X-621-71-325
PREPRINT

NASA TM X- 65680

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AUGUST 1971

GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

The mechanisms for producing a subauroral red arc (SARARC) are studied by solving a system of basic ionospheric and atmospheric equations. It is shown that many of the observed features of a SARARC can be explained within the framework of the two processes generally responsible for the ionospheric behavior during a magnetic storm: These are (1) energy conduction from the magnetosphere to the ionosphere and (2) the changes in neutral composition of the lower atmosphere caused by the increase in turbulent mixing. Both the processes trigger a complex chain of events which ultimately results in the redistribution of both the charged and neutral particles, an increase in the electron, ion, and neutral temperatures, and a decrease in the electron density in the altitude region near the F-2 peak. It is shown that both the occurence and the emission intensity of a SARARC are regulated by the neutral atmosphere, eventhough conduction of the thermal energy from the magnetosphere to the ionosphere provides the excitation energy for the optical emission. Recent satellite measurements of the ionospheric parameters have confirmed the validity of these findings and have provided grounds for rejecting several other theories which have been proposed in the literature.

THE UPPER ATMOSPHERE AS A REGULATOR OF SUBAURORAL REDARCS

INTRODUCTION

The morphological aspects of a subauroral red arc have been extensively studied over more than a decade since its discovery by Barbier in 1957. (See NAGY et al. 1970 for detailed references).

A SARARC event which is usually identified by an enhanced emission in the forbidden line of atomic oxygen OI (^1D -^3P) at 6300 Å is essentially a midlatitude or more appropriately a subauroral phenomenon. It is distinguishable from a normal auroral airglow in its characteristic enhancement in the intensity of the red line of atomic oxygen in the range of several hundred rayleighs without any noticable increase in the green (5577Å) or the other spectral lines which are characteristics of the auroral airglow. Since the excitation energy for OI (^1D) and OI (^1S) which give rise to the red and the green line emissions are respectively 1.96eV and 4.17 eV, the absence of green line emission during a SARARC event implies that some low energy source is responsible for the formation of an arc. This spectral characteristic of a SARARC has led to the formulation of several theories which postulate thermal electron excitation as the basic mechanism for producing a SARARC event. (Walker and Rees, 1968). Thus the electric field hypothesis proposed by Megil et al. (1963), the precipitating flux of low energy electrons proposed by Dalgarno (1964) and the thermal conduction hypothesis proposed by Cole (1965) have all attempted to provide a mechanism for heating the ionospheric plasma to sufficiently high temperatures. Recent measurements of a number of relevant ionospheric parameters during SARARC events have, however, given support to the concept of thermal conduction of energy from the magnetosphere along the geomagnetic field lines as means of heating the ionospheric electrons (Norton and Findlay, 1969; Roble et al. 1970, Chandra et al. 1971).

One of the basic problems in accepting the thermal conduction as the mechanism for explaining a SARARC event is its inadequacy in explaining the absence of SARARC during certain geomagnetic storms. SARARC events are known to occur during geomagnetic storms. All the magnetic storms are, however, not known to be associated with SARARCS. There is also some question about the correlation between the intensity of OI 6300 and the geomagnetic indices related to a SARARC event. Roach and Roach (1963) and Truttse (1968) found a functional relation between OI 6300 and the geomagnetic intensity. Hoch and Clark (1970) do not find any such relation using the data of recent years. Since the thermal conduction should provide energy to the ionospheric plasma in any magnetic storm, it is clear that the appearance of a SARARC depends on some additional factors. Chandra et al. (1971) have drawn attention to the fact that the changes in electron density distribution and ion composition during the SARARC event of September 28-29, 1967, were not substantially different from those observed during a magnetic storm unaccompanied by a SARARC event. Many of the observed features of the midlatitude ionosphere during a magnetic storm can be explained in terms of the changes in the neutral composition in the lower atmosphere (Chandra and Herman , 1969 ; Chandra and Stubbe , 1971). Thus, it seems reasonable to assume the two processes, i.e. the thermal conduction and the neutral composition changes in the lower atmosphere, as complementary for describing the ionospheric behavior during a SARARC event.

The purpose of this paper is to show that for a given ionospheric condition, the formation of a SARARC depends on some critical flux of energy flowing from the magnetosphere. This critical flux is greatly influenced by the changes in $[O] / [N_2]$ in the lower atmosphere. In other words the lower atmosphere regulates the critical level of the flux responsible for the formation of a SARARC.

FUNDAMENTAL EQUATIONS AND ASSUMPTIONS

The theory of airglow emissions has been extensively discussed in the literature. Since the emission of OI 6300 results from the following transition:

$$O(^1D) \longrightarrow O(^3P) + h\nu \ (6300\ A)$$

the volume emission rate of OI λ 6300 depends upon the rate of production of $O(^1D)$ The main sources of $O(^1D)$ in the upper atmosphere are (i) the dissociative recombination of O_1^+ and NO^+ with electrons and (ii) the excitation of atomic oxygen by thermal and suprathermal electrons. In calculating the volume emission rate of 6300 Å for the subauroral region we may neglect any contribution from the suprathermal electron excitation. As was shown by Chandra et al. (1971), there was no substantial increase in the flux of such particles during the SARARC event of September 28-29,

1967. In addition, we may neglect any contribution from the reaction involving NO^+ because of the spin constraints (Dalgarno and Walker 1964). Assuming, then, that the atoms in ^1D State in addition to being depopulated by spontaneous transition are also deactivated by collision with molecular nitrogen, the volume emission rate of OI 6300 is given by (Peterson et al, 1966; Rees et al, 1967; Forbes, 1970)

$$I(6300) = \frac{A(6300)}{A_d + S_d\ (N_2)\ [N_2]} \left\{ K_D \alpha_r [O_2] + \alpha_t\ [O] \right\} N_e$$

photons cm^{-2} sec^{-1}

where A(6300) and A are the Einstein coefficients with their values equal to .0069 and .0091 per sec. respectively.

