CHARACTERISTICS OF TROPOSPHERIC SCINTILATION FOR SATELLITE APPLICATIONS IN JOS

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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.

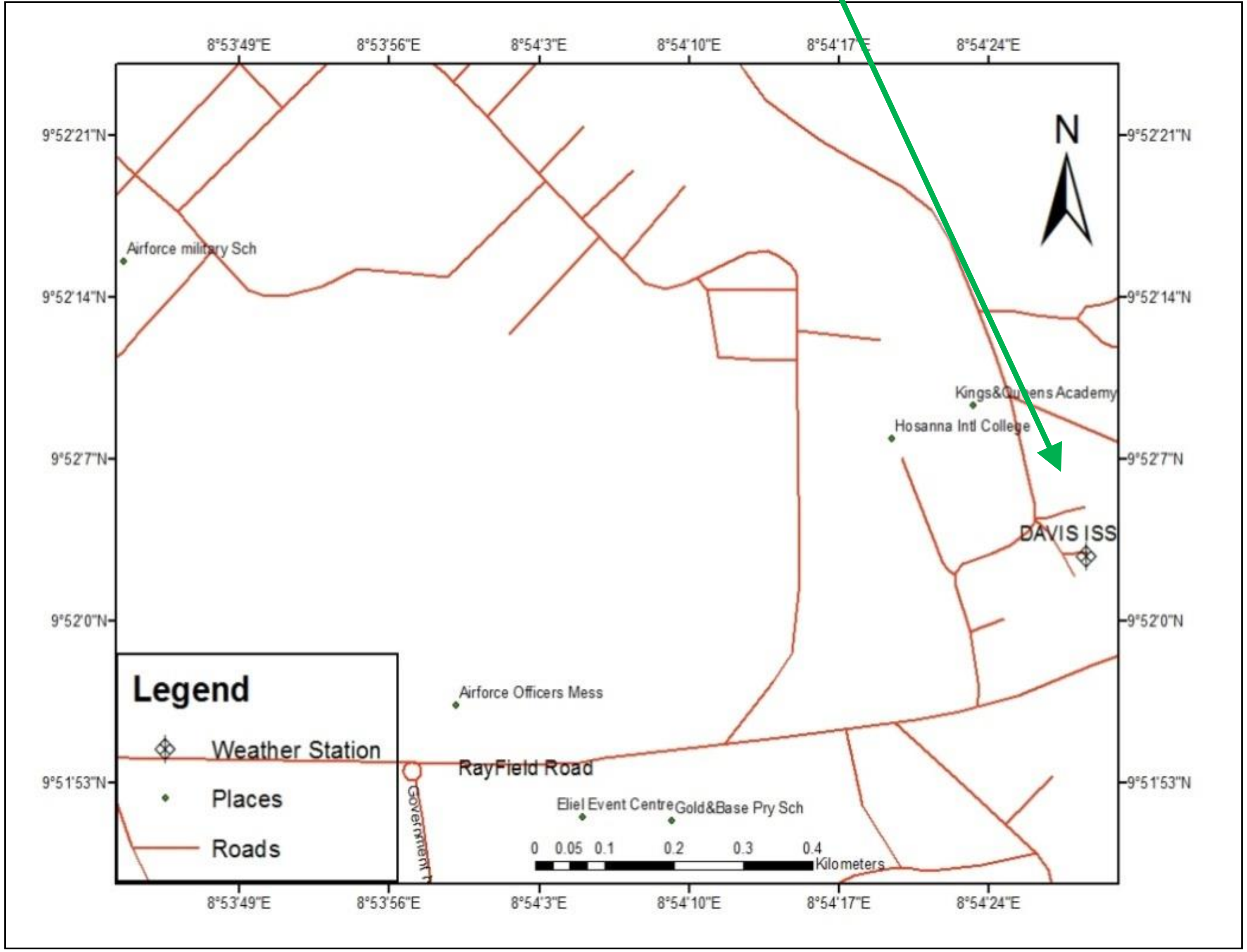
INTRODUCTION- continued

- [5] and [6] showed that scintillation depends on meteorological parameters: temperature, humidity, and the refractivity of wet periods.
- 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.

