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Mesospheric ozone variation associated with the solar proton events of August and October 1989

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Abstract. The EISCAT radar measurements of N_e electron density during the proton events of 13 August and 23 October 1989 have been analyzed. It has been established that the form of sunset variation of the electron density observed during the two events is sufficiently different. The calculation of N_e variation has been carried out using the ion chemistry model and measured proton fluxes. The interpretation of the observed N_e variations has been made by comparing calculation and measurement results The conclusion has been made that at the mesospheric altitudes, the ozone concentration was much smaller in the event of 23 October 1989 than the one on the event of 23 October 1989.

1. Introduction

It is known that in the D region of the ionosphere, anomalously high ionization occurs as a result of the entrance of energetic protons into the Earth's atmosphere. The composition of the charged and neutral particles then changes very much. The ozone depletion during the solar proton events has been experimentally confirmed. Rocket measurements carried out during the initial and final phases of the solar proton event (SPE) on 2 November 1969 [*Week et al.*, 1972] discovered the decrease in ozone concentration in the 50–70 km altitude region. The ozone concentrations measured during the final phase of this SPE event appeared to be lower than those measured during the quiet conditions [*Llewellyn and Witt*, 1977]. The ozone concentrations measured during the initial phase of the 2 November 1969 event appeared to be sufficiently lower than those measured during the final phase of the event at all altitudes: twice at 54 km, three times at 60 km, and four times at 67 km. An ozone decrease was also observed during the proton events in January and September 1971 [*McPeters et al.*, 1981]. A large decrease of the ozone content between 30 and 55 km above the polar cap region took place after the very intensive solar proton event of 4 August 1972. This decrease was defined by the NIMBUS 4 satellite measurements of back-dispersed ultraviolet [*Hearth et al.*, 1977]. A considerable decrease in ozone concentration at 55–85 km during the SPE of 13 July 1982 was registered by infrared and ultraviolet spectrometers installed at a solar mesosphere satellite (SME) [*Thomas et al.*, 1983]. Temporal, altitudinal, and latitudinal ozone behavior was studied above the American continent. The ozone decrease connected to the energetic protons entrance began near the polar cap close to 60° geographical latitude (∼65° geomagnetic latitude) and increased upon approaching the terminator. A decrease of total ozone content in the polar cap regions was registered during the proton events in September and October 1989 and in May 1990, when high-energetic particles were registered by neutron monitors at the Earth's surface [*Kasatkina et al.*, 1998; *Shumilov et al.*, 1991]. The ozone concentration decrease during the proton event of October 1989 at altitudes higher than 35 km with the maximum $[O_3]$ decrease of 20%–25% at ∼50 km was observed by rocket measurements [*Zadorozhny et al.*, 1994]. The measurements were carried out on board the research vessel at latitudes 40°–60° S.

A number of theoretical investigations [*Crutzen and Solo-*

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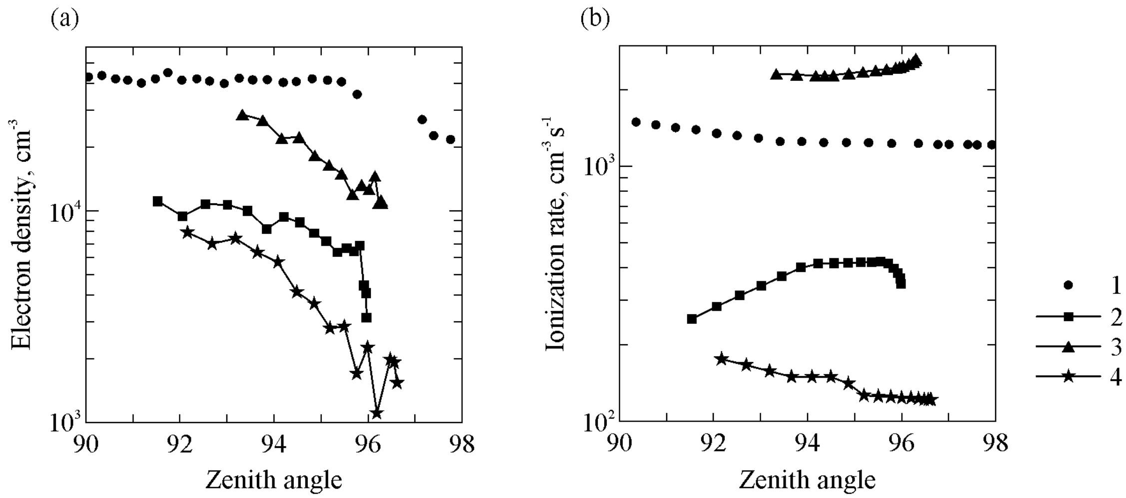

