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INVESTIGATING THE EQUATORIAL IONOSPHERIC F - REGION AT SUNRISE.

E. E. IHEONU and O. S. OYEKOLA

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ABSTRACT

The ionospheric F-layer at sunrise is investigated by applying data obtained at Ibadan (Magnetic latitude 3°S) to the electron density continuity equation. Results obtained indicate that the rate of change of electron density increases with time in the neighbourhood of ground sunrise. The movement term in the continuity equation is established as the major factor governing ionization density changes at sunrise. The results are also comparable with earlier works at the same station using horizontal drift measurements, for equinoctial and solsticial conditions

KEY WORDS: Electron density, Continuity equation, Ground sunrise, Ionization density,

Ionospheric F-layer.

1. INTRODUCTION

The upper regions of the earth's atmosphere receive continuous large doses of radiations as they are strongly heated by the absorption of solar extreme ultraviolet (EUV) and X-rays which dissociate and ionize the atmospheric gases and thus create the ionosphere.

Ionospheric sunrise represents the transitional period between quasi-equilibrium conditions attained during the night and those attained during the day. Neglecting the refractive bending of the sun's rays by the atmosphere, the local sunrise occurs when the sun is in the horizontal plane at the point of observation. Then sun's zenith angle for this event is 90°, which according to Chapman (1931) corresponds to 0600 hours, local time.

The arrival of sunrise is manifested by a rapid increase in electron temperatures and variations in the equivalent heights of the ionospheric layers and maximum ionization densities. These variations are further accompanied by changes in the different physical properties of the layers.

The behavioural patterns of electron movements and drifts, which are direct consequences of these changes, appear more complex than is often assumed, particularly, near the magnetic equator.

In this study electron movements and drift irregularities at the ionospheric F-region heights of 300, 350 and 400km are examined by adopting a systematic analysis of the various factors which govern ionization density changes at the equatorial ionospheric F-region at sunrise, using the theoretical electron density continuity equation. The movement term would be simplified by omitting horizontal drifts and diffusions and including only drifts due to vertical motion.

2 THE ELECTRON DENSITY CONTINUITY EQUATION

A form of an equation of continuity (or balance) whose terms represent the effects of the various processes which modify the electron concentration at any height can be written for electrons and ions thus: (rate of change of electron concentration) = (gain by production) - (loss by destruction) - (change due to movement).

If the movement processes result in a net drift velocity, then the change due to movement is the divergence of the flux NV. Using symbols q and L to represent production and loss respectively, the rate of change of electron density, $\frac{\delta N}{\delta t}$ can be expressed as (Rishbeth, 1988 and Umoh and Adeniji, 1995):

$$\frac{\delta N}{\delta t} = q - L(N) - div(NV) \qquad (1)$$

where N is the electron density and V the drift velocity.

E. E. IHEONU, Nigerian Building & Road Research Institute, Building Physics Unit, 15, Awolowo Road, Ikoyi,Lagos, Nigeria
O. S. OYEKOLA, Physics Department, University of Ibadan, Oyo State, Nigeria

The full continuity equation is too complicated to be solved in general, so the solutions of some simplified versions of it, will be considered.

$$div(NV) = \frac{\delta}{\delta_x}(NV_x) + \frac{\delta}{\delta_y}(NV_y) + \frac{\delta}{\delta_h}(NV_h)$$

The component $\frac{\delta}{\delta_x}(NV_x)$ *and* $\frac{\delta}{\delta_y}(NV_y)$

may be assumed to be due to horizontal variations (diffusion and/or drifts) and vertical diffusion respectively. Since electrons move more easily parallel to the earth's magnetic field, movements due to vertical diffusion will be considered restricted over or near the magnetic equator. Thus neglecting horizontal variations, the electron density continuity equation for the F-region becomes:

$$\frac{\delta N}{\delta t} = q - L - \frac{\delta}{\delta h}(NV) \qquad (2)$$

where L = βN and the divergence term has been considered in one dimension. β is the recombination coefficient. The component δ/δh (NV) is assumed to be representing movements due only to the vertical drift which is independent of height but may vary with time. In that case, (2) becomes:

$$\frac{\delta N}{\delta t} = q - \beta N - \frac{\delta N}{\delta h} \qquad (3)$$

In other words, we have assumed that movement due to the vertical component of plasma velocity is constant with height.

