1. Publication Nº	2. Version	3. Date	5. Distribution
INPE-2497-PRE/180	*3rd**	*Aug., 1982*	☐ Internal ☒ External ☐ Restricted

4. Origin *DGA* — Program *IONOSFERA/ELIS*

6. Key words - selected by the author(s)

ION PRODUCTION RATE
SOUTH ATLANTIC ANOMALY

7. U.D.C.: *523.4-853*

8. Title *INPE-2497-PRE/180*

COMMENT ON "MODELLING THE ION CHEMISTRY OF THE D REGION: A CASE STUDY BASED UPON THE 1966 TOTAL SOLAR ECLIPSE" BY SEARS ET AL.

10. Nº of pages: *10*

11. Last page: *08*

12. Revised by

Ivan Jelinek Kantor

9. Authorship *M.A. Abdu*
J.H.A. Sobral
I.S. Batista

Responsible author

13. Authorized by

Nelson de Jesus Parada
Director

14. Abstract/Notes

This comment concerns a brief assessment, based on some recent works, on the possible magnitude of ion production rates in the lower ionosphere over the south Atlantic magnetic anomaly, arising from precipitation of energetic electrons.

15. Remarks

This work is being submitted to JGR.
** Revised version, June 1983.*

COMMENT ON "MODELLING THE ION CHEMISTRY OF THE D REGION: A CASE STUDY BASED UPON THE 1966 TOTAL SOLAR ECLIPSE" BY SEARS ET AL.

M.A. Abdu, J.H.A. Sobral, I.S. Batista

Instituto de Pesquisas Espaciais - INPE
Conselho Nacional de Desenvolvimento Cietnīfico e Tecnlōgico - CNPq
12200 São Josē dos Campos, S.P., Brasil

Abstract

This comment concerns a brief assessment, based on some recent works, on the possible magnitude of ion production rates in the lower ionosphere over the south Atlantic magnetic anomaly, arising from precipitation of energetic electrons.

In a recent paper Sears et al. (1981) modelled the data set from the November 12, 1966 total solar eclipse compaign conducted in Casino, Brazil, using a D-region chemical code. One of the main conclusions from their analysis was that for adequate modelling of the D-region electron density it was necessary to include in the chemical code an ionization source function arising from the precipitation of inner radiation belt energetic electrons into the lower ionosphere over the south Atlantic anomaly. They calculated ion production profile using electron energy spectra based on the trapped flux in the energy range from 50 kev to 1.5 MeV as measured by Pfitzer an Winkler (1968), and obtained a peak value of 0.5 ion pairs $sec^{-1}cm^{-3}$ in the region of 70km, decreasing to about .05 ion pairs at a height of 100km.

The lower ionosphere ion composition and electron density data during this eclipse (Narcisi et al., 1972, Ulwick, 1972, and Metchly et al., 1969) have been modelled also earlier, by Abdu et al., (1979) to infer possible ionization rate arising from the precipitation of energetic electrons into anomaly region. They carried out their calculations by comparing the ionospheric parameters measured during the full sun and total eclipse conditions, and deducing a residual ion production rate profile, in the height region 92-108km, that could not be attributed to the residual ionizing radiation coming from the eclipsed sun, and to the scattered UV radiation. This residual ion production rate was attributed to precipitating energetic electrons in the south Atlantic anomaly. Precipitation of energetic neutral particles, resulting from the charge exchange chemistry of the outer radiation belt, is also believed to be an ionizing source over low latitude (see for example, Mizera and Blake, 1973, Tinsley 1976, Lyons and Richmond, 1978). However, the ion production rate due to this source gets important only during a storm main phase, and the height of the maximum ionization occur usually between 125 and 180km. Under magnetically moderate period the maximum ion production rate from this source, as seen from the calculations of Lyon and Richmond (1978), is less than 10 $cm^{-3}s^{-1}$ which is significantly smaller than the ion production rate that we have inferred from our eclipse data analysis (to be presented below), which refers to a lower height region (90-110km). The purpose of this comment is to point out that the ion pair production rate due to precipitating electrons considered by Sears et al. (1981) is a significant understimation of this parameter, based on our own results and that calculated from the electron energy spectrum recently measured by Gledhill and Hoffman (1981) in the anomaly region.

