CATS L2O Profile Products Quality Statements
Version Release: 2.01

01 Sept. 2017

1.0 Introduction

This document offers a general quality assessment of the CATS Level 2 Operational (L2O) Profile 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 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, many parameters in the L2O products are still assigned a product maturity level of provisional.

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

Beta:	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.
Provisional:	Limited comparisons with independent sources have been made and obvious artifacts fixed.
Validated Stage 1:	Uncertainties are estimated from independent measurements at selected locations and times.
Validated Stage 2:	Uncertainties are estimated from more widely distributed independent measurements.
Validated Stage 3:	Uncertainties are estimated from independent measurements representing global conditions.
External:	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 6.0 (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 0.5º to the left and one 0.5º 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.

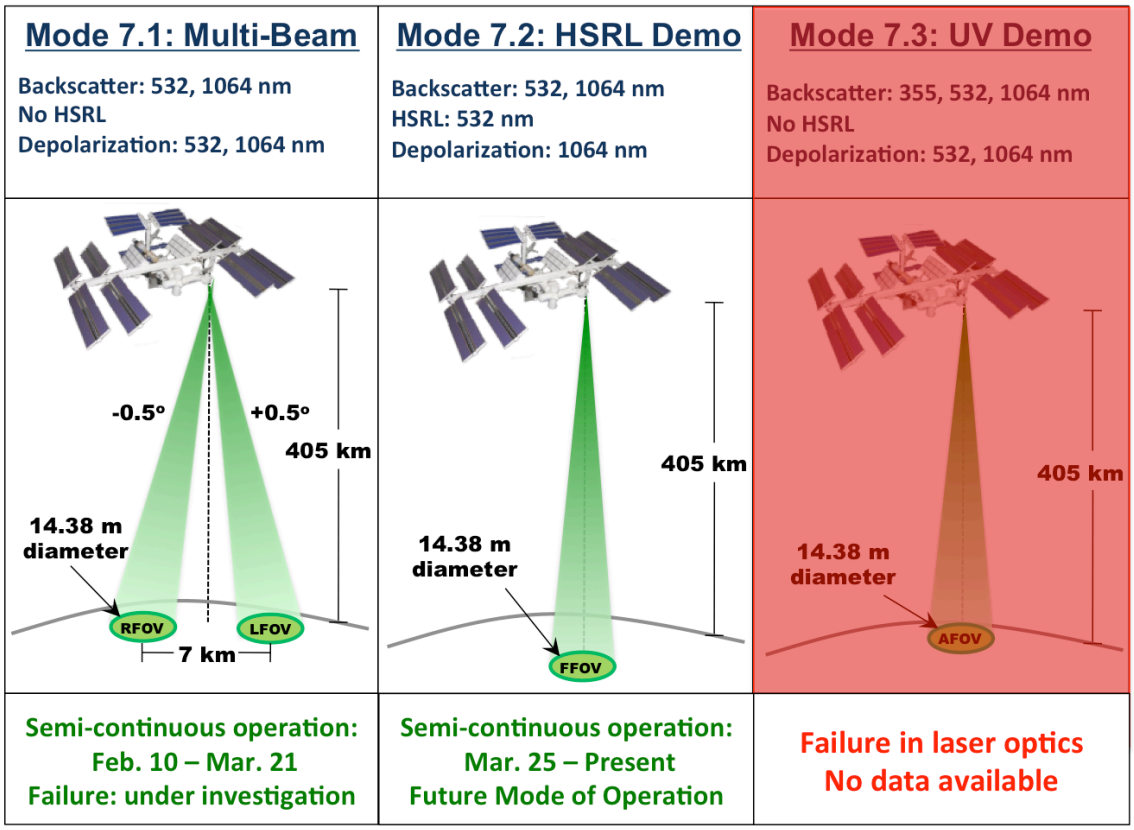

Figure 1. CATS three main Science Modes for operation, with details of each mode's capabilities and operational status.

5.0 CATS Level 2O Profile Data Products

The CATS L2O Profile 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 profiles of cloud and aerosol properties (i.e. extinction, particle backscatter). The main parameters reported in the CATS L2O data product are identification of atmospheric features and optical properties of these layers.

