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A self-consistent estimate of $O^+ + N_2$ – rate coefficient and total EUV solar flux with $\lambda < 1050$ Å using EISCAT observations

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Abstract. There are differences between existing models of solar EUV with $\lambda < 1050$ Å and between laboratory measurements of the $O^+ + N_2$ – reaction rate coefficient, both parameters being crucial for the F2-region modeling. Therefore, indirect aeronomic estimates of these parameters may be useful for qualifying the existing EUV models and the laboratory measured $O^+ + N_2$ – rate coefficient. A modified self-consistent method for daytime F2-region modeling developed by Mikhailov and Schlegel was applied to EISCAT observations (32 quiet summer and equinoctial days) to estimate the set of main aeronomic parameters. Three laboratory measured temperature dependencies for the $O^+ + N_2$ – rate coefficient were used in our calculations to find self-consistent factors both for this rate coefficient and for the solar EUV flux model from Nusinov. Independent of the rate coefficient used, the calculated values group around the temperature dependence recently measured by Hierl *et al.* in the 850–1400 K temperature range. Therefore, this rate coefficient may be considered as the most preferable and is recommended for aeronomic calculations. The calculated EUV flux shows a somewhat steeper dependence on solar activity than both, the Nusinov and the EUVAC models predict. In practice both EUV models may be recommended for the F2-region electron density calculations with the total EUV flux shifted by ±25% for the EUVAC and Nusinov models, correspondingly.

Key words: Ionosphere (ion chemistry and composition; ionosphere atmosphere interactions; modeling and forecasting)

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1 Introduction

The ionizing solar EUV flux with $\lambda < 1050$ Å and the main $O^+ + N_2$ – reaction rate coefficient in the F2 region together with the neutral composition are known to be crucial parameters for adequate modeling of the ionospheric F2 region. Unfortunately, there are serious discrepancies both between existing models of solar EUV and between different laboratory measurements of the $O^+ + N_2$ – rate coefficient. Therefore, aeronomic estimates of these parameters may be useful for qualifying the existing EUV models and laboratory measured $O^+ + N_2$ – rate coefficients.

The problems with modeling the solar EUV are discussed by Richards *et al.* (1994a and references therein). Due to the lack of measurements the fluxes in some spectral intervals of the EUVAC model (Richards *et al.*, 1994a) were chosen arbitrarily to a great extent. For instance, the fluxes in the reference spectrum F74113 were increased by a factor of 2 between 150 and 250 Å and even were tripled below 150 Å to improve the agreement between the calculated and measured photoelectron fluxes. Titheridge (1997) has proposed a factor of 4 in the EUVAC model for the radiation with $\lambda < 150$ Å to reconcile his model calculations with the E-region observations. Total EUV fluxes are also different in various models. For instance, a two-component EUV model by Nusinov (1992) widely used in our calculations gives a 50% larger total flux for radiations with $\lambda < 1050$ Å than in the EUVAC model (Richards *et al.*, 1994a).

The ion molecular $O^+ + N_2$ reaction is the main sink for O^+ ions and it controls the recombination rate in the ionospheric F2 region. This rate coefficient depends both on the temperature of the reacting species and the amount of vibrationally excited N_2 which varies with geophysical conditions (e.g., Pavlov, 1986; Ennis *et al.*, 1995; Pavlov *et al.*, 1999 and references therein). Such conditions are hard to reproduce in laboratory measurements, therefore, different temperature dependencies for this reaction rate coefficient can be found in literature. Measurements of this reaction rate by Albritton *et al.* (1977) in flow-drift tubes with helium buffer gas for $T_n = T_v = 300$ K and varying ion temperatures $300 \text{ K} \le T_i \le 6000$ K were used by St.-Maurice and Torr (1978) to derive the reaction rate depending on the effective temperature $T_{eff} = (m_i T_n + m_n T_i)/(m_n + m_i)$. The amount of vibrationally excited N_2 molecules is negligible at $T_v = 300$ K, therefore this rate coefficient does not take into account the effects of vibrational excitation. Similar flow-drift tube measurements but with argon buffer gas were provided by McFarland *et al.* (1973). Different rate constants obtained by these two groups are attributed to different buffer gases used in their measurements. The rate coefficient proposed by St.-Maurice and Torr (1978) widely used in aeronomic calculations provides the lowest values for this rate coefficient in the ionospheric temperature range. On the other hand the temperature dependence given by McFarland *et al.* (1973) is very steep. It was efficiently used in our calculations to mimic the increase of this reaction rate due to vibrationally excited N_2 at high solar activity (Mikhailov and Förster, 1997; Mikhailov and Foster, 1997; Mikhailov and Schlegel, 1998). Recent flowing afterglow measurements by Hierl *et al.* (1997) carried out at $T_n = T_i = T_v = 300$–1600 K confirmed the results by Schmeltekopf *et al.* (1968) and showed that the translation energy dependencies for the vibrationally excited species are the same as those for the species being at the ground level ($v = 0$). Effects of rotational excitations were shown to be unimportant in enhancing this reaction rate. Their rate coefficient is somewhat higher compared to St.-Maurice and Torr (1978) and McFarland *et al.* (1973) values for temperatures < 1000 K, but it steeply increases for $T > 1300$ K due to N_2^* ($v = 2$). Nevertheless, the temperature dependence for the reaction rate by McFarland *et al.* (1973) is even steeper for such temperatures. Therefore, it is interesting to have an independent estimate for this rate coefficient using an aeronomic approach.

