DOMINANT INFLUENCE OF A SOLAR ULTRAVIOLET ON THE EXCITATION OF 630.0 nm NIGHTGLOW EMISSION IN THE 23 CYCLE

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Abstract. It is well known that in maximum of the solar activity cycles the 630.0 nm emission intensity in a nightglow is increased up to two times. It was supposed that this phenomenon was caused by the solar ultraviolet variations in solar activity cycles [Fishkova, 1983].

In this report the results of photometric measurements of the 630.0 nm nightglow emission intensity of an atomic oxygen at geographical latitude 63°N at the Yakutsk meridian (130°E) during magnetic-quiet days of 1997-2007 are presented. The close connection of the 630.0 nm emission intensity with the flux of solar extreme ultraviolet (by SEM data) with a correlation coefficient 0.8-0.9 has been found. The observed increase of red line intensity essentially exceeds the possible influence of density variations of the upper thermosphere by the MSIS-86 empirical model on the excitation of this emission. Thus, the experimental confirmation of dominant influence of the solar extreme ultraviolet on the excitation of the 630.0 nm emission in the nightglow has been obtained.

1. Introduction

The red lines of atomic oxygen of 630.0 nm and 636.4 nm (1D - 3P21) are the most intense emissions of the nightglow in a visual part of spectrum in the ionosphere F region. At middle latitudes under quiet geomagnetic conditions the main process of production of O(1D) excited atoms is the dissociative recombination of ions O2+ and NO+ (Barbier, 1959, 1961; Chamberlain, 1961). Owing to a long lifetime (~110 s) of metastable levels the deactivation rate coefficient for O(1D) fast increases in the lower thermosphere and at altitudes of below 160 km the intensity of 630.0 and 636.4 nm emissions becomes negligible. Mechanisms of production of O(1D) and their deactivation cause the most volume emission rate of the red lines in a maximum of electron concentration of the ionosphere F2 layer at 250-270 km altitude. The presence of close connection of the 630.0 nm emission intensity with parameters of F2 region was shown by Barbier (1959).

The first long-term observations of Barbier in the Upper Provence (44°N, 6°E) showed the considerable growth of red emission intensity during the solar activity increase in 1953-1960 (Barbier, 1965). Subsequently, the connection of 630.0 nm emission intensity with the solar activity was confirmed for four solar cycles by data of observations in Abastumani (42°N, 43°E) in 1958-1992 (Fishkova, 1983; Fishkova et al., 1996). During the maximum of 20th, 21st and 22nd solar activity cycles the annual average intensity of red emission was increasing up to 2-2.5 times relative to the minimum. A direct dependence of the red emission intensity on the solar activity level was also obtained by results of observations at the mid-latitude Zvenigorod station (56°N, 37°E) in 1969-1973 (Truttse and Belyavskaya, 1975).

In this paper the results of photometric observations of the 630.0 nm nightglow emission at geographical latitude of 63°N at the Yakutsk meridian (130°E) in 1990-2007 are presented. It should be noted that in the longitudinal sector of American continent the registration of the nightglow emissions on this parallel is practically impossible owing to a conformity of it to the geomagnetic latitude of ~ 73°N in the auroral zone. The obtained data confirm a close connection of the 630.0 nm red emission with solar activity in the 22nd and 23rd cycles. The dependence of red line intensity on the solar extreme ultraviolet (EUV) intensity in the 23rd cycle has been analyzed.

2. Method of observations and data analysis

The regular observation data of the nightglow emissions and subauroral luminosity at Maimaga station (63°N, 130°E; geomagnetic latitude: 57°N) are used in this work. Measurements of intensity of the 630.0 nm emission and also the 427.8 nm N2+ band were carried out with a four-channel photometer in the magnetic station zenith. Each channel has a field of view of 10°. The interference band-pass filters with a half-width of 2.0 nm are installed in a temperature stabilized photometer chamber in order to detect these emissions and continuum. The photomultiplier tubes are outside of the filters chamber for the natural cooling under conditions of the low temperature of ambient air. The absolute energy calibration of photometer was
performed using a reference receiver method (Ievenko, 1995). During the observations the sensitivity of four channels was checked by the stable light source located inside the filters chamber. The photometer allows to register emissions in the nightglow from 2 Rayleigh at a signal to noise ratio equal to 2 with the time resolution of 5 s.

