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CloudSat Project

A NASA Earth System Science Pathfinder Mission

Level 1 B CPR Process Description and Interface Control Document

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Prepared by:

L. Li, CPR Level 1B Processing Engineer

S. Durden, CPR System Engineer

S. Tanelli, CPR System Engineer

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109-8099

Approvals

_________________________Date________
Deborah Vane
Deputy Project Scientist

_________________________Date________
Graeme Stephens
Project Scientist

_________________________Date________
Donald Reinke
Data Processing Center Lead Engineer

_________________________Date________
Jay Mace
Level 2 Geometrical Profile Algorithm Developer

Questions concerning the document and proposed changes shall be addressed to

Steve Durden
818-354-4719
sdurden@jpl.nasa.gov

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1. Introduction

1.1. Overview

CPR measures the backscattered power as a function of distance from the radar. The backscattered power is sampled every ~240 m; there are 125 range bins, for a total window of 30 km. The raw, Level 0 data is converted to calibrated Level 1B data using pre-launch and in-flight calibration measurements. This document presents the calibration theory and defines the Level 0 data contents, the Level 1B contents, and the conversion algorithm.

1.2. Applicable Documents

CloudSat CPR Level 3 Functional Requirements (describes the radar requirements)

*CloudSat Profiling Radar Digital Subsystem High Level Design Docu*ment (contains detailed description of the raw radar data and in-flight calibration measurements)

CPR Calibration and Validation Plan (describes the in-flight calibration approach in more detail)

CPR Functional and Performance Test Plan (describes the approach for making the pre-launch measurements that are used for calibration in Level 1 B processing)

CloudSat Level 3 Science Algorithms Requirements (describes general requirements to be met by the CloudSat data processing algorithms)

2. Algorithm Theoretical Basis

The received signal from the Cloudsat CPR is found from the weather radar equation (e.g., Meneghini and Kozu, 1990):

$$Pr = \frac{Pt\ \lambda^2 G^2 \Delta \Omega \eta}{(4\pi)^3 r^2}$$

where

- Pr is the received power at the antenna port
- Pt is the radiated power to the antenna port
- λ is the wavelength
- G is the antenna gain
- *r* is the range from CPR to the cloud or surface
- Δ is the pulse integral
- Ω is the integral of the normalized two-way antenna pattern
- η is the backscatter cross section per unit volume (reflectivity)

The calibration problem is to find the reflectivity given the radar measurements. The above equation can be re-arranged for η:

$$\eta = \frac{P_r}{P_t} C r^2 \qquad (1)$$

where

$$C = \frac{(4\pi)^3}{\lambda^2 G^2 \Delta\Omega}$$

Thus, the radar can be used to measure η if P_r, P_t, C, and *r* are known. The calibration constant C is determined from pre-launch measurements of the radar. The antenna gain and Ω are found from antenna measurements. Δ is found from laboratory measurements of the received pulse shape. The wavelength is also known from pre-launch measurements. Since C is known from pre-launch measurements it may be a fixed constant or it may have a temperature dependence and be calculated using in-flight temperature telemetry. The range *r* can be calculated from radar timing considerations. Specifically, one needs the time of the range bin within the data window (its range bin number), the start time of the data window, the number of pulses in flight, and radar propagation delays. These are all known from laboratory measurements, from the radar configuration, and from the data itself. The ratio P_r/P_t can be determined from the output of the radar receiver only if the transmitted power and the receiver gain g are known; the approach for calculating P_r and P_t is described below. Once the received power is found, the system noise floor must be estimated and subtracted to get the true received power.

This will be done operationally by using the top 30 km of the data window. The radar reflectivity, once computed, can be converted to reflectivity factor using

$$Z = \frac{\lambda^4 \eta}{\pi^5 |K|^2} 10^{18}$$

where Z is the reflectivity factor in mm^6/m^3 and $|K|^2$ is a function of the dielectric constant and is around 0.75 at 94 GHz. Z is converted to dBZ by taking 10 times the base-10 logarithm.

The transmitted power Pt at the antenna depends on the performance of the high power amplifier, which may vary over time. Therefore, a scheme has been developed for in-flight monitoring of the transmit power. Specifically, CPR will have a peak power detector, consisting of a detector diode and amplifier. The output of this calibration peak detector can be converted to the actual transmit power Pt at the antenna using a pre-launch characterization of $\mathbf{L_{cal}}$, a coupling constant relating the power detector diode output value to the transmit power. Pt at the antenna input is calculated from

$$Pt = Pt0\ L_{cal}$$

Where $\mathbf{L_{cal}}$ is a function of detector diode temperature and Pt0 is the power at the detector.

The receiver output power, Pr0 can be converted to Pr if the receiver gain is known. The receiver gain is measured in-flight by injecting power from a noise diode into the receiver and measuring the receiver output power Pnd0. By comparing Pnd0 with the known noise diode power measured prior to launch, we estimate the receiver gain g_r. There is a loss $\mathbf{L_r}$ between the antenna and receiver input which is also measured prior to launch. Using this loss and the estimated receiver gain, the received power is:

$$Pr = Pr0\ L_r\ /\ g_r$$

In summary, in flight-measurements of the noise diode output from the receiver and the calibration power detector output, along with pre-launch system measurements will allow calibration of the received backscatter from clouds.