The distribution with height of neutral atmospheric gas may be assumed to be subject to the perfect gas law equation:

$$P = nkT \qquad (4)$$

where P is the pressure; n is the number density of ionized constituents, k is Boltmann's constant (1.38 x 10^{-23} JK^{-1}) and T is the temperature of particles.

From (4),

$$dP = kT\ (dn) \qquad (5)$$

for isothermal atmosphere.

The vertical distribution of any gas is also controlled by gravity which balances the vertical pressure gradient. This balance is expressed by the hydrostatic equation:

$$P = -\rho gh = -nmgh \qquad (6)$$

where ρ is density, m is the particle mass, g is the acceleration due to gravity and h is the reference height.

$$dP = nmgdh \qquad (7)$$

Equating (5) and (7), we have:

$$kTdn = -nmgdh \qquad (8)$$

$$ndh = \frac{-kTdn}{mg} \qquad (9)$$

In the height range between 300 and 400 km, (9) may be expressed in terms of the electron density scale height since N >> n in the F - Layer. In this case,

$$Ndh = -\frac{kT_e dN}{M_e g} \qquad (10)$$

where T_e is electron temperature, M_e is electron mass and

$H_e = \frac{kT_e}{M_e g}$ is the electron density scale height.

If H_e is assumed constant in the height range from 300 to 400km, then N-h relation for the F-region at sunrise can be put in the form:

$$N = N_o\ exp\ (-h/H_e) \qquad (11)$$

Thus for equatorial ionospheric sunrise analysis. H_e can be defined by:

$$H_e = \frac{-N}{\frac{\delta N}{\delta h}} \qquad (12)$$

$$\frac{\delta N}{\delta h} = -\frac{N}{H_e} \qquad (13)$$

Substituting this value into (3), the electron density continuity equation now becomes:

$$\frac{\delta N}{\delta h} = q - \beta N + \frac{VN}{H_e} \qquad (14)$$

Thus, the vertical drift velocity, V can easily be determined. Vertical drift velocity may be defined as electron common drift velocity in addition to their random gas kinetic velocities.

3. CHOICE OF VALUES OF THE VARIOUS TERMS

3.1 The Production Term and Chapman Function

The production rate, q according to

Chapman (1931) is given by the equation:

$$q = q_o \exp [1 - Z - e^{-z} \sec\chi] \qquad (15)$$

where q_o is the maximum production for overhead sun, χ is the zenith angle of the sun and Z is the height measured from a datum level h_o corresponding to q_o, in units of the scale height of the ionizable constituent.

When χ is near 90° as near sunrise, the "plane earth" approximation assumed by Chapman, becomes invalid. The factor Sec χ varies along the path of the radiation. To incorporate the effect of the earth's sphericity, Chapman, showed that sec χ above should be replaced by a special function called Chapman function [or $Ch(R, \chi)$].

Thus (15) above becomes:

$$q = q_o \exp [1 - Z - e^{-z}\, Ch\, (R, x^o)] \qquad (16)$$

where R is radial distance in scale height.

Following Ratcliffe and Weekes (1960), q_o is found from the relation:

$$q_o = 250\, [1 + 16 \times 10^{-3}\, I\,]\ cm^{-3} sec^{-1} \qquad (17)$$

where I is the mean Zurich sunspot number = 92.3, for a typical year of high solar activity

Hence,

q_o is taken as $620\ cm^{-3} sec^{-1}$ approximately.

$Ch(R,X)$ values are taken from prepared table (Chapman, 1931).

3.2 Consideration of the Loss Term

The value of the ionization loss coefficient β decreases exponentially with height at any given time in the F-region. Coefficient of β in the continuity equation acts as recombination co-efficient. Its value is given by Picquenard (1974, p 123) as:

$$\beta = \beta_0 \exp\left[\frac{300 - h(km)}{50}\right] \qquad (18)$$

where h is the true height of reflection and $\beta_o = 1 \times 10^{-4}\ sec^{-1}$A lot of uncertainty surrounds the value of β generally in the F-region. Estimates of β are rendered difficult because of the scanty and inaccurate knowledge of the effects of movement of ionization on β in the region. The effects due to movements cannot certainly be isolated in the determination of β. For want of a better estimate, equation (18) will be adopted for the estimate of the Loss term.