Shortly after the CATS Version 2-00 L2O data products for Mode 7.2 were released, three issues were identified in the Version 2-00 L2O data products for Mode 7.2 that have been updated in the L2O V2-01:

1. The new variable "Percent Opacity" was not populated with values in the L2O V2-00 data products. The L2O V2-01 data products now contain the correct values.

2. Aerosol layers in direct contact with water clouds were flagged as opaque and the AOD was reported as -1. This was due to an error in the CEAL (Cloud Embedded in Aerosol Layer) routine and is ONLY the case for aerosol layers in direct contact with water clouds.
3. No optical properties are reported for aerosol layers directly above water clouds in the L2O V2-00 data products because the CEAL routine did not properly sequence the layers by altitude when separating them. This is ONLY an issue for above cloud aerosol layers in direct contact with water clouds and does not impact the vertical feature mask in the L2O V2-00 data products.

Please note that if you are using the L2O V2-00 data for applications other than aerosol near clouds and atmospheric opacity, then you will not see any difference between L2O V2-00 and V2-01

5.1 Profiles of Optical Properties

Particulate Backscatter Coefficient (Validated Stage 1)

Particulate backscatter coefficients are reported for each 5 km profile and 60 m range bin in which atmospheric particulates (i.e., clouds or aerosols) were detected. Range bins in which no particulates were detected contain fill values 0.0) and bins where the backscatter could not be calculated are marked invalid (-999.9). Particulate backscatter coefficients have units of km^{-1} sr^{-1}. For Mode 7.2 data, only the 1064 nm particulate backscatter coefficients are reported, derived from the sum of the parallel and perpendicular backscatter measurements (i.e., $\beta_{1064\ total} = \beta_{1064\ parallel} + \beta_{1064\ perp}$). For Mode 7.1 data, both the 532 and 1064 nm particulate backscatter coefficients are reported, and both are derived from the sum of the parallel and perpendicular backscatter measurements. The CATS L1B backscatter calibrations, and thus accuracy of the attenuated total backscatter profiles, at both 532 and 1064 nm have been improved for CATS V2-08 L1B data. This improved accuracy propagates through many of the L2O data products, including the particulate backscatter coefficient profiles.

Particulate Backscatter Coefficient Uncertainty (Provisional)

For version 1.05, the uncertainty in the particulate total backscatter coefficient contained fill values (-999.9). For V2-00, the uncertainty in the particulate total backscatter coefficient is reported for each 5 km profile and 60 m range bin in which the appropriate particulates are detected. The values reported are absolute uncertainties, not relative, thus the units are identical to the units of the particulate backscatter coefficients (km^{-1} sr^{-1}).

Total Depolarization Ratio (Validated Stage 1)

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 linear volume total depolarization ratio is defined as the ratio of perpendicular total (Rayleigh plus particle) backscatter to parallel total 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).

Total depolarization ratios are reported for each 5 km profile and 60 m range bin in which atmospheric particulates (i.e., clouds or aerosols) were detected. Range bins in which no particulates were detected contain fill values (-999.9).

When the CATS laser begins operation after being turned off (for ISS activities, instrument reboots, etc.), the laser polarization is not pure. This results in inaccurate total depolarization ratios for several granules, depending on how long the laser was off, until the laser polarization stabilizes. CATS Version 2-00 L2O data includes a new Depolarization Quality Flag (Section 5.9) to notify users of granules with depolarization ratio values of poor quality.

Total Depolarization Ratio Uncertainty (TBD)

For version 1.05, the uncertainty in the total depolarization ratio contained fill values (-999.9). For V2-00, the uncertainty in the total depolarization ratio is reported for each 5 km profile and 60 m range bin in which the appropriate particulates are detected. The values reported are absolute uncertainties, not relative.

Extinction Coefficient (Validated Stage 1)

Particulate extinction coefficients are reported for each 5 km profile and 60 m range bin in which atmospheric particulates (i.e., clouds or aerosols) were detected. Range bins in which no particulates were detected contain fill values 0.0) and bins where the extinction could not be calculated are marked invalid (-999.9). Particulate extinction coefficients have units of km^{-1}. For Mode 7.2 data, only the 1064 nm particulate extinction coefficients are reported. For Mode 7.1 data, both the 532 and 1064 nm particulate extinction coefficients are reported. The particulate extinction coefficients are derived as outlined in the CATS ATBD.