3. Algorithm Inputs

3.1. CloudSat

3.1.1. CloudSat Level 0 CPR Science Data

The CPR digital system will average the received power at each range bin and will collect various engineering and housekeeping data. These data will be written to the spacecraft recorders and downlinked. The data is formatted as 0.16 s blocks of radar data, each preceded by a header. This format is defined in the Digital Subsystem High-Level Design Document. A block with header would have the following format:

```
unsigned char block_start_ID[4];
unsigned char sec[2]; /* seconds since last VTCW update from spacecraft */
unsigned char time_code[5];    /* VTCW time code */
unsigned char msec[2];     /* millisec since last one second pulse */
unsigned char pri;    /* pulse repetition interval (1/PRF) */
unsigned char cal;       /* calibration source (nd, load, or antenna) */
unsigned char data_window_delay;  /* tx pulse to rx window (1.6 us units) */
unsigned char echos_in_flight;
unsigned char pulses_transmitted[2];  /* no. of pulses in the .16 s block */
unsigned char mode;
unsigned char pulse_width;    /* width of xmit pulse (3.1 – 3.8 us) */
unsigned char grid;          /* grid enable setup */
unsigned char pll_lock;   /* phase-locked loop lock status */
unsigned char telemetry[40];
unsigned char envelope[16];
unsigned char motor[4];
unsigned char echo[NECHO];   /* summed recv'd signals, first is cal_data */
unsigned char frame[2];   /* frame counter */
unsigned char crc[2];    /* cyclic redundancy code */
```

A file of Level 0 data available for processing would have some number of data blocks, where each block would have a format like that just presented. The Level 0 CPR data should be nearly identical to the raw data stream output from the radar; CIRA will removed duplicate packets from the raw data to crate Level 0. The cyclic redundancy code (CRC) in each block, or frame, is used to determine whether there were bit errors in the downlink for that particular frame.

3.1.2. CloudSat Level 1 A Auxiliary Data

Level 1 B processing requires the following data for geolocation and for assessment of spacecraft health during data acquisition:

Level 1A Auxiliary Data

NAME	SIZE (Bytes)	FORMAT	DESCRIPTION	VALUES	SOURCE
Data Status Bit Fields	1	1 bit 1 bit 1 bit 1 bit 1 bit 1 bit 1 bit 1 bit	Missing Frame SOH Missing GPS data valid 1PPS Lost Star tracker 1 Star tracker 2 Coast	0=false or 1=true 0=false or 1=true 0=false or 1=true 0=false or 1=true 0=off or 1=on 0=off or 1=on 0=false or 1=true	SOH DEM
Data status fixed frame table target ID	1	1-byte unsigned integer	Value indicates spacecraft pointing status	0,16=nominal CPR operation	SOH
UTC Time	9	2-byte integer 2-byte integer 1-byte integer 1-byte integer 1-byte integer 2-byte integer	Year (4-digits) Day of Year Hour Minute Second Millisecond	0 – 9999 1 – 366 0 – 23 0 – 59 0 – 59 0 – 999	SOH
Geodetic Latitude	4	float	The geodetic latitude of the boresight[1]/geoid intersection	-90.0 – 90.0	Definitive Ephemeris
Geodetic Longitude	4	float	The geodetic longitude of the boresight/geoid intersection	-180.0 – 180.0	Definitive Ephemeris
Geodetic Range	4	float	Range from spacecraft to CPR boresight intercept with the Earth Ellipsoid (km)	Approx. 705-735	Definitive Ephemeris
Elevation	2	integer	Surface elevation at geodetic lat/lon (m)	0 – 8850	DEM

[1]The radar boresight is the center of the radar beam.

3.2. Ancillary (Non-CloudSat)

This algorithm does not require ancillary data.

3.3. Control and Calibration

The following data describe the radar system. It contains measured radar parameters. The contents of this file are static; i.e., they do not change over time, unless the CPR team changes them based on calibration experiments. This information is placed in the Ray header so that data users will know what radar parameters were used in calibration.

