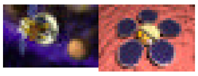

Simulation of the Continuous Excitation of Normal Modes of Mars

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(1) (2)

- Normal modes frequencies are known to be data very sensitive to the structure. These frequencies were used for the determination of the spherical Earth Model 1066 and PREM. Normal modes are routinely observed on the Earth. They however need large magnitude quakes. On Mars, only a 10^{18} Nm quake will allow amplitude in excess of 10^{-9} $ms^{-2}Hz^{-1/2}$ level (which is considered as a conservative estimate of the Martian vertical noise) at frequencies higher than 3 mHz. At frequencies higher than 5-7 mHz, the signal to noise ratio may exceed 5. Such a large quake may however occur at a rate of about one every Martian year… and possibly less due to uncertainties in the seismic activity.
- An alternative for Normal modes is to search for a continuous excitation, produced by the atmospheric turbulences. As recently discovered by Nawa *et al.* [1998], Suda *et al.* [1998], these turbulences on the Earth excite indeed continuously the fundamental branch of spheroidal Earth normal modes. As shown by Kobayashi & Nishida [1998], such excitation process on Mars might be almost as strong as on the Earth. The inversion of the detected free frequencies of the excited normal modes might then, without any quake, provide information on the shear structure of the upper Martian mantle, as well as on the state and size of the core for the gravest modes [e.g. van Hoost *et al.*, 2000]

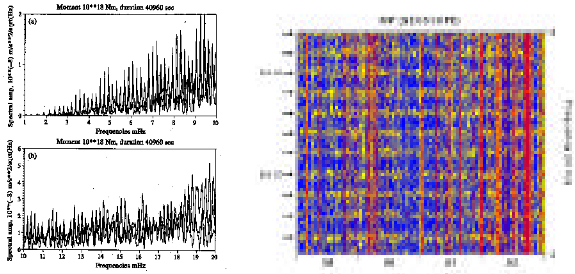
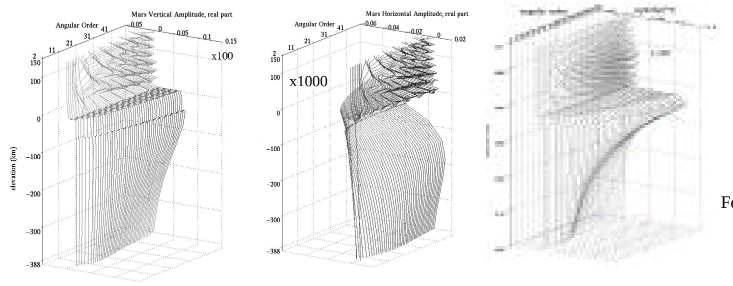


Fig 1a-b: *Two ways of normal modes excitation: left normal modes synthetics for a 10^{18} Nm moment marsquake*, right continuous excitation on Earth (from Tanimoto, 1999)

Theory of atmospheric coupled modes

Fig2a-c: *Normal mode amplitudes on Mars (vertical and horizontal) and on the Earth in the solid part and atmosphere. Amplitudes are related to the amplitude time sqrt(density). Amplification is 100 in the atmosphere for the vertical amplitudes, 1000 for the horizontal amplitude*



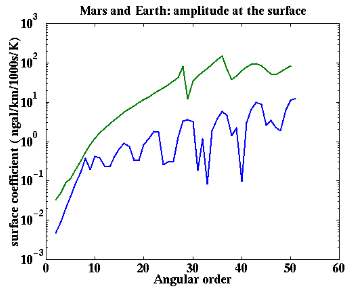
We model the permanent excitation on Mars by taking into account the coupling of the Martian Normal modes with the atmosphere, following theory developed by Lognonné et al, 1998. Compared to the Earth, the transition between the trapped atmospheric modes and the propagating modes is observed at much lower angular orders, producing a relatively stronger coupling than on Earth (see Fig 2a-c)

