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Limb Gridded Radiance User Guide

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Contents

1	Introduction	1
2	The Suomi NPP OMPS Limb Profiler Instrument	1
2.1	Viewing Geometry	1
2.2	Sensor	3
2.3	Sample Table	4
3	The LP-L1G-EV Product Overview and Preliminaries	5
3.1	L1B Calibration	5
3.2	Source and Target Grids	5
3.3	Getting Data	6
3.4	Product File Names	6
3.5	HDF5 File Format	7
3.6	Non-rectangular (Ragged) Datasets Not Used in Version 2.6	7
4	Product Details	7
4.1	The Top Level	7
4.2	Gridded Data	8
4.3	Dimensions	9
4.4	Radiances <code>/GRIDDED_DATA/Radiance</code>	9
4.5	Wavelength <code>/GRIDDED_DATA/WavelengthGrid</code>	10
4.6	Sun Normalized Radiance or Reflectance	12
4.7	Bandpass	12
4.8	Radiance Profile Example	13
4.9	Geolocation Data	16
4.10	Image Level Flags	18
4.11	South Atlantic Anomaly (SAA) Flags	18
4.12	Solar Eclipse Flag	20
4.13	Aperture (Gain) Discrimination	20
4.14	Metadata	20
4.14.1	File Level Meta Data	20
4.14.2	OrbitNumber bug	21
4.14.3	Input Pointers	21
4.14.4	Digital Object Identifier	21
5	Instrument and Satellite Operations	22
6	Chelyabinsk Bolide Example	23
7	More Information	26
A	Code Example Requirements	26
B	Data Citation Format	26

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1 Introduction

The Level 1G (L1G) product is a radiance data product derived from measurements by the limb portion of the Ozone Monitoring and Profiling Suite (OMPS) of instruments aboard the Suomi NPP satellite. The product contains a gridded version of limb radiance measurements—the spectral and spatial smile have been removed by interpolating the data onto a regular (but non-uniform) spatial (i.e. altitude)-spectral grid. This is done because often it is more convenient for users to have gridded data than to have to remove the smile themselves.

The goal of this User Guide is to provide users with a basic understand of the instrument and the manner in which the gridded product is derived from the ungridded product. This document:

- Describes the instrument and measurement geometry. (Section 2)
- Provides an overview of how Version 2.6 of the L1G product was generated from the non-gridded data. (Section 3; Version 2.5 was the first version to be released on the Goddard DAAC, although early versions have been made available through other channels.)
- Describes the organization of the orbital HDF5 files including detailed descriptions of the contents of these data files. (Section 4)
- Shows how to do wavelength selection and use of quality and status flags.
- Contains L1G usage examples with code listings, including a typical radiance profile at 305 nm and the detection of the dust cloud injected into the atmosphere by the Chelyabinsk Bolide in February 2013 (Sections 4.8 and 6, for system requirements see Appendix A).

2 The Suomi NPP OMPS Limb Profiler Instrument

2.1 Viewing Geometry

The OMPS Limb Profiler instrument measures spectrally resolved radiance profiles of the earth's atmosphere along three geographically distinct tracks by viewing the limb aft of the Suomi NPP Satellite. The measurements within each profile correspond to different tangent point altitudes and are the result of light scattered toward the instrument by the atmosphere at and above that altitude. For an illustration of the tangent point see figure 2. Corresponding to each tangent point is a sub-tangent point latitude and longitude. Because the geometry of the tangent point cause different tangent points to have slightly different sub-tangent point latitude and longitude. In the L1G the latitude and longitude of the sub-tangent point are computed at tangent point altitudes of 25, 35, 45 km.

The three geographically distinct profiles are achieved because the instrument looks through three collimating slits. The tangent points of the slits describe three tracks and above each one a vertical radiance profile is taken. The three profiles are separated by about 250 km. We refer to them as East, Center, and West; these names come from the relative position of the tangent points during the ascending, sunlit portion of the orbit, see figure 1. Near the poles the relative cardinal positions of the tracks could become inconsistent with the naming convention, however we retain the convention even there because it is intended only to be descriptive.

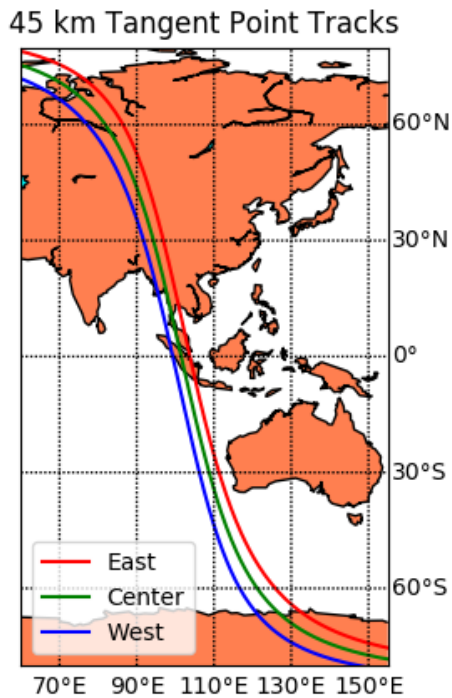


Figure 1: Orbital tracks the 45 km Tangent Point for orbit 6752.

Figure 2 shows schematically the viewing geometry of the limb instrument relative to the flight direction and earth's surface. Corresponding to each tangent point we can define solar azimuth, solar zenith, and satellite azimuth angles as well as the latitude, longitude of the sub-tangent point. These are reported out in the L1G as described in 4.9.