3.3 The Movement Term

Drift of electrons which results in the mass movement of ionization is caused by three mechanisms:

i. plasma diffusion
ii. drag due to neutral atmospheric gas motion
iii. drift motion due to applied electromagnetic action

The electron drifts are generally believed to be upwards during the day and downwards during the night. If movement of ionization is assumed to be due to vertical drift of electrons, then the effect of the transport term on the continuity equation at sunrise is to cause a decrease in the rate of electron-loss.

The value of the electron density scale height H_e in the height range 300 - 400 km is determined from the N-h profiles used for this study. The value is approximately 150km. The corresponding scale height for the ionizable constituent in the case of an isothermal atmosphere at sunrise is 50km.

4. QUANTITATIVE CONSIDERATIONS AND DISCUSSIONS

For indepth analysis and consideration of the characteristics and behaviour of the equatorial ionospheric F region at sunrise, the quarter-hourly mean variations of the electron density for all the 12 months were easily grouped into appropriate three-month seasonal periods as follows:

1. March Equinox
   February, March April
2. June Solstice
   May, June July,
3. September Equinox
   August, September, October,
4. December Solstice
   November, December, January

Due to scanty data obtained from February - April, the results and analysis of the equinoctial months are treated together for convenience.

The electron density values, N (cm^{-3}) were obtained from the expression (Skinner and Wright, 1955) :

$$N = (1.24 \times 10^4\, fN^2) \qquad (19)$$

where fN is the layer critical frequency, measured in MHz.

Several ionogram autoscaling programs are already in existence, which use various forms of line fitting with ionogram pre-processing to determine critical reflection frequencies (Fox and Blundell , 1989 and Hill and Koschmieder, 1995) and hence electron desnsities.

A ten point analysis following Kelso *(1952)* was however, used to obtain N(h) curves from ordinary wave *h(f)* curves of an ionogram. Appropriate electron density N versus time, t curves provided the observation data from which the rate of change of electron density (δN/δt) values were determined at various heights. Table 1 (a-c) show the calculated values of the various parameters in the electron density continuity equation for June Solstice, Equinox and December Solstice respectively.

We shall now examine these parameters, namely, the production function, the loss term and the movement term quantitatively relative to the observed rate of change of electron density at sunrise. Meanwhile the standard error, *SEE*, of the mean distribution adopted in this study is given by:

$$SEE = \sigma / N$$

where σ is the standard deviation of the mean value and N the number of samples.

4.1. The Rate of Change of Electron Density

Consider column 4 of Table 1 (a-c). The variations of δN/δt with x at the different seasons indicate that δN/δt increases with time, t at all seasons, at sunrise, contrary to the analysis and observation of sunrise data at Slough and Cambridge, by Rishbeth and Setty (1961) that δN/δt was constant for about 2 hours after sunrise. It will be quite interesting to examine qualitatively the effects of the various parameters in the continuity equation on the observed variations δN/δt as it increases with time and height at all seasons.

4.2 Introduction of the Production Function

If the production rate is assumed to be the dominant factor in the assessment of the ionization density changes at sunrise, then it should be possible to write as a first approximation, that

$$\frac{\delta N}{\delta t} \approx q \qquad (20)$$

Table 1a: Observed / Evaluated values of various parameters in the electron density continuity equation at sunrise (June Solstice)

χ°	$Ch(R,\chi^0)$	h (km)	$\delta N/\delta t$ $cm^{-3}sec^{-1}$	q $cm^{-3}sec^{-1}$	βN $cm^{-3}sec^{-1}$	$M = \delta N/\delta t + \beta N - q$ $cm^{-3}sec^{-1}$	v ms^{-1}
100	390.00	300	134.5	-	37.5	172.0	55.0
	273.56	350	122.2	-	12.3	134.5	48.2
	172.12	400	89.0	2.5	3.2	89.7	45.0
95	50.00	300	150.0	1.6	55.7	204.1	44.0
	41.30	350	145.6	14.2	17.9	149.3	37.0
	36.30	400	134.0	13.2	5.7	16.5	36.1
90	16.30	300	167.8	35.0	87.5	220.3	30.2
	15.00	350	156.7	33.5	30.7	153.9	22.1
	14.00	400	144.4	17.5	8.7	135.6	25.3
85	11.90	300	202.8	51.9	124.1	275.0	26.6
	9.58	350	189.0	40.8	40.8	189.0	20.5
	8.65	400	172.2	18.8	12.1	165.5	22.2
80	4.66	300	242.2	100.5	144.6	286.3	23.8
	4.55	350	234.4	48.4	50.3	236.3	21.0
	4.30	400	211.1	20.0	16.1	207.2	21.0
75	3.54	300	290.0	111.0	161.2	340.2	25.3
	3.48	350	279.0	41.9	55.2	284.3	22.7
	3.43	400	256.7	20.1	18.2	254.8	22.8