The particulate extinction coefficients of all bins in which atmospheric clouds or aerosols are detected reported regardless of the lidar ratio selection method. Histograms of CATS L2O V1-05 cirrus optical depth exhibit a peak in the frequency distribution around a COD of 2.7 as a result of the CATS "modified default" lidar ratio algorithm. This issue is only apparent in CATS L2O V1-05 data when computing extinction and optical depth in cases where the lidar ratio was iteratively reduced in order to process to the bottom of the layer (Extinction QC_Flag = 2 [transparent] or 7 [opaque]). The algorithm was updated for CATS L2O V2-00 to change the amount that the lidar ratio gets modified from a fixed value of 0.5 to the current lidar ratio adjusted by a scale factor. The value of scale factor is related to the two-way transmittance of the last high quality bin and/or the relative progress through the layer of the last high quality bin, depending on the situation. For cases where the lidar ratio was increased in order to stay within transmittance bounds (Extinction QC Flag= 3), the interval of the iteration remains a fixed value of 0.5.

Extinction Coefficient Uncertainty (Provisional)

For version 1.05, the uncertainty in the particulate extinction coefficient contained fill values (-999.9). For V2-00, the uncertainty in the particulate extinction coefficient are reported for each 5 km profile and 60 m range bin in which the appropriate particulates are detected. The values reported are absolute uncertainties, not relative, thus the units are

identical to the units of the particulate extinction coefficient (km^{-1}).

Ice Water Content (Validated Stage 1)
Ice water content (IWC) is reported for each 5 km profile and 60 m range bin in which ice clouds were detected. Range bins in which no ice clouds were detected contain fill values (0.0) and bins where the ice water content could not be calculated are marked invalid (-999.9). IWC has units of gm^{-3}. For Mode 7.2 data, only the 1064 nm IWC is reported. For Mode 7.1 data, both the 532 and 1064 nm IWC is reported. The IWC is calculated as a parameterization function of the CATS ice particle extinction retrievals as outlined in the CATS ATBD. Thus the changes discussed in the Extinction Coefficient Section will improve the accuracy of the IWC retrievals.

Ice Water Content Uncertainty (Provisional)
For version 1.05, the uncertainty in the IWC contained fill values (-999.9). For V2-00, the uncertainty in the IWC is reported for each 5 km profile and 60 m range bin in which ice particles are detected. The values reported are absolute uncertainties, not relative, thus the units are identical to the units of the IWC (gm^{-3}).

Multiple Scattering Factor (Provisional)
The multiple scattering factor, for each 5 km profile and 60 m range bin in which atmospheric particulates (i.e., clouds or aerosols) were detected, are reported at each wavelength according to layer type and subtype. Possible 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 ATBD provides a discussion of multiple scattering factors for ice clouds and several aerosol types.

For CATS, 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.

Given the improvements in the quality of the CATS backscatter data, the CATS layer effective multiple scattering factor for ice clouds was updated in V2-00 products to 0.65 (Mode 7.2). This change will also impact the retrievals of extinction and feature optical depth. The values for Mode 7.1 remained the same (0.423 at 1064 nm and 0.545 at 532 nm).

5.2 Profiles of Feature Type

Feature Type (Validated Stage 1)
For each atmospheric layer, an assessment of the feature type (e.g., cloud vs. aerosol) is reported for each 5 km profile and 60 m range bin in which atmospheric particulate layers were detected. Range bins in which no layers were detected contain fill values (-999). 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.

Based on statistical comparisons of CATS L2O V1-05 cloud and aerosol detection frequencies with CALIPSO, and aerosol type with GEOS-5, it was determined that the CATS Cloud-Aerosol Discrimination (CAD) algorithm was incorrectly classifying liquid water clouds as lofted dust mixture or smoke aerosols. This is partly due to enhanced depolarization ratios within water clouds due to multiple scattering, and an inability to utilize the backscatter color ratio in the CAD algorithm due to the noisy 532 nm backscatter data. Since true lofted dust and smoke layers tend to have large horizontal extent, a horizontal persistence test was added to the CATS Cloud-Aerosol Discrimination (CAD) algorithm for L2O V2-00 to identify liquid water clouds with enhanced depolarization ratios of small horizontal extent and correctly classify them as clouds. The result is a reduction of dust mixture and smoke aerosol detection over remote parts of the Earth's oceans in CATS L2O V2-00 data.

