**PR Power 1B-21 Swath Data [L1B_21_SWATHDATA]**

The following sizing parameters are used in describing the format:

· nray = the number of rays = 49

· nscan = the number of scans within one granule = 9150, on average

**Scan Time** (Vdata Table, record size 8 bytes, nscan records)

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Scan Time | scanTime | 8-byte float | Scan Time is the center time of 1 scan (the time at center of the nadir beam transmitted pulse). It is expressed as the UTC seconds of the day. |

**Geolocation** (SDS, array size 2 x nlay x nscan, 4-byte float):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Geolocation | geolocation(2,49) | 4-byte float | The earth location of the center of the IFOV at the altitude of the earth ellipsoid. The first dimension is latitude and<br>longitude, in that order. The next dimensions are pixel and scan. Values are represented as floating point decimal degrees. Off earth is represented as less than or equal to -9999.9 Latitude is positive north, negative south. Longitude is positive east, negative west. A point on the 180th meridian is assigned to the western hemisphere. |

**Scan Status** (Vdata Table, record size 15 bytes, nscan records):
The status of each scan is represented in terms of quality, platform and instrument control data, and fractional
orbit number.

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Missing | scanStatus.missing | 1-byte integer | Missing indicates whether information is contained in the scan data. The values are:<br>0: Scan data elements contain information<br>1: Scan was missing in the telemetry data<br>2: Scan data contains no elements with rain |
| Validity | scanStatus.validity | 1-byte integer | Validity is a summary of status modes. If all status modes are routine, all bits in Validity = 0. Routine means that scan data has been measured in the normal operational situation as far as the status modes are concerned. Validity does not assess data or geolocation quality. Validity is broken into 8 bit flags. Each bit = 0 if the status is routine but the bit = 1 if the status is not routine. Bit 0 is the least significant bit (i.e., if bit i = 1 and<br>other bits = 0, the unsigned integer value is 2**i). The non-routine situations follow:<br>Bit Meaning if bit = 1<br>0: Spare (always 0)<br>1: Non-routine spacecraft orientation (2 or 3)<br>2: Non-routine ACS mode (other than 4)<br>3: Non-routine yaw update status (0 or 1) |

| | | | |
|---|---|---|---|
| | | | 4: Non-routine instrument status (other than 1)<br>5: Non-routine QAC (non-zero)<br>6: Spare (always 0)<br>7: Spare (always 0) |
| QAC | scanStatus.qac | 1-byte integer | The Quality and Accounting Capsule of the Science packet as it appears in Level-0 data. If no QAC is given in Level-0, which means no decoding errors occurred, QAC in this format has a value of zero. |
| Geolocation Quality | scanStatus.geoQuality | 1-byte integer | Geolocation quality is a summary of geolocation quality in the scan. A zero integer value indicates "good" geolocation. A non-zero value broken down into the following bit flags indicates:<br>Bit Meaning if bit = 1<br>0: latitude limit error<br>1: geolocation discontinuity<br>2: attitude change rate limit error<br>3: attitude limit error<br>4: satellite undergoing maneuvers<br>5: using predictive orbit data<br>6: geolocation calculation error<br>7: not used |
| Data Quality | scanStatus.dataQuarity | 1-byte integer | Data quality is a summary of data quality in the scan. Unless this is 0 (normal), the scan data is meaningless to higher processing. Bit 0 is the least significant bit (i.e., if bit i = 1 and other bits = 0, the unsigned integer value is 2**i).<br>Bit Meaning if bit = 1<br>0: missing<br>5: Geolocation Quality is not normal<br>6: Validity is not normal |
| Current Spacecraft Orientation | scanStatus.scOrient | 1-byte integer | Value Meaning<br>0: +x forward<br>1: -x forward<br>2: -y forward<br>3: Inertial - CERES Calibration<br>4: Unknown Orientation |
| Current ACS Mode | scanStatus.acsMode | 1-byte integer | Value Meaning<br>0: Standby<br>1: Sun Acquire<br>2: Earth Acquire<br>3: Yaw Acquire<br>4: Nominal<br>5: Yaw Maneuver<br>6: Delta-H (Thruster)<br>7: Delta-V (Thruster)<br>8: CERES Calibration |
| Yaw Update Status | scanStatus.yawUpdateS | 1-byte integer | Value Meaning<br>0: Inaccurate<br>1: Indeterminate<br>2: Accurate |

