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Investigation into AGW/TID generated by atmospheric and geomagnetic storm activity

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## Investigation into AGW/TID generated by atmospheric and geomagnetic storm activity

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### Executive summary

The range of problems concerning the atmospheric gravity waves (AGW) and traveling ionospheric disturbances (TID) for today is a point of significant attention for geospace research. That interest is based on several reasons. For the first, modern ionospheric models cannot predict plasma disturbances induced by AGW/TID. For the second, those processes act as a passive interferes for numerous ground and space systems. For the third, AGW/TID contains information about their origin and can be used as probe signals for investigating their sources. AGW/TID are generated by different natural and anthropogenic phenomena. Powerful weather fronts, earthquakes, geomagnetic storms, volcanic eruptions are referred to the first group. The second one consists of industrial and military explosions, rocket launches, thermal, chemical, radioactive pollution and so on.

The project aims at systematic observations of AGW/TID, identification of their sources, expanding on the physical models of wave generation and propagation at the different altitudes, and advancing the understanding of the relationship between the atmospheric and space weather systems.

The main technical approach of the Project is based on remote diagnostics of the near-Earth environment using the different RF methods. Namely: Doppler multi-position HF ionospheric sounding; coherent vertical sounding of the ionosphere (CVSI); ULF magnetometry; and multi-position GNSS radiometry. Note that for processing the GNSS data in Antarctic, the algorithms for analysis of total electron content (TEC) the spaced points by the signal of the same GPS satellite were used. For the dense network of the permanent GNSS stations in Europe the algorithms of AGW/TID mapping as movie-maps demonstrating the TID propagation were developed.

Characteristic feature of all these techniques are round the clock observations, creation of digital archives and provision of Internet access to them. Two main observation sites upgraded within the Project. First one is located at the Antarctic Peninsula, that is one of the most meteorologically disturbed areas of the Globe, at the Ukrainian Antarctic Station *Akademik Vernadsky (UAS)*. And second one is Low Frequency Observatory (LFO) of IRA NASU situated at quiet mid latitude region in Ukraine.

We together with colleagues from Boston College (USA) put into operation a 2-position coherent system for measuring the Doppler frequency shifts (DFS) of probe signals in Antarctica. Transmitting and one receiving sites were situated at *UAS*; second coherent 3-channel receiving site was installed at *Palmer* station (USA). The radio path between *UAS* and *Palmer* is oriented along the meridian; the receiving sites are spaced by 54 km. Systematic measurements of DFS were carried out synchronously at both sites since May 2015 till March 2019. Quasi-periodic DFS variations stimulated by AGW/TID were found out. Their parameters like time periods, and projection of wave vectors along meridian direction were calculated and analyzed. The median daily wavelet scalograms were calculated. Seasonal dependence for scalogram's parameters which repeated from year to year was discovered. The comparison of wavelet scalogram for DFS of probe HF signals, magnetic field and surface air pressure was performed. The results of analysis show that the periods and magnitudes of DFS variations associated with AGW/TID are increased with growth of auroral activity.

A 3-position scheme of Doppler sounding of the ionosphere was realized at Ukraine in Kharkiv region during the second year of the Project. For that purposes additionally to the receiving site located at LFO two similar receiving positions were created. Reflecting points form a rectangular triangle with first cathetus of 40 km oriented in West-East direction and second one of 25 km in North-South direction. All receiving sites are remotely controlled using software designed by Project participants. TID parameters are estimated using the variations of DFS and their time

shifts between spaced sites. A large statistics of TID parameters over the Kharkiv region were obtained. A rose of directions of TID propagation was estimated.

Statistical processing of the data of oblique Doppler HF sounding of TID on the RWM (Moscow) – LFO radio path was conducted.

Large databases of DFS quasiperiodic variations with periods less than 5 minutes caused by MHD waves in the ionosphere were created for the both UAS and Ukraine regions.

Since the March 2017 at the UAS and since January 2018 at Kharkiv region the TID measurements are carried out with Doppler ionosondes designed on the base of software defined radio USRP. The algorithms for visualizing height-time diagrams of ionosphere conditions were developed. The first estimates of TID parameters using the data of CVSI were made. It was shown that the DFS variations are more informative parameter for the TID with periods lower the half-hour. For the TID with longer periods the virtual reflection height variations are better than DFS changes.

