A new concept for seismology on Venus using orbiting radar instead of landers

P. Lognonné, R.Garcia, G.Occhipinti, Département de Géophysique Spatiale et Planétaire, IPGP, Saint Maur des Fossés, France (lognonne@ipgp.jussieu.fr)
B.Banerdt, Jet Propulsion Laboratory, Pasadena, USA (bruce.banerdt@jpl.nasa.gov)
B.Romanowicz, Seismological Laboratory, UC Berkeley, Berkeley.USA (barbara@seismo.berkeley.edu)

Magellan's Venus pictures show several examples of faults and fractures suggesting movement of the planet's crust and the existence of Venus quakes. If the seismic activity of Venus is unknown, however, in contrary to Mars, Moon and Mercury, the surface of Venus exhibits few impact craters. Most Venusian impact craters appear unmodified by any weathering process. This lack of crater is interpreted as the indication for a period of catastrophic resurfacing by volcanism between 200 Myrs and 700 Myrs. Such an activity places therefore Venus as the most recently active terrestrial planet after the Earth. The impact crater data and volcanic distribution support either a catastrophic resurfacing some 500 Myrs ago or a more local or regional resurfacing model, able to generate a volcanic flux of 0.5 km^3/yr similar to the intraplate volcanic flux on Earth. Some areas are probably tectonically very active, like Ishtar Terra, with the highest topography and the third geoid height. Some theories on the formation of Ishtar Terra need stress differences of a few 100 Mpa, with time scale of the tectonic of a few 100 Myr which both can be compared to values for Earth's tectonic. We can imagine therefore a tectonic on Venus able to generate large quakes, of magnitude greater than 6. The seismic activity of the Earth is typically generating about 120 quakes per year of magnitude between 6 and 6.9 and about 14 of magnitude between 7 and 7.9. Mars is expected to have a seismic activity about 3 orders of magnitude smaller than the Earth.

We propose therefore to use the strong coupling between the atmosphere and the solid planet for detecting quakes on Venus, by searching for acoustic and ionospheric signals generated by quakes from a swarm of orbiters.

Principle of measurements

After a quake, the surface of a planet is vibrating horizontally and vertically. By continuity of the vertical displacement, the atmosphere is therefore forced to move with a vertical velocity equal to the surface vertical velocity, and this vibration is then propagating upward. Such atmospheric vibrations are producing adiabatic pressure and temperature variations. Theory is detailed in *Lognonné et al.*, 1996, *Lognonné and Clévédé*, 2003 and example of applications on Earth are detailed by *Artru et al.*, 2001, *Farges et al.*, 2002 and *Ducic et al.*, 2003. When the acoustic wave is propagating upward, its kinetic energy is conserved as long as the atmosphere viscosity is not producing significant attenuation. At low altitude therefore and due to the exponential decay of density, the amplitude of the wave is increasing exponentially. Dissipation mechanisms are encountered at high altitude. Such signals are now commonly observed on the Earth and can measure the group velocity of the Rayleigh waves (*Ducic et al., 2003*). The best way to detect ionospheric seismic signals is to use a Doppler measurement by sending an EM signal which is reflected in the ionosphere.

Strain rate sec^{-1}	Ms=3.0	Ms=4.0	Ms=5.0	Ms=6.0
Global cooling (10^{-19})	25	6	1	0
Intra-Plate (10^{18})	2512	631	126	25
Active Margin (10^{15})	251189	63096	12589	2512

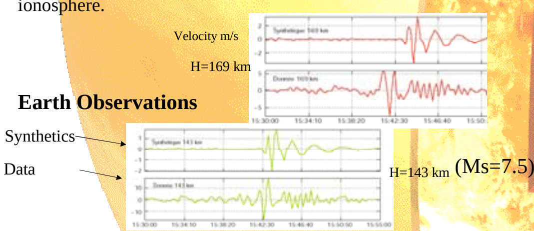
Some estimates of the Venus activity were done for a past NASA Discovery proposal VISM (Venus Internal Structure Mission) study from 1993. The range of seismicity is pretty wide, depending on the source of strain and the seismogenic layer thickness assumed. They assumed a layer thickness of 30 km, based on heat flow estimates

Experiment Strategy

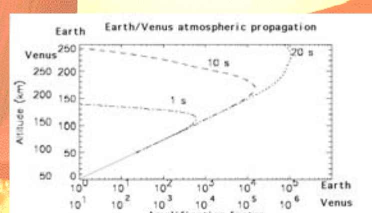
In contrary to the Earth, a sounding by the top at 150 km of altitude might be possible on Venus. Indeed, as shown below, the ionospheric structure is thinner and sounding by the top might be able to sound at altitudes below 200km due to a maximum ionisation found at about 150 km. Density electrons ranges from $5x10^3$ cm^{-3} to $15x10^3$ cm^{-3} during the night and from $5x10^5$ cm^{-3} to $5x10^5$ cm^{-3} during the day side. This gives electron plasma frequencies of 0.5-1.5 Mhz during the night and 3 Mhz-7 Mhz during the day. A 2 Mhz sounder might bounce for an electron plasma density of about $5x10^4$ cm^{-3}. Due to the weak directivity of antenna at these frequencies, several satellites, in a swarm geometry, will be necessary to achieve the necessary resolution at the ground (about 10 km). The detailed design of the experiment is now studied

