# CloudSat Reflectivity-Height Histogram Product
# Quality Statement (Version 2.0)

Yuying Zhang, Roger Marchand and Steve Klein

The CloudSat Reflectivity-Height Histogram product contains 2D histograms (joint distributions) of CloudSat observed reflectivities (in dBZe) with altitude above mean sea level. The data are stored on a vertical (altitude) grid with 480 m vertical spacing and aggregated on a simple 2 x 2 degree latitude/longitude grid.

The intent is that these data be used in the evaluation of climate model output, and we strongly encourage these data be used in combination with the CFMIP Observation Simulator Package (COSP; http://cfmip.metoffice.com/COSP.html). Examples of this type of data, including comparison with MMF climate model output can be found in Marchand et al. (2009) and Zhang et al. (2010).

If questions remain on these data not answered in this document or above references, please direct these questions to the COSP user group or directly to us Yuying Zhang (zhang24@llnl.gov) and Roger Marchand (rojmarch@u.washington.edu).

**Brief Description of Processing:**

The reflectivity-height histogram data is based on the hydrometeor-mask and reflectivity data from operational CloudSat 2B-GEOPROF data product. See Marchand et al. (2008) for a full description of this data product including details on the hydrometeor-mask generation. We note the hydrometeor-mask is often called a "cloud mask" even though the radar responds and the mask does not distinguish between clouds and precipitation. This dataset uses version R04 of 2B-GEOPROF (the latest available as of summer 2010). Changes in the next version (R05) are expected to have little impact on the histogram product.

The principal quantity contained in this dataset are histograms of reflectivity with altitude. The histogram is constructed assuming any radar range-resolution-volume with an associated hydrometeor-mask value of 20 or larger AND a reflectivity value greater than or equal to -30 dBZe is a hydrometeor. These thresholds ensure a low false detection rate (Marchand et al. 2008). Radar range-resolution-volume which does not meet both these thresholds is consider clear-of-hydrometeors.

We note that range-resolution-volumes with a hydrometeor-value of 5 AND a reflectivity value greater than or equal to -25 dBZe in the CloudSat data are indicative of surface clutter (see below discussion on known limitations) and an additional variable called "missing data" is used to track where and how often clutter is expect to influence the histogram data.

For each CloudSat beam (sampled approximately every 1.1 km along-track, but with an effective beam-width or footprint of about 1.8 km) hydrometeor reflectivity is averaged on a vertical grid with 480 m grid spacing (starting with interval 0 to 480 m above mean sea level) such that

$$\text{Average } Ze = (Ze_1 * h_1 + Ze_2 * h_2 + Ze_3 * h_3)/(h_1 + h_2 + h_3),$$

where the subscript *1* to *3* refers to (the up to three) valid CloudSat observations that can overlap each 0 to 480 m vertical interval, *Ze* is the reflectivity, and *h* is the fractional overlap between the 240 m CloudSat range-resolution-volume and the 480 m vertical interval. (The oversampling of CloudSat observations in the vertical has little impact on the results and is not considered.) Note that areas which are clear-of-hydrometeors have *Ze* = 0 and *dBZe* = 10 * log10(*Ze*) is the reflectivity in units of decibels (dB).

Any range-resolution-volume which contains clutter in any of the (nominally three) CloudSat samples is treated as entirely clear-of-hydrometeors (Average Ze = 0) for purpose of the histogram and is considered "missing data" (see below).

The average dBZe values from each beam are then histogrammed for each vertical interval on a 2 x 2 degree latitude/longitude grid using reflectivity bins that are 5 dBZe wide. The total number of beams for each region is also stored in the data product.

In addition, a count is made of the total number of beams that contain a hydrometeor (as defined here) at any interval. We call this the "column cloud fraction".

The data stored here contains all CloudSat samples (both daytime and night time overpasses). Data restricted to daytime or nighttime overpasses (or with other restrictions) is available by special request.

**Know Problems/Limitations:**

<u>(1) Surface Clutter</u>

Perhaps the most significant limitation of the CloudSat observations (and this dataset) is reduced sensitivity near the surface due to ground clutter; that is echo power coming from the surface adds to the total observed reflectivity making it difficult to discern whether or not a hydrometeor is present. For CloudSat, this region of surface clutter extends to approximately 1 km above the surface. At 500 m above the surface, only strong precipitation can be unambiguously identified. See Marchand et al. 2008 for additional information.

In version V0 of this dataset, regions near the surface which contained clutter were ignored. That is, they were not counted as cloudy or clear and did not contribute to the total measurements available in a given region. The problem with this approach is that much of the time, when a region near the surface is clear there will some clutter power present and so the region will be flagged as clutter. So regions tend to be either a detected target (usually precipitation) or clutter. Thus ignoring clutter causes the resulting cloud amounts, i.e., relative frequencies (defined as the number of detections / total measurements) to be biased high.

