Noise Tomography Concerns for Planetary Application

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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?
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

\[ \delta(\sigma) \approx 4\pi \cdot \rho \cdot a_1 \cdot a_2 \cdot \sigma_{12}^2 \left( \frac{\Omega_{12}}{\Omega_1 \cdot \Omega_2} \right)^{1/2} \cdot \overline{W} (2\sigma_{12}, r) \cdot e^{2i\sigma_{12}t} \]

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**

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

\[ C_{x_1,x_2}(t) = \frac{A^2}{2} \int_0^T dG_{Ex}^{E_x}(x_1,t;x_2,0) dt \]

e.g. Lobkis & Weaver 2001, Wapenaar 2004

**Source Isotropy (\( \lambda \ll R \))**

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

\[ \mathbb{F}[C_{x_1,x_2}(t)] = \mathbb{F} \left[ \frac{A^2}{2} \int_0^T dG_{Ex}^{E_x}(x_1,t;x_2,0) dt \right] \]

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

- If assumptions not met, noise source distribution is wrapped up in measurement to some extent
General Theory for Noise Correlation

• If assumptions not met, noise source distribution is wrapped up in measurement to some extent
• Sometimes still a good approximation:

\[ \theta \approx \frac{\lambda}{D} \]

\[ D \]

~Uniform Noise

• OK because sources outside “Fresnel zone” have phases that approximately cancel
• But source distribution still must be \textit{smooth} enough
• In any case, source distribution and velocity structure can be simultaneously determined (non-unique)
General Theory for Noise Correlation

• If assumptions not met, noise source distribution is wrapped up in measurement to some extent

• Sometimes still a good approximation:

  • OK if only 1 (or few) modes at each frequency (low $\ell$)

  • 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

Attenuated to below instrumental threshold
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

\[ \text{Attenuated to below instrumental threshold} \]

\[ \text{Attenuated to below detectable level} \]

OK...

provided T is long enough:

\[ \text{Coherent part } \propto T \]
\[ \text{Incoherent part } \propto \sqrt{T} \]

but T may need to be quite long
### Some (Surface Wave) Applications

<table>
<thead>
<tr>
<th></th>
<th>(\omega)</th>
<th>(T)</th>
<th>(D; \lambda/D)</th>
<th>Region</th>
<th>Etc.</th>
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<td>Shapiro et al. 2005</td>
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<td>Nishida et al. 2009</td>
<td>100-400s</td>
<td>17 yrs</td>
<td>λ/D&lt;0.3</td>
<td>Global</td>
<td>depths ~400km</td>
</tr>
<tr>
<td>Larose et al. 2005</td>
<td>4-10Hz</td>
<td>1 yr</td>
<td>D=50m</td>
<td>MOON Apollo17</td>
<td>depths ~10m</td>
</tr>
<tr>
<td>Stephenson et al. 2009</td>
<td>1-5Hz</td>
<td>20 mins</td>
<td>D=10-60m</td>
<td>NY City</td>
<td>SPAC method depths ~30m</td>
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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.
Expected Amplitudes on Mars (P. Lognonné)

1 Martian year Cross-correlated stack

Apollo SP

Surface waves

Body waves

Normal modes

Atmosphere hum - Q cycle stack

1 Martian year Cross-correlated stack

P

S

All events at 60°