CPR Level 1B Calibration Data

NAME/SIZE	FORMAT	DESCRIPTION
Cal_version	4-byte float	Version of the pre-launch calibration table
Frequency	4-byte float	Pre-launch measurements of radar frequency
Spatial_avg	4-byte float	Spatial average
Range_bin_size	4-byte float	Range bin size
Range_delay	4-byte float	Range delay (delay through receiver)
Alpha	4-byte float	Surface tracking parameters
Beta	4-byte float	Surface tracking parameters
Nmax	4-byte float	Surface tracking parameters
DPmax	4-byte float	Surface tracking parameters
Range_res(7)	4-byte float	Range resolution vs. pulse width
Antcoef(4)	4-byte float	Antenna gains and solid angle
Tempcoef(3)	4-byte float	dn to degC conversion
Tdsscoef(3)	4-byte float	dn to degC conversion
Tpkcoef(3)	4-byte float	dn to degC conversion
Tlnacoef(3)	4-byte float	dn to degC conversion
Tnsdcoef(3)	4-byte float	dn to degC conversion
Vpkcoef(3)	4-byte float	Detector dn to voltage conversion
Lrcoef(3)	4-byte float	coefs to get lr vs. temp
Pndcoef(3)	4-byte float	coefs to get pnd vs. temp
Lndcoef(3)	4-byte float	coefs to get Lnd vs. temp
Lcalcoef(3)	4-byte float	coefs to get Lcal vs. temp
Dsscoef(3)	4-byte float	coefs to get dssgain vs. temp
Nbcoef(3)	4-byte float	coefs to get noise-band vs.temp
Ocpcoef(3)	4-byte float	coefs to get output compression pt vs. temp
Adjcoef(3)	4-byte float	coefs 2 adjust cal-const vs.temp
Alut(7)	4-byte float	coefs to get LUT corrections for nonlinearity
Coefpk(6)	4-byte float	pk vs voltage and temp
Gaincoef(2)	4-byte float	rx nonlinearity

4. *Algorithm Summary*

To summarize, the steps in producing calibrated CPR data are:

- estimate noise diode power from data
- convert the accumulated echo values to power (sigma plus noise) in Watts
- convert the power detector measurements to transmit power in Watts
- estimate the current value of the calibration constant using CPR telemetry
- estimate noise floor mean and standard deviation from the CPR data
- estimate total time (and thus, range) to start of data window
- determine surface bin from radar profile
- compare surface bin estimate with prediction from AUX data and correct if necessary (new in 5.3)
- determine best match of the profile of backscattered power around the surface with stored high-resolution ocean surface response (new in 5.3)
- determine surface power after correction for the range-sampling bias (new in 5.3)
- estimate surface $\sigma 0$ from corrected surface power (Kozu et al. 2000)
- perform error checking and set data quality flags

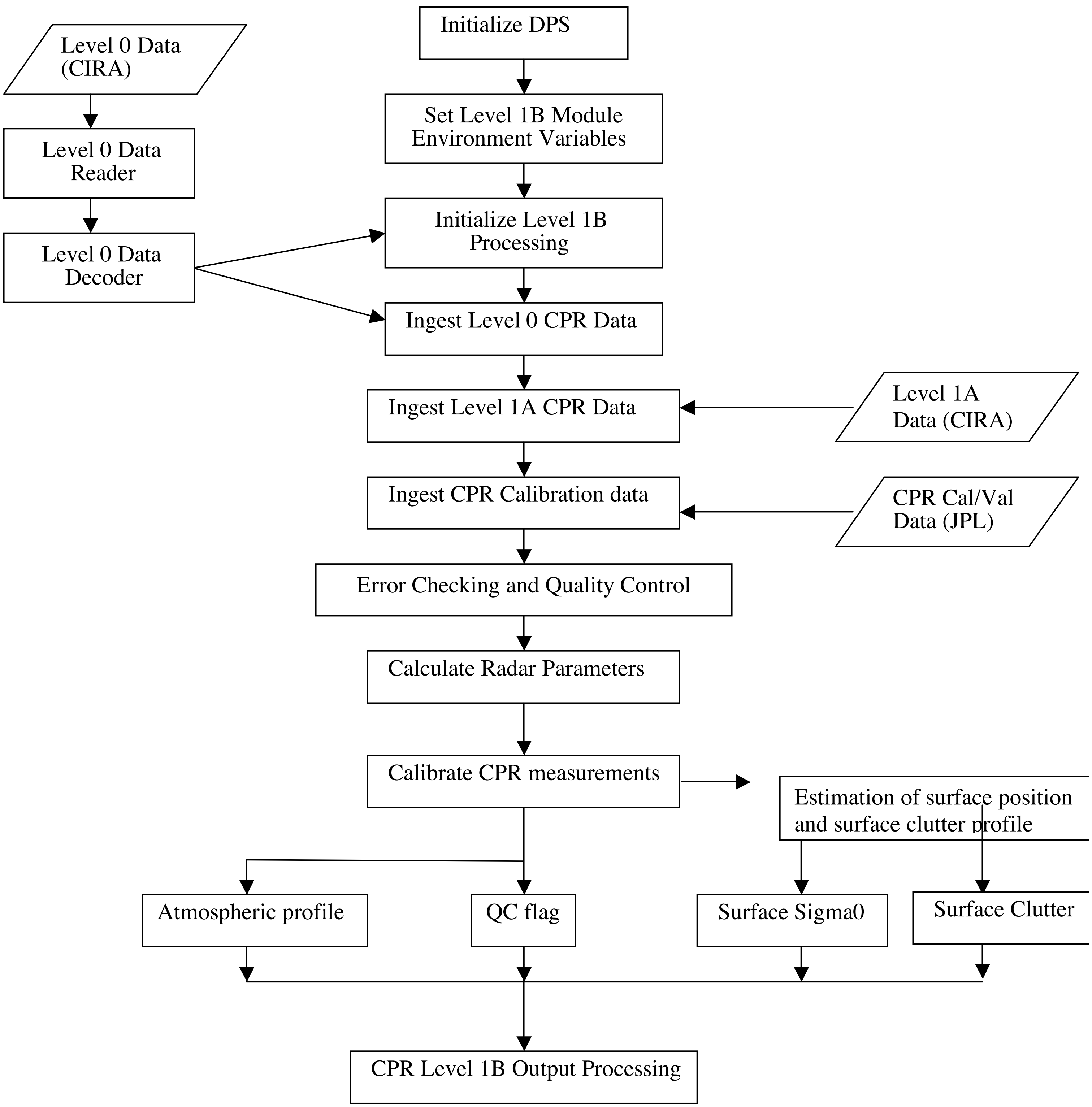
The CPR Level 1 B algorithm is written in Fortran 90 and designed to run under CIRA's CORE software. The software requires the following inputs:

