NPTEL ONLINE CERTIFICATION COURSES

EARTHQUAKE SEISMOLOGY

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Module 10 : Brief on Earthquake geodesy

Lecture 03: Joint geodetic and seismological earthquake studies

CONCEPTS COVERED

- **Joint geodetic and seismological studies**
- **Afterslip and postseismic slip**

Recap

- Geodetic methods using signals from space permits all three components of position to be measured to sub-centimeter precision.

- The popular geodetic technique to measure ground deformation are: Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), and Global positioning system (GPS).

- GPS uses a constellation of satellites transmit coded timing signals on a pair of microwave carrier frequencies synchronized to very precise on-board atomic clocks.

- GPS data can be obtained for continuous period of time or short period of time (survey mode). Survey mode is cheaper.

- The biggest limitation of geodetic data for earthquake studies is that the positions of geodetic markers before the earthquake are needed.

Recap

- For radar, d is the antenna length, so a radar a distance r above the earth's surface could resolve objects of size x, where $\theta_d = \lambda/d = x/r$

- The phase difference between radar signals with wavelength λ reflected from the Earth's surface and recorded by antennas at position A_1 and A_2 is $\phi = (4\pi/\lambda)(r_2 - r_1)$

  r_i is the range from the antenna at A_i to the reflection point.

- If differences in satellite positions between the measurements are removed, a vector surface displacement D causes a phase change

$$\phi \approx (4\pi/\lambda)\delta r, \quad \delta r = (D.\hat{r}),$$

where δr is the projection of the vector displacement along the look direction connecting the satellite and reflection point.

Recap

- Static coseismic displacement contain $1/r^2$ terms, compared to $1/r$ terms for the propagating waves. Thus, it decay more rapidly with distance from the earthquake.

- For infinite length fault, the fault-parallel displacement in the x direction, u(y), varies with distance from the fault y as

$$u(y) = \pm D/2 - (D/\pi)\tan^{-1}(y/W)$$

- For finite length faults the displacement tapers off rapidly past the fault ends. If a fault is buried and extends from depth w to depth W

$$u(y) = (D/\pi)\left[\tan^{-1}(y/w) - \tan^{-1}(y/W)\right]$$

- A fault that does not reach the surface, the displacement is both reduced in amplitude and varies more smoothly with distance than it would for a fault extending to the surface.
- Estimation of fault parameter using geodetic data is an inverse problem and has highly non unique solutions.

[redacted]

Joint geodetic and seismological earthquake studies

Why it is needed to do joint study?

- ➔ Estimation of fault parameters using inversion of geodetic data alone is highly non-unique.
- ➔ Joint inversion of geodetic and seismological earthquake data may prove to be complementary to each other.
- ➔ Seismic waves are unable to distinguish between the fault plane and the auxiliary plane while the geodetic data can identify both the planes.
- ➔ Joint data give better constraints on the fault geometry and slip on it, and inclusion of aftershock locations may provide even better constraints on fault dimensions.

Combining geodetic and seismological data

1. Figure on the right shows geodetic and seismological results for the 1994 Ms 6.7 Northridge earthquake which occurred on a buried thrust fault.

