Reply to comment on “The magnetic response of the ionosphere to pulsed HF heating” by M. T. Rietveld and P. Stubbe

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[1] We want to thank Rietveld and Stubbe [2006] (hereinafter referred to as RS) for providing us with the opportunity to clarify the issues addressed by our work, including the differences in experimental results and theoretical interpretation with the early pioneering work of Rietveld et al. [1986, 1987, 1989] and Rietveld and Stubbe [1987]. We first apologize for the inadvertent omission of Rietveld et al. [1986] that occurred accidentally when the accepted manuscript was shortened to fit the GRL length guidelines. The particular figure we refer to in our paper is Figure 1 of Rietveld et al. [1986] (hereinafter referred to as R86), that was repeated as Figure 2 of Rietveld and Stubbe [1987]. With this we want to address the more substantive issues:

[2] 1. We agree with RS that when disagreements between theory and experiment arise the theory should be questioned. For this reason we conducted our short pulse experiment. Figure 1a shows the magnetic response of the electrojet to 2.5 msec heating reproduced from Figure 1 of R86 along with our own experimental result (Figure 1b). The traces are similar with one critical exception: the approximately 1 pT field that follows turn on and extends from approximately 0.6 to 3 msecs in Figure 1b. RS admit that this feature was absent from their measurements and attribute it to the processing they used to convert their loop antenna measurements to a time plot for the magnetic field. This explains why Figure 1a does not represent the correct magnetic response of the electrojet to short pulse heating. Note that our experimental result shown in Figure 1b is consistent with the theoretical prediction derived using a three-dimensional Green’s function.

[3] 2. In our paper we referred to Figure 1b as three-component with asymmetry for pulse on vs. off. This is schematically shown in Figure 2 that approximates the observed waveform shown in Figure 2 of R86 along with our own experimental result (Figure 1b). The traces are similar with one critical exception: the approximately 1 pT field that follows turn on and extends from approximately 0.6 to 3 msecs in Figure 1b. RS admit that this feature was absent from their measurements and attribute it to the processing they used to convert their loop antenna measurements to a time plot for the magnetic field. This explains why Figure 1a does not represent the correct magnetic response of the electrojet to short pulse heating. Note that our experimental result shown in Figure 1b is consistent with the theoretical prediction derived using a three-dimensional Green’s function.

[4] 3. Rietveld and Stubbe’s previous work does not seem to have resolved many critical issues concerning the scaling of the efficiency with frequency. Consider their results shown in Figure 3 (corresponding to Figure 8 of Rietveld et al. [1989]). As seen, the theoretical curve (solid line) is in complete disagreement with the data.

[5] Furthermore the more than ten dB lower efficiency in the range below 1 kHz cannot be accounted for theoretically. A major point of our paper was to explain the puzzling efficiency variations shown in Figure 3. Note that the amplitude peaks at about 2 kHz, due to effects attributable to the dependence of the observed waveforms on frequency or equivalently pulse length. The frequency scaling for efficiencies below 2 kHz (corresponding to $\tau_0 > 25$ msecs) can be found by taking the Fourier transform of the waveform shown in Figure 2 that approximates the observed waveforms. The results are shown in Figure 4 for two values of the ratio $\alpha$ of the maximum amplitude of the square pulse to that of the impulse. It reproduces well both the sharp reduction below 2.0 kHz and the expected flattening at lower frequencies. For frequencies higher than 2 kHz, and neglecting the presence of minor enhancements at frequencies 2, 4, 6 and 8 kHz (that were first correctly attributed by Rietveld et al. [1989]) to transit time in-phase resonance with the iono-

Figure 1. Magnetic response of the ionosphere to 2.5 msec heating from (a) R86 and (b) Papadopoulos et al. [2005]. Dark line added to indicate pulse length.
spheric reflection) the decrease in the amplitude can be attributed to the fact that for times \( T < T_o \) the modified conductivity has not yet reached saturation as shown in Figure 1 of Papadopoulos et al. [2005].

4. The final point addresses the differences in our respective modeling approaches and their critique of our theory. In general both models follow a similar path to the point of calculating the spatiotemporal profile of the currents induced by the conductivity modifications. From then on, the two approaches diverge. As noted by Rietveld et al. [1989, p. 273] they used the steady state electron temperature enhancement to compute the modified conductivity. Following that, they used full wave antenna theory assuming plane wave propagation to compute the magnetic field amplitude as a function of frequency. As explained in Papadopoulos et al. [2005], we used the spatiotemporal profile of the current induced by the conductivity modification in a three dimensional Green’s function to find the waveform on the ground. The model used by Rietveld et al. [1989] to compute the theoretical scaling shown in Figure 3 does not incorporate the physics involved with the time derivative of the conductivity for two reasons:

a. It uses the steady state value of the conductivity.

b. The plane wave approximation is equivalent to a one-dimensional approximation. As noted in Morse and Feshbach [1953, pp. 867–868] the one dimensional Green’s function of equation (1) of our paper results in a magnetic field amplitude simply proportional to the current. It is only in a three dimensional analysis (the appropriate one for the problem under consideration) that a magnetic field amplitude proportional to the time derivative of the current is introduced.

9. We hope that the above remarks clarify the issues raised by Rietveld and Stubbe in their comment and establish the importance of this work in resolving critical issues of ELF/VLF generation efficiency.

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References

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