Report on DrSc thesis "Морфология и интерпретация пространственно-временных вариаций ионосферных параметров в спокойных условиях и во время возмущений различной природы" by Maksim V. Klimenko

The thesis consists of 40 publications in peer reviewed international journals and a text, which connects them, describes their results, and divides them into topical groups. All topical groups concern various aspects of ionospheric physics and they are interrelated. These groups are as follows:

(1) Numerical model-based examination of the ionosphere-thermosphere response to external disturbing factors, namely to geomagnetic storms, sub-storms, high-energy proton events and sudden stratospheric warmings.

(2) Model-based investigations and testing of methods of removing some substantial problems of ionospheric origin associated with applied tasks of radio communications, navigation and radiolocation.

(3) Specification of known and in some cases disclosed new features of spatial-temporal distribution of electron density at F-region heights, in topside ionosphere and in plasmasphere at various latitudes under quiet conditions.

(4) General scenario of processes in the ionosphere-thermosphere system at various phases of geomagnetic storm and after it end. The daytime positive ionospheric aftereffect of geomagnetic storms was disclosed, statistically confirmed and interpreted.

(5) Model-based specification, interpretation and evaluation of the role of effects of solar proton events, proton precipitations from magnetospheric tail and semi-trapped electrons from radiation belts in development of global ionospheric response to geomagnetic storms.

(6) The origin of negative ionospheric perturbations at auroral and middle latitudes during sudden stratospheric warmings was established, namely a decrease of O/N_2 due to heating of the upper atmosphere.

The results are in detail described in the 40 papers and I will not describe them all. Among particularly interesting results are the following results

- The F3-layer is formed at very low latitudes among crests of the equatorial ionization anomaly by action of the inhomogeneous vertical plasma drift.
- Longitudinal variations of the main ionospheric trough were found to be stable phenomenon independent of geophysical conditions. These longitudinal variations are more pronounced during daytime than at night and their mechanism differs between daytime and nighttime.
- Longitudinal variation of electron density at sub-auroral latitudes. The Weddel sea anomaly and Yakutian anomaly (higher nighttime/evening than noontime foF2) were found to be caused mainly by the quasi-vertical plasma drift along magnetic field lines under action of thermospheric wind.
- The plasmaspheric contribution to the total electron content (TEC) may be sometimes larger than that of the ionosphere, particularly at night under low solar activity

conditions near equator. The foF2 and TEC response to geomagnetic storms might be substantially different, which agrees with results of other authors.

- Calculations with GCM model TIP confirmed observed dominance of negative effects of geomagnetic storms at high latitudes and positive effects at low latitudes due to redistribution of thermospheric composition. Klimenko's publications disclosed various details of respective processes and mechanisms. The positive effects (increases) of midlatitude electron density in the storm recovery phase and after the end of storm he ascribes to increased O/N_2 ratio.
- Effects of sudden stratospheric warmings (SSW) on the ionosphere. The origin of negative SSW-related ionospheric disturbances at auroral and middle latitudes was attributed to decrease of the O/N_2 ratio. The key mechanism of the low-latitude ionospheric response he found to be changes of the zonal electric fields (vertical plasma drift).
- The scenario of examination of response of the ionosphere-thermosphere system has been developed using models GCM TIP a EAGLE was developed. An ionospheric response to solar proton events and proton precipitation from magnetospheric tail was found in the high latitude E region electron density and in TEC, the latter being caused partly by heating of ionospheric electrons with resulting increase of electron scale height in the topside ionosphere and plasmasphere.
- The verification of empirical ionospheric models and methods of their adaptation has been developed and realized. This was particularly important for the main ionospheric trough.

Comments to effects of SSWs on the ionosphere:

- At European middle latitudes prevail positive, not negative (these occur only sometimes) effects in foF2.
- Prevailingly accepted main drivers of low-latitude effects are effects of tides and planetary waves, particularly of strongly enhanced lunar tides.

Despite my comments to effects of SSWs, which are still even internationally not well understood, I have to claim that the results of M. Klimenko are impressive and very important for further development of ionospheric physics.

Maksim Klimenko is highly internationally recognized expert in the field of ionospheric research, particularly in F-region and topside ionosphere physics. His scientific results presented in thesis and his highly recognized position in the international ionospheric community clearly results in my recommendation to give him the degree of Doctor of physical and mathematical sciences.

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