Figure 1. Electron density measured by the EISCAT radar at 70 km (a), and ionization rate calculated by proton fluxes (b) as a function of zenith angle: 23 October 1989 (1) and 12 August 1989 (2), 13 August 1989 (3) and 14 August 1989 (4).

mon, 1980; *Frederick*, 1976; *Solomon et al.*, 1981, 1983] contain an interpretation of the experimental fact of the ozone content variation connected to intensive cases of proton entrances. It is supposed that when the energetic particles enter the Earth's atmosphere, the role of catalytic reactions that destroy ozone is increased. The relative contribution of catalyzers of different types depends on an altitude: in the mesosphere, the odd hydrogen is a dominating catalyzer in the stratosphere — the odd nitrogen.

Here, the sunset variation of N_e electron density during the two proton events of 13 August and 23 October 1989 have been investigated by model calculations and EISCAT data. By comparing theoretical calculations and measurement data, the conclusion has been made that the ozone concentration decreased in the mesosphere between the two events.

2. Experimental Data

For the analysis, satellite data on solar protons fluxes with the energy 4.2–500 Mev [*Solar Geophysical Data*, 1989] and electron density measurement data obtained by EISCAT radar in the sunset period of the proton events of 12–14 August 1989 and 23 October 1989 have been used (see Table 1).

Figure 1a shows the results of EISCAT radar measurements of electron density (N_e) at 70 km as a function of zenith angle during sunset on 23 October 1989 and 12–14 August 1989. Figure 1b shows the variation of ionization rate (Q) calculated by proton fluxes.

One can see the distinct difference between the sunset variations of the electron density during proton events observed in August and October: when the zenith angle increases electron density decreases and at a considerably greater rate in the August event than in the October one. This difference is especially obvious during the second and third day of the first event (13 and 14 August): on these days, a well-defined decrease of N_e (triangles and asterisks accordingly) took place in the moments corresponding to the beginning of the observations (χ = 93.3° and 92° accordingly). On 23 October the electron density (circles) remained ~ constant till $\chi \simeq 96°$ and then an N_e decrease was observed. Unfortunately, we cannot point to the exact moment of the beginning of the decrease, as there is a data gap in the measurements. In this work, major attention has been paid to analysis of the N_e sunset variations observed on 13 August and 23 October 1989. To explain the different behavior of the electron density observed on 13 August 1989 and on 23 October 1989 in sunset and the greater N_e values measured in October than in August, the processes responsible for electron density occurrence have been analyzed and the calculations of electron density variations using the ion chemistry model have been carried out.

Table 1. List of Experiments

Date, 1989	Time, UT	Zenith angle χ, degree	Altitude, km
12 August	2005–2245	91.5–96.0	70.00–91.00
13 August	2035–2245	93.3–96.3	70.00–91.00
14 August	2005–2245	92.2–96.3	70.00–91.00
23 October	1340–1532	88.0–96.0	49.69–80.43
	1536–1542	96.3–96.8	70.00–113.05
	1547–1600	97.1–98.3	60.71–98.15

3. Modeling and Discussion

3.1. The Ion Chemistry Model and Input Parameters

In the work [*Petrova and Brunelli*, 1990], the full list of reactions that occur in the D region of the ionosphere was presented. Temperature dependence had been introduced into the coefficients of 16 inverse reactions. Later, the coefficients of some reactions were recalculated using the more precise values of ion bond energy. The Petrova and Kirkwood ion chemistry model of the ionospheric D region contains about 130 reactions with 19 positive and 17 negative ions.

Altitude profiles of temperature and basic atmospheric components at latitude 70°N used in the calculations were taken from the atmosphere model CIRA 1972. H_2O and CO_2 concentrations were adopted to equal $10^{-6}\times$ [M] and $3\times10^{-4}\times$ [M], accordingly, where [M] is the total density of the neutral atmosphere. Concentrations of atomic oxygen O and molecular oxygen in the exited state that depend on zenith angle were taken from the model by *Turco and Sechrist* [1972]. The profile of atomic hydrogen H was taken from the work by *Moreels et al.* [1977], and NO and NO_2 profiles were taken from the model by *Shimazaki and Laird* [1970].

