

Temporal Variability of the Intertropical Discontinuity and Its Relationship with Atmospheric Pressure and Precipitation in Lagos, Nigeria (2015-2024)

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Abstract: This study investigated the temporal variability of the Intertropical Discontinuity (ITD) and its relationship with atmospheric pressure and rainfall over Lagos, Nigeria, using 120 monthly observations spanning 2015–2024. Monthly climatology, autocorrelation, cross-correlation, Granger causality and wavelet coherence analyses were employed to examine seasonal variability, temporal relationships and predictive coupling. Results revealed pronounced ITD migration from 6.70°N in January to 20.41°N in August, while atmospheric pressure peaked at 1010.9 hPa in July. Rainfall exhibited a bimodal distribution, with maxima of 285.16 mm in June and 248.66 mm in September, separated by an August minimum of 64.27 mm. ITD-pressure wavelet coherence reached 0.978 at 1.076 years but declined to 0.355 following deseasonalisation. Similarly, ITD-rainfall coherence approached 0.97 annually but weakened substantially after seasonal adjustment, retaining intermittent subannual coherence. Granger causality revealed no significant bidirectional ITD-pressure predictive relationship at 1-6-month lags ($p > 0.05$). The study distinguishes strong seasonal synchronisation from weaker anomaly coupling, demonstrating that ITD migration characterises monsoon seasonality but cannot independently explain coastal rainfall variability, thereby providing new insights into Lagos atmospheric dynamics and climate variability.

Keywords: Intertropical Discontinuity (ITD); Atmospheric Pressure; Rainfall Variability; Wavelet Coherence; West African Monsoon.

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1.0 Introduction

The Intertropical Discontinuity (ITD) is a major low-level atmospheric boundary within the West African monsoon system, separating the relatively cool and moist southwesterly monsoon flow from

the hot and dry northeasterly continental air mass originating over the Sahara and Sahel. The position of this boundary reflects the competing influence of continental heating and moist maritime air transport and therefore varies systematically with the seasonal evolution of the West African monsoon. Its seasonal northward and southward migration provides an important indicator of the progression and retreat of the West African monsoon and is associated with variations in atmospheric pressure, temperature, moisture, stability and precipitation. The ITD should, however, be distinguished from the Intertropical Convergence Zone (ITCZ), since the ITD is primarily a low-level baroclinic boundary and is generally displaced north of the principal zone of deep monsoon convection and rainfall (Osei *et al.*, 2023; Osei *et al.*, 2026).

The seasonal migration of the ITD and its relationship with atmospheric circulation, thermodynamic conditions and rainfall have been widely investigated across West Africa. Recent studies have increasingly focused on the coupled atmospheric processes associated with ITD migration and their relationships with key meteorological variables across West Africa and Nigeria. For instance, Osei *et al.* (2026) used a decade of reanalysis data to investigate the covariance between ITD and the African Easterly Jet (AEJ) under wet and dry conditions in the West African Sahel. They found a strong relationship between ITD and AEJ positions, with the relationship being stronger during wet years, and demonstrated that surface heat-flux anomalies can modify temperature gradients and consequently influence AEJ and ITD configurations. Using Atmospheric Infrared Sounder (AIRS) observations, Osei (2023) examined ITD position in relation to the thermodynamic environment and convection over West Africa and identified systematic variations in temperature, moisture and atmospheric instability across the ITD. They also found that thunderstorm days were associated with particular ITD displacements and positive moisture

and equivalent-potential-temperature anomalies. Similarly, Adekunle *et al.* analysed daily reanalysis-derived ITD positions over a 41-year period (1979–2020) to investigate the onset, peak and retreat phases of annual ITD migration across West Africa, he used daily reanalysis ITD positions spanning 41 years (1979–2020), studied the onset, peak and retreat of the annual ITD migration. They developed an ogive-based method for objectively identifying dates and examined trends and variability across latitude. Their findings showed that peak ITD migration occurred mainly in August, while onset generally occurred between April and early May and retreat occurred during October–November. They also identified significant trends in ITD latitude at several longitudes and associated these changes with variations in the Saharan Heat Low. In Nigeria, recent studies have focused on “In Nigeria, recent studies have increasingly examined rainfall variability, precipitation extremes and drought conditions, particularly in relation to regional and large-scale climate influences. For instance, Awode *et al.* (2025), in their analysis of rainfall variability and extreme events in southwestern Nigeria, confirmed the characteristic bimodal rainfall regime, identified substantial interannual variability and discussed possible influences of the Atlantic Multidecadal Oscillation (AMO) and El Niño–Southern Oscillation (ENSO), Lagos, located along the Gulf of Guinea in southwestern Nigeria, experiences a humid tropical coastal climate strongly influenced by the West African monsoon and Atlantic moisture transport, making it an important environment for examining the interaction between ITD migration, atmospheric pressure and precipitation.

Obateru *et al.* (2023) also examined rainfall trends and drought conditions in southwestern Nigeria, highlighting the substantial variability of hydroclimatic conditions within the region/. Of particular relevance to the present study is Odekunle (2010), who examined the relationship between ITD location and rainfall in northern and southern Nigeria while considering pressure differences associated with the Azores, Libyan and St. Helena anticyclones and sea-surface temperature (SST) in the Gulf of Guinea. These pressure systems contribute to the regional pressure gradients that regulate monsoon circulation and influence the seasonal displacement

of the ITD. However, the extent to which variations in surface pressure at a specific coastal location such as Lagos are temporally coupled with monthly ITD displacement remains insufficiently understood

Furthermore, recent literature increasingly conceptualises the ITD as an integral component of a coupled atmospheric system involving pressure, temperature, moisture and circulation, rather than as an isolated boundary between contrasting air masses (Ibanga *et al.*, 2024). A modelling study of the West African monsoon described the ITD as the boundary between the hot, dry Saharan environment associated with the Saharan Heat Low and the cooler, moist air mass over the Gulf of Guinea/. The associated pressure, temperature, moisture and circulation gradients are fundamental to the West African monsoon circulation and provide the physical basis for seasonal ITD migration (Fischer, 2024). Despite these advances, an important local-scale research gap remains in understanding the temporal coupling among ITD position, atmospheric pressure and precipitation in coastal southwestern Nigeria. Recent studies have considerably improved understanding of regional ITD migration, its thermodynamic environment, its relationship with atmospheric circulation, and its association with meteorological variability. However, comparatively limited attention has been given to the local temporal relationships among ITD position, atmospheric pressure and precipitation over a coastal region such as Lagos, particularly using a consistent monthly ITD record. Moreover, previous studies have rarely combined autocorrelation, cross-correlation, Granger causality and wavelet coherence to distinguish simple seasonal co-variation from predictive and time-frequency relationships among ITD position, atmospheric pressure and precipitation. Existing southwestern Nigerian rainfall studies have largely concentrated on rainfall trends, variability and extremes, while recent ITD studies have generally adopted broader West African or continental perspectives. Consequently, the combined temporal behaviour of ITD displacement, surface atmospheric pressure and precipitation in the coastal Lagos environment remains insufficiently characterised, particularly with respect to the distinction between seasonal synchronisation and anomaly-scale coupling. Therefore, this study aims to investigate the temporal



variability of the Intertropical Discontinuity and quantify its temporal, correlational, predictive and time-frequency relationships with atmospheric pressure and precipitation over Lagos, Nigeria, using monthly observations for the period 2015–2024. The study is significant because it provides a local-scale assessment of ITD behaviour and its relationship with key atmospheric and precipitation variables in a coastal West African environment. The findings will contribute to improved understanding of the atmospheric processes governing rainfall seasonality and variability in Lagos and provide quantitative evidence for distinguishing seasonal co-variability from more persistent relationships among ITD position, atmospheric pressure and precipitation. The results may also provide useful baseline information for climate variability assessment, rainfall-related risk analysis and future investigations of monsoon dynamics and precipitation predictability in coastal Nigeria

2.0 Materials and Method

2.1 Data and Sources

This study uses monthly observations for the period January 2015 to December, 2024 to investigate the temporal variability of the Intertropical Discontinuity (ITD) and its relationship with atmospheric pressure and precipitation over Lagos, Nigeria. The study period comprises 120 monthly observations, providing a consistent decade-long record for examining seasonal and interannual variations in ITD position and associated atmospheric conditions.

(i) Monthly ITD-position data for Lagos covering 2015–2024 constitute the principal independent variable in this study. The ITD position is expressed as its monthly latitudinal location, with the latitude representing the north-south displacement of the discontinuity during the annual cycle. The dataset is used to characterise the seasonal migration of the ITD and its interannual departures from the mean seasonal position.

(ii) The Atmospheric response variables comprise monthly atmospheric pressure and precipitation data for Lagos for 2015–2024. Atmospheric pressure is used to characterise variations in the near-surface pressure environment associated with changes in ITD position. Monthly precipitation, expressed in millimetres (mm), is used to characterise rainfall variability and to assess its association with ITD displacement.

The two variables provide complementary dynamical and hydrometeorological measures of the atmospheric response to seasonal ITD migration and were obtained from the Nigerian Meteorological Agency (NiMet).

(iii) Data of all variables were converted into vectors of 120-month length of time series for input into MATLAB scripts for each method.

2.2 Method of Analysis

The 120-month ITD, atmospheric pressure and precipitation series for Lagos covering January 2015 to December 2024 (120 months) were converted into time series vectors of equal length for implementing various steps of analyses.

