



## Imaging Active Tectonics Unit 4: The phenomenology of earthquakes from InSAR data - student exercise

---

Gareth Funning (University of California Riverside)

***Phenomenology: the outward characteristics or phenomena of a given process or act, considered collectively. (Oxford English Dictionary)***

*The aim of this exercise is to develop an intuition for how the patterns of surface deformation captured in radar interferograms relate to how the fault responsible for a given earthquake moved, and what else we can learn about that fault and that earthquake from the data. We will achieve this through a hands-on modeling exercise using an interactive web tool. We will also investigate how well we can resolve the various “source parameters” (quantities such as the strike, dip and fault length) of a given earthquake, by comparing different attempts to model the same data, and what the implications of this might be for estimating seismic hazard.*

### Introduction

One of the first, and still one of the most important uses of InSAR data by geodesists and geophysicists, is to characterize earthquakes. By modeling each earthquake, typically by treating the crust as an idealized elastic solid and the fault as one or more planar surfaces embedded within it, we can in principle estimate quantities such as the fault geometry, fault location, fault depth, slip amount and slip direction that provide a match to the data, and therefore provide a description of the earthquake source. These quantities are collectively known as the earthquake’s “source parameters.” In principle, if you know the source parameters of an earthquake, you can visualize the consequences (the phenomenology) of that earthquake—in terms of how it affected the surface, its likely effects on infrastructure, and how it could add or remove stresses from other faults in the region.

In this exercise, we will look at earthquake source parameters and their relationship with the deformation patterns that are measured using InSAR, and produce some models of our own.

## Earthquake source parameters

The simplest representation of an earthquake, a rectangular planar surface that moves uniformly, can be described using nine numbers (nine source parameters). In no particular order, these parameters are called:

**bottom depth   length   rake   Y position   slip   strike   top depth   X position   dip**

Using your existing knowledge of fault geometry, structural geology, your English comprehension skills and/or a process of elimination, assign these parameter names to their descriptions below:

\_\_\_\_\_ describes the orientation of the fault in map view, the azimuth of the line that fault forms when it intersects with a horizontal surface.

\_\_\_\_\_ describes the inclination of the fault surface, the maximum angle that can be formed between the fault surface and a horizontal plane.

\_\_\_\_\_ is the distance that the hanging wall moves with respect to the footwall.

\_\_\_\_\_ is an angle that is used to describe the direction of fault movement; it is the angle between the strike direction and the vector that describes the motion of the hanging wall with respect to the footwall (the slip vector).

\_\_\_\_\_ is the x coordinate of the center of the fault, projected up-dip to the surface.

\_\_\_\_\_ is the y coordinate of the center of the fault, projected up-dip to the surface.

\_\_\_\_\_ refers to the extent of the fault that slipped in the earthquake.

\_\_\_\_\_ refers to the depth to the top edge of the fault.

\_\_\_\_\_ refers to the depth to the bottom edge of the fault.

There are some conventions that we use for these parameters, to avoid ambiguity:

- The strike of a fault could potentially be one of two azimuths,  $180^\circ$  apart. By convention, we choose the direction where, if you were to stand looking along the fault, the dip of the fault is to the right. You may have learned this as the “right-hand rule.”
- By convention, the “hanging wall” of a vertical fault is the block on the right when looking along the strike direction.
- The rake of the fault is measured with positive angles being counter-clockwise. Given that this describes the direction of motion of the hanging wall with respect to the footwall, the following will always be true:
  - A rake of  $0^\circ$  describes a left-lateral strike-slip fault movement.
  - A rake of  $90^\circ$  describes a reverse fault movement.
  - A rake of  $180^\circ$  describes a right-lateral strike-slip fault movement.
  - A rake of  $-90^\circ$  ( $270^\circ$ ) describes a normal fault movement.

In general, most real earthquakes have rakes that are between two of the values described above. In that case, the fault movement will be oblique, with components of both styles of motion, e.g. an earthquake with a rake of  $30^\circ$  (between  $0^\circ$  and  $90^\circ$ , but closer to  $0^\circ$ ) will have a primary component of left-lateral strike-slip, with a secondary component of reverse slip.

What would be the strike of a fault that dipped  $45^\circ$  to the southwest?

What would be the rake of an earthquake that showed equal amounts of normal and right-lateral slip?

Draw a labeled diagram of a fault that slipped in an earthquake, in perspective view. Assume that the earthquake involved pure normal slip on a rectangular fault with a moderate dip (i.e. neither steep nor shallow). Represent and label as many of the different source parameters as you can on your diagram.

### Elastic rebound and elastic dislocation models

Earthquakes are caused by the release of stored elastic strain in the crust along faults. This process of sudden elastic unbending (strain release) that follows decades or centuries of slow elastic bending (strain accumulation) was named *elastic rebound* by Harry Fielding Reid, the scientist who first identified it, using geodetic data (from triangulation surveys), collected before and after the great 1906 earthquake in San Francisco.

This elastic rebound process is ongoing and recurring, and operates in a cycle—the *earthquake cycle*. Since faults are weaknesses in the crust, they are the most likely places to accommodate tectonic plate motions in the long term, but in the short term, the friction between the rocks on either side of the fault prevents them from moving. Instead, the stresses from the plate motions cause the crust to bend, and thus build up elastic strain. This period of strain buildup is called the *interseismic phase* of the earthquake cycle (interseismic = occurring between earthquakes). As

the crust bends, it pulls on the faults; when the stresses due to that pull exceed the frictional stresses resisting motion, the fault moves and releases stored elastic strain in an earthquake. This period of strain release is sometimes referred to as the *coseismic phase* of the earthquake cycle (coseismic = occurring at the same time as the earthquake). And as soon as the earthquake is over, the interseismic phase starts again . . .