Gold and Base (Near AFMS) Jos



Analytical Method

Refractive index, $$n = \frac{c}{v} \qquad (1)$$

$$n = 1 + N \times 10^{-6} \qquad (2)$$

Refractivity, $$N = 77.6\frac{P}{T} + 3.75 \times 10^5 \frac{e}{T^2} \qquad (3)$$

$$= \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \qquad (4)$$

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

$$N_{dry} = 77.6\frac{P}{T} \qquad (5)$$

And

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

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_{wet}, corresponding to e_s, t and humidity, H:

$$N_{wet} = 3.75 \times 10^5 \left(\frac{e}{T^2}\right)$$

$$e = \left(\frac{H \times e_s}{100}\right)$$

- standard deviation of the reference signal amplitude

$$\sigma_{X.REF} = 3.6 \times 10^{-3} + 10^{-4} N_{wet} \quad dB$$

- effective path length L in metres for height of the turbulent layer, h_L:

$$L = \frac{2h_L}{\sqrt{sin^2\theta + 2.35 \times 10^{-4}} + sin\theta},$$

$$h_L = 4{,}680m, \quad (0 \le \theta \le 10)$$

(Durodola, 2016)

- antenna averaging factor:

$$g(x) = \sqrt{3.86((x^2+1)^{11/12}.\sin\left[\frac{11}{6}tan^{-1}\frac{1}{x}\right] - 7.08x^{56}}$$

$$x = 1.22D_{eff}^2\left(\frac{f}{L}\right);\ D_{eff} = \sqrt{\eta}D;\ f = 12.245\ GHz$$

- standard deviation of the signal for the propagation path :

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

- For time percentage, p: $0.01\% < p < 50\%$

$$a(p) = -0.061(log_{10}p)^3 + 0.072(log_{10}p)^2 - 1.71log_{10}p + 3.0$$

- the fade depth, A(p), exceeded for p% of the time:

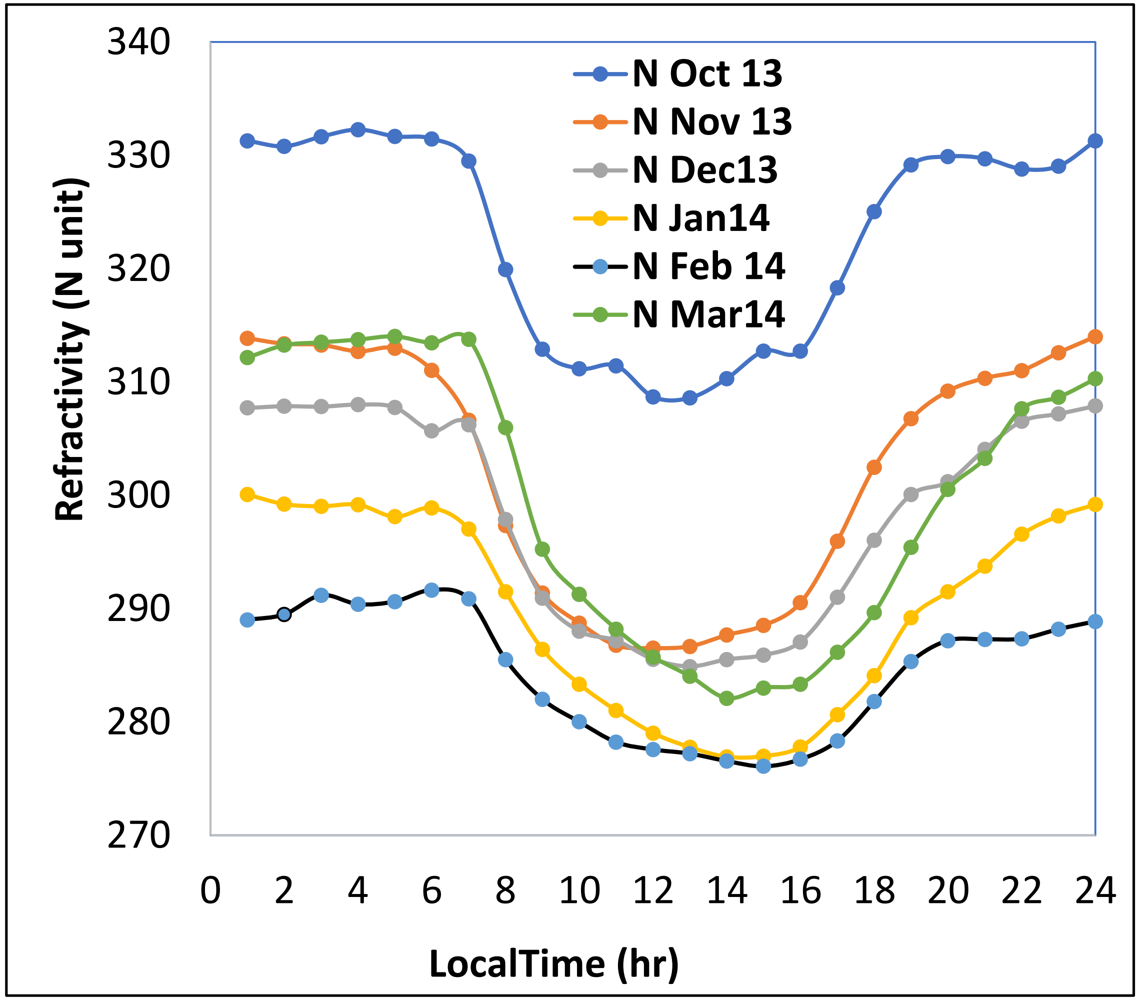
$$A(p) = a(p).\sigma \qquad dB \qquad 0 \le \theta \le 10,$$

Results and Discussion

Time (hr)	Temp (OC)	Temp (K)	H (%)	Pressure P (hPa)	N_{wet} (N Unit)
1	15.14	288.14	65.45	999.69	313.24
2	15.03	288.03	65.34	999.34	312.87
3	14.56	287.56	66.92	999.19	313.17
4	14.45	287.45	66.62	999.39	312.52
5	14.33	287.33	67.06	999.73	312.97
6	15.72	288.72	62.72	1000.17	311.04
7	19.68	292.68	50.80	1000.68	306.61
8	24.30	297.30	33.50	1001.11	297.33
9	26.69	299.69	25.65	1001.18	291.37
10	27.97	300.97	22.83	1000.73	288.73
11	29.02	302.02	20.96	1000.05	286.76
12	29.60	302.60	20.65	999.18	286.50

Time (hr)	Temp (OC)	Temp (K)	H (%)	Pressure P (hPa)	N_{wet} (Unit)
13	29.72	302.72	20.90	998.34	286.64
14	29.43	302.4259	21.55	997.75	287.19
15	28.82	301.8229	22.65	997.62	288.26
16	27.12	300.119	25.42	997.80	290.51
17	23.97	296.9728	32.67	998.27	295.94
18	20.29	293.2923	43.17	999.17	302.48
19	17.80	290.8027	51.55	1000.13	306.76
20	16.74	289.7401	56.30	1000.82	309.19
21	16.27	289.271	58.46	1001.05	310.33
22	15.88	288.88	60.10	1001.00	311.01
23	15.62	288.62	62.76	1000.72	312.58
24	15.25	288.25	64.92	1000.21	313.36