The observations are carried out at moonless nights of winter months under conditions of the good atmosphere transparency. At the geographical latitude of 63°N from the end of April till September the nights are white. For the analysis we have selected the nights of observations with current values of Kp ≤ 2 and Dst ≥ -20 nT when variations of the 630.0 nm emissions can be definitely caused by the nightglow mechanisms. At values of Kp ≥ 3-4 at geomagnetic latitudes of 56-57°N the mid-latitude red arcs (SAR arcs) usually appear and energetic particle precipitations during substorms are enhanced (Ievenko, 1999; Ievenko and Alexeyev, 2004; Ievenko et. al, 2008). Thus, 158 nights have been selected for the 1990 to 2007 observation period.

The data of zenith photometer for the 1990 to 1997 period were recorded with the multi-channel recording potentiometer. For 1998-2007 in parallel with the potentiometer a digital recording was carried out. For homogeneity of statistical series only the analog data have been used in the work. They has been digitized with a 30 min step in the range of 23-03 LT at a height of the Earth’s shadow ≥ 500 km. Furthermore, a mean value for every night of observations has been determined. Unlike the observations at mid-latitudes for the 63 parallel there is a strong seasonal dependence of the red line intensity that is caused by a fast decrease of the night duration in going from winter to spring. It is known that the excitation rate of the red emission gradually decreases during a night, and its intensity depends on the time after a sunset. Therefore, the analysis of long-term variations of the 630.0 nm emissions has been carried out using the intensity mean values for each month of observations separately.

3. Long-term variations of the nightglow 630.0 nm emission at geographical latitude 63°N

Table 1 lists the number of observation nights under magneto-quiet conditions and the corresponding mean 630.0 nm emission intensities for four months in 1990-2007. In the last column the mean intensities on years are also indicated. The changes of them are in agreement with variations of annual average values of red emission intensity at mid - latitudes in four cycles of solar activity (Fishkova, 1983; Fishkova et al., 1996). These are intensities of 82-95 Rayleigh in maxima (1991 and 2002) and of 34-50 Rayleigh in minima (1995 and 2007) of solar activity. It is seen from the Table that a long-term series of the data are fully completed on years for February and March.

Figure 1 presents the comparison of long-term variations of the 630.0 nm emission intensity with the change of F10.7 index in the 22nd and 23rd solar activity cycles. The different amplitude of the nightglow variations for February and March is caused by a seasonal dependence. By rare measurements from 1991 to 1997 one can say about the expressed tendency of considerable decrease of the red line intensity during the decay phase in the 22nd solar activity cycle. The decrease of intensity has taken place 1.5 and 3.3 times for February and March, respectively. For a series of observations in 1997-2007 a close connection of the 630.0 nm emission intensity with the F10.7 index in the 23rd solar activity cycle is
Variations of the 630.0 nm emission occur in phase with the solar activity change.

4. Connection of the 630.0 nm emission intensity with a solar extreme ultraviolet

It is known that annual average values of the F2 for night hours at mid-latitudes reflecting an ionization level of the F2 region are also changed in phase with solar activity cycles (Fishkova, 1983; Fishkova et al., 1996). It gives the basis to assume that the long-term variations of the red line intensity and also ionization of the night F2 layer are caused by the corresponding cyclic changes of solar ultraviolet radiation (Fishkova, 1983).

We have analyzed the connection of 630.0 nm emission intensity with variations of solar EUV for the 23rd solar activity cycle. Daily average intensities of EUV in the spectral interval of 26-33 nm for 1997-2007 have been taken from a dataset of CELIAS/SEM experiment aboard the SOHO spacecraft. Figure 2 shows the variations of red line intensity and EUV as a function of time for February and March in 1997-2007. The mean values of EUV are taken for days of measurements of the red line intensity in the nightglow. On the plots the change of the 630.0 nm emission occurs in phase with variations of EUV with a correlation coefficient of 0.8 and 0.9 for February and March, respectively. The increases of red line intensity 1.9 times in February and 2.8 times in March considerably exceed the standard errors of the mean. In this case there was an increase of EUV radiation ~3 times. The decrease of the red emission intensity during the reduction of EUV level in 2003-2007 is also well expressed. Two independent data samples indicate to the functional linear dependence of the nightglow 630.0 nm emission intensity on the solar EUV flux in the 23rd cycle.

Changes of solar activity also cause the considerable density variations of the upper atmosphere neutral components. At dissociative recombination the production rate of excited atoms O(1D) is mainly determined by concentration of the already visible. Variations of the 630.0 nm emission intensity occur in phase with the solar activity change.
molecular oxygen $\text{O}_2$ and ions $\text{O}^+$ (electronic density) in the layer F2 maximum. The rate of the 630.0 nm volume emission depends on the deactivation rate coefficient for $^1\text{D}$ which determined by the concentration of neutral component $\text{O}_2$ and $\text{N}_2$ at F2 region altitudes (Barbier, 1959, 1961; Chamberlen, 1963; Fishkova, 1983).