$S_d(N_2)$ = rate coefficient for quenching by N_2. Its value is taken to be 7×10^{-11} cm^3 sec^{-1}

K_D = number of excitation per dissociative recombination and includes the contribution of the cascading transition $^1S - {}^1D$. Its value is taken to to be 0.5.

α_t = rate coefficient for the reaction $O_2^+ + e$. It is taken to be equal to $7 \times 10^{-8}\ \frac{1000}{T_e}$ cm^{-3} sec^{-1} with T_e as electron temperature.

α_t = rate coefficient for collisional excitation. The expression for α_t as given by Rees et al. (1967) is as follows:

$$= 5.45 \times 10^{-11}\ T_e^{1/2}\ \exp(\ 2.27 \times 10^4 / T_e) \{\ 0.406 + 0.357 \times 10^{-4}\ T_e - (0.333 + 0.183 \times 10^{-4}\ T_e) \times \exp(-1.37 \times 10^4 / T_e) - (0.456 + 0.174 \times 10^{-4}\ T_e) \times \exp(-2.97 \times 10^4 / T_e) \}\ cm^{-3}\ sec^{-1}$$

It is obvious that in addition to the knowledge of the rate coefficients it is necessary to know the altitude profiles for $[O_2^+]$, $[NO^+]$, N_e, $[O]$ and $[N_2]$. Some of the rate coefficients, particularly α_r and α_t, are functions of electron temperature, and additional information for the altitude profile for T_e is needed, before I 6300 can be calculated.

In calculating the red line intensity for SARARC conditions, it is customary to combine the experimentally deduced profiles of electron density with the model atmosphere of the neutral constituents and use them in conjunction with the solutions of the heat-conduction equation for T_e. (Walker and Rees 1968, Roble et al. 1970). Such an approach was necessary since the experimental data for the relevant parameters were not available during magnetic and SARARC conditions. From the theoretical viewpoint, having to choose the conventional atmospheric models presents a choice which is less than satisfactory. During magnetic disturbances the neutral atmosphere undergoes changes which not only result in the increase of the neutral temperature but in the change of relative composition in the mesosphere and lower thermosphere. Because of the complex interaction between the neutral atmosphere and the ionosphere it is difficult to choose self-consistent models of the numerous interacting parameters which could describe a given situation satisfactorily. Keeping these difficulties in view, Chandra and Herman (1969) and Chandra and Stubbe (1971) developed self-consistent models for magnetic storms which were based on the simultaneous solutions of a number of coupled differential equations involving the relevant ionospheric and atmospheric parameters. Their results showed that changes in composition and temperatures during a magnetic storm in the thermospheric region can largely be explained in terms of the changes in the neutral composition in the lower atmosphere. A rather significant conclusion of these papers was the fact that the observed increase in the exospheric temperatures in the mid and high latitudes during a magnetic storm may very well result from the decrease in $[O] / [N_2]$ in the altitude range of 120 km. This is because the main sink for the neutral gas heat loss is the atomic oxygen which loses thermal energy via infrared radiation (Bates, 1951). Thus, in order to explain the increase in exospheric temperatures during a magnetic storm, it is not necessary to transport energy to the F-region altitudes but only to provide a mechanism which could alter the turbopause level so as to decrease the atomic oxygen concentration. The energy, of course, will have to be dissipated at the mesospheric height in order to bring about these changes. We shall postpone the detailed discussion of this concept for the later part of this paper and only make use of this concept for the purpose of developing theoretical models for magnetic storm and SARARC events. It is, however, important to note that the recent measurements of the neutral composition and temperature during the magnetic storm of September 30, 1970 (Taeusch et al., 1971) are entirely consistent with the concept of a decrease of $[O]/ [N_2]$ in the lower thermosphere.

In order to determine airglow intensity for specified condition of the neutral atmosphere and specified values of thermal flux fron the magnetosphere, we must solve the basic system of ionospheric and atmospheric equations. These are time dependent coupled differential equations outlined in the following:

1. Equations of continuity for O^+, O_2^+, NO^+, and H^+.
2. Heat conduction equations for O^+, H^+, electron and neutral gas.
3. Equations of motion of the various ionic and neutral constituents.

These equations are described in detail by Stubbe (1970) and are solved simultaneously in conjunction with the dynamic diffusion models of the neutral atmosphere as described by Chandra and Stubbe (1971). In solving the energy balance equations, we have included, in addition to the fine structure cooling of atomic oxygen, (Dalgarno and Deggs, 1968; Herman and Chandra, 1969), the effects of neutral wind heating as discussed by Stubbe and Chandra (1971) and also the inelastic cooling arising from the vibrational excitation of O_2 and N_2 and the excitation of atomic oxygen to ^1D caused by thermal electrons, (Lane and Dalgarno, 1969; Dalgarno, 1969; and Stubbe, 1970). These terms are generally very small compared to the fine structure cooling of atomic oxygen. Their contributions, however, become quite significant and even larger at temperatures exceeding 3000° K.

