SEISMIC INTERIOR/ATMOSPHERIC COUPLING ON VENUS. P.Lognonné, G.Occhipinti and R.Garcia, Institut de Physique du Globe de Paris, Département de Géophysique Spatiale et Planétaire, 4 Avenue de Neptune, 94100 Saint Maur des Fossés, France (Lognonne@ipgp.jussieu.fr)

Introduction: 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 Venus as the most recently active terrestrial planet after the Earth. We can imagine therefore a tectonic on Venus able to generate large quakes, of magnitude greater than 6. How however to perform such seismic measurement on a Planet were the surface temperature make the survival of any lander so difficult?

Atmospheric coupling:
The atmospheric coupling provides an alternative to classic surface measurements for seismology. After a quake, the surface of a planet is indeed 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 [1]. This coupling has been observed since the early 70s and more recent observations have been done on the Earth for quakes with magnitude greater than 7 with a good signal to noise [2,3,4]. 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 on the Earth have even been used to measure the group velocity of the Rayleigh waves [4].

Venus atmospheric coupling
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. The Venus atmosphere is therefore strongly coupled to the interior. We therefore have studied in detail its coupling efficiency for seismic waves. We have taken a Venus interior model derived from a reference Earth model [5] and with a core size adjusted to the mass of the planet and a mantle structure just corrected from the difference of pressure with depth. We have added a classical atmospheric model of the planet [6].

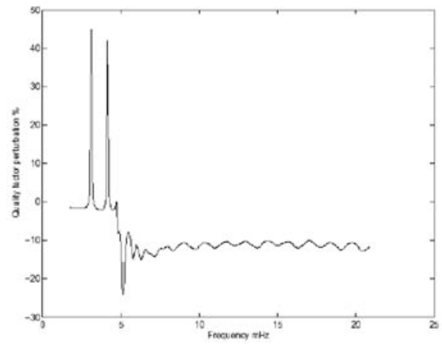

Figure 1: perturbation of the quality factor for the spheroidal fundamental normal modes. The two peaks are associated to resonances where a significant energy is transferred in the atmosphere instead of the solid planet, leading to a reduced attenuation. After slightly less than 5 mHz however, modes loose a significant fraction of their energy in the atmosphere.

A first and impressive effect of the coupling is a strong perturbation of the fundamental normal modes of the interior. The presence of the atmosphere is indeed reducing by about 15% the quality coefficient of the Normal modes and is generating, near the resonances periods of the atmosphere, larger perturbations (Figure 1). This means that about 15% of the energy of a quake will be dissipated in the Venus atmosphere. We also find that at some frequencies, a very large fraction of the seismic waves is lost in the atmosphere in heating processes (Figure 2). This transfer of energy (and of momentum) might also contribute significantly to torques transfer between the Venus atmosphere and the solid body and might therefore contribute to the past evolution of Venus' spin. It must be taken into account in future analysis.

Seismic waves and possible detection strategies
We then computed seismic waves in the Venus atmosphere. At 150 km of altitude, the attenuation of the Venus atmosphere related to viscosity and non adiabatic heat transfer is still weak and was therefore neglected. The Figure 3 shows long period vertical oscillations of the atmosphere, 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 than on Earth for the same magnitude.