In version V2 of the dataset, we have instead counted all clutter contaminated regions as "clear". This means the relative frequencies near the surface are somewhat lower than in the previous dataset. Results for the North Pacific and shown below. Because clutter DOES conceal some hydrometeors that CloudSat would have detected if there had been no clutter, the relative frequencies are now expected to be biased somewhat low. However, this bias is expected to be smaller than overestimate previously produced.

In version V2, we also include a measure of the fraction of data that is clutter contaminated. This variable is called "Missing Fraction". For example, in the figure below (right panel) we see the missing fraction is 100% for the lowest vertical bin, 0 to 480 m. At the surface, CloudSat has almost no ability to detect hydrometeors (clutter is very high).

In the second vertical bin (480 to 960 m), clutter remains important with a bit more than 50% of the measurement contaminated. In the new dataset (V2) the hydrometeor fraction is about 10%, in this vertical bin. However, the "true value" (what one would get in the absence of clutter) could be anywhere between 10% and 60%, depending on the amount of hydrometeor hidden in the clutter. Thus **WHEN THE "MISSING DATA" FRACTION IS HIGH, THE DATA SHOULD BE USED WITH CAUTION**. The reported values in V2 effectively represent the minimum value for hydrometeor amount.

If one assume the probably of a hydrometeor being in the clutter contaminated region is equal to the probably observed probability when no clutter was present, then one obtains and estimate for the "true value" as the "V2 observed fraction / (1 – missing fraction)" of ~ 20%. But this is a big assumption (which is likely not entirely correct and will still likely be biased high) and this "best" estimate is highly uncertain !

In the third vertical bin (960 to 1240 m), there is little clutter and the can use the CloudSat data with high confidence.

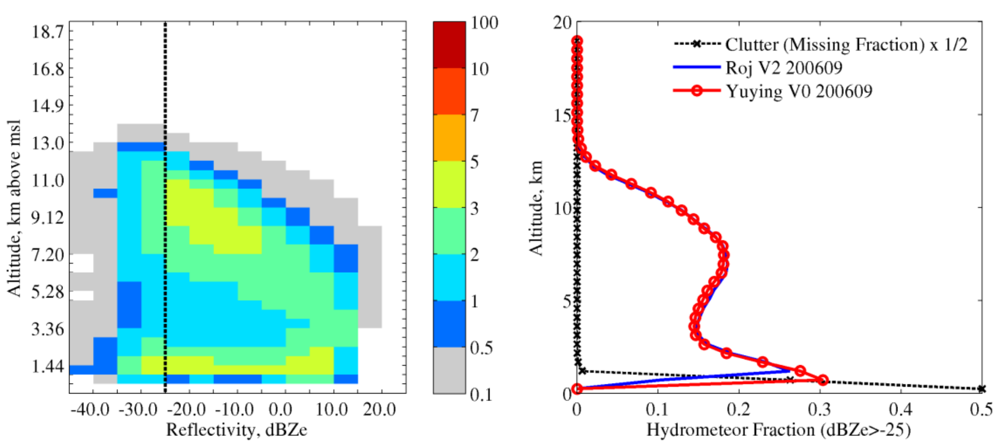


Figure 1 – (Left) Example of reflectivity height histogram for the North Pacific. (Right) Hydrometeor fraction with reflectivity greater than -25 dBZe. The blue line shows the latest version of the dataset (V2)

and the red line with circles for version (V0). The differences are small except near the surface. The difference near the surface is due to clutter. The dashed black line (right panel) shows the amount of clutter contamination. NOTE: the black line has been multiplied by 0.5, clutter contamination at the surface is 100%.

## (2) Sensitivity

At the start of the mission, CloudSat had a sensitivity of slightly better than -30 dBZe. This has dropped somewhat over the course of the mission, but is expect to remain above -25 dBZe. We therefore recommend that comparison between CloudSat and model output be restricted to reflectivities greater than -25 dBZe. **Relative frequencies below -25 dBZe are expected to be biased low, especially those below -30 dBZe.**

In the COSP release, we have removed data below the -30 dBZe. The full data are available by special request.

We stress that many hydrometeors in the atmosphere have reflectivities below what CloudSat can detect and we strongly encourage these data be used in combination with the CFMIP Observation Simulator Package to help ensure a fair comparison.

## References

Marchand, R., J. Haynes, G. G. Mace, T. Ackerman, and G. Stephens (2009), A comparison of simulated cloud radar output from the multiscale modeling framework global climate model with CloudSat cloud radar observations, J. Geophys. Res., 114, D00A20, doi:10.1029/2008JD009790.

Marchand, R., G.G. Mace, T. Ackerman, and G. Stephens (2008), Hydrometeor Detection Using Cloudsat—An Earth-Orbiting 94-GHz Cloud Radar. J. Atmos. Oceanic Technol., 25, 519–533.

Zhang , Y., S. A. Klein, J. Boyle, and G. G. Mace (2010), Evaluation of tropical cloud and precipitation statistics of Community Atmosphere Model version 3 using CloudSat and CALIPSO data, J. Geophys. Res., 115, D12205, doi:10.1029/2009JD012006.