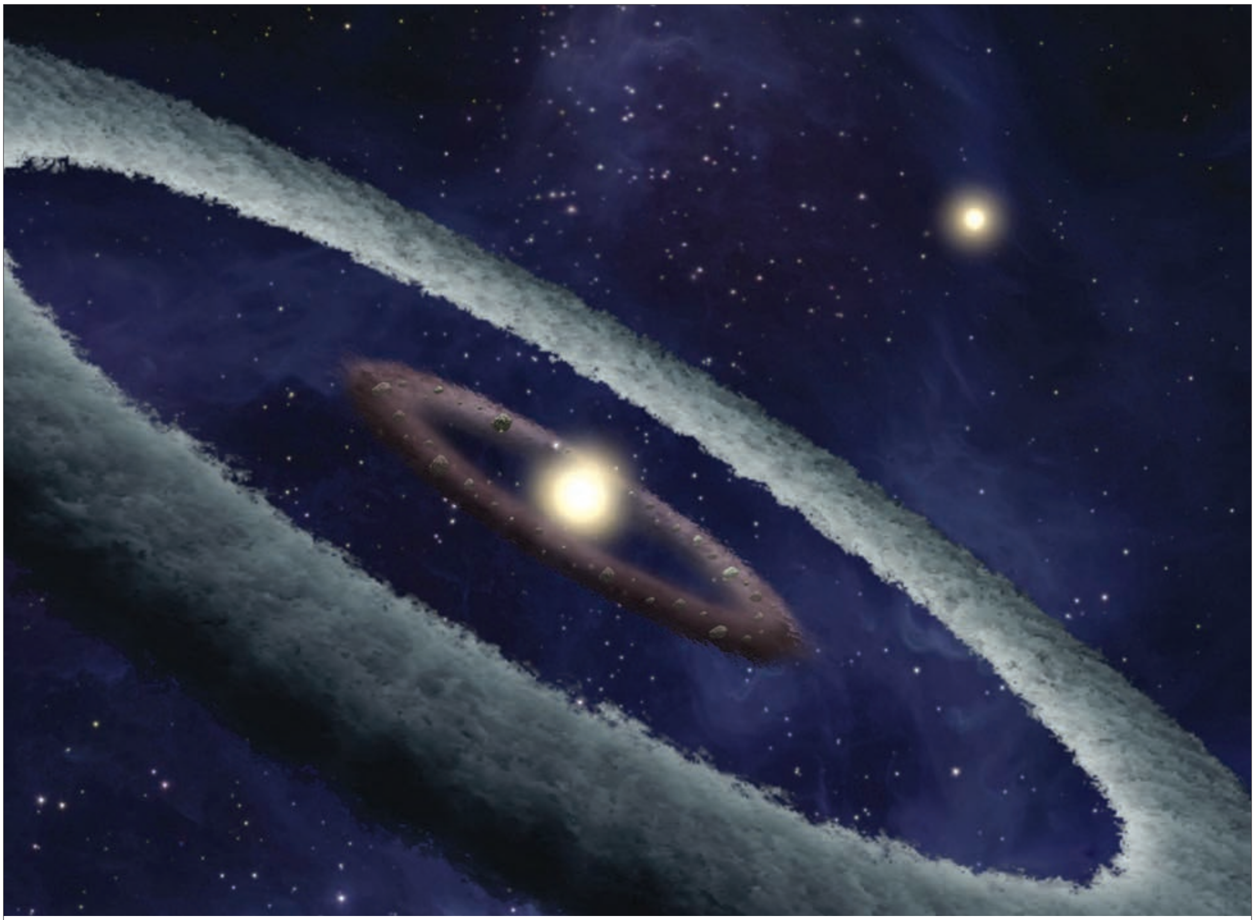

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NmF2 VARIABILITY at Equatorial and Low Latitude Stations: A Review

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Abstract: The relative variability of peak electron density, NmF2 at equatorial and low latitude stations has been studied fairly well by workers in the past decade. A review of these studies is carried out in this work. The various methods used by workers, their merits and demerits are discussed. The results with respect to diurnal influence, seasonal effect and influence of solar cycle epochs, latitudinal dependence and effect of geomagnetic activity are synthesised and discussed. Areas requiring further investigation are mentioned.

