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Comparison of Tropospheric Scintillation Models on Earth-Space Paths in Tropical Region

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Abstract: This study presents the comparison of the cumulative distribution of tropospheric scintillation models in order to see which model suits the best with the measured one. About six different models were compared and studied with the measured one. The scintillation data were taken from January 2011 till December 2011 which totals up to a 12 month period. This paper also presents the percentage fractional errors and RMS errors for scintillation fades and also scintillation enhancements. The findings show that the ITU-R has the highest RMS error for scintillation fades with value of 104.1%, whereas OTUNG has the highest RMS error for scintillation enhancements with value of 112.2%. The study also shows that Karasawa is the best model for scintillation fades, while Van de Kamp is the best model for scintillation enhancements.

Key words: CDF, earth-space, scintillation models, tropospheric scintillation

INTRODUCTION

Scintillation is defined as the rapid signal level fluctuations of the amplitude and phase of a radiowave triggered by small scale loopholes in the transmission paths with time (Jr, 2008). Scintillation is categorized into two types which are ionospheric scintillation and tropospheric scintillation. Ionospheric scintillation is the rapid signal fluctuations of the amplitude and phase of a radio wave due to the electron density loopholes in the ionosphere layer (Jr, 2008).The electron density loopholes occur in the ionosphere layer can affect frequencies up to 6 GHz. On the contrary, the tropospheric scintillation takes place when there are fluctuations on the refractive index in the first few kilometers of altitude (Jr, 2008). It is also triggered by inversion of temperature layers and gradients of high humidity. Moreover, on the line of site links up through 10 GHz and on earth-space paths at frequencies above 50 GHz, the tropospheric scintillation has been detected (Jr, 2008) .Tropospheric scintillation has both fades and enhancements which can impair the availability of low margin systems especially at low elevation angles, and obstruct tracking systems and fade mitigation techniques (Vasseur, 1999). Many prediction models have been proposed in order to evaluate the statistical distributions of scintillation (Karasawa *et al*., 1988; Ortgies, 1993; Otung, 1996; Van de Kamp *et al*., 1999; P.618-10, 2009) . Most of these scintillation models are fit for four seasons (autumn, spring, winter and summer) climate. These models are based on data collection from countries like Japan, Germany, Finland, United Kingdom, US and etc. These models may not be used for tropical countries like Malaysia, Indonesia, Thailand, Singapore and etc. This is because these countries have different patterns of climate compared to the four seasons' countries. Their climate is mainly uniform temperature, high humidity and copious rainfall. So far, there have been very few researches done on scintillation fit for tropical countries. Recent measurement done in Malaysia does not fit with any existing scintillation models (Mandeep *et al*., 2007a, b; Mandeep *et al*., 2008; Mandeep *et al*., 2011a, b; Mandeep *et al*., 2011a, b; Zali, 2011) . Hence, scintillation models need to be investigated based on scintillation data measured in tropical country. This study is focused on the tropospheric scintillation. The data were taken under consideration of clear sky (without rain). Hence any data which contributing to rain attenuation were discarded by comparing them to rain gauge data values. The aim of this paper is to present the cumulative distribution of the six tropospheric scintillation models and compare them with the measured scintillation data. Furthermore, this study is

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also discussing about the percentage fractional errors and Root Mean Square (RMS) errors.

SCINTILLATION PREDICTION MODELS

Many prediction models have been proposed in order to evaluate the statistical distributions of scintillation. Most of these prediction models are based on both theoretical studies and the experimental results. This also includes the main link parameters for example the frequency, elevation angle and antenna diameter (Vasseur, 1999). Furthermore, meteorological data for instance the humidity at ground level and mean temperature are needed in order to obtain the most reliable scintillation data (Vasseur, 1999). The scintillation models that are going to be discussed and compared in this article are:

- Karasawa Prediction Model (Karasawa *et al*., 1988)
- ITU-R Model (P.618-10, 2009)
- Van de Kamp Model (Van de Kamp *et al*., 1999)
- OTUNG Model (Otung, 1996)
- Ortgies Models (Ortgies, 1993)

The basic formulations used by most of the authors are the scintillation fade and scintillation enhancement. In order to obtain the formulas, there are a few equations that have to be used and will be discussed later.