The system of coupled equations described here has been solved for a subauroral latitude (42° geographic, magnetic dip 72°) representing a medium solar activity. The solutions have been obtained for a wide range of conditions with the heat flow varying from 0 to 10^{11} eV/cm^2 - sec and $\frac{[O]}{[O_2] + [N_2]}$ at 120 km varying over a factor of three. Such an extensive study made it necessary to exclude the energy balance equations for the neutral gas from the system of equations outlined in the preceding and instead to use an empirical model for the neutral temperature. This was a practical approach to saving several hours of computational time. The empirical model for the neutral temperature is similar to that given by Jacchia (1965), the only difference being in the diurnal amplitude and the time of maximum of the exospheric temperature which is taken to be 1.4 and 17 hours local time, respectively. This modified version of Jacchia's temperature model is used in conjuction with the dynamic diffusion model of Chandra and Stubbe (1970) which assume both the temperature and the neutral density at the lower boundary to vary with time.

The neutral constituents of the atmosphere are assumed to be O_2, N_2, O, He and H all in diffusive equilibrium. Their values, however, are specified at different levels. The values of [H] and [He] are specified at 500 km. and their temperature dependences are assumed to be of the forms given respectively by Kockarts and Nicolet (1962, 1963) and Keating et al (1970). The estimates of [H] at 500 km are, however, taken to be about 8 times higher than those given by Kockarts and Nicolet in accordance with the recent estimates of the neutral hydrogen.

The values of [O], $[O_2]$ and $[N_2]$ are specified at 120 km. Their time variations are assumed to be of the form $(1 + a \cos \omega t)$ where a is the amplitude factor, ω the earth's angular frequency and t the local time measured from noon. Unless otherwise specified 'a' has been assumed to be 0.3 throughout this paper. The temperature variation at the lower boundary (120 km) has been assumed to be of the form $T_m = 355 (1 + 0.1 \cos \omega t)$ in all the cases.

The values of $[O]$, $[O_2]$, $[N_2]$ at 120 km and 18 hours local time (this corresponds to the mean daily values) have been changed over a wide range to simulate the conditions of both the quiet and disturbed ionosphere. For a specified change in $\frac{[O]}{[O_2] + [N_2]}$, the exospheric temperature was appropriately changed in accordance with the theoretical calculations of Chandra and Stubbe (1970).

Results of Numerical Solutions

Figure 1 shows the night time variations in electron temperature at 300 km and the total emission rate of OI 6300 as a result of a constant energy flow from the magnetosphere to the ionosphere at 1500 km. In the absence of any heat flow (F=0) the electron temperature rises slowly from an initial value of about 1350°K at 2000 hours to about 1400°K at 0000 hours and then drops to about 1250°K at 0300 hours. During the same time interval the neutral temperature (not shown in the figure) dropped continuously from about 1300°K at 2000 hours to about 1100°K at 0300 hours. The fact that the electron temperature does not become equal to the neutral temperature even at 0300 hours is because of the heat source provided by the neutral wind to the ambient plasma (Stubbe and Chandra 1971). The contribution to OI 6300 emission rate in the absence of any heat flow comes almost entirely from the dissociative recombination of O_2^+ with the ambient electrons. Thus the time variation of the integrated intensity of OI 6300 essentially reflects the variation of electron density in the altitude range of 250-300 km. which roughly corresponds to the altitude range of the peak emission. With the increasing values of flux, the electron temperature rises and the contribution to the airglow intensity from the thermal excitation becomes increasingly large. For the energy flux greater than 10 eV/cm^2 - sec the emission intensity of OI 6300 is almost entirely controlled by the electron excitation of atomic oxygen.

The rapid rise of electron temperature between 20-23 hours is indicative of the fact that the rate at which the energy is being pumped into the ionosphere is much larger than the rate at which the electrons can loose their energy to the ambient medium. The rate of energy loss of the electron gas increases with electron and neutral densities as well as with electron temperature. Thus the electron temperature increases until the equilibrium is reached. With the increase of electron temperature, the contribution to the emission rate of the red line is almost entirely from the electron thermal excitation process and hence the intensity follows almost entirely the electron temperature variations.

Fig. 1 provides a good example of how a stable arc can be maintained throughout the night if the energy flow from the magnetosphere can be maintained at a constant rate. In this example, we chose to keep the flux constant with time since very little is known about its temporal variations during a SARARC event. We have investigated the effect of varying energy flux with time and also the effect of turning on and off the incoming flux for specific times. In all the cases, the electron temperature and airglow intensity followed very closely the time variation of the incoming flux.

From the example presented in Fig. 1, it is quite apparent that the heat flow from the magnetosphere can raise the F-region electron temperature to well above 2000° K in the night time and that this is in turn can produce an intense emission of the red line in the range of several hundred rayleighs. The normal emission rate for the red line is about 20 rayleighs in the night time which is almost entirely due to dissociative recombination of O_2^+. Thus any significant increase over this background emission can directly be attributed to the heat flow from the magnetosphere and can be characterized as a SARARC event. The lower limit of this emission rate is a matter of arbitrary choice. Within the framework of this definition, most of the magnetic storm events would also be characterized as SARARC events since there is always some flow of energy from the magnetosphere to the ionosphere during a magnetic storm and, except for the very intense emission of several hundred rayleighs which require a large amount of energy, a SARARC event should not be so uncommon.

