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Comment on angeo-2022-24
Anonymous Referee #2

Referee comment on "Ionospheric Effects over the People’s Republic of China from the Super-Powerful Tropospheric Western Pacific Phenomenon of September–October 2018: Results from Oblique Sounding" by Leonid Chornogor et al., Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2022-24-RC2 , 2022

Reply to Anonymous Referee #2

Dear Anonymous Referee #2,

Thank you very much for your valuable comments that have helped the Authors greatly improve the draft of their paper.

Your comments are placed together with the Authors’ answers (marked in green), and the changes made in the text of the manuscript, are also marked in green.

Authors.

Dear Dr. Ana Elias!

Thank you for the nomination to evaluate the manuscript "Ionospheric Effects over the People’s Republic of China from the Super-Powerful Tropospheric Western Pacific Phenomenon of September–October 2018: Results from Oblique Sounding" by Dr. Chernogor et al. The topic sounds interesting and within the scope of the Annales Geophysicae. The authors performed an interesting experiment to investigate the ionosphere using oblique soundings during the passage of the Super Typhoon Kong-Rey in 2018. I have few comments and suggestions to improve the manuscript to be appreciated by you and the authors and I am willing to revise the manuscript again, if you consider appropriate.

Please, see below, my comments:

Main points

1. From my point of view, the citations of the scientific works is not good form. When there are more than three works cited in the beginning of the statement, I suggest removing those citations to the end of the phrase as the suggestion below. Please, note that it repeats throughout the manuscript.

Lines 63-4: -> Observations of AGWs from meteorological origin have been reported elsewhere (Boška and Šauli, 2001; Šindelarova et al., 2009; Chernigovskaya et al., 2015).

Lines 65-6: -> Recently, theoretical studies on the coupling between the lower and upper atmosphere by the propagation of AGWs have been published as well (Hickey et al., 2001, 2011; Kuester et al., 2008, Gavrilov and Kshevetskii. 2015, Karpov and Kshevetskii, 2017).

Dear Anonymous Referee #2, Thank you very much for this comment. We have removed the multiple citation to the end of the phrases throughout the manuscript.

2. I missed connections between the paragraphs of the Introduction. It is not clear how the state of art of the investigated topic and how are, in fact, the contributions of the authors to

understanding the coupling between the typhoon and the ionosphere. I would suggest revising the Introduction to improve the text itself.

Dear Anonymous Referee #2, Thank you very much for this comment. We have re-organized the paragraphs in the Introduction (marked in green) as follows:

1 Introduction

A violent tropical cyclone arising in the northwestern Pacific Ocean is termed the typhoon. In record-breaking typhoons, the atmospheric pressure drops down to 870 hPa, whereas the pressure deficit reaches 140 hPa, and the wind speed attains a maximum of 85 m/s, with 94 m/s maximum gusts.

Prasad et al. (1975) were the first to ascertain the influence of meteorological processes, namely, a tropical cyclone on the ionosphere. Hung and Kuo (1978, 1985) described observations of traveling ionospheric disturbances (TIDs) as the manifestations of the atmospheric gravity waves (AGWs) generated by hurricanes. Krishmam Raju et al. (1981) have studied the influence of infrasound generated by thunderstorms. Observations of AGWs from meteorological origin have been reported elsewhere (Boška and Šauli, 2001; Šindelarova et al., 2009; Chernigovskaya et al., 2015).

The coupling between typhoons and the ionosphere and overlying magnetosphere occurs via a range of mechanisms. Observational studies conducted in recent years have shown that typhoons significantly influence the upper atmosphere, including the ionosphere. Recently, theoretical studies on the coupling between the lower and upper atmosphere by the propagation of AGWs have been published as well (Hickey et al., 2001, 2011; Kuester et al., 2008, Gavrilov and Kshevetskii. 2015, Karpov and Kshevetskii, 2017). Such a mechanism for coupling is naturally called the acoustic–gravity mechanism (Chernogor, 2006, 2012).

Typhoons are accompanied by water vapor condensation, the development of powerful convective lift, and the appearance of severe thunderstorms (Mikhailova et al., 2000, 2002). Lightning discharges act to generate electromagnetic emissions that may be capable of heating electrons and perturbing the electron density in the ionospheric *D* region (Nickolaenko and Hayakawa, 1995; Chernogor, 2006, 2012). The large enough fluxes of electromagnetic emissions lead to pitch angle scattering of energetic electrons in the radiation belts via wave-particle interaction, and consequently, part of the electrons precipitates into the lower ionosphere (Inan et al., 2007; Voss et al., 1984, 1998; Bortnik et al., 2006). As a result, secondary perturbations in the plasma conductivity (~100–150 km altitude) and in the geomagnetic and electric fields capable of affecting processes in the magnetosphere can arise. Such a mechanism should be considered the electromagnetic mechanism (Chernogor, 2006, 2012).

