

Review of the manuscript entitled “Effects of Earth's magnetic field variation on high frequency wave propagation in the ionosphere” by Mariano Fagre et al., submitted for a possible publication in Annales Geophysicae [angeo-2019-27]

General comment

The manuscript describes influence of substantial changes of the Earth's magnetic field that might take place in future on propagation of high frequency (HF) radio waves in the ionosphere. The propagation and downward refraction of the radio waves in the ionosphere is studied by 3D ray tracing code. The authors mainly focus on the changes of ground range R for the waves transmitted at specific frequency and elevation angle, and partly also on the changes of the so-called Spitz angle.

The main problem of the presented study is that it does not take into account any variability of electron densities in the ionosphere, which has a major effect on HF wave propagation and hence on the ground range R , whereas the changes in magnetic field have only minor effect. The authors themselves found that changes in R owing to relatively drastic variations of the Earth's magnetic field (dipole collapse or reversal) are by at most 2% for globally constant electron distribution. I expect that such R changes are much lower than R changes owing to diurnal and seasonal variability of the ionosphere and also much lower than uncertainties in the calculated R owing to uncertainties in ionospheric model, ionospheric disturbances etc. I miss any comparison with these ionospheric variations and uncertainties. Moreover, it is reasonable to expect that such dramatic future changes of the Earth's magnetic field will be associated with global changes of electron densities as the authors also partly mention in the Introduction. Therefore, I consider the presented study a sophisticated workout on ray tracing code rather than a useful geophysical investigation.

I recommend the authors to mainly focus on the Spitz angle, and discussed this point more in detail. The Spitz angle only depends on the magnetic field. Thus, the calculated changes of Spitz angle due to magnetic field variations are meaningful, unlike the changes of R which dominantly depend on ionospheric density and its variability. The minor changes of R due to magnetic field variation could be shortly mentioned in discussion for completeness.

I have also found several incorrect or confusing statements in the text (see the specific comments).

For all the reasons mentioned above, I cannot recommend the manuscript for publication in the present form. The manuscript requires substantial revision in my opinion.

Specific comments: (As I expect major revision and changes in the text, only major comments are listed. I do not provide formal or language comments at this stage.)

- a) The second part of abstract is difficult to understand without reading the article
- b) lines 44-46. Definitions of group and phase path using speed of light c in vacuum are misleading. According to my knowledge and literature that I read the phase and group path lengths are related to distances traveled by phase and group velocities along the trajectory, respectively (group path length is simply the length of the trajectory). Anyway, I think that these terms are unnecessary for the purpose of this article and could be removed.

- c) paragraph on lines 54-61. I think it could be removed as similar information is better described later, e.g, in the text starting in the end of line 100 and in the following paragraph
- d) line 141, “right-hand and left-hand polarization in the cases of the o- and x-mode, respectively” That is incorrect. Ordinary mode is left-handed (L), whereas extraordinary mode is right-handed (R). The terms L-O and R-X modes are often used, instead of simply O and X modes.
- e) Permittivity of vacuum is missing in equation (2)
- e) lines, 157-158, remove
- f) Equation (8), specify that θ changes along the ray path in the ionosphere. Using the initial values, it is only valid at the bottom or below the ionosphere.
- g) Text related to equation (9), lines 171-179. It should be mentioned that Spitze trajectories for incidence angles between zero and critical angle Φ_c , $0 < |\Phi| < \Phi_c$, are only formed for wave frequencies $f < f_{\text{OF2}}$.
- h) I think there should be $\sin(\Phi_c)$ on the left hand side of equation (9), see, e.g., Eliasson et al. (2015), J. Plasma Physics, vol. 81, 415810201, doi:10.1017/S0022377814000968 or Mjolhus (1990), Radio Sci. **25**(6), 1321–1339
- i) Is really the same ionospheric profile used over the same globe? If yes, it makes no sense. See also the general comment
- j) lines 268-269. The refractive index mainly depends on plasma density. Magnetic field \mathbf{B} and angle between \mathbf{B} and \mathbf{k} have relatively minor effect in the ionosphere.
- k) line 280, least low in equatorial belt-> largest in equatorial belt (the same in abstract)
- l) lines 325-342, this is useless here and partly out of context; without discussing the dominant effect of electron densities it makes no sense.
- m) lines 370-375. This text is suitable for Introduction rather than for conclusion.