The height variation of the ion production rate considered by Sears et al. (1981) is shown in Figure 1 (denoted as q_{PS}) together with the ion production rate deduced by Abdu et al. (1979) (denoted as q_{PA}), both values representing the same time frame and location. Abdu et al. (1979) did not extend the calculation of ion production rate to below 92km due to the possibility that insufficient knowledge of some of the complex ion chemical reaction coefficients might lead to imprecise estimation of such values. Above approximately 90km, where simple molecular ion chemistry controls the ionization balance, such uncertainties are not expected to be present.

In Figure 1 we may note that near 95-100km the ion production rate calculated by Sears et al. (1981) is less, by 3-4 orders of magnitude, than that deduced by Abdu et al. (1979) to represent the same ambient condition. This difference is so large that it raises the question as to which of these values should be representing closer the conditions that prevailed during the eclipse campaign. One of the key factors that could affect our determination of q_{PA} is the residual ion production rate, q_{RA}, that we have considered for the totality of the eclipse which is also plotted in Figure 1, (see Abdu et al., 1979, for a detailed discussion on the residual solar ionizing radiation fluxes such as that of the soft X-rays), together with the corresponding residual ion production rate, q_{RS}, calculated by Sears et al. (1981). They seem to agree reasonably well although our values are higher by approximately a factor of 2 near 100km (and less by a similar factor below 90km). Such differences are present also in the full sun ion production rates deduced by us (as that required to explain the observed ion densities of Narcisi et al., 1972) and that calculated by

Sears et al. (1981) to represent the same ambient conditions, both of which are also shown (Q) in the Figure 1. In the same figure we have presented also the ion production rate due to scattered UV radiation ($q_{L\alpha}$, $q_{L\beta}$) representing nighttime conditions, calculated by Ogawa and Tohmatsu (1966). They are significantly higher (more than by an order of magnitude near 100 km) than the ion production rate due to precipitating electrons, q_{PS}, calculated by Sears et al. (1981), but still less than the q_{PA} deduced by us by over two orders of magnitude.

We have calculated also the ion production rates using an electron energy spectrum of the form $\phi_E = 6.3 \times 10^3\ E^{-\gamma} cm^{-2} sec^{-1} kev^{-1} sr^{-1}$, where $\gamma = 1.18$, recently measured by Gledhill and Hoffman (1981) from AE-C satellite passes in the anomaly region. We have carried out this calculation using the method of Rees (1963) and assuming isotropic distribution of the downcoming electron flux (namely, uniform distribution in the upper hemisphere). The ion production rates that resulted from this calculation is also plotted in Figure 1, denoted as q_{PG}. The value near around 92 km agrees very well with the q_{PA} derived by us from rocket ion density data. However, the ion production rate obtained from the electron energy spectrum of Gledhill and Hoffman (1981) decreases with increasing altitude, whereas the height profile of q_{PA} is seen increasing with height giving rise to large difference in the vicinity of 100 km. Such differences in the height distribution could probably be caused by the following factors. The electron flux and energy spectrum of the precipitating electron could be variable with time. It could depend upon factors like magnetic activity and atmospheric pressure fluctuations and therefore upon the time, relative to magnetic activity variation, during which measurements were taken. For example, we have observed significant enhacements in the ionization of the lower ionosphere in the form of nighttime VLF phase advances and blanketing and a-type sporadic E layer enhancements, with varying intensity associated with variations in the magnetic activity (Abdu et al. 1981; and Batista and Abdu, 1977). The epoch of the November 1966 eclipse was not particularly disturbed magnetically. However, the sunspot number in November 1966 (R_z = 56) was significantly higher than during March 1976