Table 1b: Observed / Evaluated values of various parameters in the electron density continuity equation at sunrise (June Solstice)

χ	$Ch(R,\chi^0)$	h (km)	$\delta N/\delta t$ $cm^{-3}sec^{-1}$	q $cm^{-3}sec^{-1}$	βN $cm^{-3}sec^{-1}$	$M = \delta N/\delta t + \beta N - q$ $cm^{-3}sec^{-1}$	v ms^{-1}
100	390.00	300	94.4	-	57.3	151.7	31.8
	273.56	350	77.8	-	17.6	95.4	24.0
	172.12	400	44.5	2.5	4.7	46.7	16.1
95	50.00	300	127.8	1.6	63.5	189.7	35.8
	41.30	350	122.2	14.2	19.9	128.0	28.4
	36.30	400	116.7	13.2	5.5	109.0	32.4
90	16.30	300	166.7	35.0	91.7	223.4	29.2
	15.00	350	161.1	33.5	32.2	159.8	22.0
	14.00	400	157.8	17.5	10.2	150.5	24.0
85	11.90	300	214.0	51.9	127.8	290.0	27.2
	9.58	350	211.1	40.8	43.4	213.7	21.8
	8.65	400	183.3	18.8	11.9	176.4	24.1
80	4.66	300	266.7	100.5	155.6	321.8	24.8
	4.55	350	250.0	48.4	53.2	254.8	21.1
	4.30	400	200.0	20.0	16.8	196.8	19.0
75	3.54	300	300.0	111.0	172.7	361.7	25.1
	3.48	350	277.8	41.9	59.3	287.2	21.4
	3.43	400	265.6	20.1	19.0	264.5	22.8

Table 1c: Observed / Evaluated values of various parameters in the electron density continuity equation at sunrise (June Solstice)

χ°	$Ch(R,\chi^0)$	h (km)	$\delta N/\delta t$ $cm^{-3}sec^{-1}$	q $cm^{-3}sec^{-1}$	βN $cm^{-3}sec^{-1}$	$M = \delta N/\delta t + \beta N - q$ $cm^{-3}sec^{-1}$	v ms^{-1}
100	390.00	300	101.0	-	39.0	140.0	43.1
	273.56	350	90.0	-	12.8	102.8	35.4
	172.12	400	77.8	2.5	3.5	78.8	36.1
95	50.00	300	136.1	1.6	62.7	197.2	37.7
	41.30	350	100.0	14.2	20.5	106.3	23.0
	36.30	400	89.0	13.2	6.2	82.0	21.6
90	16.30	300	150.0	35.0	85.4	200.4	28.2
	15.00	350	139.0	33.5	30.7	136.2	19.6
	14.00	400	134.4	17.5	8.7	125.6	23.4
85	11.90	300	211.7	51.9	111.5	271.3	29.2
	9.58	350	211.1	40.8	38.8	209.1	23.8
	8.65	400	205.7	18.8	12.1	199.0	26.8
80	4.66	300	265.6	100.5	142.0	307.1	26.0
	4.55	350	265.7	48.4	50.3	258.6	22.7
	4.30	400	244.4	20.0	15.5	240.0	25.2
75	3.54	300	299.0	111.0	158.3	346.3	26.3
	3.48	350	272.2	41.9	57.2	279.5	21.6
	3.43	400	255.6	20.1	20.0	255.5	20.8

Table 2: Variation of F-region drift velocity v for the different seasons and whole year

Local Time (hrs)	χ^0	June Solstice (ms^{-1})	Equinox (ms^{-1})	December Solstice (ms^{-1})	Mean value of velocity for all year (ms^{-1})
0515	100	49	24	38	37 ± 6
0540	95	39	32	27	33 ± 3
0600	90	26	25	24	25 ± 1
0620	85	23	24	27	25 ± 1
0645	80	22	22	25	23 ± 1
0700	75	24	23	23	23 ± 1

By considering columns 4 and 5 of Table 1 (a-c), it is observed, contrary to expectation, that $\delta N/\delta t >> q$ at all heights and seasons. For instance at h = 300km, when $\chi = 90°$, $\delta N/\delta t$ = 168cm^{-3}sec^{-1}, 167cm^{-3}sec^{-1}, 150cm^{-3}sec^{-1} as against q = 35cm^{-3}sec^{-1} for June solstice, Equinox and December solstice respectively, giving a ratio of more than 4:1 for all the different seasons. These results clearly indicate that q alone cannot be used to explain ionization density changes at sunrise.

