Development of Mainlobe Clutter Identification Routine for TRMM Precipitation Radar

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1. Introduction

The first spaceborne precipitation radar (PR) is on board the Tropical Rainfall Measuring Mission (TRMM) satellite, which was launched into orbit in 1997. The TRMM PR operates at 13.8 GHz and observes rain in the region of +/–35 [deg] in latitude. The swath width of PR is about 220 km, which is realized by an electronic cross-track scanning of the antenna beam in 49 directions; the footprint size of the antenna beam is about 4 km [1].

For the observation of rain from space, such as using the TRMM PR, discrimination of rain from mainlobe surface clutter becomes very important for retrieving a reliable rainfall rate. Though the determination of the position of mainlobe-clutter top is rather easy over flat areas, the determination of mainlobe clutter becomes extremely difficult over high mountain areas because a large height variation of terrain within the footprint of a radar beam smears and broadens the peak shape of the surface clutter to a large extent.

A mainlobe clutter (identification) routine is installed in one of the Level-1 TRMM PR algorithm, called 1B21, for determining the position of mainlobe-clutter top [2]. The mainlobe clutter routine uses the DID digital elevation dataset [3]; here, DID stands for DTED (Digital Terrain Elevation Dataset) Intermediate Dataset. The DID dataset has the horizontal resolution of 1 km.

2. Example of mainlobe clutter

Fig. 1 illustrates typical mainlobe clutters due to (a) sea surface and (b) land surface of high mountains; both (a) and (b) are observed by the TRMM PR, whose noise level is about –110 dBm. The thin line shows the automatically detected clutter region and the thick line the region free from the mainlobe clutter. In the figure, the ordinate shows the range bin number with a 250 m interval, and the abscissa the received power in dBm. The origin of the range bin number in the figure corresponds to the surface of Earth's ellipsoid. A conversion from the range bin number to the height is straightforward.

3. Mainlobe clutter routine

Fig. 2 shows a flowchart of the mainlobe clutter routine. The mainlobe clutter routine uses the peak position of a surface clutter, which is determined by 1B21 using a peak search of the received power, Pr, of the radar signal within a search window with a help from the DID information.

Let h_surf be the height (above the sea level) of the surface clutter peak. When the DID digital elevation data is inaccurate, the surface clutter peak appears outside the peak search window; a large DID error (in accuracy) makes the algorithm 1B21 produce a wrong h_surf, which can be easily detected by examining Pr at and around h_surf. Thus far, a large DID error is found to occur over the Guiana highlands, over Tibet, over the Andes, and over some other limited areas. When a large DID error is detected, the mainlobe clutter routine makes a correction to h_surf.

The height of the mainlobe-clutter top over a flat area, h_MLCTflat, may theoretically be given by

$$\text{h\_MLCTflat} = \text{h\_surf} + \text{D\_flat} \qquad (1)$$

where D_flat denotes the difference between h_MLCTflat and h_surf. A nominal value of D_flat for a given angle of incidence of the beam can be computed using the PR characteristics (such as antenna pattern, transmitting power, and noise level) and an appropriate model for backscatter properties of Earth's surface at 13.8 GHz [4]. Over flat areas, the actual height of the mainlobe-clutter top is very close to h_MLCTflat given by (1) with the nominal value of D_flat.

Examination of the TRMM PR data indicates that an upper bound of the height of the mainlobe clutter over non-flat areas can be expressed by the following expression for the majority of cases:

$$\text{h\_UB} \cong \mathbf{Max}\{\text{h\_MLCTflat+margin, HD\_max+(HD\_max–HD\_min)}\} \qquad (2)$$

where **Max**{ } means to take the maximum value of the arguments in { }, and HD_max and HD_min are the maximum and the minimum value of DID elevation data in an 11 km * 11 km box whose center coincides with the center of the antenna beam footprint.

