



# CATS L2O Layer Products Quality Statements

## Version Release: 1.05

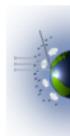
02 September 2016

### 1.0 Introduction

This document offers a general quality assessment of the CATS Level 2 Operational (L2O) Layer data products, as described in CATS Data Product Catalog, and explains the information needed by the science community for accurate and effective use of the CATS data products. We insist that all CATS data users examine this document for the latest updates before publishing any scientific papers using the CATS data products. This document describes the accuracy of CATS data products as determined by the CATS Algorithm Group. The purpose of this data quality summary is to briefly demonstrate significant validation results; inform users of areas that can lead to misinterpretation of the data; provide links to relevant documents describing the CATS data products and algorithms used to generate them; and propose planned algorithm revisions.

### 2.0 Data Product Maturity

The maturity levels of each parameter reported in the CATS L2O Layer data products are identified in this document and may be different for the various parameters since validation efforts and uncertainties of some parameters are different compared to others. The data product maturity levels for the CATS data products, adapted from the CALIPSO maturity levels, are defined in Table 1. Since CATS has only been in operation for one year, the many parameters in the L2O products are still assigned a product maturity level of provisional.



**Table 1.** CATS Maturity Level Definitions (adapted from CALIPSO)

<b>Beta:</b>	Early release products for users to gain familiarity with data formats and parameters. Users are strongly cautioned against the indiscriminate use of these data products as the basis for research findings, journal publications, and/or presentations.
<b>Provisional:</b>	Limited comparisons with independent sources have been made and obvious artifacts fixed.
<b>Validated Stage 1:</b>	Uncertainties are estimated from independent measurements at selected locations and times.
<b>Validated Stage 2:</b>	Uncertainties are estimated from more widely distributed independent measurements.
<b>Validated Stage 3:</b>	Uncertainties are estimated from independent measurements representing global conditions.
<b>External:</b>	Data are not CATS measurements, but instead are either obtained from external sources (e.g., GMAO, ISS) or fixed constants in the CATS retrieval algorithm (e.g., calibration altitude).

### 3.0 Documents and References

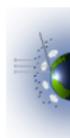
The following documents provide additional information for data users to reference:

1. [The CATS Algorithm Theoretical Basis Document \(ATBD\)](#)
2. [The CATS Data Product Catalog: Release 3.0 \(PDF\)](#)
3. [Overview of L1 Data Processing Algorithms \(PDF\)](#)
4. [CATS Instrument and Project Overview \(PDF\)](#)
5. CATS Data Read Routine in Interactive Data Language (IDL)

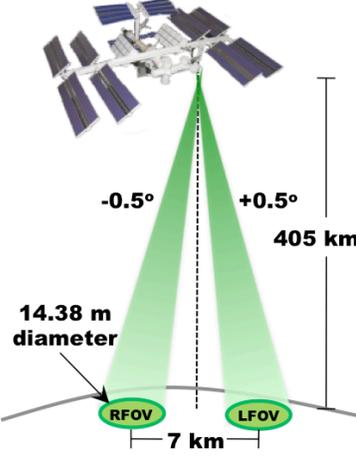
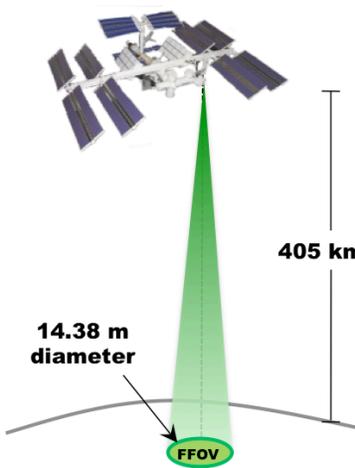
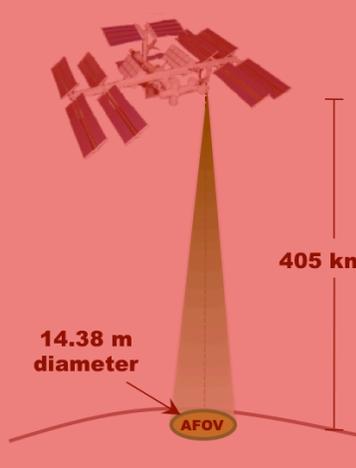
### 4.0 CATS Operating Modes

To meet the project science goals, CATS operates in three different modes using four instantaneous fields of view (IFOV) as shown in Figure 1:

- **Mode 7.1: Multi-beam backscatter detection at 1064 and 532 nm, with depolarization measurement at both wavelengths.** The laser output is split into two transmit beams, one aimed 0.5° to the left and one 0.5° to the right, effectively making two tracks separated by 7 km (~4.3 mi) at Earth's surface. This operational mode can no longer be used due to a failure in laser 1 electronics.
- **Mode 7.2: Demonstration of HSRL aerosol measurements.** This mode was designed to use the injection-seeded laser operating at 1064 and 532 nm to demonstrate a high spectral resolution measurement using the 532-nm wavelength. However, this mode has been limited to 1064 nm backscatter and depolarization ratio because issues with stabilizing the frequency of laser 2 prevent collection of science quality HSRL and 532 nm data.