Firstly, monthly time-series plots of ITD position, atmospheric pressure and precipitation were produced to examine their temporal evolution and identify prominent seasonal cycles, interannual variability anomalous periods and possible co-variations.

Secondly, autocorrelation analysis was performed separately for the ITD, atmospheric pressure and precipitation series to assess their temporal persistence and identify the extent of serial dependence at successive monthly lags. This provides an indication of the memory within each series and provides an important basis for interpreting subsequent lagged analyses.

Thirdly, cross-correlation analysis was performed separately for ITD-pressure and ITD-precipitation pairs. Statistical significance was assessed at the 5% level. The cross-correlation functions

$$r_{IP}(\tau) = \frac{\sum_{t=1}^{N-|\tau|} (I_t - \bar{I})(P_{t+\tau} - \bar{P})}{\sqrt{\sum_{t=1}^{N-|\tau|} (I_t - \bar{I})^2 \sum_{t=1}^{N-|\tau|} (P_{t+\tau} - \bar{P})^2}} \quad (1)$$

where I_t is ITD position, P_t is the atmospheric pressure, $\bar{I}$ and $\bar{P}$ are their respective means, and τ is the lag in months, and

$$r_{IR}(\tau) = \frac{\sum_{t=1}^{N-|\tau|} (I_t - \bar{I})(R_{t+\tau} - \bar{R})}{\sqrt{\sum_{t=1}^{N-|\tau|} (I_t - \bar{I})^2 \sum_{t=1}^{N-|\tau|} (R_{t+\tau} - \bar{R})^2}} \quad (2)$$

where R_t represents monthly precipitation and $\bar{R}$ is its mean, were used to quantify both the zero-lag association and lagged relationships between the variables. Positive and negative lags were examined to determine whether changes in ITD position tended to precede or follow corresponding variations in atmospheric pressure and precipitation. The results were interpreted in conjunction with the individual autocorrelation



functions to account for the influence of temporal persistence.

Fourthly, Granger causality tests were applied to examine predictive direction between ITD and atmospheric pressure and between ITD and precipitation. The tests assessed whether past values of ITD significantly improved prediction of pressure or precipitation beyond their own past values, and the reverse relationships were also examined. Appropriate lag lengths were selected using an information criterion. The Granger results were interpreted as evidence of predictive precedence rather than proof of physical causation. For the ITD-pressure relationship, the unrestricted model of the Granger causality function, could be expressed as

$$P_t = \alpha_0 + \sum_{j=1}^p \alpha_j P_{t-j} + \sum_{j=1}^p \beta_j I_{t-j} + \varepsilon_t \quad (3)$$

While the restricted model excludes the lagged ITD terms:

$$P_t = \alpha_0 + \sum_{j=1}^p \alpha_j P_{t-j} + \varepsilon_t \quad (4)$$

The null hypothesis

$$H_0: \beta_0 = \beta_1 = \beta_2 \dots = \beta_p = 0 \quad (5)$$

which means that past ITD values do not provide additional information.

The reverse direction, pressure $\rightarrow$ ITD is represented by

$$I_t = \gamma_0 + \sum_{j=1}^p \gamma_j I_{t-j} + \sum_{j=1}^p \delta_j P_{t-j} + \eta_t \quad (6)$$

with

$$H_0: \delta_0 = \delta_1 = \delta_2 \dots = \delta_p = 0 \quad (7)$$

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The same framework was applied to the ITD-precipitation relationship:

$$R_t = \lambda_0 + \sum_{j=1}^p \lambda_j P_{t-j} + \sum_{j=1}^p \mu_j I_{t-j} + \xi_t \quad (8)$$

with

$$H_0: \mu_0 = \mu_1 = \mu_2 \dots = \mu_p = 0$$

The reverse direction, precipitation $\rightarrow$ ITD is

$$I_t = \theta + \sum_{j=1}^p \gamma_j I_{t-j} + \sum_{j=1}^p \theta_j P_{t-j} + \zeta_t \quad (9)$$

Finally, wavelet coherence analysis was conducted separately for ITD-pressure and ITD-precipitation to investigate whether their relationships varied with time and temporal scale. The Morlet wavelet was used to resolve common oscillations between the paired series. Significant coherence regions were identified, while phase arrows were used to determine whether the variables were approximately in phase, anti-phase, or exhibited lead-lag relationships. The cone of influence was considered when interpreting edge regions, and

statistical significance was assessed against an appropriate red-noise background.

The continuous wavelet transformation functions, after Gristed et. al. (2004), for the ITD-pressure relationship are denoted $W_I(s, t)$ and $W_P(s, t)$ respectively. Their cross-wavelet transform is expressed as

$$W_{IP}(s, t) = W_I(s, t)W_P^*(s, t) \quad (10)$$

where * denotes the complex conjugate.

The squared wavelet coherence between ITD and pressure is then expressed as

$$R_{IP}^2(s, t) = \frac{|S(s^{-1}W_{IP}(s, t))|^2}{S(s^{-1}|W_I(s, t)|^2)S(s^{-1}|W_P(s, t)|^2)} \quad (11)$$

where s is the wavelet scale and S denotes a smoothing operator.

Similarly, for ITD precipitation, we have

$$R_{IR}^2(s, t) = \frac{|S(s^{-1}W_{IP}(s, t))|^2}{S(s^{-1}|W_I(s, t)|^2)S(s^{-1}|W_R(s, t)|^2)} \quad (12)$$

Where

$$W_{IR}(s, t) = W_I(s, t)W_R^*(s, t) \quad (13)$$

The wavelet coherence $R^2(s, t)$ ranges from 0 to 1, with values approaching 1 indicating strong localized association between the two series at a particular time and temporal scale.

For the phase relationship, the phase difference for ITD-pressure can be written as

$$\phi_{IP}(s, t) = \tan^{-1} \left[\frac{\text{Im}(W_{IP}(s, t))}{\text{Re}(W_{IP}(s, t))} \right] \quad (14)$$

and similarly

$$\phi_{IR}(s, t) = \tan^{-1} \left[\frac{\text{Im}(W_{IR}(s, t))}{\text{Re}(W_{IR}(s, t))} \right] \quad (15)$$

These phase differences are represented by arrows on the wavelet-coherence plots and allow the relative timing between ITD and pressure or precipitation to be assessed at different time scales.

4.0 Results and Discussion

Fig. 1 shows the time series of ITD, atmospheric pressure and rainfall over Lagos during 2015-2024. The ITD positions exhibit pronounced and recurrent annual cycle, characterised by northward migration from its relatively low latitudes at the beginning of the year (between December-February), attainment of its northernmost position during the middle to latter part of the year (between July and September), and subsequent southward retreat toward the end of the year. Despite the persistence of this annual cycle, appreciable interannual variations occur in both the magnitude



and timing of the maximum northward displacement.

The most pronounced excursions exceed 20°N in several years, with particularly large northward displacements evident in 2018 and 2024. Thus, while the seasonal migration of the ITD is highly regular, its annual amplitude is not invariant.

Atmospheric pressure also displays a well-defined annual cycle, although its temporal evolution differs from the smoother migration of the ITD (Fig. 1b). Pressure generally decreases during the early months of the year (reaching the minimum mostly between March-April), rises toward the middle of the year (reaching the maximum mostly between June-July) and subsequently decreases

during the latter part of the year. The recurrence of this pattern throughout the study period indicates strong seasonal organisation of surface pressure over Lagos. Visual comparison with the ITD series suggests substantial seasonal covariability, with periods of pronounced northward ITD displacement broadly corresponding to the higher-pressure portion (mostly to between September and October) of the annual pressure cycle. However, the respective turning points and extrema do not consistently occur simultaneously, suggesting that the relationship may involve a temporal phase difference rather than an instantaneous response.

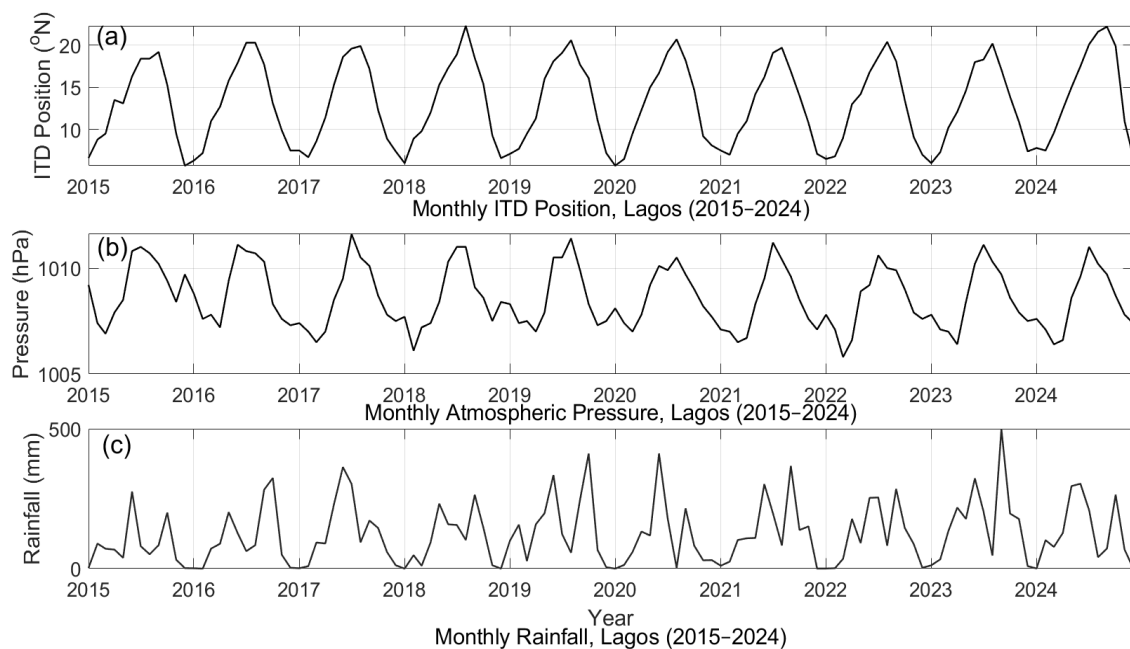


Fig. 1: Temporal Variability of the Intertropical Discontinuity and Its Relationship with Atmospheric Pressure and Precipitation in Lagos, Nigeria (2015-2024)