Karasawa scintillation prediction model: This prediction model was based on measurements made in 1983 at Yamaguchi, Japan at an elevation angle of of 6.5°, frequencies of 11.5 and 14.23 GHz and an antenna diameter of 7.6 m (Karasawa *et al*., 1988). They derived the following prediction formula using these data:

$$\sigma_{pre} = 0.0228(0.15 + 5.2x10^{-3} N_{wet})dB.f^{0.45}\sqrt{G(D_c)} / \sin^{1.3}\varepsilon \quad (1)$$

where:

σpre = The predicted signal standard deviation or "scintillation intensity"
f = Frequency in GHz
ε = Apparent elevation angle
$G(D_c)$ = An antenna averaging (Blood, 1979)
D_c = Effective antenna diameter given by:

$$D_c = D\sqrt{\eta} \quad (2)$$

D = Geometrical antenna diameter
η = Antenna aperture efficiency

In this prediction model, they claimed that the antenna averaging function also depends on the elevation angle and the height of the turbulence to be 2000 m.
If ε < 5º . sin ε in (1) should be replaced by:

$$\sin\varepsilon + \sqrt{\sin^2\varepsilon + 2h / R_e)} / 2$$

where,

h = Height of the turbulence
R_e = Effective earth radius = 8.5×10^6 *m*. (Karasawa *et al*., 1988).

The equation below is the wet term of the refractivity at ground level:

$$N_{wet} = \frac{22790Ue^{19.7t}}{(t+273)^2}(ppm) \quad (3)$$

where,

N_{wet} = Relative humidity in percentage due to water vapor in the atmosphere
t = Temperature in degrees centigrade

These meteorological input parameters should be averaged over a period in the order of a month so the model does not predict short-term scintillation variations with daily weather changes (Karasawa *et al*., 1988). The scintillation enhancement and scintillation fading equations are:

$$n(p+) = -0.0597(\log(100-p))^3 - 0.0835 (\log(100-p))^2 - 1.258(\log(100-p)) + 2.672, \text{ for } 50 < p \le 99.99 \quad (4)$$

$$n(p-) = -0.061(\log p)^3 + 0.072(\log p)^2 - 1.71(\log p) + 3.0, \text{ for } 0.01 < p \le 50 \quad (5)$$

In order to compute the cumulative time distribution for the scintillation enhancement and scintillation fade, σ_{per} has to be included in the equations as below:

$$X(p) = n(p+) \times \sigma_{per} \quad (6)$$

$$X(p) = n(p-) \times \sigma_{per} \quad (7)$$

ITU-R scintillation prediction model: The ITU-R has proposed a model with frequencies between 7-14 GHz and theoretical frequency dependence and aperture averaging effects, estimates the average scintillation intensity σ_{per} over a minimum period of one month (P.618-10 2009). The required input parameters needed for this model are signal frequency *f* (GHz), antenna diameter D (m), path elevation angle θ, average temperature, and average relative humidity which are readily available. The elevation angles used here is in the range from 4° to 32° and for antenna diameters used is between 3 and 36 m. In ITU-R scintillation model, the long-term scintillation variance is expressed as corresponded to N_{wet}, which is a function of relative humidity U (%) and temperature t (ºC), measured at ground level (P.618-10 2009):

$$N_{wet} = 3730 \frac{Ue_s}{(t+273)^2} (ppm) \tag{8}$$

$$e_s = 6.11 \exp (19.7t/(t + 273)) \tag{9}$$

where,

e_s = The saturated water vapor pressure

In ITU-R prediction model, the derivation is similar to Karasawa, Yamada and Allnutt prediction models and it is depicted in the equation:

$$\sigma_{ref} = (3.6 \times 10^{-3} + 10^{-4} \times N_{wet}) \tag{10}$$

where,

σ_{ref} = Standard deviation

The effective path length L and the effective antenna diameter, D_{eff}, according to the ITU-R:

$$L = 2h_L / \sqrt{(\sin\theta)^2 + 2.35 \times 10^{-4}} + \sin\theta m \tag{11}$$