It should be kept in mind that aeronomic estimates are indirect ones and depend on many other parameters used in the model calculations. Therefore, on one hand specially selected reliable measurements should be used for such an analysis; on the other hand one should try to minimize the influence of other parameters during calculations.

A self-consistent method for daytime F2-region modeling developed by Mikhailov and Schlegel (1997) was applied to incoherent scatter (IS) observations with the EISCAT facility to find the set of main aeronomic parameters. Summer and equinoctial daytime observations for magnetically quiet days with small electric fields ($E < 5$ mV/m) were analyzed. The EISCAT observations during such conditions correspond to a typical midlatitude F2 region (Farmer *et al.*, 1984; Lathuillere and Brekke, 1985) controlled by local processes (photoionization, recombination, diffusion and vertical drift related to thermospheric winds). To minimize the influence of other parameters the most important ones were found in a self-consistent way. So, neutral composition (O, O_2, N_2), vertical plasma drift W, T_{120} and the shape parameter S for the neutral temperature height profile, as well as a factor for the Nusinov (1992) EUV model, and a factor for the $O^+ + N_2$ – reaction rate coefficient were found using $N_e(h)$, $T_e(h)$, $T_i(h)$, $V_l(h)$ EISCAT observations. The aim of the study is to derive self-consistent estimates for the total solar EUV flux with $\lambda < 1050$ Å at various levels of solar activity as well as for the $O^+ + N_2$ – reaction rate coefficient and to compare them with existing EUV models and laboratory measured rate coefficients.

2 Method

The self-consistent method of Mikhailov and Schlegel (1997) is still under development and therefore several versions exist. One of them which seems most suitable and efficient, was used by Mikhailov and Förster (1999) in their analysis of the January 06–11, 1997 CEDAR storm period and was applied with some modifications to the present study. The difference of this approach from the initial one by Mikhailov and Schlegel (1997) is that T_{ex} is not found from the ion energy conservation in the F region, but from fitting the calculated h_mF2 to the observed one. This approach turned out to be more general as it uses the most reliable parameter, $N_e(h)$ observed with the IS method, while $T_e(h)$ and $T_i(h)$ profiles depend on the ion composition model applied during the IS data analysis (e.g., Lathuillère *et al.*, 1983; Alcaydé *et al.*, 1996). There is also a problem with the specification of the frictional term in the ion energy conservation equation when electric fields are strong enough. Moreover, for strong convection electric fields the ion velocity distribution is no longer Maxwellian (St.-Maurice and Schunk, 1979; Hubert and Kinzelin, 1992) and this basic assumption in the data analysis is not valid in such cases.

The main idea of the method is to fit a theoretical $N_e(h)$ to the observed one varying the key aeronomic parameters, and to obtain a self-consistent set of the main aeronomic parameters responsible for the observed $N_e(h)$ distribution. The basic method provides: neutral composition [O], [O_2], [N_2]; temperature $T_n(h)$ specified by T_{120}, T_{ex} and the shape parameter S; and vertical plasma drift W. As the goal of the present analysis is to find the $O^+ + N_2$ – rate coefficient and the solar EUV flux, these two parameters were included in the list of unknowns. The latter two parameters should be considered jointly as their ratio in fact mostly determines the electron concentration in the daytime F2 region.