- Level 0 CPR data file
- Level 1 A ancillary data file produced by CIRA, containing geolocation and spacecraft state-of-health data
- CPR parameter file specifying pre-launch calibration measurements (with updates using post-launch cal/val results)

Outputs:

- Level 1 B CPR data in HDF-EOS format in memory (under CORE the CPR Level 1 B data is kept in memory as an HDF structure. CORE writes the Level 1 B data to a file, after including metadata).

CloudSat Level 1B Algorithm Flowchart



5. Data Product Output Format

5.1. Format Overview

The CPR Level 1 B processing calculates and stores all the quantities needed for calculation of reflectivity: Pr, Pt, C, range, and noise floor. Actual calculation of reflectivity is left to Level 2 algorithms. This choice was made to allow the Level 2 algorithms to use alternate calculations of the noise if desired.

The format chosen for CPR Level 1 B data is somewhat similar to that for Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) (TSDIS, 1999), although the CPR format is simpler since there is no scanning. The format consists of metadata, which describes the data characteristics, and swath data, which includes the actual calibrated power measurements at each range bin, as well as other information. The following schematic illustrates how CPR data is formatted using HDF EOS. The variable nray is the number of radar blocks (frames, rays) in a granule. Each block is a 0.16 s average of radar data. Some of the data are slowly varying or constant (e.g., RayHeader variables, Roll_offset, Pitch_offset) and are scalar values. There is one value of scalar variables per granule rather than one per block.

Initially, it was planned for CPR to point at exactly nadir, so that spacecraft lat/lon would be identical with the lat/lon of the CPR footprint center. However, from launch until 7 July 2006, CPR was pointed forward by 1.7 degrees and to the right by 0.13 degrees (approximate). CPR pointing was moved to nadir on 7 July 2006. It was observed that surface return increased dramatically, due to presence of specular scattering. This was reduced by moving the pointing forward by 0.16 degrees. Hence, nadir-pointing occurred only from 7 July – 15 August 2006. As a result, the lat/lon are now corrected for off-nadir pointing. Also, the magnitude of the pointing is included in the L1B product as offset angles from nadir.

CPR Level 1B HDF-EOS Data Structure

File	HDF-EOS version		
	Structural metadata		
	1B-CPR swath	Geolocation fields	Profile_time
			UTC_start
			TAI_start
			Latitude
			Longitude
			Range_to_intercept
			DEM_elevation
			Range_to_first_bin
			RayHeader_RangeBinSize
			Pitch_offset
			Roll_offset
		Data fields	Data_quality
			Data_status
			Data_targetID
			Navigation_land_sea_flag
			RayHeader_lambda
			RayHeader_SpatAvg
			RayHeader_CalVers
			RayStatus_validity
			RayStatus_PRI
			RayStatus_pulseWidth
			RayStatus_pulsesTx
			RayStatus_antennaNoise
			TransmitPower
			TransmitPower_Avg
			RadarCoefficient
			NoiseFloorPowers
			ReceivedEchoPowers
			Sigma-Zero
			SurfaceBinNumber
			SurfaceBinNumber_Fraction
			FlatSurfaceClutter
			SurfaceClutter_Index
		Swath attributes	CloudSat metadata
			1B-CPR metadata
			1B-CPR Field attributes (scale factor, offset, long name, units, fill value, valid range)

5.2. CPR Level 1B HDF-EOS Data Contents

The following lists the contents of the CPR Level 1 B HDF files.

Profile time (array size nray, 4 byte float, range: 0 to $6x10^3$, missing value: none): seconds since start of granule.

UTC_start (scalar, 4 byte float, range: 0 to 86400, missing value: none): UTC seconds since 00:00Z in first profile of granule.

TAI_start (scalar, 8 byte float, range: 0 to 6e8, missing value: none): contains the International Atomic Time (TAI time) as the number of seconds since January 1, 1993 00:00:00Z.

