

DEVELOPMENT OF A DIGITAL ELEVATION MAP USING TRMM/PR DATA

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ABSTRACT:

The Tropical Rainfall Measuring Mission (TRMM) satellite aims to obtain more reliable rain data global scale. The major instrument for rain observation is the precipitation radar (PR) that observes vertical profile of rainfall about 240 km cross track swath with 250 m vertical resolution and 5 km of horizontal resolution (footprint size). For the rain retrieval algorithm for the PR, it is needed to distinguish the rain echo and clutter to estimate the rain profile, because the algorithm need to correct the attenuation by rainfall throughout the profile (PR uses 13.8 GHz and it is certainly attenuate in moderate to heavy rainfall) and the relatively high reflectivity clutter echo causes large error. The current algorithm tries to detect the clutter range for each ray by detecting the large change in radar echo around the earth surface range bin. In particular, this method also leads error especially for relatively heavy rainfall cases. Since the TRMM satellite has already more than 10 years of data, it is convenient to develop a clutter range map using no-rain data. As for the first step of the clutter map, an elevation map is developed using TRMM/PR data with horizontal resolution of 0.025 degrees. Since the vertical resolution of the PR is 250 m throughout the range and 125 m near surface ranges of near nadir angle bins, vertical resolution of the map can be about 10 m after averaging the many data. This map is compared with SRTM30 data and both maps show good agreement each other.

1. INTRODUCTION

1.1 Background

The Tropical Rainfall Measuring Mission (TRMM) is aimed to provided accurate rainfall information for global (tropics and sub-tropics up to 35 degrees in latitude) scale to understanding the roll of tropical rainfall for the global circulation (Simpson et. al, 1984). TRMM satellite was launched in 1997 and it has been working more than 12 years and it is still in operation. One of the major instruments onboard TRMM satellite is the Precipitation radar (PR) that is Ku-band radar.

The PR observes about 240 km swath in the cross track direction with a footprint size of about 5 km and a vertical resolution of 250 m. The minimum detectable rain rate is about 0.7 mm/h. The rain retrieval algorithm for the PR is required to not only the conversion from the radar reflectivity factor (Z factor) to rain rate (e.g. Z-R relationship) but also correct the rain attenuation since the radar uses attenuating frequency (13.8 GHz) to rain in order to obtain the accurate Z factor (Iguchi et al., 2000). For this reason, vertical profile information not only the echo from the rain but also clutters from the surface, especially for the discrimination between rain echo and clutters, is important for the retrieval algorithm.

Current rain/clutter discrimination algorithm tries to find the inflection point near the surface echo with a guide of external digital elevation map (DEM). This method sometimes leads

unrealistic value (range bin number) of clutter top information that is usually occurs very steep mountain area or heavily attenuating rainfall cases. In the mountainous region, especially for slant incident angle observation cases, clutter echo appears quite different from the clutter height inferred from DEM. This means the general DEM data cannot be simply apply to the algorithm.

1.2 Purpose of this study

The primary purpose of this study is to develop a global clutter height map for the PR algorithms. The clutter map should be developed for each incident angle (49 angle bin from -17 degrees to 17 degrees) considering the 180 degrees yaw manoeuvre (TRMM makes yaw manoeuvre about once a month to keep the better solar energy reception, so the TRMM fly to +x direction or -x direction, that is PR scans opposite direction in cross track). In addition, satellite orbit direction ascending/descending should be considered because of illumination direction relative to the Earth surface is different between ascending and descending nodes. Also the retrieval of the clutter map similar to the observed clutter map from a DEM is planned in order to extend this knowledge for the follow-on mission of TRMM, called Global Precipitation Measurement (GPM) that observes up to 65 degrees in latitude. In the GPM core satellite, dual frequency precipitation radar (DPR) will be equipped; one of two frequency is same as TRMM/PR and the radar system of both frequencies are almost identical with TRMM/PR.