Using the ion chemistry model by Petrova and Kirkwood, the calculations of vertical distributions of charged particles at 50–90 km were carried out. For this purpose, the system of 37 continuity equations was created for all types of charged particles accounted for in the model, including electrons. The system was solved concerning the concentration of each particle. In the present work, the results of calculations of the electron density sunset variation at 70 km during two proton events have been presented and compared to the EISCAT radar measurement data derived at the Swedish Institute of Space Physics in Kiruna.

3.2. Electron Sources

The main source of primary electrons during the proton events is the impact ionization of O_2 and N_2 atmospheric basic compounds by solar protons with energy in the range 1–500 Mev. Solar proton fluxes during the studied events were measured by the geostationary satellite at six energy channels: 4.2–8.7, 8.7–14.5, 15–44, 39–82, 84–200, and 110–500 MeV. [*Solar Geophysical Data*, 1989]. Using these proton fluxes, the differential spectra were reconstructed. Then profiles of the ion pair production rate $Q(h)$ were calculated using the method of *Petrova* [1977] and with the help of the neutral atmosphere CIRA 72 model. The energy at which the low-energy part of the proton fluxes is cut off by the Earth's geomagnetic field was considered to be 1.0 MeV. The calculated ionization rate (Q) at 70 km during two proton events as a function of zenith angle is shown in Figure 1b.

It can be seen that during the August event, the ionization rate change amounts to factor 10: the rate (Q) sharply increased at passing from the first day of this event to the second and dropped to the minimum values on the third day. The ionization rate underwent considerable variation with the zenith angle on the first and third days of the August event. On 13 August 1989 and on 23 October 1989 the ionization rate remained practically constant during the studied interval of zenith angles ($\chi = 93^\circ \div 97^\circ$) when simultaneous measurements of electron density were made. Comparison of Figure 1a and Figure 1b points to one more distinct fact: electron density values measured during sunset of 23 October 1989 were 1.5–3 times higher than those measured on 13 August 1989. At the same time, the ionization rate calculated by the proton fluxes was lower by 1.5 times in the October event than in the August one.

The well-defined electron density drop on 13 August 1989 (Figure 1a, triangles) took place at $\chi \le 93.3^\circ$, when the ionization rate (Figure 1b) was constant until $\chi = 94.5^\circ$, and then it began to increase slowly. The ionization rate on 23 October 1989 (Figure 1b) underwent a very slow decrease at $\chi \simeq 89^\circ - 93.5^\circ$ and was constant during the time of $\chi > 93.5^\circ - 98^\circ$. Thus, the electron density decrease that began during this event considerably later than on 13 August and exactly at $\chi = 96^\circ$ (Figure 1a, black circles) took place when the ionization rate was approximately constant.

So, one cannot explain the sunset variation of the electron density observed during the analyzed proton events by variation of the ionization rate: during the studied time period, the latter remained approximately constant. Also, one cannot explain the difference in values of electron density measured during the two events by the difference of ionization rate values: electron density measured on 23 October 1989 was higher than on 13 August 1989, but the ionization rate was lower in October.

Electrons forming proton impacts undergo a series of reactions that result in the formation of negative ions. Photodetachment of electrons from negative ions and photodissociation of the latter play an important role in electron density. To clear up whether light conditions had changed at the analyzed altitude in passing from one event to another, and if so, how, the altitude of the ozone layer shadow and the Earth as a function of a zenith angle on 13 August 1989 and 23 October 1989 in Tromsö (69.6°N and 19.2°E) has been calculated. The calculations showed that on 23 October 1989 the ozone layer shadow reached 70 km at $\chi \simeq 96.8^\circ$ and the Earth shadow at $\chi \simeq 98.3^\circ$. The well-defined N_e fall during this proton event began at $\chi \simeq 96^\circ$ (Figure 1a), when the analyzed 70-km altitude was illuminated by ultraviolet and visible light. On 13 August 1989 the zenith angle did not exceed $\chi = 96.3^\circ$ and the shadow of the Earth and the ozone layer did not rise above 38.6 km and 63.8 km, accordingly. Hence, on 13 August 1989 the 70 km altitude never appeared in the shadow of the ozone layer and the Earth and the sharp N_e electron density fall from $\chi = 93.3^\circ$ cannot be explained by cessation of photo-detachment processes. Thus, when the zenith angle remained in the interval of $93^\circ - 96.3^\circ$ during both proton events the 70-km altitude was illuminated by both visible and ultraviolet light. Hence, photo-processes cannot be responsible for the difference between the sunset variation of electron density during these two solar proton events.

