Rain height dynamics over some coastal cities of South Africa for earth-space links design

E O Olurotimi¹ and J S Ojo²
¹Department of Electronic and Computer Engineering, Durban University of Technology, Durban, 4000, South Africa
²Department of Physics, Federal University of Technology, Akure, 340001, Nigeria
Email: elisayrot@gmail.com

Abstract. One of the major parameters required for the prediction of rain-induced attenuation is the rain height. This paper presents some dynamic features of rain height measurement from TRMM-PR over two coastal cities in the Republic of South Africa. The analysis of 5-year data on the variation of bright band height, atmospheric pressure, relative humidity, and temperature reveal seasonal dependence over the studied locations. The result shows the existence of stratiform-convective interaction within the season, especially during the summer months. The observed exceedance in the probability of the bright band also shows the presence of two rain type (stratiform and convective). Comparison of rain height measurements with the recommended ITU-R reveals above 1 km variations with the percentage difference of about 30%, which could create a serious negative effect on the link design. This study suggests the adaptation of local rain height data for better accuracy of link design for the region.

Keywords-Bright band height, 0° C isotherm height, coastal cities, subtropical and TRMM-PR.

1. Introduction
The enhancement of satellite communication systems is crucial in today’s technology, specifically, those currently operating at the frequencies higher than 10 GHz. Detailed information on signal degradation is necessary to achieve a good quality of signals (QoS) along the propagation path [1, 2]. Some of these factors are present in the melting layer region (that is rain height parameters, such as 0° C isotherm and bright band height). At the frequencies above 10 GHz, satellite signals passing through the atmosphere are known to be tremendously affected by hydrometeors, which include rain height, cloud, rainfall, hail, among others, and this is known to be destructive to the signals QoS on the receiving end [1, 3-9]. Recommendations made by the International Telecommunication Union (ITU) show the importance of rain height parameters as required for various degradation evaluations as provided in [10-13]. Rain height is an interrelated parameter for the prediction of rain attenuation.

Features of rain height can be obtained through indirect means from the atmospheric melting layer region [14-17] due to the scarcity of direct measurement of rain height data in the subtropical region, Southern Africa inclusive. Using the indirect technique, the height of the bright band and 0° C isotherms were obtained from the Tropical Rainfall Measuring Mission-Precipitation Radar (TRMM-PR) as delivered in the 2A23 algorithm. This algorithm can be used to evaluate rain height data required for rain-induced attenuation evaluation along the satellite links as recommended by the ITU. The bright band is defined as the horizontal layer in which more robust radar reflectivity occurs during the transformation from the accumulated melting state of precipitation to rainfall state [14, 17-22]. The bright band height is also known as the layer that radar reflectivity improves as a result of the dielectric factor disparity between water, ice, and the ice particles summation when moving to the melting point. 0° C isotherm height is the free atmosphere height where the temperature is usually equal to 0°C, this
could be referred to as water freezing point. Figure 1 presents the schematic diagram which reveals the positions of the bright band with 0°C isotherm height along the vertical reflectivity profile. As seen in figure 1, the bright band and 0°C isotherm height lie close to one another. This does not signify that both parameters are the same, several studies had indicated that these parameters are different [17, 23, 24].

![Figure 1. Vertical profile of a typical radar reflectivity [14, 17].](Image)

In this paper, 5-year of rain height data (bright band and 0°C isotherm heights) were measured from the TRMM-PR to deduce the dynamic of rain height information over two coastal cities in South Africa. Section 2 presents the source of data and the methods used; Section 3 gives the results and discussion, while section 5 gives the conclusion.

2. Data Source and Methodology

The coastal cities selected in this work are well known as an attractive, adventurous, and well-populated cities in the Republic of South Africa (SA). The cities have a higher percentage of customers linked to satellite communication services in the Republic. The coastal cities are Durban (29° 97’ S, 30° 95’ E) and Cape Town (33° 58’ S, 18° 36’ E). SA is characterized by different climates due to its position on the globe (as surrounded by two different oceans as illustrated in [17]. Durban is known as one of the wettest cities in SA, situated laterally on the Eastern boundaries of the Republic and characterized by Coastal Savannah climate. Cape Town is one of the windiest cities of the Republic, located on the Southwest coast and characterized by a Mediterranean climate. The two locations experience four different climatic seasons, namely: autumn (mid-February to April), winter (between May and July), spring (between August and mid-October), and summer (between mid-October and mid-February) [17, 25-27].

This study presents 5-year data (2011–2015) of the bright band and 0°C isotherm heights obtained from the Tropical Rainfall Measuring Mission-Precipitation Radar (TRMM-PR). TRMM-PR is known as the most important sensor on the Tropical Rainfall Measuring Mission satellite and consists of the 2A23 algorithm as one of its algorithms. The 2A23 algorithm has the capability of detecting the bright band when there is a presence of rain. It detects the altitude of the bright band, 0°C isotherm, storm, and classifies rain type among others. The procedure for the extraction of the bright band and 0°C isotherm heights from the 2A23 algorithm is as follows: The positive values (measured in meters) are for the bright band and 0°C isotherm heights above the mean sea level, while the negative values tagged as -1111 means no bright band; -8888 means no rain; -5555 means an error occurred in the 0°C isotherm height estimation, and -9999 is the missing data [17, 24, 28, 29]. The classification of rain type in the 2A23 algorithm used two methods, namely, the vertical profile in addition to the horizontal pattern methods, to classify rain type into three categories, which are stratiform, convective and others (which either could be cloud or noise). In the vertical profile method, when the occurrence of the bright band is detected, it categorizes the rain type as stratiform. Also, rain type can be categorized as convective when the bright band is not detected, whereas the radar echo is strong; while the case of other types is when neither stratiform nor convective rain type is detected. In the case of the horizontal
pattern method, the categories of convective are first detected, when the maximum radar reflectivity in the rain region exceeds 40 dBZ. Rain type can also be categorized as stratiform when the detected rain type is non-convective and there is a certainty of rain echo existence. The other type is referred to as when the radar echo is below 0°C isotherm and a bin of a given angle is very weak. A further illustration could be found in [17, 30].