Rainfall exhibits considerably greater month-to-month and interannual variability than either ITD position or atmospheric pressure. Rainfall is generally low during the beginning and end of the year (mainly between December and January) and increases substantially during the wet season. However, the magnitude and timing of rainfall maxima vary markedly between years. Particularly large monthly rainfall totals occur in several years, including an exceptionally pronounced peak in 2023 approaching 500 mm. The rainfall series also displays evidence of the characteristic bimodal precipitation regime of coastal southwestern Nigeria, in which enhanced rainfall during the

early wet season is frequently interrupted by a mid-season reduction before rainfall increases again during the later wet-season period.

A notable feature of the combined time series is that maximum rainfall does not consistently coincide with the northernmost ITD position. The ITD generally reaches its largest northward displacement around the mature monsoon period, whereas rainfall over Lagos frequently exhibits an earlier maximum, a mid-season reduction (what has become mostly referred to as August break in Nigeria) and a subsequent secondary enhancement. This temporal structure indicates that local precipitation cannot be interpreted simply as a



monotonic function of ITD latitude. Rather, the position of the ITD provides a large-scale indicator of the seasonal evolution of the West African monsoon system, while rainfall at Lagos is additionally modulated by regional moisture availability, low-level convergence, atmospheric stability, convective processes and synoptic-scale variability.

Fig. 2 reveals that the monthly climatology of ITD, atmospheric pressure and rainfall are characterised

by three distinct and interconnected phase structure. The ITD is characterised by a regular northward migration and southward retreat; atmospheric pressure exhibits a comparatively smooth annual cycle with its maximum occurring approximately one month before the ITD maximum; and rainfall displays a strongly bimodal and much more variable seasonal regime, with the mid-season reduction in August.

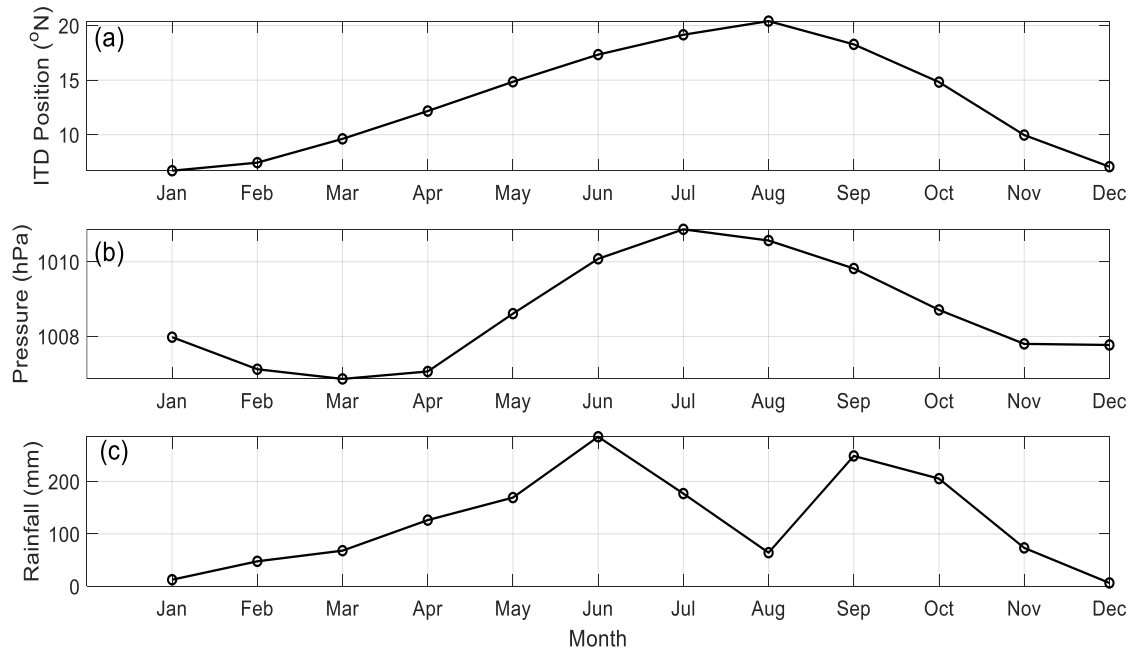


Fig. 2: Monthly Climatology over Lagos (2015-2024)

Atmospheric pressure exhibits a distinct but differently phased seasonal cycle (Fig. 2b). Mean pressure decreases from 1008.0 ± 0.64 hPa in January to the annual minimum of 1006.9 ± 0.58 hPa in March. This is followed by a sustained increase from April (1007.1 ± 0.51 hPa) through May (1008.6 ± 0.44 hPa) and June (1010.1 ± 0.62 hPa), reaching a climatological maximum of 1010.9 ± 0.46 hPa in July. Pressure remains relatively high in August (1010.6 ± 0.41 hPa) before declining through September and October to approximately 1007.8 hPa in November and December. Thus, while ITD position and atmospheric pressure both increase substantially during the transition toward the mature monsoon season, their climatological maxima do not coincide: pressure reaches its maximum in July, whereas the ITD reaches its northernmost mean position in August.

Rainfall displays the greatest seasonal amplitude and interannual variability of the three variables (Fig. 2c). Mean rainfall increases from 12.75 ± 30.79 mm in January to 47.79 ± 52.17 mm in February, 68.10 ± 37.20 mm in March and 126.34 ± 46.80 mm in April. It increases further to 169.27 ± 78.00 mm in May before reaching the primary climatological maximum of 285.16 ± 87.38 mm in June. Rainfall subsequently decreases to 176.89 ± 74.45 mm in July and falls sharply to 64.27 ± 30.20 mm in August. This mid-season reduction is followed by a pronounced resurgence to a secondary maximum of 248.66 ± 126.85 mm in September and 205.33 ± 100.33 mm in October, before rainfall decreases to 73.36 ± 52.99 mm in November and reaches its annual minimum of 6.57 ± 9.21 mm in December. The rainfall climatology therefore demonstrates a distinct bimodal wet-season regime, characterised by a primary June maximum,



an August minimum and a secondary September maximum. Table 1 summarises the statistical representation of the monthly climatology during the study period.

The climatological cycles reveal a clear seasonal relationship between the migration of the ITD and the evolution of atmospheric conditions over Lagos, but they also demonstrate that local rainfall does not respond linearly to ITD latitude. During the first half of the year, rainfall generally increases as the ITD migrates northward. Between January and June, the mean ITD position shifts from 6.70°N to 17.34°N , while mean rainfall increases from 12.75 to 285.16 mm. This broadly synchronous evolution is consistent with the progressive establishment and strengthening of the moist southwesterly monsoon regime over southern Nigeria.

The ITD illustrates a well-defined annual north-south migration (Fig. 2a). Its mean position advances progressively from $6.70 \pm 0.73^{\circ}\text{N}$ in January to $7.44 \pm 0.83^{\circ}\text{N}$ in February and $9.62 \pm 0.65^{\circ}\text{N}$ in March. The northward migration becomes more pronounced from April ($12.17 \pm 0.79^{\circ}\text{N}$), reaching $17.34 \pm 0.82^{\circ}\text{N}$ in June and $19.16 \pm 0.67^{\circ}\text{N}$ in July. The climatological northernmost position is attained in August at $20.41 \pm 1.05^{\circ}\text{N}$. Thereafter, the ITD retreats southward, declining to $18.28 \pm 1.54^{\circ}\text{N}$ in September, $14.82 \pm 2.12^{\circ}\text{N}$ in October and $7.07 \pm 0.64^{\circ}\text{N}$ by December. The comparatively large standard deviations in September and particularly October indicate greater interannual variability in the position of the ITD during its southward retreat than during much of its northward migration.