The analysis of the data of ionospheric radioscopes by the signals of GNSS received at three spaced positions located at Antarctic Peninsula area created in the frames of the LARISSA Project was carried out. It was shown that for quiet geomagnetic conditions at the daytime the TID propagate mostly toward the North and North-West; at the night and twilight the main movement direction is to North-West; mean velocity of movement estimated as 100...130 m/s, bigger speeds corresponded to the day conditions. For the geomagnetically disturbed days the probability of TID observations increased at evening and night.

Variations of the ionospheric parameters in the magneto conjugate areas of Northern America and Antarctic Peninsula were analyzed for the time of geomagnetic storm of St. Patrick's day (March 17, 2015).

A statistical analysis aimed at establishing the causes of sporadic ionospheric structures appearing and connection of their parameters with tropospheric or space sources of AGW/TID was carried out.

Within the modeling the oscillations of air volumes at tropopause and lower stratospheric heights forced by upwelling streams of tropospheric convection, which mostly observed at middle and high latitudes along the atmospheric fronts were considered as potential sources of AGW. A Kelvin-Helmholtz instability along the jet flows over atmospheric fronts, the Solar terminator, and orographic factors can be considered as natural tropospheric sources of AGW as well. Releasing the energy of geomagnetic storms take place within dynamo-region where electric currents lead to mechanical movements and heating of the environment.

It was shown that space-time correlation between atmosphere storms and level of plasma disturbances at the ionospheric heights could be explained by propagation of small- and medium-scale AGW. This part of AGW spectrum propagates with so big elevation and relatively small horizontal speed that can lead to quick ionospheric reaction on tropospheric disturbances at the not big distances from the AGW sources.

Geomagnetic storms manifest themselves through the large-scale AGW propagating towards the equator from auroral ovals. Large-scale AGW are characterized by bigger horizontal and smaller vertical velocities. Due to that the causal relationship between the processes in low and mid atmosphere with ionospheric disturbances provided by large-scale AGW could not be measured. The directions of TID propagation measured in F region are oriented against the prevailing thermospheric winds. That fact obviously indicates the filtering role of the atmosphere concerning to AGW propagation.

The Project results are highlighted on the website of the Department of Radio physics of Geospace of IRA NASU.

### **Cooperation with foreign collaborators**

During the second year the systematic communication with Coordinator of the Project Evgeny Mishin (Space Vehicles Directorate, Air Force Research Laboratory, RVBXXI) and with Kent Miller, coordinator from EOARD were conducted. The quarter reports have been sent to both organizations. A presentation concerning the Project results are planned at the seminar in AFRL in June 2019.

Observations in Antarctica were conducted in a fruitful collaboration with Dr. V. Paznukhov, and Dr. K. Groves, our colleagues from the Institute for Scientific Research of Boston College, whom installed the coherent receiving HF equipment at *Palmer* station and carried out the monitoring of TID using the technique of Frequency and Angular sounding of ionosphere by the signals transmitted from *UAS Akademik Vernadsky*. This technique was developed earlier in IRA NASU. We have an access to the database of HF measurements conducted at *Palmer* station.

Fruitful collaboration in research area of the Project was conducting in frames of association agreement with scientists from Jaroslaw Dabrowski Military Academy of Technology, Warsaw, Poland (Prof. Fiqurski and Dr. Niekell). Polish colleagues provided us with GNSS database for calculating the TEC and its variations from more than 600 spatially separated permanent receiving stations located in Central and East Europe. It made possible to developing correspond algorithms and obtaining the space-time structure of TID with high resolution. Collaboration with colleagues from Space Research Center of Polish Academy of Sciences in the field of HF ionospheric sounding was launched in the frames of Agreement of Cooperation between institutions since March 2018.

By agreement with Project coordinator Evgeny Mishin, the Project participants took part in two ionospheric heating campaigns in March and April 2018. The first campaign was conducted with Arecibo heating facility, the second one with HAARP heater. We carried out the Doppler registrations of signals of heating facilities and probe signals in

Antarctica, Ukraine and Northern Scandinavia. That became possible due to developing and upgrading the network of HF Doppler receivers performed in frames of Project.

Project results have been presented and discussed in frames of three sections of CEDAR-2017 Workshop that was held in Keystone Resort, CO, 18-23 June, 2017. The results were demonstrated and discussed with European colleagues in frames of workshop entitled “Mutual benefits between atmospheric research and radio based science over polar regions”, on December 4th, 2017 at the Royal Observatory of Belgium.