Key words: Relative variability, electron density, diurnal influence, seasonal effect

INTRODUCTION

It is well known that there is a lot of variations in the ionosphere due to the effect of solar, meteorological and geomagnetic activities. Apart from solar cycle variation, seasonal effect, latitudinal dependence, there are day-to-day and hour-to-hour variations. The variations concentrated upon most by researchers is the day-to-day variation. This is because day-to-day variation or variability is greater than other variations. Thus an understanding of day-to-day variation will help radio scientists and engineers to know to a large extent the expected deviations from monthly mean values. Bilitza (2000) pointed out the need for the variability of mean values of ionospheric parameters of which the electron density peak (NmF2) is the most frequently studied being the most easily accessible characteristics of the ionosphere (Mansilla *et al*., 2004).

The subject of this review paper is variability of equatorial and low latitude NmF2. In this study the different methods used in describing variability or VR is discussed in section 2.0. Results obtained by various workers are then reviewed with respect to diurnal, seasonal, solar cycle, latitudinal and geomagnetic influence.

This review is suppose to complement the efforts of the International Reference Ionosphere (IRI), an international project sponsored by the Committee on Space Research (COSPAR) and International Union of Radio Science (URSI) to model the Ionosphere.

MATERIALS AND METHODS

Three major methods used to determine ionospheric VR are:

- The percentage ratio of standard deviation, σ, to mean $\bar{X}$, of ionospheric parameters, i.e., VR= $\sigma/\bar{X} \times 100$ (Bilitza *et al*., 2004; Somoye, 2009a, b; Rishbeth and Mendillo, 2001; Akala *et al*., 2010a)
- The ratio of interquatile range (q_{75}-q_{25}) to median, M i.e.,

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$$VR = \frac{q_{75} - q_{25}}{M}$$

This method was employed by Kouris and Fotiadis (2002)

- The ratio of interdecile range (q_{90}-q_{10}) to median, M i.e.,

$$VR = \frac{q_{90} - q_{10}}{M}$$

The merit of the methods in (ii) and (iii) is that of easy interpretation of probability since the interquatile range covers 50% of all data points (Bilitza *et al*., 2004) and by extension the interdecile range covers 80% of all data points.

Their demerit is that 50 and 20% of the data is ignored in the second and third method, respectively. This is not the case in the use of standard deviation whose demerit is that of interpretation in terms of probability. Another method is that of ratio of monthly range to monthly median at each hour. Kouris and Fotiadis (2002) used ratio of the difference of hourly daily values from monthly median to hourly monthly median.

It should be mentioned that the foF2 and the corresponding NmF2 values used by authors are obtained mostly from Union Radio Mark 2 recorder type or DPS-4 digisonde. A Union Radio Mark 2 recorder type ionosonde has been described by Somoye (2009a) while the description of a typical digisonde is given by Huang and Reinisch (1996).

NmF2/foF2 VR Results

Results of different aspects of NmF2/foF2 are given below:

It should be mentioned that results of NmF2 VR and foF2 VR are used interchangeably just as have been done by many workers (Zhang *et al*., 2004; Abdu *et al*., 2004; Mansilla *et al*., 2004), the latter being proportional to the square of the former. This implies that foF2 corresponds to NmF2 (Abdu *et al*., 2004). The correspondence between the two parameters is clear from Fig. 1a and b which shows relative VR of NmF2 and foF2-obtained from the ratio of their standard deviation to mean- for both low and high sunspot number periods. The similarity in the plots during both low and high sunspot number periods justifies the use of one for the other by workers.

