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Modelling tropospheric radio-attenuation parameters for tropical countries. The Venezuela case

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Abstract

Several tropospheric radio-attenuation parameters for the 0.4-4.0 GHz window are modeled in the present work. Both the Hopfield and Linear models were used to obtain vertical profiles of Venezuelan tropospheric refractivity. The extinction coefficient spectra is determined via Kramers-Krönig relations. Rain attenuation contours and their monthly time evolution are presented for different Venezuelan locations.

Key words: Extinction coefficient; tropospheric attenuation parameters; troposheric refraction index.

Modelando parámetros de radio-atenuación troposférica para países tropicales. El caso Venezuela

Resumen

Se modelan varios parámetros de radio-atenuación troposférica para la ventana 0.4-4.0 GHz. Se emplean tanto el modela lineal como el de Hopfield para obtener los perfiles verticales de retractividad troposférica venezolana. El espectro del coeficiente de extinción se determina por medio de las relaciones de Kramers-Krönig. Contornos de atenuación por lluvia y su evolución mensual se presentan para diferentes localidades venezolanas.

Palabra clave: Coeficientes de extinción; índices de refracción; parámetros de atenuación troposférica.

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1. Introduction

The determination of radio-attenuation parameters is crutial in a wide variety of fields. In fact a lot of astrophysical studies (pulsars, radiogalaxies) and technological applications (GPS, communications, etc.) use the radio window as arena for data transmission/reception (1), being a fundamental problem to precisely know the involved electro-magnetic (e-m, from now on) losses.

While it is a common assumption that radio-attenuation at low-frequency bands (at least for rain effects) are negligible, we consider - on the grounds of everyday experience - that a detailed study must be carried out to determine which agents are responsible for the e-m intensity attenuation for these bands, specially on equatorial (or near-equatorial) fringes where the atmosphere is larger than higher lattitude countries. Also, it is important to bear in mind that meteorological data and high time-resolution radio-attenuation studies in tropical zones are scarce (see (2, 3) and references therein).

One of the most useful parameters to completely characterize the medium and its effect on the e-m wave propagation is the complex refraction index n_c. However, in practice, since the dispersion relations provided by the Kramers-Krönig equations make possible to obtain the imaginary part (n_i) in terms of the real part (n_r), and viceversa, it is usual to work only with one of the beforementioned quantities.

The real refraction index is, in general, a function of pressure, temperature, humidity of the medium and also of the frequency of the e-m wave. Nevertheless, expressions relating these meteorological conditions with the altitude are available with precisions as good as one part in 10^7 (4, 5). It is commonly assumed that up to 100 km the horizontal gradient of the refraction index can be taken as nearly zero (6). On the other hand, determining accurate vertical profiles for the refraction index is an extremely complicated task, in part because of the difficulty of slant distance measures (4). As consequence the use of models for estimating both the refraction and extiction indexes are very useful in this field. At radio wavelenghts refraction is increased and is made rather more variable by the presence of water vapour. The same water vapour that increases the refractivity also attenuates the radiation and generates emission by radiative transfer. Thus, it is very important to take in consideration the presence of water vapor in the troposphere.

Other agents for consideration in low latitude countries are those caused by hydrometeor scattering and attenuation. We study using a well known model the time evolution of the rain attenuation parameter for places with different altitudes and climatic conditions (7).

It is useful to remark that for tropical countries the tropopause extends to higher altitudes than in the case of other countries. Indeed, troposphere near equatorial fringe can reach 17 km (8). Consequently, special attention must be paid to this issue when planning transmission/reception applications in low latitude regions due to magnified attenuation effects.

The paper is organized as follows. In Section 2 we present the basic equations of the Standard and Hopfield tropospheric models, and we calculate the corresponding vertical gradients and tropospherical indexes. Section 3 is devoted to obtain, via the Kramers-Krönig relations, both the real and imaginary parts of the complex refraction index as a general function of frequency and altitude over sea level. The rain attenuation spectrum for several near-equatorial cities is presented in Section 4. Finally, in Section 5 a discussion and concluding remarks are included.

