TROPICAL RAINFALL MEASURING MISSION PRECIPITATION PROCESSING SYSTEM

File Specification
2B31

Version 7

March 20, 2014

0.1 2B31 - TRMM Combined

2B31, "TRMM Combined", derives vertical hydrometeor profiles using data from PR radar and TMI. It also computes the correlation-corrected mass-weighted mean drop diameter and its standard deviation, and latent heating. The following sections describe the structure and contents of the format.

Dimension definitions:

nscan	var	Number of scans in the granule.
nray	49	Number of angle bins in each scan.
Nradarrange	80	Number of radar range cells at which the rain rate is estimated. The cells range from 0 to 79. Each cell is 250m apart, with cell 79 at the earth ellipsiod.
nlayer	13	Number of layers of latent heating.

Figure 1 through Figure 4 show the structure of this product. The text below describes the contents of objects in the structure, the C Structure Header File and the Fortran Structure Header File.

FileHeader (Metadata):
FileHeader contains general metadata. This group appears in all data products. See Metadata for TRMM Products for details.

InputRecord (Metadata):
InputRecord contains a record of input files for this granule. This group appears in Level 1 and Level 2 data products. Level 3 time averaged products have the same information separated into 3 groups since they have many inputs. See Metadata for TRMM Products for details.

NavigationRecord (Metadata):
NavigationRecord contains navigation metadata for this granule. This group appears in Level 1 and Level 2 data products. See Metadata for TRMM Products for details.

FileInfo (Metadata):
FileInfo contains metadata used by the PPS I/O Toolkit (TKIO). This group appears in all data products. See Metadata for TRMM Products for details.

Swath (Swath)

SwathHeader (Metadata):
SwathHeader contains metadata for swaths. This group appears in Level 1 and Level 2 data products. See Metadata for TRMM Products for details.

ScanTime (Group)

A UTC time associated with the scan.

Year (2-byte integer, array size: nscan):
4-digit year, e.g., 1998. Values range from 1950 to 2100 years. Special values are defined

