URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Comparative statistical study of mid-latitude MSTIDs over two latitudinal regions using dense GNSS network.

R.O. Sherstyukov, A.D. Akchurin, O.N. Sherstyukov
Kazan Federal University, Kazan, Russia

Abstract

This work is devoted to potential sources and mechanisms of the mid-latitude MSTIDs formation based on the analysis and comparison of statistical data in two regions: 1 region near Samara (~ 55 N. 50 E), 2 region near Sevastopol (~ 45 N, 35 E). The data obtained using a dense GNSS receivers network (> 150 pcs.) in the European part of the Russian Federation. The study was carried out using a new statistical method for determining the vertical slopes of the MSTIDs phase front. It was found that summer nighttime MSTIDs over the region near Samara (~ 55 N, 50 E) have the traditional south-west directions of propagation and sloping forward phase fronts, while near Sevastopol (~ 45 N, 35 E) northwest directions with sloping backward phase fronts. We suggest that the influence of Mid-latitude Summer Nighttime Anomaly may be a trigger for the northwestward MSTIDs, as unlike the southwestern MSTIDs, they are observed 10 degrees south and only in the summer months and September. We do not propose the exact mechanism of their formation in this article, however, we note that sloping backward phase fronts of MSTIDs couldn't be form by the GWs with sources in troposphere. The propagation directions of the southwestward MSTIDs near Samara (~ 55 N, 50 E) are consistent with those that are expected for the growth of Perkins instability.

1 Introduction

For more than 50 years, mid-latitude MSTIDs have been studied by various instruments: ionosondes [1-4], dense networks of GPS receivers [5-7], coherent and incoherent scattering radars [8,9], Doppler radars [10,11], all-sky imagers [12,13], etc.
Midlatitude MSTIDs is usually divided into 2 main types: (1) daytime MSTIDs, with the dominant direction of propagation to the southeast and clockwise rotation with time; (2) nighttime MSTIDs, which mainly propagate to the southwest.
It is mainly believed that MSTIDs are a manifestation of gravity waves (GWs) at the heights of the ionosphere [14]. However, the GWs theory has difficulty in analyzing the dominant directions of the propagation of MSTIDs.
For example, in [15, 16], performed with all-sky imagers, it was shown that the southeastern direction of propagation prevails for nighttime MSTIDs. This preferred direction of propagation cannot be explained only by the classical theory of GWs; presumably, electrodynamic forces can also play an important role in the creation of nighttime MSTIDs [17]. One of the possible mechanisms of their creation is Perkins instability [18], because the stretching of the MSTIDs phase fronts from the northwest to the southeast in the northern hemisphere is consistent with the conditions for the growth of Perkins instability.
The search for reliable mechanisms continues, therefore, the collection of MSTIDs parameters is an urgent task. The peculiarity of this study lies in the collection of the MSTIDs parameters in several latitudinal regions. Another feature is the determination of vertical slopes of MSTIDs phase fronts using GNSS satellites.

2 Results

Let us consider the daily-seasonal parameters of the MSTIDs at different latitudes. The GNSS receivers network we use allows us to select two region with nearby receivers. The difference in latitude between the two regions is about 10 degrees (1 region near Samara ~ 55 N. 50 E, 2 region near Sevastopol ~ 45 N, 35 E). Figure 1 shows the distribution of azimuths of the direction of MSTIDs propagation relative to the observation time (UT), the color indicates the number of events.

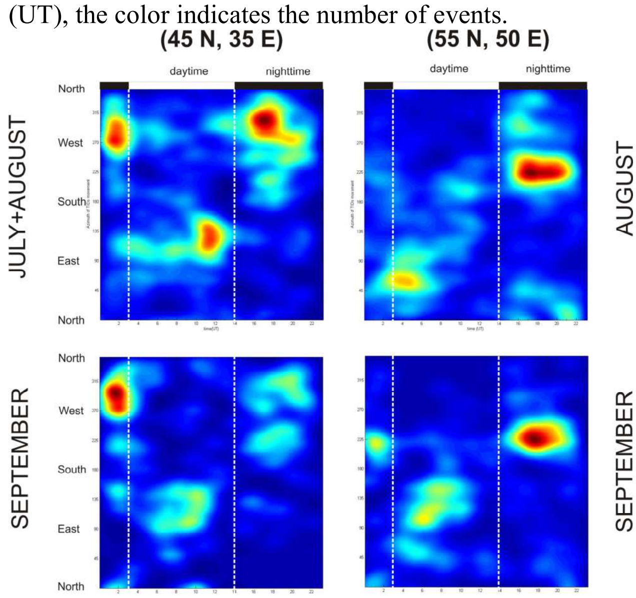

Figure 1. The diurnal distribution of azimuths of the MSTIDs propagation over two regions (1 region (right) ~ 55 N, 50 E and 2 region (left) ~ 45 N, 35 E).