2. The Refraction Models

We shall consider in this work two models describing the behaviour of the tropospheric refraction index: the linear (or US Standard) model and the Hopfield model. As usual, we present them in terms of the refractivity. The first one assumes the atmosphere an ideal gas (7),

$$N_L = 77.64\frac{P}{T} + 3.718\,10^5\frac{P_p}{T^2} \qquad [1]$$

where $P \equiv P(h)$ stands for the total atmospheric pressure, $T \equiv T(h)$ for temperature and $P_p \equiv P_p(h)$ for the water vapour partial pressure. As it is well known, the linear model is widely used to define the standard atmosphere (ITU-R).

On the other hand, the Hopfield model separates the total tropospheric refractivity in wet and dry components (9, 10),

$$N_H = N_w + N_d \qquad [2]$$

where the corresponding water vapour contribution (about 10%)

$$N_w = N_{w0}\frac{(h_w - h)^4}{h_w^4} \qquad [3]$$

with $h_w = 11.5$ km and

$$N_{w0} \equiv -12.96\frac{P_p}{T} + 3.718\,10^5\frac{P_p}{T} \qquad [4]$$

Similary, for the dry contribution, it can be written

$$N_d = N_{d0}\frac{(h_d - h)^4}{h_d^4} \qquad [5]$$

where

$$N_{d0} \equiv 77.64\frac{P}{T} \qquad [6]$$

and

$$h_d \equiv 40.136 + 1.4872\,10^{-1}(T - 273.16) \qquad [7]$$

is given in km.

The pressure P, temperature T and water vapour partial pressure P_p profiles are given by (11)

$$P = P_0(1 - 2.26\,10^{-2}\,h)^{5.225} \qquad [8]$$

$$T = T_0 - 6.5h \qquad [9]$$

$$P_p = P_{p0}10^{-\frac{h}{8}\left(1+\frac{h}{8}\right)} \qquad [10]$$

where h must be given in km. Thus, the local modelling is introduced via the parameters $\langle T_0 \rangle$ (in Kelvin degrees) and $\langle P_0 \rangle$ (in mb), shown in Table 1.

To illustrate the difference between the models under consideration, in Figure 1 the characteristic profiles for the vertical gradients provided by equations [1] and [2] are sketched for tropospheric altitudes.

Another useful parameter involved in attenuation studies is the tropospheric index T_i (7). Ussually presented only for the Linear Model, in Figure 2 we compare profiles for both models.

3. Troposheric Refraction and Extinction

In order to characterize the optical properties of the troposphere it is useful to write mathematical expressions for both refraction and extinction coefficients as functions of the frequency and the altitude over sea level. However, as we have exposed in the Introduction, not a unique functional form involving both variables is known. The reason for a multiplicative separation for each refractivity is twofold: simplicity, because it permits to integrate in the Kramers-Krönig relations without considering the altitude dependence but as a scale factor, and because altitude dependence is known through several models (Linear and Hopfield). Other functional forms were tested but the present form provided the best results. For the refractivity index we choose

Table 1
Locations under study. Coordinates are given in degrees, altitude in meters, temperature in Kelvin degrees and pressure in milibars

Location	N	W	Altitude	$\langle T_0 \rangle$	$\langle P_0 \rangle$
a. Caracas	10.5	66.9	835	22.87	1011.9
b. Ciudad Bolívar	08.2	63.6	43	28.65	1011.0
c. Coro	11.4	69.7	16	28.75	1014.9
d. Maiquetía	10.6	67.0	43	26.90	1012.0
e. Maracaibo	10.7	71.6	66	28.80	1008.2
f. Maracay	10.2	67.7	436	25.85	1014.0
g. Margarita	10.9	64.0	23	28.10	1012.9
h. Mérida	8.9	71.2	1479	20.34	1019.0
i. San Fernando	7.9	67.4	27	27.68	1011.0

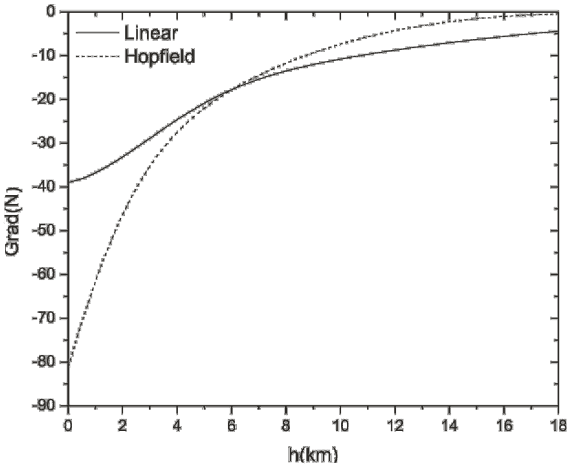

Figure 1. Vertical gradients for the Standard and Hopfield models.