Diurnal NmF2/foF2 Equatorial VR

The day-to-day variability of NmF2 at equatorial and low latitude stations is high during the night, i.e., between sunset and sunrise with the major peaks about an hour pre-sunrise

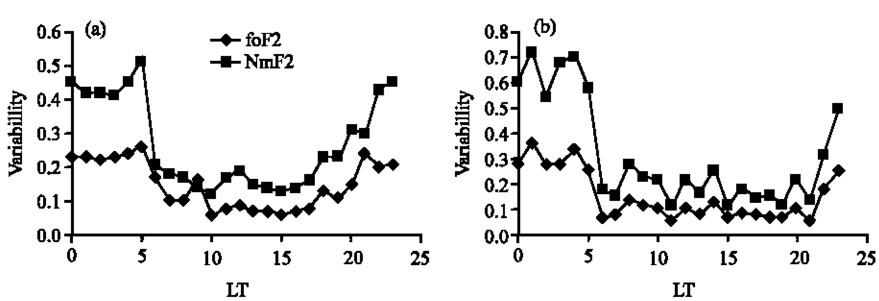

Fig. 1: Relative variability of NmF2 and foF2 during a 1958 and b 1974, respectively

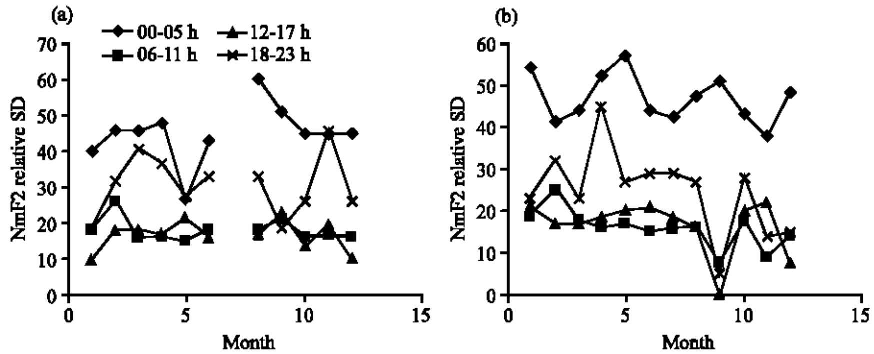

Fig. 2: Annual NmF2 relative variability of different LT-bins for 1965 and 1973, respectively. (Somoye, 2009b)

(Bilitza *et al*., 2004; Zhang *et al*., 2004; Araujo-Pradere *et al*., 2005; Somoye, 2009b; Akala *et al*., 2010a). NmF2 relative VR is reported to be between 5-15% during the daytime by these authors. Occasionally, however, daytime VR is higher than 15% during the Winter of periods of low solar activity and lower than 5% during September equinox of 1973 (Fig. 2a, b).

NmF2/foF2 nighttime relative VR is found higher than daytime relative VR being 12-45%. Bilitza *et al.* (2004) observed nighttime relative VR of 15-30% with post-midnight peak and post-sunset peak of 30-40 and 15-30%, respectively for Ouagadougou (12°N, 1.8°W, 15.9 dip), Zhang *et al.* (2004), working at Hainan (dip 22.8°N), China, obtained 12-40% nighttime variability. Nighttime VR is found to be 18-45% from the diurnal curve by Somoye (2009a, b) at Ibadan (7.4°N, 3.9°E, 6°S dip). Akala *et al.* (2010b) reported nighttime VR of 15-35% with post midnight peaks of 35-55% and a post sunset of 18-38%. The two peaks of relative VR reported by workers fall between the hour 0200 to 0500 and 2000 to 2300 h with the former, in most cases greater than the latter.

Nighttime equatorial and low latitude NmF2/foF2 relative VR is greater than that of daytime partly because of the low values of NmF2 mean values at night (Bilitza *et al*., 2004). Another reason given in literature is the decay in NmF2 mean values which not only leads to reduction but also to irregularity in the magnitude of NmF2 (Somoye, 2009b). The irregularity in the decay of NmF2 (Rishbeth and Garriott, 1969) leads to variability. Figure 3 which illustrates the absolute variability (standard deviation) of NmF2 for the March equinox of 1958 shows that absolute VR is high during nighttime than daytime.