Table 1: Monthly Climatology, Lagos 2015-2024

Month	ITD Mean	ITD SD	Pressure Mean	Pressure SD	Rainfall Mean	Rainfall SD
Jan	6.70	0.7333	1008.0	0.6391	12.75	30.788
Feb	7.44	0.8276	1007.1	0.4131	47.79	52.166
Mar	9.62	0.6460	1006.9	0.5816	68.10	37.200
Apr	12.17	0.7861	1007.1	0.5147	126.34	46.804
May	14.85	0.8593	1008.6	0.4434	169.27	77.995
Jun	17.34	0.8181	1010.1	0.6215	285.16	87.381
Jul	19.16	0.6736	1010.9	0.4596	176.89	74.446
Aug	20.41	1.0525	1010.6	0.4056	64.27	30.197
Sep	18.28	1.5433	1009.8	0.3458	248.66	126.85
Oct	14.82	2.1238	1008.7	0.3414	205.33	100.330
Nov	9.97	0.8858	1007.8	0.3266	73.36	52.994
Dec	7.07	0.6430	1007.8	0.7587	6.57	9.2121

However, the relationship changes markedly during the mature monsoon period. From June to August, the ITD continues its northward migration from 17.34°N to its annual maximum of 20.41°N , whereas rainfall over Lagos decreases sharply from its primary maximum of 285.16 mm to only 64.27 mm. Thus, the climatological northernmost ITD position coincides with the pronounced August rainfall minimum rather than with maximum precipitation over Lagos. This provides strong descriptive evidence that the local rainfall response to ITD displacement is seasonally dependent and cannot be represented simply by increasing rainfall with increasing ITD latitude. The September transition further illustrates this behaviour. As the

ITD begins its southward retreat, decreasing from 20.41°N in August to 18.28°N in September, mean rainfall increases sharply from 64.27 to 248.66 mm. The secondary rainfall maximum therefore occurs during the retreat phase of the ITD rather than during its maximum northward displacement. This seasonal reversal is consistent with the bimodal rainfall regime of coastal southwestern Nigeria and emphasizes that ITD latitude is an indicator of the broader state of the West African monsoon rather than a direct measure of local rainfall intensity.

Atmospheric pressure exhibits a comparatively smooth annual cycle and is more closely synchronised with the broad seasonal migration of



the ITD than rainfall. Following its March minimum of 1006.9 hPa, pressure rises progressively to 1010.9 hPa in July, while the ITD simultaneously migrates from 9.62°N in March to 19.16°N in July. The pressure maximum occurs one calendar month before the August ITD maximum. This apparent phase displacement suggests a possible lagged relationship between the seasonal evolution of ITD position and surface pressure; however, the direction and statistical significance of such a relationship cannot be inferred from climatological means alone and require formal cross-correlation analysis. The standard deviations provide additional evidence of differences in interannual variability among the three variables. ITD variability is relatively small during most of the northward migration but increases during the retreat phase, reaching its largest monthly standard deviation in October (2.12°). Pressure shows comparatively limited interannual variability throughout the year, with monthly standard deviations of only about 0.33–0.76 hPa. Rainfall, by contrast, exhibits much greater year-to-year variability, particularly during the second rainfall season, with standard deviations of 126.85 mm in September and 100.33 mm in October. The high rainfall variability indicates that although the seasonal migration of the ITD provides a relatively regular large-scale atmospheric framework, rainfall over Lagos is considerably more sensitive to interannual and shorter-timescale atmospheric variability. Similarly, the rainfall climatology is generally consistent with established Lagos and southern Nigerian rainfall behaviour. ITD climatology in this study agrees well with the recent West African analysis by Odekunle *et al.* (2024), who found that the ITD reaches its annual peak during approximately 4–28 August at latitudes of about 17–23°N across West Africa. The Lagos-related ITD series in this study gives a climatological maximum of $20.41 \pm 1.05^\circ\text{N}$ in August, falling almost exactly within the broad West Africa reported range. This study, of shorter period (2015–2024), also clearly reproduces a gradual northward advance followed by retreat described in the West African study (1979–2020), in reference. However, although the seasonal migration of the ITD and the bimodal rainfall regime of southern Nigeria are well established, the present results reveal a

distinct temporal decoupling between maximum ITD displacement and maximum precipitation over coastal Lagos. The 2015–2024 climatology shows that the primary rainfall maximum occurs in June, the surface-pressure maximum in July and the northernmost ITD position in August, when rainfall is markedly reduced. Rainfall subsequently increases to a secondary maximum in September during the initial southward retreat of the ITD. These results suggest that the influence of ITD displacement on Lagos precipitation is seasonally dependent rather than monotonic and highlight the need to distinguish the common seasonal cycle from anomalous ITD-rainfall coupling.

A notable feature of the climatological cycles is the temporal displacement between maximum surface pressure and maximum northward ITD position. The result shows that pressure over Lagos reaches its maximum in July (1010.9 ± 0.46 hPa) ahead of ITD position in August ($20.41 \pm 1.05^\circ\text{N}$). This approximately one-month separation suggests that the seasonal evolution of the regional pressure field may precede the ITD's maximum northward displacement. Such behaviour is physically plausible within West African monsoon dynamics, where land-ocean thermal contrasts and associated pressure gradients regulate low-level monsoon flow and contribute to ITD displacement. Previous observational and modelling studies have demonstrated links among surface pressure gradients, monsoon circulation and ITD movement. However, the present climatological phase difference alone does not establish that local Lagos surface-pressure variations drive ITD migration, since both may represent responses to the broader seasonal evolution of the West African monsoon circulation. Nevertheless, the systematic occurrence of the Lagos pressure maximum one month before the climatological ITD maximum provides a testable hypothesis that changes in atmospheric pressure may contain predictive information on subsequent ITD displacement.

Autocorrelation analysis revealed pronounced annual persistence in both ITD position and atmospheric pressure over Lagos (Fig. 3). At a lag of one month, the autocorrelation coefficients were 0.822 for ITD position and 0.744 for atmospheric pressure, indicating strong short-term persistence in both monthly series. The autocorrelation functions subsequently decreased and became



approximately zero at a lag of three months before attaining pronounced negative values at six months ($r = -0.866$ for ITD and $r = -0.588$ for pressure). Strong positive autocorrelation re-emerged at the 12-month lag, with coefficients of 0.852 and 0.807 for ITD and pressure, respectively. This annual recurrence persisted at 24 months ($r = 0.761$ and 0.708) and 36 months ($r = 0.663$ and 0.615), although its magnitude progressively decreased with increasing lag. The autocorrelation functions exhibited an alternating pattern of positive annual peaks at 12, 24 and 36 months and negative half-year troughs at 6, 18 and 30 months. The negative autocorrelations were particularly pronounced for the ITD, reaching -0.866 , -0.791 and -0.688 at these respective lags. This oscillatory structure confirms that both ITD position and atmospheric pressure are strongly dominated by recurring annual cycles, with opposite seasonal phases separated by approximately six months. The gradual reduction in the magnitude of successive annual autocorrelation peaks indicates that the

seasonal cycles are persistent but are modulated by interannual variability.

The strong annual autocorrelation observed in both variables is consistent with the climatological seasonal cycles identified in this study. The ITD undergoes a systematic annual northward migration and southward retreat, while atmospheric pressure exhibits a similarly recurrent seasonal evolution. The substantially negative ITD autocorrelation at approximately six-month intervals reflects the contrasting positions of the ITD during opposing phases of its annual migration. Importantly, the strong serial dependence in both series indicates that correlations calculated directly from the original monthly observations may be strongly influenced by their common seasonal structure. Consequently, high contemporaneous or lagged ITD–pressure correlations cannot, by themselves, be interpreted as evidence of dynamical coupling. This provides the statistical justification for examining both the original series and seasonally adjusted anomalies in the subsequent cross-correlation analysis.

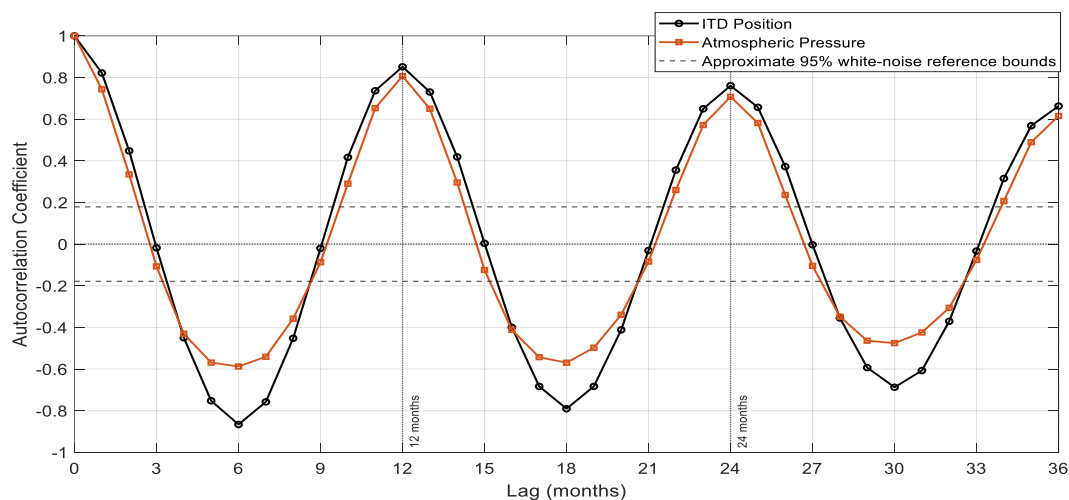


Fig. 3: Autocorrelation of ITD Position and Atmospheric Pressure Lags, Nigeria (2015-2024)

Cross-correlation analysis was performed over lags of -12 to $+12$ months to investigate the temporal relationship between ITD position and atmospheric pressure over Lagos. Negative lags represent ITD leading pressure, whereas positive lags represent pressure leading ITD. The analysis was conducted for both the original monthly observations and the corresponding deseasonalised anomalies. The raw monthly series exhibited a pronounced oscillatory cross-correlation structure, with a strong positive relationship at zero lag ($r \approx 0.81$). Correlations

decreased progressively away from zero lag and became strongly negative at approximately ± 6 months, reaching values of about -0.8 , before returning to strong positive values toward ± 12 months. This approximately 12-month periodic structure closely resembles the autocorrelation patterns independently obtained for ITD position and atmospheric pressure and indicates substantial influence of their common annual cycle.