| | | | |
|---|---|---|---|
| PR Mode | scanStatus.prMode | 1-byte integer | Value Meaning<br>0: Other Mode<br>1: Observation Mode |
| PR Status 1 | scanStatus.prStatus1 | 1-byte integer | The flags listed here indicate warnings of PR conditions (noise level, echo power and echo position, and mode change). In data processing, users should be cautions with the following as a scan with non-zero status includes questionable range bins or angle bins.<br>0: LOGAMP noise limit error<br>1: Noise level limit error (The meaning of this warning is<br>the same as the System Noize Warning Flag)<br>2: Out of PR dynamic range (Surface echo is so strong that<br>it exceeds the PR receiver dynamic range. Calibration<br>with the saturated echo may be questionable.)<br>3: Not reach surface position (If Surface echo is out of range<br>window, Bin Surface Peak and related data become uncertain.)<br>7: FCIF mode change |
| PR Status 2 | scanStatus.prStatus2 | 1-byte integer | In some cases, antenna sidelobes are directed to nadir receive surface echo positions. When the main beam is off nadir, the timing of such nadir-surface clutter can contaminate the rain echo. In “PR STATUS2,” a warning flag is set ON (1) when the nadir surface echo (at the nadir angle bin #25) exceeds a predetermined threshold. When the flag is ON, please be careful about the echoes at all angle bins around the same logical range bin number as the Bin-surface-peak at nadir (angle bin number 25). |
| Fractional Orbit Number | scanStatus.fracOrbitN | 4-byte float | The orbit number and fractional part of the orbit at Scan Time. The orbit number will be counted from the beginning of the mission. The fractional part is calculated as:<br>(Scan Time - Orbit Start Time) / (Orbit End Time - Orbit Start Time) |

**Navigation** (Vdata, record size 88 bytes, nscan records):

| **Name** | **Name in the TOOLKIT** | **Format** | **Description** |
|---|---|---|---|
| Spacecraft Geocentric Position [3] | navigate.scPosX<br>navigate.scPosY<br>navigate.scPosZ | 3 X 4-byte float | The position (m) of the spacecraft in Geocentric Inertial Coordinates at the Scan mid-Time (i.e., time at the middle pixel/IFOV of the active scan period). The order of components is: x, y, and z. Geocentric Inertial Coordinates are also commonly known as Earth Centered Inertial coordinates. These coordinates will be True of Date (rather than Epoch 2000 which are also commonly used), as interpolated from the data in the Flight Dynamics Facility ephemeris files generated for TRMM. |

| | | | |
|---|---|---|---|
| Spacecraft Geocentric Velocity [3] | navigate.scVelX<br>navigate.scVelY<br>navigate.scVelZ | 3 X 4-byte float | The velocity (ms $^{-1}$) of the spacecraft in Geocentric Inertial Coordinates at the Scan mid-Time. The order of components is: x, y, and z. |
| Spacecraft Geodetic Latitude | navigate.scLat | 4-byte float | The geodedic latitude (decimal degrees) of the spacecraft at the Scan mid-Time. |
| Spacecraft Geodetic Longitude | navigate.scLon | 4-byte float | The geodedic longitude (decimal degrees) of the spacecraft at the Scan mid-Time. Range is -180 to 179.999999. |
| Spacecraft Geodetic Altitude | navigate.scAlt | 4-byte float | The altitude (m) of the spacecraft above the Earth Ellipsoid at the Scan mid-Time. |
| Spacecraft Attitude [3] | navigate.scAttRoll<br>navigate.scAttPitch<br>navigate.scAttYaw | 3 X 4-byte float | The satellite attitude Euler angles at the Scan mid-Time. The order of the components in the file is roll, pitch, and yaw. However, the angles are computed using a 3-2-1 Euler rotation sequence representing the rotation order yaw, pitch, and roll for the rotation from Orbital Coordinates to the spacecraft body coordinates. Orbital Coordinates represent an orthogonal triad in Geocentric Inertial Coordinates where the Z-axis is toward the geocentric nadir, the Y-axis is perpendicular to the spacecraft velocity opposite the orbit normal direction, and the X-axis is approximately in the velocity direction for a near circular orbit.<br>Note this is geocentric, not geodetic, referenced, so that pitch and roll will have twice orbital frequency components due to the onboard control system following the oblate geodetic Earth horizon. Note also that the yaw value will show an orbital frequency component relative to the Earth fixed ground track due to the Earth rotation relative to inertial coordinates. |
| Sensor Orientation Matrix [3 X 3] | navigate.att1<br>navigate.att2<br>navigate.att3<br>navigate.att4<br>navigate.att5<br>navigate.att6<br>navigate.att7<br>navigate.att8<br>navigate.att9 | 3 X 3 X 4-byte float | The rotation matrix from the instrument coordinate frame to Geocentric Inertial Coordinates at the Scan mid-Time. |
| Greenwich Hour Angle | navigate.greenHourAng | 4-byte float | The rotation angle (degrees) from Geocentric Inertial Coordinates to Earth Fixed Coordinates. |