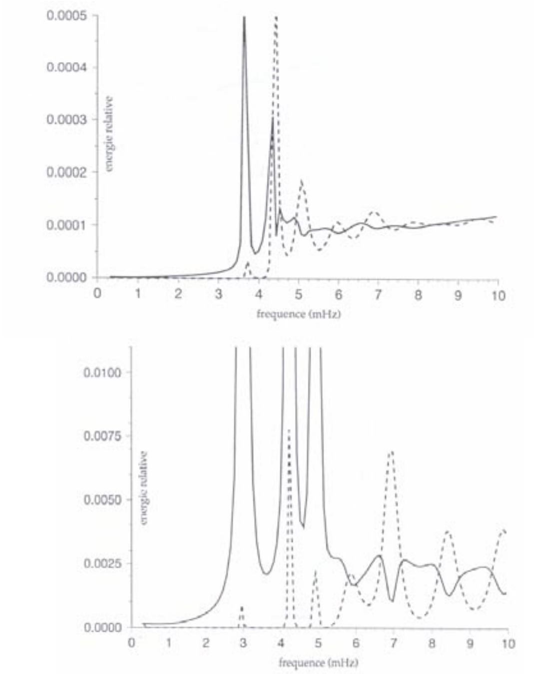

Figure 2: Top: Fraction of the energy of surface waves in the Earth Atmosphere for Rayleigh surface waves. Only 2 peaks are due to atmospheric resonances, with mainly the first one corresponding to an acoustic window. Bottom**:** Same, but for Venus. Note the very large amplification of the energy in the atmosphere and the three windows with major atmospheric-interior resonance.

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. We believe that such amplitudes can be detected with a dedicated orbiter. Indeed and in contrary to the Earth, a sounding by the top at 150 km of altitude might be possible on Venus due to a thinner ionospheric structure [6]. Such top-side sounding might get the vertical displacement at altitudes below 200km The 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 are typically observed [6]. 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 therefore 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).

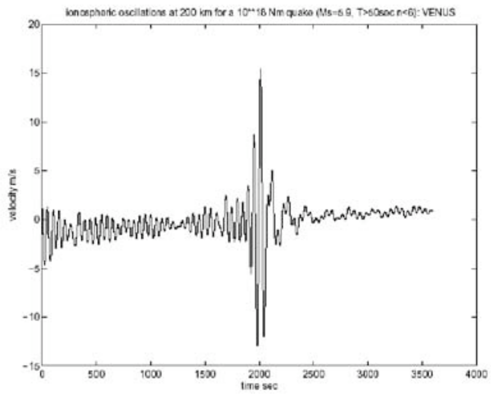

Figure 3: Synthetic low passed at 50 sec and 200 km of altitude. Peak to peak amplitudes of 30 m/s are reached

Conclusion

We have shown that on Venus, the acoustic coupling between the solid planet and the atmosphere is large as compared to the Earth, due to a better acoustic adaptation of the atmosphere with respect to the interior. This is resulting in effects approximately two orders of magnitude larger than on Earth. Venus quakes of magnitude 5.5 and greater are probably perturbing the Venus ionosphere with vertical velocities larger than 1 m/s and significant thermal heating. ESA's Venus Express mission, expected for launch in 2005, will therefore search, with its VIRTIS instrument, for atmospheric temperature anomalies related to the release of seismic energy [7]. A future step can be foreseen after this precursor experiment with a dedicated mission. A swarm of small satellites, acting as top-side sounders could probably detect quakes in the ionosphere. If feasible, this mission will determine the lithospheric structure of Venus, up to depth of several hundred kilometers.

References: [1] Lognonné P, Clévédé C, Kanamori H. 1998. *Geophys. J. Int.* 135:388--406 [2] Artru J., P. Lognonné et E. Blanc, *Geophysical Res. Lett.,* **28**, 697-700, 2001. [3] Artru J, Farges T, Lognonné P. 2004, *Geophys. J. Int.*, 158:1067--1077 [4] Ducic V, Artru J, Lognonné P. 2003. *Geophys. Res. Lett.* doi:10.1029/2003GL017812 [5] Dziewonski AM, Anderson DL. 1981. *Phys. Earth Planet. Int.* 25:297—356 [6] Venus II. Edited by Stephen W. Bougher, D.M. Hunten, and R.J. Philips. Tucson, AZ : University of Arizona Press, 1997. [7] Marinangeli LL, Baines K, Garcia R, Drossart P, Piccioni G, et al. 2004. *Lunar Planetary Sci. Conf., 35th, League City*, *TX*, Abstr. No. 1363