Behavior of the emission from atomic oxygen of the atmosphere at 557.7 nm during the events of stratospheric warming over East Siberia

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The influence of stratospheric warming on the atomic oxygen emission at 557.7-nm wavelength (airglow) was investigated based on data obtained at the Geophysical Observatory of ISTP SB RAS (52°N, 103°E) in 1997–2005. In this period, several cases of anomalous behavior of the 557.7-nm emission intensity in the absence of strong geomagnetic disturbances have been recorded. It has been found that these cases of the growth of intensity of atmospheric emission at 557.7 nm in the height region of the mesosphere and lower thermosphere, have been caused by strong stratospheric warming when the disturbance covers a wide range of atmospheric altitudes. It should be emphasized that high concentration of centers of stratospheric warming is characteristic of Asia and, in particular, of the East Siberia that can result in the formation of regional peculiarities in characteristics of the airglow.

Introduction

The observation of airglow of the upper atmosphere is an effective method of investigation of its physical and physicochemical characteristics. The intensity variations of the optical emissions are a sensitive element of disturbances in the middle and upper atmosphere.

The green line of atomic oxygen (OI) at the wavelength of 557.7 nm is the brightest discrete emission in the visible spectral range at night airglow of the midlatitude upper atmosphere; the altitudes from which this emission comes are from 85 to 115 km. In this atmospheric region, both the external effect of solar activity and the effects of dynamics and disturbances of different nature from lower atmosphere can manifest themselves.

By now for the 557.7-nm emission a great number of sources of its variations were recognized. Among those we can point out strong geomagnetic disturbances, stratospheric warming, seismic activity, acoustic gravitational waves, disturbances during spring and fall rearrangement of the atmospheric circulation,[1] and other. The most important variations of 557.7-nm emission observed result from strong geomagnetic disturbances[2] and stratospheric warming.[3,4]

Based on the experimental data, obtained at the Geophysical Observatory of ISTP SB RAS in 1997–2005, during some years in winter months the variations of 557.7-nm emission intensity were observed that greatly exceeded, by the amplitude, the variations typical for midlatitudes.

The primary goal of this study was to find out the sources of strong perturbations in the behavior of 557.7-nm atomic oxygen emission observed during winter periods in the East Siberia under calm geomagnetic conditions.

Observation data

In the present paper the following data were used in the analysis:

– data of experimental observations of 557.7-nm atomic oxygen emission obtained at Geophysical Observatory of ISTP SB RAS (52°N, 103°E) in 1997–2005. The optical measurements were carried out using a "Fenix" zenith photometer, the operating wavelengths are 557.7 and 630 nm and the spectral intervals from 360 to 410 and from 720 to 810 nm;

– spaceborne data on the vertical temperature profiles obtained using TOVS/AVHRR instrument mounted onboard a NOAA satellite. We have analyzed the temperature on isobaric surfaces of 70 and 10 hPa (the altitudes ~18 km and 30 km) for the period from November 1998 to January 2001. The data of the TOVS instrument were received and processed at the receiving station of the Center of Space Monitoring of ISTP SB RAS, Irkutsk;

– the data of Berlin Meteorological University (http://strat-www.met.fu-berlin.de) on stratospheric warming refer to the level of 10 hPa.

Results and discussion

Since 1997 regular observations of the airglow at night have been carried out at the Geophysical Observatory of ISTP SB RAS (52°N, 103°E). As a rule the observations are being carried out under clear sky moonless conditions at night. The total number of nights for observation at the above period was 645. During the period of observations, several cases were recorded of anomalous behavior of the intensity

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of 557.7-nm emission in the absence of strong geomagnetic perturbations. Sharp intensity increase of 557.7-nm emission by 100 to 300% was observed.

Figure 1 shows a series of averaged, over night, intensity of the 557.7-nm emission over the entire observation period. One can clearly see the typical seasonal behavior of the emission with the fall maxima, whose amplitude, based on data from Refs. 5 and 6, must be maximum for all midlatitude stations. However, along with these maxima of the typical seasonal behavior, the increased intensity values in winter months can occur comparable in value or exceeding the fall maxima.

To determine the sources of these disturbances, we have made joint analysis of the available experimental data on 557.7-nm emission intensity and data from Berlin Meteorological University (http://strat-www/met.fu-berlin.de) on stratospheric warming at the level of 10 hPa. Also for analysis the local data were used on the stratospheric temperature obtained during the period from November 1998 to January 2001 using TOVS/AVHRR instrument at the station of spaceborne data reception of ISTP SB RAS at the point of optical observations. The joint analysis has shown that cases of anomalous increase of 557.7-nm emission intensity during winter months coincided in time with the events of strong stratospheric warming over the East Siberia.