- Mode 7.3: Demonstration of 355-nm profiling.** This mode was designed to use the injection-seeded laser operating at 1064, 532, and 355 nm to demonstrate 355-nm laser performance. Unfortunately, due to an unexpected failure in the laser optical path, CATS will not collect data in this mode.

<b>Mode 7.1: Multi-Beam</b> Backscatter: 532, 1064 nm No HSRL Depolarization: 532, 1064 nm	<b>Mode 7.2: HSRL Demo</b> Backscatter: 532, 1064 nm HSRL: 532 nm Depolarization: 1064 nm	<b>Mode 7.3: UV Demo</b> Backscatter: 355, 532, 1064 nm No HSRL Depolarization: 532, 1064 nm
		
Semi-continuous operation: <b>Feb. 10 – Mar. 21</b> Failure: under investigation	Semi-continuous operation: <b>Mar. 25 – Present</b> Future Mode of Operation	<b>Failure in laser optics</b> <b>No data available</b>

**Figure 1.** CATS three main Science Modes for operation, with details of each mode’s capabilities and operational status.

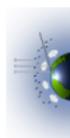
## 5.0 CATS Level 2O Layer Data Products

The CATS L2O Layer data product includes day or night vertical profiles (approximately a half orbit) of geophysical parameters derived from Level 1 data, such as the vertical feature mask and layer-integrated properties (i.e. optical depth, lidar ratio). The main parameters reported in the CATS L2O Layer data product are identification of atmospheric features and optical properties of these layers.

### 5.1 Layer Descriptors and Feature Type

#### *Number of Layers*

The number of layers found in a specific 5 km profile. The CATS layer detection is performed following the methodology described in the CALIOP Algorithm Theoretical Basis Document (ATBD; Vaughan et al. 2005). It is a threshold-based layer detection



method that uses the 1064 nm attenuated scattering ratio, unlike the CALIPSO algorithm that uses 532 nm. The CATS algorithm only performs layer detection at a single horizontal resolution of 5km horizontal (60m vertical), while the CALIOP algorithm will successively run the profile scanner at coarser and coarser horizontal resolutions ranging from 5 km to 80 km in order to detect increasingly tenuous layers (Vaughan et al. 2009). The CATS false positive rejection scheme utilizes the feature-integrated backscatter (FIB) of layers and the horizontal persistence of layers as criteria for rejecting layers.

For CATS, the layer detection is performed using the 1064 nm backscatter signal for two main reasons:

- 1) The CATS 1064 nm minimum detectable backscatter is lower than 532 nm, making it a better option for more accurate layer identification (Tables 4.1 and 4.2).
- 2) For absorbing aerosols, the absorption optical thickness increases with decreasing wavelength. This effect reduces the backscattered signal at 532 nm with respect to 1064 nm, such that the 532 nm backscatter is not sensitive to entire vertical extent of the aerosol layer [Torres et al., 2013; Jethva et al., 2014; Liu et al., 2014]. Because the 1064 nm wavelength is only minimally affected by aerosol absorption, the vertical extent of the absorbing aerosol layer is more fully captured from 1064 nm backscatter profiles rather than those from 532 nm.

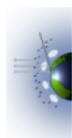
Since CATS can detect the full vertical extent of the aerosol layer above the cloud, it is extremely important that the algorithm also distinguish these as two separate layers. The CATS layer detection algorithm includes a routine to identify clouds embedded within aerosol layers. More information on the CATS layer detection algorithms is located in the CATS ATBD. For L2O V1-04, the false positive routine was updated to eliminate falsely detected layers in the upper troposphere and lower stratosphere. For L2O V1-05, the layer detection thresholds were updated to improve sensitivity to optical thin cloud and aerosols layers and compensate to lower backscatter values in the L1B V2-07 products due to more accurate calibrations.

### ***Layer Top Bin***

### ***Layer Base Bin***

The bin number at the layer top and base altitudes are reported in for every layer within a 5 km profile. The uncertainties associated with determining layer top and base locations are detailed in the CALIPSO Feature Detection ATBD (PDF). There are a few general guidelines users should be aware of when using these products:

- Strongly scattering layers are more accurately detected than weakly scattering layers.
- Because signal-to-noise ratios (SNR) are higher during nighttime compared to daytime, nighttime detection of features is easier than daytime. This is typical for all lidar systems.
- Detection of the highest layer in a 5 km profile is more reliable than lower layers in a multi-layer scene.
- The base bin/altitude reported may not be the true base. For highly scattering features, the layer base may appear lower than it really is due to multiple scattering effects. Also, opaque layers that completely attenuate the backscatter



signal will cause the reported base to be higher than reality. For L2O V1-04, the layer base bin is decreased by one bin (increase in height) when the base bin is directly above the surface detection. This was done to avoid contamination of the layer-integrated properties of the layer from the surface return signal.

