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Relationship between magnetospheric interplanetary parameters and radio refractivity for quiet and disturbed days at Minna

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The relationship of magnetospheric interplanetary parameters with radio refractivity is investigated from hourly measurement of solar wind energy and interplanetary parameters for quiet and disturbed days during dry and rainy season in Minna (Latitude 9° 36' 50" N and Longitude 6° 33' 24" E) North central, Nigeria for the year 2008. The solar wind energy, magnetospheric interplanetary parameters and radio waves are characterized by large-scale interactions. These introduce both random and systematic variations in radio refractivity which virtually causes variations in radio propagation. Data used for this work is made up of hourly interval record of solar wind energy and interplanetary parameters calculated from data obtained from the Center for Basic Space Science (CBSS), University of Nigeria, Nsukka. The data was obtained using Vantage PRO II Automatic Weather station, and also through http://omniweb.gsfc.nasa.gov/ for each day in all the months of the year in 2008. The result showed that variations of solar wind energy, radio refractivity and interplanetary parameters with time are almost an hourly cycle each following almost the same trend line for both quiet and disturbed days during dry and rainy season. The result of the correlation analysis of solar wind energy and radio refractivity also showed that solar wind energy has square of the correlation coefficients, R^2 = 0.176, R^2 = 0.040, R^2 = 0.319 and R^2 = 0.016 for both quiet and disturbed days during dry and rainy seasons which reviews weak correlation. Similarly, proton density (PD) and Dst Index, showed high correlation with square of the correlation coefficients, R^2= 0.598 and R^2 = 0.5949, respectively for quiet day during dry season, and for disturbed day during dry season only PD showed high degree of correlation with square of the correlation coefficient, R^2 = 0.543. But during rainy season, the result indicated that there is no significant correlation existing between any of the interplanetary parameters with radio refractivity for both quiet and disturbed days.

Key words: Magnetospheric interplanetary parameters, radio refractivity.

INTRODUCTION

Magnetospheric structures and boundaries are ever changing with solar wind conditions, the interplanetary magnetic field (IMF), and substorm activity (Russell et al., 1998). In order to understand and quantify magnetospheric processes, one must understand the electromagnetic field and plasma topology which, in spite of many years of *in situ* observations, has not been mapped on a global scale (Fuselier et al., 1991).

According to some researchers, magnetospheric boundaries are in constant motion during solar wind magnetosphere coupling processes (Russell, 2000), this constant motion is responsible for the overall shape of

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Earth's magnetosphere, and fluctuations in its speed, density, direction, and entrained magnetic field which strongly affect Earth's local space environment. For example, the levels of ionizing radiation and radio interference can vary by factors of hundreds to thousands, and the shape and location of the magnetopause and bow shock wave upstream of it can change by several Earth radii, exposing geosynchronous satellites to the direct solar wind (Fuselier et al., 1997).

Enhanced solar wind flow velocities and densities, such as those that can occur in coronal mass ejection (CME) events, can easily distort the dayside magnetopause and push it inside its normal location at about ten Earth radii distance (Phan et al., 1994). During large solar wind disturbances, the magnetopause can be pushed inside the geosynchronous orbit (Phan et al., 1994). At such times, the magnetic field increases to as much as twice its “quiescent” value. In addition, the magnetic field outside the magnetopause will have a polarity that is predominantly opposite to that inside the magnetosphere (Phan et al., 1994). CMEs generally form a large magnetic flux rope that propagates into interplanetary space.

The large flux rope contains very low density and a strong field that is observed to slowly rotate as the rope passes an observer. The ICME flux rope is often referred to as a magnetic cloud and if the cloud is oriented properly, it will produce a long steady period of slowly varying southward IMF at the magnetopause. If the flux rope is propagating faster than the Alfven velocity through the ambient solar wind plasma, a shock front and sheath will form in front of the cloud. The sheath may also contain large southward IMF parameters for a substantial period, prior to the encounter with the magnetic cloud. Some of the most severe magnetic storms, the so-called ‘double hit storms’ develop in response to these two subsequent intervals of sustained strong southward IMF parameters at the magnetopause leading to a complex radio refractivity changes within such period. Okoro et al. (2012) showed that solar wind-magnetosphere coupling can cause serious effect on radio refractivity in atmosphere. Thus, this work investigates the relationship between such Earth-magnetospheric interplanetary parameters with radio refractivity during solar events within the atmosphere.

Theoretical analysis

The study of the solar wind interaction with the planetary bodies is one of the main topics of space weather. During a geomagnetic storm, the sun and the magnetosphere are connected, giving rise to severe changes both in interplanetary space and terrestrial environment (Baker et al., 1998). Some examples are the acceleration of charged particles, enhancement of electric currents, auroras and magnetic field variations on the earth surface. These changes can produce important damages in electric power supplier, radio communications and spacecrafts. It is assumed that sun-earth interaction depends on solar wind. In fact, in-tense geomagnetic storms seem to be related to intense IMF with a southern component for a long time (Tsurutani and Meng, 1972). Several papers about geomagnetic storms (Dungey, 1963) have pointed out that reconnection between a southern IMF and the magnetospheric magnetic field as the physical mechanism responsible for sun-earth connection. Although several aspects on this mechanism are still open questions, it is accepted that reconnection in the day-side of magnetosphere produces a transference of magnetic flux to the magnetotail (Rickett, 1990). Then energetic particles of solar wind can go into the magnetosphere, along magnetic field lines, yielding an injection of plasma in the night-side of the magnetosphere.

The radiation belts are regions of terrestrial environment where charged particles become trapped on closed geomagnetic field lines. These particles show drifts due to magnetic field gradient and curvature as well as to gyration orbit effects. As drifts depend on the sign of charge, ions travel to West and electrons to east, giving rise to a ring current (RC) which extends from 4 to 8 terrestrial radii. Variations on this current result in variations of the magnetic field on the earth surface.

