Multi Resolution Analysis: MRA Based Bright Band Height Estimation with Precipitation Radar Data

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Abstract

A method for reconstruction of cross section of rainfall situations with precipitation radar data based on wavelet analysis of Multi-Resolution Analysis (MRA) which allows extract a peak of the radar reflectivity is proposed in order to detect bright band height. It is found that the bright band height can be estimated by using the MRA with the basis of Daubechies wavelet family. Through the comparative study between the proposed method and the conventional differentiation operator based edge detection, it is found that the proposed 3D wavelet transformation based edge detection is superior to the conventional method in terms of bright band detection performance. It is also found that the boundaries in rainfall structure can be clearly extracted with MRA.

Keywords: Bright band, Multi-Resolution Analysis, Wavelet, TRMM, Precipitation Radar.

1. INTRODUCTION

The bright band is a layer of enhanced radar reflectivity resulting from the difference in the dielectric factor ice and water and the aggregation of ice particles as they descend and melt. In accordance with Glickman, 2000, the bright band height is the altitude of maximum radar reflectivity in the bright band [1]. The layer over which the transformation from ice to water occurs defines the melting layer. The top of the melting layer is the melting level, also commonly accepted as the altitude of the 0 degree centigrade constant-temperature surface. By using Doppler radar data derived from the Doppler vertical velocity, bright band height is estimated using a negative relation between the Doppler vertical velocity and the bottom portion of the bright band where vertical gradients of radar reflectivity so that the bright band height can be estimated with the altitude at which the radar reflectivity shows its peak. White, et.al. 2002 proposed the method for bright band height detection algorithm by using the change rate of signal to noise ratio to the altitude and reflectivity profile for the purpose of monitoring the melting level forecasting [2].

One of the purposes of the precipitation radar is to estimate rainfall structure, vertical profile in particular. Radius or size parameter of raindrops can be estimated with precipitation radar data. The radar reflectivity profile can also be derived from the precipitation radar data. Then the bright band height can also be assigned by looking at the peak of the radar reflectivity. There, however, are some peaks around the bright band height so that it is not so easy to find the most significant peak at which the bright band height is situated. On the other hand, signal to noise ratio is not so easy to estimate due to the fact that signal and noise discrimination is difficult. Then a new method which allows assign the bright band height derived from precipitation radar data is required.

The method proposed here is featuring the Multi-Resolution Analysis (MRA)[1] with the most appropriate base function of Daubechies wavelet family (Arai, K., 2000) [3]. Firstly, one

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dimensional MRA is applied to the Tropical Rainfall Measuring Mission/Precipitation Radar (TRMM/PR)[2] data along with the range direction. Furthermore, two dimensional MRA is applied to the TRMM/PR data along with the range and scanning directions. Finally three dimensional wavelet analysis of MRA is applied to the same TRMM/PR data along with the range and scanning directions as well as satellite track direction.

2. PRELIMINARY EXPERIMENT

2.1 TRMM/PR

The major specification of TRMM/PR is shown in Table 1. Major design and performance parameters are described by Kozu., et.al., 2001 [4]. The backscattering cross section of raindrops can be estimated with the reference to the surface backscattering cross section without rainfall (Menrghini, et.al., 2000 [5]). The bright band height is assigned by looking at the rain echo signal (Awaka, et.al., 1997 [6]). The radar reflectivity factor, Z[3] with the rain attenuation correction for each radar beam is calculated based on the combining methods of Hitschfeld-Bordan [7] and surface reference method (Iguchi, et.al., 2000 [8]). An illustrative view of the TRMM/PR data acquisition mechanism is shown in Fig.1.

Radar type	Active phased array radar
Frequency	13.796 GHz and 13.802 GHz
Swath width	215 km
Observed range	From the ground surface to a height ≧ 15 km
Range resolution	250 m
Horizontal resolution	4.3 km
Sensitivity	S/N per pulse ≧0 dB for 0.7 mm/h rain at the rain top

TABLE 1: Major specification of the TRMM/PR (Precipitation Radar onboard TRMM satellite)

