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A RE-EXAMINATION OF IMPULSIVE VLF SIGNALS IN THE NIGHT IONOSPHERE OF VENUS

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Abstract. Singh and Russell (1986) reported that impulsive electrical signals observed by the Pioneer Venus Orbiter Electric Field Detector at all frequencies clustered about periapsis. However, the impulsive signals consist of both signals entering the instrument through the antenna and artificial pulses associated with telemetry errors as Taylor and Cloutier (1988) have pointed out. Obvious telemetry errors were not included in the original study but records of which signals were thought to be naturally occurring and which were thought to be telemetry noise were not kept. Thus we cannot check the original identifications on a point-by-point basis. We can, however, repeat the study and compare statistical results. This study indicates that there is naturally occurring noise in the dark ionosphere of Venus near periapsis as originally reported by Singh and Russell. However, the absolute rates of occurrence of the original study and the present work differ. Sometimes the rates are smaller and sometimes larger than originally reported. These differences may be due to the use of a higher threshold in the earlier study together with the lack of sufficient discrimination against telemetry dropouts. Our rates of "naturally occurring" emissions also differ from the non-spike noise rates obtained by Taylor and Cloutier although our rates of artificial signals are similar. In any event the Singh and Russell study should not be used to infer the altitude distribution of the noise since the spacecraft spends more time at low altitude than high as it traverses the dark ionosphere.

Introduction

Taylor and Cloutier (1988) advance the thesis that the majority of the impulsive bursts observed by the PVO VLF plasma wave instrument and inferred to be due to lightning in the Venus atmosphere by Singh and Russell (1986) are in fact due to telemetry noise. While there are many telemetry errors in the data set, there are also many naturally occurring bursts. Nevertheless the possible presence of telemetry errors in the Singh and Russell (1986) study together with the lack of normalization of the altitude distribution by observing time led us to redo the altitude study (Russell et al., 1988a). This latter distribution is the one that should be used and not the Singh and Russell distribution.

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The paper by Taylor and Cloutier is their second criticism of the original paper by Singh and Russell (1986) and is part of a continuing critique of the body of work on Venus lightning occurrence. It has been claimed that these waves are electrostatic plasma wave emissions from the ionospheric plasma, that they are caused by the solar wind interaction, that they are found only in ion troughs (cf. Taylor et al., 1987). While some of this criticism has been directed at only the signals in the 100 Hz channel, these signals appear at all four frequencies measured by the PVO instrument (Singh and Russell, 1986; Russell et al., 1988a) and have similar, although not identical statistics. The behavior of the PVO signals on all four frequencies is consistent with the broadband nature of lightning discharges and cannot be treated in isolation as Taylor and Cloutier (1988) have tried to do. In point of fact, the signals are found both inside and outside of ion troughs (Scarf, 1986), they have a different local time distribution than ion troughs (Russell et al., 1988b), they decrease in occurrence with increasing altitude as expected for a source in the atmosphere (Russell et al., 1988a; 1989) and the part of the signal below the electron gyro frequency is electromagnetic (Scarf and Russell, 1988). The geographic clustering first reported by Scarf et al. (1980) has been confirmed using the higher frequency channels (Russell et al., 1988c).

A reader interested in the details of these analyses is referred to the comprehensive study of the signals by Russell et al. (1989) which examines signals above the electron gyro frequency as a function of local time and geographic position and the study by Russell et al. (1988b) which examines the signals below the electron gyro frequency. These latter two studies reveal a strong local time correlation such as expected for an atmospheric weather-related source. The non-independence of local time and geographic coverage in the PVO data may have contributed to an apparent geographic correlation. Thus the geographic correlation should not be taken as support for a volcanic association of these signals. On this point we now agree with the criticisms of Taylor and coworkers. Finally, we note that as illustrated in their original work the study by Singh and Russell (1986) considered only transient signals such as expected from lightning sources and did not consider slowly varying signals.

Reanalysis of the Data

The samples of the data shown by Taylor and Cloutier (1988) are not representative of the Pioneer Venus plasma wave measurements.