Removal of the calendar-month climatology produced a markedly different relationship. Cross-



correlations between the ITD and pressure anomalies were generally weak across the entire -12 to $+12$ month lag interval, with coefficients mostly below $|r| = 0.2$. No pronounced anomaly-correlation maximum occurred at zero lag or when pressure preceded ITD by one month. In particular, the $+1$ -month relationship was weakly negative ($r \approx -0.08$). The strong periodic cross-correlation evident in the raw observations therefore largely disappeared following deseasonalisation.

The contrast between the raw and deseasonalised cross-correlations provides an important insight into the nature of the ITD-pressure relationship over Lagos. The strong zero-lag correlation and the alternating positive and negative correlations at approximately annual and half-annual intervals in the original monthly series initially suggest substantial coupling between ITD position and atmospheric pressure. However, the close correspondence of this structure with the autocorrelation functions of the individual variables demonstrates that much of the apparent relationship arises from their common seasonal evolution.

This interpretation is consistent with the climatological analysis, which showed that both variables undergo highly organised annual cycles. Atmospheric pressure reaches its climatological maximum in July, whereas the ITD reaches its northernmost mean position in August. Although this one-month displacement initially suggested the possibility that pressure variations might precede ITD migration, the deseasonalised cross-correlation does not support such an inference at the monthly anomaly scale.

After removal of the recurring seasonal cycle, the $+1$ -month pressure-leading-ITD correlation becomes weak and slightly negative. Consequently, the July-August displacement of the climatological maxima is more appropriately interpreted as part of the coordinated seasonal evolution of the West African monsoon system rather than evidence, by itself, that local surface-pressure variations over Lagos drive subsequent ITD displacement. Both variables may respond to the broader seasonal evolution of land-ocean thermal contrasts, regional pressure gradients and monsoon circulation.

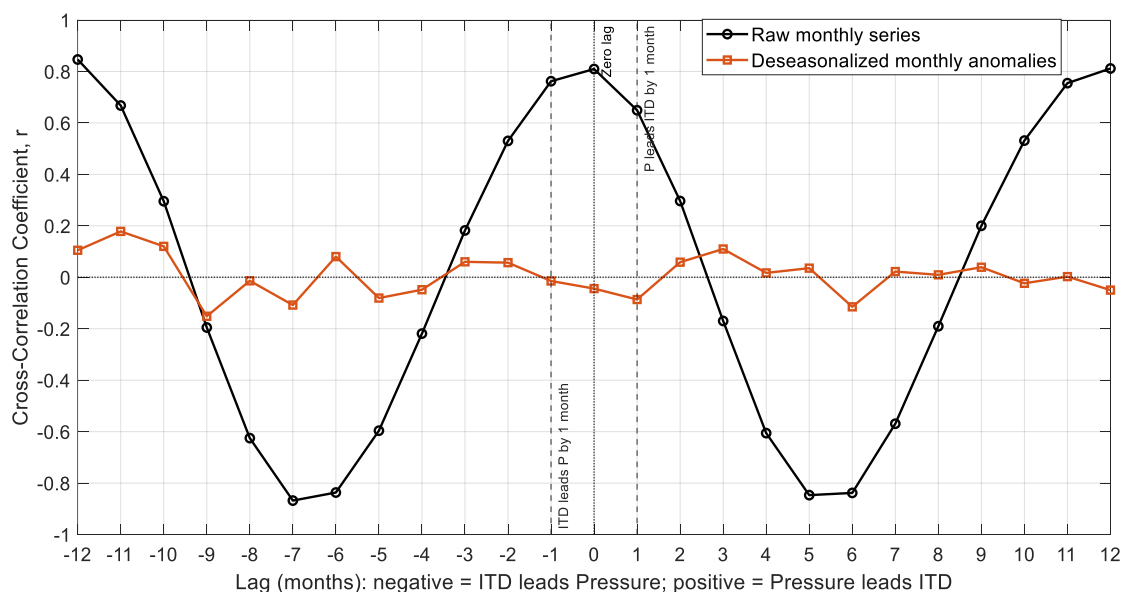


Fig. 4: Cross-Correlation between ITD Position and Atmospheric Pressure Raw Monthly Series and Deseasonalised Anomalies, Lagos (2015-2024)

The persistence of only weak anomaly correlations further indicates that departures of the ITD from its normal monthly position are not strongly explained by contemporaneous or short-lag departures in local Lagos surface pressure alone. This suggests that interannual and intraseasonal ITD variability is

likely influenced by broader regional atmospheric dynamics rather than by variations in pressure at a single coastal location.

Granger causality analysis was applied to the deseasonalised monthly ITD and atmospheric-pressure series to determine whether departures in either variable contained predictive information



about subsequent variations in the other. Lag orders of 1-6 months were examined in both directions. No statistically significant Granger-causal relationship was detected at the 5% significance level across the investigated lag orders (Fig. 5). For the Pressure $\rightarrow$ ITD direction, the p-values remained above 0.05 at all lags, with the lowest value occurring at approximately two months ($p \approx 0.16$). Similarly, ITD $\rightarrow$ Pressure showed no evidence of significant predictive causality, with p-values remaining substantially above the 0.05 threshold throughout the 1-6-month interval. Consequently, neither pressure anomalies nor ITD-position anomalies provided statistically significant additional predictive information for the other variable after accounting for their respective past behaviour.

The absence of significant Granger causality complements the cross-correlation results and provides further evidence that the strong relationship observed between the original monthly ITD and pressure series is predominantly associated with their common seasonal evolution rather than a direct short-term predictive relationship.

This result is particularly important in interpreting the one-month displacement identified in the climatological analysis. Atmospheric pressure attained its climatological maximum in July,

whereas the ITD reached its northernmost mean position in August. Although this temporal sequence initially suggested that pressure variations might precede ITD displacement, neither the deseasonalised cross-correlation nor the Granger-causality analysis supports such an interpretation. Pressure anomalies did not significantly predict subsequent ITD anomalies at any lag between one and six months.

Likewise, no significant ITD - Pressure relationship was identified, indicating an absence of detectable bidirectional predictive coupling between the two anomaly series at the monthly timescale during 2015-2024. The July-August displacement should therefore be interpreted as a feature of the coordinated seasonal evolution of the regional atmospheric circulation rather than evidence that local surface-pressure variations over Lagos directly drive subsequent ITD migration.

Thus, although atmospheric pressure reaches its climatological maximum approximately one month before the northernmost ITD position, the apparent temporal ordering does not persist after removal of the annual cycle. The weak cross-correlations between deseasonalised anomalies and the absence of significant bidirectional Granger causality indicate that the observed pressure-ITD phase displacement primarily reflects their coordinated seasonal evolution rather than a direct short-term predictive relationship between local Lagos surface pressure and ITD displacement.

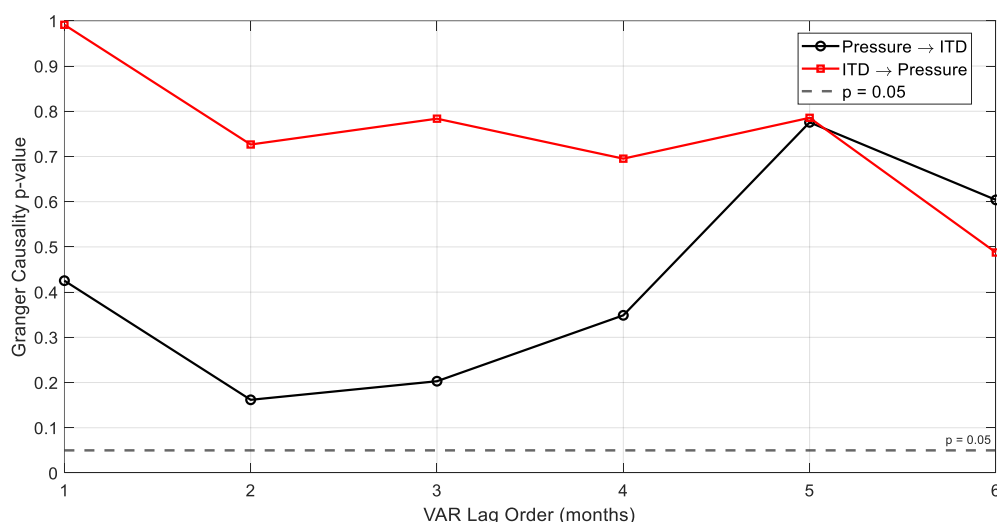


Fig. 5: Granger Causality between ITD Position and Atmospheric Pressure Deseasonalised Monthly Anomalies, Lagos (2015-2024)