4.3 Incorporation of the Loss Term

The incorporation of the loss term certainly aggravates the already unrealistic situation much further. In other words, the electron density continuity equation of the form:

$$\frac{\delta N}{\delta t} = q - \beta N \qquad (21)$$

does not improve the explanation of the observed electron density changes $\delta N/\delta t$ at sunrise.

Without further analysis and/or illustrations, the necessity to introduce the movement term now, can no longer be over emphasised. Hence, the continuity equation with the addition of the movement term will take the form:

$$\delta N/\delta t = q - \beta N + M \qquad (22)$$

where M is the transport term assumed positive since movement of electrons will generally be upwards during the early morning electron density build up period.

4.4 Addition of the Movement Term

Assuming that values of q_o and β_o adopted above are correct and movements are also assumed positive and upwards, then the movement term becomes:

$$M = \delta N/\delta t + \beta N - q \qquad (23)$$

Values of M are shown in column 7 of table 1 (a-c).

It is clear now that the transport term assumes a dominant position over the other terms q and L in the explanation of ionization density changes at sunrise. In fact, movement seems quite comparable with $\delta N/\delta t$ at 350 and 400km heights at all seasons. For instance, when $\chi = 90°$ at 350km, values of M and $\delta N/\delta t$ are respectively 154cm^{-3}sec^{-1} and 157cm^{-3}sec^{-1} for June solstice, 160cm^{-3}sec^{-1} and 161cm^{-3}sec^{-1} for the Equinox, 136cm^{-3}sec^{-1} and 139cm^{-3}sec^{-1} for December solstice.

There are generally, steady increases in movements of electrons at all heights and at different seasons before and after ground sunrise. The movement term also becomes more positive with time at all heights and at all seasons. This implies that the consequences of the movement term are to compensate for the loss term, as the destruction of electrons tends to reduce the increasing values of $\delta N/\delta t$ substantially. In other words, the effect of the movement term is to decrease the rate of loss of electrons.

Columns 8 of table 1 (a-c) show the computed values of drift velocities at the various seasons while the graphically representation are shown in fig. 1, 2 and 3 for June solstice, Equinox and December solstice respectively. Calculated standard errors are indicated by vertical lines in case (d), which represents the mean variations.

There is a continuous decrease in velocity at all heights for the solsticial months before ground sunrise. The decrease in velocity

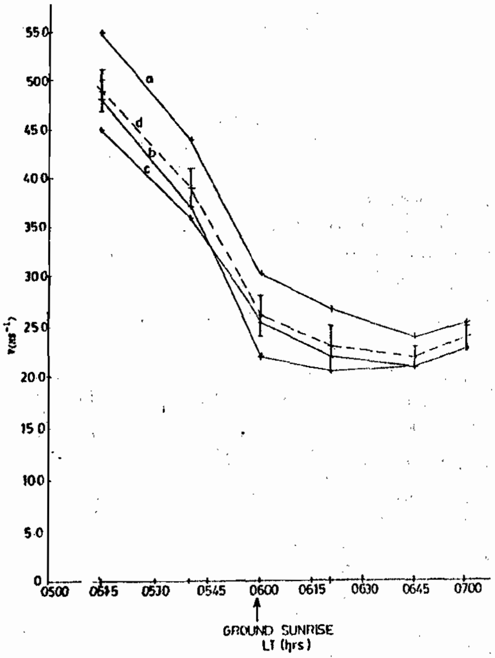

Figure 1: Time Variation of Vertical drift velocity at Sunrise (IBADAN: JUNE SOLSTICE)

(a) Variation of drift velocity at height, 300km

(b) Variation of drift velocity at height, 350km

(c) Variation of drift velocity at height, 400km

(d) Mean variation of drift velocity at height (300km – 400km)

Calculated standard errors are indicated by vertical lines in case (d).

