Noise Tomography Concerns for Planetary Application

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KISS Workshop

March 17th, 2010

Outline

- Seismic noise on the Earth
- Some theoretical considerations
- Important questions
- Results/discussion?

Primary Issues of Concern

- How large is the noise?
- How well distributed?
  - Isotropy? Depth of ‘noise sources’?
  - Coherent over seismic wavelengths?
- How much attenuation?
  - Coherent at both stations?

Seismic noise sources on Earth

The terrestrial noise spectrum

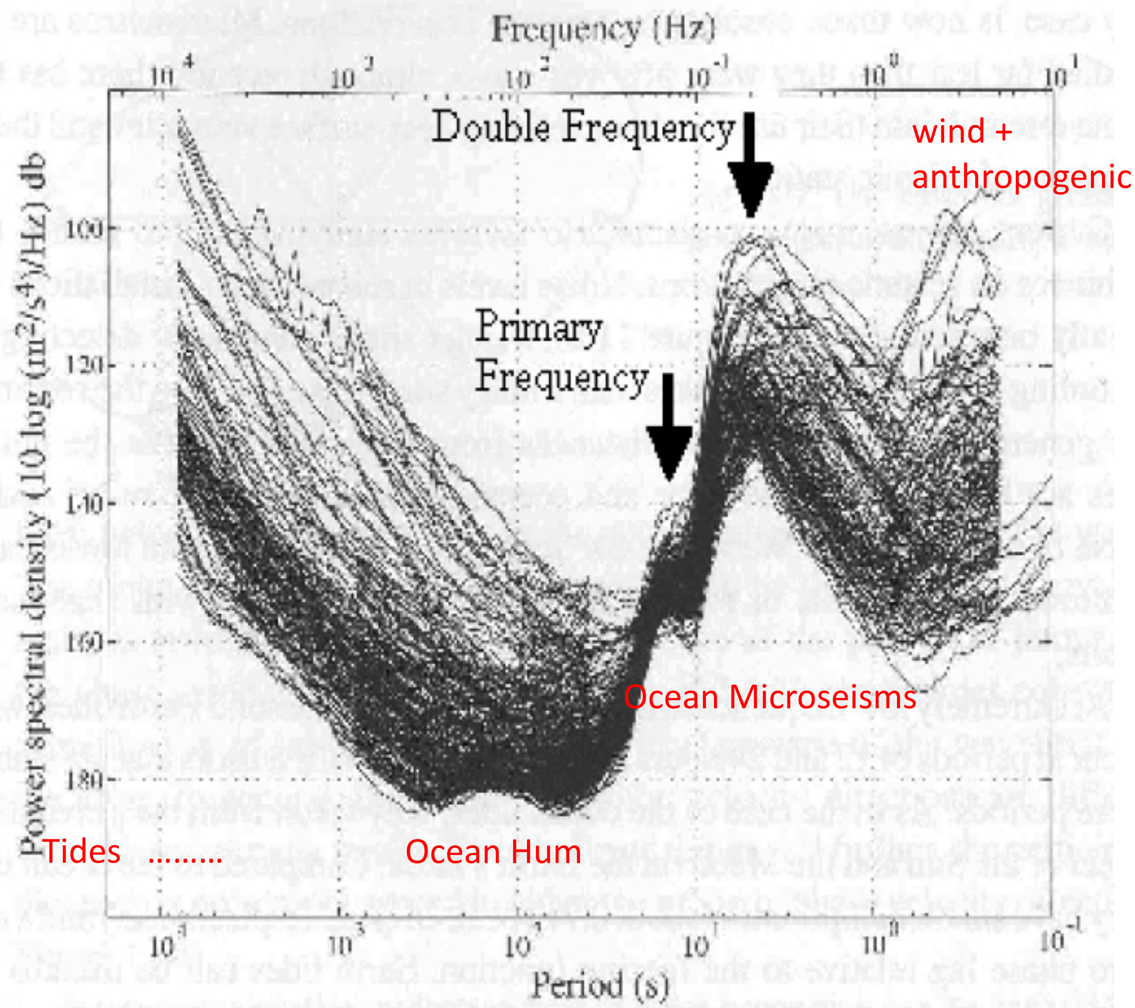
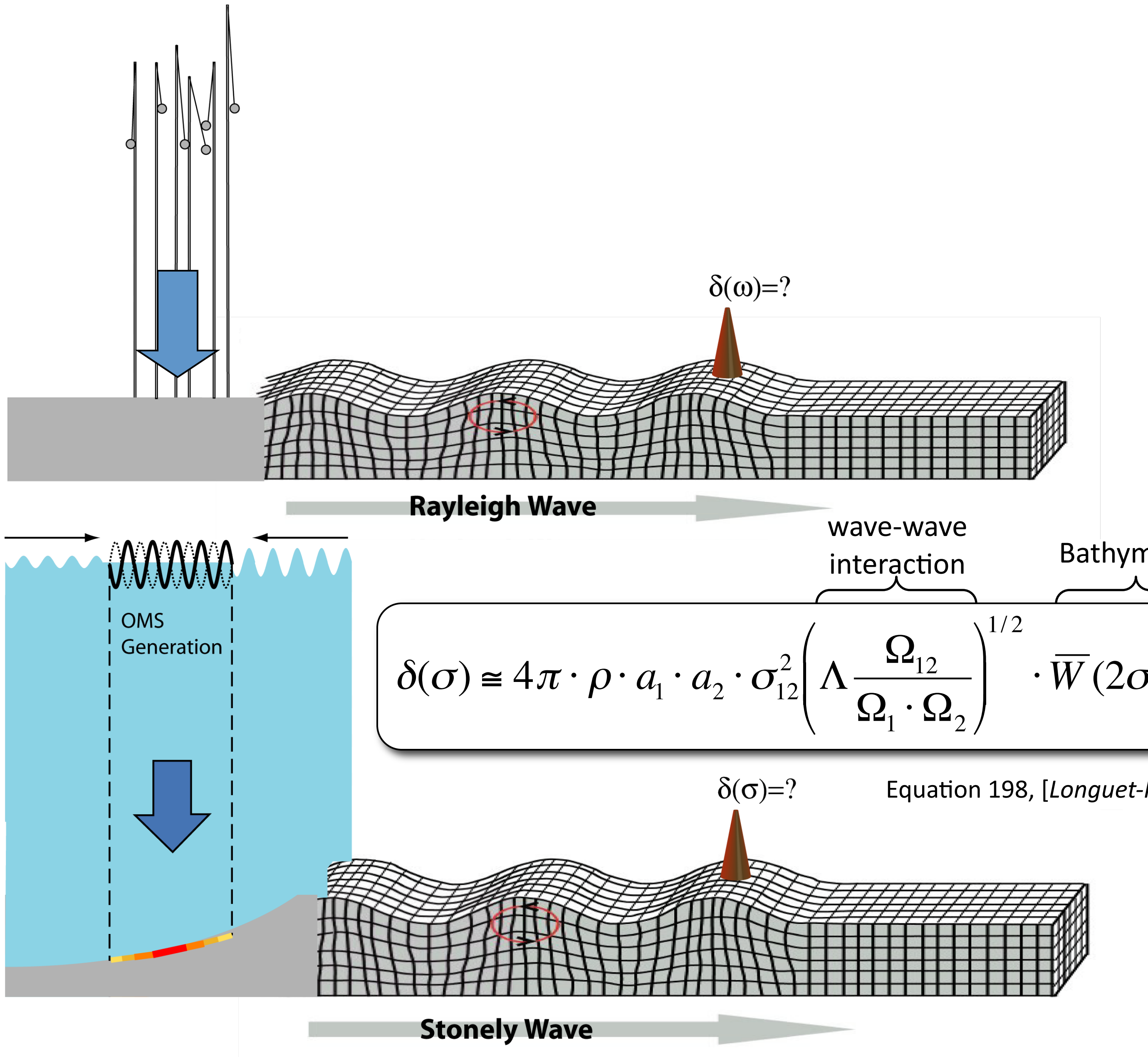


Fig. 11.6. Individual acceleration spectra at over 100 global seismic stations (vertical component) computed as the average noise levels during intervals between earthquakes (adapted from Astiz, 1997). Note the microseism peak at 5 to 8 s period and the relatively low noise levels at 20 to 200 s period.