The parameter h_mF2 is strongly controlled both by T_{ex} and the linear loss coefficient $\beta = \gamma_1[N_2] + \gamma_2[O_2]$ (Ivanov-Kholodny and Mikhailov, 1986). Our analysis has shown that no stable solution with proper h_mF2 can be obtained if T_{ex} and γ_1 are searched simultaneously. Therefore T_{ex} was not fitted in the present study. Instead we used T_{ex} values from the MSIS-83 model (Hedin, 1983). It was shown in our previous analyses (Mikhailov and Schlegel, 1997; Mikhailov and Förster, 1997, 1999) that the calculated T_{ex} for quiet time conditions coincide with the MSIS-83 model values within an accuracy of about 10% which is the accuracy of the MSIS model with respect to this parameter. The theoretical model of midlatitude F region used in this method was described by Förster *et al.* (1995). It takes into account transport process for $O^+(^4S)$ and photochemical processes only for $O^+(^2D)$, $O^+(^2P)$, $O_2^+(X^2\Pi)$, N^+, N_2^+ and NO^+ ions in the 120–520 km height range. Three $O^+ + N_2$ – reaction rate temperature dependencies (McFarland *et al.*, 1973; St.-Maurice and Torr, 1978; Hierl *et al.*, 1997) overlapping the range of laboratory measurements for this rate coefficient were used in our analysis. A two-component model of the solar EUV from Nusinov (1992) was used to calculate the photoionization rates in 35 wavelength intervals (100–1050 Å). The photoionization and photoabsorption cross sections were obtained from Torr *et al.* (1979) and Richards and Torr (1988). It should be stressed that we only search for a multiplication factor for the total EUV flux keeping the dependence on solar activity as it is given by the Nusinov model. The same is applied to the $O^+ + N_2$ – rate coefficient where the temperature dependence is specified and we search for a multiplication factor shifting the curve as a whole.

The upper boundary condition was specified at 520 km for all geophysical conditions where the observed electron concentration was used to solve the continuity equation for $O^+(^4S)$. At lower boundary $O^+(^4S)$ was supposed to be in photochemical equilibrium. We apply the stationary form of the continuity equation for daytime hours, so only periods of relative stability in N_mF2 and h_mF2 daily variations around noon were chosen for the analysis. Observed $T_e(h)$ and $T_i(h)$ profiles were used in the calculations.

The EISCAT CP-1 programme provides height profiles of N_e, T_e, T_i and V_l every 5 min with the antenna beam directed along the local geomagnetic field line. They were used to calculate median profiles over 1.5–2 h of observations (18–25 profiles) for the chosen period around noon when the F2 region is most stable. The relative stability of F2-region parameters is important as we use the stationary form of the continuity equation for electron concentration in our analysis. These median vertical profiles were then smoothed by a polynomial fitting (up to the 5th degree) before being used in calculations. Vertical plasma drift W was obtained from the observed parameters with the help of the expression (19.59) from Banks and Kockarts (1973)

$$W = V_z + \frac{k}{m_i \sum v_{ij}} \sin^2 \mathrm{I} \times \left\{ T_i \frac{\mathrm{d} \ln N_i}{\mathrm{dh}} + T_e \frac{\mathrm{d} \ln N_e}{\mathrm{dh}} + \frac{g m_i}{k} + \frac{\mathrm{d}(T_e + T_i)}{\mathrm{dh}} \right\} \quad (1)$$

where $V_z = V_l \sin \mathrm{I}$, v_{ij} are diffusion collision frequencies for O^+, related to momentum transfer collision frequencies v^* by the expression $v_{ij} = m_j/(m_i + m_j) v^*_{ij}$ (see Eq. 19.13 in Banks and Kockarts, 1973), where i applies to O^+ ions and j applies to other neutral or ionized gas species, all other symbols are standard. Collisions of O^+ ions with neutral O, O_2, N_2 and NO^+, O_2^+, N_2^+, N^+ ions were taken into account. All O^+ ion collision frequencies were taken from Banks and Kockarts (1973). The scatter of the measured V_l around the median $V_l(h)$ profile increases with height (as the observations show), so the reliability of the calculated median V_l decreases at high altitudes. Vertical plasma drift W, on the other hand, is mainly controlled by thermospheric winds and electric fields – both are height independent in the topside F2 region (below 520 km). So we assumed W to be constant above the heights: 350–450 km for solar minimum and 450–500 km for solar maximum conditions.

Using standard multi-regressional methods (Press *et al.*, 1992) we find the shape parameter S, T_{120} and factors for the MSIS [O], [O_2], [N_2] concentrations, as well as for the total EUV flux and the $O^+ + N_2$ – reaction rate coefficient, W being calculated at each step using expression (1). Although we are not dealing with heights below 150 km it was found that the method works better if the T_{120} value is regarded as a free parameter. So, T_{120} was formally added to the list of searched parameters. But it should be stressed that this is just a technical step and the extension of T_n, [O], [O_2], [N_2] down to 120 km height is just an extrapolation as we do not fit any $N_e(h)$ profile below 150–160 km height.

