GEOPHYSICAL RESEARCH LETTERS, VOL. 14, NO. 5, PAGES 571-572, MAY 1987

419

REPLY TO TAYLOR AND CLOUTIER

R. N. Singh

Institute of Technology, Banaras Hindu University

C. T. Russell

Institute of Geophysics and Planetary Physics
University of California, Los Angeles

Introduction

In our paper (Singh and Russell, 1986) we presented an analysis of impulsive VLF electric field oscillations in the low altitude, nighttime Venus ionosphere. In that paper we found that the spectral shape of the observed signals was consistent with leakage of a lightning-generated spectrum of signals above the local electron gyrofrequency and the direct propagation to the spacecraft below that frequency. We also found that these signals occurred most frequently at lowest altitudes, although the absolute occurrence rate varied from season to season perhaps, in part, owing to the slow rise in periapsis altitude after orbit 600. We also presented a likely process by which lightning generated waves could reach the Pioneer Venus spacecraft. Taylor and Cloutier (1987) ignore the major points of this paper and criticize peripheral issues, as if the mere existence of criticism were sufficient to negate our conclusions. In order to demonstrate that the analysis of Singh and Russell (1986) is incorrect, the criticism must be both valid and directed at the main points of the paper. The Taylor and Cloutier (1987) comments are neither.

Since Taylor and Cloutier (1987) claim that the Singh and Russell study is inconsistent with earlier work, it is appropriate to review briefly the prior work on the interpretation of these impulsive signals before addressing their comments directly. Scarf et al. (1980) and Scarf and Russell (1983) examined impulsive signals at 100 Hz, below the local electron gyrofrequency, at low altitudes in the Venus umbra. These signals were interpreted to be propagating in the whistler mode, guided from below along vertical magnetic field lines with their accompanying electron depletions, and generated by lightning in the Venus atmosphere. This interpretation was consistent with the temporal variation of the waves, the locations where they were observed, and the physics of plasma wave propagation. According to their model, the appearance of waves requires both a source and a propagation path. Thus, the occurrence of waves should be correlated with the appearance of radial fields and their accompanying electron and ion depletions, which provide the propagation path, and with any geographic regions on Venus that may have enhanced lightning occurrence rates. These two correlations may exist simultaneously and independently. Their simultaneous presence does not imply that ion troughs should be correlated with geographic regions. However, Taylor et al. (1985) claim that it does and hence have taken issue with the lightning interpretation. Nevertheless, their argument fails in elementary logic. The fact that A and B are correlated and B and C are correlated does not imply that A and C are correlated. Their basic thesis is seriously flawed.

The lightning hypothesis predicts that the waves are in the electromagnetic whistler mode in which the electric vector is perpendicular to the background magnetic field. If the waves were ion acoustic waves as suggested as an alternate explanation by Taylor and Cloutier (1986), then the waves would have an electric vector along the background magnetic field. An examination of the phase of the spin modulation of the electric field vectors shows unambiguously that the electric field is perpendicular to the local magnetic field and that the waves are propagating in the whistler mode (Scarf and Russell, 1987). They are electromagnetic not electrostatic. The alternative wave source proposed by Taylor and Cloutier does not stand up to this simple test. It fails other tests too. A glance at Figure 1 of Taylor and Cloutier (1987) shows that most of the emissions seen only at 100 Hz occur away from the gradients in the field, i.e., away from the current layers, and not in them as the ion acoustic wave hypothesis would predict. Only near periapsis are there waves at the field gradients and then only at some of them. Moreover it is clear that the waves identified by Scarf are all monochromatic waves and are not spread in frequency by Doppler shifting as ion acoustic waves would be (Scarf and Russell, 1987).

Singh and Russell (1986) have argued that Scarf et al. (1980) and Scarf and Russell (1983) chose criteria that were too conservative in their attempt to identify the nature of the signals and that many of the broadband impulsive signals at low altitudes in the night Venus ionosphere are also generated by lightning. While this may be viewed as a mild criticism of the earlier studies, it should not be. It was very important for Scarf and coworkers to be careful in their interpretation. As discussed above, this expanded definition of Singh and Russell gives a very favorable comparison of the spectrum with that expected for lightning. Strong altitude dependence with most frequent occurrence at lowest altitudes is observed at every frequency and during every season.