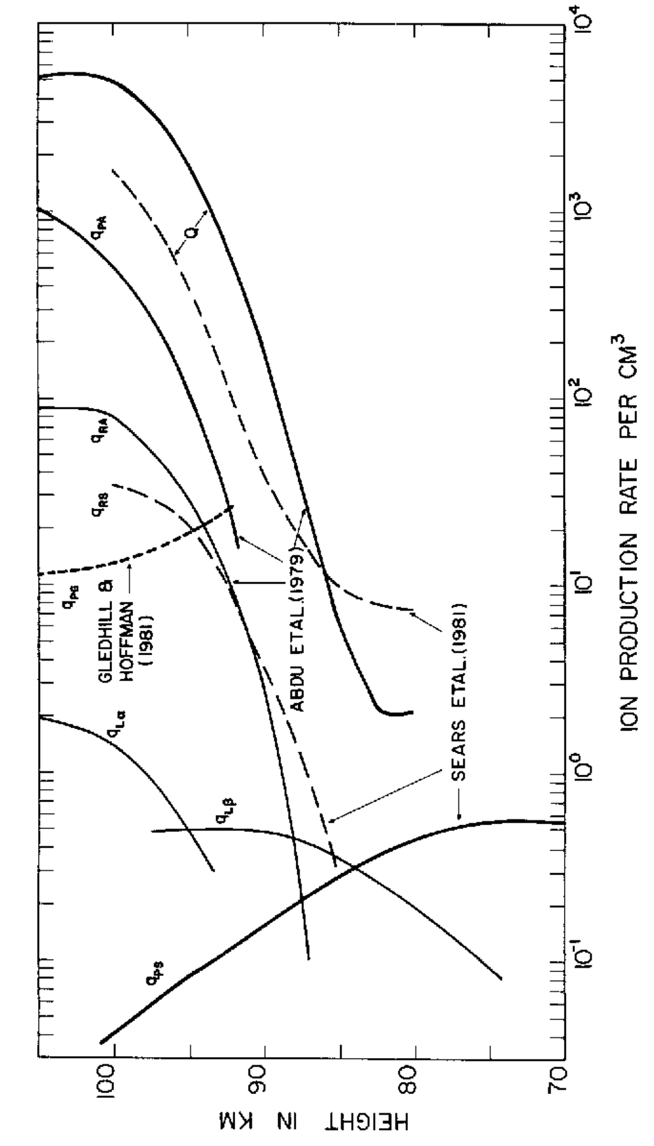
(R_z = 23), when the electron spectra of Gledhill and Hoffman (1981) was measured. If we invoke a power law spectrum to explain the q_{PA} profile, its power, γ, will be of the order of 4, whereas an exponential spectrum will have an e-folding energy of around 5 keV.

In conclusion, we would like to point out that the ion production rate due to precipitating electrons which appears to be a relatively significant source in the lower ionosphere over the Brazilian region of the south Atlantic anomaly, even under "quiet" conditions, is unlikely to be represented by its height profile calculated by Sears et al. (1981) in the height range 92-108 km. It seems to be at least 2-3 orders of magnitude higher, and probably lies between the values obtained from the electron energy spectrum measured by Gledhill and Hoffman (1981) and those deduced from ion density measurements by Abdu et al. (1979).

Figure Captions

Figure 1. Height distribution of ion production rates in the lower ionosphere.The curves marked Q represent the total ion production rates due to uneclipsed sun representing the ambient conditions during the November 1966 eclipse campaign.

q_{PA} is the ion production rate deduced by Abdu et al. (1979), from ion density data, as arising from energetic electron precipitation. q_{PS} is the rate calculated by Sears et al. (1981) using electron energy spectrum, based on the measurement of Pfitzer and Winkler (1968). q_{PG} is the ion production rate calculated by us using the electron energy spectrum measured by Gledhill and Hoffman (1981) from AE-C Satellite passes in Brazilian anomaly. q_{RS} and q_{RA} are respectively the residual ion production rate during the totality of the eclipse considered by Sears et al. (1981) and Abdu et al. (1979). $q_{L\alpha}$ and $q_{L\beta}$ are ion production rates due to scattered UV radiation representative of night conditions calculated by Ogawa and Tohmatsu (1966).



