1 services
6. Use real L1 services - need matlab interface
7. Correct for baffle scattering.
8. Incorporate non-spherical atmosphere into LIMBTRAN
9. Add variation of SZA with tangent height into LIMBTRAN

# 10 $NO_2$ from MART, Deprecated

This algorithm was developed by the OSIRIS team using a MART technique. The algorithm generates wavelength pairs from "on" line and "off" line features in the NO2 absorption spectrum. The technique is still under development. Users looking for a validated NO2 product are advised to use the $NO_2$ product derived from DOAS and Optimal Estimation.

## 10.1 Lead Person

University Of Saskatchewan is been responsible for developing the $NO_2$ retrieval algorithm based upon MART. The appropriate contact people are D. A. Degenstein, and A. E. Bourassa.

Institute of Space And Atmospheric Studies,
Physics Dept.,
University Of Saskatchewan,
Saskatoon,
Saskatchewan, Canada.
email: doug.degenstein@usask.ca, aeb192@mail.usask.ca

## 10.2 Version History

Version 2.00 was created in 2006 and supersedes all previous versions.

## 10.3 File Format

| Property | Value |
|---|---|
| Swath Name | "OSIRIS\Odin NO2MART" |
| InstrumentID | "OSIRIS-Odin" |
| DataType | "L2-NO2-Limb-Saskatoon-MART" |
| Versions | 2.10, April 2006 |

Table 23: Swath and filename strings for "$NO_2$ from Wavelength Pairs and MART"

The $NO_2$ MART data products are stored in daily files which contain profiles of $NO_2$ from each scan of OSIRIS that was suitable for analysis. Data files exist from November 2001 until the present day. There are gaps in the data product as OSIRIS would nominally run every other day from 2001 to May 2007. OSIRIS has run almost continuously since May 2007. Other gaps in the data occur when the spacecraft was running special modes, OSIRIS was undergoing engineering work or OSIRIS had technical problems. The filenames follow the guidelines given in section 3.4. The swath name and the filename components are given in Table 23.

## 10.4 Description of NO2 MART Geolocation fields

The swath geolocation fields stored in the NO2 swaths are summarized in Table 24 and described below.

**Time** The nominal time of the scan in UTC expressed as TAI93 assuming no offset between UTC and TAI93. This time corresponds to the instant when the tangent point of the OSIRIS look vector was at an altitude of 25 k.m.

**Latitude** The nominal latitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time Time.

| *Field* | *Type* | *Dimension* | *Description* |
|---|---|---|---|
| Time | `double` | nTimes | TAI 1993 |
| Latitude | `float` | nTimes | deg -90...90 |
| Longitude | `float` | nTimes | deg -180...180 |
| Altitude | `float` | nLevels | km |
| SolarZenithAngle | `float` | nTimes | deg 0...180 |
| SolarAzimuthAngle | `float` | nTimes | deg -180...180 |
| SolarScatteringAngle | `float` | nTimes | deg 0...180 |
| LocalSolarTime | `float` | nTimes | hours |
| ScanNo | `long` | nTimes | |
| ScanUpFlag | `byte` | nTimes | 1=up, 0=down |
| ScanStartTime | `double` | nTimes | TAI 1993 |
| ScanStartLatitude | `float` | nTimes | deg -90...90 |
| ScanStartLongitude | `float` | nTimes | deg -180...180 |
| ScanEndTime | `double` | nTimes | TAI 1993 |
| ScanEndLatitude | `float` | nTimes | deg -90...90 |
| ScanEndLongitude | `float` | nTimes | deg -180...180 |
| RTModel_Altitude | `float` | nLevels2 | km |

Table 24: Geolocation Fields for "$NO_2$ from Wavelength Pairs and MART"

**Longitude** The nominal longitude of the scan expressed in degrees. This corresponds to the latitude of the tangent point at time Time.

**Altitude** The geometric altitude of the primary swath data products expressed in km. The altitudes are specified with respect to the IAU 1976 reference geoid.