A search for the mainlobe-clutter top starts at a particular height denoted by h_10dB (see Fig. 3); where h_10dB is defined as the lowest height at which the received power, Pr, becomes equal to noise+10 dB when Pr is examined in the height region between h_surf+(a margin) and h_UB (for flat areas, h_UB is set to h_MLCTflat+ another margin). When it rains, it can happen that h_10dB is not found in the above height region; in such a case, h_10dB is set to h_UB.

When h_10dB is determined, the mainlobe clutter routine examines whether h_10dB belongs to a rain region (case A) or not (case B): if Pr above h_10dB is appreciable and the slope of Pr with respect to the range is small, it is judged that the height h_10dB belongs to a rain region.

Case A: When h_10dB belongs to a rain region, the slope of Pr with respect to range is examined in the lower height region starting from h_10dB down to about h_surf+D_flat until the slope exceeds the threshold, SL_th, which is a function of the antenna scan angle (SL_th is 10 dB/km near nadir and 8 dB/km at the antenna scan edges). The height at which the slope exceeds the threshold is the height of the mainlobe-clutter top, h_MLCT(det).

Case B: When h_10dB does not belong to a rain region, a search for h_MLCT(det) is made in the upper height region starting from h_10dB up to h_UB. The height h_MLCT(det) is indirectly determined via the height of clutter-free bottom, h_MLCfreeB, which is defined as the height being higher than h_MLCT(det) by one range bin (i.e., about 250m). In Case B, the height at which the slope becomes small and Pr itself becomes close to the noise level is h_MLCfreeB.

In both cases, the actual output of the mainlobe clutter routine is the range bin number corresponding to h_MLCfreeB.

The flow chart shown in Fig. 2 only outlines the mainlobe clutter routine: there exist several special cases which require extra handlings of the data not shown in the flow chart.

4. Validation

Validation of the determined clutter-free bottom is made by visually inspecting each plotted graph such as Fig. 1 and by examining some statistical data such as the monthly rainfall processed by the PR algorithm called 3A25. For example, when a very large monthly surface rainfall is found in a very arid area or in the region where the accuracy of the DID elevation data is doubtful, visual inspection on the plotted graph such as Fig. 1 is made in those suspicious areas.

With these validations, it is estimated that the mainlobe clutter routine works successfully for more than 99% of cases.

5. Concluding Remarks

The mainlobe clutter routine outlined above is installed in the TRMM PR standard algorithm 1B21 as a kind of plug-ins. Since the mainlobe surface clutter is inescapable in the observation of rain from space by radars, the outlined method would be useful to the spaceborne rain radars in the next generation.

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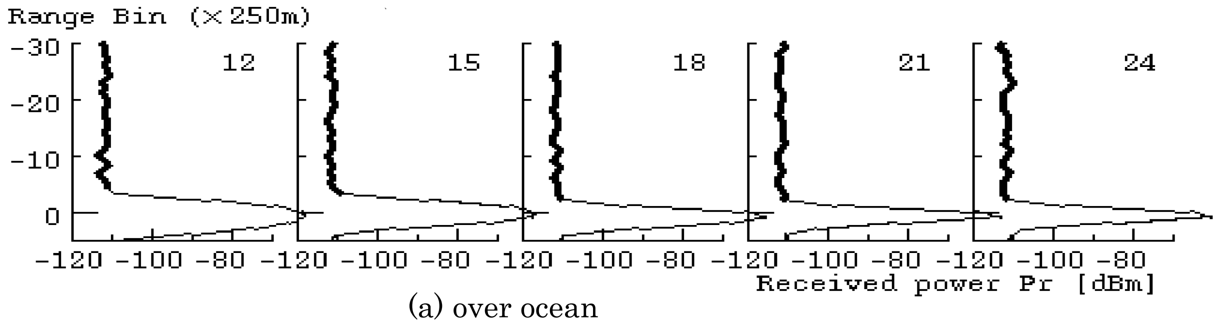
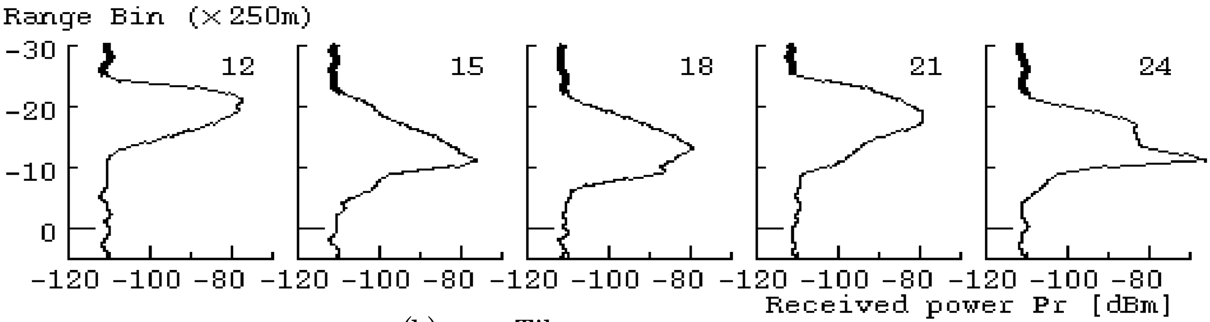


