SCHUMANN RESONANCE IN VENUS: DEPENDENCE ON VOLCANISM AND TRACER FOR LIGHTNING ACTIVITY.

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Introduction: The ground-atmosphere-ionosphere cavity in planetary atmospheres can exhibit resonance phenomenon for characteristic Schumann Resonance (SR) frequency modes. These modes are excited by electrical activity in the atmosphere i.e. lightning, dust devils etc. The magnitude of the Schumann resonance modes are dependent on the electrical properties of the ionosphere, neutral atmosphere and ground. They lie in the ELF range of the electromagnetic spectrum. On Earth, the phenomena of SR has been studied through in-situ measurement of dust devils and lightning. There are detection of various sources of electrical activities in various planets and the potential SR modes have been computed using theoretical models.

Electrical Activity in Venus: The existence of electrical activity on Venus has been a matter of debate for many decades due to series of detection and non-detections by various missions and flyby. Two potential sources of electrical activity on Venus are due to cloud lightning [1] and triboelectric charging [2] in lower atmosphere. Venera 11 and 12 Groza measurements show indication of lightning in the lower atmosphere of Venus [3] which may have been of volcanic origin [4].

Table 1. Schumann Resonance frequency for Venus atmosphere

Reference	n_1	n_2	n_3
Guglielmi and Pokhotelov [5]	9.01 + 0.56i	15.81+0.97i	22.74+1.42i
Nickolaenko and Hayakawa [6]	8.80 + 0.91i	15.77+1.38i	22.67+1.76i
Pechony and Price [7]	7.95 + 0.74i	14.17+1.20i	20.37+1.60i

An expression for SR modes is given as follows [8]:

$$f_n = \frac{c}{2\pi R}\sqrt{n(n+1)} \qquad (1)$$

Here R is the radius of the planet, c is speed of light in vacuum. However, ground is composed of various minerals and is not a perfect conductor thus allowing for penetration of SR modes in subsurface regions based on conductivity values given by [9]. Penetration depth of above mentioned SR modes are computed using Eq. (2) and presented in Figure 1.

$$\delta = \sqrt{\frac{2}{\mu_0\varepsilon_0}\frac{\left(\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon_0}\right)^2}-1\right)^{-1/2}}{\omega}} \qquad (2)$$

Where δ is penetration depth, μ_0 is the permeability of free space, and ω is the angular frequency.

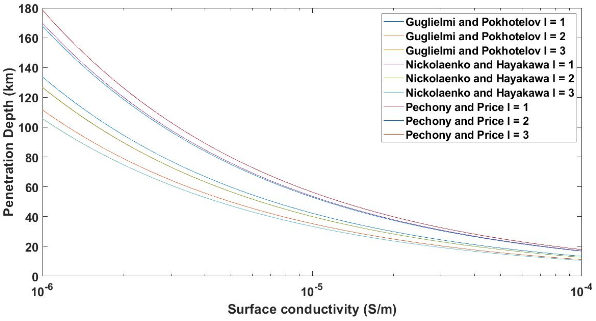

Figure 1. Penetration depth of Schumann Resonance modes based on theoretical predictions by previous works (Table 1).

Magma chambers in subsurface: Depth to the magma chambers is of size approximately equal to Caldera diameter [10]. The range of caldera diameters is around 100 m - 68 km. It is of the order of SR mode penetration depth.

Multi-layer model for ELF propagation: A multi-layer model has been used to compute the strength of ELF EM waves through the subsurface as illustrated in Figure 2. We use a two-step model [11, 12] with different depths of the magma chamber to compute the change in SR modes as a function of complex electric and magnetic altitudes h_e and h_m which is the sum of contributions from ground and ionosphere.

$$S_0^2 = \frac{h_m}{h_e} \qquad (3)$$

$$f_{nc} = f_n \frac{Re\, S_0(f_n)}{|S_0(f_n)|^2} \qquad (4)$$

$S_0(f_n)$ is a complex parameter corresponding to SR mode f_n and f_{nc} is the corrected SR frequency corresponding to the n^th mode.

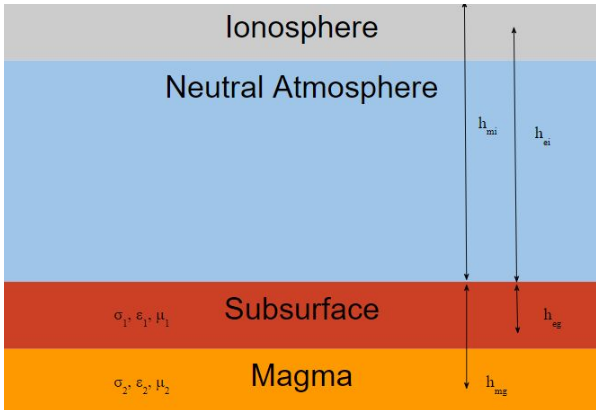

Figure 2. ELF EM wave propagation model through the ground ionosphere cavity [12]

We considered the ionospheric complex electric and magnetic heights based on [7]. Relative permittivity and permeability of Venus are taken as 5 and 1 respectively [9, 13] while the electrical permittivity and magnetic permeability for magma are taken to be 1 based on [14]. Conductivity of magma is taken to be 20000 S/m in accordance with [15].

Results: SR mode (n = 1) and corresponding Q_n is computed at various subsurface conductivity and depth to the magma chamber as presented in Figure 3 and Figure 4 respectively.

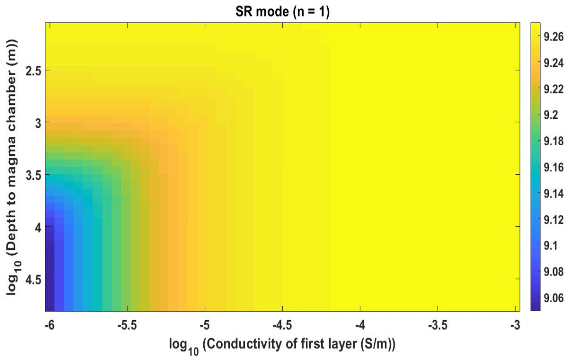

Figure 3. SR mode n =1 at various depths of the magma chamber for various soil conductivity.

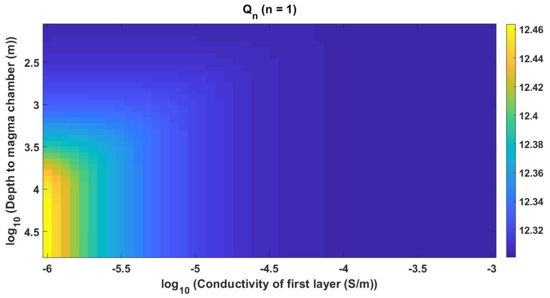

Figure 4. Q_n (n = 1) at various depths of the magma chamber for various soil conductivity.

Applications: In future lander and rover based ELF magnetometers and antennas can obtain EM spectrum identifying the SR modes generated due to potential volcanic charging. Further, the regional deviation in SR modes can be used to determine subsurface depth of the magma chamber. In addition, the SR modes may be detected from an orbiter due to propagation of SR modes through the ionosphere due to leakage in the cavity (as observed on Earth) [16] although such phenomena have not been observed on Venus. An orbiter borne electric field instrument may detect potential leakage in the Venusian ionosphere and SR modes can act as a tracer for lightning activity in the atmosphere.

References:

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