The main mechanism by which the magnetized solar wind powers the magnetosphere was first proposed by Dungey (1963). In his proposal, he stated that solar wind and magnetosphere are connected by IMF southward, and becomes connected to the terrestrial magnetic field at the sub solar point in a process known as reconnection. Reconnection produces open field lines with one end connected to the earth, by combining interplanetary field lines, not connected to the earth, with closed field lines, connected to the earth on both ends. The resulting V-shaped magnetic fields attempt to straighten and accelerate plasma (whose origin is both in the solar wind and the magnetosphere).

The earth's magnetosphere is a very dynamical system, whose configuration depends on many internal and external factors. The first factor is orientation of the earth's magnetic axis with respect to the direction of the incoming solar wind flow, which varies with time because of (i) Earth's diurnal rotation and its yearly orbital motion around sun, and (ii) frequent "side gusts" of the solar wind. The second is the state of the solar wind, in particular, the orientation and strength of the IMF**,** carried to the earth's orbit from sun due to the high electrical conductivity of the solar wind plasma. Interaction between the terrestrial and interplanetary fields becomes much more effective when the IMF turns ant-parallel to the earth's field on the dayside boundary of the magnetosphere. In this case, geomagnetic and interplanetary field lines connect across the magnetospheric boundary, which greatly enhances the

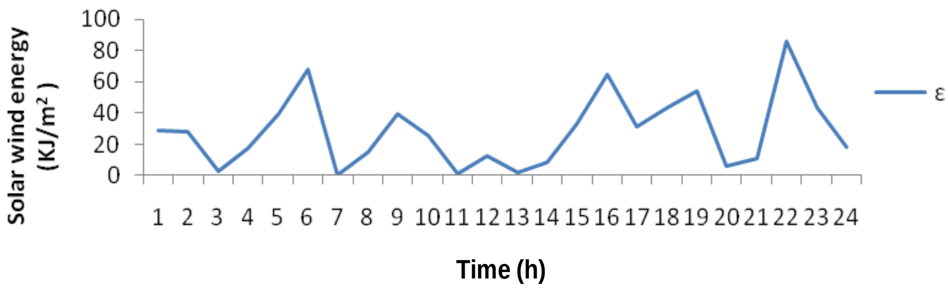

Figure 1. Variations of solar wind energy with time for quiet day during dry season.

transfer of the solar wind mass, energy, and electric field inside the magnetosphere. As a result, the magnetospheric field and plasma become involved in convection.

MATERIALS AND METHODS

The data used for this work covered the period of 1 year starting from January to December, 2008. The data are in two forms. First one is meteorological parameters which are raw recorded 5 min data of temperature, humidity and pressure. These data were provided by the Centre for Basic Space Science (CBSS), University of Nigeria Nsukka.

The second type of data is the interplanetary magnetic data obtained from OMINI website (www.ominiweb.com). This data consists of 5 min data value of solar wind velocity and IMF components of Bz(nT), Bx(nT), By(nT), PD (Ncm^{-3}), Dst Index (nT) AE Index (nT) and solar wind pressure.

From the data, hourly averages of solar wind IMF parameters for each day of the month were calculated using excel package. Solar wind energy (ε) of the magnetosphere will be calculated using:

$$\varepsilon = V_{sv} B^2 sin^4\left(\frac{\theta}{2}\right)/l_o^2 \quad (1)$$

Where V_{sv} = solar wind velocity; |*B*| = magnitude of the IMF parameter; $\theta = \arctan(B_y/B_z)\ for B_z > 0\ and$ $\theta = 180^0 - \arctan(B_y/B_z)\ for B_z \leq 0$; l_o = dayside magnetopause scale length which is equal to 7R$_E$; B$_z$ = z-component of IMF parameter; B$_y$ = y-component of IMF parameter.

Also, the hourly averages of meteorological parameters for each day of the month were calculated using excel package. From the values obtained, partial pressure of water (e) was determined from the equation as follows:

$$e = e_s.\frac{H}{100} \quad (2)$$

Where H is the relative humidity, and e$_s$ is the saturation vapour pressure determined by Clausius-Clapeyron equation given as:

$$e_s = 6.11exp\left[17.5(T - 273.16)/(T - 35.87)\right] \quad (3)$$

Employing the values of meteorological parameters (temperature, pressure and relative humidity) computed, radio refractivity was calculated using;

$$N = 77.6\frac{P}{T} + 3.37\ x\ 10^5\ e/T^2 \quad (4)$$

Where P = atmospheric pressure (hPa), e = water vapour pressure (hPa), T = absolute temperature (K).

Equation 4 may be employed for the propagation of radio frequencies up to 100 GHz (Willoughby et al., 2002).

The two results (solar wind coupling and radio refractivity) were compared to actually deduce solar-wind magnetosphere coupling effect on radio refractivity at Minna in the year 2008.

RESULTS AND DISCUSSION

The graphical representation of hourly records of variations of solar wind energy (ε), radio refractivity (N), proton density (PD) and Dst index are presented in the figures for both quiet and disturbed days during dry and rainy seasons at Minna, Nigeria. Although the research was carried out in all the months of the year, the quiet and disturbed days of the months of February and August, respectively were considered. In the same manner, the relationship of solar wind energy (ε), PD and Dst index with radio refractivity (N) are the main focus of this work. This relationship is clearly demonstrated in the plots of variations and correlations of radio refractivity with magnetospheric interplanetary parameters as can be observed in Figures 1 to 32, respectively.

Figures 1 to 8 represent variations of solar wind energy and radio refractivity with time for quiet and disturbed days during dry and rainy seasons at Minna in 2008. Figures 9 to 12 represent correlation of solar wind energy with radio refractivity for quiet and disturbed days during dry and rainy seasons.