Results & Discussions: 3.1 Seasonal variation of Refractivity, N



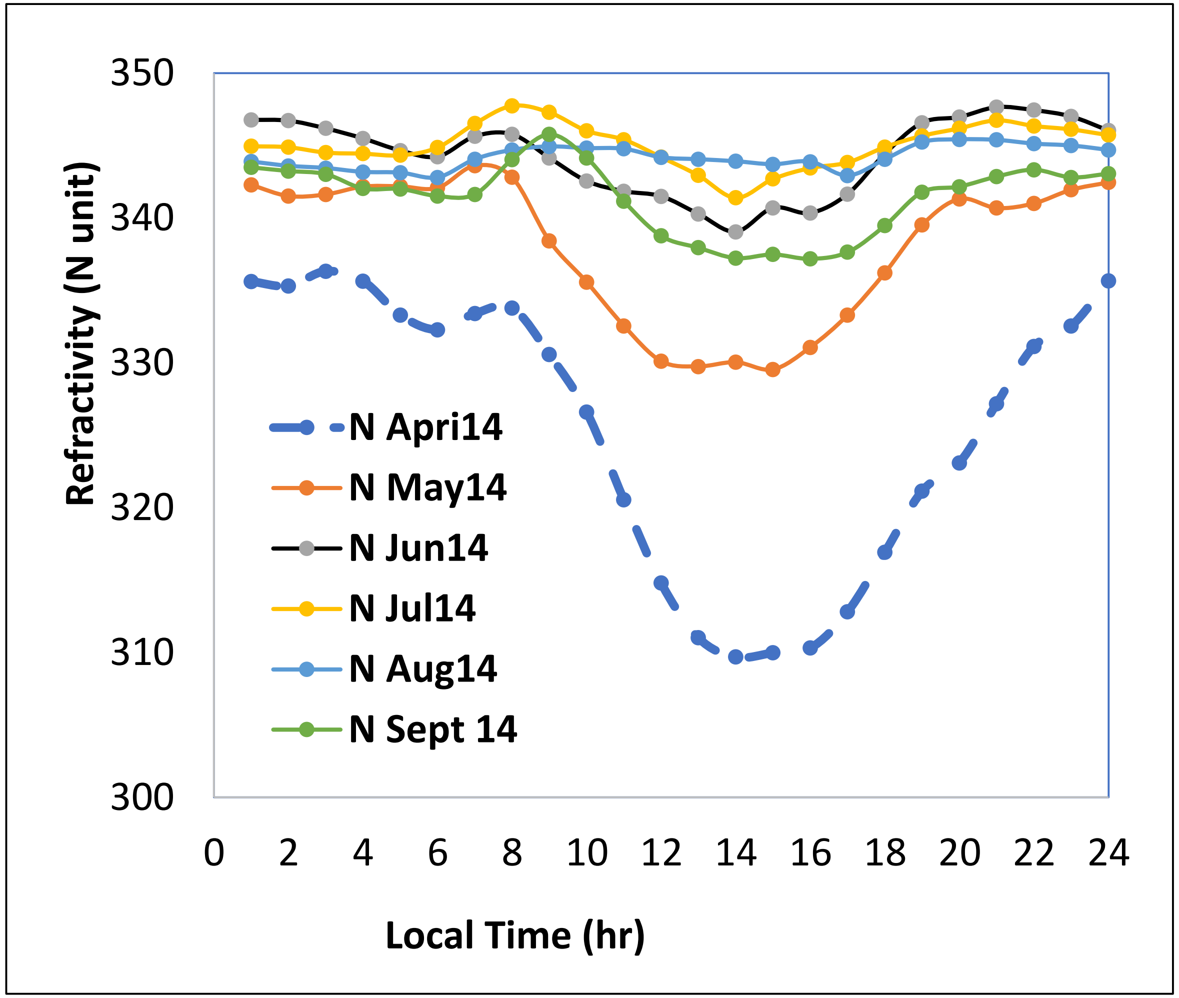


Figure 1: Hourly variation of refractivity in (a) Dry season and (b) Rainy season

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.

