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Lightning Generated Whistlers at Venus: Statistics of Poynting Flux Estimates

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Abstract

The most recent observations of lightning on Venus come in the form of whistler-mode waves detected by the Venus Express (VEX) mission. The dual fluxgate magnetometer sampled at 128 Hz allowing for detection of signals up to 64 Hz. These signals are found at all local times within the ionosphere. The entire 8.5+ year dataset has been analyzed with nearly 7 hours of whistler activity identified. The majority of the signals were detected when VEX was at ~250 km, approximately 3% of the time at this altitude. Poynting flux calculations are made for every signal detected and analyzed statistically to demonstrate that these waves have a source below the ionosphere.

1. Introduction

Lightning produces an ELF radio wave that can propagate along magnetic field lines to reach a spacecraft, such as VEX, at much higher altitudes. Venus lacks an intrinsic magnetic dipole, so the interplanetary magnetic field (IMF) drapes around the planet forming a comet-like tail. The IMF induces currents in the ionosphere that generate an opposing field. The field lines tend to be nearly horizontal to the surface around much of the planet, except in the tail where it is more radial. There must be a dip to the field in order for waves to be guided to higher altitudes on the dayside. Therefore, on the dayside a wave is less likely to enter the ionosphere at the zenith of its source and more likely to enter at angles toward the horizon, where the field lines and wave path are more aligned.

2. Signal Analysis

The dual fluxgate magnetometer onboard VEX was able to detect ELF signals up to 64 Hz at various altitudes throughout the mission [1]. We searched all available data within the ionosphere for lightning-generated whistler-mode waves. Figure 1 illustrates an example of the waves seen. We show first the ellipticity of the waves. Whistlers are right-handed circularly polarized waves, giving a red color to the dynamic spectrum. Next is the angle of the wave propagation relative to the magnetic field. Blue indicates the waves are propagating along the magnetic field. This event is just one example of 1000's of signals each confirmed to be of the whistler-mode by the same analysis.

With a complete set of whistler observations, we can then calculate the Poynting flux of the waves. The Poynting flux requires the three components each of the wave electric field and magnetic field. Unfortunately, VEX did not have an electric field sensor, but we can infer it if we know the phase velocity of the wave. In order to calculate the phase velocity, we need to employ the Venus International Reference Atmosphere model of electron density since VEX did not have any measurements coincident with whistler observations [2]. This model was constructed using Pioneer Venus data during a solar maximum period with much higher activity than during the VEX campaign, so it has been corrected to correspond to the proper conditions.

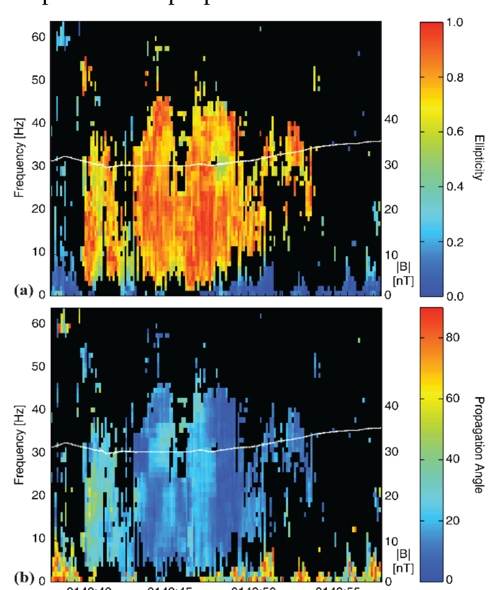

Figure 1. Ellipticity and propagation angle of the waves showing they are right-handed and propagate along the magnetic field. The white line is the total magnetic field.