In Figure 1, 2, 3 and 4, there is a corresponding fall and rise in the peaks of variations of solar wind energy as well as radio refractivity with time almost throughout the early hours of the day, but they seem to exhibit maximum increase between 0600 to 2200 h for both quiet and disturbed days during dry and rainy seasons. This is caused by diurnal variations of solar wind energy, in which case, the IMF turns anti-parallel to the earth’s field on the day side of the magnetosphere. This period is the time when there is maximum solar wind activity (solar maximum) caused by the high temperature released by

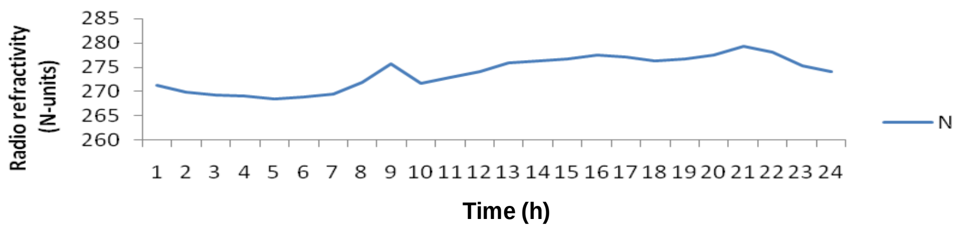

Figure 2. Variations of radio refractivity with time for quiet day during dry season**.**

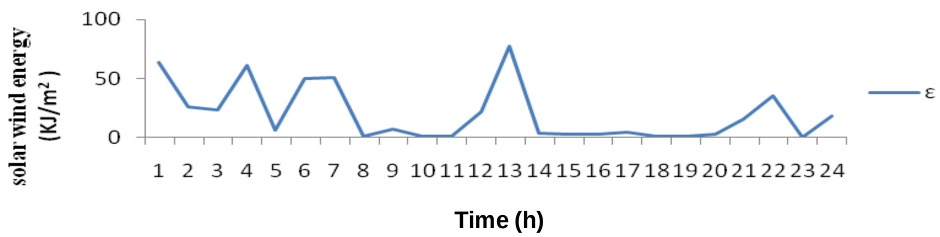

Figure 3. Variations of solar wind energy with time for disturbed day during dry season.

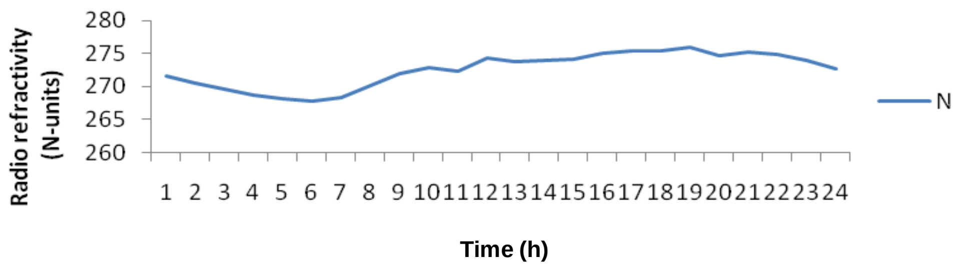

Figure 4. Variations of radio refractivity with time for disturbed day during dry season.

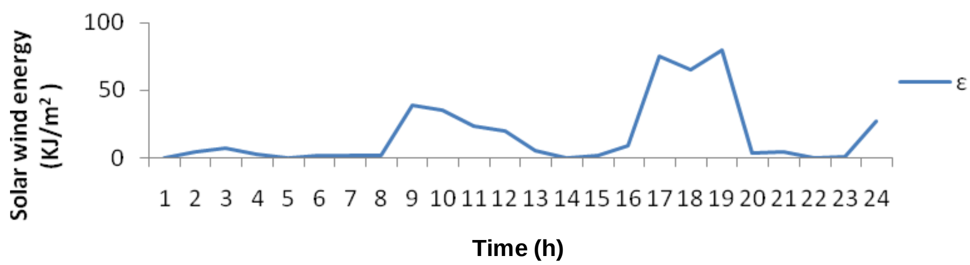

Figure 5. Variations of solar wind energy with time for quiet day during rainy season.

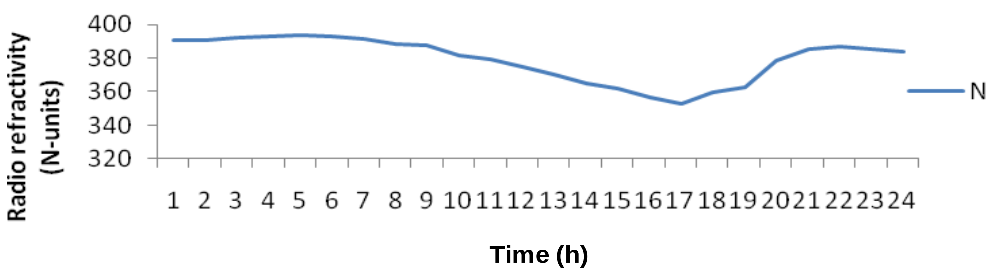

Figure 6. Variations of radio refractivity with time for quiet day during rainy season.

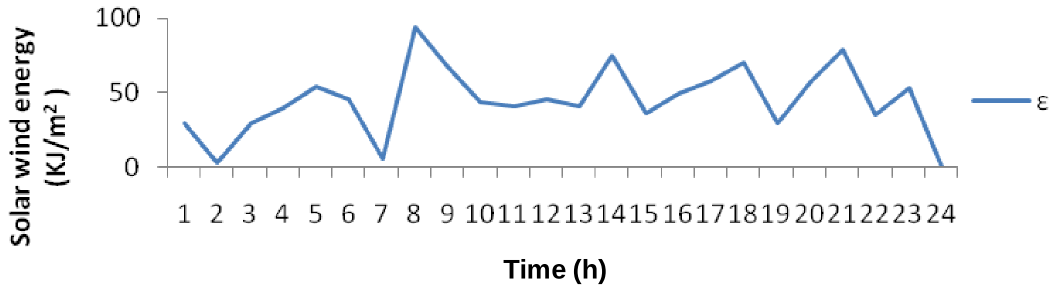

Figure 7. Variations of solar wind energy with time for disturbed day during rainy season.