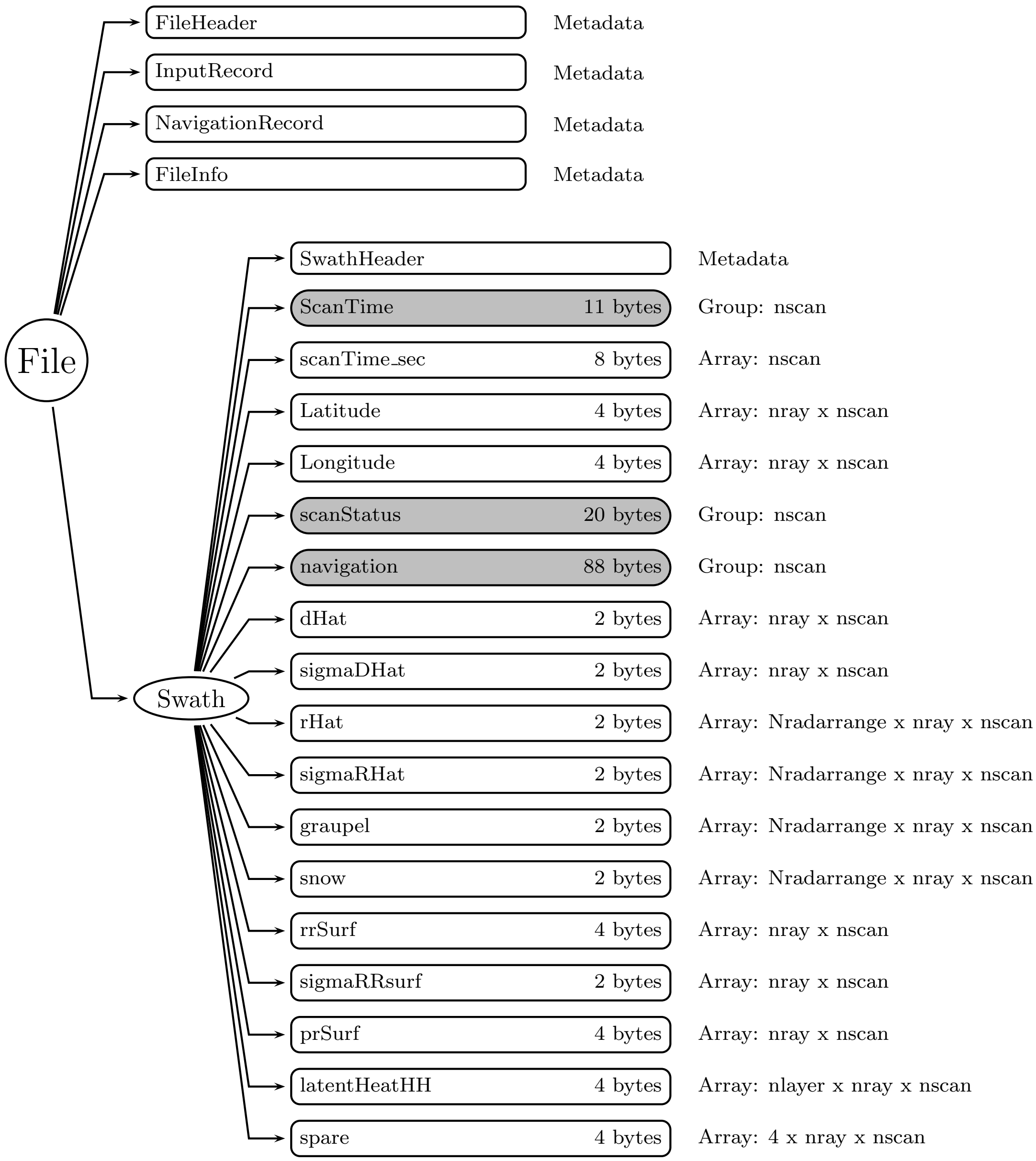

Figure 1: Data Format Structure for 2B31, TRMM Combined

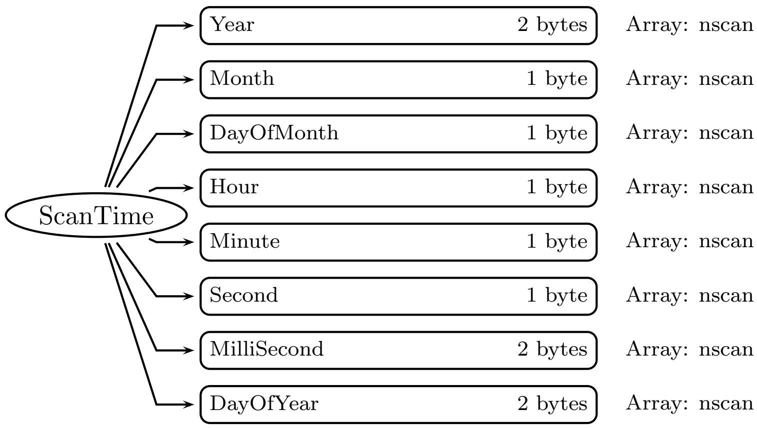

Figure 2: Data Format Structure for 2B31, ScanTime

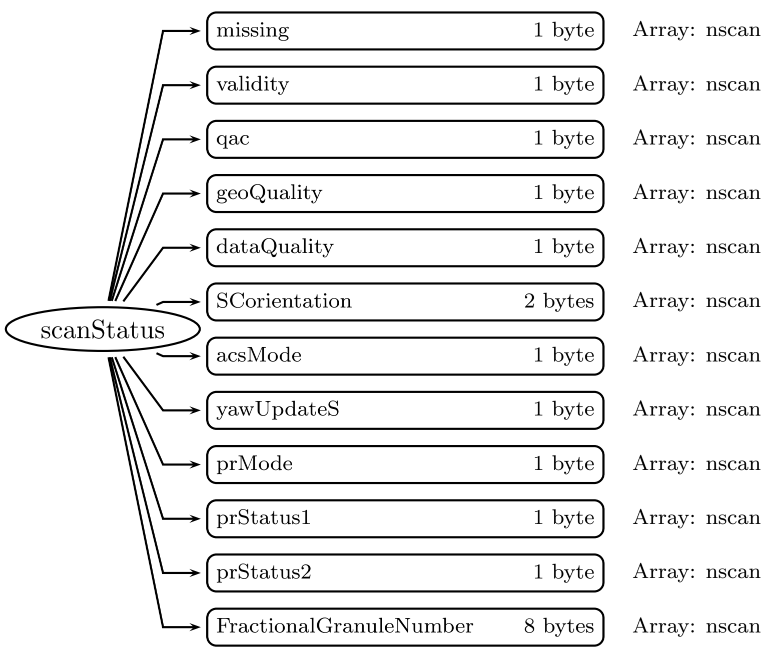

Figure 3: Data Format Structure for 2B31, scanStatus

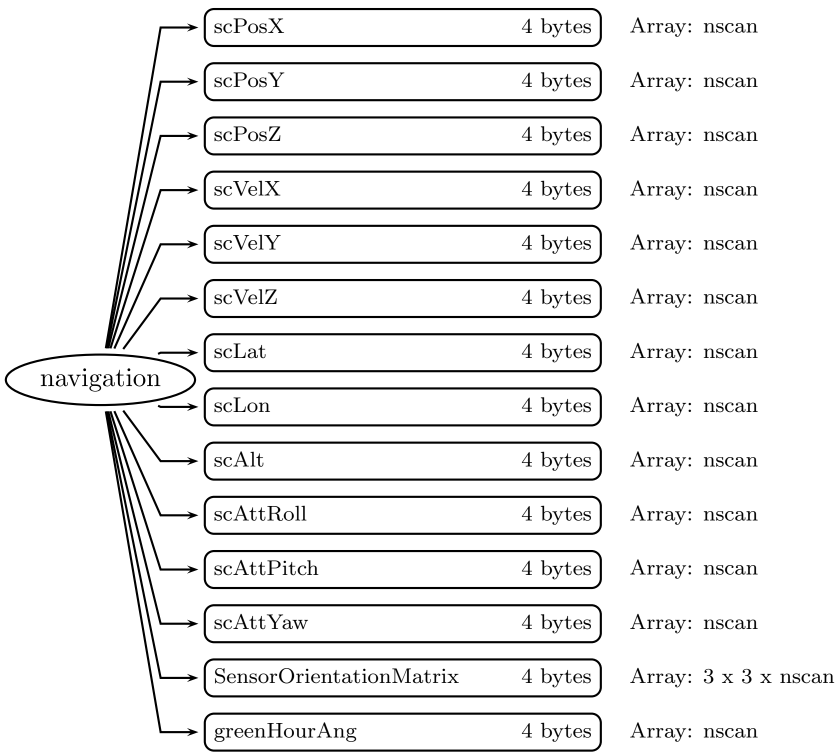

Figure 4: Data Format Structure for 2B31, navigation

as:
-9999 Missing value

Month (1-byte integer, array size: nscan):
Month of the year. Values range from 1 to 12 months. Special values are defined as:
-99 Missing value

DayOfMonth (1-byte integer, array size: nscan):
Day of the month. Values range from 1 to 31 days. Special values are defined as:
-99 Missing value

Hour (1-byte integer, array size: nscan):
UTC hour of the day. Values range from 0 to 23 hours. Special values are defined as:
-99 Missing value

Minute (1-byte integer, array size: nscan):
Minute of the hour. Values range from 0 to 59 minutes. Special values are defined as:
-99 Missing value

Second (1-byte integer, array size: nscan):
Second of the minute. Values range from 0 to 60 s. Special values are defined as:
-99 Missing value

MilliSecond (2-byte integer, array size: nscan):
Thousandths of the second. Values range from 0 to 999 ms. Special values are defined as:

-9999 Missing value

DayOfYear (2-byte integer, array size: nscan):
Day of the year. Values range from 1 to 366 days. Special values are defined as:
-9999 Missing value

scanTime_sec (8-byte float, array size: nscan):
A time associated with the scan. scanTime_sec is expressed as the UTC seconds of the day. Values range from 0 to 86400 s. Special values are defined as:
-9999.9 Missing value

Latitude (4-byte float, array size: nray x nscan):
The earth latitude of the center of the IFOV at the altitude of the earth ellipsiod. Latitude is positive north, negative south. Values range from -90 to 90 degrees. Special values are defined as:
-9999.9 Missing value

Longitude (4-byte float, array size: nray x nscan):
The earth longitude of the center of the IFOV at the altitude of the earth ellipsiod. Longitude is positive east, negative west. A point on the 180th meridian has the value -180 degrees. Values range from -180 to 180 degrees. Special values are defined as:
-9999.9 Missing value

scanStatus (Group)

missing (1-byte integer, array size: nscan):
Missing indicates whether information is contained in the scan data. The values are:

```
0 Scan data elements contain information
1 Scan was missing in the telemetry data
2 Scan data contains no elements with rain
```

validity (1-byte integer, array size: nscan):
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 other bits = 0, the unsigned integer value is 2**i). The non-routine situations follow:

```
Bit Meaning if bit = 1
0   Spare (always 0)
1   Non-routine spacecraft orientation (2 or 3)
2   Non-routine ACS mode (other than 4)
3   Non-routine yaw update status (0 or 1)
4   Non-routine instrument status (other than 1)
5   Non-routine QAC (non-zero)
```

```
6   Spare (always 0)
7   Spare (always 0)
```

qac (1-byte integer, array size: nscan):
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.

geoQuality (1-byte integer, array size: nscan):
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 the following, where bit 0 is the least significant bit (i.e., if bit i = 1 and other bits = 0 the unsigned integer value is 2**i):

```
Bit Meaning if bit = 1
0   latitude limit error
1   geolocation
2   attitude change rate limit error
3   attitude limit error
4   satellite undergoing maneuvers
5   using predictive orbit data
6   geolocation calculation error
7   not used
```

dataQuality (1-byte integer, array size: nscan):
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).

```
Bit Meaning if bit = 1
0   missing
5   Geolocation Quality is not normal
6   Validity is not normal
```

SCorientation (2-byte integer, array size: nscan):
The positive angle of the spacecraft vector (v) from the satellite forward direction of motion, measured clockwise facing down. We define v in the same direction as the spacecraft axis +X, which is also the center of the TMI scan. If +X is forward, SCorientation is 0. If -X is forward, SCorientation is 180. If -Y is forward, SCorientation is 90. Values range from 0 to 360 degrees. Special values are defined as:

-8003	Inertial
-8004	Unknown
-9999	Missing value

acsMode (1-byte integer, array size: nscan):

Value	Meaning
0	Standby
1	Sun Acquire
2	Earth Acquire
3	Yaw Acquire
4	Nominal
5	Yaw Maneuver
6	Delta-H (Thruster)
7	Delta-V (Thruster)
8	CERES Calibration

yawUpdateS (1-byte integer, array size: nscan):

Value	Meaning
0	Inaccurate
1	Indeterminate
2	Accurate

prMode (1-byte integer, array size: nscan):

Value	Meaning
1	Observation Mode
2	Other Mode

prStatus1 (1-byte integer, array size: nscan):
This status is a warning for scan data. Unless this is 0, the scan data may include a little questionable value though it is not a problem (such as break of caution limit). This field is used only for NASDA's data analysis.

prStatus2 (1-byte integer, array size: nscan):
Initialization in Onboard Surface Search Algorithm.

