Propagation of electric fields during Pi2 pulsations using satellites and ground-based observations

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Pi2 pulsations are irregular oscillations of magnetic field with the period of 40-150 s, generated in the nightside magnetosphere. Their generation and propagation processes have been investigated using numerical simulations and observations from ground and space. Pi2 pulsation is often discussed in the framework of the cavity mode or directly driven hypotheses. The high-latitude Pi2 pulsations are driven by Alfven waves toward the ionosphere, carrying transient field-aligned currents at the substorm current wedge. Low-latitude Pi2 is explained by the cavity mode or current wedge oscillation. While the latter transient response model has mainly been proposed by previous results using magnetometer data, there are only a limited number of papers using in-situ observations at the magnetosphere. Therefore, the path from the initial fast mode waves in the plasma sheet through the shear Alfven waves to Pi2 pulsations that penetrate into the ionosphere have not been directly studied yet.
The electric field is a key parameter to identify the propagation direction associated with Pi2 pulsations. Thus, in this paper, we investigate the spatial and temporal variations of electric fields associated with Pi2 pulsations using multi-point observations at ground sites and multi-point spacecraft in the magnetosphere. For the former, we identify the ionospheric response using SuperDARN (high latitude) and HF Doppler (mid latitude) radars. We obtain the magnetospheric electric and magnetic field data from THEMIS (5 probes) and Van Allen Probes (VAPs, 2 probes). Magnetospheric magnetic field data are also obtained from GOES 13 and 15.
As a case study, we find a typical Pi2 structure on 25 December 2014. In this event, all satellites at the magnetosphere were located in the nightside: THEMIS probes were in the outer magnetosphere (L~10), while VAP-A and VAP-B were outside and inside the plasmasphere (L~5 and 4), respectively (identified by electron number density data). Electric and magnetic field variations observed by VAPs show a good correlation with geomagnetic field at Kakioka (~23 h LT). The phase lags between azimuthal component of electric field and parallel component of magnetic field are ~90^{o} at VAP-B (~23 h LT) and ~150^{o} at VAP-A (~2 h LT), respectively, while the phase lags between radial component of electric field and azimuthal component of magnetic field are ~150^{o} at VAP-B and ~90^{o} at VAP-A (~2 h LT), respectively. Therefore, cavity mode resonance is dominant near the midnight meridian inside the plasmasphere, and shear Alfven waves propagate along magnetic field lines and supply energy for high-latitude Pi2 pulsations. In contrast, at post-midnight region outside the plasmasphere, fast mode waves propagate into the inner magnetosphere, and shear Alfven waves reflect at the ionosphere and form the field line resonance. In addition, THEMIS-A (L~9), D (L~10.5), and E (L~11) detect increases of electron flux with the onset of magnetospheric electric field, which indicates that they observe the structure of the substorm current wedge. In summary, our result may support the transient response model, but further studies are still required.
We also estimate the direction and magnitude of Poynting flux for the identification of the electromagnetic energy transport direction and to investigate their relationships to the ionospheric response based on SuperDARN observations. In this paper, with additional event studies, we will suggest the propagation path of Pi2 pulsations from the outer magnetosphere to the ground

via the ionosphere, and compare statistical results with the several models.