HEIGHT IN KM
ION PRODUCTION RATE PER CM^3
100
90
80
70
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
q_{PA}
q_{RA}
q_{RS}
q_{PG}
$q_{L\alpha}$
$q_{L\beta}$
q_{PS}
Q
GLEDHILL & HOFFMAN (1981)
ABDU ETAL.(1979)
SEARS ETAL.(1981)

References

Abdu, M.A., and Inez S. Batista, Sporadic E-layers phenomena in the Brazilian geomagnetic anomaly, J. Atmos. Terr. Phys., 39, 723-731, 1977.

Abdu, M.A., I.S. Batista, and J.H.A. Sobral, Particle ionization rates from total solar eclipse rocket ion composition results in the south Atlantic geomagnetic anomaly, J. Geophys. Res., 84, 4328-4334, 1979.

Abdu, M.A., I.S. Batista, L.R. Piazza, and O. Massambani, Magnetic storm associated particle precipitation in the south Atlantic anomaly: evidence from VLF phase measurements, J. Geophys. Res., 86, 7533-7542, 1981.

Batista I.S., and M.A. Abdu, Magnetic storm associated delayed sporadic E enhancements in the Brazilian geomagnetic anomaly, J. Geophys. Res., 82, 4777-4783, 1977.

Gledhill, J.A., and Hoffman, R.A., Nighttime observations of 0.2-25 keV electrons in the south Atlantic anomaly made by Atmospheric Explorer-C, J. Geophys. Res., 86, 6739-6744, 1981.

Lyons, L.R., and A.D. Richmond, Low-latitude E region ionization by energetic ring current particles, J. Geophys. Res., 83, 2201, 1978.

Mechtly, E.A., K. Seino, and L.G. Smith, Lower ionosphere electron densities measured during the solar eclipse of November 12, 1966, Radio Sci., 4, 371-375, 1969.

Mizera, P.F., and J.B. Blake, Observations of ring current protons at low latitude, J. Geophys. Res., 78, 1058, 1973.

Narcisi, R.S., A.D. Bailey, L.E. Wlodyka, and C.R. Philbrick., Ion composition measurements in the lower ionosphere during the November 1966 and March 1970 solar eclipse, J. Atmos. Terr. Phys., 34, 647-658, 1972.

Ogawa, T., and T. Tohmatsu, Photoelectronic processes in the upper atmosphere II, The hydrogen and helium ultraviolet glow as an origin of the nighttime ionosphere, Rep. Ionos. Space Res. Jap., 20, 395-417, 1966.

Pfitzer, K.A., and J.R. Winkler, Experimental observation of a large addition to the electron inner radiation belt after solar flare event, J. Geophys. Res., 73, 5899-5797, 1968.

Rees, M.H., Auroral ionization and excitation by incident energetic electrons, Planet. Space Sci., 11, 1209-1218, 1963.

Sears, R.D., M.G. Heaps, and F.E. Niles, Modelling the ion chemistry of the D region: A case study based upon the 1966 total eclipse, J.Geophys. Res., 86, 10,073-10,086, 1981.

Tinsley, B.A., Evidence that the recovery phase ring current consists of helium ions, J. Geophys. Res., 81, 6193, 1976.

Ulwick, J.C., Eclipse rocket measurements of charged particle concentration, J. Atmos. Terr. Phys., 34, 659-665, 1972.