Paper number 7L6545.
0094-8276/87/007L-6545$03.00

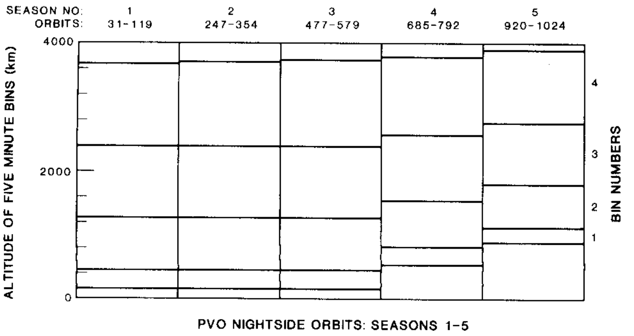

Figure 1. Seasonal altitude variation of bins used in the study of Singh and Russell (1986). As originally noted by Singh and Russell (1986) the altitude rise at lowest altitudes in season 4 and 5 could account for a decrease in peak occurrence during those seasons but since a clear altitude dependence was seen each season, accounting for the reduced low altitude occurrences would only strengthen our conclusions about the altitude dependence.

Faults?

Taylor and Cloutier (1987) fault Singh and Russell (1986) for extending the work of Scarf et al. (1980) and Scarf and Russell (1983). It seems strange to be faulted for examining the signals present and using those properties to test a hypothesis. Figure 1 of Taylor and Cloutier (1987) is a good example of the type of record observed at low altitudes. Two errors appear in it, however. They claim that the whistler events they have indicated on the plot were identified as defined by Scarf and Russell (1983). On the contrary, these events were from a list privately communicated to H. A. Taylor, Jr. using different criteria than used by Scarf and Russell (1983). These events have been published by no one except Taylor and Cloutier (1986), and they were notified of this fact before they published their article in 1986, and before they submitted this comment. Secondly, the lightning whistlers identified by Singh and Russell were not confined to the set circled but included all the impulsive signals shown. Note that the slowly varying component seen at periapsis was not considered to be whistler mode nor associated with lightning in any way.

Examination of Figure 1 of Taylor and Cloutier (1987) illustrates many of the points made by Singh and Russell (1986). First, at low altitudes the impulsive signals are broadband. They occur most often and are strongest at lowest altitudes. There is very little difference in the temporal behavior of these broadband signals and those only at 100 Hz. However, the ones at 100 Hz occur to higher altitudes presumably because they can propagate freely along the field in the whistler mode.

The second fault claimed by Taylor and Cloutier (1986) is totally incorrect. Contrary to their implication we noted that altitude varied with season and stated explicitly that "The change between orbits 695- 792 and orbits 920-1024 could be due to the higher periapsis with season". Figure 2 of Taylor and Cloutier is misleading. Our Figure 1 shows the average altitude of each of our 5-minute bins for the first 5 seasons. There is nothing special about the altitudes of season 3. Because there was a strong altitude dependence seen at every frequency and in every season, the rise in altitude of the lowest bin in the last two seasons while affecting the number of events seen in bin 1 and, to a lesser extent, in bin 2 is irrelevant. Had we corrected for this rise, the altitude fall-off would have been greater than it appeared in seasons 4 and 5, not less. This behavior strengthens our result.

In short, we believe that the case for lightning generation of whistler mode waves on Venus as originally made by W. W. Taylor et al. (1979), Scarf et el. (1980) and Scarf and Russell (1983) has become stronger through the analysis of Singh and Russell (1986), and not weaker. We urge the interested reader to read these papers and judge for him or herself. The reader should not confuse the existence of criticism with the presence of any weakness in the case for lightning.

Acknowledgments. The data used in the studies by Scarf et al. (1980), Scarf and Russell (1983), Singh and Russell (1986) are all available in the form used by the authors from the National Space Science Data Center. This work was supported by the National Aeronautics and Space Administration under research contract NAS2-12383.

References

Scarf, F. L., W. W. L. Taylor, C. T. Russell and L. H. Brace, Lightning on Venus: Orbiter detection of whistler signals, J. Geophys. Res., 85, 8158-8166, 1980.

Scarf, F. L. and C. T. Russell, Lightning measurements from Pioneer Venus Orbiter, Geophys. Res. Lett., 10, 1192-1195, 1983.

Scarf, F. L. and C. T. Russell, Comment on "Venus: Dead or Alive", Science, submitted, 1987.

Singh, R. N. and C. T. Russell, Further evidence for lightning on Venus, Geophys. Res. Lett., 13, 1051-1054, 1986.

Taylor, H. A., Jr. and P. A. Cloutier, Venus: Dead or alive, Science, 234, 1087-1093, 1986.

Taylor, H. A., Jr. and P. A. Cloutier, Comment on "Further evidence for lightning on Venus, by R. N. Singh and C. T. Russell", Geophys. Res. Lett., this issue, 1987.

Taylor, H. A., Jr., J. M. Grebowsky and P. A. Cloutier, Venus night- side ionospheric troughs: Implications for evidence of lightning and volcanism, J. Geophys Res., 90, 7415-7426, 1985.

Taylor, W. W. L., F. L. Scarf, C. T. Russell and L. H. Brace, Evidence of lightning on Venus, Nature, 279, 614-616, 1979.

(Accepted March 17, 1987.)