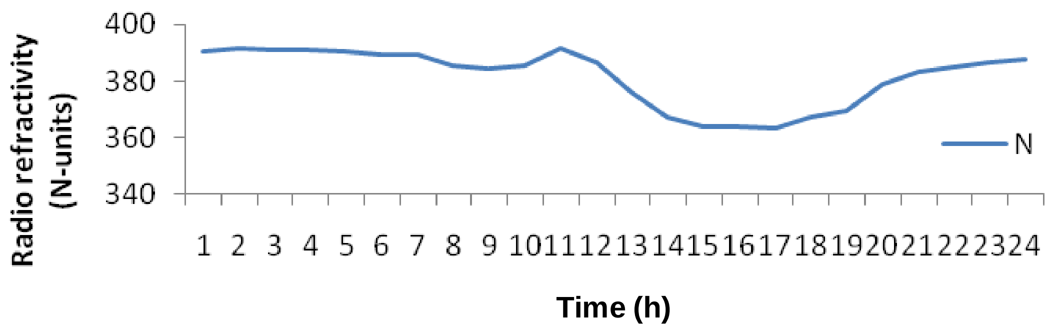

Figure 8. Variations of radio refractivity with time for disturbed day during rainy season.

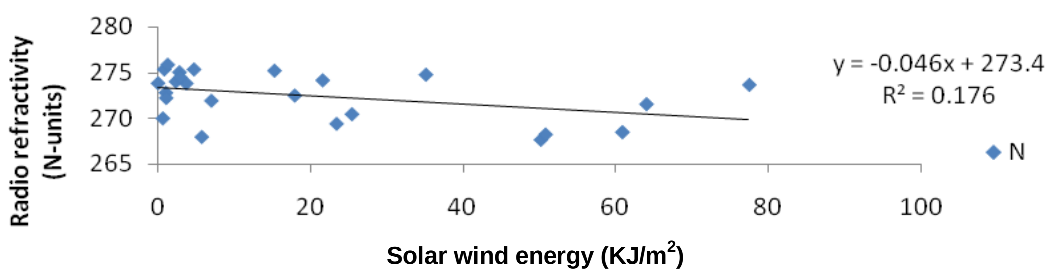

Figure 9. Correlation of solar wind energy with radio refractivity for quiet day during dry season.

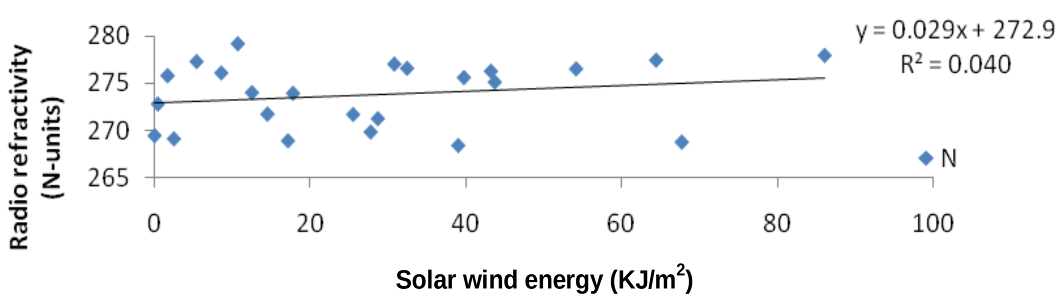

Figure 10. Correlation of solar wind energy with radio refractivity for disturbed day during dry season.

the sun during solar wind magnetosphere coupling activities. This process results in the ejection of high solar wind (stream of electrons and protons) which is the characteristics of southward continental drift observed

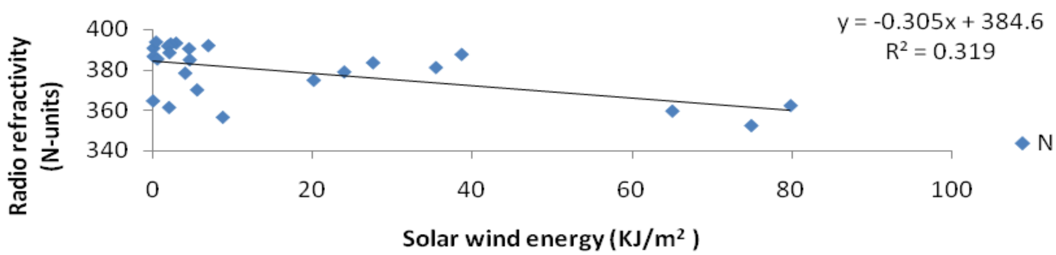

Figure 11. Correlation of solar wind energy with radio refractivity for quiet day during rainy season.

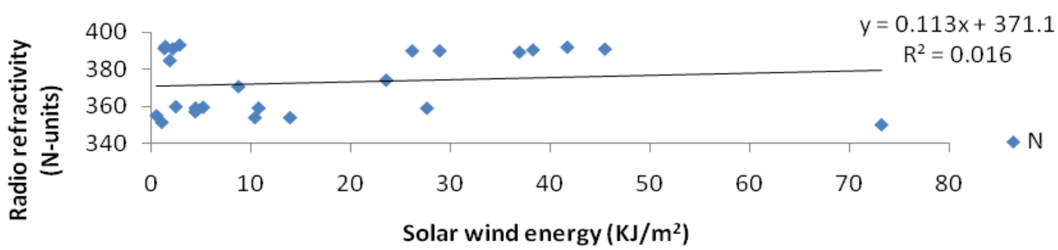

Figure 12. Correlation of solar wind energy with radio refractivity for disturbed day during rainy season.

