Engineering Seismology and Seismic Hazard – 2019

Lecture 12

Earthquake Location

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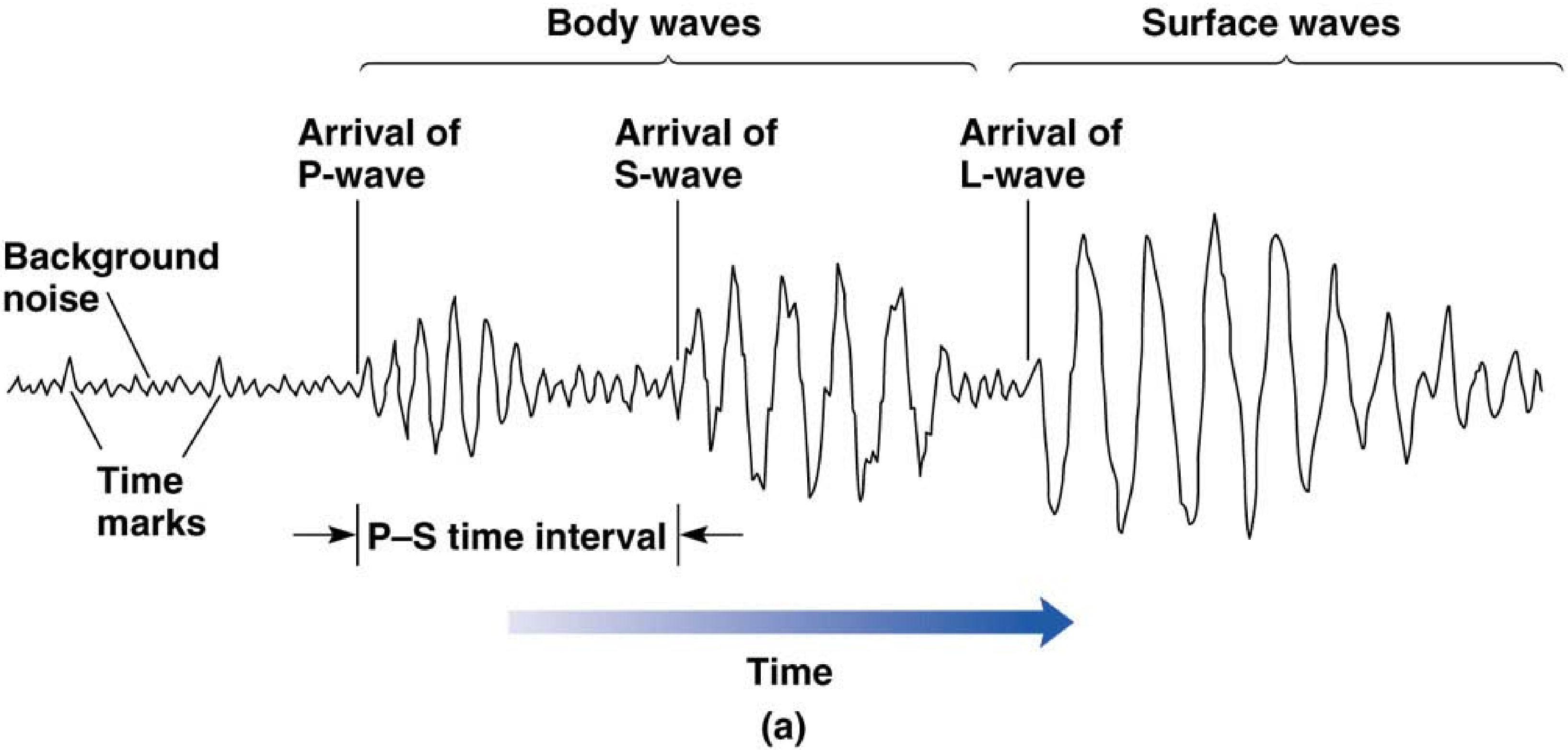
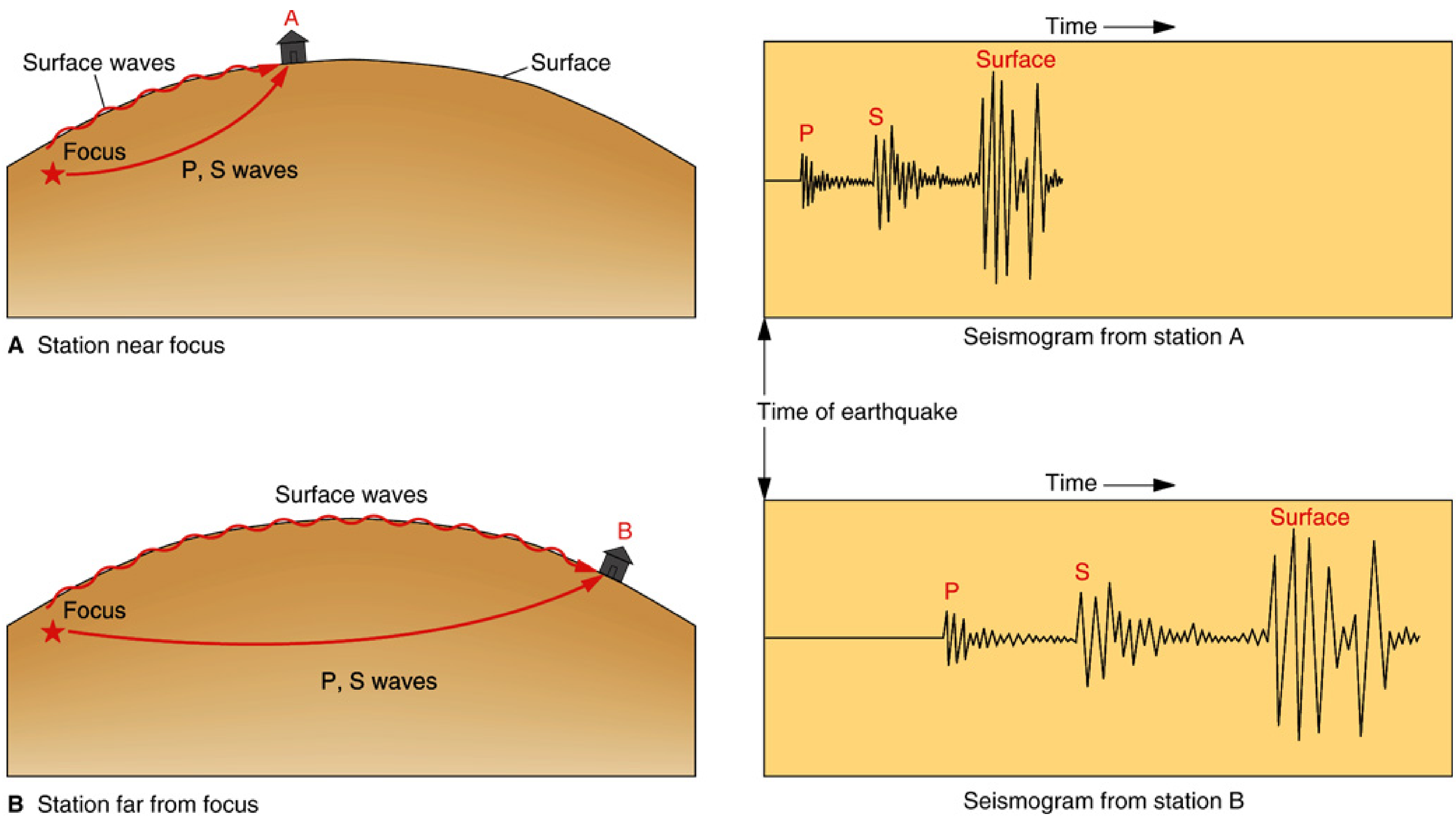
Wave Velocity