#### ***Layer Top Altitude***

#### ***Layer Base Altitude***

Layer top and base altitudes, units of kilometers above mean sea level, are reported in for every layer within a 5 km profile. CATS measures the layer top and base altitude to within 60 meters, a function of the on-board data averaging scheme. The CATS Version 2-06 L1B data release included an error in the algorithm that remaps the raw CATS data to the final CATS data frame (-2.0 to 30.0 km at 60 m vertical resolution). The error caused certain bins in Mode 7.2 to contain the same value of backscatter as the bin above. As a result, layer top and base heights are never detected at these bins in the V1-03 of the L2O data products. For CATS L1B V2-07 and L2O V1-04, this error has been corrected. Users that are analyzing cloud and aerosol top/based height distributions are advised to use the L1B V2-07 and L2O V1-04 data for their analysis. Please note that when using a small amount of data (several granules), layer detection may still favor some bins over others due to interpolation from the raw 78 m vertical bins to the 60 m vertical bins reported in the data products. This affect is very minimal when using large amounts of data (>200 granules).

#### ***Layer Top Temperature***

#### ***Layer Base Temperature***

Temperature, in degrees C, at the layer top/base altitude reported for each 5 km L2O profile. NASA Goddard Earth Observing System version 5 (GEOS-5) forecasts provided by the NASA Global Modeling and Assimilation Office (GMAO) deliver a forecast of the atmospheric temperature and pressure profiles for 72 vertical levels (0-85 km AGL) at a horizontal resolution of 10 seconds that is subset along the ISS orbit track. These parameters are read in from the L1B data product and interpolated to the CATS 5 km L2O horizontal resolution. Temperature values are interpolated from the ancillary meteorological data provided by the GMAO.

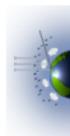
#### ***Layer Top Pressure***

#### ***Layer Base Pressure***

Pressure, in millibars, at the layer top/base altitude reported for each 5 km L2O profile. Pressure values are interpolated from the ancillary meteorological data provided by the GMAO.

#### ***Feature Type (Provisional)***

An assessment of the feature type (e.g., cloud vs. aerosol) is reported for each atmospheric layer found within a 5 km profile. The values that correspond to specific feature types are shown in Table 2. A comprehensive description of the feature types, including their derivation and physical significance, quality assessments, and guidelines for interpreting them can be found in the CATS ATBD. For L2O V1-04, layers with a base above the tropopause height, or layers with a top above the tropopause height and



weak backscatter (IATB < 0.005) are considered aerosols. Previous versions used 18 km as the threshold and not the tropopause height.

**Table 2.** Definitions of the CATS Feature Type Parameter

Interpretation of Values
0 = Invalid
1 = Cloud
2 = Undetermined
3 = Aerosol

**Cloud Phase (Provisional)**

For each atmospheric layer defined as a cloud in the feature type parameter, an assessment of the cloud phase (e.g., ice vs. liquid water) is reported. The values that correspond to specific cloud phases are shown in Table 3. A comprehensive description of the cloud phases, including their derivation and physical significance, quality assessments, and guidelines for interpreting them can be found in the CATS ATBD.

**Table 3.** Definitions of the CATS Cloud Phase Parameter

Interpretation of Values
0 = invalid
1 = water cloud
2 = unknown cloud phase
3 = ice cloud

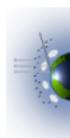
**Aerosol Type (Provisional)**

For each atmospheric layer defined as an aerosol in the feature type parameter, an assessment of the aerosol type is reported. The values that correspond to specific aerosol types are shown in Table 4. A comprehensive description of the aerosol types, including their derivation and physical significance, quality assessments, and guidelines for interpreting them can be found in the CATS ATBD.

**Table 4.** Definitions of the CATS Aerosol Type Parameter

Interpretation of Values
0 = Invalid
1 = Marine
2 = Polluted Marine
3 = Dust
4 = Dust mixture
5 = Clean/Background
6 = Polluted Continental
7 = Smoke
8 = Volcanic

For aerosols, the feature subtype is one of eight types: invalid, marine, polluted marine,



dust, dust mixture, clean/background, polluted continental, smoke, and volcanic. Smoke aerosols consist primarily of soot and organic carbon (OC), while clean/background is a lightly loaded aerosol consisting of sulfates (SO<sub>4</sub><sup>2-</sup>), nitrates (NO<sub>3</sub><sup>-</sup>), OC, and Ammonium (NH<sub>4</sub><sup>+</sup>). Polluted continental is background aerosol with a substantial fraction of urban pollution. Marine is a hygroscopic aerosol that consists primarily of sea-salt (NaCl), whereas polluted marine is a mixture of marine with smoke, dust or polluted continental aerosols. Dust mixture is a mixture of desert dust and smoke or urban pollution (polluted continental). If the CATS observables do not clearly indicate one of these 8 aerosol types, the aerosol layer is interpreted as “invalid”.