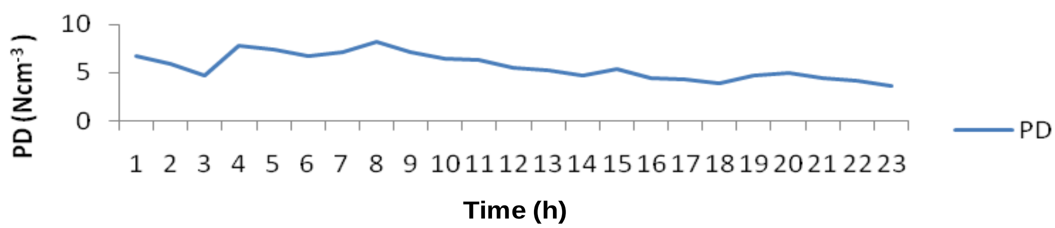

Figure 13. Variation of PD with time for quiet day during dry season.

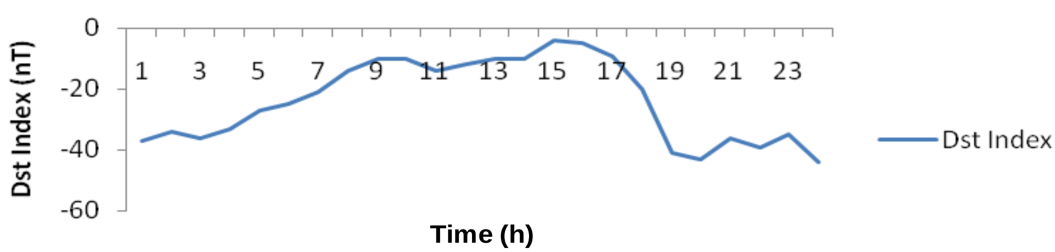

Figure 14. Variation of Dst index with time for quiet day during dry season.

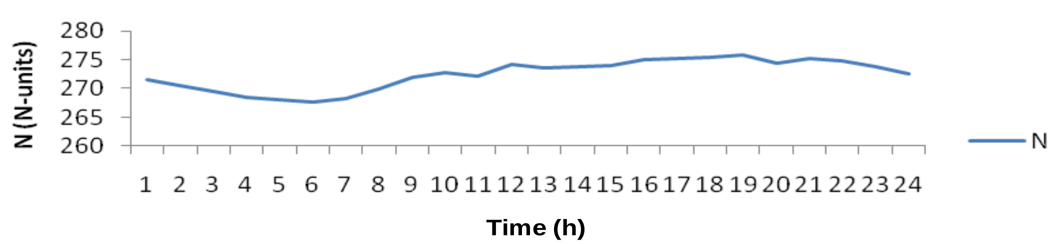

Figure 15. Variation of radio refractivity with time for quiet day during dry season.

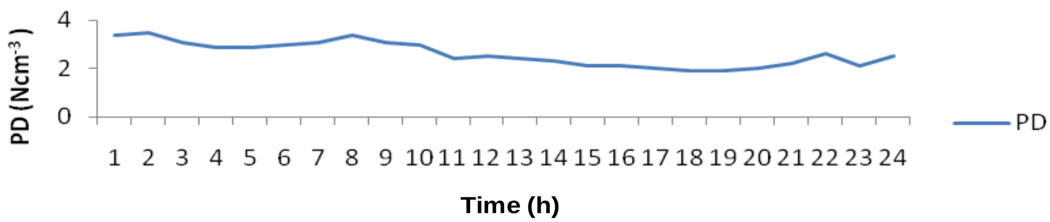

Figure 16. Variation of PD with time for disturbed day during dry season.

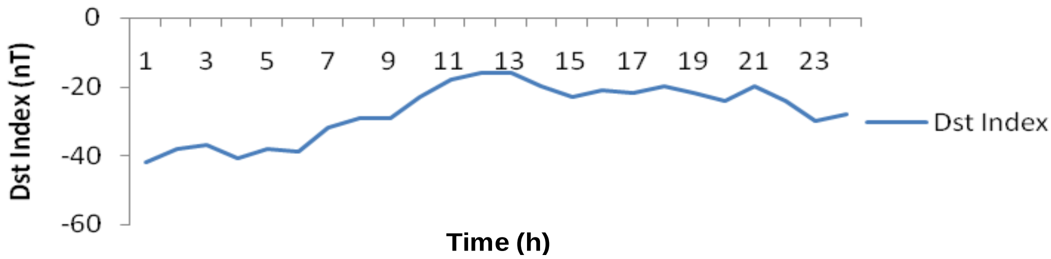

Figure 17. Variation of Dst index with time for disturbed day during dry season.

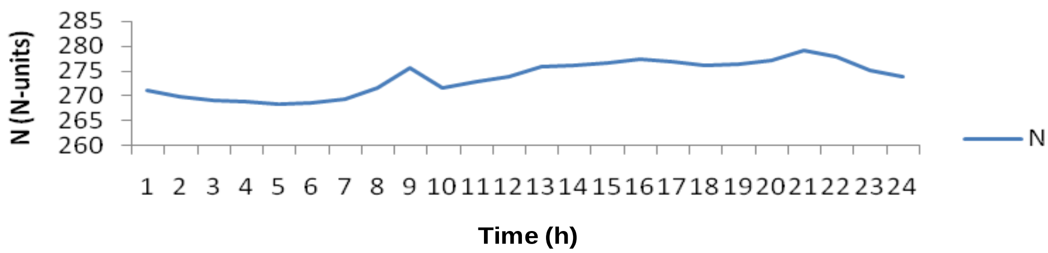

Figure 18. Variation of radio refractivity with time for disturbed day during dry season.