The present findings are broadly consistent with previous understanding of the West African

monsoon system, while providing an important qualification concerning the interpretation of local



surface pressure-ITD relationships over Lagos. Previous studies have established that the seasonal migration of the ITD is dynamically embedded within the large-scale thermal and pressure structure of the West African monsoon. Lavaysse *et al.* (2009), for example, showed that the West African/Saharan Heat Low undergoes a pronounced seasonal displacement and that its evolution is closely connected with low-level temperature, pressure and monsoon circulation. Similarly, Drobinski *et al.* (2005) associated West African monsoon onset with intensification of the Saharan Heat Low and accompanying changes in regional pressure gradients and circulation. The strong annual periodicity observed here is also consistent with recent analysis of ITD migration over West Africa. Odekunle *et al.* (2024) reported a systematic annual northward advance and southward retreat of the ITD, with its climatological peak occurring during August at approximately 17–23°N. This agrees closely with the present August maximum of 20.41°N and supports the interpretation that the strong 12-month autocorrelation and oscillatory raw ITD–pressure cross-correlation primarily reflect the recurrent seasonal dynamics of the West African monsoon. Importantly, however, the disappearance of the strong ITD–pressure relationship after deseasonalisation, together with the absence of significant bidirectional Granger causality at 1–6-month lags, indicates that local Lagos surface-pressure anomalies do not independently predict ITD displacement on these monthly timescales. This result does not contradict the established dynamical importance of atmospheric pressure to the West African monsoon. Rather, previous studies emphasize large-scale pressure gradients and the Saharan Heat Low, rather than pressure variability at an individual coastal station, as important components of monsoon dynamics. Lavaysse *et al.* (2016), for instance, emphasized that interactions between the Saharan Heat Low and West African monsoon vary according to the temporal scale considered.

This distinction is also consistent with Nigerian evidence from Odekunle (2010), who found that ITD position and large-scale anticyclonic pressure differences significantly influenced rainfall variability principally in northern Nigeria, whereas southern Nigerian rainfall variability was more

strongly associated with Gulf of Guinea sea-surface temperature. Thus, the present findings extend rather than contradict previous work: although ITD position and Lagos surface pressure exhibit strong synchronized seasonal behaviour, their deseasonalized variations show little evidence of direct short-term predictive coupling. The observed July pressure maximum followed by the The August maximum in the Intertropical Discontinuity (ITD) position is therefore more plausibly interpreted as a manifestation of its shared response to the evolving West African monsoon circulation than as evidence that local surface pressure in Lagos directly drives ITD migration.

The exceptionally high mean coherence of 0.978 near the annual period in the raw monthly series is consistent with the pronounced seasonality identified through the monthly climatology and autocorrelation analyses. Both variables exhibit strong annual recurrence, although their climatological maxima are separated by approximately one month: surface pressure peaks in July, whereas the ITD reaches its northernmost position in August. Thus, the near-annual coherence more plausibly reflects closely synchronized responses to the broader seasonal atmospheric circulation over West Africa than a direct causal relationship in which local surface pressure drives ITD displacement.

This interpretation is physically consistent with the established dynamics of the West African monsoon. The ITD marks the low-level boundary and convergence zone between dry northeasterly continental flow and moist southwesterly monsoon flow. Its seasonal migration is influenced by broader atmospheric processes, including the development and movement of the Saharan heat low, land–ocean thermal contrasts, and regional circulation patterns. The pronounced annual ITD signal identified over the 2015–2024 period is also consistent with the strong seasonal migration documented across West Africa by Odekunle *et al.* (2024).

More importantly, removal of the monthly climatology substantially altered the coherence structure. Maximum mean coherence decreased from 0.978 near the annual period in the original series to 0.355 at approximately 0.678 years in the anomaly series, while the continuous annual



coherence band was replaced by localized episodes of moderate-to-high coherence.

Wavelet coherence analysis revealed a strong time-frequency association between ITD position and atmospheric pressure in the original monthly series

during 2015-2024. A broad region of high magnitude-squared coherence persisted throughout most of the study period at approximately the annual timescale.

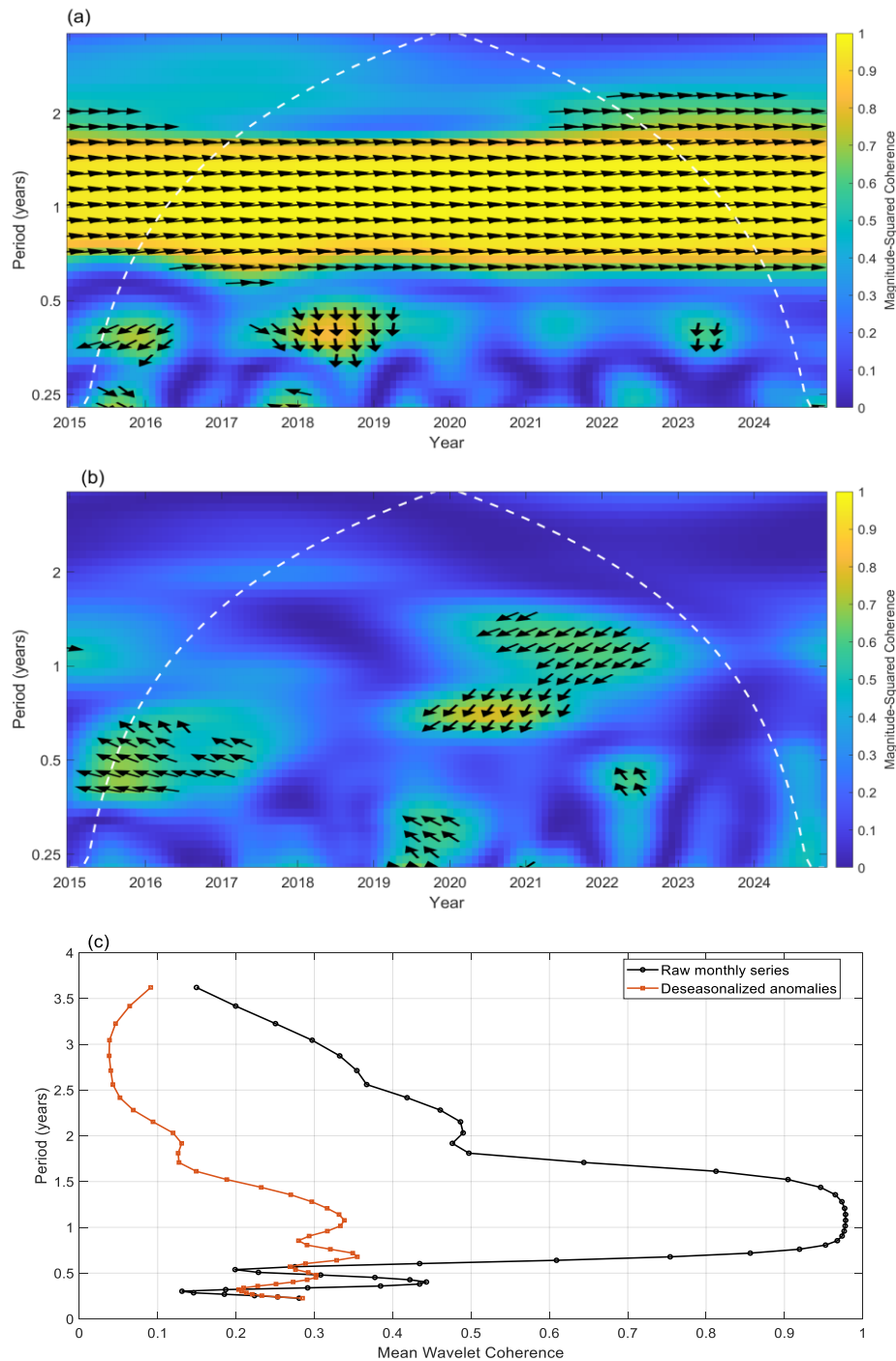


Fig. 6: Wavelet Coherence between ITD Position and Atmospheric Pressure (2015-2024 (a) Raw monthly series, (b) ITD and Pressure Anomalies (c) Deseasonalised monthly series

The maximum mean coherence was 0.978 at a period of 1.076 years, indicating that the dominant common variability between ITD position and atmospheric pressure occurred close to the annual

cycle. Phase vectors within this high-coherence band were predominantly directed toward the right with relatively small angular deviations, indicating closely synchronized seasonal variability between



the two variables. This is consistent with the climatological behaviour in which atmospheric pressure reached its maximum in July and the ITD attained its northernmost mean position in August. In addition to the dominant annual coherence, intermittent regions of enhanced coherence occurred at shorter, subannual periods, particularly around 2015-2016 and 2018-2019. These features were comparatively localized in time and displayed more variable phase relationships, suggesting that short-period ITD–pressure covariability was less temporally stable than the annual relationship.

A markedly different pattern emerged after removal of the monthly climatology. The broad and persistent near-annual coherence observed in the raw series largely disappeared, and the maximum mean coherence decreased to 0.355 at a period of 0.678 years. The remaining anomaly coherence was temporally localized, with the most prominent region occurring approximately during 2019–2021 at subannual periods and weaker coherence extending toward the annual timescale. The deseasonalized results therefore indicate that ITD and pressure anomalies exhibit intermittent rather than persistent time-frequency coupling.