**Powers** (Vdata Table, record size 6 bytes, nscan records):

| **Name** | **Name in the TOOLKIT** | **Format** | **Description** |
|---|---|---|---|
| Radar Transmission Power | powers.radarTransPower | 2-byte integer | The total (sum) power of 128 SSPA elements corrected with SSPA temperature in orbit, based on temperature test data of SSPA transmission power. The units are dBm * 100. For this variable, the TSDIS Toolkit does not provide scaling. |
| Transmitted Pulse Width | power.transPulseWidth | 4-byte float | Transmitted pulse width (s) corrected with FCIF temperature in orbit, based on temperature test data of FCIF. |

**System Noise** (SDS, array size nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| System Noise | systemNoise(49) | 2-byte integer | System Noise (dBm) is an average of the 4 measured system noise values, multiplied by 100 and stored as a 2-byte integer. The system noise consists of external noise and PR internal noise, and is recorded as the total equivalent noise power at the PR antenna output.The range is -120 dBm to -20 dBm with an accuracy of 0.9 dBm. Missing data are given the value of -32734. |

**System Noise Warning Flag** (SDS, array size nray x nscan, 1-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| System Noise Warning Flag | sysNoiseWarningFlag(49) | 1-byte integer | If the system noise level exceeds the noise level limit, the flag is set to 1. This will occur when (1) a radio interference is received, (2) system noise increases anomalously, or (3) noise level exceeds the limit due to the statistical variation of the noise. In cases (1) and (2), data should be used carefully. In case (3), this flag may be neglected.Received power levels in all range bins will increase in cases (1) and (2) as much as the increase of the system noise.<br>PR may receive radio interference in the following areas.<br>N3.1 E101.7 (in Malaysia)<br>N33.8 W118.2 (around Los Angeles)<br>S34.8 W68.4 (around Santiago)<br>N10.5 W66.9 (in Chili)<br>N4.7 E36.9 (around Ethiopia – Kenya border)<br>S32.8 W63.4 (around Amazon) |

**Minimum Echo Flag** (SDS, array size nray x nscan, 1-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Minimum Echo Flag | minEchoFlag(49) | 1-byte integer | Five values are used in the Minimum Echo Flag:<br>0: No rain. (Echoes are very weak.)<br>10: Rain possible but may be noise. (Some weak echoes above noise exist in clutter free ranges.)<br>20: Rain certain. (Some strong echoes above noise exist in clutter free ranges.)<br>11: Rain possible but may be noise or surface clutter. (Some weak echoes exist in possibly cluttered ranges.)<br>12: Rain possible but may be clutter. (Some strong echoes exist in possibly cluttered ranges.)<br>Please be careful using the Minimum Echo Flag except when it is 0 or 20. |

**First Echo Height (**SDS, array size 2 x nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| First Echo Height | binStormHeight(2,49) | 2-byte integer | The First Echo Height (storm height) is represented by the logical range bin number (1 to 400, 125-m interval). Two types of First Echo Height are estimated, depending on wheter the minimum echo flag = 10 or 20. (If the first echo is detected below the clutter-free bottom, the two types depend on whether the flag = 11 or 12.) |

**Range Bin Number of Ellipsoid** (SDS, array size nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Range Bin Number of Ellipsoid | binEllipsoid(49) | 2-byte integer | Ellipsoid Height is represented by the logical range bin number (1 to 400). This is calculated by the following equation.<br>binEllipsoid[j] = Normal sample start range bin + (Spacecraft Range - Distance between satellite and the normal sample start range)/binsize × 2 |

