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Dynamics of vertical profile of radio refractivity in Akure, South-Western Nigeria

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Abstract

This research investigated fractal and chaotic dynamics in the vertical profile radio refractivity in the atmosphere using Tsallis Entropy, Hurst Exponent and Largest Lyapunov Exponent (LLE). Daily temperature, relative humidity and radio refractivity data obtained from the European Centre for Medium Range Weather Forecasts (ECMWF) Re-Analysis Project at thirty seven (37) different atmospheric pressure level from 1979 - 2014 were used in this study. The Hurst Exponent parameter obtained, using the method of Detrended Fluctuation Analysis, in the radio refractivity profile studied showed that there is persistence across all levels. Tsallis entropy did not reveal any structure or significant variations from the tropopause to the surface. To determine if any of the radio refractivity is chaotic at any of the studied level, the Largest Lyapunov Exponent (LLE) was computed. Positive values were obtained at all levels for radio refractivity, indicating deterministic chaos in the profile of radio refractivity.

Keywords: chaos, radio refractivity, Lyapunov Exponent, atmospheric dynamics

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Introduction

Dynamical complexities in atmospheric time series has gained attention in recent times due to its ability to reveal underlying dynamics and inherent behaviour not possible with linear tools (Fuwape et al., 2016). There is the need to investigate chaoticity in radio refractivity as it is one of the most important ways of determining the effect of atmospheric parameters on communication systems. This study aims to investigate the degree of disorderliness, persistence and chaotic nature in the vertical profile (sea level to the stratosphere) of radio refractivity over Akure, South western Nigeria. Result obtained in this study will help in planning of satellite communication system over the region.

Methodology

Daily average values of 2m temperature (T), 2 m dew point temperature and surface pressure (P) from 1979 to 2014 were obtained from the archives of the European Centre for Medium Range Weather Forecasts (ECMWF) Re-Analysis Project at thirty seven (37) different atmospheric pressure levels. Radio refractivity was computed from the expression

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \qquad (1)$$

where e is the water vapour pressure. The data was detrended to remove periodicity (Ogunjo, 2015).

Entropy is the degree of disorderliness in a system. The concept of entropy is widely used to describe the state of systems in thermodynamics and statistical mechanics. Different types of entropy such as Shannon Entropy, Tsallis entropy have been introduced over the years. Tsallis entropy (Tsallis, 1988) is defined as

$$S_q = \frac{1}{q-1}\left(1-\sum_{i=1}^{n} p_i^q\right) \tag{2}$$

$q = \Re$ is a measure of the non-extensivity of the system. In the limit $q \to 1$, Tsallis entropy is equivalent to the Boltzmann Gibbs entropy. In this work, Tsallis entropy was computed using the value of 2 for q.

Hurst exponent was developed to characterized experimental noisy data and long term correlations in time series and stochastic processes. Based on the value of Hurst exponent H, a time series can be categorized as anti-persistent ($0 < H < 0.5$), persistent ($0.5 < H < 1$) or uncorrelated ($H = 0.5$). Various algorithms such as Detrended Fluctuation Analysis (DFA), Rescale Range, Wavelet based estimation techniques have been developed for the computation of Hurst exponents. In this work, the DFA approach will be used (Peng et al., 1994). The data of length N is divided into n numbers of non-overlapping segments containing l points. The linear least square fit of the local trend m of each segment is computed. The difference $\langle x_i \rangle$ between the original "walk" and the local trend is also computed. The Hurst exponent H, can be obtained as

$$F_d(l) = \left\langle \sum_{i=1}^{l} x_i(i)^2 \right\rangle \approx l^{2H} \tag{3}$$

Different quantifiers have been proposed for the determination of chaos in time series data. A Lyapunov exponent offers a simple way of distinguishing chaotic and non-chaotic systems: a positive value of Lyapunov exponent is a simple indicator of chaos in a system.

