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Postulation of Cloud Liquid Water ContentModel For Accurate Analysis of Cloud Attenuation in Tropical Regions

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Abstract: *Cloud attenuation is considered a major cause of impairment of SHF and VHF signals. Clouds are present during a large fraction of an average year which makes it necessary, that an accurate means of calculating its effects be generated, in order to effectively ascertain communication system performance under non-rainy conditions.This project aims at bringing the above objective into fruition byintroducing two efficient Cloud Liquid Water Content (LWC) models.In this paper, some features of cloud liquid water content with respect to rain and water vapor are presented. The Cloud liquid water density profile necessary for this models should be obtained from Radiosonde observation. The two models:Salonen's model and Karsten's model are suitable foruse in tropical as well as temperate locations such as the western region of Africa.*

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I. Introduction

The rapid growth of telecommunication services using frequency bandwidths above 10 GHz has facilitated a need for a more accurate investigation of propagation impairing factors, which are normally considered negligible at lower frequencies.

Major factors that impair satellite communication include rain attenuation, cloud attenuation, gaseous absorption, tropospheric scintillation, rain and ice depolarization and melting layer attenuation. Precipitation (fog, cloud or rain) however, is the main impairment factor for millimeter wave signals propagating through the atmosphere.

Accurate prediction of impairment statistics is thus very important for the design and deployment of satellite systems in tropical regions. Although raindrops have been found to be the most significant hydrometeors affecting radio wave propagation for frequency above 10 GHz, the influence of clouds and fog are very important on earth-space paths links at Ka (20/30GHz) and V (40/50GHz) bands[1].

Cloud impairments are expected to be quite severe in tropical climates like Nigeria due to high occurrence of rainfall, since rainfall and the formulation of clouds are closely related. Though rain attenuation is extremely detrimental to Electromagnetic signals, the presence of rain along a typical Earth-space link is limited to approximately 5%–10% of the time in a year, on the other hand, clouds cause a more limited impairment on the system, but are characterized by a much higher probability of occurrence (40%–80% yearly)[2].

However, one thing remains peculiar to fog, cloud and rain impairments, and that is humidity: the density and amount of suspended liquid water droplets[3]. Relative humidity is known to have a great impact on cloud formation[4]and this makes knowledge of moisture distribution of the troposphere necessary, in order to know the cloud attenuation process, and Cloud Liquid water content (LWC) plays a dominant role in attenuating electromagnetic signals. Knowledge of the atmospheric humidity profile is required in order to retrieve accurate LWC data.

Based on certain research, it has been discovered that the variation pattern of LWC has a marked relationship with the integrated water vapor (IWV) content of the atmosphere. This indicates that a threshold value of water vapor is required for formation of cloud, and once the cloud is formed LWC increases with IWV.

As it has already been ascertained by prior researches that Cloud Liquid Water Content (LWC) data is vital for efficient estimation of Cloud attenuation by the ITU-R 840.4 model[5], it is important that an accurate means of extracting this data be looked into.

II. Cloud Liquid Water Estimation Models

- **Method of Approach**

Over the past twenty years many methods have been carried out in order to obtain water vapour and cloud LWC data. However, cloud shape and structure causes the unreliability of the measured data and there are usually disagreements of up to 50% between methods.

Cloud reflectivity factor can be used to extract LWC data, but with one order magnitude of error. This is due to the non-linearity of the relationship between cloud reflectivity and Cloud LWC, as cloud reflectivity is proportional to cloud drop radius and as cloud LWC is proportional to the volume of the cloud drops.

The use of Radiosonde data is therefore suggested as it is empirical and more likely to produce correct results. The use Radiosonde ensures a reliance on the threshold of *Relative Humidity* (RH). That is, when RH exceeds a threshold value, formation of cloud layers is supposed to occur.

Another approach based on humidity takes this further still by postulating that saturation region is taken as region of RH maximum and a region of weaker temperature decrease is considered for pseudo-adiabatic lapse rate within the cloud[4]. Mathematically represented as thus:

$$\frac{d^2T}{dz^2} \geq 0$$

$$\frac{d^2RH}{dz^2} \geq 0$$

Here, humidity and temperature profiles are physically consistent with Cloud LWC profiles. This approach is adopted for the extraction of LWC data along with the two models which are discussed below.