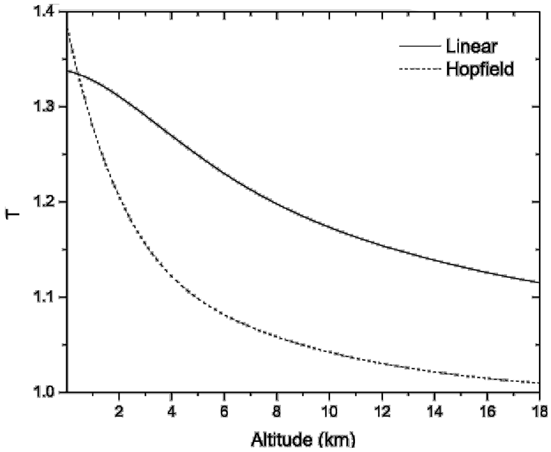

Figure 2. Typical tropospheric index values for Venezuelan locations.

$$N_{LO}(\nu,h) = \zeta N_L(h) N_O(\nu) \qquad [11]$$

and

$$N_{HO}(\nu,h) = \zeta N_H(h) N_O(\nu) \qquad [12]$$

where $N_L(h)$ and $N_H(h)$ are the refractivities related to the index of refraction n through $N = (n\text{-}1)\cdot 10^6$; $N_o(\nu)$ is given by the forced-damped harmonic oscillator model and ζ is a coupling factor determined via boundary conditions.

We obtain the corresponding extinction coefficients via the Kramers-Krönig transformation,

$$k_{LO}(\nu,h) = \frac{2\zeta n_L(h)\nu}{\pi}\int_0^\infty \frac{n_O(\nu')}{\nu'^2 - \nu^2} d\nu' \qquad [13]$$

$$k_{HO}(\nu,h) = \frac{2\zeta n_H(h)\nu}{\pi}\int_0^\infty \frac{n_O(\nu')}{\nu'^2 - \nu^2} d\nu' \qquad [14]$$

The obtained extinction coefficient is presented in Figure 3. The resemblance to

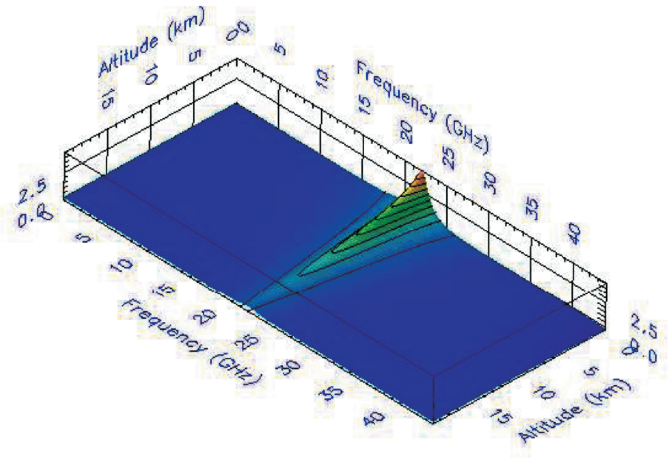

Figure 3. Extinction coefficient for the Hopfield model.

the empirical Van Vleck-Weisskopf profile (12) is notorious. The diference between the models considered is at most of the order of 12%, as expected (Figure 4).