3 Data selection and calculations

The list of 32 selected periods is given in Table 1. Only quiet days with Ap < 12 and small observed electric fields (E < 5 mV/m) were selected for the analysis. $F_{10.7}$ varied in a wide range from 73 to 258 to cover various levels of solar activity. This was necessary for checking the EUV flux dependence on solar activity given by the EUV models, as well as to cover a range for the temperature dependence of the $O^+ + N_2$ – rate coefficient as wide as possible. The condition of small electric fields is important to get a pure temperature dependence for the $O^+ + N_2$ – rate coefficient without additional effects related to the applied electric fields (Schunk *et al.,* 1975). Only summer and equinoctial, noon time sunlit periods were selected, since the auroral F2 region may be considered during such conditions as a typical midlatitude one, as mentioned before. The method provides an excellent fit of the calculated $N_e(h)$ to the observed ones especially for quiet days; examples may be found in Mikhailov and Schlegel (1997, 1998). As the calculated ion composition for quiet days turns out to be very close to the model composition used in fitting the theoretical to the measured autocorrelation functions during the IS data analysis, no correction of the routine EISCAT observations was required (Mikhailov and Schlegel, 1997).

The results of our calculations are given in Figs. 1–3. Everywhere error bars reflect the uncertainty of the numerical solution, as determined from 10–15 different estimates. Three different laboratory-measured tempera-

Table 1. List of analyzed EISCAT periods; F_{day}, F_{day-1} and FS are $F_{10.7}$-values for the given, the previous day and a three month average; E is the mean observed electric field for the given UT time-period

Date	F_{day}/F_{day-1}	FS	*A*p	UT	E mV/m
August 02, 89	195.9/192.7	208.3	6	1200–1300	≈0
August 03, 89	213.9/195.9	208.3	5	1100–1200	≈0
September 27, 90	152.6/159.6	194.0	8	1130–1300	≈3
July 02, 90	258.9/240.2	191.4	6	1230–1330	≈0
July 03, 90	245.6/258.9	191.4	7	1300–1400	≈0
July 31, 90	178.0/182.7	191.4	6	1330–1430	≈0
October 09, 90	183.9/175.9	181.2	12	1030–1230	< 5
June 05, 90	149.3/143.9	180.4	5	1330–1430	≈3
June 06, 90	156.8/149.3	180.4	10	1200–1330	< 5
September 06, 88	152.4/166.8	158.8	3	1100–1300	≈3
August 30, 88	186.5/185.4	153.1	12	1200–1330	≈3
April 02, 92	161.2/185.9	151.7	6	1200–1330	≈3
August 17, 98	136.3/139.7	129.4	3	1230–1430	≈0
August 18, 98	132.6/136.3	129.4	4	1330–1530	< 5
July 31, 92	103.2/96.9	123.7	10	1100–1230	< 5
August 01, 92	110.3/103.2	123.7	8	1220–1320	< 5
August 02, 92	124.5/110.3	123.7	5	1100–1230	< 5
August 03, 92	131.3/124.5	123.7	4	1100–1200	≈3
March 18, 88	116.1/117.4	114.2	7	1130–1330	< 3
March 19, 88	116.1/116.1	114.2	4	1230–1430	≈3
October 19, 93	88.8/87.4	94.4	9	1130–1330	< 5
May 12, 87	83.6/84.7	83.5	2	1315–1415	≈0
May 13, 87	85.6/83.6	83.5	6	1330–1500	≈0
April 15, 87	97.8/97.7	82.2	6	1200–1330	≈3
March 24, 87	75.9/75.5	76.8	5	1200–1400	≈5
July 13, 95	72.5/74.3	74.5	5	1100–1300	≈5
July 14, 95	74.4/72.5	74.5	6	1100–1300	< 3
August 06, 85	75.7/76.3	73.2	3	1100–1300	< 5
June 25, 97	71.7/69.9	72.3	7	1130–1300	< 5
June 26, 97	71.8/71.7	72.3	4	1200–1400	< 3
September 03, 85	73.1/72.8	71.9	4	1030–1200	< 5
September 04, 85	73.5/73.1	71.9	2	1130–1300	≈3

ture dependencies for the $O^+ + N_2$ – reaction rate coefficient (McFarland *et al.*, 1973; St.-Maurice and Torr, 1978; Hierl *et al.*, 1997) were used in the calculations. Regarding the dependence on temperature we imply everywhere the effective temperature T_{eff} (see Sect. 1). Figure 1 (top panel) gives three laboratory curves, the Hierl *et al.* (1997) dependence being used in the calculations. The McFarland *et al.* (1973) dependence was used in Fig. 1 (middle panel) and the Hierl *et al.* (1997) one is shown for a comparison with the calculated values. The bottom box of Fig. 1 gives the results for the St.-Maurice and Torr (1978) dependence used in calculations while the Hierl *et al.* (1997) curve again is given for a comparison.

