VENUS LIGHTNING: WHAT WE HAVE LEARNED FROM THE VENUS EXPRESS FLUXGATE MAGNETOMETER.

C.T. Russell[1,2], R.J. Strangeway[1,2], H.Y. Wei[1,2], T.L. Zhang[3], [1]ESS, University of California, Los Angeles, CA 90095-1567, [2]IGPP, University of California, Los Angeles, CA 90095-1567, [3]Space Research Institute, Austrian Academy of Science, Graz, Austria

Introduction: Lightning on Venus has been detected through the radio waves generated and freely propagating through the ionosphere to the Galileo spacecraft [1]; through its optical emissions seen by the spectrometer on the Venera-9 spectrometer [2]; by a telescope on Earth [3]; by VLF search coils dropped through the atmosphere on Venera 11-14 [4]; and by the electric field antenna on Pioneer Venus that at low altitudes observed two types of signals, one that appeared to be whistler-mode signals like those in the Earth's ionosphere generated by lightning, and another purely electrostatic that may be the signal generated by an upward discharge to the ionosphere from charge build-up on the clouds at much lower altitudes [5]. Despite the multi-variate detection of this phenomenon, there has been strong reluctance in some quarters to accept that lightning can be generated in the Venus clouds because of the paucity of water and the distance of the clouds above the surface of Venus. In fact, on Earth, only a minority of the flashes discharge to the Earth below the cloud. Moreover, the presence of water is not needed for a cloud, say of dust, to become electrically charged. So many of the lingering doubts are groundless.

Limitations of Previous Work: Part of the lingering doubt remains because lightning-generated flashes or whistler-mode signals are not continuously observable. The optical signals are in fact rare, only seen once on Venera 9 [2]; only observed on a few days telescopically [3]; and never as flashes in the PVO star sensor [6]. Whistler-mode signals below the local electron-cyclotron frequency are guided by the magnetic field direction, but this field is not always in the proper direction to connect the spacecraft to the lightning source region. Finally, the Pioneer Venus detection was of the electric component of the waves which is very difficult to measure with a small electric antenna. Doubters attribute the Pioneer Venus signals to some other processes, including plasma wake effects.

The Pioneer Venus spacecraft ultimately entered the Venus atmosphere, but just before it did, it obtained data below the ionosphere in "free space" [7]. These data were then converted to a wave power and the signal strength in nT near 100 Hz was calculated. Such a signal could be as large as 1 nT and easily detected by a fluxgate magnetometer if it were sampled rapidly enough. This calculation was used to convince the Venus Express project to install a high-rate, 128-Hz mode on the fluxgate magnetometer, and in April 2006, Venus Express was put into orbit around Venus, expecting to detect whistler-mode electromagnetic signal produced by lightning discharges [8].

Venus Express Measurements: The 128-Hz channel of the Venus Express magnetometer did not disappoint its creators [9]. While signals were not present on every orbit, when they did occur the waves were as large as predicted. The 24-hour orbit of Venus Express was similar to that of Pioneer Venus in that the spacecraft were only deep in the ionosphere and able to observe signals for a short period each orbit, but it was different in that the low-altitude region was polar and not equatorial. In the polar region, the field is essentially tangential to the surface of the planet and the ionosphere. A horizontal magnetic field strongly weakens the coupling of the atmospheric signal to the ionosphere. Fortunately, the direction of the solar wind magnetic field is almost constantly changing, and this changing field, in time, results in directional changes that allow the field to penetrate into the atmosphere. By studying these escaping signals we learn much about the lightning signals. First, their amplitudes range up to about 1 nT and are much larger than the amplitudes of whistler-mode signals due to terrestrial lightning. The signals are strongly guided along the magnetic field as are terrestrial lightning-generated electromagnetic signals. The signals are nearly circularly polarized and are right-handed, a characteristic demanded by the magnetized plasma. Very occasionally, the signals will appear left-handed over a part of the frequency band, but this can be easily explained by signal aliasing when strong signals are produced just above the instrument Nyquist frequency. The strong guidance of the waves by the magnetic field of the ionosphere means that signals are only seen at those times when the field dips into the atmosphere. In short, the characteristics we see of the whistler-mode waves we interpret as lightning-generated waves have the expected properties of waves generated in the atmosphere below the ionosphere.

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