To estimate the influence of this factor on the red line intensity we has determined the possible changes of $\text{N}_2$ and $\text{O}_2$ concentration at the latitude and longitude of the Maimaga station in the 23rd solar activity cycle using the MSIS-86 empirical model (Hedin, 1987). A calculation by this model has been carried out at the site of UK Solar System Data Centre. Table 2 lists the mean $\text{N}_2$ and $\text{O}_2$ concentrations in the interval at altitudes of 250-300 km for the local midnight during days of the red line observations in February and March of 1997-2007. In this Table the relative variations of 630.0 nm emission intensity which can be caused by the change of neutral composition at fixed ionization are also presented.

According to the MSIS-86 model during the maximum of the 23rd cycle, perhaps, there was the increase of the $\text{N}_2$ and $\text{O}_2$ concentration 2.2-4.5 times and 2.3-4.4 times, respectively. By our estimation such variations of the neutral composition in the F2 region could cause the increase of the 630.0 nm emission in the nightglow up to 1.6 times. The observed increase of red line intensity 1.9 times in February and 2.8 times in March is close connected with the EUV flux and essentially exceeds the possible influence of neutral composition variations. This factor, and also, a regular dependence of the 630.0 nm emission on the ionization of F2 night layer indicate to the dominant role of solar EUV in the excitation of the 630.0 nm emission in the nightglow.

### Table 2. Changes of the $\text{N}_2$ and $\text{O}_2$ concentration in the 23rd cycle of solar activity according to an empirical MSIS-86 model and the corresponding relative variations of the 630.0 nm emission intensity

<table>
<thead>
<tr>
<th>Years</th>
<th>February (sm$^{-3}$)</th>
<th>March (sm$^{-3}$)</th>
<th>Febr. (normalized)</th>
<th>March (normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{N}_2$</td>
<td>$\text{O}_2$</td>
<td>$\text{N}_2$</td>
<td>$\text{O}_2$</td>
</tr>
<tr>
<td>1997</td>
<td>9.6E7</td>
<td>6.1E6</td>
<td>1.3E8</td>
<td>6.2E6</td>
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<tr>
<td>2001</td>
<td>3.6E8</td>
<td>1.4E7</td>
<td>2.9E8</td>
<td>1.7E7</td>
</tr>
<tr>
<td>2002</td>
<td>4.3E8</td>
<td>2.7E7</td>
<td>5.4E8</td>
<td>2.5E7</td>
</tr>
<tr>
<td>2006</td>
<td>7.0E7</td>
<td>4.0E6</td>
<td>1.4E8</td>
<td>6.5E6</td>
</tr>
<tr>
<td>2007</td>
<td>1.1E8</td>
<td>5.4E6</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

The changes $\text{N}_2$ and $\text{O}_2$ concentration normalized to 1997 and also the normalized intensity of a red line during a maximum of 23-rd cycle by the bold font are shown on the ionization of F2 night layer indicate to the dominant role of solar EUV in the excitation of the 630.0 nm emission in the nightglow.

### 5. Conclusion

By the photometric observation data at the Yakutsk meridian (130°E) at the geographical latitude of 63°N during magnetic-quiet days of 1997-2007 the connection of the nightglow 630.0 nm emission intensity with the solar activity in the 22nd and 23rd cycles is shown. The change of mean intensity is in agreement with variations of annual average intensity of red emission at middle latitudes in the 20th - 22nd cycles (Fishkova, 1983; Fishkova et al., 1996).

The close connection of atomic oxygen red emission in the nightglow with the solar EUV intensity with the correlation coefficient of 0.8-0.9 for 1997-2007 has been found. Two independent samples of the data for February and March indicate to the functional linear dependence of the 630.0 nm emission intensity on the EUV flux. The observed increase of red line intensity essentially exceeds the possible influence of $\text{O}_2$ and $\text{N}_2$ concentration variations by the MSIS-86 empirical model on the excitation of this emission.

The regular dependence of the 630.0 nm emission on the ionization of night F2 layer is caused by the main mechanism of excitation of this line owing to the dissociative recombination of $\text{O}_2^-$ and NO$^+$ molecular ions (Barbier, 1959, 1961; Chamberlain, 1963). In its turn the night ionization is connected with the electron concentration of daytime ionosphere F- region which is determined by the value of EUV flux in the solar activity cycle. By data of the SOHO/SEM the experimental confirmation of dominant influence of the solar EUV on the excitation of the 630.0 nm emission in the nightglow in the 23rd cycle has been obtained.

### Acknowledgements

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REFERENCES


