Proceedings of ISAP'04, Sendai, JAPAN

GENERATION OF SURFACE ELEVATION MAP USING TRMM PRECIPITATION RADAR DATA

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1. Introduction

For the observation of rain from space by a Precipitation Radar (PR) [1] onboard the Tropical Rainfall Measuring Mission (TRMM) satellite, or by any other spaceborne radar, it is very important to discriminate rain echo from surface echo, the latter of which acts as a strong clutter against the desired rain echo. A mainlobe clutter identification routine [2] is installed in one of the standard TRMM PR algorithm, called 1B21. The mainlobe clutter identification routine uses a digital elevation model (DEM), called DID [3], for the first guess about the position of the surface peak in a range profile of the radar echo.

It is known, however, that the DID dataset sometimes becomes less accurate in some areas, in particular, in high mountainous areas in Tibet or in Andes. In 1B21, the DID error is corrected for by a software, but such a correction would not be necessary if accurate DEMs are available. Unfortunately, even the most recent global DEM, e.g., a 30-arc seconds DEM of the Shuttle Radar Topography Mission, SRTM30 [4], which is a kind of update to GTOPO30 [5], seems to contain some appreciable errors in certain areas.

Since the TRMM PR itself identifies the position of Earth's surface, we propose to use the TRMM PR data to generate a surface elevation (EL) map. We also discuss a usefulness of the map for the improvement in the separation of rain echo from ground clutter for the TRMM and for a similar mission in the future.

2. Generation of Surface EL Map

Table 1 shows some characteristics of the TRMM PR which are relevant to the generation of surface EL map. The TRMM PR operates at a frequency of 13.8 GHz, and has a horizontal resolution of about 4.3 km when the altitude of the TRMM satellite is 350 km. By scanning the antenna beam in 49 directions across the movement of the satellite, the TRMM PR realizes the swath width of about 215 km.

This paper describes the generation of TRMM PR surface EL map having a resolution of 60-arc seconds, i.e., a horizontal resolution of 2 km, which is about one-half of the horizontal resolution of the TRMM PR. The choice of the horizontal resolution of 2 km is made so that the comparison with DID or SRTM30, both of them have a 1-km resolution, becomes easy. This paper shows the result using one-month data of 1B21. (Based on a proposal of one of the present authors (N. Takahashi), a similar work using a much longer term data set is being made at Japan Aerospace Exploration Agency, JAXA, but with a different horizontal resolution.)

Figure 1 illustrates our basic approach to the generation of a 2-km resolution TRMM PR surface EL map. Suppose that the antenna beam center, which is defined as the intersection of the antenna boresight axis and the surface, locates at the position marked by '+' in the figure. We consider nine ($= 3 \times 3$) squares, with the middle square contains the antenna beam center; each square has a 2 km$\times$2 km size. We assign nine squares the same height, i.e., elevation, which is obtained by the following equation:

ISBN: 4-88552-207-2 C3055©IEICE

$$H_{SP} = (B_{ellipse} - B_{SP})\, R_{res}\, \cos\xi \tag{1}$$

where H_{SP} [km] is the height of the surface echo peak, $B_{ellipse}$ is the range bin number for the adopted reference ellipsoid, B_{SP} is the range bin number for the surface echo peak, R_{res} is the range resolution, which is 0.25 km (see Table 1), and ξ is the zenith angle of the antenna beam. The height H_{SP} for each box is stored in a corresponding two-dimensional array.

Figures 2(a) and 2(b) show a TRMM PR derived surface EL map which is obtained by using one-day (September 1, 1998) of data, and that by using one-month (September, 1998) of data, respectively; these maps are generated using only no-rain data in the 215-km swath. With one-month of data, the TRMM derived surface EL map covers almost the entire area between 35-degrees north and 35-degrees south in latitude.

Figure 3 shows the difference between the one-month TRMM PR EL map and the 2-km averaged SRTM30 EL map. (The one-month TRMM PR EL map has a 2 km resolution, but SRTM30 has a 1 km resolution. Though a comparison between these maps can be made with the original resolutions, as shown in the next Figure 4, the comparison here is made with the same horizontal resolution matched to the TRMM PR EL map.) The entire TRMM PR observation area is covered by eighteen SRTM30 tiles, each of which has 40 degrees range in longitude and 50 degrees range in latitude. The difference between the one-month TRMM PR EL map and the SRTM30 EL map is examined for each tile, which is indicated by a rectangle with broken lines in the figure, and the TRMM PR coverage is indicated by a solid rectangle inside the tile. The number in each solid rectangle shows the number of pixels having a large elevation difference as follows:

$$\left| H(\mathrm{SRTM30; 2km}) - H(\mathrm{TRMM}) \right| \geq 1\ \mathrm{km} \tag{2}$$

where H(SRTM30;2km) is the surface height by the 2-km averaged SRTM30, and H(TRMM) the surface height by the one-month TRMM PR EL map. Figure 3 shows that a large difference occurs over Tibet and over the Andes.