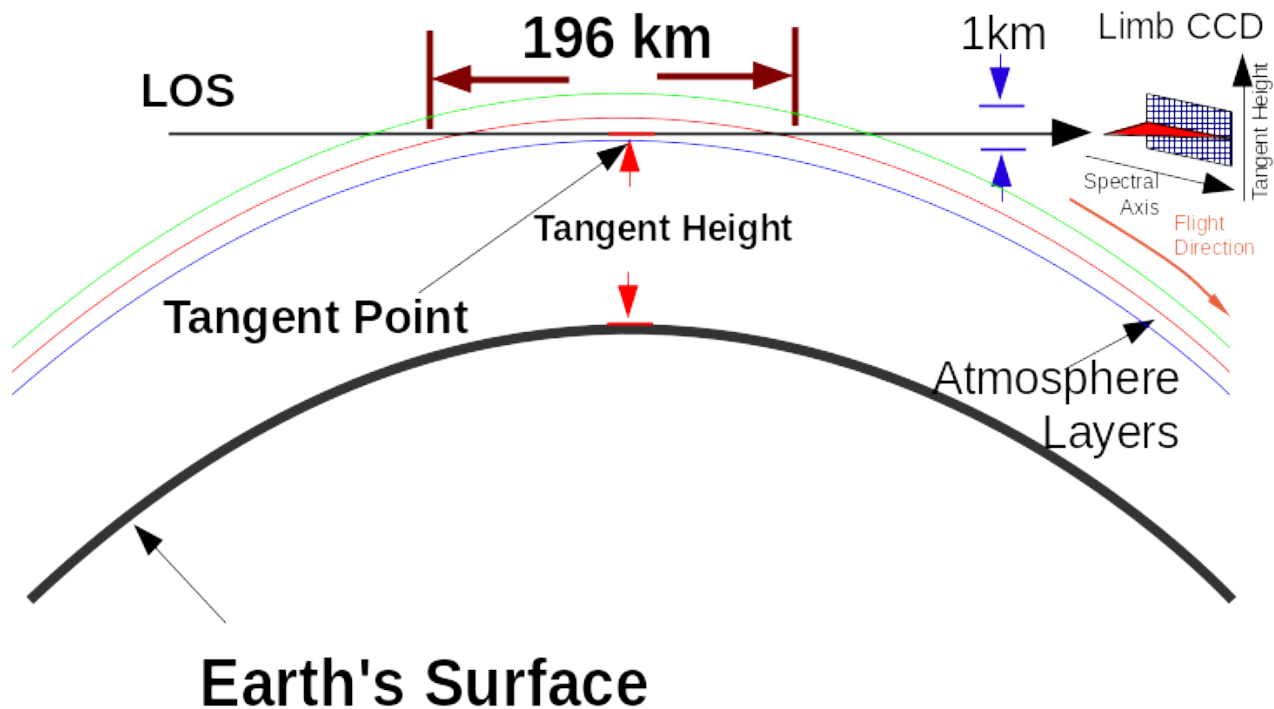


Figure 2: A single Line of Sight (LOS) intersects many layers of the atmosphere, three are illustrated here. This figure shows only a single LOS and tangent point for a single slit. The corresponding LOS and tangent points for the other two slits are in their own planes all three of which converge at the instrument.

2.2 Sensor

The vertical sampling of the instrument is approximately 1 km. Three profiles are measured simultaneously on the day side of Suomi NPPs polar orbit at approximately 19 second intervals. In nominal earth view mode this allows the instrument to capture about 160 images each orbit with solar zenith angles less than 88 degree. The set of radiance profiles over the same tangent point is referred to as a *scene*. LP measurements cover a wavelength range between 290-1000 nm. The spectral resolution varies from approximately 1.0 nm at 290 nm to approximately 40 nm at 1000 nm.

The light measured at each altitude is spectrally dispersed by a prism. The measurements are made with a 2 dimensional CCD with one dimension corresponding nominally to altitude and the other nominally to wavelength. The correspondance is not exact; the rows and columns of the CCD are not perfect lines of constant wavelength and altitude. This is explained more fully in Section 3.2. There are no scanning mirrors.

2.3 Sample Table

Data rate limitations on board the satellite require that we reduce the amount of data downlinked to roughly one third of the total number of CCD pixels on the limb sensor. This is done via a table in the instrument which selects specific pixels to be downlinked. Regions which are not downlinked are represented in the gridded product as fill values. The table can be adjusted via an uplink and this has happened several times at the beginning of the mission as the selection of pixels was optimized. Table 9 catalogs when these adjustments were made for the Suomi-NPP Limb Sensor.

This process is the case for nominal earth view measurements. On roughly a biweekly schedule the limb sensor is directed to downlink *all* pixels, but fewer images to stay within the overall data rate. This is referred to as *full frame* measurement and is gridded and distributed just as a nominal earth view measurement, but the end result has gridded coverage over almost the whole wavelength-tangent height space and fewer images along the orbit.

3 The LP-L1G-EV Product Overview and Preliminaries

The LP-L1G-EV product is formed from the calibrated radiances in the Level 1B data which have been subject to a number of processing steps to make the data easier to use. For each scene a spectrum is provided on an orthogonal, but non-uniform, wavelength-altitude grid in the LP-L1G-EV product. The non-uniformity means simply that the density of the wavelength grid is higher at the shorter wavelengths than the longer wavelength. Note that this *grid* is a different concept than the one familiar to users of Aura EOS products; in particular the latitude and longitude of the profile have not been regridded but reflect position of the measurement from the scenes original geolocation data.

The spacing in the altitude direction is nominally a uniform one kilometer with grid points centered at the half kilometer points above 0 (i.e. altitude grid points of 0.5, 1.5, 2.5 km, etc). A more detailed description of this process can be found in the *OMPS Limb Profiler Sensor Data Record (SDR) Algorithm Theoretical Basis Document* [3].

The instrument can collect about 160 images of usable data on the day side of an orbit. (Since orbit 2632 the instrument acquires 180 images per orbit, but the additional 20 images tend to be pre- or post-terminator and thus are not useful for ordinary retrievals.) Each image consists of data corresponding to three different tangent points on the earth's surface, so a nominal earth view orbit will contain about $3 \times 160 = 480$ usable hyperspectral profiles.

To increase dynamic range the instrument makes two simultaneous measurements of each profile at two different aperture sizes via separate optical paths and regions on the CCD sensor. The L1B in some cases provides radiances from both optical gains. The gridding code chooses the appropriate optical gain for use in gridding (it does not combine them). More discussion can be found in Section 4.13.

A further complication is that the satellite does not support sufficient data rate to downlink every illuminated pixel on the CCD. A selection of pixels has been made based on the expected scene intensity profile—for example UV pixels with low altitude LOSs are expected to saturate the sensor and are thus not included in the selection. This leads to gaps in the data in the L1G profiles, as will be seen in Section 4.4.

3.1 L1B Calibration

The Level L1B processing subjects the data to several calibration steps, including corrections for intra- and inter-orbital shifts in wavelength and altitude registration. The CCD pixel wavelength registration are known to shift during the orbit which are corrected using the Fraunhofer structure as described in [2, Sec. 3.2]. The altitude registration of the CCD pixels also shifts and corrections for this are based on a residual comparison with a model atmosphere, see [4].

3.2 Source and Target Grids

The raw count pixels in the images are converted to calibrated radiances and are produced in a product referred to as the Level 1B. Optical distortions within the spectrometer result in curvature at the focal plane, sometimes referred as 'smile'. Rows and columns of the CCD are not rows and columns of constant wavelength or altitude. Thus the Level 1B product is not necessarily the most convenient form in which to use the radiance data to retrieve ozone or aerosol profiles. We therefore transform these data to a rectangular wavelength-altitude grid to create the Level 1 gridded (L1G) product described in this document. The source (L1B) and target (L1G) grids are shown in Figure 3.