Navigation data (each are size nray)

Name	Format	Description
Latitude (range: -90 degrees to 90 degrees, missing value: none)	4-byte float	The latitude (degrees) of the boresight/geoid intersection.
Longitude (range: -180 degrees to 180 degrees, missing value: none)	4-byte float	The geodetic longitude (degrees) of the boresight/geoid intersection.
Range_to_intercept (range 600 km to 800 km, missing value: none)	4-byte float	Range from spacecraft to CPR boresight intercept with the Earth Ellipsoid (km)
DEM_elevation (range: -9999 to 8850 m, missing value: 9999)	2-byte integer	Surface elevation at geodetic lat/lon (m) above the Earth Ellipsoid. –9999 indicates ocean, 9999 indicates an error in its calculation.

The geodetic latitude and longitude are represented as floating point decimal degrees. Latitude is positive north, negative south. Longitude is positive east, negative west. A point on the 180^{th} meridian is assigned to the western hemisphere.

Range to First Bin (Range_to_first_bin) (r_0, m) (array size nray, 4-byte float, range: 650000 to 740000, missing value: -9999):
Range to first bin is the distance between the satellite and the starting bin number of the ray. The range to jth bin can be calculated with

$$r_j = r_0 + (j-1) * Range\_bin\_size$$

where j=1 is the first range bin. r_0 is calculated as ((EIF-1)*PRI+DWD) *Range_bin_size-range_delay. EIF is the number of echoes in flight, PRI is the pulse repetition interval, and DWD is the data window delay. **Note that if the CPR data is plotted without regard to this parameter, jumps in the data will be visible**. These are produced by changes in the radar timing parameters as often as every 30 seconds to adjust for changing altitude. Prior to plotting, each ray must be adjusted according to r_0. To do so, first calculate the range bin that corresponds to the geoid using

geoid_bin=(Range_to_intercept - Range_to_first_bin)/239.83

The next step is to compute the offset of the geoid bin to some common reference bin number, say 105:

offset=geoid_bin-105

Finally, when computing reflectivity from received power, each ray is offset, as in the following pseudo code example.

```
for j=0ul, nray-1
for i=0, nbin-1
    temp2(i+20-offset(j),j) = (rxpower(i,j))
      /powert(j)*Rcoef(j)*temp1*(Range_to_first_bin(j)+i*239.830)^2
end
end
```

RayHeader_RangeBinSize (scalar, 4 byte float, typical value: 239.8 m, missing value: -9999) size of CPR range bin in meters.

Pitch_offset (scalar, 4 byte float, range: -90 to 90): along track pointing offset of CPR, with positive corresponding to forward pointing.

Roll_offset (scalar, 4 byte float, range: -90 to 90): across track pointing offset of CPR, with positive corresponding to right pointing.

Data_quality (array size nray, 1-byte integer, range: 0 to 127): (0=false, 1=true)

Bit 0: RayStatus_validity not normal[1]
Bit 1: GPS data not valid
Bit 2: Temperatures not valid[2]
Bit 3: Radar telemetry data quality not normal[3]
Bit 4: Peak power not normal[4]
Bit 5: CPR calibration maneuver
Bit 6: Missing frame

[1]This bit is set if any of the validity flag is set.
[2]Valid temperature range is –10°C to 50°C.

[3]Valid Radar parameter ranges are: Pulse Width [0, 7]; PTT [475, 704]; Range to first bin [650, 750] Km; PRI [142,196]; Data Window Delay [0, 31].
[4]Valid Peak power range is [500, 2200] watts.

Data _status (array size nray, 1-byte integer, range: 0 to 127) Contains 7 bit flags:

Bit 0: missing frame (0=false, 1=true)
Bit 1: SOH missing (0=false, 1=true)
Bit 2: GPS data valid (0=false, 1=true)
Bit 3: 1 PPS lost (0=false, 1=true)
Bit 4: Star tracker 1 (0=off, 1=on)
Bit 5: Star tracker 2 (0=off, 1=on)
Bit 6: Coast (0=false, 1=true)

Data Status Fixed Frame Table Target ID, Data_targetID (array size nray, 1-byte integer, range: 0 to 81)
Passed into the 1B-CPR output from the 1A-AUX data.

0: CPR to point in 300 seconds - Nominal science mode
1 - 15: Target ID for testing - not planned for operational use
16: CPR to point in 160 seconds
17: CPR 15\xba to the right
18: CPR 15\xba to the left
19: CPR 10\xba to the right -- default rotation
20: CPR 10\xba to the left -- default rotation
21: CPR 5\xba to the right
22: CPR 5\xba to the left
23 - 29: Target ID for testing - not planned for operational use
30 - 36: CPR rotation - not planned for operational use
37 - 39: Not planned for operational use
40: Rotation into the OR orientation
41: Rotation into the x-track along the anti-ang momentum
42: Rotation into the x-track along ang momentum
43: Rotation into the orbit lower orientation
44: Rotation into alt. OR w/ CPR away from Sun
45 - 49: Not planned for operational use
50: Rotation into the OR orientation
51: Rotation into the x-track along the anti-ang momentum
52: Rotation into the x-track along ang momentum
53: Rotation into the orbit lower orientation
54: Rotation into alt. OR w/ CPR away from Sun
55 - 59: Not planned for operational use
60: Rotation into the OR orientation
61: Rotation into the x-track along the anti-ang momentum