An interesting result is that regardless the temperature dependence used, the calculated values group around the Hierl *et al.* (1997) curve. This may be considered as a clear indication for the Hierl *et al.* (1997) temperature dependence to be the most preferable among the three ones. Our calculations reproduced even small features of this temperature dependence such as the relative maximum around 900 K and the minimum around 1200 K. The obtained result is an independent and strong support for this rate coefficient to be recommended for aeronomic calculations.

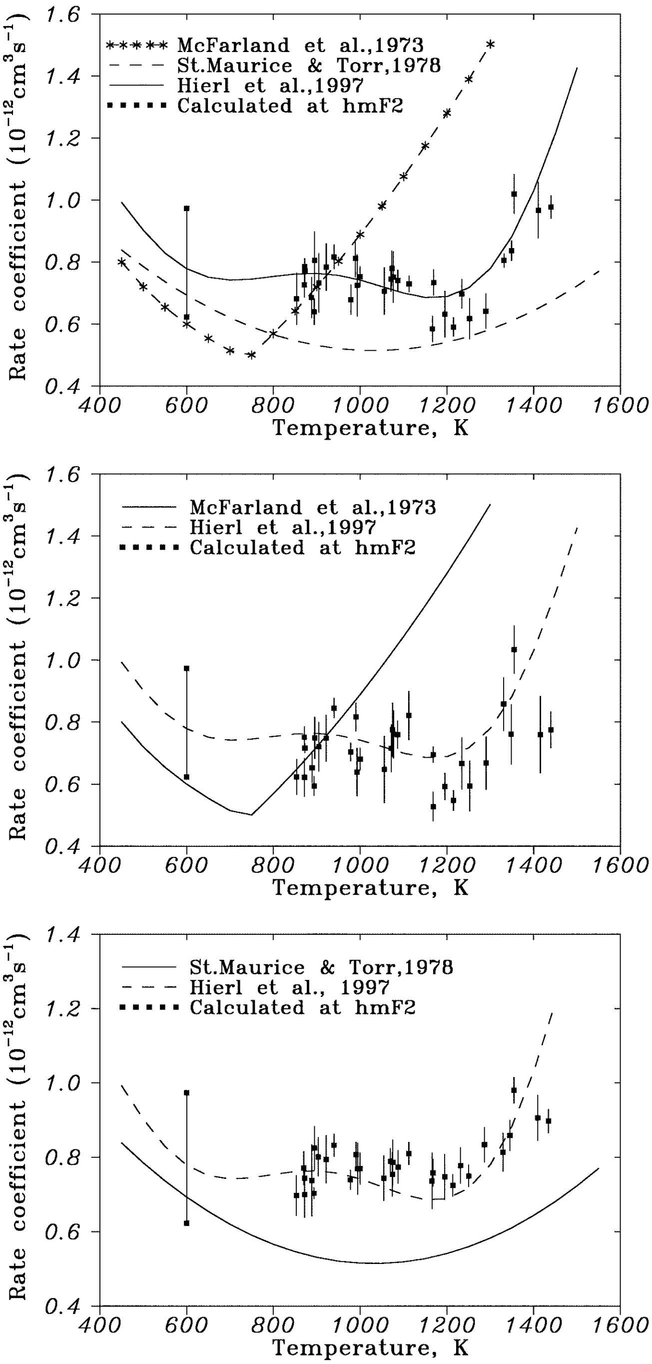

Fig. 1. Calculated $O^+ + N_2$ rate coefficients for three laboratory measured temperature dependencies: Hierl *et al.* (1997) *top panel*, McFarland *et al.* (1973) *middle panel*, and St.-Maurice and Torr (1978) *bottom panel*. Error bars at the *points* express the uncertainty of the numerical solution, while the error bar on the *left hand side* is the total experimental error of the laboratory coefficient measurements (Hierl *et al.*, 1997)

The self-consistently calculated total EUV flux with three $O^+ + N_2$ – rate coefficients is shown in Fig. 2 versus the Nusinov (1992) EUV model. The EUVAC model by Richards *et al.* (1994a) is given for a comparison. Again independent of the $O^+ + N_2$ reaction rate coefficient used, the calculated EUV fluxes demonstrate the same variation with respect to the Nusinov (1992)

