

# Investigating ducting and tropo-scatter effects on radio wave propagation in Southern Nigeria

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**ABSTRACT:** This study examines the influence of atmospheric ducting and tropo-scatter on radio wave propagation across five locations in Southern Nigeria: Akure, Abeokuta, Lagos Island, Port Harcourt, and Calabar. Meteorological data from the European Centre for Medium-Range Weather Forecasts (2012-2021) were combined with propagation models to evaluate seasonal and geographical variations in transmission loss. Results show that coastal regions, particularly Lagos Island and Port Harcourt, experience strong ducting during the wet season, with signal enhancements of 15-20 dB, with its peak around 234 dB. These conditions extend communication ranges but also increase the risk of co-channel interference. Inland regions, represented by Akure and Abeokuta, are dominated by tropo-scatter, which provides year-round beyond-line-of-sight coverage but introduces moderate fluctuations (5-10 dB) and higher error rates due to fading. The findings highlight a strong coastal–inland contrast in propagation mechanisms, underscoring the need for location-specific network planning. Coastal systems should adopt interference management strategies such as power control and directional antennas, while inland systems require robust fade margins and adaptive modulation to counter scatter-driven variability. These insights are valuable for optimising telecommunications infrastructure, improving broadcast reliability, and enhancing navigation and defence communication systems in Nigeria.

**Keywords:** Atmospheric ducting, radio wave propagation, refractivity, telecommunications, tropo-scatter.

## INTRODUCTION

Radio wave propagation is significantly influenced by the characteristics of the troposphere, especially in tropical regions where high humidity and temperature gradients are common. This study focuses on two critical atmospheric phenomena: ducting and tropo-scatter. Ducting occurs when a layer of the atmosphere acts as a waveguide, trapping and guiding radio waves over long distances, often beyond the normal line-of-sight (Liu *et al.*, 2021). Conversely, tropo-scatter involves the scattering of radio waves by turbulent irregularities in the troposphere, which enables communication beyond the horizon at the cost of signal strength (Liu *et al.*, 2019). The five study locations—Akure, Abeokuta, Lagos Island, Port Harcourt, and Calabar—represent a geographical and climatic cross-section of Southern Nigeria, offering a unique opportunity for comparative analysis. Understanding these

effects is not merely an academic exercise; it is vital for practical applications such as optimising wireless communication networks, improving the quality of radio and television broadcasts, and ensuring the reliability of navigation systems. While several studies have examined propagation effects in Nigeria, most have focused on isolated locations or single mechanisms. This study provides a comprehensive multi-site comparative investigation of atmospheric ducting and tropo-scatter propagation characteristics across Nigeria's coastal and inland regions. The analysis integrates long-term meteorological datasets (2010–2021) with advanced radio wave propagation models to evaluate spatiotemporal variability. This study provides valuable insights into spatial and seasonal contrasts that are essential for network planning and infrastructure development in the region.

## LITERATURE REVIEW

Radio wave propagation has been extensively studied, with particular emphasis on tropospheric effects such as refraction, ducting, and scattering. Early work by Sizun (2005) established the fundamental principles of tropospheric bending and scattering mechanisms, forming the theoretical foundation for later studies. In tropical climates, ducting has been shown to depend strongly on humidity, temperature inversions, and surface-layer dynamics (Ojo *et al.*, 2024).

In coastal West Africa, sea-breeze circulations and high relative humidity have been identified as major contributors to duct formation, leading to enhanced long-distance communication and, in some cases, unintended interference (Coulibaly *et al.*, 2021). Tropo-scatter, on the other hand, has been observed as a critical mechanism for beyond-line-of-sight (BLOS) communication in inland regions, though it often introduces fading and variability. Recent studies have further expanded this understanding. Ojo *et al.* (2024) statistically characterised surface duct conditions in Lagos and highlighted their strong seasonal dependence. Willoughby *et al.* (2023) reported on the estimation of radio propagation parameters using measurements of surface meteorological variables in Ede, Southwest Nigeria, emphasising the vulnerability of inland links to scatter-induced fading. More broadly, Abimbola *et al.* (2021) examined refractivity gradients across tropical Africa and confirmed the role of marine influences in strengthening ducting events. These recent findings emphasise the importance of localised, region-specific studies.

Despite these advances, a gap remains in comparative analyses that cover both inland and coastal regions of Nigeria simultaneously. Although several studies have explored propagation dynamics under different meteorological and climatic regimes, systematic cross-regional assessments that capture the interplay between diverse climatic zones remain comparatively scarce, also rapid and continuous variation in weather and climate processes, which significantly impact the design accuracy of terrestrial communication networks, further necessitate continuous investigation of the effects of multipath and ducting phenomena. This study addresses that gap by analysing ducting and tropo-scatter in five representative locations, offering a more comprehensive perspective on their seasonal and geographical variability.