Value	Meaning
0	Not initialized
1	Initialized

FractionalGranuleNumber (8-byte float, array size: nscan):
The floating point granule number. The granule begins at the Southern-most point of the spacecraft's trajectory. For example, FractionalGranuleNumber = 10.5 means the spacecraft is halfway through granule 10 and starting the descending half of the granule. Values range from 0 to 100000. Special values are defined as:

-9999.9	Missing value

navigation (Group)

scPosX (4-byte float, array size: nscan):
The x component of 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). 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.

scPosY (4-byte float, array size: nscan):
The y component of the position (m) of the spacecraft in Geocentric Inertial Coordinates. See scPosX.

scPosZ (4-byte float, array size: nscan):
The z component of the position (m) of the spacecraft in Geocentric Inertial Coordinates. See scPosX.

scVelX (4-byte float, array size: nscan):
The x component of the velocity (ms^{-1}) of the spacecraft in Geocentric Inertial Coordinates at the Scan mid-Time.

scVelY (4-byte float, array size: nscan):
The y component of the velocity (ms^{-1}) of the spacecraft in Geocentric Inertial Coordinates at the Scan mid-Time.

scVelZ (4-byte float, array size: nscan):
The z component of the velocity (ms^{-1}) of the spacecraft in Geocentric Inertial Coordinates at the Scan mid-Time.

scLat (4-byte float, array size: nscan):
The geodedic latitude (decimal degrees) of the spacecraft at the Scan mid-Time.

scLon (4-byte float, array size: nscan):
The geodedic longitude (decimal degrees) of the spacecraft at the Scan mid-Time.

scAlt (4-byte float, array size: nscan):
The altitude (m) of the spacecraft above the Earth Ellipsiod at the Scan mid-Time.

scAttRoll (4-byte float, array size: nscan):
The satellite attitude Euler roll angle (degrees) 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. 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.

scAttPitch (4-byte float, array size: nscan):
The satellite attitude Euler pitch angle (degrees) 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. 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.

scAttYaw (4-byte float, array size: nscan):
The satellite attitude Euler yaw angle (degrees) 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. 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.

SensorOrientationMatrix (4-byte float, array size: 3 x 3 x nscan):
SensorOrientationMatrix is the rotation matrix from the instrument coordinate frame to Geocentric Inertial Coordinates at the Scan mid-Time. It is unitless.

greenHourAng (4-byte float, array size: nscan):
The rotation angle (degrees) from Geocentric Inertial Coordinates to Earth Fixed Coordinates.

dHat (2-byte integer, array size: nray x nscan):
dHat is the correlation-corrected mass-weighted mean drop diameter (liquid only). It is multiplied by 100 and stored as a two-byte integer. The accuracy is 0.01 "normalized" mm. It ranges from 0.7 to 1.8 "normalized" mm (the value 0 indicates no rain or bad data). The accuracy is 0.01 "normalized" mm.

The parameters Λ, μ and No of the corresponding drop size distribution $N(D)dD = NoD^{\mu}e^{-\Lambda D}dD$, giving the number per cubic-meter of drops of diameter between D and

D + dD mm, can be obtained from dHat and the rain rate rHat using the formulas:

$$\mu = -4 + 1/(0.1521 dHat^{0.23} rHat^{0.074})$$

$$\Lambda = 1/(0.1521 dHat^{1.33} rHat^{0.23})$$

$$No = 55 rHat \Lambda^{\mu+4}/(\Gamma(\mu+4)(1-(1+0.53/\Lambda)^{-\mu-4}))$$

Similarly, the rain rate rHat mm/hr can be converted into a liquid (no solid) water M (g/m3) using the formula:

$$M = \frac{0.02878 rHat}{1-(1+0.53/\Lambda)^{-\mu-4}}$$

The average value of dHat is around 1.1 "normalized" mm, a unit which comes from the fact that dHat is related to the true mass-weighted mean drop diameter D* mm by the formula dHat = D* rHat -0.155 (with rHat in mm/hr).