$$Deff = \sqrt{\eta} D \tag{12}$$

where,
h_L = Height of the turbulent layer; h_L = 1000 m
D = Geometrical diameter
η = Antenna efficiency

whereas the antenna averaging factor is:

$$g(x) = \sqrt{3.86(x^2+1)^{11/12} . \sin\left[\frac{11}{6}\arctan\frac{1}{x}\right] - 7.80x^{5/6}} \tag{13}$$

with

$$x = 1.22 D_{eff}^2 \left(\frac{f}{L}\right)$$

where,

f = Carrier frequency

Next, the standard deviation, σ of the signal and the time percentage factor, $a(p)$, for the time percentage, p, of concern in the range $0.01 < p \leq 50$ are to be computed:

$$\sigma = \sigma_{ref} f^{7/12} g(x)/(\sin \theta)^{1.2} \tag{14}$$

$$a(p) = -0.0161 (\log_{10} p)^3 + (\log_{10} p)^2 - 1.71 \log_{10} p + 3.0 \tag{15}$$

Lastly the scintillation fade depth formula for the time percentage p is:

$$A_s (p) = a(p). \sigma \text{ dB} \tag{16}$$

The scintillation enhancement formula is not available in ITU-R model.

Otung scintillation prediction model: Work in (Otung, 1996) debates on the Prediction of Tropospheric Amplitude Scintillation. The aim of the study is to attain simple expressions for the annual and worst-month cumulative distributions of scintillation fades χ_- and enhancements χ_+ that can be applied to predict scintillation on a satellite link. This model is alike to the ITU-R model but there is a slight modification in the elevation angle. This can be seen in Eq. (17):

$$\sigma_{pre} = \frac{\sigma_{ref} f^{\frac{7}{12}} g(x)}{(\sin\theta)^{11/12}} \tag{17}$$

The scintillation data were obtained at Sparsholt, UK (51.5850' N, 1.5033' W) over a one-year period using the Olympus satellite 19.7704 GHz beacon viewed at a nominal elevation of 28.74 (Otung, 1996) . In Otung Model, he provided both worst month and annual distributions. For the annual distribution, the scintillation fades, X_{-a} and scintillation enhancement, X_{+a} are given by:

$$X_{-a} = 3.6191\sigma_{pre} e\left(\frac{-9.50142x10^{-4}}{p}[0.40454 + 0.00285p]\ln(p)\right) \tag{18}$$
$$for\ 0.01 \leq p \geq 50\%$$

$$X_{+a} = 3.1782\ \sigma_{pre} e(0.0359654p - [0.272113 - 0.00438]\ln(p)) \text{ for } 0.01 \leq p \geq 50\% \tag{19}$$

In Eq. (18) and (19), a denotes the annual distribution. For the scintillation enhancement and scintillation fade for worst-month distribution, where w denotes the worst-month, the formulas are as below:

$$X_{-w} = 6.8224\sigma_{pre} e\left(-10^{-4}\left[\frac{9.13.12}{p} + 1.8264p^2\right] - \left[\frac{0.023027}{p} + 0.51664\right]\ln(p)\right) \tag{20}$$
$$for\ 0.03 \leq p \geq 50\%$$

$$X_{+w} = 5.5499\ \sigma_{pre}{}^{e(-10-4[946.849p+4.4974p2]+[0.023573p - 0.261135]\ln(p))} \text{ for } 0.01 \leq p \geq 50\% \tag{21}$$

Van de Kamp scintillation prediction model: Van de Kamp adapted the ITU-R model in his prediction model but slightly changed the elevation angle as depicts in Eq. (22). Using scintillation measurements, this model was derived and tested at four sites in different climates such as in Finland, United Kingdom, Japan, and Texas(Tervonen *et al*., 1998). In this model, Van de Kamp introduced the cloud type information based on edited synoptic cloud reports (Van de Kamp *et al*., 1999) From his observation, he claimed that there was a significant correlation between the occurrence of scintillation and the presence of cumulus clouds (Van de Kamp *et al*., 1999). An improved version of the model was published by Salonen/Uppala cloud model, the whole earth from an ECMWF database (Mayer, 2002). It says that "Heavy clouds" are clouds with an integrated water content larger than 0.70kg /m^2. In a new empirical prediction model for the σ_n, incorporated W_{hc} in the following way (Van de Kamp *et al*., 1999):

$$\sigma_p = \frac{f^{0.45}\sqrt{g^2(De)}}{\sin^{1.3}\varepsilon} 0.98 \times 10^{-4} (N_{wet} + Q) \tag{22}$$

$$Q = -39.2 + \langle W_{hc} \rangle \text{ Q} \tag{23}$$

where

$\langle x \rangle$ = Long-term (at least) average of the parameter x

W_{hc} = Average water content of heavy clouds [kg/m^2]