## METHODOLOGY

Atmospheric parameters (temperature, pressure, and relative humidity profiles) were obtained from the European Centre for Medium-range Weather Forecast (ECMWF) at 0.25 by 0.25 resolution, from 2010-2021 for the five study locations: Akure, Abeokuta, Lagos Island, Port Harcourt, and Calabar in Nigeria. This data together

with the link parameters such as frequency ( $f$ ) in MHz, path-length ( $d$ ) in km, transmitter antenna gain ( $G_t$ ) in dB, receiver antenna gain ( $G_r$ ) in dB, horizontal angle at the transmitter ( $\Theta_t$ ) in *mrad* and horizontal angle at the receiver ( $\Theta_r$ ) in *mrad* will be used to calculate sea-level surface refractivity ( $N_o$ ), radio-refractive lapse-rate (dN), scatter angle ( $\Theta$ ), aperture to medium coupling loss, transmission loss due to tropospheric scatter and ducting (ITU-R P.530-12, 2015; ITU-R, 2019a). The radio refractivity will be evaluated using:

$$N = (n - 1) \times 10^6 = \frac{77.6}{T} \left( P + 4810 \frac{e}{T} \right) \quad (1)$$

where  $n$  is the refractive index of the atmosphere,  $T$  is the temperature (K),  $P$  is the atmospheric pressure (hPa), and  $e$  is the water vapour pressure (hPa).

Transmission loss associated with tropospheric scatter not exceeded  $p\%$  of the time will be obtained using:

$$L_{bs}(P) = F + 22 \log f + 35 \log \theta + 17 \log d + L_c - Y_p \quad (2)$$

where  $N_o$  is the sea-level surface refractivity, dN is the radio-refractive index lapse-rate,  $h_s$  is the height of the Earth's surface above sea level and  $h_b$  is the scale height (7.35 km).

The basic transmission loss associated with ducting is obtained by:

$$L_{ba} = A_{ac} + A_{ad} + A_{at} \text{ dB} \quad (3)$$

The computed losses for ducting and tropo-scatter were averaged seasonally (wet season: April–October; dry season: November–March) for each location. The results were then compared across inland (Akure, Abeokuta) and coastal (Lagos Island, Port Harcourt, Calabar) sites to highlight geographical and seasonal propagation differences (Table 1).

## RESULTS AND DISCUSSION

### Seasonal variation of ducting and tropo-scatter

The analysis of Figures 1(a-e) and 2(a-e) reveals distinct geographical and seasonal differences in the behaviour of ducting and tropo-scatter across the five study locations. In Abeokuta (Figure 1a), ducting activity was weak and sporadic. Events were mostly confined to the harmattan season (November-February), when temperature inversions formed (Akpootu and Iliyasu, 2017). Even then, the signal enhancement was limited, typically in the range of 5-8 dB, suggesting that ducting plays only a minor role in this inland location. A similar inland trend was observed in Akure (Figure 1b), where ducting also peaked during the harmattan period (Adediji and Ajewole, 2008). Enhance-

