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REPLY TO TAYLOR AND CLOUTIER

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The evidence that there are many naturally occurring VLF signals in the night ionosphere of Venus is irrefutable. The observations of the Pioneer Venus electric field detector contain thousands of signals at low altitudes in the night ionosphere which entered the instrument through the antenna and not through the telemetry stream. These signals are seen most frequently at lowest altitudes [Russell et al., 1988a; 1989a]. Their occurrence is controlled by local time [Russell et al., 1989a]. Even though the magnetic field and plasma density do have some effect on the rate of occurrence of these signals, the local time distribution of the occurrence is much unlike that of either of these quantities [Russell et al., 1988b, 1989a]. The totality of these characteristics, and the others that have been discovered, such as the polarization of the lowest frequency waves [Scarf and Russell, 1988; Russell and Strangeway, 1990], indicate that these naturally occurring waves are generated in the atmosphere presumably by electrostatic discharges. They can propagate to the spacecraft at times at the lowest frequencies measured by Pioneer Venus, below the electron gyro frequency in the whistler mode, but at the higher frequencies such propagation is impossible. Scarf et al. [1980] therefore decided that, to be certain that the signals they were interpreting as lightning could indeed be lightning, they would use only signals in the lowest frequency channel when the magnetic field was sufficiently strong that these signals occurred below the local electron gyro frequency. The importance of the Singh and Russell [1986] paper is that it pointed out the similarity at all frequencies in the morphology of the impulsive VLF noise in the night ionosphere of Venus, and it attempted to determine a physical reason for this similarity since whistler mode waves cannot propagate above the electron gyro frequency in a uniform, collisionless cold plasma. The first attempts to understand this phenomenon centered on leakage and scattering [Singh and Russell, 1986; 1987]. This appearance at higher frequencies is still puzzling. It may happen in a manner analogous to terrestrial VLF waves that appear above thunderstorms on Earth with forbidden polarization [Kelley et al., 1985]. However, the reality of these waves is beyond any doubt.

The purpose of the Singh and Russell [1986] paper was to remind the community that these higher frequency waves existed and should not be ignored in the treatment of the Venus lightning. As such it was a critique of the work of Scarf and colleagues [e.g., Scarf et al., 1980; Scarf and Russell, 1983]. Its purpose was not to perform a detailed statistical study of the occurrence rates of these signals. It counted impulsive wave events to show events were present. It did not normalize the distributions by time spent in a bin. It was not intended to be quantitative at that level. Had it been so intended, then the event definition would have had to be set down more precisely and the full data set would have had to have been treated. Such studies were needed but required much more time and resources than were available to support the initial Singh and Russell [1986] study. Such studies were done following the Singh and Russell study and now form a part of the archival literature [Russell et al., 1988a, b, c; 1989a, b; 1990; Russell and Scarf, 1990]. Thus, the statistics presented in the Singh and Russell [1986] paper are moot and have been superseded by more exacting studies. The persistent concern of the authors with the Singh and Russell [1986] study is not justified given the large body of research that shows that the waves discussed by Singh and Russell [1986] indeed exist. The fact that some of the impulsive events counted by Singh and Russell [1986] were telemetry noise is a reasonable hypothesis. That none of the waves were naturally occurring is untenable, and in fact the data shown in the commentary by Taylor and Cloutier [1990] counters their claim.

Figure 1 of Taylor and Cloutier [1990] shows the totality of data from Season 4-Bin 5. This is one of 128 such bins. We agree that the telemetry error rate at this time was high. This does not, however, imply every bin had such a high ratio of noise to signal and simple inspection of the other frequency channels, other times from periapsis and other seasons reveals this bin to be much noisier than most. However, not all the signal is telemetry noise, even though the scale chosen for their Figure 1 gives that impression. The signals seen in panel (a) of their Figure 2 are in fact naturally occurring in the plasma as are the bursts in panel b of the same Figure. The distinguishing feature of the real data as opposed to telemetry noise is its amplitude, its occurrence as multiple neighboring enhancements as opposed to isolated spikes, its occurrence predominantly on one channel while telemetry noise is simultaneous on all channels, and the characteristic decay of the signal with the instrument's response time and an undershoot below the baseline by the decay of the larger signals. The signals shown in their Figure 2 are real. This statement does not prove they are due to lightning and they certainly are not whistler mode signals at those frequencies, but they did enter the instrument through the antenna. It is evident from our further studies of these signals that the properties of the signals do change with altitude. One of the reasons Singh and Russell [1986] examined Seasons 4 and 5 as opposed to Season 3 was because of the higher periapsis altitudes of Season 4 and 5.

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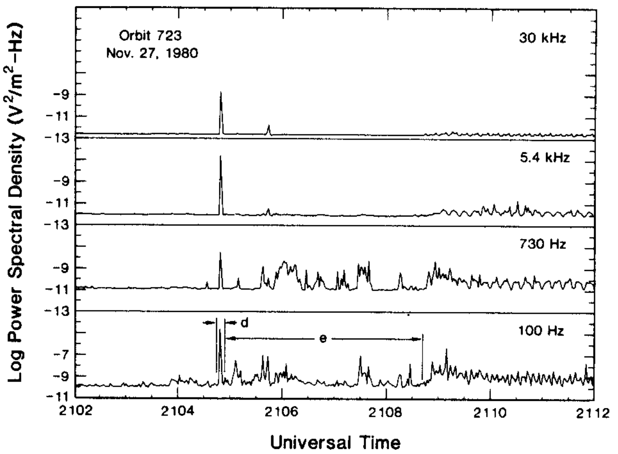

Fig. 1. Example of VLF signals seen around the crossing from darkness to sunlight. The point labelled 'd' is a telemetry spike. The region labelled 'e' contains signals from the ambient plasma. At 2108:40 the spacecraft enters ultraviolet sunlight and the noise level increases on all channels.