The increase in the quasi-stationary electric field may be of different origin (Mikhailova et al., 2000; Isaev et al., 2002, 2010; Sorokin et al., 2005; Pulinets et al., 2014). Localized ~10^{-9}–10^{-8} A/m^2 electric currents arise within thunderstorm clouds at 10–15 km altitude, which disturb the global electric circuit and increase by 1–2 orders of magnitude quasi-sinusoidal electric fields that are mapped to the ionosphere and magnetosphere and affect the motion of high-energy electrons trapped in the radiation belts. Under specified conditions, the precipitation of these electrons may occur into the ionosphere, and a repeated coupling between the subsystems in the ocean–atmosphere–ionosphere–magnetosphere (OAIM) system occur (Chernogor, 2006, 2012). This mechanism for coupling may be termed the electric mechanism (Chernogor, 2006, 2012). Thus, powerful typhoons are capable of governing the coupling between the subsystems in the OAIM system. A lot of studies deal with the acoustic–gravity mechanism, and therefore this mechanism has been studied better than the others.

The major role AGWs play in coupling different atmospheric regions under the influence of typhoons and hurricanes on the upper atmosphere is discussed by Okuzawa et al. (1986), Xiao et al. (2007), Vanina–Dart et al. (2007), Afraimovich et al. (2008), Polyakova and Perevalova (2011, 2013), Zakharov and Kunitsyn (2012), Suzuki et al. (2013), Chou et al. (2017), Li et al. (2017, 2018), Chum et al. (2018), Zakharov et al. (2019, 2022). These researchers invoked various measurement techniques for probing the ionosphere: GPS technology, ionosondes, rocket techniques, and HF Doppler technique.

The manifestations of the ionospheric response to the super typhoons Hagibis, Ling-Ling, Faxai, and Lekim in radio wave characteristics in the 5–10 MHz band have been studied by Chernogor et al. (2021, 2022) and Zheng et al., (2022). The variations in the main features of radio waves have been determined, and aperiodic and quasi-sinusoidal perturbations in the electron density have been ascertained.

The effect of sudden stratospheric warming events, variations in space weather, solar activity, and of AGWs on the coupling between the subsystems in the atmosphere–ionosphere system has been analyzed in the review by Yiğit et al. (2016), whereas twenty years earlier, the review by Hocke and Schlegel (1996) only pointed to the AGW/TID relationship. Since then, data have been compiled for some parameters of medium-scale traveling ionospheric disturbances (MSTIDs), one of the mechanisms for affecting the ionosphere by typhoons. The parameters of interest to typhoon/ionosphere coupling studies include the propagation direction. Of particular interest to the current study, which is conducted in the area roughly to the west of Japan, are data collected in Japan. Using airglow images, Kubota et al. (2000) and Shiokawa et al. (2003) showed a clear preference for southwestward propagation, while Fukushima et al. (2012) observations made over a seven-year period in Indonesia estimated the propagation direction to be within ±30 degrees from the source directions of MSTIDs in 81% of the MSTID events. Otsuka et al. (2008) investigated a relationship between nighttime MSTIDs and sporadic *E* layer, another phenomenon of interest to typhoon/ionosphere coupling. Observations made in the western hemisphere are in agreement with those made over the Pacific Ocean (Paulino et al., 2016; Frissell et al. 2014; Paulino et al., 2018). The latter study by Paulino et al. is noteworthy because it showed that the observed anisotropy in the propagation direction can fully be explained by the filtering process of the wind.

The results of recent observations are presented in papers by Kong et al. (2017), Li et al. (2018), Zhao et al. (2018), Song et al. (2019), Wen and Jin (2020), Chen et al. (2020), Ke et al. (2020), Zhao et al. (2020), Das et al. (2021), Freeshah et al. (2021), Chernogor et al. (2021, 2022), Zakharov et al. (2019, 2022). The influence of typhoons on the ionosphere might be expected to significantly depend on typhoon parameters, local time, season, solar cycle changes, and on the state of atmospheric and space weather. To date, there remains insufficient knowledge about this influence and therefore the study of the ionospheric response to any new typhoon is of interest. In this paper, Super Typhoon Kong-Rey, the most powerful worldwide typhoon in 2018, has been chosen to analyze the ionospheric response to the typhoon action.