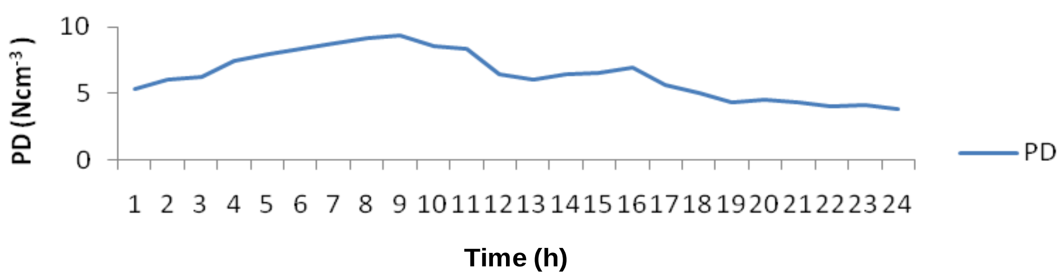

Figure 19. Variation of PD with time for quiet day during rainy season.

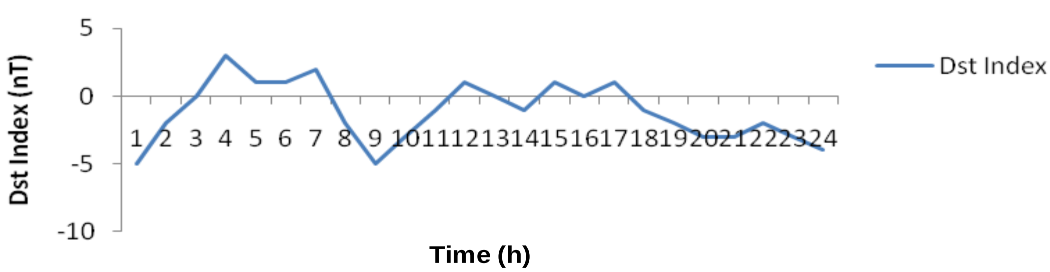

Figure 20. Variation of Dst index with time for quiet day during rainy season.

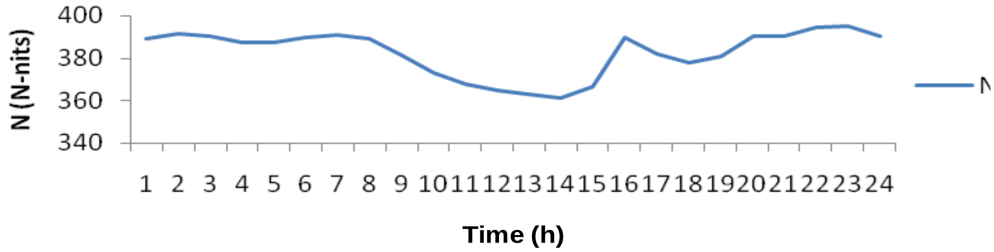

Figure 21. Variation of radio refractivity with time for quiet day during rainy season.

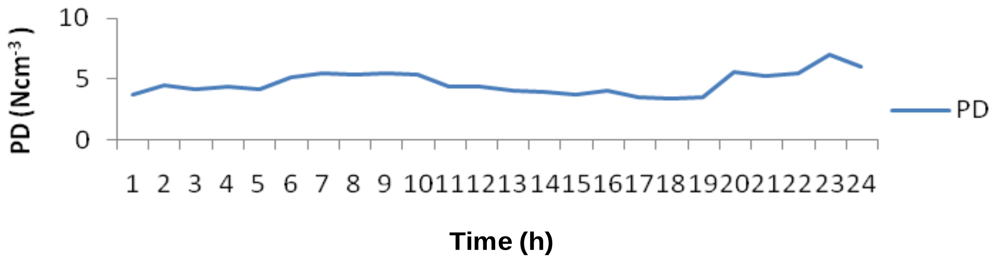

Figure 22. Variation of PD with time for disturbed day during rainy season.

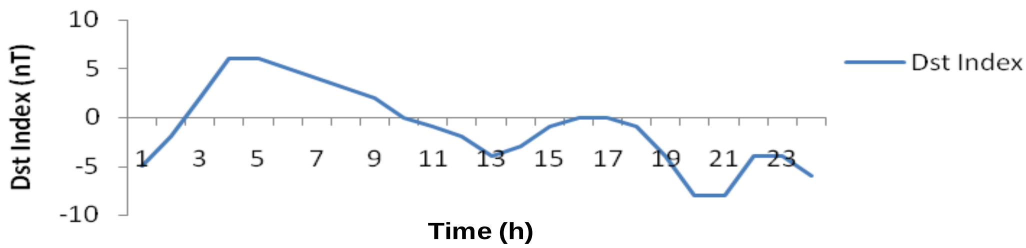

Figure 23. Variation of Dst index with time for disturbed day during rainy season.

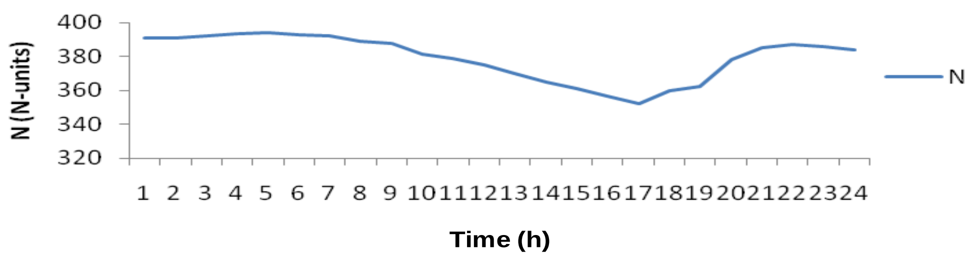

Figure 24. Variation of radio refractivity with time for disturbed day during rainy season.