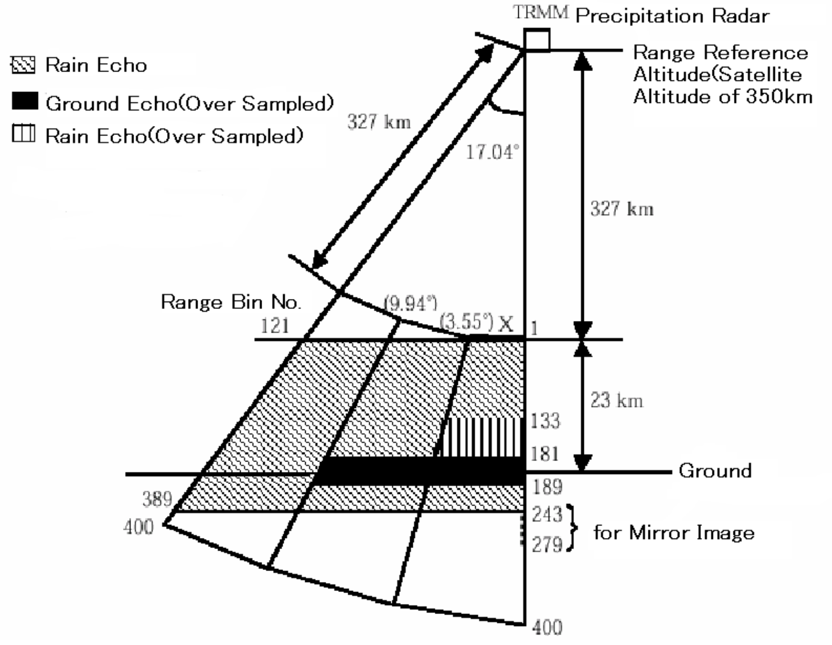

FIGURE 1: Range and scanning directions and numbering (Range bin No.1 is corresponding to the 23 km of the altitude from the sea level while the range bin No. 140 is corresponding to the ground with the range resolution of 250 m while the angle bin No. in the scanning direction ranges from 0 to 49 with the 4.3 km of the horizontal resolution).

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[2] http://trmm.gsfc.nasa.gov/

[3] http://apollo.lsc.vsc.edu/classes/remote/lecture_notes/radar/conventional/re_distributed.html

2.2 Proposed Method

Bright band is defined as the layer which contains melted ice crystals (Ice crystals covered with water) situated in between ice crystal and water cloud layers as shown in Fig.2. Fig.2 shows reflectivity in microwave of wavelength region of vertical profile of the clouds in rainfall areas acquired with one dimensional microwave profiler. Vertical axis shows altitude from the sea level and atmospheric pressure while horizontal axis shows distance in one dimensional measurement line. In Fig.2, green colored portions are rainfall areas while blue, in particular, light blue colored areas are ice crystal dominant layer. There are bright bands (yellow and red colored portions) between ice crystal and rainfall cloud layers. It is obvious that the bright bands can be extracted through differentiation of vertical reflectivity profile. Typically, the differentiation of one dimensional vertical reflectivity profile extracts not so clear bright bands and also it may not extract 3D shape of the bright bands. The method proposed here is to allow clarify 3D shape of the bright bands by using two dimensional vertical profiler of rain radar onboard earth observation satellite (Precipitation Radar: PR on Tropical Rainfall Measuring Mission: TRMM) and to allow extraction of much clear bright bands by using 3D image of radar echo with 3D wavelet transformation.

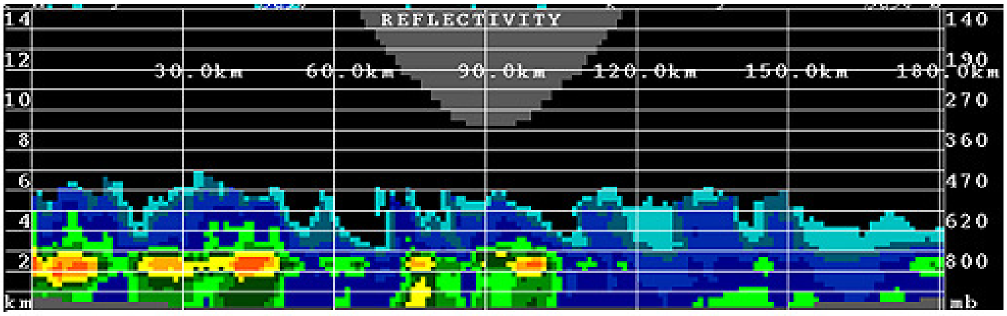
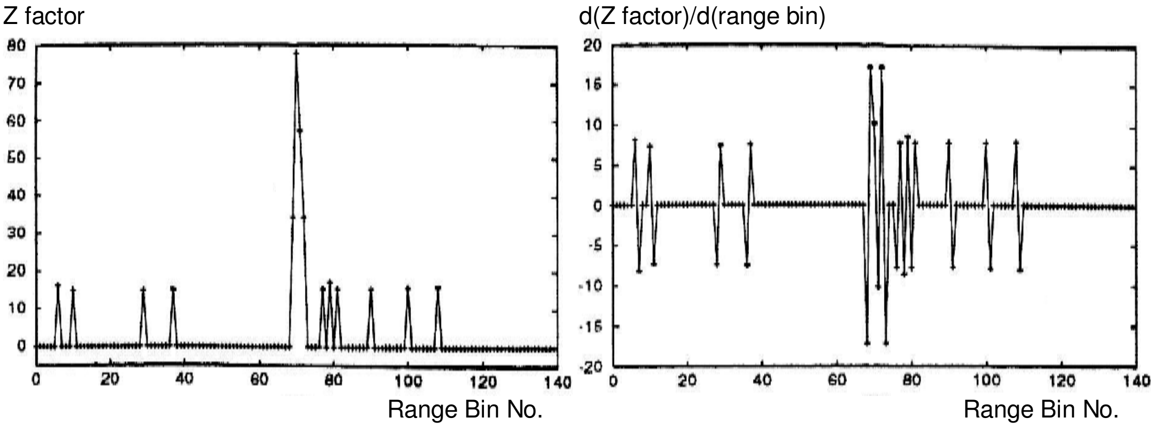


