Comparison of Cloud Models for Propagation Studies in Ka-band Satellite Applications

Feng Yuan[1], Yee Hui Lee[1], and Yu Song Meng[2]
[1]School of Electrical and Electronic Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore
[2]National Metrology Centre, Agency for Science, Technology and Research (A*STAR), 1 Science Park Drive, Singapore 118221, Singapore
yuan0053@e.ntu.edu.sg, eyhlee@ntu.edu.sg, ysmeng@ieee.org, meng_yusong@nmc.a-star.edu.sg

***Abstract* - In this paper, comparison and analysis of different cloud models are performed for detecting the cloud and its vertical structure for Ka-band satellite applications. One-month radiosonde data is processed for cloud detection and its base height calculation using some published cloud models. With the ceilometer (CL31) data as reference, it is found that the Salonen Uppala model is the most suitable one for cloud detection in this study.**

***Index Terms* — Ceilometer, Ka-band, Propagation, Satellite.**

I. Introduction

Recently, cloud attenuation on satellite signal propagations has required attention especially at high frequencies [1] such as Ka-band (20/30 GHz). In a tropical country like Singapore, more than 80% of observed clouds are convective clouds. They are mostly thick cumulus clouds that are heavy with water and very high in water vapour content, and consequently accounts for a significant amount of attenuation. To estimate the cloud attenuation, radiosonde data has been well-accepted for cloud detection firstly [1-4].

In our previous work [5], online free radiosonde data with low vertical resolution has proved feasible to study the cloud attenuation in the tropical region. As a continued work, some researches have been performed on comparison and analysis of different cloud models for detecting the cloud and its vertical structure, and are reported in the following.

II. Prediction Models and Data Description

A. Cloud Vertical Structure Models

In this part, two major cloud detection methods to detect the cloud and its vertical structure are described; the first one is to adopt a constant threshold of relative humidity (RH), for example, Decker model [2]; the second type is to define a mathematical relationship to calculate a varied threshold for critical humidity (e.g, Salonen Uppala [SU] model [1]).

The Decker model applies a specific relative humidity as a fixed threshold and shown below

$$RH > 95\%. \tag{1}$$

The height of cloud base is determined as the first level at which the RH value is larger than 95%, and the cloud top height is the last level fulfill this criteria within the same cloud layer. This threshold (named as "De95") is set at a relatively high value, and could make misdetection of the cloud using radiosonde data. Han and Westwater [3] then suggested a new specific value (named as "De90") as

$$RH > 90\%. \tag{2}$$

For the second type of cloud detection method, Salonen and Uppala [1] proposed a critical humidity function (the SU model) as a varied threshold

$$U_c = 1 - \alpha \cdot \sigma(1-\sigma)[1+\beta(\sigma-0.5)] \tag{3}$$

where $\alpha = 1.0$ and $\beta = \sqrt{3}$. It is noted that σ is the ratio of the pressure at the measured level and on the surface level. If the measured humidity U_m is higher than U_c at the same pressure level, the considered level is assumed to be in a cloud.

B. Data Description

One-month (February 2013) online radiosonde data [6] at 48698 WSSS Singapore observation site (1.37ºN, 103.98ºE) is used to determine the cloud vertical structure and then for performance evaluation of the cloud models mentioned above.

Ceilometer (CL31) data from the same month is used as reference as in [4]. Although it is claimed to detect up to three layers of a cloud, the information of two upper layers is very limited and may be less accurate. Therefore in this paper, only the first layer data (cloud base height) is used.

III. Results and Discussion

A. Critical Humidity Threshold

Fig. 1 shows the measured relative humidity profile and the three critical humidity thresholds corresponding to the altitude of a radiosonde. It is observed that for the SU model, its threshold is mostly like a U-bend curve. For the Decker model (De95 and De90), the thresholds are two horizontal lines which are not varied with the altitude.

Another observation in Fig.1 is that, in the range less than 7000 m where low and medium clouds (containing high amount of water droplets) exist and contribute significantly in the cloud attenuation, the criteria of SU cloud detection is easy to meet. However for the De95 and De90 models, the criteria (higher critical humidity thresholds in general) is difficult to meet, and this might lead some misdetection.