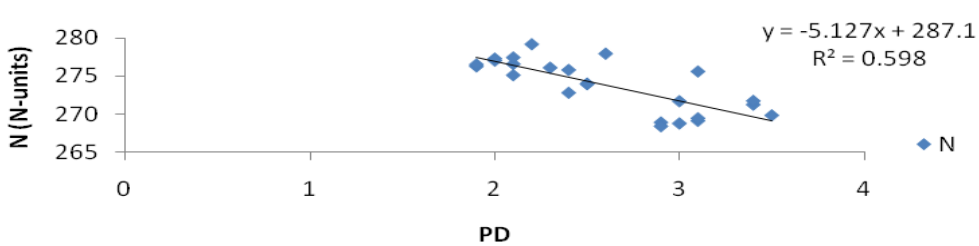

Figure 25. Correlation of PD with radio refractivity for quiet day during dry season.

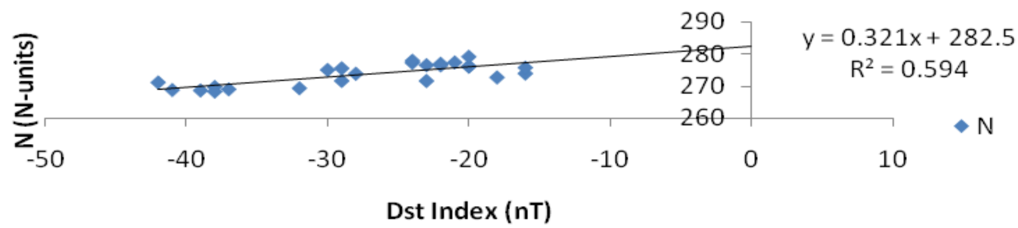

Figure 26. Correlation of Dst Index with radio refractivity for quiet day during dry season.

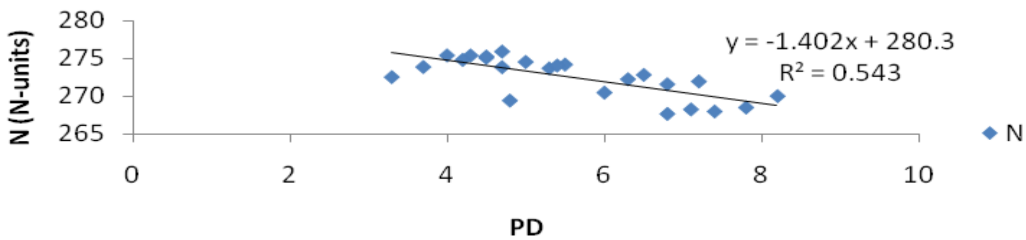

Figure 27. Correlation of PD with radio refractivity for disturbed day during dry season.

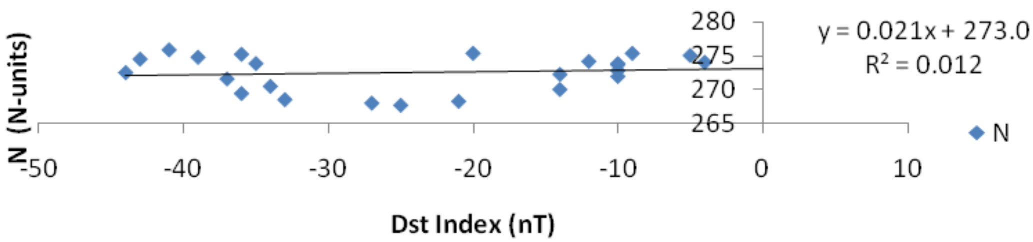

Figure 28. Correlation of Dst index with radio refractivity for disturbed day during dry season.

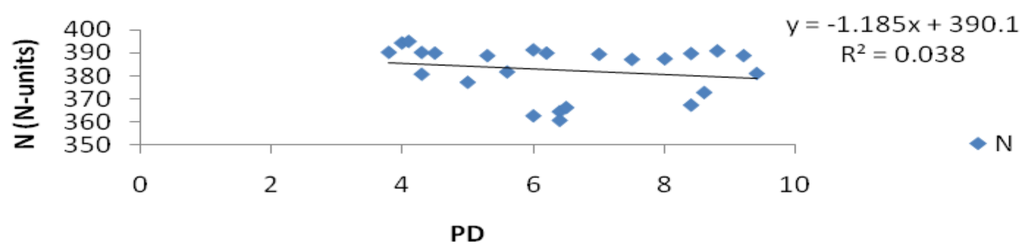

Figure 29. Correlation of PD with radio refractivity for quiet day during rainy season.

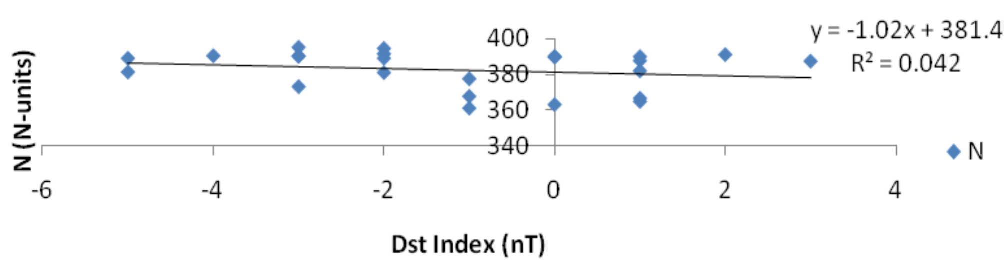

Figure 30. Correlation of PD with radio refractivity for quiet day during rainy season.

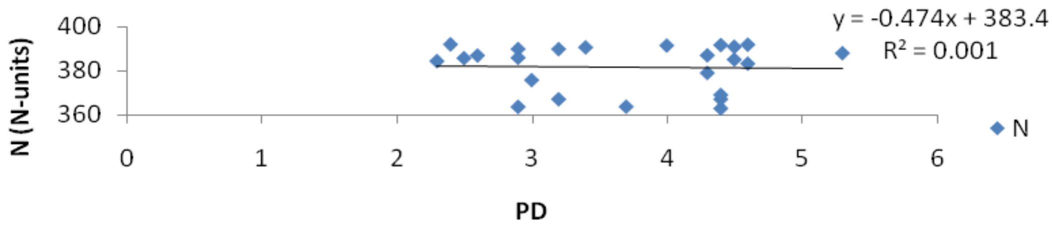

Figure 31. Correlation of PD with radio refractivity for disturbed day during rainy season.