FIGURE 2: Typical one dimensional radar reflectivity profiler in vertical direction which allows extraction of bright bands

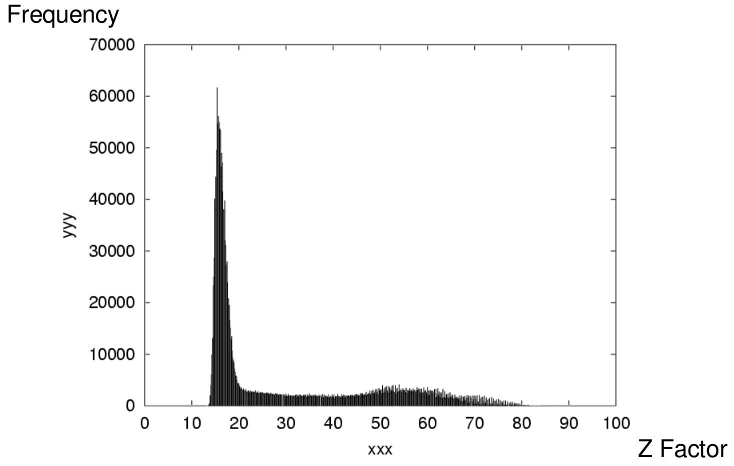
The aforementioned Z factor which represents radar reflectivity as well as rain rate are derived from the TRMM/PR data. The bright band height is situated at the peak of the radar reflectivity. It, however, is not always that the bright band height corresponds to the height at which the Z factor shows the peak. Also it is not so easy to assign the bright band height because it is varied by location by location. Other than these, it is difficult to detect the peak of the radar reflectivity from the acquired noisy and gradually changed Z factor in time. An example of the acquired Z-factor is shown in Fig.3 (a). In the Fig.3 (a), there is the peak at around the range bin No.73 and the leading edge is started from the range bin No.70 and ended at around No.75 so that the bright band height is situated around at the range bin No.73 in this case. In order to identify the peak more clearly, the proposed method utilizes MRA with the most appropriate base function. The original signal is decomposed to two different wavelet frequency components, high and low through MRA analysis. If the low component is filled with zero, after that an original resolution of image is reconstructed with the high and the zero filled low components, the edge in the original image is sharply enhanced as is shown in Fig.3 (b).

Fig.4 shows the histogram of the original Z factor and the absolute value of the edge enhanced Z factor by the proposed method. Although the maximum Z factor is around 80, the bright band height are situated at around 70 to 80 of Z factors for each angle bin. Also the bright band height seems to be situated at around 0 to 4 of the absolute value of the edge enhanced Z factor based on the proposed method.

