CHARACTERISTICS OF TROPOSPHERIC SCINTILATION FOR SATELLITE APPLICATIONS IN JOS

Durodola, O. M., O. S. Macaulay and E. K. Makama

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Abstract

• This paper presents the study of the variation of refractivity, N, over a 24h diurnal period; computed from meteorological values of temperature T, atmospheric pressure, P and humidity H from a DAVIS ISS weather station

• The values of refractivity, N derived from 14 months data obtained in Jos, Nigeria (09°58'N, 008°57'E, 1192m) were applied to ITU-R P.834 model to estimate scintillation fade depth for each hour of the day for each month

• Results:
  ➢ Low correlation values of N in dry season due to low values of humidity, H;
  ➢ Varying values of refractivity in rainy season mainly due to variations P and H;
  ➢ Minimum and maximum values of radio refractivity N were 276, 330 and 338, 348 units in dry and rainy season respectively.
  ➢ Minimum and maximum values of scintillation fade depth were 0.95 dB, 2.05 dB; and 1.788 dB, 2.20 dB during dry and rainy seasons, respectively.
INTRODUCTION

- Adverse effects of atmospheric layers on the propagation of satellite signals necessitates constant research/redesign of communication systems.
- A propagating signal encounters turbulence and rapid changes in the refractive index of the atmosphere along its path.
- This causes signal level fluctuations [1, 2] especially for systems that operate at high frequency and low elevation angles [2], such as in Nigeria.
- Such Tropospheric fluctuations create random amplitudes, phases, and angles of arrival in radio signals, called scintillation.
- Scintillation intensity is described by the standard deviation of its amplitude probability distribution, which increases with relative humidity.
- Authors of [3, 4] showed that scintillation occurs continuously, irrespective of whether the sky is clear or rainy.

- The intensity of the tropospheric scintillation is very high at low elevation angles and antenna size [7].

- to provide empirical reference for planning wave propagation within the troposphere, this paper sets
  - to compute the surface radio refractivity
  - investigate the impact of each meteorological parameter
  - and the scintillation fade depth following ITU-R prediction model in [8].

- This is especially useful in determining the coverage and quality of service of communication signals at the location.
Experimental site

• DAVIS ISS weather station installed at the ground surface in Gold and Base, Jos (09°58'N, 008°57'E, 1192m), Nigeria (near AFMS).

• Measured the surface pressure, temperature, and relative humidity from October 2013 to September 2014.

• The one-minute data for each hour of the day was averaged to give a data point for each hour of the day.

• Then the average for each hour was taken over the month to give a data point for the month.
Analytical Method

Refractive index,

\[ n = \frac{c}{v} \]  
\[ n = 1 + N \times 10^{-6} \] (1) (2)

Refractivity,

\[ N = 77.6 \frac{P}{T} + 3.75 \times 10^5 \frac{e}{T^2} \] (3)
\[ = \frac{77.6}{T} \left( P + 4810 \frac{e}{T} \right) \] (4)

The two terms in equation (3) are the dry and wet components of refractivity given by:

\[ N_{dry} = 77.6 \frac{P}{T} \] (5)

And

\[ N_{wet} = 3.75 \times 10^5 \frac{e}{T^2} \] (6)

The dry term \( N_{dry} \) contributes about 70% to the total value of refractivity while the wet term \( N_{wet} \) is mainly responsible for its variability (and SCINTILLATION)
Analytical Method

- From \( t \), calculate saturation water vapour pressure, \( e_s (hPa) \):
  \[
e_s = a \exp\left(\frac{bt}{(t+c)}\right)
  \]
- \( N_{\text{wet}} \), corresponding to \( e_s \), \( t \) and humidity, \( H \):
  \[
  N_{\text{wet}} = 3.75 \times 10^5 \left(\frac{e}{T^2}\right)
  \]
  \[
e = \left(\frac{H \times e_s}{100}\right)
  \]
- standard deviation of the reference signal amplitude
  \[
  \sigma_{X,\text{REF}} = 3.6 \times 10^{-3} + 10^{-4} N_{\text{wet}} \text{ dB}
  \]
- effective path length \( L \) in metres for height of the turbulent layer, \( h_L \):
  \[
  L = \frac{2h_L}{\sqrt{\sin^2 \theta + 2.35 \times 10^{-4} + \sin \theta}} ,
  \]
  \[
  h_L = 4.680 \text{m}, \quad (0 \leq \theta \leq 10) \quad \text{(Durodola, 2016)}
  \]
- antenna averaging factor:
  \[
  g(x) = \sqrt{3.86((x^2+1)^{11/12}.\sin \left[\frac{11}{6}\tan^{-1} \frac{1}{x}\right]\right) - 7.08x^{56}}
  \]
  \[
x = 1.22D_{\text{eff}}^2(\frac{f}{L}); \; D_{\text{eff}} = \sqrt{\eta D}; \; f = 12.245 \text{ GHz}
  \]
- standard deviation of the signal for the propagation path :
  \[
  \sigma = \sigma_{\text{ref}} f^{7/12} \frac{g(x)}{(\sin \theta)^{1.2}}
  \]
- For time percentage, \( p \): \( 0.01\% < p < 50\% \)
  \[
  a(p) = -0.061(\log_{10}p)^3 + 0.072(\log_{10}p)^2 - 1.71\log_{10}p + 3.0
  \]
- the fade depth, \( A(p) \), exceeded for \( p\% \) of the time :
  \[
  A(p) = a(p).\sigma \quad \text{dB} \quad 0 \leq \theta \leq 10,
  \]
## Results and Discussion