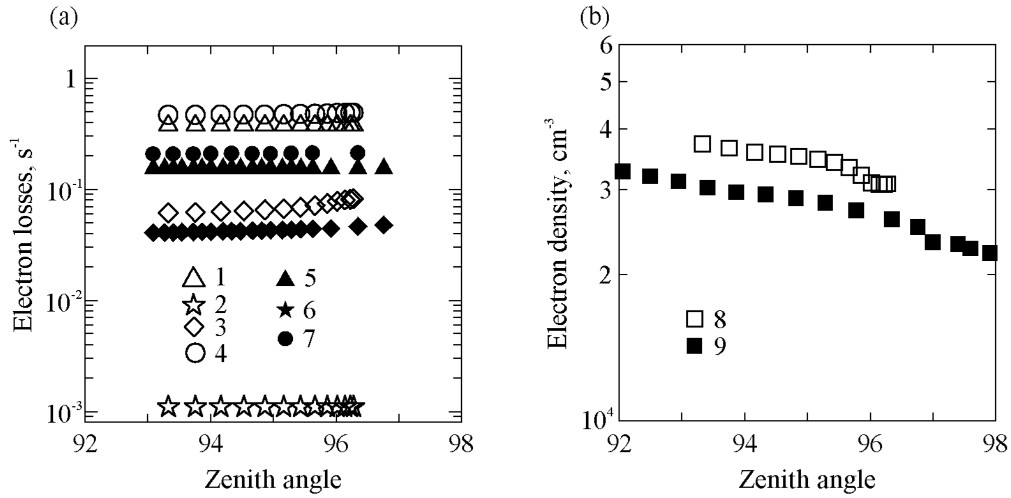

Figure 2. Comparison of electron loss rates (a) and electron density (b), computed at 70 km for the proton events of 13 August 1989 (white signs) and 23 October 1989 (black signs): 1–4, loss rates for the first event equal to $k_1 \times [O_2]^2$, $k_2 \times [O_3]$, $\sum \alpha_{di} \times N_i^+$, accordingly, and the total losses, 5–7, are the same for the second event; 8 and 9, electron density variation for the first and second event, accordingly.

So, neither proton fluxes and photo-processes can be responsible for the difference in value and behavior of the electron density observed during these two proton events. Thus, processes in which electrons are lost have to be investigated.

3.3. Electron Losses

Electrons formed as a result of impact ionization of the neutral atmosphere by energetic protons are lost in positive ion recombination and neutral atmosphere particle collision processes. Using the ion chemistry model by Petrova and Kirkwood, the rates of electron loss processes have been calculated. The main loss processes are:
three body attachment electron reaction with molecular oxygen

$$e + O_2 + O_2 \rightarrow O_2^- + O_2 \quad (1)$$

associative dissociation

$$e + O_3 \rightarrow O^- + O_2 \quad (2)$$

recombination with positive ions, the most numerous of which at 70-km altitude are clusters of $H^+(H_2O)_n$ type

$$e + H^+(H_2O)_n \rightarrow H + n\,(H_2O)$$

Figure 2a shows the rates of electron loss processes calculated for the events of 13 August 1989 and 23 October 1989. Figure 2b shows the calculated variation of N_e electron density. The calculations were carried out under the supposition that the ozone concentration was equal to 2.2×10^8 cm^{-3} [*Week et al.*, 1972] and did not change during the proton event and at passing from the first proton event to the second.

The loss rates for the August event are shown by white symbols; loss rates for the October event are indicated by black symbols. Triangles show losses in process (1) equal to $k_1 \times [O_2]^2$, asterisks show losses in process (2) equal to $k_2 \times [O_3]$. Losses in recombination equal to $\sum \alpha_{di} \times N_i^+$ are shown by rhombus, and total losses are shown by circles.

One can see (Figure 2a) that the process (1) electron losses are greatest in both events. Recombination losses (rhombs) are considerable as well, but they are of an order of magnitude lower than the losses in process (1). The losses in process (2) with the chosen ozone concentration are very small. Let us analyze more carefully all electron loss processes.