**Table 1.** Seasonal mean values for temperature, pressure, relative humidity, ducting and tropo-scatter.

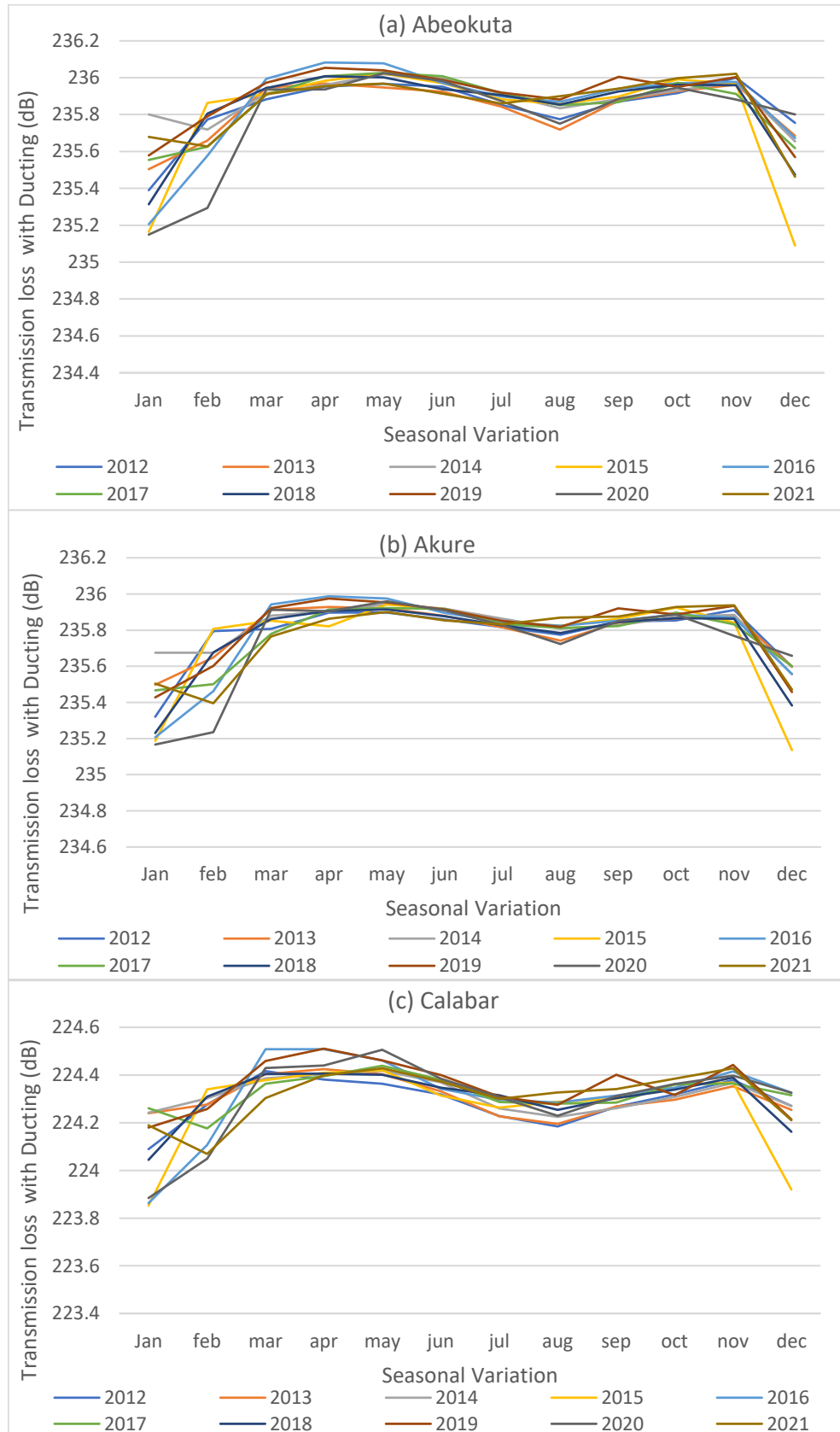
Parameters	Location	Seasonal Mean Values from 2012 - 2021											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature	Abeokuta	301.6708	302.538	302.0712	301.5285	300.6427	299.4184	298.7744	298.4477	298.8801	299.5542	300.6511	301.1812
	Akure	299.6692	300.7768	300.3473	299.7567	298.9541	297.9449	297.3585	297.1237	297.4516	298.1603	299.2129	299.2917
	Calabar	300.7811	301.4162	300.7876	300.401	299.8929	298.9421	298.2199	298.1606	298.4857	298.9714	299.6298	300.2224
	L. Island	300.5054	301.1749	301.3663	301.3271	300.8213	299.6207	298.7643	298.3481	298.8883	299.7521	300.6918	300.6758
	P. Harcourt	300.6467	301.2241	300.8634	300.7171	300.2547	299.2101	298.5532	298.5452	298.7384	299.2415	299.8486	300.2816
Pressure	Abeokuta	99814.71	99708.87	99713.43	99746.82	99876.89	100039.6	100106.4	100084.9	100031.8	99904.64	99806.03	99801.04
	Akure	97356.74	97257.82	97265.71	97297.1	97418.06	97565.67	97623.5	97600.46	97554.38	97433.95	97345.37	97355.01
	Calabar	100583	100490.7	100510	100538.1	100659.8	100827.1	100902.5	100876.4	100821.5	100681.4	100581.6	100579.8
	L. Island	100928.4	100828.7	100830.2	100857.6	100982.1	101150.1	101225.1	101208.1	101146.5	101009.5	100908.5	100920.1
	P. Harcourt	100884.8	100793.2	100810.3	100836.1	100958.1	101127.3	101201.8	101175.7	101120.2	100981.4	100882.7	100880.5
Relative Humidity	Abeokuta	90.70203	92.75669	95.13638	95.90288	96.65934	97.2725	97.23594	97.07882	97.34739	97.16691	96.40994	92.69653
	Akure	90.45435	92.6311	95.8328	96.63497	97.38065	97.81649	97.78499	97.65194	97.90328	97.64407	96.74936	92.74921
	Calabar	95.22978	95.7041	97.26696	97.67511	98.04065	98.3346	98.42927	98.33019	98.41554	98.26984	98.06907	96.64367
	L. Island	95.85035	96.70929	97.11634	97.08875	97.21884	97.62792	97.75915	97.78472	97.81868	97.56347	97.30697	96.27364
	P. Harcourt	95.31384	96.06867	97.19421	97.35569	97.66772	97.94613	97.95793	97.75282	98.08179	97.9505	97.71826	96.35665
Ducting	Abeokuta	235.4338	235.6736	235.932	235.9904	236.0093	235.9639	235.8863	235.8289	235.9093	235.9561	235.9653	235.5783
	Akure	235.3684	235.5798	235.8636	235.9103	235.9328	235.894	235.8355	235.7979	235.8543	235.8867	235.8723	235.5015
	Calabar	224.0844	224.2165	224.4055	224.4281	224.4302	224.3565	224.2797	224.2543	224.3055	224.3396	224.3907	224.227
	L. Island	233.6913	233.8992	234.0083	233.9985	233.9534	233.8652	233.7783	233.7308	233.7979	233.8633	233.9458	233.7792
	P. Harcourt	231.6314	231.7993	231.9531	231.9641	231.9626	231.8734	231.7924	231.7571	231.8307	231.8692	231.9068	231.7419
Troposcatter	Abeokuta	961.7202	1014.007	1044.24	1069.997	1059.316	1020.211	978.5969	939.581	982.6655	1031.313	1120.353	1059.714
	Akure	769.3064	797.0534	838.3532	857.4786	850.8345	820.1636	795.8912	778.0617	800.6275	830.2008	913.7074	878.6294
	Calabar	1131	1121.483	1150.188	1176.528	1166.213	1123.434	1091.012	1073.537	1089.741	1113.298	1153.682	1218.838
	L. Island	1370.577	1363.576	1295.68	1297.402	1223.627	1139.387	1113.446	1092.248	1107.332	1151.344	1257.433	1394.808
	P. Harcourt	1152.476	1171.412	1193.167	1210.577	1186.817	1126.226	1088.015	1072.063	1091.396	1120.188	1154.77	1212.77

ments were slightly stronger than in Abeokuta, reaching up to 10 dB, but still relatively modest compared to coastal sites.

