Planetary seismology: inspirations from recent Earth studies

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Bolivia 06/09/94 Mw=8.2 h=647km station: BKS time window: 10.0-60.0 hrs
Solidity of the inner core

<table>
<thead>
<tr>
<th>Mode</th>
<th>Mean period (s)</th>
<th>No. of observations</th>
<th>s.e.m. (s)</th>
<th>Comp. period</th>
<th>Rel. error (%)</th>
<th>Inner core energy</th>
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</thead>
<tbody>
<tr>
<td>$S_0$</td>
<td>613.57</td>
<td>11</td>
<td>0.236</td>
<td>614.59</td>
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<td>0.181</td>
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</table>

Nine modes—r.m.s.

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<tr>
<th>Mode</th>
<th>Mean period (s)</th>
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<th>Comp. period</th>
<th>Rel. error (%)</th>
<th>Inner core energy</th>
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</table>

$\rightarrow V_{s-ic}=3.517 \text{ km/s}$

Dziewonski and Gilbert, Nature 1971
Also Dziewonski, Science, 1971—radial modes
Different methods to compute synthetics including highly accurate 3D numerical ones
- Fast computers: many simulations
Without any quake-like events

- **Single broadband station:**
  - Single component (Z):
    - Seismic Noise PSD Spectrum
    - Hum from stacking of noise spectra -> free oscillation frequencies -> internal structure
  - Three components?

- **Two broadband stations:**
  - Single component (Z):
    - Noise correlation methodology

- **Array (3 or more stations):**
  - Noise source location
Seismic Noise Power Density Spectrum

After Nishida et al., GRL, 2002
Observed noise spectra stacks
437 days without earthquakes

Suda et al., 1998
Tanimoto and Um, 1999
With two stations...
Continuous wavefield monitoring
Single 3 component versus 2 Z stations?

- Two Z stations !!
  - Noise spectra
  - Hum
  - Noise correlations
  - Robustness/redundancy
More than two stations (regional array)
Rhie and Romanowicz, 2004
Jan 2, 2000
Mw 5.8
$\Delta = 36.31^\circ$

(a) FNET

(b) Straight stack
3rd root stack
Phase Weighted Stack
01/02/2000
Mw 5.7
Δ = 74.17°

T = 240 s
F-NET: search for maximum stack amplitude

Day 2000.031  time interval: 54,500-55,500 sec

Back-Azimuth/phase velocity

Period/phase velocity

PREM model

Rhie and Romanowicz, Nature, 2004
Jan. 2000: 6-hour moving averages - stacks at FNET and BDSN

M7
M6
M5

F-NET
BDSN

Seismically quiet period
N. Pacific storms

Rhie and Romanowicz, G-cubed, 2006
Days 2000/03.5 to 2000.034 3h running average with 30mn shift
Grid search for source locations, maximizing stack amplitudes at F-NET, BDSN and 10 stations in Europe

Time interval: 6 hours on 2000.031
With at least one large enough “quake” recorded

- Single station
- Two stations
- Regional array \((N \geq 3)\)
- Global network \((N \geq 3)\)
Monterey bay Ocean Bottom Broadband seismic station

MBARI/UCB
San Andreas
04/23/02
Mw 3.7
D = 53.4 km

Moment tensor
Solution with 5
BDSN stations

Moment tensor
Solution using
Only MOBB
Bolivia 06/09/94 Mw=8.2 h=647km  station: BKS  time window: 10.0-60.0 hrs
Waveform modelling techniques
Synthetic seismograms on Europa as a function of ice shell thickness

Mw = 5.0 normal fault distance 20 deg – depth = 300m

Δ = 680 km

Panning et al., 2006
High versus low attenuation

Panning et al., 2006
Observation from orbiter: Moving source analysis

Observation point starts 410 km east of the source at the event origin time and moves North with an apparent surface velocity of 1.4 km/s calculated in the high Q 5 km thick ice shell model.
Several stations: lateral heterogeneity
“Degree 2” structure

Dziewonski et al., submitted
Full Waveform Tomography

- Long period (30s-400s) 3-component seismic waveforms

- Subdivided into wavepackets and compared in time domain to synthetics (mode asymptotics $\rightarrow$ SEM).

- $u(x,t) = G(m) \rightarrow du = A \, dm$
  - $A = \frac{\partial u}{\partial m}$ contains Fréchet derivatives of $G$
Vertical Component Fits

Starting Model

3rd iteration Model

Data

Courtesy of Ved Lekic, BSL
K-means clustering with N clusters – applied to SEM based upper mantle model

N=3

N=4

N=5

N=6

Lekic, 2009 Thesis