3.4. Electron Attachment to Neutrals

Figure 2a shows that the losses in process (1) and the total electron losses in the August event exceed the losses in the October event by approximately 2.5 times due to the higher density of the neutral atmosphere in August (1.12×10^{-3} kg m^{-3}) in comparison with October (7.20×10^{-4} kg m^{-3}). In spite of the higher total rate of loss in August, the calculated electron density for the 13 August 1989 event is higher than for 23 October 1989. This is demonstrated in Figure 2b. The relation between the electron density measured during the events is inverse (Figure 1a). Thus, a seasonal distinction of the neutral atmosphere density (smaller density and, accordingly, smaller losses in October compared to August) cannot explain the excess of electron density measured on 23 October 1989 over that of 13 August 1989.

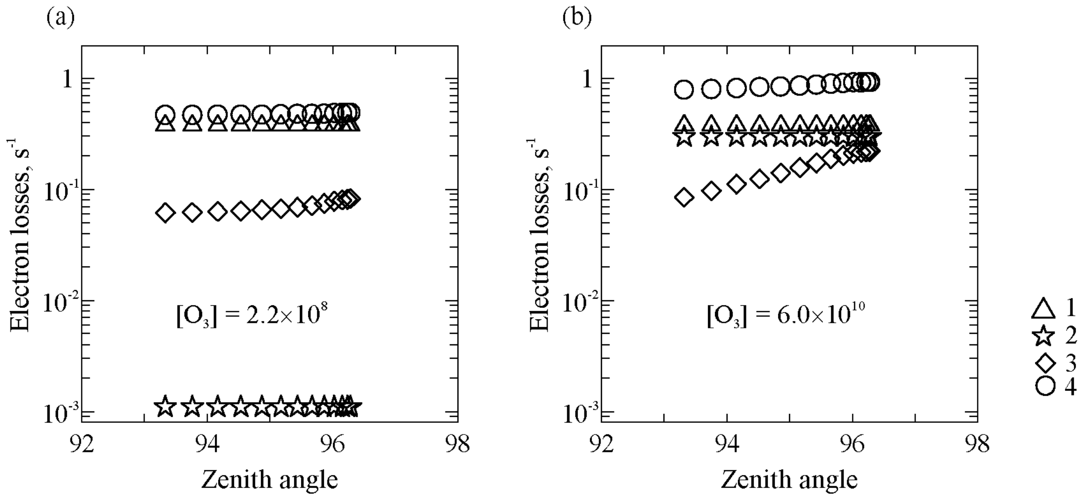

Figure 3. Rates of electron losses at 70 km during the 13 August 1989 event calculated for ozone density values equal to $[O_3] = 2.2 \times 10^8$ cm^{-3} (a) and $[O_3] = 6.0 \times 10^{10}$ cm^{-3} (b). Captions are the same as in Figure 2a.

3.5. Associative Dissociation

It is experimentally established that during some proton events, a reduction of the ozone concentration is observed. Hence, the rate of process with the participation of ozone (2) can change at passing from one proton event to another. To examine whether the change of ozone concentration influences electron density sunset variation, the rates of electron loss processes at 70 km for the event of 13 August 1989 have been calculated by two ozone values of $[O_3]$ equal to 2.2×10^8 cm^{-3} and 6.0×10^{10} cm^{-3}. The first value was measured of sunset on 4 November 1969, at the fall of the proton event that had begun on 2 November 1969 [*Week et al.*, 1972], and the second value was taken from the model [*Turco and Sechrist*, 1972] and is the largest theoretical value $[O_3]$ at 70 km. The results of calculations are shown in Figure 3. The loss rates of processes (1) and (2) are shown, accordingly, by triangles and asterisks. The rate of recombination is shown by rhombs and the total losses by circles.

One can see (Figure 3a) that for low density of ozone ($[O_3] = 2.2 \times 10^8$ cm^{-3}), the frequency of process (2) equal to $k_2 \times [O_3]$ is negligibly small. The most losses are those in process (1). The rate of this process ($k_1 \times [O_2]^2$) exceeds the rate of the recombination approximately by one order of magnitude. As the rate of basic loss process (1) does not vary with the zenith angle, the total loss variation is only small. For high density of ozone ($[O_3] = 6.0 \times 10^{10}$ cm^{-3}) (Figure 3b), the contribution of process (2) in electron loss becomes comparable with losses in process (1); therefore, total losses increase approximately twice. At high $[O_3]$, the variation of total losses becomes more noticeable than at low $[O_3]$, following the more significant variation of recombination losses.