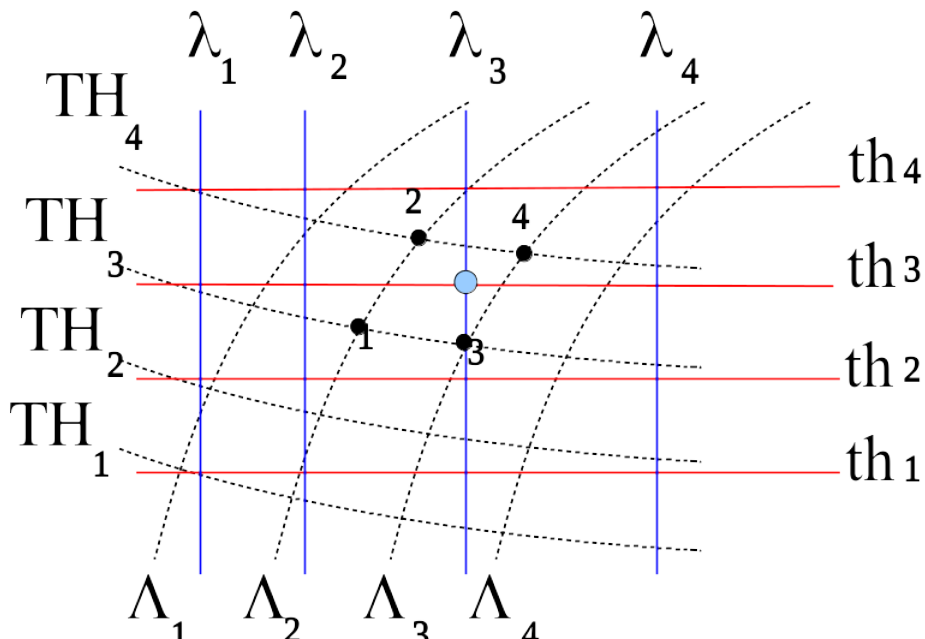


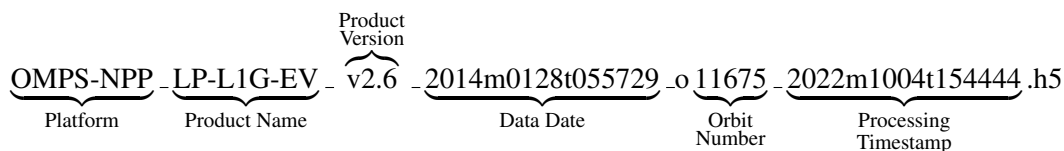
Figure 3: Non-orthogonal and orthogonal grid points. The dashed black lines labeled with capital letters indicate the non-orthogonal lines of constant CCD row and column indexes—TH and Λ are the nominal tangent height and wavelength indexes, respectively. The blue and red lines indicate the orthogonal lines of constant wavelength and tangent height, respectively. The blue circle is a target grid point for the L1G product and the numbered black dots (i.e. centers of CCD pixels) are the source data used in the bilinear interpolation. This figure is a simplification, in reality the non-orthogonal constant lines do not necessarily cross through the center of neighboring CCD pixels; so, for example, source points 1 and 2 will not quite be at the same wavelength and neither will 1 and 3 be at the same height. They will be on curves slightly offset from each other. During ground processing the calibration tables (and geolocation in the case of height) are used to determine the wavelength and height of each CCD pixel.

3.3 Getting Data

The version 2.6 data can be found at this URL: `FIXME`

3.4 Product File Names

The product file names follow this pattern:



3.5 HDF5 File Format

Data are provided in the HDF5 file format. The HDF5 library is required to read the files. This library is available from The HDF Group (www.hdfgroup.org). In addition to interfaces in C and Fortran, which The HDF Group develops and distributes, there is a high quality interface for Python called H5py distributed independently (and used for code examples in this document). These are all open source. The HDF Group also distributes a number of tools for exploring and manipulating HDF5 files. The graphical tool HDFView is highly recommended, especially for those just starting with HDF5 or the OMPS data. The HDF5 library is also incorporated into many common commercial data analysis tools: Matlab, IDL, TecPlot, Mathematica, etc.

The HDF5 file consists of **Datasets** which is the HDF5 terminology for arrays and **Groups** which contain datasets and other groups (thus groups behave analogously to folders or directories in your computer's file system). Both the datasets and the groups are given descriptive names. Because the objects are named they can be accessed by name rather than by numerical byte offset into the file which is a tremendous advantage afforded by the HDF5 format.

Furthermore, the HDF5 library shields users from needing to understand the byte order of numerical data or the actual layout of the data on disk. The datasets in HDF5 include dimensional and type information and HDF5 library can query the file to determine these which is often necessary for C or Fortran users. The higher level languages (Python, IDL, Matlab, etc.) generally have convenience functions which reduce some of the programming burden. These are a good starting point for users new to HDF5.

3.6 Non-rectangular (Ragged) Datasets Not Used in Version 2.6

Version 2.6 of the L1G product, in contrast to the Version 2.0, no longer has non-rectangular datasets. This is because the gridded data contains the same number of wavelengths for each event. Since the wavelengths are now fixed for each event the multi-dimensional Wavelength data set is no longer needed and has been dropped in favor of a one dimensional WavelengthGrid dataset. Furthermore, as a result of this change the dataset NumberOfPrimary channels is no longer needed and has been removed starting at Version 2.5.

4 Product Details

The hyper-spectral profile data has several basic components, most obviously are the wavelength and corresponding radiance intensity. These are stored in the **Wavelength** and **Radiance** datasets, respectively (see also 4.6).

Furthermore, because the data are vertical profile data above points on the earth's surface there are also altitude data in the **TangentHeightGrid** **TangentHeight** datasets and geolocation information for the tangent point itself in Latitude and Longitude datasets.

The organization of these datasets is described in the following sections.

4.1 The Top Level

HDF5 files encourage the organization of data in a hierarchical fashion. The top level contains 4 groups and one dataset as seen in Figure 4. New in 2.6 is that it also contains four datasets which are part of the dimension scales system. These are **DimAcrossTrack**, **DimAlongTrack**, **DimVertical**, and **DimWavelength** and they correspond to the dimension scales attributes on each of the individual datasets

in the file. The Dimension Scale system is described in https://docs.hdfgroup.org/hdf5/develop/group___h5_d_s.html.

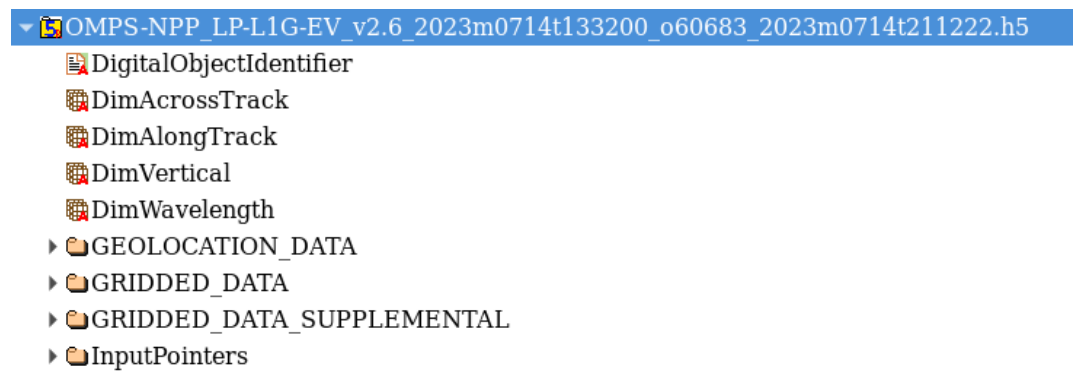


Figure 4: The top level group.

The LP-L1G-EV product contains two important groups, the GRIDDED_DATA group and the GEOLLOCATION_DATA group. Using the HDFView TreeView window an example of the contents of the GRIDDED_DATA group is shown in Figure 5 and the names of the datasets and their associated data descriptions are in Table 3 for GRIDDED_DATA. The GRIDDED_DATA_SUPPLEMENTAL group will not be described in its entirety because much of it used for internal data processing needs, specifically NASA level 2 retrieval codes, and is expected to be removed in future versions.

4.2 Gridded Data

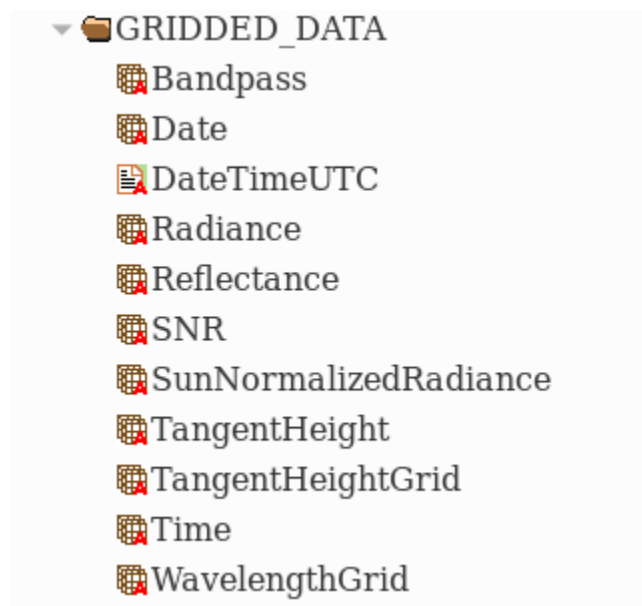


Figure 5: The GRIDDED_DATA group.