In presenting the numerical examples in Fig. 1 we only considered the effect of changing the heat flux at the upper boundary. All the other parameters, including the neutral composition at the lower boundary were exactly the same for the entire range of flux values. In Figs. 2-a and 2-b, we consider the effect of changes in the neutral composition at the lower boundary. Figure 2-a shows the altitude profile at midnight for O^+ and H^+ for the three cases labeled as A, B and C. Cases A and B are exactly the same except for their heat values at the upper boundary. These are 0 and 10^{10} eV/cm^2-sec respectively. Cases B and C are similar with respect to their flux values at the upper boundary but differ with respect to their neutral composition and the exospheric temperature. Comparing the various parameters in Figs. 2-a and 2-b for cases A, B and C, it follows that during the night both the heat flux from the magnetosphere and the decrease in $\frac{[O]}{[O_2]+[N_2]}$ have similar effects on electron temperature and electron density in the region of the F_2 maximum. In both the cases, $[O^+]$ decreased near the F2 peak and the electron temperature increased throughout the ionosphere though for quite different reasons. Comparing the altitude profiles of the airglow and the integrated intensity for cases A, B and C, we note a transition from an emission given almost entirely by dissociative recombination to an emission given almost entirely by thermal impact excitation. Both the increase in the peak intensity and the peak height are characteristic of these transitions. Comparison of cases B and C are particularly important in our discussion. In both the cases the heat flux at the upper boundary is exactly the same yet the total emission rate for case C is 209 R compared to 57 R for case B. This increase in intensity of almost a factor of 4 is the result of only 30% decrease in $[O]/[O_2]+[N_2]$ at 120 km. Thus in a given situation even though there may be sufficient thermal energy to excite a moderate arc, the actual occurence of an arc may very much depend upon the extent of variation of the neutral composition in the lower atmosphere. This example clearly points out the importance of the atmosphere in regulating a SARARC event.

The numerical results presented in Figs. 2-a and 2-b compare very well with the optical and the ionospheric measurements during the SARARC event of Sept. 28-29, 1967. The emission intensity of 6300A during this event was only in the range of 150-200 R and therefore it was characterized as a weak arc. The importance of this event was, however, marked by the fact that a number of relevant ionospheric parameters were measured for the first time during a red arc period (Norton and Findley, 1969; Chandra et al., 1971). These parameters show the following changes in the region L=2.3 to 3.0 during an arc period as compared to their values during the normal periods: (1) Electron temperature at 900 km increased to above 4000°K from a normal value in the range of $1500-2000^{\circ}$K, and at 2000 km, it rose to above 5000 K from a normal value of about 2500°K. (2) At 900 km the ratio of heavier to lighter ions changed from 1 to 5 indicating a sharp change in the transition height (the height at which $[O^+] = [H^+]$ even though there was no significant change in the electron density at this altitude. (3) the electron density near the F2 peak decreased sharply during an arc event. Comparing these results with the numerical example presented in Fig. 2-a and 2-b, we may conclude that this event could very well have been caused by a heat flux of the order of 10^{10} eV/cm^2-sec. However, it is difficult to explain the ion composition results purely on the basis of the heat flux. We note from curves A, B and C of Fig. 2-a that a significant increase in the transition height can be brought about only through the changes in the neutral temperature and composition.

The series of events which take place in the ionospheric and atmospheric system caused either by the neutral composition changes or by the changes in the heat flux from above are very difficult to describe in a simple way. The cause and effects are so tightly coupled that it is often difficult to identify them separately. It is, however, possible to get some understanding from the following simple explanation. A decrease in atomic oxygen in the lower atmosphere has the effect of increasing the neutral temperature because atomic oxygen provides a heat sink for the neutral gas (Bates, 1951).

The increased neutral temperature has the net effect of causing redistribution of the neutral consitutents which results in the increase of $[O_2]$ and $[N_2]$ in the entire diffusive region of the atmosphere. In the case of atomic oxygen the dec[illegible]ase persists only in the altitude of about 300 km and below. The effect of increased temperature is to gradually reduce the difference with altitude. The net effect of increasing $[O_2]$ and $[N_2]$ is to increase the electron loss rate near the F2 peak causing a depletion of electrons in this region. The decrease in electron density decreases the heat capacity of the electron gas. Thus with a given heat flux at the upper boundary , a decrease $[O]/[O_2]+[N_2]$ helps to augment the electron temperature even more, consequently increasing the 6300A emission. This enhancement in the emission intensity can not increase indefinitely with the decrease in $[O]/[O_2]+[N_2]$ for the simple reason that emission caused by a thermal excitation of atomic oxygen is not only a function of electron temperature but also electron and atomic oxygen density (eqn. 1). A decrease in $\frac{[O]}{[O_2]+[N_2]}$ has a net effect of decreasing the electron density which in turn causes a decrease in the emission rate of the red line.

An Iso-intensity contour plot showing the effects of composition at the lower boundary and the heat flux at the upper boundary is shown in Fig. 3. It is seen in this presentation that for the lower flux values, (in the range of 10^{10} eV/cm^2-sec) the intensity increases with the decrease in $\frac{[O]}{[O_2]+[N_2]}$ and even causes a transition from a non-arc to an arc condition.