MFN= 002282
01 SID/SCD
02 2497
03 INPE-2497-
04 CEA
05 S
06 as
10 Abdu, Mangalathyil Ali
10 Sobral, Jose Humberto Andrade
10 Batista, Inez Staciarini
12 Comment on "Modeling the Ion Chemistry of the D Region: A Case Study Based Upon the 1966 Total Solar Eclipse" by Sears et al
14 2406-2408
30 Journal of Geophysical Research
31 89
32 A4
40 En
41 En
58 DAE
59 903108
61 <PI>
64 abr. <1984>
68 PRE
76 AERONOMIA
83 In a recent paper, Sears et al. [1981] modeled the data set from the November 12, 1966, total solar eclipse campaign conducted in Casino, Brazil, by using a D region chemical code. One of the main conclusions from their analysis was that for adequate modeling of the D region electron density it was necessary to include in the chemical code an ionization source function arising from the precipitation of inner radiation belt energetic electrons into the lower ionosphere over the south Atlantic anomaly. They calculated ion production profile by using electron energy spectra based on the trapped flux in the energy range from 50 kev to 1.5 MeV as measured by Pfitzer and Winkler [1968], and obtained a peak value of 0.5 ion pairs s-1cm-3 in the region of 70 km, decreasing to about 0.05 ion pairs at a height of 100 km.

88 - D region
88 - solar eclipses
88 - total solar eclipse
88 - electron density
88 - inner radiation belt

87 região D
87 eclipes solar
87 eclipse total do sol
87 densidade de eletrons
87 cinturão de radiação interna

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 89, NO. A4, PAGES 2406–2408, APRIL 1, 1984

Comment on "Modeling the Ion Chemistry of the *D* Region: A Case Study Based Upon the 1966 Total Solar Eclipse" by Sears et al.

M. A. ABDU, J. H. A. SOBRAL, AND I. S. BATISTA

Instituto de Pesquisas Espaciais-INPE, Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq

In a recent paper, *Sears et al.* [1981] modeled the data set from the November 12, 1966, total solar eclipse campaign conducted in Casino, Brazil, by using a *D* region chemical code. One of the main conclusions from their analysis was that for adequate modeling of the *D* region electron density it was necessary to include in the chemical code an ionization source function arising from the precipitation of inner radiation belt energetic electrons into the lower ionosphere over the south Atlantic anomaly. They calculated ion production profile by using electron energy spectra based on the trapped flux in the energy range from 50 kev to 1.5 MeV as measured by *Pfitzer and Winkler* [1968], and obtained a peak value of 0.5 ion pairs s^{-1} cm^{-3} in the region of 70 km, decreasing to about 0.05 ion pairs at a height of 100 km.

The lower ionosphere ion composition and electron density data during this eclipse [*Narcisi et al.*, 1972; *Ulwick*, 1972; *Metchly et al.*, 1969] have also been modeled earlier by *Abdu et al.* [1979] to infer possible ionization rate arising from the precipitation of energetic electrons into anomaly region. They carried out their calculations by comparing the ionospheric parameters measured during the full sun and total eclipse conditions and deducing a residual ion production rate profile, in the height region 92–108 km, that could not be attributed to the residual ionizing radiation coming from the eclipsed sun and to the scattered ultraviolet radiation. This residual ion production rate was attributed to precipitating energetic electrons in the south Atlantic anomaly. Precipitation of energetic neutral particles, resulting from the charge exchange chemistry of the outer radiation belt, is also believed to be an ionizing source over low latitude (see, for example, *Mizera and Blake* [1973], *Tinsley* [1976], and *Lyons and Richmond* [1978]). However, the ion production rate due to this source gets important only during a storm main phase, and the height of the maximum ionization occur usually between 125 and 180 km. Under magnetically moderate periods the maximum ion production rate from this source, as seen from the calculations of *Lyon and Richmond* [1978], is less than 10 cm^{-3} s^{-1}, which is significantly smaller than the ion production rate that we have inferred from our eclipse data analysis (to be presented below), which refers to a lower height region (90–110 km). The purpose of this comment is to point out that the ion pair production rate due to precipitating electrons considered by *Sears et al.* [1981] is a significant underestimation of this parameter, on the basis of our own results and those calculated from the electron energy spectrum recently measured by *Gledhill and Hoffman* [1981] in the anomaly region.