4.3 Dimensions

The data are stored as HDF5 datasets, i.e. arrays. The semantics of the dataset dimensions are defined in Table 2 along with a dimension label. These labels are used in Tables 3 and 4 which describe the product’s datasets. While neither label nor the description are stored in the product files themselves a metadata name was added in 2.6 as part of the Dimension Scale system to satisfy the recommended metadata used by the GES DISC data distribution system.

Dimension Label	Description	Dimension Scale Dataset Name
nTimes	The image dimension. Each index in this dimension corresponds to an image taken at different time. The index is ordered—larger indexes are later in time.	DimAlongTrack
nSlit	The slit dimension. There are three slits and the ordering is left, center right.	DimAcrossTrack
nTH	The tangent height dimension. This dimension corresponds to the tangent height of the grid points. Higher indexes correspond to higher altitudes.	DimVertical
nWave	The wavelength dimension. This dimension corresponds to the wavelength of the grid points. The valid indexes are discussed in Section 3.6.	DimWavelength

Table 2: Dimension labels and descriptions

4.4 Radiances /GRIDDED_DATA/Radiance

The gridded radiances are in the Radiance dataset. This array covers the whole altitude and wavelength range of the instrument, from starting wavelength around 272 nm to an ending one near 1058 nm and in altitude from 0.5 to 100.5 km. The measurements from two apertures are combined in this array, however even when using both measurements it is not possible to fill in all grid points with the current bilinear interpolation algorithm. Missing grid points are left as fill values. Grid points may be missing because of saturation or because the sample table which controls which pixels are downlinked did not include pixels near enough to a grid point for the bilinear interpolation algorithm to compute it. Figure 6 shows an example of a radiance spectrum of the center slit for one scene.

Due mostly to scene variability (e.g. saturation) it is possible for some of pixels to lack radiance data at an altitude and wavelength present in other images in the same orbit. This is indicated by a fill value at the corresponding grid pixel in the L1G product.

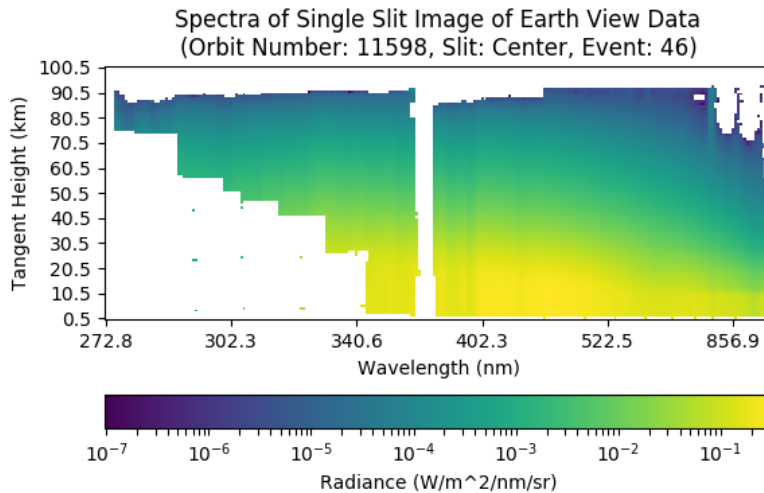


Figure 6: Radiance image for a single limb scene corresponding to the center slit for a single 19 second reporting period. The white regions are fill values where there was insufficient ungridded data to interpolate to a grid point. Note that even wavelengths which are fill values at all altitudes are included here—in contrast to Version 2.0. For example, the white band near 370 nm is all fill values; a consequence of using a sample table which does not down link data near the filter boundary, see section 2.3 for an overview of the sample table and [2, Sec. 3.4] for details on the filters. The isolated pixels at short wavelengths and low altitude are real and come from data which were sampled for the stray light correction effort.

4.5 Wavelength `/GRIDDED_DATA/WavelengthGrid`

The **WavelengthGrid** dataset is the authoritative source of wavelength information in Version 2.6 of the product. It holds a one dimensional array of wavelengths. In Version 2.6 of the product it is 266 elements long. Each element corresponds to an index of the Wavelength dimension of the **Radiance** and **Sun Normalized Radiance** datasets.

Dataset Name	Description	Dimensions	Units	Abbrv
Bandpass	Bandpass of the grid pixel. See Section 4.7 for more details.	nTimes x nSlit x Wavelength	microns	μm
Date	Date encoded in 32 bit integer. When formatted as a decimal number the date appears in the digits as YYYYMMDD	nTimes x nSlit	Unitless	NA
DateTimeUTC	Date string in Universal Coordinated Time. Format example is 2012-02-10T05:49:32.954987Z	nTimes x nSlit		
Radiance	Radiance values combined and interpolated to the grid point.	nTimes x nSlit x nTH x nWave	Watt squared per steradian	$\text{Wm}^{-2}\text{nm}^{-1}\text{sr}^{-1}$
Reflectance	I/F values combined and interpolated to the grid point, see Section 4.6. (In file metadata incorrectly indicates <i>unitless</i> .)	nTimes x nSlit x nTH x nWave	per steradian	sr^{-1}
SunNormalizedRadiance	Alias to Reflectance	nTimes x nSlit x nTH x nWave	per steradian	sr^{-1}
SNR	Estimate of detector noise and <i>not</i> an estimate of random measurement uncertainty.	nTimes x nSlit x nTH x nWave	Unitless	NA
TangentHeight	Height above surface along normal to WGS84 ellipsoid.	nTimes x nSlit x nTH	kilometers	km
TangentHeightGrid	The parent set of all tangent heights used for the tangent height dimension.	101	kilometers	km
Time	Seconds since midnight.	Dataset 5, 3	seconds	s
WavelengthGrid	The parent set of all wavelengths used for the wavelength dimension of the grid		microns	μm

Table 3: Field names, description, dimensions, and associated units for GRIDDED_DATA group.

4.6 Sun Normalized Radiance or Reflectance

The reflectance, or sun normalized radiance, dataset is computed by dividing the radiance by a ‘day-one’ solar irradiance measurement *before* the gridding procedure is applied. The motivation for normalizing before gridding is that it will provide better cancellation of the Fraunhofer lines in cases where the grid point lies near a one of the lines.

4.7 Bandpass

A full width at half maximum (FWHM) is provided at each grid point for a Gaussian approximation of the bandpass. This can be used to compute the convolved radiance, I_{conv} , of simulated values using the formula:

$$I_{conv} = \frac{\sum_j I_j e^{-(\lambda_T - \lambda_j)^2 / 2\sigma_T^2}}{\sum_j e^{-(\lambda_T - \lambda_j)^2 / 2\sigma_T^2}} \quad (1)$$

where j ranges over the wavelength grid on which the unconvolved radiances, I_j , are computed and λ_j is the corresponding wavelength for each unconvolved I_j value; and λ_T is the wavelength of interest (i.e. one of the wavelengths in the WavelengthGrid datasets). Finally, $\sigma_T = \frac{FWHM_T}{2\sqrt{2\ln 2}}$ is the standard deviation and $FWHM_T$ is the bandpass approximation reported in the L1G datafile at λ_T . Because formula involves the ratio of sums of identical Gaussians the normalization constants typically used with Gaussians cancel.