Figure 4 shows a detail of the large difference over Tibet, or rigorously speaking, in the SRTM30 tile e060n40, where the tile is specified by the notation e060n40 which indicates longitude and latitude of the upper left corner of the tile. The thin line in the figure shows a histogram of the difference between the 1-km resolution SRTM30 EL and the 2-km resolution TRMM PR EL; four 1-km resolution SRTM30 ELs in a 2 km×2 km square are compared with the 2-km resolution TRMM PR EL in the same 2 km×2 km square. The thick line in the figure shows a histogram of the difference between the 2-km averaged SRTM30 EL and the the 2-km resolution TRMM PR EL.

The large difference between SRTM30 EL and TRMM PR EL seems to occur because of errors in SRTM30, though we can not deny a possibility of a large error in the TRMM PR EL in very rare cases.

3. Use of Surface EL Map for a Separation of Rain Echo from Surface Clutter

Figure 5 illustrates a concept of clutter free bottom [2]; in a given range profile of the radar echo, the echo below the clutter free bottom belongs to the surface echo which is just a clutter to the observation of rain. Determination of the clutter free bottom needs an accurate position of the surface peak in the radar echo profile, and the position of the surface echo can be estimated from a digital EL map. Experience shows that the accuracy of EL map should be within ±0.5 km for the TRMM PR, and a similar accuracy is required for the future Global Precipitation Measurement (GPM) core satellite dual frequency precipitation radar (DPR) [6][7], because a Ku-band radar of the GPM DPR will have characteristics similar to those of the TRMM PR.

As to the horizontal resolution, a 2-km horizontal resolution of EL map seems to be sufficient for the determination of clutter free bottom in the case of the TRMM PR, hence also in the case of the GPM DPR.

Figure 4 and the similar figures for the other tiles indicate that the 2-km averaged SRTM30 EL map does not satisfy the required accuracy of ±0.5km in some areas, in particular over Tibet or over the

Andes, but a correction for by the TRMM PR EL map seems to be promising. Though the correction using the TRMM PR EL map is limited to the area between 35-degrees north and 35-degrees south in latitude, the accuracy of the 2-km averaged SRTM30 in the remaining area of GPM DPR coverage would be good because there do not exist so many high mountains outside of the TRMM PR coverage.

4. Concluding Remarks

This paper describes the generation of a 2-km resolution EL map using one-month of TRMM PR data. As far as the horizontal resolution is considered, such a 2-km resolution EL map seems to be sufficient for the purpose of determining the clutter free bottom in the radar echo profile of a space borne radar whose footprint size is about a few km in diameter. For the determination of the clutter free bottom in the case of the future GPM DPR, a 2-km averaged SRTM30 map with corrections made by the 2-km resolution TRMM PR EL map seems to be promising.

We plan to generate the 2-km resolution TRMM PR EL maps using different months of data; for example, using the data in January or February when the north hemisphere is in winter. (Over high mountain areas, the use of winter data is preferable because snow, but not rain, falls in winter. Since very small attenuation is expected in the case of snowfall, the observed radar echo is very close to the profile without snowfall even at 13.8 GHz, the frequency of the TRMM PR; thus higher accuracy in the position of the surface peak is expected.)

To validate the TRMM PR EL map, we need to examine the individual range profile of radar echo at the location where a large difference is observed between the TRMM PR EL and the SRTM30 EL.

Acknowledgments: The authors thank Japan Aerospace Exploration Agency, JAXA, for enabling us to engage in the development of TRMM PR algorithms. One of the authors (J. Awaka) thanks Japan Society for the Promotion of Science (JSPS) for the Grant-in-Aid for Scientific Research.

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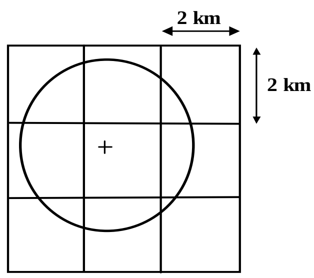
Table 1 Some characteristics of TRMM PR

Satellite altitude	350 km (before boost) *
Frequency	13.8 GHz
Range resolution	250 m (normal sample)
Horizontal resolution	4.3 km (at nadir)
Scan angles	-17° to +17° (49 angle bins)
Swath width	215 km

* Altitude was changed to 400 km in August 2001.