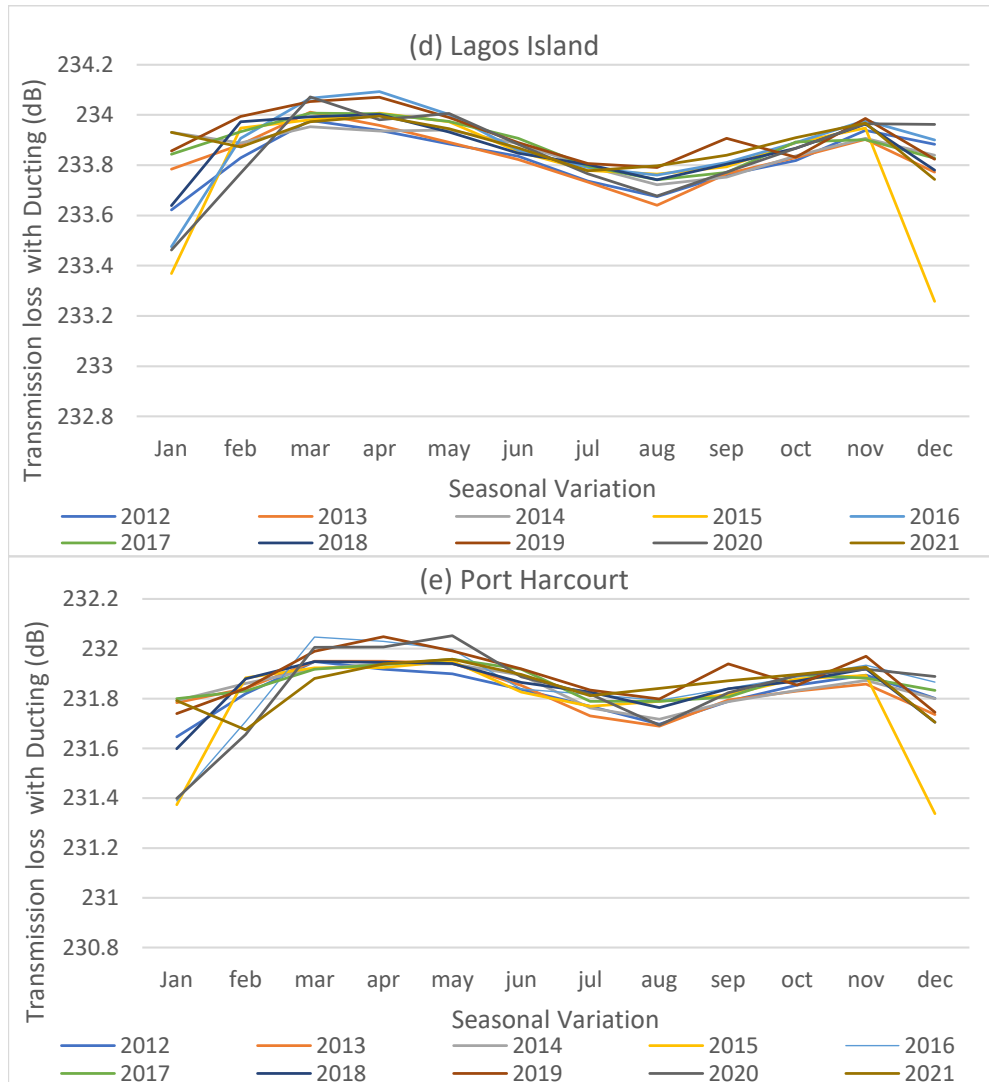
In Calabar (Figure 1c), a coastal location, ducting

was more pronounced and strongly seasonal. During the wet season (April-October), high humidity and marine air intrusions created sharp refractivity gradients that resulted in signal

enhancements of 10-15 dB (Akinwumi *et al.*, 2015). At Lagos Island (Figure 1d), ducting effects were most dominant. Wet season conditions produced ducting events with enhancements of 10-15 dB,