$$\alpha = \sqrt{\frac{(\lambda + 2\mu)}{\rho}} \qquad \beta = \sqrt{\frac{\mu}{\rho}} \qquad \alpha > \beta$$



Travel Time and Distance



(*from McGraw-Hill, 2005*)

S-P Lag Time

Travel time for P and S wave can be formalized as:

$$t_P = \frac{D}{\alpha} + t_0$$

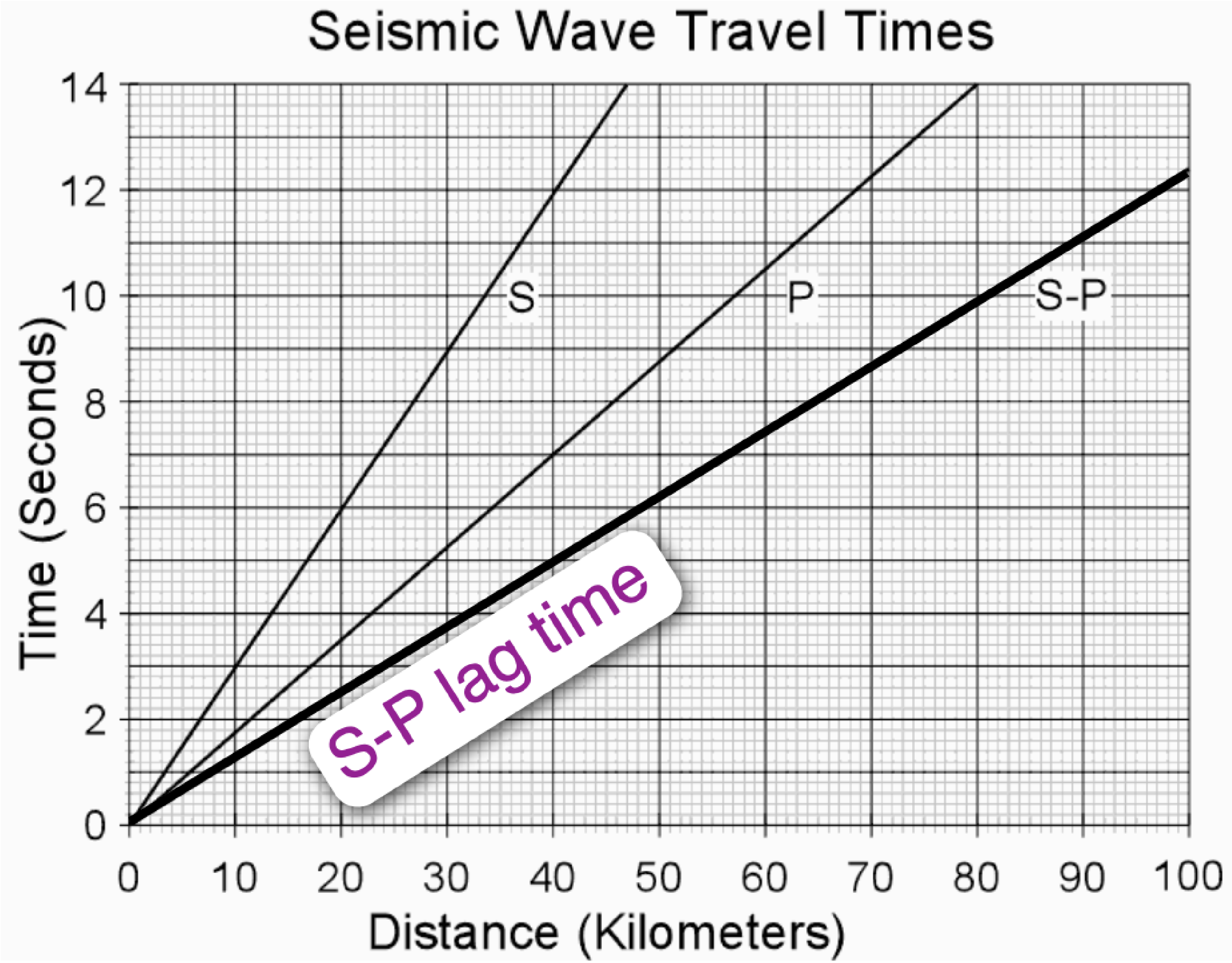
$$t_S = \frac{D}{\beta} + t_0$$

Therefore, the S-P time will be simply:

$$t_S - t_P = \frac{D}{\beta} - \frac{D}{\alpha} = \left(\frac{1}{\beta} - \frac{1}{\alpha}\right) D$$