What is the difference between the displacements due to earthquakes as measured from stream offsets using LiDAR, and those measured by collecting SAR images a few weeks before and after an earthquake? Would you expect to see the same pattern of displacements in both, and why/why not?

With knowledge of earthquake source parameters, and by making a few simplifying assumptions about the crust (e.g. that it is isotropic and we know its rigidity), we can calculate the expected surface displacements due to an earthquake. This is made possible by the careful work of the Japanese researcher Yoshimitsu Okada, who successfully integrated the elastic equations to produce an exact, analytical solution to the problem *without making any mistakes* (not by any means a trivial endeavor—in Okada’s 1985 paper that contains the solution, the relevant pages are printed in landscape and in a small font, so all the terms would fit on the page!) Computer codes built on these equations are known as *elastic dislocation model codes* (dislocation here is another name for fault), and are the basis for the models produced by the Visible Earthquakes tool that we will be using.

## Make your own elastic dislocation model of an earthquake

Here we will model the InSAR data for the 1995 Dinar, Turkey, earthquake using Visible Earthquakes, an online tool that makes elastic dislocation models that can be compared with real InSAR data of earthquakes.

1) Visit the Visible Earthquakes tool at <https://visible-earthquakes.appspot.com/start>

At the top of the screen, there is a Getting Started tab; if you click on that tab, you will get a page that contains information on how the tool works, and what to do. In what follows beneath, we are going to assume that you have read that page. (You might want to keep it open in a separate tab or window, in case you want to consult it when using the tool.)

2) From the list of earthquakes on the main Visible Earthquakes page, scroll down to the Dinar, Turkey event. Click on the Model button.

- You may need to login here, if you have not already. If you have a Google/Gmail account, it is easiest to link that to the tool; otherwise you can click on the Sign Up link, and use whatever username and password you like.
- Once logged in, you may have to click once more on Visible Earthquakes and repeat Step 2 above.

3) Using the clickable interface, move the various fault controls and sliders until the pattern you can see in the model window on the right matches the unwrapped InSAR data on the left.

- Note how the source parameter values at the bottom of the screen change as you manipulate the model.
- In order to assess how well your latest model fits the data, you can click the Compute Residual button at the top right of the screen. This will show you what is left when the model is subtracted from the data (the residual). You want the color bar for the residual to cover as little range as possible. (Click “Continue Modeling” if you want to keep working on your model.)
- If you make a change that makes your model look worse, then there is an undo facility that you can use to revert to a better version.

4) Once you think you have a model that fits the data acceptably well, ask the instructor to check it over. If your model is approved, note down the source parameters here:

Strike: _____	Center X position: _____
Dip: _____	Center Y position: _____
Rake: _____	Top depth: _____
Slip: _____	Bottom depth: _____
Length: _____	Magnitude: _____

At this point, you can submit your model to the Visible Earthquakes database. Click on the Submit Model button at the bottom right of the window. A pop-up window will appear and ask you a few questions:

- Confidence: what is your level of confidence in your solution? Choose a term from the drop-down list that reflects it.
- About Me: choose a term that reflects your experience level.
- Group: use the name that the instructor gives you. *You must use the exact same spelling that the instructor uses, otherwise you will not be able to compare your results with others in the class!*

Explain why you chose the level of confidence in the model that you did.

How accurate do you think your parameter estimates are, and why?

5) Repeat the modeling process for another earthquake, selected for you by the instructor. Again, get the instructor to check over your model once you think you have a good match, and take note of the source parameters:

Earthquake name: \_\_\_\_\_

Strike: \_\_\_\_\_

Center X position: \_\_\_\_\_

Dip: \_\_\_\_\_

Center Y position: \_\_\_\_\_

Rake: \_\_\_\_\_

Top depth: \_\_\_\_\_

Slip: \_\_\_\_\_

Bottom depth: \_\_\_\_\_

Length: \_\_\_\_\_

Magnitude: \_\_\_\_\_

Submit the model to the database once you have written all the values down, again making sure to use the exact same group name that the instructor provided.

6) Sketch a perspective diagram of the fault responsible for the earthquake you modeled (as you did for the idealized normal faulting earthquake earlier), making sure that the source parameters of the earthquake are realistically represented.

7) Discuss, as a class, the similarities and differences between the different earthquakes modeled by different groups. (The instructor will lead this discussion.) Note down the most important or striking differences, and suggest possible reasons.

## Uncertainty and nonuniqueness

As a class, compile each person's source parameters from the earthquakes you have modeled into a spreadsheet. Using the chart function of the spreadsheet, produce histograms of each of the source parameters – this will go faster if the task is divided up amongst the class.

We can use these histograms to consider how well constrained the models generated by you and your classmates are, and what the causes of any variations might be. Such considerations are important in the geosciences, as they provide a way of evaluating how good a model, or set of models is, how much confidence we have in our findings, and how repeatable our results are.

Which parameters show the most variation? Which show the least?

Are there any parameters for which your results differ from the majority of your classmates?  
Which parameters, and by how much?

What does such variation represent? (Assume that your classmates were submitting their models in good faith, i.e. they each thought that their model fit the data well.)

Suggest reasons why the most variable parameters could be so different in different peoples' results.

Suggest reasons why the least variable parameters could be so similar in different peoples' results.

Reflect upon the accuracy of your results in the light of seeing those of your classmates. Are you more or less confident in your results now, and why?

What might be the consequences of this variability for forecasting future earthquake hazards?

## Acknowledgements

The Visible Earthquakes tool was originally developed by Rowan Cockett (3point Science) and Gareth Funning (UC Riverside), with support from UNAVCO and the GETSI project. The current version of the Visible Earthquakes was updated by AranzGeo, now owned by Seequent.