In this lecture, we will examine several different applications of seismic tomography, including local earthquake, teleseismic and wide-angle reflection/refraction tomography.

Most of these applications utilize seismic traveltime data, but we will also include one example of surface waveform inversion.

Recently, there have been significant advances made in the field of full waveform tomography, which involve the use of sophisticated codes to directly solve the elastic wave equation. While these techniques show much promise, further development is required if they are to supercede the more traditional approaches discussed here.
Local earthquake tomography (LET) is a common tool for imaging subsurface structure in seismically active areas. Apart from the source-receiver geometry, one of the distinguishing features of LET compared to the other types of tomography discussed here, is the need to relocate earthquake hypocenters (spatial location and origin time) as part of the image reconstruction. This is because accurate hypocenter location requires an accurate knowledge of the velocity structure in the region occupied by the earthquakes and the recorders whose data are used in the location process. The following example shows a series of cross-sections through a 3-D P-wave model of a region in the southern central Andes derived using LET.
16,488 P-wave arrivals from 764 events have been used to constrain this 3-D model, which is described using 2496 velocity nodes.

It is also quite common practice in LET studies to invert for $V_p/V_s$.

This example has been taken from the JGR paper of Graeber and Asch (1999).
Checkerboard resolution tests for the model shown on the previous page.

The top plots show the input checkerboard, and the bottom two plots show the recovered model at two different latitudes.

From the JGR paper of Graeber and Asch (1999).
Like local earthquake tomography, teleseismic tomography has been used extensively to map the structure of the crust and lithosphere.

Studies are often carried out on a variety of scales ranging from 10s of km to 100s of km.

Usually, the horizontal extent of the receiver array and the source distribution determines the depth to which features may be resolved.

Most teleseismic studies are carried out in 3-D, partly because it is difficult to line up an array of recorders on roughly the same great circle as a set of teleseismic earthquakes with good angular coverage.
The TIGGER experiment

72 broadband and short period recorders deployed in northern Tasmania in 2002 to record distant (teleseismic) earthquakes.
Seismic tomography II
The Tasmanian lithosphere

- Teleseismic source distribution

- 101 teleseismic events
- 110 phases
- P, PP, PcP, ScP, PKiKP
- 6,520 paths
- Good coverage from north and east
- Poor coverage from south and west
Relative arrival time residuals

Traveltime residual

Teleseismic wavefront

Fast lithosphere

Slow lithosphere

ak135 reference
Relative arrival time residual patterns

Mariana Islands (P)

South Sandwich Islands (P)
Tomographic scheme

Iterative non-linear inversion scheme

\[ m_{n+1} = m_n + \delta m_n \]

Model parameterization
Cubic B-splines

Traveltime prediction
Fast marching method

Inversion method
Subspace inversion

\[ \delta m = -A [A^T (G^T C_d^{-1} G + \varepsilon C_m^{-1} + \eta D^T D) A]^{-1} A^T \gamma \]
Seismic tomography II
The Tasmanian lithosphere

- Synthetic recovery tests

![Input and Recovered Velocity Profiles](image-url)
Seismic tomography II
The Tasmanian lithosphere

![Map of the Tasmanian lithosphere with seismic tomography results. The map shows variations in $\delta v_p$ (m/s) with depth and longitude. Significant features include a high-velocity anomaly near 41.4 S and 15 km depth.]
- Proposed TFS does not correspond to wavespeed transition zone.

- Rawlinson et al. (2006), *JGR*, 111.
Wide-angle tomography exploits refraction and wide-angle reflection data in order to constrain variations in seismic structure.
The example below shows the result of an inversion of wide-angle data for the structure of the Tasmanian Moho.
It is possible to combine multiple datasets in a simultaneous inversion. The example below shows the result of combining the Tasmanian teleseismic and wide-angle datasets.
Seismic tomography II
Surface wave tomography

- Long period surface waves can be inverted for 3-D seismic structure.
- In this example, waveform inversion has been used to construct 1-D path-average models of Rayleigh-wave phase velocity.
- Seismic tomography is then applied to produce 2-D horizontal velocity slices at different depths.
It has only recently been shown that it is possible to extract information from the ambient seismic noise-field by long term cross-correlation of waveforms recorded at two separate locations.

It turns out that the cross-correlation produces an estimate of the Green’s function between two points; that is, the signal that would arrive at one point if the source waveform were a delta function located at the other point.

A number of papers have been published recently that have inverted the group traveltimes of short period Rayleigh waves for crustal velocity structure.

One advantage of this technique is that path coverage is controlled largely by the placement of receivers.
The plot below shows Rayleigh wave Green’s functions extracted from the cross-correlation of one month of data from a short period seismic array in southern NSW.
Tomographic imaging results using group travel times of Rayleigh wave Green’s functions extracted from ambient seismic noise recorded in Australia.