For the crust, it is possible to assume: $\beta \approx 0.6\,\alpha$

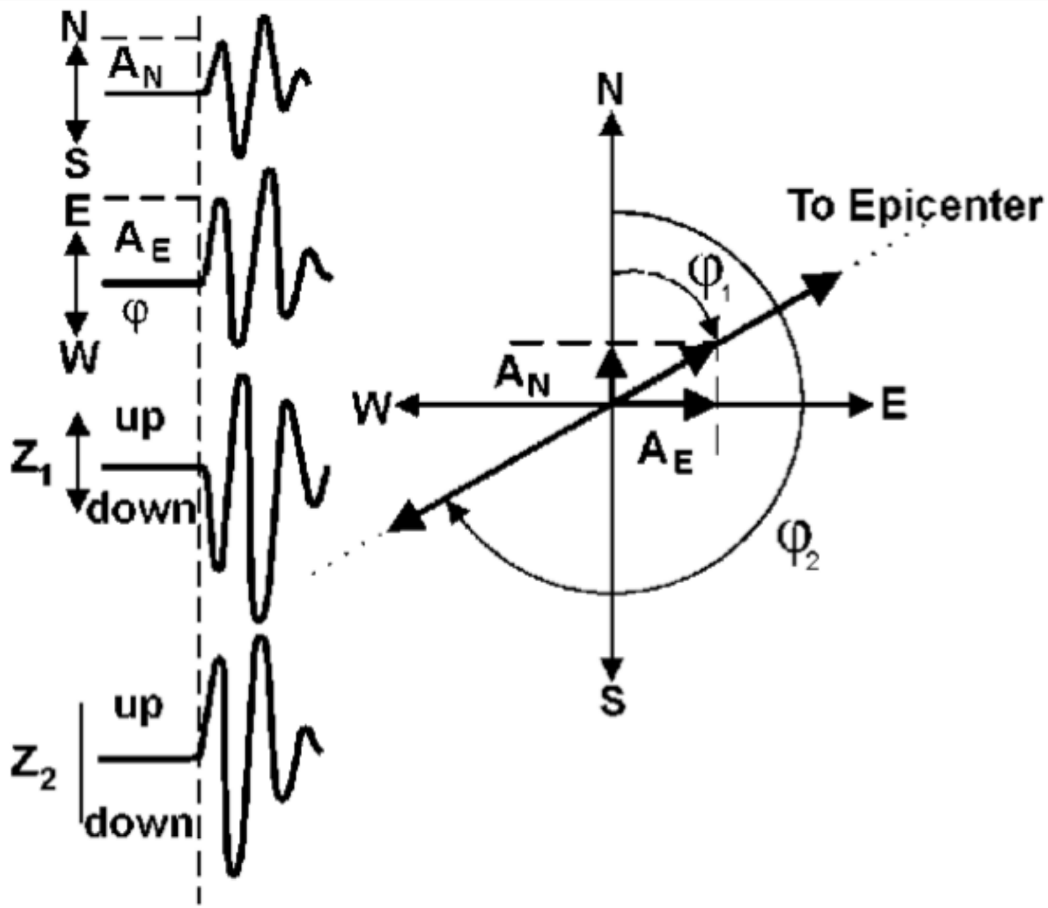
Travel Time Curves



Single Station Solution

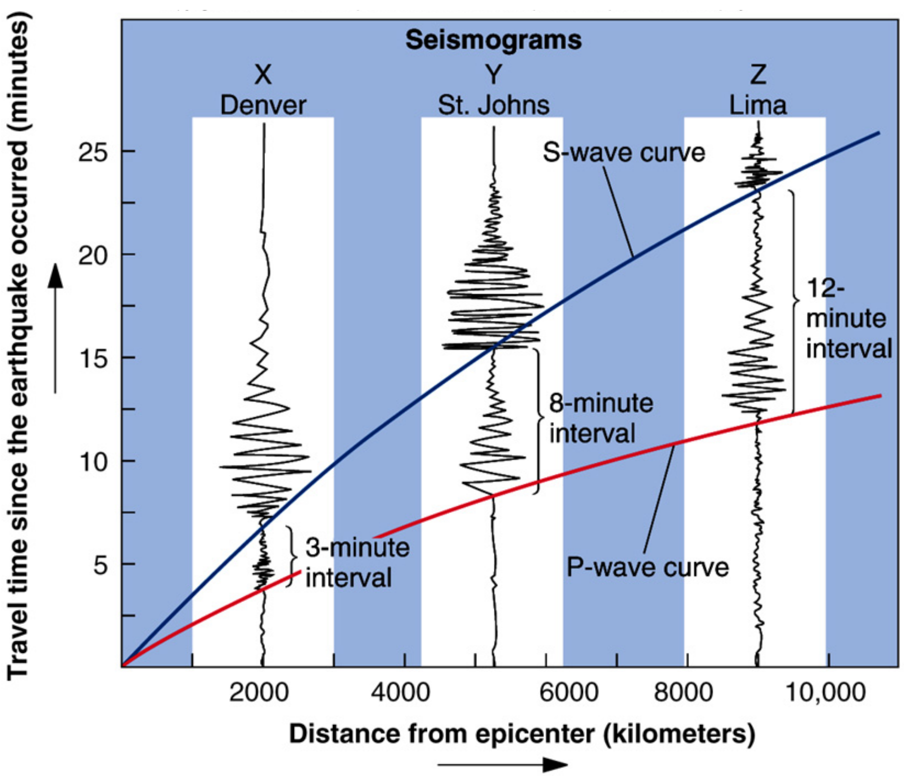
In theory, we could use just one station for the solution, as the propagation direction (azimuth) can be obtained by analyzing the ground motion polarization on the horizontal components.
An famous example was the Friuli earthquake of 1976.