The wavelet-coherence results demonstrate that the strong relationship between ITD position and atmospheric pressure over Lagos is dominated by their common seasonal evolution. The

This result indicates that the apparent strength of the ITD–pressure relationship in the original monthly data is largely attributable to their common annual cycle. The residual relationship between anomalous ITD displacement and anomalous Lagos surface pressure is comparatively weak, temporally variable and frequency dependent. Such nonstationary relationships are precisely those for which wavelet coherence provides an advantage over conventional correlation analysis). The wavelet results are consequently consistent with the preceding cross-correlation and Granger-causality analyses. Although strong association was observed in the original series, cross-correlation weakened markedly after deseasonalization, while no significant Pressure-ITD or ITD-Pressure Granger relationship was detected at lags of 1–6 months. Taken together, these findings indicate that the July pressure maximum preceding the August ITD maximum represents a reproducible

phase relationship within the seasonal monsoon cycle, but does not constitute evidence that local pressure anomalies over Lagos independently drive subsequent ITD displacement.

This distinction may constitute an important contribution of the present study. Previous Nigerian studies have demonstrated the climatic relevance of ITD migration and its spatially varying relationship with surface climate; for example, Odekunle (2010) found that ITD position significantly accounted for interannual rainfall variability principally in northern Nigeria and also emphasized the influence of larger-scale pressure differences. The present results extend this perspective to coastal Lagos by explicitly separating the strong climatological ITD–pressure synchronization from the much weaker deseasonalized relationship. The combination of climatology, autocorrelation, cross-correlation, Granger analysis and wavelet coherence therefore suggests that Lagos surface pressure is better interpreted as a locally observed component of the evolving West African monsoon circulation than as an independent short-term driver of ITD migration. Wavelet coherence analysis revealed a strong time-frequency association between ITD position and atmospheric pressure in the original monthly series during 2015-2024 (Fig 6a). A broad region of high magnitude-squared coherence persisted throughout most of the study period at approximately the annual timescale. The maximum mean coherence was 0.978 at a period of 1.076 years (Fig. 6c), indicating that the dominant common variability between ITD position and atmospheric pressure occurred close to the annual cycle. Phase vectors within this high-coherence band were predominantly directed toward the right with relatively small angular deviations, indicating closely synchronised seasonal variability between the two variables. This is consistent with the climatological behaviour in which atmospheric pressure reached its maximum in July and the ITD attained its northernmost mean position in August. In addition to the dominant annual coherence, intermittent regions of enhanced coherence occurred at shorter, subannual periods, particularly around 2015-2016 and 2018-2019. These features were comparatively localised in time and displayed more variable phase relationships, suggesting that short-period ITD–pressure covariability was less



temporally stable than the annual relationship. A markedly different pattern emerged after removal of the monthly climatology. The broad and persistent near-annual coherence observed in the raw series largely disappeared (Fig. 6b), and the maximum mean coherence decreased to 0.355 at a period of 0.678 years (Fig. 6c). The remaining anomaly coherence was temporally localised, with the most prominent region occurring approximately during 2019-2021 at subannual periods and weaker coherence extending toward the annual timescale. The deseasonalised results therefore indicate that ITD and pressure anomalies exhibit intermittent rather than persistent time-frequency coupling.

The wavelet-coherence results demonstrate that the strong relationship between ITD position and atmospheric pressure over Lagos is dominated by their common seasonal evolution. The exceptionally high mean coherence of 0.978 near the annual period in the raw monthly series is consistent with the pronounced seasonality previously identified from the monthly climatology and autocorrelation analyses. Both variables exhibit strong annual recurrence, while their climatological maxima are separated by only approximately one month, with pressure reaching its maximum in July and the ITD its northernmost position in August. The near-annual coherence therefore represents closely synchronized components of the West African seasonal circulation rather than necessarily indicating a direct local pressure forcing of ITD displacement. This interpretation is physically consistent with the established dynamics of the West African monsoon. The ITD represents the low-level convergence between dry northerly continental flow and moist southwesterly monsoon flow, while its seasonal displacement is embedded within broader interactions involving the Saharan heat low, land-ocean thermal contrasts and regional atmospheric circulation. The pronounced annual ITD signal obtained over 2015-2024 is also consistent with the strong annual migration documented over West Africa by Odekunle *et al.* (2024).

More importantly, removal of the monthly climatology substantially altered the coherence structure. Maximum mean coherence decreased from 0.978 near the annual period in the original

series to 0.355 at approximately 0.678 years in the anomaly series, while the continuous annual coherence band was replaced by localized episodes of moderate-to-high coherence. This result indicates that the apparent strength of the ITD-pressure relationship in the original monthly data is largely attributable to their common annual cycle. The residual relationship between anomalous ITD displacement and anomalous Lagos surface pressure is comparatively weak, temporally variable and frequency dependent. Such nonstationary relationships are precisely those for which wavelet coherence provides an advantage over conventional correlation analysis (Grinsted *et al.*, 2004).

The wavelet results are consequently consistent with the preceding cross-correlation and Granger-causality analyses. Although strong association was observed in the original series, cross-correlation weakened markedly after deseasonalisation, while no significant Pressure-ITD or ITD-Pressure Granger relationship was detected at lags of 1-6 months. Taken together, these findings indicate that the July pressure maximum preceding the August ITD maximum represents a reproducible phase relationship within the seasonal monsoon cycle, but does not constitute evidence that local pressure anomalies over Lagos independently drive subsequent ITD displacement. Previous Nigerian studies have demonstrated the climatic relevance of ITD migration and its spatially varying relationship with surface climate; for example, Odekunle (2010) found that ITD position significantly accounted for interannual rainfall variability principally in northern Nigeria and also emphasized the influence of larger-scale pressure differences. The present results extend this perspective to coastal Lagos by explicitly separating the strong climatological ITD-pressure synchronization from the much weaker deseasonalised relationship.

The combination of climatology, autocorrelation, cross-correlation, Granger analysis and wavelet coherence therefore suggests that Lagos surface pressure is better interpreted as a locally observed component of the evolving West African monsoon circulation than as an independent short-term driver of ITD migration.

The wavelet coherence analysis reveals a strong seasonal relationship between ITD position and



rainfall over Lagos, although the relationship differs from that observed between ITD and atmospheric pressure.

Fig. 6(a) shows persistent high coherence between ITD and rainfall in the raw monthly series, particularly at periods of approximately 0.8-1.5 years throughout 2015-2024. Coherence exceeds 0.9 over much of the annual band, with predominantly rightward phase arrows indicating

broadly synchronized seasonal variability. This resembles the ITD–pressure relationship, for which maximum mean coherence reached 0.978 at a period of 1.076 years. The common annual coherence suggests that ITD migration, atmospheric pressure and rainfall are all strongly influenced by the seasonal evolution of the West African monsoon.

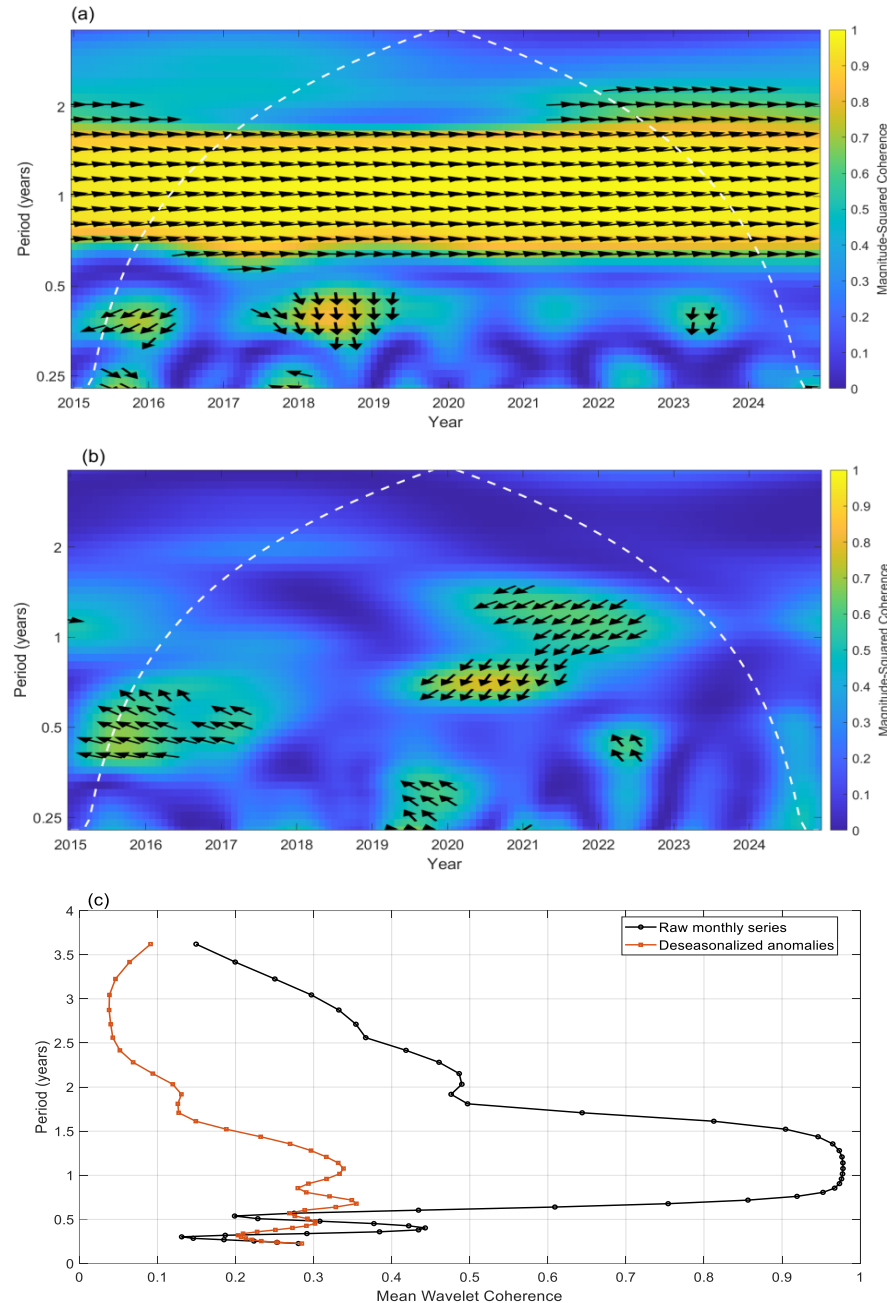


Fig. 6: Wavelet Coherence between ITD Position and Atmospheric Pressure (2015-2024 (a) Raw monthly series, (b) ITD and Pressure Anomalies (c) Deseasonalised monthly series