4.8 Radiance Profile Example

A common type of plot to make is the profile of radiances at a given wavelength vs altitude. Since the data are produced at a fixed set of wavelengths presented in the WavelengthGrid dataset we need to select one from that set. Since the wavelengths used in physical problems are unlikely to be at exactly the values in WavelengthGrid, a value from WavelengthGrid near the desired one will need to be found via search.

An example of profiles, both radiance and reflectance, near 305 nm is presented in Figure 7. The code listing demonstrates the key technique of searching for a wavelength in the data near the a target, 305 nm in this example, and using the result of that search for further processing. Note that unlike the more complex bolide example (Example 13) here we are only concerned with a profile at a single scene and so need only to identify the wavelength index for that one scene. The Python code used to produce Figure 7 is shown in Listing 1.

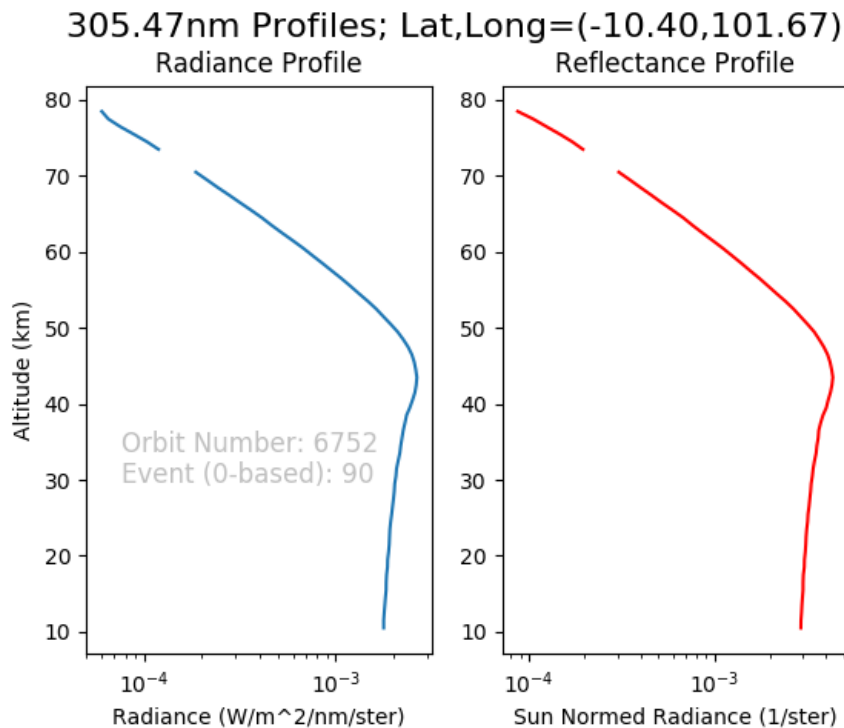


Figure 7: The radiance and reflectance profiles at 305 nm, image number 90 (or the 91st image) of the 180 taken for the orbit. This particular scene is the right slit. The gap near 70 km is due to missing values; the program listing demonstrates how to detect them.

```
1 import h5py
2 import numpy
3 from matplotlib import pyplot
4
5 BolideOrbitFile = 'OMPS-NPP_LP-L1G-EV_v2.6_2013m0215t060054_o06752_2022m1004t063415.h5'
6
7 Slit = 2 # Right slit
8 TargetWavelength = .305 # microns
9 Event = 90
10
11 with h5py.File(BolideOrbitFile, 'r') as fid:
12     WavelengthGrid = fid['/GRIDDED_DATA/WavelengthGrid'][...]
13     ClosestWavelength = WavelengthGrid[WavelengthGrid.searchsorted(TargetWavelength)]
14
15     TargetLocation = numpy.where(WavelengthGrid == ClosestWavelength)[0][0]
16
17     RadianceRaw = fid['/GRIDDED_DATA/Radiance'][Event, Slit, :, TargetLocation]
18     Mask = RadianceRaw < -998
19     Radiance = numpy.ma.array(RadianceRaw, mask = Mask)
20     ReflectanceRaw = fid['/GRIDDED_DATA/Reflectance'][Event, Slit, :, TargetLocation]
21     Mask = ReflectanceRaw < -998
22     Reflectance = numpy.ma.array(ReflectanceRaw, mask = Mask)
23
24     TangentHeight = fid['/GRIDDED_DATA/TangentHeight'][Event, Slit, :]
25     Latitude_45km = fid['/GEOLOCATION_DATA/Latitude_45km'][Event, Slit]
26     Longitude_45km = fid['/GEOLOCATION_DATA/Longitude_45km'][Event, Slit]
27     OrbitNumber = fid.attrs['OrbitNumber'][0]
28
29 fig, (ax1, ax2) = pyplot.subplots(ncols=2)
30 fig.suptitle('{:4.2f}nm Profiles; Lat, Long=({:4.2f}, {:4.2f})' \
31             .format(1000*WavelengthGrid[TargetLocation], Latitude_45km, Longitude_45km), font
32 ax1.plot(Radiance, TangentHeight)
33 ax1.set_xlabel('Radiance (W/m^2/nm/ster)')
34 ax1.set_ylabel('Altitude (km)')
35 ax1.set_title('Radiance Profile')
36 ax1.set_xscale('log')
37 ax1.annotate('Orbit Number: {} \nEvent (0-based): {}'.format(OrbitNumber, Event), (.1, .3), font
38
39 ax2.plot(Reflectance, TangentHeight, color='r')
40 ax2.set_xlabel('Sun Normed Radiance (1/ster)')
41 ax2.set_title('Reflectance Profile')
42 ax2.set_xscale('log')
43
44 pyplot.show()
```

Listing 1: Python 3 program to plot an OMPS Limb radiance profile at 305 nm. Python uses 0-based indexing hence right slit is slit number 2.

Line 15 Search for the index of the closest wavelength to 305 nm using `numpy.where`. The result, **TargetLocation**, will be a an array of an array, hence the double index—`[0][0]`—used to extract the index.

Lines 18 & 19 Use the masked array facility to mask out those radiance values which are fill values, -999 in this case. The **plot** command will use the mask for both the radiances and the tangent heights to maintain the same ordered pairs. The same procedure is used for Reflectance values.

Lines 25 & 26 The latitude and longitude of the pixels at 45 km are used. This was an arbitrary choice.

4.9 Geolocation Data

The geolocation data group is shown in Figure 8 with detailed descriptions of the datasets in Table 4.



Figure 8: The GEOLOCATION_DATA group.

The various SolarZenithAngle, SatelliteAzimuth and SatelliteZenith angle datasets are defined in a coordinate system centered at a tangent point in which the 0 of the zenith direction is normal to the ellipsoid. For the azimuth angle 0 is defined as the direction of North and positive azimuth is East of North. The azimuth angles are defined between -180 and 180 degrees.

Calibration information allows the geolocation code to compute a tangent point for each CCD pixel. For a static scene the geolocation information varies slightly with wavelength due to detector smile and varies with altitude because of simple trigonometry: different tangent points in the same profile have slightly different lat/lons.