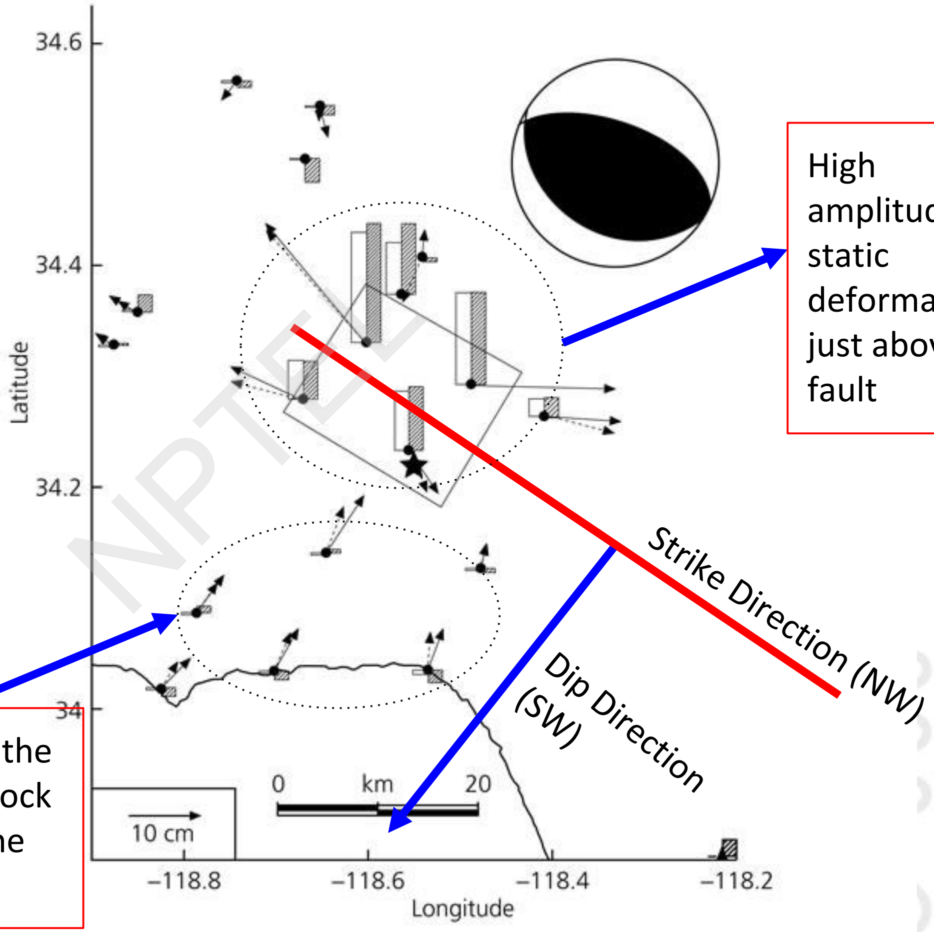
1. Focal mechanism and aftershock distribution indicate thrust faulting on a NW-striking, SW-dipping fault.

1. GPS data show the significant vertical and horizontal motions concentrated above the fault.

1. Note the Directions of the static deformation of down-dip sites towards the fault.

1. Static deformation is high above the fault.

Figure 4.5-9: Geodetic and seismological results for the 1994 Northridge earthquake.



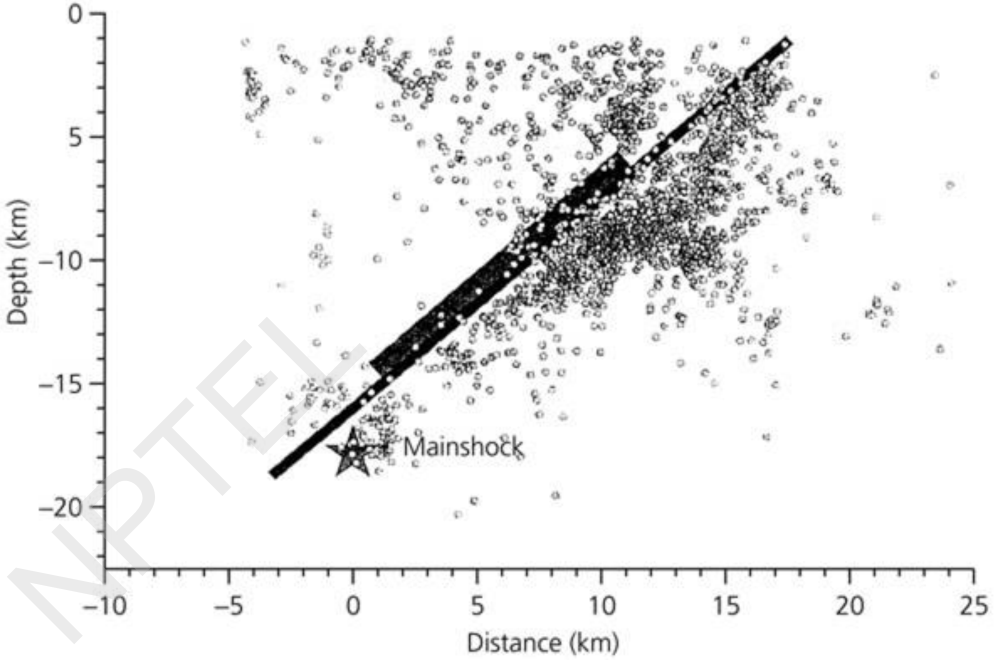
High amplitude static deformation just above the fault

