Detecting atmospheric perturbations produced by Venus quakes

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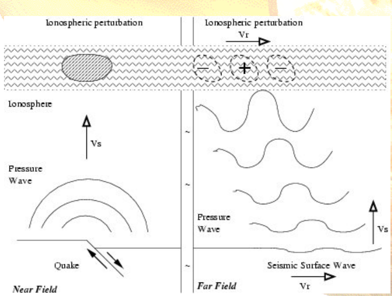
The possibility to detect seismic activity on Venus by using the mechanical coupling of the solid-atmosphere system is investigated. First, the atmospheric attenuation of infrasonic waves produced by quakes is theoretically determined from a pure CO2 atmospheric model, demonstrating that frequencies below 0.1 Hz are amplified by a factor of 10 000 above 120 km altitude. With a simple quake model, an upper limit of infrasonic adiabatic temperature and density perturbations above the source is estimated. Then, we demonstrate that the temperature increase due to high altitude acoustic energy dissipation above a quake is large enough to be measured by remote sensing methods. Finally, the expected post-seismic effects are analyzed in the framework of the VIRTIS instrument on board the ESA Venus Express mission.

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 infrasounds are producing adiabatic pressure and temperature variations. Theory is detailed in *Lognonné et al.*, 1998, *Lognonné and Clévédé*, 2002 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 until attenuation mechanisms are filtering out the high frequency energy along the path. So, due to the exponential decay of density, the amplitude of the wave is increasing exponentially and then dissipated in the high atmosphere. Such signals are now commonly observed on Earth and allowed to measure the group velocity of the Rayleigh waves (*Ducic et al., 2003*). The best way to detect such infrasonic signals in the upper atmosphere on Earth is through the perturbations of the ionospheric plasma created by these signals.

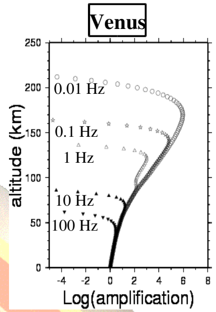
Common observing systems are Doppler ionospheric sensors (*Farges et al.*, 2002) and ionospheric tomography through GPS data of dense receiver networks (*Garcia et al.*, 2005b).



Physical mechanism of ground atmosphere coupling (from *Garcia et al.*, 2005b)

Infrasounds in Venus Atmosphere

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 (ρc) is about 60 times greater than on Earth. The attenuation of infrasonic waves in the atmosphere of Venus is computed assuming a pure CO2 atmosphere, and taking into account the classical (viscosity and thermal conductivity effects), rotational and vibrational attenuation mechanisms.

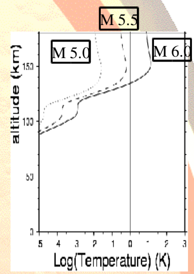


Amplification factor of infrasonic waves in the atmosphere of Venus for different wave frequencies

Local atmospheric temperature perturbation:

The dissipation of the initial acoustic pulse emitted by the seismic rupture has been modeled by using a reverse fault source model, plane wave propagation in the atmosphere and energy estimates coming from the acoustic attenuation model. The average local temperature increase, due to the dissipation of a 50 s source signal, is estimated above a source area of 50 km radius for different quake magnitudes.

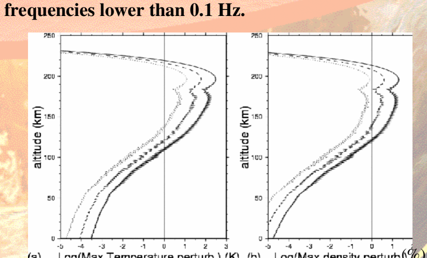
For magnitudes greater than 5.5, the upper atmosphere heating by the dissipation of acoustic waves is reaching **1K, at altitudes above 130 km,** during more than 200 seconds.



Local temperature increase above the source area for different quake magnitudes

Adiabatic temperature and density perturbations:

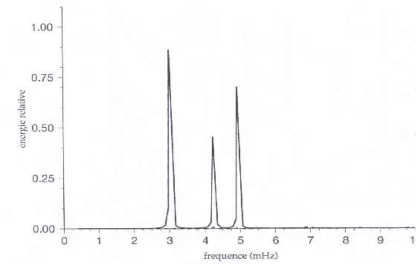
The adiabatic temperature and density perturbations produced by the infrasonic waves are also estimated by computing at each altitude the maximum adiabatic temperature and density perturbation perturbation above the source area for different quake magnitudes. For a quake **magnitude larger than 5.5 significant temperature and density perturbations are observed above 120 km, at frequencies lower than 0.1 Hz.**



Maximum adiabatic Temperature and Density perturbations above the source of different quake magnitudes (5.0, 5.5 and 6.0).

Background excitation of atmospheric normal modes:

The dynamics of the atmosphere of Venus is exciting the coupled system planet/atmosphere in the infrasonic and seismic bands. Such excitation of solid normal modes by the atmosphere has already been observed on Earth seismic data. Moreover, because the solid part of the planet is coupled to the atmosphere, the observation of atmospheric normal modes brings constraints on the solid part of the planet. So, the observation of temperature and density perturbations in the infrasonic band at upper atmosphere altitudes is very likely, and it will inform us bout the structure of the solid part of the planet.



Energy of fundamental (n=0) solid normal modes in the atmosphere of Venus as a function of frequency when the coupled system planet/atmosphere is considered. Note that three fundamental solid modes enter in resonance with the atmosphere of Venus.

Upper atmosphere probes of temperature and density perturbations:

In order to detect temperature and density perturbations in the upper atmosphere of Venus, we must find species presenting emission of absorption lines sensitive to these parameters above 120 km altitude. Good candidates for such probes are O2 nightglow and CO2 non-LTE emissions. These two ray lines are in the spectral range detected by instruments onboard Venus Express, in particular VIRTIS-M thermal imaging spectrometer. In collaboration with the VIRTIS Co-I team, an observation mode relevant to the detection of background atmospheric normal modes has been defined, whereas transient effects of Venus quakes will be searched in the rest of the data set.

The next step is the estimate of the upper atmosphere probes responses to density and temperature perturbations.

For future missions, the probing of the vertical velocity of ionospheric layers, by a swarm of ionospheric doppler sounders from orbit, is certainly the best way to investigate these waves.

Summary and conclusion:

Venus quakes of magnitude 5.5 and greater are perturbing the atmosphere of Venus by creating significant temperature and density perturbations above the source area. Moreover, background excitation of atmospheric normal modes is expected and will inform us about the solid part of the planet.

The VIRTIS-M data will be processed in order to detect the atmospheric normal modes, and investigate transient seismic/infrasonic signals in the upper atmosphere of Venus through emission lines of upper atmosphere species.

Future theoretical studies will investigate the sensitivity of molecular emissions to the density and temperature perturbations, and the absorption of infrasonic waves in biphasic media such as the Venus clouds.

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