+ : beam center

Figure 1 grid box

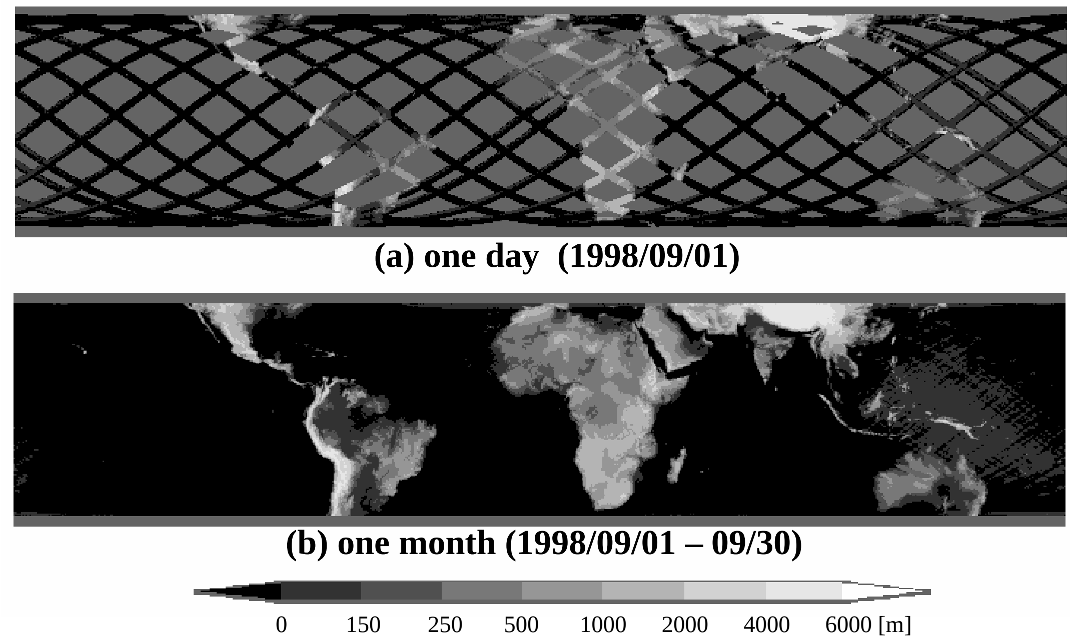


Figure 2 Example of surface EL map using the TRMM PR data

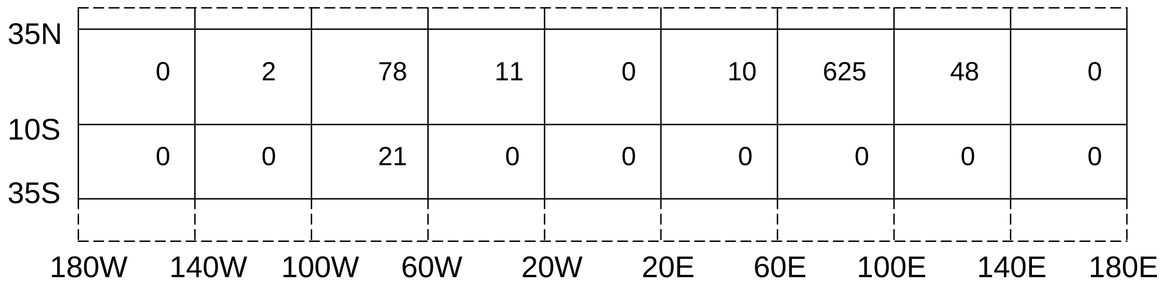


Figure 3 Number of pixels where the difference between the (2-km averaged) SRTM30 EL and the TRMM PR derived EL is larger than or equal to 1 km. These numbers are obtained for each tile defined by SRTM30.

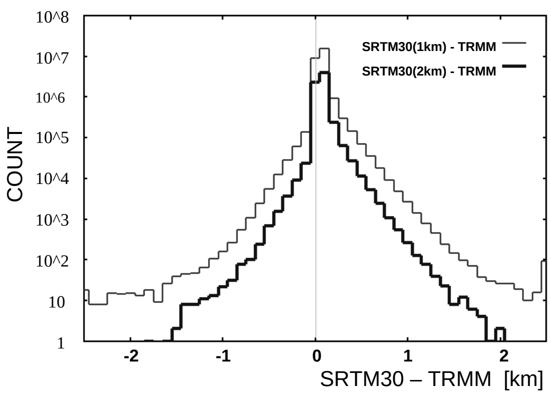


Figure 4 Details of the difference between the SRTM30 EL and the TRMM PR derived EL in the SRTM30 tile e060n40.

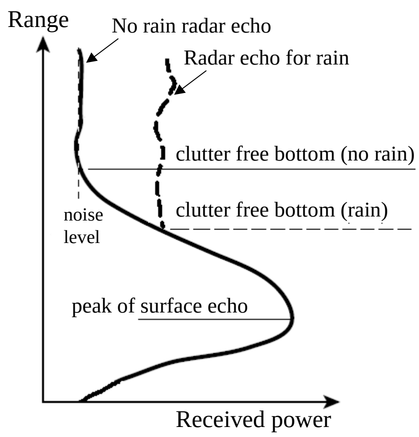


Figure 5 Clutter free bottom