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<th>Temp (K)</th>
<th>H (%)</th>
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Results & Discussions: 3.1 Seasonal variation of Refractivity, N

Figure 1: Hourly variation of refractivity in (a) Dry season and (b) Rainy season

URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020
Results and Discussions:

- Figures 1(a) and 1(b) show the monthly variations of N in dry season and wet season, respectively.

- During the dry season, which begins from mid Oct, maximum N was 332; and Feb had the minimum N of 276 units.

- In the various months, all the curves follow a similar pattern that mimics the diurnal solar activity on the troposphere. –
  - In the early hours of the day (00:00 – 08:00) value of N is fairly constant at its peak.
  - By 10:00, N drops sharply to about 90% of its value and remains constant until late noon, 16:00
  - By 19:00, N rises back to its peak value for the day.
3.1 Results and Discussions:

• Contrarily, during the rainy season, for all the curves, except April, the value of refractivity N, is fairly constant throughout the day.

• Rainy season Monthly variation:
  • Peak values of N: 342 - 348,
  • Minimum values of N: 338 - 340

• April shows a pattern akin to dry season curves; it dips sharply from 338 to 308; April may be classed as a dry season month in Jos.

• The seasonal variations show a maximum and minimum value for dry season, while the rainy season has a constant average refractivity index of about 345 units.
3.2.1 Effect of Humidity on N

Figure 2: Hourly variation of Relative humidity in (a) Dry season and (b) Rainy season

URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020
Results & Discussions: 3.2.2 Effect of Temperature on N

Figure 3: Hourly variation of Temperature in (a) Dry season and (b) Wet season

URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020
Results and Discussions: 3.2.3 Effect of Pressure on N

Figure 4: Hourly variation of Pressure in (a) Dry season and (b) Wet season
Results and Discussions: 3.2 Seasonal Variation of T, H, P & their effects on N

Figures 2 through 4 inspects how each meteorological parameters of refractivity index, N, by comparing the various curves with Figure 1.

• By inspection, in the dry season, refractivity curves seem to mimic the relative humidity curves, and the inverted form of the temperature curves.
• While in rainy season, N curves tend to mimic the pressure curves.
• This suggests that for the purpose of modelling, during dry season, N could be modelled with a simple inverse-temperature-dependent model, or a model proportional to relative humidity.
• On the other hand, during the rainy season, a pressure–dependent model may suffice.
• This modelling hypothesis would be subject for further investigations and future research.
Results & Discussions: 3.3: Seasonal Variation of Scintillation Fade Depth

Figure 5: Hourly variation of scintillation fade depth in a) Dry season and b) Wet season.
## Results & Discussions: 3.3 Seasonal Variation of Scintillation Fade Depth

Diurnal trends of scintillation fade depth are shown in Figures 5 (a) and 5(b) for dry season and wet season respectively.

- **Dry season:**
  - fairly constant in the early hours of the day (00:00 to 07:00); sharply declines from 07:00 to 10:00
  - a fairly constant value during the hours of 10:00 to 15:00; then rises for the rest of the day.
  - The period of decline is the period hottest period of the day when the atmospheric humidity is lowest.
  - The peak fade depth of 1.85dB was in Oct, while the least value of 0.95dB was in January.

- **Wet season:**
  - where scintillation fade is fairly constant at the early hours of the day (00:00 to 07:00)
  - with a sharp rise and low decline due to excess humidity.
  - Again, April exhibits a trend similar to that of dry season curves.
  - The peak scintillation fade depth was 2.20dB in July while the least was 1.81dB in April.

- These findings are useful input for microwave propagation link budget planning in Jos

**URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020**
<table>
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<th>Month</th>
<th>Refractivity</th>
<th>Scintillation fade depth dB</th>
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CONCLUSION

• Diurnal variation of N:
  • in the dry season: N minimum, mid-morning to late afternoons (10:00 – 16:00)
  • N maximum: evening to early morning hours (18:00 – 08:00)
  • In the rainy season, a fairly constant N average of about 345 units.

• Scintillation fade depth:
  • Scintillation fade depth varied significantly within the hours of the day.
  • For each month, minimum level scintillation fade depth between 10:00 and 15:00 hours of the day, a period of maximum diurnal solar activity.

• Future research:
  • Develop different single-parameter models for dry season and the rainy season.
  • Use a $T^{-1}$-dependent model for dry season,
  • Use a $P$-dependent model for rainy season.