62: Rotation into the x-track along ang momentum
63: Rotation into the orbit lower orientation
64: Rotation into alt. OR w/ CPR away from Sun
65 - 69: Not planned for operational use
70: Rotation into the OR orientation
71: Rotation into the x-track along the anti-ang momentum
72: Rotation into the x-track along ang momentum
73: Rotation into the orbit lower orientation
74: Rotation into alt. OR w/ CPR away from Sun
75 - 80: Not planned for operational use
81: Body into the x-track along the anti-ang momentum
82 - 255: Not planned for operational use

ID 0 is control frame 0.
IDs 16-22 are control frame 0, CPR calibration.
IDs 40-44 are control frame 1, 4 thruster closed loop.
IDs 50-54 are control frame 2, 1 thruster open-loop.
IDs 60-64 are control frame 3, 2 thruster open-loop.
IDs 70-74 are control frame 4, 4 thruster open-loop.
ID 81 is control frame 5.

Navigation_land_sea_flag (array size nray, 1-byte) Flag indicating land or ocean. Note that inland lakes are not identified as water and have a valid elevation in the DEM_elevation variable.

RayHeader_lambda (typical value: 0.003187 m, missing value: none) 4-byte float Wavelength (m).

RayHeader_SpatAvg (range: 0.16 s to 0.48 s, missing value: -9999) 4-byte float Spatial averaging time in second (s).

RayHeader_CalVers (range: 0 to 5, missing value: none) 4-byte float. Version number of the calibration table

Ray_Status variable (array size nray, combined record size 14 bytes):
The status of each ray is represented in terms of platform and instrument control data, and orbit parameters. See Table 1 for the data contents and format.

Table 1: Ray Status

Name	Format	Description
Validity (**RayStatus_validity**, range: 0 to 3, missing value: none)	2-byte integer in algorithm, 1-byte unsigned integer in product.	Validity is a summary of status. It is broken into 8 bits flags. Each bit = 0 for routine status, 1 for non-routine status. The non-routine situation follow: Bit Meaning if bit = 1 0 Non-routine spacecraft orientation

		1 Non-routine CPR mode 2 Receiving only mode or ptt =0, bad calibration 3-7 Not used
Pulse Repetition Interval (**RayStatus_PRI**, range: 140 to 208, missing value: 0)	1-byte character in algorithm, 1-byte unsigned integer in product.	PRI in units of 1.6 microsec
Pulse width (**RayStatus_pulseWidth**, range: 3.1 to 3.8, missing value 0)	1-byte character in algorithm, 1-byte unsigned integer in product.	Pulse width, 0 – 7 is 3.1-3.8 microsec. This is likely to be fixed at 3.3 throughout the mission.
Pulses transmitted (**RayStatus_pulsesTx**, range: 580 to 678, missing value 0)	2-byte integer	Number of transmit events that occurred in the burst
Antenna noise (**RayStatus_antennaNoise**, range: 1e-15 to 2e-14, missing value: -9999)	4-byte float	Cal measurement of antenna in units of W; measurement is average of (EIF-1)*120 samples. EIF is calculated as int(altitude/(PRI*1.6e-6*2.9979e8/2)+1).

Transmit Powers (TransmitPower) (P_r , W) (array size nray, 4 byte float, range 1500 to 2000, missing value: -9999):
The estimated radar transmission power, 4-byte float. This estimate has approximately 0.3 dB measurement noise. Using the orbit-averaged power is recommended so that the noise is smoothed out.

Averaged Transmit Power (TransmitPower_Avg) (P_r , W) (4 byte float, range 1500 to 2000, missing value: -9999):
The estimated radar transmission power, 4-byte float, averaged over an entire granule. This is the preferred parameter for tracking the transmit power.

CPR Calibration coefficients (RadarCoefficient) (m^{-3}) (array size nray, 4-byte float, range 0.01 to 0.10, missing value: -9999):
The Radar calibration constant given by,

$$C = \frac{(4\pi)^3}{\lambda^2 G^2 \Delta\Omega}$$

where the antenna gain and Ω are found from antenna measurements. Δ is found from laboratory measurements of the received pulse shape. The wavelength λ is known. G is the antenna gain, including ohmic losses.

Noise Floor Power and Standard Deviation (NoiseFloorPowers) (W) (array size 2 x nray, 4-byte float, range 1e-15 to 2e-14, missing value: -9999):
The noise floor is estimated from range bins 16-35 and is found in element 1 of the first dimension. The standard deviation is found in element 2 of the first dimension. This estimate and its standard deviation will be provided in the Level 1B CPR data but will not be subtracted. The user will need to subtract the value provided or a new noise estimate from the received echo power in all range bins.