**Figure 1.** Seasonal mean total transmission loss associated with ducting in (a) Abeokuta (b)Akure (c) Calabar.



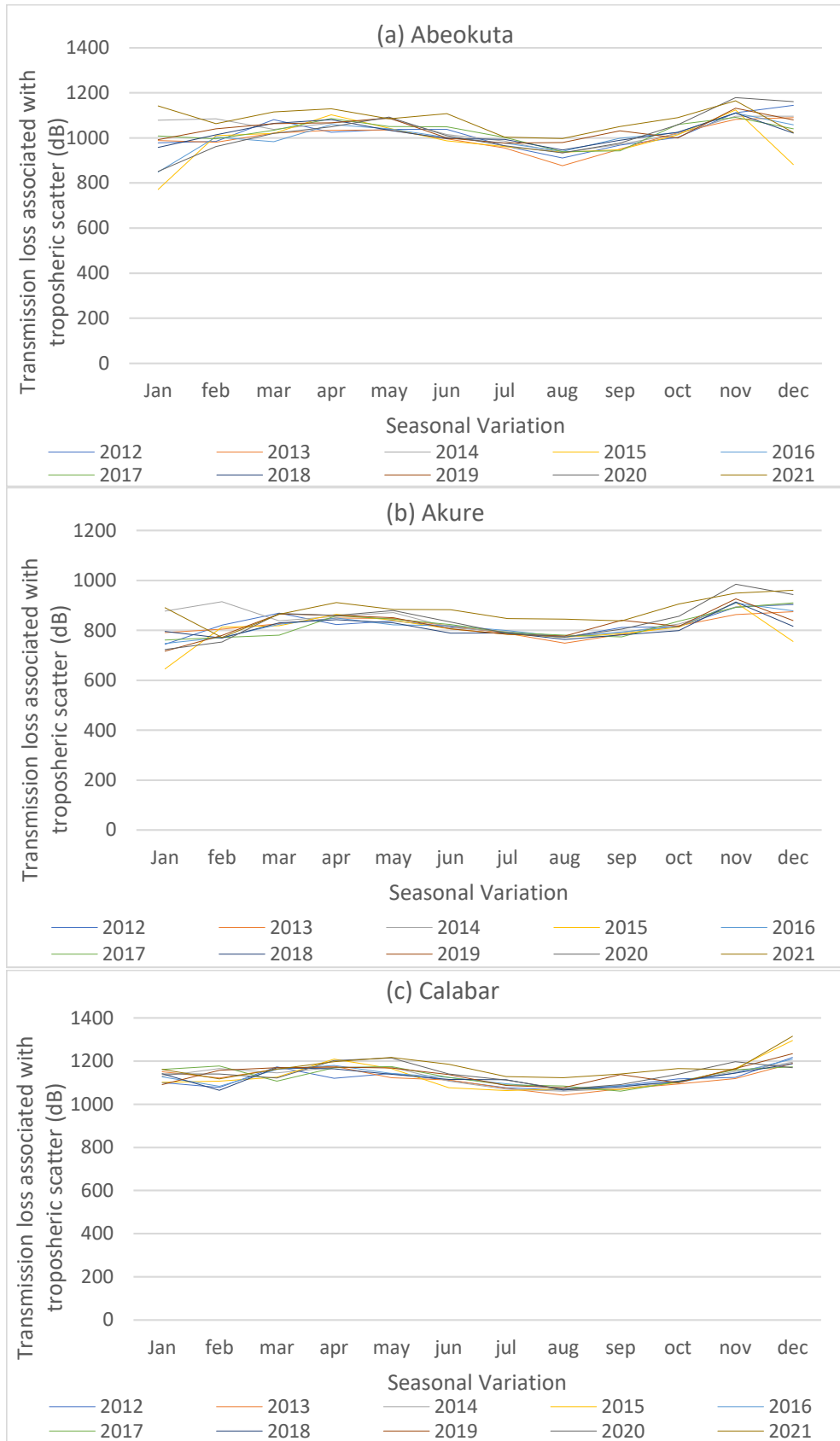
**Figure 1 continued.** Seasonal mean total transmission loss associated with ducting in (d) Lagos-Island (e) Port-Harcourt.

and it has its peak approaching 234 dB. This was attributed to evaporation ducts formed under persistent humid marine conditions, which frequently extend FM broadcast coverage far beyond the intended service area (Akpootu *et al.*, 2019). Port Harcourt (Figure 1e) displayed a similar coastal behavior, with strong wet-season ducting producing enhancements of 15-20 dB. While beneficial for extended coverage, these conditions also increased the risk of co-channel interference in both Lagos and Port Harcourt (ITU-R, 2019b).

