ment correctly that it contains 33 points with three or more events in a 5° by 5° square. However, they then state, "We identified considerably more surface regions with three or more events than those shown in Fig. 2," and in their figure 3B they show a map in which the same numerical criterion is used (three events in a 5° by 5° square), but with the new data set. They end up with a map containing more than 250 "clustered events" that they compare with the one we produced (*3*). They then state that "the frequency distributions for 5, 10, and 15 points per surface region show the same results; there is no evidence for clustering"; in fact, as shown in Fig. 3, the 15-point distribution from the new data set continues to show clustering.

Taylor and Cloutier state that the PVO plasma wave "scenario, including proposed evidence of clustering of lightning over surface highland regions, has encouraged the acceptance of currently active volcanic output. . . ." However, the first suggestion of active volcanism on Venus was published in 1967 (*14*); Ksanfomaliti commented on the possibility of lightning from an erupting volcano in his 1979 papers on the Venera wave measurements (*15*, *6*). In the period from 1979 to 1982 more discussions of this concept arose because of direct measurements in the interior, surface, and atmosphere of Venus (Venera landing photographs; radar maps for Arecibo, PVO, and Venera 15 and 16 showing volcanic structures, absence of plate tectonics, and high radar reflectivity; and observations of atmospheric sulfur content). Critical information suggesting present-day volcanism includes discussions of gravity anomalies (*16*) and, in their discussion of heat transport on Venus, Solomon and Head (*17*) stated, "the Venus surface, if most of the heat loss occurs by volcanism, should be densely covered with thousands of distinct centers of current or recent volcanic activity." These concepts are supported by subsequent detailed analysis of the ages of the volcanic structures on the Venus surface (*18*) and by PVO measurements of SO_2 variability since 1978 (*19*).

Indirect but significant support for the volcano concept also comes from ray tracing with the Venera and PVO wave data, studies of atmospheric chemistry, and variations in the haze characteristics (*20*), and from a re-analysis of one Venera 9 optical event originally discussed by Krasnopol'skii in terms of detection of lightning flashes (*21*). The intensity of the Venera event detected on 26 October 1975, however, was much too high to have indicated lightning, and Venera may have detected a volcanic eruption that could have served to initiate the SO_2 enhancement subsequently observed by the PVO. In short, there are many reasons to believe that Venus has active volcanism, quite independent of the wave observations.

