UDC 550.388.2

S.V. PANASENKO, PhD, head of department, Institute of ionosphere, Kharkiv;
M.T. RIETVELD, Prof., senior scientist, EISCAT Scientific Association, Ramfjordmoen, Norway;
C. LA HOZ, Prof., UiT the Arctic University of Norway, Tromsø, Norway;
I.F. DOMNIN, D.Sc., Prof., director, Institute of Ionosphere, Kharkiv

TRAVELLING IONOSPHERIC DISTURBANCES OVER KHARKIV, UKRAINE, ACCOMPANYING THE OPERATION OF EISCAT HEATER FACILITY

We have detected the travelling ionospheric disturbances (TIDs) over Kharkiv with periods of 40 – 80 min occurring in the time range between 09:00 and 10:30 UT on November 22 and between 10:00 and 12:00 UT on November 23, 2012 during and after the operation of the EISCAT heater facility. The duration of these disturbances were less than 120 – 180 min. The relative amplitudes of the TIDs in electron density ranged from 0.05 to 0.15 and those in electron and ion temperatures were about 0.02 – 0.05. Assuming that these TIDs have been generated in the heated region, we described the possible mechanisms of their generation.

Key words: travelling ionospheric disturbances, powerful HF radio waves, incoherent scatter radar, heater facility.

Introduction. The ionospheric modification by high power HF radio waves is a kind of the active experiment conducted regularly after putting in use the ionospheric heating facilities in USA, Norway and Russia (former USSR). Powerful radio waves result in significant perturbations involving an increase in electron temperature, a change in electron density, low-frequency radiation of ionospheric current systems, generation of ionospheric irregularities with a wide range of scales, pump-induced artificial optical emissions, etc., in the irradiated ionospheric region [1, 3]. Some recent results of such experimental studies have been published in the papers [4, 5].

Large scale disturbances during heating experiments have been detected at the distances of the order of 1000 km, along with local ones. They appear in the F-region as traveling ionospheric disturbances (TIDs) related to generation and propagation of acoustic-gravity waves (AGWs) in the upper atmosphere. Such disturbances were determined to be strongly depending on space weather conditions, the time of day, season of the year, the mode of the heating facility operation, etc (see, e.g., [6]). Furthemore, since the parameters of these artificial disturbances appear to be close to the parameters of natural perturbations originating constantly in the ionosphere, it is often difficult to separate these two

types of events. Nevertheless, the efforts to detect the disturbances occurring far from the heated plasma volume have been continuing [7 – 9]. *Domnin et al.* [7] found wave disturbances in the ionosphere over Kharkiv, Ukraine during the operation of "Sura" facility. *Kunitsyn et al.* [8] reported about wavelike disturbances coming out from the ionospheric region over the "Sura" heater. *Mishin et al.* [9] observed AGWs induced by HAARP HF heating. *Pradipta and Lee* [10] presented the results indicating the origin of AGWs from the edge of the HAARP facility heated region.

The purpose of this paper is to present and analyze the TIDs in the ionospheric F region measured by the Kharkiv incoherent scatter radar during the operation of the EISCAT heating facility.

Instrumentation and data sets. In 2012 a coordinated experimental campaign was conducted. The facilities employed included the EISCAT Heater, Dynasonde and incoherent scatter (IS) radar, located near Tromsø, Norway as well as IS radar and ionosonde, located near Kharkiv, Ukraine. The experiments were done at the morning hours on November 22 – 24.

The ionospheric heater transmitted pump waves with O-mode polarization having a frequency from 4.04 to 7.10 MHz. On November 22, 2012, it was operated during 05:33 – 09:00 UT period in 15-min cycles (9 min on, 6 min off), after which the pump modulation of 15 min on, 15 min off was alternated with ± 2 min square wave modulation during 15-min period, 15 min off. On November 23, 2012, the heater operation with 15-min cycles was from 05:03 until 09:00 UT followed by such pump modulation as in previous day. On November 24, 2012, the HF pump cycles were different. A sporadic-E layer appeared during the observations, so this experiment was exluded from the study. The effective radiated power increased from 140 to 850 MW being dependent on pump frequency and antenna array. The antenna beam was directed to the magnetic zenith which is 12° south of zenith.