Q = Long-term average parameter and hence constant for each site, so that all seasonal dependence of σ_p is still represented by N_{wet}

Furthermore, Van de Kamp also adopted formulas for scintillation enhancement and scintillation fade depth. These formulas are shown in Eq. (24) to (27):

$$a_1(p) = -0.0515(\log_{10}p)^3 + 0.206(\log_{10}p)^2 - 1.5\text{-}81 \log_{10} p + 2.18 \tag{24}$$

$$a_2(p) = -0.172(\log_{10}p)^2 - 0.454 \log_{10} p \; 0.274 \tag{25}$$

where,

$a_1(p)$ and $a_2(p)$ = Time percentage factors:

$$E_p(p) = a_1(p)\,\sigma_p - a_2(p)\,\sigma^2_x \text{ for } 0.001 \le p \le 20 \tag{26}$$

$$a_p(p) = a_1(p)\,\sigma_p + a_2(p)\,\sigma^2_x \text{ for } 0.001 \le p \le 20 \tag{27}$$

where,

$E_p(p)$ and $a_p(p)$ are scintillation enhancement and scintillation fade depth, respectively. The scintillation enhancement and scintillation fade depth in Van de Kamp model are meant for the percentage factors from 0.001 till 20, but this is different in ITU-R, Karasawa and Otung Models. In those three models the percentage factor starts from 0.001 and ends at 50.

Ortgies prediction models: These models consist of two models which are Ortgies-N and Ortgies-T. The experimental data were taken from Olympus satellite measurements at Darmstadt, Germany. The frequency used here were at 12.5, 20 and 30 Ghz (Ortgies, 1993) . Ortgies introduced a log-normal pdf for long term distribution of scintillation intensity with parameters of μ and s which are mean and standard deviation of ln (σ^2_x) respectively(Ortgies, 1993). These two models are based on direct linear relationships between mean surface measurement and monthly mean normalized log variance of scintillation ln (σ^2_x) (Ortgies, 1993). The Ortgies-T (Ortgies-Temperature) model takes the monthly mean surface Temperature (T) as a predictor:

$$\ln(\sigma^2_{pre}) = \ln[g^2(x).k^{1.21}(\sin\theta)^{-2.4}]\; 12.5 + 0.0865(T) \tag{28}$$

While the Ortgies-N (Ortgies-Refractivity) model considers monthly mean log-variance of signal log-amplitude to monthly mean wet component of surface refractivity (N_{wet}) as a predictor:

$$\ln(\sigma^2_{pre}) = \ln[g^2(x).k^{1.21}(\sin\theta)^{-2.4}] - 13.45 + 0.0462(N_{wet}) \tag{29}$$

Summary of previous works: Table 1 depicts the overview of previous works on the scintillation models. It shows information like the research work, approach used, scintillation model, the strengths and weaknesses.

Data analysis: The scintillation data were taken separately from the raining event. Any spurious signals related to rain were omitted accordingly. The experimental data were taken at 10.982 GHz of Ku-band signal. The 2.4 m diameter dish antenna fixed on the rooftop of the IIUM engineering building is used to receive signals from MEASAT 3. The spectrum analyzer is used to sample the receive signal in 0.1 s interval. The elevation angle of the dish antenna is positioned at 77.5º. The scintillation data were taken from January 2011 till December 2011 which total up to a 12-month period.