The atmospheric seismic source can be expressed following theory developed by Lognonné et al., 1995. The pressure glut moment is related to the non Hooke pressure and to the Reynold stresses of the global circulation and turbulences and can be expressed as

$$M_{ij} = (p + \kappa \quad {}^{k}u_k)\delta_{ij} + \rho u_i u_j$$

For a global source, this gives the acceleration of a given normal mode with time as:

$$a_{\ell,m}(t) = \int_{-\infty}^{t} d\tau\ e^{i\omega_\ell (t-\tau)} \int_0^{+\infty} dz\ A^{ij}{}_\ell(z) \int d\Sigma\ \bar{Y}_\ell^m(\theta,\phi) \frac{m_{ij}(z,\theta,\phi,\tau)}{R\rho_0(z)}$$



where R is the universal gas constant per unit of mass. $\frac{m_{ij}(z,\theta,\phi,\tau)}{R\rho_0(z)}$ has the dimension of a temperature. For the isotropic term related to the pressure, and assuming that the Hook pressure is much less than the real pressure, we have

$$a_{\ell,m}(t) = \int_{-\infty}^{t} d\tau\ e^{i\omega_\ell (t-\tau)} \int_0^{+\infty} dz\ A_\ell(z) \int d\Sigma\ \bar{Y}_\ell^m(\theta,\phi) T(z,\theta,\phi,\tau)$$

The Figure 3 gives the A term at the surface for Earth and Mars. At very low orders, the sensitivity of normal modes to the temperature fluctuations (e.g. and their associated pressure fluctuation) is almost comparable for Mars and Earth. At higher angular order, the sensitivity is about one order of magnitude smaller. However, the amplitude of the source term (e.g. the temperature variations is much higher, as well as the thickness of the boundary layer: The boundary layer on the Earth is about 1 km large, when it might be up to 8 km on Mars).

Fig 3: *sensitivities on Mars and Earth with respect to temperature fluctuations*

Pressure glut modeling with a global circulation model

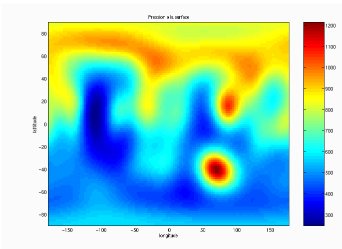


Fig4: *GCM pressure field at T=0*

We use a Global circulation model to model the pressure and wind fields. Such model, for numerical reasons, is not able to simulate the boundary layer turbulences, which are expected as ones of the major sources for the continuous excitation of normal modes. This provides therefore only minimum estimate only for the low order normal modes (L<10).The time step is 150 sec, which means that amplitudes are non aliased only for modes with angular orders less than 15. The amplitudes are above the detection threshold of the instrument noise. However, environmental noise at these frequencies might be significant: on the Earth for example, and for such angular orders, the continuous excitation of normal modes is not observed.

Future studies will take into account the turbulences in the boundary layers and will increase the resolution in time, in order to obtain estimates up to 100 sec.

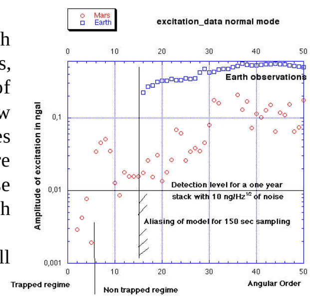
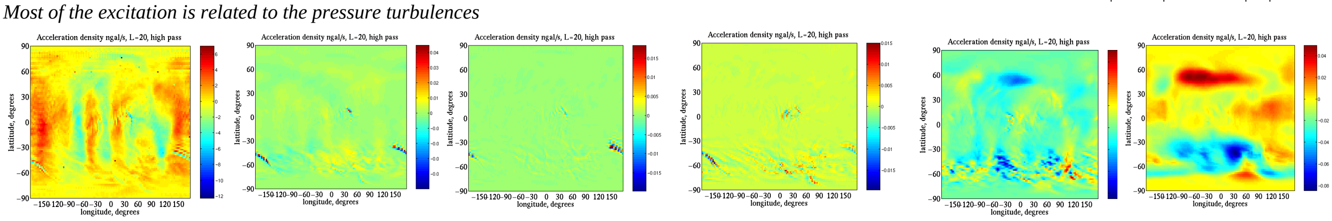


Fig5: *Amplitudes of the forcing terms integrated vertically with the normal mode L=20 (very small differences are expected for L=10 to L=20 for these functions, due to the smooth dependence of the eigenfunctions, see Fig 2a-c). Source terms for pressure and Reynold stresses ($V_r V_\theta$, $V_r V_\phi$, $V_\theta V_\phi$, $V_\theta V_\theta$, $V_\phi V_\phi$). Most of the excitation is related to the pressure turbulences*



References: Lognonné, P et al, An Ultra-Broad Band Seismometer on InterMarsnet, *Planetary Space Sciences*, **44**, 1237-1249, 1996. Kobayashi, N., and K. Nishida, Continuous excitation of planetary free oscillations by atmospheric disturbances, *Nature*, **395**, 357-360, 1998. 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 et al., The NetLander Very Broad band seismometer, *Planet. Space Sc*., **48**, 1289-1302, 2000.