The diagnostics of ionospheric plasma was performed by the Kharkiv IS radar being at the distance of about 2400 km. The time variations in incoherent scatter power, electron density and electron and ion temperatures being observed at different altitudes have been analyzed.

Results. Figure 1 presents temporal variations of pump frequency as well as F2-region critical frequency f_oF2 over EISCAT heater site. As seen in this figure, the heating was in underdense conditions from the experiment start to about 08:00 UT both on November 22 and November 23, followed by overdense conditions. After about 08:00 UT, the pump frequency increased stepwise to be slightly less than f_oF2 (see Figure 1). The F2-region critical frequency over Kharkiv during these experiments was greater and fell within the range of 5.0 to 10.6 MHz and 5.4 to 10.0 MHz on November 22 and 23, respectively.

The temporal variations of the main ionospheric parameters over Kharkiv obtained from the IS radar data are indicated in Figures 2 and 3. These data covering the height range of 200 – 325 km have been filtered to detect the oscillations initiated by AGWs. The analysis shows that the fluctuations with the largest relative amplitudes were in the range of 40 – 80 min.

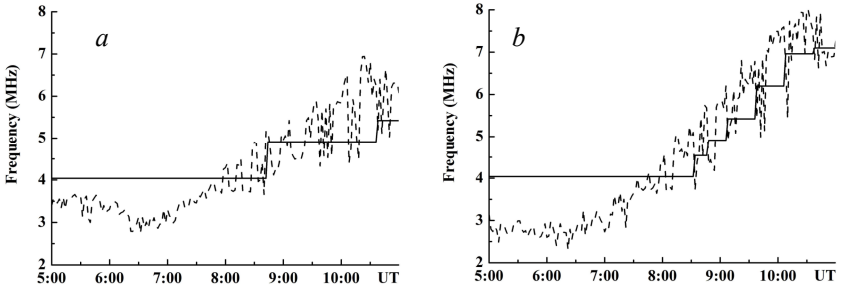

Fig. 1 – Pump frequency (solid line) and F2-region critical frequency measured by the Dynasonde (dashed line) during the EISCAT heating experiments conducted on: *a* – November 22; *b* – November 23, 2012

The main criterion for TIDs selection was the occurrence of fluctuations with close dominant periods in the electron density, the electron temperature and the ion temperature simultaneously during almost the same time interval. Moreover, these fluctuations must cover a height range more than 50 km.

The strong variations in all ionospheric parameters being analysed occured between 04:00 – 07:00 UT and again 12:00 – 17:00 UT on November 22, 2012. Their relative amplitude values reached 0.05 – 0.2 for different parameters depending on the height (see Figure 2). On November 23, 2012, such fluctuations with similar relative amplitudes were observed during 04:30 – 07:30 UT and 14:00 – 17:00 time intervals (see Figure 3). These TIDs arose before the start or after the end of heating experiments. They are likely to be caused by the passage of solar terminators over Kharkiv IS radar site.

A pronounced TID was observed during the time interval from about 09:00 to 10:30 UT on November 22, 2012. As illustrated in Figure 2, the fluctuations with the dominant period of about 60 min were primarily observed at heights of 200 – 290 km. The values of the relative amplitude ranged from 0.05 to 0.15 for the electron density and 0.02 – 0.05 for the electron and ion temperatures. The duration of oscillations was usually about 2 periods. The TID was also detected during the heating experiment conducted on November 23, 2012. Its parameters

were similar to that described above, but the time interval with oscillations was from about 10:00 to 12:00 UT (see Figure 3).