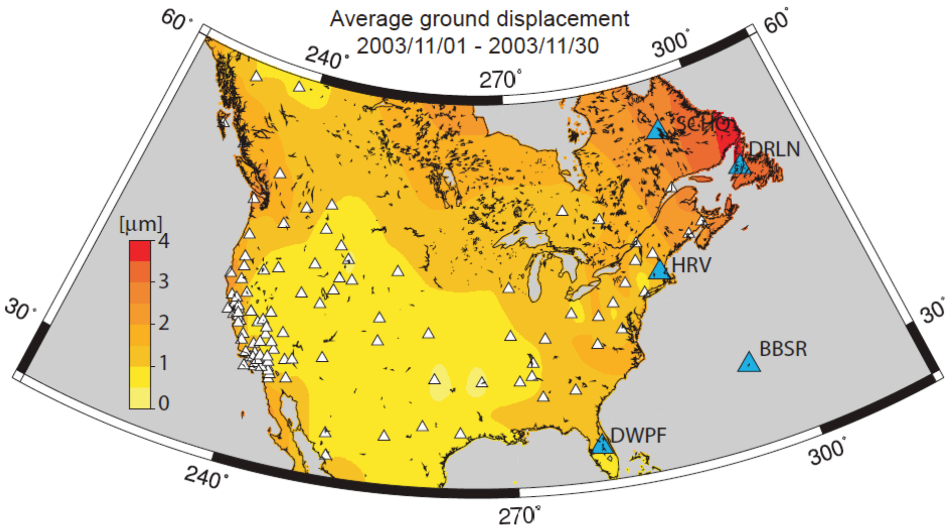
Seismic excitation by nonlinear gravity-wave interaction