On the basis of the analysis of loss process rates the supposition was made that the lack of N_e variation observed for a long time in the 23 October 1989 event (Figure 1a) is explained by low ozone concentration, and the quick N_e decrease with growth of the zenith angle that is observed in 13 August 1989 event is linked with high O_3 concentration. The calculations have confirmed this supposition.

Figure 4 shows the variation of the electron density calculated for 13 August 1989 (a) and 23 October 1989 (b) for four values of ozone: 5×10^7, 2.2×10^8, 10^9, and 6×10^{10} cm^{-3}. The first and the second values correspond to data observed in the sunset period of the initial phase and the fall of the proton event 2 November 1979, accordingly [*Week et al.*, 1972]. The third value is taken according to measurement high latitudes in quiet conditions [*Llewellyn and Witt*, 1977]. The fourth value taken from the model [*Turco and Sechrist*, 1972] represents the highest theoretical value and is referred to as $\chi = 98°$. The results of calculations are compared with the measured data.

Figure 4a, which represents the calculations for the 13 August 1989 event shows that the measured variation of electron density is satisfactorily described by the model calculation with the supposition of high ozone concentration, $[O_3] = 6 \times 10^{10}$ cm^{-3}. At smaller $[O_3]$ concentration, the form of the calculated sunset variation is sufficiently different from the measured one: $[O_3]$ decrease causes the growth of N_e electron density and of χ zenith angle, at which the electron density fall takes place: for $[O_3] = 10^9$ cm^{-3}, the sharp fall of N_e occurs at $\chi = 95°$; for $[O_3] = 2.2 \times 10^8$ cm^{-3} and 5×10^7 cm^{-3}, the electron density changes with the zenith angle very slowly. The electron density variation calculated for 13 August 1989 by low ozone concentrations is similar to the variation measured on 23 October 1989.

Figure 4b which presents calculations for the 23 October 1989 event shows that at high $[O_3] = 6.0 \times 10^{10}$ cm^{-3} concentration, electron density falls sharply at $\chi \geq 93°$, as on 13 August 1989 and that the measured electron density exceeds the calculated one by 1.5–4 times. The best consistency of the calculation with the experiment in the 23 October 1989 event is reached under the supposition of decreased

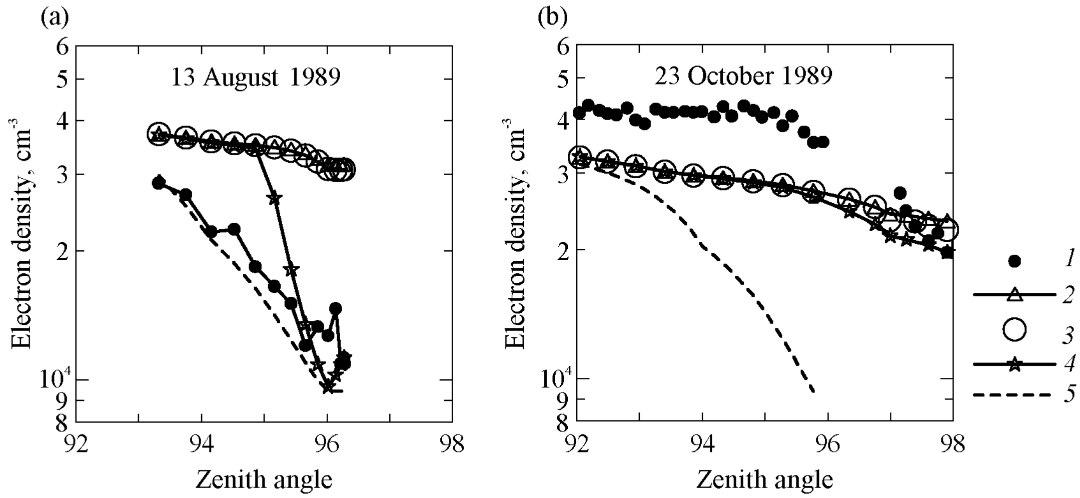

Figure 4. Measurements of electron density variation at 70 km (1) and calculations (2–5) carried out by four values of $[O_3]$ ozone concentration: 5.0×10^7 cm^{-3} (2), 2.2×10^8 cm^{-3} (3), 10^9 cm^{-3} (4), and 6.0×10^{10} cm^{-3} (5) during 13 August 1989 proton event (a) and 23 October 1989 proton event (b).