The height variation of the ion production rate considered by *Sears et al.* [1981] is shown in Figure 1 (denoted as q_{PS}) together with the ion production rate deduced by *Abdu et al.* [1979] (denoted as q_{PA}), both values representing the same time frame and location, *Abdu et al.* [1979] did not extend the calculation of ion production rate to below 92 km owing to the possibility that insufficient knowledge of some of the complex ion chemical reaction coefficients might lead to imprecise estimation of such values. Above approximately 90 km, where simple molecular ion chemistry controls the ionization balance, such uncertainties are not expected to be present.

In Figure 1 we may note that near 95–100 km the ion production rate calculated by *Sears et al.* [1981] is less, by 3–4 orders of magnitude, than that deduced by *Abdu et al.* [1979] to represent the same ambient condition. This difference is so large that it raises the question as to which of these values should be representing closer the conditions that prevailed during the eclipse campaign. One of the key factors that could affect our determination of q_{PA} is the residual ion production rate q_{RA} that we have considered for the totality of the eclipse that is also plotted in Figure 1 (see *Abdu et al.* [1979] for a detailed discussion on the residual solar ionizing radiation fluxes such as that of the soft X rays), together with the corresponding residual ion production rate q_{RS} calculated by *Sears et al.* [1981]. They seem to agree reasonably well although our values are higher by approximately a factor of 2 near 100 km (and less by a similar factor below 90 km). Such differences are present also in the full sun ion production rates deduced by us (as that required to explain the observed ion densities of *Narcisi et al.* [1972]) and those calculated by *Sears et al.* [1981] to represent the same ambient conditions, both of which are also shown (Q) in Figure 1. In the same figure we have presented also the ion production rate due to scattered ultraviolet radiation ($q_{L\alpha}$, $q_{L\beta}$) representing nighttime conditions, calculated by *Ogawa and Tohmatsu* [1966]. They are significantly higher (more than by an order of magnitude near 100 km) than the ion production rate due to precipitating electrons q_{PS}, calculated by *Sears et al.* [1981], but still less than the q_{PA} deduced by us by over two orders of magnitude.

We have calculated also the ion production rates by using an electron energy spectrum of the form $\phi_E = 6.3 \times 10^3\ E^{-\gamma}$ cm^{-2} s^{-1} keV^{-1} sr^{-1}, where $\gamma = 1.18$, recently measured by *Gledhill and Hoffman* [1981] from AE-C satellite passes in the anomaly region. We have carried out this calculation by using the method of *Rees* [1963] and by assuming isotropic distribution of the downcoming electron flux (namely, uniform distribution in the upper hemisphere). The ion production rates that resulted from this calculation are also plotted in Figure 1, denoted as q_{PG}. The value near around 92 km agrees very well with the q_{PA} derived by us from rocket ion density data. However, the ion production rate obtained from the electron energy spectrum of *Gledhill and Hoffman* [1981] decreases with increasing altitude, whereas the height profile of q_{PA} is seen increasing with height, giving rise to large differences in