Dataset Name	Description	Dimensions	Units	Abbrv
Latitude_25km	The latitude of the tangent point at the indicated reference altitude.	nTimes x nSlit	degrees	
Latitude_35km			degrees	
Latitude_45km			degrees	
Longitude_25km	The longitude of the tangent point at the indicated reference altitude.	nTimes x nSlit	degrees	
Longitude_35km			degrees	
Longitude_45km			degrees	
MidImg_SecTAI93	Time of mid-point of image acquisition time in seconds since TAI93.	nTimes	seconds	
OrbitalPhase	All fill values. Reserved for future use.	nTimes		
SatelliteAzimuth_25km	The satellite azimuth at the tangent point at the indicated reference altitude. The coordinate system is described in the text.	nTimes x nSlit	degrees	
SatelliteAzimuth_35km			degrees	
SatelliteAzimuth_45km			degrees	
SolarAzimuth_25km	The solar azimuth at the tangent point at the indicated reference altitude. The coordinate system is described in the text.	nTimes x nSlit	degrees	
SolarAzimuth_35km			degrees	
SolarAzimuth_45km			degrees	
solarBeta	The solar β angle.	nTimes	degrees	
SolarZenithAngle_25km	The solar zenith angle of the tangent point at the indicated reference altitude.[WHAT DOES THIS MEAN?]	nTimes x nSlit	degrees	
SolarZenithAngle_35km			degrees	
SolarZenithAngle_45km			degrees	
SpacecraftAltitude	The spacecraft altitude above the WGS84 ellipsoid.	nTimes x nSlit	kilometers	km
SpacecraftCenteredSolarAzimuth	Solar Azimuth and Elevation as measured from the center of the spacecraft.	nTimes	degrees	
SpacecraftCenteredSolarElevation			degrees	
SpacecraftLatitude	The latitude and longitude of the spacecraft ground point on the WGS84 ellipsoid.	nTimes	degrees	
SpacecraftLongitude			degrees	
SwathLevelQualityFlags	Flags describing various aspects of the measurement.	nTimes	unitless	
TangentPointEarthRadius	Radius of earth at tangent point.		kilometers	km

Table 4: Field names, description, dimensions, and associated units for GEOLOCATION_DATA group.

Bits	Description
0-1	Mercury
2-3	Venus
4-5	South Atlantic Anomaly (SAA)
6-7	Mars
8-9	Jupiter
10-11	Saturn
12-13	Uranus
14-15	Neptune
16-17	Pluto+Charon
18-19	Moon (Earth's)
20	Attitude Maneuver in Progress
21	Non-nominal Attitude
22-23	spare
24	Solar Eclipse
25-31	spare

Table 5: Swath-level geolocation flags for OMPS LP. Flags corresponding to a Celestial body indicate presence of that body in one of the three fields of view, see Table 6

Since most retrieval algorithms utilize a single set of angles and lat/lon for an entire spectrum of vertical radiance profiles we provide only geolocation only at three discrete altitudes. In the L1G product the angles and lat/lon reported are an average of those values corresponding to CCD pixels whose tangent heights fall within ± 0.5 km of a specified reference altitude. The reference altitudes used in the L1G are 25, 35, and 45 km.

4.10 Image Level Flags

An 'image', as used in this document refers to data collected across all slits during a particular (nominally 19 second) reporting period. Image level flags indicate instrument-level phenomena which apply to all altitudes and wavelengths (and possibly all three slits) of a specific image. They depend on the position and attitude of the satellite and not the tangent point of the profile. The link between a specific profile and the relevant flags is the index in the *nTimes* dimension. For historical reasons the flag dataset is named SwathLevelQualityFlags instead of ImageLevelFlags.

Tables 5 and 6 describe bits dedicated to flagging a celestial body visible in a given slit (the small angle subtended by celestial bodies, including the moon, guarantee that any particular body can be in only one slit at a time); estimate of the relative intensity of SAA particle hits on an OMPS sensor; and the likely presence of solar eclipse conditions.

4.11 South Atlantic Anomaly (SAA) Flags

Passage through the South Atlantic Anomaly is flagged at the image level because the effect on the CCD of charged-particle hits (primarily protons of solar origin trapped in the earth's magnetic field) depends only on the spacecraft latitude, longitude, and altitude. While individual pixels may be affected, causing errors in the number of counts, the geolocation of a *pixel*, i.e. the tangent point, is irrelevant to

Value	Description
0	Not in field of view
1	In Left Slit
2	In Center Slit
3	In Right Slit

Table 6: Interpretation of 2-bit celestial object flags.

the estimate of the probable number of hits to the CCD; only the spacecraft's (and therefore instrument's) orbital position determines the values of these flags. The link between a particular radiance profile and the SwathLevelQualityFlags is the image number.

The estimated intensity of the SAA reported in the LIG is based on a pre-computed 'SAA map' because accurate estimates based on transient detection in the Earth View images themselves are not yet available. The SAA map was created using 'doors closed' dark data and shows SAA intensity over a geographic region. The intensity of the SAA effect is defined as the product of the number of particle hits and the energy of the particle hits. The Figure 9 shows contours of SAA intensity corresponding to the thresholds used to construct the flags. There are four flag states possible within the SAA flag, see Table 7 for their descriptions.

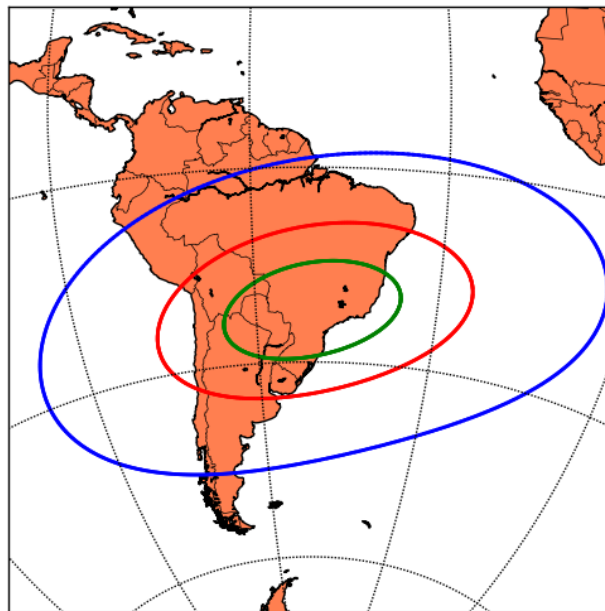


Figure 9: The South Atlantic Anomaly showing contour lines of particle hit intensity. The energy of the particles is not uniform, a fact which is taken into account in the SAA flags. The green curve marks 70% of maximum intensity, the red 40%, and the blue 5%.

Bits 4-5 in Binary (Decimal)	Description
00 (0)	< 5% of nominal maximum SAA intensity
01 (1)	5-40% of nominal maximum SAA intensity
10 (2)	40-75% of nominal maximum SAA intensity
11 (3)	> 75% of nominal maximum SAA intensity

Table 7: The SAA flag consists of bits 4 and 5 (0 based) of the first byte of the 32-bit SwathLevelQualityFlags dataset. Intensity is defined as particle energy \times number of hits per energy bin

The nature of the effect of particle hits on a CCD means that such events can mimic actual sensor data. There is no transient handling algorithm in software producing the L1G algorithm input, therefore users of the L1G product need to be aware that data collected while the OMPS-NPP is in the SAA (SAA flag other than 00) may have elevated levels of noise in the measurements. This is of particular concern in algorithms which use an altitude normalization technique because a transient at a normalization point will effect all altitudes at that wavelength.

4.12 Solar Eclipse Flag

For OMPS Limb, exactly where the shadow of the moon falls on the earth's surface may not be a useful measure of how sunlight may be affected for measurements during an eclipse. Therefore, the eclipse algorithm sets a flag in SwathLevelQualityFlags based on the time rather than the specific path of the eclipse. This flag is intended as a qualitative warning for OMPS Limb Earth view and solar calibration measurements. Bit 24 of the SwathLevelQualityFlags elements indicates a possible solar eclipse during this image somewhere on Earth (generally relevant only on daytime side of Terminator): 0 indicates, no eclipse; 1 indicates eclipse.

