Excitation of poloidal Pc 5 waves associated with the substorm nose structure: Arase observation

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In the terrestrial magnetosphere, poloidal ultra-low frequency (ULF) waves are frequently observed during substorm activities (Engebretson et al., 1992; Ren et al., 2015; Shi et al., 2018). Understanding the relation between substorm and poloidal ULF wave excitation is connected to investigation of energy flow from the solar wind to the magnetosphere. Recently, Yamamoto et al. (2019) found that protons at 10–30 keV injected by a substorm excite eastward propagating poloidal waves through drift-bounce resonance. These protons showed rapid temporal variations in flux intensity and the radial gradient of their phase space density, which triggered two wave packets of the poloidal waves. However, case studies of the drift-bounce resonance for this energy range (< ˜50 keV) are seldom reported, and hence poloidal waves excited through other excitation scenarios remain to be investigated.

In the present study, we examined poloidal Pc 5 waves and steady spatial structure of energetic proton distributions observed by the Arase satellite (Miyoshi et al., 2018) on 19 November 2018. The poloidal waves with a frequency of 4.5 mHz were detected by Arase during 02:40-03:40 UT. The apogee of Arase satellite was located at ˜21 MLT, and its geomagnetic latitude ranged from 0° to 10° during the event. The energetic protons at ˜5 and ˜15 keV penetrated down to L = 5.1–5.4 and created the multiple-nose structure (e.g., Ferradas et al., 2016). Since the SuperMAG Auroral Electrojet (SME) index (Newell and Gjerloev, 2011) increased up to ˜260 nT just before the Arase satellite detected the nose structure, the multiple-nose structure is associated with a small substorm (so-called substorm nose structure).

The proton pitch angle distributions at 10–20 keV measured by the LEP-i and MEP-i instruments onboard Arase showed clear "fishbone-like" structure, and the phase of the proton flux oscillations varies with pitch angles. These features indicate that the proton fluxes are modulated through drift-bounce resonance (e.g., Zhu et al., 2020). Using the ion sounding technique (e.g., Su et al., 1977; Kivelson and Southwood, 1983), we also estimated the azimuthal wave number (m number) of the poloidal waves. We obtained the m number to be +150 (eastward propagation) from the LEP-i measurements. While the energy gradient of proton phase space density (f_{H+}) at 10–20 keV was negative during most of the wave period, the radial gradient of f_{H+} was anti-earthward and about 10 times greater than the energy gradient. In the linear theory of Southwood et al. (1969), steep anti-earthward gradient can excite poloidal waves if m number of the wave is positive. Therefore, we propose that the anti-earthward gradient formed by the substorm nose structure excites the poloidal waves through drift-bounce resonance. The radial extent of the poloidal waves coincides with that of the steep anti-earthward gradient (L = 5.3–6.1). This supports our interpretation. We also calculated the wave growth rate derived by Southwood et al. (1969), and found that the wave growth rate exceeds the damping rate by the ionosphere (γ / ω ˜ 0.3, where γ and ω are the wave growth rate and the wave angular frequency, respectively). Thus we consider that the

poloidal waves were observed even on the nigh side, where the ionospheric damping is strong (γ_{damp}/ω ~ 0.1, Newton et al., 1978).

Keywords: ULF waves, ring current, nose structure, drift-bounce resonance