Not all the panels displayed in their Figure 1 were used in the studies by Singh and Russell [1986] or Russell and Singh [1989]. Only signals that were obtained in ultraviolet darkness were used. To determine when the instrument was in shadow the electric field detector output was used. Its interference level increases markedly in sunlight at the lower frequencies. Figure 1 illustrates a typical exit from darkness. At 2108:40 the noise level increases on all channels. At 30 kHz which Taylor and Cloutier [1990] have chosen to display, this effect is still noticeable as a small ripple on orbits 695 to 700, and 785 to 792. On the remaining 77 panels there are 30 strong spikes that appear to be telemetry noise. Figure 2(a) shows at least 11 spikes that appear to be real. Russell and Singh [1989] counted only 10 real impulses and 28 artificial ones in this same bin. We attribute the difference in counts to a possible shift in the definition of the bin start and stop times used by Taylor and Cloutier [1990]. We note there are no times given in their Figure 1. In any event the percentage of real signals in this period of poor telemetry error rate is about 26%. We note that this bin (Season 4, bin 5, 30 kHz) is not representative of the Pioneer Venus results. For example in all of Season 1, there are only 3 telemetry spikes spread over 8 bins so that most bins contain no telemetry errors [Russell and Singh, 1989].

As stated above the studies of Singh and Russell [1986] and Russell and Singh [1989] did not contain sunlit data. The tables and plots allowed for counting events up to 20 minutes either side of periapsis, these data were scanned to find the time of entry and exit from darkness but no bursts occurring in sunlight were included. It is possible that occasional transcription errors could have assigned a count to an incorrect bin since the study was performed by hand, but the data that were scanned for events were obtained only in darkness. The 41 events that occur in bins 1, 2, and 8 represent a sum over all four frequency channels and represent an "error" rate of only 6%. The location of the data we used in Seasons 1, 2, 4 and 5 in these and subsequent studies is shown in Figure 2. Note how close the locations of bins 1, 2, 8 (see their Figure 3) come to the shadow line, we have observed. Use of periapsis times rounded to the nearest minute could explain some of these "errors". Figure 3 of Taylor and Cloutier [1990] has no relevance to the studies of Singh and Russell [1986] or Russell and Singh [1989]. The sunlit data simply were not used.

In summary, the paper by Singh and Russell [1986], albeit flawed, has served its intended purpose by bringing attention to the morphology of the signals seen in the upper three channels of the Pioneer Venus electric field detector. This paper was not intended to provide quantitative occurrence rates, only the similarity of the occurrence at all four frequencies. Following studies have provided these quantitative rates. We do not understand the persistent concern of Taylor and Cloutier with the Singh and Russell [1986] study in the face of all of these later studies. This latest paper is their third comment on this work whereas we know of no criticism of the follow-on work. By analyzing 1 of 128 bins, they have not "refuted" anything. In fact their plots agree with the statistics in Russell and Singh [1989], not disagree.

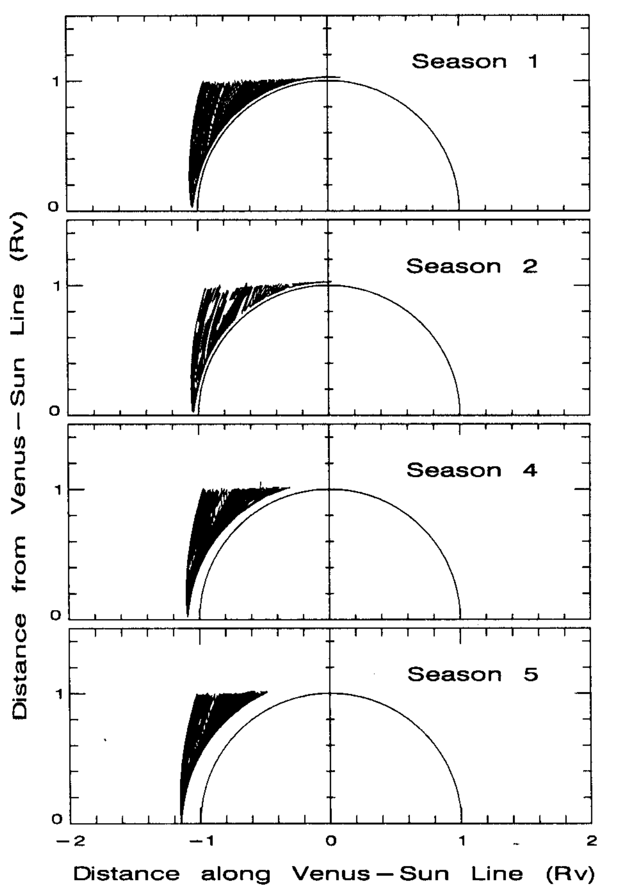

Fig. 2. Location of Pioneer Venus spacecraft in seasons 1, 2, 4 and 5 when spacecraft noise level dropped and VLF signals could be identified. Distance perpendicular to Venus-Sun line is plotted against distance along Venus-Sun line.

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