Reply to comment by T. Kikuchi and T. Araki on “Propagation of the preliminary reverse impulse of sudden commencements to low latitudes”


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[1] We appreciate Kikuchi and Araki’s [2002] giving us the opportunity to compare in more detail the two different models of how the preliminary reverse impulses (PRI) of sudden commencements (SC) propagate to the ground. The inconsistency between the Earth-ionosphere waveguide model [Kikuchi and Araki, 1997a; 1997b] and our observations [Chi et al., 2001] is most clearly demonstrated by the discontinuity in PRI arrival time at approximately the plasmapause latitude as shown in Figure 1. Neither the waveguide model nor any SC-related current (including the Chapman-Ferraro current and the field-aligned current) can result in this jump in arrival time across the plasmapause latitude. On the contrary, this discontinuity is well explained by Tsurutani’s MHD waves model [Tsurutani, 1964] because the wave slows down as it encounters the dense plasma sheath.

[2] Although the MHD wave model of Chi et al. [2001] was only applied to the arrival time of PRIa, it can explain also the observed onset time of PRIb. The onset signals the first wave front reaching the observatory, whereas the arrival time, defined by the time at maximum amplitude, represents the arrival of wave energy coming from all possible propagation paths. In the MHD waves model, the first wave front arrives at the ground observer travels along a path very close to the line connecting Q, Pm, and P (see Figure 2). For any different location on the Earth, the corresponding wave path only shifts slightly in space, and therefore the travel time would almost be identical. This explains why the onset occurs simultaneously across all latitudes. The travel path that conserves the greatest wave energy varies more significantly as the location of ground station changes, and therefore there is a more vivid differentiation in the arrival time.

[3] The notion of the invisibility of the converted transverse (CT) mode for ground observatory is unlikely to be applicable in reality. A fast-mode wave can be converted into Alfven waves in the inhomogeneous magnetosphere [Southwood and Kivelson, 1990; Honma and Toshikawa, 1992].

Figure 1. The PRI arrival time observed at 23 magnetometer stations for the SC event on September 24, 1998. A slowdown of PRI propagation is clearly seen near the plasmapause latitude, an important feature that can be explained only by the MHD waves model. The error bars indicate the time resolution of magnetometer data.
Figure 2. Tamao's model of PRI propagation from the source location to a ground observer at \( P \) via multiple paths in the magnetosphere. The inset shows the temporal variation of \( |R_n| \) at \( P \). The first wave front reaches the ground observer through the path \( P_0 \), whereas the path that conserves the lowest wave amplitude is \( P_0' \) followed by a field-aligned propagation to \( P \) (After Tamao [1964]. Graphics taken from Chiu et al. [2001]).

1996). As a consequence, the MHD waves that carry the PRI signal to low latitudes can no longer be perfectly screened by the ionosphere. The observation of an SC signal (mainly in the transverse mode above the E region and the PRI simultaneously accessed by ground stations below the spacecraft path [Drake et al., 1984]) provides strong evidence that transverse SC signals in space can be seen on the ground.

[4] It is important to note that the MHD waves model also explains the propagation of the magnetospheric pulsations driven by solar wind pulses. Studies have found that some ground magnetic pulsations have one-to-one correspondence to solar wind pressure variations [Korotova and Sibeck, 1994, 1995; Matsunaka et al., 1995], and travel time analysis indicates that the wave signals travel in the magnetosphere at MHD wave speeds. In particular, Weygand et al. [2001] showed that the solar wind-driven Pc5 pulsations observed by a chain of ground stations at different latitudes exhibited the same arrival-time pattern as the zigzag profile shown in our PRI study. These driven pulsations and SCs have many similarities in physics because both of them originate from changes in solar wind pressure. However, it does not imply that the Earth-ionosphere waveguide model can explain the propagation of these pulsations.

[5] In relation to our study that shows inconsistency with the Earth-ionosphere waveguide model, the observations of ground electric fields associated with PRI signals contradict what the waveguide model predicts. Barooah et al. [1997] presented a case in which the amplitude of the preliminary impulse signal was \( <1 \) nT. The vertical electric field would have had a perturbation \( <10^{-3} \) mV/m if the signal were a zeroth-order TM mode, but the observation shows that it was less than 1 mV/m. Further study on the Earth-ionosphere waveguide, such as numerical simulation of the subject, could be valuable in examining the model in detail.

[6] In summary, we believe it is correct to say that MHD waves provide the dominant scheme for PRI signals, to propagate to low-latitude regions. The MHD theory of PRI propagation can be certainly be refined in several aspects, such as the impact of homogeneous plasma and the propagation of signals through the realistic ionosphere. However, the Earth-ionosphere waveguide theory requires very significant changes if it is to explain the timing of PRI propagation and resolve the differences between its theory and observations.

References


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