In this study, the annual mean rain height value (km), \( h_r \), associated with 0°C isotherm height (km), \( h_o \), as recommended by ITU-R Rec. P.839-4 can be expressed as [31]:

\[ h_r = h_o + 0.36 \]  

(1)

3. Results and discussion

Figure 2 presents the variation of 5-year monthly mean bright band height and some atmospheric parameters (atmospheric pressure, relative humidity and temperature) over the studied locations. It was generally observed that the bright band height (BBH) and other parameters are all monthly and seasonal dependence. It was further observed that Durban recorded its highest BBH value of about 3938.3 m in the month of September while Cape Town recorded its highest BBH value of 4001.8 m in the month of August. Both locations recorded their lowest values in January at about 3708.6 m and 3639.9 m for Durban and Cape Town, respectively. It could also be observed in Durban that the bright band height values slightly fall from early autumn through the end of the season; rise higher during winter, and then it slightly falls at the beginning of the spring and rises back as it recorded its highest peak in the middle of the season. The values further fall at the end of spring through the following season (summer) till January and rise at the end of summer months. During autumn in Cape Town, BBH values rise at the beginning and fall at the end, then rise a bit high and higher in the first two months of the winter season then fall a bit at the end of the season. BBH values further rise at the beginning of spring where it recorded its highest peak, then fall through to November, as it rises a bit in December and fall in January, then rises at the end of summer months.

Atmospheric pressure recorded its highest values with about 1022.3 mb in July over Durban, and the lowest values of about 1013 mb were recorded in February over Durban while the highest and lowest value was experience in Cape Town in January and February, respectively. The same trend could be observed for the Temperature values over the studied locations. The temperature recorded its highest values in January and February in Durban with about 22.8°C and only in January with about 21.2°C at Cape Town. Temperature also recorded its lowest values in July over the two locations with about 16.2 and 12.2°C over Durban and Cape Town, respectively. Relative humidity recorded its highest value in December with about 84.2% and in August with about 77.2% over Durban and Cape Town, respectively. While its lowest values were recorded in June with about 65.4% and April with about 68.8% over Durban and Cape Town, respectively.

Figure 3 presents the variation of 5-year mean seasonal BBH. Generally, we observed the same trend over both locations of study. Spring recorded the highest BBH values of about 3.898 and 3.964 km, followed by winter with about 3.877 and 3.941 km, then summer with about 3.788 and 3.813 km, while autumn recorded the lowest values of about 3.759 and 3.750 km over Durban and Cape Town, respectively. This work agrees with the findings of [32], that the seasonal dependence of the bright band height was revealed in the subtropical regions when studying the global variation.
Figure 2. Monthly mean variations of bright band heights with atmospheric parameters over Durban and Cape Town.

In figure 4, the probability exceedance of the height of the bright band is presented. The probabilities over the observed regions show that BBH is location dependence despite both locations belonging to the coastal zones. Also, the exceedance over the two locations is bimodal (two peaks), which implies, the two rain type categories (stratiform and convective) are dominant over these locations. The existence of a similar pattern within the exceedance probability also shows the stratiform-convective interaction within the two locations. We also observed that the bright band height varies between 2.5 and 4.7 km in Durban while it is about 3.3 and 4.4 km in Cape Town.
Figure 4. Probability exceedance of bright band heights over Durban and Cape Town.

Figure 5 shows the comparison of the annual mean of rain height distribution concerning 0° C isotherm height measured from TRMM-PR over the study locations with ITU-R Rec. P.839-4. It could be observed that rain height slightly varied from month to month and from one location to another. It must be noted that the recommended ITU-R annual mean rain height value is 3.36 km for the region of study. The measurement indicates that rain height can fluctuate from one location to another and slightly fluctuate from one month to another. Also, the ITU-R value underestimated the rain height values over the studied locations. The measured rain height varies from the recommended ITU-R value with about 1.01 and 1.04 km over Durban and Cape Town, respectively. Due to the variation in the observed rain height, we, therefore, recommended the use of local rain height for proper computation of link designs for the studied locations.

Figure 5. Comparison of annual mean rain height with the ITU recommended value.

4. Conclusions
The dynamic of rain height information from TRMM-PR measurement over some coastal cities in the Republic of South Africa has been presented. The results show that the monthly mean bright band height varies from one location to another, which shows that there is a seasonal dependence of bright band height in the subtropical locations. The probability exceedance reveals the presence of two rain type and distribution of rain heights compared with recommended ITU-R prediction reveals an underestimation to the measured values. The implications of this study reveal that local values of rain height are highly important in proper computations of link designs to provide a good quality of service to the end users.
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