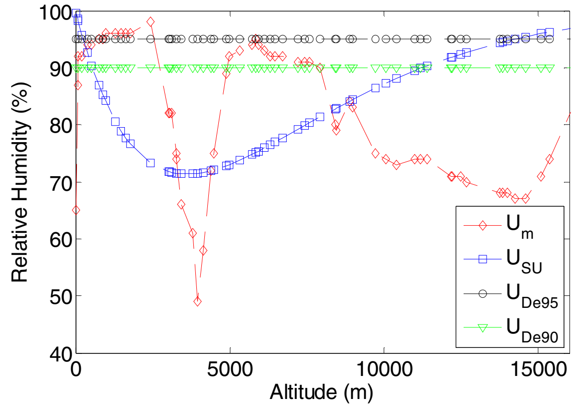

Fig. 1. The measured relative humidity profile versus the cloud detection thresholds.

B. *Cloud Base Height*

Fig. 2 shows the results of the cloud base heights estimated using the models (SU, De95 and De90) and the cloud base heights detected by a ceilometer (CL31) which are used as reference here as in [4]. From Fig. 2, it is found that less cloud detections are observed for De95 model, which is due to its high threshold as we discussed above. The SU and De90 models present more consistent results referring to the ceilometer data.

Statistically with one-month ceilometer data as a reference, the SU model has a 98% correct cloud detection; the De90 model has an 82% correct cloud detection; while De95 only has a 42% correct cloud detection. Therefore it could be concluded that, the De95 model with a relatively high threshold has poor performance for cloud detection in the tropical region.

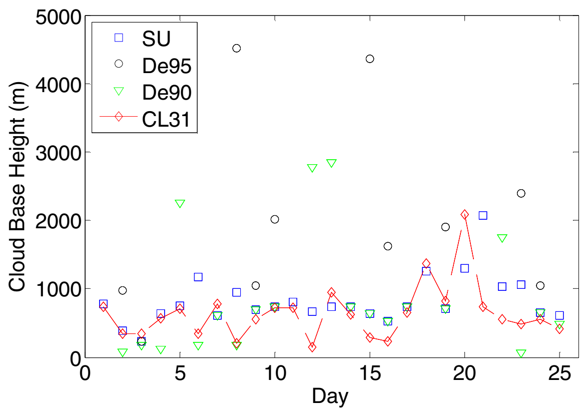

Fig. 2. Comparison of cloud base height determined using different methods with the ceilometer (CL31).

From Fig. 2, it is clearly observed that there are some differences between the cloud base heights detected by the ceilometer and estimated using the SU and De90 models based on the radiosonde data, although both the models have good cloud detection abilities.

Fig. 3 then shows the histograms of the difference between the cloud heights detected by the ceilometer and the heights estimated using the SU and De90 models. As one pin of 500 m, it can be seen that SU has more correct detection in the range of -250 m to 250 m, and the De90 model intends to have a larger variation. Another possible reason for such a deviation may be due to the low resolution of the online radiosonde data used.

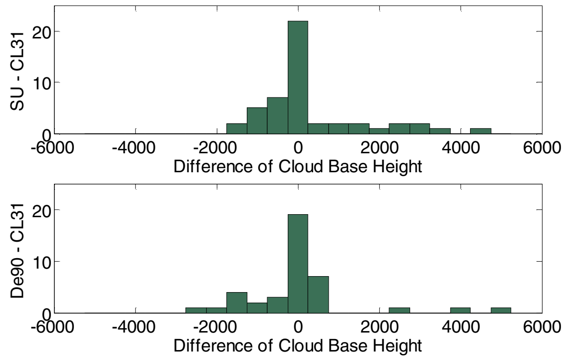

Fig. 3 Histograms of the difference between the cloud heights detected by the ceilometer and the heights estimated using the SU and De90 models.

IV. Conclusion

In this paper, comparison and analysis of different cloud models are performed for detecting the cloud and its vertical structure for satellite applications in the tropical region.

To evaluate the cloud detection ability of three models (SU, De95 and De90), the critical humidity threshold and the cloud base height with the ceilometer data as reference are investigated. The results indicate that for the De95 model, its threshold for cloud detection is too high to reach, while the SU and De90 models are found to be better for cloud detection, especially the SU model. Further research will be performed for better estimation of the cloud base heights.

References

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