Paper number 3A1865.
0148-0227/84/003A-1865$02.00

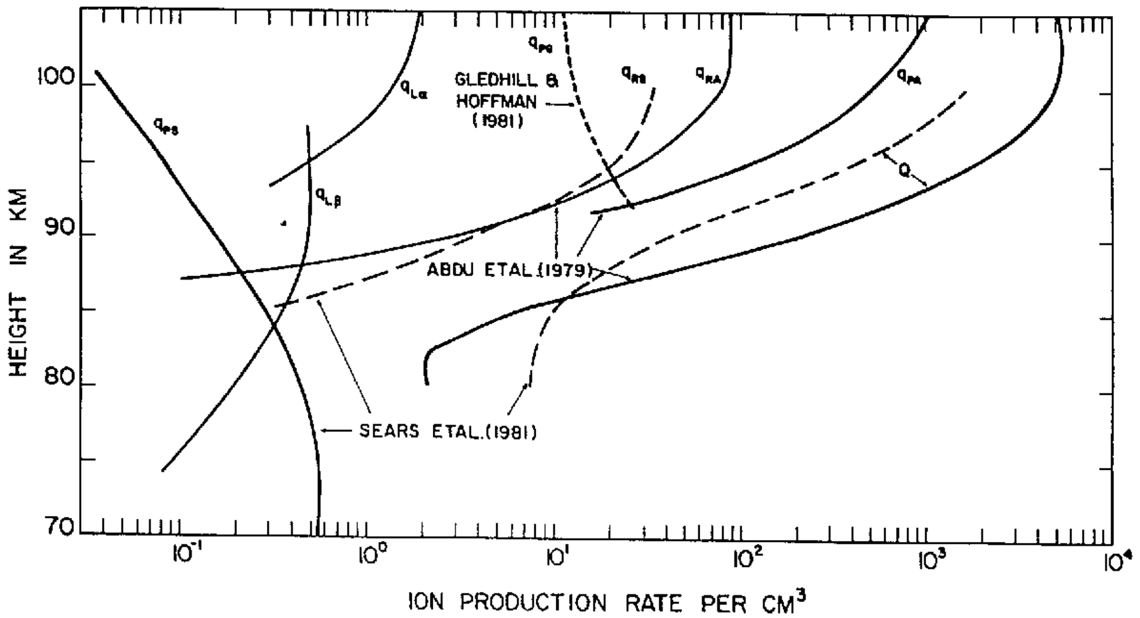


Fig. 1. Height distribution of ion production rates in the lower ionosphere. The curves marked Q represent the total ion production rates due to uneclipsed sun representing the ambient conditions during the November 1966 eclipse campaign. The ion production rate deduced by *Abdu et al.* [1979] from ion density data, as arising from energetic electron precipitation is represented by q_{PA}. The rate calculated by *Sears et al.* [1981] using electron energy spectrum, based on the measurement of *Pfitzer and Winkler* [1968], is represented by q_{PS}. The ion production rate calculated by using the electron energy spectrum measured by *Gledhill and Hoffman* [1981] from AE-C satellite passes in Brazilian anomaly is represented by q_{PG}. The residual ion production rate during the totality of the eclipse considered by *Sears et al.* [1981] and *Abdu et al.* [1979] are represented by q_{RS} and q_{RA}, respectively. Ion production rates due to scattered ultraviolet radiation representative of night conditions calculated by *Ogawa and Tohmatsu* [1966] are represented by $q_{L\alpha}$ and $q_{L\beta}$.

the vicinity of 100 km. Such differences in the height distribution could probably be caused by the following factors. The electron flux and energy spectrum of the precipitating electron could be variable with time. It could depend upon factors like magnetic activity and atmospheric pressure fluctuations and therefore upon the time, relative to magnetic activity variation, during which measurements were taken. For example, we have observed significant enhancements in the ionization of the lower ionosphere in the form of nighttime VLF phase advances and blanketing and a-type sporadic *E* layer enhancements, with varying intensity associated with variations in the magnetic activity [*Abdu et al.*, 1981; *Batista and Abdu*, 1977]. The epoch of the November 1966 eclipse was not particularly disturbed magnetically. However, the sunspot number in November 1966 (R_z = 56) was significantly higher than it was during March 1976 ($R_z = 23$), when the electron spectra of *Gledhill and Hoffman* [1981] was measured. If we invoke a power law spectrum to explain the q_{PA} profile, its power γ will be of the order of 4, whereas an exponential spectrum will have an e-folding energy of around 5 keV.