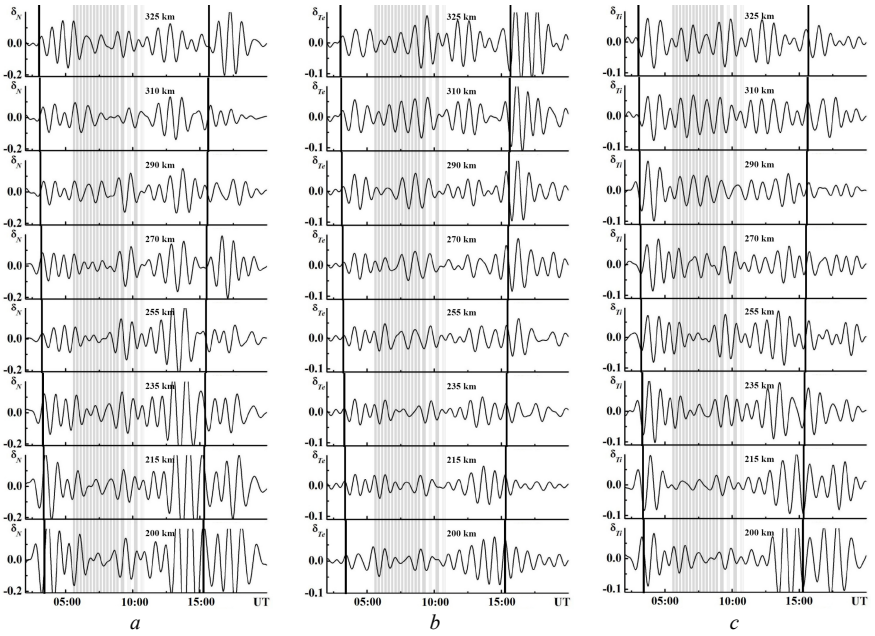

Fig. 2 – Relative fluctuations of *a* – electron density, *b* – electron temperature and *c* – ion temperature filtered in 40 – 80 min band, at different altitudes on November 22, 2012. The shadow strips indicate heater-on times. The solid lines mark the times of sunrise and sunset terminator moving in the atmosphere above the Kharkiv incoherent scatter radar location.

Discussion. As is well known (see, e. g., [9]), the strong effects of high power HF radio wave on the F2 region are produced when the pump frequency is equal to the upper hybrid resonance (UHR) frequency near the F2-peak. This became possible only after a change in the heating conditions from underdense to overdense, i.e after about 08:00 UT. Thus, if the TID observed after 09:00 UT on November 22 and after 10:00 UT on November 23, 2012 originated in the heated ionospheric region, their apparent horizontal velocity are not less than 330 – 660 m/s taking into account a transit time of 1 – 2 hours and the distance of about 2400 km. Such apparent horizontal velocities are associated with AGWs. However, since the exact time of wave disturbance onset is unknown, we

can not exclude the propagation of waves of another type, e. g. magnetohydrodynamic in nature.