RESULTS AND DISCUSSION

In this section, six models namely Karasawa, ITU-R, Otung, Van de Kamp, Ortgie-T and Ortgies-N are discussed and compared with the measured scintillation data. Scintillations consist of enhancements which refer to the positive signal level and fade which refer to the negative signal level. Scintillation fades normally affect the simple earth station step tracking systems or Uplink Power Control (UPPC) systems, which rest on the length of time constant used in the particular system (Banjo and Vilar, 1986). Scintillation enhancements on a satellite uplink cause an increment in intermodulation noise in a satellite transponder consumed in multicarrier (Banjo and Vilar, 1986). Table 1 depicts the models comparison according to the location, elevation angle, frequency and data sampling. Many predictions models were developed

Table 1: Previous works

Research work	Approach	Scintillation model	Strengths	Weaknesses
A new prediction method for tropospheric scintillation on earth-space paths, 1988	Intelsat	Karasawa, Yamada Allnutt-	includes meteorological parameters, N_{wet} -this model can be applied to wide regions with different climates	-data measured in four seasons only, not include tropical, desert or polar regions
Propagation data and prediction mehtods required for the design of earth-space telecommunication systems, 2009	N/A	ITU-R	-includes meteorological parameters, N_{wet} -this model can be applied to wide regions with different climates	-data measured in regions other than temperate climatic regions -cannot be used in a dry atmosphere -does not provide worst-month scintillation -cannot be used in tropical climate
Prediction of slant-path amplitude scintillations form meteorological parameters	Olympus satellite	Ortgies-N Ortgies-T	-includes meteorological parameters, N_{wet}	-cannot be used in tropical climate
Prediction of tropospheric amplitude scintillation on a satellite link, 1996	Olympus satellite	Otung	-provide worst-month and annual distributions of scintillation	-cannot be used for tropical climate
Prediction model for the diurnal behaviour of the tropospheric scintillation variance, 1998	Olympus satellite	Van De Kamp	-includes cloud information -significant improvement on the accuracy of scintillation variance	-this method based on data from limited sites because of scarcity of experimental data -cannot be used for tropical climate

Table 2: Models comparison according to the location, elevation angle, frequency and data sampling

Model	Location	Elevation angle (˚) angle (˚)	Type of antenna /diameter (m)	Frequency (Ghz)	Data sampling	Satellite
Karasawa (Karasawa *et al*., 1988)	Yamaguchi, Japan	6.5	Dish antenna/7.6	11.452	1 s	Intelsat-V
ITU-R	Global	>4	Dish antenna/3-36	7-14	NA	NA
Van de Kamp (Van de Kamp, Tervonen *et al*., 1999)	Global	3-33	Dish antenna/	7-30	0.05 s	Satellite links in Europe, Japan and US
OTUNG (Otung, 1996)	Sparsholt, UK	28.74	Diamond shaped antenna/1.2	19.7704	0.1s	Olympus
(Mandeep *et al*., 2007a, b; Mandeep *et al*., 2011a, b; Zali, 2011)	Penang, Malaysia	40.1	Dish antenna/2.4	12.255	1.0 s	Superbird-C
Ortgies-T Ortgies-N	Darmstadt, Germany	27	1.8 and 3.7	12.5, 20 & 30	1.0 s	Olympus
Measured (IIUM)	Kuala Lumpur, Malaysia	77.5	Dish antenna/2.4	10.982	0.1 s	MEASAT 3