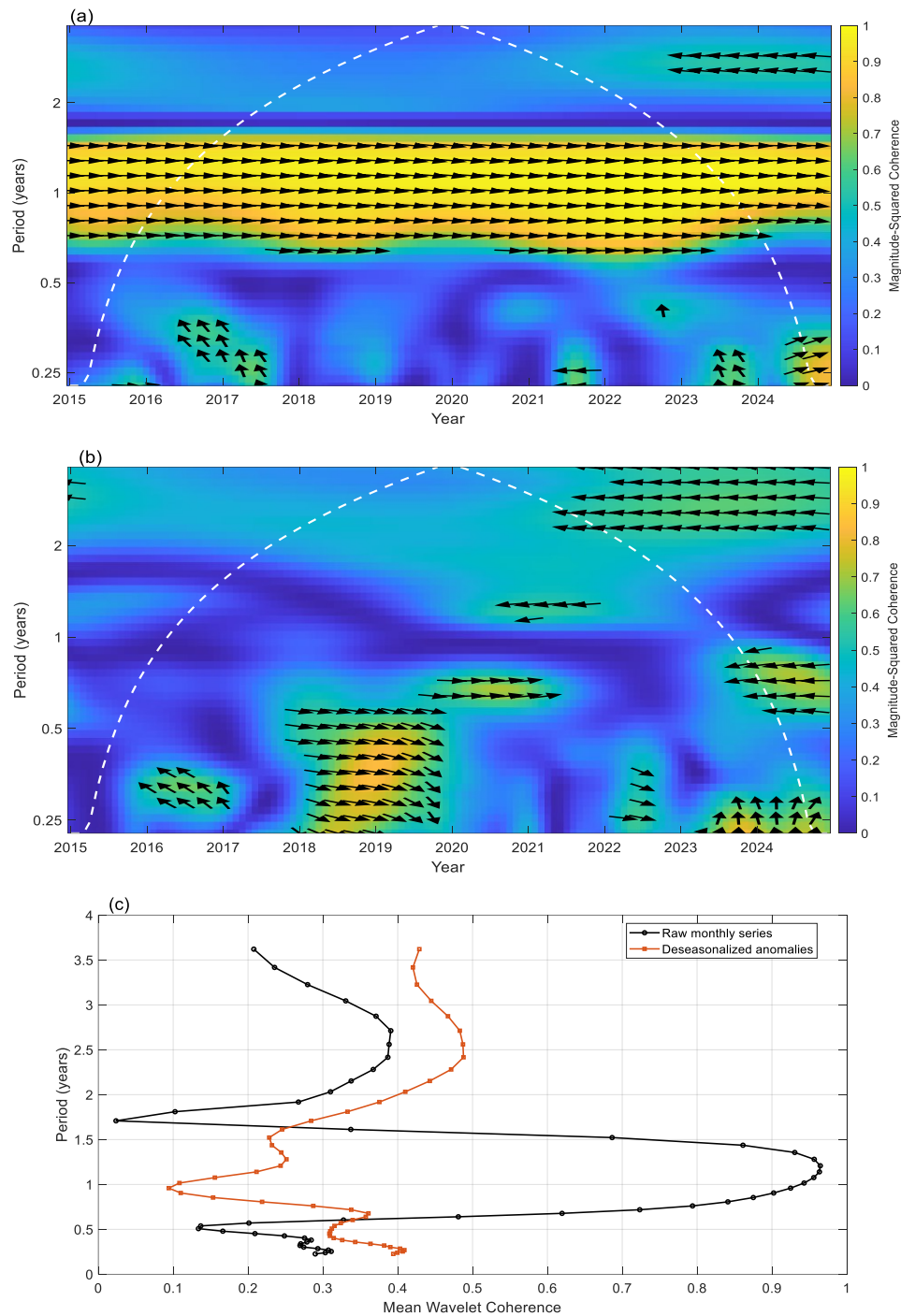


Fig. 7: Wavelet Coherence between ITD and (a) Rainfall Anomalies Deseasonalised Monthly Series, and (c) Mean Wavelet Coherence Lags, Nigeria (2015-2024)

However, Fig. 7(b) reveals a different relationship after deseasonalisation. The persistent annual coherence largely disappears, while localized regions of moderate-to-high coherence remain, particularly around 2018–2020 at periods of approximately 0.25–0.5 years. Additional coherence occurs around 2023–2024 at shorter periods, although some of these features are

affected by the cone of influence. Fig. 7(c) confirms that the mean coherence of the rainfall anomalies is substantially lower than that of the raw series near the annual period. Nevertheless, the remaining localised coherence indicates that anomalous ITD displacement may be associated with rainfall variability during particular periods,



rather than through a stable relationship throughout the decade.

The comparison with ITD-pressure is particularly informative. Both relationships exhibit strong annual coherence that weakens after deseasonalisation. However, ITD-rainfall anomalies display distinct episodes of relatively high subannual coherence, whereas the ITD-pressure anomaly relationship was generally weaker and more spatially restricted in the time-frequency domain. This suggests that rainfall may respond to variations in the monsoon circulation through processes not adequately represented by local surface pressure alone. The climatological results provide a physical explanation. Rainfall reaches its primary maximum in June (285.16 mm), atmospheric pressure peaks in July (1010.9 hPa), and the ITD reaches its northernmost position in August (20.41°N), when rainfall decreases to 64.27 mm. Rainfall subsequently increases to a secondary maximum of 248.66 mm in September as the ITD retreats southward. Thus, rainfall does not increase monotonically with northward ITD displacement. Instead, the rainfall response depends on the seasonal position of the ITD and the accompanying moisture transport, atmospheric convergence, convection and regional circulation conditions.

These findings suggest that the ITD-pressure relationship primarily reflects the coordinated annual evolution of the monsoon system, whereas the ITD-rainfall relationship is more seasonally dependent and exhibits intermittent subannual coupling. This interpretation is consistent with Odekunle (2010), who reported that the relationship between ITD position and rainfall varies geographically across Nigeria, with more complex rainfall controls in southern Nigeria.

The findings in this study suggest that rainfall over Lagos is associated with the seasonal migration of the ITD, but its variability is modulated by additional atmospheric processes, while local pressure predominantly reflects the broader seasonal circulation rather than independently controlling ITD migration.

5.0 Conclusion

This study investigated the temporal variability of the Intertropical Discontinuity (ITD) and its relationship with atmospheric pressure and rainfall over Lagos, Nigeria, using 120 monthly

observations spanning 2015-2024. The results revealed a pronounced annual north-south migration of the ITD, from a mean minimum of 6.70°N in January to a maximum of 20.41°N in August. Atmospheric pressure attained its climatological maximum of 1010.9 hPa in July, approximately one month before the northernmost ITD position. Rainfall exhibited a bimodal distribution, with a primary maximum of 285.16 mm in June, an August minimum of 64.27 mm, and a secondary maximum of 248.66 mm in September, demonstrating that rainfall does not increase monotonically with northward ITD displacement.

Wavelet coherence analysis revealed strong annual synchronisation between ITD position and atmospheric pressure, with maximum mean coherence of 0.978 at a period of 1.076 years, declining to 0.355 at 0.678 years following deseasonalisation. Similarly, ITD-rainfall mean coherence approached 0.97 near the annual period but decreased substantially after removal of the seasonal cycle, although intermittent subannual coherence persisted. Deseasonalised cross-correlation and Granger-causality analyses further revealed no significant predictive relationship between ITD and pressure anomalies at lags of 1-6 months ($p > 0.05$).

The principal contribution of this study is the quantitative distinction between strong climatological synchronisation and weaker, temporally variable anomaly relationships among ITD position, atmospheric pressure and rainfall over coastal Lagos. The findings indicate that local atmospheric pressure primarily reflects the seasonal evolution of the West African monsoon, while rainfall responds more complexly to ITD migration, moisture availability and atmospheric circulation. Consequently, ITD position provides a useful indicator of seasonal monsoon conditions but cannot independently explain monthly rainfall variability. These findings improve understanding of the seasonal phase relationships and limitations of ITD-based interpretations of coastal West African climate variability.

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Declarations

Conflict of Interest

The authors declared no conflict of interest

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Ethical consideration

Has been declared in Section 2.7

Data Availability

Data shall be made available upon request

Author Contributions

All components of the work were done by the author.