***Sky Condition (Provisional)***

For each 5 km profile, an assessment of the sky condition (e.g., cloudy vs. clear) of the column is reported. The values that correspond to specific sky conditions are shown in Table 5. A comprehensive description of the algorithms used to determine feature types can be found in the CATS ATBD.

**Table 5. Definitions of the CATS Sky Condition Parameter**

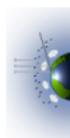
Interpretation
0 = clean skies (no clouds/aerosols)
1 = clear skies (no clouds)
2 = cloudy skies (no aerosols)
3 = hazy/cloudy (both clouds/aerosols)

**5.2 Layer-Integrated Properties**

***Integrated Attenuated Backscatter (Provisional)***

The integrated attenuated backscatter (IAB or  $\gamma'$ ), which has units of sr<sup>-1</sup> and is reported at 532 and 1064 nm for each atmospheric layer within a 5 km profile. The primary sources of uncertainty in the CATS IAB are the calibration constant, signal noise, and accuracy of the top and base determination. However, there are a few things CATS data users should be aware of:

1. The CATS backscatter signal is more robust at 1064 nm than 532 nm. For Mode 7.1, this is attributed to the fact that the laser is outputting more energy at 1064 nm (1.40 mJ compared to 0.88 mJ at 532 nm). For Mode 7.2, data at 532 nm is noisy due to issues with stabilizing the seeded laser (laser 2). Since the frequency stability is poor on laser 2, it is not aligned properly with the CATS etalon causing very weak signal transmission.
2. Both CATS wavelengths in daytime conditions have lower signal to noise ratio (SNR) and higher minimum detectable backscatter for Mode 7.1 than nighttime. The poorer performance during daytime is due to solar background noise, typically an issue for daytime operation of any lidar.
3. The low depolarization purity of CATS measurements at 532 nm, if uncorrected, causes a high bias in the integrated values of backscatter and depolarization ratio at 532 nm, as well as a low bias in the 1064-532 backscatter color ratio. This data is corrected for the poor depolarization purity at 532 nm, but biases in the 532 nm



layer-integrated products (attenuated backscatter, color ratio, and depolarization ratio) of 5-10% still remain.

4. Initial telescope alignment procedures were conducted 5-9 February, 2015 for the LFOV and RFOV. The result was slightly better alignment in the RFOV optical path, as minimum datable backscatter for the RFOV was 10% lower than the LFOV for data up to 09 March 2015. Additional telescope alignment procedures for the LFOV in early March reversed the affect. Thus, the LFOV signal is more robust for data after 09 March, 2015. Users should keep this in mind when comparing data from the two IFOVs.
5. The 1064 nm signal in mode 7.2 is very robust, with higher SNR and lower minimum detectable backscatter than the Mode 7.1 data. **We highly recommend using the 1064 nm data for any analysis that is wavelength-independent (i.e. layer detection, relative backscatter intensity).**

#### ***Integrated Attenuated Backscatter Uncertainty (TBD)***

For version 1.05, the uncertainty in the integrated attenuated backscatter contains fill values (-999.99). For future versions, the uncertainty in the integrated attenuated backscatter will be reported for each layer within a 5 km profile. The values reported will be absolute uncertainties, not relative, thus the units will be identical to the units of the particulate backscatter coefficients ( $\text{sr}^{-1}$ ).

#### ***Attenuated Backscatter Statistics***

This variable reports the minimum, maximum, mean, and standard deviation of the 532 and 1064 nm attenuated total backscatter coefficients for each layer within a 5 km profile, in units  $\text{km}^{-1} \text{sr}^{-1}$ .

#### ***Integrated Volume Depolarization Ratio (Provisional)***

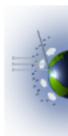
Pulsed lasers, such as the ones used in the CATS instrument, naturally produce linearly polarized light. Using a beam splitter in the receiver optics, the perpendicular and parallel planes of polarization of the backscattered light are measured. The integrated volume depolarization ratio is defined as the ratio of perpendicular integrated attenuated backscatter to parallel integrated attenuated backscatter, and has values between 0.2 and 0.6 for non-spherical particles such as ice crystals. Deriving accurate depolarization ratios from CATS data requires knowledge of the relative gain between the perpendicular and parallel channels of the CATS receiver, referred to as the polarization gain ratio (PGR). Integrated volume depolarization ratios are reported for each layer within a 5 km profile.

#### ***Integrated Volume Depolarization Ratio Uncertainty (TBD)***

For version 1.05, the uncertainty in the integrated volume depolarization ratio contains fill values (-999.99). For future versions, the uncertainty in the integrated volume depolarization ratio will be reported for each layer within a 5 km profile. The values reported will be absolute uncertainties, not relative.

#### ***Volume Depolarization Ratio Statistics***

This variable reports the minimum, maximum, mean, and standard deviation of the 532 and 1064 nm volume depolarization ratio for each layer within a 5 km profile.