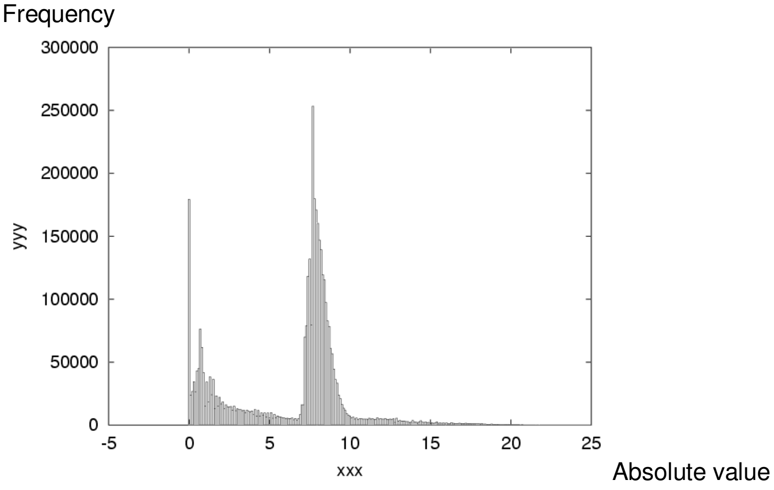


(a)Original Z factor (b)Edge enhanced Z factor using the proposed MRA analysis for bright band assignment

FIGURE 3: An example of Z-factor which represents radar reflectivity with the rain attenuation correction for each radar beam and the edge enhanced Z factor using MRA analysis for bright band assignment.



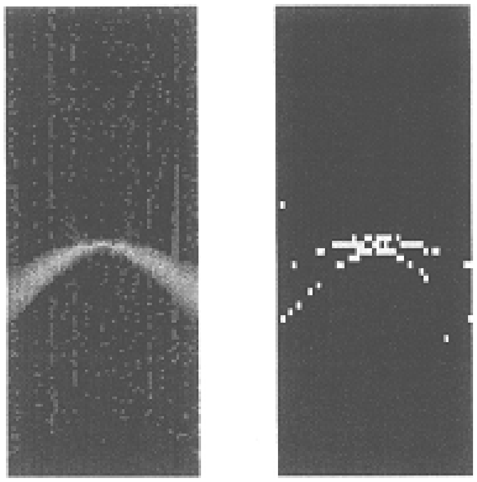
(a) Z Factor



(b) Absolute Value

FIGURE 4: Histogram of the original Z factor and the absolute value of the edge enhanced Z factor by the proposed method.

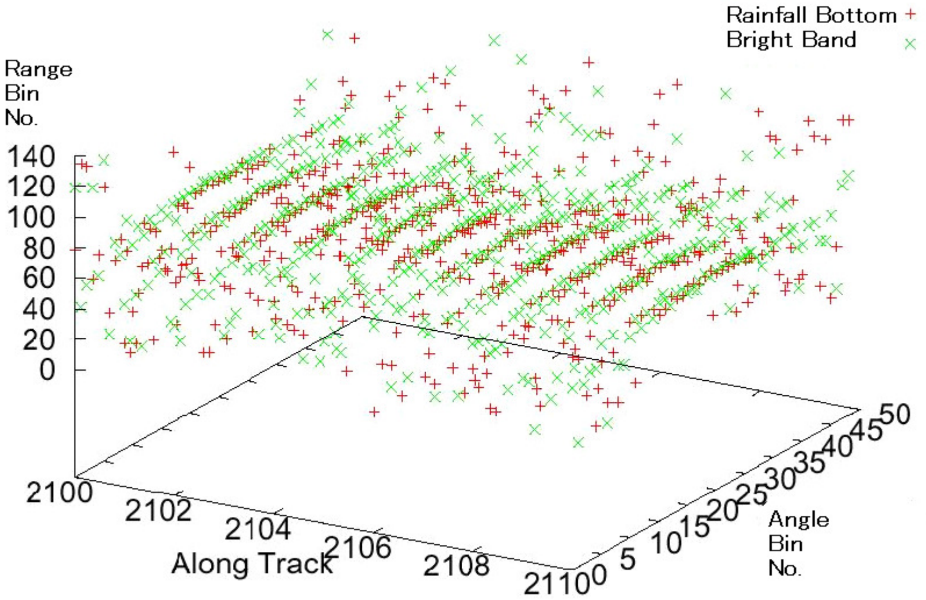
Fig.5 (a) shows the original Z factor of the image and (b) shows edge enhanced Z factor image. Also Fig.6 shows the altitude of the rainfall bottom and the bright band height estimated by the proposed method. In the figure, one dimensional MRA analysis is applied to the original Z factor data in the range bin direction. The rainfall rate is estimated by range bin by range bin. After that detected rainfall bottom and the bright band height estimated with the proposed method are plotted along with the angle bin and the satellite track directions. Truth data for the bright band height is too difficult to get. It, however, seems reasonable through a consideration from rainfall bottom.