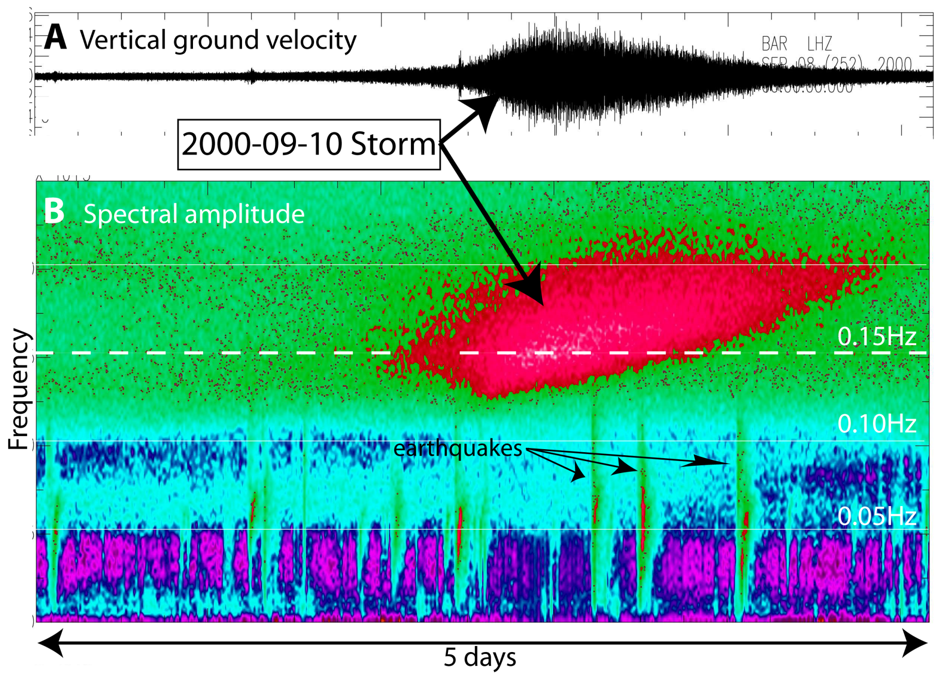


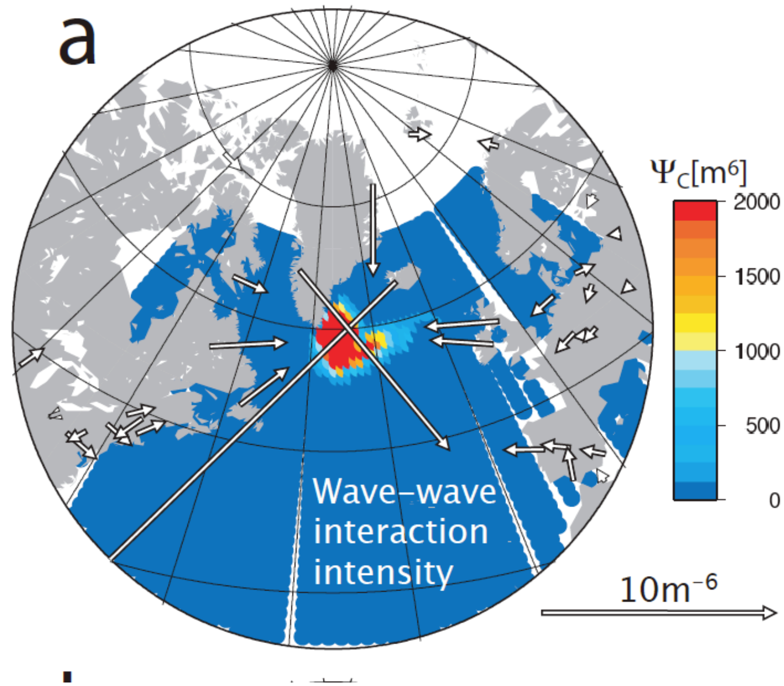
$$\delta(\sigma) \cong 4\pi \cdot \rho \cdot a_1 \cdot a_2 \cdot \sigma_{12}^2 \overbrace{\left(\Lambda \frac{\Omega_{12}}{\Omega_1 \cdot \Omega_2}\right)^{1/2}}^{\text{wave-wave interaction}} \cdot \overbrace{\overline{W}(2\sigma_{12}, r)}^{\text{Bathymetry}} \cdot e^{2i\sigma_{12}t}$$

Equation 198, [*Longuet-Higgins*, 1950]

One reason noise tomography works so well on Earth is because the noise source is dominant.







Seismic noise sources on other planetary bodies?

- Moon [Larose et al, 2005]
- Mars [Lognonne]
- Venus ?
- Jovian moons?

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General Theory for Noise Correlation

- Noise: Distributed sources with random phases (over long enough time T)
- u(x,t)=displacement
- G(x,t;x_0,t_0) satisfies $\frac{\partial^2 G}{\partial t^2} - \mathcal{L}[G] = \delta(x - x_0)\delta(t - t_0)$
- C_{xy}(t)=cross correlation of u(x,t), u(y,t)

General Theory for Noise Correlation

Equipartition

$$u(x,t) = A\sum_k s_k(x)\cos(\omega_k t + \phi_k)$$

$$C_{x_1x_2}(t) = \frac{A^2}{2}\frac{dG^{Ex}(x_1,t;x_2,0)}{dt}$$

e.g. Lobkis & Weaver 2001,
Wapenaar 2004

Source Isotropy (λ<<R)

$$\bar{\rho}(\theta) = \int_T \rho(\theta,t)dt = \rho_0$$

$$\mathbb{F}[C_{x_1x_2}(t)] = \mathbb{F}\left[\frac{A^2}{2}\frac{dG^{Ex}(x_1,t;x_2,0)}{dt}\right]$$

e.g. Snieder 2004,
Sanchez-Sesma & Campillo 2006

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General Theory for Noise Correlation