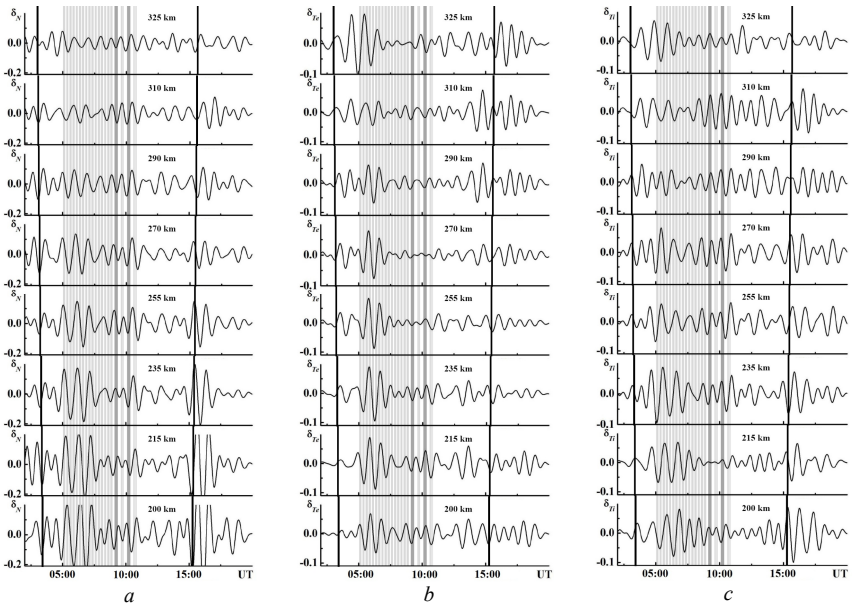

Fig. 3 – Same as Fig. 2 but for relative fluctuations on November 23, 2012

Possible mechanisms for AGW generation in the heated region have been proposed in [7, 8, 10]. The authors of [8] indicated the heater-induced wave disturbances to be generated at the edge of the heated region by sharp thermal gradients. *Mishin et al.* [7] and *Chernogor* [10] concluded that such disturbances can be produced by periodic heating of neutral gases. Moreover, other mechanisms may involve the modulation of ionospheric currents in the dynamo region, UHR region and in the ionospheric F-region by the propagating radio wave [10]. The detailed estimations made by *Chernogor* [10] showed the most effective mechanism of TIDs generation during the ionospheric heating is modulation of the effective electron collision frequency in the UHR region.

The main problem we met is that we have no possibility to obtain the arrival direction of TIDs. Therefore, based only on the results of these measurements we can not assert that the observed TIDs arrived from the heated region. However, even in the case of finding the arrival detection, the origin of the observed TIDs is not obvious. The AGWs producing the TIDs are known to be omnipresent in the atmosphere due to a large number of their natural and man-made sources. In

particular, the detected TIDs could be generated in the polar region, although the experiments have been conducted during magnetically very quiet conditions when the planetary *Ap* and *Kp* indexes not exceed 7 and 1, respectively. Thus, long-term, regular measurements are needed to detect and identify high-power radio wave-induced TIDs as well as estimate their parameters during different space weather conditions.

Conclusions. TIDs in electron density, electron and ion temperatures have been detected in the ionospheric F2-region with Kharkiv IS radar during the operation of the EISCAT heating facility. An increase in relative amplitudes of wave disturbances with periods of 40 – 80 min in the height range from 200 to 290 km has been observed. Such disturbances are likely caused by AGW propagation generated by periodic HF modification of the ionosphere, although they can be generated by many other natural or man-made origins of AGWs and TIDs. The possible mechanisms for AGW generation in the modified region are the modulation of ionospheric currents in the UHR region or in the dynamo region by high power radio waves, the periodic heating of neutral gas and sharp thermal gradients at the edge of the heated region.

References: 1. *Stubbe P.* Ionospheric modification experiments the Tromsø Heating Facility / *P. Stubbe, H. Kopka, M.T. Rietveld, A. Frey, P. Høeg, H. Kohl, E. Nielsen, G. Rose, C. LaHoz, R. Barr, H. Derblom, Å. Hedberg, B. Thidé, T. B. Jones, T. Robinson, F. Brekke, T. Hansen, O. Holt* // J. Atm. Terr. Phys. – 1985. – Vol. 47, No 12. – P. 1151-1163. **2.** *Fejer J.A.* Ionospheric modification experiments with the Arecibo Heating Facility / *J.A. Fejer*, *C.A. Gonzales*, *H.M. Ierkic*, *M.P. Sulzer, C.A. Tepley, L.M. Duncan, F.T. Djuh, S. Ganguly, W.E. Gordon* // J. Atm. Terr. Phys. – 1985. – doi: 10.1016/0021-9169(85)90086-8. **3.** *Migulin V.V.* Investigation in the U.S.S.R. of non-linear phenomena in the ionosphere // *V.V. Migulin, A.V. Gurevich* // J. Atm. Terr. Phys. – 1985. – Vol. 47, No 12. – P. 1181-1187. **4.** *Vierinen J.* High latitude artificial periodic irregularity observations with the upgraded EISCAT heating facility / *J. Vierinen, A. Kero*, *M.T. Rietveld* // J. Atm. Sol.-Terr. Phys. – 2013. – V. 105 – 106. – P. 253-261. **5**. *Frolov V.L.* Sounding of the ionosphere disturbed by the "Sura" heating facility radiation using signals of the GPS satellites / *G.P. Komrakov*, *V.E. Kunitsyn*, *A.M. Padokhin*, *A.E. Vasiliev*, *G.A. Kurbatov* // Radiophys. Quantum Electron. – 2010. – Vol. 53, No 7. – P. 379-400. **6.** *Garmash K.P.* Elegtromagnetic and geophysical effects in the near-Earth plasma, stimulated by high power high frequency radio waves / *K.P. Garmash, L.F. Chernogor* // Electromagnetic phenomena. – 1998. – V. 1. No 1. – P. 90-110. (in Russian) **7.** *Mishin E.* F2-region atmospheric gravity waves due to high-power HF heating and subauroral polarization streams / *E. Mishin, E. Sutton, G. Milikh, C. Roth, M. Förster* // Geophys. Res. Lett. – 2012. – Vol. 31, L11101, doi: 10.1029/2012GL052004. **8.** *Domnin I.F.* Results of Radiophysical Study of Wave Disturbances in the Ionospheric Plasma During Its Heating by High-Power HF Radio Transmission of "Sura" facility / *I.F. Domnin*, *S.V. Panasenko, V.P. Uryadov, L.F. Chernogor* // Radiophysics and Quantum Electronics. – 2012. – Vol. 55, No 4. – P. 253-265. **7.** *Kunitsyn V.E.* Sounding of HF heating-induced artificial ionospheric disturbances by navigational satellite radio transmissions / *V.E. Kunitsyn, E.S. Andreeva, V.L. Frolov, G.P. Komrakov, M.O. Nazarenko, A.M. Padokhin* // Radio Sci. – 2012. – Vol. 47, RS0L15, doi:10.1029/2011RS004957. **8.** *Pradipta R.* Investigation of acoustic gravity waves created by anomalous heat sources: experiments and theoretical analysis / *R. Pradipta, M.C. Lee* // Physica Scripta. – 2013. – Vol. 155, 014028, doi:10.1088/0031-8949/2013/T155/014028. **9.** *Gurevich A.V.* Nonlinear Phenomena in the Ionosphere / *A.V. Gurevich* – New York, Heildelberg,