$$\phi = atan\left(\frac{A_E}{A_N}\right)$$

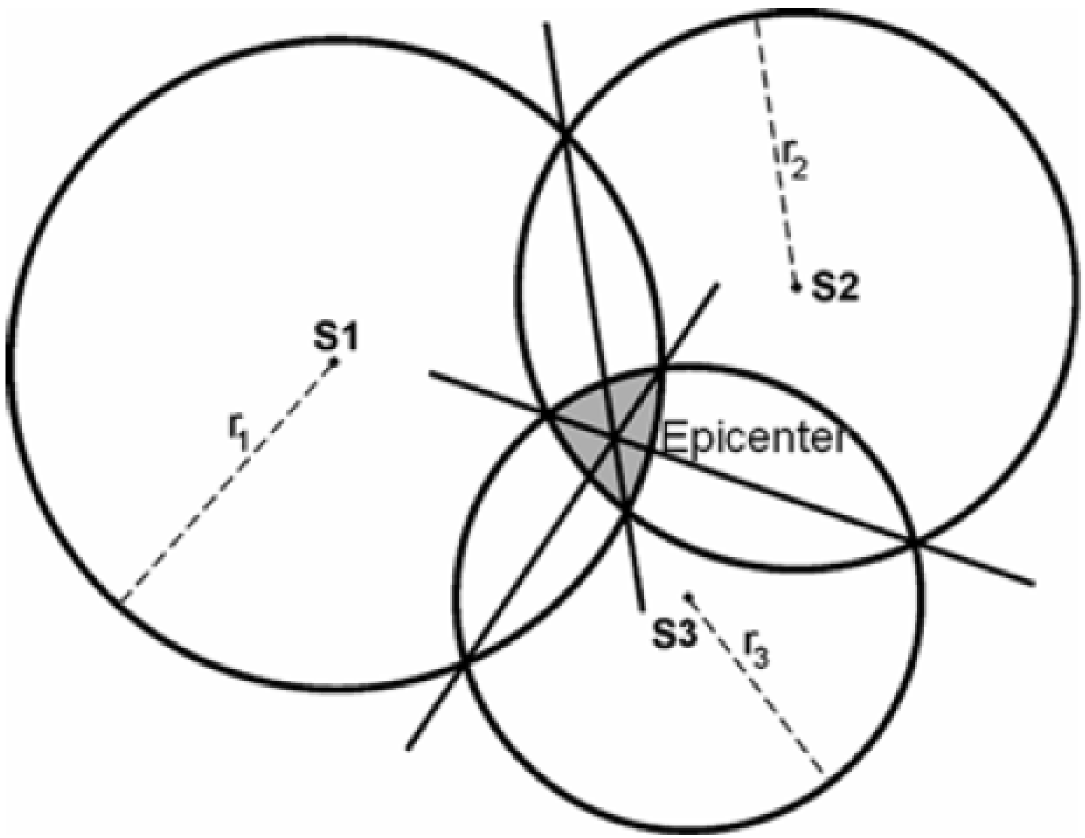


Epicenter Triangulation

To localize the epicentre from teleseismics, we need at least three recording stations



Depth and Errors



Modern Location Solution

The aforementioned methods do work, but are affected by large uncertainty. It is nowadays preferred to locate earthquakes to use more sophisticated inversion techniques, such gradient methods of global optimization (grid search).