At high flux values the decrease in $[O]/[O_2]+[N_2]$, in fact, results in the decrease of the arc intensity. This is clearly understandable in the light of the discussion presented earlier. If we assume that the decrease in $[O] / [O_2] + [N_2]$ or the increase in the exospheric temperature shown in Fig. 3 is an index of a magnetic disturbance, it is clear from this illustration that the arc intensity may not be necessarily proportional to the strength of a magnetic disturbance. This explains the lack of correlation between the arc intensity and magnetic indices noted by Hoch and Clark (1970). In presenting the numerical results in fig. 1-3, we have assumed that the day to night variation in density at 120 km is the same both during the quiet and disturbed conditions. Since the actual variations in density over a period of a day have not been measured experimentally, such an assumption was considered to be reasonable. We have studied the effects of varying the diurnal phase and amplitude at 120 km over a wide range. These boundary changes produced changes in the rate of variations of all the ionospheric parameters including the airglow intensity. However, these changes were not in the nature of altering the basic conclusions of figures 1-3.

Concluding Remarks

Our main objective in this paper was to study the role of the neutral atmosphere in producing a SARARC event once the hot electrons reach the top of the ionosphere. The mechanism of transferring energy to the thermal electrons in the plasmasphere is not clearly understood partly because of the paucity of observational data on the energy spectrum. Cole (1965, 1970) who first proposed the concept of the magnetospheric thermal conduction suggested that the ring current protons which he assumed to be in the energy range of 1 kev can efficiently transfer their energy to the thermal electrons via collision. Cornwell et al. (1971) have argued that the energy available from the Coulomb interaction may not be sufficient to excite a SARARC of about 1 KR intensity. For a 100- γ Dst magnetic disturbance which typically gives rise to a SARARC of about 1 KR, the energy available from collision according to their estimate is about .03 ergs/cm^2 - sec (1.8 x 10^{10} ev/cm^2 sec). This they argue can produce a red arc of only 100 R intensity. A KR arc would require an additional energy of about .04 ergs/cm^2 - sec. Cornwell et al (1971) have suggested that the source of this additional energy may be the ion cyclotron waves which are generated as a result of the instability in the ring current during the recovery phase of a magnetic storm. The ion cyclotron waves thus generated loose their energy to the thermal electrons in the plasmasphere via Landau damping. From the numerical examples presented in this paper we have shown that allowing for the changes in the neutral composition during a magnetic storm a thermal energy of about .03 ergs is sufficient to produce an arc of 1 KR. Thus the energy consideration itself is not a sufficient reason for invoking the concept of ion cyclotron waves. Notwithstanding, ion cyclotron waves may be a real physical phenomena in their own right.

Summarizing the main points of this paper, we note that during a magnetic storm, the thermal energy is deposited in the various regions of the atmosphere. In the altitude region above 1000 km, this energy is primarily dissipated by thermal electrons which in turn transfer it to the low altitudes. In the altitude region of 100-120 km the main effect of energy dissipation is to change the circulation pattern and increase the turbulent mixing. This in turn causes a change in turbopause level and change in the relative concentration of the neutral constituents. Both the processes i.e. the energy dissipated in the top and the lower atmosphere, trigger a complex chain of events which ultimately result in the redistribution of both the charged and neutral particles, increase in electron and ion temperatures and decrease in electron density in the altitude region of the F2 - peak. The increase in the emission intensity of the red line over the normal night time emission is thus merely a consequence of heating thermal electrons to sufficiently high temperatures. Since the emission intensity is an exponential function of electron temperature, the transition from a relatively weak to bright emission is rather sharp once a certain threshold value of electron temperature is reached. From this viewpoint a SARARC does not signify a new physical process and can be explained within the framework of the processes normally affecting magnetic storms.

Acknowledgement

The work described in this paper was carried out at NASA-Goddard Space Flight Center and at the Max Planck Institut für Aeronomie and is published with the permission of the directors.

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FIGURE CAPTIONS

Fig 1 Night time variations of the electron temperature and 6300 Å emission as a function of incident energy at 1500 km. The number densities of O, O_2 and N_2 at 120 km corresponding to 1800 hours local time are respectively 8.00×10^{10}, 1.13×10^{11} and 6.00×10^{11} /cm^3.

Fig 2a Altitude profiles of $[O^+]$ and $[H^+]$ showing the effects of energy flow at 1500 km and neutral composition at 120 km

Fig 2b Altitude profiles of 6300 Å emission and electron temperature showing the effects of changes in energy flow at 1500 km and neutral composition at 120 km.

Fig 3 Iso-intensity contours of integrated 6300 Å emission as a function of heat flux at 1500 km and neutral composition at 120 km