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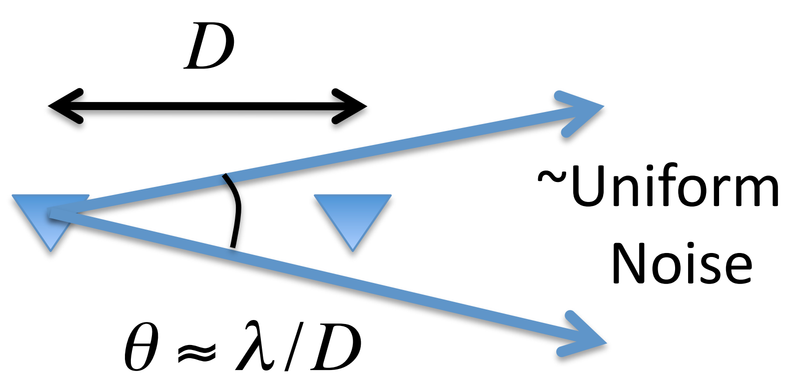
- Sometimes still a good approximation:



- OK because sources outside "Fresnel zone" have phases that approximately cancel
- But source distribution still must be ***smooth*** enough
- In any case, source distribution and velocity structure can be simultaneously determined (non-unique)

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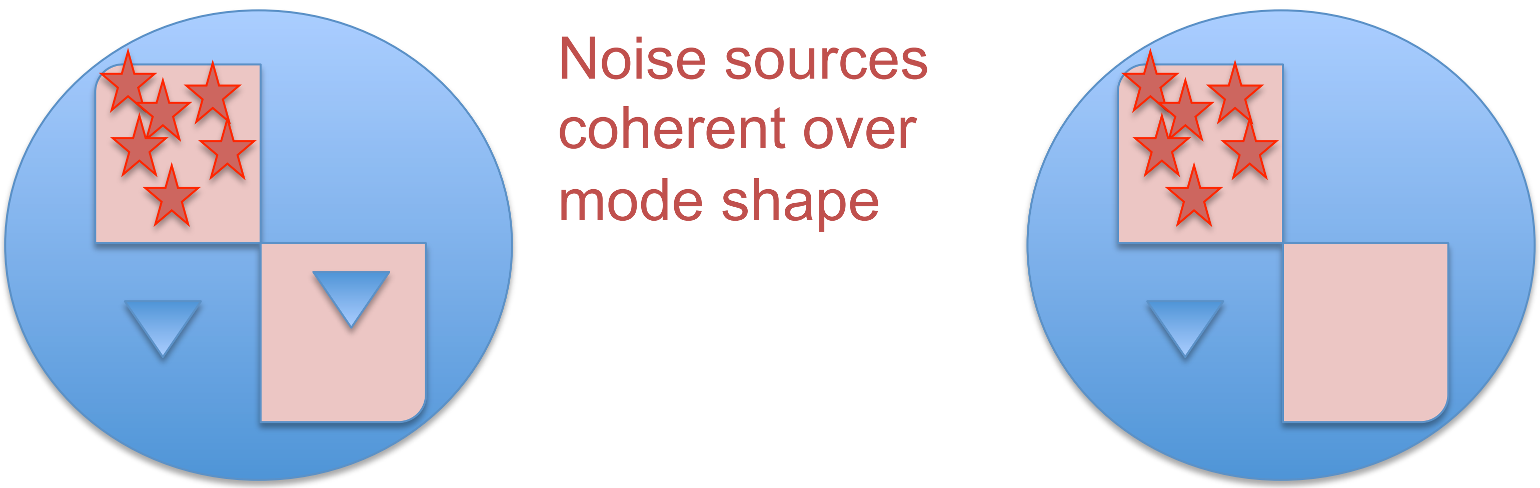
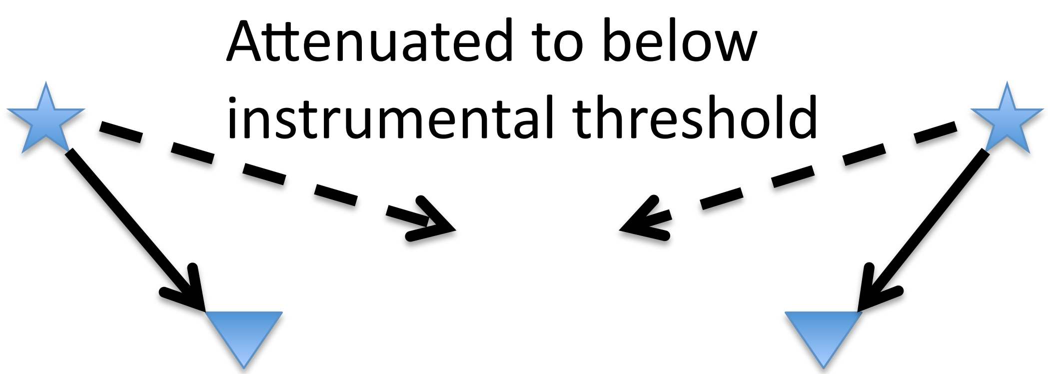