The scientific objectives of this study is to determine the response of the ionosphere to the approaching super typhoon Kong-Rey making use of variations in Doppler spectra, Doppler shift, and HF signal amplitudes recorded at oblique propagation paths, as well as to estimate the parameters of the ionospheric perturbations. An estimate of the joint influence of the typhoon and the dusk terminator is a phenomenon of interest. The observations were made using the Harbin Engineering University, the People's Republic of China (PRC), multifrequency multiple path coherent software defined radio system for probing the ionosphere at oblique incidence.

3. In the present manuscripts, the authors are assuming that the periodic oscillations in the Doppler shift signal might be gravity waves from typhoons. They can be, but gravity waves can be produced by several other atmospheric processes, even small scale structures compared to typhoons. So, in this case, from my point of view, it will be very welcome, further analysis on the periodic structure in order to resolve the phases and find out the propagation direction of the wave structures. Certainly, they are propagating from the region of the typhoon. If the authors could address this point, the scientific discussion on gravity waves will be stronger and more convincing.

Dear Anonymous Referee #2, Thank you very much for this comment. Especially we are grateful to you for the last sentence in the following paragraph we have inserted into the Discussion section (after the first two paragraphs):

In order to find out that the observed Doppler shift variations are associated with the typhoon, the Doppler variations were low-pass filtered, and the Doppler variations, with periods of greater than 40 min, were found to occur during the period 10:00–14:00 UT, October 02, 2018, along all propagation paths. A characteristic feature, a fading, which could be traced in all temporal dependences of the identified Doppler variations, was selected to be analyzed. The UT moments, t^*, when this feature arrived at each propagation path midpoint are presented in Table 4. At 12:00 UT on October 02, 2018, the typhoon center was located at (18.9° N, 131.2° E) at the distances D from the propagation path midpoints, with the midpoint of the 9.750 MHz propagation path being closest (2,492 km) to the typhoon center, while other midpoints were found to be at (2,492 + ΔD) km ranges, where the characteristic feature arrived with time delays of Δt with respect to the arrival time at the 9.750 MHz midpoint. As can be seen in Table 4, the ΔD and Δt yield the values of the apparent speeds, v, quite close to each other. These estimates testify to the adequacy of the assumption that the propagation of the disturbances from the typhoon is the cause of the observed Doppler shift variations. The mean value of the speed of the strongest 60 – 70-min period component, estimated to be 205±6 m/s, corresponds to a TID with wavelength equal to approximately 800 km. Taking a look at the Kong-Rey trajectory in Figure 1, one can notice that the TIDs traveled northwestward in this case, contrary to the southwestward direction observed in this area of the world in the climatological study by Shiokawa et al. (2003).

Table 4. Distances D over which TIDs traveled at apparent speeds v and arrived at the propagation pass midpoints from the center of typhoon Kong-Rey with relative time delays Δt at the UT moments t^*.

f (MHz)	6.015	6.055	6.080	6.175	6.600	9.500	9.520	9.750
D (km)	2,574	2,454	3,296	2,826	2,595	2,803	2,963	2,492
ΔD (km)	120	38	842	372	141	349	509	0
t^* (UT)	11:00	10:53	12:00	11:20	11:03	11:15	11:25	10:50
Δt (min)	10	3	70	30	12	28	38	-
v (m/s)	200	210	200	205	195	205	220	-

Specific points:

1. Line 93: The minimum value of the pressure is different from the value presented in the first paragraph of the introduction.

Dear Anonymous Referee #2, Thank you very much for this comment. Indeed, they should differ because the Introduction is concerned with features of typhoons in general, while Line 93 refers to typhoon Kong-Rey.