4.13 Aperture (Gain) Discrimination

As described in [2, Sec. 2.1] the Limb instrument uses two different apertures (large and small) via two different optical paths. These data are consolidated into the single spectral profile presented in the L1G product. For the L1G version 2.6 only the large aperture is used for gridded pixels at a wavelength shorter than 450 nm, and only the small aperture is used at wavelengths above (or equal to) 450 nm. The benefit of this discrimination is that systematic errors associated with the optical path remain consistent along the profiles in the two different wavelength regimes. (Version 2 of the product used a more complicated scheme.) Care should be taken with any algorithm which incorporates radiance profiles from both below and above 450 nm.

4.14 Metadata

4.14.1 File Level Meta Data

Table 8 describes the top level file attributes. Some top level attributes are not useful for product users but are provided for quality assessment tasks, as described in section 5.

Attribute Name	Description
APP Version†	Version of code used to produce product.
DOI	Digital Object Identifier
L1_SAMP_TBL†	Reference information for instrument sampling configuration.
L1_SAMP_TBL_VER†	Reference information for instrument sampling configuration.
L2_SAMP_TBL†	Reference information for instrument sampling configuration.
L2_SAMP_TBL_VER†	Reference information for instrument sampling configuration.
OrbitNumber	Orbit number
ProfileID†	Reference information for instrument mode configuration.

Table 8: Select top level attributes. Version 2.6 conforms more closely to the significant metadata requirements of GES DISC and thus it is no longer practical to describe all the top level attributes in this document. The table here is the subset of attributes from the previous version of the documentation. Attributes marked with † are not generally useful for product users.

4.14.2 OrbitNumber bug

The Orbit Number bug present in V2.5 is not present in 2.6. The orbit number attribute is correct.

4.14.3 Input Pointers

The product file has a group called **Input Pointers**. It contains information about how the data processing proceeded for the file in question. In general this is of little interest to the end user. However, its contents may be useful in specific situations when requesting help on the product. Figure 10 shows the TreeView of the input pointers. The dataset **ControlFileContents** is a string containing a data structure in the YAML data serialization language.



Figure 10: The InputPointers group.

4.14.4 Digital Object Identifier

The data are provided with Digital Object Identifiers (DOIs). These are a form of World Wide Web addresses. They can be used to get updated information about the product from the producer’s web site as well as reference the data used in a publication.

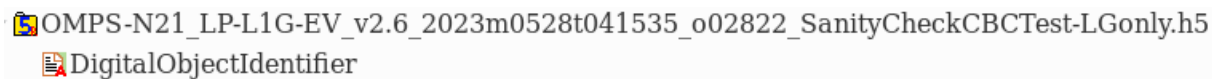


Figure 11: The DigitalObjectIdentifier dataset.

The DOI is contained in a top level character dataset. The dataset is encoded in JavaScript Object Notation (JSON)–data serialization language that is simple for humans to read. In addition, parsers

exist in many languages so that software can automatically parse the string and resolve its different components.

The DOI for the product consists of two components. One is the DOI itself. The second is the DOI authority for resolving the DOI into a Web address, also known as the Landing Page. Figure 12 shows an example of the value of the DigitalObjectIdentifier dataset.

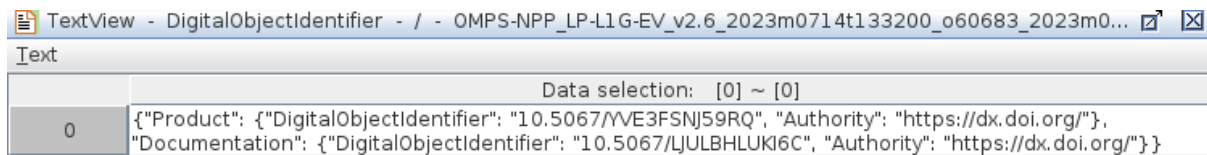


Figure 12: An example of the digital object identifier dataset as viewed in HDFView.

The DOI is used by forming a web address and loading it in a web browser. Version 2.6 of the product contains a DOI for data as well as one for documentation.

The Uniform Resource Locator (URL) corresponding to data product in Figure 12 is:

`https://dx.doi.org/10.5067/YVE3FSNJ59RQ`

and the address corresponding the documentation is:

`https://dx.doi.org/10.5067/LJULBHLUKI6C`

5 Instrument and Satellite Operations

The Suomi NPP satellite is occasionally commanded to execute maneuvers which could interrupt nominal limb earth view measurements or cause the instrument to point in an unusual direction while executing nominal earth view measurements. Furthermore, the OMPS’s operation can change from orbit to orbit. As discussed above, the nominal earth view sample table can change because a better one is developed. Also, the instrument is regularly (and irregularly, on an *ad-hoc* basis) commanded to run in a different measurement mode which takes *non-nominal* earth view data (e.g. captures other than 180 images per orbit or uses a special sample table) or no limb earth view data at all. Additionally, communication failures can cause data to be incomplete or lost altogether.

The impact of this variation on the user is expected to be minimal. An important consideration is that software using the L1G data files should not ‘hard code’ the sizes of the arrays, in particular the number of images. Furthermore, while the size and the values of the wavelength-altitude grid are fixed in a particular version of the L1G it could be changed in future versions and thus the correspondence between wavelength index and wavelength, or between altitude index and altitude would change. It is therefore good practice to not ‘hard code’ wavelength or array indexes into software which uses the L1G, but determine them dynamically.

For orbits for which no data are available no L1G file is released.

When interpreting results from the OMPS data it can sometimes be useful to know the corresponding mode of the instrument or satellite. For example, an unexpected discontinuity between orbits should be checked against changes to satellite or instrument operations. It is not practical to provide a complete accounting of the operating mode for all orbits in this document.

The volume of data and the fact that any static table would be out-of-date as soon as it was published would undermine the utility of such a table. Instead, an overview is presented here while an authoritative account is provided on the OMPS website. The orbit ranges in Table 9 are the ranges during which the respective sample table was loaded on the instrument for nominal earth view measurements. For the first 3737 orbits early operations type activities were undertaken making the catalog of earth view orbits too complex for this document.

Orbits	Load Date	End Date	Name	Description
1-3737	10/28/11	02/06/12	Various	Mix of early operations Sample Tables
3738-4658	02/06/12	09/20/12	84.5	Minor smear pixel revision to operational table
4659-10788	09/20/12	11/26/13	0.4	Minor revision to move wavelength registration columns
10789-11612	11/26/13	01/23/14	0.5	First revision for improved spectral coverage
11613-12010	01/23/14	02/20/14	0.6	Second revision for spectral coverage
12011-13101	02/20/14	05/08/14	0.7	Third revision for spectral coverage
13102-current	05/08/14	still current	0.8	Small changes to improve IR coverage

Table 9: Sample Table Upload History. The orbit ranges indicate the orbits for which the sample table was the nominal earth view sample table. Before orbit 3738 the instrument changed operating modes too frequently for it to be practical to include a description in this document. After orbit 3738 tests are still occasionally run (at least once per week) interrupting the nominal earth view measurements.

On both a regular (weekly) and also irregular basis the instrument is put into a mode in which nominal earth view data are not collected. This can lead to either missing orbits or earth view data using an alternate sample table. A notable example of this is the weekly Full Frame data in which all pixels on the CCD are downlinked but only 32 (instead of 160 or 180) images are captured during the day side pass. A gridded product is produced for Full Frame mode data as with nominal earth view, but the wavelength and altitude coverage will be greater at the expense of along track coverage which is reduced by 80%.