**Range Bin Number of Clutter-free Bottom** (SDS, array size 2 x nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Range Bin Number of Clutter-free Bottom | binClutterFreeBottom(2,49) | 2-byte integer | This is the bottom range-bin number (logical range bin number) in clutter-free range bins estimated by the algorithm provided by Dr. Awaka (Hokkaido Tokai Univ. in Japan).<br>binClutterFreeBottom(1,49): clutter free certain,<br>binClutterFreeBottom(2,49): clutter free probable. |

**Range Bin Number of Mean DID** (SDS, array size nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Range Bin Number of Mean DID | binDIDHmean(49) | 2-byte integer | binDIDHmean represents the range bin number corresponding to the mean height of all DID data samples available in a 5×5 km area that overlaps most with the footprint. |

**Range Bin Number of Top of DID** (SDS, array size 2 x nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Range Bin Number of Top of DID | binDIDHtop(2,49) | 2-byte integer | binDIDHtop(1,46) represents the range bin number corresponding to the highest value (top) of all DID data samples in a 5×5 km box, and binDIDHtop(2,49), the range bin number corresponding to the highest value in a 11×11 km box. |

**Range Bin Number of Bottom of DID** (SDS, array size 2 x nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Range Bin Number of Bottom of DID | binDIDHbottom(2,49) | 2-byte integer | The definition is the same as that of binDIDHtop(2,49) except that the value represents the lowest value (bottom) of all DID samples in a 5×5km or 11×11km box. |

**Satellite Local Zenith Angle** (SDS, array size nray x nscan, 4-byte float):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Satellite Local Zenith Angle | scLocalZenith(49) | 4-byte float | The angle, in degrees, between the local zenith and the beam's center line. The local (geodetic) zenith at the intersection of the ray and the earth ellipsoid is used. |

**Spacecraft Range** (SDS, array size nray x nscan, 4-byte float):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Spacecraft Range | spacecraftRange(49) | 4-byte float | Distance (m) between the spacecraft and the center of the footprint of the beam on the earth ellipsoid. |

**Bin start of Oversample** (SDS, array size 2 x 29 x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Bin start of Oversample | osBinStart(2,29) | 2-byte integer | The first dimension is the Bin Start of Oversample and Surface Tracker Status. The second dimension is the ray. The number of rays is 29 because this information only applies to the rays<br>that have oversample data (rays #11 to #39). The third dimension is the scan. The Bin Start of Oversample is the starting range bin number of the oversample (either surface or rain) data, counting from the top down. The Surface Tracker Status has the value of 0 (Lock) or 1 (Unlock), where Lock means that (1) the on board surface detection detected the surface and (2) the surface detected later by processing on the ground fell within the oversample bins. Unlock means that<br>Lock was not achieved. The range bin number is defined in this volume in the section on Precipitation Radar, Instrument and Scan Geometry. |

**Land/Ocean Flag** (SDS, array size nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Land/Ocean Flag | landOceanFlag(49) | 2-byte integer | Land or ocean information. The values of the flag are:<br>0 = Water (ocean or inland water)<br>1 = Land<br>2 = Coast (not water or land ) |

**Topographic Height** (SDS, array size nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Topographic Height | surWarningFlag(49) | 2-byte integer | The topographic mean height (m) of all DID samples in a 5 x 5 km. |

**Bin Number of Surface Peak** (SDS, array size nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Bin Number of Surface Peak | binSurfPeak(49) | 2-byte integer | The bin surface peak indicates the logical range bin number of the peak surface echo.If the surface is not detected, Bin Surface Peak is set to a value of -9999. Note that the echo peak may appear either in the normal sample data or in the over-sample data. |

**Normal Sample** (SDS, array size 140 x nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Normal Sample | normalSample(140,49) | 2-byte integer | The normal sampled PR received powers are recorded (unit: dBm/100). The data is stored in the array of 49 angles * 140 elements.Since each angle has a different number of samples, the elements after the end of sample are filled with a value of -32767. If a scan is missing, the elements are filled with the value -32734. The range is -120 dBm to -20 dBm with an accuracy of 0.9 dBm. |

**Surface Oversample** (SDS, array size 5 x 29, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Surface Oversample | osSurf(5,29) | 2-byte integer | The PR records the over-sampled data in five range bins around the surface peak detected on board (not Bin Surface Peak) in a total of 29 angle bins (nadir ± 14 angles) to examine the surface peak precisely. If the surface tracker status is lock-off, the data position is unknown. To use the oversample data, fill the five data starting at “Bin Start of Over Surface” in every other logical range bin, then merge with the interleaving normal sample data. The range is -120 dBm to -20 dBm with an accuracy of 0.9 dBm. |

