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Observation of large-scale TIDs during minor CIR /HSS - and ICME-driven magnetic storms occurred in October 2022

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Magnetic storms cause significant perturbations in the atmosphere and magnetosphere and often initiate traveling atmospheric and ionospheric disturbances (TADs and TIDs, respectively), propagating from high to middle and even low latitudes. Despite the fact, that the main attention is usually paid to extreme or severe magnetic storms, new publications reported that during moderate and even minor storms of different drivers, the energy is effectively deposited to the magnetosphere and ionosphere resulting in changes in background atmospheric and ionospheric state, generation of acoustic-gravity waves and TIDs [1].

Our study is aimed at detecting and characterizing large-scale TIDs observed over the European region during two space weather events having different drivers. The first magnetic storm driven by high-speed stream / corotating interaction regions (HSS / CIR) event occurred during 13 – 16 October 2022. The second magnetic storm was initiated by the arrival of interplanetary coronal mass ejection (ICME) and took place on 21 – 24 October 2022. There were the periods of moderate solar activity, with the F10.7 varying from 114.4 to 129.4 s.f.u. and from 103.9 to 113.6 s.f.u, respectively. The *Dst*-index reached its minimum values of -62 nT at 11 UT on 14 October and -70 nT at 18 UT on 22 October. The maximum *Kp* values for the analyzed periods were 4.667 and 5.333, respectively (https://wdc.kugi.kyoto-u.ac.jp/, https://kp.gfz-potsdam.de/).

We employed the data from European dense GNSS receiver network stored in Madrigal database (https://cedar.openmadrigal.org/openmadrigal) together with those acquired by four European ionosondes (JR055, DB049, EB040, AT138) for joint analysis. The ionograms with a 5-min cadence were manually scaled. The methodologies are described in detail in [1,2].

During HSS/CIR-driven event, we observed large-scale TIDs during the recovery phase of the storm. The time intervals where such TIDs propagated southward are 11 – 18 UT on 14.10.2025 and 17 – 20 UT on 15.10.2025. GNSS observations show the nearly constant presence of perturbations at high latitudes. The dominant TID periods were 60 – 80 min and the horizontal phase velocities equaled about 600 m/s. The relative amplitudes in *NmF2* variations ($\delta NmF2$) usually did not exceed 0.1 (or 10 % from background). The detrended TEC variations (dTEC) have absolute amplitudes of 0.3 – 0.6 TECU. During the ICME-driven storm, the large-scale TIDs observed near the period where the *Dst*-index was minimal (10 – 20 UT on 22.10.2025) and also during the following substorm occurred at the recovery phase (17 – 21 UT on 23.10.2025). During the first interval, $\delta NmF2$ variations had greater relative amplitude for all ionosondes (0.15 – 0.2) than for previous event, while other characteristics had similar values.

Thus, both minor HSS/CIR- and ICME-driven magnetic storms led to significant intensification of large-scale TIDs propagating to middle latitudes.

1. S. V. Panasenko, K. D. Aksonova, D. Burešova, et. al., "Large-scale traveling ionospheric disturbances over central and eastern Europe during moderate magnetic storm period on 22–24 September 2020", *Advances in Space Research*, **72**, 10, November 2023, pp. 4364-4378, doi: 10.1016/j.asr.2023.09.035.

2. S. V. Panasenko, Y. Otsuka, M. van de Kamp, et. al., "Observation and characterization of traveling ionospheric disturbances induced by solar eclipse of 20 March 2015 using incoherent scatter radars and GPS networks", *Journal of Atmospheric and Solar-Terrestrial Physics*, **191**, September 2019, 105051, doi: 10.1016/j.jastp.2019.05.015.