### ***Integrated Spectral Depolarization Ratio (Provisional)***

The integrated spectral depolarization ratio (Mode 7.1 data only) is defined as the ratio of 1064 nm integrated volume depolarization ratio to 532 nm integrated volume depolarization ratio, and can help determine aerosol layer types as outline in the CATS ATBD. Integrated spectral depolarization ratios are reported for each layer within a 5 km profile.

### ***Integrated Spectral Depolarization Ratio Uncertainty (TBD)***

For version 1.05, the uncertainty in the integrated spectral depolarization ratio (Mode 7.1 data only) contains fill values (-999.99). For future versions, the uncertainty in the integrated spectral depolarization ratio will be reported for each layer within a 5 km profile. The values reported will be absolute uncertainties, not relative.

### ***Spectral Depolarization Ratio Statistics***

This variable reports the minimum, maximum, mean, and standard deviation of the spectral depolarization ratio (Mode 7.1 data only) for each layer within a 5 km profile.

### ***Integrated Attenuated Total Color Ratio (Provisional)***

The integrated attenuated total color ratio is defined as the ratio of 1064 nm integrated attenuated backscatter to 532 nm integrated attenuated backscatter, and can help distinguish cloud and aerosol layers as outline in the CATS ATBD. Integrated attenuated total color ratios are reported for each layer within a 5 km profile.

### ***Integrated Attenuated Total Color Ratio Uncertainty (TBD)***

For version 1.05, the uncertainty in the integrated attenuated total color ratio contains fill values (-999.99). For future versions, the uncertainty in the integrated attenuated total color ratio will be reported for each layer within a 5 km profile. The values reported will be absolute uncertainties, not relative.

### ***Attenuated Total Color Ratio Statistics***

This variable reports the minimum, maximum, mean, and standard deviation of the total color ratio for each layer within a 5 km profile.

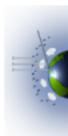
## ***5.3 Layer Optical Properties***

### ***Measured Two-Way Transmittance***

The measured two-way particulate transmittance is reported for each layer where an extinction profile could be calculated within a 5 km profile. The measured two-way particulate transmittance for a layer is the ratio of the two-way particulate transmittance at the bottom of the layer and the two-way particulate transmittance at the top of the layer, and typical values are between 0 and 1.

### ***Measured Two-Way Transmittance Uncertainty***

For version 1.05, the uncertainty in the measured two-way transmittance contains fill values (-999.99). For future versions, the uncertainty in the measured two-way



transmittance will be reported for each layer within a 5 km profile. The values reported will be absolute uncertainties, not relative.

### ***Two-Way Transmittance Measurement Region***

The two-way transmittance measurement region, reported in km, defines the "clear air" region immediately below the layer used to compute the measured two-way transmittance to derive the constrained lidar ratio of a layer.

### ***Feature Optical Depth (Provisional)***

The optical depth of all atmospheric particulate layers, clouds, and aerosol throughout the column are reported for each 5 km profile. The optical depths are obtained by integrating the 532 (Mode 7.1 only) and 1064 nm cloud and/or aerosol extinction within the layer. Since the feature optical depths are a layer integral product, any large uncertainties or poor extinction retrievals from bins within the layer will propagate downward and may impact the quality of all the feature optical depths. Therefore, users are strongly encouraged to use the feature optical depth uncertainties, extinction QC flag, and feature type score to assess the quality of the feature optical depths.

CATS data users should be aware of three main things when using feature optical depth data:

1. CATS is only capable of penetrating to the layer base if the total feature optical depth is less than ~4. If the feature is opaque to the lidar, then the reported feature optical depths are set to -1.0 because the lidar is only measuring the apparent base of the layer, not the true optical depth of the layer.
2. The extinction QC values for the layer should be examined to determine if the extinction retrievals were bad. In general, solutions where the final lidar ratio is unchanged (extinction QC = 0) yield physically plausible solutions more often.
3. Features with invalid or undetermined feature type, cloud phase, or aerosol type, may have erroneous optical depths.

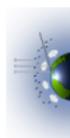
### ***Feature Optical Depth Uncertainty (TBD)***

There are three main sources (ignoring multiple scattering) of the uncertainty in the feature optical depth, estimated at each wavelength:

- signal-to-noise ratio (SNR) within a layer
- calibration accuracy
- accuracy of the lidar ratio used in the extinction retrieval

Except for constrained solutions, where a lidar ratio estimate can be obtained directly from the attenuated backscatter data, lidar ratio uncertainties are almost always the dominant contributor to optical depth uncertainties, and the relative error in the layer optical depth will always be at least as large as the relative error in the layer lidar ratio. For version 1.05, the uncertainty in the feature optical depth contains fill values (-999.99). For future versions, the uncertainty in the feature optical depths will be reported for each layer within a 5 km profile. The values reported will be absolute uncertainties, not relative.