"normalized units" are defined as follows: If a variable X, expressed in grams, is correlated with the rain rate R and a variable Y is defined where Y = X * R0.37 R, then the unit of Y is called "normalized grams".

sigmaDHat (2-byte integer, array size: nray x nscan):
Sigma-D-hat is the RMS uncertainty in D-Hat. It ranges from 0.00 to 2.00 "normalized"* mm and is multiplied by 100 and stored as a two-byte integer. The accuracy is 0.01 "normalized" mm. See description of dHat.

rHat (2-byte integer, array size: Nradarrange x nray x nscan):
R-hat is the instantaneous rain rate (liquid only) at the radar range gates. It ranges from 0.0 to 500.0 mm/hr and is multiplied by 10 and stored as a two-byte integer. The accuracy is 0.1 mm/hr.

sigmaRHat (2-byte integer, array size: Nradarrange x nray x nscan):
Sigma-R-hat is the RMS uncertainty in the R-hat estimated at the radar range gates. It is multiplied by 10 and stored as a two-byte integer. It ranges from -125 to 125 mm/hr (the negative sign indicating estimates based on a "rain-possible" detection by the radar rather than the "rain-certain" associated with positive values). The values -125 and 125 are reserved for cases where the RMS uncertainty could not be accurately estimated. The accuracy is 0.5 mm/hr.

graupel (2-byte integer, array size: Nradarrange x nray x nscan):
"graupel" content estimated at the radar range gates. It is multiplied by 1000 and stored as a two-byte integer. It ranges from 0 to 10 g/m^3. "graupel" is defined as frozen hydrometeors with a density of 600 Kg/m^3. "graupel" thus is mostly bigger, denser frozen hydrometeors, and would represent aggregates, graupel, and hail.

snow (2-byte integer, array size: Nradarrange x nray x nscan):
"snow" content estimated at the radar range gates. It is multiplied by 1000 and stored as a two-byte integer. It ranges from 0 to 10 g/m^3. "snow" is defined as frozen hydrometeors with a density of 100 Kg/m^3. "snow" thus is mostly smaller, fluffier frozen hydrometeors.

rrSurf (4-byte float, array size: nray x nscan):
RR-Surf is the surface rainfall rate (liquid only). It ranges from 0.0 to 500.0 mm/hr. The accuracy is 0.1 mm/hr.

sigmaRRsurf (2-byte integer, array size: nray x nscan):
Sigma-RR-Surf is the RMS uncertainty in RR-Surf. It is multiplied by 100 and stored as a two-byte integer. It ranges from -125 to 125 mm/hr (the negative sign indicating estimates based on a "rain-possible" detection by the radar rather than the "rain-certain" associated with positive values). The values -125 and 125 are reserved for cases where the RMS uncertainty could not be accurately estimated. The accuracy is 0.5mm/hr.

prSurf (4-byte float, array size: nray x nscan):
The surface precipitation rate (liquid plus solid). It ranges from 0.0 to 500.0 mm/hr. The accuracy is 0.1 mm/hr.

latentHeatHH (4-byte float, array size: nlayer x nray x nscan):
latentHeatHH is the "hydrometeor heating" in K/hr calculated from the vertical fluxes of the different hydrometeor species and using average archival temperature/pressure/humidity soundings which depend on longitude and latitude only. In version 6 all the precipitation is assumed to be liquid. Heating is listed for 13 layers. The first entry in the array is the heating in the layer between 18 km and 16 km above the earth ellipsoid. The layers have the following upper and lower boundaries defined in km above the earth ellipsoid:

```
First layer        18      16
Second layer       16      14
Third layer        14      12
Fourth layer       12      10
Fifth layer        10       8
Sixth layer         8       7
Seventh layer       7       6
Eighth layer        6       5
Ninth layer         5       4
Tenth layer         4       3
Eleventh layer      3       2
Twelvth layer       2       1
Thirteenth layer    1       0
```

spare (4-byte float, array size: 4 x nray x nscan):
Contents and ranges are not public.