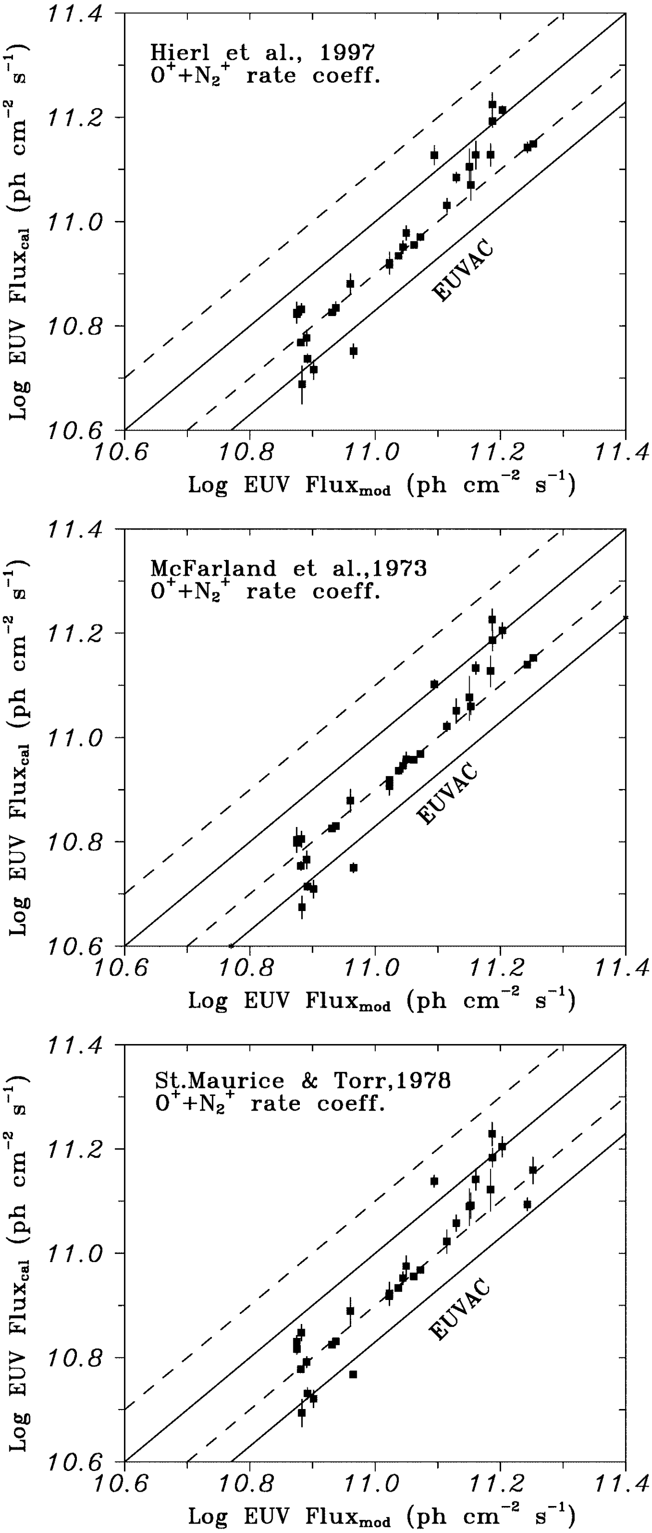

Fig. 2. Calculated total solar EUV flux as predicted by the Nusinov (1992) model. Three laboratory-measured rate coefficients of $O^+ + N_2$ were used in calculations. *Dashed lines* indicate a ±25% uncertainty band around the model. Error bars at the points express the uncertainty of the numerical solution. *Solid line* is the EUVAC (Richards et al., 1994a) model flux