### ***Lidar Ratio***



The particulate extinction-to-backscatter ratio, or lidar ratio, is required to retrieve extinction and backscatter coefficient profiles, as well as optical depth from CATS measurements. There are 4 basic categories of lidar ratio input sources: constrained, unconstrained default, modified default, and opaque. The lowest uncertainties are found for transparent layers in which the AOD, and thus extinction coefficient, can be directly retrieved (or “constrained”) using the transmission loss through the layer. All other cases require a default value based on the type and subtype of the layer being analyzed.

CATS ice cloud lidar ratios are assigned based on relationships with layer integrated depolarization ratio and geographic location, shown in Table 6, as retrieved from CPL and CALIPSO data. Values of 18.0 sr and 22.0 sr are used for liquid water clouds and clouds of unknown phase, respectively. For aerosols, the lidar ratio is assigned from a look-up table based on the aerosol type and the values are very similar to those used in CALIPSO, CPL and GLAS algorithms, as shown in Table 7. If this lidar ratio remains unmodified through the solution process, we describe this category as “unconstrained default” or just default.

**Table 6:** CATS Ice Cloud Default Lidar Ratios

Location	Land Type	Sp
Mid-Latitude	Land	24.0
Mid-Latitude	Ocean	30.0
Tropics	Land	28.0
Tropics	Ocean	32.0

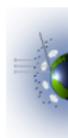
**Table 7:** CATS Aerosol Default Lidar Ratios

Aerosol Type	532 nm	1064 nm
Marine	25.0	45.0
Marine Mixture	45.0	40.0
Dust	45.0	55.0
Dust Mixture	35.0	45.0
Clean/Background	55.0	35.0
Polluted Continental	65.0	35.0
Smoke	70.0	40.0
Volcanic	45.0	35.0

This parameter reports the lidar ratio in use at the conclusion of the extinction processing for each layer, equivalent to the “Final Lidar Ratio” in CALIPSO data products.

***Ice Water Path (Provisional)***

Ice water path (IWP) is the integral of ice water content (IWC) from ice cloud layer top to layer base, reported for each ice cloud layer within a 5 km profile. Ice water path has units of gm<sup>-2</sup>. For Mode 7.2 data, only the 1064 nm IWP is reported. For Mode 7.1 data,



both the 532 and 1064 nm IWP is reported. The IWC is calculated as a parameterization function of the CATS ice particle extinction retrievals as outlined in the CATS ATBD.

### ***Ice Water Path Uncertainty (TBD)***

For version 1.05, the uncertainty in the IWP contains fill values (-999.99). For future versions, the uncertainty in the IWP will be reported for each ice cloud layer within a 5 km profile. The values reported will be absolute uncertainties, not relative, thus the units will be identical to the units of the IWP ( $\text{gm}^{-2}$ ).

### ***Layer Effective Multiple Scattering Factor (Provisional)***

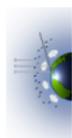
The layer effective multiple scattering factors, for each layer within a 5 km profile, are reported at each wavelength according to layer type and subtype. Values range from just above 0, which indicates significant contributions to the backscatter signal from multiple scattering, to 1, which corresponds to minimal (if any) multiple scattering (single scattering only). Multiple scattering effects are different for various aerosols particle types, ice particles, and water droplets. The CATS and CALIPSO ATBDs provides a discussion of multiple scattering factors for ice clouds and several aerosol types. For CATS, the layer effective multiple scattering factors in V1-05 products are:

- *Ice Clouds*: Comparing CATS and CPL lidar ratios and extinction coefficients within ice clouds result in values of 0.673 (Mode 7.2) and 0.423 (Mode 7.1) at 1064 nm and 0.545 (Mode 7.1) at 532 nm (Note: these values are still being tested and may be updated in future data product versions). Scaling the CALIPSO layer effective multiple scattering factor of 0.60 using instrument measurement geometries yield higher values (closer to the Mode 7.2 1064 nm value), so these Mode 7.1 factors likely include instrument biases in addition to multiple scattering effects.
- *Water Clouds*: Values of 0.55 (Mode 7.2, 1064 nm), 0.50 (Mode 7.1, 532 nm), and 0.40 (Mode 7.1, 1064 nm) are used for water cloud effective multiple scattering factors at both wavelengths based on scaling the CALIPSO values. More work will be conducted to update this value for future versions.
- *Aerosols*: A value of 1.00 is used for both wavelengths because simulations of multiple scattering effects on AOD retrievals suggest the effects are small in most cases. CALIPSO also uses a value of 1.0.