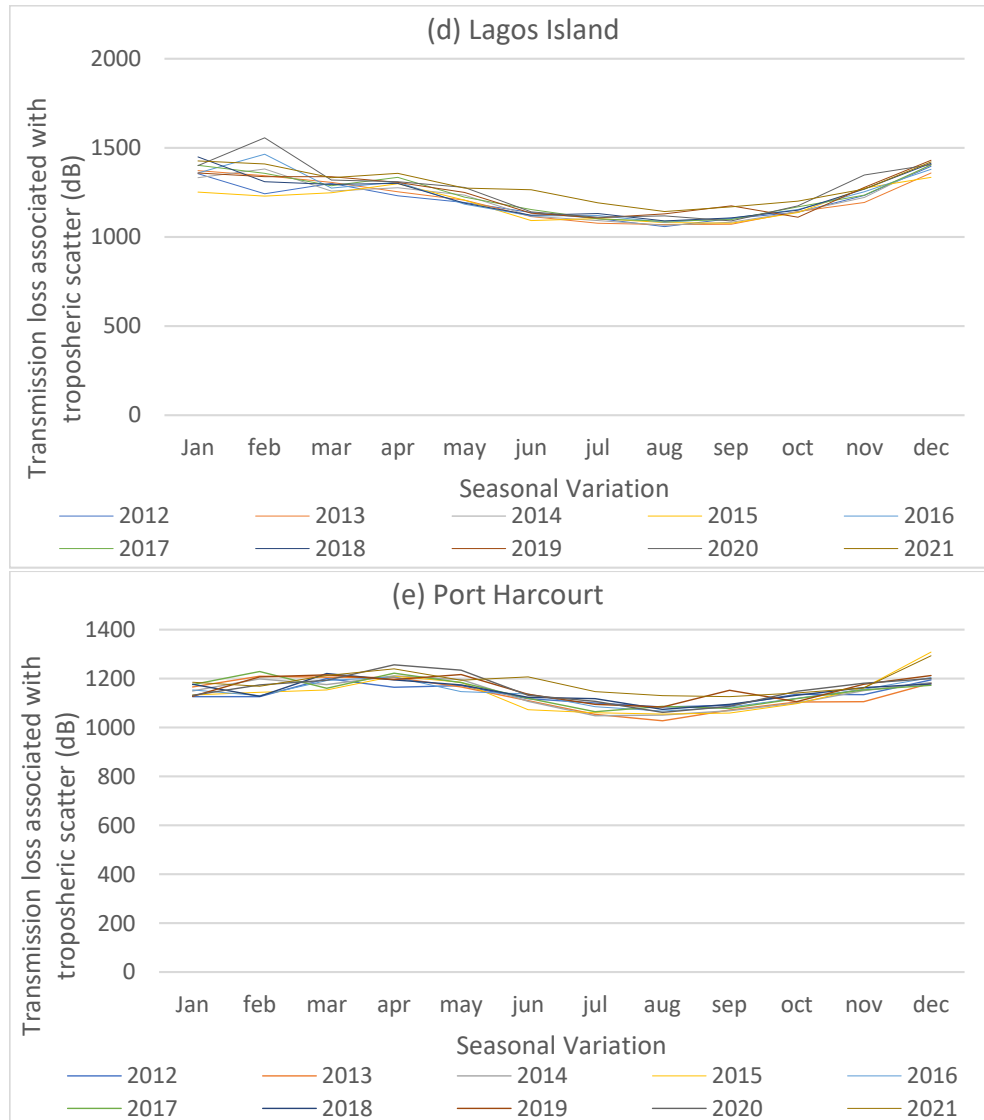
Figures 2(a-e) illustrate the corresponding seasonal behaviour of tropo-scatter. In Abeokuta (Figure 2a), scatter dominated year-round, producing moderate fluctuations of 5-10 dB. These variations were linked to convective turbulence during the wet season (Tanko *et al.*, 2022). Akure (Figure 2b) experienced the strongest inland scatter effects, with fluctuations exceeding 10 dB. Scatter

provided consistent beyond-line-of-sight communication, but frequent fading made links less reliable. In Calabar (Figure 2c), scatter was present but weaker than ducting. Losses increased during the dry season (December-March), when wind shear enhanced turbulence (Ikharo *et al.*, 2023). During the wet season, scatter effects were suppressed by stable marine air masses (Bello *et al.*, 2024). Lagos Island (Figure 2d) showed scatter as a secondary effect compared to ducting, with notable variability during the dry season when instability and wind shear were stronger (Akpootu *et al.*, 2019). Port Harcourt (Figure 2e) exhibited scatter effects similar to Lagos, though slightly more intense during transitional periods (March-April and September-October), when atmospheric instability was greatest (Adediji and Ajewole, 2008).

Overall, these results demonstrate a clear coastal-inland contrast: ducting dominates in coastal cities, especially



**Figure 2.** Seasonal mean total transmission loss associated with tropo-scatter in (a) Abeokuta (b) Akure (c) Calabar.



**Figure 2 continued.** Seasonal mean total transmission loss associated with tropo-scatter in (d) Lagos-Island (e) Port-Harcourt.

