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Interactive comment on "Even moderate geomagnetic pulsations can cause fluctuations of foF2 frequency of the auroral ionosphere" *by* Nadezda Yagova et al.

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Dear Referee,

thank you for your helpful report. Point-by-point answers are given below

Anonymous Referee #2 Received and published: 19 August 2020 In their manuscript "Even moderate geomagnetic pulsations can cause fluctuations of foF2 frequency of the auroral ionosphere", Yagova et al. explore variations of the ionosphere F2 region critical frequency (foF2) and ultra-low frequency (ULF) waves in the Pc5 and Pi3 frequency bands detected at auroral latitudes. Using ground magnetometer and

ionosonde data spanning years 2014 and 2015, the authors examine the power, coherence and phase difference of perturbations in the daytime ionosphere and Pc5/Pi3 geomagnetic pulsations, distinguishing a subset of events during periods of magnetic quiescence and moderate magnetic storms with coherence greater than 0.5 from ULF wave signatures in the ionosphere observed under conditions favourable to strong geomagnetic storms. This extends previous studies by Pilipenko et al. (2014a and 2014b) that considered ULF wave-driven oscillations in the ionosphere F2 region during strong and small magnetic storms. Furthermore, the manuscript presents a new methodology to the automated detection of the foF2 critical frequency from ionograms that could be of interest for the research community working on determining factors that influence the amplitude and phase of perturbations in the ionosphere as these are detected on the ground. There are, however, several issues that hinder my recommendation of this manuscript for publication in Annales Geophysicae in its present form. There are major issues with the English language use, several typographical errors and in general, it is poorly written making it difficult to understand the scientific rationale behind this study.

Thank you very much for the comments. We are working on improvement of the language of the MS.

For example, in line 19, it reads: "Modulation of ionospheric parameters by Pc5 pulsations was reported : : :", without detailing which parameters are meant here. In the same line, it goes on to say: "Majority of publications are based on the radar observation : : :" (which would more correctly read "The majority of publications are based on radar observations : : :"), without making it clear to which publications the authors refer.

These points will be clarified

It would be worthwhile to establish in the Introduction the need for a study such as the present by listing past publications focused on perturbations in the ionosphere driven by ULF waves. Early results on geomagnetic pulsations in the

ULF wave frequency range associated with total electron content (TEC) fluctuations date back to 1976 and include the following: - Davies & Hartmann (1976), Short-period fluctuations in total columnar electron content, Journal of Geophysical Research, https://doi.org/10.1029/JA081i019p03431 - Okuzawa & Davies (1981), Pulsations in total columnar electron content, Journal of Geophysical Research, https://doi.org/10.1029/JA086iA03p01355

In the previous version, we have briefly mentioned only auroral Pc5 pulsations, while the papers by Davies (1976) and Okuzawa (1981) were devoted to Pc3-4 pulsations at lower latitudes. In the revision we plan to extend the Introduction section and include these and some other references.

Total electron content variations have been proven a powerful tool in the detection of ionospheric signatures of ULF waves at high latitudes as well as data from ionosondes exploiting the radio-wave reflecting properties of the ionosphere, as it is detailed by Watson et al. (2015). It is not clear to me and perhaps the reader how the results of Watson are different from those of Kozyreva et al. (2019) briefly mentioned in line 29. Nor the difference with those of Pilipenko et al. (2014b) derived from data collected during a different magnetic storm.

This analysis will be included into the Introduction section and to Discussion. We plan to give a more thorough analysis of observational results in the Introduction section and of physical mechanisms in the Discussion.

The following publications could be added to improve the placement of this work in the context of existing literature: - Baddeley et al. (2005), On the coupling between unstable magnetospheric particle populations and resonant high-m ULF wave signatures in the ionosphere, Annales Geophysicae, https://doi.org/10.5194/angeo-23-567-2005 - Buchert et al. (1999), Ionospheric conductivity modulation in ULF pulsations, Journal of Geophysical Research, https://doi.org/10.1029/1998JA900180

The references will be added to the MS

In lines 31 and 32, the authors note that the association of waves with moderate amplitudes with variations of the foF2 critical frequency have not been studied. However, how their amplitude is defined as moderate is not described nor later in the manuscript. As mentioned in the title of the manuscript, the reader is waiting for more details on these moderate geomagnetic pulsations, in my mind.