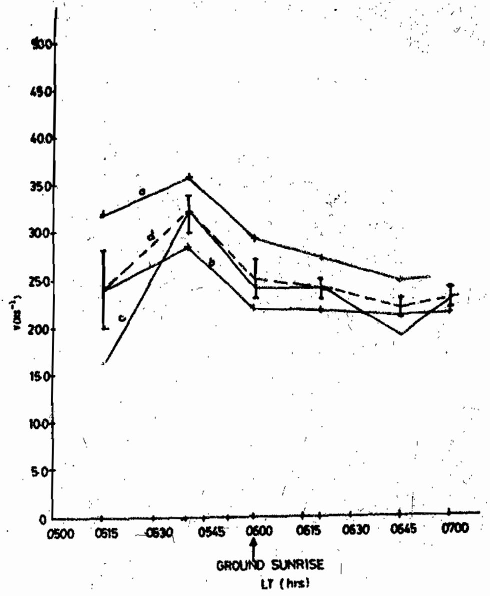

Figure 2: Time Variation of Vertical drift velocity at Sunrise (IBADAN: EQUINOX)

(a)	Variation of drift velocity at height, 300km
(b)	Variation of drift velocity at height, 350km
(c)	Variation of drift velocity at height, 400km
(d)	Mean variation of drift velocity at height (300km – 400km)

Calculated standard errors are indicated by vertical lines in case (d).

continues after ground sunrise at 300 and 350km heights for about 45 minutes before a sudden rise in velocity. The trend is similar at the 400km height before ground sunrise but the continuous decrease in the values of the velocity at this height after ground sunrise occurs for only about 20 minutes before a gradual rise thereafter. The maximum velocity obtained at this season was 55ms^{-1} observed at h = 300km while the minimum velocity was 21ms^{-1} obtained at h = 350km, giving a difference in velocity of about 34ms^{-1}.

The results for the equinoctial months showed more irregular variations at all heights and somehow in contrast with the variations described at the June solstice. The maximum and minimum velocities obtained were:

32ms^{-1} at h = 300km and

16ms^{-1} at h = 400km respectively,

giving a difference in velocity of about 16ms^{-1}.

In December solstice, the variation of velocity before ground sunrise tended to be similar to that of June solstice at h = 300km but quite off mark after ground sunrise.

For the other heights, the variations if compared with those in June solstice showed remarkable differences. The maximum and minimum velocities were: 43ms^{-1} at h = 300km and 20ms^{-1} at h = 350km, thus giving a difference in velocity of 23ms^{-1}.

Since the velocities showed such contrasting seasonal variations generally, their practical interpretations could be misleading if viewed in isolation. The overall means seasonal variations provide some significant results that could be worthwhile and would be considered in due course.

Table 2 shows the calculated values of the mean drift velocity V for the different seasons and whole year between 0515 and 0700 hours. The general variations in the magnitude of the velocities from season to season and entire year are shown in fig.4. At ground sunrise, the average velocities were 26 ms^{-1}, 25ms^{-1} and 24ms^{-1} for June solstice, equinoctial months and December solstice, respectively.

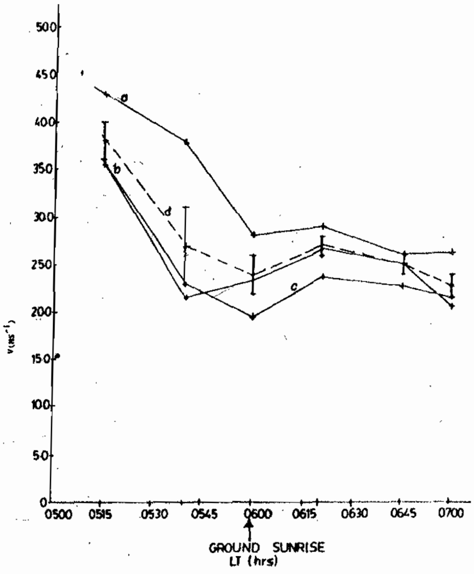

Figure 3: Time Variation of Vertical drift velocity at Sunrise (IBADAN: DECEMBER SOLSTICE)

(a)	Variation of drift velocity at height, 300km
(b)	Variation of drift velocity at height, 350km
(c)	Variation of drift velocity at height, 400km
(d)	Mean variation of drift velocity at height (300km – 400km)

Calculated standard errors are indicated by vertical lines in case (d).