In conclusion, we would like to point out that the ion production rate due to precipitating electrons that appears to be a relatively significiant source in the lower ionosphere over the Brazilian region of the south Atlantic anomaly, even under "quiet" conditions, is unlikely to be represented by its height profile calculated by *Sears et al.* [1981] in the height range 92–108 km. It seems to be at least 2–3 orders of magnitude higher and probably lies between the values obtained from the electron energy spectrum measured by *Gledhill and Hoffman* [1981] and those deduced from ion density measurements by *Abdu et al.* [1979].

References

Abdu, M. A., I. S. Batista, and J. H. A. Sobral, Particle ionization rates from total solar eclipse rocket ion composition results in the south Atlantic geomagnetic anomaly, *J. Geophys. Res.*, *84*, 4328–4334, 1979.

Abdu, M. A., I. S. Batista, L. R. Piazza, and O. Massambani, Magnetic storm associated particle precipitation in the south Atlantic anomaly: Evidence from VLF phase measurements, *J. Geophys. Res. 86*, 7533–7542, 1981.

Batista, I. S., and M. A. Abdu, Magnetic storm associated delayed sporadic E enhancements in the Brazilian geomagnetic anomaly, *J. Geophys. Res.*, *82*, 4777–4783, 1977.

Gledhill, J. A., and R. A. Hoffman, Nighttime observations of 0.2–25 keV electrons in the south Atlantic anomaly made by Atmospheric Explorer-C, *J. Geophys. Res.*, *86*, 6739–6744, 1981.

Lyons, L. R., and A. D. Richmond, Low-latitude *E* region ionization by energetic ring current particles, *J. Geophys. Res.*, *83*, 2201, 1978.

Mechtly, E. A., K. Seino, and L. G. Smith, Lower ionosphere electron densities measured during the solar eclipse of November 12, 1966, *Radio Sci.*, *4*, 371–375, 1969.

Mizera, P. F., and J. B. Blake, Observations of ring current protons at low latitude, *J. Geophys. Res.*, *78*, 1058, 1973.

Narcisi, R. S., A. D. Bailey, L. E. Wlodyka, and C. R. Philbrick, Ion composition measurements in the lower ionosphere during the November 1966 and March 1970 solar eclipse, *J. Atmos. Terr. Phys.*, *34*, 647–658, 1972.

Ogawa, T., and T. Tohmatsu, Photoelectronic processes in the upper atmosphere, II, The hydrogen and helium ultraviolet glow as an origin of the nighttime ionosphere, *Rep. Ionos. Space Res. Jpn.*, *20*, 395–417, 1966.

Pfitzer, K. A., and J. R. Winkler, Experimental observation of a large addition to the electron inner radiation belt after solar flare event, *J. Geophys. Res. 73*, 5899–5797, 1968.

Rees, M. H., Auroral ionization and excitation by incident energetic electrons, *Planet. Space Sci.*, *11*, 1209–1218, 1963.

Sears, R. D., M. G. Heaps, and F. E. Niles, Modeling the ion chemistry of the *D* region: A case study based upon the 1966 total eclipse, *J. Geophys. Res.*, *86*, 10,073–10,086, 1981.

Tinsley, B. A., Evidence that the recovery phase ring current consists of helium ions, *J. Geophys. Res.*, *81*, 6193, 1976.

Ulwick, J. C., Eclipse rocket measurements of charged particle concentration, *J. Atmos. Terr. Phys.*, *34*, 659–665, 1972.

M. A. Abdu, I. S. Batista, and J. H. A. Sobral, Instituto de Pesquisas Espaciais-INPE, Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq, 12200 São José dos Campos, São Paulo, Brazil.

(Received December 6, 1982;
accepted November 7, 1983.)