**Rain Oversample** (SDS, array size 28 x 11, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Rain Oversample | osRain(28,11) | 2-byte integer | The PR records the over-sampled data at 28 range bins in a total of 11 angle bins (nadir ± 5 angles) to record the detailed vertical profile of the rain.The 125m interval dataset in heights from 0 km to 7.5 km can be generated by interleaving the Normal Samples with the Surface oversamples and rain oversamples. The data are merged in the same way as the Surface Oversample. The range is -120 dBm to -20 dBm with an accuracy of 0.9 dBm. |

**PR Reflectivity 1C-21 Calibration Coefficients [L1B21_L1C21_HEADER]**
The 1C-21 product has the same format as 1B-21.

**PR Reflectivity 1C-21 Ray Header [L1B21_L1C21_HEADER]**
The 1C-21 product has the same format as 1B-21.

**PR Reflectivity 1C-21 Swath Data [L1C_21_SWATHDATA]**
The 1C-21 product has the same format as 1B-21. In 1C-21, the normal sample, surface oversample and rain oversample contain radar reflectivity factors (dBZ, $mm^6/m^3$) which are converted from the PR received powers in the corresponding places in 1B21 output. The radar equation used is

$$\Pr(range) = \frac{\pi^3 |K|^2}{2^{10} \ln 2} \frac{Pt * Gt * Gr * along * cross * c * pulse}{wavelength^2} \frac{1}{range^2} Zm$$

$$dBZ_m = 10 \log\left(10^{(Ps/10)} - 10^{(Pn/10)}\right) - C + 20 \log(range)$$

*Ps: 1B21 received power*
*Pn：1B21 noise level*
*range： Distance*

$$C = Pt + Gt + Gr + 10\log(along \times cross) + 10\log(c \times pulse) - 20\log(wavelength) + C0$$

*Pt: transmitter power (in power)*
*pulse： transmitter pulse width (in power)*
*Gt: transmit antenna gain (in ray header)*
*Gr: receive antenna gain (in ray header)*
*along： Along-track beam width (in ray header)*
*cross： Cross-track beam width (in ray header)*
*c： speed of light*
*wavelength： wave length (in ray header)*
*C0: Radar Constant (in ray header)*

If received power is below the noise level, the reflectivity is filled with a dummy value of -32700.

・Note that the radar reflectivity factors given in 1C-21 are apparent values and include rain or atomospheric
attenuation.

**Normal Sample** (SDS, array size 140 x nray x nscan, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Normal Sample | normalSample(140,49) | 2-byte integer | The normal sampled PR radar refrectivity factors are recorded (unit: dBZ/100). The data is stored in the array of 49 angles * 140 elements.Since each angle has a different number of samples, the elements after the end of sample are filled with a value of -32767. If a scan is missing, the elements are filled with the value -32734. If received power is below the noise level, the reflectivity is filled with a dummy value of -32700. The range is -20 dBZ to 80 dBZ with an accuracy of 1.0 dBZ. |

**Surface Oversample** (SDS, array size 5 x 29, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Surface Oversample | osSurf(5,29) | 2-byte integer | The PR records the over-sampled data in five range bins around the surface peak detected on board (not Bin Surface Peak) in a total of 29 angle bins (nadir ± 14 angles) to examine the surface peak precisely. If the surface tracker status is lock-off, the data position is unknown. To use the oversample data, fill the five data starting at “Bin Start of Over Surface” in every other logical range bin, then merge with the interleaving normal sample data. The range is -20 dBZ to 80 dBZ with an accuracy of 1.0 dBZ. |

**Surface Oversample** (SDS, array size 28 x 11, 2-byte integer):

| Name | Name in the TOOLKIT | Format | Description |
|---|---|---|---|
| Rain Oversample | osRain(28,11) | 2-byte integer | The PR records the over-sampled data at 28 range bins in a total of 11 angle bins (nadir ± 5 angles) to record the detailed vertical profile of the rain.The 125m interval dataset in heights from 0 km to 7.5 km can be generated by interleaving the Normal Samples with the Surface oversamples and rain oversamples. The data are merged in the same way as the Surface Oversample. The range is -20 dBZ to 80 dBZ with an accuracy of 1.0 dBZ. |