Motion of the hanging block towards the fault

Combining geodetic and seismological data

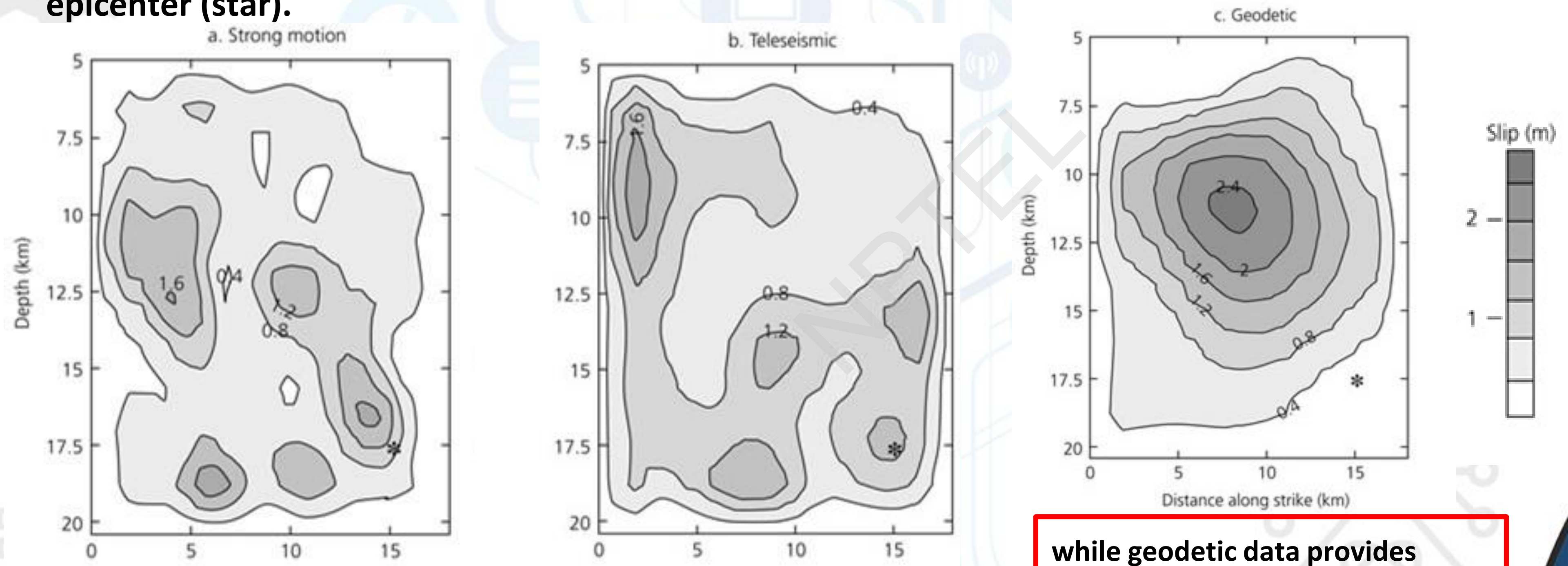
6. Both these data if modelled together provides good results by assuming that about 2.5 m of slip occurred on a fault plane similar to that which one would infer from the aftershocks.