As a first step of this study an elevation map using the surface clutter information is developed. Since the vertical (along the ray) resolution of the PR data is 250 m and over-sampled data with 125 m resolution is available for near nadir angles (about +/- 10 degree in +/- 17 degree full swath), we need to integrate many data with various satellite altitude (the satellite altitude is maintained within +/- 1.25 km) for better accuracy of the data. The horizontal resolution of the map should be set to less the footprint size (about 5 km) and it is set to 0.025 degree in latitude and longitude.

2. METHOD

2.1 Elevation map

Basic idea to calculate the elevation map is as follows: 1) the range bin number of the Earth surface is calculated using “no rain” PR data (binSurfPeak in TRMM 1B21 product), 2) the distance between the binSurfPeak and the range bin number of the Earth ellipsoid (binEllipsoid in TRMM 1B21 product) is calculated ($[\text{binEllipsoid} - \text{binSurfPeak}] * 125 \text{ m}$), and 3) finally the elevation is calculated applying incident angle assuming the spherical shape of the Earth locally. Even the range resolution of the PR data is 125 m (with over-sampling data), various incident angle data and various satellite altitude condition make it possible to reduce the resolution significantly.

Since the target spatial resolution is 0.025 degrees, significant amount of data is needed for the statistically meaningful estimation. Note that the map is created between 35 degree south to 35 degree north because of inclination angle of TRMM is 35 degrees.

2.2 Validation of geolocation

The reliability of this elevation map depends on the assumptions such as satellite attitude information and geolocation information in the TRMM products. These are closely related each other. Evaluation of the geolocation determination in TRMM products is also implemented in this study. Three approaches are used to examine: 1) taking correlation between the elevation map calculated in this study (hereafter it is called as TRMM DEM) and a general DEM such as GTOPO30 or SRTM; in this case SRTM30 data is used for comparison. This approach also validates the TRMM DEM itself. 2) Comparison of coast line location between TRMM and SRTM; TRMM/PR’s system noise data and normalized radar cross section (NRCS) of the surface echo clearly shows a change between ocean and land, this information can be used for coast detection. 3) Comparison of coast line location between TRMM and SRTM3; this approach is similar to the NRCS method in 2) but it uses TRMM/PR’s surface echo profile to determine the sub-footprint size resolution. Details of these methods and the comparison results are shown in section 3.3.

3. RESULT

3.1 TRMM/PR DEM

Figure 1 shows an example of a TRMM DEM with its standard deviation. In order to save the file size, this figure is created with 0.1 degree resolution both for latitude and longitude. First of all, the global map looks reasonable at a first glance.

Standard deviation of each grid exceeds 100 m for mountain area such as Himalayan Mountains and Andes Mountains. It is, however, less than 10 m or even 5 m at around plain area. This indicates that large number accumulation leads relatively high accuracy and the larger errors in the mountain region are caused by the larger footprint size of TRMM/PR that gives various peak of the surface echo by various incident angle data. It also explains that the highest value of the TRMM DEM is just above 6 km whereas the actual peak reaches more than 8 km.

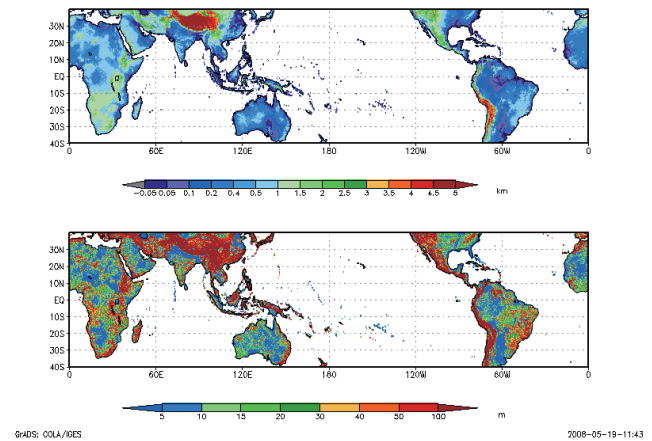


Figure 1. (Top) TRMM DEM (Bottom) standard deviation of TRMM DEM samples.