→Scan direction (Angle Bin)

(a) Z factor (b) Detected edge

FIGURE 5: Original Z factor and the edge enhanced Z factor images as a function of angle bin No.



FIGIURE 6: An example of the detected rainfall bottom and the bright band height by the proposed method of one dimensional MRA analysis

2.3 Bright Band Estimation With z Factor Based on Multi-resolution Analysis: mra

The proposed method for bright band assignment is the same as is described in the previous section. Namely,

(1) Decomposition of MRA is applied to the Z factor (radar reflectivity factor) data of TRMM/PR,
(2) Low frequency component is filled with zero then
(3) Reconstruction of MRA is applied to the decomposed data without low frequency component
(4) Edge enhanced Z factor of which zero crossing point corresponds to the bright band height..

There are two, three or more than three dimensional MRA analysis, not only one dimensional (1D) MRA. By using two dimensional (2D) MRA, the edge in the range bin and the angle bin directions can be extracted. Also three dimensional (3D) MRA allows extraction of edge in the range, angle and satellite track directions. More effective bright band assignment with MRA analysis is expected.

3. EXPERIMENTAL RESULTS

3.1 Data Used

The TRMM/PR data is acquired during from 16:13:47 to 17:46:10 on 20 April 2003. The area covered with TRMM/PR is illustrated in Fig.7. As shown in Fig.7, Typhoon is situated at eastern offshore of Philippine at that time (the acquisition times of TRMM/PR and GMS/VISSR[4] are different so that the typhoon locations in the images are different a little bit). In the center, bright bands layer is situated in the stratiform[5] of the typhoon clouds. Blue colored line in Fig.7 shows satellite track of TRMM/PR swath. At the eastern part of Philippine, green colored portions are observed. These are portions of typhoon.

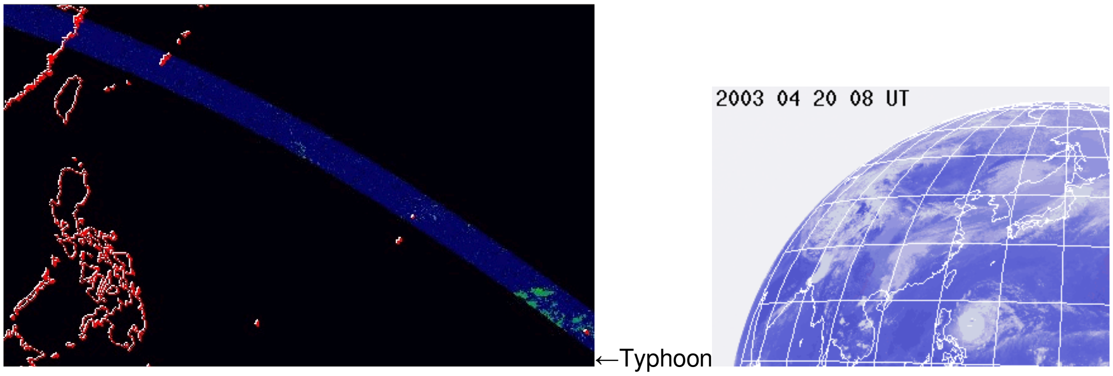


FIGURE 7: The area of interest (The eastern offshore of Philippine, light blue area shows satellite track while green colored portion is heavy rainfall areas (Typhoon)) and Geostationary Meteorological Satellite VISSR derived typhoon image acquired in the almost same time for acquisition of TRMM/PR

3.2 Experimental Results

The Z factor derived from the TRMM/PR data, the estimated bright band height based on the MRA with 1D wavelet transformation and the edge enhanced image of the Z-factor with the Sobel operator[6] are shown in Fig.8.

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[4] http://idn.ceos.org/portals/Metadata.do?Portal=idn_ceos&KeywordPath=%5BKeyword%3D%27GMS%27%5D&OrigMetadataNode=GCMD&EntryId=GMS-VISSR-MSC-JWA&MetadataView=Full&MetadataType=0&lbnode=mdlb3