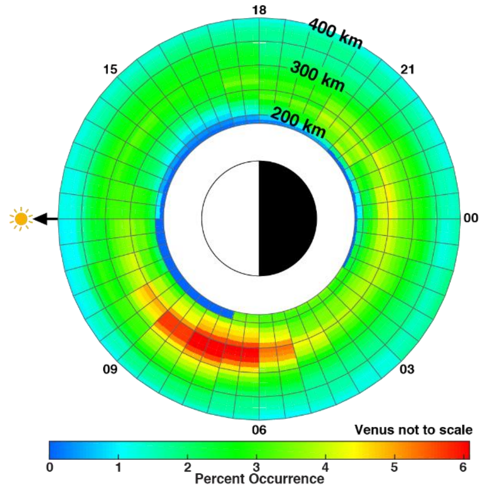

Figure 2. Percent occurrence of whistler-mode wave observations as a function of altitude and local time.

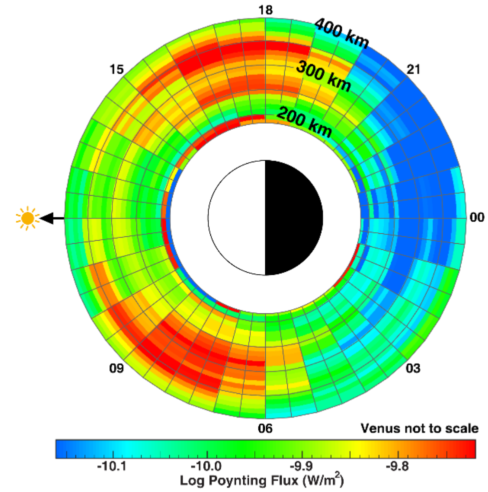

Figure 3. Median Poynting flux as a function of altitude and local time.

3. Statistics

The mission was in orbit from 2006-2014 and in that time there were nearly 7 cumulative hours of whistler observations below 400 km. In some cases, there was continuous activity for over a minute, implying a connection to an electrical storm below. These signals were most frequently seen when the spacecraft was at ~250 km altitude. Figure 2 shows the percent of time whistlers were detected as a function of altitude and local time. Most signals were observed within 200-350 km altitude with a rate of ~3% of the time the spacecraft spent at these altitudes. The peak near the dawn terminator is due to strong radial component of the field, which occurs when the ionosphere is strongly magnetized during solar minimum [3]. Whistlers are more likely to be detected here because of the field configuration, not necessarily because there is more lightning. It is clear from the figure that whistlers are ubiquitous at all local times. It should be noted that the lowest latitude of a detection was ~50°.

4. Discussion

VEX observed regular whistler activity due to lightning in the atmosphere of Venus. It is clear from figure 3 that the wave power is typically strong at the dayside flanks of the terminators. This is likely due to the flaring of the ionospheric field, which provides a radial component for the wave guidance. The signals appear to be stronger on the dayside because the weaker signals will attenuate if there is not a good field guide connected to the spacecraft.

VEX spanned almost one solar cycle, so we can compare observations during the solar minimum and maximum periods. Because the ionosphere becomes strongly magnetized during solar minimum, detection rates are about twice as high compared to solar maximum. The Poynting flux during solar maximum shows a decrease with increasing altitude providing further evidence that the waves were generated below the ionosphere. This conclusion is less clear during solar minimum because the waves are able to propagate to higher altitudes with less attenuation. A large sample of case studies are left for future work to highlight trends that might be lost to statistical averaging. In summary, lightning generated whistlers were observed throughout the entirety of the VEX mission, most commonly near 250 km altitude. Poynting flux estimates confirm that these waves were produced below the ionosphere.

Pioneer Venus (PVO) was able to detect the electric component of lightning-generated waves at 100 and 700 Hz, but on the nightside at lower latitudes. The observations of VEX were mainly above 70°N latitude. The improved capability of VEX over PVO has greatly increased our knowledge of Venus lightning. The Indian Space Agency (IRSO) has announced plans for a future Venus orbiter at low latitudes. If a lightning oriented investigation were included, their data would be very complementary to previous studies.

5. References

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