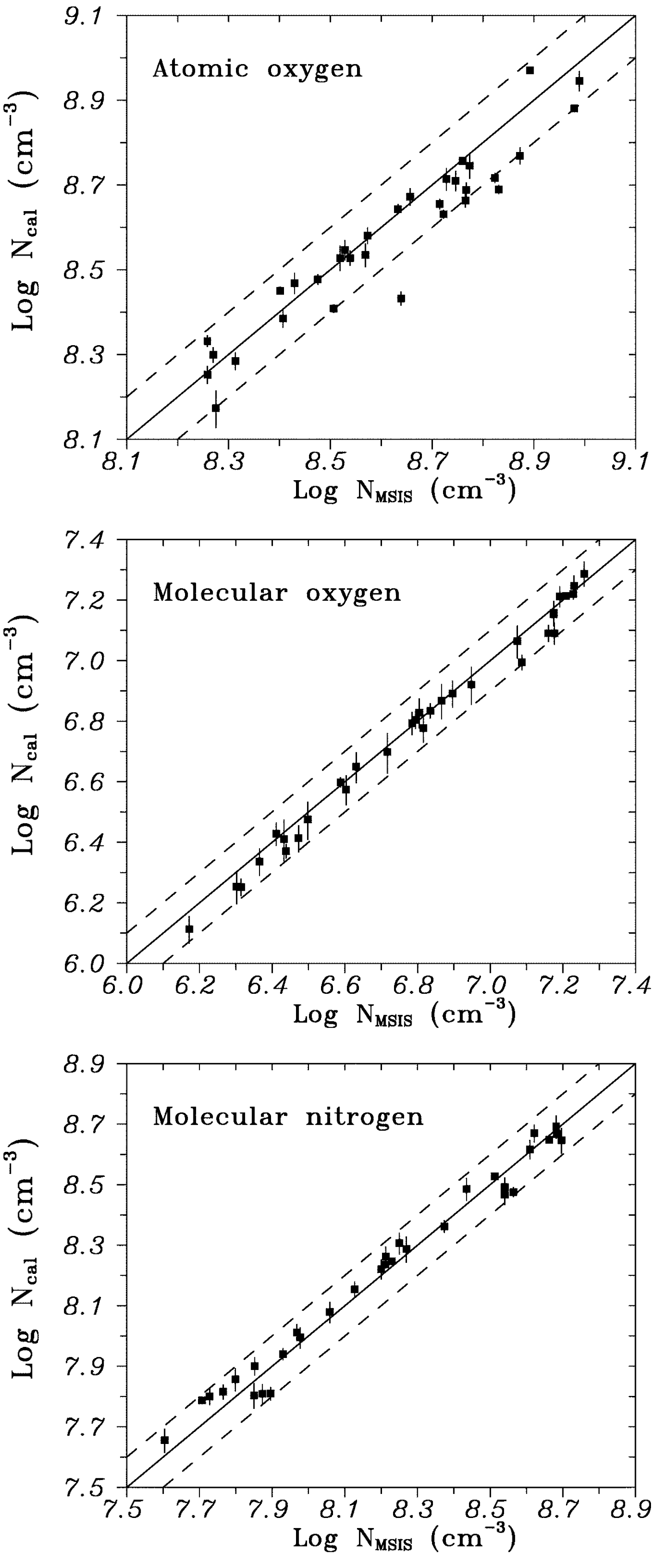

Fig. 3. Calculated neutral gas concentrations versus MSIS-83 model values at the h_mF2 height. The Hierl *et al.* (1997) rate coefficient of $O^+ + N_2$ was used in the calculations. *Dashed lines* indicate a ±25% band around the model. Error bars at the *points* express the uncertainty of the numerical solution

EUV model. Dashed lines characterize the ±25% uncertainty band around the Nusinov (1992) model. The calculated points are within this band for high and middle solar activity, but are 30–35% below the model prediction in solar minimum conditions. On the contrary, the EUVAC model underestimates the EUV fluxes at solar maximum, but provides close values at solar minimum.

Figure 3 gives a comparison of our calculations with MSIS-83 neutral composition at the height of the F2-layer maximum. The results of calculations with the Hierl *et al.* (1997) temperature dependence are shown as an example. Dashes give the $\pm 25\%$ uncertainty band around the MSIS-83 model. All three neutral species are within this band at all levels of solar activity. This is a typical result for quiet time periods provided by our method (Mikhailov and Schlegel, 1997; Mikhailov and Förster, 1999).

4 Discussion

The results of the temperature dependence of the $O^+ + N_2$ – reaction rate (Fig. 1) are interesting. On one hand they demonstrate the capabilities of the method used to extract important aeronomic parameters from the IS observations. On the other hand the close agreement of calculated values to the Hierl *et al.* (1997) experimental curve indicates that this laboratory-measured dependence seems to be reliable and can be recommended for practical use. Unfortunately, this dependence cannot be checked for temperatures below 850 K using daytime EISCAT observations. But our analysis of the night-time N_mF2 increase effect observed at Millstone Hill (Mikhailov and Förster, 1999) when thermospheric temperature was as low as 690 K, has shown that model calculations may be reconciled with the observations if a low ($\cong 5 \times 10^{-13}$ cm^{-3} s^{-1}) $O^+ + N_2$ – rate coefficient is used. Such low rate coefficient values are provided by the McFarland *et al.* (1973) temperature dependence around 750 K (Fig. 1, top). Although the total estimated experimental error is stated as $\pm 25\%$ (Hierl *et al.*, 1997) and thus allows such low rate coefficient values (see error bar in the left-hand side of Fig. 1) one may think that the Hierl *et al.* (1997) values are too high around 700–750 K.