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REFERENCES AND NOTES

1. H. A. Taylor, Jr., and P. A. Cloutier, *Science* **234**, 1087 (1986).
2. W. W. L. Taylor, F. L. Scarf, C. T. Russell, *Nature (London)* **279**, 1979; L. V. Ksanfomaliti, F. L. Scarf, W. W. L. Taylor, in *Venus*, D. Hunten, L. Colin, T. M. Donahue, V. I. Moroz, Eds. (Univ. of Arizona Press, Tucson, AZ, 1983), pp. 565–603; F. L. Scarf, *Adv. Space Res.* **5** (no. 8), 31 (1985).
3. F. L. Scarf *et al.*, *J. Geophys. Res.* **85**, 8158 (1980).
4. F. L. Scarf and C. T. Russell, *Geophys. Res. Lett.* **10**, 1192 (1983).
5. H. A. Taylor, Jr., J. M. Grebowsky, P. A. Cloutier, *J. Geophys. Res.* **90**, 7415 (1985); *ibid.* **91**, 4599 (1986); H. A. Taylor, Jr., *Eos* **67**, 501 (1986); *ibid.*, p. 644 (1986); see also *Sci. News* **129**, 214 (5 April 1986) and *New Sci.* **110**, 35 (15 May 1986).
6. L. V. Ksanfomaliti, *Nature (London)* **284**, 244 (1980).
7. For electrons, f_c^{-1}, in hertz, equals 28 B, where B is the magnetic field magnitude in nanotesla; f_p^- equals 9000 $(N)^{1/2}$, where N is the number density in cubic centimeters. For positive ions with mass number M (in proton masses), we find $f_c^+ = f_c^-/1846\,M$ and $f_p^+ = f_p^-/[1846\,M]^{1/2}$.
8. In a magnetized plasma, the wave modes of interest all propagate nearly parallel to **B**.
9. For whistlers, V(phase) is approximately $c\,[f_c^-]^{1/2}/f_p^-$, where c is the speed of light; for local plasma oscillations such as ion acoustic waves, V(phase) is approximately $[kT/m_i]^{1/2}$, where k is Boltzmann's constant, T is the electron temperature, and m_i is the actual ion mass, which we take to be the mass of an oxygen ion. See, for instance, *The Theory of Plasma Waves* by T. H. Stix (McGraw-Hill, New York, 1962) for further details about the wave characteristics.
10. True examples of ion acoustic waves are readily found in the Orbiter data set. One type appears in Fig. 1; the relatively smooth high-frequency peak centered around periapsis has been explained by S. A. Curtis *et al.* [*J. Geophys. Res.* **90**, 6631 (1985)] in terms of ion acoustic waves generated by CO_2 impact ionization. F. L. Scarf *et al.* [*Adv. Space Res.* **5**, 185 (1985)] have provided additional examples of ion acoustic waves associated with auroral-type field-aligned currents. In all of these cases the spectrum extends to the upper channels in a manner consistent with the Doppler shift analysis.
11. The analysis of the wave amplitude as a function of the angle between the electric antenna and the projection of **B** in the spin plane can be carried out when (i) **B** has a large component in the spacecraft spin plane and (ii) the duration of the wave sequence is comparable with the 13-second Pioneer Venus spin period. Since most of the 100-Hz bursts occur on time scales that are short when compared with 13 seconds, we have not used this technique in previous publications.
12. For real ion acoustic waves, such as the broadband enhancements detected near periapsis and attributed to CO_2 impact ionization, we find a polarization peak parallel to **B**.
13. The correlation of the occurrence of these waves with the presence of ion (and electron) troughs has a simple explanation in terms of lightning-generated whistler waves. That is, the radial magnetic configuration that allows the signals to propagate upward through the ionosphere also tends to allow plasma diffusion away from the planet, as noted by Scarf *et al.* (*3*). These density depletions can form whistler ducts that help guide the signals to the spacecraft.
14. G. T. Davidson and A. D. Anderson, *Science* **156**, 1729 (1967).
15. L. V. Ksanfomaliti, *Kosmich. Issled* **17**, 747 (1979).
16. R. J. Phillips and M. C. Malin, in *Venus*, D. Hunten, L. Colin, T. M. Donahue, Eds. (Univ. of Arizona Press, Tucson, AZ, 1983), pp. 159–214. This paper, prepared before publication of the Scarf-Russell map (*4*), contains a drawing showing an active volcano at Beta Regio.
17. S. C. Solomon and J. W. Head, *J. Geophys. Res.* **87**, 9236 (1982).
18. D. B. Campbell, J. W. Head, J. K. Harmon, A. A. Hine, *Science* **226**, 167 (1984).
19. L. W. Esposito, *ibid.* **223**, 1072 (1984).
20. L. V. Ksanfomaliti, in *Advances in Space Research*, vol. 4 (Pergamon, Elmsford, NY, 1985), pp. 91–98.
21. V. A. Krasnopol'skii, in *Venus*, D. Hunten, L. Colin, T. M. Donahue, Eds. (Univ. of Arizona Press, Tucson, AZ, 1983), pp. 459–483.

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Response: Scarf and Russell (*1*) raise issues that may distract the reader from the central theme of our article (*2*), namely, that the electric field measurements by the Pioneer Venus Orbiter (PVO) are unrelated to either the lower atmosphere or the surface of Venus. In addition, Scarf and Russell make several assertions that we believe are inconsistent with past interpretations and are incorrect. Our specific responses are as follows.

Scarf and Russell contend that the PVO electric field noise is topographically related. In our article, we emphasized that the 100-Hz noise attributed to lightning and volcanism was not, as Scarf and Russell state, uniquely clustered over highland topography, but rather that the noise appears randomly across the nightside of Venus. We provided ample evidence to support this perception in our figures 3 and 4. In their figure 3, Scarf and Russell present noise distributions from only a portion of the complete data set and state that these noise events are clustered over the highlands. However, these restricted results do not provide convincing evidence for highland clustering of the noise.