C Structure Header file:

```
#ifndef _TK_2B31_H_
#define _TK_2B31_H_

#ifndef _L2B31_NAVIGATION_
```

```
#define _L2B31_NAVIGATION_

typedef struct {
    float scPosX;
    float scPosY;
    float scPosZ;
    float scVelX;
    float scVelY;
    float scVelZ;
    float scLat;
    float scLon;
    float scAlt;
    float scAttRoll;
    float scAttPitch;
    float scAttYaw;
    float SensorOrientationMatrix[3][3];
    float greenHourAng;
} L2B31_NAVIGATION;

#endif

#ifndef _L2B31_SCANSTATUS_
#define _L2B31_SCANSTATUS_

typedef struct {
    signed char missing;
    signed char validity;
    signed char qac;
    signed char geoQuality;
    signed char dataQuality;
    short SCorientation;
    signed char acsMode;
    signed char yawUpdateS;
    signed char prMode;
    signed char prStatus1;
    signed char prStatus2;
    double FractionalGranuleNumber;
} L2B31_SCANSTATUS;

#endif

#ifndef _L2B31_SCANTIME_
#define _L2B31_SCANTIME_
```

```
typedef struct {
    short Year;
    signed char Month;
    signed char DayOfMonth;
    signed char Hour;
    signed char Minute;
    signed char Second;
    short MilliSecond;
    short DayOfYear;
} L2B31_SCANTIME;

#endif

#ifndef _L2B31_SWATH_
#define _L2B31_SWATH_

typedef struct {
    L2B31_SCANTIME ScanTime;
    double scanTime_sec;
    float Latitude[49];
    float Longitude[49];
    L2B31_SCANSTATUS scanStatus;
    L2B31_NAVIGATION navigation;
    float dHat[49];
    float sigmaDHat[49];
    float rHat[49][80];
    float sigmaRHat[49][80];
    float graupel[49][80];
    float snow[49][80];
    float rrSurf[49];
    float sigmaRRsurf[49];
    float prSurf[49];
    float latentHeatHH[49][13];
    float spare[49][4];
} L2B31_SWATH;

#endif

#endif
```

Fortran Structure Header file:

```
STRUCTURE /L2B31_NAVIGATION/
    REAL*4 scPosX
    REAL*4 scPosY
    REAL*4 scPosZ
    REAL*4 scVelX
    REAL*4 scVelY
    REAL*4 scVelZ
    REAL*4 scLat
    REAL*4 scLon
    REAL*4 scAlt
    REAL*4 scAttRoll
    REAL*4 scAttPitch
    REAL*4 scAttYaw
    REAL*4 SensorOrientationMatrix(3,3)
    REAL*4 greenHourAng
END STRUCTURE

STRUCTURE /L2B31_SCANSTATUS/
    BYTE missing
    BYTE validity
    BYTE qac
    BYTE geoQuality
    BYTE dataQuality
    INTEGER*2 SCorientation
    BYTE acsMode
    BYTE yawUpdateS
    BYTE prMode
    BYTE prStatus1
    BYTE prStatus2
    REAL*8 FractionalGranuleNumber
END STRUCTURE

STRUCTURE /L2B31_SCANTIME/
    INTEGER*2 Year
    BYTE Month
    BYTE DayOfMonth
    BYTE Hour
    BYTE Minute
    BYTE Second
    INTEGER*2 MilliSecond
    INTEGER*2 DayOfYear
END STRUCTURE
```

```
STRUCTURE /L2B31_SWATH/
    RECORD /L2B31_SCANTIME/ ScanTime
    REAL*8 scanTime_sec
    REAL*4 Latitude(49)
    REAL*4 Longitude(49)
    RECORD /L2B31_SCANSTATUS/ scanStatus
    RECORD /L2B31_NAVIGATION/ navigation
    REAL*4 dHat(49)
    REAL*4 sigmaDHat(49)
    REAL*4 rHat(80,49)
    REAL*4 sigmaRHat(80,49)
    REAL*4 graupel(80,49)
    REAL*4 snow(80,49)
    REAL*4 rrSurf(49)
    REAL*4 sigmaRRsurf(49)
    REAL*4 prSurf(49)
    REAL*4 latentHeatHH(13,49)
    REAL*4 spare(4,49)
END STRUCTURE
```