Seasonal NmF2/foF2 VR

Daytime NmF2/foF2 does not show much of seasonal variation except for stations located in the neighbourhood of the crest of equatorial anomaly i.e., ±20° latitude. For such stations, June solstice or summer and the equinox have higher VR of about 5% than December solstice or winter (Bilitza *et al*., 2004; Somoye, 2009a). This difference may be latitudinal. Zhang *et al.* (2004), however, working at Hainan (dip 22.8°N) in the neighbourhood of the equatorial anomaly maximum reported daytime NmF2 VR of less than 15% for Summer, Winter and the equinox with lowest values at the equinox. The difference in the result of Zhang *et al*. (2004) and those of Bilitza *et al*. (2004), Somoye (2009a) and Akala *et al*. (2010a) may be due to longitudinal effect. The longitude of Hainan is 109°E while those of Ouagadougou and Ibadan are 1.8°W and 3.9°E, respectively. Nighttime VR of NmF2/foF2 is found higher in June solstice and September equinox than the other two

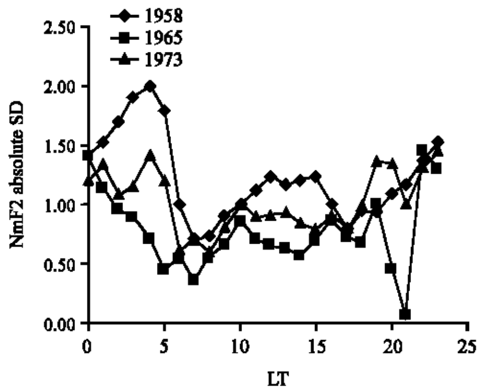

Fig. 3: Diurnal NmF2 (absolute variability) SD for March Equinox. (Somoye, 2009a)

seasons by Akala *et al.* (2010a) which is the same as reported by Bilitza *et al.* (2004). Somoye (2009b) also got the same result for NmF2 VR of 1958, a year of high sunspot number. He reported that NmF2 VR of 1965 and 1973, years of moderate and high sunspot numbers, respectively are greater at the equinox. The least nighttime NmF2 VR at summer observed by Zhang *et al.* (2004) is possibly due to the same longitudinal difference in daytime VR.

Comparison of Low Latitude Stations with Mid Latitude Stations

Comparison of NmF2/foF2 relative VR at low latitude stations and mid latitude stations indicates that relative VR is higher at equatorial and low latitude stations than at mid- latitude stations. Rishbeth and Mendillo (2001), Araujo-Pradere *et al.* (2004) and Rawer *et al.* (2003) observed higher relative VR at low latitude stations than at mid- latitude stations. Somoye (2009b) compared the relative VR of Ibadan and Singapore, two low latitude stations with that of Slough-a mid- latitude station. He obtained results which show that relative NmF2 VR is higher at the low latitude station at night during both periods of low and high solar activity. No latitudinal difference is observed by him in daytime relative VR. During high solar activity, Somoye (2009b) reported that daytime relative VR is higher at Slough than the other two stations. Rishbeth and Mendillo (2001) pointed out that variability is smaller at most mid-latitude stations than equatorial stations. Latitudinal dependence of foF2 VR is also reported by Ezquer *et al.* (2004).

Solar Cycle Effect of VR

Solar cycle effect of daytime relative VR is not significant at equatorial and low latitude areas. Diurnal plots of relative VR at Ibadan (7.4°N, 3.9°E, 6°S dip) during 1958 (high sunspot number period), 1965 (low sunspot number period) and 1973 (moderate sunspot number period) by Somoye (2009b) shows that daytime relative VR is less than 15% during these epochs of solar cycle. Comparison of diurnal plots of relative VR of the month of July for Ibadan (7.4°N, 3.9°E, 6°S dip), Singapore (1.3°N, 103.8°E, 17.6°S dip) and Slough (51.5°N, 359.4°E, 66.5°S dip) during 1970 (high sunspot number year, Rz) and 1971 (moderate sunspot year) by him reveals that while daytime VR of the other two latitude stations is similar during both years, it is not the same for Slough.