$[O_3] = 10^9$ cm^{-3} concentration. But the distinction between the measured and calculated variation remains: as has been said above, the measured electron density remains approximately at the same level in the interval $\chi = 93^\circ - 96^\circ$; at $\chi \simeq 96^\circ$, it falls very quickly. Calculated N_e is falling very slowly from $\chi = 93^\circ$. In this case, at $\chi < 96^\circ$, the measured N_e still exceeds the calculated one by ~1.3 times; at $\chi > 96^\circ$, the distinction is diminishing; at $\chi = 98^\circ$, it disappears completely. The decrease in ozone concentration from 10^9 cm^{-3} up to 2.2×10^8 cm^{-3} only slightly rises the calculated electron density N_e at $\chi \geq 96^\circ$. Further decrease of $[O_3]$ to 5.0×10^7 cm^{-3} does not solve the problem of consistency between the calculation and experiment: the electron density values calculated for two $[O_3]$ values that differ by 4.4 times (2.2×10^8 cm^{-3} and 5.0×10^7 cm^{-3}) coincide.

Comparison of Figures 4a and 4b allows us to conclude that:

- At high $[O_3]$ ozone concentration, the reduction of the electron density N_e begins at a smaller zenith angle than it does at low $[O_3]$, and it occurs quicker;
- Measurement of electron density variation during the 13 August 1989 proton event is satisfactorily described by the model calculation with the ozone concentration equal to $[O_3] = 6.0 \times 10^{10}$ cm^{-3}; during the 23 October 1989 proton event better agreement between the experiment and the calculation takes place at $[O_3] \leq 10^9$ cm^{-3}. We can say that during the 13 August 1989 event the ozone concentration was considerably higher than during the 23 October 1989 event.

The last conclusion agrees with the results of a theoretical estimation of ozone content made in October 1989 [*Reid et al.*, 1991]. By using the dynamic-chemical model and measured fluxes of 1–100 MeV protons, the calculations of NO, O_3 concentration, and T temperature at 75°S were carried out for 12 August–6 December 1989. The conclusion has been made that at the end of October 1989, we should expect a decrease in the ozone content with a maximum of 20% near 40–45 km. The ozone concentration decrease in October 1989 was observed by rocket measurements $[O_3]$ [*Zadorozhny et al.*, 1994] at altitudes greater than 35 km with a maximum decrease of 20–25% at ~50 km.

However, in the case of 23 October 1989 at zenith angles $\chi < 96^\circ$, the calculation gives values of N_e that are underestimated by approximately by 1.3 times as compared with the measured values. To explain this distinction, the role of recombination of electrons and positive ions has been studied.

3.6. Recombination

As Figure 3 shows, the important process for electron loss is recombination with positive ions, which at 70 km are mainly proton hydrates $H^+(H_2O)_n$. The concentration of these ions depends on the temperature to a large extent, as the cluster decay rate contains a temperature factor as an exponent $\exp(-D/T)$ where D is the bond energy of the ion-cluster: the higher T, the greater the rate of cluster decay and the lower their concentration. And as ions of this type have a higher recombination coefficient compared to primary ions NO^+ and O_2^+, the temperature increase should lead to a decrease of electron loss in recombination and growth in electron density.

There was a temptation to explain the experimental fact of electron density excess N_e measured on 23 October 1989 over N_e measured on 13 August 1989 by a seasonal difference in temperature T. This difference exists, but only at mesopause altitudes, which means that in winter, T is higher than in summer. This leads to higher values of electron den-