## ***5.4 CATS Geolocation***

### ***CATS Geolocation (Validated Stage 1)***

Knowledge of the location of the CATS laser spot on the earth is required for the useful analysis of the CATS backscatter data. The location of the CATS laser spots are calculated from the position, velocity, and attitude information found in the ISS Broadcast Ancillary Data (BAD) together with the known angular offset of the laser line-of-site (LOS) vector from the instrument's nadir vector in the CATS L1B processing. The geolocation parameters reported in the CATS L2O data products have three elements for each 5 km L2O profile. These elements represent the first, mean, and last value of the 13 L1B profiles that make up one 5km L2O profile:



1. **Index Top Bin (all IFOVs)** – The bin id of the CATS data frame where the top of the CATS profile is located, as computed from the ISS BAD.
2. **CATS Latitude (all IFOVs)** – Ground latitude of the CATS laser spot, in degrees, as computing from the ISS BAD.
3. **CATS Longitude (all IFOVs)** – Ground longitude of the CATS laser spot, in degrees, as computing from the ISS BAD.
4. **CATS Angle (all IFOVs)** – The off-nadir viewing angle of the CATS laser spot, in degrees, as computing from the ISS BAD.
5. **Lidar Surface Altitude (all IFOVs)** - This is the surface elevation at each laser IFOV footprint, in kilometers above local mean sea level, obtained from identifying the backscatter return of the earth's surface.
6. **Solar Azimuth Angle** – Solar azimuth angle, in degrees, reported for each 5 km L2O profile. Solar azimuth angle values are interpolated from the ancillary meteorological data provided by the GMAO.
7. **Solar Zenith Angle** - Solar zenith angle, in degrees, reported for each 5 km L2O profile. Solar zenith angle values are interpolated from the ancillary meteorological data provided by the GMAO.

### ***5.6 Instrument Parameters and Laser Energy***

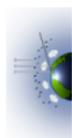
There are several parameters that report details on instrument constants, calibration, performance, and laser energy. These parameters are:

1. **Horizontal Resolution** - This is an HDF metadata field that defines the horizontal resolution of the CATS data profiles, which is currently set to 5 km.
2. **Bin Size** - This is an HDF metadata field that defines the size, in kilometers, of the CATS vertical (range) bins. The bin size is 60 meters or 0.06 km.
3. **Number Bins** - This is an HDF metadata field that defines the number of vertical bins in each CATS data frame. Since the CATS data frame ranges from -2.0 km to 28.0 km, and the bin size is 0.06 km, there are 533 bins in each profile.
4. **Number 5 km Profiles** - This is an HDF metadata field that defines the number of 5 km CATS L2O profiles in the granule file.
5. **Bin Altitude Array** – Altitude, in kilometers, at the middle of each of the 533 vertical bins in each CATS data frame, which ranges from roughly -2.0 km to 30.0 km.

### ***5.7 Time and Profile Parameters***

The following parameters are reported in the Level 2O data product to identify each 5 km CATS L2O record (profile).

1. **Profile UTC Date** - This is an HDF metadata field that defines the date (DDMMYYYY) of each 5 km CATS L2O record.
2. **Profile UTC Time** - This is an HDF metadata field that defines the time, in fraction of the day, of each 5 km CATS L2O record. The time reported in the CATS L2O data products have three elements for each 5 km L2O profile. These elements represent the first, mean, and last value of the 13 L1B profiles that make up one 5km L2O profile



3. **Profile ID** - This is an HDF metadata field that contains the ID number of each 5 km CATS L2O record.
4. **Day Night Flag** - This is an HDF metadata field that identifies the illumination condition (day or night) of each 5 km CATS L2O record.

### 5.7 Ancillary Data

There are two ancillary data parameters, other than those already listed from GMAO and the ISS, in the CATS L2O data products:

1. **Surface Type (all IFOVs)** - International Geosphere/Biosphere Programme (IGBP) classification of the surface type at each laser IFOV footprint. The IGBP surface types reported by CATS are the same as those used in the CERES/SARB surface map.
2. **DEM Surface Altitude (all IFOVs)** - This is the surface elevation at each laser IFOV footprint, in kilometers above local mean sea level, obtained from the 1x1 km GMTED2010 digital elevation map (DEM) (see [http://topotools.cr.usgs.gov/gmted\\_viewer/](http://topotools.cr.usgs.gov/gmted_viewer/) for details).

### 5.9 Quality Flags

#### *Feature Type Score (Provisional)*

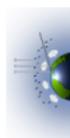
The feature type score provides a numerical confidence level for the classification of layers by the CATS cloud-aerosol discrimination (CAD) algorithm, reported for each atmospheric layer within a 5 km profile.

The CATS feature type score is similar to the CALIPSO CAD Score, but the CATS feature type score is an integer value ranging from -10 to 10 for each atmospheric layer (CALIPSO CAD Score ranges from -100 to 100). Table 8 illustrates that the sign of the feature type score identifies a layer as either cloud (positive) or aerosol (negative), while the magnitude of the feature type score represents the confidence in our classification. A value of 10 indicates complete confidence that the layer is a cloud, while -10 indicates the accurate classification of an aerosol layer. When the feature type score equals 0, the layer is just as likely to be a cloud as it is an aerosol, and thus the classification is undetermined. If the optical and physical properties of the layer are considered invalid for clouds and aerosols, these layers are assigned a feature type score of -999.

