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New model simulations of multi-frequency HF beacon signal absorption for direct observation of D and E-region constituents

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This paper presents the first numerical study on a new concept for the direct measurement of D-region absorption in the HF band. Numerical simulations based on the Appleton–Hartree and Garrett equations of refractive index are presented. Electron temperature as a result of HF radio pumping of the ionosphere is included in the calculations using proper numerical formulation. Both O- and X-mode radio wave polarizations are taken into consideration. A global map of HF absorption in the northern hemisphere is calculated. Detailed calculations of HF radio wave absorption as it propagates through the lower atmosphere are presented. The effect of several parameters on the amount of absorption is calculated. The best frequencies to be used for the purpose of this study are discussed. A machine learning model is developed and the capability of the model in estimation of D and E-region constituents includes N_2, O, O_2, as well as T and Ne is examined. Such a technique can also lead to global mapping of HF absorption and improve OTHR (over-the-horizon-radar) performance.

In summary, the concept of developing a multi-frequency HF radio sounding technique for detailed measurement of the D-region absorption is investigated in this paper for the first time. The detailed calculations of absorption amplitude (dB km^{-1}) and total phase variation in the natural D-region ionosphere, as well as an artificially ionosphere pumped by a high-power radio wave, are considered. The HF absorption profiles and total HF absorption are calculated using the Garrett and Appleton–Hartree formula of refractive index. There is a small difference in estimated HF absorption between the two models, especially for unheated ionospheric conditions. The effect of three different cooling formulations associated with N_2 and O_2 vibrational and rotational excitation was found to be negligible in natural ionosphere. Performing such experiments in heated and unheated ionospheric plasma could be used to calibrate the instrument and to use the best cooling model and refractive index for the artificially modulated lower ionosphere.

The two O-mode and X-mode transmissions along with transmission frequencies of 2, 8, 16, 24, and 28 MHz associated with the proposed REEIMA HF beacon (Radio Explorer for Earth, Ionosphere, Mesosphere, and Atmosphere) are used to determine the absolute D-region absorption along with the possibility of estimating D-region parameters such as neutral densities. It has been shown that the variation of each background neutral density including N_2, O_2, and O produces a distinct effect on the absorption value of O- and X-mode as well as different transmission frequencies. A machine learning technique is developed based on the model simulation results using empirical data from the MSIS and IRI models for 2019. The accuracy of model appears to be encouraging for the estimation of the background temperature and neutral density profiles. Moreover, therefore, the proposed technique can eliminate the effect of electron density variation and the possible error in OTHR measurement by using temporal evolution of HF absorption. Previous studies have shown that riometers may overestimate the absorption by a factor of 2 in the D-region ionosphere when modified by high-power radio waves despite changes in electron density and heater parameters.

A global map of HF absorption in the northern hemisphere associated with two transmission frequencies of 4 and 16 MHz are presented. It has been shown that diurnal and seasonal variation of global HF absorption is pronounced enough for such a technique to be implemented globally with a distributed network of HF receivers on the ground. The mission can be implemented to improve OTHR and SuperDARN observations in both hemispheres.

References

[1] Mahmoudian, A., Kosch, M. J., & Baghaei, R. M. (2023). Global simulations of multi-frequency HF signal absorption for direct observation of middle atmosphere temperature and composition. Journal of Geophysical Research: Space Physics, 128, e2022JA030930. https://doi.org/10.1029/2022JA030930