4. The Rain Effect

Among the hydrometeors, rain is the most important radio-attenuation parameter for tropical countries. For practical applications, the rain specific attenuation can be modeled by means of the expression (7, 13)

$$\Gamma_{li} = K_i R^{\alpha i} \qquad [15]$$

where R corresponds to rainfall (in mm/h) and the parameters K_i and α_i depend both on frequency. The index i is introduced to take into account the different polarizations of the rain drops. Γ_{li} is given in db/km. For frequencies between 0.4 and 4.0 GHz, the time and frequency variation of the rain attenuation for several locations is presented in Figure 5, after reducting data of the last 30 years.

5. Concluding Remarks

In this work, a characterization of the optical medium of propagation of e-m waves in terms of the refractivity gradient and tropospheric index is presented for a tropical zone. Equally, we have window for several Venezuelan locations. The aim of these results is to inittiate an attenuation map for equatorial countries that may help to predict communication disruptions and other undesirable effects.

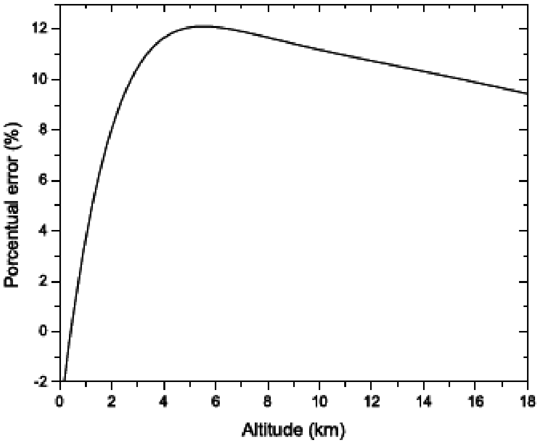

Figure 4. Porcentual error between Linear and Hopfield models for the extinction coefficient.

We have also proposed a simple model for tropospheric refraction and extinction indexes in terms of both altitudes and frequencies. With the aid of the Kramers-Krönig relations the model permits to find the extinction coefficient once the refractive index is