Table 2. Definitions of the CATS Feature Type Parameter

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

Cloud Phase (Validated Stage 1)
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 for each 5 km profile and 60 m range bin in which cloud layers were detected. Range bins in which no cloud layers were detected contain fill values (-999). 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. Statistical comparisons of CATS V1-05 ice and water cloud detection frequencies with CALIPSO V4.1 data yield very

similar results.

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 (Validated Stage 1)

For each atmospheric layer defined as an aerosol in the feature type parameter, an assessment of the aerosol type is reported for each 5 km profile and 60 m range bin in which atmospheric particulate layers were detected. Range bins in which no aerosol layers were detected contain fill values (-999). 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 ($SO4^{2-}$), nitrates ($NO3^{-}$), OC, and Ammonium ($NH4^{+}$). 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 7 aerosol types, the aerosol layer is interpreted as "invalid".

The CATS L2O V1-05 aerosol typing algorithm was unable to classify polluted continental aerosols over water, as the algorithm required surface type and layer elevation and thickness criteria for discriminating spherical smoke and polluted continental aerosols owing to similarity between backscatter and depolarization properties.

Therefore, in the V2-00 aerosol typing algorithm, simulated aerosols from the NASA Goddard Earth Observing System version 5 (GEOS-5) model are incorporated to help discriminate smoke from polluted continental aerosols when CATS observations (surface type, layer elevation, and layer thickness) alone could not identify an aerosol type for spherical aerosols. Aerosols in GEOS-5 are constrained by the utilization of the MODIS derived Quick Fire Emission Database (QFED) for carbonaceous aerosols, the use of advanced emission inventories of nitrates and sulfates, and through the assimilation of MODIS Aerosol Optical Thickness (AOT) for constraining the aerosol loading.

The CATS aerosol typing routine for L2O V2-00 now employs the GEOS-5 aerosol speciation information sampled along the ISS track to assist the algorithm in differentiating smoke aerosols from polluted continental aerosols over land only when GEOS-5 simulates an aerosol layer within the detection limits of CATS at the exact altitude of the CATS observed aerosol layer. The result is an increase of polluted continental aerosol detection, particularly over water, and a decrease in smoke aerosol detection over highly populated regions of the Earth (China, Europe, Eastern U.S.) in CATS L2O V2-00 data.

Comparing the frequency of occurrence of aerosol type between CATS and CALIPSO, it was determined that CATS had a high bias in smoke layers in regions where smoke is known to mix with dust (e.g. south Asia). Therefore, CATS depolarization-based thresholds for classifying dust and dust mixture were reduced from 0.30 and 0.20 to 0.25 and 0.15, respectively.

Superficial "striping" is also visible in the CATS L2O V1-05 aerosol type browse images for horizontally homogeneous dust and smoke aerosol layers. Horizontal persistence tests were added to the CATS aerosol typing algorithm to avoid this "striping" and report aerosol types that are more consistent with the profiles in an 80 km range surrounding a specific 5 km CATS L2O V2-00 profile.

Sky Condition (Validated Stage 1)

For each 5 km profile, an assessment of the sky condition (e.g., cloudy vs. clear) of the column is reported for each profile. 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)

Horizontal Resolution of Layer Detection (Provisional)

The horizontal resolution an atmospheric layer was detected at is reported for each atmospheric layer within a 5 km profile. The values correspond to the horizontal

resolution needed to detect that specific layer. There are only three values that can be reported:

- 0 = a layer was not detected
- 5 = the layer was detected at 5 km
- 60 = the layer was detected at 60 km

Layers detected at 60 km are common in the CATS L2O V2-00 daytime data, but rarely reported in the nighttime data, as these layers are typically detected at 5 km.