7. Two geodetic solutions are shown (on the right), one with uniform slip and one with variable slip on a larger fault.



Combining geodetic and seismological data

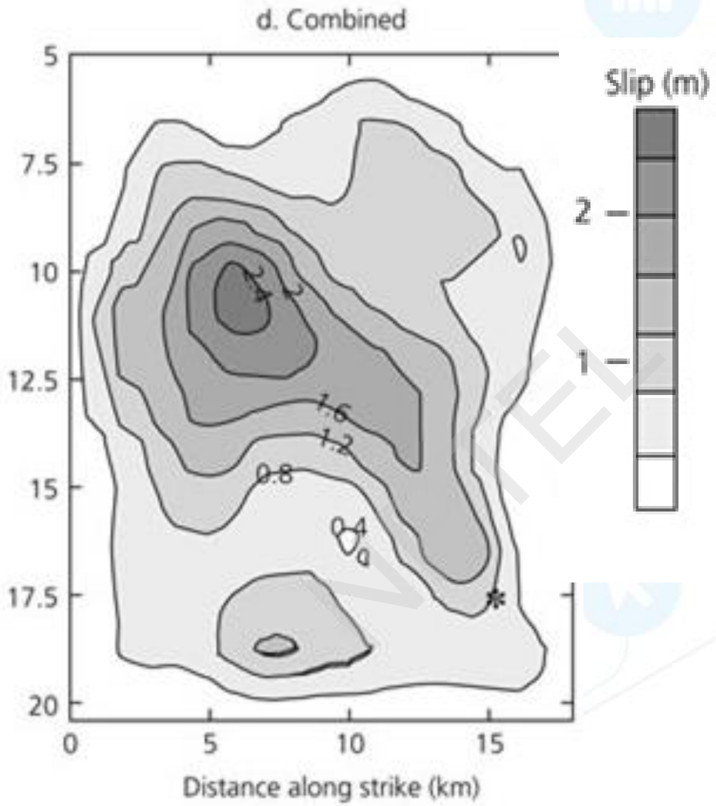
- ➔ Let's take a look at combining strong motions data, teleseismic data with geodetic data for Northridge earthquake.
- ➔ Strong motion data provides details high frequencies in source time function and may further be utilized to understand the slip process. Such details are ambiguous in teleseismic data due to attenuation.
- ➔ Slip distribution from inversion of individual datasets are provided below. Interestingly, largest slip is not at the epicenter (star).



Results from different data types differ. Seismic data resolves the slip during rupture process. Both seismic data yields high slip in the NW corner.

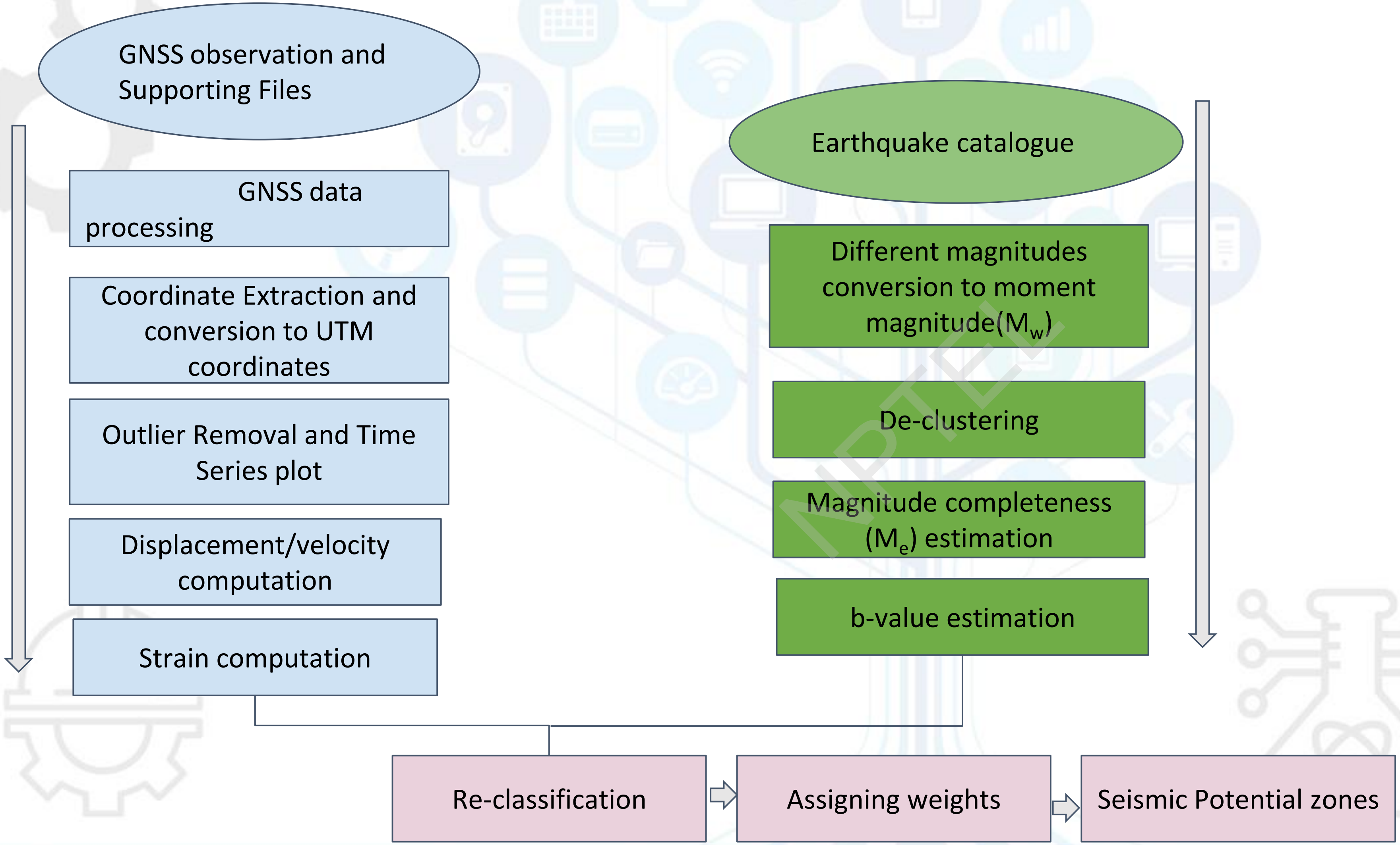
while geodetic data provides smoother image which depends on end results.