**SolarZenithAngle** The solar zenith angle expressed in degrees at the nominal tangent point of the scan. 0° is sun overhead, 90° is sun on the horizon.

**SolarAzimuthAngle** The solar azimuth angle expressed in degrees at the nominal tangent point of the scan. 0° is due North, 90° is due East, 180° is South and 270° is West.

**SolarScatteringAngle** The solar scattering angle expressed in degrees at the nominal tangent point of the scan. 0° corresponds to forward scatter and 180° corresponds to backscatter.

**LocalSolarTime** The local solar time at the nominal tangent point expressed in hours, 0...24.

**ScanNo** The unique identification number of this scan. This number is generated from 1000∗orbit number+ (scan in orbit).

**ScanUpFlag** Indicates if the scan was going up (1) or going down (0). OSIRIS image sampling rates are known to be different between upward and downward scans.

**ScanStartTime** The UTC start time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanStartLatitude** The latitude of the tangent point in degrees at the start of the scan.

**ScanStartLongitude** The longitude of the tangent point at the start of the scan.

**ScanEndTime** The end time of the scan expressed as TAI93 assuming no offset between UTC and TAI93.

**ScanEndLatitude** The latitude of the tangent point at the end of the scan.

**ScanEndLongitude** The longitude of the tangent point at the end of the scan.

**RTModel_Altitude** The geometric altitude of the model inputs expressed in km. The altitudes are with respect to the IAU 1976 reference geoid. This secondary altitude scale is introduced as model inputs for radiative transfer and inversion are on a different altitude scale.

### 10.5 Description of NO2 MART Data fields

The swath data fields stored in the NO2 swaths are summarized in Table 25 and described below.

| ***Field*** | ***Type*** | ***Dimension*** | ***Description*** |
|---|---|---|---|
| NO2 | `float` | nLevels × nTimes | vmr |
| NO2Precision | `float` | nLevels × nTimes | vmr |
| NO2NumberDensity | `float` | nLevels × nTimes | $cm^{-3}$ |
| RTModel_Albedo | `float` | nTimes | |
| RTModel_NeutralDensity | `float` | nLevels2 × nTimes | $cm^{-3}$ |
| RTModel_NeutralTemperature | `float` | nLevels2 × nTimes | K |
| RTModel_NO2Apriori | `float` | nLevels2 × nTimes | $cm^{-3}$ |
| RTModel_NO2Density | `float` | nLevels2 × nTimes | $cm^{-3}$ |

Table 25: Data Fields for "$NO_2$ from Wavelength Pairs and MART"

**NO2** The set of $NO_2$ profiles expressed as a volume mixing ratio. Each profile is derived from the ratio of NO2NumberDensity to RTModel_NeutralDensity at each altitude. Note that NO2NumberDensity is the fundamental product.

**NO2Precision** The error in the set of $NO_2$ profiles expressed as a volume mixing ratio.

**NO2NumberDensity** The set of $NO_2$ profiles expressed as number density. These are the profiles derived directly from the inversion algorithm. Molecules/$cm^3$.

**RTModel_Albedo** The ground albedo value used in the radiative transfer code. The ground albedo is assumed to have no wavelength dependence.

**RTModel_NeutralDensity** The neutral density profile used in the radiative transfer model and for conversion from number density to volume mixing ratio.

**RTModel_NeutralTemperature** The neutral density temperature profile used in the radiative transfer model in the inversion algorithms. Most inversions change the cross-section of $NO_2$ with temperature.

**RTModel_NO2Apriori** The a-priori $NO_2$ model, expressed as a number density. Molecules/$cm^3$.

**RTModel_NO2Density** The $NO_2$ profile used in the last iteration of the radiative transfer model expressed as a number density. This is identical to the primary data product, NO2NumberDensity in the altitude range of overlap but is extended by the climatology at altitude ranges not covered by the scan. Molecules/$cm^3$.

## 11 Future Algorithms

We anticipate that the following products will be available as research work comes to fruition,

1. OCLO height profiles using limb-based DOAS.
2. Cloud deck altitude
3. Nominal albedo

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