Percent Opacity (Provisional)

The quantification of opacity is reported for each 5 km CATS L2O V2-00 profile. The values correspond to the fraction of the total number of L1B 350 m profiles that make up that L2O 5 km profile in which no surface return was detected. For CATS, a profile is considered opaque if no surface return is detected in all L1B 350 m profiles that make up that L2O 5 km profile. The opacity flag has a value of either 1 (opaque profile) or 0 (transparent profile). Thus, the percent opacity will be 1.0 for opaque profiles, and some value less than 1.0 for transparent profiles. Please note that the opacity flag distinguishes when the backscatter signal becomes completely attenuated due to that feature.

5.3 Column Optical Properties

Column Optical Depth (1064 nm – Validated Stage 1, 532 nm - Provisional)
Cloud Optical Depth (1064 nm – Validated Stage 1, 532 nm - Provisional)
Aerosol Optical Depth (1064 nm – Validated Stage 1, 532 nm - 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 profiles, reported in these profile products. Since the column optical depths are a column integral product, any large uncertainties or poor extinction retrievals from layers within the column (i.e. clouds or aerosols) will propagate downward and may impact the quality of all the column optical depths. Therefore, users are strongly encouraged to use the column optical depth uncertainties, extinction QC flag, and feature type score to assess the quality of the column optical depths.

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

1. CATS is only capable of penetrating to the surface if the total column optical depth is less than ~4. If the column is opaque to the lidar, then the reported column optical depths are set to -1.0 because the lidar is only measuring the apparent base of the lowest feature observed, not the true optical depth of the column.
2. The extinction QC values in the column should be examined to determine if any of 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 impact the quality of the column optical depths. For example, if the top-most

feature in the column has an unknown cloud phase, it is possible that the assigned lidar ratio may be incorrect, impacting the extinction retrieval for that feature and all the data below that feature.

The optical depth of all atmospheric particulate layers, clouds, and aerosol throughout the column are reported for each 5 km profile, regardless of the lidar ratio selection method. Histograms of CATS L2O V1-05 cirrus optical depth exhibit a peak in the frequency distribution around a COD of 2.7 as a result of the CATS "modified default" lidar ratio algorithm. This issue is only apparent in CATS L2O V1-05 data when computing extinction and optical depth in cases where the lidar ratio was iteratively reduced in order to process to the bottom of the layer (Extinction QC_Flag = 2 [transparent] or 7 [opaque]). The algorithm was updated for CATS L2O V2-00 to change the amount that the lidar ratio gets modified from a fixed value of 0.5 to the current lidar ratio adjusted by a scale factor. The value of scale factor is related to the two-way transmittance of the last high quality bin and/or the relative progress through the layer of the last high quality bin, depending on the situation. For cases where the lidar ratio was increased in order to stay within transmittance bounds (Extinction QC Flag= 3), the interval of the iteration remains a fixed value of 0.5.

Column Optical Depth Uncertainty (Provisional)
Cloud Optical Depth Uncertainty (Provisional)
Aerosol Optical Depth Uncertainty (Provisional)
There are three main sources (ignoring multiple scattering) of the uncertainty in the column 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 column optical depth contains fill values (-999.9). For V2-00, the uncertainty in the column optical depths is reported for each 5 km profile. The values reported are absolute uncertainties, not relative.

5.4 Meteorological Data (External)

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. These parameters, listed below, are output in the Level 2O files for each 5 km profile and for each 533 CATS vertical bins:

1. **Pressure Profile**- Pressure, in millibars, reported for each 5 km L2O profile at the 533 CATS altitudes recorded in the Bin Altitude Array field. Pressure values are

interpolated from the ancillary meteorological data provided by the GMAO.

2. **Relative Humidity Profile** - Relative humidity reported for each 5 km L2O profile at the 533 CATS altitudes recorded in the Bin Altitude Array field. Relative humidity values are interpolated from the ancillary meteorological data provided by the GMAO.
3. **Surface Wind Velocity** - Surface wind velocity, in meters per second, are reported for each 5 km L2O profile as eastward (zonal) and northward (meridional) surface wind stress. Surface wind speed values are interpolated from the ancillary meteorological data provided by the GMAO.
4. **Wind Velocity 10 m**- wind velocity 10 meters above the earth's surface, in meters per second, are reported for each 5 km L2O profile as eastward (zonal) and northward (meridional) surface wind stress. Wind velocity values are interpolated from the ancillary meteorological data provided by the GMAO.
5. **Temperature Profile** - Temperature, in degrees C, reported for each 5 km L2O profile at the 533 CATS altitudes recorded in the Bin Altitude Array field. Temperature values are interpolated from the ancillary meteorological data provided by the GMAO.
6. **Tropopause Height** - Tropopause height, in kilometers, reported for each 5 km L2O profile. Tropopause height values are interpolated from the ancillary meteorological data provided by the GMAO.
7. **Tropopause Temperature** - Tropopause temperature, in degrees C, reported for each 5 km L2O profile. Tropopause temperature values are interpolated from the ancillary meteorological data provided by the GMAO.
8. **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.
9. **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.

