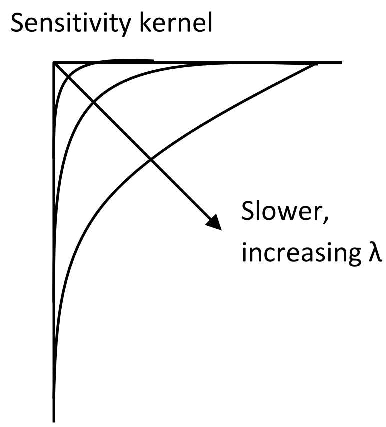
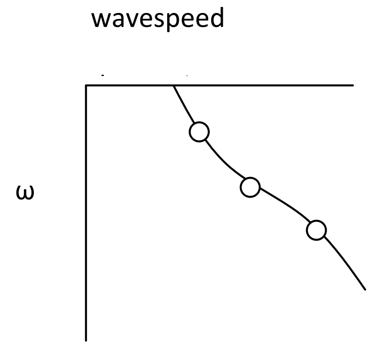
12.510 Introduction to Seismology
Spring 2008

Continents: Qucik review. Surface wave Tomography
Love waves-SH
Raleigh waves-P-SV
Sinusoidal-acoustic

➔Evanescence wave $A(z) * \mathrm{e}^{-\eta\omega z}$





low frequency wave is more sensitive to deep structure. Therefore, low frequency wave should arrive earlier than high frequency wave.

➔Different modes: Fundamental and Higher modes/overtones.

Surface wave Tomography

Recall from the travel time tomography:

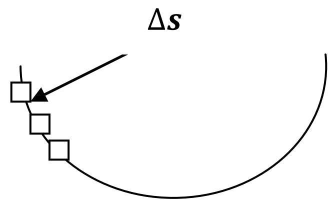
$$\boldsymbol{d} = \boldsymbol{A}\boldsymbol{m} \tag{1}$$

where $\boldsymbol{d}$**,** is the data; $\boldsymbol{A}$**,** is the projector; and $\boldsymbol{m}$ is the model.

$$\boldsymbol{d_i} = \int_{\boldsymbol{volume}} \boldsymbol{G_i}(\boldsymbol{r})\boldsymbol{\mu}(\boldsymbol{r})\boldsymbol{dr} \tag{2}$$

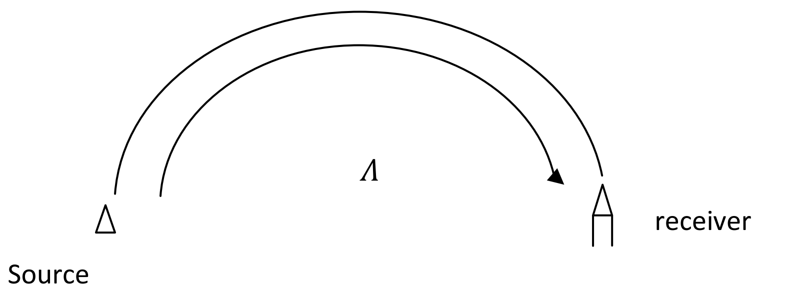
Where $\boldsymbol{d_i}$ is the observation; $\boldsymbol{G_i}(\boldsymbol{r})$ is green's function/kernel (Sensitivity kernel) e.g. travel time tomography; and $\boldsymbol{\mu}(\boldsymbol{r})$ is the model perturbation.

$$\boldsymbol{\delta t} = \boldsymbol{T_{obs}} - \boldsymbol{T_{ref}} = \int_{\boldsymbol{path}} \Delta \boldsymbol{sdl} \text{ Integration over the ray path} \tag{3}$$



When we do surface wave tomography, we measure the phase (or group) velocity: δc_i for an earthquake i. As with the body wave tomography, we will look at perturbations between the model and the data:

$$\delta_c(\omega) = \frac{1}{\Lambda}\int_{waves\ \ path} \delta_c(\omega, \theta, \varphi) dl \tag{4}$$



$$\begin{gathered} d = Am \\ A^T d = A^T Am \\ (A^T A)^{-1} A^{-1} d = \widehat{m} \end{gathered} \tag{5}$$

Those phase velocity maps are first constructed for a particular frequency. But, because of the evanescence of the surface waves, we can see what frequency is sensitive to a particular depth. Convert ω to z. To do so, we look at the sensitivity kernel for different frequencies. We use $\frac{\partial c}{\partial \beta}$ and we get

$$\delta c(\omega) = \frac{1}{\Lambda}\int_{waves\ \ path} \left[\left(\frac{\partial c}{\partial \beta}\right)_{\omega, z} \delta\beta(\theta, \varphi, \delta) dz \right] dl \tag{6}$$

is a phase velocity map of particular frequency ω.

$$\partial c = \frac{\delta c}{\delta \beta} \partial \beta \tag{7}$$

The unknown is $\delta\beta(\theta, \varphi, \delta)dz = m$ 3D model of β. Using the decay of the amplitudes with z, we can talk about a certain z and not only a frequency. Nevertheless,

phase velocity map at a certain frequency ➔ more robust
phase velocity map at a certain depth ➔ make an assumption, the model depends on the sensitivity kernel.

$\left(\frac{\delta c}{\delta\beta}\right)_z$: 1D Earth model, with an average velocity for each depth
Only data from the top upper mantle (<660 km) can be used. Phases that sample too deep must be excluded. To do so, windows are applied on seismograms in order to drop phases with too high phase velocity (select phases in order to use 1D earth model)

If Rayleigh waves are used, c depends not only on β, but on α and ρ too.

The sensitivity kernel is not zero for α and ρ, we equation (7) at large depths (>80km) where 90% of it becomes β. In shallow crustal depths, we can use the following equation.

$$\delta c = \underbrace{\left(\frac{\partial c}{\partial \beta}\right)\delta\beta}_{90\%} + \left(\frac{\partial c}{\partial \alpha}\right)_{\omega,z} \delta\alpha + \left(\frac{\partial c}{\partial p}\right)\delta p \tag{8}$$

Interferometry

Long-term cross-correlation ➔ new data for imaging/tomography.

$$\frac{dc_{AB}(t)}{dt} = -G_{AB}(t) + G_{BA}(-t) \tag{9}$$

It could be thought of as “turning stations into virtual sources.”

Waveform modeling

1. Non linear waveform inversion:
   Try to find the best-fitting model $\rightarrow$ end up with series of 1D model $\beta(z)$

2. Construct 3D model for all 1D models

Figure removed due to copyright restrictions.

Figure: Sensitivity of 1-D waveform inversions to focal depths. The effects of varying focal depth for two events: (a) focal depth 2 km (b) focal depth 9 km. Fits of final synthetic (dashed) to observed (solid) seismograms for shifts in focal depths of 10-50 km are shown on the left and the corresponding inversion velocity models (thin lines) are shown on the right along with the velocity model for the correct depth (thick line). The misfit and maximum frequency achieved by the waveform inversion are denoted to the right of each waveform fit.
Maggi, Alessia & Priestley, Keith
Surface waveform tomography of the Turkish-Iranian plateau.
Geophysical Journal International 160 (3), 1068-1080.
doi: 10.1111/j.1365-246X.2005.02505.x

Updated by: Sami Alsaadan
Sources: April 20,2005 by Sophie Michelet
"An Introdution to Seismology, Earthquakes, And Earth Structure" by Stein &Wysession (2007).