6 Chelyabinsk Bolide Example

To illustrate the use of OMPS limb data an image of the Chelyabinsk bolide dust cloud was generated from a single orbit of data. On 15 February 2013 a bolide (or meteor) exploded 23.3 km above Chelyabinsk, Russia. It has been shown that dust injected into the atmosphere by the bolide was detectable by the OMPS Limb L1G instrument [1]. This feature can be seen clearly in a single orbit of OMPS Limb data, see Figure 13.

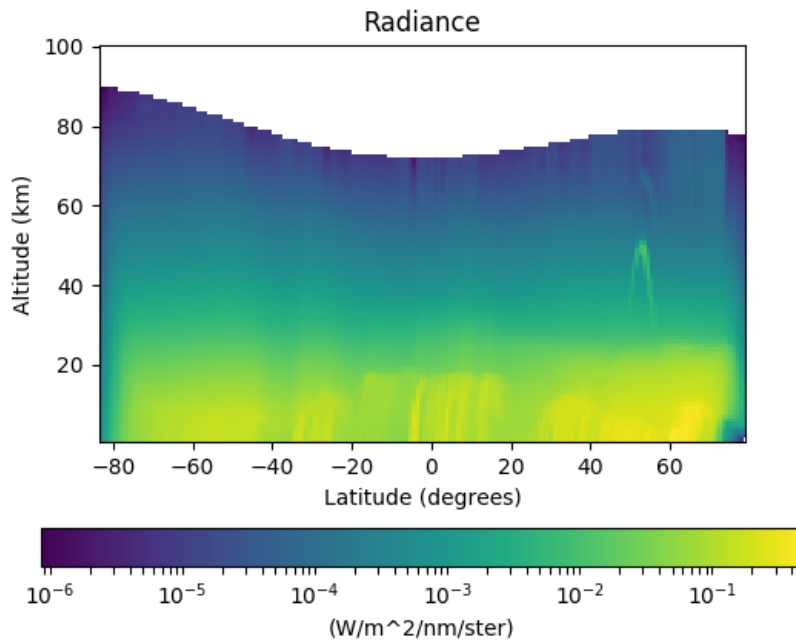


Figure 13: OMPS Limb L1G radiance data at approximately 724 nm, showing the Chelyabinsk bolide dust trail from Suomi NPP orbit 6752 on 15 February 2013. The dust is detected at about 50 km high, 55 degrees North latitude. White pixels indicate no corresponding radiance data.

```
1  #!/usr/bin/env python3
2  import h5py
3  import numpy
4  from matplotlib import pyplot
5  from matplotlib.colors import LogNorm
6
7  BolideOrbitFile = 'OMPS-NPP_LP-L1G-EV_v2.6_2013m0215t060054_o06752_2022m1004t063415.h5'
8
9  Slit = 2 # Right slit
10 TargetWavelength = .724 # microns
11
12 with h5py.File(BolideOrbitFile, 'r') as fid:
13     WavelengthGrid = fid['/GRIDDED_DATA/WavelengthGrid'][...]
14     ClosestWavelength = WavelengthGrid[WavelengthGrid.searchsorted(TargetWavelength)]
15
16     TargetWavelengthIndex = numpy.where(WavelengthGrid == ClosestWavelength)
17
18     Radiance = fid['/GRIDDED_DATA/Radiance'][...]
19     RadianceImage = Radiance[:, Slit, :, TargetWavelengthIndex[0][0]].transpose()
20     TangentHeight = fid['/GRIDDED_DATA/TangentHeight'][...]
21     Latitude_45km = fid['/GEOLOCATION_DATA/Latitude_45km'][:, Slit]
22
23 MaskedRadianceImage = numpy.ma.array(RadianceImage, mask=RadianceImage < -998)
24 pyplot.imshow(MaskedRadianceImage, origin='lower',
25               extent=[Latitude_45km.min(), Latitude_45km.max(),
26                       TangentHeight.min(), TangentHeight.max()], norm=LogNorm())
27
28 pyplot.title('Radiance')
29 pyplot.ylabel('Altitude (km)')
30 pyplot.xlabel('Latitude (degrees)')
31 pyplot.colorbar(orientation='horizontal', label="(W/m^2/nm/ster)")
32 pyplot.show()
```

Listing 2: Python 3 program used to create the image in Figure 13. The latitudes on the abscissa in this figure are computed by specifying the min and max values and dividing the axis up into equal parts. This is valid to the extent that the latitude increases linearly with event. This orbit consisted 180 events, the 10 or so events at the both ends of the orbit are of lower quality because tangent points are on the dark side of the terminator.

Line 13 The wavelength grid is loaded into WavelengthGrid variable. This array contains the complete set of wavelengths used to grid the data.

Line 14 Identify the wavelength in the superset closest to the target wavelength of 724 nm.

Line 16 Locate the index in the WavelengthGrid array corresponding to 724 nm.

Line 19 Use the array of TargetLocation to extract radiances corresponding to TargetWavelength (TargetLocations[0][0]) from the 4D Radiance array. The slit is specified by Slit, so the result is a set of 2D arrays of radiances, with dimensions number of altitudes x number of events.

Lines 23 and 24 The fill value used in this dataset is -999, so the mask marks all those array elements which are fills (radiances are never negative.) This example is taking advantage of the Numpy masked array facility; the Matplotlib plotting software will automatically choose white for pixels where the mask elements which are True. (Note that the mask here has the opposite sense as the mask used in Fortran 90 where the good values are the True values in the mask.)

7 More Information

Contact Information

Name: GES DISC Help Desk
URL: <https://disc.gsfc.nasa.gov>
E-mail: gsfc-help-disc@lists.nasa.gov
Phone: 301-614-5224
Fax: 301-614-5228
Address: Goddard Earth Sciences Data and Information Services Center
Attn: Help Desk
Code 610.2
NASA Goddard Space Flight Center
Greenbelt, MD 20771 USA

Additional OMPS and ozone data products

(including per orbit operating mode table.)
<https://ozoneaq.gsfc.nasa.gov>

Suomi-NPP mission web page

https://www.nasa.gov/mission_pages/NPP/main/index.html

A Code Example Requirements

The Python examples in this guide were run using Python 3. They used the following modules:

- numpy
- h5py
- matplotlib

B Data Citation Format

These data can be cited in publications as:

Glen Jaross (2019), OMPS-NPP L1G LP Radiance Vertical Profile Gridded swath 3slit V2.6, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: *[data access date]*, doi: 10.5067/Q0V6DTPZHSHV

References

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- [2] Glen Jaross, Pawan K. Bhartia, Grace Chen, Mark Kowitt, Michael Haken, Zhong Chen, Philippe Xu, Jeremy Warner, and Thomas Kelly. OMPS Limb Profiler instrument performance assessment. *Journal of Geophysical Research: Atmospheres*, 119(7):4399–4412.
- [3] Glen Jaross, Didier F. Rault, Mark Kowitt, Grace Chen, and Michael Haken. OMPS Limb Profiler Sensor Data Record (SDR) Algorithm Theoretical Basis Document. https://ozoneaq.gsfc.nasa.gov/public/OMPS/ATBDs/ATBD_NASA_LP_SDR_v3.pdf.
- [4] L. Moy, P. K. Bhartia, G. Jaross, R. Loughman, N. Kramarova, Z. Chen, G. Taha, G. Chen, and P. Xu. Altitude registration of limb-scattered radiation. *Atmospheric Measurement Techniques*, 10(1):167–178, 2017.