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Understanding Venus's Seismicity Using SmallSat Radio Occultation Observations

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Abstract

Two long-standing questions regarding Venus's geological and atmospheric evolution include: 1) *What physical processes drive Venus's seismicity*, and 2) *how do surface features and seismic events couple with Venus's atmosphere and ionosphere*? Despite the absence of global plate tectonics, radar images of the surface from the Magellan spacecraft suggest that Venus has as many active mantle plumes as Earth, the seismic activity of which could generate infrasonic signatures in its neutral atmosphere and ionosphere. Akatsuki observations and recent modeling efforts also reveal that topography-induced gravity waves are also detectable in Venus's neutral atmosphere. Similar to Earth, acoustic and gravity waves establish strong couplings between Venus's surface, atmosphere, and ionosphere via non-linear wave dynamics. In this presentation, we will define the orbital and science requirements of small satellite (SmallSat) constellations that could characterize temperature perturbations caused by Venus's geophysical features and events.

1. Introduction

Occultation sounding is a remote sensing technique that vertically scans a planetary atmosphere to retrieve its properties in a fine vertical resolution by measuring the amount of bending of propagating signals between a pair of occulting spacecraft over a planet's limb. Radio occultations (RO) between an orbiting spacecraft around Venus and a ground-based antenna on Earth have been used to probe the vertical thermal structure and wave activity of Venus's atmosphere, with measurements conducted by the Pioneer Venus Orbiter (PVO), Magellan, Venus Express (VEX), and Akatsuki missions. The PVO and the Magellan missions revealed temperature inversion layers at different latitudes on Venus [1] and small-scale temperature oscillations caused by vertically propagating gravity waves [2]. The VEX mission captured a double cyclonic vortex over Venus's south pole [3], whereas the Akatsuki mission observed a 10,000 km long inter-hemispheric bow-shaped structure above the cloud-top at ~65 km [4], and Magellan's gravity and topography data suggest that Venus hosts volcanic and quake activity. These surface and atmospheric features could trigger gravity (and acoustic) waves that propagate into Venus's neutral atmosphere and ionosphere. The only operating satellite orbiting Venus today is Akatsuki, but it provides vertical temperature profiles only when it occults behind Venus's limb as seen from Earth. Although Akatsuki still orbits Venus, it provides a limited number of vertical atmospheric profiles with reduced planet-wide and temporal coverage due to its orbital constraints. Observing Venus's atmosphere globally over an extended period of time requires two or more satellites performing ROs capable of detecting gravity (and acoustic) waves generated from surface-atmosphere interactions. This goal aligns well with the recent success of the MarCO CubeSats [5] in remote sensing Mars's atmospheric limb and the planetary science community's interest in understanding how SmallSats could contribute to planetary exploration. *Measurements of gravity waves (and/or acoustic waves) provide a powerful means of understanding the Venusian surface-atmosphere dynamic coupling*.

2. Methodology

We will explore various SmallSat constellation concepts and will use our in-house RO simulator to simulate locations of potential RO profiles around the planet. These locations will serve as a guide to assess the feasibility of detecting gravity wave-induced (and in the future, acoustic wave-induced) atmospheric perturbations. If time permits, we will also use our in-house Wave Perturbation (WP) analytical model to simulate vertical propagation of gravity waves in the Venus's atmosphere forced by vertical surface displacement (from the surface up to 100 km) given background information about Venus's air density, temperature, and wind profiles from a state-of-the-art, 3D, and first-principles physics-based Venus general circulation model (GCM).

3. Summary and Conclusions

We will modify JPL's advanced occultation simulator to account for Venus's planetary properties in order to estimate the locations of RO soundings acquired by a constellation of three SmallSats. Our preliminary results show that during seven Earth days' time period, we obtain more than 1,500 occultations with dense spatial coverage that sample 75-110 degrees East and 75-110 degrees West longitude regions from the South to the North pole of Venus (cf., Figure 1).

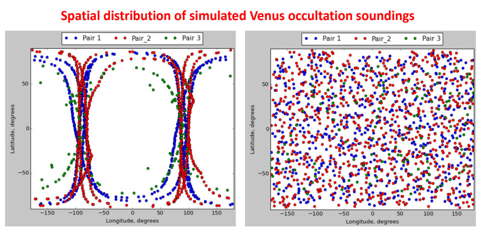

Figure 1: This is an example of radio occultation profile locations using three SmallSats placed at 90 degrees inclination in a circular orbit around Venus. Occultation soundings with respect to Venus's surface (left) and rotating atmosphere (right).

These are regions of high interest, because they coincide with Venus's bow-shaped structures. At latitudes greater than 80 degrees, in both hemispheres, we obtain a good spatial coverage at almost all longitudes. Such high latitude occultation soundings could be potentially beneficial to probe the vertical thermal structure and wave activity of the polar vortices. Exploring various combinations of three SmallSats at different occultations plans and altitudes would allow for increased number of RO soundings. A constellation of three SmallSats could fill in the spatial-temporal gaps and complement observations from the Akatsuki satellite, and could also provide synergistic observations from future Venus balloon-borne platforms that cannot retrieve high resolution vertical profiles. RO measurements could also help improve state-of-the-art global circulation models (GCMs) of Venus by providing atmospheric observations, which are key components in understanding the circulation and dynamic properties of Venus's atmosphere.

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