Results & Discussions: 3.2.1 Effect of Humidity on N

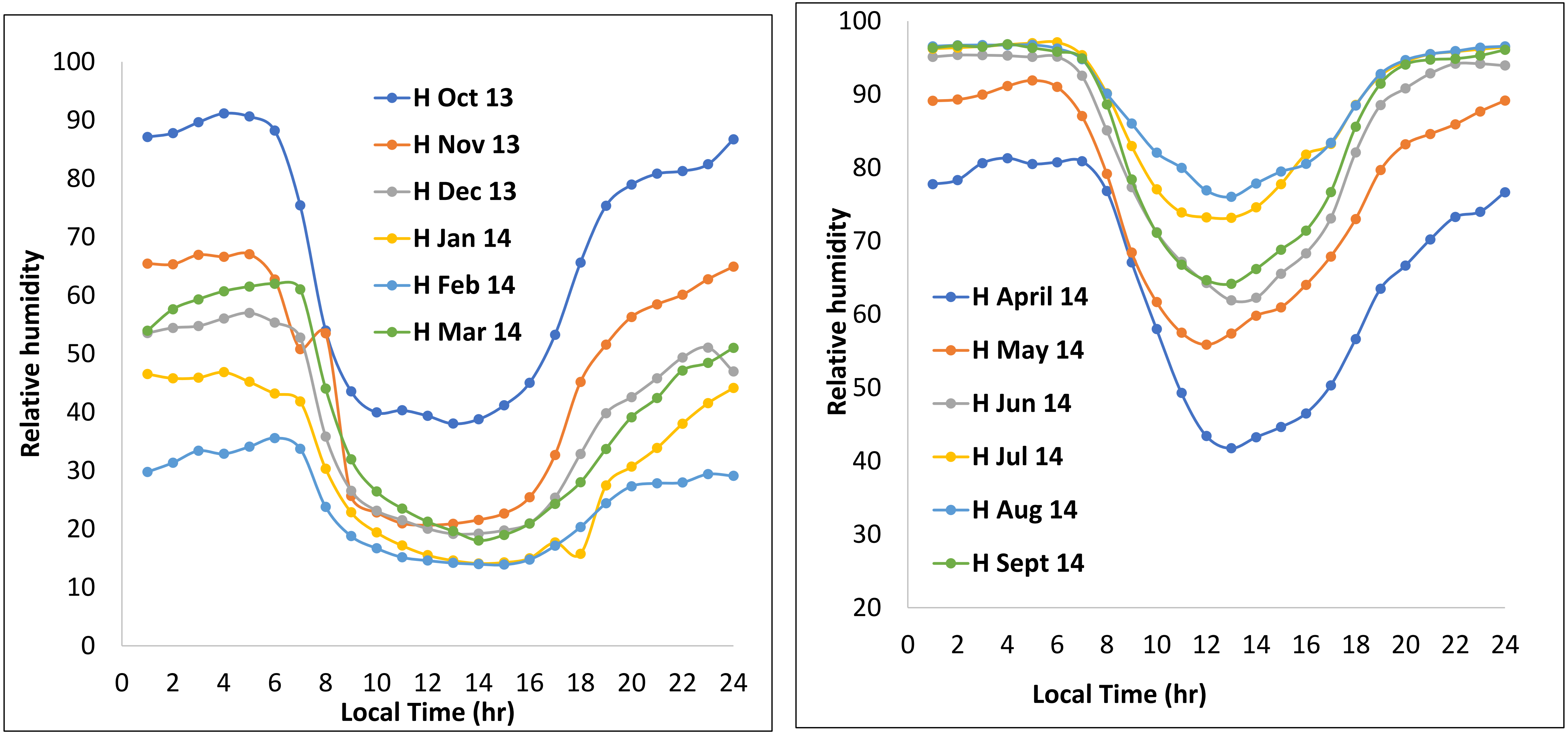


Figure 2: Hourly variation of Relative humidity in (a) Dry season and (b) Rainy season