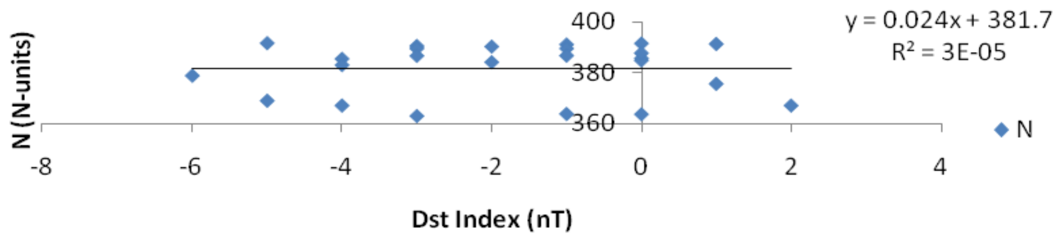

Figure 32. Correlation of Dst index with radio refractivity for disturbed day during rainy season.

during dry season having energies ranging from 10 to 100 kev. The maximum peaks observed in Figures 1 to 8 also signify the period known as "disturbed period"; which is the period when solar wind magnetic field and that of the earth magnetosphere reconnects resulting in the outflow of plasma aurora zones with a high energy into the magnetosphere. During the time of these events, the energy transported from solar wind into the magnetosphere creates geomagnetic variation and drives different types of pulsations such as changes in temperature, pressure, humidity in the atmosphere. Since radio refractivity is a function of temperature, it also changes as the solar wind changes during disturbed period.

As can be observed in Figures 5 to 8 during rainy season, there is a minimum decrease in solar wind activities (solar minimum) as indicated in the trend line of the figures, owing to the weather condition of the atmosphere during the period. This period which is noted by slow solar activity in the atmosphere is dominated by cool and moisture weather condition due to rainy season which leads to decrease in temperature during solar wind magnetosphere coupling within the period. This equally leads to decreased radio refractivity within the period as well for both quiet and disturbed days.

In Figures 9 to 12, the correlation analysis of solar wind energy with radio refractivity was done to estimate the extent at which radio refractivity depend on solar wind activities for both quiet and disturbed days during dry and rainy season. In Figures 9 and 10, the square of correlation coefficients of solar wind energy, with radio refractivity for quiet and disturbed days during dry season are, respectively 0.176 and, 0.0401. Also, in Figures 11 and 12, the square correlation coefficients of solar wind energy with radio refractivity for quiet and disturbed days during rainy season are 0.3198 and 0.0.16, respectively. These results clearly review that the there is weak correlation between solar wind energy and radio refractivity during solar wind-magnetosphere interactions with radio refractivity. This thus shows that solar wind is not the sole cause of fluctuations in radio refractivity, but the fluctuations should be attributed to other magnetospheric interplanetary parameters or local effects.

However, the slope of the trend lines shows that solar wind changes mostly with positive slope in rainy season within most of the times. This may be caused by advection processes, cooling of the earth's surface through radiation and compression of air masses during this period of the year.

Figures 13 to 24 are the hourly variations of interplanetary parameters and radio refractivity with time for both quiet and disturbed days during dry and rainy season. From time variations in the amplitude of interplanetary parameters and radio refractivity periodicity plots, it is observed that almost all the interplanetary parameters follow the same sporadically change in amplitude of their movement as the radio refractivity for both quiet and disturbed days during dry and rainy seasons. But in some cases, while radio refractivity changes with time in positive direction, some of the interplanetary parameters change in negative direction for both quiet and disturbed days during dry and rainy season. These concurrent disparities on the nature of the trend line within different intervals in the movement of interplanetary parameters, as well as radio refractivity, show that certain significant fluctuations on interplanetary parameters are marked by the absence of similar fluctuations on radio refractivity within that period.

The significant effect of the interplanetary parameters on radio refractivity has also been found when the square of the correlation coefficients values were considered. Figures 25 to 32 depict the correlations of interplanetary parameters with radio refractivity for both quiet and disturbed days during dry and rainy season for the year 2008. It is noticed from the figures that the square of the correlation coefficient is quite high for the cases of PD and Dst Index with their square of the correlation coefficients (R^2 = 0.598) and (R^2 = 0.5949) for quiet days during dry season (Figures 25 and 26). Similarly, for disturbed days during dry season, it was observed that only PD exhibits high correlation with square of the correlation coefficient (R^2 = 0.543). From these results, it can be clearly stated that the change in radio refractivity is sorely caused by the change in PD and Dst Index for both quiet and disturbed days during dry season. In contrast, during quiet and disturbed days for rainy season, it was observed that all the interplanetary parameters exhibit very weak correlation with radio refractivity (Figures 27 to 32). Therefore, the change in radio refractivity is not dependent on the change in interplanetary parameters for quiet and disturbed day during rainy season.

Conclusion

This work has clearly shown that radio refractivity has corresponding variations with solar wind energy as well as other magnetospheric interplanetary parameters with time. However, the trend lines of variation of solar wind energy with time, exhibit positive gradient within the period of the research. This may be caused by advection processes, cooling of the earth's surface through radiation and compression of air masses during this period of the year. However, from the result of the correlations, it was observed that solar wind energy exhibits weak correlation with radio refractivity, while magnetospheric parameters exhibit strong correlation with radio refractivity within all the periods of investigation. Having these facts in mind, one can say that, the random and systematic fluctuations, observed during radio wave propagation, emanating from the deviation of radio refractive index of the radio wave in the atmosphere, is due to the influence of magnetospheric parameters interaction with radio wave.

ACKNOWLEDGEMENT

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