Generally nighttime VR is higher during periods of low solar activity than periods of high solar activity though this is not strictly a low latitude feature (Ezquer *et al.*, 2004; Bilitza *et al.*, 2004; Kouris and Fotiadis, 2002; Rishbeth and Mendillo, 2001; Aravinda and Iyer, 1990; Jayachandran *et al.*, 1995; Mosert *et al.*, 2003). From the diurnal plots of relative VR by Bilitza *et al.* (2004) and Akala *et al.* (2010a) for Ouagadougou, post midnight VR peak of 40% during 1978 obtained by Akala *et al.* (2010b) is slightly higher than the post midnight VR peak of 38% during 1985 observed by Bilitza *et al.* (2004). While 1978 is a high sunspot period (Rz = 93), 1985 is a low sunspot period (Rz = 18). Somoye (2009a) obtained results that shows that nighttime VR of NmF2 during 1973, a period of moderate sunspot number (Rz = 38) is sometimes higher than that of 1965 (low sunspot number period). He also used the plot of correlation coefficient, r, between NmF2 and Rz to show that relative VR of NmF2 is inversely proportional to Rz at some hours of the night while at other hours it is directly proportional with Rz. More work needs to be done by workers to ascertain the increase or decrease of NmF2 relative VR with sunspot number, Rz, at different times of the day.

Effect of Geomagnetic Activity on Equatorial/Low Latitude VR

Variability is reported to increase during geomagnetic storms at all latitudes (Mansilla *et al.*, 2004; Araujo-Pradere *et al.*, 2004, 2005; Rishbeth and Mendillo, 2001). Araujo-Pradere *et al.* (2005) mentioned that variability tends to increase with geomagnetic activity in Winter and equinox but remain fairly constant in Summer at low latitudes. Araujo-Pradere *et al.* (2005) reported that VR at low latitudes during equinox is as low as 10% because of weak inter hemispheric flow at this season of year. Araujo-Pradere *et al.* (2004) and Akala *et al.* (2010b), however, observed similar high variability during both perturbed and unperturbed conditions at low latitude areas. The variability of foF2 is observed to show post-midnight and post-sunset peaks during six different geomagnetic storms of 1989 except one (that of 20-22 October,1989) studied by Akala *et al.* (2010b) which is a more or less similar result to that of unperturbed condition(Akala *et al.*, 2010a). In the day-to-day variability, the contribution of geomagnetic and meteorological sources are said to be greater than that of solar ionising flux during the day and the night (Forbes *et al.*, 2000; Rishbeth and Mendillo, 2001). Of about 20% VR during daytime 13 and 15% are ascribed to geomagnetic and meteorological, respectively by Rishbeth and Mendillo (2001) since the sum of the squares of these latter values makes the total relative VR to be about 20%. These values are for mid-latitude stations. For low latitude stations, contributions from geomagnetic and meteorological sources may be greater since VR is greater at the low latitude than at mid latitude. Effect of geomagnetic activity on NmF2/foF2 needs to be investigated further as reports of few workers are available in this regard.

CONCLUSION

The review of NmF2 relative variability at equatorial and low latitude stations has been carried out. The various methods of obtaining relative variability is described. NmF2/foF2 relative VR is found (1) generally greater during the night than during the day. (2) by some workers to increase with decrease in Rz in the night and to decrease with increase in Rz during the day. Some others, however, found VR alternating between increasing and decreasing with Rz during the day and during the night. More work needs to be done to ascertain the true position. (3) greater at equatorial and low-latitude station than at mid-latitude stations. The reverse is the case during the day. (4) dependent on geomagnetic activity. (5) to show little or no seasonal variation during the day except for stations located around the equator anomaly crest. Nighttime NmF2/foF2 VR is reportedly higher during June Solstice and September equinox.

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