When a more extensive set of data is shown, it is readily apparent that the noise distribution is widespread, not clustered. To verify this point, we show in Fig. 1 the distribution of 100-Hz noise attributed to lightning by Scarf and Russell for all PVO orbits up to orbit 1895. By comparing panels A and C of this figure it may be seen that the vast majority (~85%) of the 100-Hz events are observed outside the outlines of the highland regions. Figure 1 also illustrates the nightside tracks of the Soviet Vega 1 and 2 balloons, which traversed regions within which Scarf and Russell allege copious lightning activity. As Kerr reported (*3*), the Vega instruments found no evidence of lighting in crossing these regions.

As Fig. 1 and our earlier work (*4*) show, the 100-Hz noise exists in many patchy regions lying apart from the elevated topography and is highly correlated with the nightside ion troughs that are believed to result from the solar wind interaction with the ionosphere. The ion troughs, like the 100-Hz noise, are widely encountered across the nightside during periapsis passes, and consequently the distribution of these features over much of the low latitude surface regions is unrelated to the planet's surface.

Scarf and Russell assert that studies from the geological community have provided "[c]ritical information suggesting present-day volcanism" on Venus. On the contrary, we find no evidence in any geological studies for volcanic eruptions during the current decade, although a number of studies have suggested past and possibly future volcanic activity. Geologists typically refer to time in geologic terms, and have discussed the term "volcanic activity" without reference to timing except on the most uncertain scales. Clearly, the interpretations of Scarf and Russell are the source of any notion of present-day volcanism on Venus.

The specifications used by Scarf and Russell in their assertions about the noise-lightning relation have been clearly documented. They state (*5*) that to be attributed to a lightning source, a 100-Hz noise pulse must occur when the magnetic field is strong and steady and with a mostly radial orientation. In Fig. 2, we show time series of electric and magnetic field data provided by Scarf and Russell (*6*). In the lower panel some, but not all, of the 100-Hz noise impulses are attributed by them to "lightning events." A comparison of these "events" with the characteristics of the time series of the total magnetic field, B_t, and the radial, or x-component of the field, B_x, shown in the upper panels, reveals fundamental inconsistency in the data interpretation. It is seen that half of the "events" identified, the four events lying to the right and to the left of the four impulses near 19:21 universal time, do not satisfy the detection criteria. Specifically, three of these "events" occur when the field is very weak (less than the 10-gamma magnitude specified), and the fourth occurs at a time when both the field amplitude and direction are rapidly changing. This discrepancy is compounded by the fact that numerous similar impulses appear at 100 Hz, but are unexplained. Together, these points document the uncertain nature of the asserted identification of "lightning-induced whistlers." We believe the interpretation by Scarf and Russell of the electric field data is incorrect, and we find no justification for the inference of lightning.