Berlin: Springer – Verlag, 1978. – 465 pp. **10.** *Chernogor L.F.* The mechanisms for generation of infrasound oscillations in the upper atmosphere by high power radio transmission / *L.F. Chernogor* // Radio Physics and Radio Astronomy. – 2012. – Vol. 17, No 3. – P. 240-252. (in Russian)

Received 08.09.2014

UDC 550.388.2

Travelling ionospheric disturbances over Kharkiv, Ukraine, accompanying the operation of EISCAT heater facility / S. V. Panasenko, M. T. Rietveld, C. La Hoz, I. F. Domnin // Bulletin of NTU "KhPI". Series: Radiophysics and ionosphere. – Kharkiv: NTU "KhPI", 2014. – No. 47 (1089). – P. 92-98. Ref.: 10 titles.

Обнаружены перемещающиеся ионосферные возмущения (ПИВ) над Харьковом с периодами 40 – 80 мин, имевшие место в течение 09:00 – 10:30 UT 22 ноября и с 10:00 до 12:00 UT 23 ноября 2012 г. в период и после работы нагревного стенда EISCAT. Продолжительность этих возмущений не превышала 120 – 180 мин. Относительные амплитуды ПИВ концентрации электронов составляли 0.05 – 0.15, а ПИВ температур электронов и ионов равнялись 0.02 – 0.05. В предположении, что эти ПИВ были сгенерированы в нагретой области, описаны возможные механизмы их генерации.

Ключевые слова: перемещающиеся ионосферные возмущения, мощные радиоволны, радар некогерентного рассеяния, нагревный стенд.

Виявлено рухомі іоносферні збурення (РІЗ) над Харковом з періодами 40 – 80 хв, що мали місце впродовж 09:00 – 10:30 UT 22 листопада та з 10:00 до 12:00 UT 23 листопада 2012 р. в період і після роботи нагрівного стенда EISCAT. Тривалість цих збурень не перевищувала 120 – 180 хв. Відносні амплітуди РІЗ концентрації електронів складали 0.05 – 0.15, а РІЗ температур електронів та іонів дорівнювали 0.02 – 0.05. За припущення, що ці РІЗ були згенерровані в нагрітій області, описано можливі механізми їх генерації.

Ключові слова: рухомі іоносферні збурення, потужні радіохвилі, радар некогерентного розсіяння, нагрівний стенд.