Representative examples have been shown by Taylor et al. (1979), Scarf et al. (1980), Singh and Russell (1986), Singh et al. (1987) and Russell et al. (1989). These signals rise rapidly and then decay to background with the 0.5s time constant of the instrument unless another signal appears. Taylor et al. (1979) show an example of this at 30 kHz. The samples shown in Figures 1 and 2 of Taylor and Cloutier (1988) are easily recognized as being artifacts because of the negative dips for many of the bursts at 730 Hz as well as glitches in the magnetic field. These are readily recognized in the PVO data. To determine the occurrence rate of telemetry errors we reexamined the high resolution plasma wave and magnetic field data for the first 5 seasons when the spacecraft was in darkness. In season 1 we found only 3 data dropouts at 30 kHz compared with 61 occurrences of real signals above a threshold of $9x10^{-7}V/(m\text{-}Hz^{1/2})$. The choice of this threshold is one of several factors that governs the occurrence rates. The one chosen here is close to the instrument threshold. The "multiflash" nature of some of the signals also introduces some arbitrariness in the absolute count rate. To confirm that these signals were real we examined all the data when the telemetry rate was sufficient to resolve the decay of the 30 kHz signal (4 samples/sec). Every event examined had the expected decay. All of the signals examined had to enter the instrument through the sensor and not through the telemetry process.

In season 2 quite the reverse occurred. There were 20 occurrences of natural signals at 30 kHz versus 77 occurrences of telemetry noise. During this season Venus was close to the sun as seen from the Earth leading to increased telemetry noise and was directly behind the sun so that no data could be obtained when the spacecraft was over the local times of greatest VLF noise (Russell et al., 1989). In season 3 when Venus was near inferior conjunction there were no telemetry spikes but there were 81 occurrences of naturally occurring noise at 30 kHz. In season 4, periapsis was no longer being controlled so that it rose to higher altitudes where the natural signals were observed less often. In season 4 there were only 54 occurrences of natural noise versus 75 telemetry spikes. In season 5 when periapsis rose even further, there were only 21 occurrences of natural noise versus 23 occurrences of telemetry spikes. Over all 5 seasons there were 237 natural occurrences and 178 telemetry spikes.

An important point in the original Singh and Russell (1986) paper was that the signals occurred more often near periapsis. If the signals occurred randomly, one would expect them to occur uniformly as a function of time from periapsis. Apparently they did not. However, these distributions were not normalized for the time spent in each "bin". Because only data in darkness was used, and because the spacecraft spends more time in darkness at low altitudes than high, it was also possible that this concentration at low altitude reflected the extra observing time there. Thus the study was redone (Russell et al., 1988a). This study showed that there was a very strong altitude dependence of the occurrence rate.

In short both naturally occurring signals and telemetry spikes in the 30 kHz channel of the Pioneer Venus Electric Field Detector can be distinguished both by the instrumental decay of the natural signal and by the occurrence of simultaneous spikes in the magnetometer data in the case of telemetry spikes. Repeating the study reaffirms qualitatively the conclusions of Singh and Russell (1986). The variation in occurrence rate between observers is probably due to differing criteria in determining what constitutes an "event". These variations should not be taken to indicate that the observed transient events at low altitudes are not naturally occurring. Nevertheless, it is necessary to perform a normalization by observation time to demonstrate conclusively that there is an altitude fall off.

A Detailed Comparison of Occurrences

Taylor and Cloutier (1988) divided the observed signals into two types: artificial spikes, which are due to telemetry errors, and non-spike noise which they infer to be the signal measured by the antenna. In Table 1 we present their occurrence rates of non-spike noise, TCR, and artificial, TCA, signals compared with our real signals from this work, (This Work Real or TWR), and artificial signals, TWA, as well as the original counts of Singh and Russell (1986). Examination of Table 1 shows that the two counts of telemetry spikes, TWA and TCA, are similar but not identical. As shown in Table 2 these "artificial" rates have a correlation coefficient that ranges from 0.83 to 0.99. The counts of "real" signal, TWR and TCR, are much less similar, in fact they are anticorrelated. This is perhaps largely due to the inclusion of sunlit data in the Taylor and Cloutier study of the non-spike noise that did not occùr in the present study or in the work of Singh and Russell. Sunlit data have a much higher noise level than those obtained in darkness. However, this alone does not appear to explain all the differences. There appear to be other differences in the definitions of our naturally occurring events and their "non-spike" noise. Finally, the compilation of Singh and Russell, SR, usually lies in between the rates for the real and artificial signals. By season the correlation coefficient for the SR rate and the "artificial" signals ranges from 0.49 to 0.97 and for the SR rate and the real signals from 0.36 to 0.85. In Table 2 correlation coefficients greater than 0.7 are significant at the 95% level.

