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Test Particle Simulations of Ion Acceleration by BBELF waves at Ionospheric Altitudes

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The Earth's ionospheric ions flow out from the polar regions, particularly in the cusp region, through the heating process caused by low-frequency plasma waves. In this process, ions are heated perpendicular to a magnetic field line and then accelerated parallel to the field line by conserving the first adiabatic invariant [Yau and André, 1997]. Among the waves considered to contribute to this heating, the most common is the BroadBand Extremely Low Frequency (BBELF) wave, characterized by a smooth power spectrum that follows a power-law distribution from DC to the lower hybrid resonance frequency. Previous studies, such as those by Shen et al. (2020), have conducted simulations to investigate how BBELF waves heat ions. However, detailed heating mechanisms, including in the presence of magnetic field gradient, remain only partially understood.

In this research, test particle simulations were conducted to investigate how waves with BBELF spectra heat O+ and H+ ions in the plasma and magnetic field environment of the polar region. The altitude range was set between 400 and 2000 km, above the peak density of the ionosphere, and the three-dimensional equations of motion of ions were numerically solved using the fourth-order Runge-Kutta method. Ions outflowing from the cusp region undergo bulk upward motion at low altitudes due to bipolar diffusion resulting from electron precipitation and frictional heating by convection. As these ions ascend, they eventually reach wave-heating regions, where they gain additional energy. To examine how the velocity of bulk upflow affects wave heating, initial conditions were set such that the ions had an energy of 0-20 eV in the parallel direction and 0.2 eV in the perpendicular direction. The wave electric field was assumed to be purely perpendicular to the background magnetic field and was modeled by superimposing multiple waves with different frequencies, possessing a power spectrum that follows a power-law distribution to represent the BBELF spectrum.

We focus on the time scale of pitch angle changes due to the mirror force and the different responses of O+ and H+ ions to energy input by BBELF waves.