Combining geodetic and seismological data



Combined results both from seismic and geodetic data which provides much constrained slip distribution process.

Combining geodetic and seismological data



GNSS observation and Supporting Files

GNSS data processing

Coordinate Extraction and conversion to UTM coordinates

Outlier Removal and Time Series plot

Displacement/velocity computation

Strain computation

Earthquake catalogue

Different magnitudes conversion to moment magnitude(M_w)

De-clustering

Magnitude completeness (M_e) estimation

b-value estimation

Re-classification

Assigning weights

Seismic Potential zones

Time evolution of the rupture inferred from the waveforms

- ➔ Time evolution of the rupture process is shown in the figures below and in the following slides. These are inferred from the seismic waveform data, since these are sensitive to the rupture process of an earthquake.
- ➔ Rupture began at the epicenter and moved up-dip and northwestward.

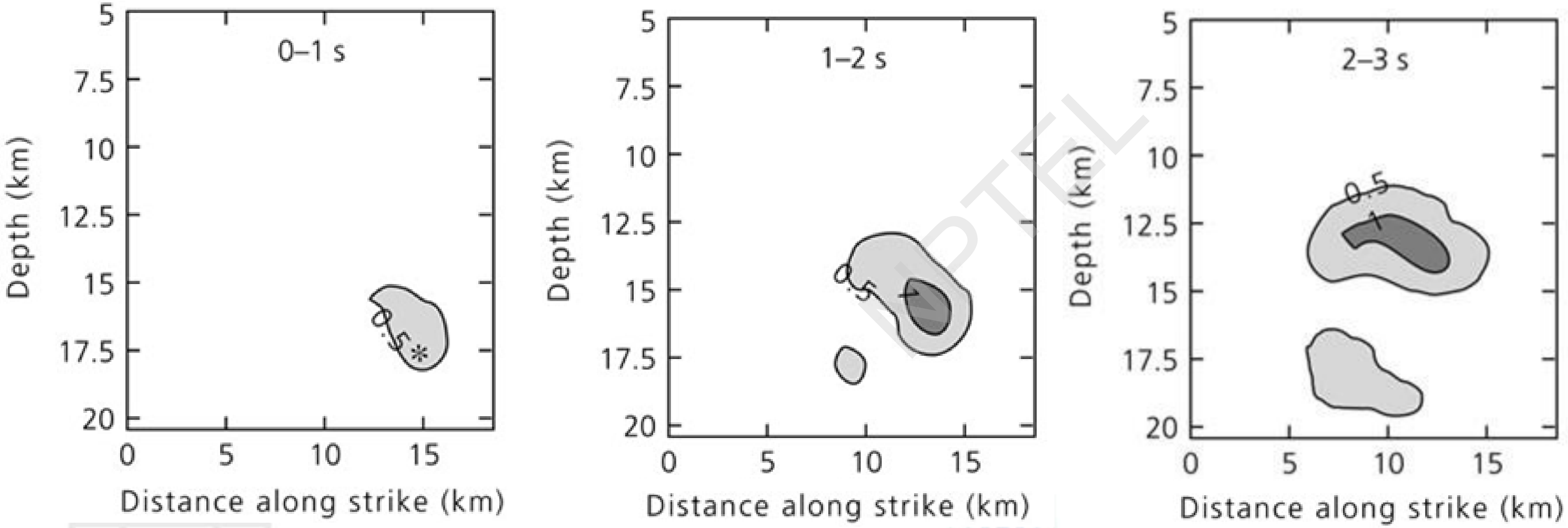


Figure 4.5-11: Time history of the rupture of the 1994 Northridge earthquake.

Time evolution of the rupture inferred from the waveforms

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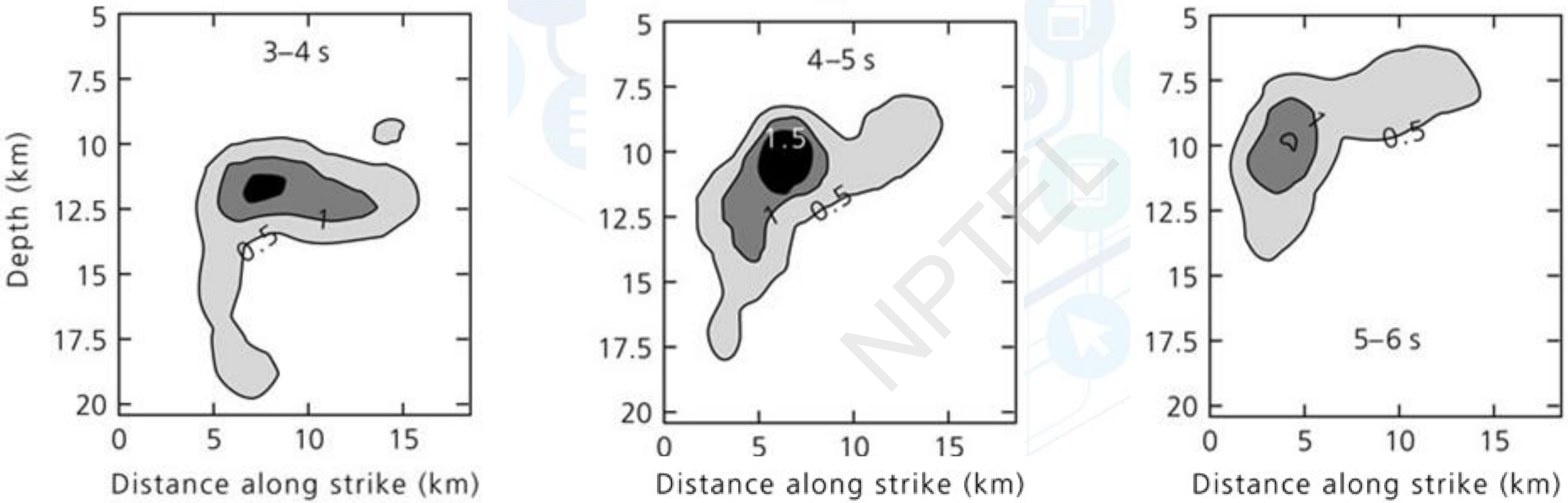
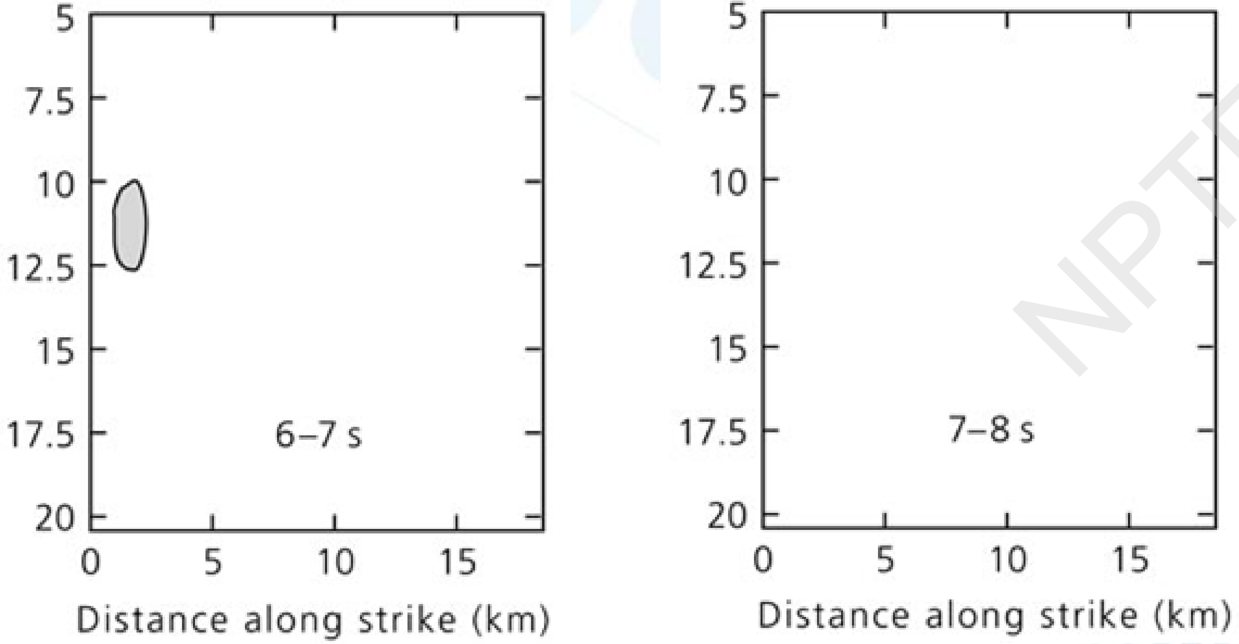