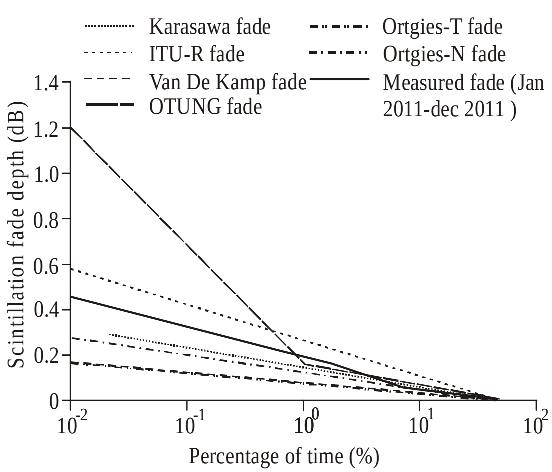

Fig.1: Cumulative distribution of scintillation fade depth

suitable model needs to be developed to cater the climate in order to obtain the suitable model according to the weather conditions of a country. But most of the models developed cannot be used in tropical countries. Hence a in tropical countries. From Table 2, the measured one and (Mandeep *et al*., 2007a, b; Mandeep *et al*., 2008a, b; Mandeep *et al*., 2011a, b; Zali, 2011) are from the same country but differ in the location, elevation angle and data sampling time. This is also different in other six models. Figure 1 depicts the cumulative time distribution for scintillation fade depth for the six models together with the measured one. These plots excluding the black coloured one which represent the measured data were obtained using Eq. (1) till (29). The measured one is comprised one year period data from January 2011 till December 2011. From Fig. 1, OTUNG model deviates significantly from other models inclusive of the measured one. This is due to the difference in the elevation angle, the type antenna used here which was diamond shaped, the frequency and the location of the experimental data that were collected. These parameters can be seen in Table 2. This is different in ITU-R, Karasawa, Van de Kamp models, and also the Ortgies models where their plots are comparable with the measured one. The Van de

Table 3: Percentage fractional errors and RMS for scintillation fade depth

Percentage of time (%)	IIUM (dB)	ITU-R (dB)	Error (%)	Kara sawa (dB)	Error (%)	Otung (dB)	Error (%)	Van de Kamp (dB)	Error (%)	Ortgies-T (dB)	Error (%)	Ortgies-N (dB)	Error (%)
10	0.03	0.11	-267	0.06	-100	0.06	-100	0.03	0	0.03	0	0.06	-100
7	0.07	0.14	-100	0.07	0	0.07	0	0.04	+43	0.04	+43	0.070	
3	0.13	0.19	-46	0.11	+15	0.11	+15	0.05	+62	0.06	+54	0.09	+31
1	0.22	0.25	-14	0.14	+36	0.17	+23	0.07	+68	0.08	+64	0.12	+45
0.3	0.24	0.32	-33	0.17	+29	0.50	-108	0.1	+58	0.12	+50	0.15	+38
0.07	0.33	0.45	-36	0.20	+39	0.81	-123	0.15	+55	0.14	+58	0.20	+39
0.03	0.39	0.48	-23	0.25	+36	0.92	-136	0.18	+54	0.15	+62	0.25	+36
0.01	0.5	0.57	-14	0.27	+46	1.2	-140	0.19	+62	0.17	+66	0.28	+44
RMS (%)		104.1		46.5			97.2			54.2	53.5		49

Table 4: Percentage fractional errors and RMS for scintillation enhancement

Percentage of time (%)	IIUM (dB)	Otung (dB)	Error (%)	Van de Kamp (dB)	Error (%)	Ortgies-T (dB)	Error (%)	Ortgies-N (dB)	Error (%)
10	0.03	0.09	-200	0.03	0	0.002	+93	0.001	+97
7	0.06	0.11	-83	0.04	+33	0.003	+95	0.002	+97
3	0.11	0.16	-45	0.05	+55	0.004	+96	0.003	+97
1	0.2	0.23	-15	0.07	+65	0.006	+97	0.004	+98
0.3	0.22	0.45	-105	0.12	+45	0.007	+97	0.005	+98
0.07	0.26	0.62	-138	0.15	+42	0.009	+97	0.008	+97
0.03	0.34	0.73	-115	0.18	+47	0.01	+97	0.009	+97
0.01	0.45	0.86	-91	0.19	+58	0.02	+96	0.01	+98
RMS (%)			112.2		47		96		97.4