3.2 Comparison with SRTM

TRMM DEM is compared with SRTM30 data (0.01 degree grid data). Figure 2 shows a scatter plot of TRMM DEM versus SRTM30. In this plot SRTM30 data are re-sampled with 0.25 grid resolution. The result shows that both are correlated very well with the correlation coefficient of 0.974 and the slope from the least square fitting is almost one. The standard deviation is about 160 m that may be caused by the errors pointed in the previous section. It should be noted that TRMM DEM calculates negative elevation that may be come from the estimation error.

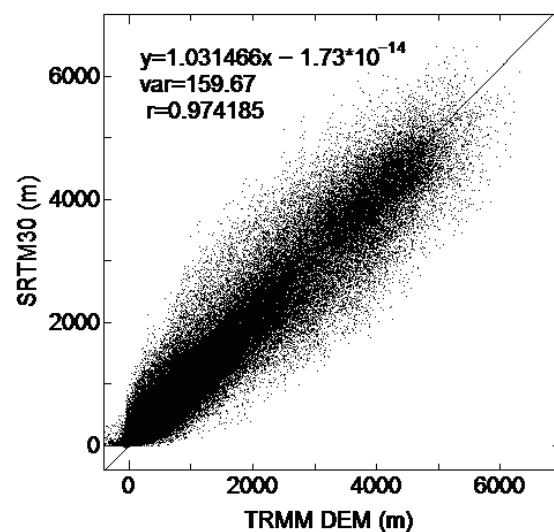


Figure 2. Scatter plot of TRMM DEM versus SRTM30. Data are sampled only over land.

3.3 Validation of geolocation of TRMM

3.3.1 Comparison with SRTM30: TRMM DEM data is utilized to validate the geolocation information of TRMM products. For this purpose, correlation coefficient between TRMM DEM and SRTM30 with grid offsets within +/- 2 grid offset is examined. Figure 3 shows an example of correlation coefficient map sampled between 30 degree north and 36 degree north. This figure clearly indicates the maximum value appears at the centre indicating the geolocation error is at least less than 0.025 degrees.

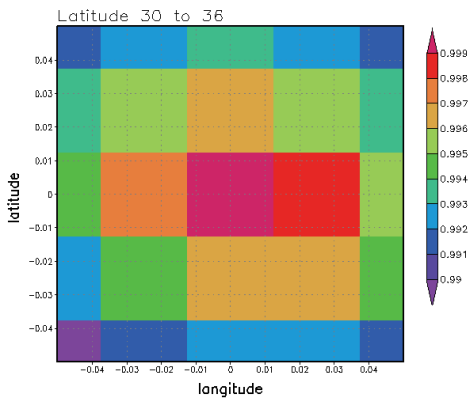


Figure 3. Correlation coefficients between TRMM DEM and SRTM30 for various grid offsets. This case shows latitude range is 30 – 36 degree north.

For finer error estimation, a centre of gravity of the correlation map (e.g. Fig. 3) is calculated and plotted for various latitude regions (5 degree intervals). Figure 4 shows the result of centre of gravity offset from the zero biased centres. The result indicates the offsets are less than 0.05 grids that correspond to less than 137.5 meter. It is almost negligible in terms of satellite navigation. At the same manner, the latitude dependency is also negligible.

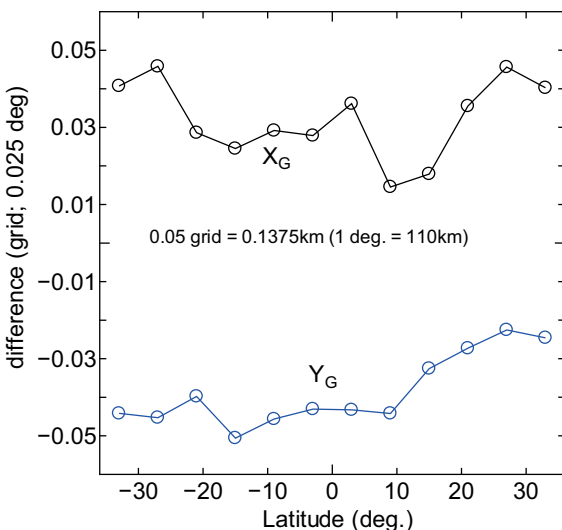


Figure 4. TRMM geolocation offset for various latitude estimated from the correlation coefficient between TRMM DEM and SRTM30