Time evolution of the rupture inferred from the waveforms

Figure 4.5-11: Time history of the rupture of the 1994 Northridge earthquake.



Such models are giving our best look to date into the rupture process, and are being combined with experimental and theoretical studies of rock fracture to explore the complex physics of earthquake faulting.

Afterslip or postseismic slip

- Geodetic data after earthquakes also sometimes show a phenomenon called afterslip or postseismic slip.
- Deformation goes on “silently” (without a seismic signal) for some time after an earthquake and its seismologically observed aftershocks.
- For plate boundaries, this motion is sometimes thought of as a postseismic portion of the seismic cycle, during which the motion slows from the rapid coseismic motion to the slower steady interseismic motion.
- It is often unclear whether the postseismic motion reflects continued slip on the earthquake fault or not.

Summary

- Seismic waves have an ambiguity in distinguishing between the fault plane and the auxiliary plane, the geodetic data do not as static displacements models do not have nodal plane perpendicular to fault plane.

- We use strong motion data, Teleseismic data and geodetic data that provides good constraints on fault geometry and slip on it.

- Geodetic data that depend on the difference in position before and after an earthquake provide no information about what happened during the earthquake, whereas seismological data can sometimes show how the rupture evolved.

- The results for the different data types differ because each is sensitive to different features of the slip.

- In post-seismic slip deformation goes on “silently” (without a seismic signal) for some time after an earthquake and its seismologically observed aftershocks.

REFERENCES

- Stein, Seth, and Michael Wysession. An introduction to seismology, earthquakes, and earth structure. John Wiley & Sons, 2009.
- Lowrie, William, and Andreas Fichtner. Fundamentals of geophysics. Cambridge university press, 2020.
- Kearey, Philip, Michael Brooks, and Ian Hill. An introduction to geophysical exploration. Vol. 4. John Wiley & Sons, 2002.
- https://geologyscience.com/geology-branches/structural-geology/stress-and-strain/
- Seismology course, Professor Derek Schutt, Colorado State Univ., USA.

THANK YOU !