- **Salonen's Model**

The Salonen model[6] identifies clouds when the relative humidity exceeds the critical humidity function RHc. The mathematical representation is given below.

$$RHc = 1 - \alpha\sigma(1-\sigma)[1+\beta(\sigma - 0.5)](1)$$

$where: \alpha \; and \; \beta \; are \; the \; empirical \; variables$

$$\alpha = 1.0; \; \beta = \sqrt{3}\,;$$

$$\sigma = {P(i)}\big/{P(0)}$$

$where \; P(i) and \; P(0) are \; the \; pressures \; at \; the \; considered \; level \; and \; ground \; level \; respectively$

The Liquid water content of this model is a function of the temperature profile of the atmosphere. That is for any temperature greater than 0^{o}C, the Liquid Water Content is significant. The Liquid Water Content (LWC) as a function of temperature (T^{o}C) and height (Hc) from the base has been postulated as follows:

$$TWC = W_o\rho_w(1+cT)\left(\frac{H_c}{H_r}\right)^a \; (2)$$

$$where: a = 1.4; c = \frac{0.041}{°\text{C}}; Wo = \frac{0.14gm}{m^3} for \; each \; radiosconde \; ascent$$

And vapour concentration is given as a function of water vapour saturation pressure which is temperature dependent.

$$v = 7.223e_w(\theta) = 1.739 \times 10^9 u\theta^5 \frac{gm}{m^3} \qquad (3)$$

$$where: \theta = \frac{300}{Tt + 273}, \qquad e_w(\theta) = 100\% \; RH, \qquad Tt = dry \; bulb \; temperature.$$

- **Karsten's Model**

Karsten's model[7] proposes that cloud is formed at 95% relative humidity. Again the phase of the water is determined by its temperature profile. If temperature is above 0°C, liquid water is formed. The cloud liquid water content (LWC) can be calculated by the relation.

$$LWC = LWC_{ad}(1.239 - 0.145 \ln \Delta h), Kg/m^3 \qquad (4)$$

Where Δh = height above the cloud base; LWC_{ad} = the cloud liquid water content (LWC) from the adiabatic concept of thermodynamics. We have that:

$$LWC_{ad} = \int \rho(z)\frac{Cp}{L}(\Gamma_d - \Gamma_s)dz \qquad (5)$$

Where: ρ(z) = air density, Cp = specific heat at constant pressure, L=latent heat of vaporization, Γd = dry adiabatic lapse rate, Γs = moist adiabatic lapse rate. Γs varies from 4˚C/km to 9.8˚C/km depending on the seasonal variation of temperature. The air density is calculated from the ideal gas equation. Also considered is Cp = 1.0035 J·g–1·k–1, L = 80 cal/gm.

LWC is then calculated for each pressure level at a particular Radiosonde ascent. The Integration of the extracted LWC profile over height gives the total value of LWC at each ascent.

III. Data Acquisition

Radiosonde balloon must be released from the chosen tropical location over which characteristics of the troposphere are desired to be known. Radiosonde measurements are obtained twice a day (early hours of the morning and evening will be suitable).

The data of temperature, pressure and dew point temperature at different heights with a resolution of few tens of meters to few hundreds of meters up to a total height of 15 km should be measured, in order to have as much data as possible. Temperature should be measured by the carbon rod thermistor which measures the temperature from –90˚C to 60˚C with a resolution of 0.1˚C. Pressure should be measured by an aneroid barometer with a resolution of 1 mb. Dew point temperature can be obtained from relative humidity measured by a carbon hygristor with a resolution of 2% RH. All listed equipment are attached to the Radiosonde balloon.

IV. Results and Conclusion

The expected results based on the utilization of Karsten's model and Salonen's model for a tropical region as performed by Chakraborty et al are shown in the figures below[4]. There will be a few noticeable trends:

- These two profiles show same nature; however the values of LWC are greater with the Salonen's model than with the Karsten's model as the adiabatic LWC is reduced due to circulation of air mass accompanied by precipitation and ice particles.
- LWC obtained from Karsten's maintains a linear relation with that obtained from Salonen's model indicating again these two models are in good agreement regarding the nature of variation in tropical location.
- Though the two models maintain an agreement in trend, Salonen's model constantly gives higher LWC values.
- A few variations of the LWC data along the year due to seasonal differences causes a difference between the LWC data of the two models. However, the difference between amounts of cloud LWC obtained from two models is reduced by only 10% of the maximum value.
- Salonen's model gives a more acceptable data for Cloud LWC, but the Karsten's model is more relevant as it considers adiabatic (no temperature loss or gain) cloud LWC in addition to temperature profile while calculating cloud LWC.