When all 32 data points are used the correlation coefficient between the SR rate and the TWA rate is 0.94 compared with 0.41 between the SR rate and the TWR rate. The former rate is significant well above the 99% level while the latter is significant up to the 98% level. This suggests that the Singh and Russell compilation includes a mix of both natural and artificial signals, and that there may be more artificial signals than real signals in the SR rate. This behavior would occur if Singh and Russell (1986) used a higher threshold than we have used here. On the other hand, both correlations are significant to a high degree of confidence. Deciding on exactly what percentage is real and what artificial in the SR rate is moot because these studies have been superceded. We refer interested readers to the work of Russell et al. (1988a) and subsequent papers for the accurate occurrence rates. In view of the existence of these more accurate rates the rates given by Singh and Russell (1986) should no longer be used.

Table 1. Occurrence of Impulsive VLF Signals Near Periapsis

	Season 1					Season 2				
Minutes from Periapsis	TWR	TCR	SR	TWA	TCA	TWR	TCR	SR	TWA	TCA
-20 to -15	0	60	0	0	0	0	11	0	0	0
-15 to -10	0	76	0	0	0	0	24	0	1	1
-10 to -5	8	8	4	1	1	0	4	10	7	9
-5 to 0	12	9	0	0	0	12	10	26	30	28
0 to 5	21	15	2	2	3	7	5	28	29	32
5 to 10	9	4	0	0	0	1	4	13	7	12
10 to 15	11	9	0	0	0	0	30	12	3	14
15 to 20	0	19	0	0	0	0	13	5	0	3
	Season 4					Season 5				
Minutes from Periapsis	TWR	TCR	SR	TWA	TCA	TWR	TCR	SR	TWA	TCA
-20 to -15	0	21	2	0	0	0	13	1	0	1
-15 to -10	0	44	0	0	1	0	26	2	0	4
-10 to -5	7	16	12	9	13	4	22	6	3	8
-5 to 0	25	12	24	18	28	7	6	7	4	6
0 to 5	10	5	36	28	40	4	4	6	7	7
5 to 10	6	6	8	11	8	4	14	5	6	8
10 to 15	6	57	6	9	13	2	24	5	3	6
15 to 20	0	20	1	1	1	0	14	7	0	2

Table 2. Correlation of Various Occurrence Rates

	Season 1	Season 2	Season 4	Season 5
TWR vs TWA	0.70	0.95	0.70	0.76
TWA vs TCA	0.99	0.95	0.98	0.83
TWR vs TCR	-.63	-.30	-.36	-.50
SR vs TWA	0.74	0.94	0.97	0.49
SR vs TWR	0.36	0.85	0.71	0.62

Season 3

In their 1987 comment Taylor and Cloutier question the omission of the season 3 statistics. To answer their concern we include season 3 statistics in Table 3. We see that season 3 is similar to season 1 but with even fewer artificial signals.

Table 3. Occurrence of Impulsive Signals in Season 3

Minutes from Periapsis	Natural	Artificial
-20 to -15	0	0
-15 to -10	0	0
-10 to -5	1	0
-5 to 0	33	0
0 to 5	39	0
5 to 10	8	0
10 to 15	0	0
15 to 20	0	0

Conclusions

The original study by Singh and Russell (1986) was a qualitative study of where impulsive signals occurred in the night ionosphere of Venus using all four frequency channels of the plasma wave instrument. As correctly pointed out by Taylor and Cloutier (1988), the data set used in this study included a significant fraction of artificial signals in addition to the intended naturally occurring ones. Follow-up studies have avoided the telemetry errors and normalized the occurrence rates properly by observing time. Moreover, the 30 kHz channel was only one channel of the 4 analyzed. The occurrence of real signals is more frequent in the other lower frequency channels, and thus they are even less sensitive to telemetry errors which occur at the same rate on all channels. The later studies in which artificial signals were excluded reveal that signals occur most often at low altitudes in the night ionosphere. This in turn suggests an atmospheric source. Further, the strong local time asymmetry found (Russell et al., 1989) indicates an atmospheric rather than an ionospheric source because no known ionospheric process has such an asymmetry whereas lightning is expected to have such an asymmetry. Those interested in determining the robustness of our conclusions to varying event definitions are invited to obtain the data from the NSSDC on either digital tape or microfiche and test them with their own methods. We believe the case for lightning on Venus is much more secure than this apparent controversy might imply.

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