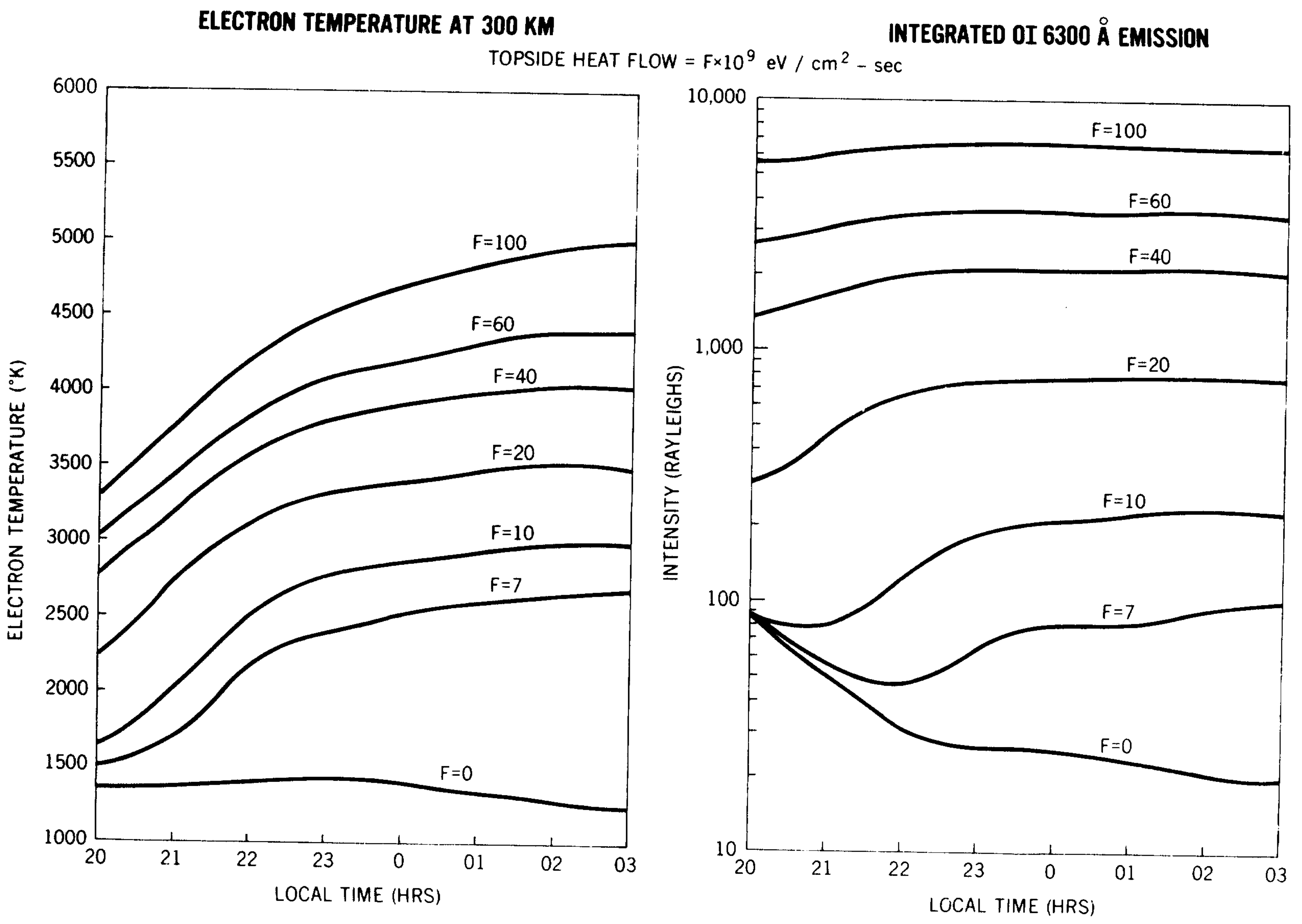
ELECTRON TEMPERATURE AT 300 KM
INTEGRATED OI 6300 Å EMISSION
TOPSIDE HEAT FLOW = F×10^9 eV / cm^2 - sec
ELECTRON TEMPERATURE (°K)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
F=100
F=60
F=40
F=20
F=10
F=7
F=0
20
21
22
23
0
01
02
03
LOCAL TIME (HRS)
INTENSITY (RAYLEIGHS)
10,000
1,000
100
10
F=100
F=60
F=40
F=20
F=10
F=7
F=0
LOCAL TIME (HRS)

