Computing of normal modes for a spherical Planet with a realistic atmosphere: Venus, a good benchmark

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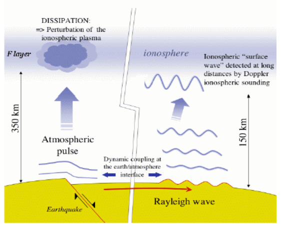
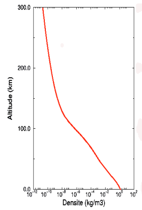
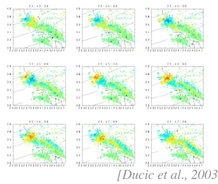




$\rho v^2 = Constant$ →

from 10,000 to 100,000
of amplification between
<u>150 and 250 Km altitude</u>

Thanks to technological advances over the past fifteen years the atmosphere is now a new medium for seismological investigation. Surface waves emitted after large earthquakes are known to induce, by dynamic coupling, atmospheric infrasonic and gravity waves propagating upward through the atmosphere. Those waves have been detected recently at ionospheric heights using a variety of techniques, such as Doppler or GPS ionospheric sounding. Recently, theoretical works (*[artru et al. 2004]*) presented the detection of several Earthquakes with a HF Doppler network to confirm the quantitative modeling of co- and post-seismic perturbation compute with a normal mode theory for a planet with realistic atmosphere (*[Lognonné et al. 1998]*) where the viscosity dissipation has been taken into account (*[artru at al., 2001]*). And the dense GPS networks provide a sufficient coverage to image ionospheric perturbations such as those produced by Earthquakes (*[Ducic et al., 2003]*).

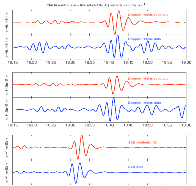


[Ducic et al., 2003]

Earth Observations

Doppler sounding →

← GPS dense network

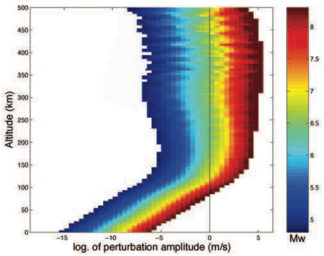


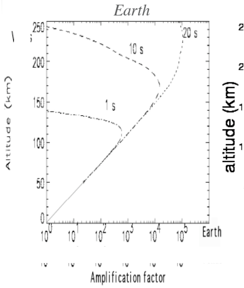
[artru et al. 2004]

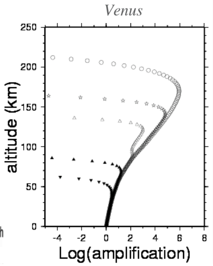
These and other observations have allowed to better understanding the coupling mechanism and practically most of the post-seismic signals can be explained by a dynamic coupling at the solid Earth-atmosphere interface: in essence the vertical displacement near the ground, either near the epicenter or in the tele-seismic distances due to Rayleigh waves, induces upward propagating waves in the atmosphere. Although the amplitude is very small on the ground, the oscillations are strongly amplified towards top of the atmosphere because of the conservation of kinetic energy and the exponential decrease of density with height. In order to know the amplitude of post-seismic signal we compute here the amplification of acoustic waves with altitude by normal mode theory for Earth-Atmosphere and Venus-Atmosphere systems.

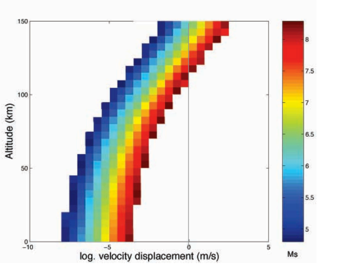
Effect of the atmosphere on Seismic waves and Rayleigh Normal modes

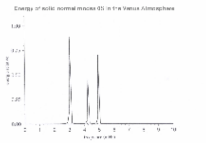
The Venus atmosphere is strongly coupled to the interior. At the surface, pressure is about 90 bars, density about 60 kg/m3, acoustic velocities slightly higher (410 m/s) than on Earth and ground coupling, it is about 60 greater than on Earth. This coupling is perturbing strongly the fundamental normal 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.

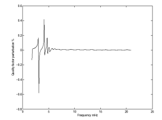




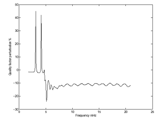




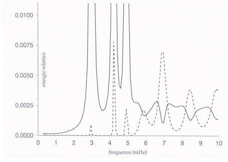


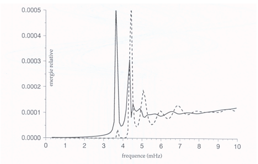


Frequency perturbations

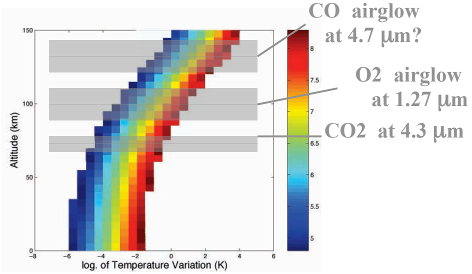


Quality factor perturbations





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.*



In the context of ESA's Venus Express mission, we compute the temperature perturbation induced by a Venus-quake for an adiabatid atmosphere. The VIRTIS spectrometer borded, is able to measure the temperature of the atmosphere by airglow tecnics on an altitude ranging between 60 and 100 km.

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 better than the VIRTIS spectrometer grace to the thin structure of Venus ionosphere. 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.