Seismic signals at 140-170 km of altitude

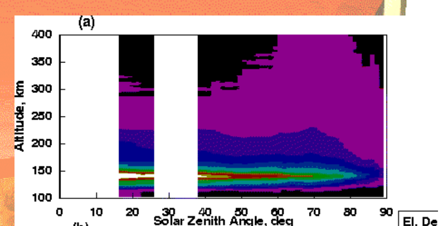
Earth Observations



IPGP/CEA-DASE (Farges et al., 2002)



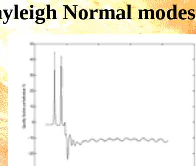
Amplification with altitude: comparison between Earth and Venus



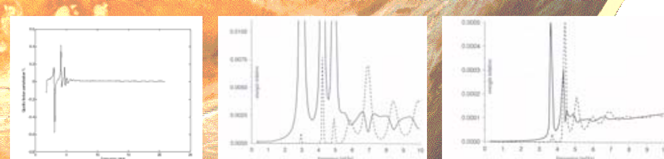
Ionospheric structure (Fox and Kliore, 1997)

Effect of the atmosphere on Seismic waves and Rayleigh Normal modes

The Venus atmosphere is strongly coupled to the interior. At the surface, pressure is about 90 bars, density about 60 kg/m^3, acoustic velocities slightly higher (410 m/s) than on Earth and ground coupling (ρc) is about 60 greater than on Earth. This coupling is perturbing strongly the fundamental normal modes of the interior. The presence of the atmosphere is reducing by about 15% the quality coefficient of the Normal modes and is generating, near the resonances periods of the atmosphere, perturbation of a few percents. At 150 km of altitude, the attenuation of the Venus atmosphere is still weak and can be neglected for surface waves.

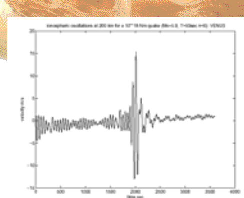


Quality factor perturbations

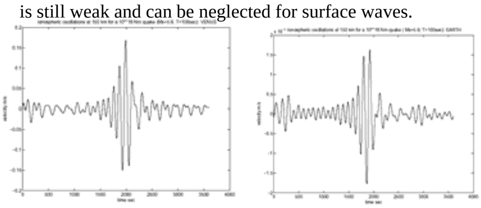


Frequency perturbations

***Right**: Fraction of the energy of surface waves in the Earth Atmosphere for Rayleigh surface waves. Only 2 peaks are in atmospheric resonance, with mainly the first one corresponding to an acoustic window. **Left.** Same, but for Venus. Note the very large amplification of the energy in the atmosphere and the three windows with major atmospheric-interior resonance. These frequency windows will be used for searching acoustic and Rayleigh waves.*



Synthetic low passed at 50 sec and 200 km of altitude. Peak to peak amplitudes of 30 m/s are reached



Long period vertical oscillations, for a 10^{18} Nm quake (Ms=5.9) and for period larger than 100 sec. Due to the difference in the acoustic coupling at the ground, ionospheric signals at 150 km of altitude will be about 100 stronger on Venus for the same magnitude. This is about 1.3 Ms magnitude. Ionospheric velocity oscillations are about 0.3 m/s at these periods, corresponding to wavelength larger than 300 km. They will be about one order of magnitude larger at 20 sec

Summary and conclusion: Venus quakes of magnitude 5.5 and greater are probably perturbing the Venus ionosphere with vertical velocities larger than 1 m/s. A swarm of small satellites, acting as top-side sounders could probably detect these signals. A detailed technical study will determine more precisely the characteristic of such a mission. If feasible, this mission will determine the lithospheric structure of Venus, up to depth of several hundred kilometers.

Reference:

*Artru J., P. Lognonné et E. Blanc, Normal modes modeling of post-seismic ionospheric oscillations, Geophysical Res. Lett., **28**, 697-700, 2001.*

T. Farges, J. Artru, P. Lognonné, A. Le Pichon, Effets des séismes sur l'ionosphère, Choc, CEA, 2002

*Lognonné, P., C. Clévédé and H. Kanamori, Normal mode summation of seismograms and barograms in an spherical Earth with realistic atmosphere, Geophys. J. Int., Geophys. J. Int., **135**, 388-406,1998.P. Lognonné and E. Clévédé, Chapter 10: Normal modes of the Earth and Planets, Handbook on Earthquake and Engineering Seismology, IASPEI Centennial Publications, H. Kanamori, P. Jennings and W. Lee editors, 2002*

*V.Ducic, J. Artru and P. Lognonné, Ionospheric remote sensing of the Denali Earthquake Rayleigh surface waves, Geophys. Res. Lett., **30(18)**, 1951, doi:10.1029/2003GL017812, 2003*