3.3.2 Comparison of coast location: The second geolocation validation is using system noise and NRCS of PR data. The system noise in PR contains not only the PR’s receiver system itself but the radiation from the Earth via antenna. For the microwave region, sea surface is seen cold because of low emissivity whereas the high temperature almost same as the physical temperature is seen over land. Therefore a discontinuity of system noise can be seen at the coast line.

The smoothness of the Earth surface, of course, changes at the coast line. So the NRCS also shows clear discontinuity at the coast line. In this analysis, for the simplicity, only cases the satellite flew nearly east-west direction because PR scans cross track direction. The advantage of this method is simpler but it has only footprint size resolution. Averaging many data makes it possible to reduce the resolution. The comparison between the detected coast line and the coast line flag in TRMM products shows that the offset is less than 0.001 degrees.

3.3.3 Use of surface echo profile: The range profile of surface echo for slant incident angle reflects the horizontal surface condition (Takahashi and Iguchi, 2008). This is also utilized to detect the precise location of coast line. Since the range profile data of ocean is stable, the range profile is compared with the typical ocean surface echo profile. Note that the echo profile change with incident angles and near nadir angle data cannot be used for this analysis. Same as the reason in section 3.3.2, only one case that satellite flew east-west direction, South Africa, is selected for the analysis.

Figure 5 shows the differences of range profile data from the reference profile. Note that the range profile covers larger area of footprint size and the difference in the range profile from the reference profile tend to be smaller as the range become farther from the centre, so that the coast line location can be determined by more than one incident angle data and the discontinuity should be determined if at least two profile show similar change. Also, the range location is converted to latitude because the satellite flew east to west in this case. In this figure, large differences appear to start at certain latitude (e.g. -34.09 degree for scan 8914) even though the erroneous difference appears south of it. The starting point of the difference is determined as the coast line.

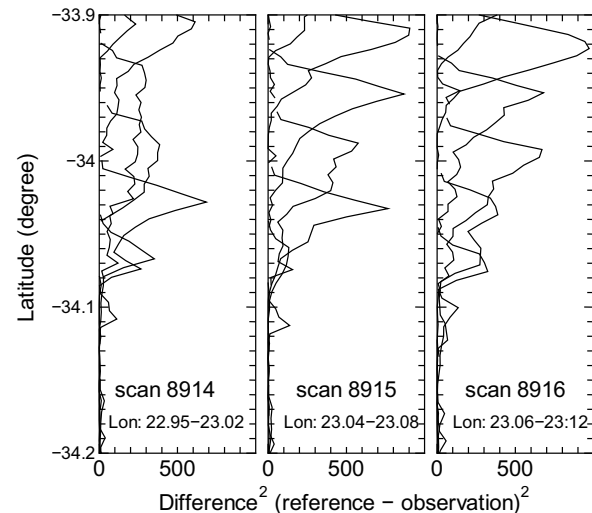


Figure 5. Difference between range profile and reference profile converted to latitude location. Data source is 1B21 data, dated 9 February, 1998 (orbit number is 1153).

Figure 6 shows the result of the comparison using data of South Africa. In this case, SRTM3 (that is 0.001 degree grid data) is used as the reference of the location of the coast line. Note that this is plotted with the same manner as Figure 5 and the location is determined by single profile data for each circle. The result indicates the coast location is determined within 1 km for the most cases (the minimum resolution will be about 500 m based on the range resolution and incident angle of PR). Although this result is not good as the results in sections 3.3.1 and 3.3.2, it is significantly less than the footprint size and it is good performance determined by only instantaneous data.

