Numerical studies of high-power high frequency wave heating of the ionosphere at different latitudes

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With a large amount of heating experiments conducted in the past over three decades, it has become technologically feasible to construct ground-based HF radar systems capable of delivering radio frequency (RF) energy to the ionospheric plasma, with power densities sufficient to alter the ionospheric electron thermal budget and plasma characteristics. Lots of experimental results not only lead to deeper understanding on the microscopic and macroscopic, long-term and short-term, and linear and nonlinear processes triggered by the HF heating of the ionosphere but also make the comparison of theory, experiment, and simulation available. However, as far as we know, most of these experiments were conducted at higher latitudes so that the numerical models selected corresponding high-latitude ionosphere to simulate the heating effects and compare with the experimental results. Thus, it keeps meaningful to study the ionospheric response to the injections of powerful high frequency (HF) radio waves at different latitudes though at this time there is no possibility to combine the results of simulation and experiment at low latitudes together.

In this work a realistic numerical model for self-consistent ionospheric heating by HF waves in conjunction with an updated ionospheric transport code is developed. Both ohmic dissipation and anomalous absorption of the HF radiation are included. Ionospheric parameters at three sites (Alaska, Wuhan and Fuzhou) are chosen with the ambient magnetic field structure, the regular gradient of background non-homogeneous ionospheric plasma, as well as the altitudinal dependence of transport coefficients of the charged particles taken into account. The processes of formation and relaxation of strong disturbances of the electron temperature and concentration within the altitude range of 60-400 km at the three sites above are numerically investigated and compared with each other. The time scales of response, saturation, and cooling are determined. The cases of ionospheric heating at different frequencies, overdense and underdense, and at different effective radiation power (ERP) are also examined, which is followed by an attempt to mathematically descript the dependences of marked ionospheric changes on heating frequency and ERP. Results obtained from numerical experiments give good explanations of the experimentally observed altitudinal distribution of density enhancements or depletions by the interplay of chemical processes and transport processes. The escape of the accelerated electrons can explain the electron temperature fluctuations. The ionosphere usually reaches its saturation state within 8-minute heating and its cooling equilibrium, not exactly equal to the initial ionosphere, within 3 minutes after the heater is turned off. Results also confirm the possibility of conducting heating experiments at low latitudes such as Wuhan or Fuzhou. However, in the same heating type of underdense or overdense heating, power density at lower latitudes should at least increase by more than 40 percent to obtain similar ionospheric turbulence at higher latitudes.