The influence of stratospheric warming on variations of the airglow of the atmosphere were investigated in a series of papers.[3,4] The authors attracted attention, in particular, to the increase of 557.7-nm emission intensity by 50–100% during stratospheric warming and explained this fact by activation of the vertical atmospheric circulation reaching, in some cases, the altitudes of mesosphere and lower thermosphere (the region from where 557.7-nm atmospheric emission occurs).

In the analyzed period, we can isolate several more significant manifestations of the stratospheric warming in the behavior of the 557.7-nm emission.

1) Intense local warming at the end of January–February 1998 when the localization of warming was practically at the point of the emission observations (53°N, 103°E) and the temperature was 248 K. The peak temperature 267 K was recorded in early February with the source coordinates 74°N and 92°E. The 557.7-nm emission intensity averaged over a night increased by more than 100% at the temperature rise by about 17 K. On February 1st the maximum value of the emission intensity of 1500 Rl was recorded. The time delay relative to the temperature rise was about 4 days. This event has been described in the literature earlier.[7,8]

2) The warming in January 2000 over Siberia–Mongolia–Manchuria, which lasted until the beginning of February. Maximum temperature of 260 K was recorded on February 4 at the center with coordinates 73°N, 120°E. Since January 17 we observed sharp increase of 557.7-nm emission intensity that lasted until January 22. On January 20 we detected anomalously high values of 557.7-nm emission intensity, the maximum reached 2013 Rl.

Figure 2 shows the variations of averaged over night intensity of 557.7-nm emission and atmospheric temperature at the surfaces of 10 and 70 hPa for stratospheric warming in January 2000. A sharp increase of the emission intensity after January 17 is well seen from the Figure. The averaged over might intensity increased by about 500 Rl whereas the temperature at 10 hPa level increased by ~ 15 K.

3) The warming observed in the upper stratosphere over Asia early in December 2000. Many sources of warming were located close to the observation point. The peak temperature of 267 K was recorded at the center with coordinates 65°N and 93°E. The 557.7-nm emission intensity increased during 4 days by 2.5 times, the peak value recorded was 650 Rl.

4) The warming in the middle of December 2001–January 2002 over Siberia when at the level of 10 hPa the temperature rose by more than 30 K. By the beginning of January 2002 the stratospheric warming of the "major" type was observed, after which during a certain period the perturbations in the temperature distribution were yet observed. At the same time, in the second half of January over Siberia the area of enhanced temperature appeared again.

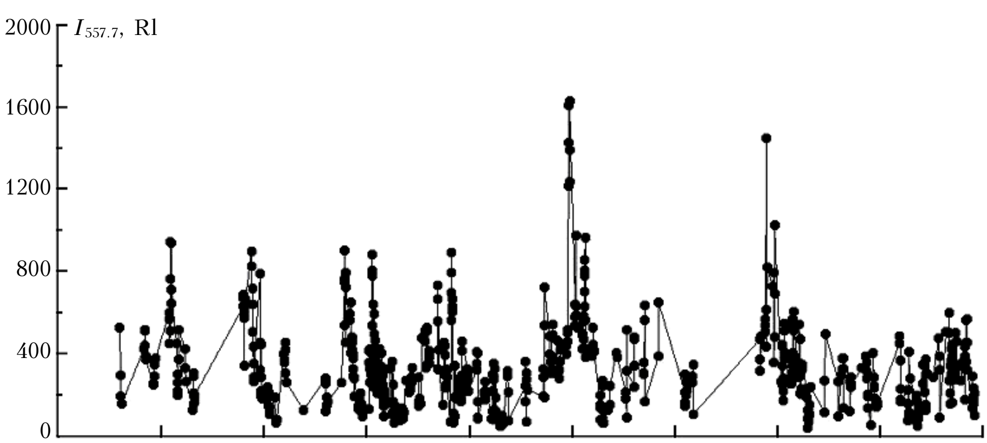


Fig. 1. Intensity of the 557.7-nm emission averaged over a night.