The other problem connected with the $O^+ + N_2$ – rate coefficient is its dependence on vibrationally excited N_2^* (Pavlov, 1986; Ennis *et al.*, 1995; Pavlov *et al.*, 1999 and references therein). A theoretical calculation of this effect is hampered by some uncertainties resulting in a worsening of the agreement between F2-region modeling and observations (Richards *et al.*, 1994b, c). For this reason effects of vibrational excitation are not included in theoretical models, such as TDIM by Schunk (1988), CTIM by Fuller-Rowell *et al.* (1996), GTIM by Decker *et al.* (1994) and some others. On the other hand, it can be found in the literature (e.g., Pavlov and Buonsanto, 1997; Pavlov *et al.*, 1999 and references therein) that an inclusion of effects of N_2^* vibrational excitation improves the agreement with observations. The effect of N_2^* should be most pronounced in summer at high solar activity (e.g., Ennis *et al.*, 1995) when thermospheric temperatures are high. Our analysis includes such periods with temperatures as high as 1400 K (Fig. 1). According to Pavlov and Buonsanto (1997) the distribution of vibrationally excited nitrogen is mostly Boltzmann-like for $v \leq 2$. The amount of vibrationally excited N_2 ($v = 2$) which could contribute to the total rate constant as $K_2(T) = 38K_0(T)$ (Pavlov *et al.*, 1999) is only about 1% at $T = 1500$ K. Therefore, no appreciable effects related to vibrationally excited N_2 can be expected at usual thermospheric temperatures; they will be seen at higher temperatures only. So, the Hierl *et al.* (1997) temperature dependence may be used in practice together with T_{eff}, at least for T_{eff} up to 1400 K.

The EUV flux calculations (Fig. 2) give practically identical results for the three different temperature dependencies of the used $O^+ + N_2$ – rate coefficient. The fluxes are close to the Nusinov (1992) EUV model at solar maximum, about 25% smaller than the model values at medium activity and about 30–35% at solar minimum. On the contrary, the EUVAC model gives close EUV values at solar minimum, but underestimates the fluxes by 30–35% at solar maximum. The overall agreement of the calculations to the EUV models seems surprising keeping in mind the quality and scatter (due to calibration problems) of the initial experimental material used for the EUV models derivation (Nusinov, 1984; Bruevich and Nusinov, 1984; Richards *et al.*, 1994a). The calculated EUV fluxes demonstrate a somewhat steeper dependence on solar activity than both EUV models predict. This is the first independent (aeronomic) check of the existing EUV models. The difference obtained in the dependence on solar activity needs additional analysis which is outside of the scope of this work. Nevertheless, the results of our calculations allow us to conclude the following: As the ionospheric F2 region is formed by the whole spectrum with $\lambda < 1050$ Å, this deviation from the EUV models may be taken into account in F2-region practical calculations. A correction may be introduced on average by shifting the total EUV flux of EUVAC and the Nusinov (1992) model by $\pm 25\%$, correspondingly. The uncertainties with the $\lambda < 250$ Å radiation (see Introduction) are not important for the F2 region calculations as this radiations contribute to the ionization rate at lower altitudes only.

5 Conclusions

The main results of our analysis are the following:

1. A self-consistent method developed by Mikhailov and Schlegel (1997) was extended to extract additional important aeronomic parameters (total solar EUV flux and $O^+ + N_2$ – reaction rate coefficient) using routine incoherent scatter F2-region observations. The method was applied to 32 daytime summer and equinoctial EISCAT observations for quiet periods (Ap < 12) and various levels of solar activity ($F_{10.7} = 73$–258) to check the existing solar EUV models and laboratory measured temperature dependencies of the $O^+ + N_2$ – reaction rate.

2. Three groups of independent calculations with temperature dependencies of the $O^+ + N_2$ – rate coefficient given by McFarland *et al.* (1973), St.-Maurice and Torr (1978), and Hierl *et al.* (1997) have shown the calculated rate-coefficient values to group around

the Hierl *et al.* (1997) dependence in the 850–1400 K temperature range regardless of the rate coefficient used in the calculations. Therefore, the recently measured temperature dependence of the $O^+ + N_2$ – rate coefficient can be considered as the most preferable and is recommended for aeronomic calculations.

3. The self-consistently determined total EUV solar fluxes with $\lambda < 1050$ Å show similar variations with solar activity level, independent of the $O^+ + N_2$ – rate coefficient used in the calculations. The calculated EUV fluxes are close to the Nusinov (1992) EUV model at solar maximum, apart from about 25% differences from the model values at medium activity and 30–35% differences at solar minimum. On the contrary, the EUVAC model by Richards *et al.* (1994a) gives close values at solar minimum, but underestimates the EUV fluxes by 30–35% at solar maximum. The calculated fluxes show a steeper dependence on solar activity than both models predict. As the ionospheric F2 region is formed by the whole spectrum with $\lambda < 1050$ Å, in practice both EUV models may be recommended for F2-region electron density model calculations if the total flux shifted by $\pm 25\%$ for the EUVAC and Nusinov models, correspondingly.

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