Results, Discussion and Conclusion

The results obtained in this research work are presented in Figure 1. The mean radio refractivity values decreased in the stratosphere until the beginning of the troposphere where a curved increase was observed. The decay stop at the beginning of the boundary layer (900 hPa). The vertical profile of entropy in radio refractivity is shown in Fig. 1(a). The profile show little variations throughout the atmosphere with a range of 0.95 - 0.985. In this small range, an increase was observed from the stratosphere up to the range of the freezing height. This is significant in the design of communication systems, as the result shows that significant changes occur at the freezing height. At this point, a decrease up to about 800hPa followed by an oscillatory decent till the top of the boundary layer. Within the boundary layer, variation in entropy values could be observed. Figure 1(b) shows the vertical profile of Hurst exponents obtained for radio refractivity. All values obtained showed persistence in radio refractivity values in the atmosphere. High values were obtained for 950 and 850 hPa pressure levels while low extreme was found at the isotherm layer. The LLE for radio refractivities in the atmosphere is shown in Fig. 1(c). Very high values were found at the stratosphere, 800 hPa and 950 hPa pressure levels. All values obtained were found to be positive, hence, radio refractivity values in the atmosphere can be said to be chaotic. Our current result is in agreement with that of Adediji and Ogunjo (2014) who reported chaos in radio refractivity data from ground level to 200 m in steps of 50 m using entropy, Lyapunov exponents and recurrence quantification analysis over the same location. The implication of this result for communication purpose is significant. As Lyapunov exponent is an indicator of predictability, reliability of microwave communication links in chaotic regime is limited. Hence, proper planning of microwave link budget is important for efficient and reliable communication network.

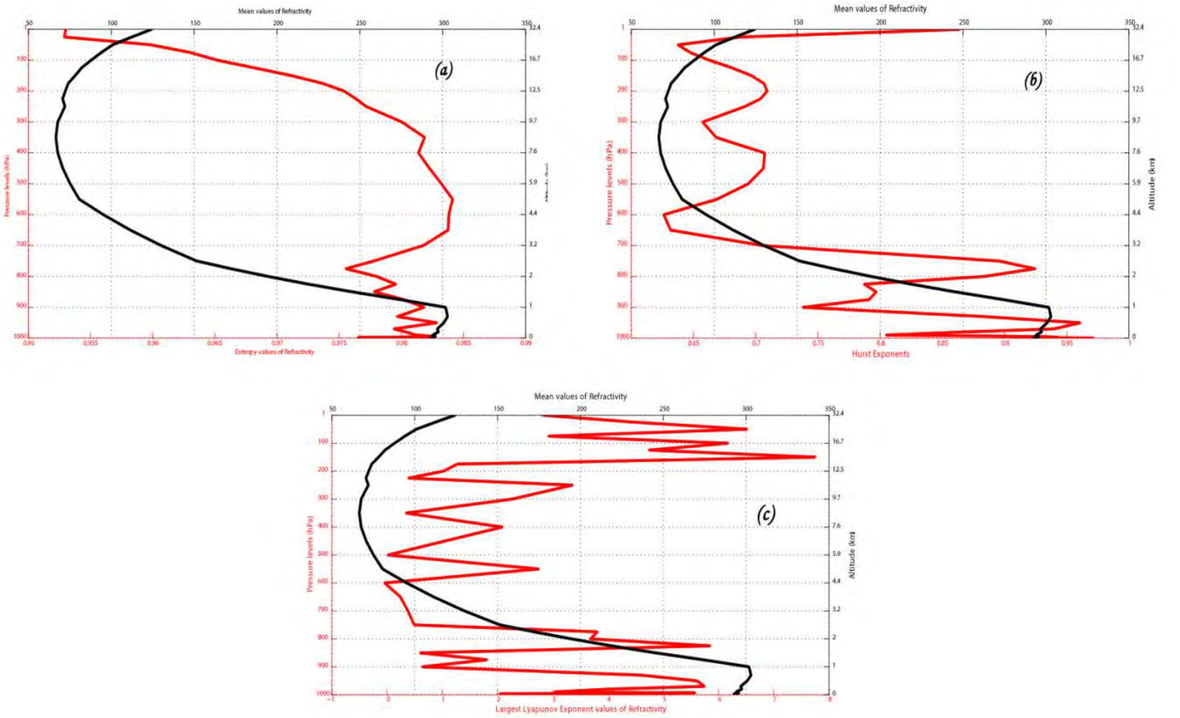

Figure 1: Vertical profiles of radio refractivity with associated (a) entropy values (b) Hurst Exponent (c) Largest Lyapunov Exponent over the study location.

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