Received Echo Powers (ReceivedEchoPowers) (W) (array size 125 X nray, 4-byte float, range: 1e-15 to 1e-6, missing value: -9999):
Echo Power (P_r) is the calibrated range gate power in watts, made in-flight and averaged. Powers at and near surface (within 3 range bins) are contaminated by surface backscatter. The fist range bin also appears contaminated and is set to –9999 in the Level 1 B data. The user of the Level 1 B CPR data can generate the backscattering cross section η by subtracting noise and then using the following equation,

$$\eta = \frac{P_r}{P_t} C r^2 .$$

Once the radar reflectivity is computed, it can be converted to reflectivity factor using

$$Z = \frac{\lambda^4 \eta}{\pi^5 |K|^2} 10^{18}$$

Sigma-Zero (100*dB) (array size nray, 2-byte integer, range: -1000 to 4000, missing value: -9999):

The Sigma-Zero is the normalized surface cross section (not corrected for attenuation). It’s multiplied by 100 and stored as 2-byte integers.
Changed in version 5.3: this parameter is now calculated using TransmitPower_Avg, and is corrected for range-sampling bias (if a good estimate of surface clutter was found, see below) and an upgraded estimate of the range target response integral Δ.

Surface Bin Number (SurfaceBinNumber) (array size nray, 2-byte integer in algorithm, 1-byte unsigned integer in product, range: 100 to 125, missing value: 255): Changed in version 5.3: this parameter is now improved by comparing the initial estimate (maximum power between range bin 90 and 125) with a prediction from AUX data (Range_to_intersect, DEM_elevation and Range_to_first_bin). If a discrepancy is detected, a new search for a peak around the predicted position is performed. This method corrects the unreliable estimates due to large attenuation over the ocean, and mitigates the problems over land. Areas of complex orography or areas with poor DEM information may cause unreliable estimates. Also, in some instances no surface signature is present in the profile: in these two cases the SurfaceBinNumber is assigned the value predicted from the AUX data and the SurfaceClutter_Index (see below) is assigned missing value.

Profile of Surface Clutter (FlatSurfaceClutter) (array size 14 X nray, 4-byte float, range: 1e-15 to 1e-6, missing value: -9999) - new in version 5.3: this is the estimated profile of received power contributed by a flat surface (from 5 bins above SurfaceBinNumber to 8 bins below). The 6th bin of this profile corresponds to the SurfaceBinNumber. This estimate is reliable only over water or flat surface, in general it is not as reliable over land or ice, especially when orographic features are present (in these cases, the surface response differs significantly from that of a flat surface). Also, the flat surface response used to estimate this profile is optimized for epoch 02 (that is, the period pointing at 0.16 degrees off-nadir), estimates are somewhat less accurate for epoch 01 and significantly less accurate for epoch 00. The quality of this estimated profile is represented by the SurfaceClutter_Index (see below). If a low value of SurfaceClutter_Index is reported, the FlatSurfaceClutter can be subtracted from ReceivedEchoPowers (after co-locating in range the bins) to reveal presence of atmospheric returns above the surface. The maximum Surface Clutter Rejection ratio achievable by subtracting this estimate is between 6 and 12 dB, depending on the relative position of the bin with respect to the surface. See: CloudSat_2B_GEOPROF_Quality_Statement_R04.

Fractional offset of the surface bin (SurfaceBinNumber_Fraction) (array size nray, 4-byte float in algorithm, 4-byte float in product, range: -0.5 to 0.5, missing value: -99) - new in version 5.3: this is the estimated offset (expressed as fraction of the range sampling bin) between the center of SurfaceBinNumber and the actual surface range. The estimate is reliable over ocean and in absence of significant rain echo (see SurfaceClutter_Index). Missing value is assigned to this field if either no valid surface return is observed in the profile or if the SurfaceClutter_Index (see below) exceeds 2 (i.e., the surface return does not match well the flat surface response).

Index of quality of Surface Clutter estimation (SurfaceClutter_Index) (array size nray, 4-byte float in algorithm, 4-byte float in product, range: higher than -0.1, missing value: -99): this parameter is the sum squared error between the observed profile of power (in dB) around the surface bin (5 or 3 bins, see below) and the best matching flat surface response used to generate FlatSurfaceClutter. If negative, it means that a very good match was found for the 5 bins around the surface bin number (the negative value is obtained by subtracting 0.1. so that -0.1 represents a perfect match). If positive, it means that the best match was selected using only the 3 bins around surface bin number. A value of -99 indicates that no match was found. A value larger than 2 indicates a dubious match, and no SurfaceBinNumber_Fraction is estimated. A missing value indicates that there was a large discrepancy between the radar estimated SurfaceBinNumber and the one predicted from AUX data, so that no Surface Clutter estimation was performed.