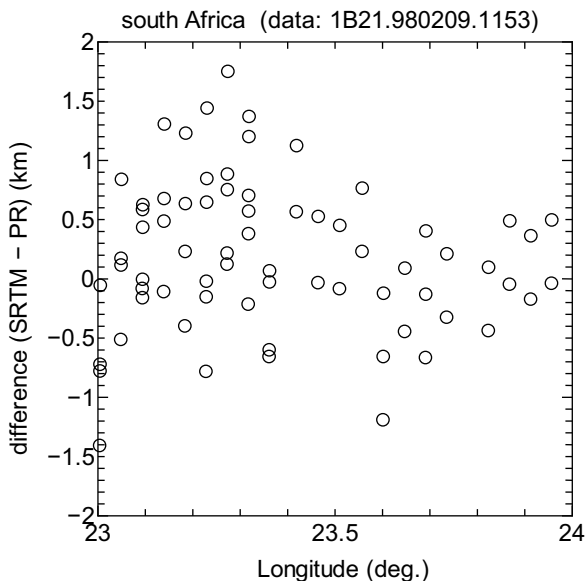


Figure 6. Coast detection error using range profile data. Data source is same as Figure 5.

4. SUMMARY

This article demonstrated the capability to utilize the TRMM/PR data for elevation map. Current map development algorithm uses the surface peak height. However, for the steep mountainous region, it must be considered to utilize the highest range of clutter. For example, Figure 7 shows range profile very close (less than 1km) to the Mount Everest. This figure shows the peak location of around 7 to 7.5 km and the clutter starts around 8.74 km. The latter number is close to the height of Mount Everest (8.846 km) and the difference is about 100m. For this reason, clutter top range bin must be considered for the DEM development. In addition, PR's receiver filter response must also be considered, because it broadens the profile even impulse input.

For the future plan, clutter map for various incident angle and other condition will be developed.

Using TRMM DEM data, the satellite geolocation is validated with other validation methods. The result indicates that TRMM satellite is well controlled and the satellite attitude information is almost perfectly reflected in the satellite attitude data.

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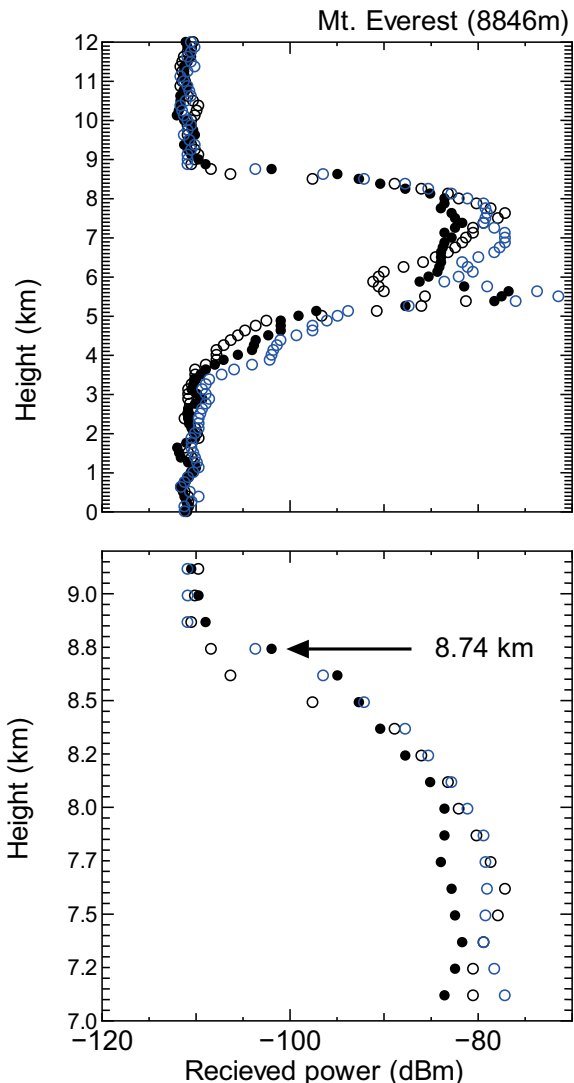


Figure 7. Vertical profiles of clutter echo sampled closes (less than 1 km) to the Mount Everest.