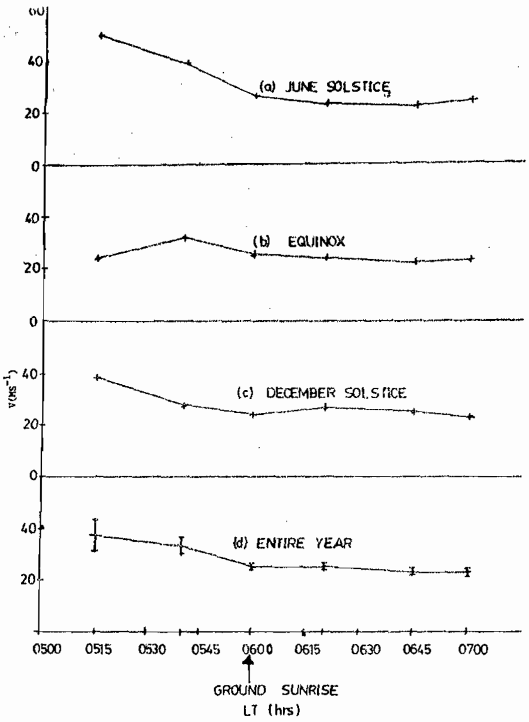

Figure 4: Mean variation of F-region drift velocity for the seasons and entire year

Calculated standard errors are indicated by vertical lines in case (d).

The velocities at ground sunrise seem comparable at all seasons. However before ground sunrise, specifically at 0515 hours (when χ = 100°), the average velocities were 49ms^{-1}, 24ms^{-1} and 38ms^{-1} for June solstice, equinoctial months and December solstice respectively.

The main conclusions on the vertical drift velocity were as follows:

i. At ground sunrise, the velocity for the whole year had a magnitude of 25±1ms^{-1} on the average.

ii. There was a clear seasonal variation in the magnitude of velocity during June solstice, Equinox and December Solstice, with June Solstice having a wider spectrum of velocity than in equinox and December Solstice.

iii. The mean magnitude of velocity for June solstice was found to be 31±4ms^{-1} while those for December solstice and Equinox were 27±2ms^{-1} and 25±1ms^{-1} respectively.

iv. The overall mean drift velocity for all year round had a value of 28± 2ms^{-1}

For the F-region during June solstice at Ibadan (geog.lat. 7.43°N, 3.88°E, Mag.lat.3.0°S), the drift velocity varied between 22 ± 1ms^{-1} and 49 ± 2ms^{-1}. In the equinoctial period, the variation in velocity was between 22 ± 1ms^{-1} and 32 ± 2ms^{-1} while in the December Solstice, the drift velocity variation was between 23±2ms^{-1} and 38±2 ms^{-1}

The average drift velocity of 28±2ms^{-1} obtained for the F-region at Ibadan in the present work, is of the same order of magnitude with the values obtained for the same station by Bamgboye (1969), Morris (1967) , Onolaja (1977). Kolawole (1973) and Oyinloye (1968).

Due to less collisions in the F-region, drift velocities should be greater than those of the E-region. However, majority of Ibadan results, in some of the works cited above, including the general results obtained in the present study indicate comparable drifts in the two regions.

This development may not be unconnected with the assumption adopted based on the inaccurate knowledge of the effects of movement of ionization on the loss coefficient β in the F-layer. Problems associated with the determination of loss coefficient are treated in some detail by Awojobi (1966). In addition, it is possible that the early morning build-up of ionization may have contributed to this situation since some results for Ibadan were average values of the drift velocities obtained in the day – time. Differences in the methodology of investigation adopted by most workers may also have had its contributory effect on the results.

5. CONCLUSION

The results in the present study have shown that the rate of change of electron density increases with time before and after ground sunrise, in the equatorial region contrary to the observation by Ratcliffe and Setty (1961) that $\delta N/\delta t$ was constant for about 2 hours after sunrise.

It has also been indicated that the movement term is the dominant factor in the explanation of ionisation density changes at sunrise.

The range of velocity was wider in summer than during the other seasons. For June Solstice, the range of velocity was between 22±1ms^{-1} and 49±2ms^{-1} while for equinox and December Solstice, the range of velocities were from 22±1ms^{-1} to 32±2ms^{-1} and 23±1ms^{-1} to 38±2ms^{-1}, respectively.

The drift results are quite comparable with horizontal drift measurements obtained at Ibadan, in both the E and F - regions.

It has thus been established that electron movements (and hence vertical drift velocities) in the ionospheric F-region at sunrise, cannot be ignored in the solution of the electron density continuity equation or in the determination of drift measurements whereby horizontal drifts or diffusions are treated in isolation.

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