(a) over ocean



(b) over Tibet

Fig. 1 Examples of mainlobe clutter (thin lines) (a) over flat area and (b) over non-flat area. The number at the upper-right of each profile indicates the angle bin number, N_ang, of the antenna scan angle: N_ang takes values from 0 to 48 with N_ang=24 corresponding to the nadir and N_ang=0 and 48 to the scan edges.

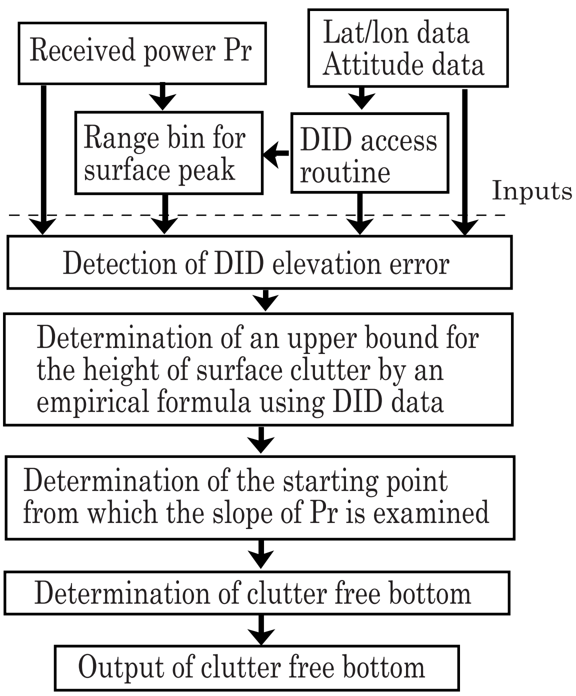


Fig. 2 Flowchart of clutter routine

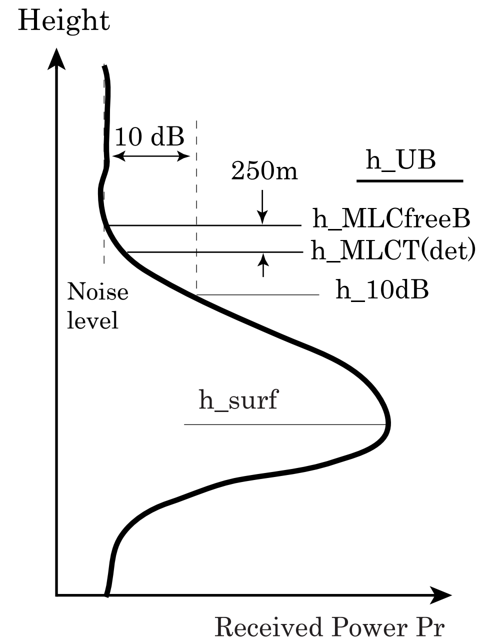


Fig. 3 Definition of heights essential to the clutter routine