In July and August, daytime MSTIDs for 2 region (~ 45 N) are observed with traditional southeastern directions, while for 1 region (~ 55 N), the directions change from northeast to southeast (see Figure 1). The difference of MSTIDs characteristic may be due to the fact that for the 2 region (~ 45 N), data were used for half of July and half of August, due to the absence of full data, and for the first region (~ 55 N), data were used only for August. It should also be noted that the propagation directions of daytime MSTIDs for September look consistent, in both regions the southeastern directions are mainly observed (see Figure 1).

Nevertheless, for the summer months, the propagation directions of nighttime MSTIDs are different, so for the 1 region (~ 55 N), southeastern directions are observed, and for the 2 region (~ 45 N) northeastern. This trend is observed for three months: July, August, September.

The method for determining the vertical slopes of MSTIDs phase fronts is based on the fact that the GNSS sounding method is sensitive to the orientation of the satellite-receiver lines-of-sight (LOS) relative to the vertical slope of phase front of the MSTID. The TEC variations are maximum when the vertical slope of the phase front coincides with the elevation angle of the satellite-receiver LOS [19].

Consider the case when we observe the MSTIDs and determine the vertical slope of their phase front. At 22: 00-22:40, August 30, 2019, we were able to observe the MSTIDs, in the form of clear banded structures with TEC variations > 0.3 TECU and horizontal wavelength of more than 250 km on two-dimensional TEC perturbation maps by G30 satellite (see Figure 2 (bottom and right)) with LOS orientation in the yellow zone (see Figure 2 (top)). At the same time, satellite G13 in the red zone (see Figure 2 (top)) does not detect the similar banded structures (see Figure 2 (bottom and left)).

This case is indicative, since the satellites have an almost mirror position relative to each other, their elevation angles at 22:20 are 58 and 60 degrees, and the azimuths are 270 and 120 degrees. In this case, the MSTIDs propagating in the northwest direction, which is observed from the yellow zone by satellite G30 and is not observed from the red zone by satellite G13, can have only a sloping backward phase front, i.e., the normal of the phase front is directed upward. This case is also of interest because most of the MSTIDs with southern propagation directions have a sloping forward phase front (the normal of the phase front is directed downward).

It should be noted that even such a large MSTID for midlatitudes (with amplitudes greater than 0.3 TECU and a horizontal wavelength of more than 250 km.) cannot be observed simultaneously by GNSS satellites in the yellow and red zones. Therefore, the relative position of azimuths of the satellite-receiver LOS and the azimuth of MSTIDs propagation uniquely determine the observed the vertical slope (sloping forward or sloping backward) of the phase front of the midlatitude MSTIDs.

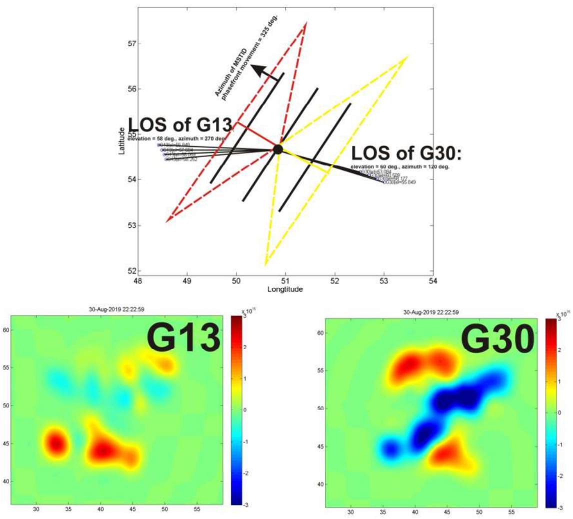

Figure 2. The arrangement of the horizontal phase fronts of the MSTIDs and the LOS of satellites G13 and G30 (top). The satellite-receiver LOS are indicated by the thin black lines, the horizontal phase fronts of the MSTIDs are indicated by heavy black lines, the arrow shows the phase front propagation direction. Two-dimensional maps of TEC variations for satellites G13, G30, August 30, 22:22 UT, 2019 (bottom)

To illustrate and determine the vertical slope of the phase front, figures 3 are constructed, on which the azimuths of MSTIDs propagation (y-axis) and the azimuths of the satellite-receiver LOS (x-axis) are plotted for all cases when MSTIDs can be detected. The color indicates the number of detected MSTIDs. Thus, for each MSTID, the slope of its phase front is determined. In the figure, the zones with the corresponding vertical slopes of the phase front are marked and bounded by white dashed lines.