	SurfaceBin Number	SurfaceBinNumber Fraction	SurfaceClutter Index	Sigma-Zero
Nav estimate was out of window - No valid radar signature	Missing	Missing	Missing	Missing
Nav estimated Surface Bin Number (integer) - No valid radar surface signature	VALID	Missing	Missing	Missing
Bad SC match - no attempt to refine	VALID	Missing	Missing	NOT CORRECTED
3 Bin Match (5 bin match was marginal)	VALID	VALID	POSITIVE	CORRECTED
5 Bin Match (best match)	VALID	VALID	NEGATIVE	CORRECTED

6. Operator Instructions

As discussed in section 4 the Level 1 B CPR data processing software will be integrated into CORE. It will be called using the standard CORE procedure for calling modules to operate on data files. The output will be in the form of an HDF-EOS structure in memory, which can be saved by CORE and passed on to Level 2 processing.

The Level 1B CPR data quality can be monitored efficiently using Ray Status flags, namely validity and data quality, along with a few other radar parameters. Following variables can be checked on an orbit basis.

1. Plot validity and data quality flags; many non-zero flags indicates that there was an anomaly that was being dealt with in radar operation mode or some problem in the radar.

2. Plot pulses transmitted; this should generally be near 600 pulses. A much lower value indicates that the radar was not transmitting a large part of the orbit.

3. Plot transmitted power; this should be >1500 W over the orbit.

4. Plot sigma zero, especially over ocean; the typical ocean value should be within a few dB of 10 dB. The L1B code automatically computes the % of missing surface returns and the average surface bin number.

5. Plot noise floor power over an orbit. Its variation should be within the range of 2.0E-15 watt to 1.6E-14 watt.

7. References

T. Kozu, S. Satoh, H. Hanado, T. Manabe, M. Okumura, K. Okamoto, T. Kawanishi, 2000: Onboard surface detection algorithm for TRMM Precipitation Radar, IEICE Trans. Commun., E83-B, 2021-2031.

R. Meneghini and T. Kozu, Spaceborne Weather Radar. Boston: Artech House, 1990.

TSDIS, Interface Control Specification, Volume 3, 1999.

8. Acronym List

CIRA	Cooperative Institute for Research in the Atmosphere
CORE	CloudSat Operational and Research Environment
CPR	Cloud Profiling Radar
CRC	cyclic redundancy code
EOS	Earth Observing System
HDF	Hierarchical Data Format
IFOV	Instantaneous field of view
PRF	Pulse Repetition Frequency
SDPT	Science Data Production Toolkit
TRMM	Tropical Rainfall Measuring Mission
TSDIS	TRMM Science Data Information System
VTCW	Vehicle Time Code Word

9. List of changes

For each item, a. describes pre-change, and b. post-change.

9.1. Changes in version 5.3

1) Corrected: invalid values for non-operating profiles
   a. Incorrect missing values were reported for some data fields when the radar is not transmitting.
   b. Fixed.
2) Upgraded: SurfaceBin_Number estimation
   a. SurfaceBinNumber was defined as the bin where maximum power echo between bins 100 and 125 was observed. The surface bin number calculated this way was unreliable in areas with extreme topography or in areas of rain or other strong atmospheric backscatter.
   b. The initial SurfaceBinNumber estimate is now compared to the surface bin number predicted by the AUX data (i.e., using Range_to_intersect, DEM_elevation and Range_to_first_bin). If the two estimates differ by more than 4 bins a new local search for a surface signature (i.e., a "3-bin peak") is initiated at the position predicted by the AUX data. If a surface signature is not found, a missing value is assigned to the SurfaceClutter_Index and SurfaceBinNumber_Fraction, while the AUX-predicted bin number is assigned to SurfaceBinNumber.
3) New: FlatSurfaceClutter
   a. Not present.
   b. 14 bin profile of the estimated contribution to the ReceivedEchoPower by a flat surface.
4) New: SurfaceBin_Fraction
   a. Not present.
   b. When the illuminated surface can be approximated as a flat surface, the relative offset between the center of SurfaceBinNumber and the actual surface range is provided (as fraction of 239.83 m) in this field. The estimated accuracy of this field is 1 m rmse over a flat surface. The accuracy degrades rapidly as the surface gets rougher (e.g., over land).
5) New: SurfaceClutter_Index
   a. Not present
   b. Describes the quality of the match between the observed ReceivedEchoPowers around the SurfaceBinNumber and the best matching response from a flat surface. Values between -0.1 and 0 indicate excellent match over the 5 bins around SurfaceBinNumber, values above 0 indicate that the match is only over the 3 bins around SurfaceBinNumber. The larger this value (sum squared error in dB) the worse the quality of the surface clutter estimate. A value of 2 is used as threshold in 2B-GEOPROF to decide whether to remove the estimated clutter from the ReceivedEchoPowers or not.
6) Upgraded: Sigma-Zero estimation
   a. Was computed using the instantaneous value of the transmit power, and the measured received power at the SurfaceBinNumber. The variable bias due to finite sampling in range was approximated by a constant bias in the range response integral Δ.
   b. Is now computed using the orbitally averaged value of transmit power, the updated value of the range response integral Δ and, when a good surface clutter estimate is available, the estimated peak power of the surface echo.