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Some problems of energy balance in the Earth's aeronomy

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Introduction

Modeling of the processes of ionization and optical excitation in the terrestrial upper atmosphere experiences permanent problems with more accurate consideration of energetic balance in the Earth's aeronomy. Some aspects of this problem need to be explained in more details. Actually it means that our knowledge of the main input parameter-values of the Sun X-ray and EUV fluxes is still insufficient. Unfortunately there are no reliable models of energetic characteristics of these fluxes during the solar flares of various intensity [1].

The "ground state" of the ionosphere and thermosphere is determined by the flux of solar EUV and soft X-ray radiation, the dominant global energy source for them. But the state of the ionosphere-thermosphere system varies in response to changes both in this solar irradiance and in the energy received from the magnetosphere, with the latter causing the more extreme variability in the state of the system.

The problems of additional sources of energy in the thermosphere and in the middle atmosphere, including the polar ionosphere are also worth of special attention.

Model and experimental gaps at the aeronomy

Currently in the physics of the solar-terrestrial relations and, first of all, in aeronomy, there exists a paradox situation. The models of the ionosphere and upper atmosphere of the Earth both on the global scale for all levels of solar activity, and for particular geographic zones and solar-geophysical disturbances (from magnetic storms and substorms to solar flares) are created. However still are absent everyday patrol measurements of the main input parameter of such models, that is of the spectral distribution of the absolute flux of the solar radiation in the soft x-ray and extreme ultraviolet ranges capable to ionize all the upper atmosphere gases. So though ionospheric models capable to describe its main parameters from day to day and also sudden ionospheric disturbances (SID) in the periods of solar flares are created, it is impossible to realize this models in practice due to the absence of the data on the absolute fluxes of the solar ionizing radiation and its variations related both to the solar rotation and periods of solar flares. For example, till now there is no particular measurements in the entire spectral range of the radiation ionizing the upper atmosphere (0.05–134 nm) for a solar flare of different classes. Therefore there is no possibility to check the model of SID and its development in time in various ionospheric regions.

The comparison between the community standard IRI empirical model and physics-based model shown that major discrepancies can be seen in both the horizontal and vertical structure of the electron density. It is unclear whether these discrepancies are the result of deficiencies in general circulation models, perhaps having to do with inadequate or missing physical processes, or are the results improper solar and geomagnetic inputs or uncertainties in the observational database used to construct the empirical models.

The next aspects of energy balance problem are considered:

- the absence of our knowledges of absolute spectral fluxes for energy penetrated to terrestrial upper atmosphere especially of ionizing irradiation from full Sun;

- the deficiency additional sources of ionoproduction and excitation at upper atmosphere as geocoronal resonance scattering radiation of solar EUV lines and the photoelectron and Auger electron fluxes from the conjugate points. For Auger electrons the angular distribution is nearly isotropic. The latter fact is especially important for energetics of ionosphere, since Auger electrons constitute the major part of the flux of fast ionospheric electrons carrying off energy from the planetary atmospheres [2];

- the shortcoming of ion formation processes (including the Auger effect, doubly photo-ionization) and optical excitation (including the exciting of the photoelectrons, Auger electrons and secondary electrons) - vibratory and electronic (including high excited - Rydberg states) [3]. Rydberg atoms and molecules participate in all basic processes in the near-Earth space plasma: excitation, ionization, recombination, and emission of atoms, molecules, and their ions, which is bound to show up in the energetic parameters of the upper atmosphere. Formation of ions in particular electronic excited states usually has not been considered though such processes are of major importance in the energetics of photoabsorption processes. This is caused by two reasons. First, all known variations of short-wave solar radiation are strongest in the spectral range where photoabsorption is defined completely by photoionization to highly excited states. Second, photoelectrons and Auger electrons gain the major part of energy of ionizing fluxes of solar radiation.

The increase of solar ionizing fluxes during solar flares causes the increase of the energy absorption in the atmosphere. In this case the relative magnification of solar fluxes have the maximum in the short wavelength spectral range below 2–4 nm, while the absolute increase of these fluxes is completely determined by the long wavelength part of the spectrum of ionizing solar radiation. However, for strong solar flares, the contribution of X–ray radiation to the additional ionization and to the increase of excitation of UV–emission of upper atmosphere exceeds the contribution of the EUV–radiation. This fact is connected with the main role of X–ray solar radiation in the generation of ionospheric photoelectron and Auger–electron spectra – the principal factor of additional ionization and UV–excitation.