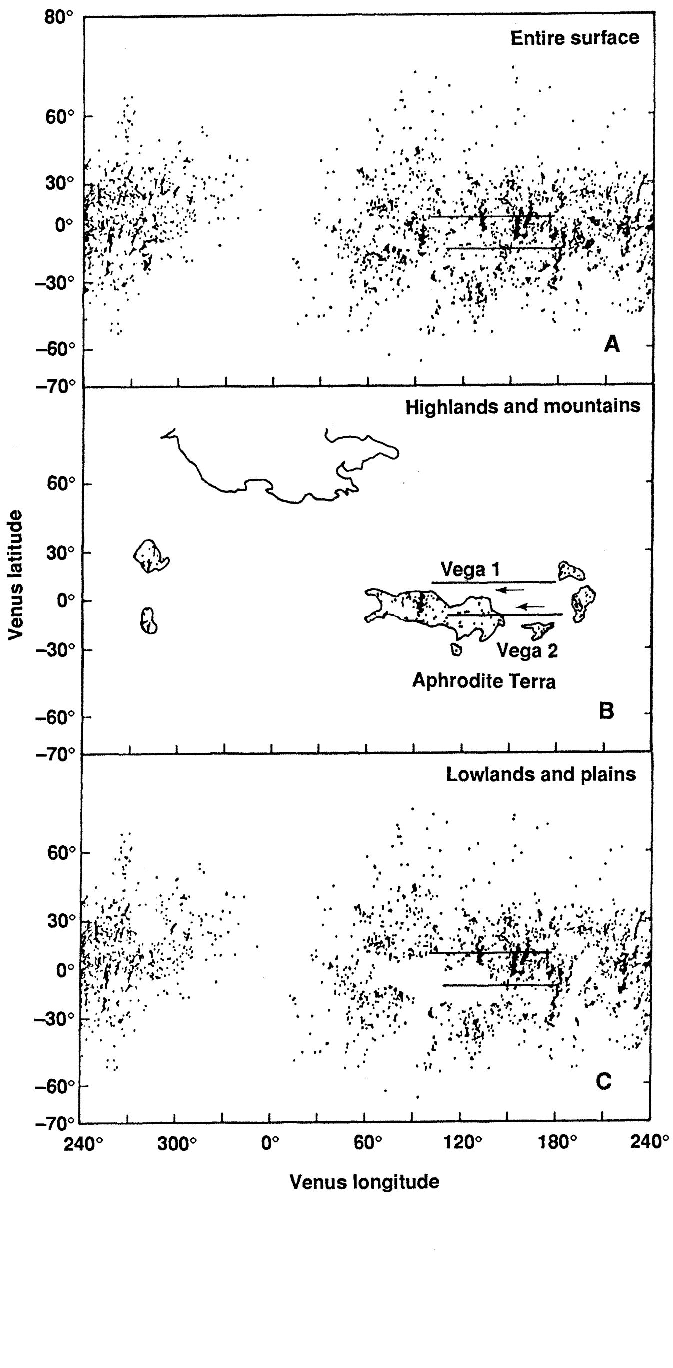

Fig. 1. Distribution of 100-Hz noise attributed to lightning in relation to elevated surface topography (PVO orbits 1 through 1895) and overflight of Vega 1 and 2 balloons (nightside portions of Vega trajectories are shown as solid lines). (**A**) One dot represents each 100-Hz "lightning" event, as identified by Scarf and Russell, and arrows mark the trajectories of Vega 1 and 2. Lack of noise events near 0° longitude results from limitations in overflight coverage from PVO orbits. In (A) it is seen that both Vega 1 and 2 crossed regions in which many "lightning" signals have been identified from the PVO. In (**B**) it is seen that relatively few of the total events appearing in (A) are positioned above the outlined highland regions. In (**C**) all events appearing over the lowlands are shown independently, emphasizing that the majority of the events do not appear over the highlands.

We have established that the 100-Hz events persistently occur within regions of plasma depletion, or ion troughs. We have argued that the free energy associated with these plasma discontinuities offers a ready source for plasma instabilities which could readily provide the source of the observed noise. However, Scarf has rejected the very existence of this demonstrated correlation, and in (*7*) states:

> It has been shown above that the appearance of an ion trough is not a necessary condition for simultaneous detection of 100-Hz whistlerlike noise bursts, and thus there is certainly no cause-and-effect relation involving these phenomena.

He also says,

> If a careful comparison did confirm that these O^+ troughs and superthermal populations are always detected in association with 100-Hz signals previously identified as lightning whistlers, then it would indeed be clear that one must question or even discard the lightning interpretation.

On the other hand, in note 13 of their comment (*1*), Scarf and Russell state otherwise.

Thus the authors are inconsistent, saying that a trough-noise relation exists, but not abandoning the lightning interpretation. The relation indeed prevails, and stands as a distinct challenge to any attempt to interpret this noise as being due to lightning.

In our investigation (*2*) we did not attempt a detailed analysis of the electric field and magnetic field signals. A credible investigation of the so-called polarization would require a statistical analysis of a large number of orbits. Thus, the treatment of the polarization of the noise in the comment by Scarf and Russell is not relevant as a com-