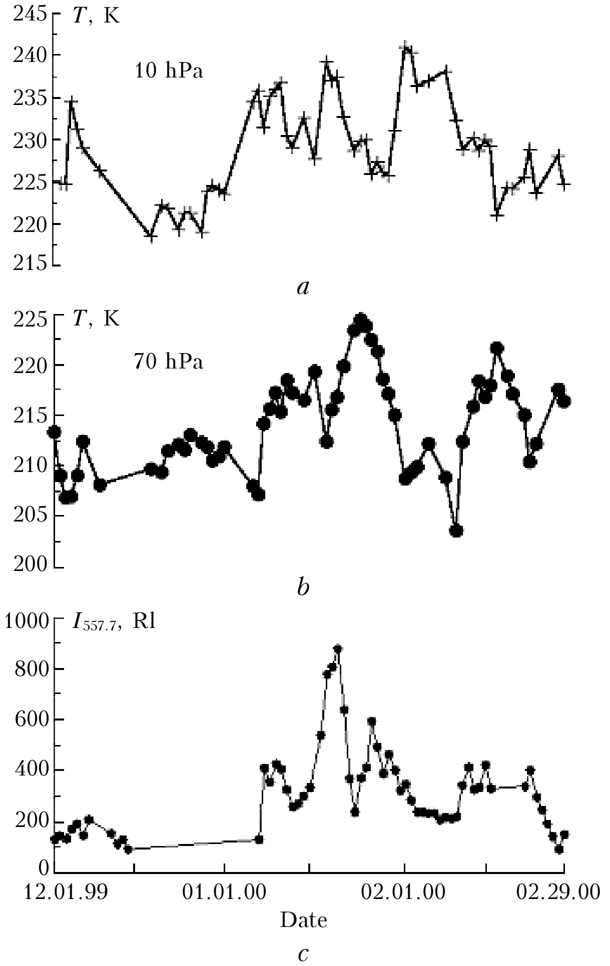


Fig. 2. Temperatures on isobaric surfaces 10 (*a*) and 70 hPa (*b*) based on the TOVS/AVHRR data at the place of optical observations and averaged, over a night, 557.7-nm emission intensity (*c*) in the period from December 1999 until February 2000.

Since December 17 we observed very sharp increase of 557.7-nm emission, because the averaged over night intensity increased during 2 days from 506 to 1600 Rl, the peak night intensity increased from 921 Rl to the extreme value of 2235 Rl (December 22).

It should be noted that this extreme intensity value $I_{557.7}$ = 2013 Rl in January 2000 was maximum over the entire period of observations under calm geomagnetic conditions. A comparable in value intensity of the 557.7-nm emission was recorded only during strong geomagnetic storm on November 20, 2003 (Fig. 1).[2] In the literature no data have been found about that high intensity of the 557.7-nm emission during the events of stratospheric warming. Anomalously high intensity in December 2001 was recorded until the end of observation session on December 22. In January–February 2002 emission intensity was recorded (averaged over night intensity reached about 1kRl, maximum intensity reached values above 1600 Rl) (Fig. 3).

No data on local temperature were available for this event. However, because the strong stratospheric warming covers enormously large areas of the hemisphere in winter, for estimating temperature variations during this warming the data from Ref. 9 were used for local temperatures at the point with coordinates (63°N, 129.7°E). Based on these data, the warming began after December 11, 2001, the temperature at the level of 10 hPa reached maximum ~ 257 K on December 18. In analyzing the temperatures of the stratosphere and lower thermosphere over a period from December 2001 to February 2002, the authors of Ref. 9 drew the conclusion that the warming began at altitudes of maximum radiation intensity of 557.7-nm oxygen line and further propagated to the lower layers.

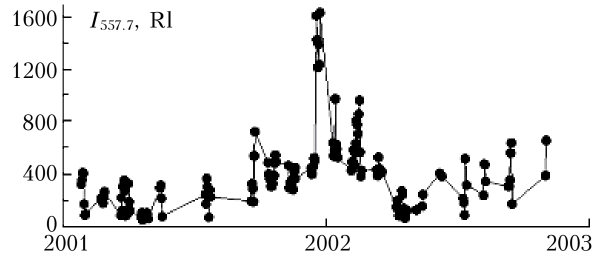


Fig. 3. Variations of averaged over night intensity of 557.7-nm emission in 2001 and 2002.