**Table 8.** The interpretation of the CATS Feature Type Score.

Layer Type	CAD Score
Cloud	1 to 10
Aerosol	-10 to -1
Undetermined	0
Bad Data	-999

The CATS CAD algorithm is a multidimensional probability density function (PDF) technique that is based on the CALIPSO algorithm. The PDFs were developed based on



CPL measurements obtained during over 11 field campaigns and 10 years. The attributes of the operational CATS PDFs depend on the CATS mode of operations. Measured cloud/aerosol properties available include layer altitudes and thickness, attenuated backscatter, depolarization, and attenuated backscatter color ratio (1064/532-nm). Ancillary data, such as mid-layer temperature can also be utilized. More details about the CATS CAD algorithm are available in the CATS ATBD.

***Cloud Phase Score (Provisional)***

The cloud phase score provides a numerical confidence level for the classification of cloud phase by the CATS cloud phase (CP) algorithm, reported for each atmospheric layer within a 5 km profile.

The CATS CP score is similar to the CATS Feature Type Score, but the sign of the CP score identifies a layer as either ice (positive) or liquid water (negative), while the magnitude of the CP score represents the confidence in our classification. A value of 10 indicates complete confidence that the layer is an ice cloud, while -10 indicates the accurate classification of a liquid water cloud. When the CP score equals 0, the layer is just as likely to be ice as it is liquid water, and thus the classification is undetermined. If the optical and physical properties of the layer are considered invalid for ice clouds and liquid water clouds, these layers are assigned a CP score of -999. For V1-05, the cloud phase score was updated to represent less confidence in layers with mid-layer temperatures between 0 and -20 C. More details about the CATS CP algorithm are available in the CATS ATBD.

***Opacity Flag***

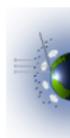
For CATS, a feature is considered opaque if it is the lowest layer detected in a 5 km profile and the earth’s surface is not detected. The opacity flag has a value of either 1 (opaque layer) or 0 (transparent layer). Please note that the opacity flag distinguishes when the backscatter signal becomes completely attenuated due to that feature.

***Lidar Ratio Selection Method***

This is an integer indicating a specific lidar ratio selection method, as defined by Table 9.

**Table 9.** Definition of CATS Lidar Ratio Selection Method Flag

Interpretation of Values
0 = generic default
1 = aerosol GEOS5 lookup table
2 = cloud lookup table
3 = 1064 lidar ratio used 532 OD (for ice clouds only)
4 = constrained result using clear zone just below layer
5 = constrained result with opaque layer
6 = lowered lidar ratio by a max of 15sr to reach layer bottom
7 = raised lidar ratio by a max of 15sr to reach layer bottom
8 = open slot (not used)
9 = missing



### ***Constrained Lidar Ratio Flag***

This is an integer indicating the constrained lidar ratio condition, as defined by Table 10.

**Table 10.** Definition of CATS Constrained Lidar Ratio Flag

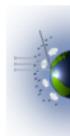
Interpretation of Values
0 = useful value using nominal “constrained” procedure
1 = useful value using opaque “constrained” procedure
2 = constrained lidar ratio outside thresholds
3 = below layer clear zone too small
4 = clear zone signal error > threshold
5 = Tp_sq < allowed min
6 = Tp_sq at or below 0.0
7 = useful 1064 lidar ratio using 532 OD (for ice clouds only)
8 = Tp_sq at or below 0.0 in opaque cloud conditions
9 = missing

### ***Extinction QC Flag***

This is an integer indicating a specific extinction condition, as defined by Table 11.

**Table 11.** Definition of CATS Extinction QC Flag

Interpretation of Values
-1=calculation not attempted
0 = layer extinction analysis nominal
1 = layer hit earth’s surface before layer bottom reached, adjusted bottom
2 = Tp_sq below min, lowering lidar ratio thru iteration process
3 = Tp_sq above max, raising lidar ratio thru iteration process
4 = # of iterations maxed out
5 = signal inside layer saturated before bottom
6 = layer is opaque, layer OD= -1
7 = open slot (not used)
8 = layer OD out of bounds (invalid) OD= -999.99
9 = layer OD invalid because final lidar ratio out of bounds



## 5.10 Metadata Parameters

Below is a list of metadata parameters not discussed in the previous sections:

Parameter
ProductID
Product_Version_Number
Product_Creation_Date
Product_Creator
Granule_Start_DateTime
Granule_Stop_DateTime
Granule_Production_DateTime
Granule_Start_Latitude
Granule_Start_Longitude
Granule_Stop_Latitude
Granule_Stop_Longitude
Granule_Start_RDM
Granule_Stop_RDM
Granule_Start_Record_Number
Granule_Stop_Record_Number
LIB_Input_Version_Number

## 6.0 Data Release Versions

CATS Level 2 Operational Layer Data Product			
Night/Day Granules layer products			
Release Date	Version	Data Date Range	Maturity Level
March 2016	1.03	3/25/2015 to Present (Mode 7.2)	Provisional
June 2016	1.04	3/25/2015 to Present (Mode 7.2)	Provisional
Aug. 2016	1.05	2/10/2015 to Present (All Modes)	Provisional