5.5 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. For more details about improvements to the CATS geolocation algorithms, please see the CATS L1B Products Quality Statement for Version 2.08. 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.

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 (DDMMYYY) 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.

5.8 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 Mean Elevation (all IFOVs)** - This is the surface elevation at each laser IFOV footprint, in kilometers above local mean sea level. The DEM for version prior to V2-08 were obtained from the 1x1 km GMTED2010 digital elevation map (DEM) (see **http://topotools.cr.usgs.gov/gmted_viewer/** for details). The CATS V2-08 L1B data release includes a new Digital Elevation Model (DEM) from JPL created for CloudSat and CALIPSO. The DEM has a horizontal resolution of ~500 m. For CATS L1B V2-08, the DEM from JPL is interpolated and reported in the data products with a horizontal resolution of 350 m.

5.9 Quality Flags

Depolarization Quality Flag (Provisional)

CATS V1-05 1064 nm depolarization ratios within cirrus clouds for Mode 7.2 yielded more variability than expected compared to CPL 1064 nm and CALIOP 532 nm data. When the CATS laser begins operation after being turned off (for ISS activities, instrument reboots, etc.), the laser polarization is not pure. This results in inaccurate depolarization values for several granules, depending on how long the laser was off, until the laser polarization stabilizes. CATS Version 2-00 L2O data includes a new Depolarization Quality Flag to notify users of granules with depolarization ratio values of poor quality (Table 6). Granules with suspect depolarization values are now indicated with values of 1 or 2 in the Depol_Quality_Flag variable and users should only use granules with Depol_Quality_Flag = 0 for studies of particle sphericity. The Mode 7.1 laser does appear to suffer from a similar issue, but not to the same extent. That laser stabilizes more quickly.

Table 6. Definitions of the CATS Depolarization Quality Flag

Interpretation of Values
0 = Valid, good quality depolarization data
1 = Depolarization ratio biased low due to recent laser turn on
2 = Depolarization ratio biased high as laser stabilizes

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. For each atmospheric layer, the feature type score is reported for each 5 km profile and 60 m range bin in which atmospheric particulate layers were detected. Range bins in which no layers were detected contain fill values (-999).

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 7 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 7. 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. For each cloud layer, the CP score is reported for each 5 km profile and 60 m range bin in which clouds were detected. Range bins in which no clouds were detected contain fill values (-999).

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. More details about the CATS CP algorithm are available in the CATS ATBD. 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.

Extinction QC Flag

This is an integer indicating a specific extinction condition, as defined by Table 8.

Table 8. Definition of CATS Extinction QC Flag.

Interpretation of Values
-1 = calculation not attempted 0 = non-opaque layer extinction analysis nominal 1 = layer hit earth's surface before layer bottom reached, adjusted bottom 2 = lowering lidar ratio thru iteration process successful 3 = raising lidar ratio thru iteration process successful 4 = # of iterations maxed out, analysis stopped 5 = signal inside layer saturated before bottom, analysis stopped 6 = layer is opaque, layer OD= -1, initial lidar ratio accepted 7 = layer is opaque, layer OD= -1, lidar ratio iteration successful 8 = layer OD out of bounds (invalid) OD= -999.9 9 = layer analysis 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
L1B_Input_Version_Number

6.0 Data Release Versions

CATS Level 2 Operational Profile Data Product			
Night/Day Granules profile 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
July 2017	2.00	3/25/2015 to Present (All Modes)	Validated Stage 1
Sept. 2017	2.01	2/10/2015 to Present (All Modes)	Validated Stage 1