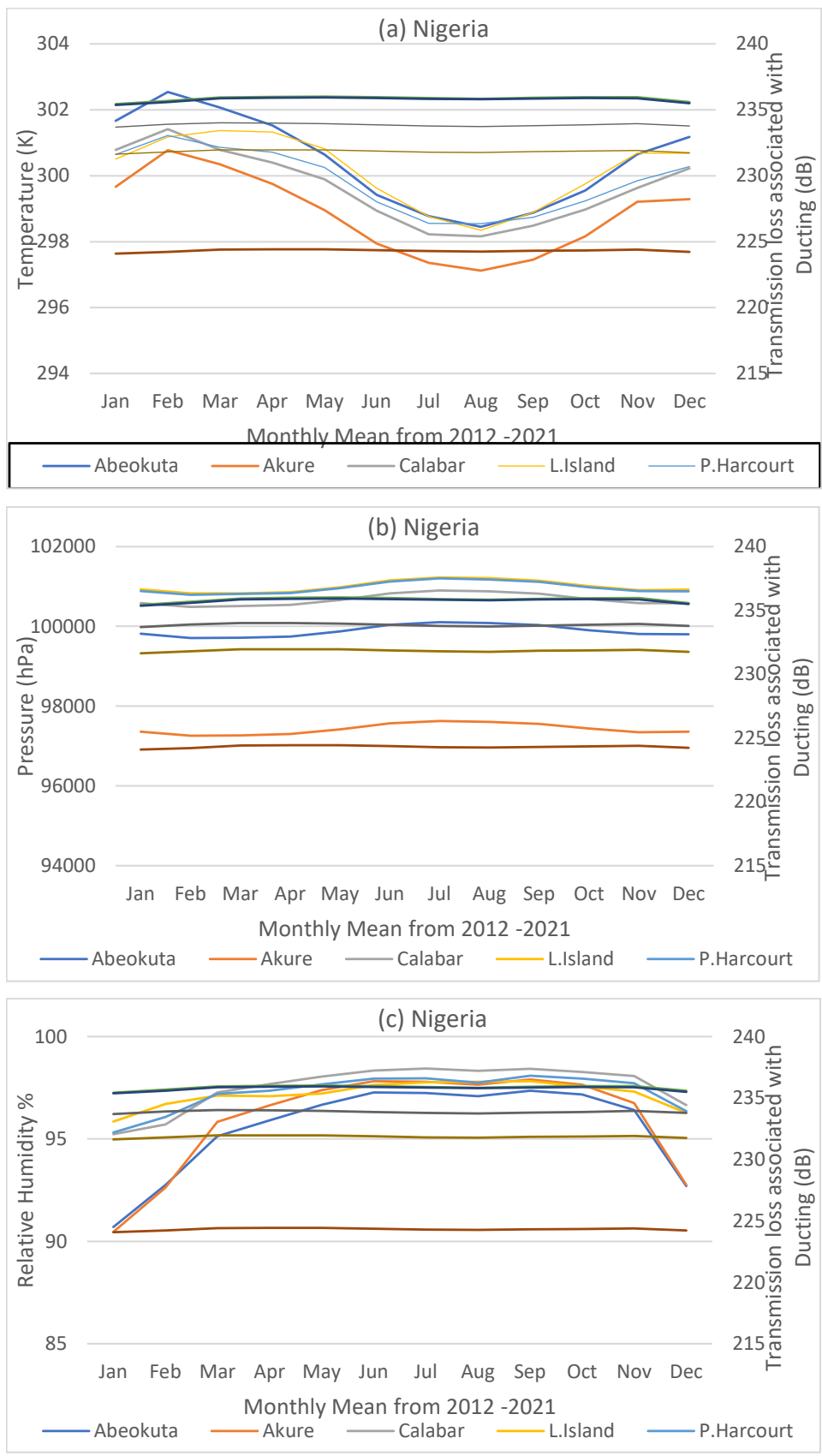
during the wet season, while tropo-scatter is the primary propagation mechanism in inland regions, persisting throughout the year with moderate intensity (Ikharo *et al.*, 2023; Akinwumi *et al.*, 2015; ITU-R, 2019b).

**Impact on radio signal performance**

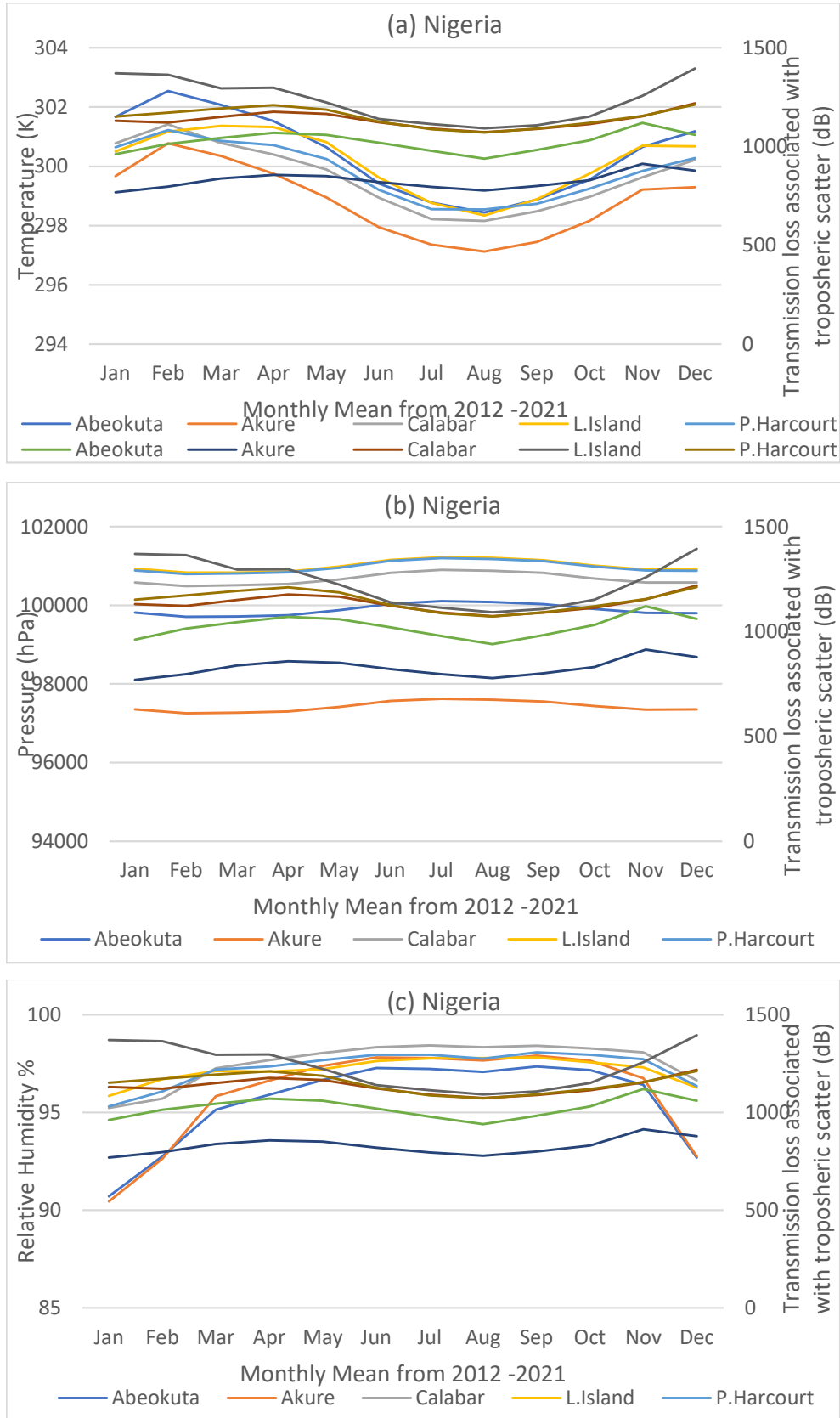
The contrasting roles of ducting and tropo-scatter have direct implications for radio signal performance. In coastal regions, ducting significantly enhanced long-distance communications such as television broadcasting and military links (Figure 3a-c) (Akpootu and Iliyasu, 2017). Field strengths often exceeded predicted values by 40-60%, with Lagos Island showing enhancements of up to 20 dB over paths extending 150 km (Akpootu *et al.*, 2019).