Figure 1

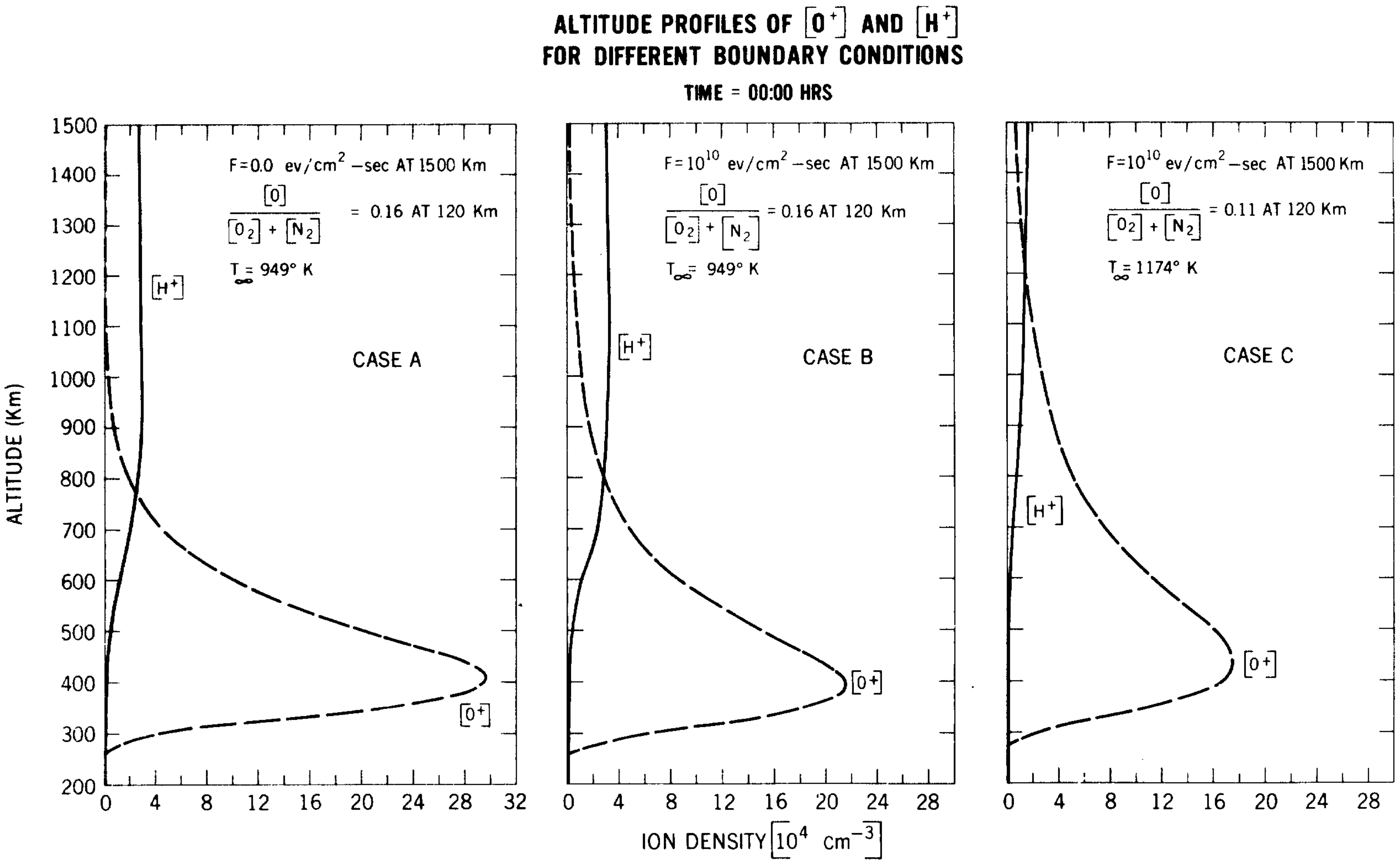
ALTITUDE PROFILES OF [O+] AND [H+]
FOR DIFFERENT BOUNDARY CONDITIONS
TIME = 00:00 HRS
ALTITUDE (Km)
F=0.0 ev/cm2 -sec AT 1500 Km
[O]/([O2]+[N2]) = 0.16 AT 120 Km
T∞ = 949° K
CASE A
F=10^10 ev/cm2 -sec AT 1500 Km
[O]/([O2]+[N2]) = 0.16 AT 120 Km
T∞ = 949° K
CASE B
F=10^10 ev/cm2 -sec AT 1500 Km
[O]/([O2]+[N2]) = 0.11 AT 120 Km
T∞ = 1174° K
CASE C
[H+]
[O+]
ION DENSITY [10^4 cm^-3]