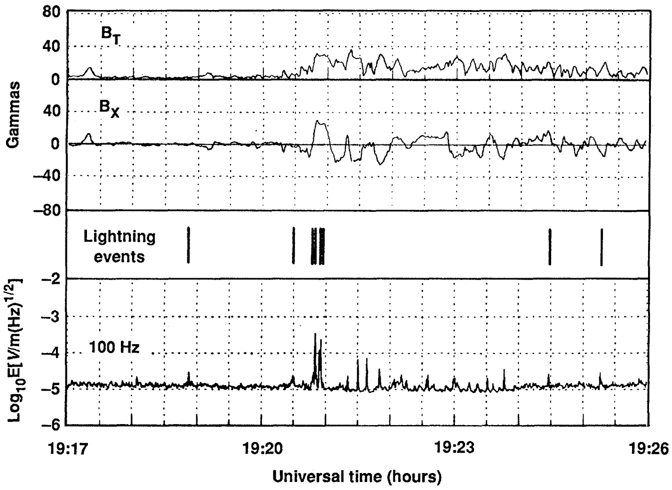

Fig. 2. A comparison of electric field (lower panels) and magnetic field (upper panels) for a portion of PVO orbit 44, 17 January 1979. Electric field data show results of Scarf's latest interpretation (*1*) of "new" eight bursts of 100-Hz noise said to result from lightning discharges. Four of these bursts, the two on the far left and the two on the far right, occur in association with weak, variable magnetic fields, with no sustained evidence of a pronounced radial direction (B_x dominates in radial configuration of field). The identification of these signals is inconsistent with the stated criterion of a strong, steady, radially oriented magnetic field, as specified by Scarf and Russell (*5*).

ment on our work. Detailed analysis such as that required for the polarization study was performed by Scarf and Russell, with the use of their digitized high resolution data for a brief portion of a single orbit, number 526, on a computer. Contrary to the statement by Scarf and Russell that "we made these determinations using high-resolution data identical to those on file at the National Space Science Data Center," the necessary digitized data are indeed not in the archive. We have been unsuccessful in our formal efforts to obtain free access to the necessary high-resolution data, on tape. Thus the publication of detailed data withheld from others is an unfair practice which we protest, and which we assert undermines the scientific objectives of investigation.

Fortunately, however, we can show that the analysis of Scarf and Russell demonstrates the fallacy of their conclusions. First, the polarization diagrams in their figure 2 show significant amplitudes of E at all angles with respect to **B**, rather than strongly peaked amplitudes nearly orthogonal to **B**. In fact, in both examples the largest amplitudes have a tendency to occur near 45° from **B**, indicating that the wave mode is neither purely electromagnetic nor purely electrostatic and ruling out the identification of pure whistler waves. Second, the smooth variation of amplitudes with angle (time) over the 12-second spin period shows that these waves must be continuous over the spin period and cannot be produced by a number of discrete impulsive events of varying intensity and location, as would occur with lightning strokes. Such a continuous and slowly varying distribution further reinforces the interpretation of a spatial region of localized instability around the spacecraft. Thus we believe that these polarization studies refute both the alleged identification of whistler waves and the alleged impulsive characteristics of the events.

We have shown (*2*) that the events Scarf and Russell say are lightning signals are localized within ion troughs and randomly distributed with respect to topography. In a separate paper (*8*) we have presented evidence that the waves have short wavelengths and a low velocity, which led us to suggest that electrostatic waves were a more plausible interpretation than electromagnetic whistler waves. Either type of wave could result from instabilities within ion troughs, so that wave mode identification is, in fact, immaterial. It is known that superthermal ion beams (often observed in association with these troughs) can generate whistler waves propagating parallel to the mean magnetic field (*9*). In summarizing our position on wave mode identification, we stated (*8*)

> In view of the wide-reaching science implications depending upon interpretation of these signals, however, it is emphasized that the important issue is not what type of local instability is responsible, but rather that the evidence clearly indicates that some type of local instability, and not atmospheric lightning, is responsible for these signals.

We cannot and do not rule out past or future volcanic activity at Venus. That is not our objective, nor is it appropriate. We do, however, maintain that the PVO electric field results and their interpretation by Scarf and Russell are responsible for a widespread notion that there has been very recent active volcanism and copious lightning on Venus, a notion that we reject as incorrect and misleading.

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REFERENCES

1. F. L. Scarf and C. T. Russell, *Science* **240**, 222 (1988).
2. H. A. Taylor, Jr., and P. A. Cloutier, *ibid.* **234**, 1087 (1986).
3. R. A. Kerr, *ibid.* **231**, 1369 (1986).
4. H. A. Taylor, Jr., *et al., J. Geophys. Res.* **91**, 4599 (1986).
5. F. L. Scarf and C. T. Russell, *Geophys. Res. Lett.* **10**, 1192 (1983).
6. ——, Pioneer Venus Archive, National Space Science Data Center.
7. F. L. Scarf, *J. Geophys. Res.* **91**, 4594 (1986).
8. H. A. Taylor, Jr., *et al., ibid.* **92**, 9907 (1987).
9. H. K. Wong and M. L. Goldstein, *ibid.*, p. 12419.

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