The results were also presented and discussed at

- URSI General Assembly and Scientific Symposium, August 19-26th (Montreal, Canada);
- Fourth UK-Ukraine-Spain Meeting on Solar Physics and Space Science, 28 August - 1 September, 2017 (Kyiv, Ukraine);
- AGU Fall Meeting, 11-15 December 2017 (New Orleans, USA);
- EUREF Symposium 2017, May 17-19 (Wroclaw, Poland);
- 17-th Ukrainian Conference on Space Research, August 21–25, 2017 (Odesa, Ukraine);
- VIII International Antarctic Conference, May 16-18, 2017 (Kyiv, Ukraine);
- International Radio Electronic Forum – 2017 (Kharkiv, Ukraine);
- 42<sup>nd</sup> COSPAR Scientific Assembly 2018, July 14 - 22, 2018 in Pasadena, California, US;
- XXXV SCAR, Davos, Switzerland, 15-26 June 2018;
- 18-th Ukrainian Conference on Space Research, September 21–25, 2018 (Kyiv, Ukraine);
- 2019 URSI Asia Pacific Radio Science Conference AP-RASC-2019, 09-15 March, 2019, India Habitat Centre, New Delhi.

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### Papers

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8. G. Nykiel, M. Figuski, **Yu.M. Yampolski, Y.M. Zanimonskiy**. Continental-wide maps of TEC variations as a tool for monitoring of ionosphere. Status and prospects. Poster presented at the EUREF Symposium 2017. May 17-19. Wroclaw, Poland.
9. **A. Zalozovski, Y. Yampolski**, E. Mishin. Response of ionospheric sporadic structures over the Antarctic Peninsula (Akademik Vernadsky) on geomagnetic and meteorological activities. CEDAR-2017 Workshop, Keystone, CO, USA, 18-23 June 2017. [Electronic resource]: [http://cedarweb.vsp.ucar.edu/wiki/images/8/83/2017CEDAR\\_Polar\\_Zalozovskyy.pdf](http://cedarweb.vsp.ucar.edu/wiki/images/8/83/2017CEDAR_Polar_Zalozovskyy.pdf)
10. **A. Zalozovski, Y. Yampolski**, V. Paznukhov, E. Mishin, **A. Sopin**. Daily and seasonal variations of TID parameters over the Antarctic Peninsula CEDAR-2017 Workshop, Keystone, CO, USA, 18-23 June 2017. [Electronic resource]: [http://cedarweb.vsp.ucar.edu/wiki/images/f/f7/2017CEDAR\\_gwave\\_Zalozovskyy.pdf](http://cedarweb.vsp.ucar.edu/wiki/images/f/f7/2017CEDAR_gwave_Zalozovskyy.pdf)