Figure 2a

ALTITUDE PROFILES OF 6300 Å EMISSION AND ELECTRON TEMPERATURES FOR DIFFERENT BOUNDARY CONDITIONS

TIME = 00:00 HRS

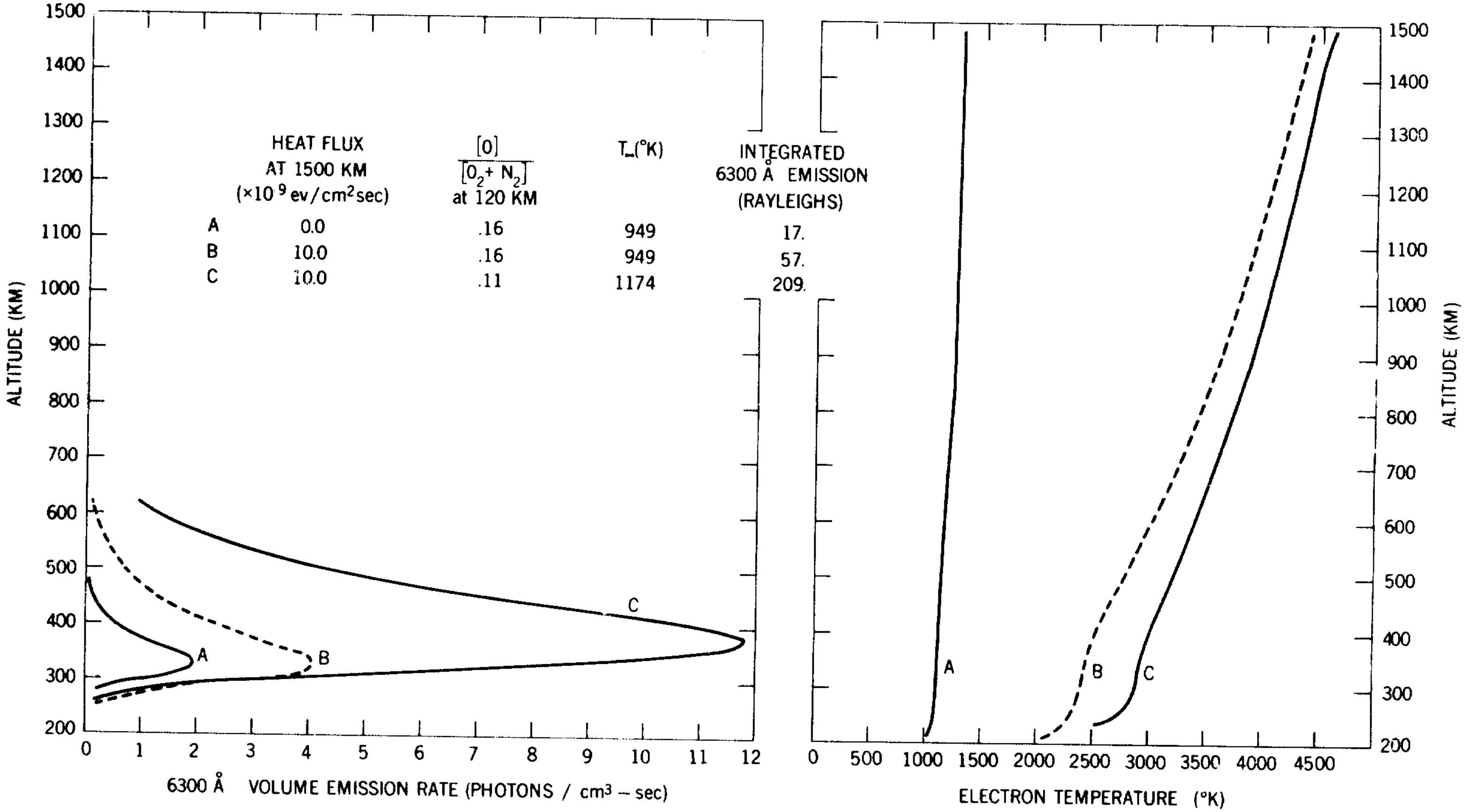

Figure 2b

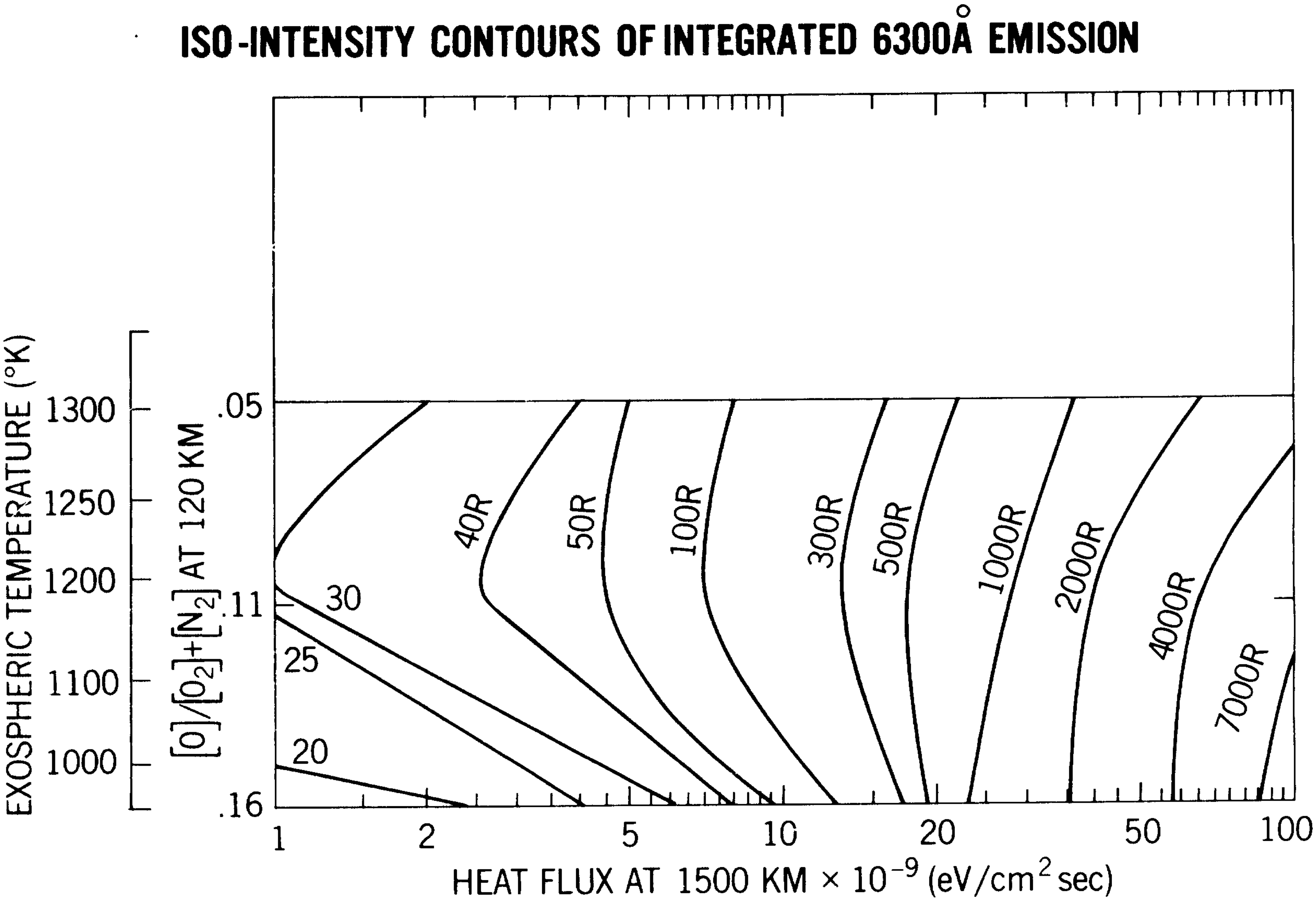
ISO-INTENSITY CONTOURS OF INTEGRATED 6300Å EMISSION
EXOSPHERIC TEMPERATURE (°K)
1300
1250
1200
1100
1000
[O]/[O2]+[N2] AT 120 KM
.05
.11
.16
40R
50R
100R
300R
500R
1000R
2000R
4000R
7000R
30
25
20
1
2
5
10
20
50
100
HEAT FLUX AT 1500 KM × 10^-9 (eV/cm^2 sec)

Figure 3