Results & Discussions: 3.2.2 Effect of Temperature on N

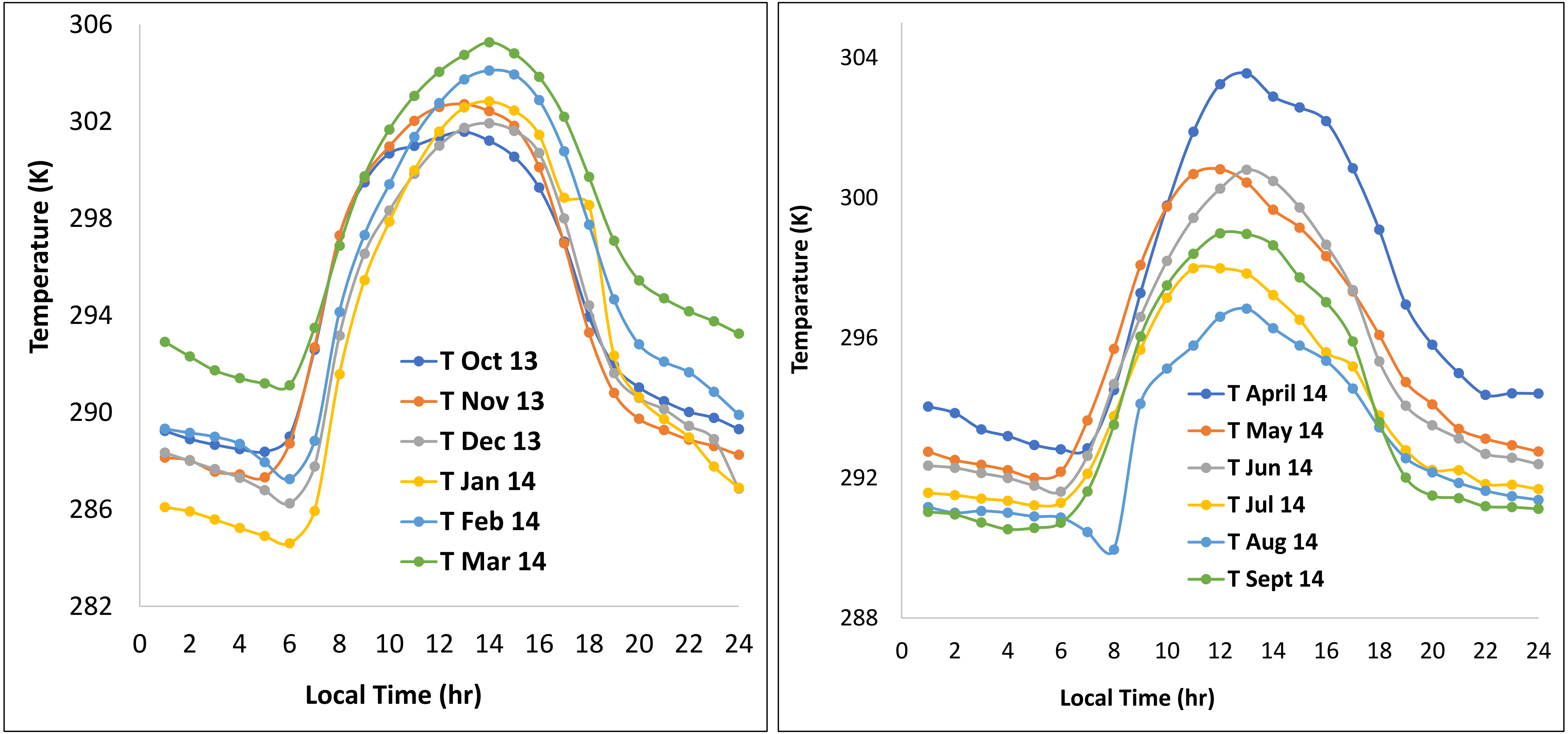


Figure 3: Hourly variation of Temperature in (a) Dry season and (b) Wet season

Results and Discussions: 3.2.3 Effect of Pressure on N

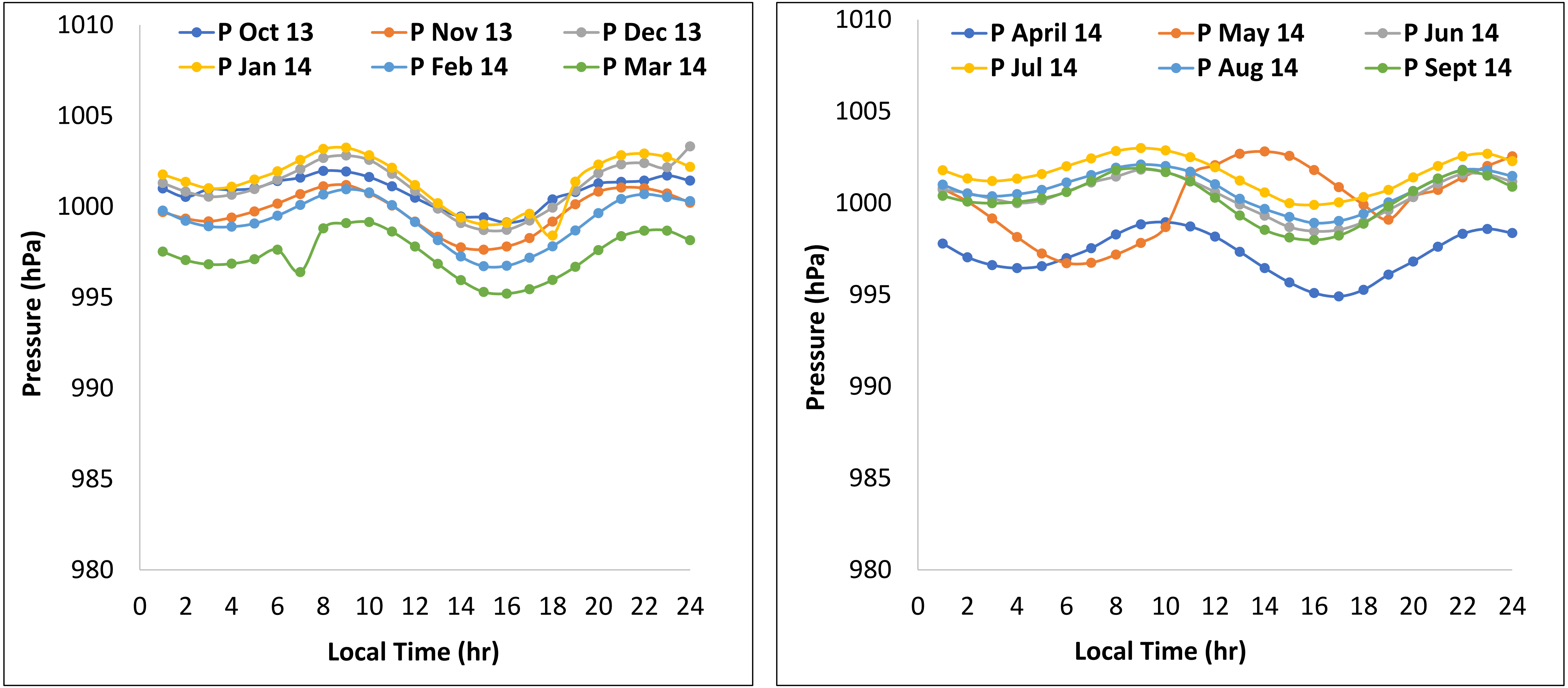


Figure 4: Hourly variation of Pressure in (a) Dry season and (b) Wet season

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