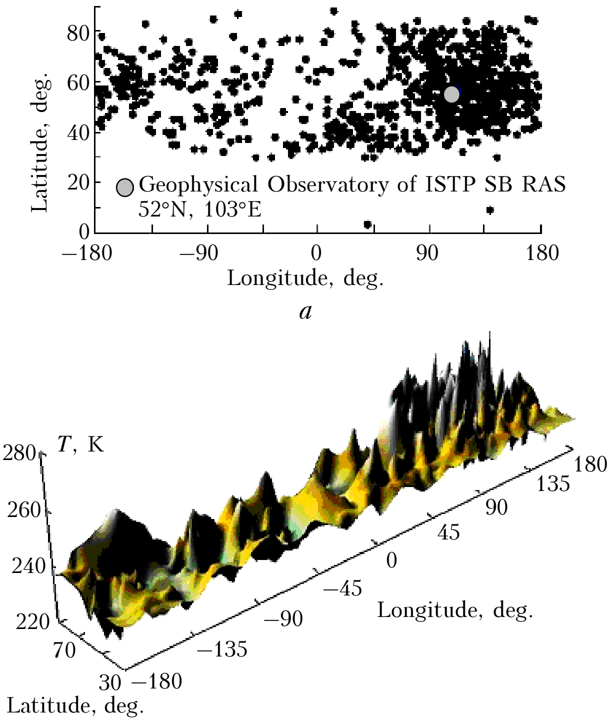
The analogous events, associated with a considerable growth of intensity of the 557.7-nm emission, which was followed by stratospheric warming, were also observed in December 1998 and in February 1999.

Thus, the performed analysis of anomalous increase of intensity of the 557.7-nm emission during winter months of 1998, 2000, and 2001–2002 has shown that these events can be due to the effect of stratospheric warming in the region of optical observations.

Stratospheric warming can give rise to perturbations of atmospheric parameters (thermobaric field, density, chemical composition) at altitudes of their localization. Perturbations, taking place during strong winter stratospheric warming, are not limited by the stratosphere, but occur in a wide altitude range from tropospheric altitudes up to the altitudes of the upper mesosphere[10] and lower thermosphere[4] (the region where atmospheric emission at 557.7 nm occurs). During the events of stratospheric warming strong variations are observed of dynamic regime in the middle atmosphere.[11] The characteristic feature of stratospheric warming is a sharp decrease of the dominating westerly winter zonal winds and their change to easterly winds in the stratosphere and mesosphere.

It is known[12] that the stable system of zonal winds safely screens the upper atmosphere from the lower atmosphere, but in the periods of zonal wind inversion the penetration of energy is possible. It is exactly the situation that occurred during periods of strong stratospheric warming when the generation is amplified and the propagation upward of wave perturbations of different scale becomes stronger.

Stratospheric warming is observed almost every winter. During these events of warming the geographic irregularity of distribution is typical. For Asian region and, in particular, for the East Siberia, the large concentration of centers of stratospheric warming is typical. Figure 4 shows the distribution of daily data on the regions of localization of sources of stratospheric warming and temperatures in these sources for the period from 1997 to 2002. Note that their concentration in the Asian region and, in particular, at the site of the Geophysical Observatory of ISTP SB RAS (52°N, 103°E) is high.



b

Fig. 4. Distribution of localization of sources of stratospheric warming (*a*) and temperatures in sources of warming (*b*) during the period from 1997–2002.

The data, presented in this paper, confirm the above[13] assumption about the role of stratospheric warming in the formation of regional peculiarities in the behavior of green emission of the atomic oxygen. The 557.7-nm emission is the integral characteristic of altitude distributions of temperature and atmospheric components (O, O_2) participating in the processes of excitation of this emission at the altitudes of its existence. Because of this fact one can expect the existence of regional characteristics of atmospheric parameters at these altitudes related to high concentration of sources of stratospheric warming. Therefore, the effect of stratospheric warming on the physicochemical and dynamic parameters of the atmosphere and ionosphere in the winter period for this region can be very significant and this effect should be taken into account.

Conclusion

Based on the experimental data obtained at the Geophysical Observatory of ISTP SB RAS (52°N, 103°E) in 1997–2005 we have isolated some cases of anomalous increase of the intensity of 557.7-nm emission being caused by stratospheric warming. The intensity variations of the 557.7-nm emission caused by stratospheric warming are found to be comparable in value with the variations characteristic of the seasonal behavior of this emission, and in some cases can exceed those essentially.

The values of the 557.7-nm emission intensity recorded during the events of stratospheric warming in January 2000 (2013 Rl) and in December 2001 (2235 Rl) can be referred to the extreme ones ever recorded intensity perturbations of this emission in midlatitudes.

Geographical irregularity of stratospheric warming and their high concentration in Asia, and, in particular, over East Siberia, can form regional (and, probably, latitude-longitudinal) characteristics of variations of the 557.7-nm emission.

Acknowledgements

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