However, this same mechanism introduced interference risks, as FM signals from Lagos and Port Harcourt were sometimes received more than 200 km beyond their intended coverage (ITU-R, 2019b).

Inland regions, where tropo-scatter dominated, relied on this mechanism for beyond-line-of-sight (BLOS) links, especially in rural areas (Figure 4a-c) (Tanko *et al.*, 2022). While scatter provided consistent coverage, it introduced moderate fluctuations (5-10 dB) and higher bit-error rates (BER) due to multipath fading. These effects were strongest at midday, when thermal instability peaked, and reduced after sunset as the atmosphere stabilised (Bello *et al.*, 2024). Thus, ducting enhanced coverage but compromised frequency coordination in coastal areas, while tropo-scatter supported inland communication at the cost of link reliability.



**Figure 3.** Seasonal mean total transmission loss associated with ducting and (a) Temperature (b) Pressure (c) Relative Humidity.



**Figure 4.** Seasonal mean total transmission loss associated with tropo-scatter and (a) Temperature (b) Pressure (c) Relative Humidity.

### Comparative analysis: Coastal vs inland dynamics

A clear coastal-inland dichotomy emerged in the propagation mechanisms across Southern Nigeria. Coastal cities such as Lagos Island, Port Harcourt, and Calabar were strongly influenced by marine air masses and high humidity, which generated steep refractivity gradients often exceeding 100 N-units/km (Akinwumi *et al.*, 2015; Ikharo *et al.*, 2023). These conditions favoured the formation of evaporation and surface-based ducts, especially during the wet season, leading to signal enhancements of 15-20 dB (Akpootu *et al.*, 2019). While beneficial for long-distance communication, these ducts frequently cause coverage overreach and co-channel interference, making frequency management a critical challenge for coastal networks (ITU-R, 2019c).

Inland locations, including Akure and Abeokuta, were dominated by tropo-scatter, driven by convective turbulence and thermal instability (Tanko *et al.*, 2022). Scatter events were more frequent but less intense, producing variations typically within the 5-10 dB range. Although this mechanism enabled consistent beyond-line-of-sight connectivity, it increased fading and error rates, especially during peak daytime heating (Bello *et al.*, 2024). An exception occurred during harmattan, when dry Saharan air occasionally induced sporadic inland ducting (Ikharo *et al.*, 2023). This comparative analysis shows that network design in coastal regions must prioritise interference management, while inland networks require strategies to mitigate fading and improve reliability.

### Conclusion

This study investigated the effects of atmospheric ducting and tropo-scatter on radio wave propagation across five locations in Southern Nigeria, highlighting distinct geographical and seasonal dynamics. Coastal regions such as Lagos Island, Port Harcourt, and Calabar were dominated by ducting, particularly in the wet season, with signal enhancements reaching 15-20 dB and, in Lagos, with peak values of about 234 dB. These conditions extended coverage but also introduced significant risks of interference and frequency overreach. Inland locations, including Akure and Abeokuta, were dominated by tropo-scatter, producing moderate but frequent signal variations (5-10 dB), which enabled beyond-line-of-sight communication but reduced link stability through fading and increased error rates.

The comparative analysis confirms that propagation mechanisms in Southern Nigeria are strongly location-dependent, requiring tailored strategies for network design. Coastal networks must focus on interference mitigation through frequency coordination, directional antennas, and adaptive power control, while inland networks should prioritise fade margin allocation, diversity reception, and adaptive modulation to ensure reliability.

### CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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