[5] http://www-das.uwyo.edu/~geerts/cwx/notes/chap10/con_str.html

[6] http://en.wikipedia.org/wiki/Sobel_operator

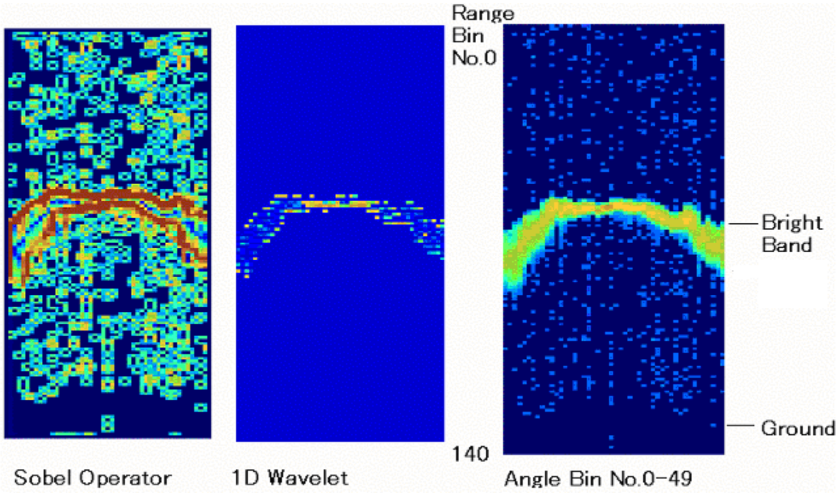

FIGURE 8: Z-factor derived from the TRMM/PR data (Right), the estimated bright band height based on the MRA with 1D wavelet transformation (Center) and the edge enhanced image of the Z-factor image with the Sobel operator (Left).

On the other hand, the estimated bright band height based on the MRA with 1D, 2D and 3D wavelet transformations are shown in Fig.9.

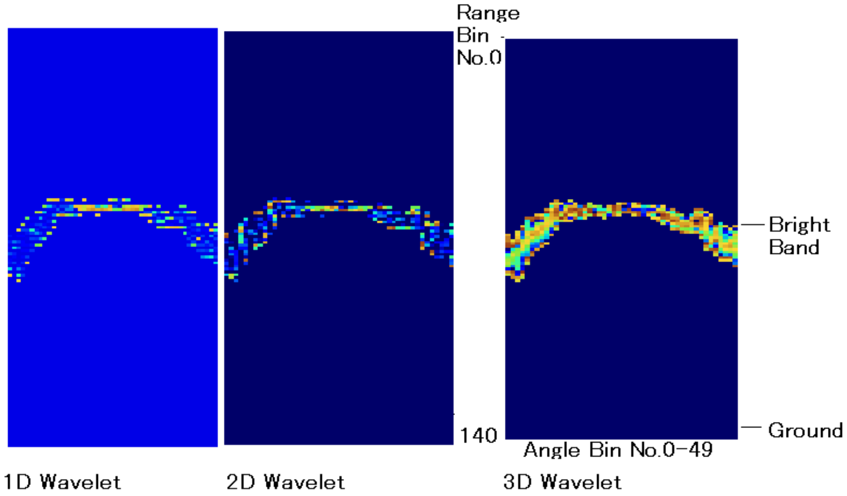

FIGURE 9: Estimated bright band height based on the MRA with 1D, 2D and 3D wavelet transformations.

Through a comparison of the estimated bright band height among the 1D, 2D and 3D wavelet transformations, the bright band height can be seen in the 3D wavelet transformation followed by 2D and 1D wavelet transformations. In the result from 1D wavelet transformation, only the vertical profile of the Z factor is used so that the edges detected is much less than 2D and 3D wavelet transformations. Almost same experiment with the rain rate and Z factor derived from TRMM/PR data of the northern part of Argentina which was acquired on Dec.21 1997 support the results. It is also confirmed that the dual orthogonal Daubechies wavelet[7] base function is appropriate in comparison to the Haar (Arai , 2000.) [3] due to the fact that the edge shape is more likely to Daubechies rather than Haar base function.

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[7] http://academicearth.org/lectures/splines-and-orthogonal-wavelets-daubechies-construction

4. CONCLUDING REMARKS

It is found that the bright band height can be estimated by using the MRA with the basis of Daubechies wavelet family. It is also found that the boundaries in rainfall structure can be clearly extracted with MRA.

Although it is obvious that the bright bands can be extracted through differentiation of vertical reflectivity profile, typically, the differentiation of one dimensional vertical reflectivity profile extracts not so clear bright bands and also it may not extract 3D shape of the bright bands. It is confirmed that the proposed method allow clarify 3D shape of the bright bands by using two dimensional vertical profiler of rain radar onboard earth observation satellite (Precipitation Radar: PR on Tropical Rainfall Measuring Mission: TRMM) and also allows extraction of much clear bright bands by using 3D image of radar echo with 3D wavelet transformation in comparison to the conventional one dimensional Sobel differentiation operator.

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