Thank you very much for this comment. In the next version the data analysis will be improved and a classification of the intervals in accordance with spectral power density at frequencies of PSD local maxima will be added. This will allow to quantify such terms as “moderate”.

In lines 62 and 63, could the authors explain in quantitative terms how high the signal intensity at the reflection boundary should be as well as the amplitude ratio of the signal intensity at the reflection boundary to the power above it? Later, in lines 68 and 71, the authors note that a threshold for the time derivative of the foF2 critical frequency is calculated from the variance over a time interval of length t1. Is the variance of the foF2 critical frequency meant? How is the length of the time interval t1 defined?

The description of the approximation procedure will be extended. Besides, the parameters values used as the initial point of approximation will be added as a supplementary file.

Section 2.2 would benefit from an ionogram on which the described method has been used to detect the ionosphere F2 region critical frequency, clearly illustrating the new method for the foF2 critical frequency automated detection.

Figure 1, its capture, and the text explaining the procedure will be improved to make the detail of the approximation procedure clearer.

In Figures 4 and 7, it would be worthwhile to note the frequency of the primary and secondary maximum in power and provide further explanation at which frequency the coherence is taken for the statistics provided in Section 3.1.2.

The explanations will be added. Actually, in the present version, there is a difference in the examples, where 2 frequencies are used and statistical results where only the first spectral maxima are analyzed. This point will be improved in the revised version.

In Section 3.1.1, in addition to the details offered for the two intervals in March and July 2015, the two examples could be utilised to introduce the criteria set for selecting similar events for subsequent statistical analysis.

The classification of events will be improved. Really, in the present version, not identical criteria are used at different stages of data analysis. The choice of event class is not random but it may be difficult to discriminate between different types of events taken for comparison with coherent b-foF2 events in each case. The explicit classification will be given in the beginning of the Data processing section.

In Figures 9, 10, 12 and 13, as these are described in Section 3.1.2, what does "occurrence" and the symbol "D" mean in this context? Do the authors refer to "probability of occurrence"?

Yes, that is the empirical probability density, the term will be explicitly explained in the text

As they stand, the conclusions reached and briefly summarised in the first paragraph of Section 4 of this manuscript are a bit vague. Although it is suggested that this study is focused on variations of the ionosphere's critical frequency foF2 during quiet and moderately disturbed geomagnetic conditions, the most favourable values of the Dst index lay between -100 and -50 nT. Under such conditions, how often would it be expected to detect events are associated with ULF geomagnetic pulsations? How would the low occurrence rate (3%) of coherent events change if periods of highly disturbed conditions or quiescence were excluded? Please also consider commenting on the solar wind conditions that are favourable for the occurrence of coherent events and specifically, provide the range of solar wind speed and dynamic pressure values.

The new classification of all the intervals analyzed will give answers to all these questions. You are absolutely right, that in the previous version of our MS, the problems caused by the method of foF2 detection from the ionogram in the disturbed ionosphere can hardly be discriminated with the ionospheric Pc5/Pi3 occurrence probability. In the next version we shall limit ourselves with the disturbance levels, for which the detection procedure is valid and concentrate only on the intervals when quality of foF2 detection allows for the spectral analysis. For these intervals, we shall analyze the specific features of high coherent b-foF2 pulsations and space weather conditions favorable for their occurrence. Probabilities of coherent b-foF2 pulsations under favorable conditions will be given explicitly in the text.

Lastly, there are inconsistencies in the referencing style and specifically, on page 9 and 10, the year of publication in Mager et al. (2013), Min et al. (2017) and Viall et al. (2009) should be moved to the end of each reference.

The references will be corrected

Please also note the supplement to this comment:
https://angeo.copernicus.org/preprints/angeo-2020-16/angeo-2020-16-AC1-supplement.pdf

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