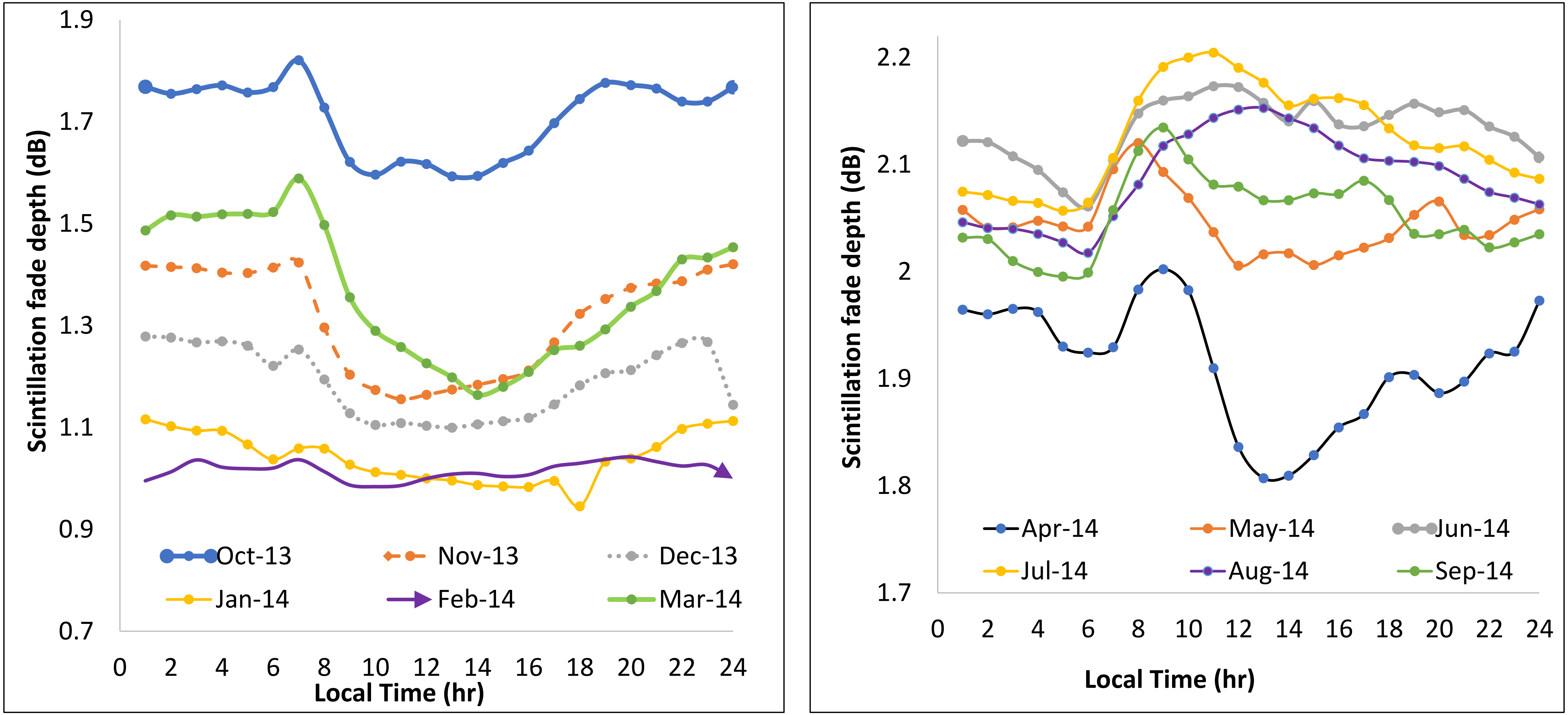


Figure 5: Hourly variation of scintillation fade depth in a) Dry season and b) Wet season

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

Summary of findings

Month	Refractivity		Scintillation fade depth dB	
	Min	Max	Max	Min
Oct_2013	308.69	331.24	1.82	1.59
Nov_2013	282.09	313.77	1.42	1.17
Dec_2013	284.89	308.01	1.28	1.11
Jan_2014	276.55	300.07	1.12	0.95
Feb_2014	276.55	291.64	1.04	0.98
Mar_2014	282.09	336.32	2.05	1.16
April_2014	309.05	347.78	2.00	1.81
May_2014	329.54	344.87	2.12	2.00
June_2014	339.05	345.64	2.17	2.06
July_2014	341.39	347.74	2.21	2.06
Aug_2014	342.25	346.13	2.15	2.02
Sept_2014	337.23	345.77	2.13	2.02
Oct_2014	330.66	371.21	2.09	1.79

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.

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