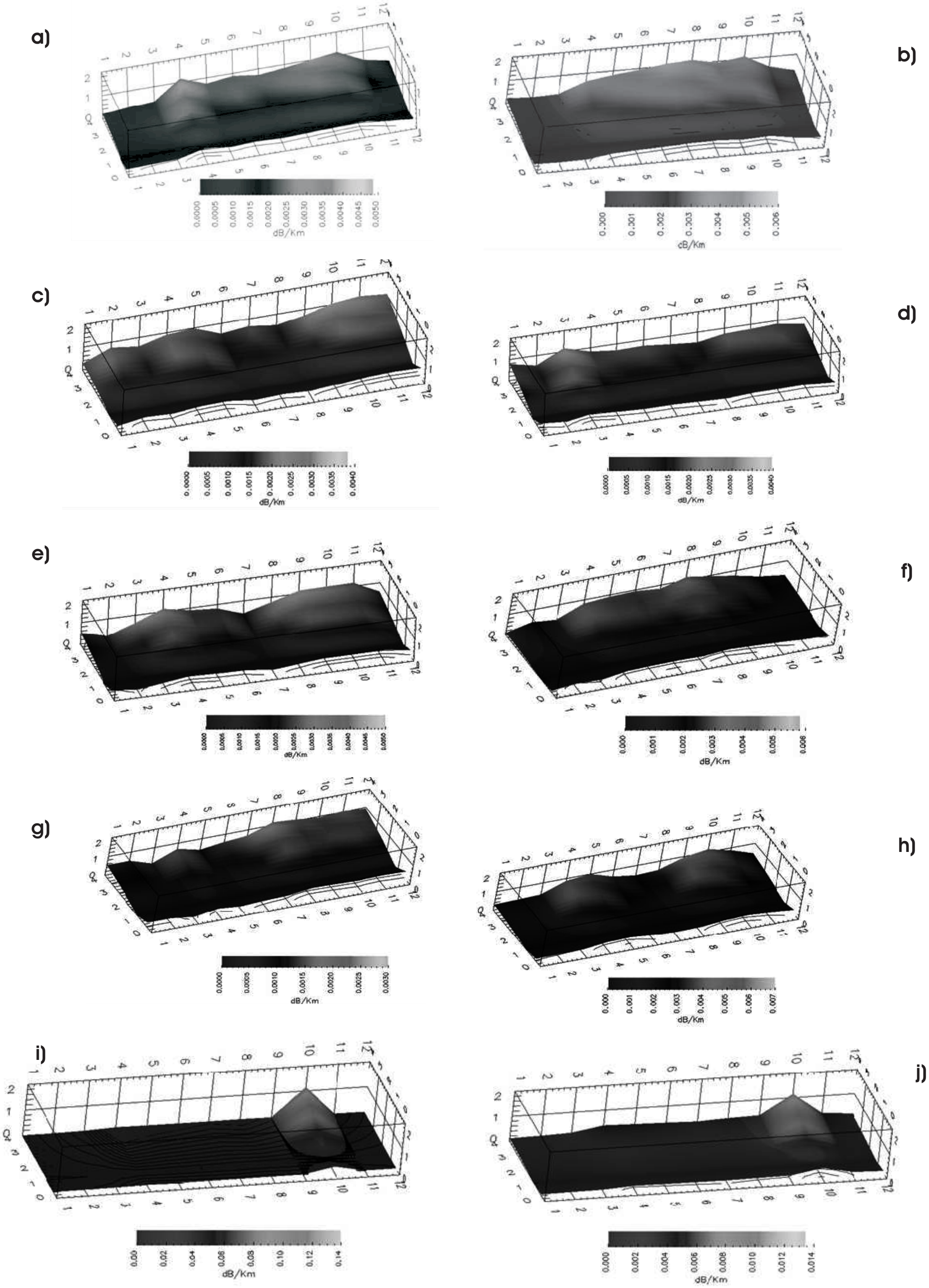

Figure 5. Mean rain attenuation for the locations of Table 1. The last graphic correponds to average value for Venezuela.

known. For the models studied, we have obtained a very similar profile to that of Van Vleck-Weisskopf. The porcentual error between the extinction coefficient for the Linear and Hopfield models is, in the worst case, of the order of 12%, as expected. It is important to notice that if extinction coefficient measurements are made, the proposed model is able to provide a local refractive index profile that may help to characterize the low lattitude tropospheric medium. The nature of these observations resembles that of optical photometry and the use of Bouguer law for determination of the atmospheric extinction coefficient.

The model also provides an easy way to evaluate the local e-m attenuation if certain assumptions about the atmosphere thermodynamics are considered. For instance, to consider the medium in local thermodynamical equilibrium usually gives results similar to experimental data.

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References

1. BERG H. *Allgemeine Meteorologie*, Dmmler s Verlag, Bonn. pp. 312, 1948.
2. CARDAMA A., JOFRE L., RIUS J.M. ***Antennas***, Ediciones UPC, Universitat Politécnica de Catalunya. pp. 52-70, 1998.
3. CRUZ S.L., RUF C.S., K.S.J. ***Radio Sci*** 33(5): 1319 – 1334, 1998.
4. DUTTON J.A. ***Dynamics of Atmospheric Motion***, Dover Publications, New York (USA), pp. 17, 1995.
5. EMILIANI M.D., AGUDELO J., GUTIERREZ E., RESTREPO J., FRADIQUE-MENDEZ C. ***IEEE Antennas Propag*** 46(6): 54 – 68, 2004.
6. GUO G., LI S. ***Int J Infrared Milli*** 21(7): 1103 – 1111, 2000.
7. HOPFIELD H.S. ***J Geophys Res*** *74*(18): 4487 – 4499, 1969.
8. HOPFIELD H.S. ***Radio Sci*** 6(3): 357 – 367, 1971.
9. MACMILLAN D.S. ***Geophys Res Lett*** 22(9): 1041 – 1044, 1995.
10. MU˜NOZ A.G., HERNÁNDEZ L. ***Rev Tec Ing Univ Zulia*** 26(1): 10 – 19, 2003.
11. OWEN J.C. ***Appl Optics*** 6(1): 51 – 58, 1967.
12. YEO T., KOOI P., LI L. ***IEEE Trans Antennas Propagat*** 49(1): 80 – 83, 2001.
13. ZHANG W., MOAYERI N. ***Tech rep*** IEEE 802.16cc-99/24, 1999.