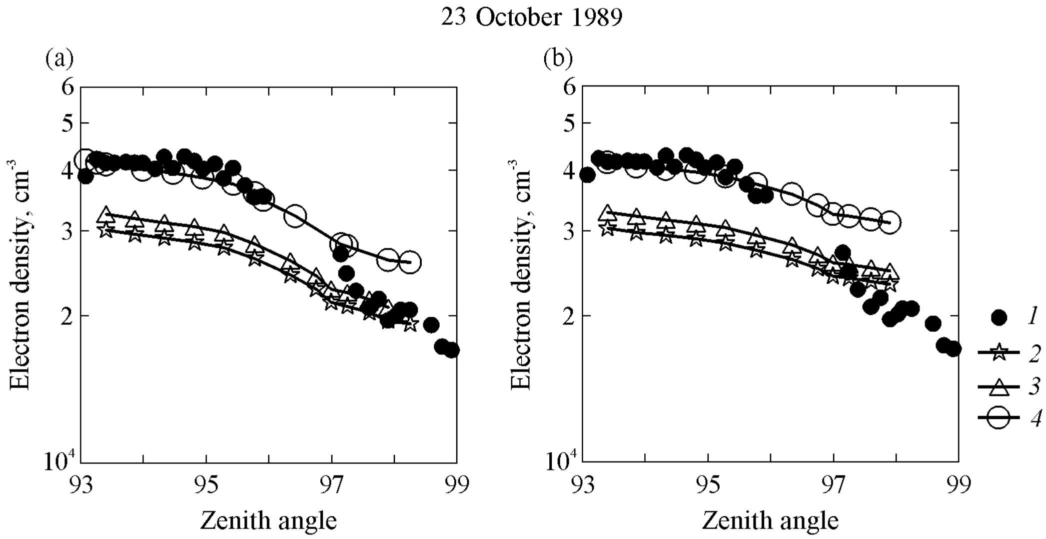

Figure 5. Comparison of electron density variation measured on 23 October 1989 (1), with calculated one (2–4) for two values of ozone concentration equal to 10^9 cm^{-3} (a) and 5×10^7 cm^{-3} (b) for three temperature values: 219°K (2), 230°K (3) and 250°K (4).

sity in winter than in summer. However, at 70-km altitude, the temperature taken from the CIRA 72 atmosphere model and used for calculations was approximately the same in August and October and equals 221°K and 219°K, respectively.

The supposition has been made that during the 23 October 1989 proton event temperature rose in comparison whith that of the standard atmosphere. Considerable temperature growth in the disturbed atmosphere of high latitudes was established experimentally [*Faire and Murphy*, 1972] and is observed in the upper mesosphere at altitudes higher than ~68 km. The excess temperature measured during the November 1969 SPE at 70 km was equal to approximately 30°K over the standard.

Using the model calculations, the dependence of electron density on temperature has been investigated. Figure 5 shows calculations of electron density sunset variation on 23 October 1989 carried out for three values of temperature equal to 219°K, 230°K, and 250°K and for two values of ozone concentration equal to 10^9 cm^{-3} and 5×10^7 cm^{-3}. The calculation results have been compared with the measurement data presented as well.

Figure 5a shows that the measured variation coincides in the interval $\chi = 93° - 97°$ with the calculated one for $[O_3] = 10^9$ cm^{-3} and the temperature $T = 250°$K. At $\chi > 97°$, the calculated electron density exceeds the measured one and the conclusion can be made that the temperature growth was likely to be limited to the time interval corresponding to $\chi = 93° - 97°$. For $[O_3] = 5 \times 10^7$ cm^{-3}, the excellent agreement between the calculation for $T = 250°$K and the experiment takes place only at $\chi = 93° - 96°$.

So, the excess electron density values measured on 23 October 1989 over those measured on 13 August 1989 when the ionization rate in October was lower than in August can be explained under a supposition that in the 23 October 1989 event at mesospheric altitudes, considerable temperature growth took place at lower ozone concentration.

4. Conclusions

1. The analysis of EISCAT radar electron density measurements at 70 km in sunset (93.3°–96.6°) during two proton events observed on 13 August and 23 October 1989 has been carried out. It has been established that:

- The form of the sunset N_e variation during two events is sufficiently different: in the first event, the sharp fall of electron density is observed in the moment corresponding to the beginning of the observation ($\chi = 93.3°$); in the second event, N_e remains at the level of the day values until the moment $\sim 96°$, then it falls slowly;
- The electron density measured on 13 August 1989 is lower than N_e measured on 23 October 1989. At the same time, the ionization rate calculated by proton fluxes in the first event is higher than in the second one.

2. Using the ion chemistry model, the calculation of sunset N_e variation during two solar protons events has been carried out. The important role of ozone in the formation of electron density sunset variation has been shown. The conclusion has been made that at passing from the event of 13 August 1989 to the event of 23 October 1989 an ozone density decrease took place at mesosphere altitudes. This

conclusion agrees with the results of the theoretical estimations of other authors and rocket measurements of ozone concentration made in October 1989.

3. The excess of electron density values measured on 23 October 1989 over those measured on 13 August 1989 can be explained by the supposition that in the event of 23 October 1989 the temperature at mesospheric altitudes was considerable higher compared to the temperature from the standard atmosphere model.

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