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12. **A.V. Zalizovski, O.V. Koloskov, Yu.M. Yampolski.** RF diagnostics of troposphere-ionosphere coupling at the Ukrainian Antarctic station Akademik Vernadsky. Workshop - Mutual benefits between atmospheric research and radio based science over Polar Regions. Report of Contributions. – Royal Observatory of Belgium, 2017. – P. 16-17.
13. **A.V. Koloskov, Y.M. Yampolski, A.V. Zalizovski, A.S. Kashcheyev, S.B. Kashcheyev, A.O. Sopin, Y.M. Zanimonskiy, E. Mishin, V. Paznukhov.** HF and GNSS-TEC diagnostic of wavelike ionospheric disturbances over the Antarctic Peninsula. URSI General Assembly and Scientific Symposium, August 19-26th, 2017: symp. proc. – Montreal, Canada, 2017. – G35P-3.
14. **V. Paznukhov, K. Groves, K. Kraemer, Y. Yampolski, A. Kashcheyev, A. Sopin, S. Kashcheyev, A. Zalizovsky.** First results of bistatic HF observations of ionospheric irregularities in Antarctic Peninsula region. URSI General Assembly and Scientific Symposium, August 19-26th, 2017: symp. proc. – Montreal, Canada, 2017. – G35P63.
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16. **A.V. Zalizovski, O.V. Koloskov, Yu.M. Yampolski.** RF diagnostics of troposphere-ionosphere coupling at the Ukrainian Antarctic station Akademik Vernadsky. Workshop - Mutual benefits between atmospheric research and radio based science over Polar Regions. Report of Contributions. – Royal Observatory of Belgium, 2017. – P. 16-17.
17. **A.V. Zalizovski, Y.M. Yampolski.** A connection of sporadic E layers of the ionosphere over the Antarctic Peninsula with geomagnetic activity. 17-th Ukrainian Conference on Space Research, Book of abstracts, Odesa, August 21–25, 2017, p. 148.
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19. **E.M. Zanimonskiy, A.A. Koloskov, A.I. Reznichenko.** Comparison of results of TEC evaluation using global maps and data of individual GNSS stations. International Radio Electronic Forum – 2017. Radiolocation, Satellite navigation, Radio monitoring. Proceedings of the Forum. – Kharkiv, Kharkiv National University of Radio Electronics, 2017. – p. 205 – 206 (in Russian).
20. **Yu.M. Yampolski, L.N. Lytvynenko, A.V. Zalizovski, A.V. Koloskov.** Geospace research in Antarctica, in Ukraine and in the Arctic (results and prospects). VIII International Antarctic Conference, Book of abstracts, Kyiv, May 16-18, 2017, p. 32 (in Russian).
21. **Sopin, A.A. Y.M. Yampolski, V.V. Paznukhov, S.B. Kashcheyev, A.V. Zalizovski.** Two-position HF sounding of the ionosphere at the UAS-Palmer radio path. VIII International Antarctic Conference. Book of abstracts, Kyiv, May 16-18, 2017, p. 165-167 (in Russian).
22. **Kashcheyev, S.B., A.V. Koloskov, A.S. Kashcheyev, I.I. Pikulik, B.Yu. Gavrylyuk, Yu.M. Yampolski.** Modernization of the electromagnetic observatory at UAS. VIII International Antarctic Conference. Book of abstracts, Kyiv, May 16-18, 2017, p. 32 (in Russian).
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24. **Y.M. Zanimonskiy, O.V. Dudnik, G. Nykiel, M. Figurski.** Investigation of magnetospheric effects of geomagnetic storm using data from European GNSS network and low-orbit satellites. Conference: Astronomy and space physics in the Kyiv University At: Kyiv, Ukraine. May 2018.
25. **Nykiel G., Y. Zanimonskiy, A. Koloskov, M. Figurski.** Estimation of the height of ionospheric inhomogeneities based on TEC variations maps obtained from GPS observations. Presented COSPAR Scientific Assembly 2018, July 14 - 22, 2018 in Pasadena, California, US.  
[https://www.cospar-assembly.org/uploads/documents/AbstractCD\\_COSPAR-18.iso](https://www.cospar-assembly.org/uploads/documents/AbstractCD_COSPAR-18.iso)
26. **Andriy Zalizovski, Yuri Yampolski, Alexander Koloskov, Sergey Kashcheyev, Bogdan Gavrylyuk.** Response of parameters of HF signals at the long radio paths on solar activity. 2019 URSI Asia Pacific Radio Science Conference AP-RASC-2019, 09-15 March, 2019, India Habitat Centre, New Delhi. Proceedings: We-G06-6.
27. **Andriy Zalizovski, Beata Dziak-Jankowska, Iwona Stanislawka, Yuri Yampolski.** Connection between sporadic E layers and geomagnetic field variations at the Antarctic Peninsula and Europe. 2019 URSI Asia

### Prospects of future development

Using and expanding the results and infrastructure obtained within the current Partner Project P667, we propose to develop a physics-based engineering model for predicting variations in the parameters of HF radio signals caused by traveling ionospheric disturbances and MHD waves. In frames of the P667 Project some coherent systems of HF receiving and transmitting facilities have been created (three in the Antarctic and three in Ukraine). A huge amount of experimental data on variations in the parameters of HF signals caused by the propagation of TID, MHD waves and plasma turbulence has been collected and partly analyzed. A causal relationship between geophysical disturbances (such as weather and magnetic storms) and sporadic ionospheric structures was shown. Simplified models for the propagation of TID and MHD waves in the ionosphere have been developed.

Accumulated experience makes possible to develop a physics-based engineering model for predicting HF signal behavior on both short and tilt medium-length radio paths (up to 3000 km) for HF propagation in high- and mid-latitude ionosphere. Proposals for the new Partner Project have been sent to EOARD, AFOSR through “grants.gov” service.

Project manager



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For the Coordinating Institution

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