As we know, the travel time can be generically written in the form:

$$t = \frac{D}{v} + t_0 = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} + t_0$$

The problem is clearly non-linear on three unknown parameters (x, y, z and t_0), but can be solved using non-linear least squares (see recap)

$$\vec{m}_N \approx \vec{m}_0 + (J^T J)^{-1} J^T (\vec{d}_{obs} - \vec{d}_0)$$

Computing Partial Derivatives

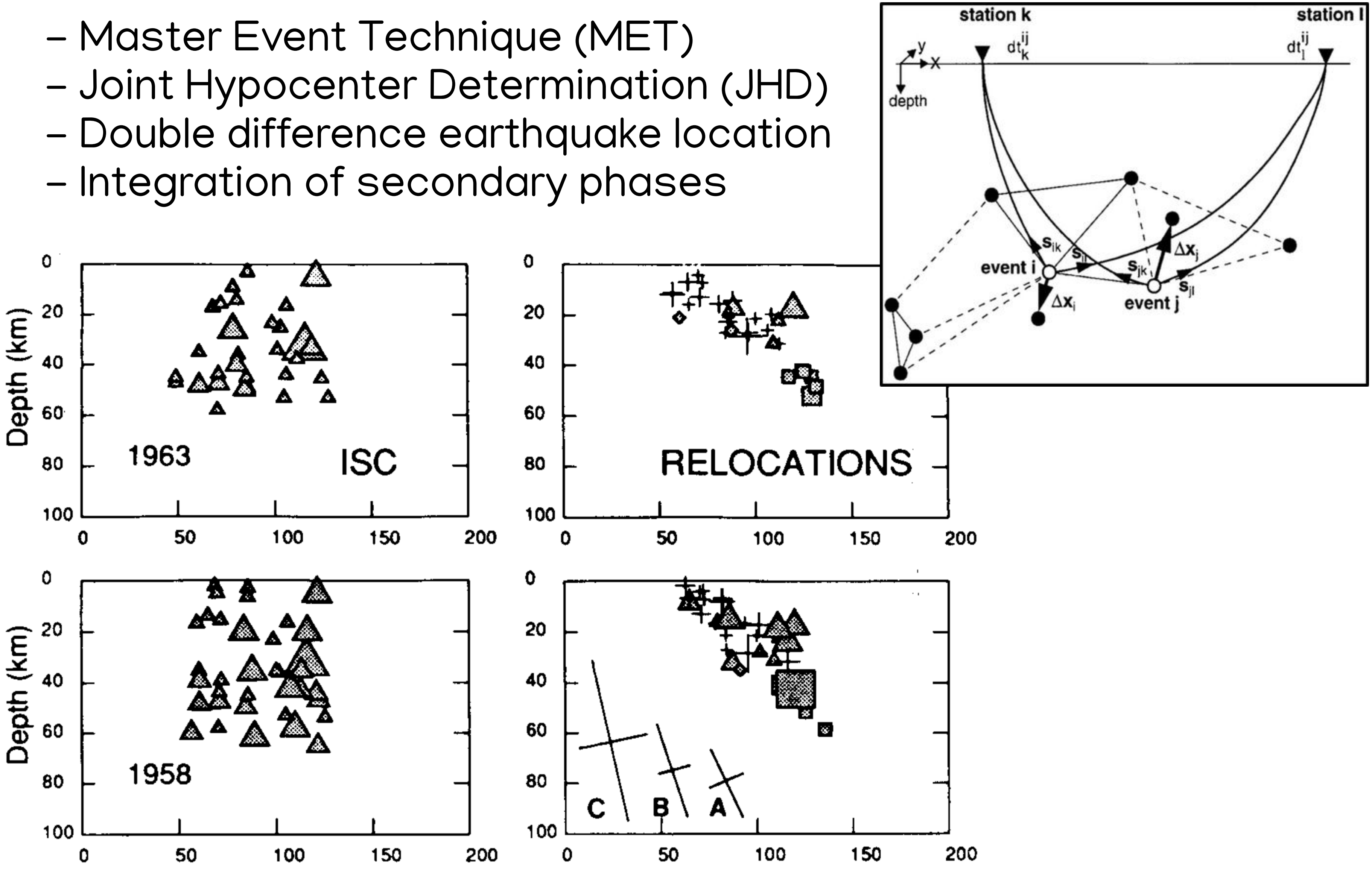
The matrix of partial derivatives can be obtained analitically:

$$
\boldsymbol{J}=\frac{\partial t}{\partial m}=\begin{bmatrix}
\dfrac{1}{v}\dfrac{(x-x_0)}{\sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}}\\
\dfrac{1}{v}\dfrac{(y-y_0)}{\sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}}\\
\dfrac{1}{v}\dfrac{(z-z_0)}{\sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}}\\
1
\end{bmatrix}
$$

While for the initial guess model we can use the base result from simple methods such as the lag-time.

Advanced Methods

– Master Event Technique (MET)
– Joint Hypocenter Determination (JHD)
– Double difference earthquake location
– Integration of secondary phases



Exercise with T.A.