- OK if only 1 (or few) modes at each frequency (low ℓ)

- In any case, source distribution and velocity structure can be simultaneously determined (non-unique)

One Potential Misconception

- Each noise source must be seen by ***both*** stations
- i.e., stations must share noise sources so that there is ***coherency*** between stations



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~~Attenuated to below instrumental threshold~~

Attenuated to below detectable level

OK…

but T may need to be quite long

provided T is long enough:
Coherent part $\propto T$
Incoherent part $\propto \sqrt{T}$

Some (Surface Wave) Applications

	ω	T	D; λ/D	Region	Etc.
Shapiro et al. 2005	7-20s	30 days	D>200km λ/D<0.5	Near CA coast	depths ~20km
Lin et al. 2009	7-40s	1-2 yrs	λ/D<0.3	Western US	Eikonal method

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Nishida et al. 2009	100-400s	17 yrs	λ/D<0.3	Global	depths ~400km
Larose et al. 2005	4-10Hz	1 yr	D=50m λ/D~0.1	MOON Apollo17	depths ~10m
Stephenson et al. 2009	1-5Hz	20 mins	D=10-60m λ/D~5-10	NY City Cultural noise	SPAC method depths ~30m

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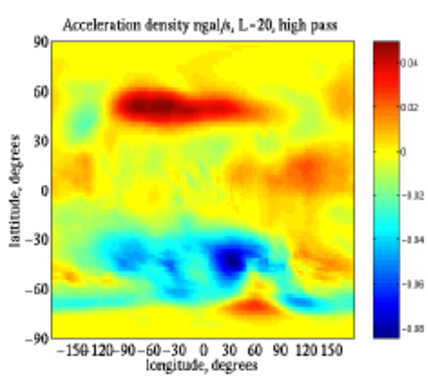
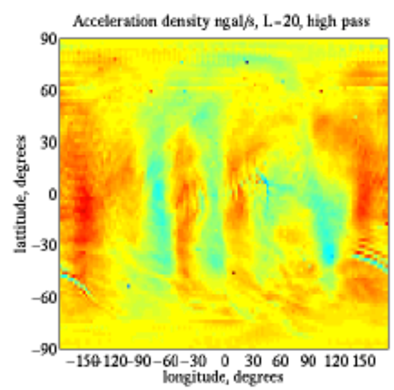
Modelling results: P. Lognonne

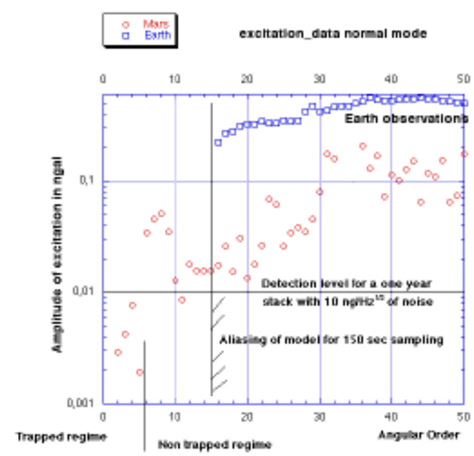
- Global Circulation models can be used for estimating the seismic excitation of the atmosphere
- This does not take into account the turbulences in the boundary layer, which is an additional source
- Amplitude are smaller than those on the Earth, but open the perspective of seismology without quakes on Mars, especially if two stations are deployed

Longitudinal stresses





pressure stresses



Expected Amplitudes on Mars (P. Lognonne)

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