At present there is no information in real time about the value of flux and spectral distribution of ionizing solar radiation during current solar flares. It is also impossible to calculate the characteristics of solar flares, which are the most important for ionospheric modeling. This circumstance confirms the necessity of the creation of the permanent space patrol of EUV and soft X–ray solar radiation. None of the current solar EUV irradiance measurements (from SOHO, SNOE, TIMED, SORCE or CORONAS-F) can be provided near real-time due to contact rate being only a few times per day and less from those spacecrafts, and also these measurements carried out only several times per day or/and only at the limited spectral ranges.

The second gap is in our knowledge of the response of the ionospheric and upper atmospheric UV–emission parameters on the solar flares of different classes. The main growth of the solar ionizing flux during flares takes place in soft X–ray region, where the principal part of quantum energy is transferred to photoelectrons and Auger electrons at a photoionization. Therefore, the important stage of ionospheric modeling is connected with the correct calculation of ionospheric photoelectrons up to maximum energies. For the verification of calculation models it is necessary to have the possibility to carry out the comparison of calculation results with experimental photoelectron spectra measured at ionospheric altitudes.

In fact, these measurements were not carried out, and at present only the data for high altitude have been published (the spacecraft ISIS, the satellite Interkosmos–19, the satellites DE–B and FAST). These data confirm the considerable (several times even for quiet Sun) decrease of the intensities of photoelectron fluxes in all models which do not take into account Auger electrons. But the principal gap in the experimental determination of the ionospheric and upper atmospheric response on the solar flares is the absence of the quantitative measurements of this additional effect. Really, at the ground radio sounding of ionosphere during solar flares usually there were the conditions of full radiowave absorption and therefore the experimental data about the flare growth of the ionization for different ionospheric regions are rare. The emissions of dayglow in the upper atmosphere only for UV–spectral range (for example, in 135–160 nm, that is, the Lyman–Birge–Hopfield system of bands N_2), are determined by the direct process of electron excitation and thus show the direct response to the growth of solar ionizing flux during flare. These measurements are very rare. At the same time, only a combined experiment, providing simultaneous measurements of the solar ionizing flux, UV–dayglow emissions and of the ionospheric photoelectron spectrum, will allow verification the predicting models.

The observations of the cosmonauts in the long-term flights enabled to discovered the large role of the resonance scattered in the geocorona of EUV emission of solar irradiation at the nightside upper ionospheric ionization and optical excitation [4]. Such a manifestation of the solar flare effect on the nocturnal terrestrial upper ionosphere up to 20 % in electron density has been detected for the first time. It was found out that previous calculations of the nocturnal photoionization of the upper atmosphere ignored the presence of a strong anisotropy of radiation from the geocorona, primarily over the zenith angle. The most intense radiation is incident from above on the nocturnal ionospheric F-region from the dawn segment at zenith angles close to 90 degrees. This is a key feature in consideration of the additional ion formation in the upper atmosphere, because, at the zenith angles of 70-90 degrees, the ionizing radiation with wavelengths of 30-91 nm is totally absorbed at the F-region altitude.

Moreover, consideration was given to the existence of the upward positive double charged ions of atomic oxygen ion flux from the F-region to the plasmasphere during the first tens of hours after a strong magnetic storm. This results in a significant increase in the this ionic density in the geocorona: up to 100-fold at altitudes higher than 1600 km (see data of GEOS-1, DE-1, EXOS-D (AKEBOHO), Interkosmos–24 and Interkosmos–25. This ion layer mainly contributes to the EUV geocoronal ionizing radiation (at the lines 30.4-, 50.7-, 70.3- and 83.3- nm)) [5]. That measurements at this spectral range carried out for terrestrial plasmosphere at the spacecraft IMAGE.

Conclusion

So far, no simultaneous measurements of the solar spectral irradiance and the global-scale character of the atmospheric and ionospheric composition and dynamics have been made. And neither irradiance models nor measurements are yet able to specify the absolute magnitude of soft X-ray and EUV irradiance to better than a factor of 2 at many geoeffective wavelengths. This aspect presents the key part of the energy balance problem in the terrestrial aeronomy. The solution of this problem would be possible if permanent absolute monitoring (for example Space Solar Patrol Mission) is provided for ionizing irradiation of full Sun with high spectral resolution - near 1 nm, and with temporal registration at the whole spectral range near one minute (that is close to duration of subflares and short (impulsive) phase of large flares) [6].

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