Of greatest interest are the vertical slopes of the phase front for the summer months and their comparison for the two regions of observation. As already noted, the differences of direction propagation direction differences are observed for nighttime MSTIDs in July, August and September. At these months, in 1 region (~55 N), southwestern MSTIDs and in 2 regions (~45 N) northwestern MSTIDs, are observed. As it turned out, these MSTIDs differ also in the vertical slope of the phase front. The nighttime MSTIDs in 1 region (~ 55 N) have a traditional sloping forward phase front (see Figure 3 (right)), and in 2 region (~ 45 N) MSTIDs have a sloping backward phase front (see Figure 3 (left))

The same characteristics of the vertical slopes of the daytime and nighttime MSTIDs are observed in September. The vertical slopes of the MSTIDs phase fronts at nighttime in the two regions are also differ (doesn’t shown in this paper).

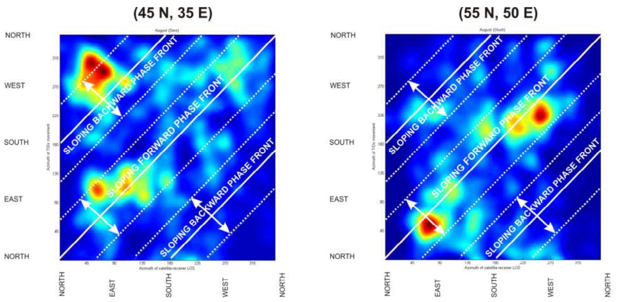

Figure 3. The azimuths of the MSTIDs propagation (Y axis) and the corresponding azimuths of the satellite-receiver LOS (X axis) for which MSTIDs are observed (for August). Color indicates the number of detected MSTIDs. The 1 region (~55 N, ~50 E) in the right, the 2 region (~45 N, ~35 E) in the left. The dotted lines limit the zones of sloping forward/backward phase fronts.

3 Discussions and conclusions

Jacobson et al. (1995) reported that daytime and nighttime MSTIDs over Los Alamos (35.9 N, 106.3 W) have different seasonal variations in terms of the frequency of occurrence and the direction of propagation [20]. They showed that daytime MSTIDs are frequently occurs during the winter and the equinoxes and have a dominant southward propagation direction, while nighttime MSTIDs are often found during the summer solstice and the autumn equinox and have a dominant west/northwest directions.

Mercier (1996) showed that over Nancy, France (47.3 N, 2.2 E), two modes of time distribution with dominant directions to the southeast in the daytime and to the southwest at night are observed [21]. Based on our observations, we can conclude that the directions of nighttime MSTIDs in the works of Jacobson and Mercier do not coincide due to the difference of latitudes of observation.

Nighttime MSTIDs are associated with the development of Perkins instability, i.e. electrodynamic forces are the main source of nighttime MSTIDs. Nevertheless, Medvedev et al. (2017) showed that most of the nighttime and daytime MSTIDs have preferred directions corresponding to the wind filtering mechanism [22]. The MSTIDs formed by GWs with alleged tropospheric sources should have a sloping forward phase front [23]. Using a new method, which allows us to collect statistics of the vertical slopes of phase fronts by GNSS sounding, we were able to establish that nighttime MSTIDs with northwestward directions have a sloping backward phase fronts, so they cannot be associated with GWs, in any case, with GWs extending from heights below the F region. However, the we do not propose in this work a mechanism of forming the northwestward MSTIDs, assuming only that the Mid-latitude Summer Nighttime Anomaly could be trigger, since in the autumn and winter the northwestward MSTIDs in the region >45 N and 35-50 E not observed. The data for the spring months have not yet been processed.