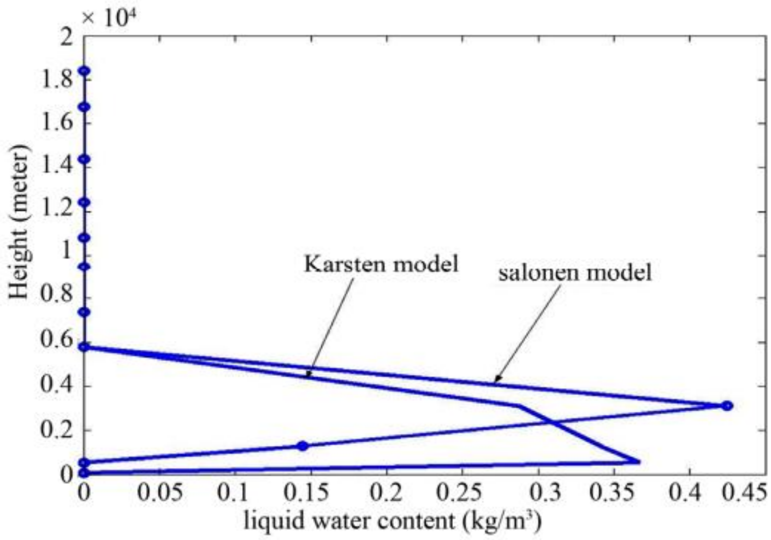

Figure 1: A typical profile of cloud liquid water density obtainedfrom radiosonde measurements using Salonen's model and Karsten's model

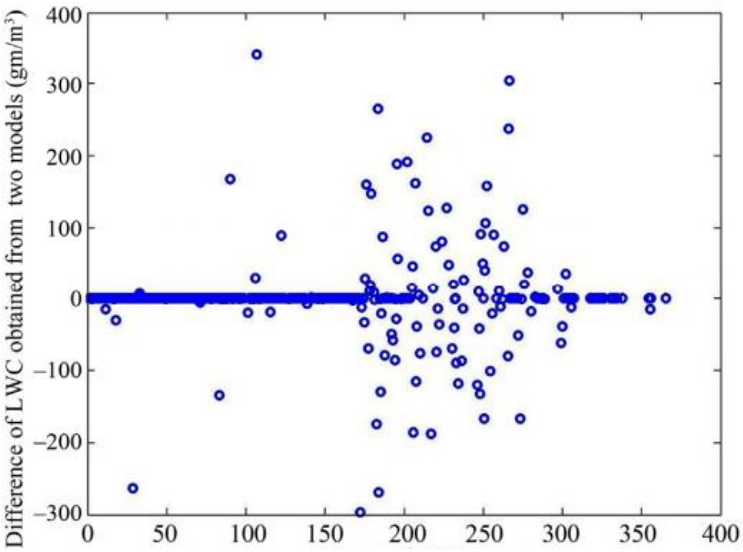

Figure 2: A plot of difference in the values of LWC obtained from the two models

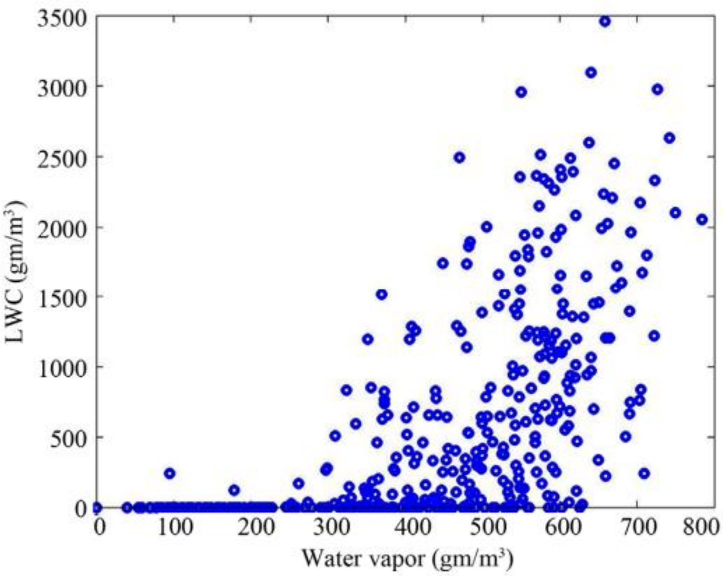

Figure 3: Variation of liquid watered content (LWC) andintegrated water vapour (IWV)

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