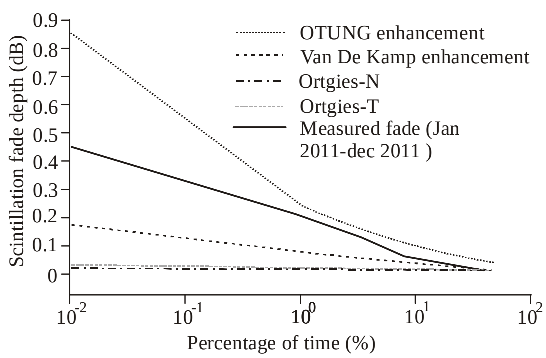

Fig. 2: Cumulative distribution of scintillation enhancements

Kamp model has to include the cloud information which is available in the measured data. But, the Van de Kamp model underestimates the measured plot. This is also same in the Ortgies models. The ITU-R model and the Karasawa model are the most comparable with the measured plot. The Karasawa model is suitable for the countries which have four seasons. This also applies in the ITU-R model. The ITU-R model is a global model, where it can be applied into any weathers including equatorial region. Hence, which model is the best suited with the measured scintillation fades and enhancements will be based on the percentage fractional errors shown in Table 3 and 4. From Fig. 1, it can be deduced that the measured fades stretch up to 0.5 dB at 0.01% of time. On the other hand, this is different in other four models. For Karasawa, the scintillation fade stretches up to 0.3 dB at almost 0.015% of time. This is different in ITU-R, where the scintillation fade stretches up to 0.57 dB at 0.01% of time. ITU-R model takes into account the wet term refractivity which is why the plot is above the Karasawa fade. Whereas for Karasawa fade, is below the ITU-R and the measured fade due to the dry climate in Japan. Meanwhile, Fig. 2 depicts the scintillation enhancements. In Fig. 2, about four models are compared. There are Van de Kamp, OTUNG, Ortgies-T and Ortgies-N. The ITU-R model does not provide any equation for scintillation enhancement, whereas for the Karasawa model, the scintillation enhancement starts from 50% of percentage of time till 99.99% of percentage of time. This is difficult in making any comparison between the two. The scintillation enhancements for the measured plot stretch up to 0.45 dB at 0.01% of time. As can be seen, the Ortgies models deviate significantly from the measured one. This is also applied in Van de Kamp model and in Otung. On the contrary, Table 3 and 4 are the percentage fractional errors and RMS errors for both scintillation fades and enhancements of the respective models to the measured scintillation data. It is a powerful tool to measure model performance (Bendat and Piersol, 2011) . The percentage fractional error, ε_f and RMS error can be calculated using the equations below:

$$\varepsilon_f = (xmea - xpred \,/\, xmea)\ x\ 100\% \tag{30}$$

$$RMS\ \ error = \left(\frac{1}{n}(x_1^2 + x_2^2 + \ldots + x_n^2\right)^{1/2} \tag{31}$$

For scintillation fades at 10% of time, the ITU-R, Karasawa, OTUNG and Ortgies-N gave extremely high percentage fractional errors, which are -90.9, -83.3, -83.3 and -80%, respectively. While for scintillation enhancements at 10% of time, the Ortgies-T and Ortgies-N gave very high percentage fractional errors which are +800 and +350 respectively. Moreover, the highest RMS error for scintillation fades is the ITU-R model with value of 65%. The reason being is that the model is based on the wet term refractivity, hence cannot be used in the dry atmosphere. This model also gives a fixed value of the height of the turbulent layer with respect to the surface temperature. This is incorrect as the height of the turbulent layer varies with the surface temperature and humidity. Meanwhile, for the scintillation enhancements, the highest RMS error is the Ortgies-T model with the value of 1913%. The reason why the error is extremely high is due to the difference in the elevation angles (6.5º-30º) and also the difference in climates in Ortgies models (Ortgies 1993) .Whereas in measured one the elevation angle used is 77.4º. Mostly it has sunny and raining seasons. The Ortgies-N model has the lowest RMS error with value of 42.4% for scintillation fades; While Karasawa model has the lowest RMS error with value of 40.3% for scintillation enhancements.

CONCLUSION

Six models namely Karasawa, ITU-R, Van de Kamp, OTUNG and Ortgies (Ortgies-N and Ortgies- T) models were compared with the measured scintillation data. The ITU-R model does not provide any equation for the scintillation enhancement. The measured fades stretch upto 0.30 dB at 0.01% of time. The measured enhancements stretch upto 0.27 dB at 0.01% of time. The highest RMS error for scintillation fades is the ITU-R whereas for scintillation enhancements are the Ortgies-T.The best model for scintillation fades is the Ortgies-N.While for the scintillation enhancements, the best model is Karasawa.In a nutshell, both of these models are not suitable to predict scintillation data in Malaysia because both gave high RMS errors. Therefore, we need to innovate a new scintillation prediction model that fits with the Malaysia's tropical climate.

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