4 Acknowledgements

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

5 References

1. Booker H., The role of acoustic gravity waves in the generation of spread-F and ionospheric scintillation, Journal of Atmospheric and Terrestrial Physics, Vol. 41, No. , P. 501-515, 1979.
2. Booker, H. G., P. K. Pasricha, and W. J. Powers, Use of scintillation theory to explain frequency-spread on F-region ionograms, J. Atmos. Terr. Phys., 48, 327354, 1986.
3. Bowman, G. G., Movements of ionospheric irregularities and gravity waves, J. Atmos. Terr. Phys., 30, 721-734, 1968.
4. Bowman, G. G., A review of some recent work on mid-latitude spread-F occurrence as detected by ionosondes, J. Geomag. Geoelectr., 42, 109-138, 1990.
5. Saito, A., Miyazaki, S., and Fukao, S.: High resolution mapping of TEC perturbations with the GSI GPS network over Japan, Geophys. Res. Lett., 25, 3079–3082, 1998.
6. Kotake, N., Otsuka, Y., Tsugawa, T., Ogawa, T., and Saito, A.: Statistical study of medium-scale traveling ionospheric disturbances observed with the GPS networks in Southern California, Earth Planets Space, 59, 95–102, 2007.
7. Sherstyukov, R.O., Akchurin, A.D., Sherstyukov, O.N., Collocated ionosonde and dense GPS/GLONASS network measurements of midlatitude MSTIDs, Advances in Space Research, 61, 7, 1 April 2018, pp. 1717-1725
8. Ogawa, T., N. Nishitani, Y. Otsuka, K. Shiokawa, T. Tsugawa, and K. Hosokawa (2009), Medium-scale traveling ionospheric disturbances observed with the SuperDARN Hokkaido radar, all-sky imager, and GPS network and their relation to concurrent sporadic E irregularities, J. Geophys. Res., 114, A03316.
9. Djuth, F. T., Zhang L. D., Livneh D. J., Seker I., Smith S. M., Sulzer M. P., Mathews J. D., and Walterscheid R. L. (2010), Arecibo's thermospheric gravity waves and the case for an ocean source, J. Geophys. Res., 115, A08305, doi:10.1029/2009JA014799.
10. Georges, T. M. (1968), HF Doppler studies of traveling ionospheric disturbances, J. Atmos. Terr. Phys. 30, 735-746.
11. Petrova, I. R., Bochkarev, V. V., Teplov, V. Y., & Sherstyukov, O. N. (2007). The daily variations of doppler frequency shift of ionospheric signal on middle-latitude radio lines. Advances in Space Research, 40(6), 825-834. doi:10.1016/j.asr.2007.06.043
12. Seker, I., D. J. Livneh, and J. D. Mathews (2009), A 3-D empirical model of F region Medium-Scale Traveling Ionospheric Disturbance bands using incoherent scatter radar and all-sky imaging at Arecibo, J. Geophys. Res., 114, A06302, doi:10.1029/2008JA014019.

13. Lee, C. C., Y. A. Liou, Y. Otsuka, F. D. Chu, T. K. Yeh, K. Hoshinoo, and K. Matunaga (2008), Nighttime medium-scale traveling ionospheric disturbances detected by network GPS receivers in Taiwan, J. Geophys. Res., 113, A12316, doi:10.1029/2008JA013250.
14. Hines, C. O.: Internal atmospheric gravity waves at ionospheric heights, Can. J. Phys., 38, 1441–1481, 1960.
15. Shiokawa, K., Ihara, C., Otsuka, Y., and Ogawa, T.: Statistical study of nighttime medium-scale traveling ionospheric disturbances using midlatitude airglow imagers, J. Geophys. Res., 108, 1052, doi:10.1029/2002JA009491, 2003a.
16. Martinis, C., Baumgardner, J., Wroten, J., and Mendillo, M.: Seasonal dependence of MSTIDs obtained from 630.0 nm airglow imaging at Arecibo, Geophys. Res. Lett., 37, L11103, doi:10.1029/2010GL043569, 2010.
17. Kelley, M. C. Electrodynamics of midlatitude spread F. Electrohydrodynamic waves? A new look at the role of electric fields in thermospheric wave dynamics [Text] / M. C Kelley, C.A. Miller // Journal Of Geophysical Research. – 1997. – Vol. 102, No. A6. – P. 11539-1154.
18. Perkins, F.: Spread F and ionospheric currents, J. Geophys. Res., 78, 218–226, 1973.
19. Sherstyukov, R.O., Akchurin, A.D., Sherstyukov, O.N., Features of observing for weak MSTIDs by GNSS satellites, 2019 URSI Asia-Pacific Radio Science Conference, AP-RASC 2019, doi: 10.23919/URSIAP-RASC.2019.8738525.
20. Jacobson, A. R., R. C. Carlos, R. S. Massey, and G. Wu, Observations of traveling ionospheric disturbances with a satellite-beacon radio interferometer: Seasonal and local time behavior, J. Geophys. Res., 100, 1653–1665, 1995.
21. Mercier, C., Some characteristics of atmospheric gravity waves observed by radio-interferometry, *Ann. Geophys.*, 14, 42-58, 1996.
22. Medvedev, A. V., K. G. Ratovsky, M. V. Tolstikov, A. V. Oinats, S. S. Alsatkin, and G. A. Zherebtsov (2017), Relation of internal gravity wave anisotropy with neutral wind characteristics in the upper atmosphere, J. Geophys. Res. Space Physics, 122, 7567–7580, doi:10.1002/ 2017JA024103.
23. Vadas, S. L. (2007), Horizontal and vertical propagation and dissipation of gravity waves in the thermosphere from lower atmospheric and thermospheric sources, J. Geophys. Res., 112, A06305, doi:10.1029/2006JA011845.