2. I also missed some citations on periodic gravity waves/MSTID, which could sustain the argumentation of the authors. Please, see some suggestions:

Dear Anonymous Referee #2, Thank you very much for this collection of interesting studies. We have included the suggested citations into the Introduction section (marked in green) after Line 72, as follows:

The effect of AGWs, sudden stratospheric warming events, variations in space weather, and of solar activity on the coupling between the subsystems in the atmosphere–ionosphere system has been analyzed in the review by Yiğit et al. (2016), whereas twenty years earlier, the review by Hocke and Schlegel (1996) could only point to the AGW/TID relationship. Since then, data have been compiled for some parameters of medium-scale traveling ionospheric disturbances (MSTIDs), one of the mechanisms for affecting the ionosphere by typhoons. The parameters of interest to typhoon/ionosphere coupling studies include the propagation direction. Of particular interest to the current study, which is conducted in the area roughly to the west of Japan, are data collected in Japan. Using airglow images, Kubota et al. (2000) and Shiokawa et al. (2003) showed a clear preference for southwestward propagation, while Fukushima et al. (2012) observations made over a seven-year period in Indonesia estimated the propagation direction to be within ±30 degrees from the source directions of MSTIDs in 81% of the MSTID events. Otsuka et al. (2008) investigated a relationship between nighttime MSTIDs and sporadic *E* layer, another phenomenon of interest to typhoon/ionosphere coupling. Observations made in the western hemisphere are in agreement with those made over the Pacific Ocean (Paulino et al., 2016; Frissell et al. 2014; Paulino et al., 2018). The latter study by Paulino et al. is noteworthy because it showed that the observed anisotropy in the propagation direction can fully be explained by the filtering process of the wind.

Into the Reference list, we have also inserted the references:

Frissell, N. A., Baker, J. B. H., Ruohoniemi, J. M., Gerrard, A. J., Miller, E. S., Marini, J. P., West, M. L., and Bristow, W. A.: Climatology of medium-scale traveling ionospheric disturbances observed by the midlatitude Blackstone SuperDARN radar, *J. Geophys. Res. Space Physics*, 119, 7679– 7697, doi:10.1002/2014JA019870, 2014.
Fukushima, D., Shiokawa, K., Otsuka, Y., and Ogawa, T.: Observation of equatorial nighttime medium-scale traveling ionospheric disturbances in 630-nm airglow images over 7 years, *J. Geophys. Res.*, 117, A10324, doi:10.1029/2012JA017758, 2012.
Hocke, K. and Schlegel, K.: A review of atmospheric gravity waves and travelling ionospheric disturbances: 1982-1995, *Ann. Geophys.*, 14, 917–940, https://doi.org/10.1007/s00585-996-0917-6, 1996.
Kubota, M., Shiokawa, K., Ejiri, M. K., Otsuka, Y., Ogawa, T., Sakanoi, T., Fukunishi, H., Yamamoto, M., Fukao, S., Saito, A.: Traveling ionospheric disturbances observed in the OI 630-nm nightglow images over Japan by using a Multipoint Imager Network during the FRONT Campaign, Geophys. Res. Lett., 27, 4037–4040, https://doi.org/10.1029/2000GL011858, 2000.
Otsuka, Y., Tani, T., Tsugawa, T., Ogawa, T., Saito, A.: Statistical study of relationship between medium-scale traveling ionospheric disturbance and sporadic E layer activities in summer night over Japan, J. Atmos. Solar-Terr. Phys., 70, 2196-2202, ISSN 1364-6826, https://doi.org/10.1016/j.jastp.2008.07.008, 2008.
Paulino, I., Medeiros, A. F., Vadas, S. L., Wrasse, C. M., Takahashi, H., Buriti, R. A., Leite, D., Filgueira, S., Bageston, J. V., Sobral, J. H. A., and Gobbi, D.: Periodic waves in the lower thermosphere observed by OI630 nm airglow images, Ann. Geophys., 34, 293–301, https://doi.org/10.5194/angeo-34-293-2016, 2016.
Paulino, I., Moraes, J. F., Maranhão, G. L., Wrasse, C. M., Buriti, R. A., Medeiros, A. F., Paulino, A. R., Takahashi, H., Makela, J. J., Meriwether, J. W., and Campos, J. A. V.: Intrinsic parameters of periodic waves observed in the OI6300 airglow layer over the Brazilian equatorial region, Ann. Geophys., 36, 265–273, https://doi.org/10.5194/angeo-36-265-2018, 2018.
Shiokawa, K., Ihara, C., Otsuka, Y., and Ogawa, T.: Statistical study of nighttime medium-scale traveling ionospheric disturbances using midlatitude airglow images, *J. Geophys. Res.*, 108, 1052, doi:10.1029/2002JA009491, 2003.

Dear Anonymous Referee #2, Thank you very much for your comments. Your suggestions and comments have helped the Authors to significantly improve the manuscript.

Sincerely,
Authors.